of Electrical

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MTE Corporation is the International Power Quality Resource for line/load reactors, transformers, matrix harmonic filters, RFI/EMI filters, DC link chokes, and other PQ products. Offices in North America, Europe, Asia and Latin America.

Power Quality Division:

- Line/Load Reactors
- Matrix Harmonic Filters
- DC Link Chokes
- RFI/EMI Filters
- Surge Arrestors
- 3rd Harmonic Filters
- Motor Protection Filters
- Software

Technical Articles:

- Harmonic Mitigation of 12-Pulse Drives with Unbalanced Input Line Voltages
- Reactors Provide a Low-Cost Solution to Inverter/Drive Power Quality
- Load Reactors - Increase VFD System Performance & Reliability
- Solving Motor Failures
- Low Cost ASD Motor Protection
- Solving SCR Line Voltage Notching
- Economical Solutions to Meet Harmonic Distortion Limits

Power Quality Tutorials:

Both the system engineer and the user of motor drives will find these tutorials a valuable desktop reference. Peruse these tutorials on-line or print copies for future use. You'll find these to be concise yet comprehensive.

RFI / EMI Filter Tutorial
Identifies typical EMI / RFI noise sources, applicable EMC standards and advises recommended solutions.
Available in: HTML or PDF.

Line Reactor Tutorial
Explains the purpose of line reactors, demonstrates the effects of line reactance on input current harmonic distortion and provides considerations for selection and ratings.
Available in: HTML or PDF.

Load Reactor Tutorial
Explains the purpose of load reactors and demonstrates their usefulness as motor and VFD protection, as well as motor temperature and noise reduction.
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Motor Protection Filter Tutorial
Illustrates the need for motor protection filters, identifies typical motor specifications and describes alternative motor protection solutions.
Available in: HTML or PDF.

Harmonic Filter Tutorial
Describes the expected harmonic current distortion based on either drive HP rating or input impedance, explains IEEE-519 and it's application in industry and demonstrates effects of alternative solutions.
Available in: HTML or PDF.

Reference Desk

See our Power Quality Tutorials / Desktop Reference to specify the right product for your application.

EC Declarations of Conformity

- AC Line/Load Reactor (Components)
- RFI/EMI-Passive Filters for Electromagnetic Interference Suppression PDF.

MTE Terms and Conditions of Sale

Electricity Abroad

News Releases:

- New MTE Corporation Matrix™ Harmonic Filters Announced
- News Release Archive

Application Notes:

- Reactor Selection for the Line Side of DC Motor Controllers Available in HTML or PDF.
- How to use a 3-phase line reactor for a single-phase application Available in HTML or PDF.
- Selection and Use of the MTE Motor Protection Filter Available in HTML or PDF.
- Solving DC Drive Harmonics with Matrix Harmonic Filters Available in PDF

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Company Profile

History

MTE Corporation was formed in 1982 for the purpose of acquiring four, independent, magnetic and electronic companies, located in the Milwaukee, Wisconsin area. In 1983 the acquisition was completed which brought together the companies known as Milwaukee Transformer Co., Transformer Design Inc., Hytran Inc., and Milwaukee Electronics Corporation. Each of these companies specialized in a different field of magnetics and transformer design and were long established companies in their respective fields. The clear objective of this acquisition was to build the best magnetics company in the country by capitalizing on the individual strengths of each of the companies, while bringing to each a new dimension in management, marketing and quality under the new MTE Corporation.

By 1988, Milwaukee Electronics was sold and the remaining companies merged into MTE Corporation operating divisions, maintaining the same specialization they had as independent companies. Milwaukee Transformer and Transformer Design, subsequently the Industrial Products Division, produces a full range of dry type transformers, reactors, chokes, etc. for the commercial and industrial marketplace. A wide spectrum of products are manufactured using laminated core, C-core and amorphous metal core technologies. Fabrication techniques include open frame, and encapsulated units. Encapsulated units typically include potting in molded epoxy, plastic or metal enclosures. This division also produces custom ballasts used in Municipal Street lighting systems which employ high-pressure sodium vapor lighting.

A new division was formed in 1990 called the Power Quality Division. This division produces various Power Quality devices; in particular 3-phase Line/Load Reactors sold under the copyrighted name "Guard-AC". AC Reactors have widespread applications in power quality and energy conservation. Reactors are widely used in conjunction with variable speed drives and other electronic equipment to protect the equipment from unwanted power surges and to help bring harmonics into compliance with IEEE, IEC and U.S. utility standards for harmonics distortion and power factor. Today, this division offers a complete range of electrical power quality solutions.

International Power Quality Leadership

MTE has vaulted into a leadership role in the power quality industry with its unique Reactor design. "Guard-AC" Reactors and other power quality products, are presently sold through over 250 distributors in the United States, Canada, Latin America, Asia and Europe. MTE Corporation's Canadian and European distribution was enhanced in 1998 by the establishment of a European sales office/warehouse manned by MTE personnel in the United Kingdom and a sales/ warehouse facility in Toronto, Canada. These facilities support distributors and OEMs throughout all of Europe and Canada. In 2000, two Regional Sales Managers were hired to manage sales and provide technical support to customers in Latin America and Asia / Pacific Rim. The company also has one directly employed sales engineer in China. Distributorships have been established in Australia, mainland China, Hong Kong, Indonesia, Japan, Korea, Malaysia, Singapore, Taiwan, Thailand, and the Philippines.

New Product Development

New power quality products continue to be added each year to the MTE product offering. A Harmonics Analyzer was added in 1994, also a line of 3-phase Surge Arrestors plus a line of RFI Filters in 1995. In 1996 a standard line of DC Link Chokes for the drive OEM market was introduced. In 1997 a Sine Wave Filter was introduced specifically for the protection of motors from IGBT spikes. A single-phase 3rd Harmonic Filter was introduced in 1997 as was a new, patented, 3-phase Broad Band Harmonic Filter. In late 1998, a U.S. patent was awarded to the company for a 1-phase Broad Band Harmonic Filter. MTE continues to be an innovator and leading provider of power quality equipment. In January, 2001, the company introduced a new harmonic filter which improves upon the cost and performance of previous industry offerings, providing customers with the least cost means of effectively mitigating harmonics.

High Quality Design and Manufacturing

The engineering and technical staff of MTE Corporation is outstanding. Our team of professional design engineers has over 100 years collective experience in the magnetics industry and are complemented by almost as much experience in manufacturing. Eight degreed engineers are currently employed at MTE, of which four are registered professional engineers. MTE quality standards are maintained at the highest level across the broadest customer base of any company our size in the country. We operate with Statistical Process Control and our modern manufacturing cells enable us to supply to many just-in-time programs established by our customers. Our electrical test department is equipped with an extensive list of precision test equipment to insure that all parts can be tested for compliance with specified performance parameters. Test lab capabilities include in-circuit (real life) testing for power quality products including VFD loads and long lead length testing systems.

Facilities

The manufacture of precision, high quality power quality components and equipment can only be accomplished with high quality precision equipment operated by well trained and dedicated personnel. To attain this goal, MTE has maintained the highest standards of training by long-time qualified trainers, lead persons, foremen and supervisors. MTE has also selectively purchased, over the years, new manufacturing equipment to complement its production capability. In 1989, MTE constructed a new 25,000 square foot building, designed to be a state-of-the-art office, technical and manufacturing facility devoted to the manufacture of high-tech magnetic components. During 1995, production capabilities were expanded through the establishment of a manufacturing operation in Juarez, Mexico. To satisfy a growing demand for our power quality products, a new 4500 square foot addition to the manufacturing section of the Menomonee Falls building was completed in February 1997 and a new 9000 square foot distribution center was opened in January 1999. MTE now has four manufacturing facilities and maintains more than $1,000,000 in finished goods inventory at its distribution center in Menomonee Falls, WI.

Officers

MTE Corporation is a privately owned corporation, employing over 100 people in one of the finest production facilities in the country and has significant ability for future growth in the high-tech and power quality marketplace.

The officers of MTE Corporation are:

Norbert D. Miller - President/CEO
Karl M. Hink - Executive Vice President/Chief Operating Officer
John A. Houdek - Vice President of Marketing/Sales
Bruce Schram - Manager, Advanced Technology
Henry Nechvatal - Director of Corporate Quality

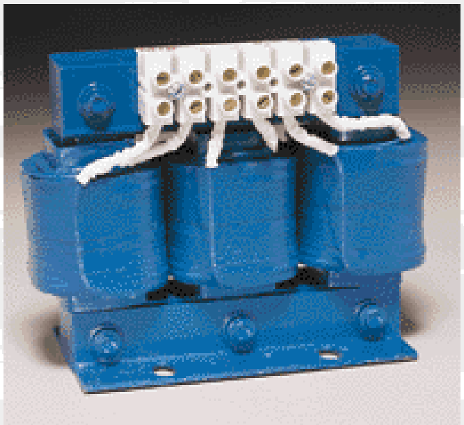
Prior to joining MTE Corporation, Mr. Miller was Vice President of Engineering for Hamlin Incorporated, an international manufacturer of electrical and electronic components. Before joining MTE Corporation, Mr. Houdek was Marketing Manager for a U.S. manufacturer of magnetic devices. Mr. Hink was formerly the founder and President of Thor Technology Corp., a manufacturer of Variable Speed Drives. Before joining MTE Corporation, Mr. Schram was Engineering Manager for a U.S. Manufacturer of Magnetic Devices. Mr. Nechvatal was Director of Corporate Quality for Zenith Controls Incorporated, an international manufacturer of automatic transfer switches and switchgear.

The corporation and its officers have an outstanding reputation in the business community. The company has excellent financial relations with its bankers through working capital and long term building agreements with Bank One in Milwaukee, Wisconsin. The company is headquartered at W147 N9525 Held Drive, Menomonee Falls, WI. 53051.

Line/Load Reactors

Product Overview

- ***Product Overview***
- ***Detailed Product Data***
- ***Selection Tables***
- ***Specification Table***
- ***Application Notes***



Solve Motor Drive Problems... Input or Output

Harmonic Compensated
3-Phase and 1-phase
IGBT Compatible

- dv/dt Protection
- Reduce Peak Voltage in Long Lead Applications
- Harmonic Reduction
- 4000 Volt Dielectric Strength

Same Product handles Input or Output!

Input:

- Reduce Harmonic Distortion
- Absorb Surges and Spikes
- Extend Rectifier Life
- Reduce SCR Voltage Notching
- Improve Total Power Factor

Output:

- Reduce Peak Voltage
- Increase Motor Efficiency
- Reduce Motor Noise
- Reduce Motor Temperature
- Extend Motor Life

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Motor Protection Filters

Detailed Product Data

"LC" Type Filers
dv/dt Filters

For use with AC inverters with switching frequency set to 5Khz or higher.

The Benefits of Using MTE's Motor Protection Filters:

- Reduce DV/DT
- Reduce Motor Peak Voltage
- Extend Motor Life
- Reduce Motor Temperature

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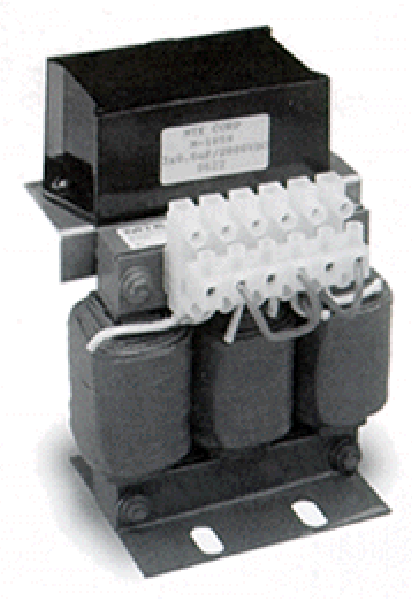
The Motor Protection Filters combine the advantages of an IGBT Protected AC Reactor with a capacitor network to form a "Low Pass" filter. Reactors have long been praised for their ability to absorb surges and spikes and to slow down the rate of rise of spikes. These basic characteristics of reactors make them very effective at taming the PWM waveform even by themselves. When combined with our capacitor network, you get all of the benefits of having an output reactor plus a near sinusoidal voltage waveform.

Use Motor Protection Filters anytime the distance between the inverter (VFD) and motor exceeds the critical lead length (see page 3), or whenever you desire performance or protection greater than what a reactor provides by itself.



Near Sinusoidal Output

MTE Corporation Motor Protection Filters change the typical IGBT (PWM) motor voltage, from a pulsed waveform with fast voltage rise time to a **near sinusoidal** waveform.

These filters help extend motor life by reducing the motor peak voltage as well as significantly reducing dv/dt of the output voltage waveform.

Motor Insulation Protected

Long Lead motor drive applications can experience motor terminal peak voltages of twice the DC bus voltage. This means that motor terminal peak voltage could be 1700 volts (600V drives) or 1300 volts peak for 480 volt drives. The highest peak

"LC" Type Filers
dv/dt Filters

For use with AC inverters with switching frequency set to 5Khz or higher. **The Benefits of Using MTE's Motor Protection Filters:**

- Reduce DV/DT
- Reduce Motor Peak Voltage
- Extend Motor Life
- Reduce Motor Temperature

For Application Engineering Assistance, Call:
1-800-455-4MTE, or
262-253-8200
e-mail: E-Mail: apprengrg@mtecorp.com

voltages are typically experienced in low HP applications. Use our Motor Protection Filters to protect your motors from insulation breakdown due to voltage stress. Frequently a reactor alone will offer adequate protection for high HP motors.

Technical Information

Voltage Reflection

In IGBT transistorized inverter applications where long motor cables are used, a phenomenon called voltage amplification can be experienced. The severity of this condition is determined by cable length, motor surge impedance and cable surge impedance. The reflection coefficient (p) indicates what percentage of the incident (original VFD output) voltage will be reflected and therefore added to the incident voltage at the motor terminals.

$$\textbf{Reflection Coefficient} = \frac{Z_m - Z_c}{Z_m + Z_c}$$

Where Z_m = Motor Surge Impedance and Z_c = Cable Surge Impedance

Typical Reflection Coefficients and Surge Impedances for Various Motor Ratings Are:

HP	R	Z_m	Z_c
25 HP	0.90	1500 ohms	80 ohms
50 HP	0.83	750 ohms	70 ohms
100 HP	0.76	375 ohms	50 ohms
200 HP	0.65	188 ohms	40 ohms
400 HP	0.52	94 ohms	30 ohms

Lower horsepower motors experience higher voltage reflection (due to the large mis-match in motor vs. cable impedance), thus the highest motor terminal peak voltage is experienced in these situations.

Critical Lead Length

The distance along a motor cable where voltage amplification begins to occur is called the "Critical Lead Length". It is dependent upon two key factors: the speed at which an electromagnetic pulse travels on the cable and voltage rise time. The speed of propagation of an electromagnetic pulse is typically 100 to 150 meters/ microsecond (approximately one-half the speed of light). The voltage rise time is defined as the amount of time for the voltage pulse to rise from 1 0% to 90% of the DC bus voltage. The rise time is dependent on the type of transistors being used.

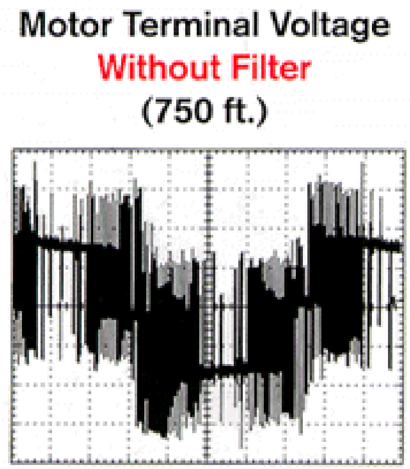
$$\textbf{Critical Lead Length} = \frac{100\ \text{m/u sec} \times \text{Rise Time (u sec)}}{2}$$

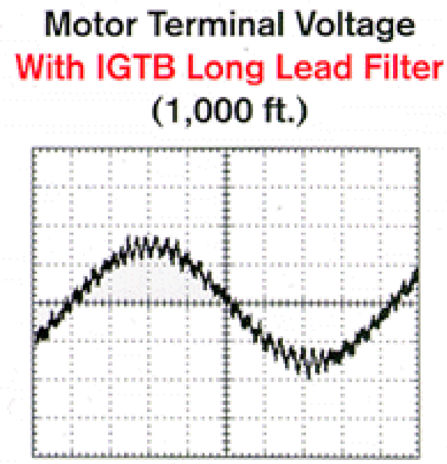
Pulse Rise Time	Critical Lead Length
6 microseconds	300 meters
2 microseconds	100 meters
1 microseconds	50 meters
0.5 microseconds	25 meters
0.1 microseconds	5 meters
0.05 microseconds	2.5 meters

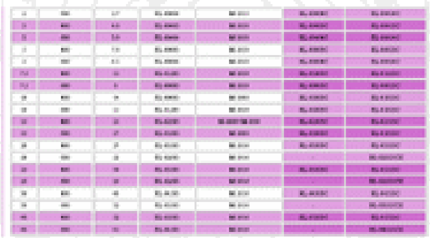
The critical lead length does not indicate that motor failure will occur beyond this distance, but rather that the motor peak voltage will begin to exceed the DC bus voltage and will continue to increase as the cable length extends beyond the critical lead length. Theoretically, voltage doubling can occur, while in real practice the voltage can actually exceed twice the DC bus voltage.

Typical "LC" Filter Performance

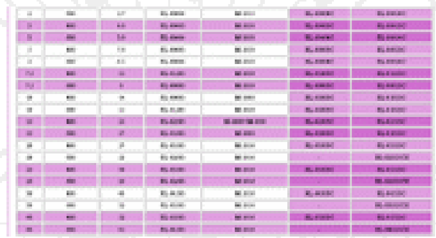
The LC Filter reduces dv/dt and peak voltage by converting the PWM output to a near sinusoidal waveform. This near sinusoidal waveform is much friendlier to a motor and results in reduced temperature and noise. The LC Filter extends the possible motor lead length to thousands of meters. Our Motor Protection Filters utilize 5% impedance reactors which are IGBT PROTECTED and frequency compensated.







[Selection Tables]



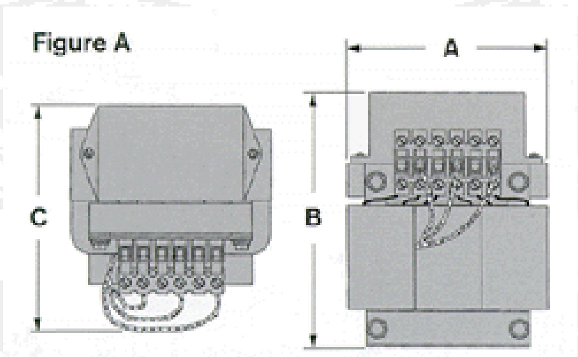
Specifications:

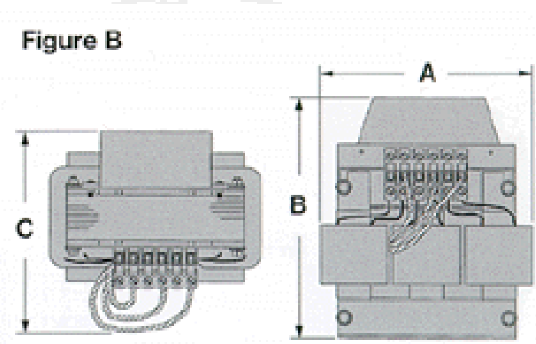
Enclosed Dimensions (inches/mm)

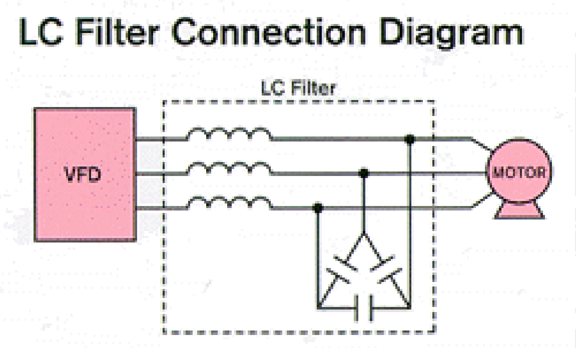
Model	Cabinet	Width	Depth	Height
RL-00212C thru RL-01213C	Cab-8	8/203	6/153	8/203
RL-01813C thru RL-10013C	Cab-13	13/330	13/330	13/330
RL-13013C thru RL-60013C	Cab-17	17/432	17/432	24/610
RL-75013C	Cab-24	24/610	24/610	30/762

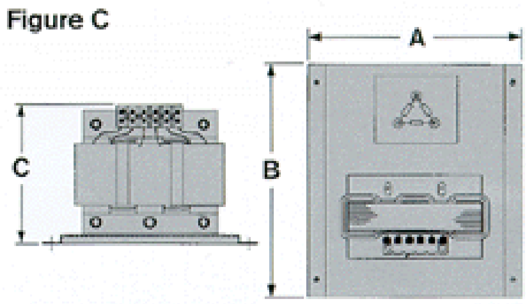
Open Dimensions (inches/mm)

Model	Figure	A	B	C
RL-00202C thru RL-01213C	A	4.63/118	6.00/153	4.50/115
RL-00803C thru RL-01203C	B	6.00/153	6.75/172	5.25/134
RL-01803C	B	8.05/205	7.87/200	5.00/127
RL-02503C thru RL-05503C	C	12/305	13/331	8/203









Note: Inverter switching frequency must be set at 5Khz or higher.

NEMA Standard MG-1 defines motor insulation capacity for Design B and Inverter Duty motors.

Motor Type	MG-1 Standard	Peak Voltage	Rise Time	dv/dt (volts/u sec)
Design B	Part 30	1000	>2 u sec.	500
Inverter Duty	Part 31	1600	>0.1 u sec.	16,000

[Product Overview]
[Motor Protection Filters Selection Table]

lotor Protection Filters Selection Table

Motor Protection Filters, also sometimes referred to as "dv/dt", "LC", or "Sine Wave", must be sized according to the motor HP rating.
One filter per motor, no Parallel or Series Connection of two filters allowed.

UNDER NO CIRCUMSTANCES may the Drive Switching (Carrier) Frequency be lower than 5KHz.

480V

HP	Motor Amps	Open Filter Assy	Nema 1 Filter Assy
1	1.8	RL-00202C	RL-00212C
1.5	2.6	RL-00202C	RL-00212C
2	3.4	RL-00403C	RL-00413C
3	4.8	RL-00403C	RL-00413C
5	7.6	RL-00803C	RL-00813C
7.5	11	RL-01203C	RL-01213C
10	14	RL-01803C	RL-01813C
15	21	RL-02503C	RL-02513C
20	27	RL-03503C	RL-03513C
25	34	RL-03503C	RL-03513C
30	40	RL-04503C	RL-04513C
40	52	RL-05503C	RL-05513C
50	65	-	RL-08013C
60	77	-	RL-08013C
75	96	-	RL-10013C
100	124	-	RL-13013C
125	156	-	RL-16013C
150	180	-	RL-20013C
200	240	-	RL-25013C
250	300	-	RL-32013C
300	360	-	RL-40013C
400	480	-	RL-50013C
500	600	-	RL-60013C
600	720	-	RL-75013C

600V

HP	Motor Amps	Open Filter Assy	Nema 1 Filter Assy
1	1.4	RL-00203C7	RL-00213C7
1.5	2.1	RL-00203C7	RL-00213C7
2	2.7	RL-00404C7	RL-00414C7
3	3.9	RL-00404C7	RL-00414C7
5	6.1	RL-00804C7	RL-00814C7
7.5	8	RL-00803C7	RL-00813C7
10	11	RL-01203C7	RL-01213C7
15	17	RL-01803C7	RL-01813C7

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Matrix™ Harmonic Filters

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- ***Matrix Technical User Manuals***

Now Available! **380 - 415 Volts, 50HZ Selection Tables**

***The Matrix Harmonic filters have replaced our former broad band harmonic filters.

Best Economical Solution To Harmonics

Matrix Harmonic Filters provide broad band reduction of harmonics and can increase true power factor. Not only do they improve upon former broad band filtering and 12-pulse harmonic reduction techniques, but they are also suitable for a wider range of applications. Matrix Harmonic Filters can be installed in either variable torque or constant torque applications and can be applied on either diode or SCR rectifiers. Matrix Harmonic Filters offer the best value for harmonic filtering.

Typical Applications

Use Matrix Harmonic Filters to minimize harmonic current distortion in these and other 6-pulse rectifier applications:

- Fans and Pumps
- Water Treatment Facilities
- HVAC Systems
- AC or DC Motor Drives
- Diode or SCR Rectifiers
- Rectifier Type Welders
- Induction Heating Equipment
- UPS Equipment
- Elevators

PERFORMANCE GUARANTEE

Select and install the appropriate Matrix Harmonic Filter in a variable torque AC variable frequency drive application, within our published system limits and we guarantee that the input current distortion will be less than or equal to the 12% THID or TDD (for filters purchased with -12 suffix) or 8% THID or TDD (for filters purchased with the -8 suffix). This performance guarantee applies for loading conditions ranging from 0% to 100% load. If a properly sized and installed filter fails to meet its specified THID or TDD level, MTE will provide necessary modifications or a replacement filter at no charge.

Matrix filters can also provide similar performance in other drive applications such as constant torque, DC drives and other phase controlled rectifiers, but actual THID or TDD levels can vary by load and/or speed and therefore cannot be guaranteed. Consult factory for assistance when applying Matrix filters on these types of equipment.

(Subject to Minimum System Requirements)

Suitable For All Six-Pulse Rectifiers

Matrix Harmonic Filters can be used with virtually all types of six-pulse rectifiers including six diodes, six SCRs or 3-diodes with 3-SCRs. They are suitable for use with both SCR pre-charge and full phase control front ends. Use the Matrix Harmonic Filters on any six pulse rectifier regardless of whether or not it has an internal ac line reactor or dc link choke.

Solve Power Quality Problems

Matrix Harmonic Filters solve more than just harmonic distortion problems. They also provide series impedance to a drive protecting against voltage spikes which otherwise could cause overvoltage tripping or damage to the drive components. Additionally, they:

- **Protect** upstream equipment including capacitors, conductors and transformers from the damaging effects of harmonics,
- **Prevent** nuisance tripping of circuit breakers or fuse blowing which can result from the presence of harmonics,
- **Improve** system voltage waveform, and
- **Minimize** interference with other equipment

Meet IEEE-519

Matrix Harmonic Filters enable most ac drive systems to comply with both the current and voltage distortion limits of IEEE-519 and other international harmonic distortion standards such as AS-2279, BS G5/4, and EN61000-3-4.

IEEE-519 Current Distortion Limits

ISC/ IL	TDD (total demand distortion)
<20	5%
20 < 50	8%
50 < 100	12%
100 < 1000	15%
> 1000	20%

IEEE-519 Voltage Distortion Limits

Special Applications (hospitals, airports)	3%
General system applications	5%
Dedicated systems (100% convertor load)	10%

System Analysis Not Required If applied correctly within their published system limits, Matrix Harmonic Filters will not create system resonance conditions or import harmonics from other sources.

UL Listed (UL-508C) Matrix Harmonic Filters are UL listed (File E180243) for both USA and Canada.

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Matrix™ Harmonic Filters

Performance Characteristics

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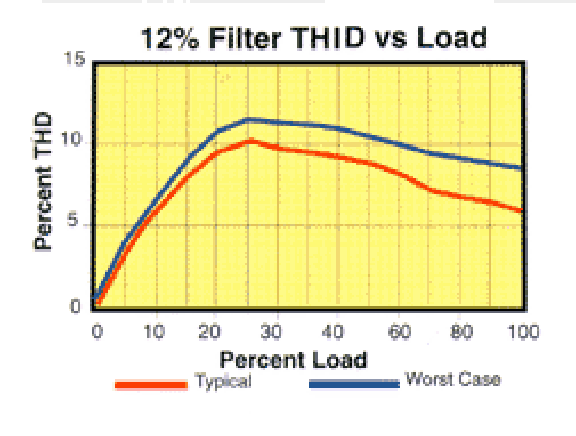
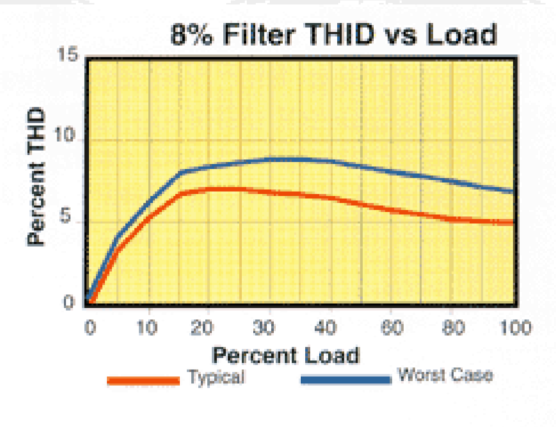
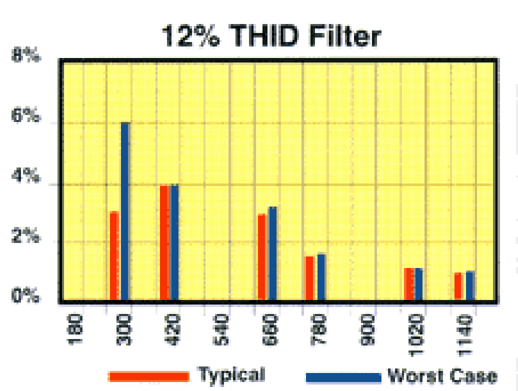
- *Matrix Technical User Manuals*

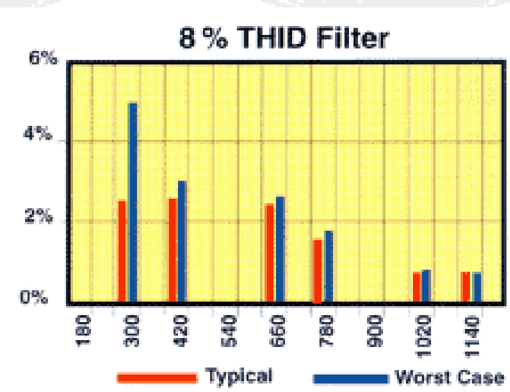
Total Harmonic Current Distortion (THID) vs. Load

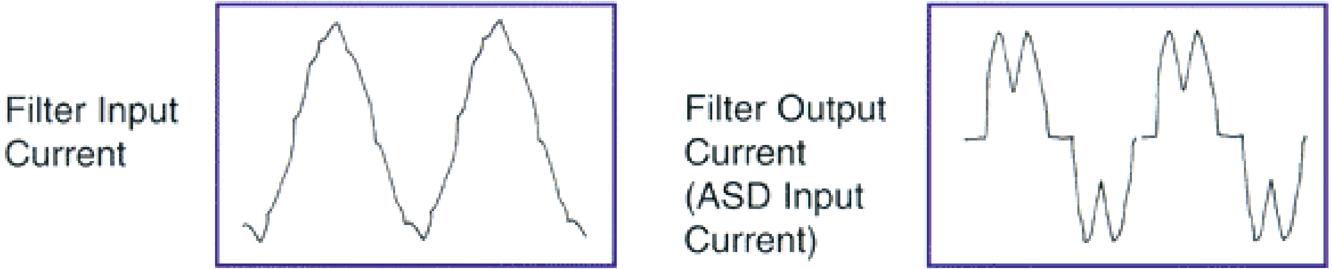
Matrix Harmonic Filters are available for either 12% total harmonic current distortion (THID) or 8% THID at the filter input. Although these levels are guaranteed, actual performance may be better depending on the electrical system characteristics.










Filter Input Current
Filter Output Current (ASD Input Current)

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Matrix™ Harmonic Filters

Theory of Operation

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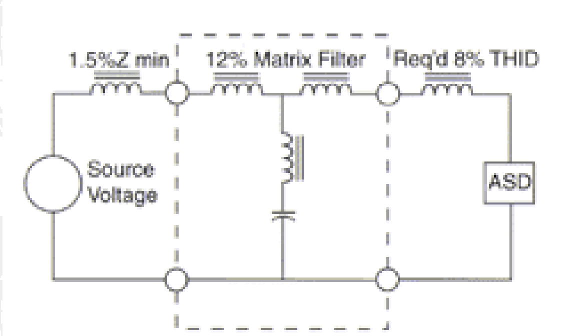
Matrix Harmonic Filters are multi-stage low pass filters which improve upon classical filter techniques by achieving broad band attenuation of all harmonic frequencies, while maximizing the attenuation of the fifth harmonic.

Harmonics Minimized

In the past, a low pass filter typically achieved <12% total harmonic current distortion (THID), but the 5th harmonic often represented as much as 10% THID. The Matrix Harmonic Filters achieve reduction of all harmonic frequencies with significant attenuation of the 5th harmonic, (typically as low as 3% to 6%). You can select filters to achieve total harmonic current distortion of either 12% THID or 8%THID over the entire operating range (from 0% to 100% load). The performance is guaranteed!

System Resonance Avoided

Matrix Harmonic Filters are carefully designed to minimize the possibility of system resonance problems. They can be installed with confidence, within the system conditions and ratings specified, to filter undesired line harmonics without creating adverse reactions on the power system. Special measures have been taken with this design to prevent oscillation and resonance conditions from occurring.



Avoids Importation of System Harmonics

Special care was taken in the design of Matrix Harmonic Filters to prevent the attraction of harmonics from other sources on a shared power system. This means you can install Matrix Harmonic Filters without worrying about other non-linear loads connected to the power system.

Low Power Loss

Power loss of Matrix Harmonic Filters is kept to an absolute minimum and is typically less than 1% of the connected load.

Modular Design

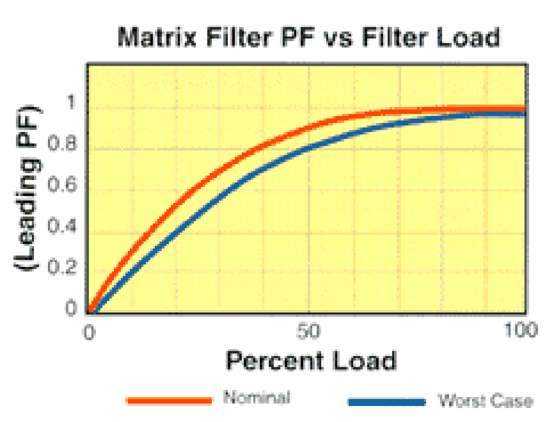
Matrix Harmonic Filters offer modular design to simplify installation. The basic panels offer 12% THID, and can be modified to achieve 8% THID by simply adding the appropriate standard AC line reactor. Units rated above 15HP (11KW) are supplied on two panels, one for the magnetics and one for the capacitors. This allows the installer to locate capacitors in the bottom or other cool part of the enclosure and the magnetics panel near the top, to achieve optimum ventilation of the filter.

Low Capacitance

Matrix Harmonic Filters accomplish broad band harmonic filtering with about half the capacitance of the former technology broad band filters. This minimizes leading current under light loading conditions and improves compatibility with stand-by power generators.

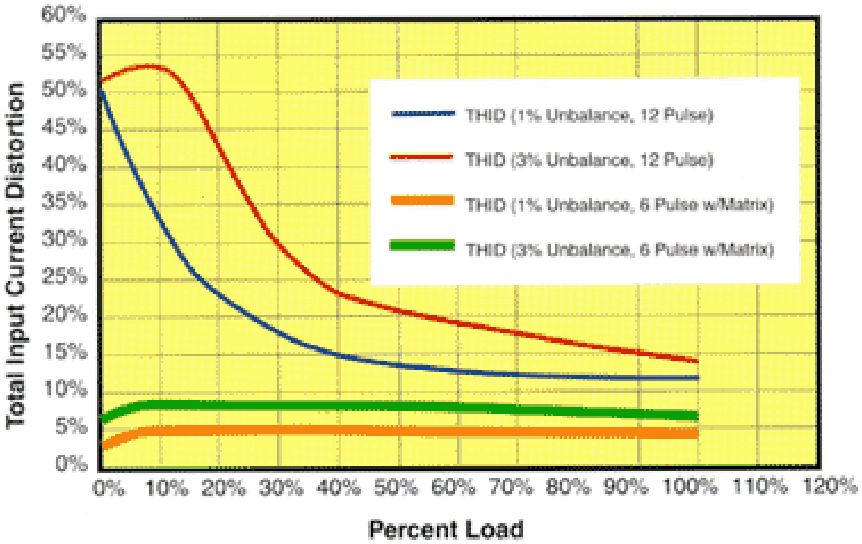
Power Factor (Leading) vs. Load

Displacement power factor associated with Matrix Harmonic Filters is always leading. At full load it is nearly unity, but it becomes more leading as the load is reduced. The filter standby current, under no-load conditions, is typically about one-third of its normal full load current rating. In some cases it may be desirable to have a leading power factor which may help to improve the overall facility power factor. However, if this is not desired, a contactor can be used to disconnect the capacitor under no load or light load conditions.



Matrix Harmonic Filters Outperform 12-Pulse Rectifiers

Matrix Filter (8% THID) vs. 12-Pulse Rectifier with Unbalanced Line Voltage



The chart above demonstrates the actual test results of a 12-pulse rectified variable frequency drive (using series connected bridge rectifiers and isolation transformers for best case results) compared to a six-pulse drive with the standard 8% THID Matrix Harmonic Filter.

Matrix Harmonic filters reduce the distortion better than 12-pulse rectifiers, from 0-100% load. They also perform better when line voltages are not balanced (as demonstrated in the chart above).

PRODUCT SPECIFICATIONS:

Input Voltage: 480 volts ± 10%, 60Hz, 3-phase
Output Voltage (based on 480 volt input):
Max output voltage (no load): 502 Vrms, 710 Vpk
Min output voltage (full load): 460 Vrms, 600 Vpk
Ambient Temperature:
Storage: -40 °C to +90°C
Operating: -40 °C to +50°C
Altitude: 1000 meters maximum
Ambient Temperature: 50°C

MINIMUM SYSTEM REQUIREMENTS
to achieve guaranteed performance

The guaranteed performance levels of this filter will be achieved when the following conditions are met:

Source Impedance: 1.5% minimum to 6.0% maximum
System Voltage: 480 volts (line to line) ±10%
Frequency: 60Hz ±0.75Hz
Balanced line voltage: within 1%
Background voltage distortion: 0%THVD

The presence of background voltage distortion will cause motors and other linear loads to draw harmonic currents. Likewise, additional harmonic currents may flow into the Matrix filter if there is harmonic voltage distortion already on the system.

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Matrix™ Harmonic Filters

Selection Tables

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- *Matrix Technical User Manuals*

480 Volts, 60Hz Selection Tables

The input current ratings of motor drives can vary significantly among different drive manufacturers. This selection table offers a generic method of selection suitable for most adjustable speed drives. Refer to the filter maximum load current rating to verify proper selection.

* 12% THID Guaranteed
8% THID (typical at rated load)

These filters typically offer < 8% THID at rated load and are guaranteed to provide < 12% THID from 0% to 100% load.

HP	Max Load Amps	12% THID Filters	
		Open Panel	Nema 1
3	6	M3-0003PD-12	M3-0003ND-12
5	10	M3-0005PD-12	M3-0005ND-12
7.5	14	M3-0007PD-12	M3-0007ND-12
10	18	M3-0010PD-12	M3-0010ND-12
15	27	M3-0015PD-12	M3-0015ND-12
20	34	M3-0020PD-12	M3-0020ND-12
25	43	M3-0025PD-12	M3-0025ND-12
30	51	M3-0030PD-12	M3-0030ND-12
40	66	M3-0040PD-12	M3-0040ND-12
50	82	M3-0050PD-12	M3-0050ND-12
60	97	M3-0060PD-12	M3-0060ND-12
75	121	M3-0075PD-12	M3-0075ND-12
100	157	M3-0100PD-12	M3-0100ND-12

* 8% THID Guaranteed
5% THID (typical at rated load)

These filters typically offer < 5% THID at rated load and are guaranteed to provide < 8% THID from 0% to 100% load.

HP	Max Load Amps	8% THID Filters	
		Open Panel	Nema 1
3	6	M3-0003PD-8	M3-0003ND-8
5	10	M3-0005PD-8	M3-0005ND-8
7.5	14	M3-0007PD-8	M3-0007ND-8
10	18	M3-0010PD-8	M3-0010ND-8
15	27	M3-0015PD-8	M3-0015ND-8
20	34	M3-0020PD-8	M3-0020ND-8
25	43	M3-0025PD-8	M3-0025ND-8
30	51	M3-0030PD-8	M3-0030ND-8
40	66	M3-0040PD-8	M3-0040ND-8
50	82	M3-0050PD-12	M3-0050ND-8
60	97	M3-0060PD-8	M3-0060ND-8
75	121	M3-0075PD-8	M3-0075ND-8
100	157	M3-0100PD-8	M3-0100ND-8

125	197	M3-0125PD-12	M3-0125ND-12
150	228	M3-0150PD-12	M3-0150ND-12
200	304	M3-0200PD-12	M3-0200ND-12
250	382	M3-0250PD-8	M3-0250ND-12
300	457	M3-0300PD-12	M3-0300ND-12

125	197	M3-0125PD-8	M3-0125ND-8
150	228	M3-0150PD-8	M3-0150ND-8
200	304	M3-0200PD-8	M3-0200ND-8
250	382	M3-0250PD-8	M3-0250ND-8
300	457	M3-0300PD-8	M3-0300ND-8

Minimum system requirements to achieve guaranteed performance:

Source Impedance:	1.5% min to 6.0% max
System Voltage:	480 volts (line to line), 60hz
Balanced Line Voltage	within 1%
Background voltage distortion	0% THVD

5% THID Filters: The basic construction of the 5% THID filter uses the 8% THID filter module and a separate output stage reactor. Panel mounted versions will consist of the 8% THID module and a separate reactor to be customer mounted.

It's easy to upgrade a 8% THID filter to 5% THID.
8% THID filters can easily be modified in the field to achieve 5% THID, by adding the output stage reactor to the standard 8% THID module. See reactor selection table to order this if desired.

NOTE: If source impedance is less than 1.5% impedance, you will need to add an input reactor of at least 1.5% impedance in order to have guaranteed performance. For best value and performance, choose a 3% line reactor whenever source impedance is less than 1.5%. **See reactor selection table** to order this if required.

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380 - 415 Volts, 50Hz Selection Tables

The input current ratings of motor drives can vary significantly among different drive manufacturers. This selection table offers a generic method of selection suitable for most adjustable speed drives. Refer to the filter maximum load current rating to verify proper selection.

* 12% THID Guaranteed
8% THID (typical at rated load)

These filters typically offer < 8% THID at rated load and are guaranteed to provide < 12% THID from 0% to 100% load.

HP	Max Load Amps	12% THID Filters	
		Open Panel	Nema 1
3	6	M3-0003PC-12	M3-0003NC-12
5	10	M3-0005PC-12	M3-0005NC-12
7.5	14	M3-0007PC-12	M3-0007NC-12
10	18	M3-0010PC-12	M3-0010NC-12
15	27	M3-0015PC-12	M3-0015NC-12
20	34	M3-0020PC-12	M3-0020NC-12
25	43	M3-0025PC-12	M3-0025NC-12
30	51	M3-0030PC-12	M3-0030NC-12
40	66	M3-0040PC-12	M3-0040NC-12
50	82	M3-0050PC-12	M3-0050NC-12
60	97	M3-0060PC-12	M3-0060NC-12
75	121	M3-0075PC-12	M3-0075NC-12
100	157	M3-0100PC-12	M3-0100NC-12
125	197	M3-0125PC-12	M3-0125NC-12
150	228	M3-0150PC-12	M3-0150NC-12
200	304	M3-0200PC-12	M3-0200NC-12
250	382	M3-0250PC-8	M3-0250NC-12
300	457	M3-0300PC-12	M3-0300NC-12

* 8% THID Guaranteed
5% THID (typical at rated load)

These filters typically offer < 5% THID at rated load and are guaranteed to provide < 8% THID from 0% to 100% load.

HP	Max Load Amps	8% THID Filters	
		Open Panel	Nema 1
3	6	M3-0003PC-8	M3-0003NC-8
5	10	M3-0005PC-8	M3-0005NC-8
7.5	14	M3-0007PC-8	M3-0007NC-8
10	18	M3-0010PC-8	M3-0010NC-8
15	27	M3-0015PC-8	M3-0015NC-8
20	34	M3-0020PC-8	M3-0020NC-8
25	43	M3-0025PC-8	M3-0025NC-8
30	51	M3-0030PC-8	M3-0030NC-8
40	66	M3-0040PC-8	M3-0040NC-8
50	82	M3-0050PC-12	M3-0050NC-8
60	97	M3-0060PC-8	M3-0060NC-8
75	121	M3-0075PC-8	M3-0075NC-8
100	157	M3-0100PC-8	M3-0100NC-8
125	197	M3-0125PC-8	M3-0125NC-8
150	228	M3-0150PC-8	M3-0150NC-8
200	304	M3-0200PC-8	M3-0200NC-8
250	382	M3-0250PC-8	M3-0250NC-8
300	457	M3-0300PC-8	M3-0300NC-8

Minimum system requirements to achieve guaranteed performance:

Source Impedance:	1.5% min to 6.0% max
System Voltage:	380 to 415 volts (line to line), 50hz
Balanced Line Voltage	within 1%
Background voltage distortion	0% THVD

NOTE: If source impedance is less than 1.5% impedance, you will need to add an input reactor of at least 1.5% impedance in order to have guaranteed performance. For best value and performance, choose a 3% line reactor whenever source impedance is less than 1.5%. **See reactor selection table** to order this if required.

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Matrix™ Harmonic Filters

Application Notes & Data

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- *Matrix Technical User Manuals*

Application Notes

Solving DC Drive Harmonics with Matrix Harmonic Filters Available in PDF.

Application Data

12% THID Filters (480V, 60Hz)

Catalog Number	Total Watts	Maximum Load Amps	No Load Current (amps)
M3-0003PD-12	47	6	1.7
M3-0005PD-12	66	10	2.3
M3-0007PD-12	98	14	4
M3-0010PD-12	114	18	4.6
M3-0015PD-12	166	27	8
M3-0020PD-12	204	34	11
M3-0025PD-12	275	43	11
M3-0030PD-12	295	51	16
M3-0040PD-12	390	66	16
M3-0050PD-12	475	82	23
M3-0060PD-12	586	97	23
M3-0075PD-12	659	121	28
M3-0100PD-12	837	157	41
M3-0125PD-12	971	197	64
M3-0150PD-12	1018	228	81
M3-0200PD-12	1521	304	101

8% THID Filters (480V, 60Hz)

Catalog Number	Output Reactor Included	Total Watts	Maximum Load Amps	No Load Current (amps)
M3-0003PD-8	RL-00804	40	6	1.7
M3-0005PD-8	RL-00802	63	10	2.3
M3-0007PD-8	RL-01202	98	14	4
M3-0010PD-8	RL-01803	108	18	4.6
M3-0015PD-8	RL-02502	170	27	8
M3-0020PD-8	RL-03502	212	34	11
M3-0025PD-8	RL-03502	257	43	11
M3-0030PD-8	RL-04502	323	51	16
M3-0040PD-8	RL-05502	374	66	16
M3-0050PD-8	RL-08002	506	82	23
M3-0060PD-8	RL-08002	584	97	23
M3-0075PD-8	RL-10002	655	121	28
M3-0100PD-8	RL-13002	838	157	41
M3-0125PD-8	RL-16002	1051	197	64
M3-0150PD-8	RL-20002	1057	228	81
M3-0200PD-8	RL-25002	1775	304	101

Matrix™ Harmonic Filters

Dimensions

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12% THID Panel Mounted Filters

Catalog Number	Weight Lbs/kg	Magnetics Panel			Capacitor Panel			
		Width in/mm	Height in/mm	Depth in/mm	Width in/mm	Height in/mm	Depth in/mm	# Panels Required
M3-0003PD-12	27/12.3	9/228.5	17/431.8	7.5/190.5	Capacitors included on magnetics panel. Separate capacitor panel is not required.			
M3-0005PD-12	35/15.9	9/228.5	17/431.8	7.5/190.5				
M3-0007PD-12	35/15.9	9/228.5	17/431.8	7.5/190.5				
M3-0010PD-12	45/20.5	9/228.5	17/431.8	7.5/190.5				
M3-0015PD-12	50/22.7	13/330.2	17/431.8	7.75/197				
M3-0020PD-12	85/39	13/330.2	17/431.8	9.75/247.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0025PD-12	85/39	13/330.2	17/431.8	9.75/247.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0030PD-12	105/48	13/330.2	17/431.8	9.75/247.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0040PD-12	125/57	13/330.2	17/431.8	9.75/247.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0050PD-12	150/68	17/431.8	17/431.8	10.5/266.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0060PD-12	150/68	17/431.8	17/431.8	10.5/266.7	6.5/165.1	12/304.8	11.65/295.9	1
M3-0075PD-12	200/91	17/431.8	17/431.8	10.5/266.7	6.5/165.1	15/381	11.65/295.9	1
M3-0100PD-12	215/97	21/533.4	21/533.4	11/279.4	6.5/165.1	15/381	11.65/295.9	2
M3-0125PD-12	250/114	21/533.4	21/533.4	11/279.4	6.5/165.1	15/381	11.65/295.9	2
M3-0150PD-12	275/125	21/533.4	21/533.4	11/279.4	6.5/165.1	15/381	11.65/295.9	3
M3-0200PD-12	380/173	25/635	38/965.2	16/406.4	25/635	38/965.2	16/406.4	1
M3-0250PD-12	450/205	25/635	38/965.2	16/406.4	25/635	38/965.2	16/406.4	1
M3-0300PD-12	575/261	25/635	38/965.2	16/406.4	25/635	38/965.2	16/406.4	1

8% THID Panel Mounted Filters:

8% THID filters use the standard 12% THID panel(s) and a separately mounted (open type) AC line Reactor.
Use this table to select reactors to increase source impedance or to convert to 12% THID filter to an 8% THID filter.

Matrix™ Harmonic Filters

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3-10 HP	**75 HP**
15 HP	**100-150 HP**
20-40 HP	**200-300 HP Vertical Mounting**
50-60 HP	**200-300 HP Horizontal Mounting**

(Dimensions subject to change, consult factory for certified drawings)

Harmonic Analysis Software

MTE Corporation has created a visual basic program that performs harmonic analysis.

To Download this file, please visit our website www.mtecorp.com.

NOTE: This link will open a browser window (you must have a connection to the internet to access the website).

DC Link Chokes

Detailed Product Data

- ***DC Bus Reactors***
- ***DC Link Chokes***

1000 Volts DC
Filters 300/360 Hz Ripple Current

DC Link Reactors from MTE Corporation offer an economical solution to several power quality issues related to variable speed drives and inverters. Add them in series with the internal DC bus to:

- Reduce AC Input Line Harmonics
- Help Meet IEEE-519 Limits
- Absorb Voltage/Current Spikes
- Reduce dV/dT and dI/dT rates
- Solve nuisance overvoltage tripping
- Reduce DC Bus Transient Overvoltage

Detailed Product Data

Site Search | Calendar of Events | Company Profile | Sitemap
Power Quality Products | Technical Articles | Information Desk | Contact MTE

DC Link Chokes from MTE Corporation offer an economical solution to several power quality issues related to variable speed drives and inverters. Add them in series with the internal DC bus to:

- **Reduce AC input line harmonics**
- **Help meet IEEE-519 limits**
- **Absorb voltage/current spikes**
- **Reduce AC ripple on DC bus**
- **Reduce dv/dt and di/dt rates**
- **Solve nuisance overvoltage tripping**
- **Reduce DC Bus transient overvoltage**

1,000 Volts DC
Filters 360 Hz Ripple Current

Use **DC Link Chokes** in many applications such as:

- **AC PWM inverters/drives**
- **DC to AC inverters**
- **Variable frequency motor drives**
- **Electric vehicle inverters**

When added **between the input rectifier and bus capacitor** the link choke will affect the DC bus waveform and the AC input waveform. In this location the DC reactor will reduce the amount of AC ripple on the DC bus, reduce the AC input line harmonics and offer protection against nuisance tripping due to voltage spikes such as those caused by capacitor switching.

DC link chokes offer the advantage of maximizing the circuit inductance for power quality reasons, but without causing an AC input line voltage drop. DC link chokes can be used individually, typically on the positive DC bus, or in pairs with one each on both the positive and negative bus. When two DC reactors are used on the bus, the inductance is additive. You will need twice as much inductance on the DC bus as used on the AC input (per phase) to accomplish the same performance experienced with AC input reactors. For best performance combine the use of both an AC input reactor and a DC link choke.

MTE Corporation DC Link Chokes are an economical means of filtering and controlling the DC bus voltage and current in a variable speed drive/inverter. They help reduce AC input line current harmonic distortion while absorbing DC bus voltage spikes. Link Chokes add protection and filtering but should not be considered a direct alternative to AC input or output reactors. While DC Link Chokes increase the internal filtering and have the ability to absorb spikes, because of their circuit location they do not protect the input bridge rectifier. They do not offer protection for the inverter output circuit due to their location on the DC bus.

DC AMPS	INDUCTANCE mH	CAT. NO
1	35.00	1RB001
1	60.00	1RB002
1	80.00	1RB003
2	10.00	2RB001
2	15.00	2RB002
2	20.00	2RB003
2	50.00	2RB004
4	5.00	4RB001
4	12.00	4RB002
4	15.00	4RB003
4	25.00	4RB004
9	2.00	9RB001
9	3.22	9RB002
9	7.50	9RB003
9	11.50	9RB004
12	1.00	12RB001
12	2.10	12RB002
12	4.00	12RB003
12	6.00	12RB004
18	0.65	18RB001
18	1.375	18RB002
18	2.75	18RB003
18	3.75	18RB004
18	6.00	18RB005
25	0.45	25RB001
25	1.00	25RB002
25	1.275	25RB003
25	1.75	25RB004
25	4.00	25RB005
32	0.85	32RB001
32	1.62	32RB002
32	2.68	32RB003

DC AMPS	INDUCTANCE mH	CAT NO.
40	0.50	40RB001
40	0.75	40RB002
40	1.00	40RB003
40	2.50	40RB004
50	0.625	50RB001
50	0.97	50RB002
50	1.35	50RB003
50	2.00	50RB004
62	0.32	62RB001
62	0.61	62RB002
62	0.67	62RB003
62	1.20	62RB004
62	1.50	62RB005
80	0.31	80RB001
80	0.40	80RB002
80	0.50	80RB003
80	0.75	80RB004
80	1.25	80RB005
92	0.20	92RB001
92	0.60	92RB002
92	1.00	92RB003
110	0.25	110RB001
110	0.30	110RB002
110	0.45	110RB003
125	0.11	125RB001
125	0.22	125RB002
125	0.50	125RB003
125	0.85	125RB004
150	0.15	150RB001
150	0.22	150RB002
150	0.32	150RB003
150	0.65	150RB004

DC AMPS	INDUCTANCE mH	CAT NO.
200	0.12	200RB001
200	0.21	200RB002
200	0.40	200RB003
200	0.50	200RB004
240	0.09	240RB001
240	0.25	240RB002
240	0.35	240RB003
300	0.08	300RB001
300	0.135	300RB002
300	0.32	300RB003
450	0.055	450RB001
450	0.11	450RB002
450	0.14	450RB003
450	0.25	450RB004
500	0.043	500RB001
500	0.09	500RB002
500	0.14	500RB003
500	0.19	500RB004
600	0.04	600RB001
600	0.11	600RB002
600	0.18	600RB003
700	0.044	700RB001
700	0.06	700RB002
700	0.15	700RB003
850	0.036	850RB001
850	0.065	850RB002
850	0.11	850RB003
1000	0.02	1000RB001
1000	0.042	1000RB002
1000	0.10	1000RB003

SPECIFICATIONS:

- UL-508 Component recognized (File #El 80243)
- 1000 Volts DC maximum
- For ripple frequency of 300hz or 360hz
- 50 C Temperature rise
- Suitable for 40 C ambient temperature
- Class B Insulation System (130 C)
- Suitable for ripple current of 10% peak-to-peak
- Touch safe terminals in many ratings

SPECIAL FEATURES:

- Solid Copper Box lug type terminals on most sizes
- Specially constructed and Epoxy impregnated for low noise
- Customized ratings also available - Contact the factory for custom mounting, inductance, current or ripple requirements.

Matrix™ Harmonic Filters

Product Overview

- ***Product Overview***
- ***Performance Characteristics***
- ***Theory of Operation***
- ***Selection Tables***
- ***Application Notes & Data***
- ***Dimensions***
- ***Outline Drawings***
- ***Download Harmonic Analysis Software***
- ***Matrix Harmonic Filters Specifications PDF.***
- ***Matrix Technical User Manuals***

Now Available! **380 - 415 Volts, 50HZ Selection Tables**

***The Matrix Harmonic filters have replaced our former broad band harmonic filters.

Best Economical Solution To Harmonics

Matrix Harmonic Filters provide broad band reduction of harmonics and can increase true power factor. Not only do they improve upon former broad band filtering and 12-pulse harmonic reduction techniques, but they are also suitable for a wider range of applications. Matrix Harmonic Filters can be installed in either variable torque or constant torque applications and can be applied on either diode or SCR rectifiers. Matrix Harmonic Filters offer the best value for harmonic filtering.

Typical Applications

Use Matrix Harmonic Filters to minimize harmonic current distortion in these and other 6-pulse rectifier applications:

- Fans and Pumps
- Water Treatment Facilities
- HVAC Systems
- AC or DC Motor Drives
- Diode or SCR Rectifiers
- Rectifier Type Welders
- Induction Heating Equipment
- UPS Equipment
- Elevators

PERFORMANCE GUARANTEE

Select and install the appropriate Matrix Harmonic Filter in a variable torque AC variable frequency drive application, within our published system limits and we guarantee that the input current distortion will be less than or equal to the 12% THID or TDD (for filters purchased with -12 suffix) or 8% THID or TDD (for filters purchased with the -8 suffix). This performance guarantee applies for loading conditions ranging from 0% to 100% load. If a properly sized and installed filter fails to meet its specified THID or TDD level, MTE will provide necessary modifications or a replacement filter at no charge.

Matrix filters can also provide similar performance in other drive applications such as constant torque, DC drives and other phase controlled rectifiers, but actual THID or TDD levels can vary by load and/or speed and therefore cannot be guaranteed. Consult factory for assistance when applying Matrix filters on these types of equipment.

(Subject to Minimum System Requirements)

Suitable For All Six-Pulse Rectifiers

Matrix Harmonic Filters can be used with virtually all types of six-pulse rectifiers including six diodes, six SCRs or 3-diodes with 3-SCRs. They are suitable for use with both SCR pre-charge and full phase control front ends. Use the Matrix Harmonic Filters on any six pulse rectifier regardless of whether or not it has an internal ac line reactor or dc link choke.

Solve Power Quality Problems

Matrix Harmonic Filters solve more than just harmonic distortion problems. They also provide series impedance to a drive protecting against voltage spikes which otherwise could cause overvoltage tripping or damage to the drive components. Additionally, they:

- **Protect** upstream equipment including capacitors, conductors and transformers from the damaging effects of harmonics,
- **Prevent** nuisance tripping of circuit breakers or fuse blowing which can result from the presence of harmonics,
- **Improve** system voltage waveform, and
- **Minimize** interference with other equipment

Meet IEEE-519

Matrix Harmonic Filters enable most ac drive systems to comply with both the current and voltage distortion limits of IEEE-519 and other international harmonic distortion standards such as AS-2279, BS G5/4, and EN61000-3-4.

IEEE-519 Current Distortion Limits

ISC/ IL	TDD (total demand distortion)
<20	5%
20 < 50	8%
50 < 100	12%
100 < 1000	15%
> 1000	20%

IEEE-519 Voltage Distortion Limits

Special Applications (hospitals, airports)	3%
General system applications	5%
Dedicated systems (100% convertor load)	10%

System Analysis Not Required If applied correctly within their published system limits, Matrix Harmonic Filters will not create system resonance conditions or import harmonics from other sources.

UL Listed (UL-508C) Matrix Harmonic Filters are UL listed (File E180243) for both USA and Canada.

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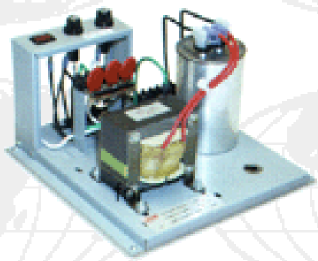
3rd Harmonic Filters



Detailed Product Data

- ***Single Phase***
- ***120 & 240 Volts AC***
- ***50 & 60 Hz Versions***

3rd Harmonic Filters
Solve Harmonic Distortion Problems

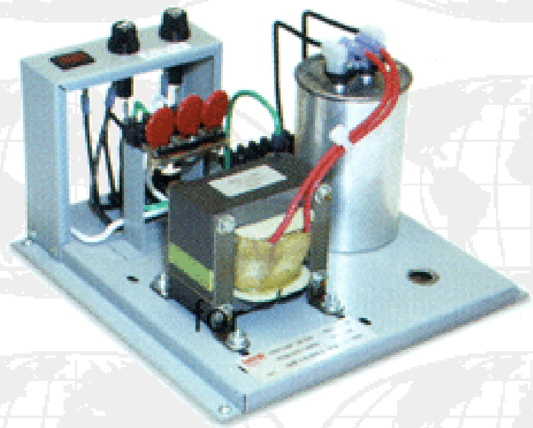
3rd Harmonic Filters by MTE Corporation will substantially reduce harmonic currents caused by:

- Personal Computers
- Electronic Ballasts
- Lighting Dimmer Controls
- Uninterruptible Power Supplies
- 1-Phase Motor Drives/Inverters

Use 3rd Harmonic Filters to:

- Reduce Neutral Currents
- Reduce Transformer Loading
- Protect Electrical Systems
- Reduce Fire Hazard
- Improve Power Factor

Detailed Product Data
Download Harmonic Analysis Software



3rd Harmonic Filters

Single Phase 50Hz or 60Hz

The Benefits of Using MTE's 3rd Harmonic Filters:

- Reduce Triplen Harmonics
- Reduce Neutral Current
- Minimize Dangerous Third Harmonics

For Application Engineering Assistance,
E-Mail: apprengrg@mtecorp.com

Harmonic Reduction

The 3rd Harmonic Filter reduces each of the individual harmonics from 3rd through 9th. Typical reduction of the 3rd harmonic is often as much as 80%-90%. Triplen harmonics, which add together in the neutral conductor, are minimized with this filter.

Reduce System Re-Wiring Costs

The presence of triplen harmonics may require that you increase the neutral conductor size on your electrical system or to replace standard transformers with K-factor rated transformers. The use of our 3rd Harmonic Filter may allow you to save these costs because the triplen harmonic can be reduced significantly.

Packaging Options

The 3rd Harmonic Filter is available as an open chassis type Hard Wire version. Use the Hard Wire version for industrial panel wiring applications where the load is directly wired to the filter.

The International Power Quality Resource

Hardwire Style Filter

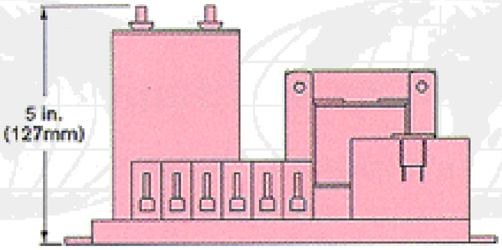
Selection Table

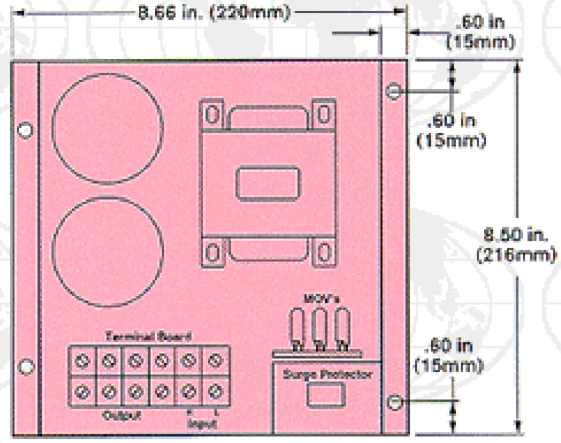
Volts	Amps	Style	Outlets	Cat. No
120	5	Hard-Wire	0	5PHF
120	10	Hard-Wire	0	10PHF
120	15	Hard-Wire	0	15PHF
240	5	Hard-Wire	0	5PHF2
240	10	Hard-Wire	0	10PHF2
240	15	Hard-Wire	0	15PHF2

For 50 HZ: Add suffix "X" and specify country. For higher current ratings consult factory.

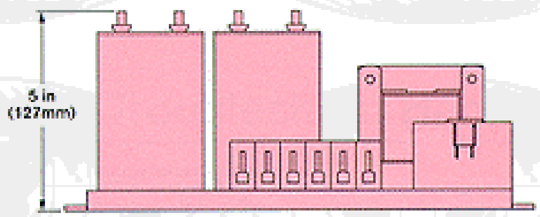
3rd Harmonic Filters, by MTE Corporation, utilize passive blocking filter technology to attenuate the unwanted harmonics associated with single phase, non-linear loads (3rd, 5th, 7th, and 9th). Because we utilize an in-line filter concept, there is no concern about system resonance or filter overloading problems that may exist when using parallel or shunt type filters.

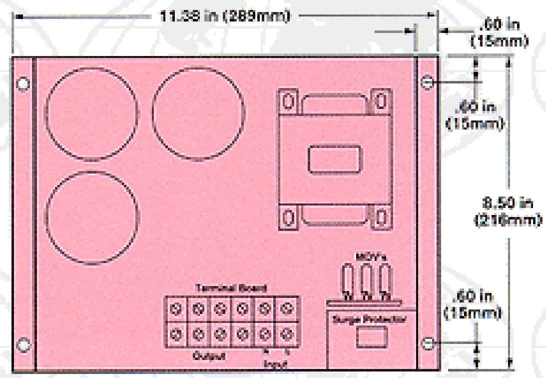
Model 5PHF





Model 10-15PHF



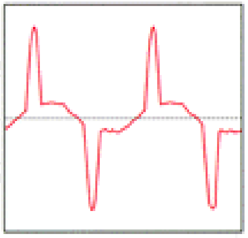


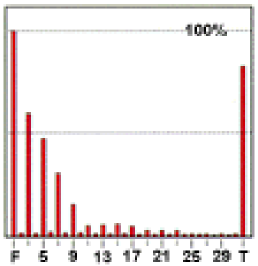
Specifications

Model	Amps	Volts	VA	Width (in./mm)	Depth (in./mm)	Height (in./mm)
5PHF	5	120	600	8.66/220	8.5/216	5/127
10PHF	10	120	1200	11.25/285	8.5/216	5/127
15PHF	15	120	1800	11.25/285	8.5/216	5/127
5PHF2	5	240	1200	8.66/220	8.5/216	5/127
10PHF2	10	240	2400	11.25/285	8.5/216	5/127
15PHF2	15	240	3600	11.25/285	8.5/216	5/127

Actual Performance

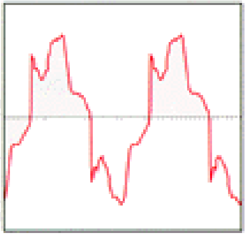
Input Current: 4- Personal Computers with No Filter

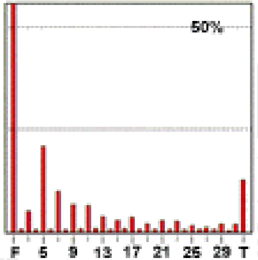




Circuit	H	%	H	%	THD thru the 31st
Total 5.9 Amps rms	3	59.2	19	2.1	% THD 82.8
Fund 4.5 Amps rms	5	46.7	21	2.4	
Har 3.7 Amps rms	7	29.3	23	2.1	% Odd 82.8
	9	14.5	25	0.8	% Even 2.5
	11	4.0	27	0.7	% Triplen 61.2
	13	4.6	29	0.6	
	15	5.5	31	0.6	K factor 10.7
	17	4.2			

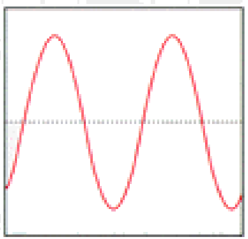
Input Current: 4- Personal Computers with 5PHF Filter

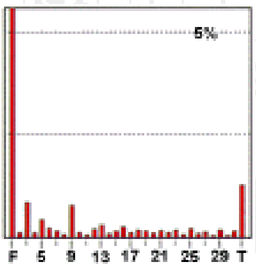




Circuit	H	%	H	%	THD thru the 31st
Total 4.35 Amps rms	3	5.1	19	2.1	% THD 26.4
Fund 4.28 Amps rms	5	20.7	21	2.9	
Har 1.11 Amps rms	7	9.7	23	2.6	% Odd 82.8
	9	6.7	25	1.3	% Even 2.5
	11	6.3	27	1.2	% Triplen 9.4
	13	3.7	29	2.0	
	15	2.7	31	2.0	K factor 5.7
	17	3.4			

Input Voltage: 4- Personal Computers with 5PHF Filter





Circuit	H	%	H	%	THD thru the 31st
Total 111.5 Volts rms	3	0.8	19	0.1	% THD 1.3
Fund 111.5 Volts rms	5	0.4	21	0.1	
Har 1.4 Volts rms	7	0.1	23	0.1	% Odd 1.2
	9	0.7	25	0.2	% Even 0.4
	11	0.0	27	0.1	% Triplen 1.1
	13	0.3	29	0.2	
	15	0.1	31	0.1	K factor 1.0
	17	0.1			

Product Overview

FI/EMI Filters

Product Overview

- ***Product Overview***
- ***Recommended Installation Practices***
- ***Circuit Diagrams***
- ***Insertion Loss***
- ***Specifications***
- ***Selection Tables***
- ***Declaration of Conformity PDF***

Type "RF" Filters Solve Noise Problems

MTE Corporation type "RF" filters offer an economical solution to many facility interference problems caused by the high frequency emissions of adjustable speed motor drives and inverters. Type "RF" filters can prevent drives and inverters from interfering with other sensitive electronic loads by reducing both common mode and differential mode noise emissions.

RFI/EMI Filters
Single Phase & Three Phase
50/60 Hertz
Available in Ratings up to 600 Volts

Typical drive and inverter applications include:

- **AC Motor Drives**
- **DC Motor Drives**
- **Uninterruptible Power Supplies**
- **Active Harmonic Filters**

Help Meet EMC Directive

The "RF" series of filters are specially designed to provide sufficient attenuation of the conducted RFI and EMI associated with adjustable speed drive and inverter applications. Usually, drive and inverter systems using these filters will be able to meet the stringent requirements of the EMC Directives (Class A) and the FCC limits for conducted noise emissions. Actual testing may be necessary to verify system compliance.

Touch Safe Construction

In compliance with international safety standards, and in conformance with the CE low voltage directive, type "RF" filters are supplied as standard with touch safe terminations on all units rated through 150 amps. Units rated higher than 150 amps, provide tab terminals for customer addition of wiring devices.

Protect Sensitive Loads From RFI / EMI

Micro-processor based equipment can be sensitive to low levels of voltage distortion and electrical noise. The "RF" series of filters is intended for installation on equipment causing the electrical noise in order to protect other sensitive electronic loads. Sensitive electronic loads, which can be protected, when the "RF" filters are applied to offending drives / inverters include:

- Micro-processor based equipment
- Computers
- Automated lighting controls
- Telecommunication equipment
- Laboratory measurement equipment
- Energy management systems
- Radio transmitters / receivers
- Television / CCTV
- Photo electric sensors

FI/EMI Filters

Recommended Installation Practices

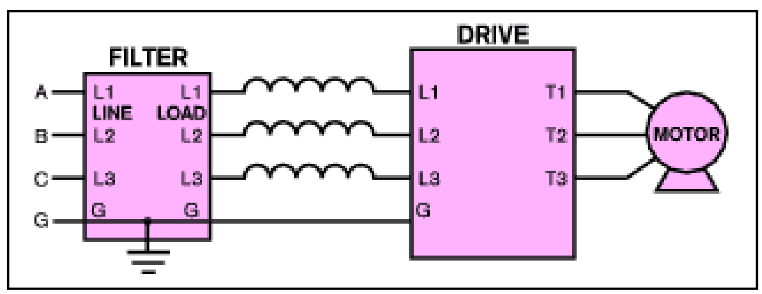
- *Product Overview*
- ***Recommended Installation Practices***
- *Circuit Diagrams*
- *Insertion Loss*
- *Specifications*
- *Selection Tables*
- *Declaration of Conformity PDF*

Filter Connection

Our type RF2 and RF3 filters are intended for use at the input side of an adjustable speed drive or inverter. Do **NOT** attempt to use these on the output (load) side of an inverter or drive.
Good wiring practices will minimize RFE/EMI problems.

- **Route all conductors as close to the panel as possible**
- **Physically separate the filter input and output conductors**
- **Keep drive input and output leads separated**
- **Always keep power and control wiring separated**
- **Use shielded wiring where possible**
- **Use single point grounding (connect system ground to filter)**

Connect the incoming power conductors to the "Line" side terminals of the filter. Connect the "Load" side terminals to the line reactor or drive input terminals. Note that the ground termination "G" may also be designated by "E" or "PE". Keep all wiring as close as possible to the grounded panel (ground plane).

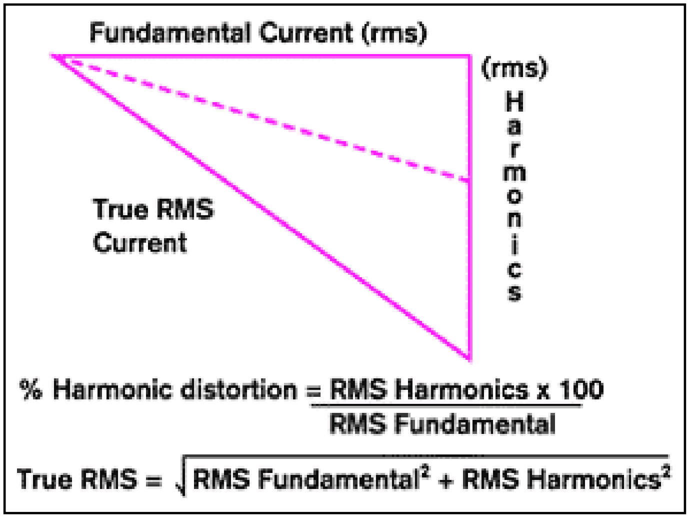


Filter Mounting

Connect the power system ground (earth connection) directly to the filter ground (earth) termination prior to connecting any other wires. Filter grounding is required to assure safety and desired filter performance. For the best ground connection, use a multi stranded copper conductor or copper strap. Mount the filter as close as possible to the RFI/EMI source (drive, inverter, UPS, etc.). For best performance, mount filter directly to a bare metal grounded panel. Use shielded conductors to minimize radiated high frequency noise levels.

Current Ratings

The "RF" series filters are rated in True RMS (trms) amperes. Harmonic current distortion will increase the trms current of a system above the fundamental current (typically motor FLA) of the connected loads. Line reactors (3% or 5% impedance) are useful in reducing harmonic current distortion and the trms current. If minimum 3% impedance line reactors are included in the installation, then the trms amperes will be lower and the filter can be sized for the reduced load current.



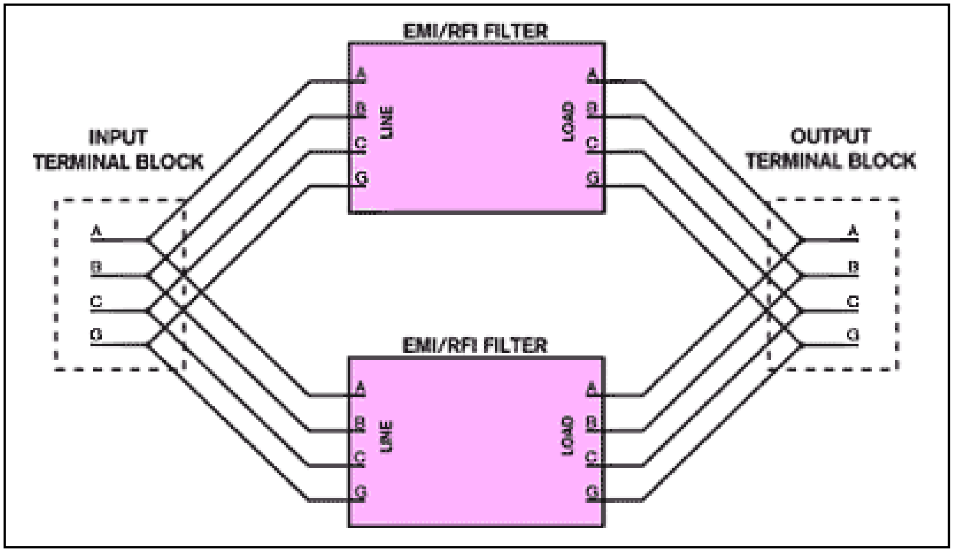
If you know the trms amperes of the load to be connected to the filter, then select the filter directly from the RMS amperes selection tables. If you are not sure of the trms amperes, you can select the filters based on the horsepower (or KW) rating of the load to be connected. Determine if a reactor (minimum 3% impedance) will be used in addition to the RFI filter and select accordingly.

Parallel Connection for Higher Ratings

Type "RF" filters may be connected in parallel to achieve higher current ratings provided that identical models are used, and the connection allows each individual filter to share current equally. The use of two separate distribution (terminal) blocks will make this easier. Derate each filter by 10% whenever connecting in a parallel configuration and always follow the NEC or local electrical codes.

Typical drive and inverter applications include:

- **AC Motor Drives**
- **DC Motor Drives**
- **Uninterruptable Power Supplies**
- **Active Harmonic Filters**



Technical Support
E-Mail: apprengrg@mtecorp.com
1-800-455-4MTE ext 218

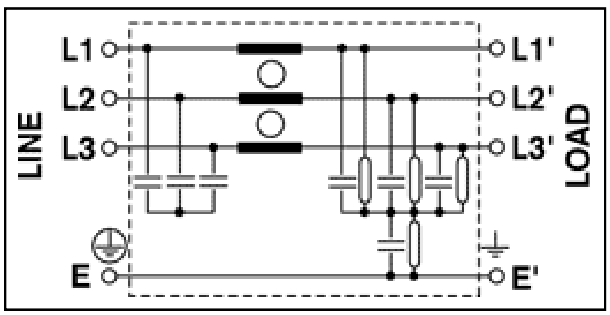
FI/EMI Filters

Circuit Diagrams

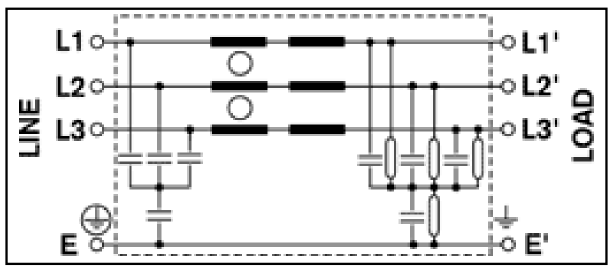
- *Product Overview*
- *Recommended Installation Practices*
- *Circuit Diagrams*
- *Insertion Loss*
- *Specifications*
- *Selection Tables*
- *Declaration of Conformity PDF*

Three Phase Filters

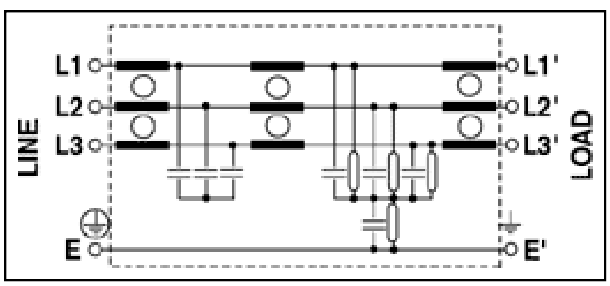
Circuit D



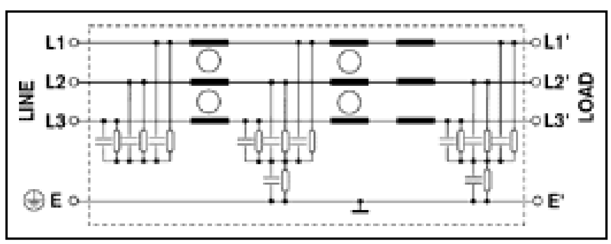
Circuit J



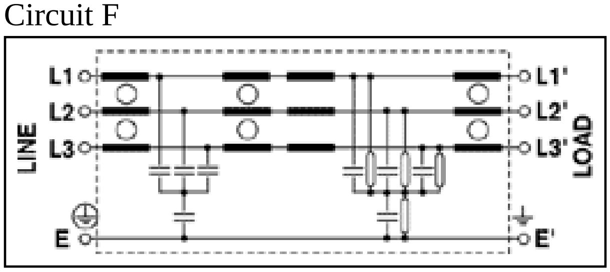
Circuit E



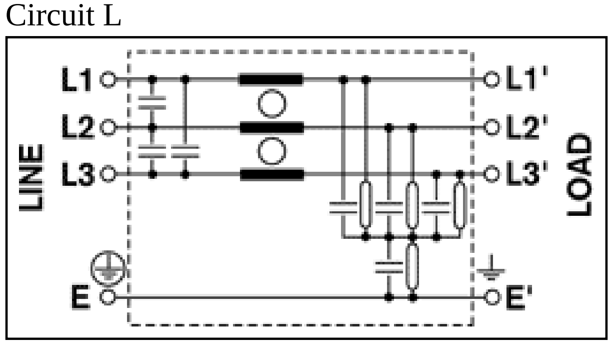
Circuit K



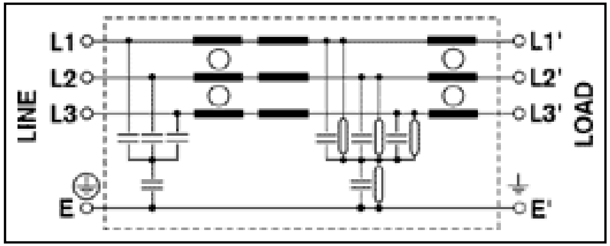
Circuit F



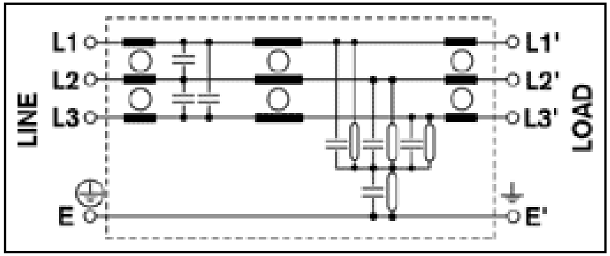
Circuit L



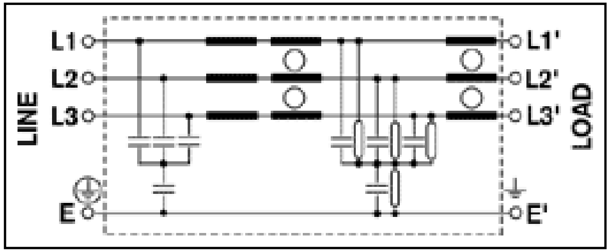
Circuit G



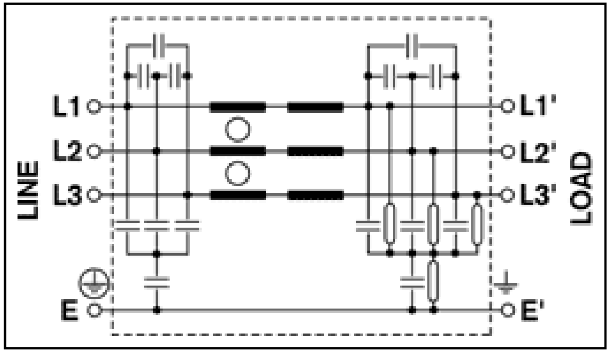
Circuit M



Circuit H

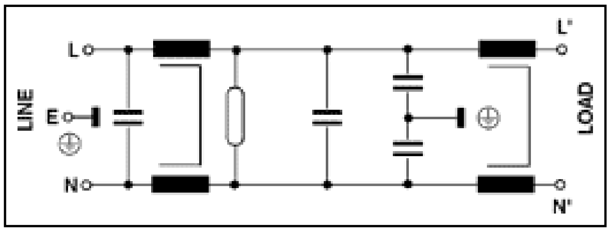


Circuit N



Single Phase Filters

Circuit U



FI/EMI Filters

Insertion Loss

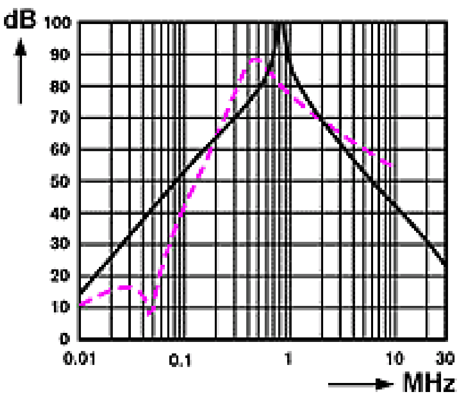
- *Product Overview*
- *Recommended Installation Practices*
- *Circuit Diagrams*
- *Insertion Loss*
- *Specifications*
- *Selection Tables*
- *Declaration of Conformity PDF*

INSERTION LOSS:

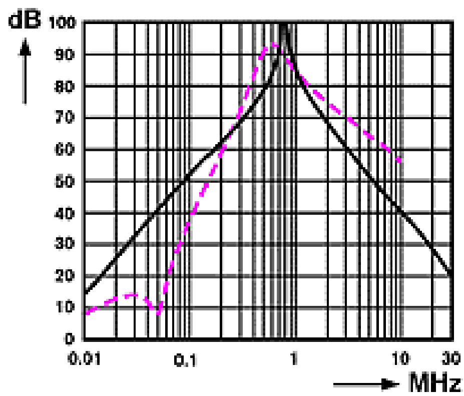
Insertion loss data illustrates the typical reduction of both common mode and differential mode noise based on the standard test circuit. Common mode noise occurs between a phase or neutral conductor and ground, while differential mode noise occurs between phase conductors or between phase and neutral conductors.

Three Phase Filters

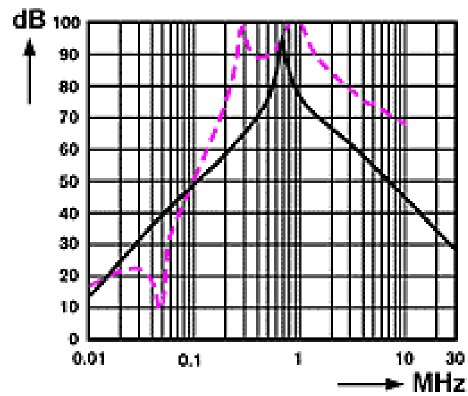
RF3-0006-4
RF3-0006-6



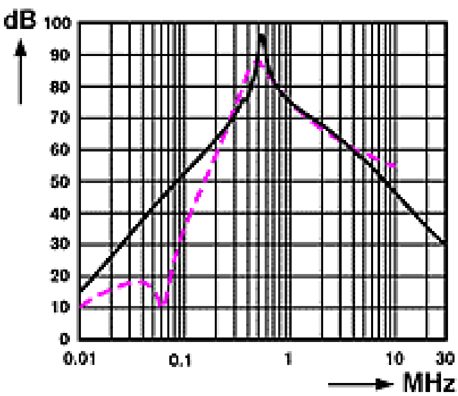
RF3-0010-4
RF3-0010-6



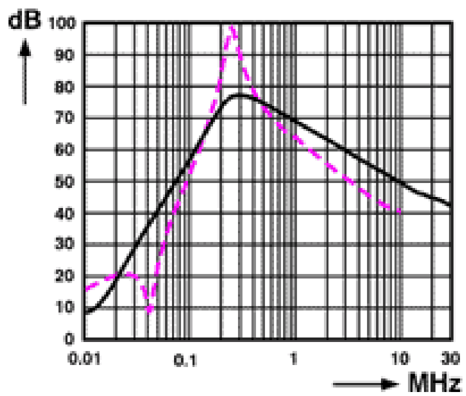
RF3-0018-4
RF3-0018-6



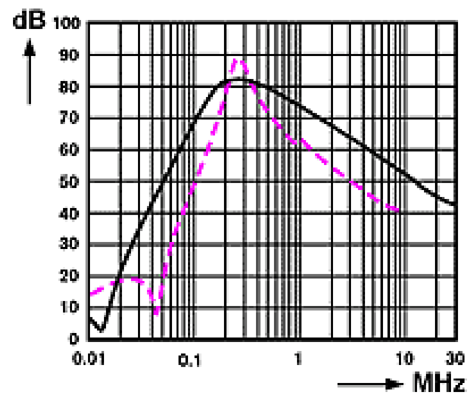
RF3-0025-4
RF3-0025-6



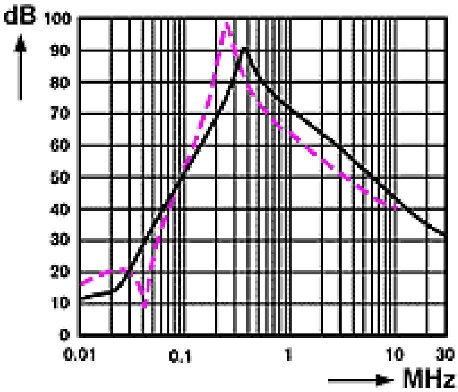
RF3-0033-4
RF3-0033-6



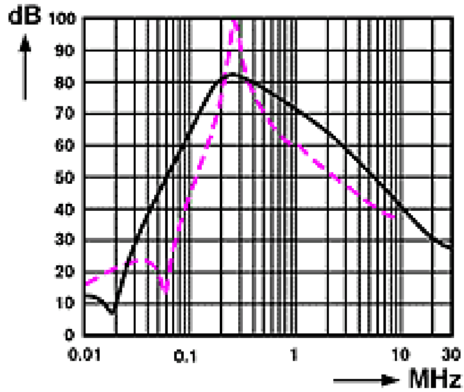
RF3-0050-4
RF3-0050-6



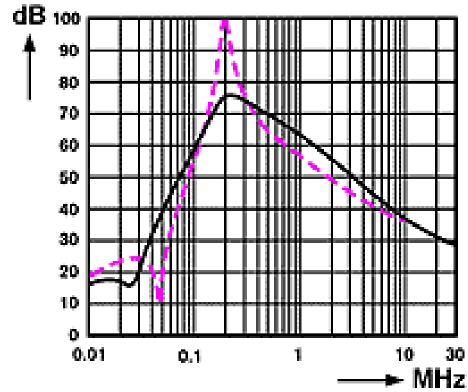
RF3-0070-4
RF3-0070-6



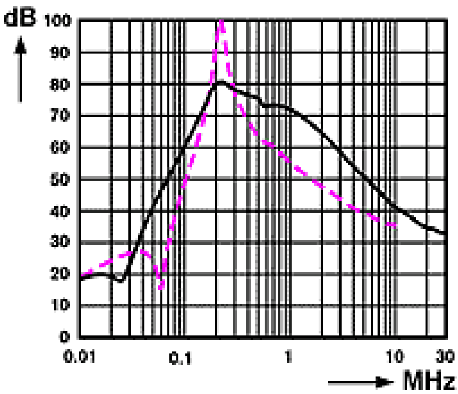
RF3-0090-4
RF3-0090-6



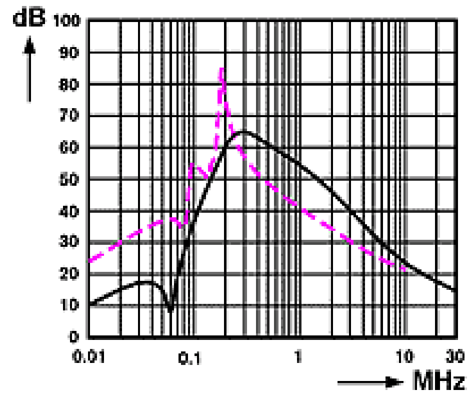
RF3-0130-4
RF3-0130-4
RF3-0130-6



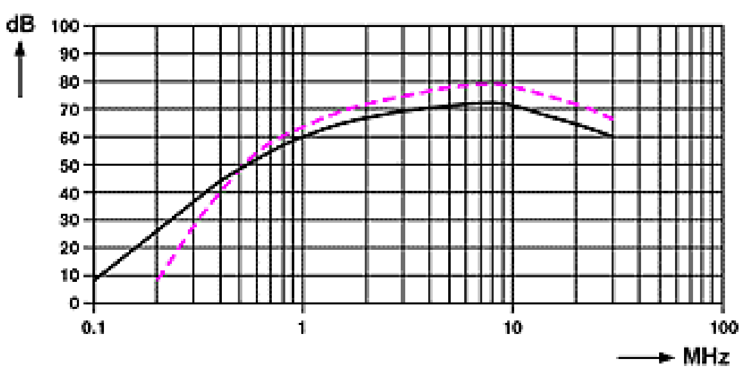
RF3-0150-4



RF3-0130-4
RF3-0330-4



RF2-01010-2
RF2-01016-2
RF2-01020-2



FI/EMI Filters

Specifications

- *Product Overview*
- *Recommended Installation Practices*
- *Circuit Diagrams*
- *Insertion Loss*
- *Specifications*
- *Selection Tables*
- *Declaration of Conformity PDF*

Three Phase Filters

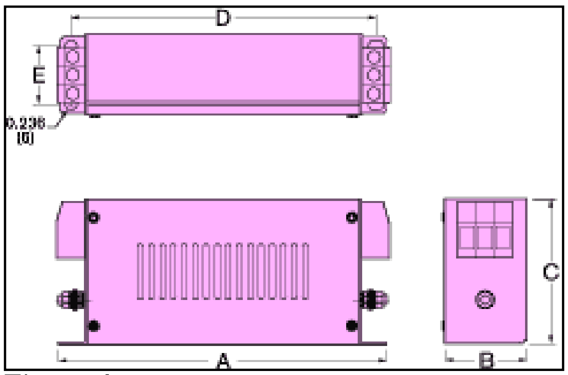


Figure A

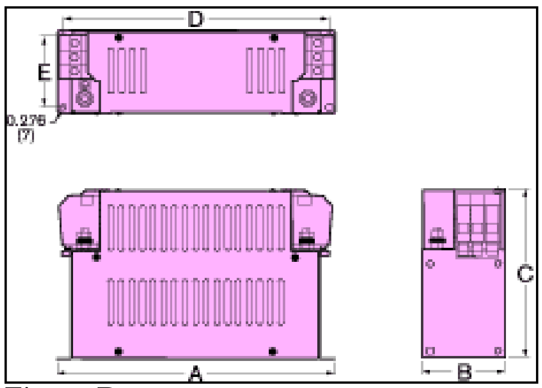


Figure B

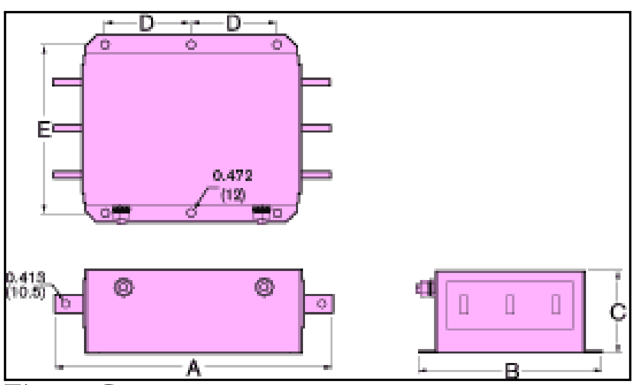


Figure C

Single Phase Filters

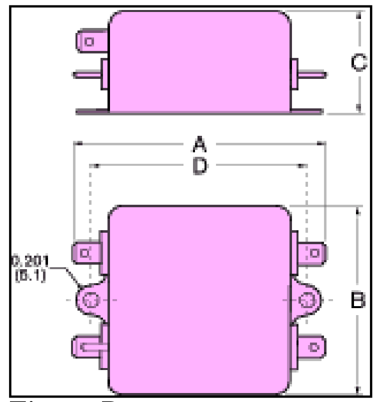


Figure P

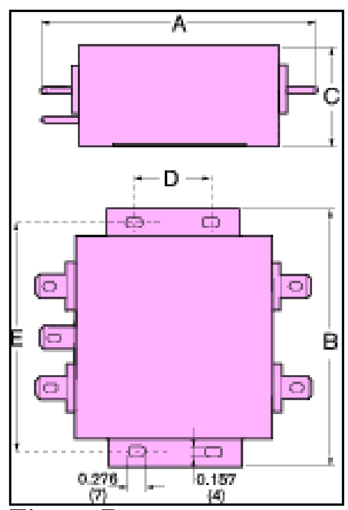


Figure R

RFI/EMI Specification Table

Part No.	Figure	Circuit	Rated Amps	A (in.)	A (mm)	B (in.)	B (mm)	C (in.)	C (mm)	
480 Volts Three-Phase (50/60 HZ)										
RF3-0006-4	A	D	6	7.0	179	1.8	45	3.1	79	

RF3-0010-4	A	D	10	7.0	179	1.8	45	3.1	79	Chart continued below
RF3-0018-4	A	D	18	9.0	229	2.2	55	.5	114	
RF3-0025-4	A	E	25	9.0	229	2.2	55	4.5	114	
RF3-0033-4	B	F	33	10.7	272	2.9	74	6.3	161	
RF3-0050-4	B	F	50	12.3	312	3.7	93	7.5	190	
RF3-0070-4	B	F	70	12.3	312	.7	93	7.5	190	
RF3-0090-4	B	G	90	12.6	319	5.0	126	8.8	224	
RF3-0130-4	B	H	130	12.6	319	5.0	126	8.8	224	
RF3-0150-4	B	J	150	13.1	334	5.0	126	8.8	224	
RF3-0330-4	C	K	330	15.2	386	10.2	260	4.6	116	

Part No.	Figure	Circuit	Rated Amps	A (in.)	A (mm)	B (in.)	B (mm)	C (in.)	C (mm)	Chart continued below
600 Volts Three-Phase (50/60 HZ)										
RF3-0006-6	A	L	6	7.2	83	1.8	45	3.1	79	
RF3-0010-6	A	L	10	7.2	183	1.8	45	3.1	7	
RF3-0018-6	A	L	18	9.2	233	2.2	55	4.5	114	
RF3-0025-6	A	M	25	9.2	233	2.2	55	4.5	114	
RF3-0033-6	B	F	33	10.7	272	2.9	74	6.3	161	
RF3-0050-6	B	F	50	12.3	312	.7	93	7.5	190	
RF3-0070-6	B	F	70	12.3	312	3.7	93	7.5	190	
RF3-0090-6	B	G	90	12.3	312	3.7	93	7.5	190	
RF3-0130-6	B	N	130	13.1	334	5.0	126	8.8	224	
RF3-0150-6	B	N	150	13.1	334	5.0	126	8.8	224	
RF3-0330-6	C	K	330	15.2	386	10.2	260	4.6	116	

Part No.	Figure	Circuit	Rated Amps	A (in.)	A (mm)	B (in.)	B (mm)	C (in.)	C (mm)	Chart continued below
240 Volts Single Phase (50/60 HZ)										
RF2-0010-2	P	U	10	3.7	93	2.1	53	1.6	40	
RF2-0016-2	P	U	16	3.7	93	2.1	53	1.6	40	
RF2-0020-2	R	U	20	4.9	125	4.1	105	1.6	40	

Part No.	D (in.)	D (mm)	E (in.)	E (mm)	Weight (lb.)	Mass (kg)	Diss. Watts	Max Wire Size AWG (mm^2)	Leakage Current (mA)	Max. Torque In-Lb	N-m
480 Volts Three-Phase (50/60 HZ)											
RF3-0006-4	6.57	167	1.26	32	1.4	0.65	3.5	11 (4)	37	7	0.8
RF3-0010-4	6.57	167	1.26	32	1.5	0.7	4.2	11 (4)	34	7	0.8
RF3-0018-4	8.54	217	1.65	42	2.4	1.1	11	7 (10)	37	18	2
RF3-0025-4	8.54	217	1.65	42	2.9	1.3	11	7 (10)	67	18	2
RF3-0033-4	10.16	258	2.36	60	6.0	2.7	16	7 (10)	81	18	2
RF3-0050-4	11.73	298	3.11	79	8.2	3.7	16	1 (35)	114	44	5
RF3-0070-4	11.73	298	3.11	79	9.3	4.2	19	1 (35)	107	44	5
RF3-0090-4	11.73	298	4.41	112	13.5	6.1	18	1 (35)	154	44	5
RF3-0130-4	11.73	298	4.41	112	13.5	6.1	25	000 (70)	154	80	9
RF3-0150-4	11.73	298	4.41	112	19.6	8.9	28	0000 (95)	396	177	20
RF3-0330-4	4.72	120	9.25	235	24.3	11	40	N/A	264	N/A	N/A

Part No.	D (in.)	D (mm)	E (in.)	E (mm)	Weight (lb.)	Mass (kg)	Diss. Watts	Max Wire Size AWG (mm2)	Leakage Current (mA)	Max. Torque In-Lb	N-m
600 Volts Three-Phase (50/60 HZ)											
RF3-0006-6	6.57	167	.26	32	1.4	0.65	3.5	9 (6)	27	16	1.8
RF3-0010-6	6.57	167	1.26	32	1.5	0.7	4.2	9 (6)	27	16	1.8
RF3-0018-6	8.54	217	1.65	42	2.4	1.1	11	9 (6)	178	16	1.8
RF3-0025-6	8.54	217	1.65	42	2.9	1.3	11	9 (6)	178	16	1.8

RF3-0033-6	10.16	258	2.36	60	6.0	2.7	16	7 (10)	119	18	2
RF3-0050-6	11.73	298	3.11	79	8.2	3.7	16	1 (35)	178	44	5
RF3-0070-6	11.73	298	3.11	79	9.3	4.2	19	1 (35)	178	44	5
RF3-0090-6	11.73	298	3.11	79	9.3	4.2	19	1 (35)	178	44	5
RF3-0130-6	11.73	298	4.41	112	19.6	8.9	28	000 (70)	297	80	9
RF3-0150-6	11.73	298	4.41	112	19.6	8.9	28	0000 (95)	297	177	20
RF3-0330-6	4.72	120	9.25	235	24.3	11	40	N/A	180	N/A	N/A

Part No.	D (in.)	D (mm)	E (in.)	E (mm)	Weight (lb.)	Mass (kg)	Diss. Watts	Max Wire Size AWG (mm2)	Leakage Current (mA)	Max. Torque In-Lb	N-m
240 Volts Single Phase (50/60 HZ)											
RF2-0010-2	2.95	75	N/A	N/A	0.5	0.23	2.8	N/A	2 x 0.21	N/A	N/A
RF2-0016-2	2.95	75	N/A	N/A	0.6	0.26	9	N/A	2 x 0.21	N/A	N/A
RF2-0020-2	2.01	51	3.74	95	1.3	0.59	12	N/A	2 x 0.21	N/A	N/A

FI/EMI Filters

Selection Tables

- *Product Overview*
- *Recommended Installation Practices*
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(Higher ratings may be accomplished by connecting two filters in parallel - consult factory for assistance.)
The filter must be sized based on the Total RMS Current. The presence of a reactor with at least 3% impedance reduces the current and, in many cases, allows the use of a smaller filter.

RFI Filter Selection Tables for Three-Phase 50/60 Hz

HP	KW	Installation **Without** an Existing Input Line Reactor (Minimum 3% Impedance)					
		208V	240V	380V	400V / 415V	480V	600V
1.0	0.75	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
1.5	1.1	RF3-0010-4	RF3-0010-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
2.0	1.5	RF3-0018-4	RF3-0010-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
3.0	2.2	RF3-0018-4	RF3-0018-4	RF3-0010-4	RF3-0010-4	RF3-0010-4	RF3-0006-6
5.0	3.7	RF3-0025-4	RF3-0025-4	RF3-0018-4	RF3-0018-4	RF3-0010-4	RF3-0010-6
7.5	5.6	RF3-0033-4	RF3-0033-4	RF3-0025-4	RF3-0018-4	RF3-0018-4	RF3-0018-6
10	7.5	RF3-0050-4	RF3-0050-4	RF3-0025-4	RF3-0025-4	RF3-0025-4	RF3-0018-6
15	11	RF3-0070-4	RF3-0070-4	RF3-0050-4	RF3-0033-4	RF3-0033-4	RF3-0025-6
20	15	RF3-0090-4	RF3-0090-4	RF3-0050-4	RF3-0050-4	RF3-0050-4	RF3-0033-6
25	19	RF3-0130-4	RF3-0130-4	RF3-0070-4	RF3-0070-4	RF3-0050-4	RF3-0050-6
30	22	RF3-0130-4	RF3-0130-4	RF3-0070-4	RF3-0070-4	RF3-0070-4	RF3-0050-6
40	30	RF3-0330-4	RF3-0150-4	RF3-0090-4	RF3-0090-4	RF3-0090-4	RF3-0070-6
50	37	RF3-0330-4	RF3-0330-4	RF3-0130-4	RF3-0130-4	RF3-0130-4	RF3-0090-6
60	45	RF3-0330-4	RF3-0330-4	RF3-0130-4	RF3-0130-4	RF3-0130-4	RF3-0090-6
75	56	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0150-4	RF3-0150-4	RF3-0130-6
100	75	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0150-6
125	93	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0330-6
150	112	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0330-6
200	150	---	---	---	---	---	RF3-0330-6

250	187	---	---	---	---	---	---
300	225	---	---	---	---	---	---

HP	KW	Installation **With** an Existing Input Line Reactor (Minimum 3% Impedance)					
		208V	240V	380V	400V / 415V	480V	600V
1.0	0.75	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
1.5	1.1	RF3-0010-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
2.0	1.5	RF3-0010-4	RF3-0010-4	RF3-0006-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
3.0	2.2	RF3-0018-4	RF3-0010-4	RF3-0010-4	RF3-0006-4	RF3-0006-4	RF3-0006-6
5.0	3.7	RF3-0018-4	RF3-0018-4	RF3-0010-4	RF3-0010-4	RF3-0010-4	RF3-0006-6
7.5	5.6	RF3-0025-4	RF3-0025-4	RF3-0018-4	RF3-0018-4	RF3-0018-4	RF3-0010-6
10	7.5	RF3-0033-4	RF3-0033-4	RF3-0018-4	RF3-0018-4	RF3-0018-4	RF3-0018-6
15	11	RF3-0050-4	RF3-0050-4	RF3-0033-4	RF3-0025-4	RF3-0025-4	RF3-0018-6
20	15	RF3-0070-4	RF3-0070-4	RF3-0033-4	RF3-0033-4	RF3-0033-4	RF3-0025-6
25	19	RF3-0090-4	RF3-0090-4	RF3-0050-4	RF3-0050-4	RF3-0050-4	RF3-0033-6
30	22	RF3-0130-4	RF3-0090-4	RF3-0050-4	RF3-0050-4	RF3-0050-4	RF3-0033-6
40	30	RF3-0130-4	RF3-0130-4	RF3-0070-4	RF3-0070-4	RF3-0070-4	RF3-0050-6
50	37	RF3-0150-4	RF3-0150-4	RF3-0090-4	RF3-0090-4	RF3-0070-4	RF3-0070-6
60	45	RF3-0330-4	RF3-0330-4	RF3-0130-4	RF3-0090-4	RF3-0090-4	RF3-0070-6
75	56	RF3-0330-4	RF3-0330-4	RF3-0130-4	RF3-0130-4	RF3-0130-4	RF3-0090-6
100	75	RF3-0330-4	RF3-0330-4	RF3-0150-4	RF3-0150-4	RF3-0150-4	RF3-0130-6
125	93	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0330-6
150	112	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0330-6
200	150	---	---	RF3-0330-4	RF3-0330-4	RF3-0330-4	RF3-0330-6
250	187	---	---	---	---	RF3-0330-4	RF3-0330-6
300	225	---	---	---	---	---	RF3-0330-6

RFI Filter Selection Tables for Single-Phase 50/60 Hz

HP	KW	Installation **Without** an Existing Input Line Reactor (Minimum 3% Impedance)		
		120V	208V	240V
0.17	0.12	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.25	0.18	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.33	0.25	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.50	0.37	RF2-0016-2	RF2-0010-2	RF2-0010-2
0.75	0.55	RF2-0020-2	RF2-0016-2	RF2-0010-2
1.00	0.75	qty 2 RF2-0016-2	RF2-0016-2	RF2-0016-2
1.5	1.1	qty 2 RF2-0016-2	RF2-0016-2	RF2-0016-2
2.0	1.5	qty 2 RF2-0020-2	RF2-0020-2	RF2-0020-2
3.0	2.2	qty 3 RF2-0020-2	qty 2 RF2-0016-2	qty 2 RF2-0016-2
5.0	3.7	---	qty 3 RF2-0020-2	qty 3 RF2-0016-2
7.5	5.5	---	---	---

HP	KW	Installation **With** an Existing Input Line Reactor (Minimum 3% Impedance)		
		120V	208V	240V
0.17	0.12	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.25	0.18	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.33	0.25	RF2-0010-2	RF2-0010-2	RF2-0010-2
0.50	0.37	RF2-0016-2	RF2-0010-2	RF2-0010-2
0.75	0.55	RF2-0020-2	RF2-0010-2	RF2-0010-2
1.00	0.75	RF2-0020-2	RF2-0016-2	RF2-0010-2
1.5	1.1	qty 2 RF2-0016-2	RF2-0016-2	RF2-0016-2
2.0	1.5	qty 2 RF2-0020-2	RF2-0020-2	RF2-0016-2
3.0	2.2	qty 3 RF2-0016-2	qty 2 RF2-0016-2	qty 2 RF2-0016-2
5.0	3.7	---	qty 3 RF2-0016-2	qty 2 RF2-0020-2
7.5	5.5	---	qty 3 RF2-0020-2	qty 3 RF2-0020-2

RFI Filter Selection Table for Three-Phase 50/60 Hz

Load Current (Total True rms)*	Supply up to 480V	Supply up to 600V
6A or less	RF3-0006-4	RF3-0006-6
10A or less	RF3-0010-4	RF3-0010-6
18A or less	RF3-0018-4	RF3-0018-6
25A or less	RF3-0025-4	RF3-0025-6
33A or less	RF3-0033-4	RF3-0033-6
50A or less	RF3-0050-4	RF3-0050-6
70A or less	RF3-0070-4	RF3-0070-6
90A or less	RF3-0090-4	RF3-0090-6
130A or less	RF3-0130-4	RF3-0130-6
150A or less	RF3-0150-4	RF3-0150-6
330A or less	RF3-0330-4	RF3-0330-6

*Including added rms magnitude due to current distortion

RFI Filter Selection Table for Single-Phase 50/60 Hz

Load Current (Total True rms)*	Supply up to 240V
10A or less	RF2-0010-2
16A or less	RF2-0016-2
20A or less	RF2-0020-2

*Including added rms magnitude due to current distortion

Surge Arrestors

Detailed Product Data

- ***3-Phase***
- ***50/60Hz, 600 volts max.***

PR-O-TECT surge arrestors help to protect sensitive electronics equipment from dangerous voltage transients and spikes.

Typical applications include:

- Adjustable Speed Drives
- SCR Controllers
- Rectifier Circuits
- Machine Tool Controls
- Packaging Equipment
- Elevator Drive Systems
- Printing Presses
- Woodworking Equipment
- Traffic Controls
- UPS Systems
- Industrial Controls

Detailed Product Data

PR-O-TECT™

For enhanced surge/spike protection, PR-O-TECT surge arrestor modules can be factory installed and wired onto a Three Phase Reactor. In this installation the reactor and surge arrestor module work together for maximum attenuation of spikes. The reactor helps to extend the module life by attenuation the most severe parts of the spike.

Installation of surge arrestor modules is simple - the green wire is connected to your system ground terminal. The other wires connect to each of your three phase conductors and the neutral if your system is a Wye power system.

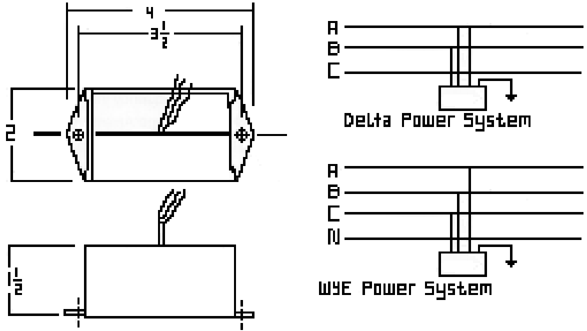
SURGE ARRESTORS

(Three Phase)

PR-O-TECT Three Phase Surge Arrestors offer protection of diodes, transistors, thyristors, SCR'S, etc. from dangerous voltage transients. They can reduce overall system operating costs by reducing equipment down time and maintenance costs, while improving system efficiency and reliability. Surge arrestors will reduce the effect of lightning and even reduce radio frequency interference. Use PR-O-TECT Surge Arrestors to protect adjustable speed drives, process control equipment, servo drives, uninterruptible power supplies and other sensitive electronic equipment.

	208 VOLTS	240 VOLTS	380 VOLTS	480 VOLTS	600 VOLTS
Part Number	M-1778	M-1777	M-1781	M-1776	M-1775
Rated AC Voltage	250	275	420	550	680
Average Power Dissipation	1 Watt	1 Watt	1 Watt	1 Watt	1 Watt
Transient Energy (Joules)	130 j	140 j	160 j	210 j	250 j
Peak Current 8/20 us (Amps)	6500	6500	6500	6500	6500
Varistor Voltage	390	430	680	910	1100
Max Clamping Voltage	650	710	1120	1500	1815
Max Clamping Current	100	100	100	100	100
Capacitance @1KHz	700pf	630pf	420pf	320pf	250pf
Response Time	<15nsec	<15nsec	<15nsec	<15nsec	<15nsec
Number of Internal MOV's	3	3	3	3	3
Number of Leads	4	4	4	4	4
Operating Temperature	from -40C to +80C				
Wire Size	All leads are 14 AWG				

Dimensions:



Product Overview

MTE CORPORATION
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Matrix™ Harmonic Filters

Outline Drawings (480V,60Hz)

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- *Performance Characteristics*
- *Theory of Operation*
- *Selection Tables*
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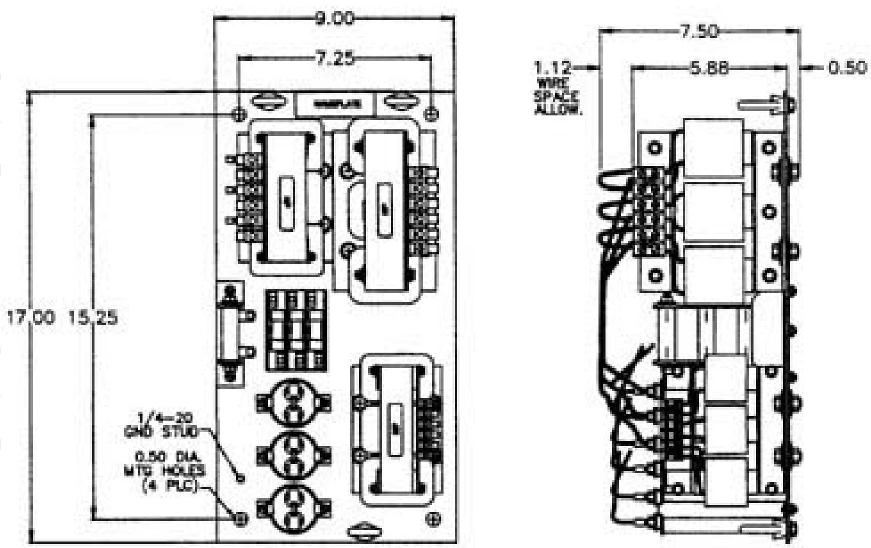
- *Download Harmonic Analysis Software*
- *Matrix Harmonic Filters Specifications PDF.*
- *Matrix Technical User Manuals*

3-10 HP

(Dimensions subject to change, consult factory for certified drawings)



3 – 10 HP

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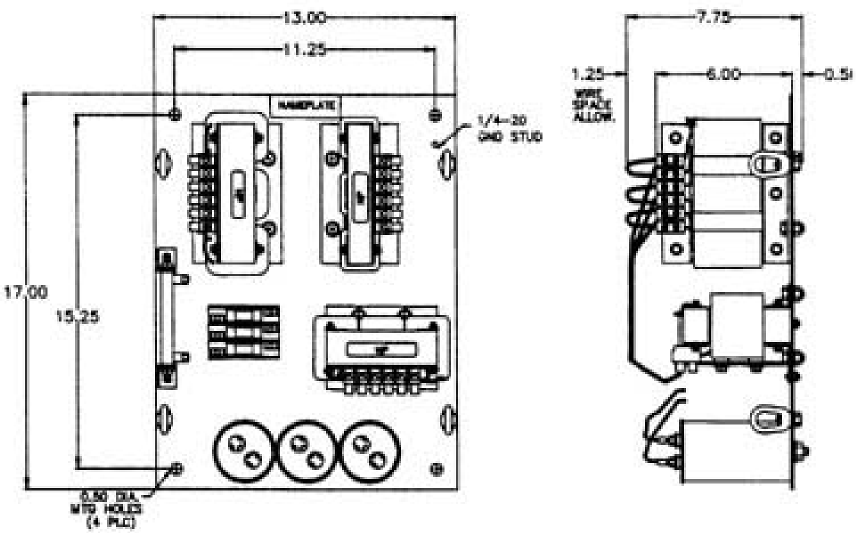
15 HP

(Dimensions subject to change, consult factory for certified drawings)



15HP

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20-40HP

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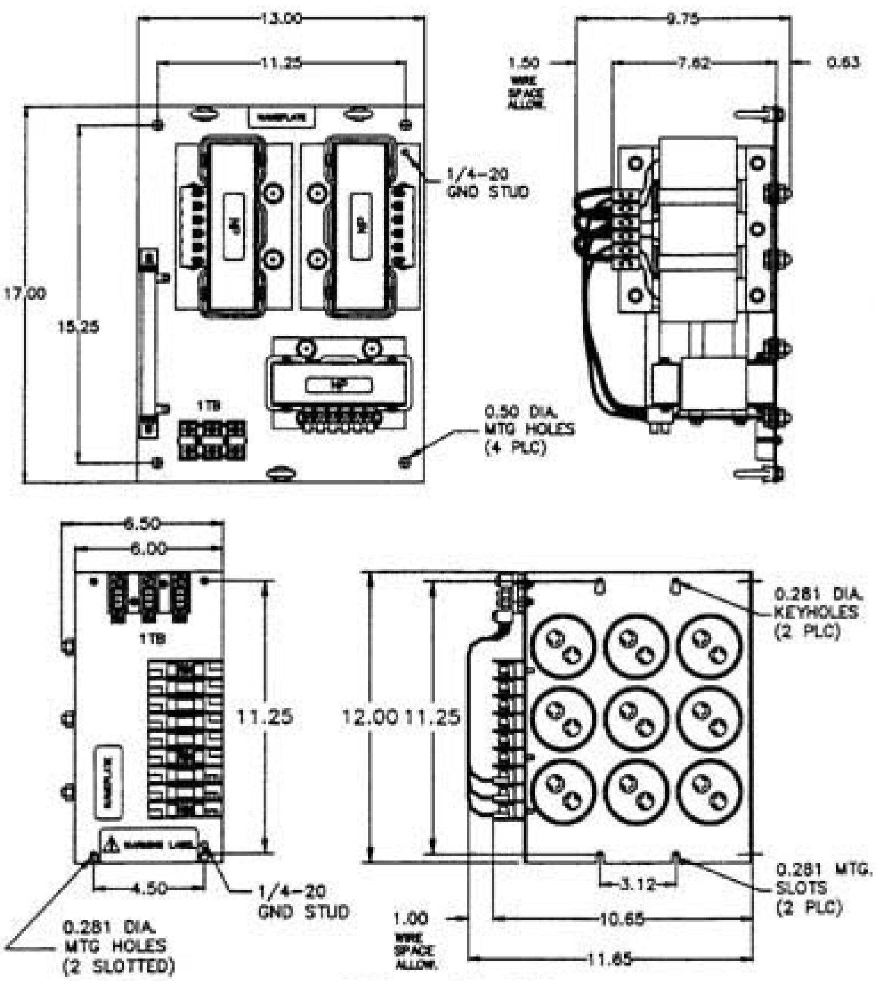

20 – 40 HP

Matrix™ Harmonic Filters

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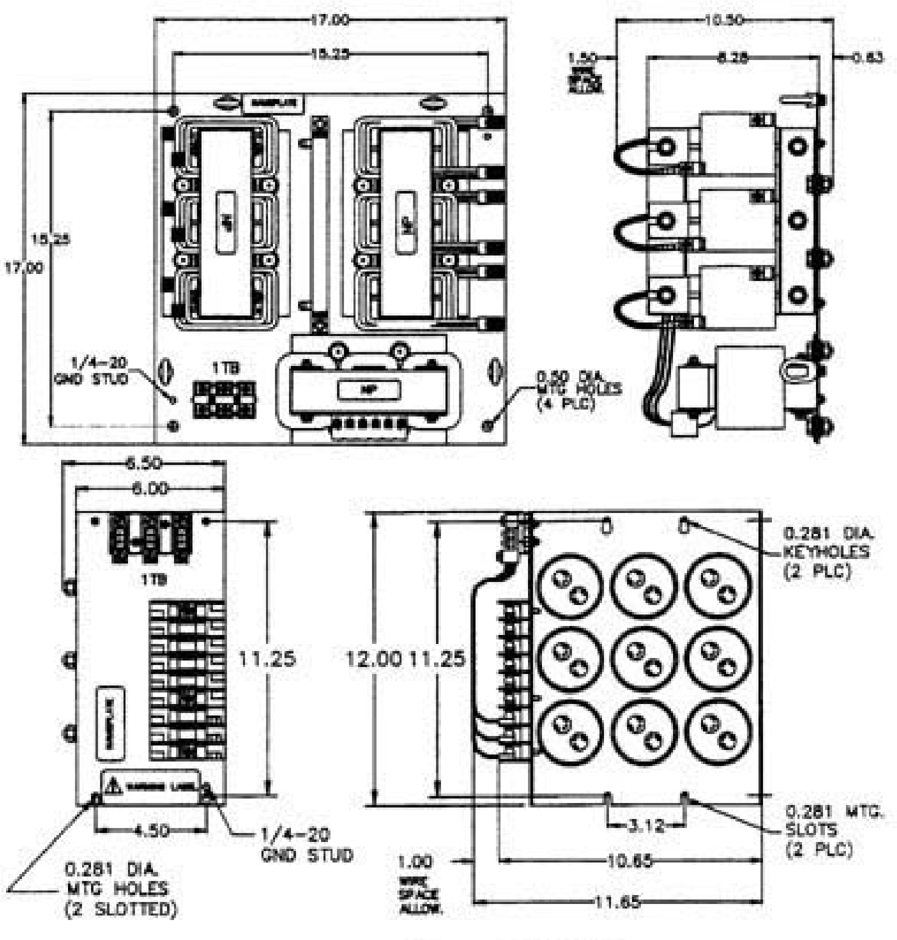
50-60 HP

(Dimensions subject to change, consult factory for certified drawings)



50 – 60 HP

Matrix™ Harmonic Filters

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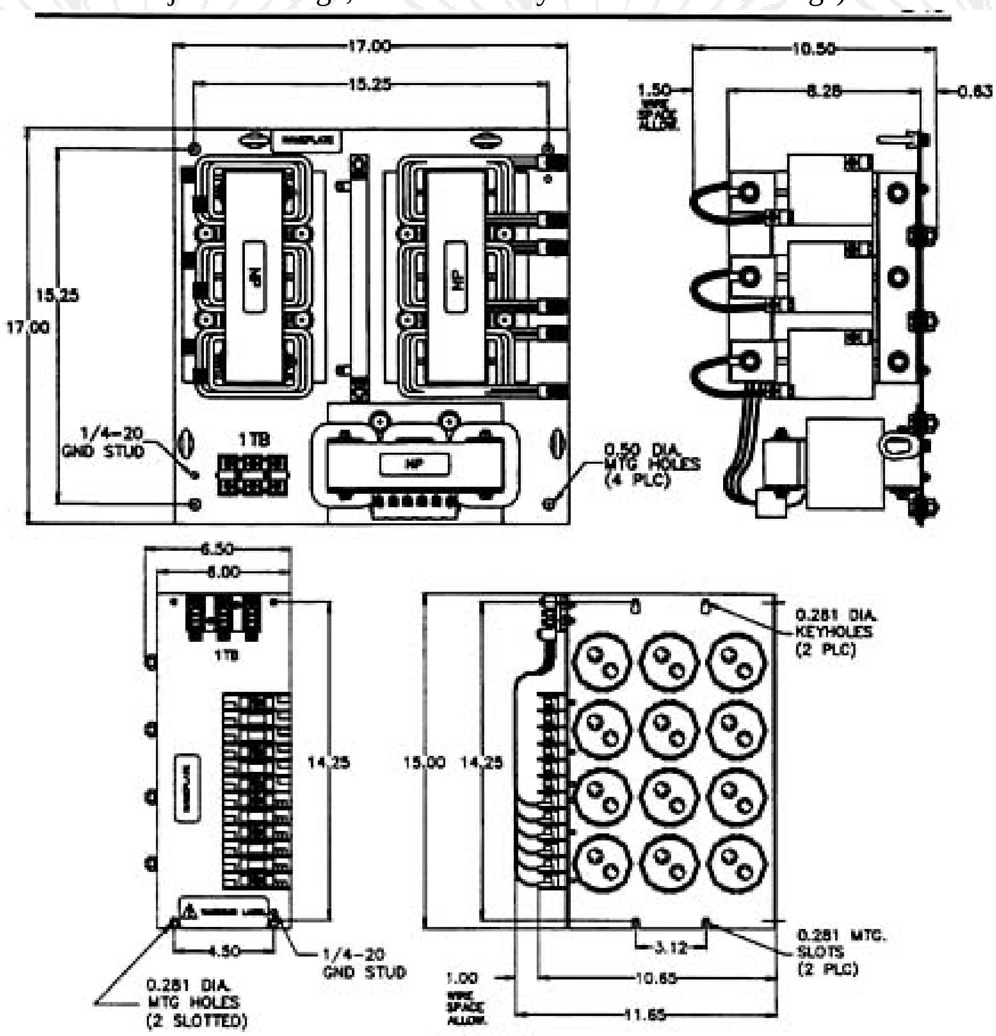
75 HP

(Dimensions subject to change, consult factory for certified drawings)



75 HP

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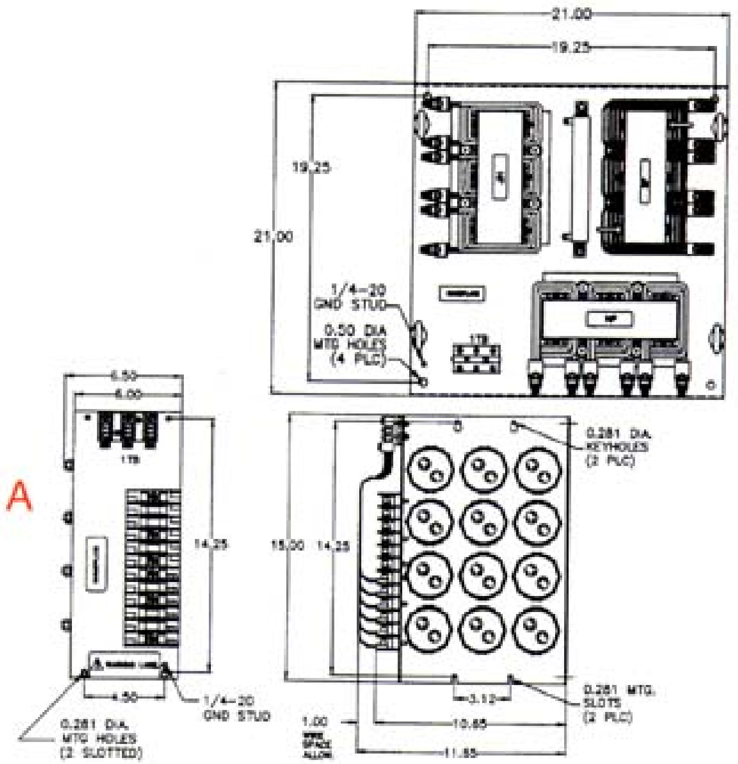
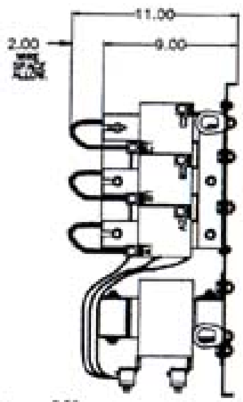
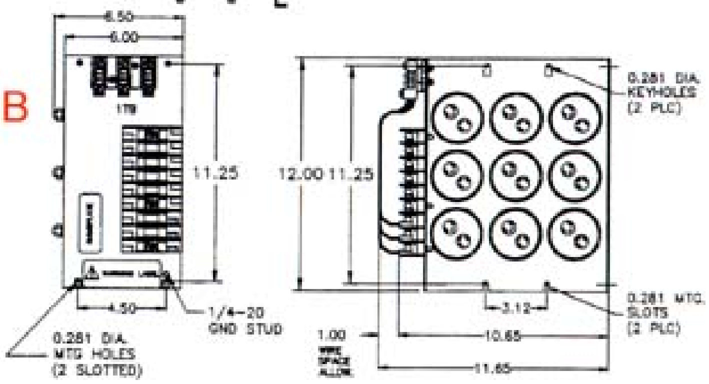
100-150 HP





HP	No. of CAP ASSY'S A	B
100	1	1
125	2	0
150	3	0

B



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Menomonee Falls, WI 53052 USA
1-800-455-4MTE
Tel: 1-262-253-8200
Fax: 1-262-253-8222
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Fax: +1-905 884-6258	Fax: +44 (0) 1493 604455	Fax: +(52) 722 199-4158	Fax: +(65) 67869860

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Broad Band Harmonic Filters	3rd Harmonic Filters	Reference Desk	Rep/Career Opportunities
RFI/EMI Filters	Surge Arrestors	Request more information	Home Page

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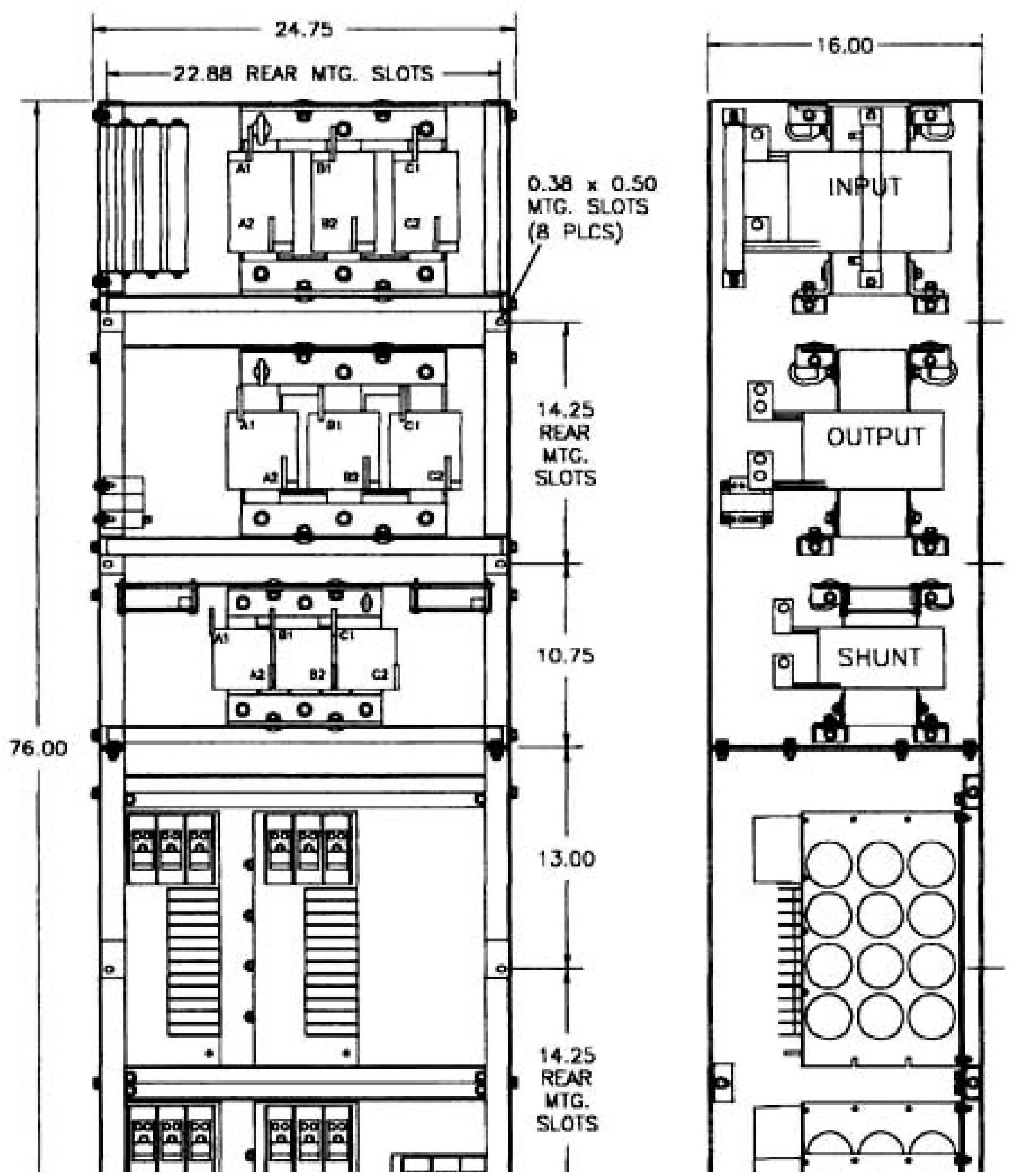
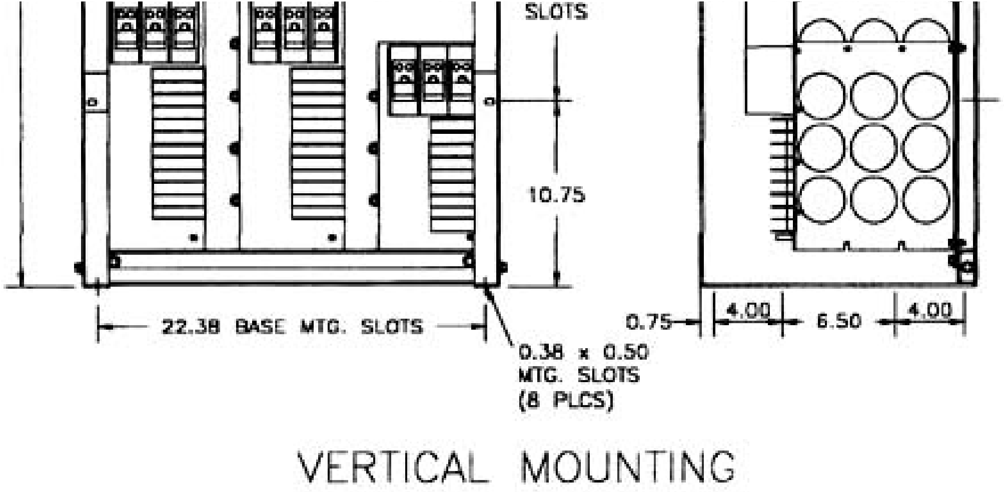
200-300HP Vertical Mounting

(Dimensions subject to change, consult factory for certified drawings)




SLOTS
10.75
22.38 BASE MTG. SLOTS
0.38 x 0.50
MTG. SLOTS
(8 PLCS)
0.75
4.00
6.50
4.00
VERTICAL MOUNTING

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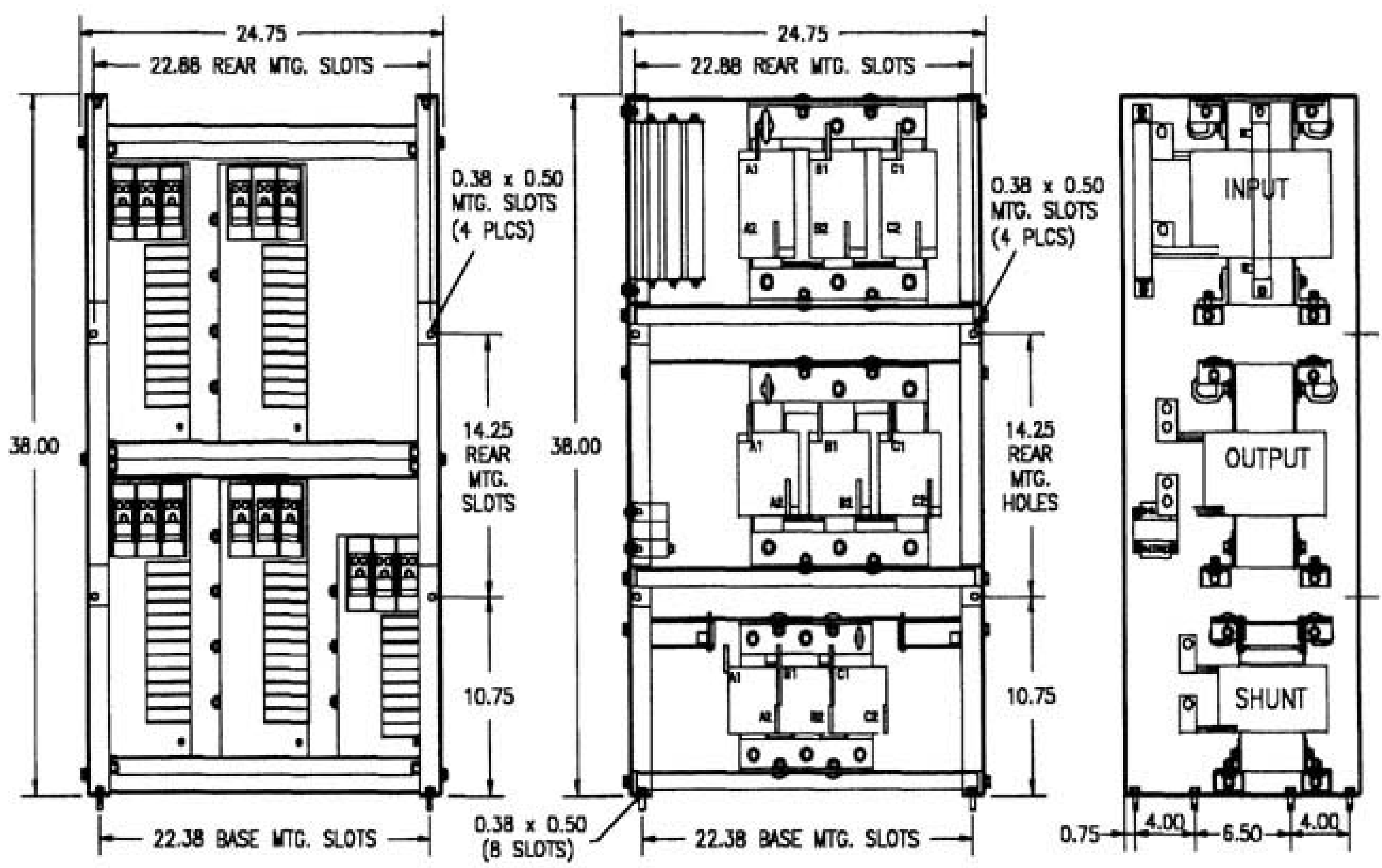
200-300HP Horizontal Mounting

(Dimensions subject to change, consult factory for certified drawings)



HORIZONTAL MOUNTING

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Matrix™ Harmonic Filters

Reactor Selection Table

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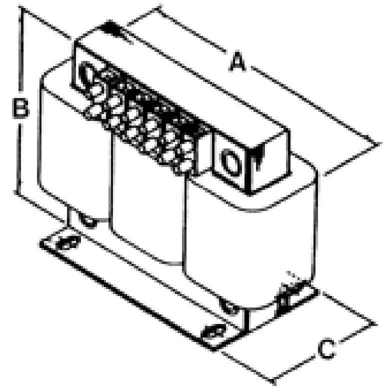
When additional reactance is required
Use this table to select reactors to increase source impedance or to convert to 12% THID filter to an 8% THID filter.

HP	KW	Reactor to convert 12% THID to 8% THID filter	Reactor to increase Source impedance to 3% minimum
3	2.2	RL-00804	RL-00402
5	3.7	RL-00802	RL-00802
7.5	5.5	RL-01202	RL-01202
10	7.5	RL-01803	RL-01802
15	11	RL-02502	RL-02502
20	15	RL-03502	RL-03502
25	19	RL-03502	RL-03502
30	22	RL-04502	RL-04502
40	30	RL-05502	RL-05502
50	37	RL-08002	RL-08002
60	45	RL-08002	RL-08002
75	56	RL-10002	RL-10002
100	75	RL-13002	RL-13002
125	93	RL-16002	RL-16002
150	112	RL-20002	RL-20002
200	150	RL-25002	RL-25002
250	186	RL-32002	RL-32002
300	225	RL-40002	RL-40002

REACTOR DIMENSIONS:

Dimensions for additional reactors used to increase source impedance or to convert from 12% THID to 8% THID.

Catalog Number	A	B	C	Weight lbs/kg
	inches/mm			
RL-00402	4.4/112	4.1/104	2.8/71	4/1.8
RL-00802	6.0/152	4.8/122	3.0/76	8/3.6
RL-01202	6.0/152	5.0/127	3.3/84	10/4.5
RL-01802	6.0/152	5.3/135	3.5/89	12/5.4
RL-02502	7.2/183	5.8/147	3.5/89	14/6.3
RL-03502	7.2/183	5.8/147	4.0/102	16/7.3
RL-04502	9.0/229	7.4/188	4.7/119	22/13
RL-05502	9.0/229	7.4/118	4.7/119	27/12
RL-08002	10.8/274	8.5/216	6.5/165	51/23
RL-10002	10.8/274	8.3/210	5.7/144	51/23
RL-13002	10.8/274	8.4/213	5.7/144	57/26
RL-16002	10.8/274	8.3/211	6.0/152	50/23
RL-20002	10.8/274	8.3/211	8.3/210	67/30
RL-25002	14.4/366	11.4/290	10/254	106/48
RL-32002	14.4/366	11.4/290	10.5/267	125/57
RL-40002	14.4/366	11.4/290	12.1/307	155/70



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Matrix™ Harmonic Filters

Application Notes

Solving DC Drive Harmonics with Matrix Harmonic Filters   Available in PDF.

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Line/Load Reactors

Detailed Product Data

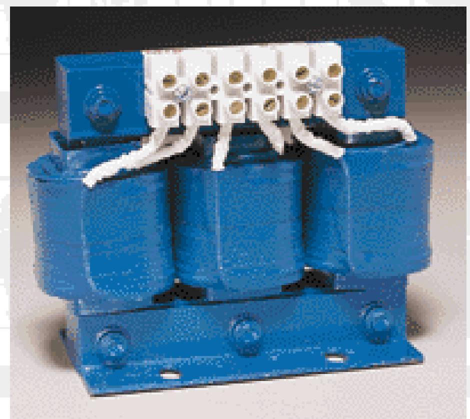
- *Product Overview*
- ***Detailed Product Data***
- *Selection Tables*
- *Specification Table*
- *Application Notes*

Benefits of Using Line/Load Reactors

Guard-AC Line/load reactors help keep your equipment running longer by absorbing many of the power line disturbances which otherwise damage or shut down your inverters, variable speed controllers, or other sensitive equipment. They are the modern technology solution to inverter and drive application problems. Guard-AC reactors are harmonic compensated and IGBT protected to assure optimum performance in the presence of harmonics. They are very effective at reducing harmonics produced by inverters and drives, and in most cases will help you to meet IEEE 519. Use our harmonic compensated reactors on either the input or output of an adjustable speed drive/inverter. There is no need to de-rate our "harmonic compensated" reactors for harmonics.

Guard-AC reactors are manufactured to the exacting standards of MIL-1-45208, VDE-0550, are UL recognized and CSA certified. All UL approvals are for USA and Canada.

- UL-506 File #E53094 (lamp through 1200 amps)
- CSA File #LR29753-13 (1200 amps or less) 9
- UL-508 File #El80243 (1 amp through 1200 amps)



Impedance Rating

3% impedance reactors are typically sufficient to absorb power line spikes and motor current surges. They will prevent nuisance tripping of drives or circuit breakers in most applications.

All higher current reactors offer UL recognized insulation systems and construction.

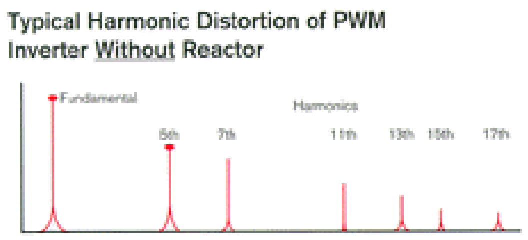
3-Phase Reactors

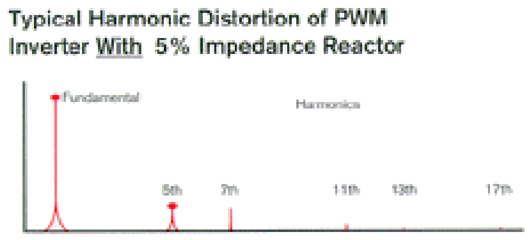
Line/Load Reactors

5% impedance reactors are best for reducing harmonic currents and frequencies. Use them when you must comply with IEEE 519, to reduce motor operating temperature, or to reduce motor noise.

- Protect Motors from Long Lead Effects
- Reduce Output Voltage dv/dt
- Virtually Eliminate Nuisance Tripping
- Extend Semiconductor Life
- Reduce Harmonic Distortion
- Reduce Surge Currents
- Reduce Motor Temperature
- Reduce Motor Audible Noise
- Improve True Power Factor
- Helps Meet IEEE 519 or IEC 1000-3-4

For Application Engineering Assistance, Call:
1-800-455-4MTE, or
262-253-8200
e-mail: E-Mail: apprengrg@mtecorp.com





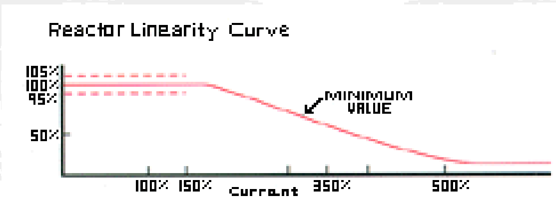
Harmonic Reduction

Because all standard Guard-AC reactors are compensated for harmonics (current and frequency), they are extremely effective at reducing the amount of harmonics which are produced by a drive/inverter. Use 5% impedance, harmonic compensated reactors for best reduction of harmonic distortion.

Percent Harmonics vs Total Line Impedance Total Input Impedance								
Harmonic	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
5th	40	34	32	30	28	26	24	23
7th	16	13	12	11	10	9	8.3	7.5
11th	7.3	6.3	5.8	5.2	5	4.3	4.2	4
13th	4.9	4.2	3.9	3.6	3.3	3.15	3	2.8
17th	3	2.4	2.2	2.1	0.9	0.7	0.5	0.4
19th	2.2	2	0.8	0.7	0.4	0.3	0.25	0.2
%THID	44.13	37.31	34.96	32.65	30.35	28.04	25.92	24.68
TRMS	1.09	1.07	1.06	1.05	1.05	1.04	1.03	1.03

Reactor Linearity

This curve illustrates the linearity of Guard-AC reactors. Even at 150 percent of their current rating, these reactors still have 100% of their nominal inductance. This assures maximum filtering of distortion even in the presence of severe harmonics and best absorption of surges. The typical tolerance on rated inductance is plus-or-minus 5 percent.



You Benefit From These Unique Features

HARMONIC COMPENSATION makes Guard-AC reactors suitable for use on either the drive input or drive output. They are designed to carry full rated fundamental current plus handle current and frequencies associated with harmonics-up to 50 percent more.

TERMINALS are provided as standard to save installation cost and minimize panel space. Finger proof (IP20) terminals are provided through 80 amps, solid copper box lugs above that to 400 amps.

EPOXY IMPREGNATION minimizes audible noise in the reactor and enhances structural integrity.

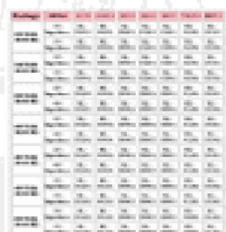
IGBT PROTECTION allows all MTE standard reactors to be used on the output of variable frequency drives including IGBT types with switching frequencies up to 20 KHZ. A premium dielectric system is utilized to protect the first, last and end turns from the potentially high circuit peak voltages and fast dv/dt which are experienced in applications with long leads between the inverter and motor. Additionally, the general dielectric system of each reactor is UL approved (UL-506) for 4000 volts rms.

HIGH SATURATION CURRENT RATING of Guard-AC reactors maximizes their surge current protection capability. Guard-AC reactors absorb many of the power line disturbances which cause nuisance trips on voltage source inverters.

Motor Protection Reactors help to protect motors from the high peak voltages and fast rise times (dv/dt) which can be experienced in IGBT inverter applications when the distance between the inverter and motor is long.

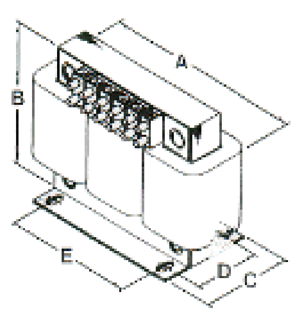
REACTOR SELECTION TABLES

REACTOR SPECIFICATIONS TABLES

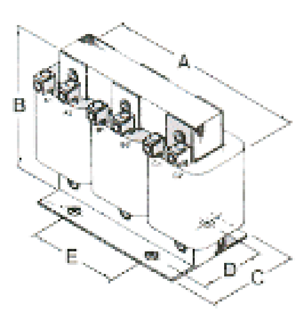


Outline Dimensions

All Guard-AC reactors are supplied with field wiring terminals, as illustrated. Units rated 80 amperes or below are supplied with the international terminal block as shown. Reactors rated above 80 amperes thru 400 amperes are supplied with solid copper box lugs. Larger reactors are supplied with copper tab type terminals. Refer to these outline drawings and the table on page 7 for reactor dimensions.



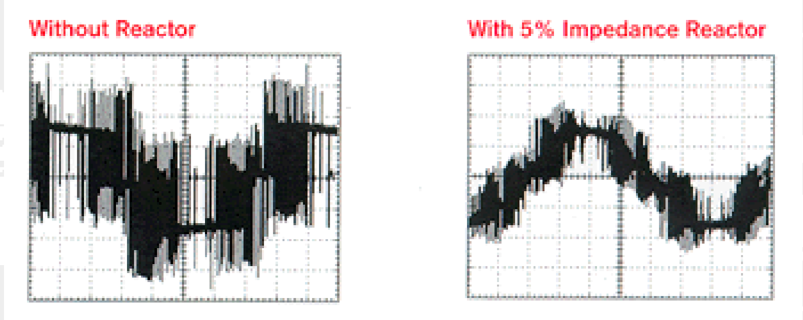
(80 amperes and below)



(above 80 amperes)

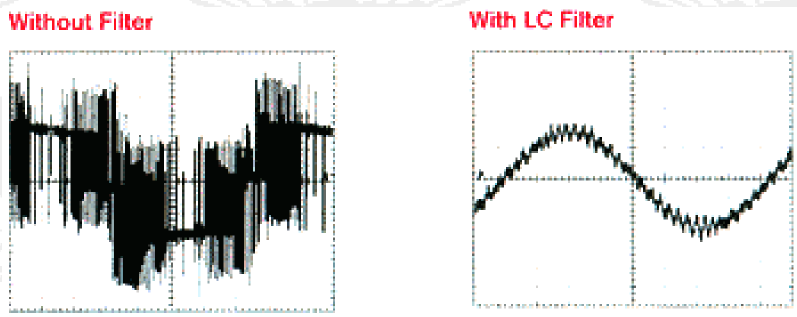
Motor Protection

Reactors help to protect motors from the high peak voltages and fast rise times (dv/dt) which can be experienced in IGBT inverter applications when the distance between the inverter and motor is long.



LC Type (dv/dt) Long Lead Filters

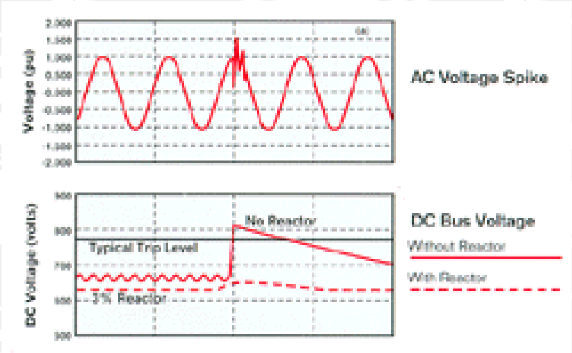
These filters are available to improve the inverter output wave form from a PWM type to a nearly sinusoidal waveform.



Capacitor modules are also available for addition in the field when you already have our 5% impedance reactor installed. Ask for our IGBT Long Lead Filter brochure for more details.

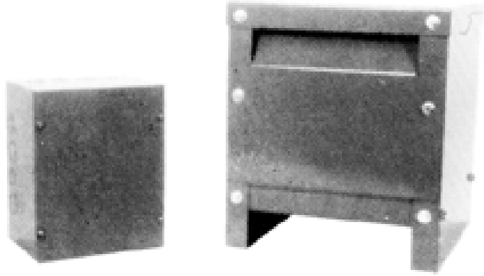
Voltage Spike Protection

A 3% impedance reactor is very effective at protecting against damage to or nuisance tripping of AC voltage source inverters, due to voltage spikes.



Voltage spikes on the AC power lines cause elevation of the DC Bus voltage which may cause the inverter to "trip-off" and indicate an over-voltage protection condition. Use reactors to absorb these line spikes and offer protection to the rectifiers and DC Bus capacitors while minimizing nuisance tripping of the inverter.

NEMA 1 Cabinets



All Guard-AC reactors are available as either open type or in a NEMA Type 1 general purpose enclosure. To order a reactor mounted in a cabinet, simply change the second last digit of the part number from "0" to "1". Example RL-00802 becomes RL-00812.

Reactor Part Number	Type	W	H	D	WGT. (LBS)	Cabinet
RL-002XX, RL-004XX, RL-008XX, RL-012XX, RL-01801, RL-01802	Wall Mount	8	8	6	7	CAB-8
RL-01803, RL-025XX, RL-035XX RL-045XX, RL-055XX, RL-080XX, RL-100XX, RL-130XX, RL-160XX, RL-200XX, RL-25001	Floor	13	13	13	31	CAB-13
RL-25002, RL-25003, RL-320XX, RL-400XX, RL-500XX, RL-600XX	Floor	17	24	17	45	CAB-17
RL-750XX	Floor	24	30	24	83	CAB-24

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Line/Load Reactors

Selection Tables

- *Product Overview*
- *Detailed Product Data*
- ***Selection Tables***
- *Specification Table*
- *Application Notes*

- 3-Phase Reactors: Line-Load Selection Table **1**/.75-**10**/7.5 **HP**/kw
- 3-Phase Reactors: Line-Load Selection Table **15**/11-**100**/75 **HP**/kw
- 3-Phase Reactors: Line-Load Selection Table **125**/93 **750**/550 **HP**/kw

Line/Load Reactors

Specification Table

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600 Volts, 50/60 hz (Open Type)

Part Number	Fundamental Amps	Max. Amps	Inductance	Watts Loss	Cabinet	A mm/in.	B mm/in.	C mm/in.	D mm/in.	E mm/in.	Wgt. Kg/Lbs.
RL-00201	2	3	12.0mh	7.5	CAB-8	112/4.4	102/4.0	74/2.8	50/2.0	36/1.44	1.8/4
RL-00202	2	3	20.0mh	11.3	CAB-8	112/4.4	102/4.0	74/2.9	50/2.0	36/1.44	1.8/4
RL-00203	2	3	32.0mh	16	CAB-8	112/4.4	102/4.0	74/2.9	50/2.0	36/1.44	1.8/4
RL-00204	2	3	6.0mh	10.7	CAB-8	112/4.4	102/4.0	69/2.7	44/1.73	36/1.44	1.4/3
RL-00401	4	6	3.0mh	14.5	CAB-8	112/4.4	102/4.0	74/2.9	50/2.0	36/1.44	1.8/4
RL-00402	4	6	6.5mh	20	CAB-8	112/4.4	102/4.0	74/2.9	50/2.0	36/1.44	2.3/4
RL-00403	4	6	9.0mh	20	CAB-8	112/4.4	102/4.0	79/3.1	54/2.1	36/1.44	1.8/5
RL-00404	4	6	12.0mh	21	CAB-8	112/4.4	102/4.0	91/3.6	66/2.6	36/1.44	2.7/6
RL-00801	8	12	1.5mh	19.5	CAB-8	152/6.0	122/4.8	79/3.1	54/2.1	50/2.0	3.1/7
RL-00802	8	12	3.0mh	29	CAB-8	152/6.0	122/4.8	79/3.1	54/2.1	50/2.0	3.2/8
RL-00803	8	12	5.0mh	25.3	CAB-8	152/6.0	122/4.8	86/3.4	63/2.5	50/2.0	5.0/11
RL-00804	8	12	7.5mh	28	CAB-8	152/6.0	122/4.8	86/3.4	63/2.5	50/2.0	5.9/13
RL-01201	12	18	1.25mh	26	CAB-8	152/6.0	122/4.8	79/3.1	54/2.1	50/2.0	4.0/9
RL-01202	12	18	2.5mh	31	CAB-8	152/6.0	122/4.8	79/3.1	54/2.1	50/2.0	4.5/10
RL-01203	12	18	4.2mh	41	CAB-8	152/6.0	122/4.8	94/3.7	70/2.75	50/2.0	8.1/18
RL-01801	18	27	0.8mh	36	CAB-8	152/6.0	122/4.8	79/3.1	54/2.1	50/2.0	4.0/9
RL-01802	18	27	1.5mh	43	CAB-8	152/6.0	122/4.8	86/3.4	53/2.5	50/2.0	5.4/12
RL-01803	18	27	2.5mh	43	CAB-13	183/7.2	145/5.7	97/3.8	66/2.6	76/3.0	7.3/16
RL-02501	25	37.5	0.5mh	48	CAB-13	183/7.2	142/5.6	86/3.4	60/2.3	76/3.0	5.0/11
RL-02502	25	37.5	1.2mh	52	CAB-13	183/7.2	142/5.6	86/3.4	60/2.3	76/3.0	6.3/14
RL-02503	25	37.5	1.8mh	61	CAB-13	183/7.2	145/5.7	97/3.8	66/2.6	76/3.0	8.1/18
RL-03501	35	52.5	0.4mh	49	CAB-13	183/7.2	142/5.6	97/3.8	66/2.6	76/3.0	6.3/14
RL-03502	35	52.5	0.8mh	54	CAB-13	183/7.2	145/5.7	97/3.8	66/2.6	76/3.0	7.3/16
RL-03503	35	52.5	1.2mh	54	CAB-13	229/9.0	178/7.0	122/4.8	80/3.2	76/3.0	14/30
RL-04501	45	67.5	0.3mh	54	CAB-13	229/9.0	178/7.0	122/4.8	80/3.2	76/3.0	10/23

RL-04502	45	67.5	0.7mh	62	CAB-13	229/9.0	178/7.0	122/4.8	80/3.2	76/3.0	13/28
RL-04503	45	67.5	1.2mh	65	CAB-13	229/9.0	178/7.0	135/5.3	93/3.6	76/3.0	18/39
RL-05501	55	82.5	0.25mh	64	CAB-13	229/9.0	178/7.0	122/4.8	80/3.2	76/3.0	11/24
RL-05502	55	82.5	0.50mh	67	CAB-13	229/9.0	178/7.0	122/4.8	80/3.2	76/3.0	12/27
RL-05503	55	82.5	0.85mh	71	CAB-13	229/9.0	178/7.0	142/5.6	99/3.9	76/3.0	18/41
RL-08001	80	120	0.20mh	82	CAB-13	274/10.8	208/8.2	142/5.6	88/3.5	92/3.6	19/43
RL-08002	80	120	0.40mh	86	CAB-13	274/10.8	211/8.3	142/5.6	88/3.5	92/3.6	23/51
RL-08003	80	120	0.70mh	96	CAB-13	274/10.8	213/8.4	160/6.3	117/4.6	82/3.6	25/55
RL-10001	100	150	0.15mh	94	CAB-13	274/10.8	211/8.3	142/5.6	88/3.5	92/3.6	21/47
RL-10002	100	150	0.30mh	84	CAB-13	274/10.8	208/8.2	147/5.8	93/3.6	92/3.6	23/51
RL-10003	100	150	0.45mh	108	CAB-13	274/10.8	213/8.4	160/6.3	106/4.2	92/3.6	33/74
RL-13001	130	195	0.10mh	108	CAB-13	229/9.0	179/7.04	124/4.9	80/3.16	76/3	13/29
RL-13002	130	195	0.20mh	180	CAB-13	274/10.8	213/8.4	171/6.75	93/3.66	92/3.63	26/57
RL-13003	130	195	0.30mh	128	CAB-13	274/10.8	213/8.4	184/7.25	106/4.16	92/3.63	29/64
RL-16001	160	240	0.075mh	116	CAB-13	274/10.8	213/8.4	146/5.75	80/3.16	92/3.63	18/40
RL-16002	160	240	0.150mh	149	CAB-13	274/10.8	213/8.4	152/6	88/3.47	92/3.63	22/50
RL-16003	160	240	0.230mh	138	CAB-13	274/10.8	213/8.4	181/7.13	106/4.16	92/3.63	31/67
RL-20001	200	300	0.055mh	124	CAB-13	274/10.8	213/8.4	152/6	106/4.16	92/3.63	22/48
RL-20002	200	300	0.110mh	168	CAB-13	275/10.8	213/8.4	216/8.5	112/4.41	92/3.63	31/67
RL-20003	200	300	0.185mh	146	CAB-13	274/10.8	267/10.5	237/9.35	150/5.91	92/3.63	46/100
RL-25001	250	375	0.045mh	154	CAB-13	274/10.8	208/8.17	184/7.25	106/4.16	92/3.63	31/68
RL-25002	250	375	0.090mh	231	CAB-17	366/14.4	356/14	210/8.25	131/5.16	117/4.6	49/106
RL-25003	250	375	0.150mh	219	CAB-17	366/14.4	356/14	288/11.35	148/5.82	117/4.6	64/140
RL-32001	320	480	0.040mh	224	CAB-17	366/14.4	356/14	168/6.6	129/5.07	117/4.6	50/110
RL-32002	320	480	0.075mh	264	CAB-17	375/14.75	356/14	257/10.13	149/5.88	117/4.6	57/125
RL-32003	320	480	0.125mh	351	CAB-17	366/14.4	356/14	330/13	181/7.13	117/4.6	86/190
RL-40001	400	600	0.030mh	231	CAB-17	366/14.4	356/14	254/10	131/5.16	117/4.6	46/100
RL-40002	400	600	0.060mh	333	CAB-17	394/15.5	356/14	292/11.5	172/6.76	117/4.6	71/155
RL-40003	400	600	0.105mh	293	CAB-17	394/15.5	356/14	368/14.5	284/7.26	117/4.6	91/200
RL-50001	500	750	0.025mh	266	CAB-17	394/15.5	356/14	267/10.5	140/5.5	117/4.6	55/120
RL-50002	500	750	0.050mh	340	CAB-17	394/15.5	356/14	330/13	172/6.76	117/4.6	82/180
RL-50003	500	700	0.085mh	422	CAB-17	394/15.5	356/14	375/14.75	248/9.76	117/4.6	132/290
RL-60001	600	900	0.020mh	307	CAB-17	394/15.5	356/14	279/11	168/6.66	117/4.6	73/160
RL-60002	600	900	0.040mh	414	CAB-17	394/15.5	356/14	356/14	172/6.76	117/4.6	96/210
RL-60003	600	840	0.065mh	406	CAB-17	394/15.5	356/14	394/15.5	235/9.26	117/4.6	132/290
RL-75001	750	1125	0.015mh	427	CAB-24	559/22	508/20	254/10	168/6.63	183/7.2	91/200
RL-75002	750	1125	0.029mh	630	CAB-24	559/22	508/20	317/12.5	197/7.76	183/7.2	141/310
RL-75003	750	1125	0.048mh	552	CAB-24	559/22	508/20	376/14.8	242/9.51	183/7.2	183/400

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Line/Load Reactors

Application Notes

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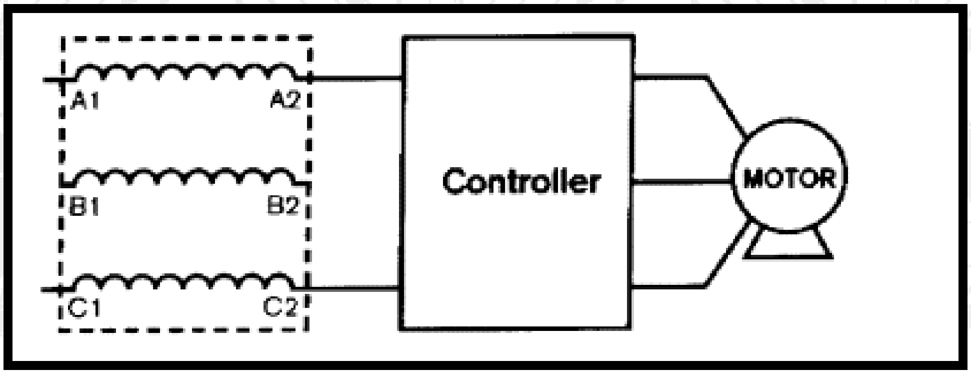
- Reactor Selection for the Line Side of DC Motor Controllers Available in HTML or PDF
- How to use a 3-phase line reactor for a single-phase application Available in HTML or PDF

How to Select the Reactor That's Right for Your DC Drive!

This application note shows how to determine which reactor will work best for your DC motor drive. The selection methods described are step-by-step and easy to follow. These instructions are very helpful in determining the right reactor.

Reactor Selection for the Line Side of DC Motor Controllers

MTE three-phase AC reactors are not just for use with AC variable frequency drives. Use MTE reactors on the input of DC motor controllers to provide protection for the drives, and improve the quality of power supplied to other loads on the distribution system. To reduce the "notching" of the supply voltage that will be caused by a three-phase DC motor drive, apply a 3% impedance MTE reactor to the drive input.



Quick Selection

Selection of MTE reactors for DC drive input applications of lower horsepower are made directly from the MTE reactor selection table. Because higher horsepower DC drives may demand more line current than AC drives of the same HP, these applications should use the reactor for the next larger horsepower rating on the chart.

The DC motor drive applications (3-phase supply) for which the next larger reactor should be considered are:

600 Vac $\geq$ 75 HP DC
480 Vac $\geq$ 100 HP DC
208-240 Vac $\geq$ 20 HP DC

For example, to select a reactor for a 200 HP DC drive application supplied by 480V 3-phase power, simply use the 3% impedance selection from the table for 480V, 250 HP.

If a mathematical method of selection is desired, one is presented below.

Mathematical Selection

Data required to perform the calculations are: full-load DC current from the motor nameplate, three-phase supply voltage (line to line), and supply frequency.

Determine the current that will be demanded from the AC supply under full load condition. This is about (0.85) * (full load amps of DC motor).

Calculate the inductance that provides 3% impedance for the application under full load. The formula for this is:

$$L = \frac{Z * V}{I * 2 * \pi * f * \sqrt{3}}$$

Where L = inductance in Henries

Z = percent impedance desired (0.03 in this case)

V = supply voltage (line to line)

I = fundamental load current demanded from AC line (Amperes)

f = supply frequency (Hz)

Once the required ampacity and inductance are known, a reactor may be chosen from the specification table for MTE reactors. The reactor's fundamental current rating should be equal to or somewhat greater than the calculated demand from the AC supply. The inductance of the reactor should be selected as near as possible to the ideal value calculated above.

Example:

An MTE reactor is required for the line side of a DC motor drive. The drive is supplied with 480V 60 Hz three-phase power. The motor is 500Vdc, 125 HP, having a full load current of 205A.

First, the current demanded from the supply at full load is calculated:
0.85 * 205 = 174.25, or a full load demand of about 175 Amperes.

Second, the required inductance is calculated:
$L = (Z*V) / (I * 2 * \pi * f * \sqrt{3})$
L = (.03 * 480) / (175 * 2 * 3.1416 * 60 * 1.732) = 0.000126, or 0.126 mH

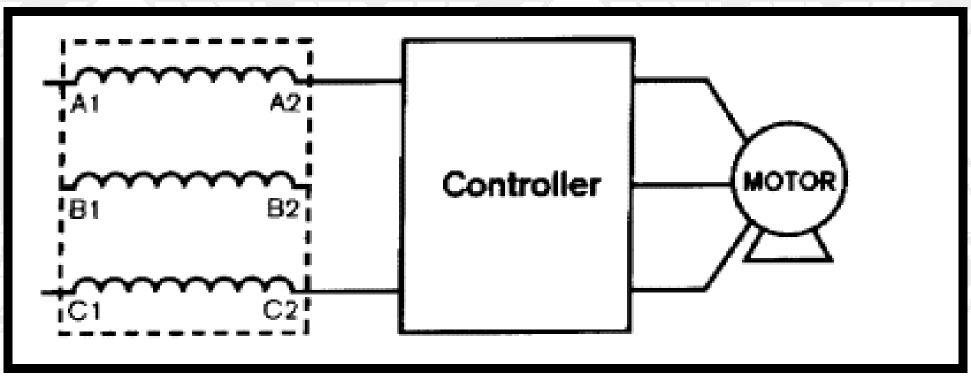
The MTE reactor fundamental current rating nearest to but not less than 175A is the 200A rating. The 200A MTE reactor inductance that is nearest to the calculated ideal value is the 0.110mH of the model RL-20002.

How to use a 3-phase line reactor for a single-phase application!

The illustration below demonstrates how a 3-phase line reactor can be used for a single-phase application. Using the mathematical method below you can calculate the inductance to determine what type of reactor is needed.

Reactors for Single Phase Applications

MTE three-phase Line / Load Reactors can be used for single-phase applications by routing each of the two supply conductors through an outside coil, and leaving the center coil disconnected. For the drive input application shown in (Figure 1.), the incoming supply lines connect to terminals A1, C1, and outgoing lines from A2, C2. The "B" terminals for the center coil are not connected. The sum of the inductance of the two coils is the total inductance applied to the circuit.



(Figure 1.)

As an example, consider a single-phase application of 2HP supplied by 240 Vac. The reactor must carry 12A (fundamental current) according to the NEC table for single-phase motor current. A 5% impedance is desired. For a 60Hz supply, the formula to calculate required inductance is: L = (ZV) / (377I), where L is inductance in Henries, Z is percent impedance, V is supply voltage, and I is full load amps.

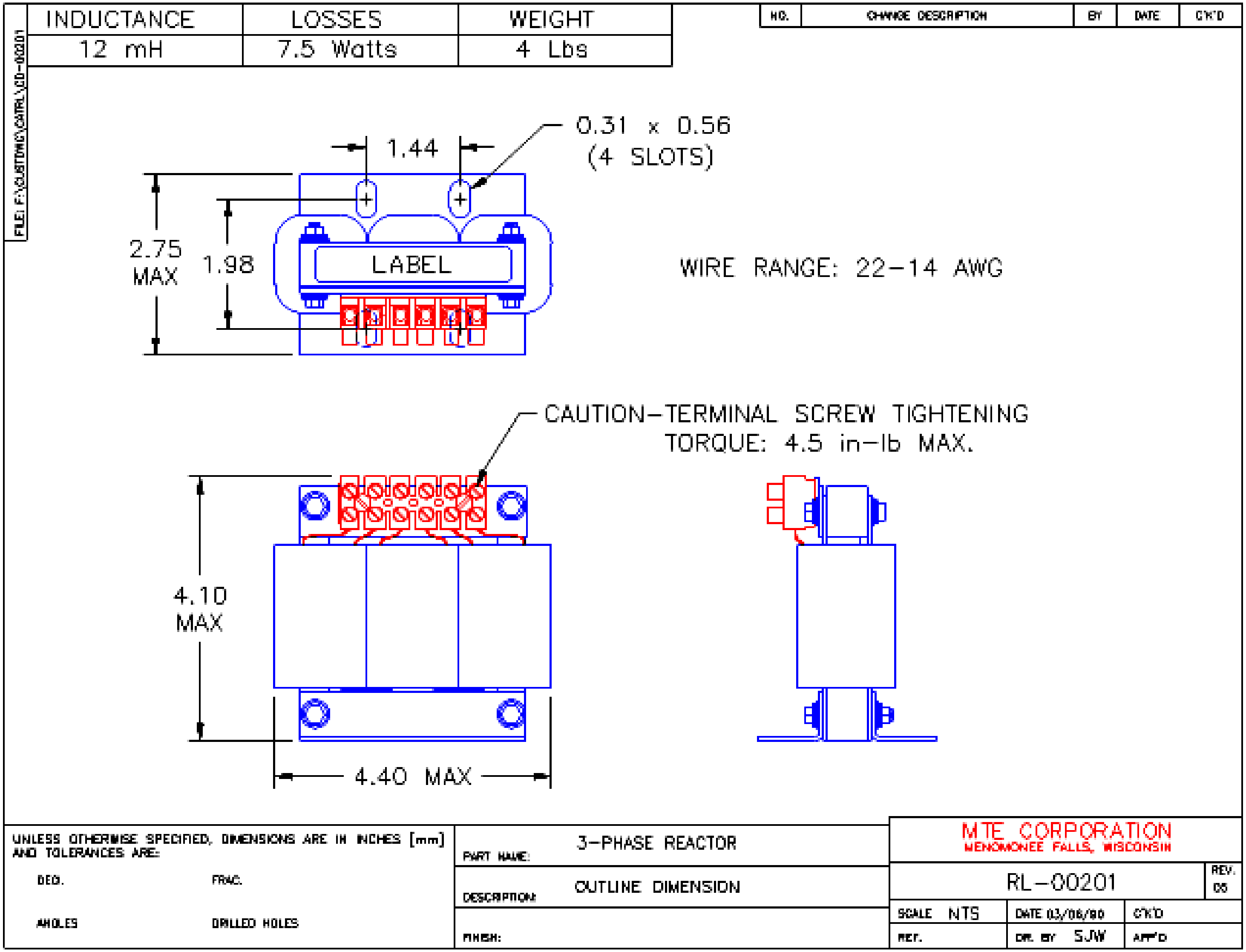
For above example: 0.00265 = (0.05 x 240) / (377 x 12), indicating a total required inductance of 2.65 mH. Based upon this result, MTE part number RL-01201, which has an inductance per coil of 1.25mH, a fundamental current rating of 12A, and a maximum continuous current rating of 18A, will work. When connected for a single-phase application, the sum of the two coils will provide a total inductance of 2.5mH, or an effective impedance of 4.7%, calculated as Z = (I x 377 x L) / V, or .047 = (12 x 377 x .0025) / 240. For a 50Hz supply, modify the formulas by substitution of the factor 314 in place of 377.

SELECTION TABLE
SINGLE-PHASE MOTOR DRIVE APPLICATIONS

HP	120 V	208 V	240 V	480 V
1/6	RL-00801	RL-00401	RL-00402	RL-00202
1/4	RL-00801	RL-00401	RL-00401	RL-00202
1/3	RL-01201	RL-00401	RL-00401	RL-00201

1/2	RL-01801	RL-00801	RL-00802	RL-00403
3/4	RL-02501	RL-00801	RL-00801	RL-00402
1	RL-02501	RL-01201	RL-00801	RL-00402
1-1/2	RL-03501	RL-01201	RL-01201	RL-00803
2	RL-03501	RL-01801	RL-01201	RL-00803
3	RL-05501	RL-02501	RL-01801	RL-01202
5	RL-10001	RL-03501	RL-03501	RL-01802
7-1/2	RL-13001	RL-04501	RL-04501	RL-02502
10	RL-13001	RL-05501	RL-05501	RL-02502
15		RL-08001	RL-08001	RL-03502
20		RL-10001	RL-10001	RL-04502
25		RL-13001	RL-13001	RL-05502
30				RL-08002
40				RL-10002
50				RL-13002

These selections provide typical percent impedance rating of 5%.



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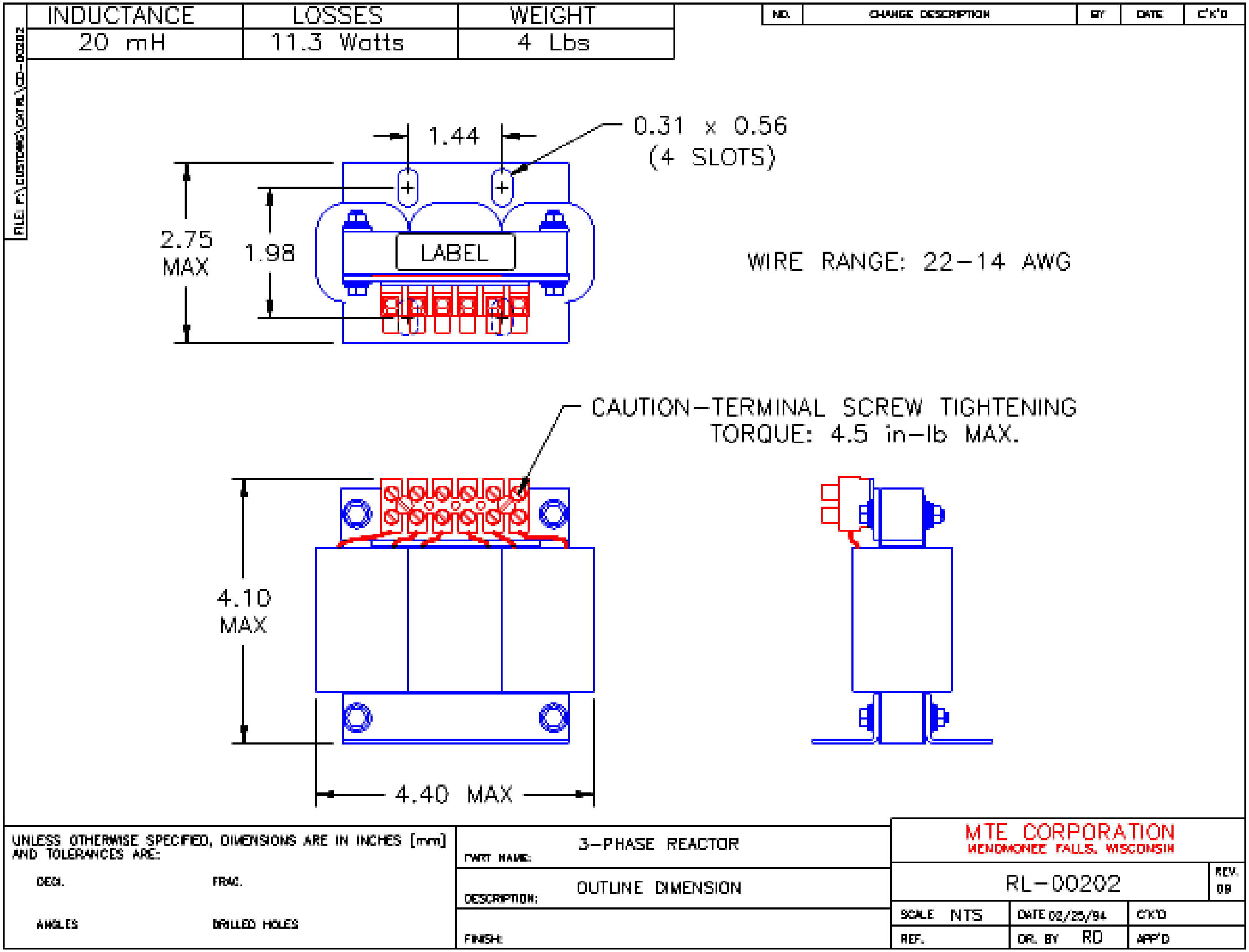

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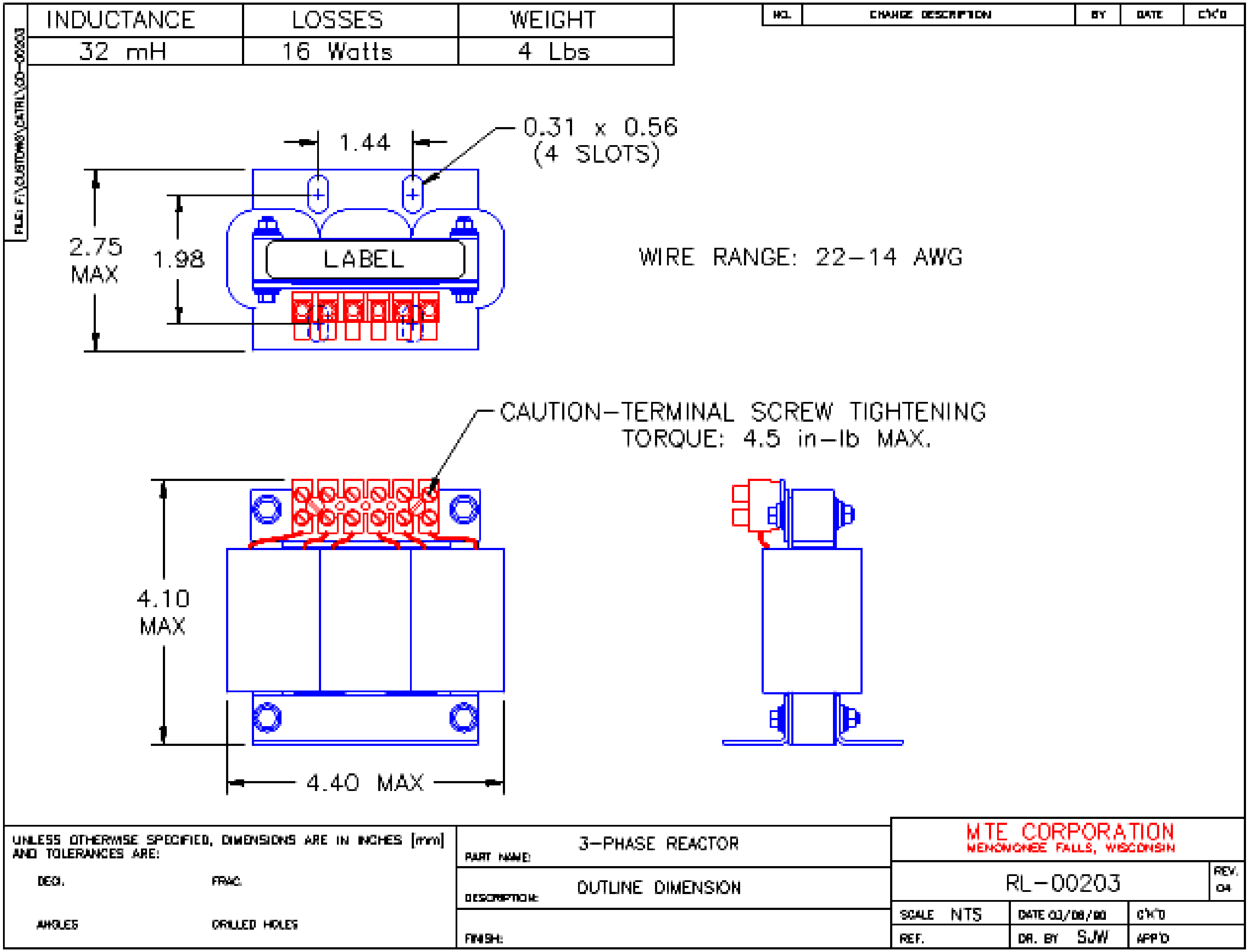

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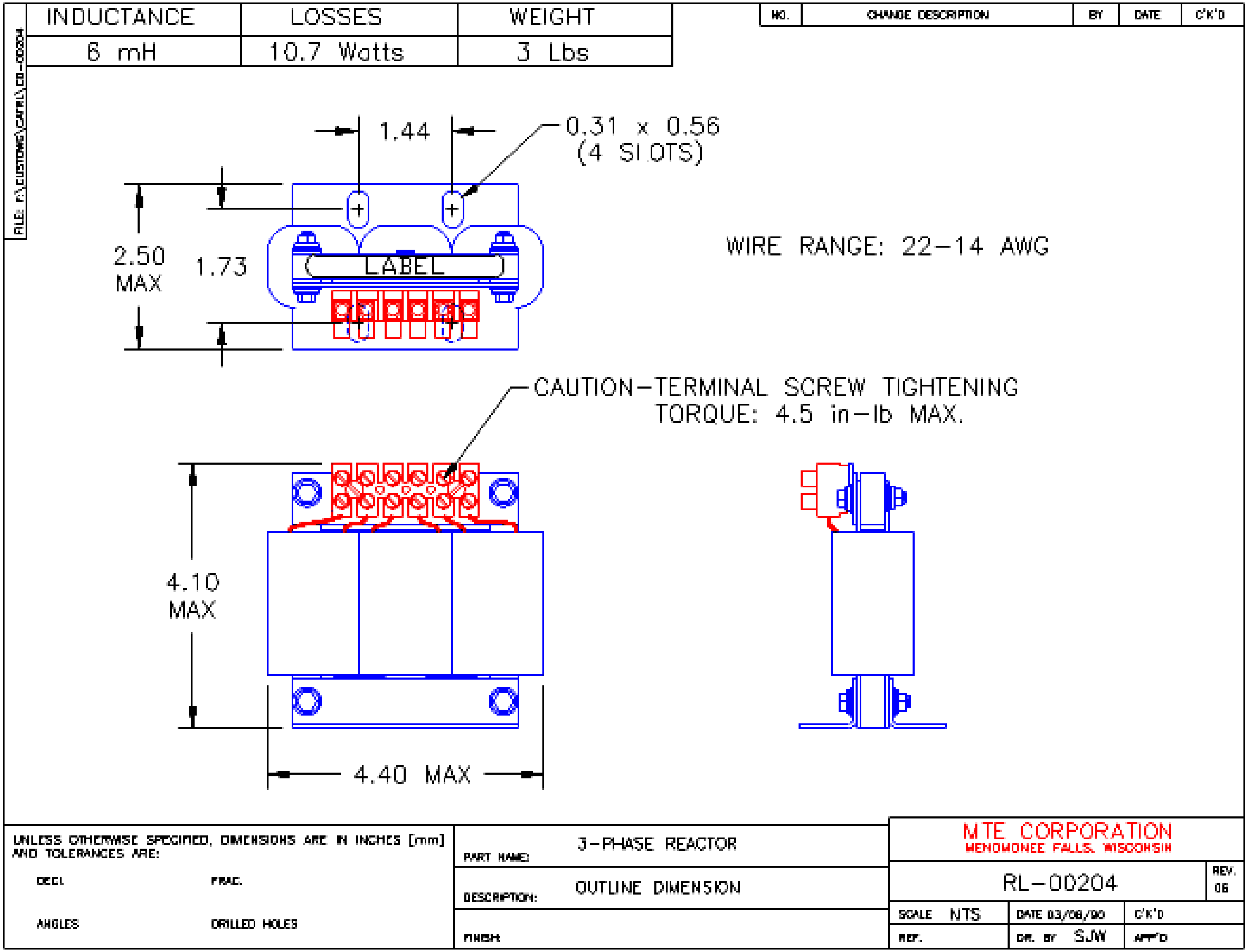

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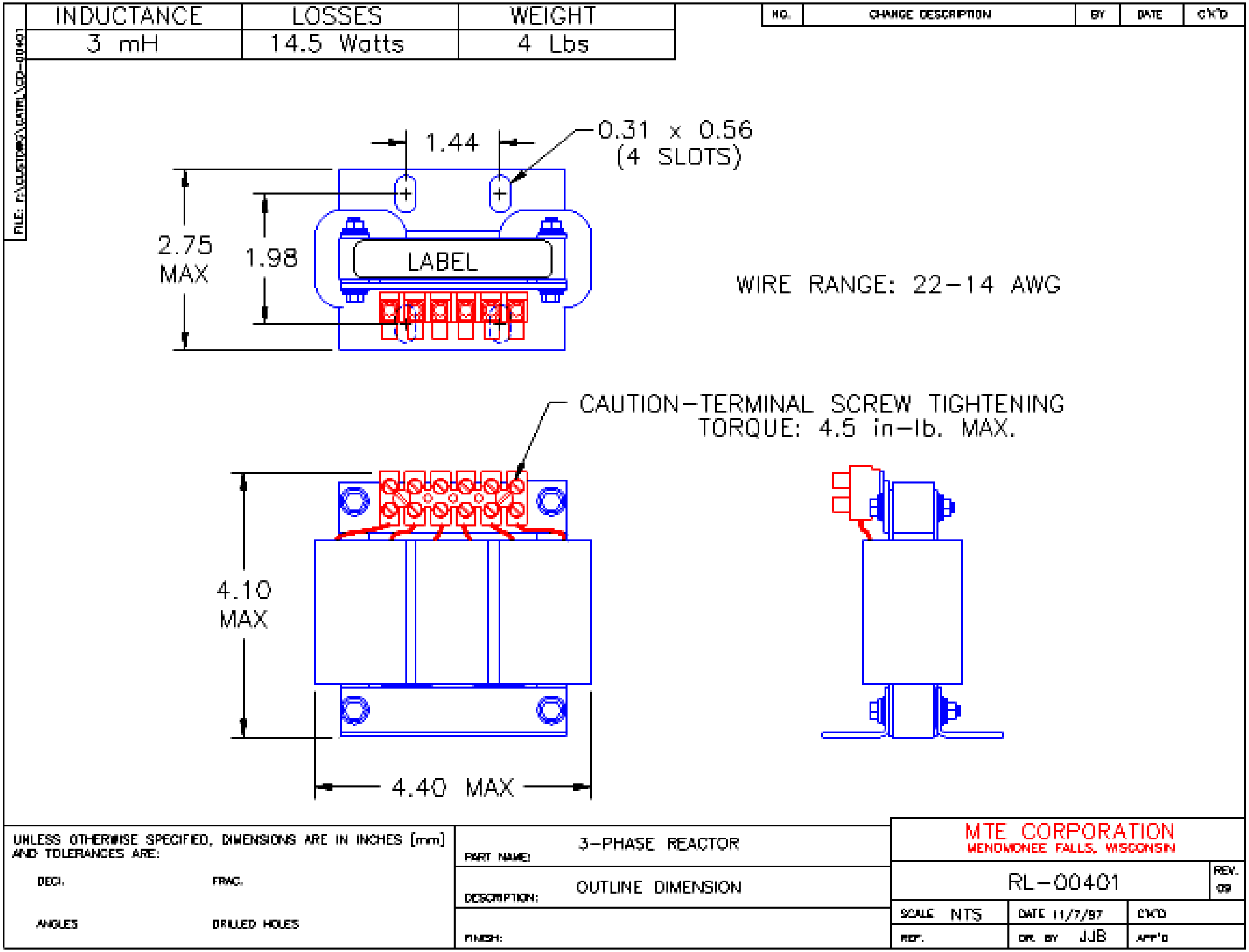

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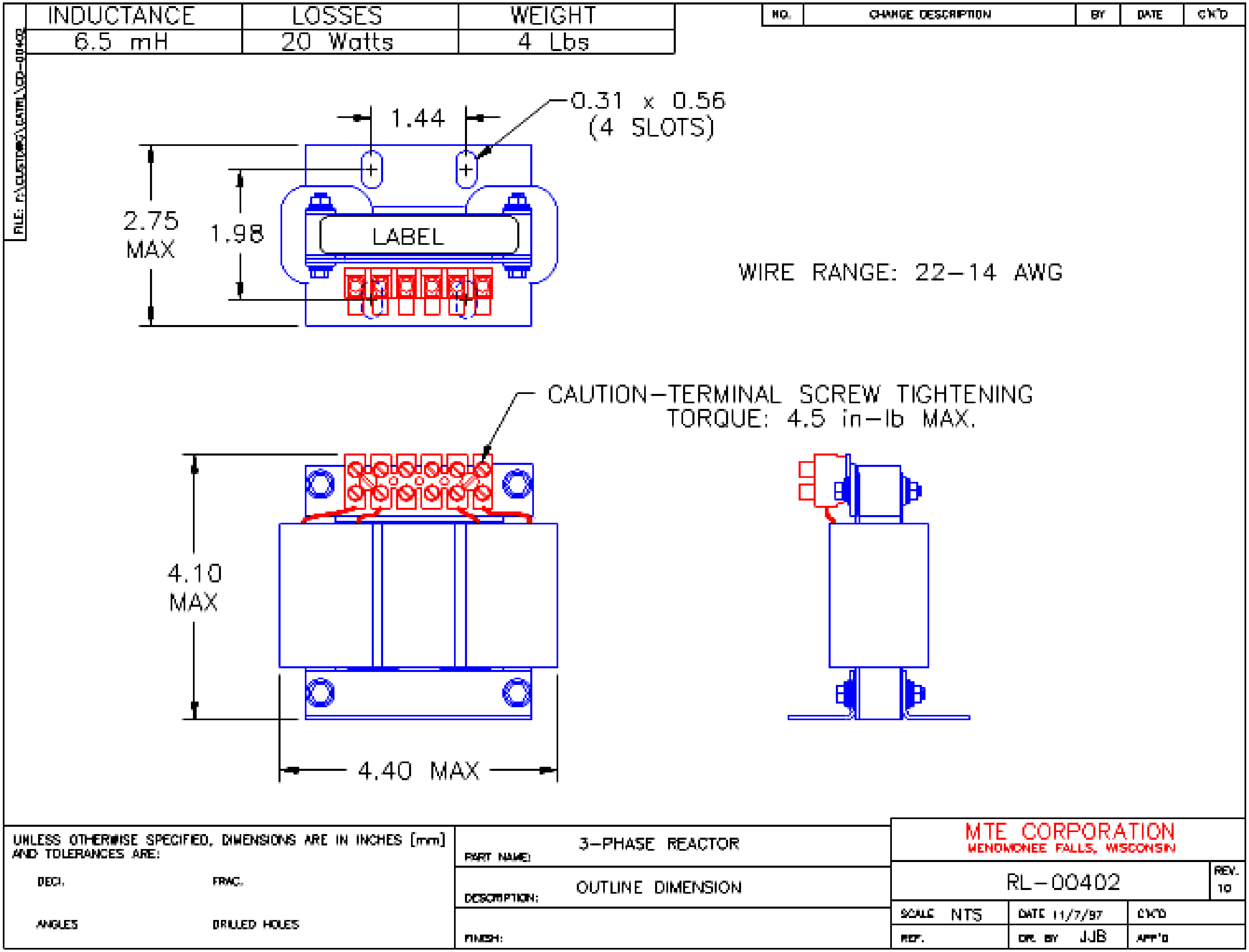

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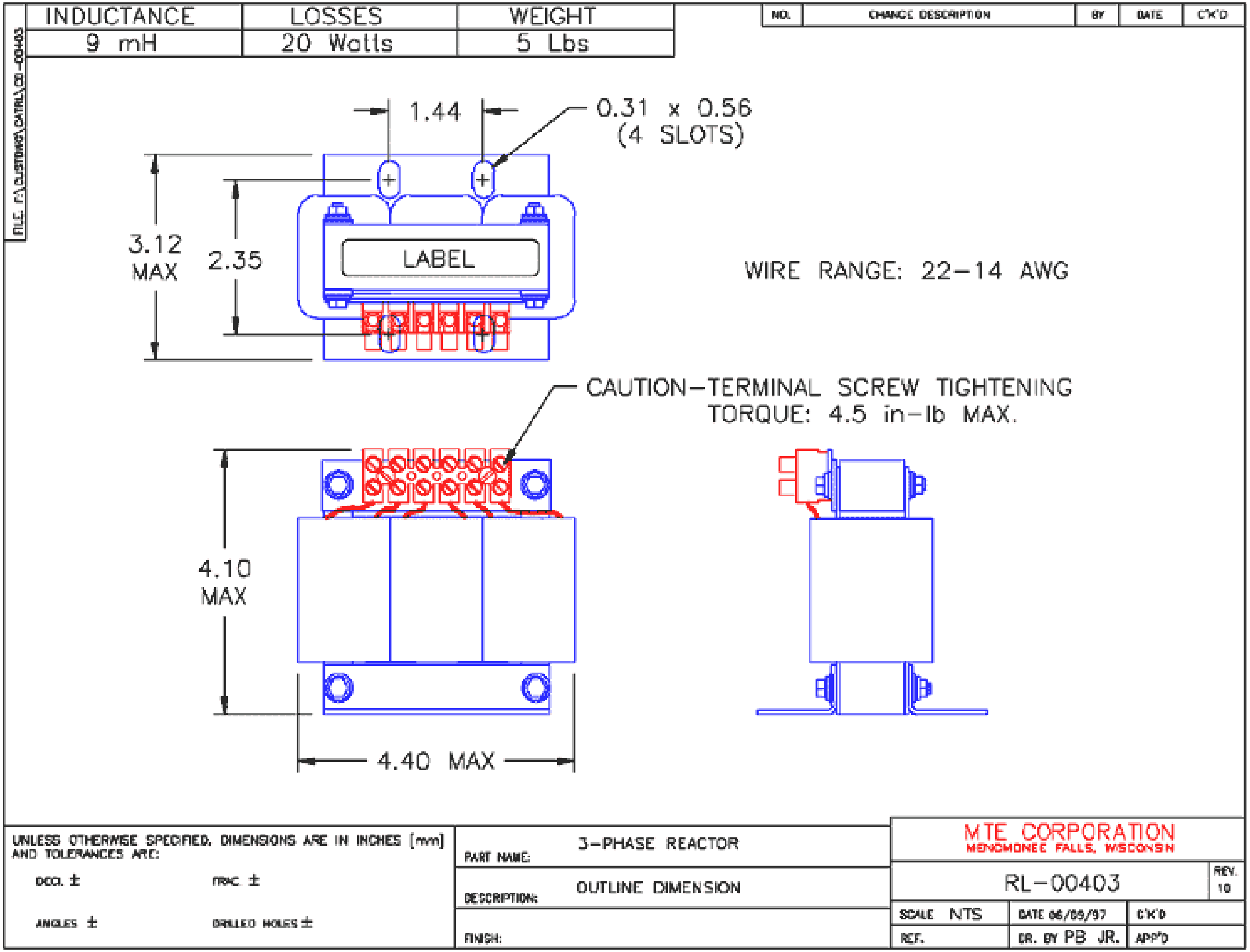

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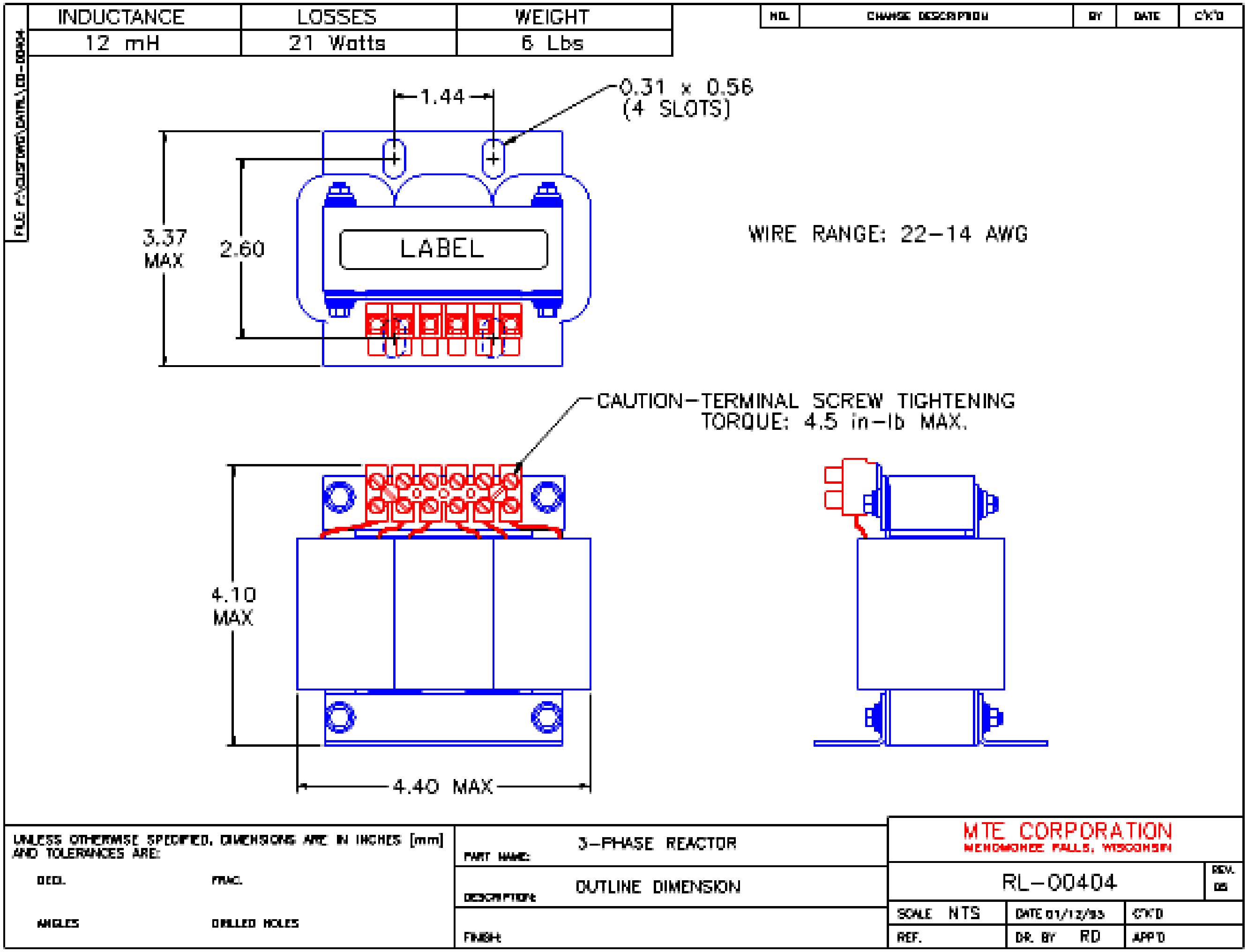

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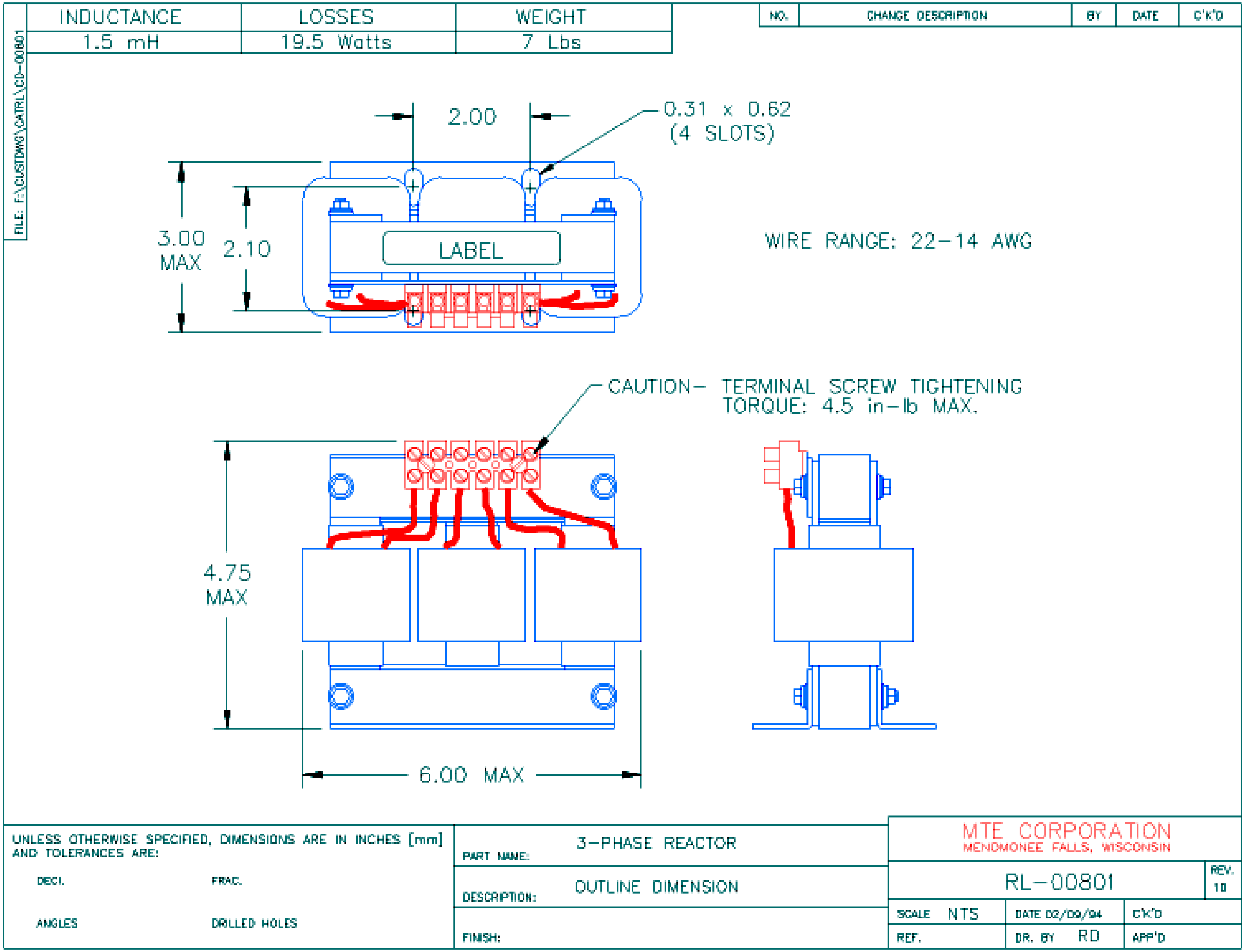

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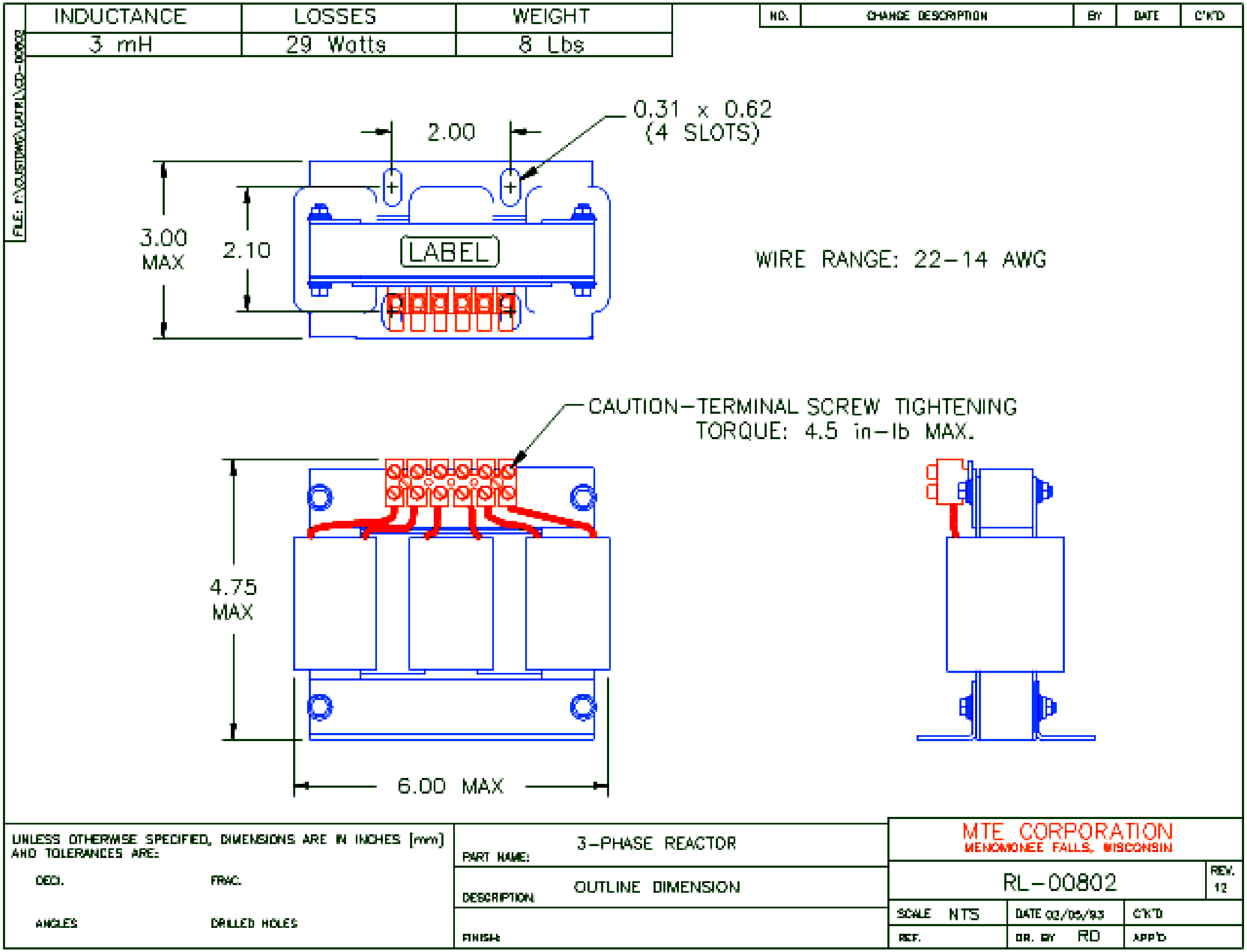

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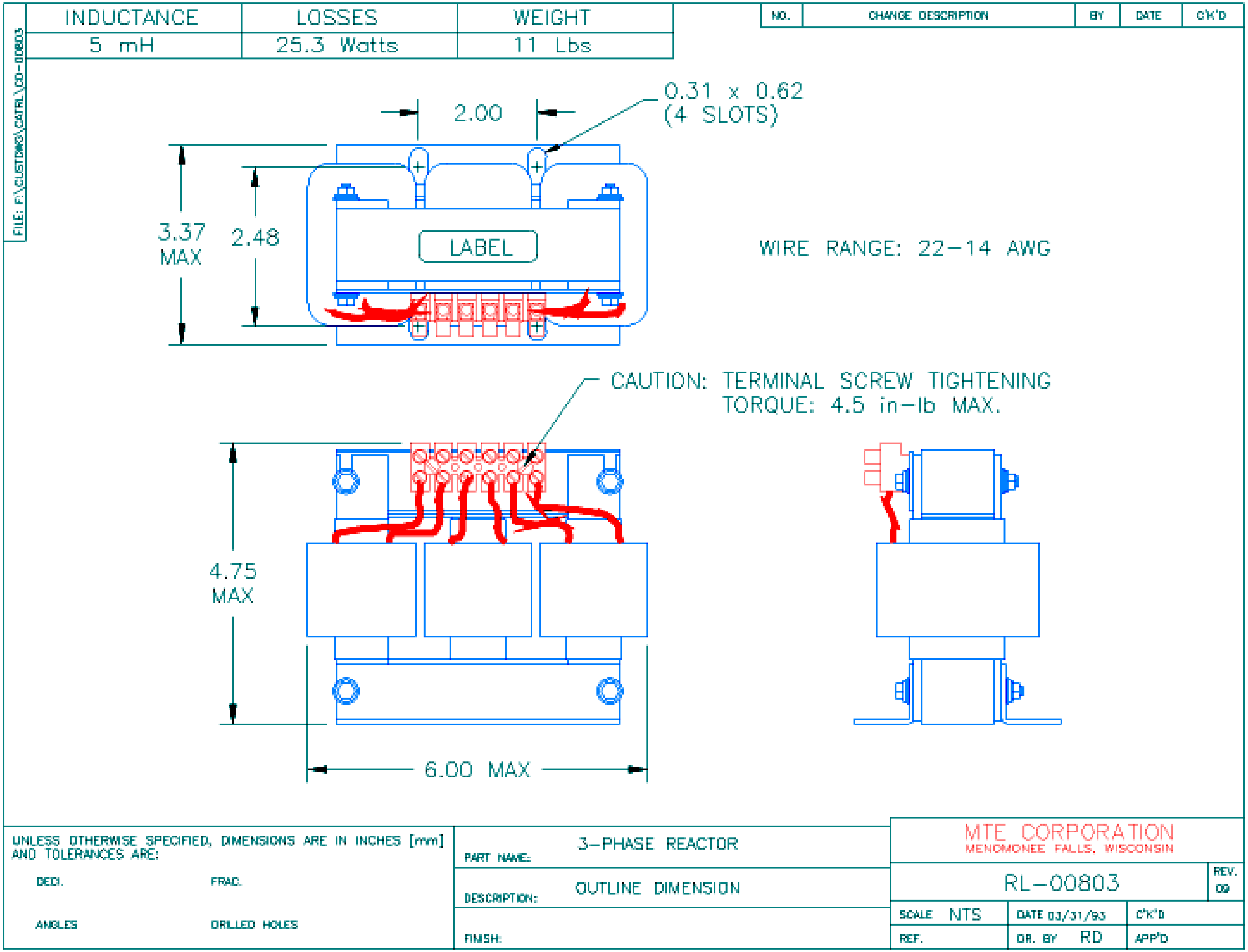

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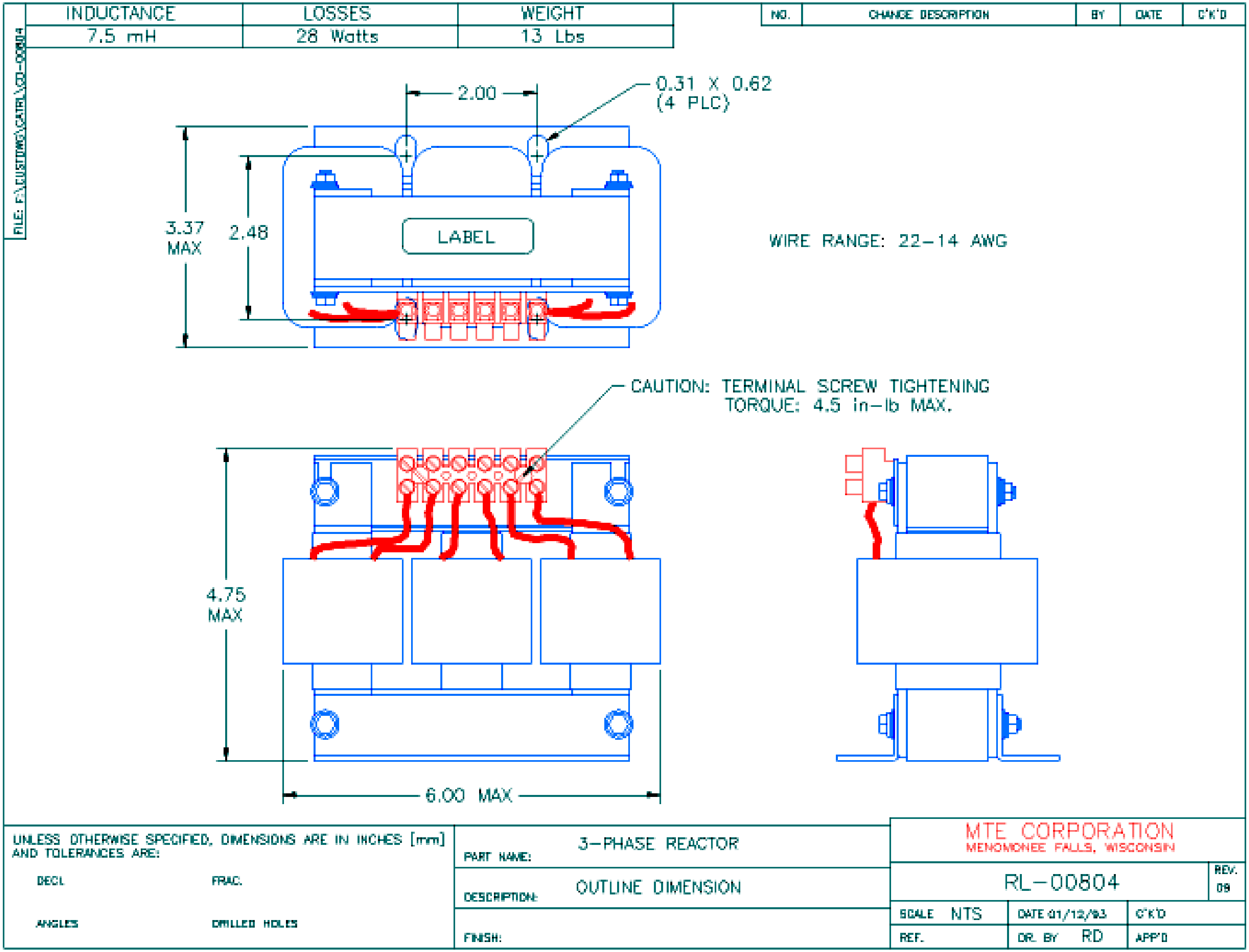

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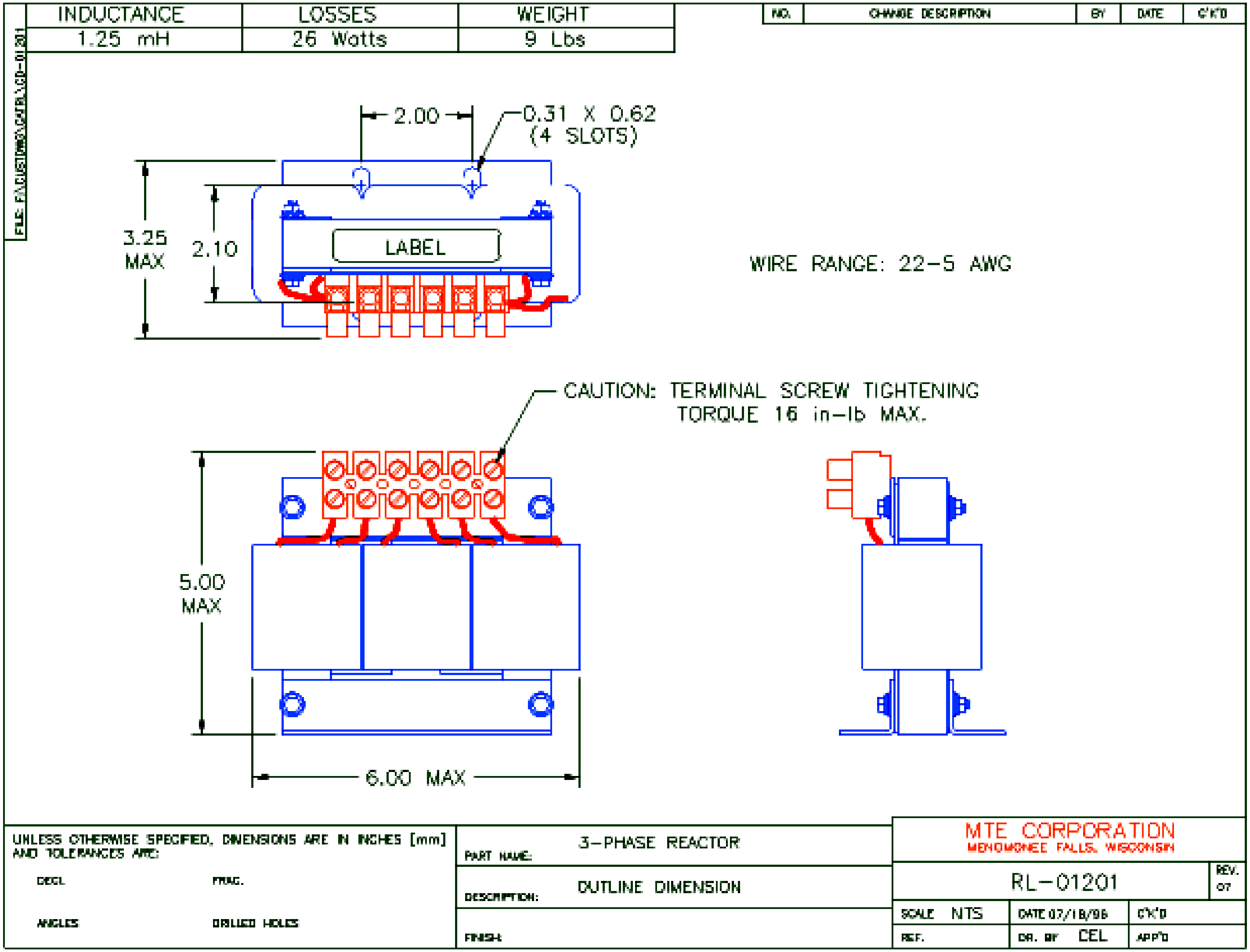

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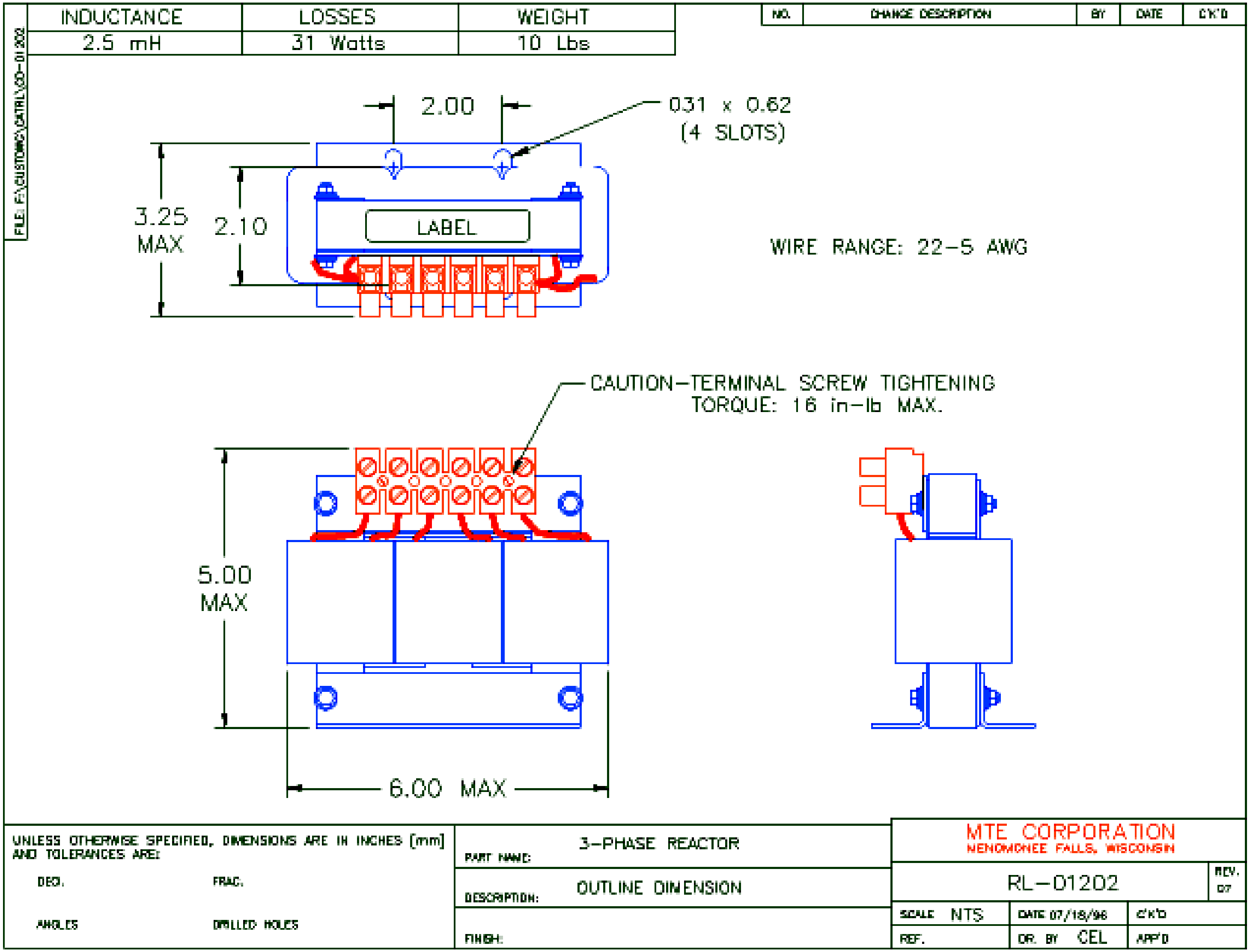

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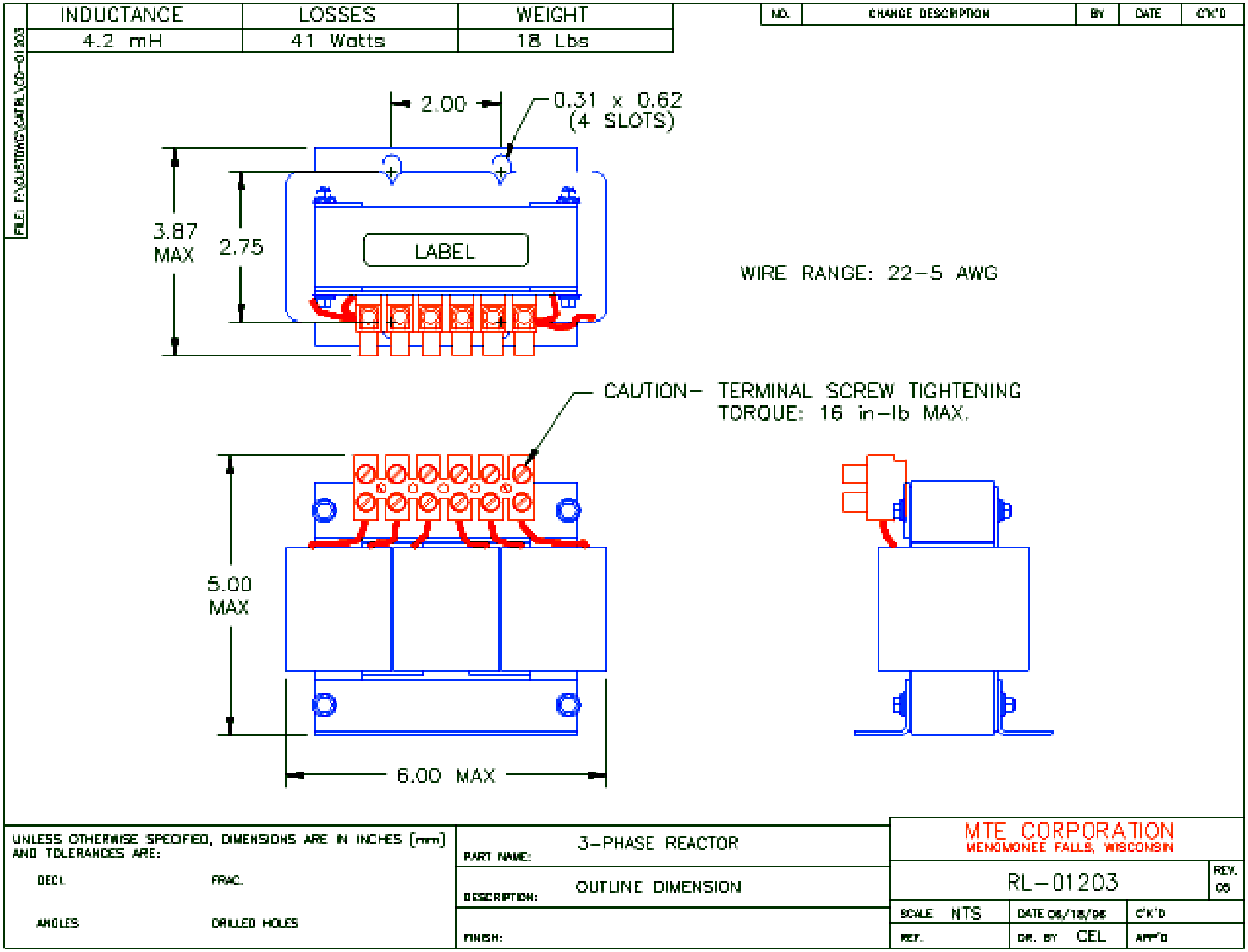

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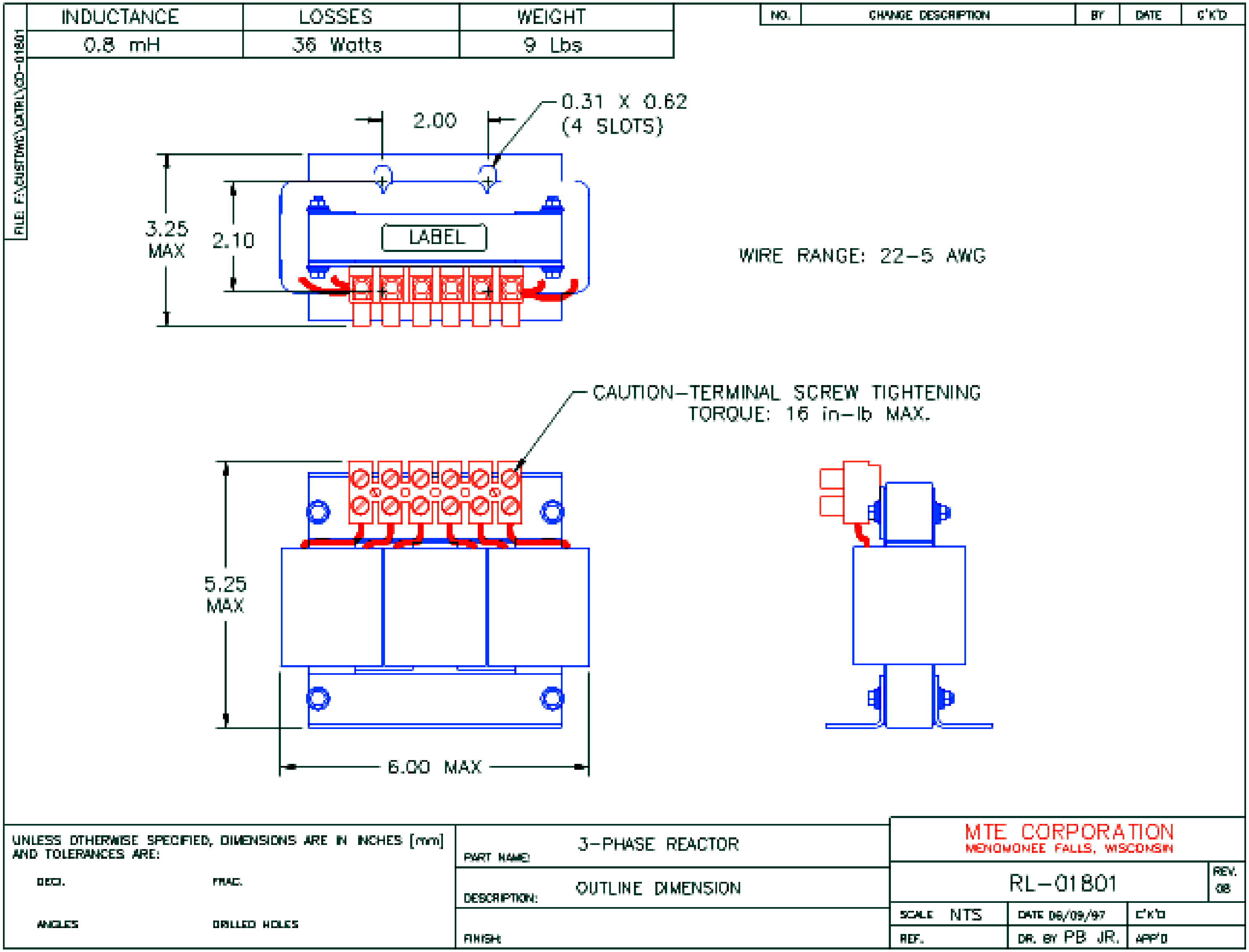

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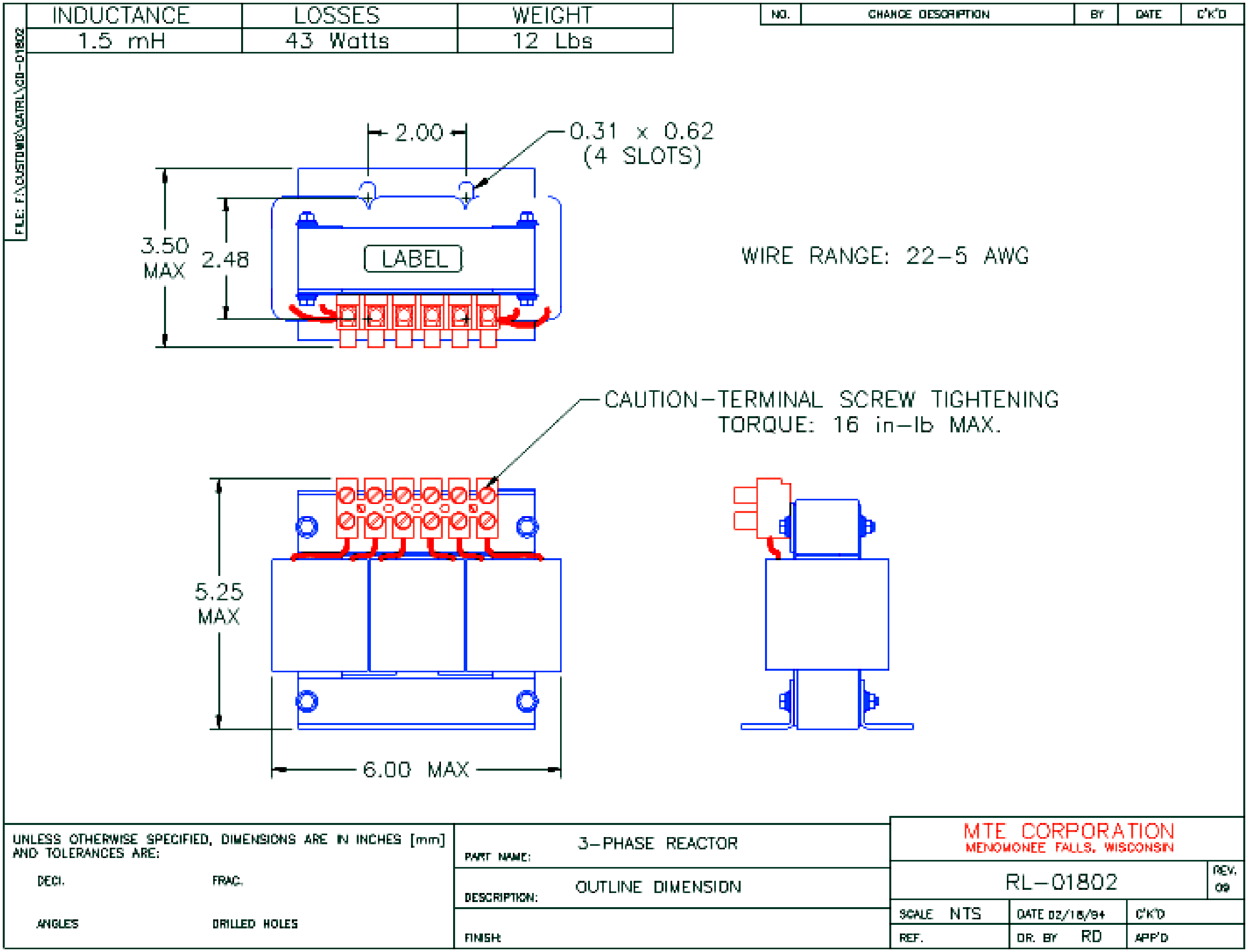

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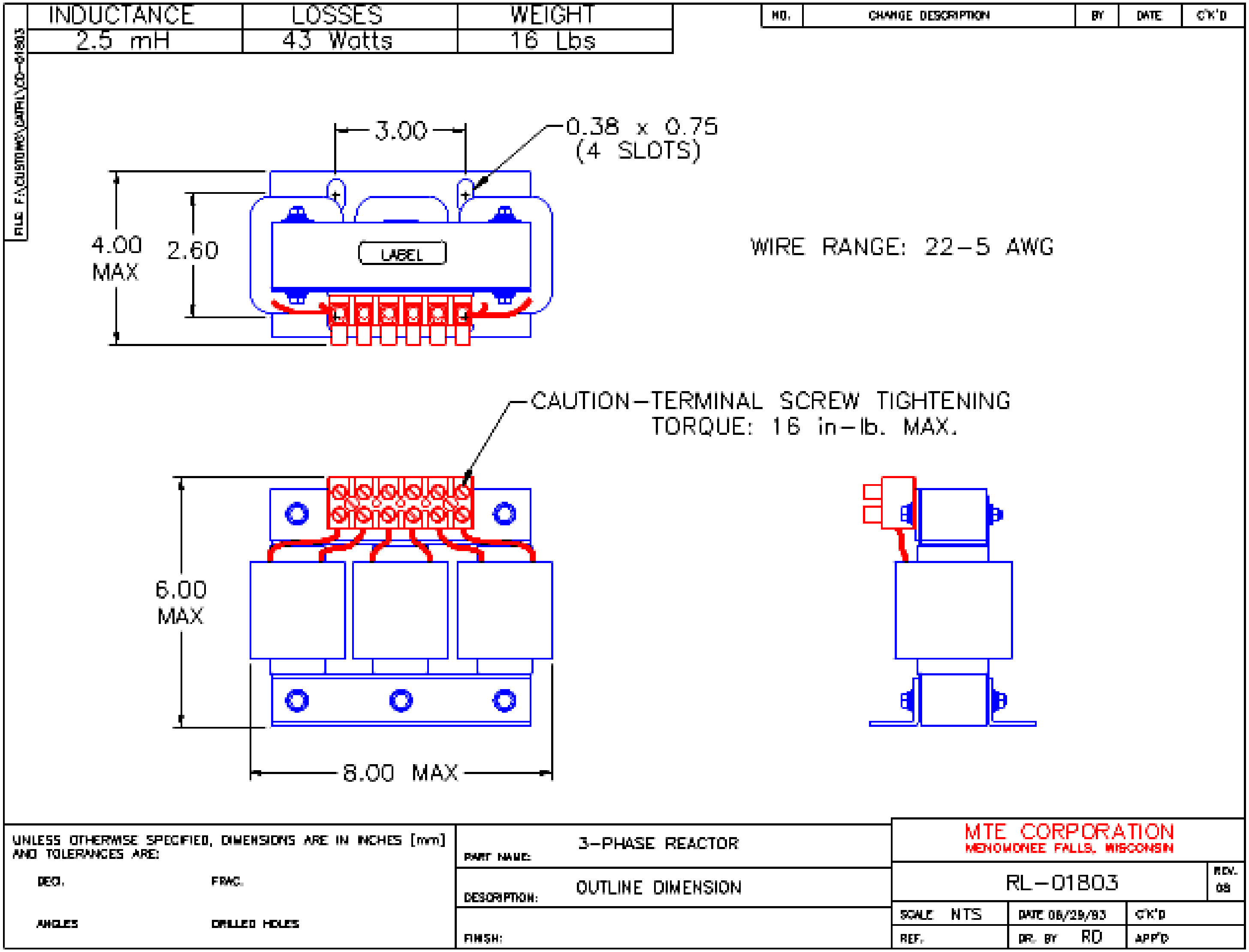

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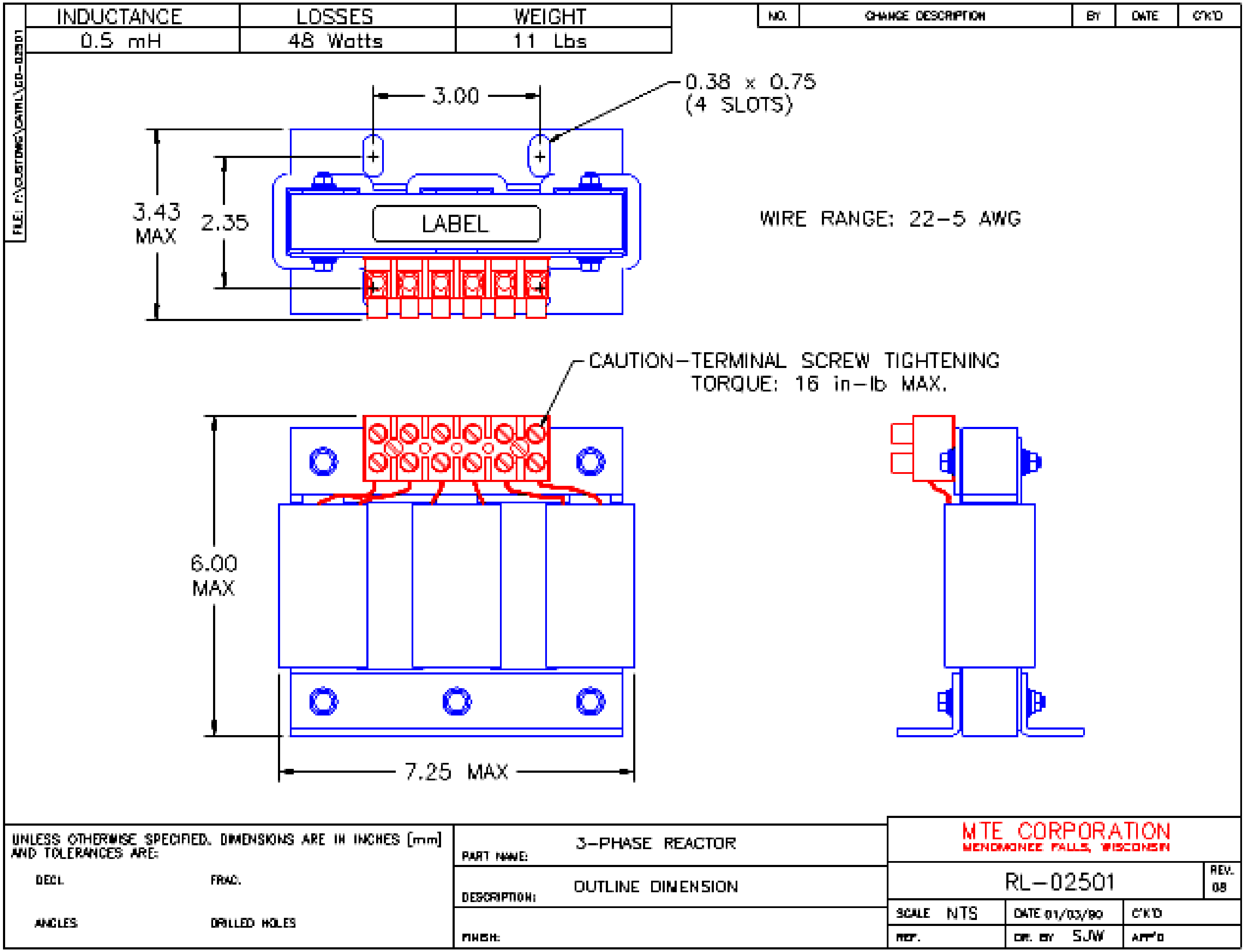

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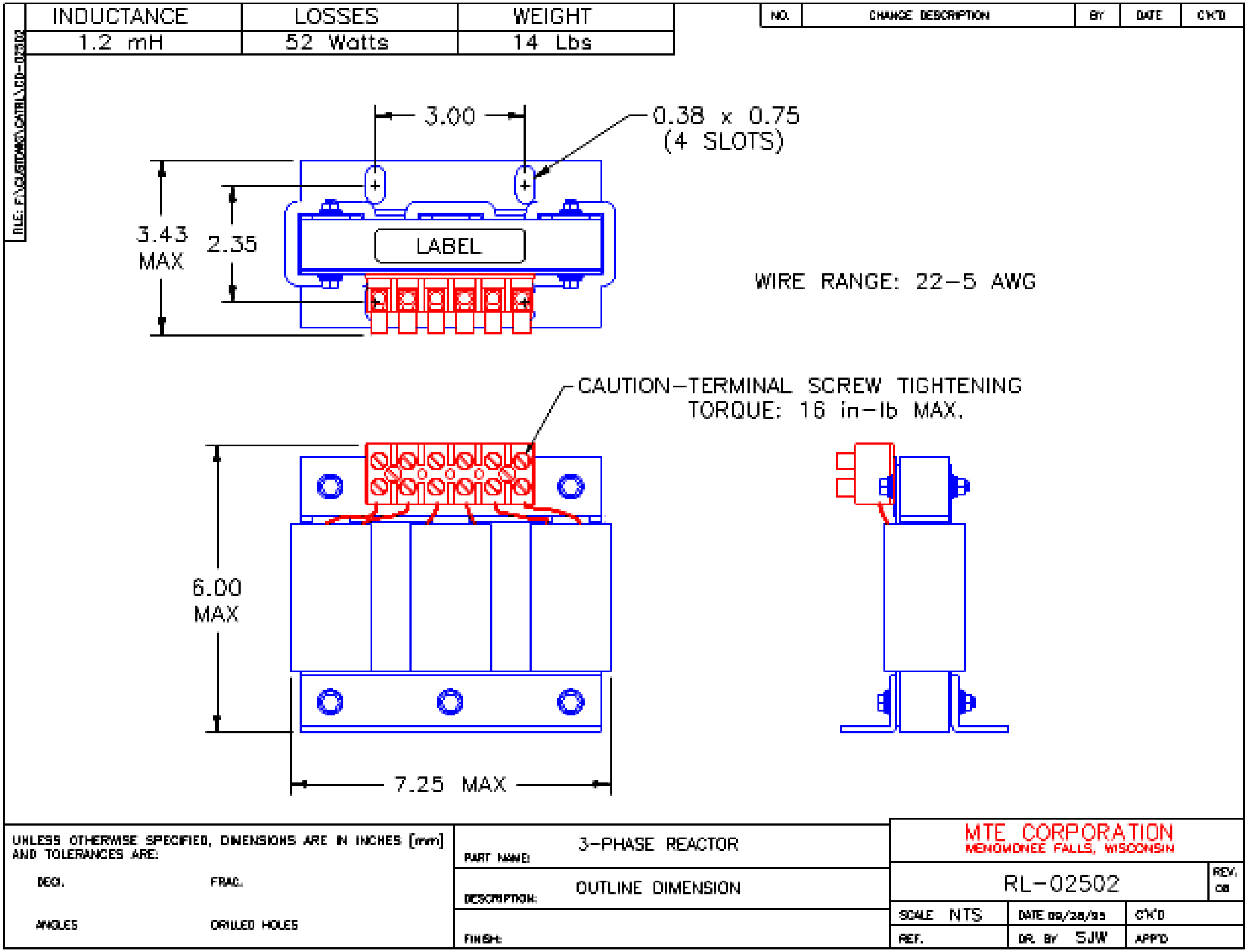

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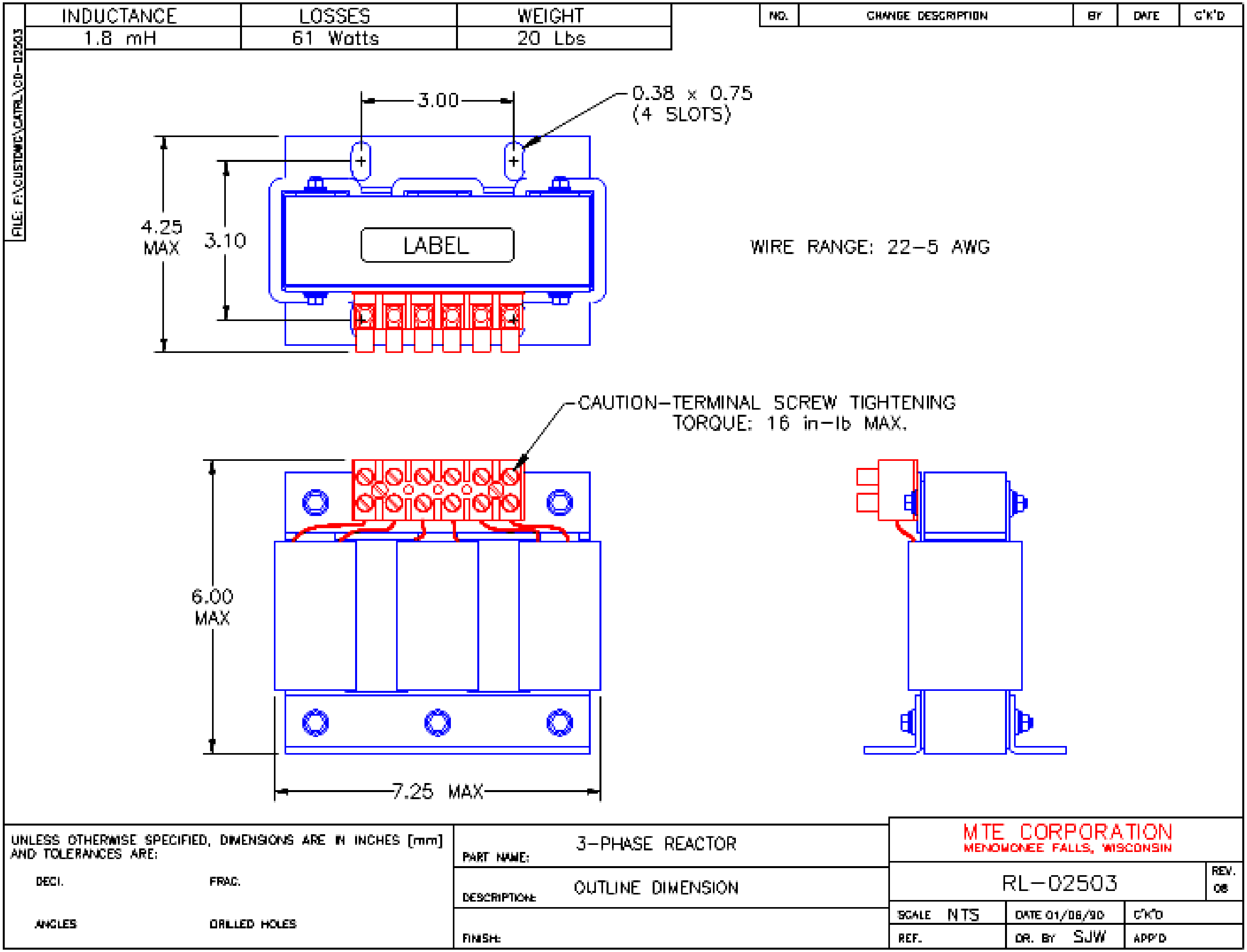

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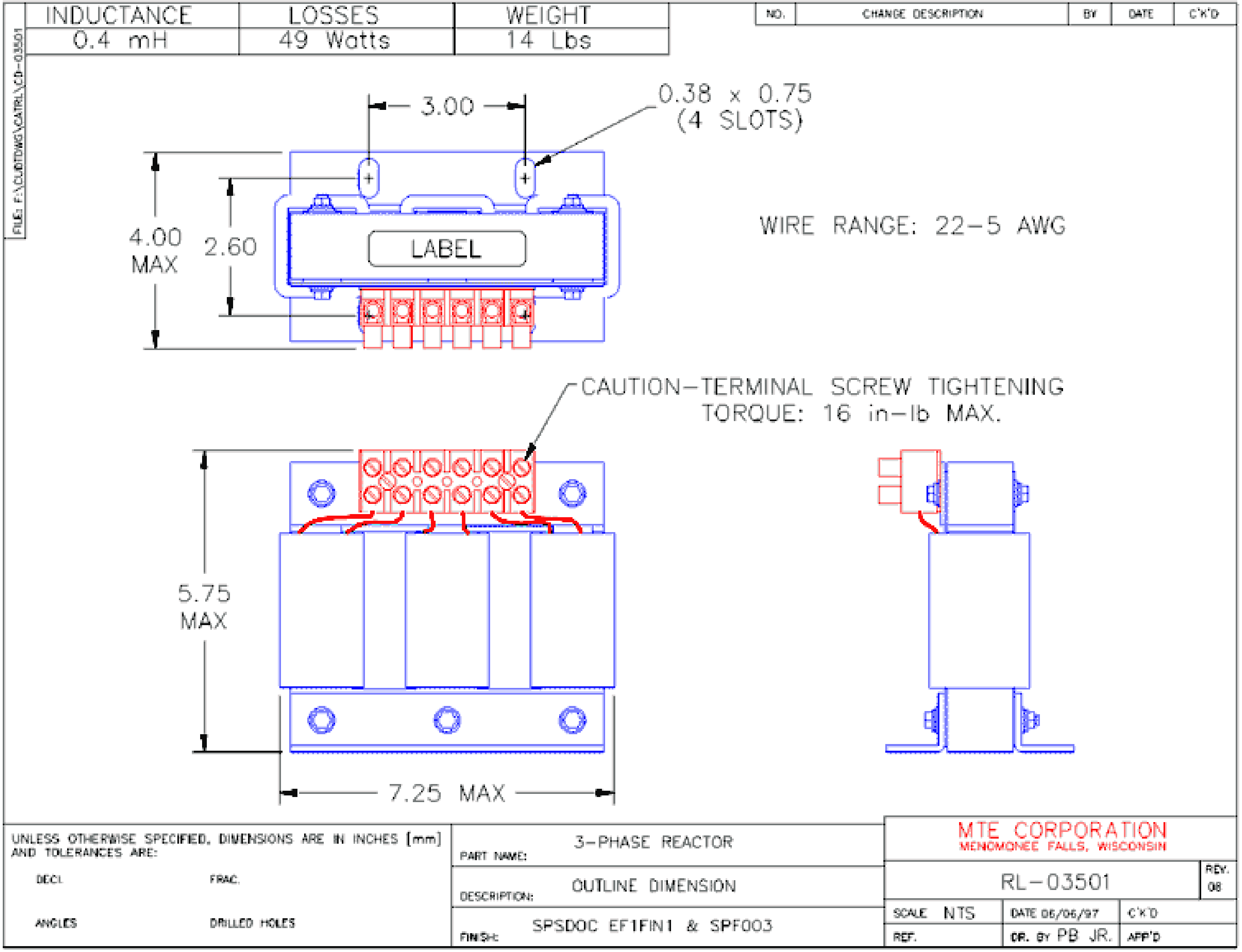

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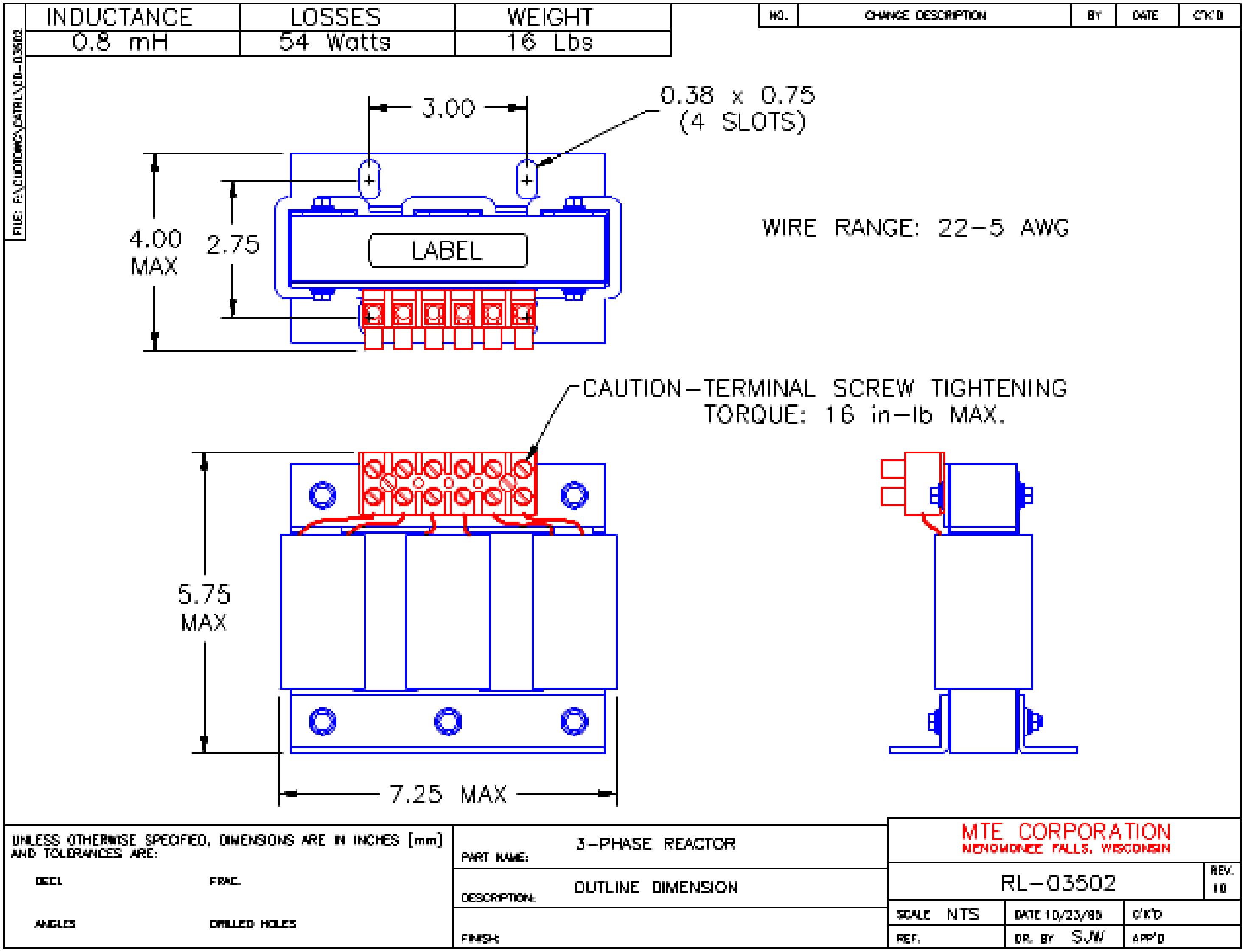

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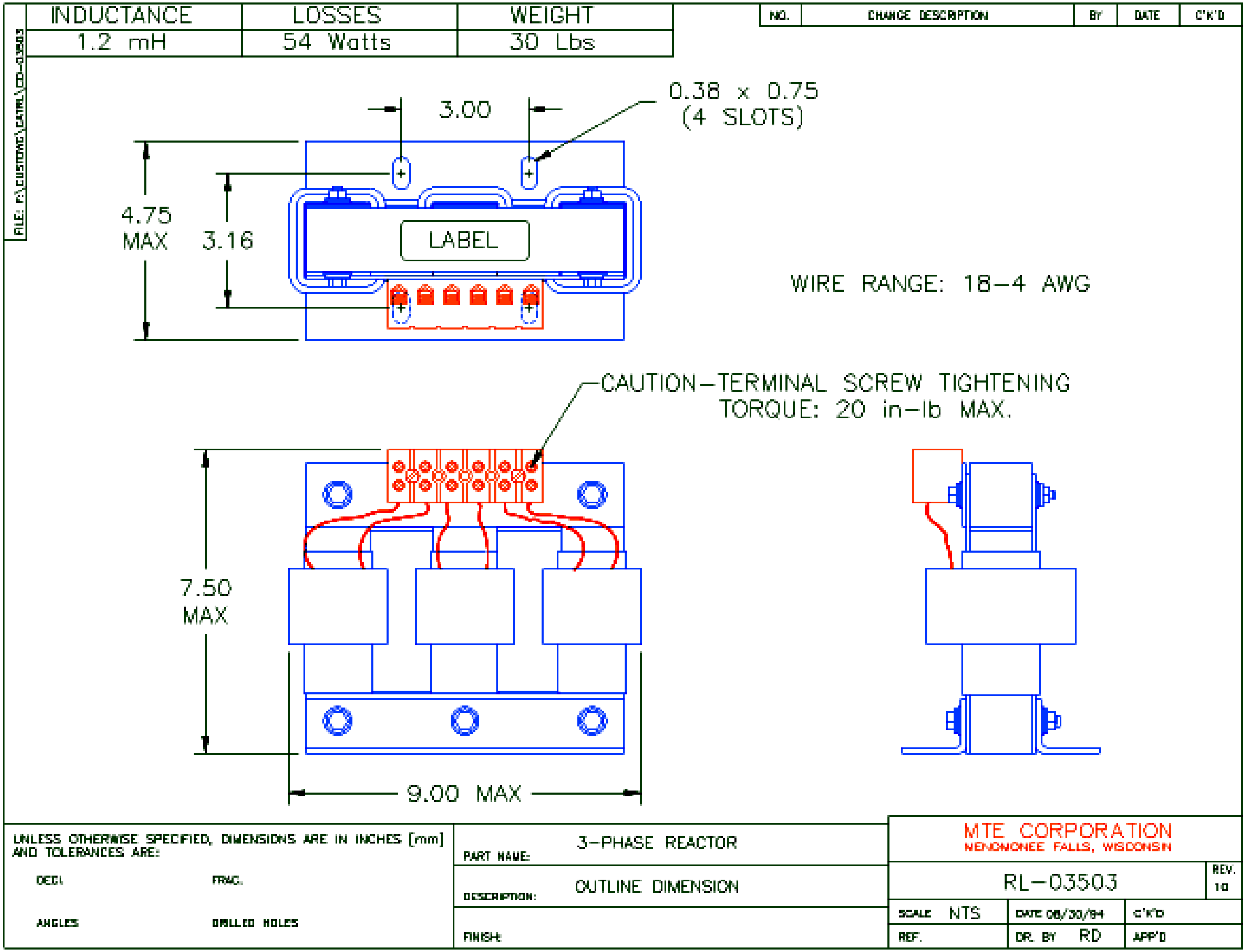

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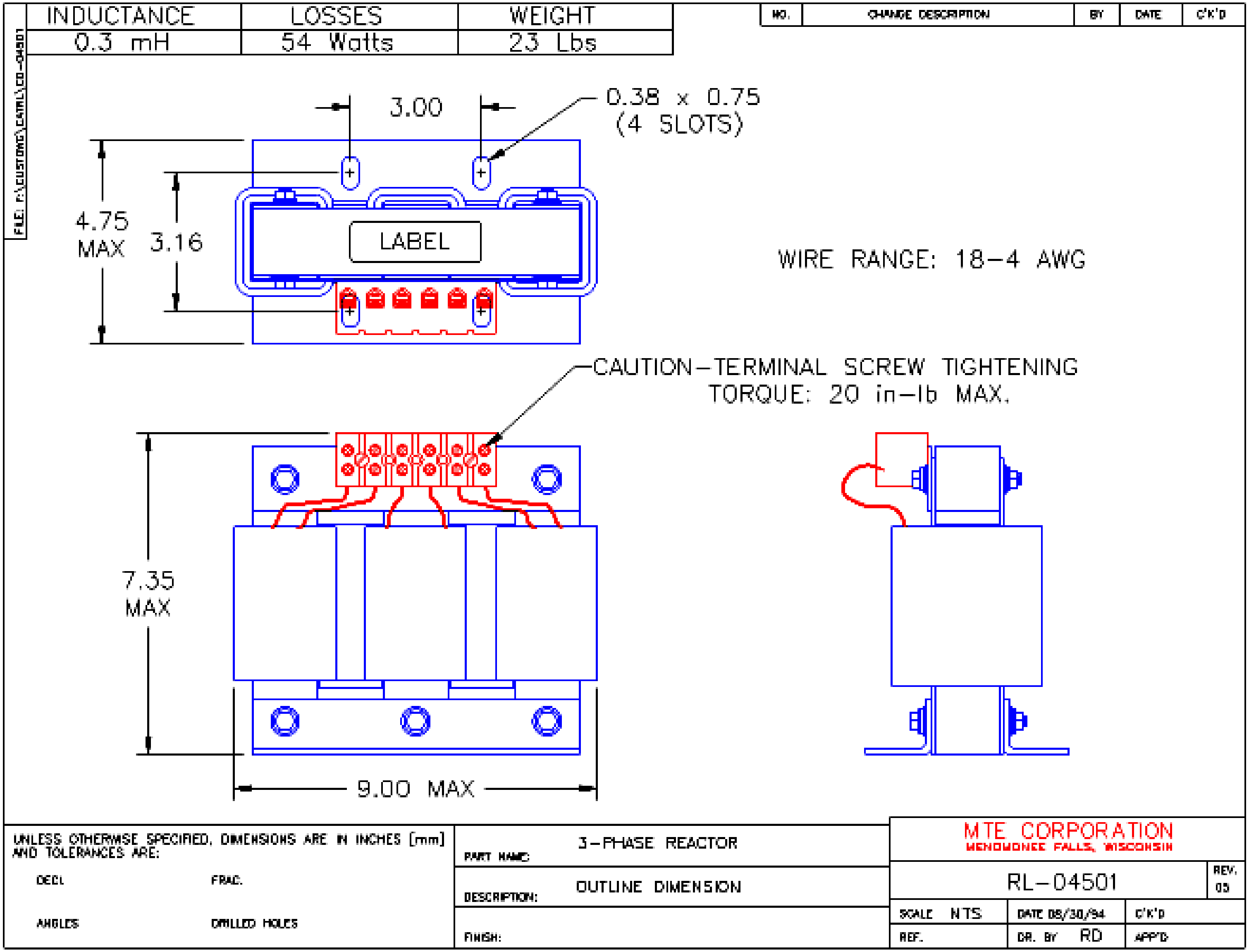

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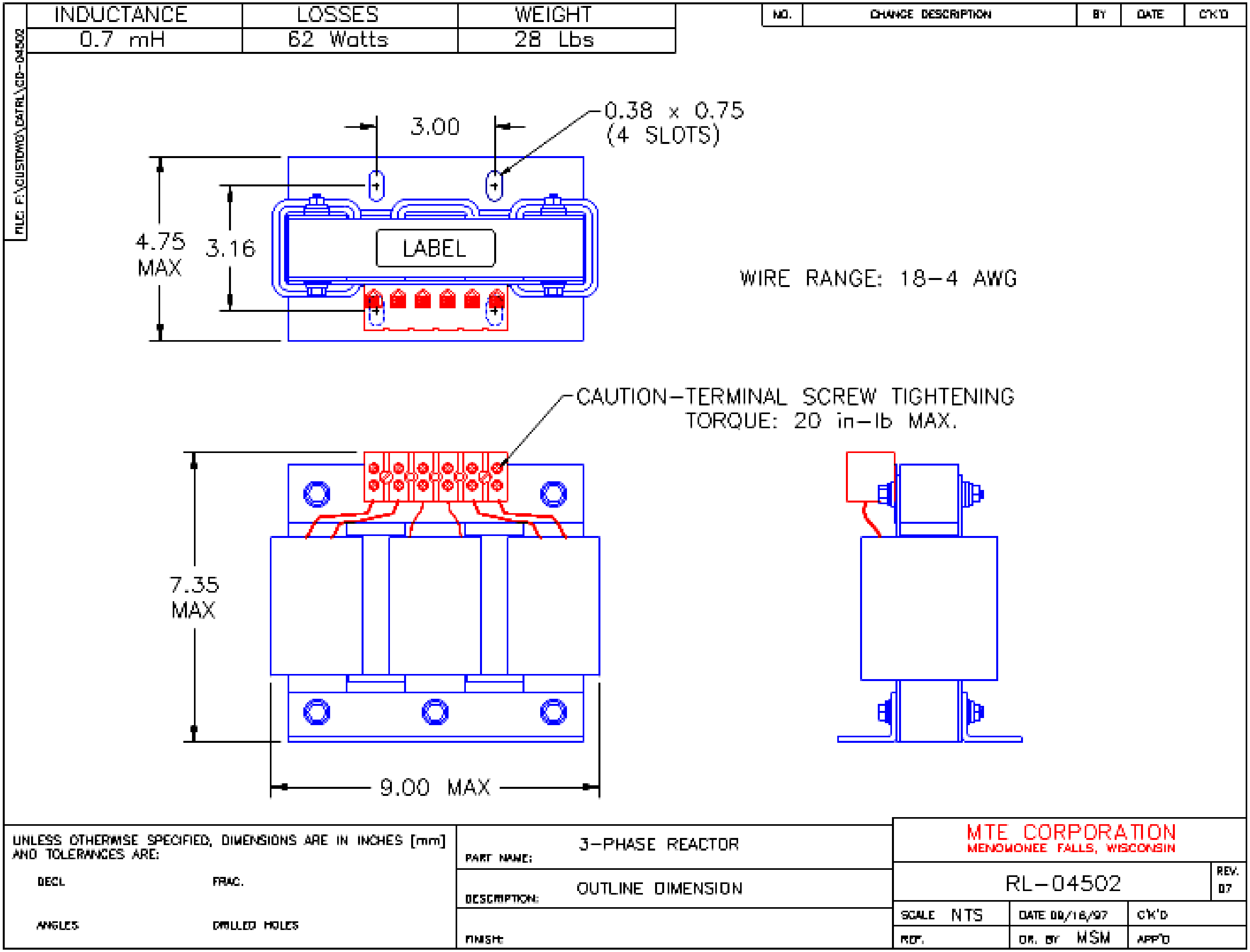

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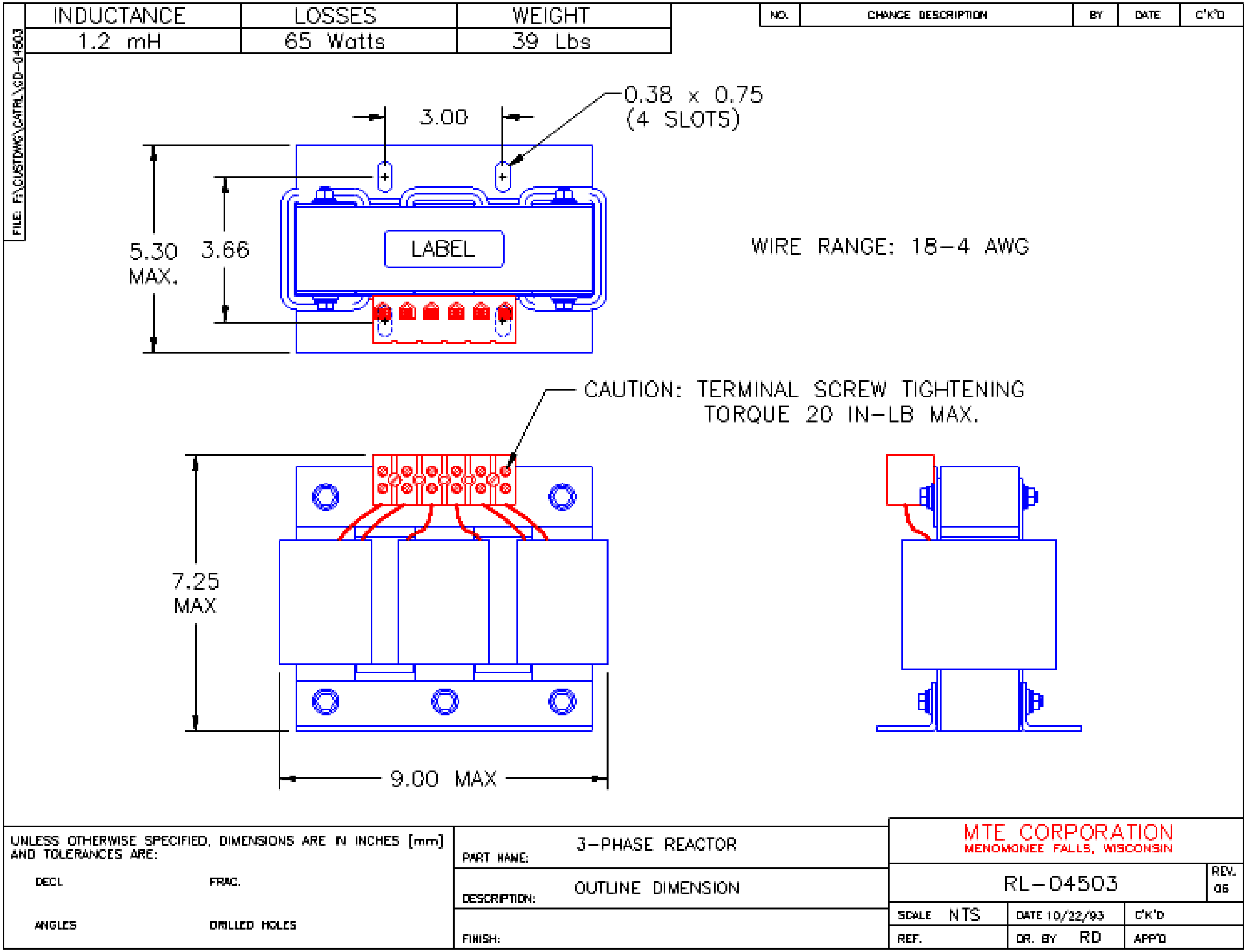

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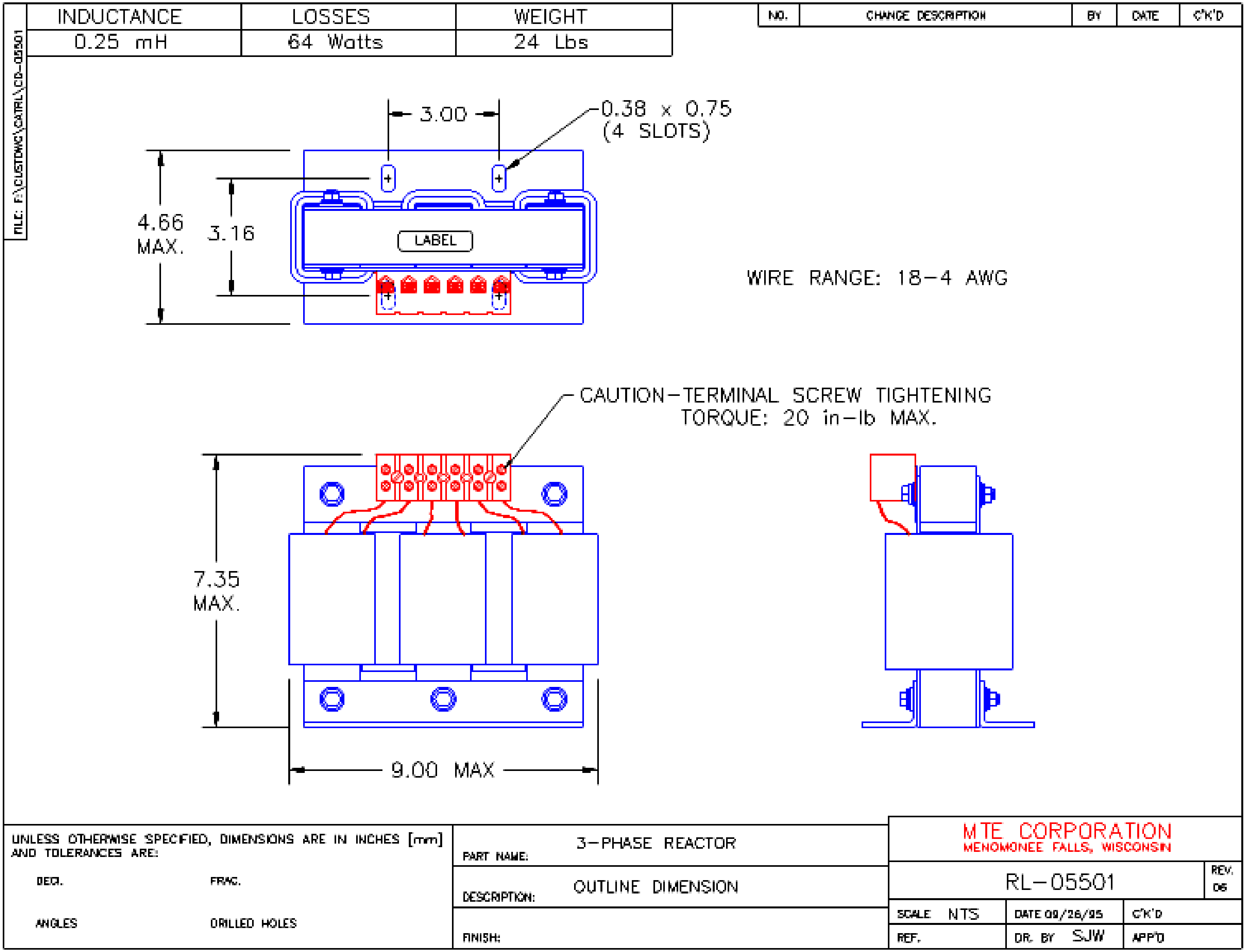

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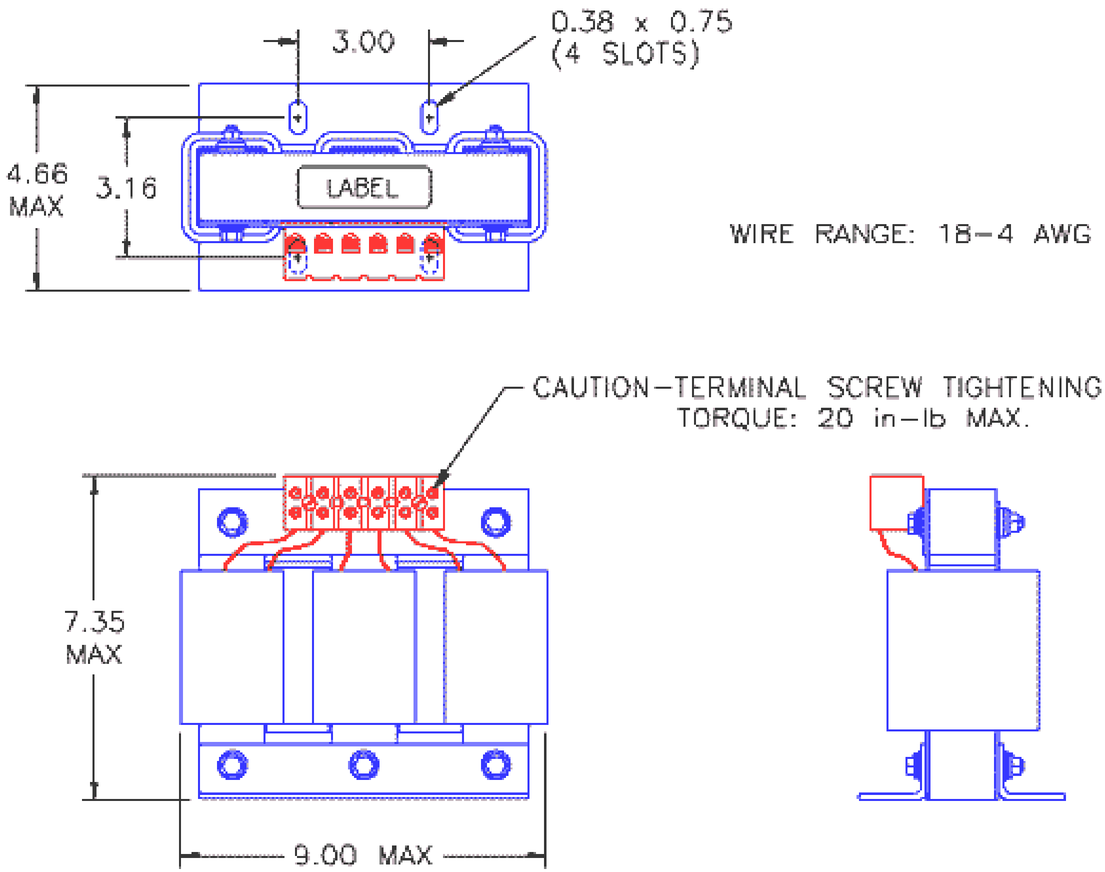
FILE: F:\CUSTOMS\DATA\CD-05502

INDUCTANCE	LOSSES	WEIGHT
0.5 mH	67 Watts	27 Lbs

NO.	CHANGE DESCRIPTION	BY	DATE	C'K'D



UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES [mm] AND TOLERANCES ARE:

DECI.   FRAC

ANGLES   DRILLED HOLES

PART NAME: 3-PHASE REACTOR

DESCRIPTION: OUTLINE DIMENSION

FINISH:

MTE CORPORATION
MENOMONEE FALLS, WISCONSIN

RL-05502   REV. 07

SCALE NTS | DATE 04/27/94 | C'K'D
REF | DR. BY RD | APP'D

BACK

Line/Load Reactors

Selection Tables

- *Product Overview*
- *Detailed Product Data*
- *Selection Tables*
- *Specification Table*
- *Application Notes*

Line/Load Selection Table **15**/11-**100**/75 **HP**/kw

600 Volts, 50/60 hz (Open Type)

Selection Table 1/.75 through 10/7.5

Ratings	HP/kw	**15**/11	**20**/15	**25**/18.5	**30**/22	**40**/30	**50**/37.5	**60**/45	**75**/55	**100**/75
208 Volts 50/60 HZ	3% Impedance	RL - 04501	RL - 05501	RL - 08001	RL - 10001	RL - 13001	RL - 16001	RL - 20001	RL - 25001	RL - 32001
	5% Impedance	RL - 04502	RL - 05502	RL - 08002	RL - 10002	RL - 13001	RL - 16002	RL - 20002	RL - 25002	RL - 32002
240 Volts 50/60 HZ	3% Impedance	RL - 04501	RL - 05501	RL - 08001	RL - 08001	RL - 10001	RL - 13001	RL - 16001	RL - 20001	RL - 25001
	5% Impedance	RL - 04502	RL - 05502	RL - 08002	RL - 08002	RL - 10002	RL - 13001	RL - 16002	RL - 20002	RL - 25002
380 Volts 50/60 HZ	2% Impedance	RL - 02501	RL - 03501	RL - 04501	RL - 04501	RL - 08001	RL - 08001	RL - 10001	RL - 10001	RL - 16001
	4% Impedance	RL - 02502	RL - 03502	RL - 04502	RL - 04502	RL - 08002	RL - 10002	RL - 10002	RL - 16002	RL - 20002
400 Volts 50/60 HZ	2% Impedance	RL - 02501	RL - 03501	RL - 04501	RL - 04501	RL - 05501	RL - 08001	RL - 08001	RL - 10001	RL - 13001
	4% Impedance	RL - 02502	RL - 03502	RL - 04502	RL - 04502	RL - 05502	RL - 08002	RL - 08002	RL - 10002	RL - 13001
415 Volts 50/60 HZ	2% Impedance	RL - 02501	RL - 03501	RL - 04501	RL - 04501	RL - 05501	RL - 08001	RL - 08001	RL - 10001	RL - 13001
	4% Impedance	RL - 02502	RL - 03502	RL - 04502	RL - 04502	RL - 05502	RL - 08002	RL - 08002	RL - 10002	RL - 13001
480 Volts 50/60 HZ	3% Impedance	RL - 02502	RL - 03502	RL - 03502	RL - 04502	RL - 05502	RL - 08002	RL - 08002	RL - 10002	RL - 13002
	5% Impedance	RL - 02503	RL - 03503	RL - 03503	RL - 04503	RL - 05503	RL - 08003	RL - 08003	RL - 10003	RL - 13003
600 Volts 50/60 HZ	3% Impedance	RL - 01802	RL - 02502	RL - 02502	RL - 03502	RL - 04502	RL - 05502	RL - 08002	RL - 08002	RL - 10002
	5% Impedance	RL - 01803	RL - 02503	RL - 02503	RL - 03503	RL - 04503	RL - 05503	RL - 08003	RL - 08003	RL - 10003

Selection Table 125/93 through 750/550

Line/Load Reactors

Selection Tables

- *Product Overview*
- *Detailed Product Data*
- *Selection Tables*
- *Specification Table*
- *Application Notes*

Line-Load Selection Table **1**/.75-**10**/7.5 **HP**/kw

600 Volts, 50/60 hz (Open Type)

Ratings	**HP/kw**	**1**/.75	**1.5**/1.1	**2**/1.5	**3**/2.2	**5**/3.7	**7.5**/5.5	**10**/7.5
208 Volts 50/60 HZ	3% Impedance	RL - 00401	RL - 00801	RL - 00801	RL - 01201	RL - 01801	RL - 02501	RL - 03501
	5% Impedance	RL - 00402	RL - 00802	RL - 00802	RL - 01202	RL - 01802	RL - 02502	RL - 03502
240 Volts 50/60 HZ	3% Impedance	RL - 00401	RL - 00801	RL - 00801	RL - 01201	RL - 01801	RL - 02501	RL - 03501
	5% Impedance	RL - 00402	RL - 00802	RL - 00802	RL - 01202	RL - 01802	RL - 02502	RL - 03502
380 Volts 50/60 HZ	2% Impedance	RL - 00204	RL - 00402	RL - 00401	RL - 00802	RL - 00801	RL - 01201	RL - 01801
	4% Impedance	RL - 00201	RL - 00402	RL - 00402	RL - 00803	RL - 00802	RL - 01202	RL - 01802
400 Volts 50/60 HZ	2% Impedance	RL - 00201	RL - 00402	RL - 00402	RL - 00802	RL - 00801	RL - 01201	RL - 01801
	4% Impedance	RL - 00202	RL - 00404	RL - 00403	RL - 00803	RL - 00802	RL - 01202	RL - 01802
415 Volts 50/60 HZ	2% Impedance	RL - 00201	RL - 00402	RL - 00402	RL - 00802	RL - 00801	RL - 01201	RL - 01801
	4% Impedance	RL - 00202	RL - 00404	RL - 00403	RL - 00803	RL - 00802	RL - 01202	RL - 01802
480 Volts 50/60 HZ	3% Impedance	RL - 00201	RL - 00201	RL - 00402	RL - 00402	RL - 00802	RL - 01202	RL - 01802
	5% Impedance	RL - 00202	RL - 00202	RL - 00403	RL - 00403	RL - 00803	RL - 01203	RL - 01803
600 Volts 50/60 HZ	3% Impedance	RL - 00202	RL - 00202	RL - 00403	RL - 00403	RL - 00803	RL - 00802	RL - 01202
	5% Impedance	RL - 00203	RL - 00203	RL - 00404	RL - 00404	RL - 00804	RL - 00803	RL - 01203

Selection Table 15/11 through 100/75.

Line/Load Reactors

Selection Tables

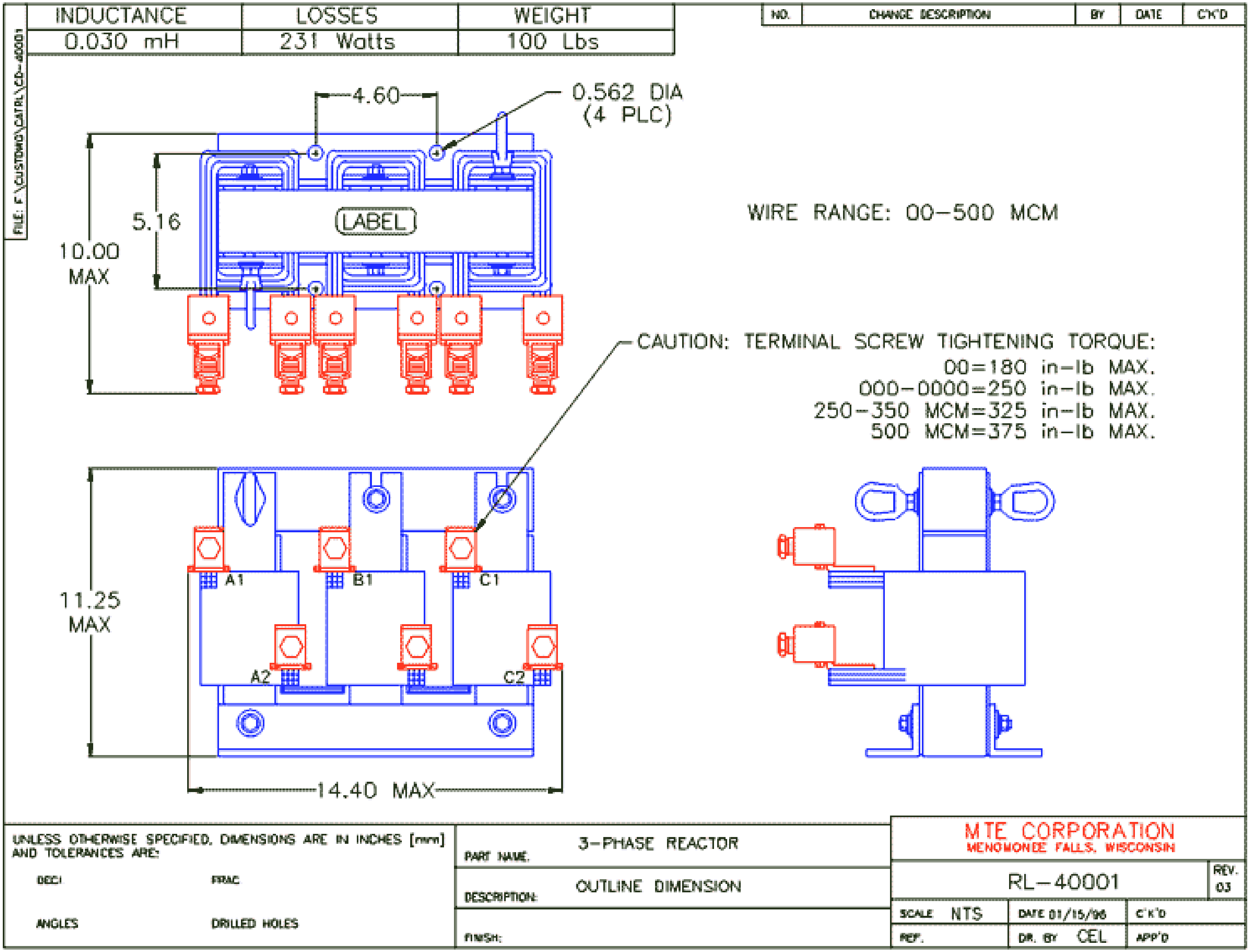
- *Product Overview*
- *Detailed Product Data*
- *Selection Tables*
- *Specification Table*
- *Application Notes*

Line/Load Selection Table **125**/93 **750**/550 **HP**/kw

600 Volts, 50/60 hz (Open Type)

Selection Table 15/11 through 100/75.

Ratings	**125**/93	**150**/112	**200**/150	**250**/187	**300**/225	**350**/262	**400**/300	**500**/375	**600**/450	**750**/550
208 Volts 50/60 HZ	RL - 40001	RL - 50001	RL - 60001	RL - 75001						
	RL - 40002	RL - 50002	RL - 60002	RL - 75002						
240 Volts 50/60 HZ	RL - 32001	RL - 40001	RL - 50001	RL - 60001	RL - 75001					
	RL - 32002	RL - 40002	RL - 50002	RL - 60002	RL - 75002					
380 Volts 50/60 HZ	RL - 20001	RL - 25001	RL - 32002	RL - 40001	RL - 40001	RL - 50001	RL - 60001	RL - 75002		
	RL - 08002	RL - 25002	RL - 32003	RL - 40002	RL - 40002	RL - 50002	RL - 60002	RL - 75003		
400 Volts 50/60 HZ	RL - 20002	RL - 25002	RL - 32002	RL - 32001	RL - 40001	RL - 50001	RL - 50002	RL - 75002		
	RL - 20003	RL - 25003	RL - 32003	RL - 32002	RL - 40002	RL - 50002	RL - 60003	RL - 75003		
415 Volts 50/60 HZ	RL - 20002	RL - 20002	RL - 25001	RL - 32001	RL - 40001	RL - 50001	RL - 50001	RL - 75002	RL - 75002	
	RL - 20003	RL - 20003	RL - 25002	RL - 32002	RL - 40002	RL - 50002	RL - 50002	RL - 75003	RL - 75003	
480 Volts 50/60 HZ	RL - 16002	RL - 20002	RL - 25002	RL - 32002	RL - 40002	RL - 50002	RL - 50002	RL - 60002	RL - 75002	
	RL - 16003	RL - 20003	RL - 25003	RL - 32003	RL - 40003	RL - 50003	RL - 50003	RL - 60003	RL - 75003	
600 Volts 50/60 HZ	RL - 13002	RL - 16002	RL - 20002	RL - 25002	RL - 32002	RL - 40002	RL - 40002	RL - 50002	RL - 60002	RL - 75002
	RL - 13003	RL - 16003	RL - 20003	RL - 25003	RL - 32003	RL - 40003	RL - 40003	RL - 50003	RL - 60003	RL - 75003



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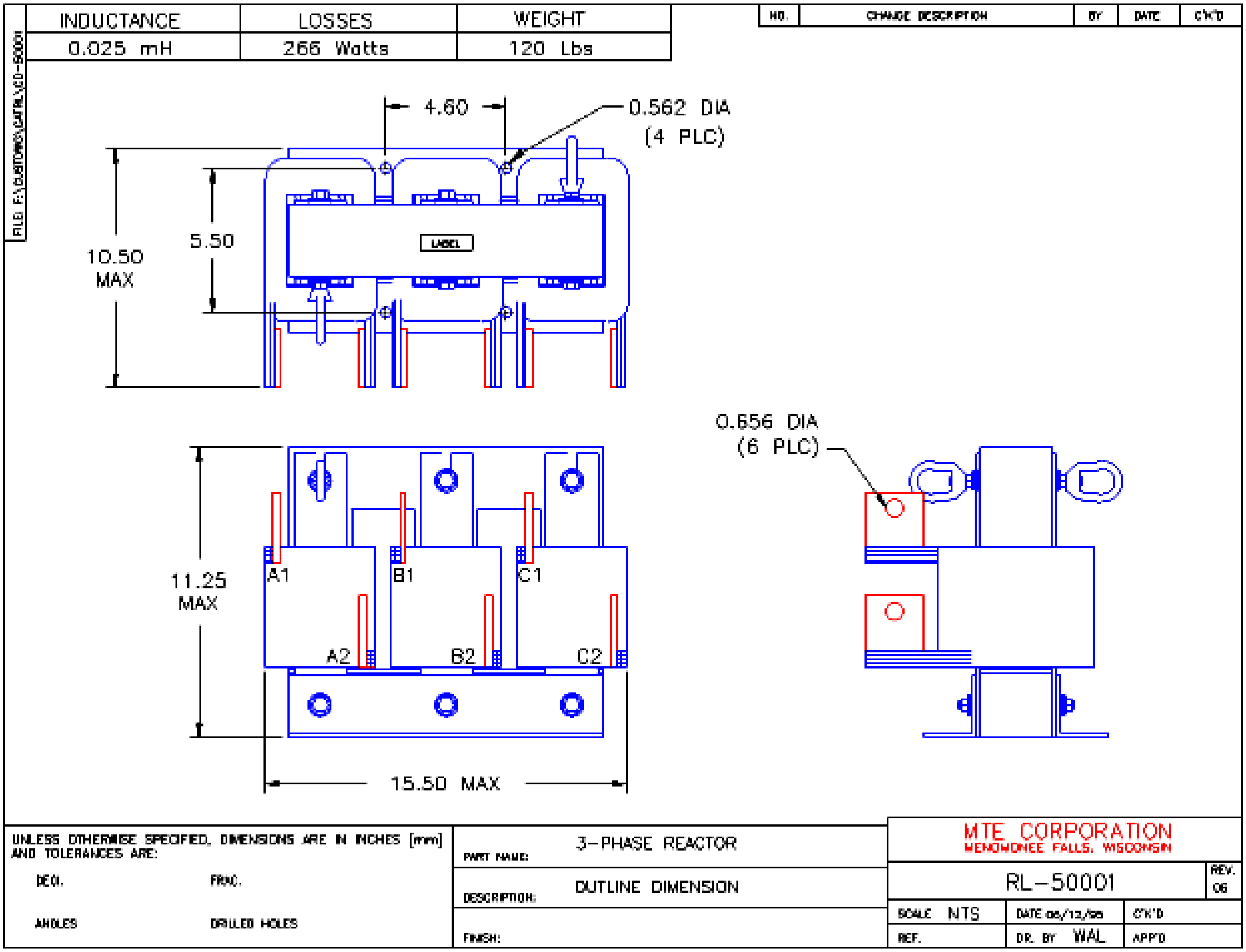

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For Sales Support: E-Mail: sales@mtecorp.com

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Tel: 1-262-253-8200
Fax: 1-262-253-8222
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Fax: +1-905 884-6258	Fax: +44 (0) 1493 604455	Fax: +(52) 722 199-4158	Fax: +(65) 67869860

INDUCTANCE	LOSSES	WEIGHT
0.020 mH	307 Watts	160 Lbs

NO.	CHANGE DESCRIPTION	BY	DATE	C'K'D

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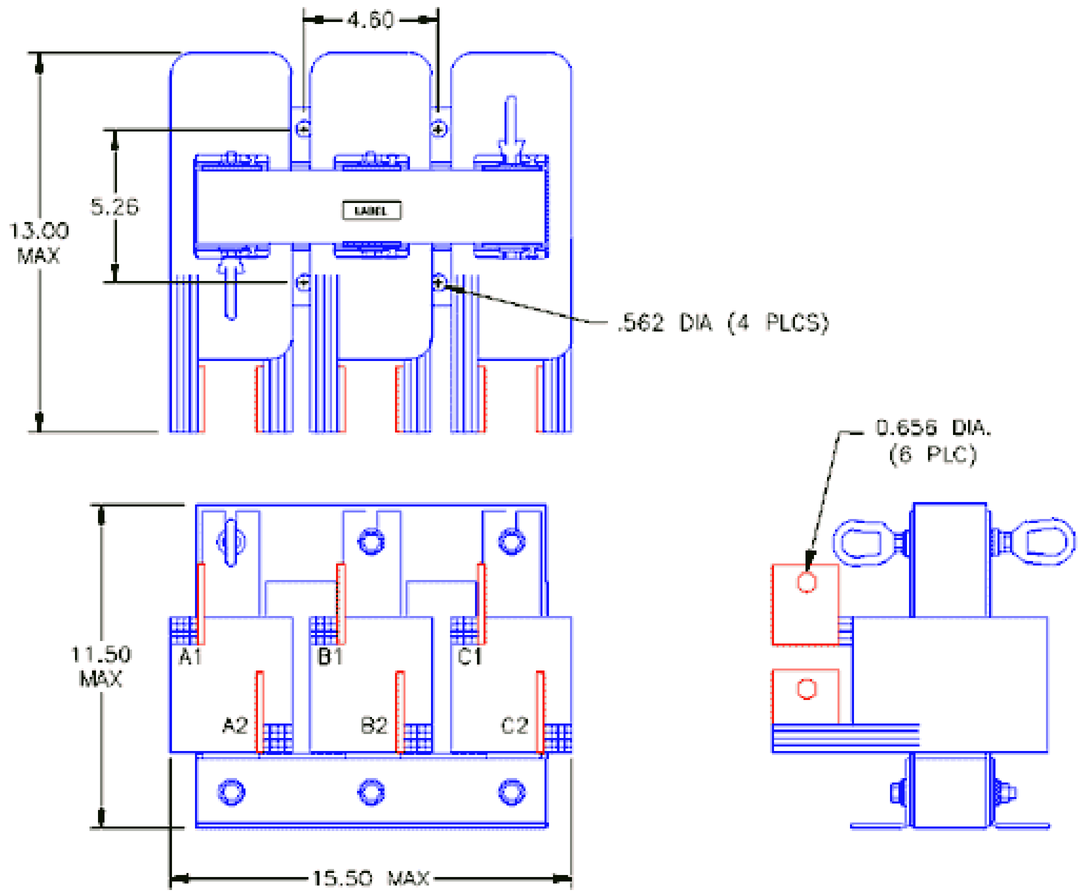

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES [mm] AND TOLERANCES ARE:

DECI.

FRAC.

ANGLES

DRILLED HOLES

PART NAME: 3--PHASE REACTOR

DESCRIPTION: OUTLINE DIMENSION

FINISH:

MTE CORPORATION
MENOMONEE FALLS, WISCONSIN

RL-60001

REV. 05

SCALE NTS	DATE 04/24/97	C'K'D
REF.	DR. BY MSM	APP'D

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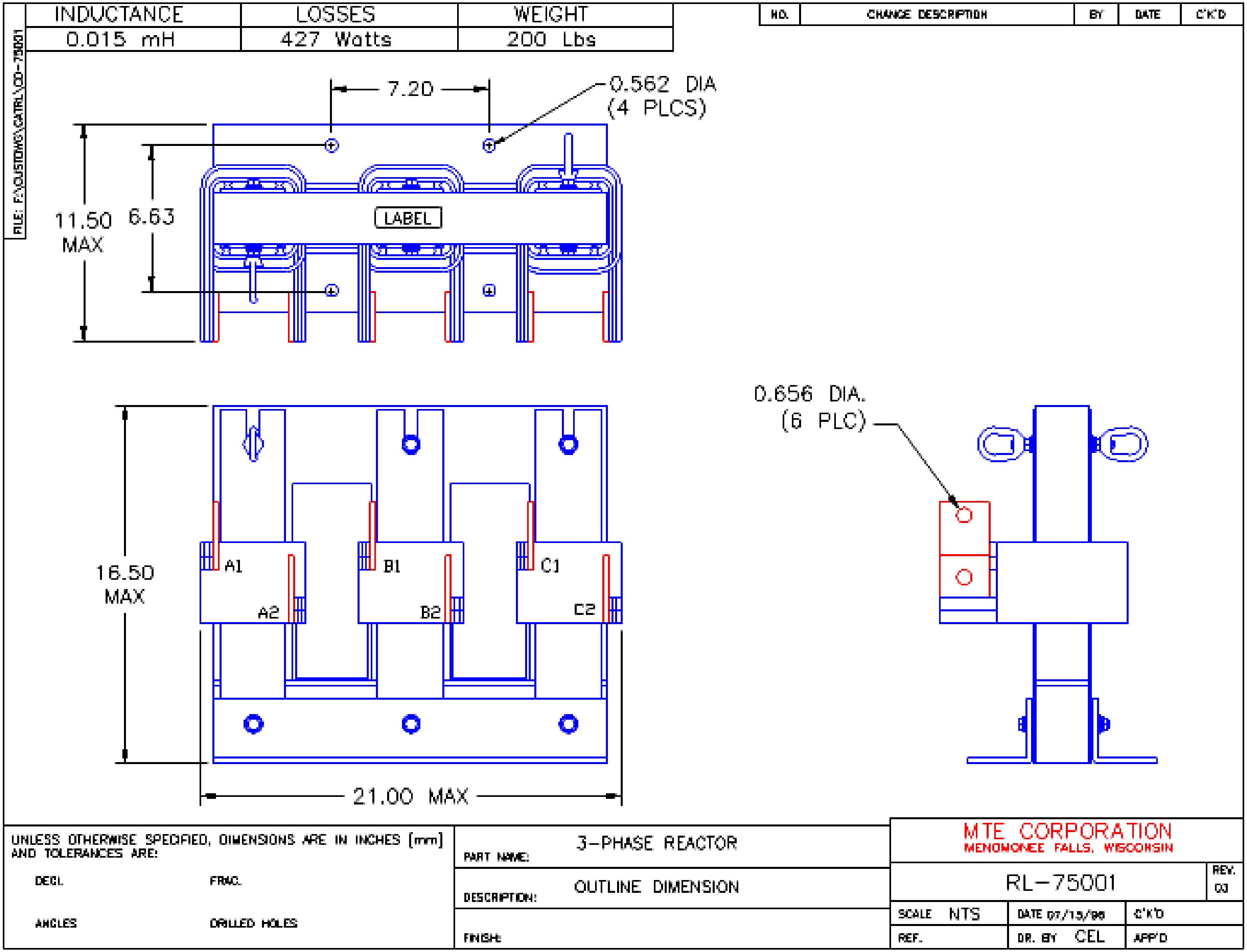

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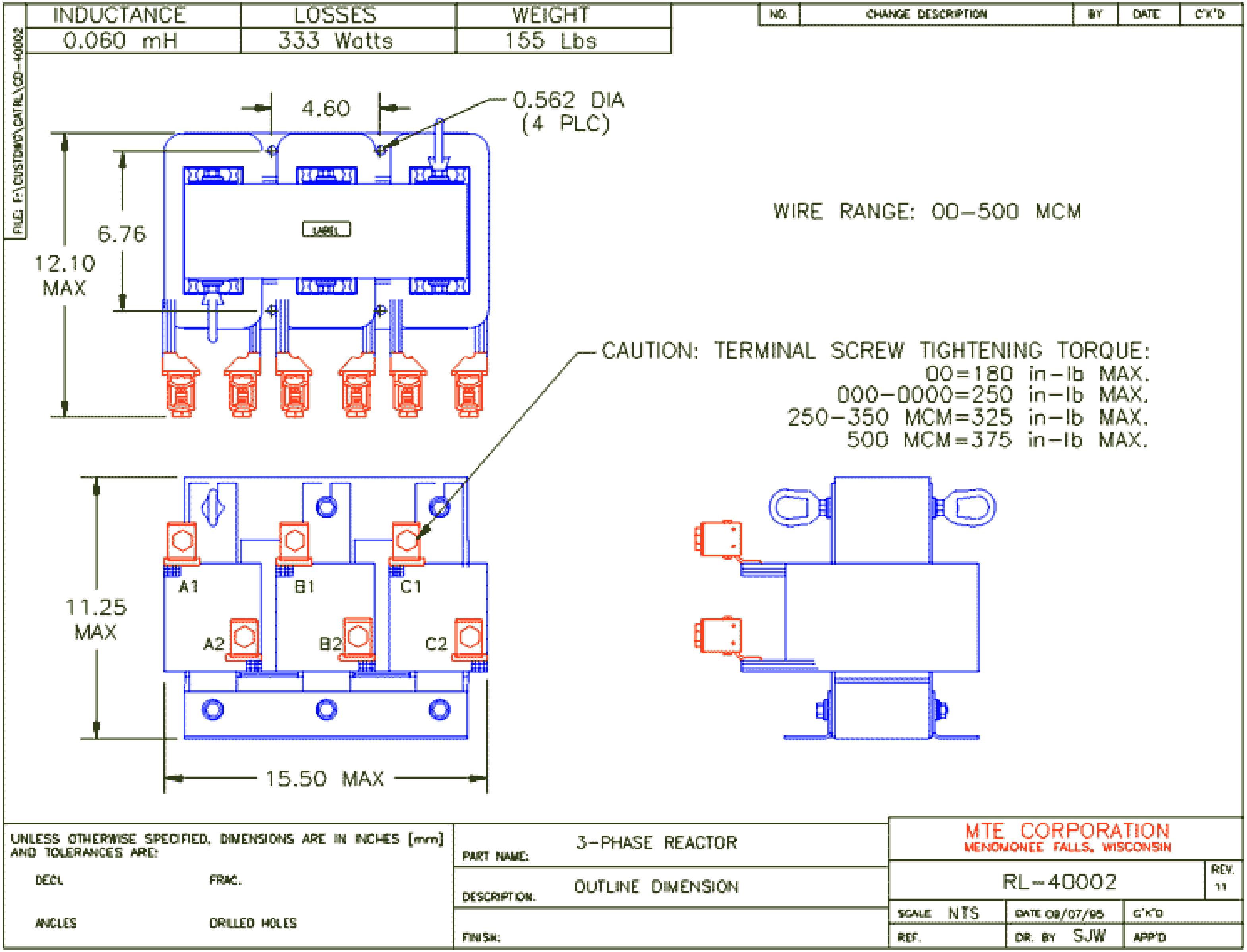

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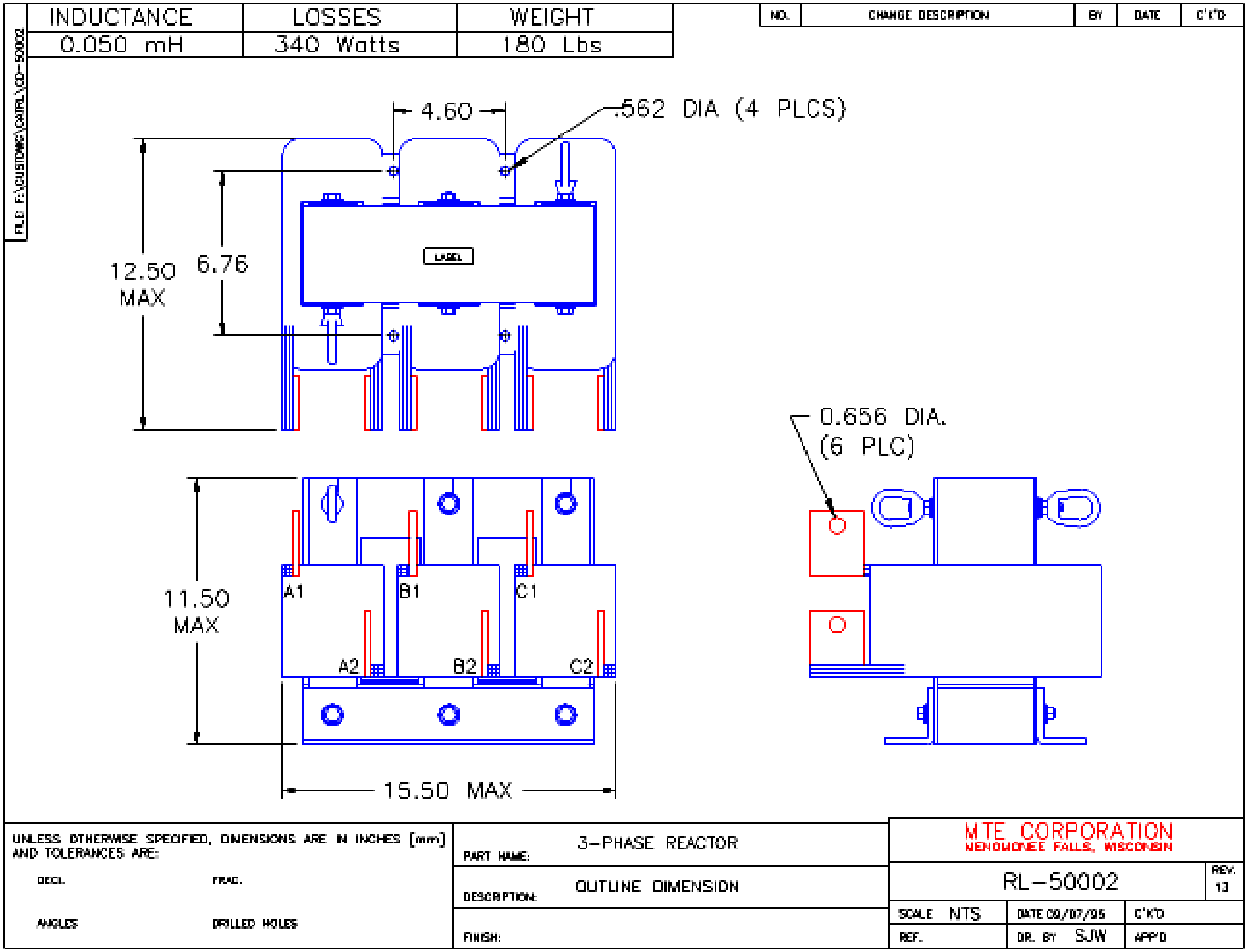

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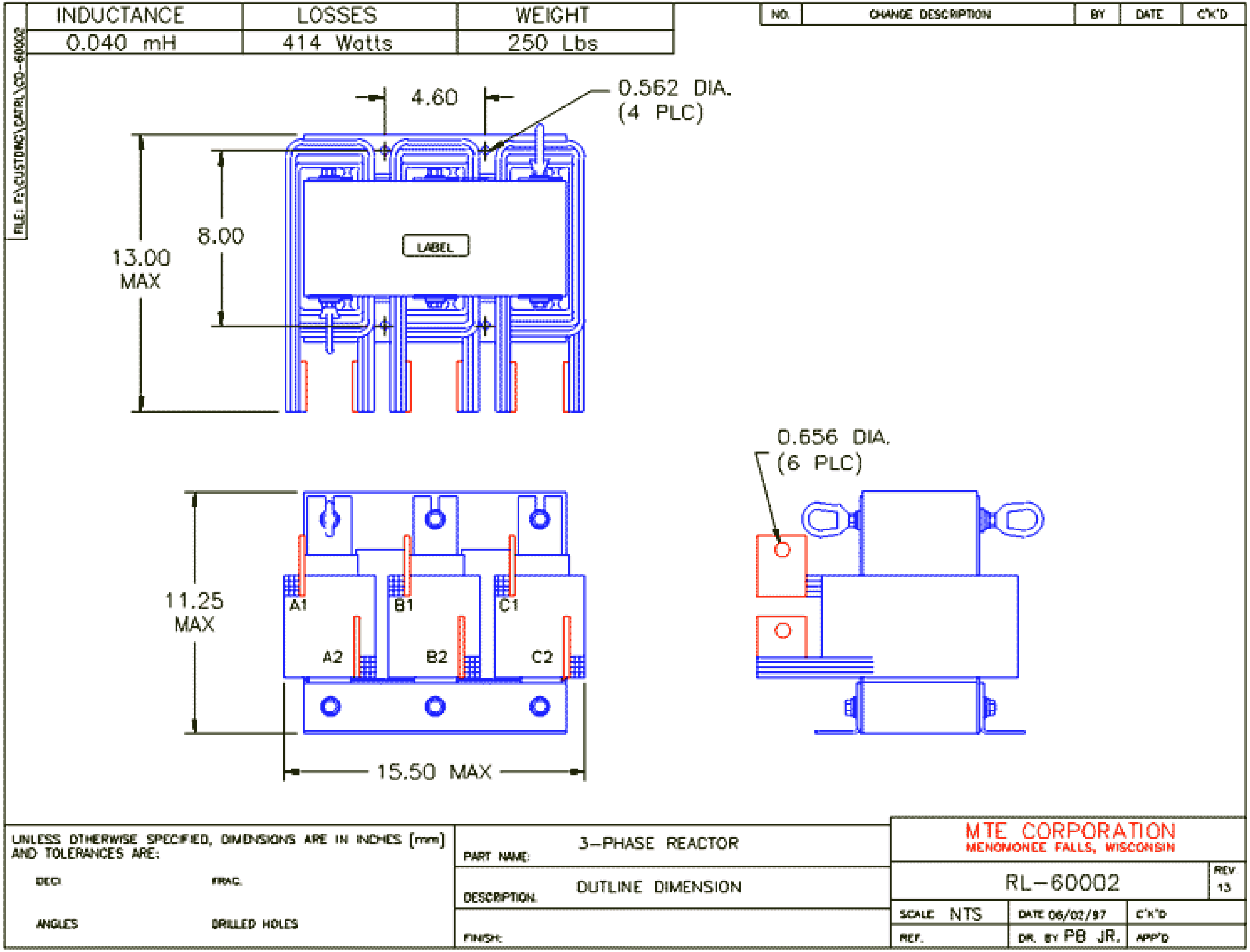

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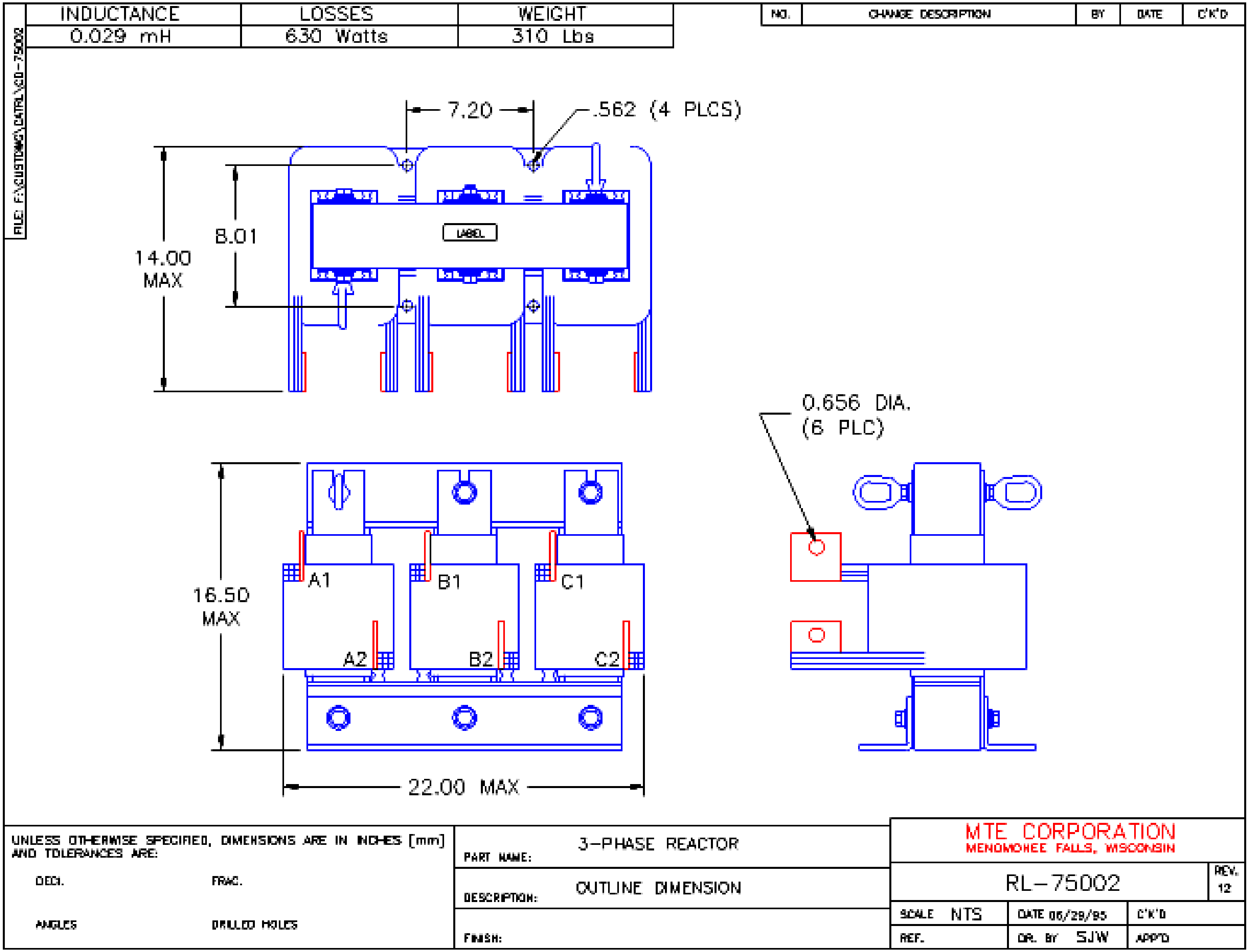

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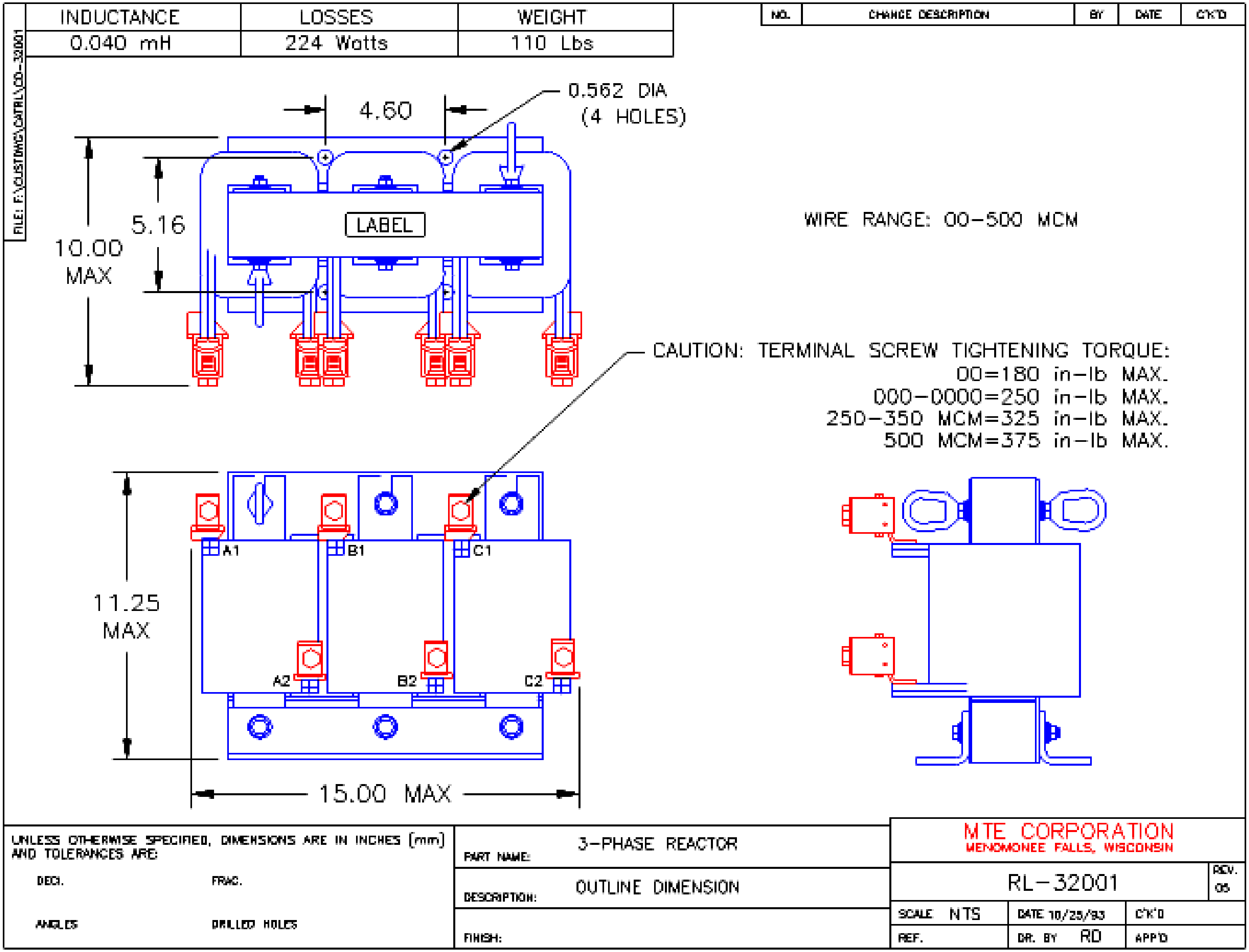

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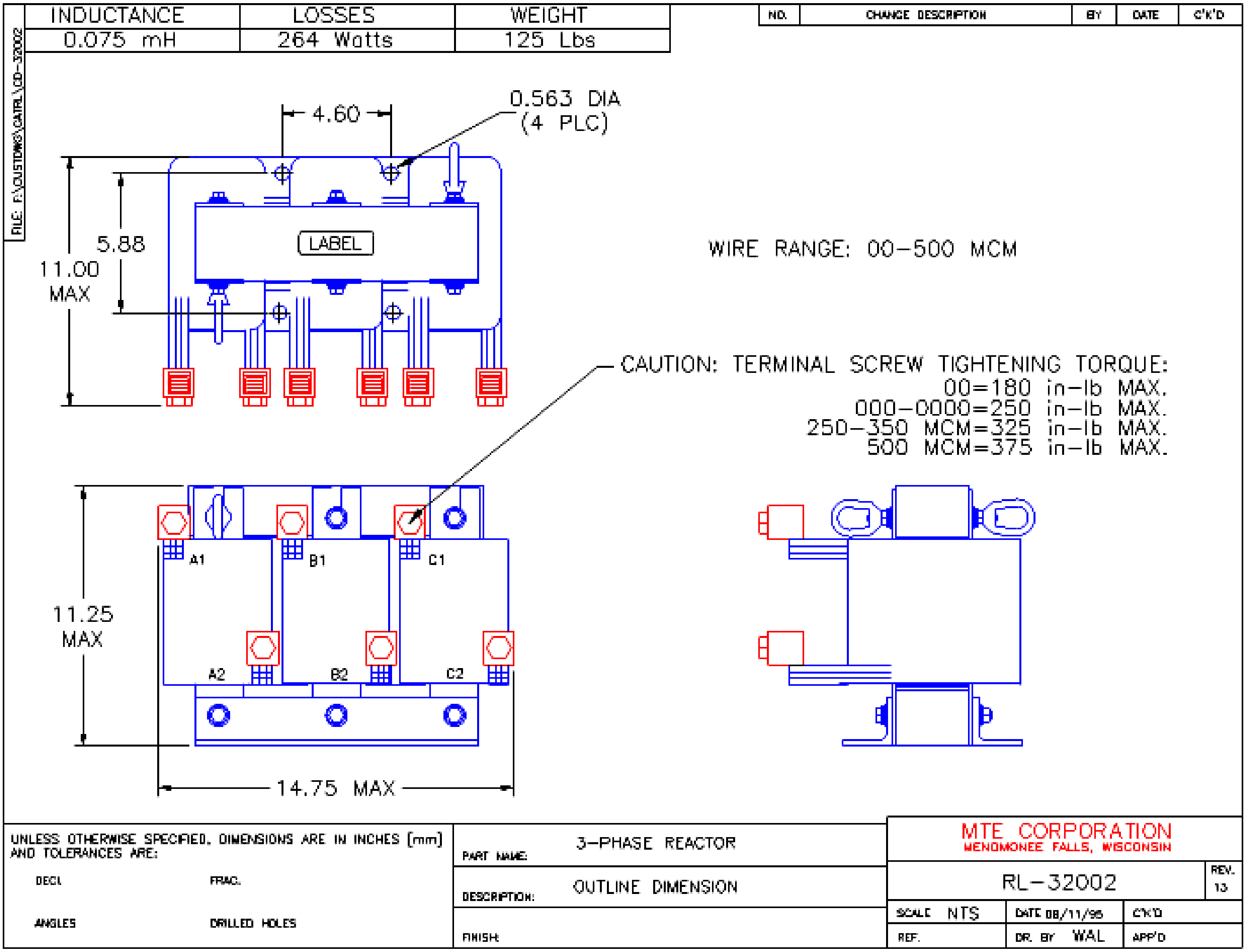

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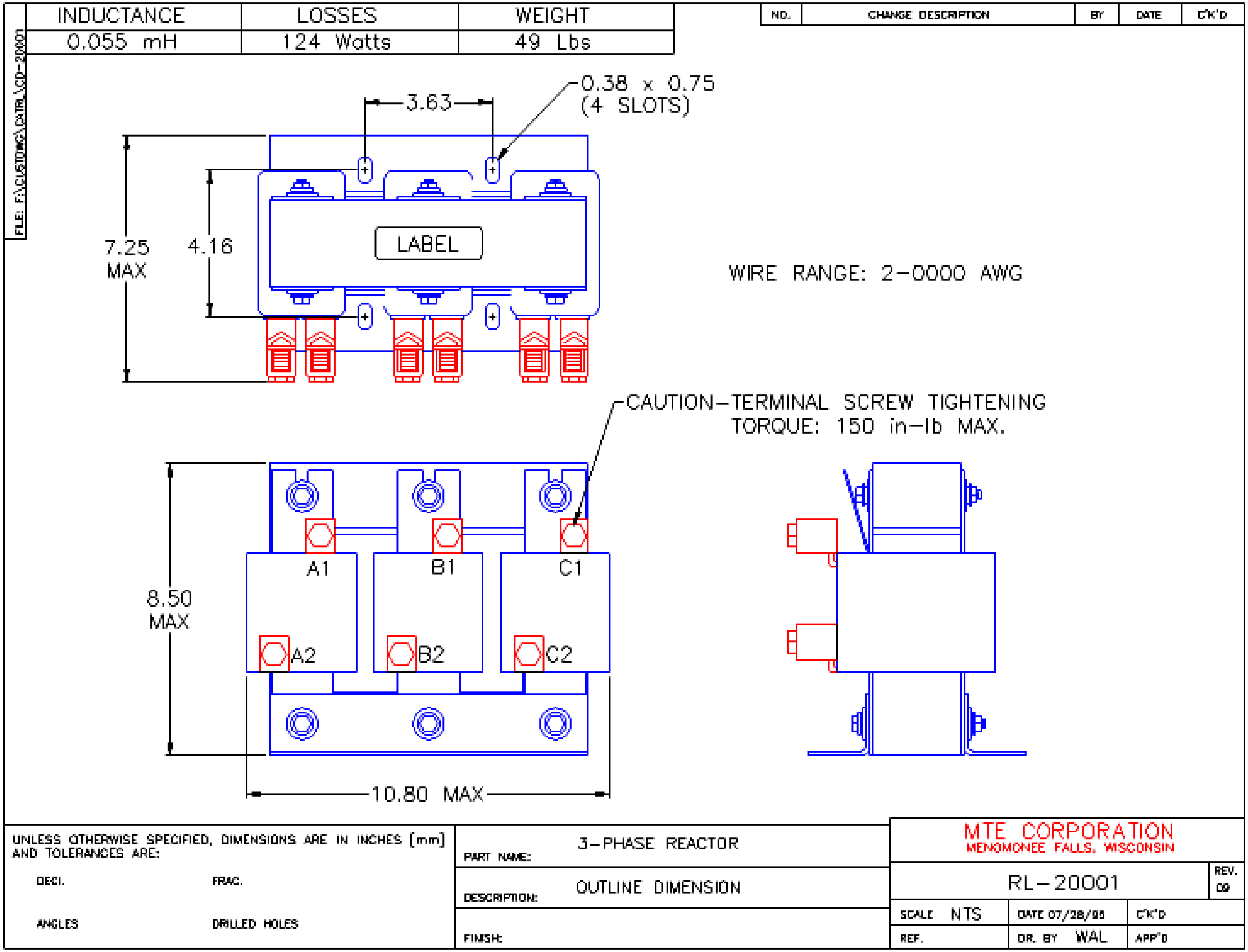

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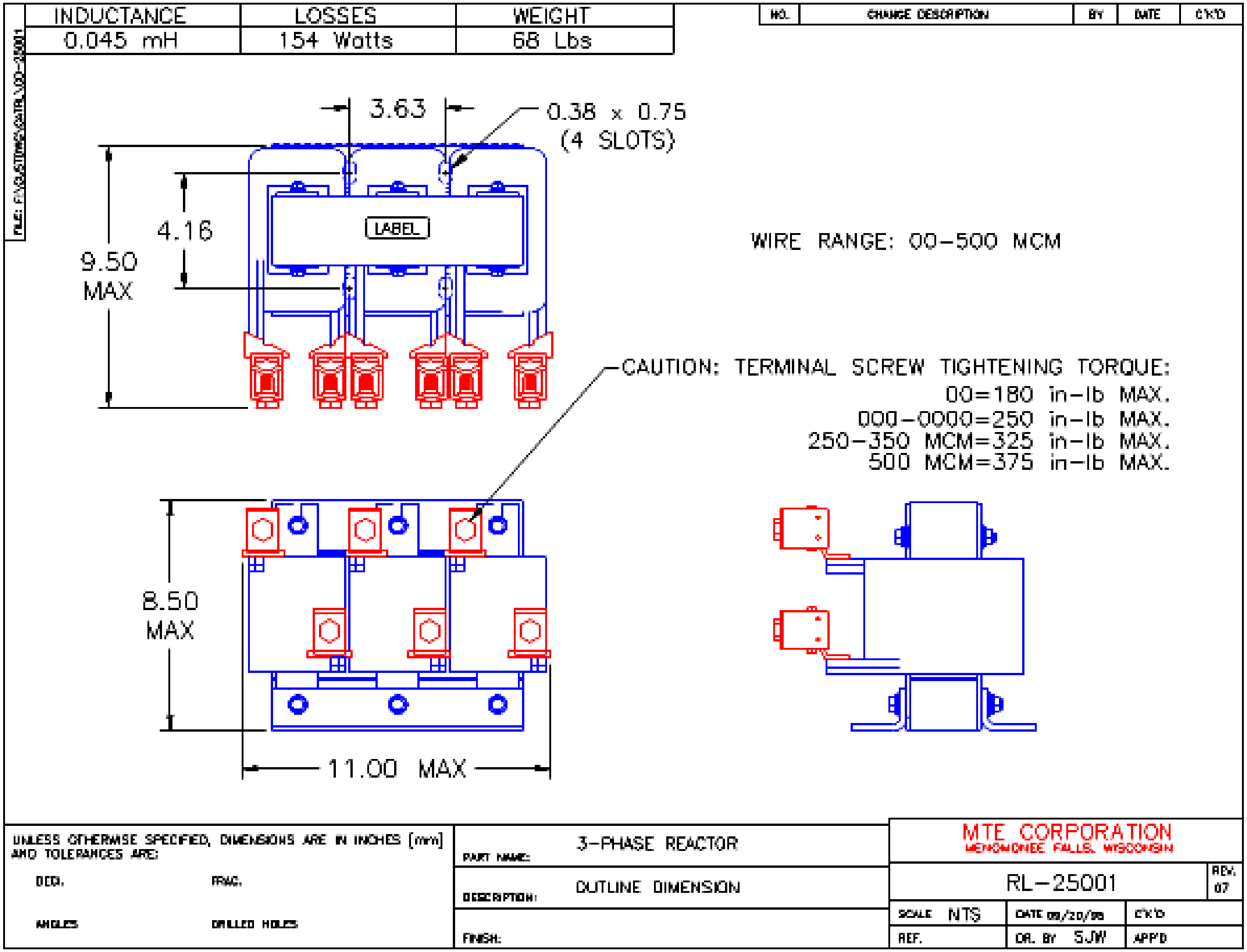

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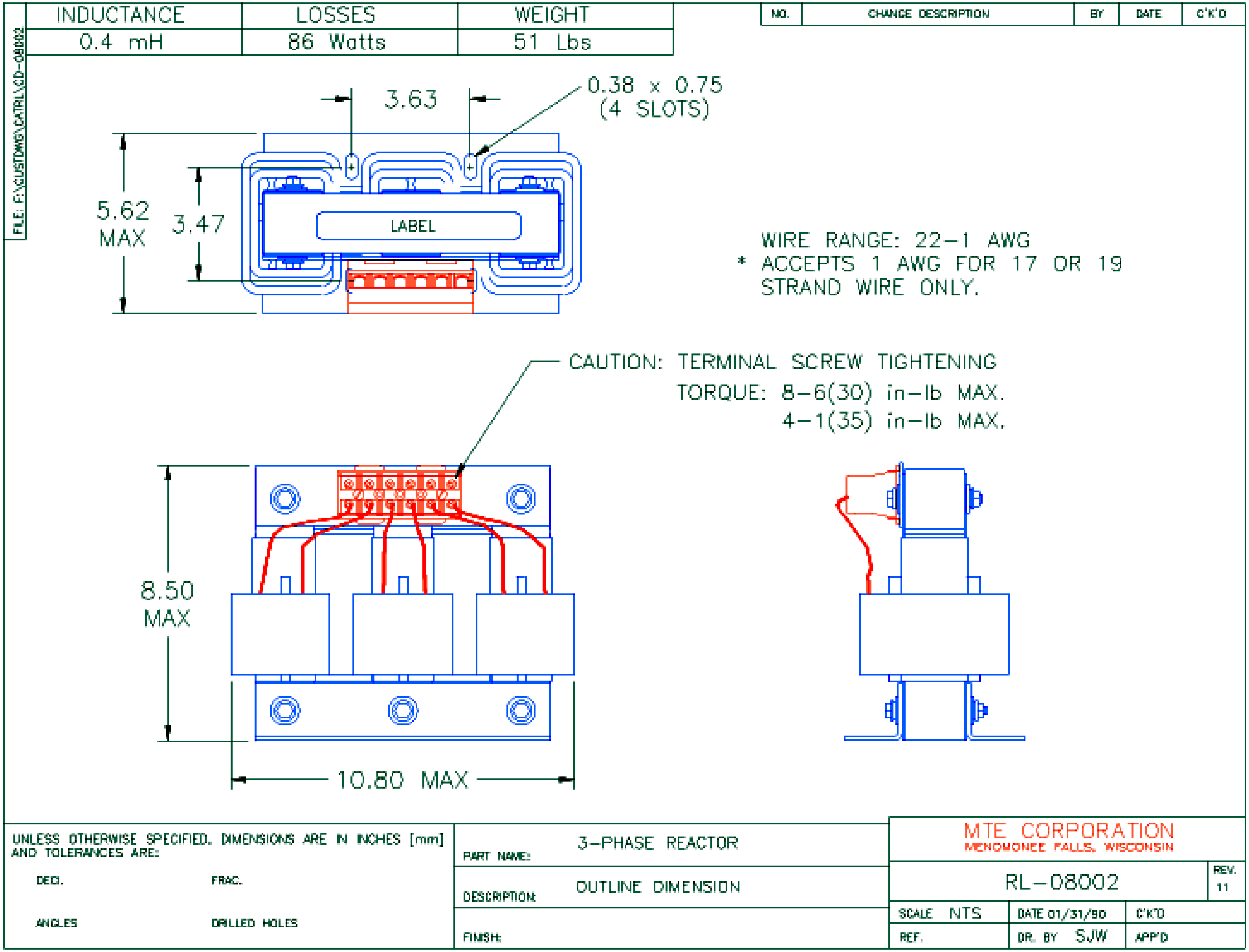

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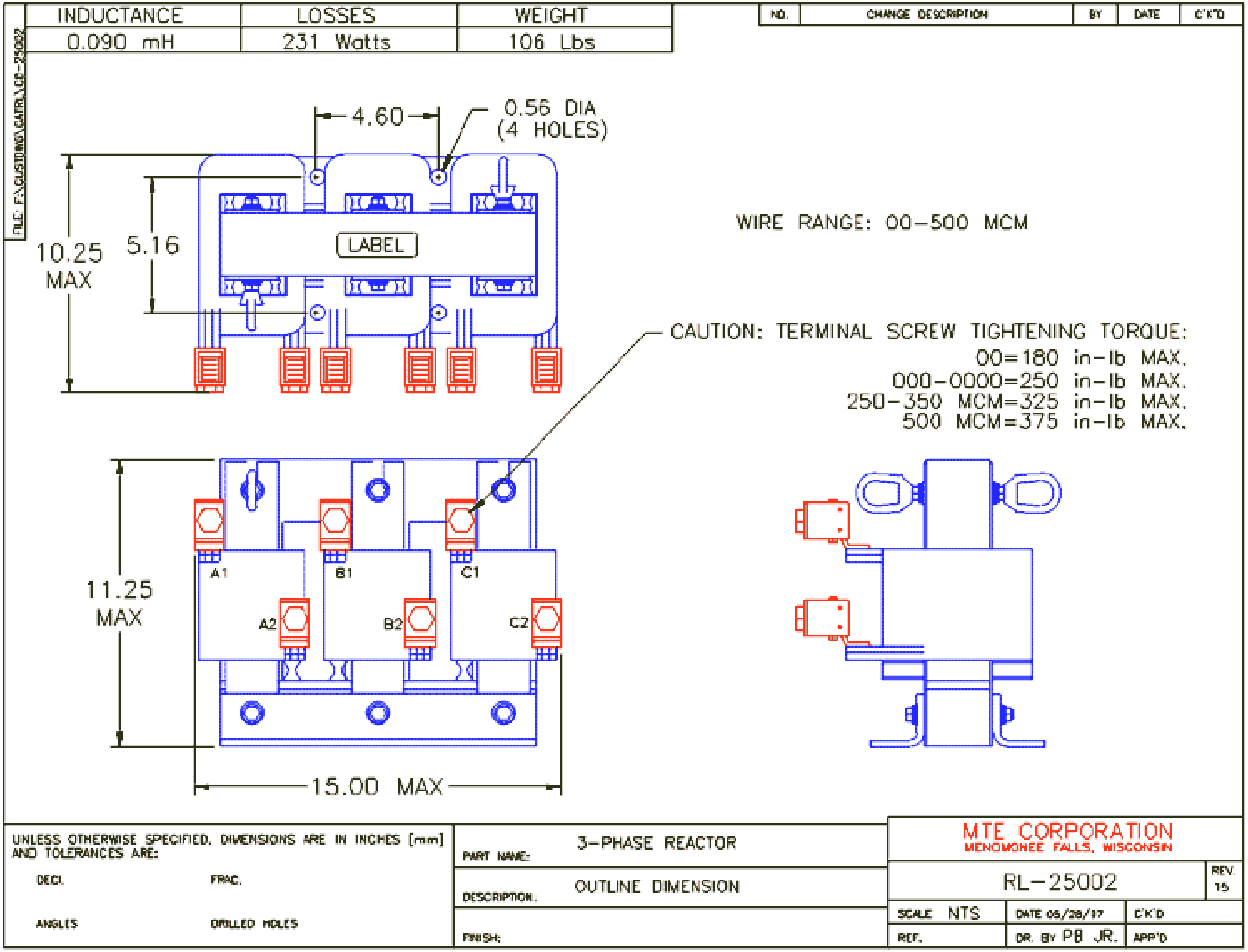

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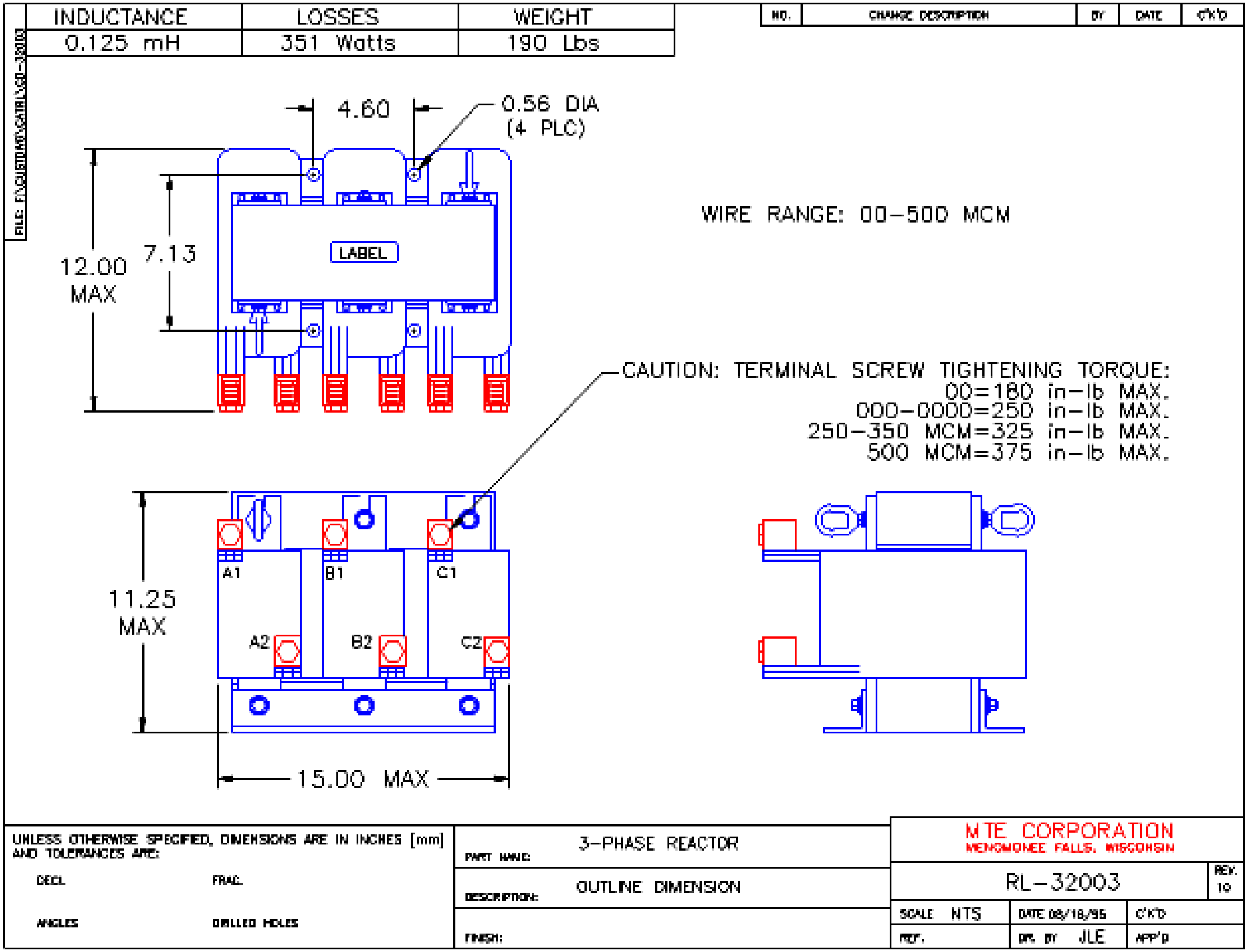

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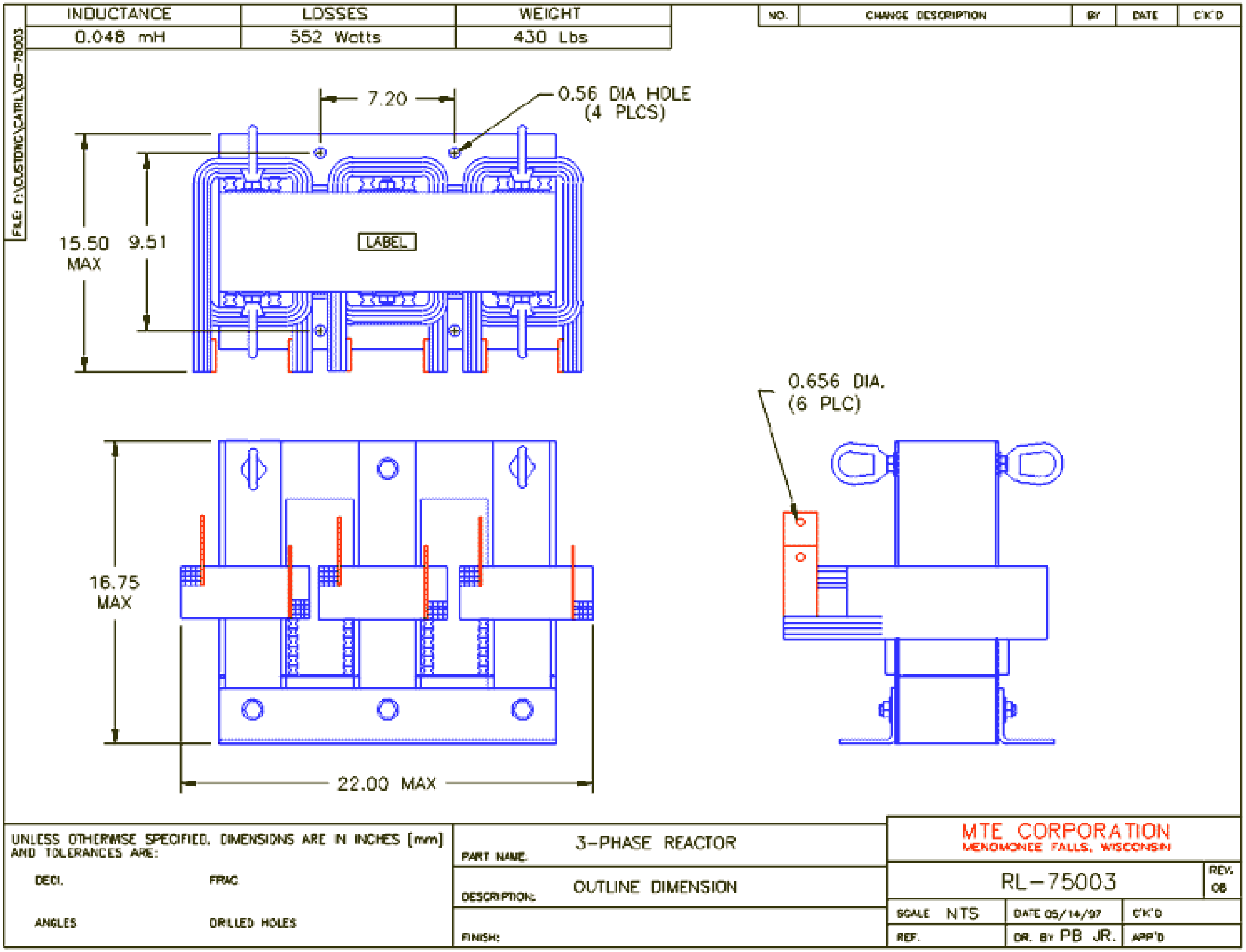

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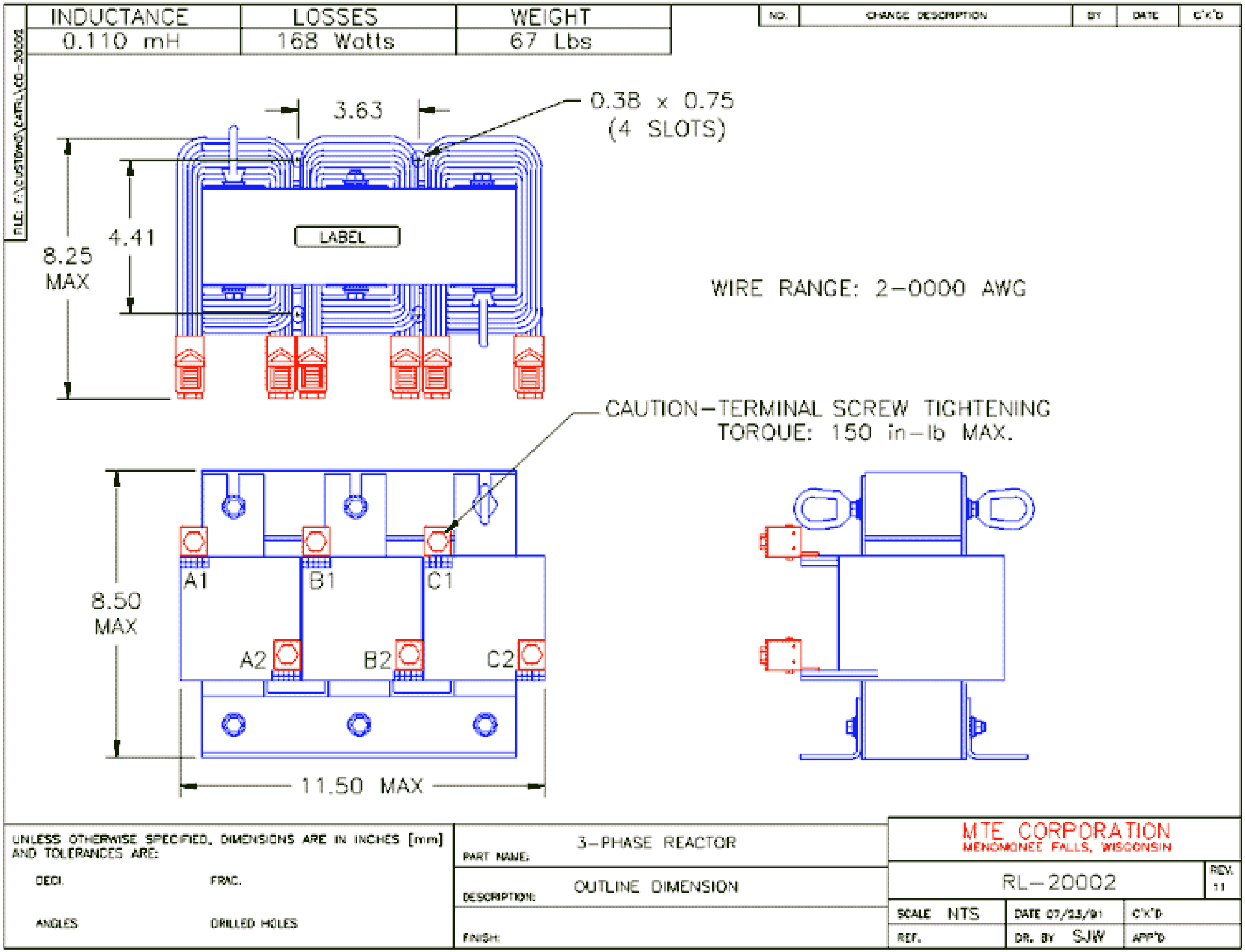

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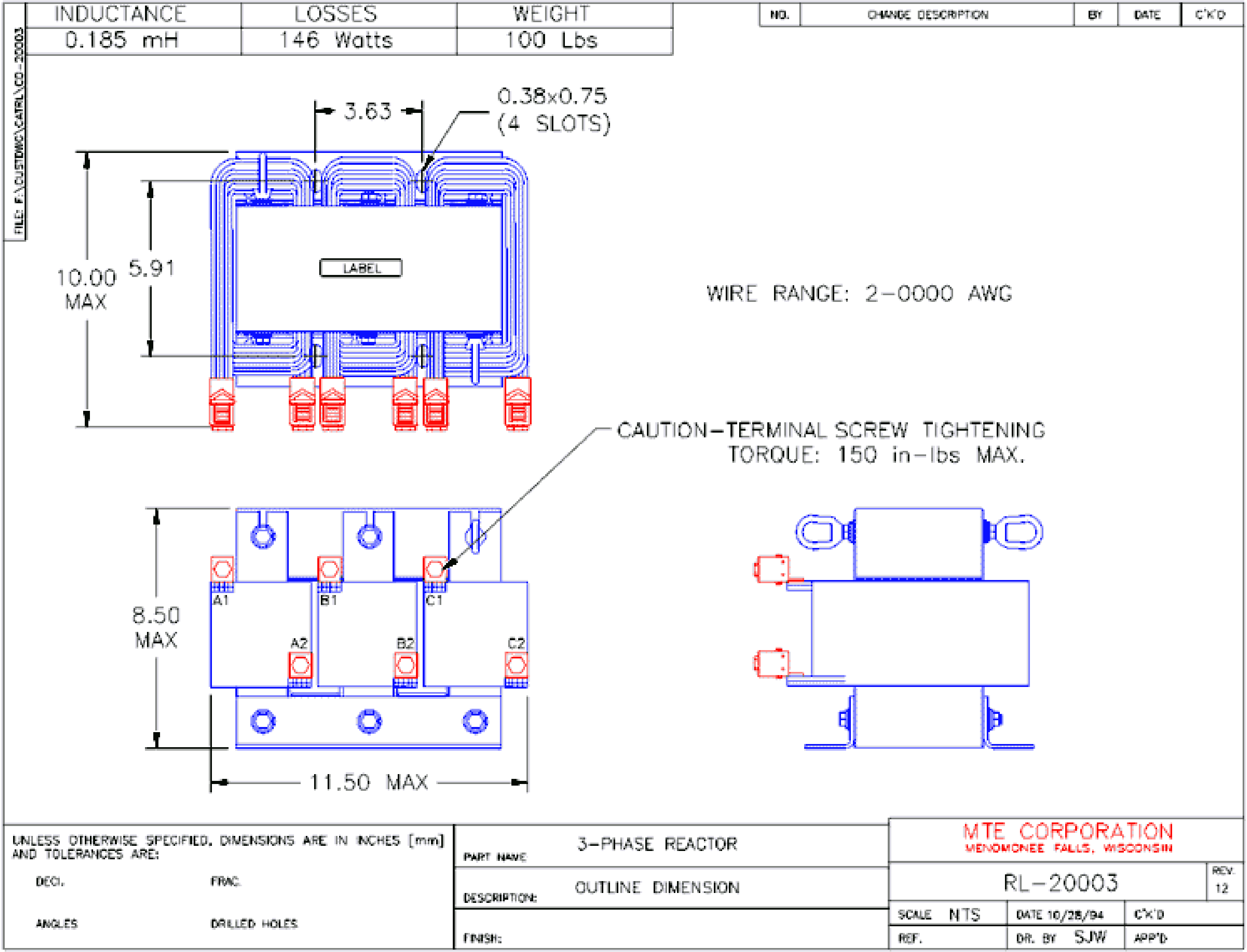

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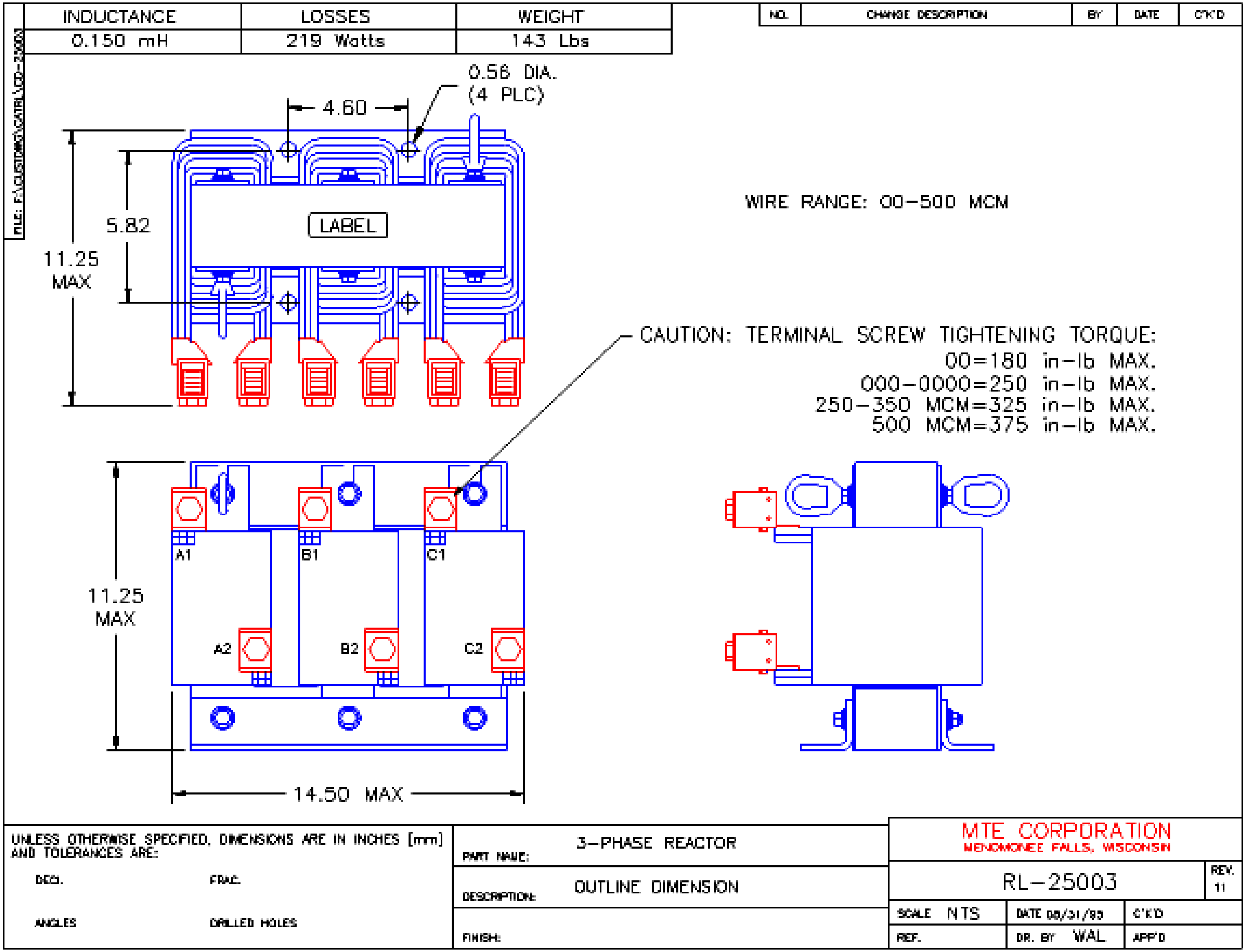

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INDUCTANCE	LOSSES	WEIGHT
0.065 mH	406 Watts	290 Lbs

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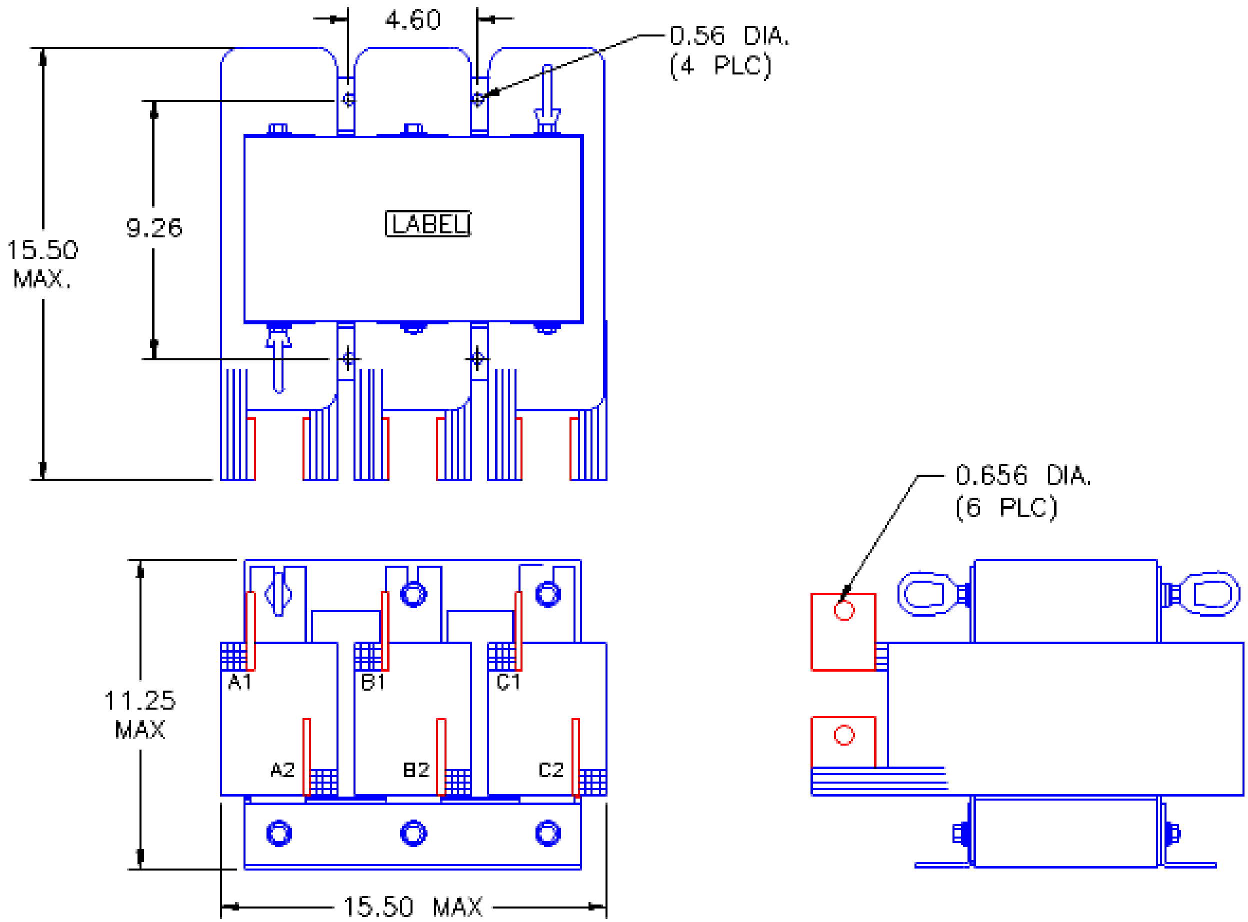

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES [mm] AND TOLERANCES ARE:

DEC. FRAC.

ANGLES DRILLED HOLES

PART NAME: 3-PHASE REACTOR

DESCRIPTION: OUTLINE DIMENSION

FINISH:

MTE CORPORATION
MENOMONEE FALLS, WISCONSIN

RL-60003 REV. 11

SCALE NTS | DATE 07/25/05 | C'K'D
REF. | DR. BY SJW | APP'D

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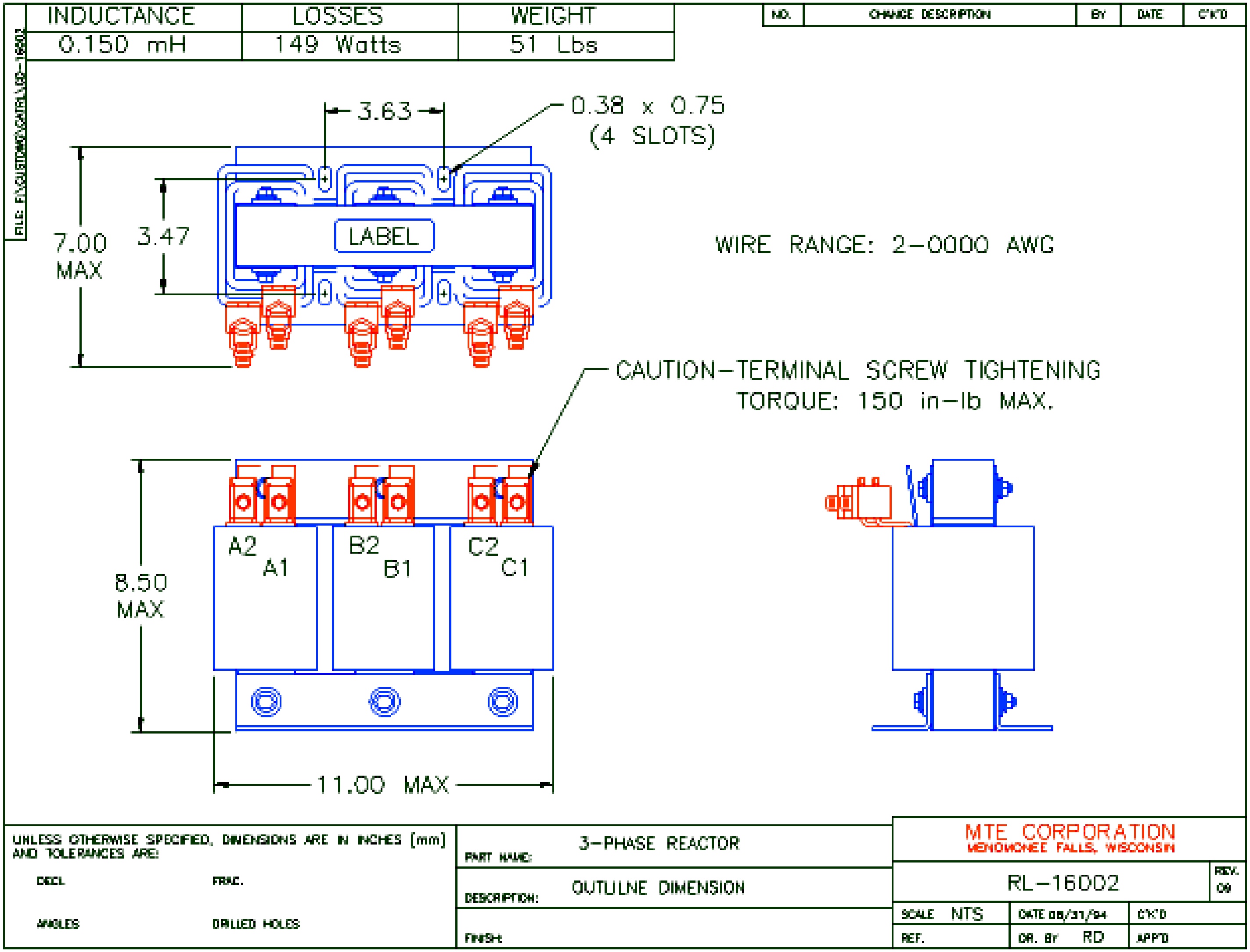

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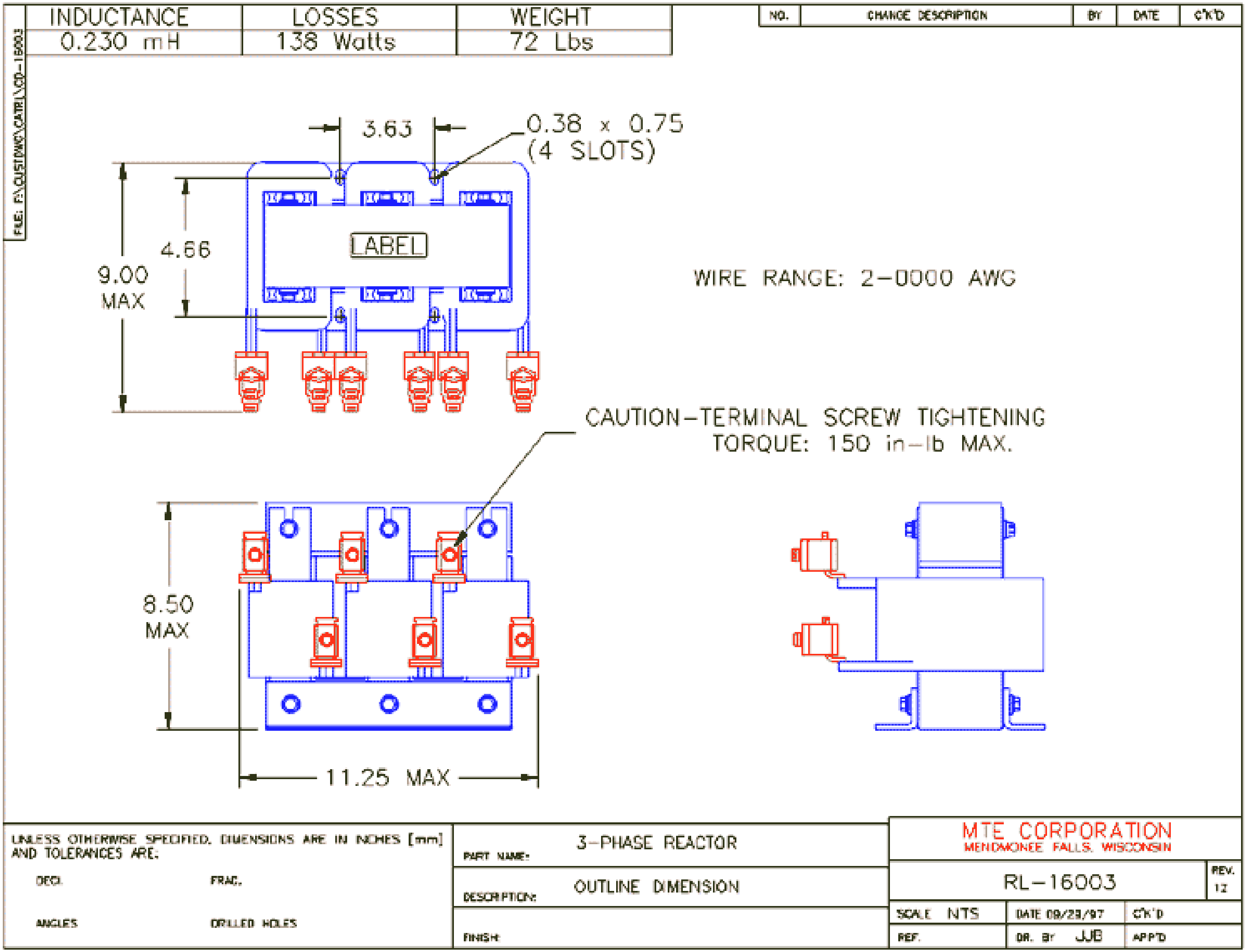

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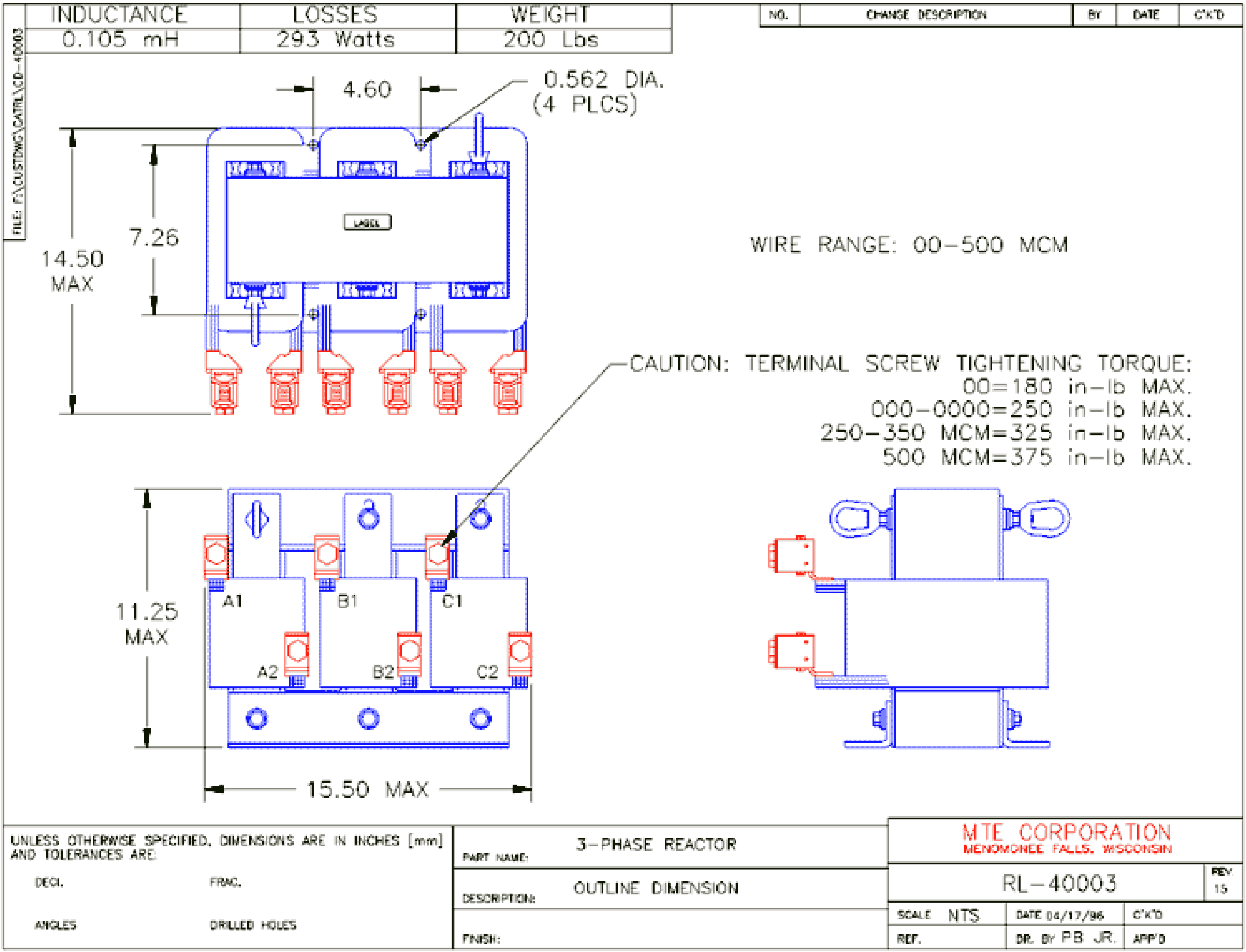

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INDUCTANCE	LOSSES	WEIGHT
0.085 mH	422 Watts	290 Lbs

NO.	CHANGE DESCRIPTION	BY	DATE	C'K'D

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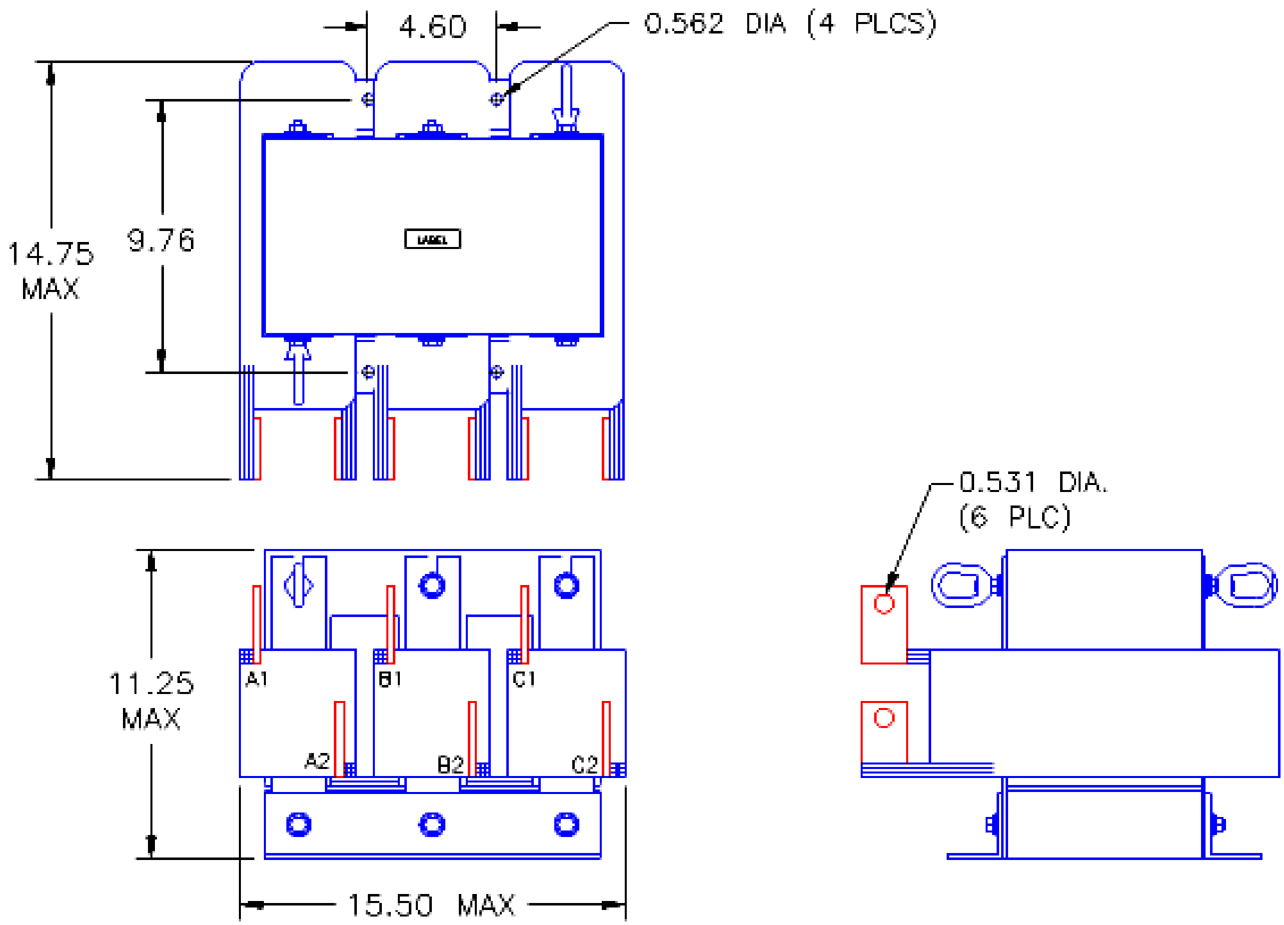

UNLESS OTHERWISE SPECIFIED, DIMENSIONS ARE IN INCHES [mm] AND TOLERANCES ARE:

DECI.

FRAC.

ANGLES

DRILLED HOLES

PART NAME: 3-PHASE REACTOR

DESCRIPTION: OUTLINE DIMENSION

FINISH:

MTE CORPORATION
MENOMONEE FALLS, WISCONSIN

RL-50003

REV. 14

SCALE NTS | DATE 07/28/95 | C'K'D

REF. | DR. BY SJW | APP'D

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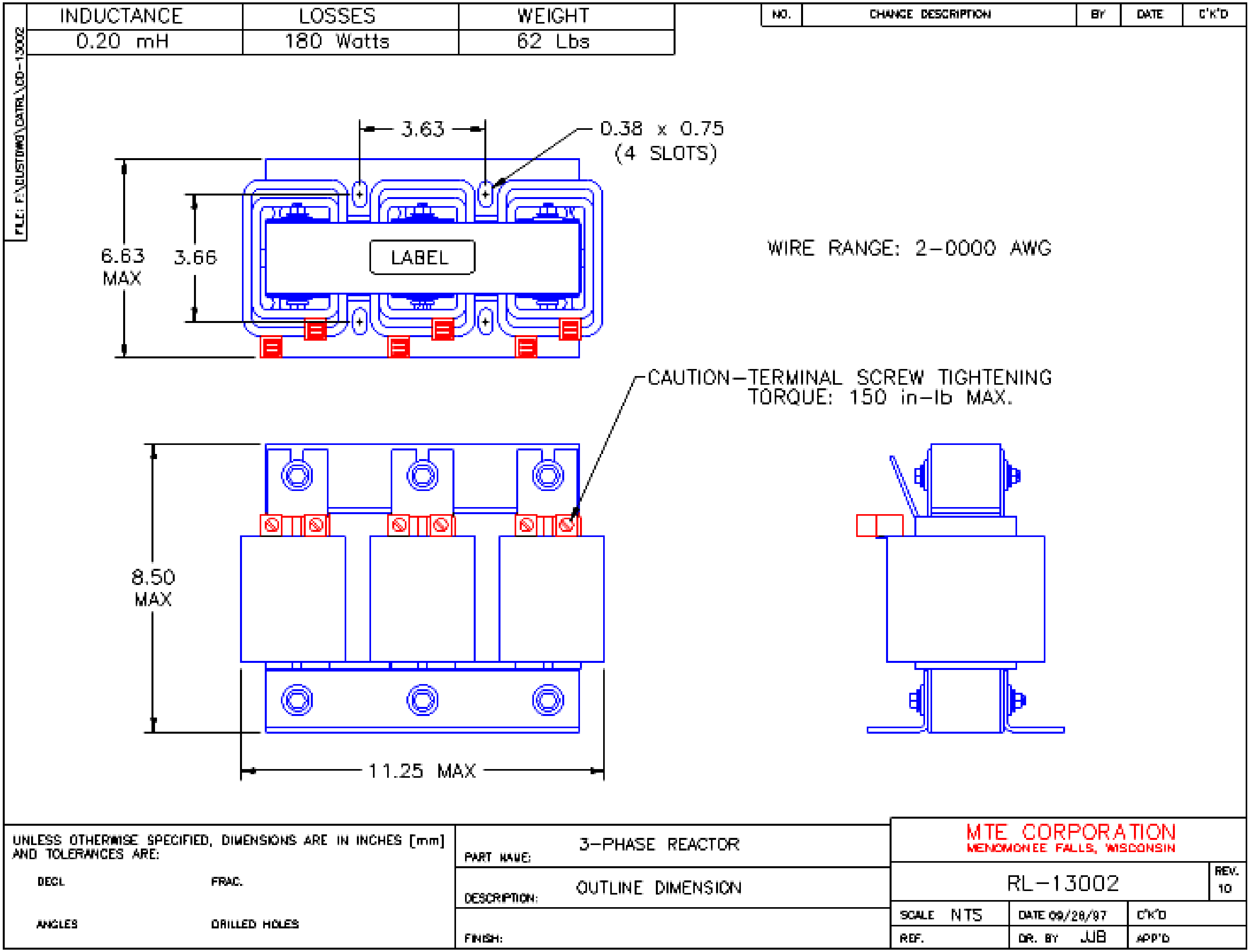

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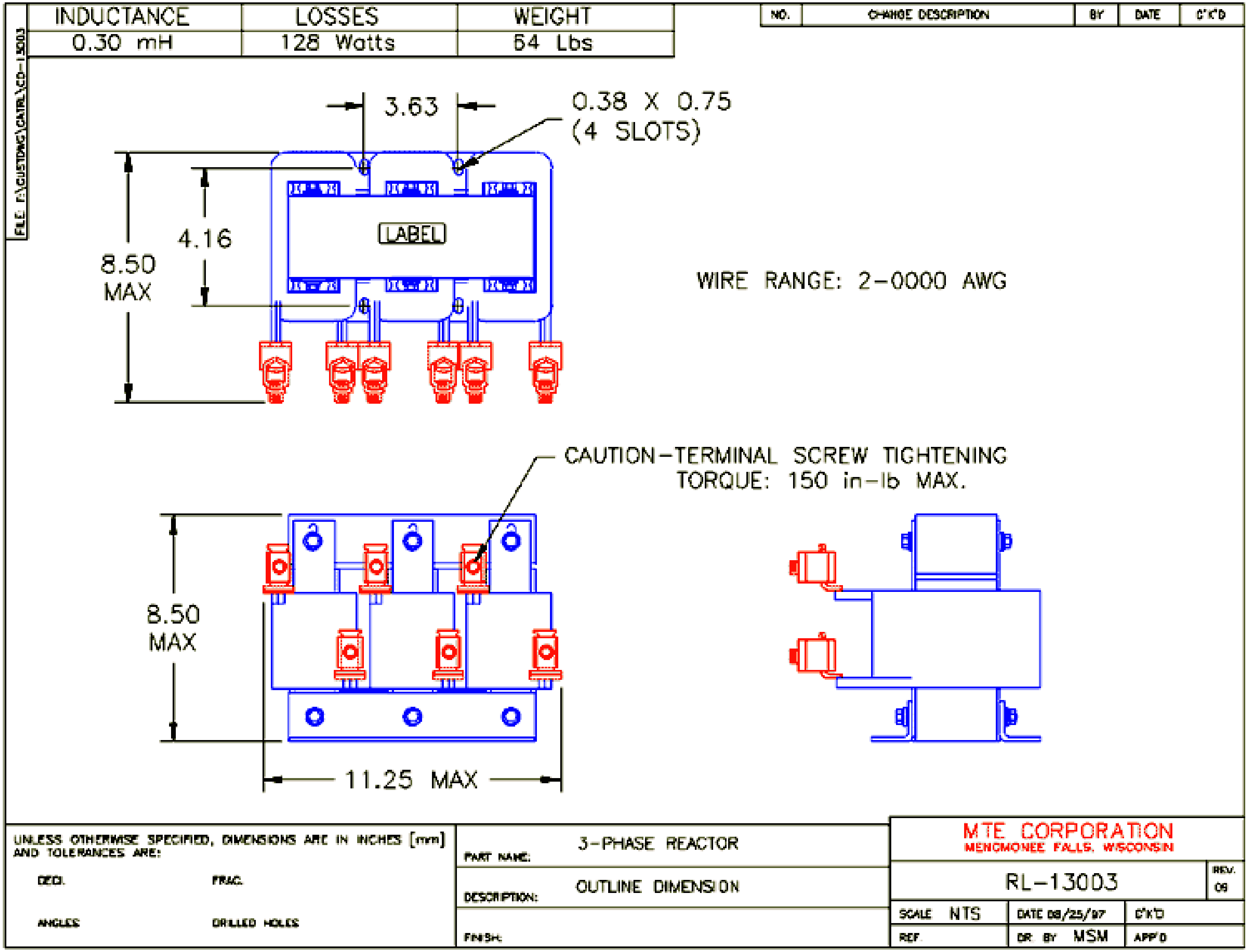

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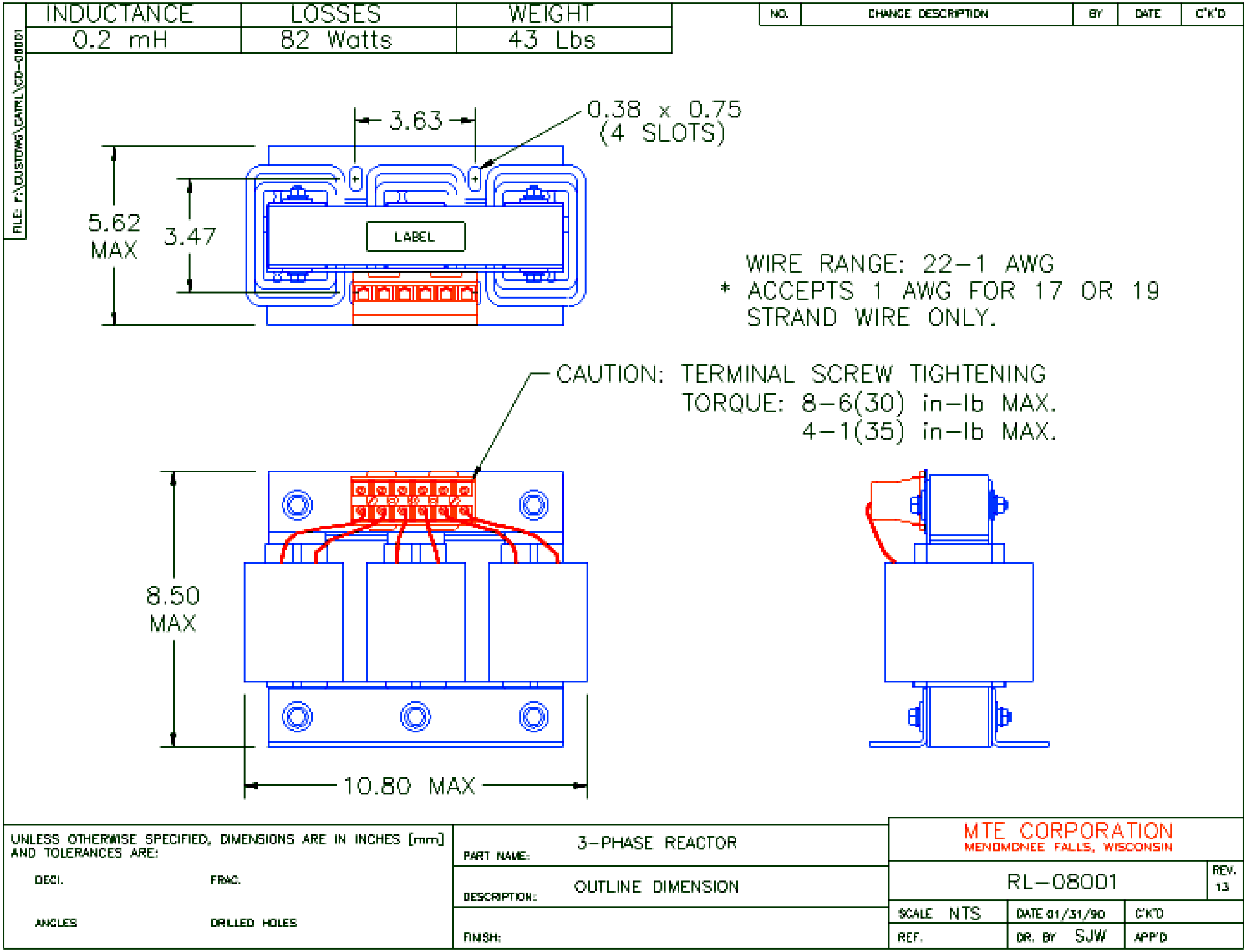

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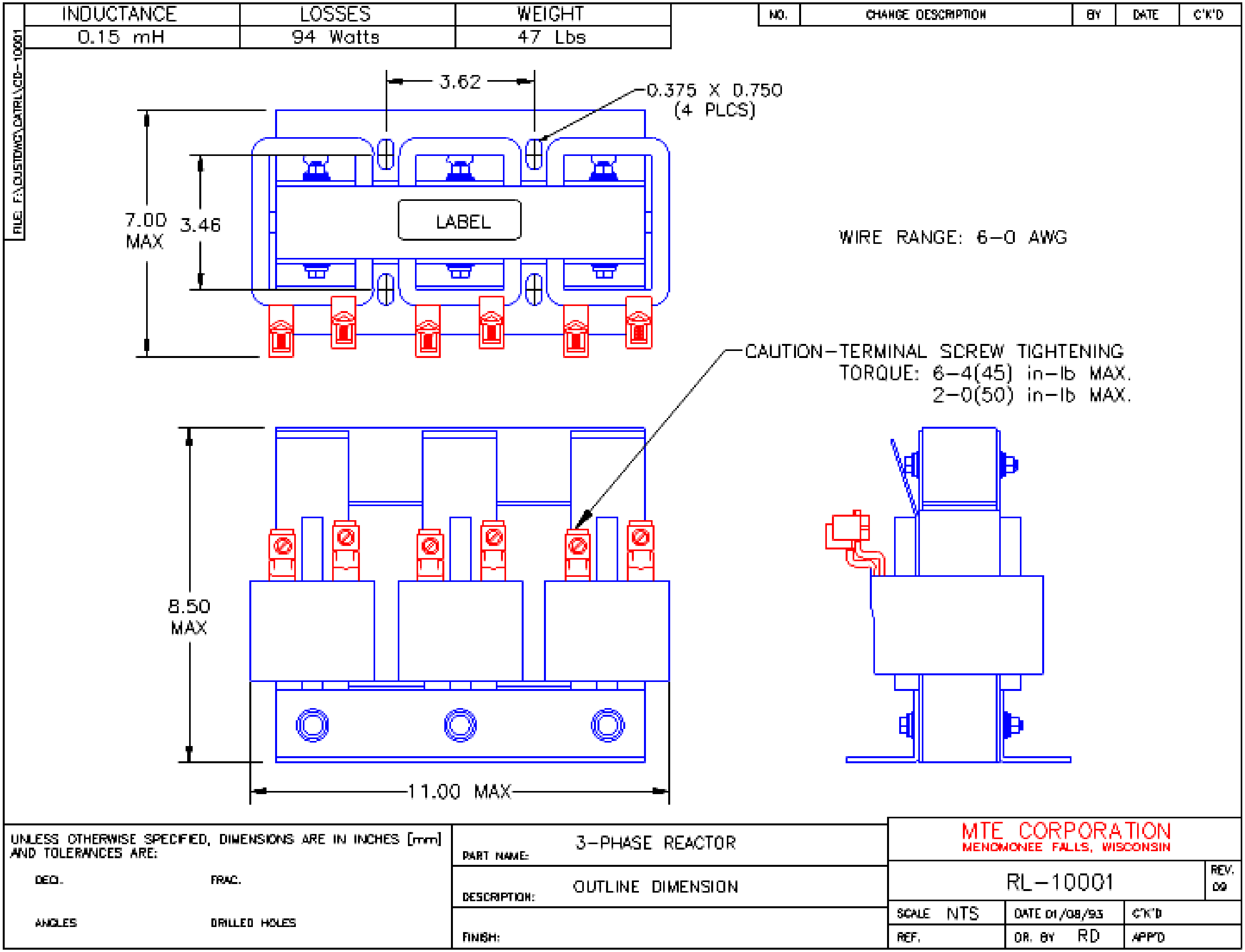

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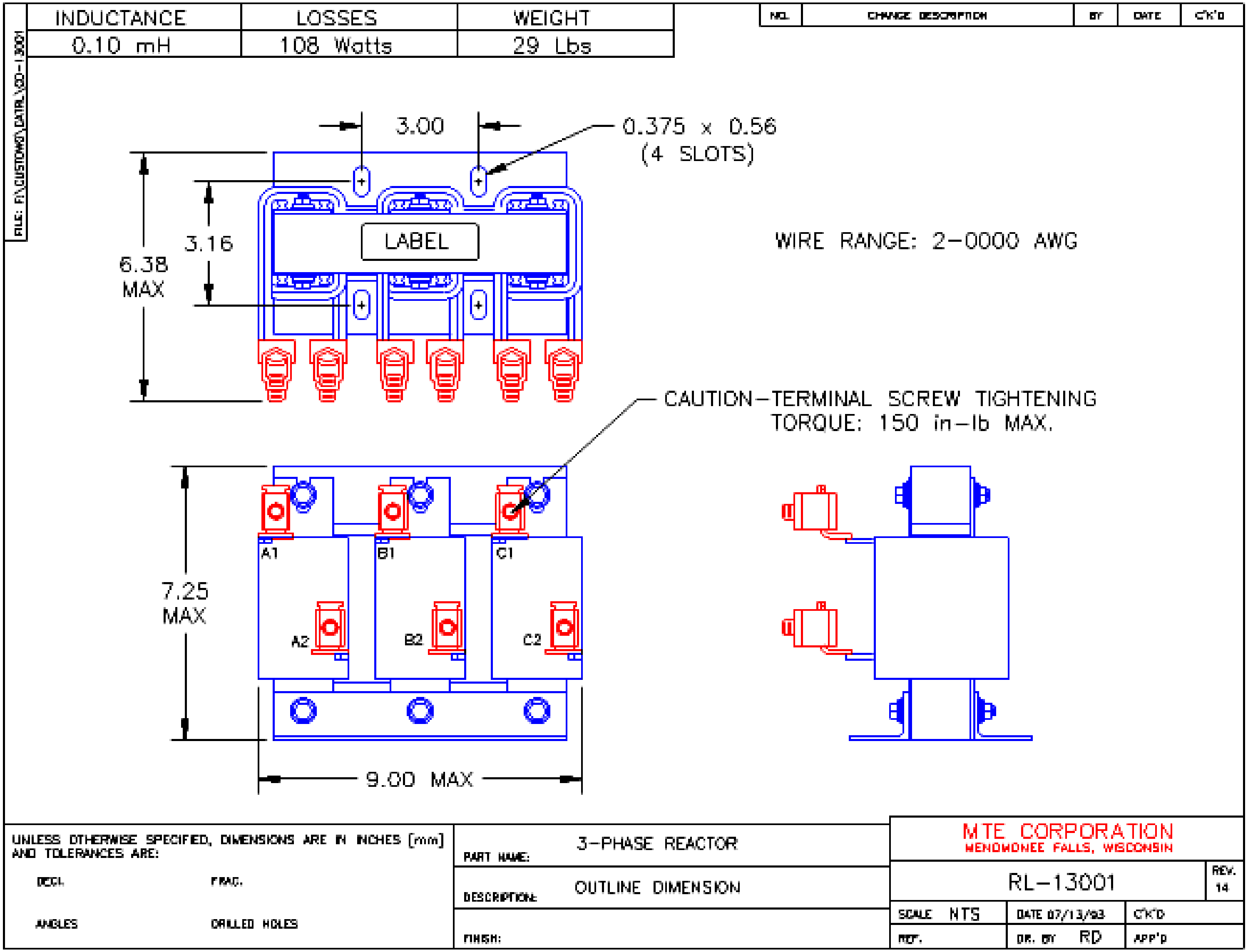

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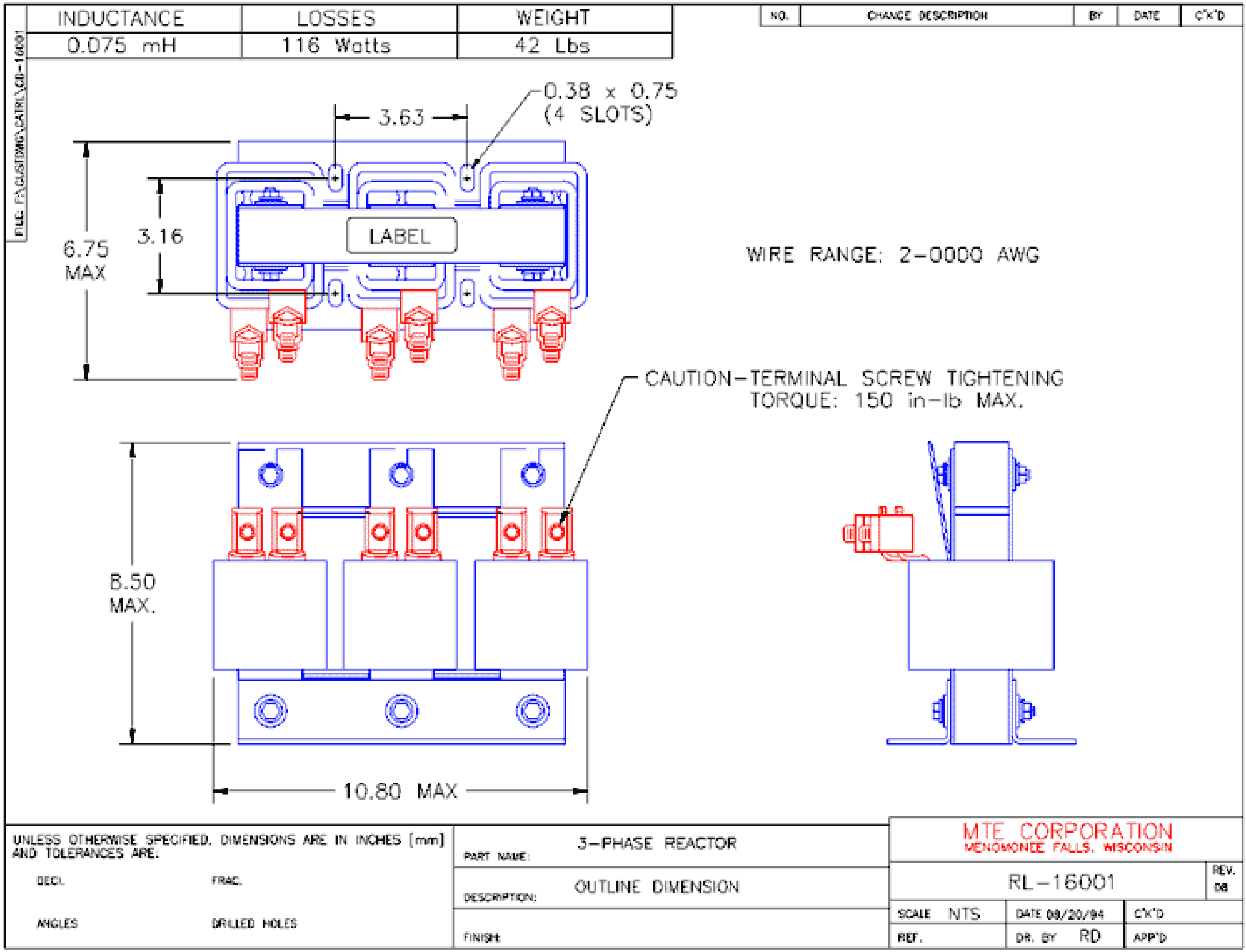

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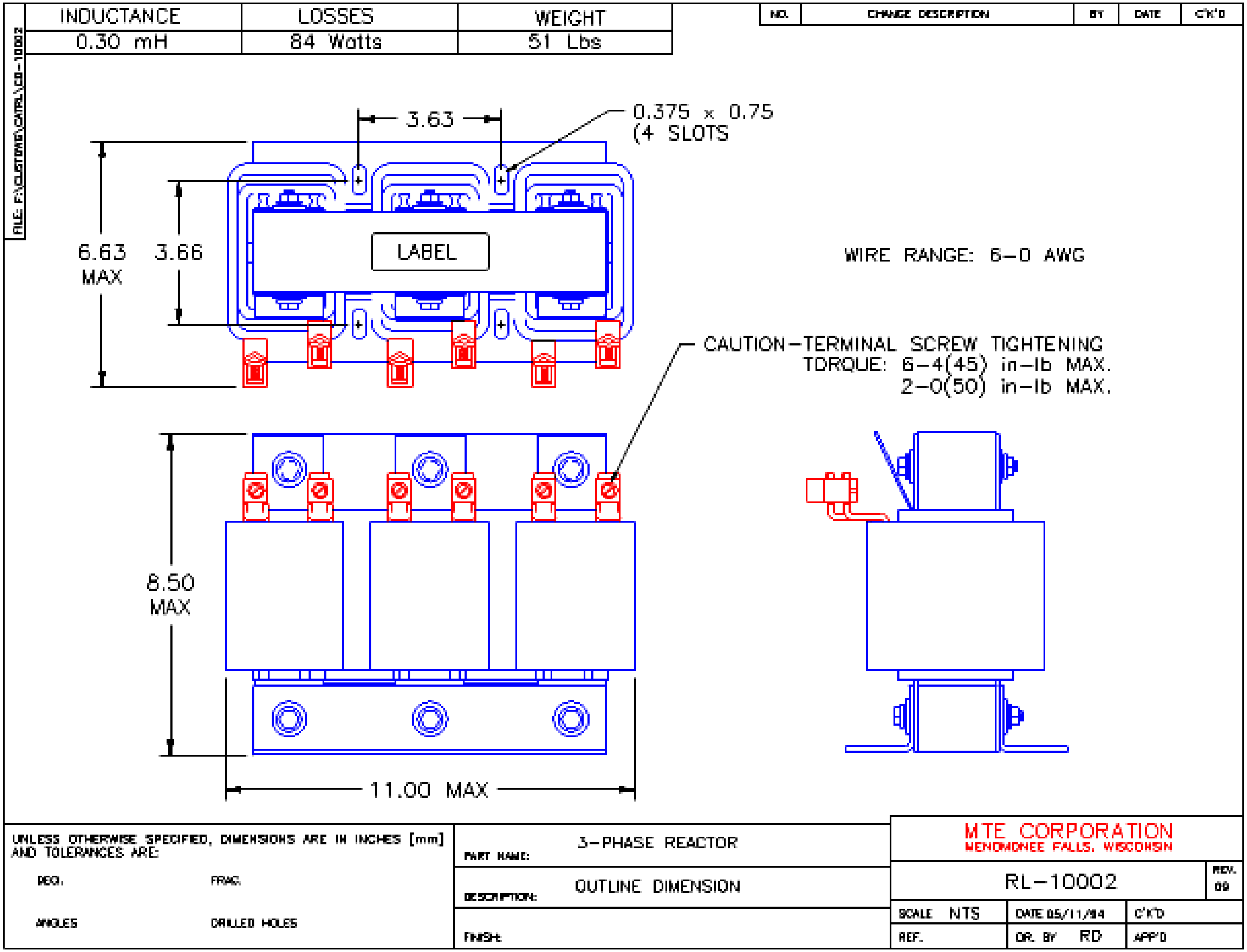

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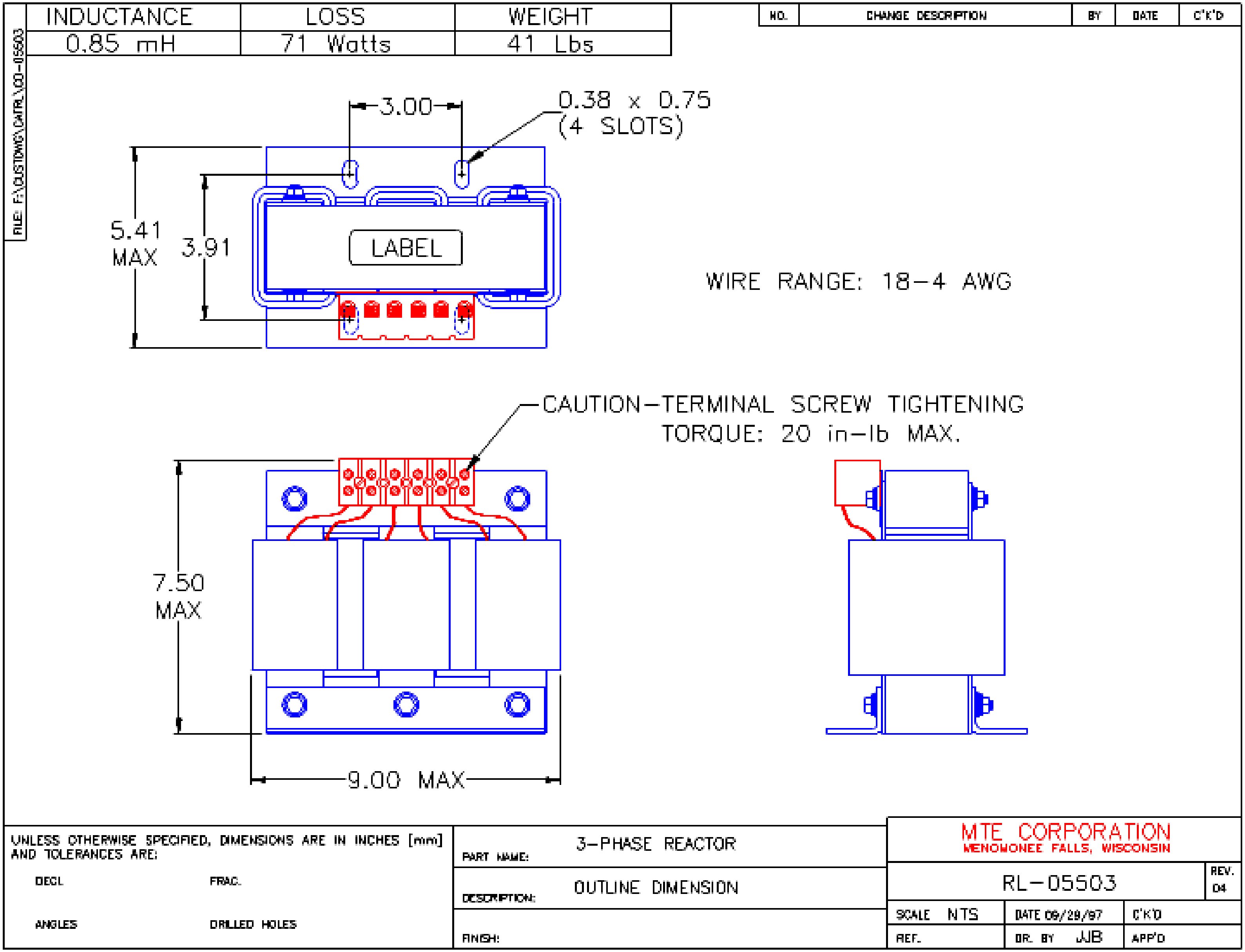

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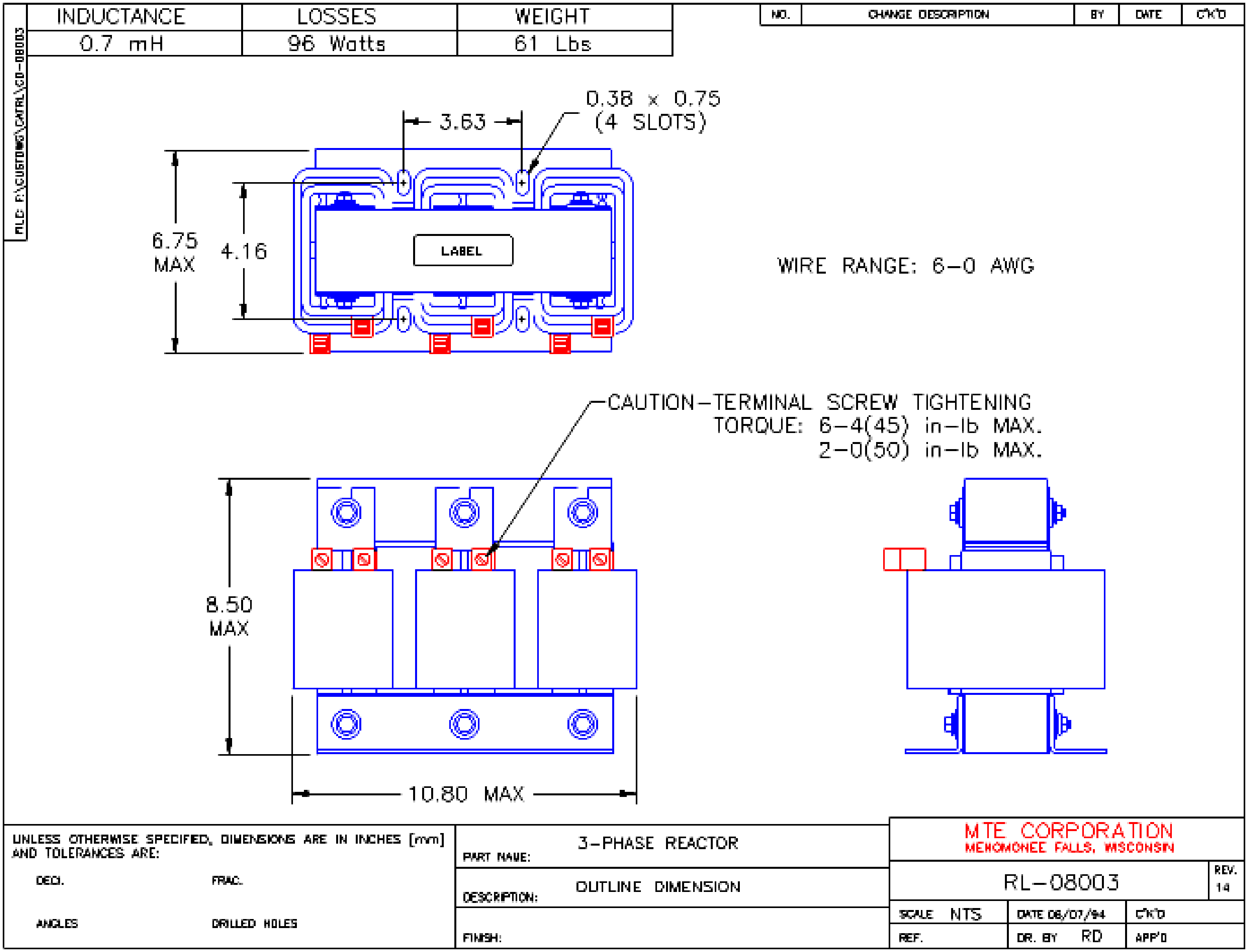

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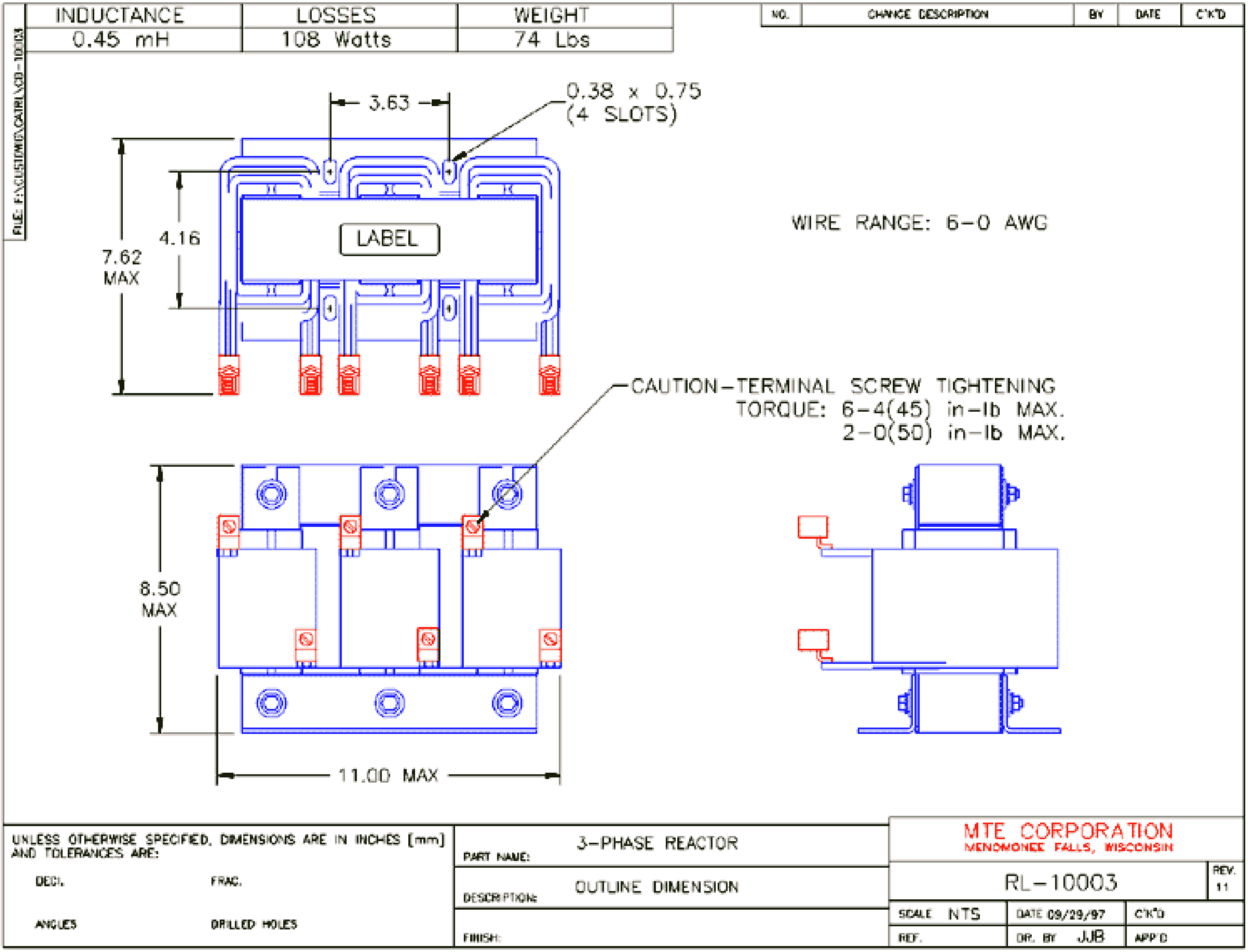

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BACK

Harmonic Mitigation of 12-Pulse Drives with Unbalanced Input Line Voltages

Karl M. Hink MTE Corporation

ABSTRACT

Twelve-pulse drives are frequently specified by consulting engineers for heating, ventilating and air conditioning applications because of their theoretical ability to reduce harmonic current distortion, but very little information has been published showing how twelve-pulse drives perform under actual operating conditions with unbalanced input line voltages. This paper presents test data which demonstrate that twelve-pulse drives do not achieve the level of harmonic mitigation most engineers expect and that these drives may not meet the requirements of IEEE-519 under practical operating conditions. The actual performance of twelve-pulse and six-pulse drives is compared to the performance of a six-pulse drive fed by a Matrix Harmonic Filter. The Matrix Harmonic Filter provides superior harmonic mitigation at lower cost.

In the mid 1960s when power semiconductors were only available in limited ratings, twelve-pulse drives provided a simpler and more cost effective approach to achieving higher current ratings than direct paralleling of power semiconductors. This technique is still employed today in very large drive applications. A typical diagram of a large twelve-pulse drive appears in figure 1. The drive's input circuit consists of two six-pulse rectifiers, displaced by 30 electrical degrees, operating in parallel. The 30-degree phase shift is obtained by using a phase shifting transformer. The circuit in figure 1 simply uses an isolation transformer with a delta primary, a delta connected secondary, and a second wye connected secondary to obtain the necessary phase shift. Because the instantaneous outputs of each rectifier are not equal, an interphase reactor is used to support the difference in instantaneous rectifier output voltages and permit each rectifier to operate independently. The primary current in the transformer is the sum of each six-pulse rectifier or a twelve-pulse wave form.

Theoretical input current harmonics for rectifier circuits are a function of pulse number and can be expressed as:

$$h = (np + 1) \text{ where } n= 1, 2, 3,\ldots \text{ and } p = \text{pulse number}$$

For a six-pulse rectifier, the input current will have harmonic components at the following multiples of the fundamental frequency.

5, 7, 11, 13, 17, 19, 23, 25, 29, 31, etc.

For the twelve-pulse system shown in figure 1, the input current will have theoretical harmonic components at the following multiples of the fundamental frequency:

11, 13, 23, 25, 35, 37, etc.

Note that the 5th and 7th harmonics are absent in the twelve-pulse system. Since the magnitude of each harmonic is proportional to the reciprocal of the harmonic number, the twelve-pulse system has a lower theoretical harmonic current distortion.

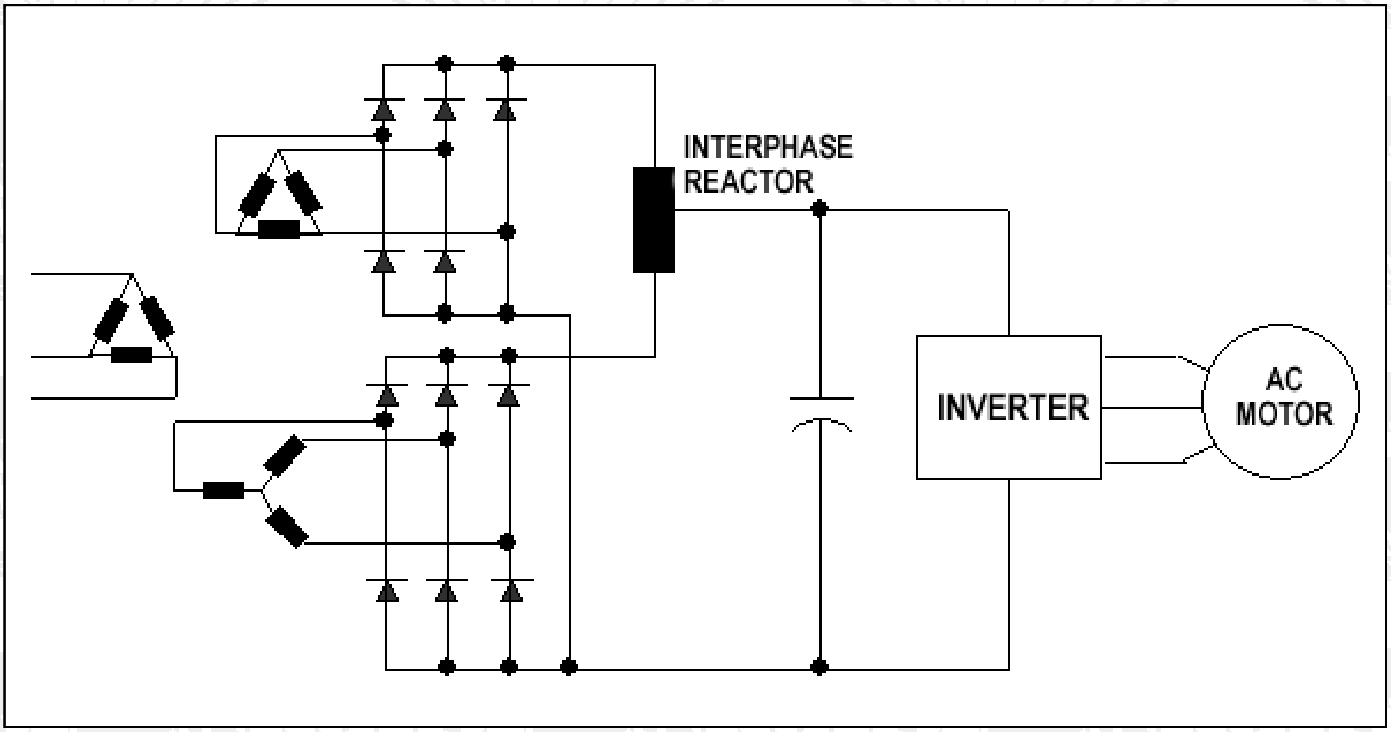


Figure 1

The problem with the circuit shown in figure 1 is that the two rectifiers must share current exactly to achieve the theoretical reduction in harmonics. This requires that the output voltage of both transformer secondary windings match exactly. Because of differences in the transformer secondary impedances and open circuit output voltages, this can be practically accomplished for a given load (typically rated load) but not over a range in loads. This is a very significant problem of the parallel twelve-pulse configuration.

A twelve-pulse system can also be constructed from two six-pulse rectifiers connected in series. In this configuration, two six-pulse rectifiers, each generating one half of the DC link voltage, are series connected. Refer to figure 2. In this connection, problems associated with current sharing are avoided and an interphase reactor is not required. For applications where harmonics rather than high current ratings are the issue, this solution is much simpler to implement than the parallel connection.

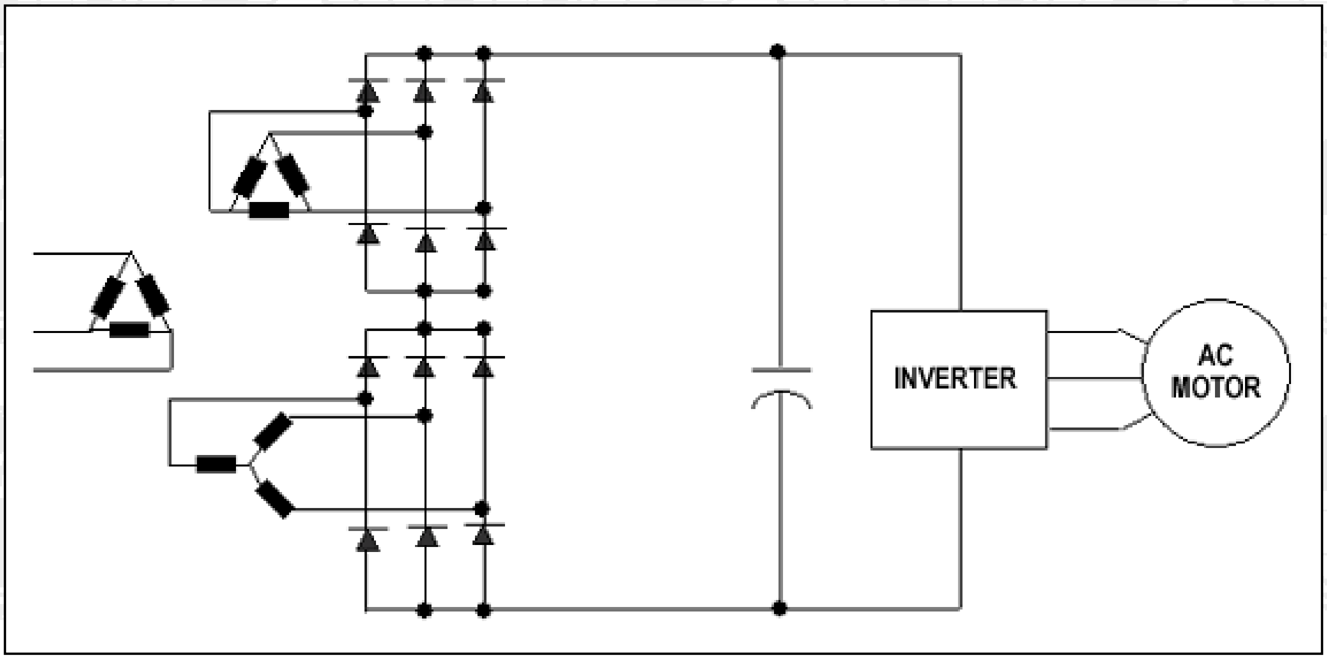


Figure 2

Using the series rectifier connection, it is very easy to construct a twelve-pulse drive from a standard six-pulse drive if the six-pulse drive has its DC bus terminals available or permits access to one side of the DC bus. Many standard AC drives provide terminals in the DC bus to accommodate an external DC link choke. These same terminals can be used to add an external rectifier converting the drive to twelve-pulse operation. Refer to figure 3. In this case there is no need for extra circuitry to control inrush current for the second rectifier. The net result is a system solution well within the means of many system integrators.

There are many fine textbooks and articles in which rectifier circuits are examined and analyzed in detail. However, most of the analysis is performed under the assumption of balanced three-phase line voltages. Our practical experience suggests that this assumption is not valid for many industrial and commercial power systems, particularly systems with nonlinear loads. As we traveled around the United States working primarily with drive applications, our impression was that most power systems were operating with 1% to 3% unbalance at the point of utilization.

ANSI C84.1 - 1995 defines percent voltage unbalance as:

$$\frac{100 \text{ X (max. deviation from average voltage)}}{\text{(Average Voltage)}}$$

This same standard also reports that based on field surveys, 98% of power systems are within 0 - 3.0% voltage unbalance range and 66% are within 0 - 1.0% unbalance at the point of common coupling. The standard recommends that electric supply systems be designed and operated to the limit of a maximum voltage unbalance to 3% when measured at the electric utility revenue meter under no-load conditions. Load unbalance within the building power distribution system adds to the utility unbalance at the point of utilization.

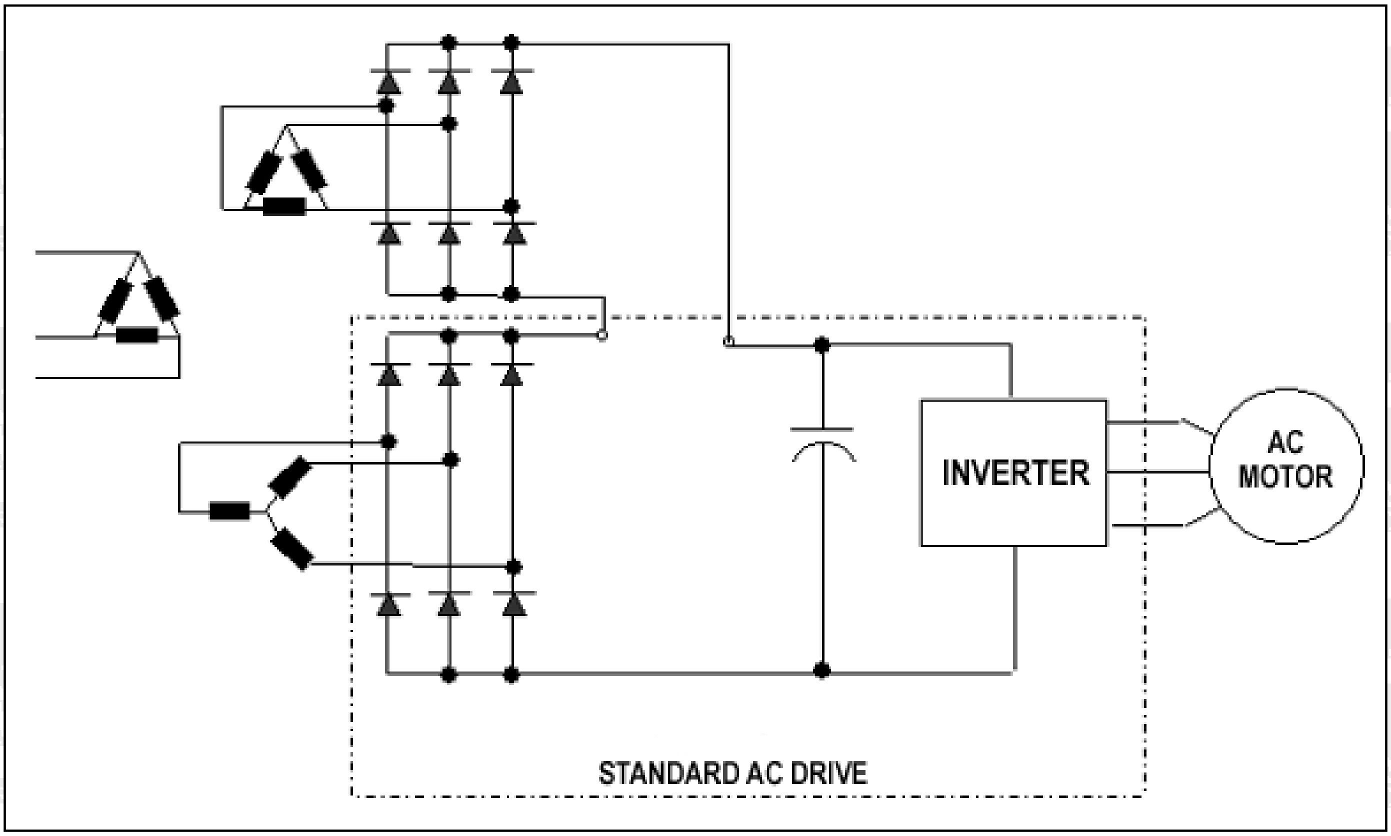


Figure 3

To determine how a twelve-pulse drive system operates under unbalanced line voltage conditions, we constructed a 30 HP twelve-pulse drive from a standard delta delta-wye isolation transformer and standard six-pulse drive using the series bridge connection shown in figure 3. An auto transformer could have been used in place of the isolation transformer. The auto transformer costs less and requires less mounting space, but the isolation transformer was selected because it provides better performance and is readily available from stock. The system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The input total harmonic current distortion, THID, is shown in figure 4. THID varied from 12% at full load with balanced line voltages to 65% at 17% load with a 3% unbalance. The data show that the harmonic performance of twelve-pulse drives degrades rapidly with increasing line voltage unbalance. Many users expect that THID should not exceed specified limits from no load to full load. The graph reveals that THID in twelve-pulse drives is very much a function of load. Good performance also requires balanced line voltages.

To determine how a six-pulse drive system operates under unbalanced line voltage conditions, we tested a 30 HP drive with a 5% line reactor operating from a power source with a 1% impedance. This system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The total harmonic current distortion, THID, is shown in figure 5. THID varied from 29% at full load with balanced line voltage to 95% at 5% load with a 3% line voltage unbalance. The harmonic performance of the twelve-pulse drive is significantly superior to a six-pulse drive under all conditions of line unbalance.

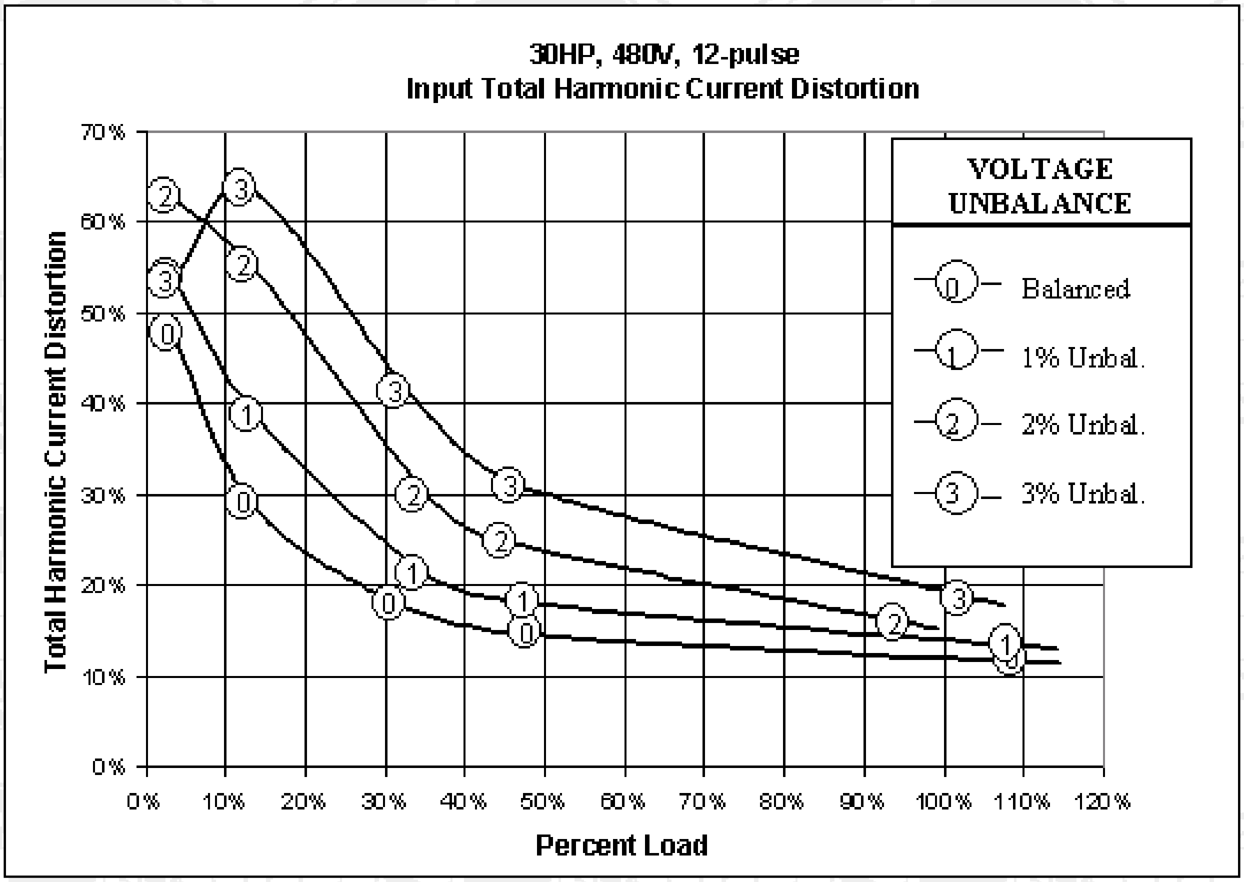


Figure 4

It is interesting to compare the performance of the twelve-pulse drive with a standard six-pulse drive fitted with an MTE Matrix Harmonic Filter under similar conditions of unbalanced line voltages. The Matrix Harmonic Filter is a type of low pass harmonic filter designed to work with standard six-pulse drives. A Matrix Harmonic Filter was tested feeding a 30 HP six-pulse drive. This system was tested with line voltage unbalance ranging from 0% to 3% and with loads ranging from 5% to 110%. The input total harmonic current distortion, THID, is shown in figure 6. THID varied from 4.7% at full load with balanced line voltage to 9% at 25% load with a 3% line voltage unbalance. The low pass filter provides better harmonic performance than the twelve-pulse system throughout the load range and is significantly less sensitive to voltage unbalance. At 25% load with a 1% line voltage unbalance, the twelve-pulse drive has an input total harmonic current distortion of 29% while the six-pulse drive fed from a low pass Matrix Harmonic Filter has a THID of 7% under the same operating conditions.

Conclusion

Drives are applied in heating, ventilating, and air conditioning applications because loads are variable and users demand energy efficiency and comfort. Varying loads result in load unbalances within building power distribution systems which add to the utility line voltage unbalance at the point of common coupling. Harmonic mitigation techniques which are not effective with line voltage unbalances of 1% to 3% at the point of utilization will not as a practical matter achieve useful results. The data in this report show that a standard six-pulse drive fed from a low pass Matrix Filter provides superior harmonic performance to a twelve-pulse drive in applications with variable loads and line voltage unbalances ranging from 0% to 3%.

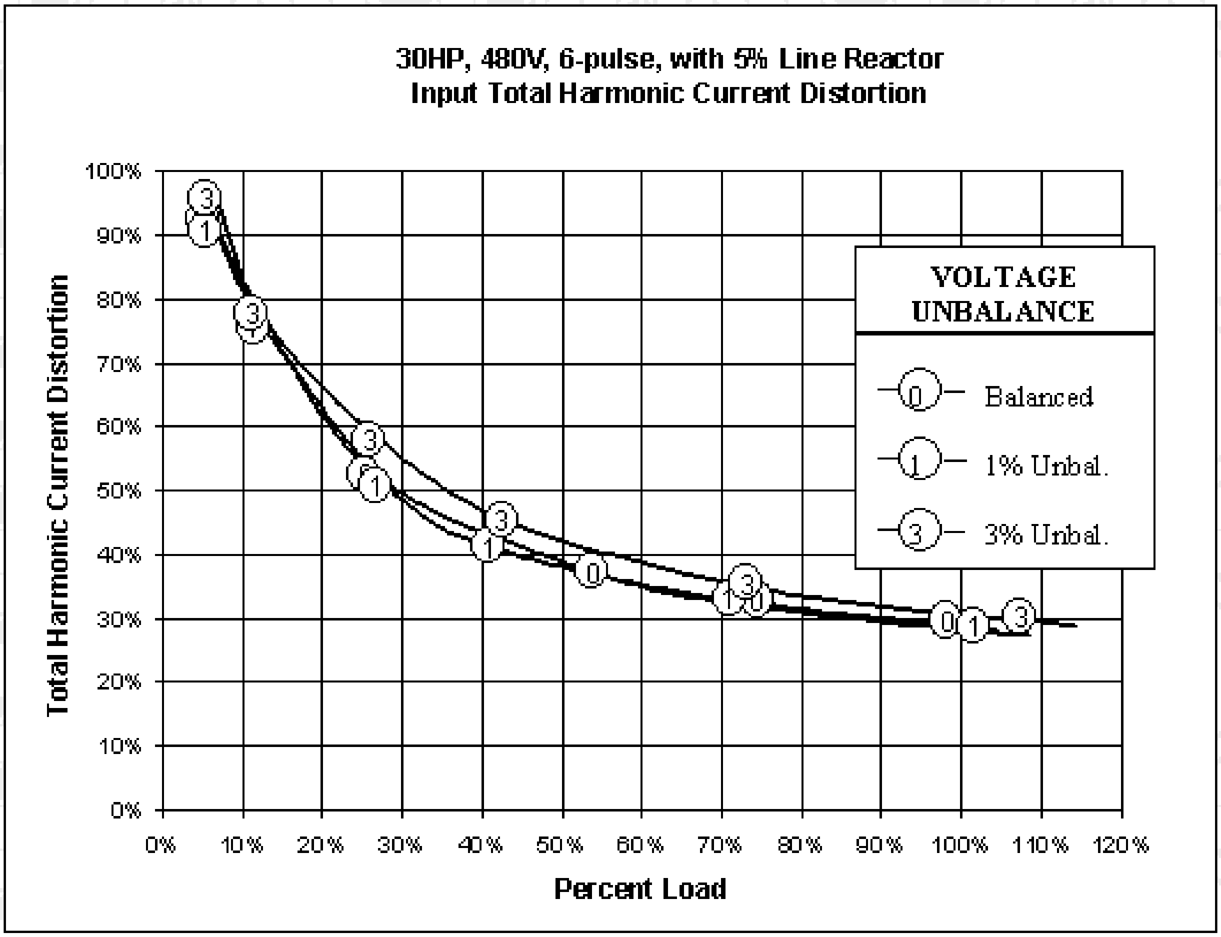

30HP, 480V, 6-pulse, with 5% Line Reactor
Input Total Harmonic Current Distortion
Total Harmonic Current Distortion
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
120%
Percent Load
VOLTAGE UNBALANCE
Balanced
1% Unbal.
3% Unbal.

Figure 5

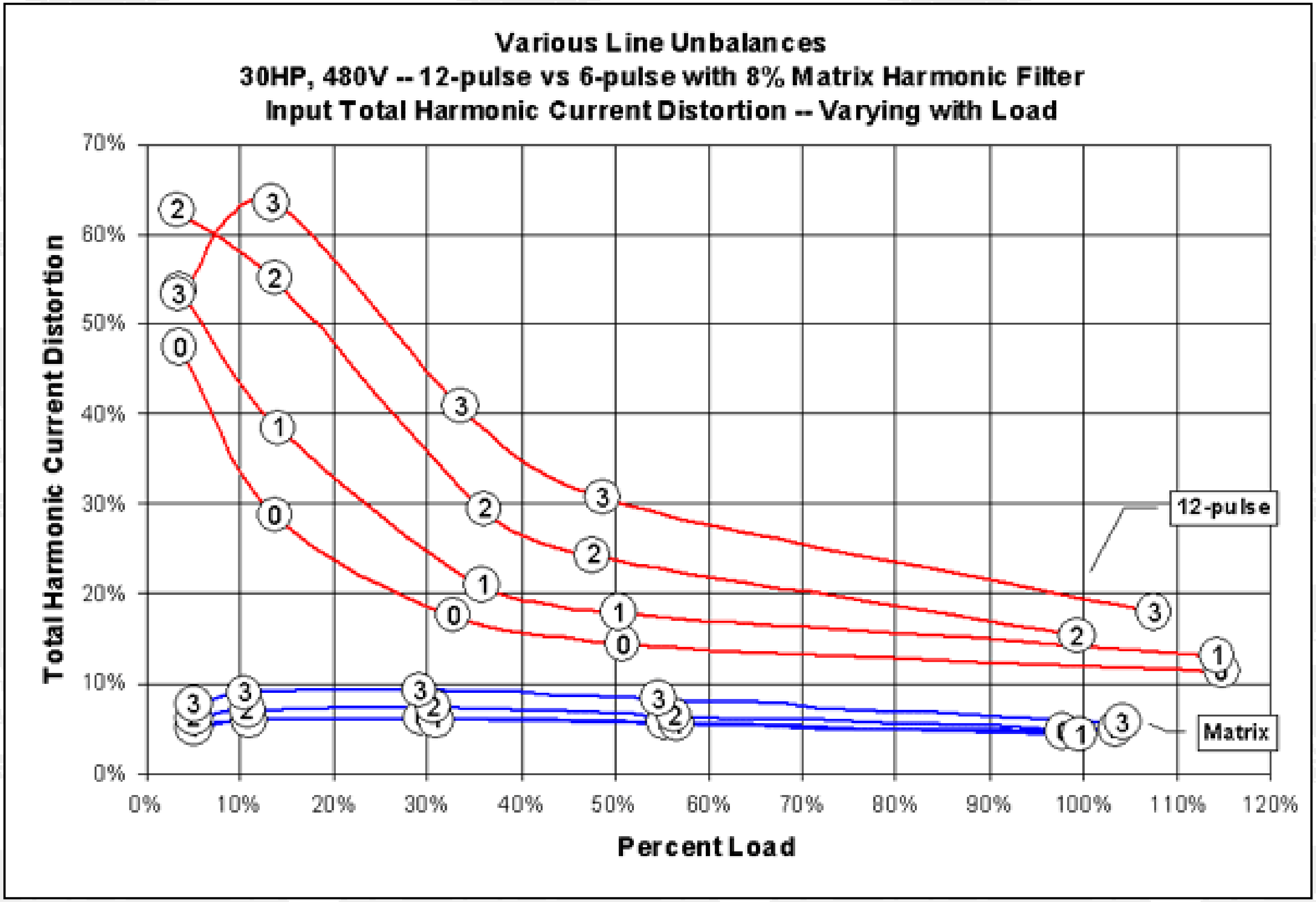
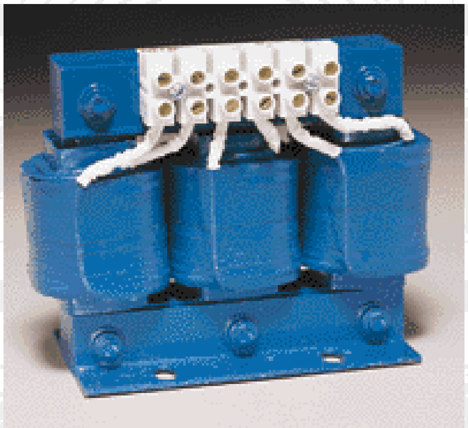

Various Line Unbalances
30HP, 480V -- 12-pulse vs 6-pulse with 8% Matrix Harmonic Filter
Input Total Harmonic Current Distortion -- Varying with Load
Total Harmonic Current Distortion
70%
60%
50%
40%
30%
20%
10%
0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
110%
120%
Percent Load
12-pulse
Matrix

Figure 6

Reactors Provide a Low-Cost Solution to Inverter/Drive Power Quality

Fred A. Lewis & John A. Houdek MTE Corporation

Three phase line reactors offer an economical solution to a variety of application problems in variable-speed drive installations. Reactors solve problems on either the input or the output of the drive if the reactor is compensated to handle the effects of harmonics.



To see where these reactors fit in today's technology, we have to go back 25 years to the introduction of low-voltage industrial drives. Often, the installation required a voltage step-up or step-down and line isolation was almost universally recommended. The isolation transformer provided both line isolation and voltage transformation. It became standard practice to include a drive isolation transformer with nearly every drive installation.

The reactor acts as a current-limiting device and filters the waveform and attenuates electrical noise and harmonics associated with the inverter/drive output.

As the industry progressed, drive voltage ratings increased. Some even developed with dual voltage ratings. Multiple power systems appeared in industrial plants and dual voltage motors became more popular. With these and other improvements, it became less necessary to alter the line voltage supplying the drive. Then, the drive industry developed internal isolation and ground fault protection systems. Thus the need for external isolation all but disappeared. The result was a significant cost reduction for a drive system and sales of the new electronic drives soared.

Line reactors protect ASD's, extending motor life, reducing power line distortion, attenuating harmonics and eliminating nuisance tripping.

Soon, users of these new, economical and efficient drives began experiencing nuisance problems not previously encountered with the older, isolation transformer protected systems. With the isolation transformer gone, the quality of the power delivered to the drive became more evident. The drives were very sensitive to line fluctuations and other nuisance problems not noticed before. A solution had to be found because the isolation transformer was too expensive to be put back into the circuit.

The line reactor was developed as a low-cost solution to the problem. The reactor acts as a current-limiting device and filters the waveform and attenuates electrical noise and harmonics associated with the inverter/drive output. In this respect, the line reactor even surpasses the isolation transformer at a fraction of the transformer's cost. Line reactor costs are typically just 1/5 the cost of a comparable isolation transformer.

Among the harmonic compensated line reactors benefits are:

- Virtual elimination of nuisance tripping of drives due to utility power factor correction capacitor switching
- Attenuation of line harmonics
- Extended switching component life (transistors, SCRS)
- Extended motor life
- Reduced motor operating temperature (20 to 40°C)
- Reduced audible motor noise (3 to 5 db)
- Minimized power disturbances
- Filtered electrical noise (pulsed distortion and line notching)
- Waveform improvement

Harmonic Compensation

As the name implies, line reactors are typically used on the line side of an ASD (adjustable-speed drive), as shown in Figures 2(a) and 2(b) for single and multiple motors. Some higher level design reactors, are harmonic compensated and can be successfully used on the load side of the drive (between the drive and motor) as well as the input (line) side of the circuit. Figure 3(a) shows a typical reactor on the load side of a single motor and Figure 3(b) is the configuration for multiple motors.

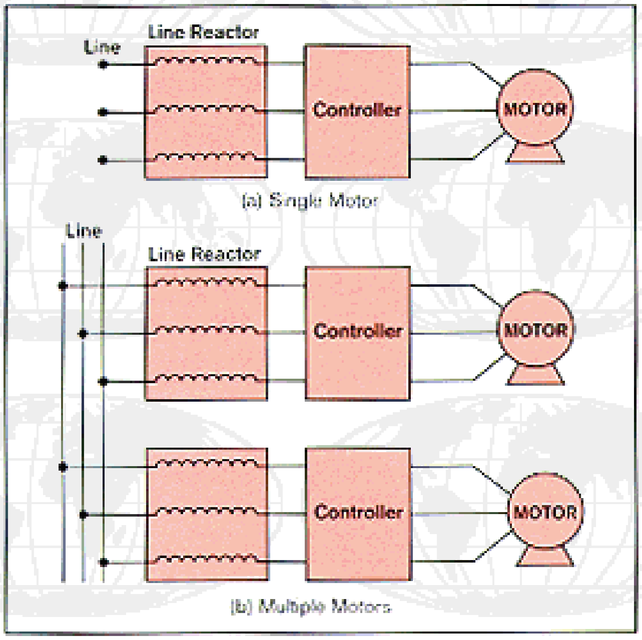


Figure 2. Typical Line Reactor Configuration

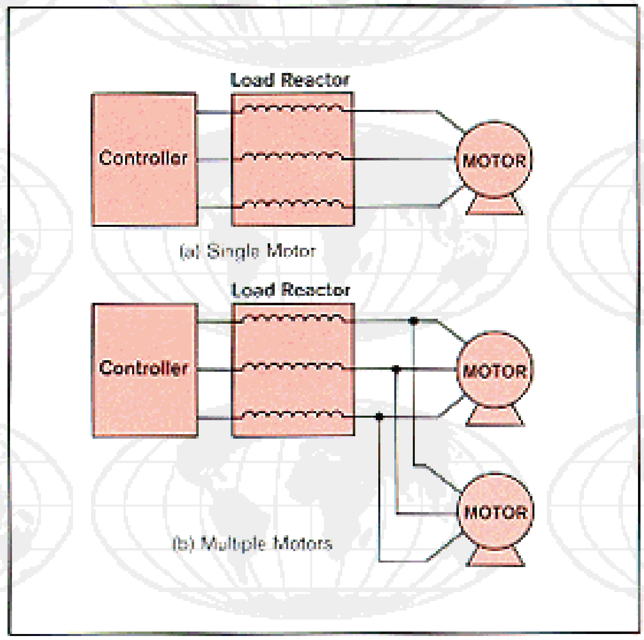


Figure 3. Typical Load Reactor Configuration

Harmonic compensated line reactors are specially designed to handle the waveform's harmonic content. This compensates for the effect of higher total rms current as well as higher frequencies present in the waveform and may be used effectively on either the line or load side of any ASD.

Reactors are used on the load side of an ASD as a current-limiting device to provide protection for the drive under motor short circuit conditions. Here, the line reactor slows the rate of rise of the short circuit current and limits the current to a safe value. By slowing the rate of current rise the reactor allows ample time for the drive's own protective circuits to react to the short circuit and trip out safely. Also, the reactor absorbs surges created by the motor load that might otherwise cause nuisance tripping of the drive. Machine jams, load swings and other application changes to the drive load cause motor load surges.

Looking at the load side reactor from the motor view, the ability of the reactor to filter the waveform produced by the ASD improves motor performance and the total system performance. Due to higher frequency pulses generated by the drive to produce the waveform, motors typically run hotter than normal, resulting in lower efficiency and shorter life. Unprotected motors must often be oversized to compensate for the higher frequencies and harmonic currents that are present in the drive output waveform. Waveform filtering by the reactor reduces the load side harmonic content, reduces thermal current affecting the motor and filters pulsed distortion. The reactor attempts to recreate a perfect sine wave, thus improving motor efficiency. This extends motor bearing life, increases horsepower output by 25-30%, and can reduce audible noise by as much as 3-5 decibels. Tests have shown that motor temperatures can be reduced as much as 20 to 40ºC using a harmonic-compensated reactor.

On the line side of the ASD system, reactors also serve bidirectional functions. When the local utility switches power factor correction capacitors onto the electrical power grid, it creates voltage spikes. The proper impedance reactor in the input circuit virtually eliminates nuisance tripping of drives due to these voltage spikes. Also, the reactor can protect from line sags because it performs a line stabilizing function. Initially, this may seem unusual because the reactor adds impedance to the circuit, which causes a voltage drop. An important, overlooked factor is that the reactor has significant inductance so it opposes any rapid change in current. Most voltage sags are the result of excessive loading or current surges. Thus, by stabilizing the current waveform, the reactor can indirectly solve both overvoltage and undervoltage tripping problems.

Looking on the line side from the opposite direction, the reactor filters out both pulsed and notched distortion. This minimizes interference with other sensitive electronic equipment (other ASDS, PCs, mainframe computers, logic controllers, telecommunications systems, monitoring equipment). The line reactor has been proven effective in reducing harmonics emitted by the drive onto the incoming power line.

Harmonic distortion test results shown in Figure 4 verify the effects of harmonic current distortion on the input side of a 5HP inverter ASD.

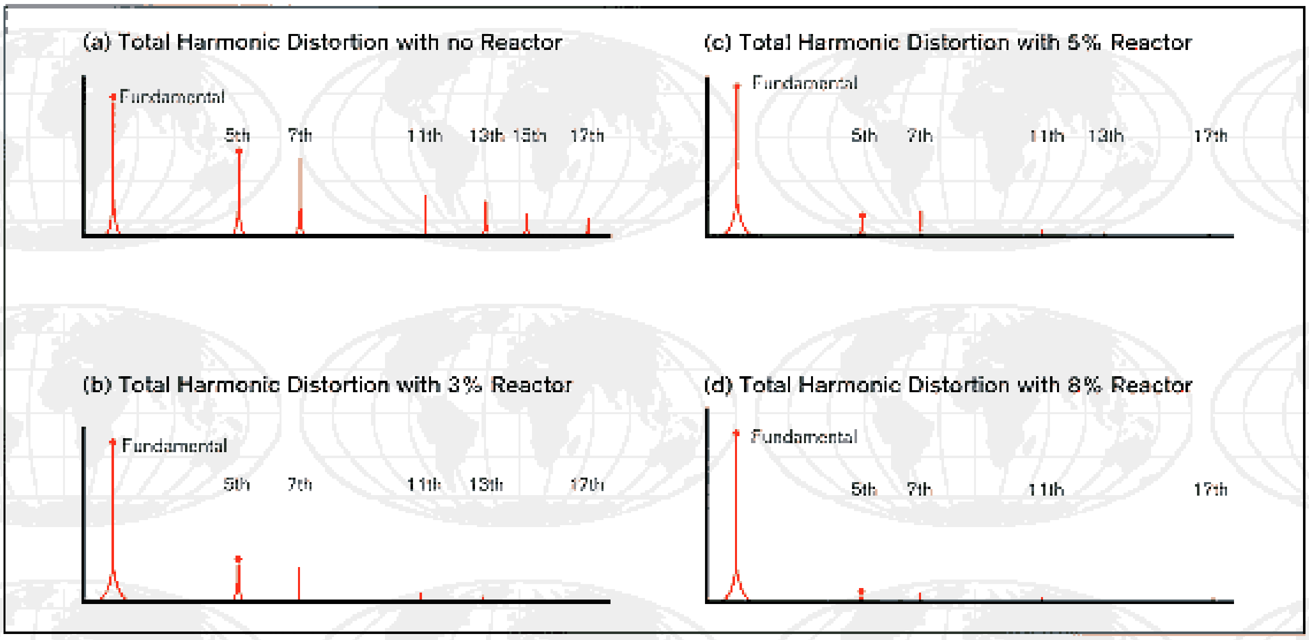


Figure 4. Harmonic Distortion Test Results

Reactor Impedance

Line reactors are rated in percent impedance to retain some conformity with the ratings of conventional drive isolation transformers. We can determine the impedance rating of a conventional isolation transformer with the following procedure:

1. Short circuit the secondary winding.
2. Increase the primary voltage while monitoring secondary current.
3. Measure the primary voltage that causes rated secondary current to flow.
4. Compare this value with the rated primary voltage to obtain a ratio equal to the transformer impedance rating.

Reactor impedance must be measured differently because the reactor is a series, current-dependent device as opposed to the transformer that is a parallel, voltage-dependent device. To determine percent impedance of a single-phase reactor, measure its voltage drop with rated current flowing through it. Compare this voltage with the line voltage for percent impedance. You can connect two phases in series with single-phase voltage applied. Measure the total voltage drop across both coils and compare it with the system voltage for the impedance rating. For example, if the voltage drop across the reactor is 12V for a 480V line, the percent impedance is 12/480 X 100, or 2.5%.

Test a three-phase reactor with all three phases energized at rated current. With all phases energized, measure the voltage across any one phase and divide it by the system voltage. Multiply this value by 1.73 (square root of 3) and again by 100 for percent impedance. As an example, if the reactor drop is 8.3V with a 480V line, the percent impedance is 8.3/480 X 1.73 X 100, or 2.99%.

If you energize only one phase of a three-phase reactor and compare the voltage drop with the system voltage for the impedance calculation, the calculated value indicates only 70-75% of actual value.

Line reactors are rated in percent impedance to retain some conformity with the ratings of conventional drive isolation transformers.

It is difficult for the user to test a reactor for conformance to a specification when reactors are rated only in percent impedance. For a more accurate test verification, it is helpful to find the reactor's actual inductance. This can be done in a manner similar to the impedance calculation as follows:

First, energize all three phases of the reactor at rated current. The measured voltage equals the current times the inductive reactance (X_L, which is 2(pi) times the frequency times the inductance). For a 60Hz system, the inductance equals the voltage divided by the current times 6.28 (2(pi)) times 60.

Using a meter or bridge system to test line reactors usually produces false readings for two reasons. First, this is only for single-phase testing so it indicates a value that is 25-30 % less than actual. Second, meter or bridge tests are at such a low current level that the reactor's core and gap remain unenergized.

Reactors are installed in HVAC equipment, machine tools, elevators, printing presses, UPS equipment, computer mainframes, harmonic filters, robotics equipment, ski lifts, wind generators, electric cars, trams, and many other types of equipment using drives or inverters. For additional information, contact the authors at (414) 253-8200.

Load Reactors -

Increase VFD System Performance & Reliability

John A. Houdek - VP - Marketing
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Reactors have been used for many years to solve problems in variable speed drive installations. About ten years ago the use of line reactors started to become more common as they helped to solve typical problems on the input (line side) of variable frequency drives (VFD) and SCR controllers. They often have been used as low cost substitutes for 1:1 isolation transformers. The typical problems that line reactors solved were drive nuisance tripping, voltage notch reduction (for SCR controllers) and harmonic attenuation. They were called "line reactors" because they were always used on the "line side" or input of a variable speed drive. Attempts to use "line reactors" on the output side of a drive tended to fail because the line reactors typically overheated due to the harmonic content of the output waveform.

In 1989 the industry experienced the introduction of Harmonic Compensated Reactors which now offered a product that was suitable for use on either the input or output of a variable speed drive. Harmonic compensation meant the reactor was designed to handle the harmonic spectrum and high frequency carrier waves which are typical on the output side of a variable speed drive. Not only are the frequencies higher, but the RMS current is also higher whenever harmonics are present. (Example: 100%fundamental current+100% harmonic current = 141% RMS current; via Pythagorean theorem). Harmonic compensated reactors would not only handle these conditions from a thermal perspective, but they also offered full performance and inductance in the presence of even severe harmonics. Therefore Harmonic Compensation offered an assurance of both safety and performance.

Now that reactors could be used on the output of a VFD, many more application problems could be solved. The most typical problems included motor temperature rise, motor noise, motor efficiency, and VFD short circuit protection.

Motor Temperature Reduction

Motors operated on a VFD tend to run warmer than when they are operated on pure 60hz, such as in an across-the-line stator application. The reason is that the output waveform of the VFD is not pure 60hz,, but rather it contains harmonics which are currents flowing at higher frequencies. The higher frequencies cause additional watts loss and heat to be dissipated by the iron of the motor, while the higher currents cause additional watts loss and heat to be dissipated by the copper windings of the motor. Typically the larger horsepower motors (lower inductance motors) will experience the greatest heating when operated on a VFD.

Reactors installed on the output of a VFD will reduce the motor operating temperature by actually reducing the harmonic content in the output waveform. A five percent impedance, harmonic compensated reactor will typically reduce the motor temperature by 20 degrees Celsius or more. If we consider that the typical motor insulation system has a "Ten Degree C Half Life" (Continual operation at 10 degrees C above rated temperature results in one half expected motor life), then we can see that motor life in VFD applications can easily be doubled. Harmonic compensated reactors are actually designed for the harmonic currents and frequencies whereas the motor is not.

Motor Noise

Because the carrier frequency and harmonic spectrum of many Pulse Width Modulated (PWM) drives is in the human audible range, we can actually hear the higher frequencies in motors which are being operated by these drives. A five percent impedance harmonic compensated reactor will virtually eliminate the higher order harmonics (11th & up) and will substantially reduce the lower order harmonics (5th & 7th). By reducing these harmonics, the presence of higher frequencies is diminished and thus the audible noise is reduced. Depending on motor size, load, speed, and construction the audible noise can typically be reduced from 3 - 6 dB when a five percent impedance harmonic compensated reactor is installed on the output of a PWM drive. Because we humans hear logarithmically, every 3dB cuts the noise in half to our ears. This means the motor is quieter and the remaining noise will not travel as far.

Motor Efficiency

Because harmonic currents and frequencies cause additional watts loss in both the copper windings and the iron of a motor, the actual mechanical ability of the motor is reduced. These watts are expended as heat instead of as mechanical power. When a harmonic compensated reactor is added to the VFD output, harmonics are reduced, causing motor watts loss to be reduced. The motor is able to deliver more power to the load at greater efficiency. Utility tests conducted on VFD's with and without output reactors have documented efficiency increases of as much as eight percent (at 75% load) when the harmonic compensated reactors were used. Even greater efficiency improvements are realized as the load is increased.

Short Circuit Protection

When a short circuit is experienced at the motor, very often VFD transistors are damaged. Although VFD's typically have over correct protection built-in, the short circuit current can be very severe and its rise time can be so rapid that damage can occur before the drive circuitry can properly react. A harmonic compensated reactor (3% impedance is typically sufficient) will provide current limiting to safer values, and will also slow down the short circuit current rise time. The drive is allowed more time to react and to safely shut the system down. You still have to repair the motor but you save the drive transistors.

Other Applications

Output reactors solve other problems on the load side of VFD's in specialized applications also. Some of these include: Motor protection in IGBT drive installations with long lead lengths between the drive and motor, Drive tripping when a second motor is switched onto the drive output while another motor is already running, and Drive tripping due to current surges from either a rapid increase or decrease in the load.

Conclusion

Whether you are using reactors on the input or output of a VFD the best performance results will always be achieved using reactors which are fully compensated for the harmonics which are present. This assures maximum inductance and thus best attenuation of harmonics with maximum current surge protection. Harmonic compensated reactors have proven to be the most cost effective solution to a wide variety of typical VFD application problems. Use them on the input or output of your drives to improve the total system performance and reliability.

Recommended percent impedance for typical applications:

3% -Current surge protection
3% -Voltage transient protection
3% -Drive nuisance tripping
3% -Voltage notch reduction (SCR's)
3% -Capacitor switching spike protection
3% -Motor short circuit protection
3% -Multiple motor applications

5% -Harmonic reduction
5% -Motor temperature reduction
5% -Motor noise reduction
5% -Motor efficiency improvement
5% -IGBT w/ long lead lengths

Solving Motor Failures Due to High Peak Voltages and Fast Rise Times (*dv/dt*)

The evolution of power semiconductors has been so dramatic that today an insulated gate bi-polar transistor (IGBT) can be turned on in just 0. I micro-second. This results in the voltage rising from zero to peak in only one-tenth of a microsecond. Unfortunately, there are many motors in existence that do not have sufficient insulation to operate under these conditions.

High Peak Voltages can be experienced at the motor terminals especially when the distance between the inverter (drive) and the motor exceeds about 15 meters. This is typically caused by the voltage doubling phenomenon of a transmission line having unequal line and load impedance's. Motor terminal voltage can reach twice the DC bus voltage in long lead applications. When the characteristic load impedance is greater than the line impedance, then voltage (and current) is reflected from the load back toward the source (inverter). The absolute peak voltage is equal to the sum of the incident peak voltage traveling toward the motor plus the reflected peak voltage. If the load characteristic impedance is greater than the characteristic line impedance, then the highest peak voltage will be experienced at the load (motor) terminal. If the DC bus voltage is 850 volts, then motor terminal voltage could reach 1700 volts peak.

Fast Voltage Rise Times of 1600 volts per microsecond can be typical as the motor lead length exceeds just a few hundred feet. Voltage rise time is referred to as dv/dt(change in voltage versus change in time). When the rise time is very fast the motor insulation system becomes stressed. Excessively high dv/dt can cause premature breakdown of standard motor insulation. Inverter duty motors typically have more phase-to-phase and slot insulation than standard duty motors (NEMA design B).

When motors fail due to insulation stress caused by high peak voltage and fast voltage rise times (high dv/dt) they have common symptoms. Most failures of these types occur in the first turn as either a phase-to-phase short or phase to stator short. The highest voltage is seen by the first turn of the winding and due to motor inductance and winding capacitance of the motor, the peak voltage and dv/dt decay rapidly as the voltage travels through the winding. Normally, the turn to turn voltage in a motor is quite low because there are many turns in the winding. However, when the dv/dt is very high the voltage gradient between turns and between phase windings can be excessively high, resulting in premature breakdown of the motor insulation system and ultimately motor failure. This problem is most prevalent on higher system voltages (480 & 600 volts) because the peak terminal voltage experienced often exceeds the insulation breakdown voltage rating of the motor.

Standard Motor Capabilities established by the National Electrical Manufacturers Association (NEMA)and expressed in the MG- I standard (part 30), indicate that standard NEMA type B motors can withstand ***1000 volts peak*** at a minimum rise time of 2 u-sec (microseconds). Therefore to protect standard NEMA Design B motors, one should limit peak voltage to ***1KV*** and reduce the voltage rise to less than 500 volts per micro-second.

SOLUTIONS

There are several solutions available to solve this problem, each offering a different degree of protection at a different price.

1. ***Inverter Duty motors*** should be considered for all new IGBT drive installations. They offer increased winding slot insulation, increased first turn insulation, and increased phase- to-phase turn insulation. They are more expensive than standard design B motors but are the best motor for the job when it will be controlled by an IGBT variable frequency inverter. The NEMA Standard MG- I (part 3 1) indicates that inverter duty motors shall be designed to withstand 1600 volts peak and rise times of >0.1µsec. Nevertheless, it is wise to confirm the actual motor capability with the manufacturer.
2. ***Minimize Cable Length*** between the inverter and motor. Quite often this is somewhat uncontrollable, especially when the application is downhole pumping where the motor is required to be a great distance from the inverter. The longer the cable, the greater the capacitance of the cable, the lower the impedance of the cable and thus a greater mis-match will result between the characteristic line and load impedance's, resulting in higher peak voltage at the motor (load) terminals. Minimize this length whenever possible to avoid problems.
3. ***Tuned Inductor & Capacitor*** (LC) ***Filters*** are an effective means of taming the output voltage waveform and protecting the motor. An "LC" circuit can result in the best voltage waveform but at a relatively high cost and with some future considerations. Of course these filters are "low pass shunt type filters" tuned for some specific frequency, often in the range of 1 kHz to 2Khz. Because these filters have essentially zero impedance at there resonant frequency, it is very important that the inverter switching frequency not be set too low. The threat exists that someone may vary the carrier frequency (at a later date) without consideration for the existence of a low pass filter resulting in damage to the inverter or filter. One should be very careful when applying this type of filter on the output of an inverter with variable carrier frequency. LC filters for this purpose cost approximately 3-4 times the cost of a load reactor.
4. ***RC Snubber Networks*** can reduce the slope of the voltage waveform leading edge and reduce the peak voltage of the waveform but they have a minimal effect on the actual waveshape. They perform marginally when compared to the other solutions discussed herein. At an intermediate cost, they provide a marginal benefit. The cost of these network can be 2-3 times the cost of a load reactor.
5. ***Load Reactors*** are the most cost effective means of solving high dv/dt and peak voltage problems associated with IGBT inverters. Typical experience is that peak voltage is limited to I 000 volts or less (actual value varies based upon system voltage). Voltage rise time (dv/dt) is typically extended to several micro-seconds resulting in only about 75 - 200 volts per micro- second rise times. Usually the load reactor is all that is needed to adequately protect the motor from dv/dt and to allow full warranty of the motor in IGBT inverter applications. (Some motor manufacturers do not offer a warranty in IGBT applications if a load reactor is not installed).

Whether you install the load reactor at the inverter or at the motor, it will provide you with protection for your motor. It offers the best dv/dt reduction when it is placed at the inverter and this is usually the easiest place to add the reactor. Placement at the inverter also provides voltage stress protection for the motor cables. Of course there are some applications that may require the addition of the load reactor at the motor terminals. This will also provide very good protection of the motor because the IGBT protected reactor acts like the first turns of the motor. The motor is protected well in this case, however the motor cables are not protected from voltage stress.

"Guard-Ac" Line/Load Reactors manufactured by **MTE Corporation**, are specially constructed with IGBT protection. They have a **4000 volt rms(5600Vpeak)** insulation dielectric strength and are approved by both CSA and UL (UL506 & UL508). Only reactors approved to UL506 have the high dielectric strength (4000 volts) required for IGBT applications. MTE Corporation Line / Load reactors also feature **"Triple Insulation"** on the first two and last two turns of each coil providing over 10,000 volts strength. Our standard Line/Load Reactors are suitable for use on IGBT inverter outputs with switching frequencies up to 20Khz.

LOW COST ASD MOTOR PROTECTION STOPS DAMAGE TO MOTORS DUE TO ASD dv/dt EFFECTS

By: Mahesh Swamy, Ph.D.

and

John A. Houdek

Abstract: The use of Adjustable Speed Drives (ASDs), also known as Variable Frequency Drives(VFDs), has gained tremendous popularity in recent times because of its power savings and speed control features. The voltage waveform being applied across the windings of an induction motor being fed from an ASD is Pulse Width Modulated (PWM). In general, the output is modulated at a carrier frequency ranging from 1.0-kHz, to 19.0-kHz, When the distance between the motor and the ASD is long and there exists a mismatch in the cable and motor surge impedances, there is voltage amplification at the motor terminals. This is attributed to a phenomenon known as "Voltage Reflection". The overvoltage at the motor terminals, which depends on the distance between the motor and the ASD as well as on the impedance mismatch between the cable and the motor surge impedances, can reach as high as 1.9 times the DC bus voltage of the ASD. The overvoltage can cause premature insulation failure in the motor. This paper documents the overvoltage for long lead lengths and also suggests solutions to overcome them. Four different remedies are suggested Experimental results achieved on using the different mitigation techniques are also presented.

Introduction

The phenomenon of reflection of electromagnetic (*em*) waves on an electric conductor is very similar to a wave in water. At a given point, the magnitude of the water wave varies with time and its phase is retarded. As one moves away from the origin of the wave, the amplitude diminishes and eventually subsides. However, if there exists a barrier to the movement of the waves, there is reflection. Consequently, the amplitude of oscillation at a given point is the sum of the incident and the reflected wave at that point. Similar results are observed when *em* wave travels on a transmission line. If a load on a transmission line is physically at infinite distance from the source, there exists no reflection - similar to a water wave originating in a pond with boundary at infinity. One can electrically create an infinite transmission line (a line having no reflection) if the surge impedance at the terminating end matches the cable surge impedance. However, in most cases the motor and cable surge impedances are mismatched which causes voltage reflections; Voltage reflection further causes voltage amplification at the motor terminals since usually the motor and the ASD are physically separated by long lead lengths.

Long Transmission Line Theory as Applied to Motor-ASD Case [1]

Let the voltage at any given point which is *x* meters away from the *load end*, be denoted by V_x. This voltage is the sum of incident and reflected waves at that point. Let the incident wave be denoted as v^+ and the reflected wave be denoted as v^-. V_x is given by:

$$V_x = v^+ + v^- \qquad (1)$$

Referring to Figure 1, the following is evident:

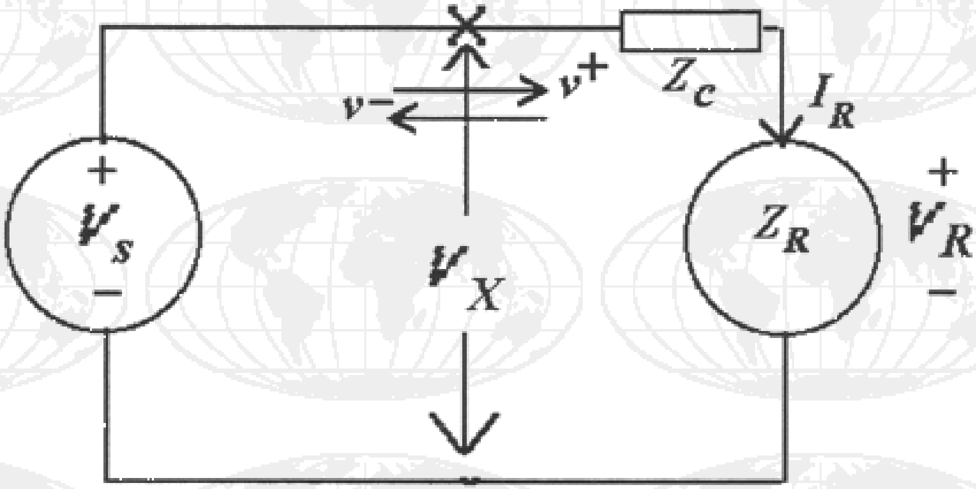


Fig. 1: Schematic diagram of a transmission line showing incident and reflected voltage wavefronts. S and R indicate sending and receiving ends.

The incident wave, v^+, is equal to the sum of the receiving end voltage and the drop across the surge impedance of the cable. Similarly, the reflected wave, v^-, is equal to the difference between the receiving end voltage and the drop across the surge impedance. From these observations, one can rewrite the voltage at any given point on the transmission line as follows:

$$V_x = \frac{V_R + I_R Z_C}{2} e^{ax} e^{jbx} + \frac{V_R - I_R Z_C}{2} e^{-ax} e^{-jbx} \qquad (2)$$

V_x is voltage at a point x units away from the receiving end;

V_R is voltage at receiving end;

I_R is current at receiving end;

Z_c is characteristic impedance of line; = ÖL/C;

L is phase inductance per unit length;

C is line-ground capacitance per unit length;

$\gamma =$ $\alpha + j\beta$;
α is attenuation constant;
β is phase constant;

The exponential terms are used in equation (2) to help explain the variations of the voltage waveform as a function of the distance along the line. The first term in equation (2) denotes the "Incident" wave while the latter term in equation (2) denotes the "Reflected" wave. Based on equation (2), the following points are worth noting:

(a) x is zero at the receiving end and increases as one moves away from the receiving end toward the point of interest on the transmission line. On moving away from the receiving end (for increasing values of *x*), the incident wave increases in magnitude and advances in phase;

(b) On moving away from the receiving end (for increasing values of *x*), the reflected wave diminishes in magnitude and retards in phase;

(c) If the terminating point is at infinite distance from the point of interest (i.e., *x* is at infinity), then there exists no reflected wave;

(d) If the terminating impedance is equal to the characteristic impedance, i.e., $Z_R = Z_C$, there exists no reflected wave. A line terminated in its characteristic impedance is known as a *flat line* or an *infinite line*.

Bundled conductor lines have lower values of Z_C as they have lower L and higher C than lines with single conductors per phase;

(e) From equation (2), it is interesting to note that under no load conditions, $I_R = 0$. This results in the incident wave to be equal and in phase with the reflected wave at the point of termination, i.e., at $x = 0$. Hence, the actual voltage at the point of termination which is given by equation (1), equals 2 times the incident voltage wave. This shows the voltage doubling effect under open or no load conditions;

Coefficient of Reflection [1]
As explained earlier, any *em* wave traveling on an electrical conductor exhibits the phenomenon of reflection, exception being an infinite transmission line or a line terminated in its *characteristic impedance*. Referring to Figure 1, the value of the terminating impedance, Z_R , is given by the ratio of the voltage and current at the point of termination. The voltage and current components are made up of the incident and reflected waves. Mathematically, this can be represented as:

$$Z_R = \frac{v_R^+ + v_R^-}{i_R^+ + i_R^-} \qquad (3)$$

Z_R is the terminating impedance;

v_R^+ is the incident voltage wave at termination;

v_R^- is the reflected voltage wave at termination;

i_R^+ is the incident current wave at termination;

i_R^- is the reflected current wave at termination;

Further, the incident and reflected current components can be expressed as:

$$i_R^+ = v_R^+/Z_C \qquad (4)$$

$$i_R^- = v_R^-/Z_C \qquad (5)$$

Substituting for i_R^+ and i_R^- in equation for Z_R:

$$v_R^- = \frac{Z_R - Z_C}{Z_R + Z_C} v_R^+ \qquad (6)$$

The ratio of the reflected wave to the incident wave is known as the "coefficient of reflection" and is denoted as ρ_R at receiving end. For voltage, the coefficient is:

$$\rho_R = \frac{Z_R - Z_C}{Z_R + Z_C} = v_R^-/v_R^+ \qquad (7)$$

The reflection phenomenon exists at the sending end as well. The coefficient of reflection at the sending end is denoted by ρ_S. For voltage, the coefficient is:

$$\rho_S = \frac{Z_S - Z_C}{Z_S + Z_C} = v_S^-/v_S^+ \qquad (8)$$

From equations (7) and (8), a few interesting remarks can be made:

(a) If at point of termination there is a short-circuit, then $Z_R = 0$; and $\rho_R = -1$; $v_R^- = v_R^+$ and so the sum of reflected and incident voltages at the point of termination is Zero, i.e.,

$(v_R^- + v_R^+ = 0)$;

(b) If the point of termination is an open circuit, then $Z_R = \infty$, $\rho_R = 1$; and so the sum of reflected and incident voltages at point of termination is $2v_R^+$;

(c) If at the point of termination, $Z_R = Z_C$, then there exists *no reflection* since $\rho_R = 0$;

(d) Mismatched impedance causes overvoltage when $Z_R >> Z_C$ and ρ_R approaches a value of Unity; If $Z_R << Z_C$, then ρ_R is negative, and reflection exists but it does not result in voltage amplification at termination;

(e) As mentioned earlier, coefficient of reflection for Source (ρ_S) exists well. Typically, source impedance Z_S, is Zero and hence, ρ_S is approximately -1. Note that under ideal conditions, the rms value of sending end voltage does not change from its nominal value;

Applying the above theories to the case of a motor being fed via an ASD, one can come to a few interesting conclusions. The mismatch between cable and motor surge impedance is the highest for small motors; Also, in all cases, the coefficient of reflection is positive, which means that there always exists amplification of the voltage at the motor terminals.

Typical motor and cable surge impedances for popular sizes of motors is given below [2]:

HP	Z_R	Z_C	P^R
25	1500Ω	80Ω	0.9
50	750Ω	70Ω	0.83
100	375Ω	50Ω	0.76
200	188Ω	40Ω	0.65
400	94Ω	30Ω	0.52

Smaller hp motors have larger inductance and less amount of Slot Insulation which results in a higher surge impedance compared to larger hp motors.

Critical Cable Length

The phenomenon of reflection occurs irrespective of the distance between the motor and the ASD as evidenced from the discussions in the preceding paragraphs. The magnitude of the voltage at a given point on the transmission line is a function of the distance *x* from the terminating point as shown by equation (2). The worst case of reflection at the terminating point occurs under open circuit conditions. In order to estimate the *critical length* at which the magnitude of the sum of the incident and reflected wave is higher than the peak value of the incident wave, one has to know the speed of propagation of *em* waves on the transmission line.

If the speed of propagation of the *em* wave is assumed to be *v* and the rise time of the PWM wavefront (defined as the time taken for the output to go from 10% to 90% of its peak value) is t_r , then the distance traveled by the wavefront during its rise time is simply v x t_r. If the terminating point is at a position where the incident wave has just reached 50% of its full value and if total reflection is assumed, i.e., P^R = 1.0, then the sum of the incident and reflected waves will yield 100% of the peak value of the incident wave. Any distance greater than this critical length would allow the incident wave to build up to more than 50% of its peak value and if total reflection is considered, the effective wavefront at the terminating point will be greater than 1.0 p.u. Thus the critic cable length is given by:

$$L_{CR} = \frac{v \text{ x } t_r}{2} \quad (9)$$

The speed of propagation of a wavefront over the conductor depends on the inductance and capacitances per unit length of the conductor. Mathematically, it is given by:

$$v = \frac{1}{\sqrt{L x C}} \text{ m/sec} \quad (10)$$

Typical values for the speed of propagation, *v*, range from 100 to 150 *m/µsec.* The rise time of typical IGBTs used in ASDs range from 0.4 to 0.6 µsec. Using equation (10), the critical length is calculated to vary from **20 to 45 meters**.

Mitigation Techniques

As shown in the preceding paragraphs, most long lead length cases involving induction motors fed from ASDS, there exists voltage amplification. This overvoltage at the motor terminals can deteriorate the insulation system of the motor thereby causing premature motor failures. Four different techniques are discussed in this section which help alleviate the overvoltage problem encountered by motors fed from ASDs at long distances. These four techniques are: (i) Use of 3-phase load reactors; (ii) Use of RC snubbers at the motor terminals; (iii) Applying low pass filter section to wave shape the output from an ASD; and (iv) Isolated form of the technique used in (iii) above.

3-Phase Load Reactors

By using a 3-phase load reactor in between the motor and the ASD, one can change the characteristic impedance of the motor or that of the source depending on where the inductor is physically placed. Typical values of impedance used is 0.03 p.u (3% impedance). A higher value of impedance can cause a larger drop across the inductor thereby reducing the fundamental component of the voltage at the motor terminals. This can result in torque reduction and in some cases yield unsatisfactory operation at low speeds and high torque loads. For centrifugal load applications, inductance of 0.05 p.u. (5% impedance) may also be used without conspicuous deterioration in torque characteristics at practical operating points.

Adding a 3-phase load reactor at the motor end will result in altering the surge impedance of the motor. The line inductance component of the surge impedance of the motor is artificially made high which causes the overall surge impedance of the motor to be higher than normal. The mismatch between the surge impedances of the motor and the cable is aggravated thereby resulting in a higher coefficient of reflection and a higher voltage at the terminating point. Since the terminating point now has the 3-phase inductor first and then the motor terminals, the overvoltage is experienced by the windings of the reactor instead of the motor. The reflected voltage traveling along the conductor back to the sending end will have a higher amplitude because of the larger degree of mismatch at the terminating point.

Adding a 3-phase load reactor at the ASD end will result in altering the surge impedance of the cable. Typically, the surge impedance of the cable is lower than that of the motor. By increasing the surge impedance of the cable artificially, the coefficient of reflection is made lower which reduces the magnitude of reflected wavefront. The reflected voltage traveling back on the conductor toward the motor is hence reduced which helps reduce the stress on the cable.

To demonstrate the effectiveness of a load reactor connected at the drive end of the motor cable, an experiment was performed using IGBT inverter rated 3 HP to drive a motor which was located a distance of 750 feet from the drive. Figure 2.1 illustrates the actual voltage waveform experienced at the motor terminals without any mitigation device in use. Notice however, Figure 2.2 illustrates the same motor /drive combination only now a load reactor (5 percent impedance) was added at the drive terminals and the motor was now moved to a distance of 1000 feet. The relative cost for this solution based on a 5HP, 480 volt drive/motor combination is about $150.

No reactor
Motor at 750 feet
(200 Volts per division)

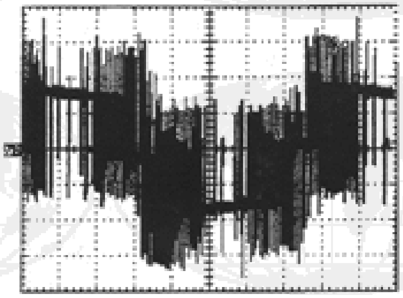


Fig. 2.1

w/5% Impedance reactor
Motor at 1000 feet
(200 Volts per division)

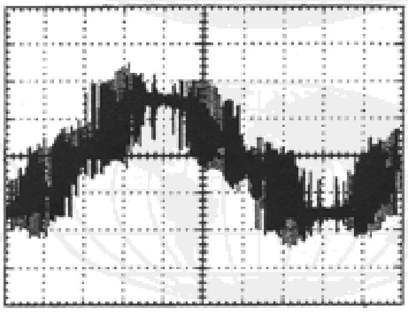


Fig. 2.2

RC Snubbers

The RC snubber is the simplest and lowest cost of methods employed. In its simplest form it consists of resistors and capacitors configured as shown in Fig. 3.1. The RC snubber is typically installed at the motor terminals and acts as an impedance matching network. The snubber components are carefully selected to cause the load impedance to match the characteristic impedance of the motor cables. When the motor surge impedance is equal to the line characteristic impedance, then voltage reflection does not occur and excessive voltage will not be experienced at the motor terminals.

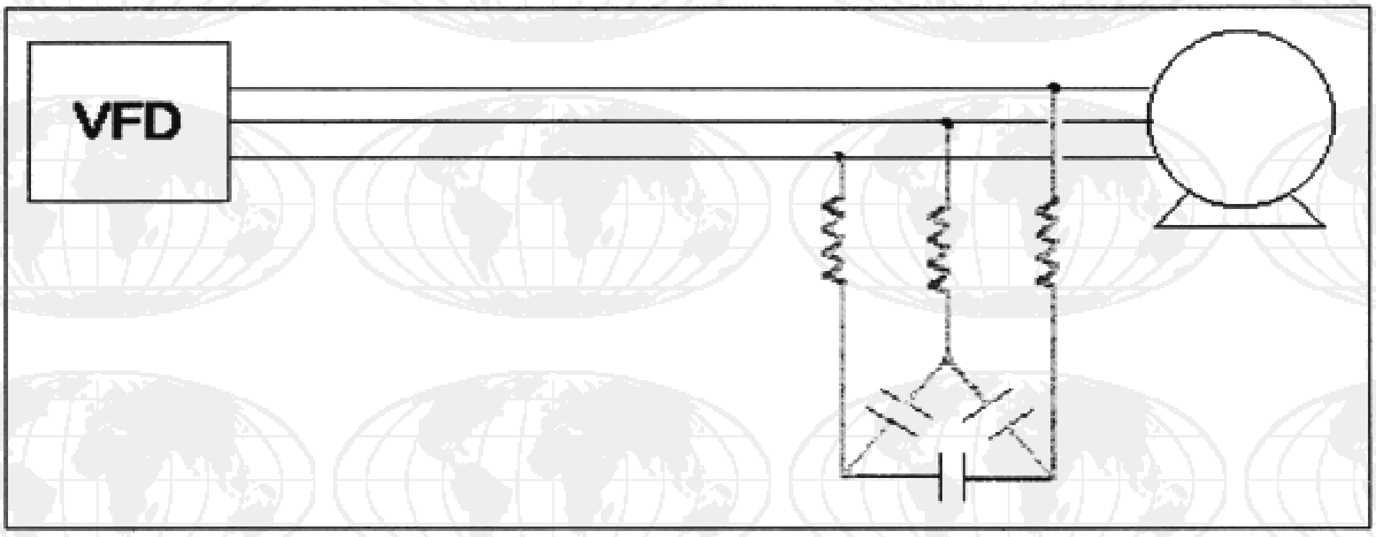


Figure 3.1

Using the same drive/motor combination as above with the motor 1000 feet from the inverter, the performance of the basic snubber network in Figure 3.3 was satisfactory. Of course Figure 3.2 repeats the waveform for the motor voltage without any mitigating device when the motor is 750 feet from the inverter.

Motor Voltage (750 ft.)
(200 Volts per division)

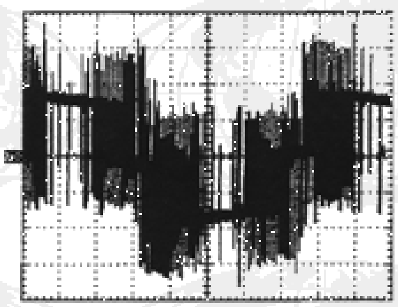


Fig. 3.2

w/RC Snubber Network
Motor at 1000 feet
(200 Volts per division)

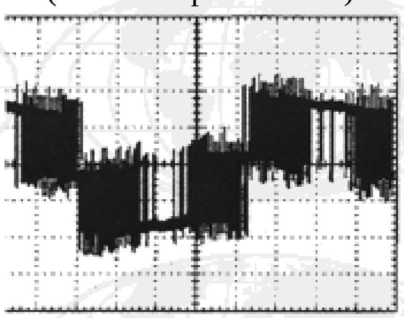


Fig. 3.3

The snubber network will also extend the voltage rise time to several microseconds while clamping the peak voltage. As shown in Fig. 3.3 the snubber circuit (or impedance matching network) can effectively minimize motor terminal voltage spikes and offer very good protection for the motor. Snubber networks can cost less than $50.00 but must be located at the motor terminals as they are a cable terminating device. In some cases it may be necessary to match the snubber impedance to the actual line impedance in order to maximize its effect.

LC Filter

The LC filter combines a load reactor and a capacitor network to form a low pass filter as illustrated in Figure 4.1 . The basic concept is that the filter network has a resonant frequency of approximately 1 to 1.5 kHz and frequencies higher than that will be absorbed by the filter and not passed on to the motor. Of course it is important that the inverter switching frequency be set to 5khz to prevent excessive filter current and drive malfunction. In fact, it has been found that the performance of this basic LC filter network, while very good at 5 kHz, actually improves as the switching frequency is increased.

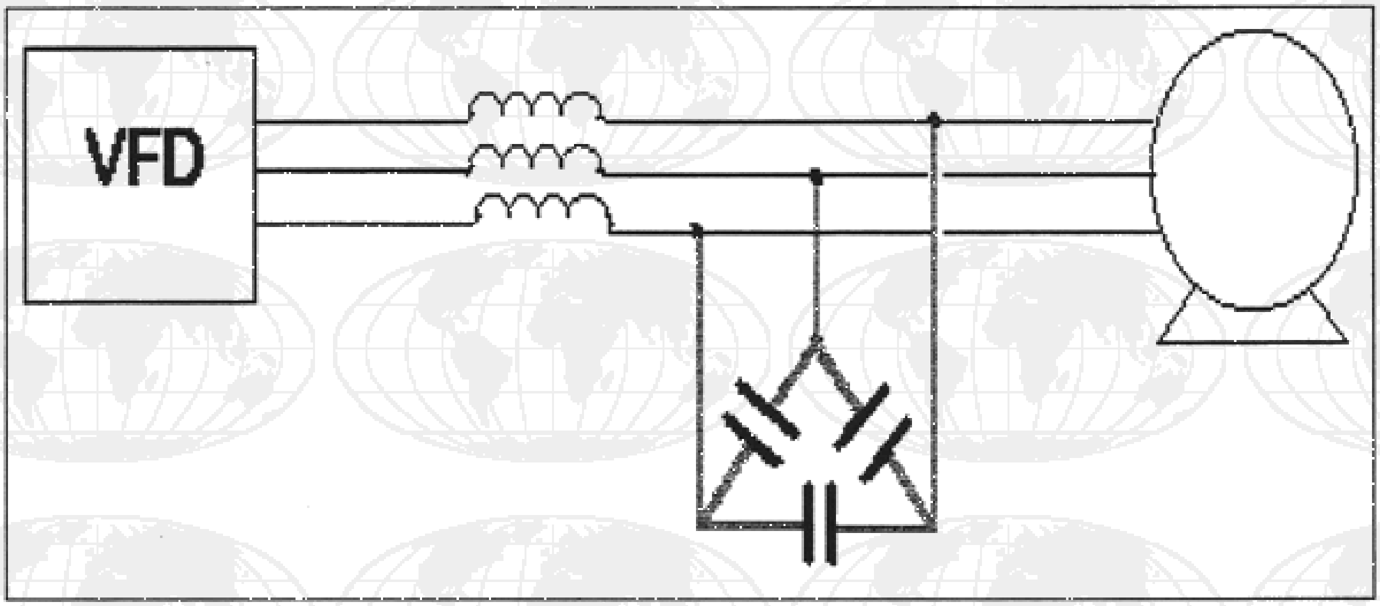


Figure 4. 1

The beauty of this filter, as one can see in Figure 4.3 is that the motor sees a voltage waveform that is nearly sinusoidal. Figure 4.2 shows our original waveform while the motor was connected 750 feet away from the inverter. Look at Figure 4.2 now to see the actual motor voltage waveform, using the LC filter, and with the motor reconnected at 1000 feet distance from the inverter. The relative cost of this solution, based on a 5HP drive/motor combination is less than $250.

No FIlter, Motor at 750 feet
(200 Volts per division)

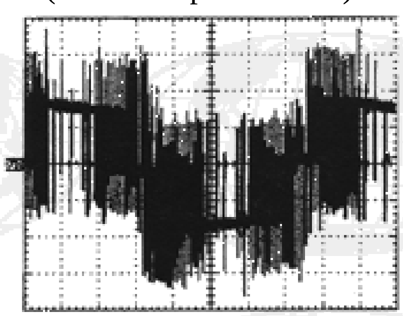


Fig. 3.2

w/LC Filter
Motor at 1000 feet
(200 Volts per division)

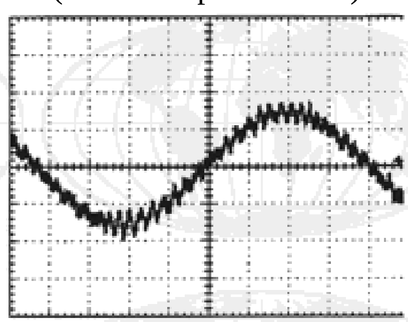


Fig. 3.3

As the capacitor requirement (for tuning purposes) becomes greater, it is practical to add a dampening resistor in series with the capacitor network. An alternative to this however, is the LC filter with isolated capacitors.

LC Filter with Isolated Capacitor:

This network follows the same basic principles the basic LC filter except it utilizes an isolation transformer to feed the capacitors. Large values of capacitance can be used because the transformer ratio reduces the capacitor current on the transformer primary side. We get the full effect of the capacitor in conjunction with the series inductor, while minimizing the capacitor current and capacitive reactance as seen by the inverter output circuit. The transformer impedance offers the dampening which is desirable for large values of capacitance. The transformer also offers some inductance which allows the use of a lower inductance value of series reactor thereby reducing the voltage drop and improving motor torque.

The waveforms accomplished with this isolated capacitor technique are quite similar to the waveforms captured with the basic LC filter as the concept is the same. Overall system performance is optimized with this filter network because a sinusoidal waveform is provided for the motor while voltage drop is minimized. Motor life is extended due to the improved waveform. The relative cost of this network, based on 5HP drive/motor combination is about $450.

Conclusion

Employing ASDs for speed control of induction motors located at large distances have been found to be subject to high values of voltages across the windings. This potentially could result in premature insulation failure. The theory behind the phenomenon of voltage reflection as applied to the ASD-motor combination has been discussed. It has been pointed out that impedance mismatch causes voltage reflection. The physical separation between the ASD and motor combined with impedance mismatch is the main reason for voltage amplification at the motor terminals. Critical lead length for typical IGBT inverters used in all modern ASDs is developed. Four different techniques of overcoming the voltage stress across the motor windings are discussed. Experiment results achieved on using these techniques are presented. The snubber circuit is shown to be the most economic solution. The isolated capacitor wave shaping network is seen to be the most expensive. Advantages and relative disadvantages of each of the four techniques has also been presented.

Solving SCR Line Voltage Notching

By: John A. Houdek, MTE Corporation

October, 1995

When Silicon Controlled Rectifiers (SCR's) are used in electrical controls, we frequently experience line voltage distortion in the form of "notches" in the waveform. The types of equipment that frequently utilize SCR control schemes and thus experience notching include DC motor speed controls and induction heating equipment.

Line notches are just that - an irregularity in the voltage waveform that appears as a notch as illustrated in Figure 1. They are typically present in the waveform during SCR commutation or at the time when one phase SCR is being turned off and the next one turned on. For this very small duration of time, we actually experience a short circuit between the two phases. Of course when we have a short circuit, the current goes high and the voltage goes very low. This is exactly what is experienced during a notch.

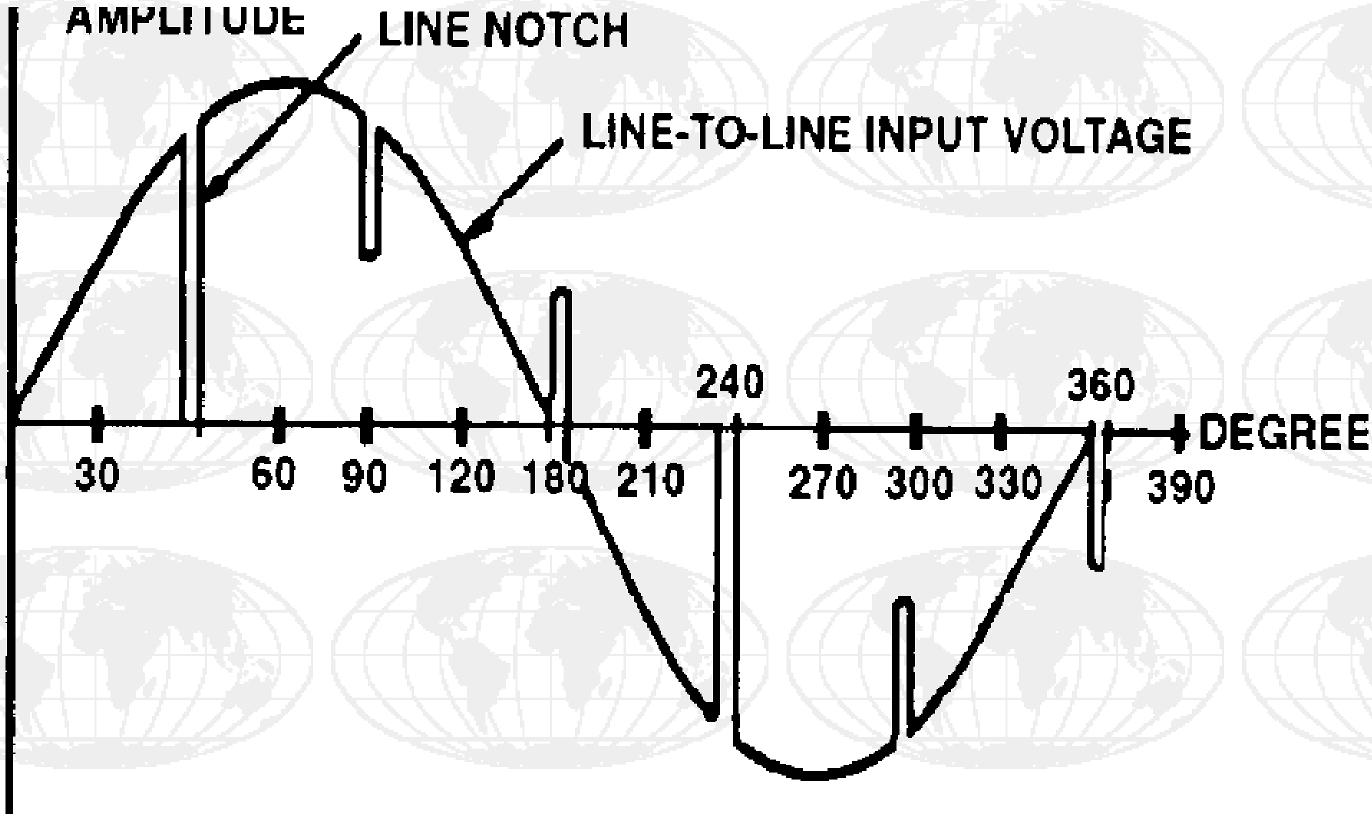


Figure 1

The notch appears at the moment then current is actually rising very quickly but due to the shortage of the phases, the voltage is shorted and approaches zero. In the most severe cases, the notch does in fact touch the zero voltage axis. This causes the biggest problems.

Zero Voltage Crossing

During a normal cycle of sinusoidal voltage, the voltage crosses the "x" axis, or zero, at 0 degrees and again at 180 degrees. During normal conditions, there are two zero crossings in each cycle. Some electronic equipment is designed to be triggered on the zero crossing or when the voltage is zero. This allows equipment to be activated without the surge currents or inrush currents that would be present if switched while voltage was present. Some equipment uses the zero crossings for an internal timing signal. Some digital clocks operate this way.

When notches are present, particularly in three phase equipment, we can experience extra zero crossings. Instead of two zero crossings in each cycle of voltage, we can actually experience *four* notches. Think about it. There are now four signals in each cycle which tell other equipment to "turn on". That means the equipment will turn on twice as fast, run twice as fast or turn on at very wrong times resulting in damage.

The September/October, 1992 issue of Power Quality Magazine contained an article called "Clean Air, Dirty Power: The Two Timing Clock", written by Dave Hall. It described how a digital clock was running twice its normal speed due to the presence of line voltage notches. Reducing the notch depth solves this problem because zero - voltage crossings are limited to two per cycle as in a sinusoidal waveform.

Solution

The solution is quite economical and easy to install. There is no magic involved, it just follows good engineering sense. It is very easy to understand if we consider the DC drive or other SCR controller as a source of "notch voltage" and then analyze how that voltage is impressed onto the impedances in the circuit back to the source.

It is of utmost concern that we understand and consider where other sensitive equipment connects to that same voltage source. In order to protect the sensitive equipment, we must reduce the notches before they get to that equipment. We will do this through the creation of a simple voltage divider network.

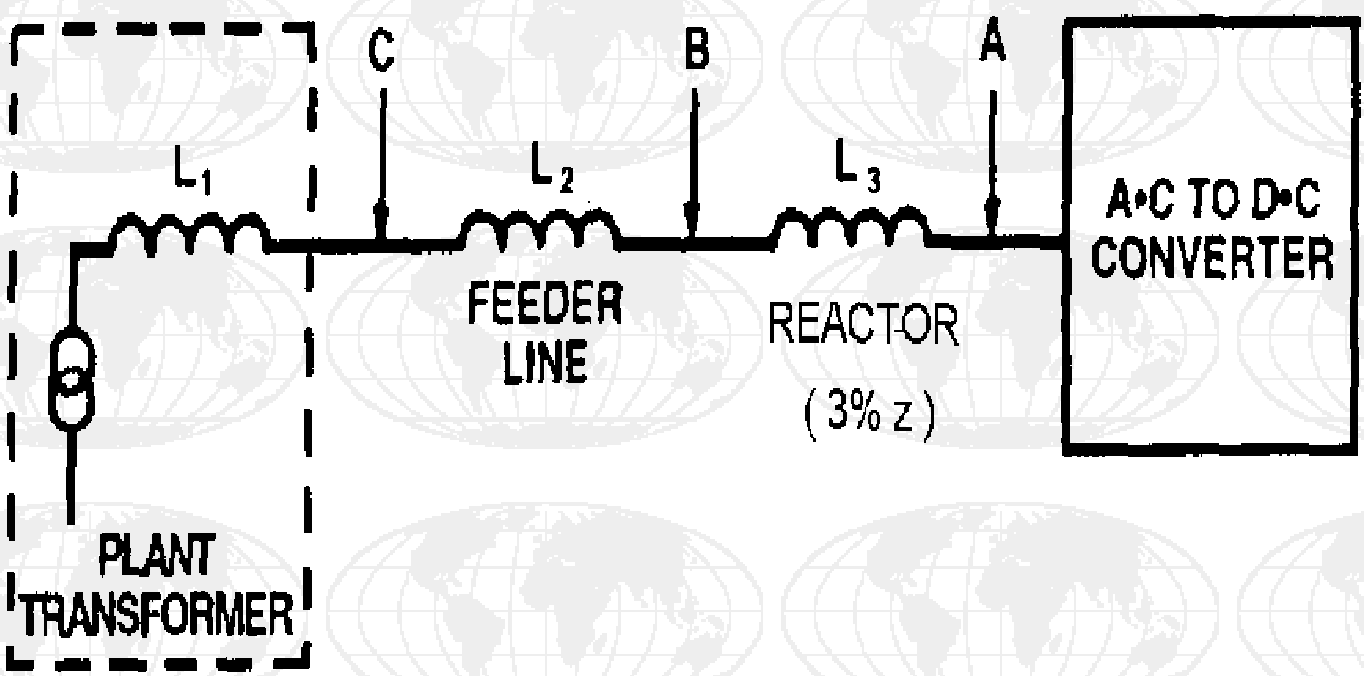


Figure 2

If we add impedance, in the form of inductive reactance, in series with the SCR controller, and between the controller and the point of other equipment connection, (point B) then the notch voltage will distribute itself across the new impedance (reactance) and the pre-existing line to source impedance. If the added impedance is one-half as much as was already present, then 1/3 of the notch voltage is dropped across the new impedance and two thirds still remains at the point of common connection with the other equipment.

$$\text{NOTCH DEPTH} = \frac{L1 + L2}{L1 + L2 + L3}$$

Figure 3

If the new impedance is equal to the existing input impedance, then the notch distributes equally across the two impedances. One-half the original notch voltage is now present at the point of common connection (B).

Notice that if the new impedance is added anywhere else but between the SCR controller and the sensitive equipment, it will have minimal impact on the notch voltage. Placing the reactance on the opposite side of point B offers no improvement to the notching problem.

Use a **3% impedance reactor** to solve three phase voltage notching problems. Experience shows that it is normally sufficient to reduce the notch voltage, at the point of common connection with other sensitive equipment, to about 50% or less of it's initial value (depth). Of course this eliminates the multiple zero crossings and typically solves the interference problems with neighboring equipment. It is typically not recommended to use a 5% impedance reactor with SCR circuits because the reactor not only reduces the depth of the notch, but it also increases the notch width. Excess impedance could increase the notch width (time) too much causing problems in the controller itself.

HARMONIC REDUCTION USING BROAD BAND HARMONIC FILTERS

Mahesh M. Swamy; Ph.D.
MTE Corporation

Introduction

Events over the last several years have focused attention on certain types of loads on the electrical system that result in power quality problems for the user and utility alike. Equipment which has become common place in most facilities including computer power supplies, solid state lighting ballast, adjustable speed drives (ASDs), and uniterrruptible power supplies (UPSs) are examples of non-linear loads. Non-linear loads generate voltage and current harmonics which can have adverse effects on equipment designed for operation as linear loads (i.e., loads designed to operate on a sinusoidal waveform of 50 or 60 Hz.). Transformers which bring power into an industrial environment are subject to higher heating losses due to harmonic generating sources (non-linear loads) to which they are connected. Harmonics can have a detrimental effect on emergency generators, telephones and other electrical equipment as well. When reactive power compensation (in the form of passive power factor improving capacitors) is used with non-linear loads, resonance conditions can occur that may result in even higher levels of harmonic voltage and current distortion thereby causing equipment failure, disruption of power service, and fire hazards in extreme conditions.

The electrical environment has absorbed most of these problems in the past. However, the problem has now reached a magnitude where Europe, the US, and other countries have proposed standards to responsibly engineer systems considering the electrical environment. IEEE 519-1992 and IEC 555 have evolved to become a common requirement cited when specifying equipment on newly engineered projects. The **broad band harmonic filter** was designed in part, to meet these specifications. The present IEEE 519-1992 document establishes acceptable levels of harmonics (voltage and current) that can be introduced into the incoming feeders by commercial and industrial users. Where there may have been little cooperation previously from manufacturers to meet such specifications, the adoption of IEEE 519-1992 and other similar world standards now attract the attention of everyone.

Harmonic Limit Calculations based on IEEE 519-1992

The IEEE 519-1992 relies strongly on the definition of the point of common coupling or PCC. The PCC from the utility view point will usually be the point where power comes into the establishment (i.e., point of metering). However, the IEEE 519-1992 document also suggests that **"within an industrial plant, the point of common coupling (PCC) is the point between the nonlinear load and other loads"** [1]. This suggestion is crucial since many plant managers and building supervisors feel that it is equally if not more important to keep the harmonic levels at or below acceptable guidelines within their facility. In view of the many recently reported problems associated with harmonics within industrial plants [2], it is important to recognize the need for mitigating harmonics at the point where the offending equipment is connected to the power system. This approach would minimize harmonic problems, thereby reducing costly downtime and improving the life of electrical equipment. If one is successful in mitigating individual load current harmonics, then the total harmonics at the point of the utility connection will in most cases meet or better the IEEE recommended guidelines. In view of this, it is becoming increasingly common for specifiers to require non-linear equipment suppliers to adopt the procedure outlined in IEEE 519-1992 to mitigate the harmonics to acceptable levels at the point of the offending equipment. For this to be interpreted equally by different suppliers, the intended PCC must be identified. If this is not defined clearly, many suppliers of offending equipment would likely adopt the PCC at the utility metering point, which would not benefit the plant or the building but rather the utility.

Having established that it is beneficial to adopt the PCC to be the point where the ASD connects to the power system, the next step is to establish the short circuit ratio. Short circuit ratio calculations are key in establishing the allowable current harmonic distortion levels. For calculating the short circuit ratio, one has to determine the available short circuit current at the ASD input terminal. If the short circuit value available at the secondary of the utility transformer feeding the establishment (building) is known, and the cable impedance and other series impedances in the electrical circuit between the secondary of the transformer and the ASD input are also known, then one can calculate the available short circuit at the ASD input. **In practice, it is common to assume the same short circuit current level as at the secondary of the utility transformer feeding the ASD**. The next step is to compute the fundamental value of the rated input current into the ASD. One can rely on the NEC amp rating for induction motors to obtain this number. NEC amps are fundamental amps that a motor draws when connected directly to the utility supply. An example is presented here to recap the above procedure.

A 100-hp ASD/motor combination connected to a 480-V system being fed from a 1500-kVA, 3-Ph transformer with an impedance of 4% is required to meet IEEE 519-1992 at its input terminals. The rated current of the transformer is: 1500*1000/(sqrt(3)*480) which is calculated to be 1804.2 Amps. The short circuit current available at the secondary of the transformer is equal to the rated current divided by the per unit impedance of the transformer. This is calculated to be: 45,105.5 A. The short circuit ratio which is defined as the ratio of the short circuit current at the PCC to the fundamental value of the non-linear current is computed next. NEC amps for 100-hp, 460-V is 124 Amps. Assuming that the short circuit current at the ASD input is practically the same as that at the secondary of the utility transformer, the short-circuit ratio is calculated to be: 45,105.5/124 which equals 363.75. On referring to the IEEE 519-1992 Table 10.3 [1], this short circuit ratio falls in the 100-1000 category. For this ratio, the total demand distortion (TDD) at the point of ASD connection to the power system network is recommended to be 15% or less. For reference, Table 10.3 [1] is reproduced below:

Current Distortion Limits for General Distribution Systems (120 V through 69,000 V)						
Maximum Harmonic Current Distortion in percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{sc} / I_L	**<11**	**$11 \le h \le 17$**	**$17 \le h \le 23$**	**$23 \le h \le 35$**	**$35 \le h$**	**TDD**
< **20***	4.0	2.0	1.5	0.6	0.3	**5.0**
20<50	7.0	3.5	2.5	1.0	0.5	**8.0**
50<100	10.0	4.5	4.0	1.5	0.7	**12.0**
100<1000	12.0	5.5	5.0	2.0	1.0	**15.0**
>1000	15.0	7.0	6.0	2.5	1.4	**20.0**

Even harmonics are limited to 25% of the odd harmonic limits above.

* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc} / I_L where I_{sc} is the maximum short circuit current at PCC and

I_L is the maximum demand load current (fundamental frequency) at PCC.

TDD is **Total Demand Distortion** and is defined as the harmonic current distortion in % of maximum demand load current. The maximum demand current could either be a 15 minute or a 30 minute demand interval.

Why ASDs Generate Harmonics?

The current waveform at the inputs of an ASD is not continuous. It has multiple zero crossings in one electrical cycle. Hence, the current harmonics generated by ASDs having DC bus capacitors are caused by the pulsed current pattern at the input to the rectifier stage. The DC bus capacitor draws charging current only when it gets discharged due to the motor load. The charging current flows into the capacitor when the input rectifier is forward biased which occurs when the instantaneous input voltage is higher than the steady-state DC voltage across the DC bus capacitor. The pulsed current drawn by the dc bus capacitor is rich in harmonics due to the fact that it is discontinuous as shown in Fig. 1. The voltage harmonics generated by ASDs are due to the flat-topping effect caused by an AC source charging the DC bus capacitor without any intervening impedance. The distorted voltage waveform gives rise to voltage harmonics that could lead to possible network resonance.

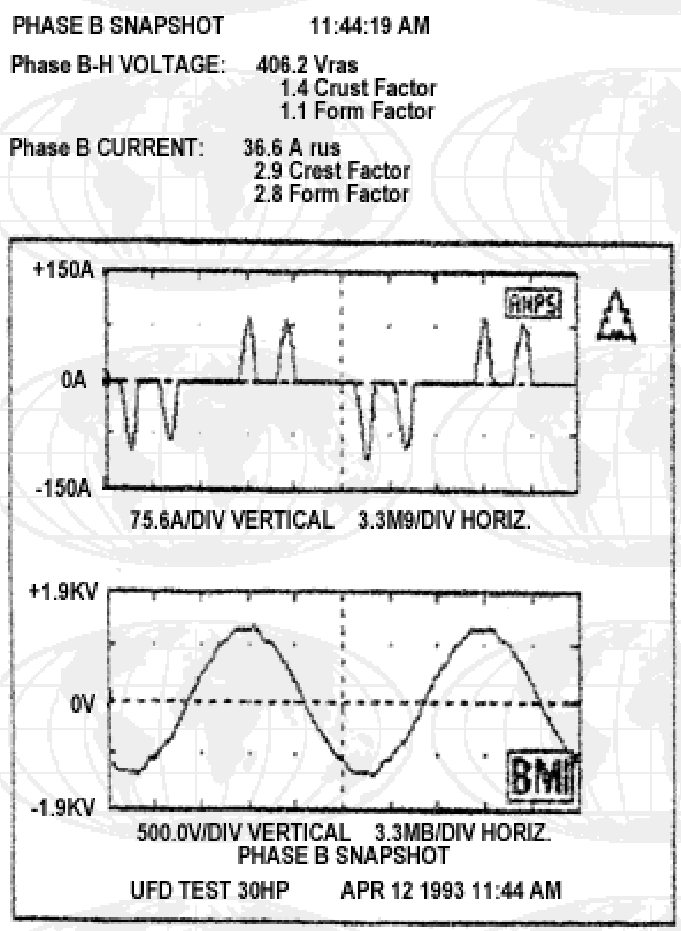


Fig. 1: Typical pulsed current waveform as seen at input of a VFD.

The order of current harmonics produced by a semiconductor converter during normal operation is termed as Characteristic Harmonics. In a three-phase, six-pulse converter with **no DC bus capacitor,** the characteristic harmonics are non-triplen odd harmonics (e.g., 5th, 7th, 11th, etc.). In general, the characteristic harmonics generated by a semiconductor converter is given by:

$$h = kq \pm 1$$

where h is the order of harmonics; k is any integer, and q is the pulse number of the semiconductor converter (six for a six-pulse converter). When operating a six-pulse rectifier-inverter system with a DC bus capacitor (Voltage Source Inverter or VSI), one may start observing harmonics of orders other than those given by the above equation. Such harmonics are called Non-Characteristic harmonics. Though of lower magnitude, these also contribute to the overall harmonic distortion of the input current. The per unit value of the characteristic harmonics present in the theoretical current waveform at the input of the semiconductor converter is given by **1/h** where h is the order of the harmonics. In practice, the observed per unit value of the harmonics is much greater than 1/h. This is because the theoretical current waveform is a rectangular pattern made up of equal positive and negative halves, each occupying 120 electrical degrees. The pulsed discontinuous waveform observed commonly at the input of the ASD digresses greatly from the theoretical waveform.

Harmonic Mitigating Techniques

Various techniques of improving the input current waveform are discussed below. The intent of all techniques is to make the input current more continuous so as to reduce the overall current harmonic distortion. The different techniques can be classified into four broad categories:

(a) Introduction of line reactors and/or dc link chokes;

(b) Passive Filters (Series, Shunt, and Low Pass broad band filters);

(c) Phase Multiplication (12-pulse, 18-pulse rectifier systems); and

(d) Active Harmonic Compensation.

The following paragraphs will briefly discuss the available technologies, their relative advantages and disadvantages. The term 3-phase line reactor or just reactor is used in the following paragraphs to denote 3-phase line inductors.

(a) 3-Phase Line Reactors

Line reactors offer significant magnitudes of inductance which can alter the way that current is drawn by a non-linear load such as an input rectifier bridge. The reactor makes the current waveform less discontinuous resulting in lower current harmonics. Since the reactor impedance increases with frequency, it offers larger impedance to the flow of higher order harmonic currents. It is thus instrumental in impeding higher frequency current components while allowing the fundamental frequency component to pass through with relative ease.

On knowing the input reactance value, one can estimate the expected current harmonic distortion. A table illustrating the expected input current harmonics for various amounts of input reactance is shown below:

Percent Harmonics vs Total Line Impedance
Total Input Impedance

Harmonic	3%	4%	5%	6%	7%	8%	9%	10%
5th	40	34	32	30	28	26	24	23
7th	16	13	12	11	10	9	8.3	7.5
11th	7.3	6.3	5.8	5.2	5	4.3	4.2	4
13th	4.9	4.2	3.9	3.6	3.3	3.15	3	2.8

17th	3	2.4	2.2	2.1	0.9	0.7	0.5	0.4
19th	2.2	2	0.8	0.7	0.4	0.3	0.25	0.2
%THID	44.13	37.31	34.96	32.65	30.35	28.04	25.92	24.68
True rms	1.09	1.07	1.06	1.05	1.05	1.04	1.03	1.03

Input reactance is determined by the accumulated impedance of the ac reactor, dc link choke (if used), input transformer and cable impedance. To maximize the input reactance while minimizing ac voltage drop, one can combine the use of both ac input reactors and dc link chokes. One can approximate the total effective reactance and view the expected harmonic current distortion from the above chart. The effective impedance value in % is based on the actual loading as derived below:

$$Z_{eff} = \frac{\sqrt{3} * 2 * \pi * f * L * I_{act\,(fnd.)}}{V_{L-L}} \quad X\ 100$$

where $I_{act(fnd.)}$ is the fundamental value of the actual load current and V_{L-L} is the line-line voltage. The effective impedance of the transformer as seen from the non-linear load is:

$$Z_{eff,x\text{-}mer} = Z_{x\ mer} * I_{act(fnd.)} / I_r$$

where $Z_{eff,x\text{-}mer}$ is the effective impedance of the transformer as viewed from the non-linear load end; $Z_{x\text{-}mer}$ is the nameplate impedance of the transformer; and I_r is the nameplate rated current of the transformer.

On observing one conducting period of a diode pair, it is interesting to see that the diodes conduct only when the instantaneous value of the input ac waveform is higher than the dc bus voltage by at least 1.4 V. Introducing a three phase ac reactor in between the ac source and the dc bus makes the current waveform less pulsating since the reactor is an electrical equipment which impedes sudden changes in current. The reactor also electrically differentiates the dc bus voltage from the ac source so that the ac source is not clamped to the dc bus voltage during diode conduction. This feature practically eliminates flat topping of the ac voltage waveform caused by many ASDs when operated with weak ac systems.

(b) DC Link Choke

Based on the above discussion, it can be noted that any inductor of adequate value placed in between the ac source and the dc bus capacitor of the ASD will help in improving the current waveform. These observations lead to the introduction of a DC link choke which is electrically present after the diode rectifier bridge and before the dc bus capacitor. The dc link choke performs very similar to the three phase line inductance. The ripple frequency that the dc link choke has to handle is six times the input ac frequency for a six-pulse ASD. However, the magnitude of the ripple current is small. One can show that the effective impedance offered by a dc link choke is about 50% of its equivalent ac inductance. In other words, a 3% ac inductor is equivalent to a 6% dc link choke from impedance view point. This can be mathematically derived equating ac side power flow to dc side power flow as follows:

$$P_{ac} = \frac{3^*V_{L-N}^2}{R_{ac}} \qquad P_{ac} = P_{dc}$$

$$V_{dc} = \sqrt{6}\, V_{L-N}$$

$$P_{dc} = \frac{V_{dc}^2}{R_{dc}} \qquad \text{Hence, } R_{dc} = 2^*R_{ac}$$

In the above derivation, it is assumed that the ac to dc semiconductor converter is equipped with a large DC bus capacitor which makes the dc bus voltage equal to sqrt(2) times the input line-line ac voltage. The dc link choke is less expensive and smaller than a 3-phase line reactor and is often included inside an ASD. However, as the derivation shows, one has to keep in mind that the effective impedance offered by a dc link choke is only half its numerical impedance value when referred to the ac side. DC link chokes are electrically after the diode bridge and so they do not offer any significant spike or overvoltage surge protection to the diode bridge rectifiers. It is, thus, a good engineering practice to incorporate both dc link choke and a 3 phase line reactor in an ASD for better overall performance.

(c) Passive Filters

Passive filters consist of passive components like inductors, capacitors, and resistors arranged in a pre-determined fashion either to attenuate the flow of harmonic components through them or to shunt the harmonic component into them. Passive filters can be of many types. Some popular ones are: Series Passive filters, Shunt Passive filters, and Low Pass broad band Passive filters. Series and Shunt passive filters are effective only in a narrow proximity of the frequency at which they are tuned. Low Pass broad band passive filters have a broader bandwidth and attenuate almost all harmonics above their cutoff frequency.

Series Passive Filter

One way to mitigate harmonics generated by non-linear loads is to introduce a series passive filter (Fig. 2) in the incoming power line so that the filter offers a high impedance to the flow of harmonics from the source to the non-linear load. Since the series passive filter is tuned to a particular frequency, it offers a high impedance to only its tuned frequency component. Series passive filters are popular for 1-ph application where it is effective in minimizing the 3rd harmonic which is the most offending harmonic in 1-ph systems. The series passive filter offers some impedance to harmonic components around its tuned frequency and as one moves away from the tuned frequency in either directions, the impedance offered keeps diminishing. It is generally designed to offer low impedance at the fundamental frequency. A major drawback of this approach is that the filter components have to be designed to handle the rated load current. Further, one filter section is not adequate to attenuate all the different harmonic spectrum present in the non-linear load current. Unlike the shunt passive filter, the series passive approach when used as a dedicated filter does not introduce any other extraneous resonance circuit. In other words, the dedicated series passive filter does not interfere with an existing power system.

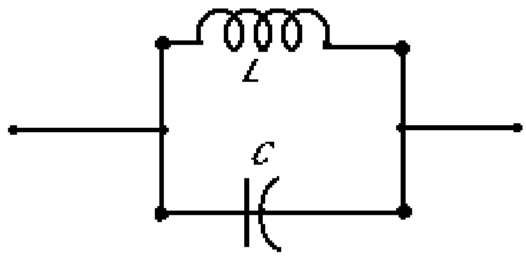


Fig. 2: Series type tuned harmonic filter topology.

Shunt Passive Filter

The second and more common approach is to use a shunt passive filter (Fig. 3). The shunt passive filter is placed across the incoming line and is designed to offer very low impedance to the harmonic currents present in the non-linear load current spectrum. The shunt passive filter processes flow of electrical energy at fundamental frequency from the source but offers a lower impedance path for the flow of harmonic energy needed by the non-linear load. In other words, the harmonic component needed by the non-linear load is provided by the shunt filter rather than the ac source. The fundamental frequency energy component flowing into the shunt filter also provides leading VARs which can be used for power factor correction. Similar to the series tuned filter, the shunt tuned filter is only effective at and around its tuned frequency. In other words, like the series tuned filter, one section of a shunt tuned filter alone is inadequate to provide all the harmonic energy needed by a typical non-linear load (ASD).

The commonly used shunt filter sections comprise of individual sections tuned for the 5th, the 7th, and perhaps a high-pass section typically tuned near the 11th harmonic. Unfortunately, if care is not taken, the shunt filter will try to provide the harmonic energy needed by all non-linear loads connected across the same bus. In this process, it could get overloaded and if it is fused, the fuse could blow. The filter sections could also suffer serious and permanent damage. Such a phenomenon is known as importing of harmonics. In order to avoid import of harmonics, it is important to use series line reactors which impede the harmonic energy flow to other sources from the shunt tuned filter sections. However, the addition of extra line inductance can contribute to a slightly new set of problem. As mentioned earlier, the shunt capacitor in the filter provides leading VARs at fundamental frequency. Leading VAR generation is always associated with a rise in bus voltage. The inductor used in preventing import of harmonics is instrumental in buffering the line voltage from the voltage at the input to the non-linear load (ASD). Thus, the rise in fundamental voltage caused by the filter is now present only at the ASD input which could trip on overvoltage. If not, the overvoltage tolerance margin would be compromised and the ASD could be more vulnerable to fault out on overvoltage thereby causing nuisance trips. The situation could be more serious if the installation happens to be close to a capacitor-switching utility substation.

Fig. 3: Shunt type tuned harmonic filter topology.

The shunt passive filter, although used commonly in the industry for harmonic mitigation, has a serious problem of potentially causing power system resonance. The passive filter components introduced in the circuit can interact with existing network impedances and set up other unintended tuned circuit which could get excited due to the presence of appropriate harmonic components at appropriate levels. This would mean that designing and implementing a shunt tuned filter network requires an in-depth study of the existing power system network into which the filters are going to be introduced. The location of the shunt filters is also a very important issue to be considered. A central location could cause more harm than benefit under system resonance conditions as it would jeopardize the entire system instead of affecting only a localized area. Even if a study is conducted and the tuned filters are designed carefully and are placed strategically to avoid undue system resonance, the problem is not resolved forever. The reason is that any future expansion or change in the electrical network could change the system dynamics and could warrant a newer study and possible relocation and/ or redesign of the tuned filter traps.

Low Pass Broad Band Filter

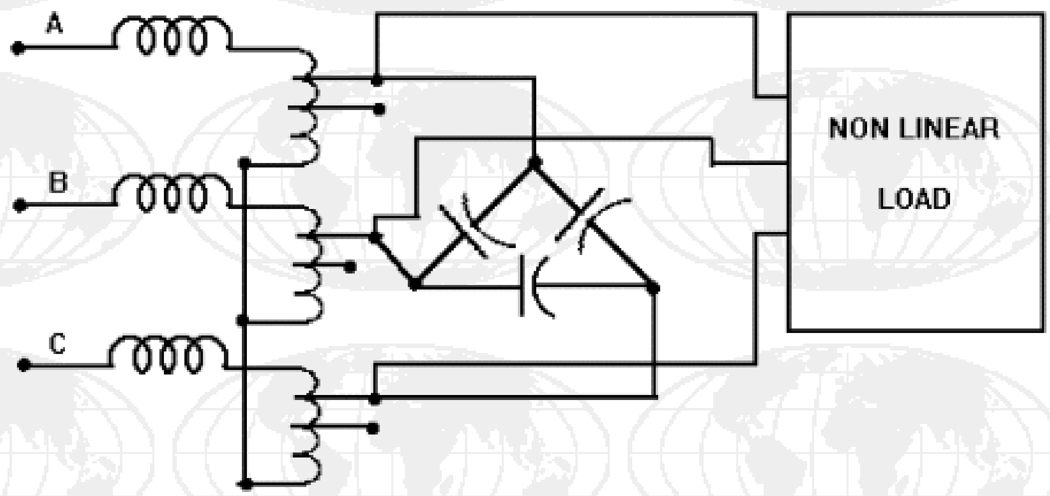
From the preceding discussions on series and shunt passive filters, it is clear that both approaches have certain disadvantages. The low pass broad band filter is however a unique type of filter which incorporates the advantages of both the series and shunt type filters and has neither of their disadvantages. The biggest advantage of the low pass, broad band harmonic filter is that it need not be configured in multiple stages or sections as the shunt and series type do. In other words, one filter section achieves the performance close to the combined effect of a 5th, 7th, and a high-pass shunt tuned filter section. Further, the inherent series impedance present in the filter topology prevents import and export of harmonics from and to other non-linear loads on the system.

The best type of passive filter is a **capacitor**. The impedance of a capacitor reduces as the frequency increases. Hence, a capacitor can effectively supply all the harmonic energy needed by a typical ASD. However, there exists two major drawbacks of using simply a capacitor. The first problem is that of importing harmonics. Any non-linear load that needs harmonic energy will extract it from the capacitor being proposed for use. This will undoubtedly overload the capacitor and can potentially cause irreversible damage to it. The second major problem is that the capacitor behaves like a power factor correction capacitor at fundamental frequency. Power factor correction is generally associated with a rise in ac bus voltage. This can potentially cause an overvoltage condition at the input of an ASD and consequently send it into a fault condition.

Both the above problems can be resolved using existing passive elements. By introducing a large valued line reactor in series with the main ac line and electrically ahead of the shunt capacitor will limit import and export of harmonics to and from the capacitor and ASD network. Introducing the reactor not only impedes the flow of harmonic currents but also electrically differentiates between the input ac supply and the capacitor terminals. The overvoltage caused by the capacitor is now limited to only its terminals and does not show up at the ac input side due to the presence of the large inductor. In order to prevent the ASD from tripping due to overvoltage from the capacitor, a buck transformer is used ahead of the capacitor. In other words the load side of the inductor is connected to a buck transformer which bucks the voltage before it is fed to the capacitors. The capacitor boosts it back up to a nominal value merely due to its power factor corrective action at fundamental frequency. The capacitor is connected right at the input to the ASD. The dc bus capacitor in the ASD draws pulsating current when it is discharged due to the loading effect. This sudden charging current is very effectively and efficiently provided by the ac capacitor of the broad band filter. Any intervening impedance in the form of a dc link choke or an extra ac line inductor in the electrical path between the ac capacitor and the dc bus capacitor hampers the much needed immediate transfer of harmonic energy. Hence, the best performance of the low pass, broad band harmonic filter is achieved when there exists no impedance between the ac capacitor and the dc bus capacitor. The majority of the harmonic energy requirement of the ASD can be met by appropriately sizing the ac capacitor which is made to provide for it. The ac source is hence required to supply only a part of the harmonic energy requirement of the ASD which is then reflected as low THD values in the input current spectrum. The 3-phase ac source thus provides energy to the capacitor network at fundamental frequency and the capacitor in turn by virtue of its basic nature provides the bulk of the harmonic energy required by the ASD.

Yet another way of analyzing the performance is by considering the capacitor network to a be a viable ac source. Thus, there exists two ac sources from which the harmonic energy requirement of the ASD can be met - the utility ac source, and the capacitor network. In all likelihood, it will be met by the capacitor since it is electrically closer to the ASD and also it offers a lower impedance at the harmonic order compared to the utility transformer and large series inductor of the broad band filter, when viewed from the ASD side. This is yet one more reason why the inductor of a sufficiently large value is introduced in series with the ac line as part of the broad band harmonic filter. Fig. 4 shows the schematic representation of the patented broad band harmonic filter.

ELECTRICAL SCHEMATIC FOR INPUT BROAD-BAND HARMONIC FILTER



Low Pass Filter Effect on Diode Ripple Current

During the input rectifier diode conduction period, the dc bus capacitor clamps the voltage across the ac capacitor to its existing value. Energy from the ac capacitor is transferred to the dc bus capacitor instantly. The charging current is not impeded and hence the ripple content of this charging current can be high which means that the input diode rectifiers are subject to a larger ripple current magnitude. However, this scenario is true only at light load conditions since the capacitor seems oversized under light load conditions. The magnitude of current being transferred from the ac capacitor to the dc bus capacitor under light load conditions is much lower than the rating of the diodes and so this does not merit any serious consideration. At full rated load, the ac capacitor is almost depleted and the current flowing through the large series reactor into the ac capacitor is also used partially to charge the dc bus capacitor. Flow of current through the large reactor smoothes out the ripples more than what a dc link choke or a 5% line reactor could have provided. Hence, the ripple content in the current flowing through the diode in reality is lower than the case with either a 5% ac reactor or a comparable dc link choke.

Application Issues while using Low Pass Broad band Filter

The probability of harmonic resonance occurring with the broad band harmonic filter in a power system is extremely low. This is because the low pass cutoff frequency is kept deliberately low which is very difficult and improbable to be excited in a 3-phase ac network. A detailed analysis of the interaction between a low pass filter section with a typical existing power system network is discussed in the following paragraphs. The analysis clearly shows that the low pass filter section does not interfere with the existing system and even when it does, it helps in lessening pre-existing potential problems in the network. Hence, the low pass filter renders itself for use without the need to perform complicated, expensive, and time consuming system study. The low pass filter in its original form cannot be used for ASD application since there is an inherent overvoltage across the filter capacitors which is electrically connected to the ASD input. A patented form of the low pass filter section alleviates this problem by making use of a buck transformer which is strategically placed in the topology.

The performance of the low pass filter has been found to be consistent through out the load range of the non-linear load (ASD). The overall current harmonic distortion has been found to be reduced from a typical value of 90 to 100% down to 9 to 12% under rated load conditions. Under light load conditions, the current THD has been observed to be in the low 4 to 8% range. This observation leads to a very important aspect of the broad band harmonic filter. **A broad band harmonic filter can now be used to correct harmonic problems created by multiple Drive loads.** In other words, as an example, one 100 hp broad band filter can be used to filter out the harmonics generated by either 10 of 10hp ASDs or 4 of 25hp ASDs or any such combination totaling 100hp of ASD load.

Because of the typical arrangement of passive components in the broad band filter, the patented low pass filter can be used only with non-linear loads and should not be used as a general purpose harmonic filter. It is specifically designed to be used with ASD loads and other non-linear loads having the same topology as the front end of an ASD.

At loads less than the rated load, the broad band harmonic filter generates leading VARs without causing voltage rise on the line side or on the power system side. This feature is similar to that of an idling synchronous motor (also known a synchronous condenser) under over-excited conditions used for providing leading power factor in many industrial applications.

Investigations on Network Interaction with the Broad Band Harmonic Filter

The broad band harmonic filter is basically a low pass LC filter section interposed in between the utility and the ASD. The LC network is tuned in such a way so as not to cause network resonance. In the broad band harmonic filter used by MTE Corporation, the LC network is tuned to resonate in the neighborhood of 100 Hz. On a 60 Hz. system, it is quite improbable that a low pass LC filter tuned to around 100 Hz. would cause resonance. In order to explain resonance conditions in a network, it is interesting to consider a typical industrial plant layout. Let the industrial location be assumed to have certain power factor correcting capacitors located at the secondary of the main feed transformer. The leakage inductance of the transformer and the power factor correcting capacitor together form a resonant circuit. Let the plant be supplied by a 3000-kVA, 4% main feed transformer, having a secondary line-line voltage of 480-V. Further, let there be power factor correcting capacitor worth 150-kVA, located on the secondary-side (480-V side) of the 3000-kVA transformer. From these assumed data, the leakage inductance and the capacitor together form a resonant circuit with a tuned frequency of around 1341 Hz. This is close to the 22nd harmonic and is rather a high frequency value which is unlikely to cause any resonance. Further, let there be an existing fifth harmonic filter having a typical tuned frequency of around 280 Hz., supplying a 45-kVA non-linear load. If one assumes that the tuned filter capacitor is about 10% of the size of the power factor correcting capacitors, then an overall network resonance point can be established. The overall network will now have two resonance points of concern - the first is that of the tuned filter itself which is 280 Hz. and a new resonance frequency which after quite a few iterations can be shown to be in the neighborhood of 2000 Hz. The tuned filter can get overloaded if it is not properly protected from importing harmonics in the neighborhood of 280Hz. The new higher frequency point of 2000 Hz. strictly depends on the ratio of the filter capacitor to the power factor correcting capacitor. The larger the filter capacitor, the smaller will be the new resonance point.

Let a broad band filter be introduced into the above network. For sake of argument, let the broad band filter be assumed to be supplying a 45-kVA non-linear load. Because of the different topology of the low pass filter section, the element which would interact with the external network would include the load resistance being supplied by broad band filter. The newly introduced broad band filter network introduces a new resonance point which is dependent on the loading condition of the broad band filter. On performing a PSpice simulation, it is seen that there exists three distinct resonance points. The first due to the leakage inductance of the power transformer in the neighborhood of 1.1 khz, the second due to the fifth harmonic tuned filter (trap) close to 300hz, and finally the third one due to the broad band harmonic filter close to 100 hz. The simulation results clearly show that the broad band harmonic filter does not interact with the rest of the electrical network. Consequently, the network's existing resonance points are not disturbed. This shows that the low pass broad band filter does not even interact with the rest of the electrical network. A simple electrical diagram is helpful in understanding the above argument and is shown below:

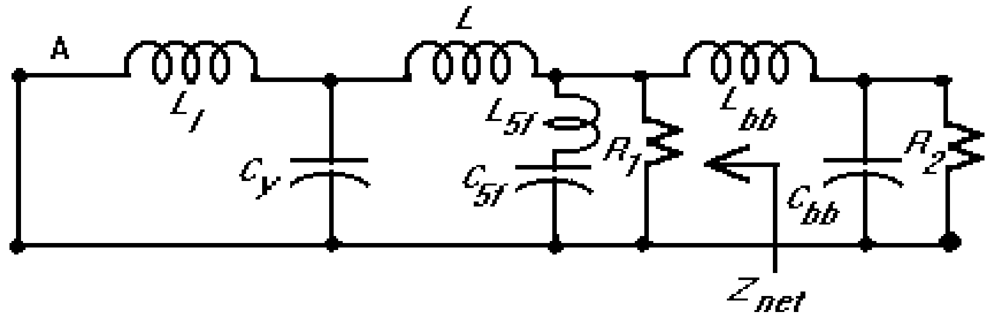


Fig. 5: Simplified one-line representation of an electrical network with a 5th harmonic tuned filter and a broad band harmonic filter.

Phase Multiplication

As discussed previously, the characteristic harmonics generated by a semiconductor converter is a function of the pulse number for that converter. A 12-pulse converter will have the lowest harmonic order of 11. In other words, the 5th, and the 7th harmonic orders are theoretically non-existent in a 12-pulse converter. Similarly, an 18-pulse converter will have harmonic spectrum starting from the 17th harmonic and upwards. The lowest harmonic order in a 24-pulse converter will be the 23rd. The size of passive harmonic filter needed to filter out the harmonics reduces as the order of the lowest harmonic in the current spectrum increases. Hence, the size of the filter needed to filter out the harmonics out of a 12-pulse converter is much smaller than that needed to filter out the harmonics of a 6-pulse converter. However, a 12-pulse converter needs two 6-pulse bridges and two sets of 30^0 phase shifted ac inputs. The phase shift is either achieved using an isolation transformer with one primary and two phase shifted secondary windings or auto-transformer which provide phase shifted outputs. Many different auto-transformer topologies exist and the choice of a topology over the other involves a compromise between ease of construction, performance, and cost. An 18-pulse converter would need three 6-pulse diode bridges and three sets of 20^0 phase shifted inputs; similarly, a 24-pulse converter would need four 6-pulse diode bridges and four sets of 15^0 phase shifted inputs. The transformers providing the phase shifted outputs for multipulse converters have to properly designed to handle circulating harmonic flux.

(d) Active Harmonic Compensation

Most passive techniques discussed above aim to cure the harmonic problems once they have been created by non-linear loads. However, drive manufacturers are developing drives which do not generate low order harmonics. These drives use Active front ends. Instead of using passive diodes as rectifiers, the active front end ASDs make use of active switches like IGBTs along with parallel diodes. Power flow through a switch becomes bi-directional and can be manipulated to recreate a current waveform which linearly follows the applied voltage waveform.

Apart from the active front ends, there also exists shunt active filters used for actively introducing a current waveform into the ac network which when combined with the harmonic current, results in an almost perfect sinusoidal waveform.

One of the most interesting active filter topology for use in retrofit applications is the combination of a series active filter along with shunt tuned passive filters. This combination is also known as the Hybrid Structure and was introduced into the market by the authors cited in reference [2]. Manufacturers of smaller power equipment like computer power supplies, lighting ballast, etc. have successfully employed active circuits.

Most active filter topologies are complicated and require active switches and control algorithms which are implemented using Digital Signal Processing (DSP) chips. The active filter topology also needs current and voltage sensors and corresponding Analog to Digital (A/D) converters. This extra hardware increases the cost and component count, reducing the overall reliability and robustness of the design.

Typical Test Results of Low Pass Broad band Filter

This section deals with some typical test results observed on implementing the broad band harmonic filter of Fig. 4. The test results depict the actual operating condition of the load. The true power is seen to be leading under light load condition. However, there is no overvoltage at the input ac supply which shows that the leading power factor due to the filter can be likened to an overexcited synchronous motor connected across the input ac supply.

40-hp ASD with filter

a. Power Input: 26.07 kW

b. True Power Factor: 0.91 (leading)

c. Displacement Power Factor: 0.92 (leading)

d. Average Voltage THD: 2.3%

e. Average Current THD: 7.5%

30-hp ASD with filter

a. Power Input: 20.13 kW

b. True Power Factor: 0.82 (leading)

c. Displacement Power Factor: 0.83 (leading)

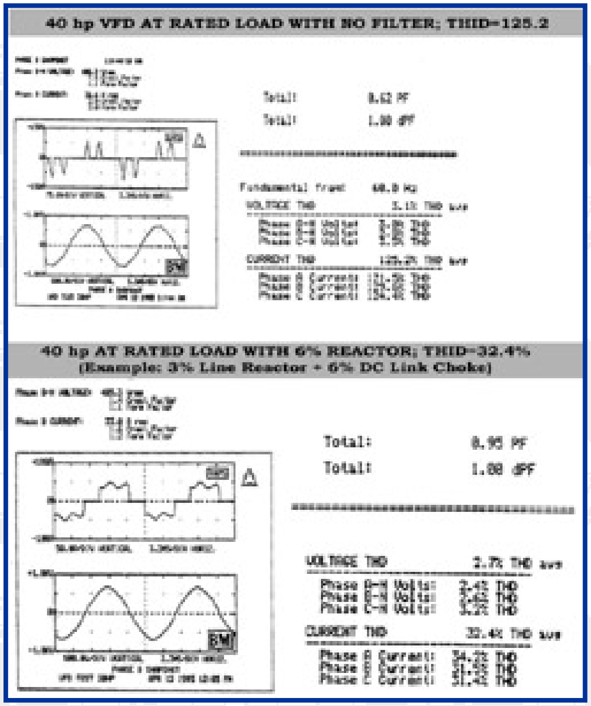
d. Average Voltage THD: 2.0%

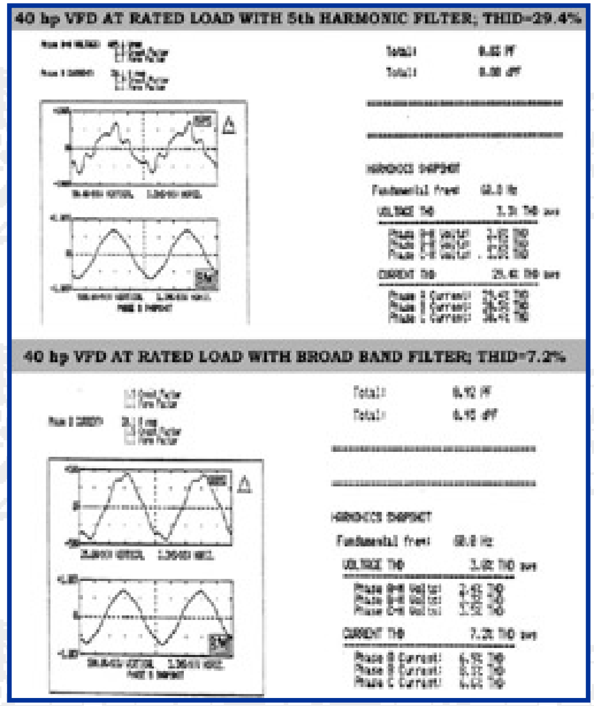
e. Average Current THD: 9.0%

Conclusion

The report discusses generation of current harmonics by non-linear loads and the IEEE-519-1992 standard to limit the quantity of these harmonics. A methodology of applying this standard to a practical industrial site has been discussed. Different harmonic mitigating techniques presently available in the industry has been highlighted. The patented broad band harmonic filter is described. An explanation is provided to show that the broad band harmonic filter does not interfere with the existing power system network to create extraneous resonance points. Experimental test results from various industrial sites show that the broad band harmonic filter is successful in mitigating (limiting) the harmonics generated by ASDs to the IEEE 519-1992 recommended values as applied to the input of an ASD. The improvement in true power factor, transformer de-rate values, and telephone influence factor are important advantages of using the broad band harmonic filter. Further, the ability of the filter to feed multiple ASDs reduces space requirements and increases the cost effectiveness of the filter-drive combination.

Click the images below for filter performance & comparison diagrams.





References

[1] "IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems", **IEEE Std. 519-1992.**

[2] Mahesh M. Swamy, Steven Rossiter, et. al, "Case Studies on Mitigating Harmonics in ASD Systems to meet IEEE 519-1992 Standards, **"IEEE IAS Annual meeting, 1994, pp. 685-692".**

[3] F. Z. Peng, H. Akagi, and A. Nabae, "A New Approach to Harmonic Compensation in Power Systems - A Combined System of Shunt Passive and Series Active Filters, **"IEEE Trans. on Industry Applications, vol. 26, No. 6, Nov./Dec. 1990".**

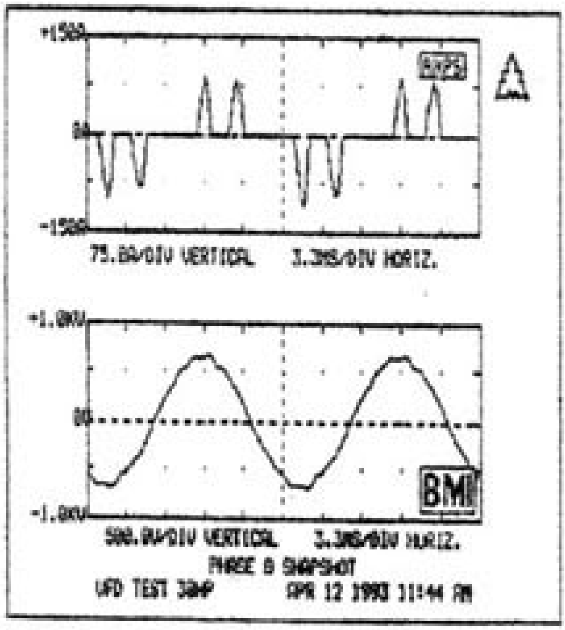
[4] Brian Prokuda, "Power Quality Site Surveys for Industrial and Commercial Buildings, "**IEEE A&CPS Conference 1994, pp. 97-103".**

40 hp VFD AT RATED LOAD WITH NO FILTER; THID=125.2

PHASE B SNAPSHOT 11:44:18 AM

Phase B-N VOLTAGE: 486.2 Vrms
1.4 Crest Factor
1.1 Form Factor

Phase B CURRENT: 36.6 A rms
2.9 Crest Factor
2.0 Form Factor



Total: 0.62 PF

Total: 1.00 dPF

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Fundamental freq: 60.0 Hz

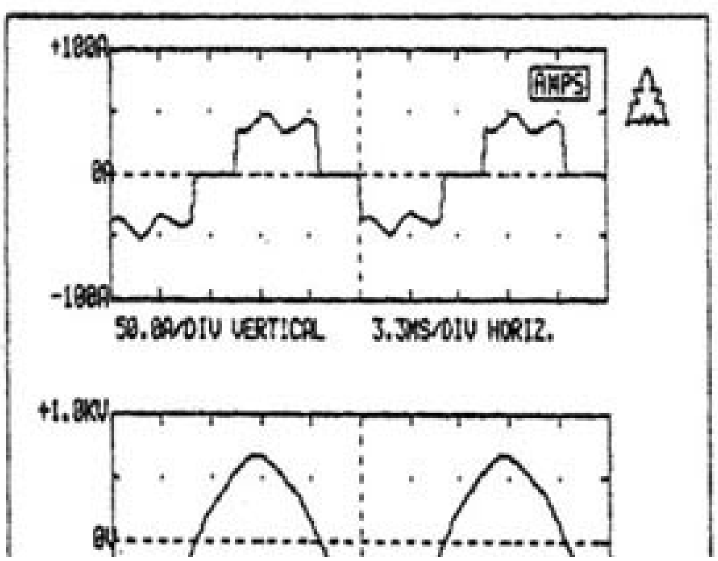
VOLTAGE THD	3.1% THD avg
Phase A-N Volts:	3.0% THD
Phase B-N Volts:	2.8% THD
Phase C-N Volts:	3.5% THD

CURRENT THD	125.2% THD avg
Phase A Current:	121.5% THD
Phase B Current:	129.6% THD
Phase C Current:	124.4% THD

40 hp AT RATED LOAD WITH 6% REACTOR; THID=32.4%
(Example: 3% Line Reactor + 6% DC Link Choke)

Phase B-N VOLTAGE: 485.3 Vrms
1.4 Crest Factor
1.1 Form Factor

Phase B CURRENT: 33.0 A rms
1.6 Crest Factor
1.2 Form Factor

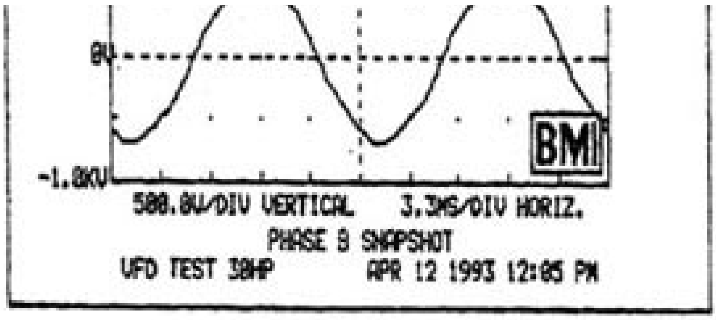


Total: 0.95 PF

Total: 1.00 dPF

====================================

VOLTAGE THD	2.7% THD avg
Phase A-N Volts:	2.4% THD
Phase B-N Volts:	2.6% THD
Phase C-N Volts:	3.2% THD



Phase B-N Volts: 2.6% THD
Phase C-N Volts: 3.2% THD

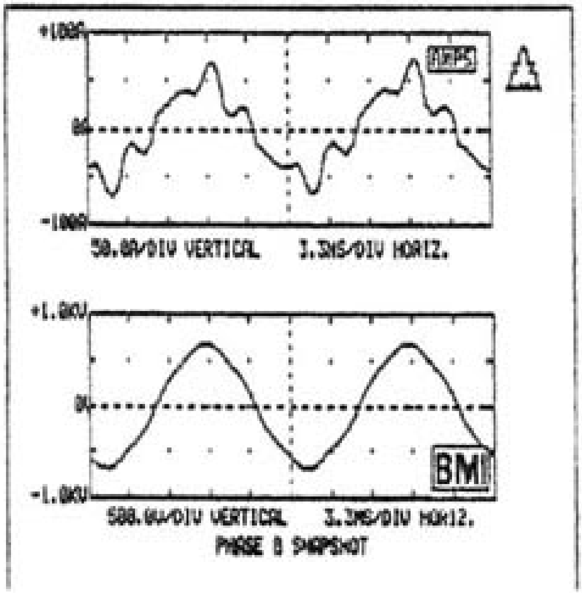
CURRENT THD 32.4% THD avg

Phase A Current: 34.2% THD
Phase B Current: 31.5% THD
Phase C Current: 31.4% THD

40 hp VFD AT RATED LOAD WITH 5th HARMONIC FILTER; THID=29.4%

Phase B-N VOLTAGE: 485.6 Vrms
1.5 Crest Factor
1.1 Form Factor

Phase B CURRENT: 38.1 A rms
1.9 Crest Factor
1.1 Form Factor



Total: 0.83 PF

Total: 0.88 dPF

HARMONICS SNAPSHOT

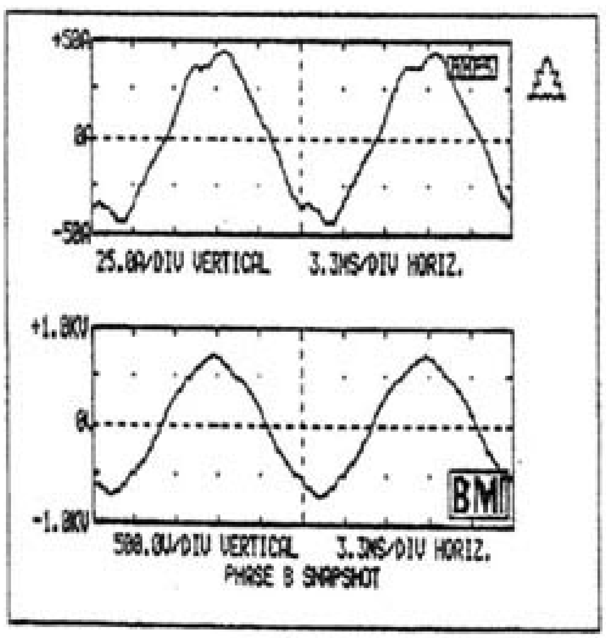
Fundamental freq: 60.0 Hz

VOLTAGE THD	3.3% THD avg
Phase A-N Volts:	2.8% THD
Phase B-N Volts:	3.3% THD
Phase C-N Volts:	3.0% THD
CURRENT THD	29.4% THD avg
Phase A Current:	29.4% THD
Phase B Current:	28.5% THD
Phase C Current:	30.4% THD

40 hp VFD AT RATED LOAD WITH BROAD BAND FILTER; THID=7.2%

1.5 Crest Factor
1.1 Form Factor

Phase B CURRENT: 30.1 A rms
1.5 Crest Factor
1.1 Form Factor



Total: 0.92 PF

Total: 0.93 dPF

HARMONICS SNAPSHOT

Fundamental freq: 60.0 Hz

VOLTAGE THD	3.0% THD avg
Phase A-N Volts:	2.4% THD
Phase B-N Volts:	3.3% THD
Phase C-N Volts:	3.5% THD
CURRENT THD	7.2% THD avg
Phase A Current:	6.9% THD
Phase B Current:	8.1% THD
Phase C Current:	6.6% THD

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Electricity Abroad

Disclaimer
Key Terms
Common Plug Types
Characteristic Listings by Country - A thru F, G thru M, N thru Z

Introduction

To assist U.S. manufacturers, exporters and individuals living or traveling abroad, these pages list the characteristics of electric current available and the type of attachment plugs used in most countries. These pages are based on a handbook published in 1998 by the U.S Department of Commerce. The tables indicate the type of current (alternating or direct current), number of phases, frequency (hertz), and voltage, as well as the stability of the frequency and the number of wires to a commercial or residential installation. This information pertains to domestic and commercial service only. It does not apply to special commercial installations involving relatively high voltage requirements or to industrial installations.

For most countries listed here, two nominal voltages are given. The lower voltages are used primarily for lighting and smaller appliances, while the higher voltages are used primarily for air conditioners, heating, and other large appliances. Travelers planning to use or ship appliances abroad should acquaint themselves with the characteristics of the electric supply available in the area in which the appliance is to be used. In some cases, a transformer may be used to correct the voltage. However, if the appliance requires exact timing or speed and if the frequency of the foreign electricity supply differs from the one the appliance was designed for, frequency converters are available for most applications. Some foreign hotels have circuits providing approximately 120 volts which allow guests to use electric shavers and other low-wattage U.S. appliances.

Disclaimer

The information presented here was compiled over a period of months from a large number of sources. Consequently, there is some possibility of errors or omissions for which we cannot assume responsibility. In addition, this information should not be taken as final in the case of industrial or highly specialized commercial installations. It would be impossible for us to maintain complete data on every foreign industrial installation. For special equipment for commercial use or heavy equipment for industrial use, the current characteristics for the area of installation should be obtained from the end user.

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The cooperation of various government and private agencies in providing data is gratefully acknowledged. Special thanks go to the U.S. Foreign and Commercial Service of the U.S. Department of Commerce and the Foreign Service of the U.S. Department of State.

Key to Terms Used

Type of current-a.c. indicates alternating current; d.c. indicates direct current.
Frequency-Shown in number of hertz (cycles per second). Note that even if voltages are similar, a 60-hertz U.S. clock or tape recorder will not function properly on 50 hertz current.
Number of phases-1 and 3 are the conventional phases that may be available.
Nominal voltage-The term nominal voltage is used to denote the reported voltage in use in the majority of residential and commercial establishments in the country or city. Direct current nominal voltages are 110/220 and 120/240. The lower voltage is always 1/2 of the higher voltage. On a direct current installation, the lower voltage requires two wires while the higher voltage requires three wires.

Alternating current is normally distributed either through 3 phase wye ("star") or delta ("triangle"), 4-wire secondary distribution systems. In the wye or star distribution system the nominal voltage examples are 120/208, 127/220, 220/380, and 230/400. The higher voltage is 1.732 (the square root of 3) times the lower voltage. In a delta or triangle system, 110/220 and 230/460 are examples of nominal voltages. The higher voltage is always double the lower voltage. The higher voltage is obtained by using 2 or 3 phase wires and the neutral wire while the lower voltage is the voltage between the neutral wire and one phase wire. The higher voltage may be single or 3 phase while the lower voltage is always single phase and used primarily for lighting and for small appliances.
Type of attachment plug in use-Attachment plugs used throughout the world come in various forms, dimensions and configurations too numerous for this document. The basic and most commonly used types of plugs are listed by country. Adapters may be purchased to change from the American plug type to other types.
Number of wires to the consumer-The number of wires which may be used by the consumer is shown. Normally, a single phase, 220/380 volt system or 127/220 system will have two wires if only the lower voltage is available (one phase wire and the neutral). It will have three wires if both the higher and lower voltages are available (two phase wires and the neutral) and where three phase motors will be used, four wires will be available for the higher voltage (the three phase wires and the neutral wire).
Frequency stability-"Yes" indicates that the frequency is stable and that service interruptions are rare.

If you need assistance with electric power frequency conversion, or have questions concerning the content of these pages please contact MTE Corporation.

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Common Plug Types Used Around the World

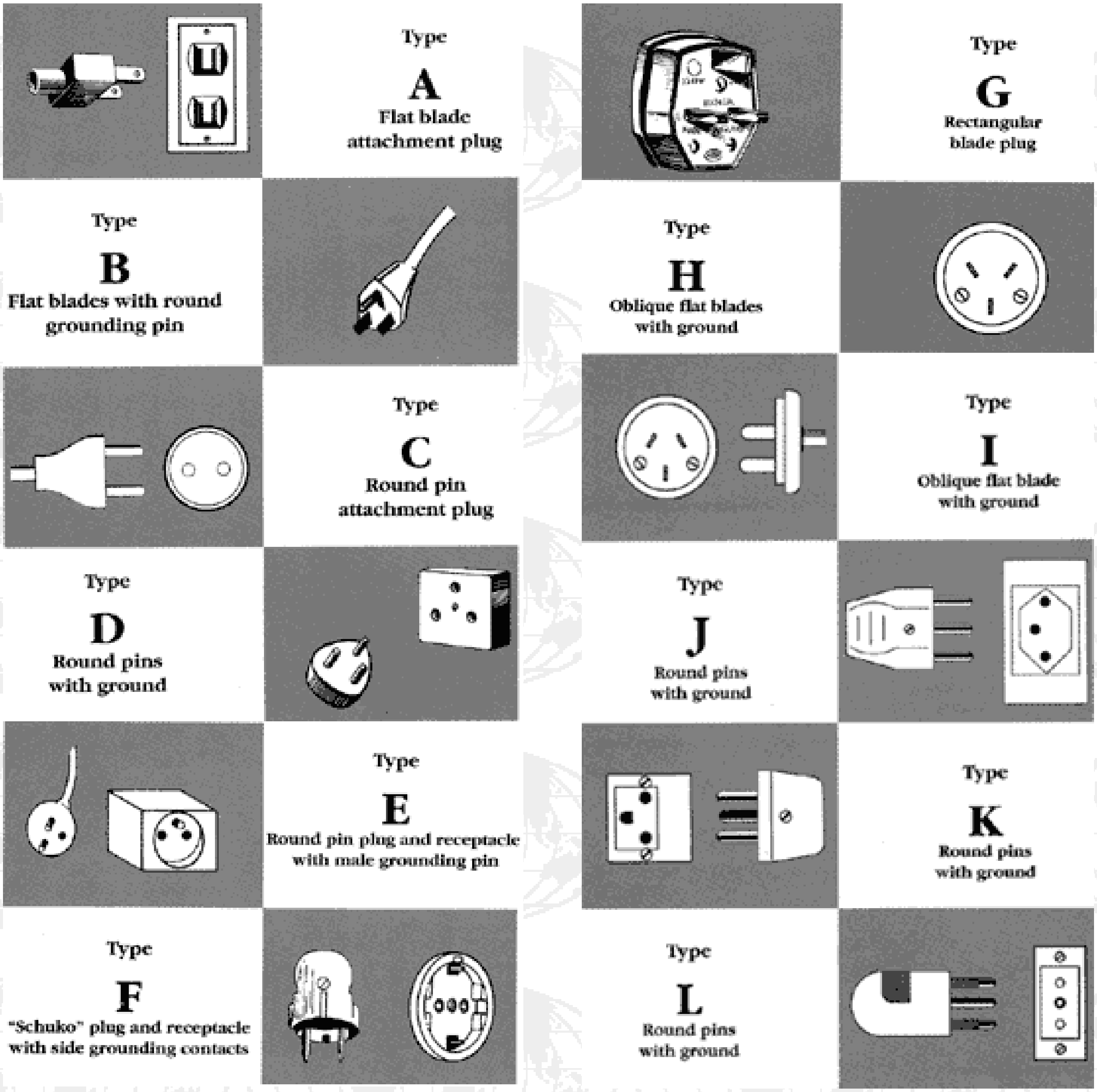
Country	Plug Type
Afghanistan	D
Albania	C
Algeria	C, F
Angola	C
Argentina	C, I
Australia	I
Austria	C
Bahamas	A, B
Bahrain	G
Bangladesh	A, C, D
Barbados	A, B, F, H
Belarus	C
Belgium	A, C, E
Belize	A, B, H
Benin	D
Bermuda	A, B
Bolivia	A, C
Botswana	C, D, H
Brazil	A, B, C
Brunei	G
Bulgaria	F
Burkina Faso	B, E
Burma	C, D, F
Burundi	C, E
Cameroon	C, E
Canada	B

Country	Plug Type
Laos	A, B, C, E, F
Lebanon	B, C, D, G
Lesotho	D
Liberia	A, B
Luxembourg	F
Macedonia	C, F
Madagascar	C, D, E, J, K
Malawi	G
Malaysia	G
Mali, Rep. of	C, E
Malta	G
Mauritania	C
Mauritius	G
Mexico	A, B
Monaco	C, D, E, F
Morocco	C, E
Mozambique	C, D, F
Namibia	C
Nepal	C, D
Netherlands	F
New Zealand	H
Nicaragua	A
Niger	A, C, E
Nigeria	C, D, H
Northern Ireland	A, C, H
Norway	C, F

Canary Islands	C, E	Oman	H
Cape Verde, Rep. of	C, F	Pakistan	B, C, D
Cayman Islands	A, B	Palau	A, B
Central African Republic	C, E	Panama	A, B, I
Chad	E	Paraguay	C
Chile	C, F, L	Peru	A, C
China, Peoples Rep. of	C, D, G, H	Philippines	A, B, C
Colombia	A, B	Poland	C, E
Congo, Dem. Rep of (form. Zaire)	E	Portugal	C, F
Congo, Peoples Rep. of	C, E	Qatar	D, G
Costa Rica	A, B	Romania	C, F
Cyprus	G	Russia	C
Czech Republic	E	Rwanda	C, J
Denmark	C, K	Saudi Arabia	A, B, G
Djibouti, Rep. of	C, E	Scotland	A, C, H
Dominican Republic	A	Senegal	C, D, E, K
Ecuador	A, B, C, D	Serbia-Montenegro	F
Egypt	C	Seychelles	D,
El Salvador	A, B, C, D, E, F, G, I, J, L	Sierra Leone	D, G
England	A, C, H	Singapore	B, H
Equatorial Guinea	C, E	Slovak Republic	E
Eritrea	C	Somalia	C
Ethiopia	C	South Africa	D
Fiji	I	Spain	C, F
Finland	C, F	Sri Lanka	D
France	E	Sudan	C, D
Gabon	D, E	Suriname	C, F
Gambia, The	G	Swaziland	D
Germany, Fed. Rep. of	F	Sweden	C, F
Ghana	D, G	Switzerland	C, E, J
Gibraltar	C, G	Syria	C
Greece	C, F	Tajikistan	C, I
Greenland	C, K	Tahiti	A
Grenada	G	Taiwan	A, B
Guatemala	A, B, G, H, I	Tanzania	D, G
		Thailand	A, B, C, D, E, G, J, K
		Togo	C

Guinea	C, F, K
Guinea-Bissau	C
Guyana	A, H
Haiti	A, B, H
Honduras	A
Hong Kong	H
Hungary	C, F
Iceland	B
India	C, D, G
Indonesia	C, E, F
Ireland	G
Israel	C, H
Italy	L
Ivory Coast	C, E
Jamaica	A, B, C, D
Japan	A, B, I
Jordan	C, F, G, L
Kazakstan	C, G, H
Kenya	G
Korea	C
Kuwait	C, G

Trinidad and Tobago	A, B
Tunisia	C, E
Turkey	C, F
Turkmenistan	B, F
Uganda	G
Ukraine	C
United Arab Emirates	C, D, G
Uruguay	C, F, I, L
Uzbekistan	C, I
Venezuela	A, B, H
Wales	A, C, H
Western Samoa	H
Yemen, Rep. of	A, D, G
Zambia	C, D, G
Zimbabwe	D, G



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Country or City	Type and frequency of current	Number of Phases	Nominal Voltage	Number of Wires	Frequency stability OK for elect. clocks
Afghanistan	a.c. 50	1,3	220/380	2,4	Yes
Albania	a.c. 50	1,3	220/380	2,4	No
Algeria	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Angola[1,2,3]	a.c. 50	1,3	220/380	2,4	Yes
Argentina	a.c. 50	1,3	220/380	2,4	Yes
	d.c.		220/440	2,3	Yes
Australia[1,2]	a.c. 50	1,3	240/415	2,3,4	Yes
Austria[1,2]	a.c. 50	1,3	220/380	3,5	Yes
Bahamas	a.c. 60	1,3	120/240	2,3,4	Yes
			120/208		
Bahrain[1,2]	a.c. 50	1,3	230/400	2,3,4	Yes
	a.c. 60	1	110/115	3	Yes
Bangladesh[1,2,3]	a.c. 50	1,3	220/440	3,4	No

Barbados[1,2]	a.c. 50	1,3	115/230	2,3,4	Yes
			115/200		
Belarus	a.c. 50	1,3	220/380	2,4	Yes
Belgium[1,2]	a.c. 50	1,3	220/400	2,3,4	Yes
Belize[1,3]	a.c. 60	1,3	110/220	2,3,4	Yes
			220/440		
Benin	a.c. 50	1,3	220/380	2,4	Yes
Bermuda[1,2,3]	a.c. 60	1,3	120/240	2,3,4	Yes
			120/208		
Bolivia	a.c. 50	1,3	110/220	2,4	Yes
Botswana	a.c. 50	1,3	231/400	2,4	Yes
Brazil[1]					
Alagoinhas	a.c. 60	1,3	127/220	2,3,4	Yes
Americana	a.c. 60	1,3	127/220	2,3,4	Yes
Anapolis	a.c. 60	1,3	220/380	2,3,4	Yes
Aracaju	a.c. 60	1,3	127/220	2,3,4	Yes
Aracatuba	a.c. 60	1,3	127/220	2,3,4	Yes
Araraquara	a.c. 60	1,3	127/220	2,3,4	Yes
Bage	a.c. 60	1,3	220/380	2,3,4	Yes
Baixo Guandu	a.c. 60	1,3	127/220	2,3,4	Yes
Barbacena	a.c. 60	1,3	127/220	2,3,4	Yes
Barra Mansa	a.c. 60	1,3	127/220	2,3,4	Yes
Barretos	a.c. 60	1,3	127/220	2,3,4	Yes
Bauru	a.c. 60	1,3	127/220	2,3,4	Yes
Belem	a.c. 60	1,3	127/220	2,3,4	Yes
Belo Horizonte	a.c. 60	1,3	127/220	2,3,4	Yes
Blumenau	a.c. 60	1,3	220/380	2,3	Yes

Boa Vista (Rio Branco)	a.c. 60	1,3	127/220	2,3,4	Yes
Botucatu	a.c. 60	1,3	127/220	2,3,4	Yes
Braganca	a.c. 60	1,3	127/220	2,3,4	Yes
Brazilia, D.F.	a.c. 60	1,3	220/380	2,3,4	Yes
Cachoeira	a.c. 60	1,3	127/220	2,3,4	Yes
Cachoiera do Itapemirim	a.c. 60	1,3	127/220	2,3,4	Yes
Campinas	a.c. 60	1,3	127/220	2,3,4	Yes
Campos	a.c. 60	1,3	127/220	2,3,4	No
Caruaru	a.c. 60	1,3	220/380	2,3,4	Yes
Caxias do Sul	a.c. 60	1,3	220/380	2,3,4	Yes
Cel Fabriciano	a.c. 60	1,3	110/220	2,3	Yes
Cidade Industrial (Betim)	a.c. 60	1,3	127/220	2,3,4	Yes
Colatina	a.c. 60	1,3	127/220	2,3,4	Yes
Corumba	a.c. 60	1,3	127/220	2,3,4	Yes
Curitiba	a.c. 60	1,3	127/220	2,3,4	Yes
Feira de Santana	a.c. 60	1,3	127/220	2,3,4	Yes
Florianopolis	a.c. 60	1,3	220/380	2,3,4	Yes
Fortaleza	a.c. 60	1,3	220/380	2,3,4	Yes
Franca (Sao Paulo)	a.c. 60	1,3	127/220	2,3,4	Yes
Goiania	a.c. 60	1,3	220/380	2,3,4	Yes
Goias	a.c. 60	1,3	220/380	2,3,4	Yes
Governador Valadares	a.c. 60	1,3	127/220	2,3,4	Yes
Ilheus	a.c. 60	1,3	127/220	2,3,4	Yes
Itabuana	a.c. 60	1,3	127/220	2,3,4	Yes
Itajai	a.c. 60	1,3	220/380	2,3	Yes
Jequie	a.c. 60	1,3	220/380	2,3,4	Yes
Joao Pessoa	a.c. 60	1,3	220/380	2,3,4	Yes
Joinville	a.c. 60	1,3	220/380	2,3,4	Yes
Juiz de Fora	a.c. 60	1,3	120/240	2,3,4	Yes
Jundiai	a.c. 60	1,3	220	2,3	Yes
Livramento	a.c. 60	1,3	220/380	2,3,4	Yes
Londrina	a.c. 60	1,3	127/220	2,3,4	Yes
Macapa	a.c. 60	1,3	127/220	2,3	Yes
Maceio (Alagoas)	a.c. 60	1,3	220/380	2,3,4	Yes

Manaus	a.c. 60	1,3	110/220	2,3	Yes
Marilia	a.c. 60	1,3	127/220	2,3,4	Yes
Mossoro	a.c. 60	1,3	220/380	2,3,4	Yes
Natal (Rio Grando Norte)	a.c. 60	1,3	220/380	2,3,4	Yes
Niteroi	a.c. 60	1,3	127/220	2,3,4	Yes
Nova Friburgo	a.c. 60	1,3	220/380	2,3	Yes
Olinda	a.c. 60	1,3	220/380	2,3,4	Yes
Ouro Preto	a.c. 50	1,3	127/220	2,3,4	Yes
Paranagua	a.c. 60	1,3	127/220	2,3	Yes
Parnaiba	a.c. 60	1,3	220/380	2,3	Yes
Paulista	a.c. 60	1,3	127/220	2,3,4	Yes
Pelotas	a.c. 60	1,3	220/380	2,3,4	Yes
Petropolis	a.c. 60	1,3	127/220	2,3,4	Yes
Piracicaba	a.c. 60	1,3	127/220	2,3,4	Yes
Ponta Grossa	a.c. 60	1,3	127/220	2,3	Yes
Porto Alegre	a.c. 60	1,3	127/220	2,3,4	Yes
Porto Velho	a.c. 60	1,3	127/220	2,3	Yes
Recife	a.c. 60	1,3	220/380	2,3,4	Yes
Rebeirao Preto	a.c. 60	1,3	127/220	2,3,4	Yes
Rio Branco	a.c. 60	1,3	127/220	2,3,4	Yes
Rio De Janeiro	a.c. 60	1,3	127/220	2,3,4	Yes
Salvador	a.c. 60	1,3	127/220	2,3,4	Yes
Santo André	a.c. 60	1,3	127/220	2,3	Yes
			220/380		
Santos	a.c. 60	1,3	127/220	2,3,4	Yes
Sao Bernardo do Campo	a.c. 60	1,3	220/380	2,3	Yes
Sao Caetano do Sul	a.c. 60	1,3	115/230	2,3	Yes
Sao Luiz	a.c. 60	1,3	110/220	2,3	Yes
Sao Paulo	a.c. 60	1,3	115/230	2,3	Yes
Sorocaba	a.c. 60	1,3	127/220	2,3,4	Yes
Teresina	a.c. 60	1,3	110/220	2,3	Yes
Uberaba	a.c. 60	1,3	127/220	2,3,4	Yes
Vitoria	a.c. 60	1,3	127/220	2,3,4	Yes
Volta Redonda	a.c. 60	1,3	125/216	2,3,4	Yes

Brunei[1,2]	a.c. 50	1,3	240/415	2,4	Yes
Bulgaria	a.c. 50	1,3	220/380	2,4	No
Burkina Faso	a.c. 50	1,3	220/380	2,4	No
Burma[1,2,3]	a.c. 50	1,3	230/400	2,4	No
Burundi[3]	a.c. 50	1,3	220/380	2,4	No
Cambodia	a.c. 50	1,3	220/380	2,3,4	No
Cameroon	a.c. 50	1,3	220/380	2,4	Yes
Canada[1]	a.c. 60	1,3	120/240	3,4	Yes
Cape Verde[2]	a.c. 50	1,3	220/380	2,3,4	No
Cayman Islands[1,3]	a.c. 60	1,3	120/240	2,3	Yes
Central African Rep.[2,3]	a.c. 50	1,3	220/380	2,4	Yes
Chad	a.c. 50	1,3	220/380	2,4	No
Chile	a.c. 50	1,3	220/380	2,3,4	Yes
China, People's Rep.	a.c. 50	1,3	220/380	2,3,4	No
Colombia	a.c. 60	1,3	110/220	2,3,4	Yes
			150/260		
Congo, Dem. Rep. of the[1,2] *(formerly Zaire)*	a.c. 50	1,3	220/380	2,3,4	Yes
Congo, Rep. Of[1,2,3]	a.c. 50	1,3	220/380	2,4	No

Costa Rica	a.c. 60	1,3	120/240	2,3,4	Yes
Cyprus[1,2]	a.c. 50	1,3	240/415	2,4	Yes
Czech Republic	a.c. 50	1,3	220/380	2,3,4	Yes
Denmark	a.c. 50	1,3	220/380	2,3,4	Yes
Djibouti, Rep. Of	a.c. 50	1,3	220/380	2,4	Yes
Dominican Republic	a.c. 60	1,3	110/220	2,3	Yes
Ecuador[1]	a.c. 60	1,3	120/208	2,3,4	Yes
			127/220		
Egypt	a.c. 50	1,3	220/380	2,3,4	No
El Salvador[1]	a.c. 60	1,3	115/230	2,3	Yes
England	a.c. 50	1	230/415	2,4	Yes
Eritrea	a.c. 50	1,3	220/380	2,4	Yes
Ethiopia	a.c. 50	1,3	220/380	2,4	Yes
Fiji[3]	a.c. 50	1,3	240/415	2,3,4	Yes
Finland	a.c. 50	1,3	230/400	2,4,5	Yes
France	a.c. 50	1,3	220/380	2,4	Yes

Notes:

1. The neutral wire of the secondary distribution system is grounded.
2. A grounding conductor is required in the electrical cord attached to appliances.
3. Voltage tolerance is plus or minus 4 to 9%
4. Voltage tolerance is plus or minus 10%
5. Voltage tolerance is plus or minus 20 to 30%
6. Voltage tolerance is plus or minus 4.5 to 20.5%

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Country or City	Type and frequency of current	Number of Phases	Nominal Voltage	Number of Wires	Frequency stability OK for elect. clocks
Gabon[1,2]	a.c. 50	1,3	220/380	2,4	Yes
Gambia, The[1,2]	a.c. 50	1,3	220/380	2,4	No
Germany,Fed. Rep. Of[1,2,3]	a.c. 50	1,3	230/400	2,4	Yes
Ghana	a.c. 50	1,3	240/415	2,4	No
Gibralter	a.c. 50	1,3	240/415	2,4	Yes
Great Britain	see United Kingdom				
Greece	a.c. 50	1,3	220/380	2,4	Yes
Greenland	a.c. 50	1,3	220/380	2,3,4	Yes
Grenada[1,2,3]	a.c. 50	1,3	230/400	2,4	No
Guatemala	a.c. 60	1,3	120/240	2,3,4	Yes
Guinea	a.c. 50	1,3	220/380	2,3,4	No

Guinea-Bissau	a.c. 50	1,3	220/380	2,3,4	No
Guyana[1,2]	a.c. 50	1,3	110/220	2,3,4	Yes
Haiti	a.c. 60	1,3	110/220	2,3,4	No
Honduras	a.c. 60	1,3	110/220	2,3	No
Hong Kong	a.c. 50	1,3	202/415	3,4	Yes
Hungary[2,3]	a.c. 50	1,3	220/380	2,3,4	Yes
Iceland	a.c. 50	1,3	220/380	2,3,4	Yes
India[3]	a.c. 50	1,3	230/400	2,4	Yes
Indonesia[1]					
Bandjarmasin	a.c. 50	1,3	127/220	2,4	No
Bandung	a.c. 50	1,3	220/380	2,4	Yes
Bogor	a.c. 50	1,3	220/380	2,4	Yes
Cilacap	a.c. 50	1,3	220/380	2,4	Yes
Cirebon	a.c. 50	1,3	220/380	2,4	Yes
Jakarta	a.c. 50	1,3	220/380	2,4	Yes
Malang	a.c. 50	1,3	220/380	2,4	Yes
Medan	a.c. 50	1,3	127/220	2,4	Yes
Padang	a.c. 50	1,3	127/220	2,4	No
Palembang	a.c. 50	1,3	127/220	2,4	Yes
Semarang	a.c. 50	1,3	220/380	2,4	Yes
Sukabumi	a.c. 50	1,3	220/380	2,4	Yes
Surabaya	a.c. 50	1,3	220/380	2,4	Yes
Surakarta	a.c. 50	1,3	220/380	2,4	Yes
Ujungpandang	a.c. 50	1,3	127/220	2,4	No
Yogyakarta	a.c. 50	1,3	220/380	2,4	Yes
Ireland[1,2,3]	a.c. 50	1,3	220/380	2,4	Yes

Israel[1,2,4]	a.c. 50	1,3	220/380	2,4	Yes
Italy[1,2,4]					
Ancona	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Bari	a.c. 50	1,3	220/380	2,4	Yes
Bologna	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Brindisi	a.c. 50	1,3	220/380	2,4	Yes
Cagliari	a.c. 50	1,3	220/380	2,4	Yes
Catania	a.c. 50	1,3	220/380	2,4	Yes
Como	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Cremona	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Florence	a.c. 50	1,3	220/380	2,4	Yes
Genoa	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
La Spezia	a.c. 50	1,3	220/380	2,4	Yes
Latina	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Leghorn	a.c. 50	1,3	220/380	2,4	Yes
Milan	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Naples	a.c. 50	1,3	220/380	2,4	Yes
Palermo	a.c. 50	1,3	220/380	2,4	Yes
Perugia	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Pescara and Chieti	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Pisa	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Ragusa	a.c. 50	1,3	220/380	2,4	Yes
Rome	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Sassari	a.c. 50	1,3	220/380	2,4	Yes
Siena	a.c. 50	1,3	220/380	2,4	Yes

Siracusa	a.c. 50	1,3	220/380	2,4	Yes
Taranto	a.c. 50	1,3	220/380	2,4	Yes
Trieste	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Turin	a.c. 50	1,3	220/380	2,4	Yes
Udine	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Venice	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Verona	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Ivory Coast	a.c. 50	1,3	220/380	3,4	Yes
Jamaica[1,3]	a.c. 50	1,3	110/220	2,3,4	Yes
Japan[1]	a.c. 50	1,3	100/200	2,3	Yes
Jordan[1,2]	a.c. 50	1,3	220/380	2,3,4	Yes
Kazakstan	a.c. 50	1,3	220/380	2,3,4	Yes
Kenya[2,3]	a.c. 50	1,3	240/415	2,4	No
Korea Rep. of[1,2,3]	a.c. 60	1,3	220/380	2,4	Yes
Kuwait[3]	a.c. 50	1,3	240/415	2,4	Yes
Laos	a.c. 50	1,3	220/380	2,4	Yes
Lebanon[1]					
Aley	a.c. 50	1,3	110/190	2,4	No
			220/380		
Beirut	a.c. 50	1,3	110/190	2,4	No
			220/380		
Bhamdoun	a.c. 50	1,3	110/190	2,4	No

			220/380		
Brummana	a.c. 50	1,3	110/190	2,4	No
			220/380		
Chtaure	a.c. 50	1,3	220/380	2,4	No
Dhour el Choueir	a.c. 50	1,3	220/380	2,4	No
Sidon	a.c. 50	1,3	220/380	2,4	No
Sofar	a.c. 50	1,3	220/380	2,4	No
Tripoli	a.c. 50	1,3	110/190	2,4	No
			220/380		
Tyre	a.c. 50	1,3	110/190	2,4	No
			220/380		
Zahleh	a.c. 50	1,3	220/380	2,4	No
Lesotho[1,2]	a.c. 50	1,3	220/380	2,4	Yes
Liberia[1]	a.c. 60	1,3	120/240	2,3,4	No
Luxembourg[1,2]	a.c. 50	1,3	230/400	2,4	Yes
Macedonia	a.c. 50	1,3	220/380	2,4	Yes
Madagascar[1,2]	a.c. 50	1,3	127/220	2,3,4	Yes
			220/380		
Malawi[3]	a.c. 50	1,3	230/400	3,4	No
Malaysia[1,2]	a.c. 50	1,3	240/415	2,3	Yes
Mali, Rep. Of[1,2]	a.c. 50	1,3	220/380	3,4	No
Malta[1,2]	a.c. 50	1,3	240/415	2,4	Yes
Mauritania[1,2,5]	a.c. 50	1,3	220/380	2,3	No
Mauritius[1,2]	a.c. 50	1,3	230/400	2,4	Yes

Mexico[1]	a.c. 60	1,3	127/220	2,3,4	Yes
Monaco	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Morocco[1,2]					
Agadir	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Asilah	a.c. 50	1,3	127/220	2,4	Yes
Beni-Mellal	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Berrechid	a.c. 50	1,3	127/220	2,4	Yes
Chaouen	a.c. 50	1,3	127/220	2,4	Yes
Casablanca	a.c. 50	1,3	127/220	2,4	Yes
El-Hoceima	a.c. 50	1,3	220/380	2,4	Yes
El-Jadida	a.c. 50	1,3	127/220	2,4	Yes
Fes	a.c. 50	1,3	127/220	2,4	Yes
Kasba-Tadla	a.c. 50	1,3	127/220	2,4	Yes
Khemisset	a.c. 50	1,3	220/380	2,4	Yes
Khenifra	a.c. 50	1,3	220/380	2,4	Yes
Khouribga	a.c. 50	1,3	127/220	2,4	Yes
Ksar-El-Kebir	a.c. 50	1,3	127/220	2,4	Yes
Ksar-Es-Souk	a.c. 50	1,3	127/220	2,4	Yes
Larache	a.c. 50	1,3	127/220	2,4	Yes
Mohammedia	a.c. 50	1,3	127/220	2,4	Yes
Marrakech	a.c. 50	1,3	127/220	2,4	Yes
Meknes	a.c. 50	1,3	127/220	2,4	Yes
Midelt	a.c. 50	1,3	127/220	2,4	Yes
Nador	a.c. 50	1,3	127/220	2,4	Yes
Ouarzazete	a.c. 50	1,3	127/220	2,4	Yes
Oued-Zem	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Ouezzane	a.c. 50	1,3	127/220	2,4	Yes
Rabat	a.c. 50	1,3	127/220	2,4	Yes
Safi	a.c. 50	1,3	127/220	2,4	Yes
Sefrou	a.c. 50	1,3	127/220	2,4	Yes
Sidi Kacem	a.c. 50	1,3	127/220	2,4	Yes

			220/380		
Sidi Slimane	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Souk-El-Arba Gharb	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Settat	a.c. 50	1,3	127/220	2,4	Yes
Tangier	a.c. 50	1,3	127/220	2,4	Yes
Taroudant	a.c. 50	1,3	127/220	2,4	Yes
Taza	a.c. 50	1,3	127/220	2,4	Yes
Tetouant	a.c. 50	1,3	127/220	2,4	Yes
Tiznit	a.c. 50	1,3	127/220	2,4	Yes
Youssoufia	a.c. 50	1,3	127/220	2,4	Yes
Mozambique[2]	a.c. 50	1,3	220/380	2,4	Yes

Notes:

1. The neutral wire of the secondary distribution system is grounded.
2. A grounding conductor is required in the electrical cord attached to appliances.
3. Voltage tolerance is plus or minus 4 to 9%
4. Voltage tolerance is plus or minus 10%
5. Voltage tolerance is plus or minus 20 to 30%
6. Voltage tolerance is plus or minus 4.5 to 20.5%

Introduction
Disclaimer
Key Terms
Common Plug Types
Characteristic Listings by Country - A thru F, G thru M, N thru Z

Electricity Abroad

Disclaimer | Key Terms | Common Plug Types

Characteristic Listings by Country (N thru Z)

Characteristic Listings by Country A thru F, G thru M

Country or City	Type and frequency of current	Number of Phases	Nominal Voltage	Number of Wires	Frequency stability OK for elect. clocks
Namibia[1,2]	a.c. 50	1,3	220/380	2,4	Yes
Nepal[1]	a.c. 50	1,3	220/380	2,4	No
Netherlands[1]	a.c. 50	1,3	220/380	2,4	Yes
New Zealand[1,2]	a.c. 50	1,3	230/400	2,3,4	Yes
Nicaragua	a.c. 60	1,3	120/240	2,3,4	Yes
Niger	a.c. 50	1,3	220/380	2,4	No
Nigeria[1]	a.c. 50	1,3	220/380	2,4	Yes
Northern Ireland	a.c. 50	1,3	230/415	2,4	Yes
Norway	a.c. 50	1,3	220/380	2,4	Yes
Oman[2]	a.c. 50	1,3	240/415	2,4	Yes
Pakistan[1]	a.c. 50	1,3	230/400	3	No

Palau	a.c. 60	1,3	120/240	4	No
Panama	a.c. 60	1,3	120/240	2,4	Yes
Paraguay	a.c. 50	1,3	220/380	2,4	Yes
Peru	a.c. 60	1,3	220/380	2,4	Yes
Philippines[1,2]	a.c. 60	1,3	125/216	2,4	Yes
Poland	a.c. 50	1,3	220/380	3,4	Yes
Portugal[1]	a.c. 50	1,3	220/380	2,3,4	Yes
Qatar	a.c. 50	1,3	240/415	2,3,4	Yes
Romania[3]	a.c. 50	1,3	220/380	2,4	No
Russia	a.c. 50	1,3	220/380	2,4	Yes
Rwanda	a.c. 50	1,3	220/380	2,4	Yes
Saudi Arabia[3]	a.c. 60	1,3	127/220	2,4	Yes
Scotland	a.c. 50	1,3	230/415	2,4	Yes
Senegal[1,3]	a.c. 50	1,3	127/220	2,3,4	No
Serbia - Montenegro	a.c. 50	1,3	220/380	3,4,5	Yes
Seychelles	a.c. 50	1,3	240/450	2,4	Yes
Sierra Leone	a.c. 50	1,3	230/400	2,4	No
Singapore[1]	a.c. 50	1,3	230/400	2,3	Yes

Slovak Republic	a.c. 50	1,3	220/380	2,4	Yes
Somalia					
Berbera	a.c. 50	1,3	230	2,3	Yes
Brava	a.c. 50	1,3	220/440	2,4	Yes
Chisimaio	a.c. 50	1,3	220	2,3	No
Hargeisa	a.c. 50	1,3	220	2,3	Yes
Merca	a.c. 50	1,3	110/220	2,4	No
Mogadishu	a.c. 50	1,3	220/380	2,4	No
South Africa[1,2,3]					
Alberton	a.c. 50	1,3	220/380	2,3,4	Yes
Beaufort West	a.c. 50	1,3	230/400	2,4	Yes
Benoni	a.c. 50	1,3	230/400	2,3,4	Yes
Bethlehem	a.c. 50	1,3	220/380	2,4	Yes
Bloemfontein	a.c. 50	1,3	220/380	2,4	Yes
Boksburg	a.c. 50	1,3	230/400	2,4	Yes
Brakpan	a.c. 50	1,3	220/380	2,3,4	Yes
Caledon	a.c. 50	1,3	220/380	2,4	Yes
Cape Town	a.c. 50	1,3	220/380	2,4	Yes
Carltonville	a.c. 50	1,3	220/380	2,4	Yes
Cradock	a.c. 50	1,3	230/400	2,4	N.A.
De Aar	a.c. 50	1,3	220/380	2,4	Yes
Durban	a.c. 50	1,3	220/380	2,4	Yes
East London	a.c. 50	1,3	220/380	2,4	Yes
Germiston	a.c. 50	1,3	230/400	2,3,4	Yes
Grahamstad	a.c. 50	1,3	250/430	2,4	Yes
Johannesburg	a.c. 50	1,3	220/380	2,3,4	Yes
	d.c.		230/460	2,3	
Kimberly	a.c. 50	1,3	220/380	2,3,4	Yes
King Williams	a.c. 50	1,3	220/380	2,3,4	Yes
			250/433		
Klerksdorp	a.c. 50	1,3	230/400	2,3,4	Yes
Kroonstad	a.c. 50	1,3	230/400	2,3,4	Yes
Krugersdorp	a.c. 50	1,3	220/380	2,4	Yes
Ladysmith, N.	a.c. 50	1,3	220/380	2,4	Yes
Malmesbury	a.c. 50	1,3	220/380	2,4	Yes

Oudtshoorn	a.c. 50	1,3	220/380	2,4	Yes
Paarl	a.c. 50	1,3	230/400	2,4	Yes
Parys	a.c. 50	1,3	220/380	2,3,4	Yes
Pietermaritzburg	a.c. 50	1,3	220/380	2,4	Yes
Port Elizabeth	a.c. 50	1,3	250/433	2,4	Yes
Pretoria	a.c. 50	1,3	240/415	2,3,4	Yes
Queenstown	a.c. 50	1,3	220/380	2,4	Yes
Robertson	a.c. 50	1,3	220/380	2,4	Yes
Roodeport	a.c. 50	1,3	230/400	2,4	Yes
Rustenburg	a.c. 50	1,3	220/380	2,4	Yes
Senekal	a.c. 50	1,3	220/380	2,3,4	Yes
Somerset West	a.c. 50	1,3	230/400	2,4	Yes
Springs	a.c. 50	1,3	220/380	2,3,4	Yes
			230/400		
Stellenbosch	a.c. 50	3	220/380	4	Yes
Tulbagh	a.c. 50	1,3	220/380	2,4	Yes
Uitenhage	a.c. 50	1,3	220/380	2,4	Yes
Umkomaas	a.c. 50	1,3	220/380	2,4	Yes
Umtata	a.c. 50	1,3	230/400	2,3,4	Yes
Upington	a.c. 50	1,3	230/400	2,4	Yes
Vereeniging	a.c. 50	1,3	220/380	2,4	Yes
Virginia	a.c. 50	1,3	230/400	2,4	Yes
Vryheid	a.c. 50	1,3	230/400	2,3,4	Yes
Walvis Bay	a.c. 50	1,3	230/400	2,3,4	Yes
Welkom	a.c. 50	1,3	220/380	2,4	Yes
Wellington	a.c. 50	1,3	230/400	2,4	Yes
Worcester	a.c. 50	1,3	230/400	2,4	Yes
Spain[1]	a.c. 50	1,3	220/380	2,3,4	Yes
Sri Lanka[1,3]	a.c. 50	1,3	230/400	2,4	Yes
Sudan[1]	a.c. 50	1,3	240/415	2,4	Yes
Suriname	a.c. 60	1,3	127/220	2,3,4	Yes
Swaziland	a.c. 50	1,3	230/400	2,4	Yes

Sweden[1,2]	a.c. 50	1,3	230/400	2,3,4,5	Yes
Switzerland[1,2]	a.c. 50	1,3	220/380	2,3,4	Yes
Syria	a.c. 50	1,3	220/380	2,3	No
Tahiti	a.c. 60	1,3	127/220	2,3,4	No
Taiwan[1]	a.c. 60	1,3	110/220	2,3,4	Yes
Tajikistan	a.c. 50	1,3	220/380	2,3	No
Tanzania[1,2,3]	a.c. 50	1,3	220/380	2,4	Yes
Thailand[3]	a.c. 50	1,3	220/380	2,4	Yes
Togo	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Trinidad and Tobago[3]	a.c. 60	1,3	115/230	2,3,4	Yes
			230/400		
Tunisia[1,2,3]	a.c. 50	1,3	127/220	2,4	Yes
			220/380		
Turkey[1]	a.c. 50	1,3	220/380	2,3,4	Yes
Turkmenistan	a.c. 50	1,3	220/380	2,3	Yes
Uganda[1,2]	a.c. 50	1,3	240/415	2,4	No
Ukraine[1]	a.c. 50	1,3	220/380	2,4	Yes
United Arab Emirates	a.c. 50	1,3	220/380	2,4	Yes

United Kingdom[1,2,3]					
England	a.c. 50	1	230/415	2,4	Yes
Northern Ireland	a.c. 50	1,3	230/415	2,4	Yes
Scotland	a.c. 50	1,3	230/415	2,4	Yes
Wales	a.c. 50	1,3	230/415	2,4	Yes
Uruguay[2,3,6]	a.c. 50	1,3	220/380	2,4	Yes
Uzbekistan	a.c. 50	1,3	220/380	2,4	Yes
Venezuela	a.c. 60	1,3	120/240	2,3,4	Yes
Viet Nam					
Ban Me Thuot (Sic)	a.c. 50	1,3	220/380	2,4	No
Can Tho	a.c. 50	1,3	127/220	2,4	No
			220/380		
Dalat	a.c. 50	1,3	120/208	2,4	No
			220/380		
Da Nang	a.c. 50	1,3	127/220	2,4	No
Hanoi	a.c. 50	1,3	127/220	2,4	No
			220/380		
Hue	a.c. 50	1,3	127/220	2,4	No
Khanh Hung (Soc Trang)	a.c. 50	1,3	220/380	2,4	No
Nha Trang	a.c. 50	1,3	127/220	2,4	No
Saigon	a.c. 50	1,3	120/208	2,4	No
			220/380		
Wales	a.c. 50	1,3	230/415	2,4	Yes
Western Samoa	a.c. 50	1,3	230/400	2,3,4	Yes
Yemen Rep. of	a.c. 50	1,3	220/380	2,4	No
Zambia[1,2,4]	a.c. 50	1,3	220/380	2,4	Yes
Zimbabwe[4]	a.c. 50	1,3	220/380	2,3,4	Yes

Notes:

1. The neutral wire of the secondary distribution system is grounded.
2. A grounding conductor is required in the electrical cord attached to appliances.
3. Voltage tolerance is plus or minus 4 to 9%
4. Voltage tolerance is plus or minus 10%
5. Voltage tolerance is plus or minus 20 to 30%
6. Voltage tolerance is plus or minus 4.5 to 20.5%

Introduction
Disclaimer
Key Terms
Common Plug Types
Characteristic Listings by Country - A thru F, G thru M, N thru Z

Milestone: 250th "Harmonic Suppressor" Sold

Contact-. Mr. Karl Hink, (262) 253-8200

Menomonee Falls, WI
MTE Corporation announced the sale and installation of the 250th Broad-Band Harmonic Suppressor. The company has provided these suppressors in a range of sizes from 3 HP up to 1000 HP, enabling their customers to achieve compliance with IEEE-519 harmonic distortion limits. The Broad-Band Harmonic Suppressors have been used along with 6-pulse drives as an alternative to 12 or 18 pulse drives with a savings of as much as 50%. Unlike former techniques of mitigating harmonics, MTE's Broad-Band Harmonic Suppressor offers guaranteed results, will not import harmonics from other loads, will not cause system resonance and eliminates the need for a system analysis.

MTE Corporation is a world leader in the design and manufacture of electrical power quality products for commercial and industrial applications. Whether offering protection of your desktop computing equipment or protecting the complete industrial facility from power line spikes, harmonic distortion or other disturbances, MTE has the most economical solution. With a worldwide network of distributors and sales representatives, MTE can handle all of your power quality and electrical transformer needs.

European Expansion

MTE Europe announced the expansion of its European sales and ware-housing operations. To accommodate an increase in both inside and out-side sales staff plus larger product inventories, the company Is moving to larger facilities in Great Yarmouth, England. The expansion has been implemented to maintain the highest level of customer service and product availability for a rapidly growing customer base throughout all of Europe.

The company's AC Line/Load Reactors, with IGBT protection and harmonic compensation, have long been the standard of the industry throughout North America and are becoming favored throughout Europe as well. The larger inventories will make other products such as the popular Broad-Band Harmonic Suppressor, (Motor Protection Filters), DC Link Chokes and hand-held harmonic analyzers more readily available to all of their European customers. The trained sales staff is capable of assisting customers in the proper selection and application of a wide variety of power quality products.

MTE Corporation is a world leader in the design and manufacture of electrical power quality products for commercial and industrial applications. Whether offering protection of your desktop computing equipment or protecting the complete industrial facility from power line spikes, harmonic distortion or other disturbances, MTE has the most economical solution. With a worldwide network of distributors and sales representatives, MTE can handle all of your power quality and electrical transformer needs.

New Manufacturing Facility

Contact-. Mr. Karl Hink, (262) 253-8200

Menomonee Falls, WI
MTE Corporation announced the opening of a new factory specializing in the manufacture of its popular Broad-Band Harmonic Suppressor. The "Harmonic Suppressor TM" has become a popular alternative to 12 and 18 pulse drives due to its superb harmonic suppressing ability at a savings of as much as 50%. Six-pulse drives using the Harmonic Suppressor TM Will meet IEEE-519 at a fraction of the cost of 12 and 18 pulse drives. The new facility, located in Menomonee Falls, Wisconsin, is the firm's fourth manufacturing plant. MTE specializes in the manufacture of power quality products such as Line/Load Reactors, Harmonic Suppressors and Motor Protection Filters.

MTE Corporation is a world leader in the design and manufacture of electrical power quality products for commercial and industrial applications. Whether offering protection of your desktop computing equipment or protecting the complete industrial facility from power line spikes, harmonic distortion or other disturbances, MTE has the most economical solution. With a worldwide network of distributors and sales representatives, MTE can handle all of your power quality and electrical transformer needs.

EMI/RFI Filters

- ✓ EMI Sources
- ✓ EMC Standards
- ✓ Solutions

RFI/EMI Filter Applications

- Adjustable Speed Drives

- Computers
- Automatic Lighting
- Telecommunications
- Laboratory Equipment
- Factory Automation
- Radio Controls
- Overhead Cranes
- AM Radio Equipment
- TVs and Monitors
- Energy Mgt Systems

Adjustable Speed Drives

Conducted Electromagnetic Interference Problems

Drive EMI Affects:

- Communication Links
- Control Signals
- Encoder Feedback
- Programmable Controllers
- Remote I/O
- Sensors
- Vision Systems

Adjustable Speed Drives

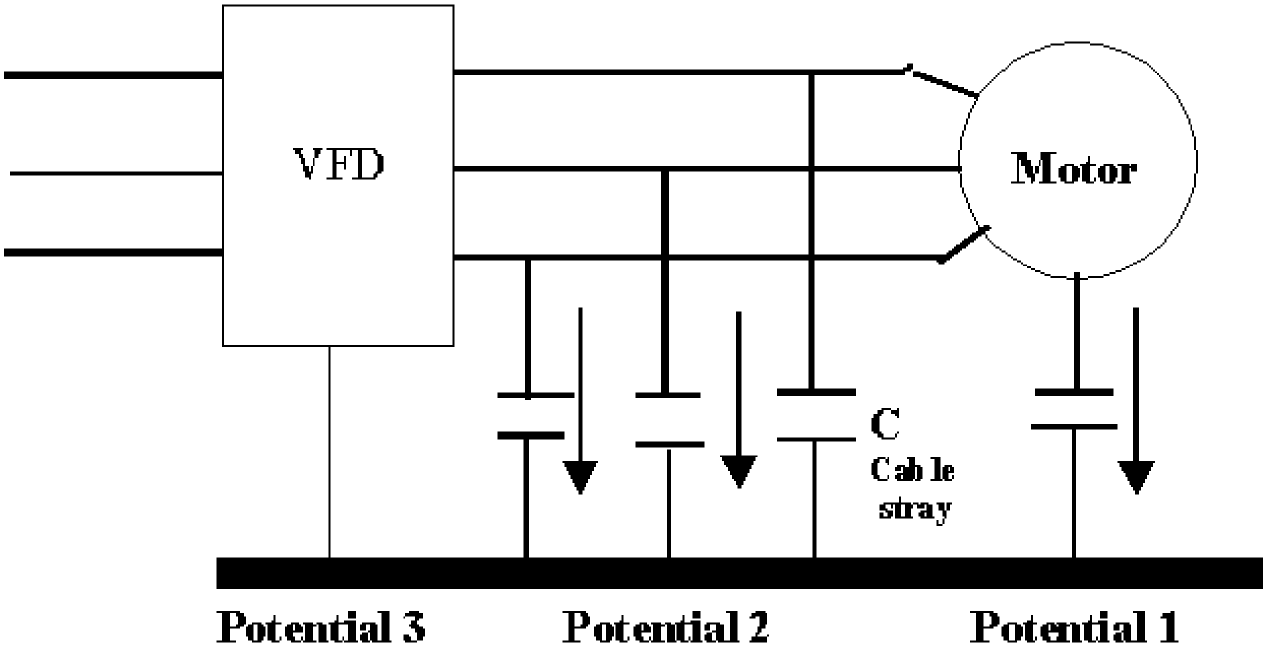
Conducted Electromagnetic Interference Problems

Power Switching Devices Cause EMI

- Improvements in static switching devices have led to higher speeds
- Higher speed devices generate more EMI
- The problem: Common mode high frequency noise

I = c dv/dt

Capacitive Coupled Noise Current from Unshielded Phase Conductor of VFD

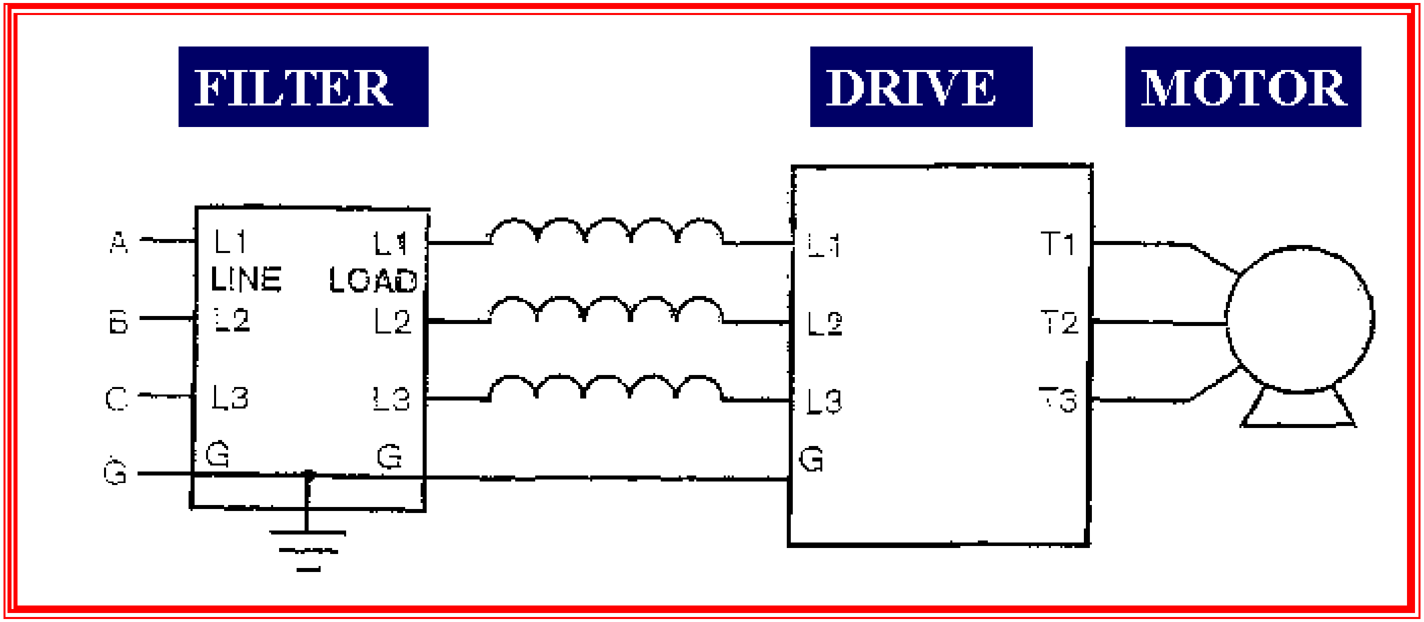


EMI Mitigation

- Wiring Practices
  - Shield power cables
  - Separate power and control
- EMI/RFI Filter
- Line Reactors

Required to achieve CE conformity

RFI/EMI Filter Connection Diagram for CE Conformance



RFI/EMI Filter Insertion Loss

- I.L. (dB) = 20 $\text{Log}_{10}\ V_{out}/V_{in}$
- 50 ohm source; 50 ohm load
- Useful for comparison
- Does not predict actual results

MTE CE Series Filters

Typical Insertion Loss

• 100 KHz	68 dB (uV)
• 150 KHz	72 dB (uV)
• 1 MHz	68 dB (uV)
• 10 MHz	67 dB (uV)

European (CE) RFI/EMI Filter Requirements

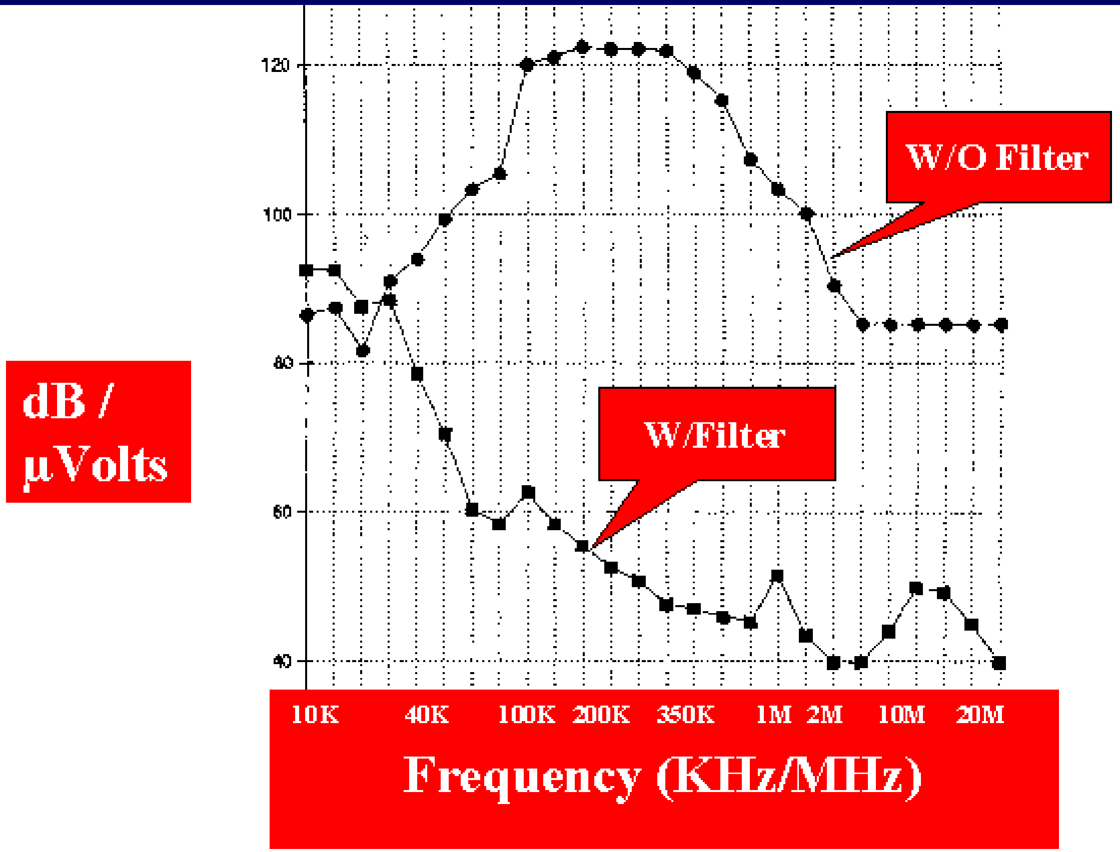
EMC Directive Limits

• 150 KHz - <500 KHz	66 dB (uV)
• 500 KHz - <5 MHz	60 dB (uV)
• 5 MHz - <30 MHz	60 dB (uV)

Typical CE Series RFI/EMI Filter Performance

Freq	50K	100K	150K	500K	1M	5M	10M	30M
Limits (dB)	66	66	66	60	60	60	60	60
VFDs (dB)	100	105	120	120	115	90	85	82
w/CE (dB)	70	58	59	45	43	40	40	40

PWM Drive RFI Interference



RFI/EMI Filters
FCC Limits

● 500 KHz - <2 MHz	60 dB (uV)
● 2 MHz - <30 MHz	70 dB (uV)

RFI/EMI Filter Selection

- Install on VFD input only
- Size for total RMS current:
  - w/o AC reactor (1.5 x fundamental)
  - w/3% AC reactor (1.1 x fundamental)
  - w/5% AC reactor (1.06 x fundamental)
- Select proper voltage rating
- Connect in parallel for higher current ratings

MTE Gives You...

- Delivery from stock
- Availability of high current ratings
- All standard voltages available
- Lowest installed cost
- High insertion loss
- A global delivery system

Line Reactors

- ✓ Purpose
- ✓ Harmonics Reduction
- ✓ Ratings Considerations

Line Reactors Increase Drive Reliability

- Minimize catastrophic drive failures due to transient over-voltages
- Minimize nuisance over-voltage trips due to line transients:
  - Utility power factor correction
  - Switching large AC motor loads
  - Switching large transformers
  - High AC line conditions

Line Reactors Increase Drive Reliability (cont)

- Minimize line-side fuse operation during unsymmetrical voltage sags:
  - Utility system line-to-ground faults
  - Unbalanced phase currents
- Reduce harmonics
- Improve effective power factor

Drive/Line Reactor Economics
(480 VAC User Prices)

10 HP AC Inverter	$ 1838
10 HP Motor	$ 552
Circuit Breaker	$ 362
Safety Switch	$ 105
Operator Control Station	$ 307
Input Reactor—NEMA I	$ 218
Installation	$ 1500
Total	**$ 4882**

Cost of Catastrophic Failure

10 HP Inverter	**$ 1838**
Labor	**$ 200**
Total	**$ 2038**
	+
	Down Time

Cost of Nuisance Trips

Labor	$ 50
	+
	Down Time

How Much Reactor Do I Need?

3% reactor eliminates 95% of nuisance trips

5% reactor eliminates 99+% of nuisance trips

Reactors Reduce Harmonic Distortion

Harmonic Number	INPUT IMPEDANCE						
	0.50%	1%	1.5%	2%	2.5%	3%	5%
5th	0.8	0.6	0.5	0.46	0.42	0.4	0.32
7th	0.6	0.37	0.3	0.22	0.2	0.16	0.12
11th	0.18	0.12	0.1	0.09	0.08	0.073	0.058
13th	0.1	0.075	0.06	0.058	0.05	0.049	0.039
17th	0.073	0.052	0.04	0.036	0.032	0.03	0.022
19th	0.06	0.042	0.03	0.028	0.025	0.022	0.008
% THD - I	102.5	72.2	59.6	52.3	47.6	44.13	34.96
Amps Increase	43%	23%	17%	13%	11%	9%	6%

Input harmonic current distortion depends on total input line impedance. (Data is for 6-pulse diode bridge).

Line Reactor Ratings

- Maximum voltage rating
- Thermal current rating — I_{RMS}
  - Must be $\geq$ VFD Input Current Rating
- Fundamental current rating — I_{FUND}
- Percent impedance =

$$\left(\frac{(100)\ \sqrt{3}\ \ 2\Pi\ f\ L}{V_{L}^{\ L}} \right) I_{\ FUND}$$

Line Reactor Ratings

- Maximum ambient temperature
- Maximum altitude without derating
- Temperature rise
- Maximum switching frequency
- dv/dt rating
- Dielectric strength
- Agency approvals

MTE Line Reactors

- Harmonic Compensated
- Impedance based on Fundamental amps
- TRMS Amp rating sufficient for VFD input current
- $\geq$16,000 volt/usec dv/dt rating
- CE, UL, cUL, CSA (1-1200 amps)

MTE Gives You...

- The lowest cost
- The lowest installed cost
- The full measure of impedance
- The most durable product
- Delivery from stock
- A global delivery system

Input Reactor Spec

Each variable frequency drive must be equipped with an input reactor offering no less than 4.5% effective impedance at rated motor amps (the fundamental current). They must be harmonic compensated and be UL-506 and UL-508 approved. Nema 1 enclosed units must be UL Listed. The continuous current rating of the reactor must be equal to or greater than the rms input current rating of the drive. Reactors must be copper wound with a UL class H (180 C) insulation system. They must be suitable for an ambient temperature of 45 C and a have a maximum temperature rise of 115 C. Their watts loss must be less than 1% of the rated load. Box lug type terminals must be provided on all reactors rated from 2 amps thru 400 amps. Higher current reactors may be supplied with copper tab type terminals. Reactor must be MTE Corporation type "RL" series.

Power Factor Correction Capacitor De-Tuning Reactor Specification

Each Power Factor Correction Capacitor Bank must be equipped with a series connected de-tuning reactor to prevent importation of harmonics. They must be UL-506 and UL-508 approved. Nema 1 enclosed units must be UL Listed. The reactor must be rated to handle 110% of the capacitor fundamental current continuously to compensate for capacitor tolerance and aging. It must also be rated to handle fifth harmonic current of a magnitude equal to 15% of the capacitor fundamental current rating. The nameplate must indicate the rated fundamental and harmonic currents and frequencies. Reactors must be copper wound with a UL class H (180 C) insulation system. They must be suitable for an ambient temperature of 40 C and a have a maximum temperature rise of 100C. When applied in an ambient of 25C their temperature rise must be only 80C. Their watts loss must be less than 1% of the capacitor KVAR rating. Box lug type terminals are acceptable on all reactors rated up to 50 amps. Reactors rated higher than 50 Amps must be supplied with copper tab type terminals. Reactor must be MTE Corporation type “RL” series.

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LOAD REACTORS

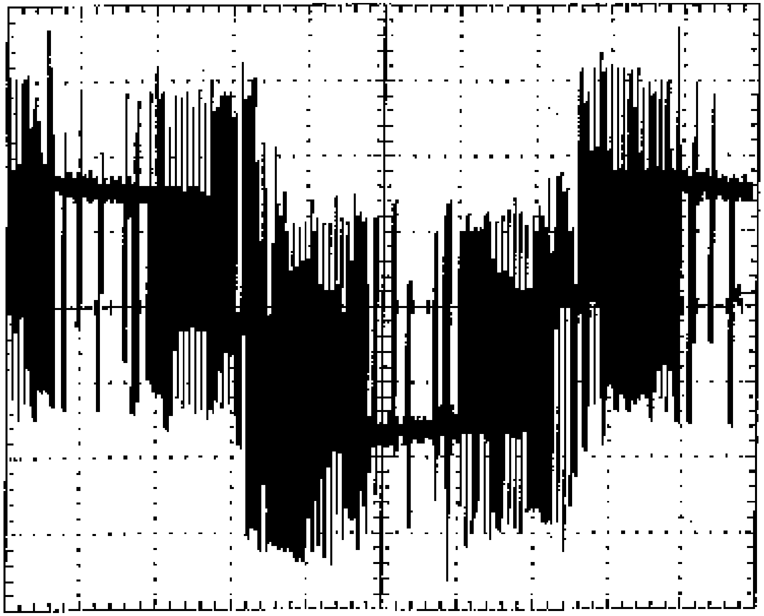
AC Load Reactors Increase Motor & Drive Reliability

- **Prevent premature motor insulation failures:**
  - Reduce peak voltage
  - Reduce turn to turn-over voltage
  - Minimize repetitive voltage stress

- **Reduced motor temperature:**
  - Increased motor insulation life (x2 to x4)

- **Output short circuit protection:**
  - Allows time for over-current shutdown circuits to act before power devices are destroyed

No Reactor
750 ft 240 V-60 Hz



Output Device = None

Circuit Length = 750 ft

Load = 3Ø 240V, 3-1/4 A

f_{SW} = 6KHz

f_{FUND} = 60 Hz

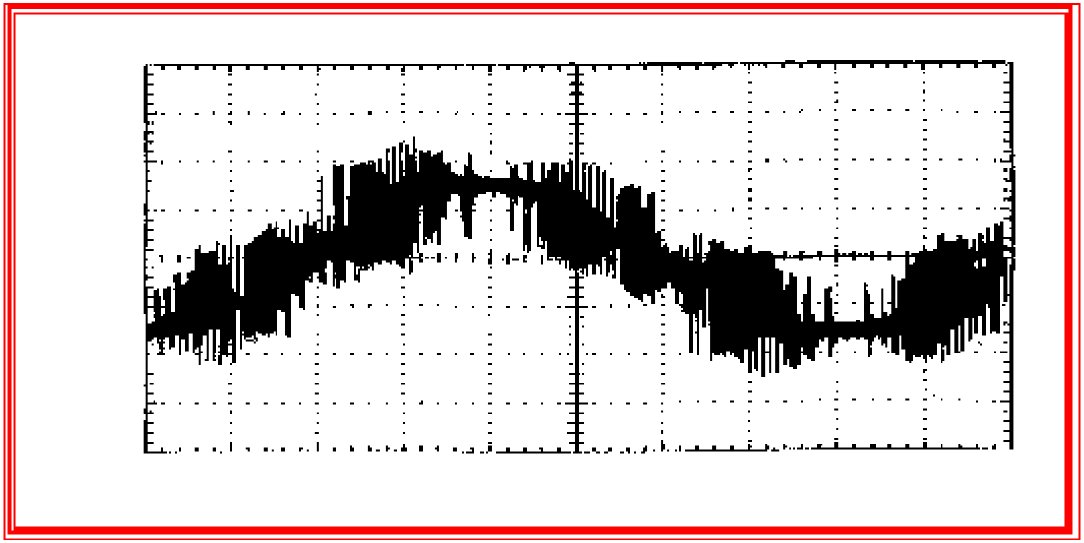
NEMA Design "B" Motor Specs

- 1000 volts peak (maximum)
- $\geq$ 2 μsec voltage rise time
- $\leq$ 500 V per μsec

NEMA Inverter Duty Motor Specs

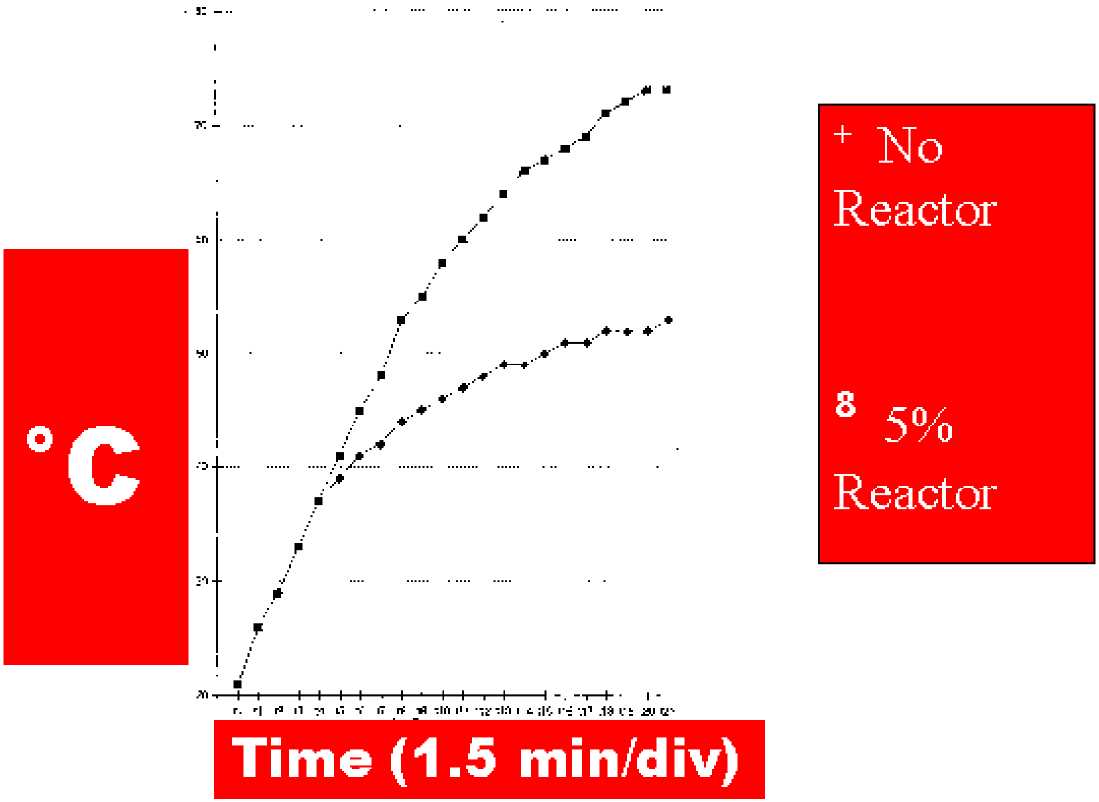
- 1600 volts peak (maximum)
- $\geq$ 0.1 μsec voltage rise time
- $\leq$ 16,000 V per μsec

5% Reactor, 1000 ft, PWM

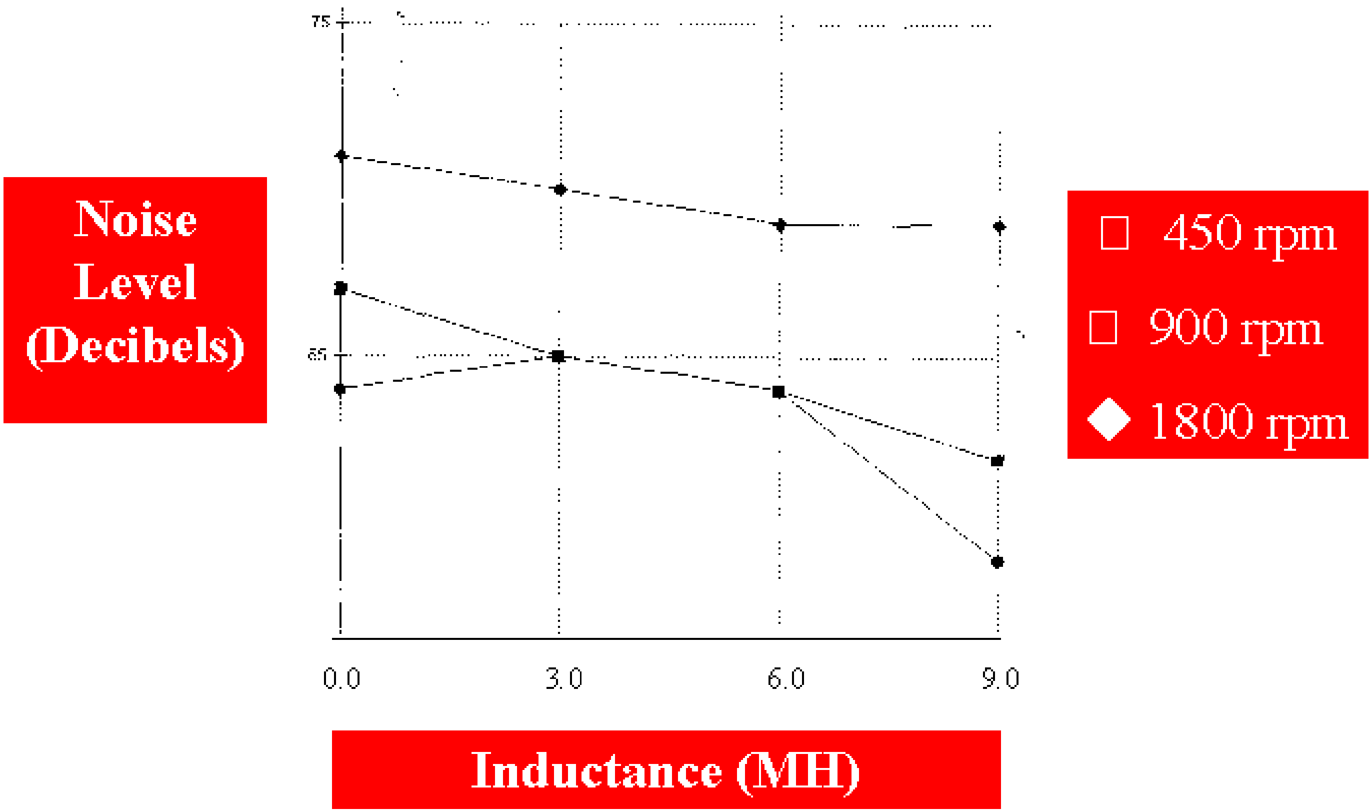


Rise Time ≥ 4μsec

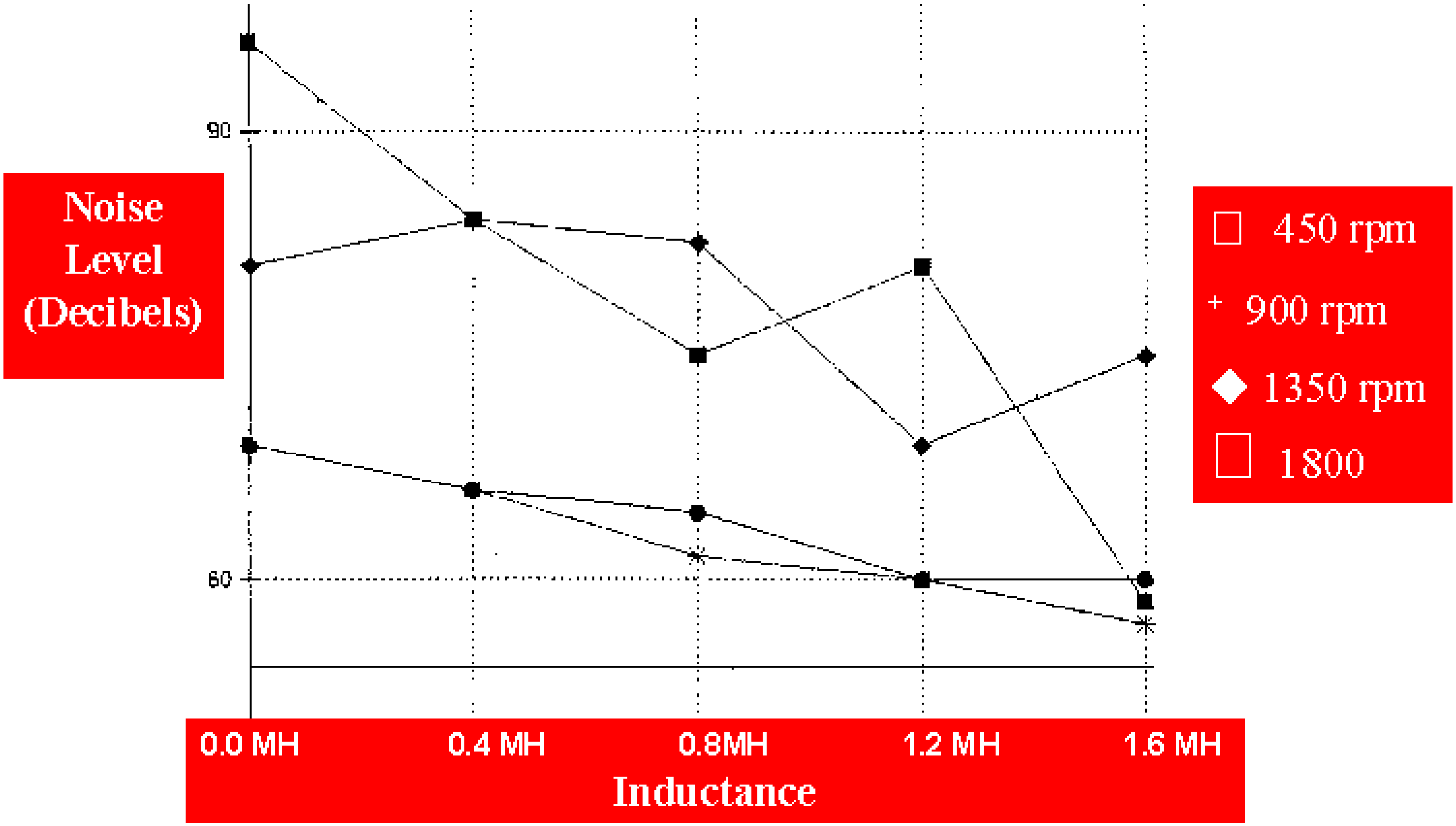
Reduction in Motor Temperature



AC Load Reactors Decrease Audible Noise: 5HP, 460V PWM



AC Load Reactors Decrease Audible Noise: 50 HP, 460V, PWM



Load Reactor Summary

- Low cost motor protection filter
- Low cost long lead filter
- MTE reactors can be used in both line and load applications
- Load reactors extend motor life
- Load reactors decrease motor noise

MTE Load Reactors

- IGBT Protected
- 16,000 volt/usec dv/dt rating
- 5600 V peak dielectric strength
- Suitable for switching frequencies up to 20Khz
- Same reactor line or load side

Load Reactor Spec

Each variable frequency drive must be equipped with an output reactor offering no less than 4.5% effective impedance at rated motor amps (the fundamental current). Output reactors must be IGBT protected to withstand spikes of 16,000 volts per microsecond. They must be high frequency compensated and suitable for use with switching frequencies up to 20KHZ. They must be UL-506 and UL-508 approved. Nema 1 enclosed units must be UL Listed. The continuous current rating of the reactor must be equal to or greater than the rms output current rating of the drive. Reactors must be copper wound with a UL class H (180 C) insulation system. They should be suitable for an ambient temperature of 45 C and a have a maximum temperature rise of 115 C. Their watts loss must be less than 1% of the rated load. Box lug type terminals should be provided on all reactors rated up to 400 amps. Higher current reactors may be supplied with copper tab type terminals. Reactor should be MTE Corporation type "RL" series.

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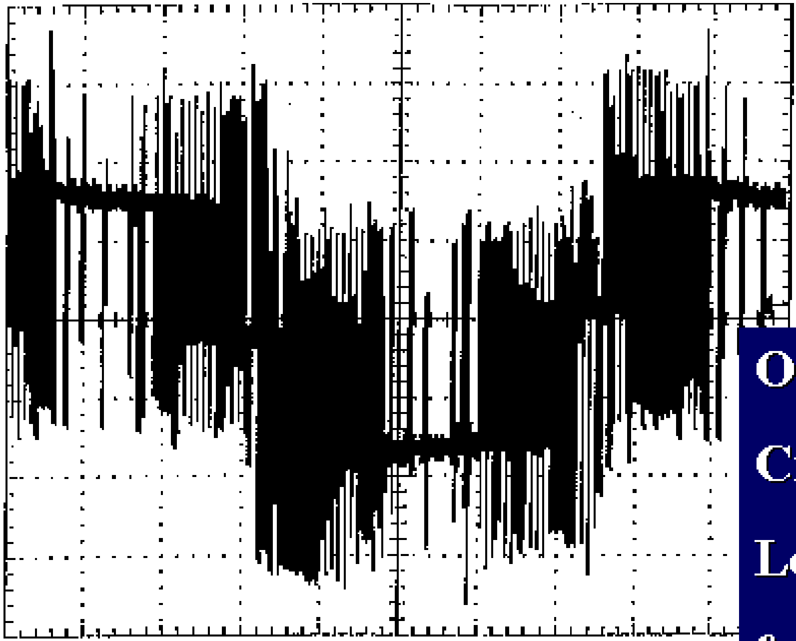
Motor Protection Filters

- ✓ Purpose
- ✓ Motor Specs
- ✓ Alternatives

MTE Motor Protection Filters...

- Eliminate motor repetitive voltage stress failures
- Eliminate long lead motor over voltage problem

Drive Output Voltage



Output Device = None

Circuit Length = 750 ft

Load = 3Ø 240 V, 3-1/4 A

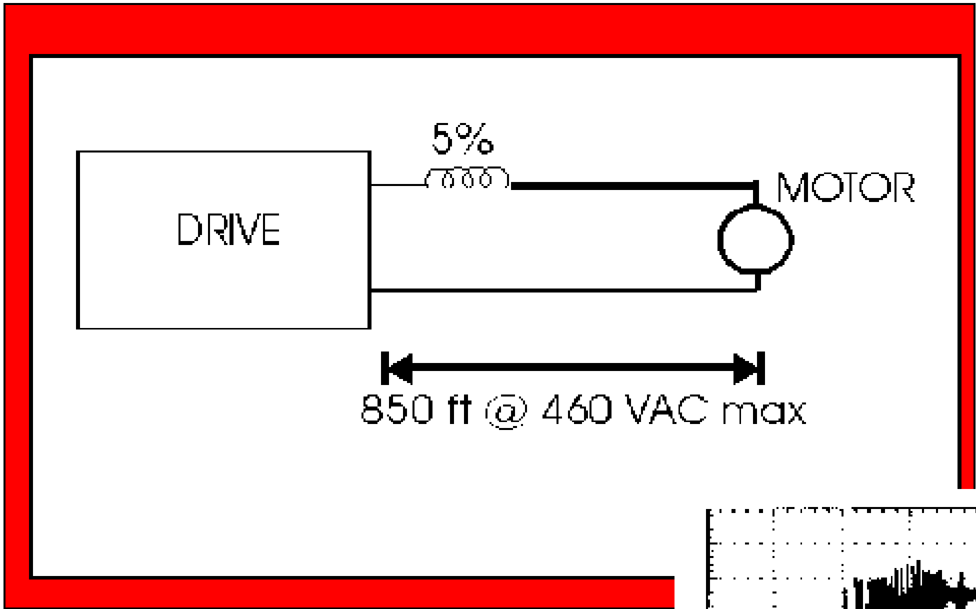
f_{SW} = 6KHz

f_{FUND} = 60 Hz

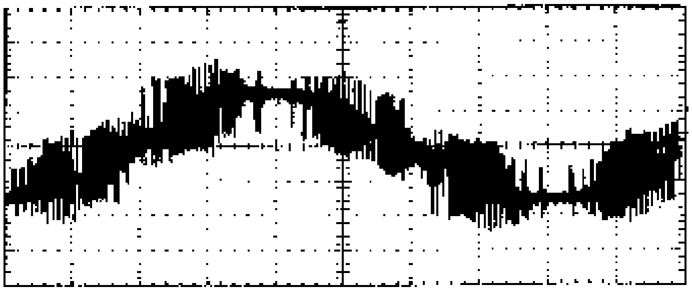
Motor Protection Filter Options

- Single element low pass filter
- High frequency snubber
- Dual element low pass filter

Single Element Low Pass Filter



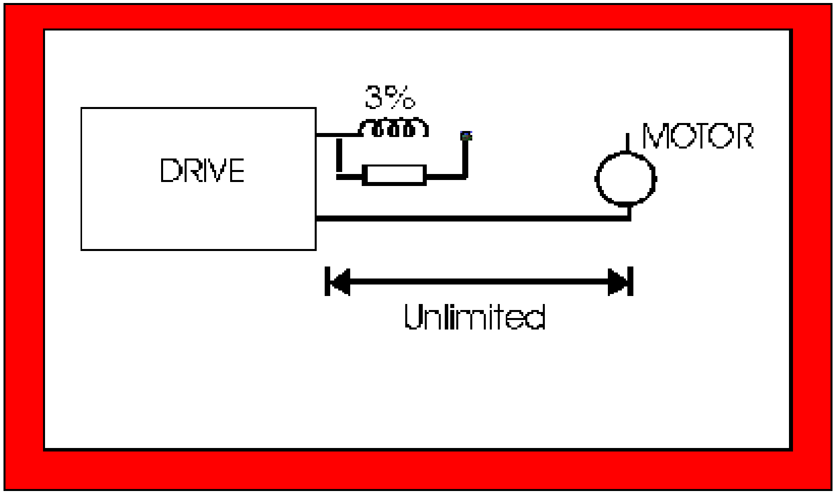
**5% Reactor,
1000 ft,
240V--60 Hz,
6KHz**



Rise Time $\geq$ 4µsec

$f_{SWITCH} \leq 20$ KHz

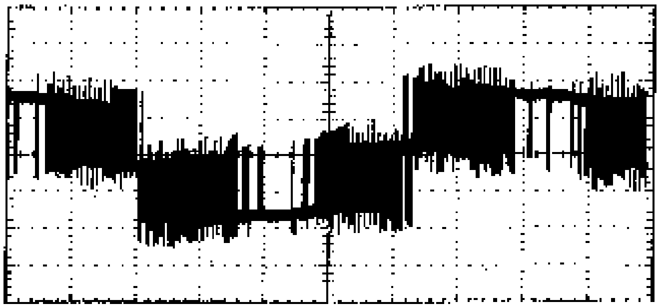
High Frequency Snubber



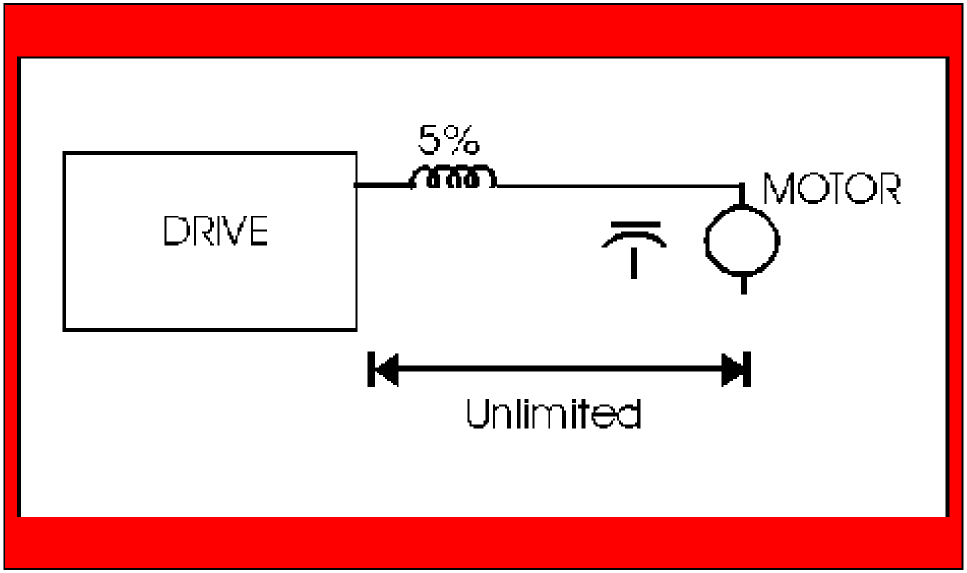
1000 ft,
240V—60 Hz,
3KHz

Rise time $\geq$ 2µsec

$f_{SWITCH} \leq$ 3.75KHz



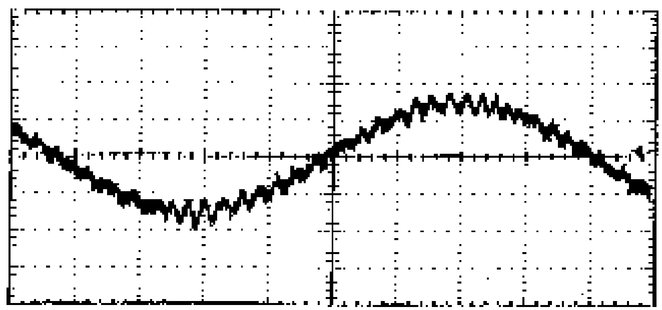
Dual Element Low Pass Filter



LC Filter,
1000 ft,
240V--60 Hz,
6KHz

Rise Time $\geq$ 2µsec

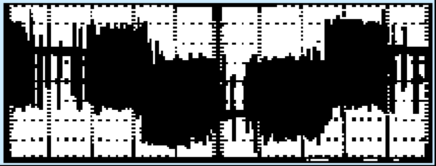
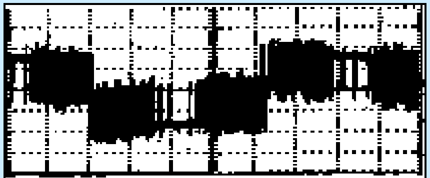
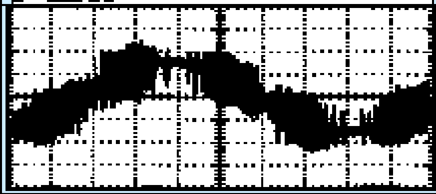
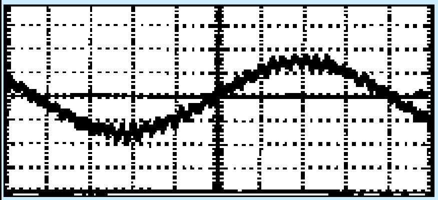
5KHz $\leq f_{SWITCH} \leq$ 20KHz



MTE Gives You...

- The lowest utilization cost
- Full range of solutions:
  - Reactors
  - Snubbers
  - Sine wave filters
- Total motor insulation protection
- The most durable product available
- Stocked components
- A global delivery system

Motor Protection Filter Alternatives

OPTION	WAVEFORM	COST (5HP/460v)
Do Nothing		$0
MTE Snubber		$278
MTE 5% Reactor		$153
MTE Motor Protection Filter		$233

Output Reactor Spec

Each variable frequency drive must be equipped with an output reactor offering no less than 4.5% effective impedance at rated motor amps (the fundamental current). Output reactors must be IGBT protected to withstand spikes of 16,000 volts per microsecond. They must be high frequency compensated and suitable for use with switching frequencies up to 20KHZ. They must be UL-506 and UL-508 approved. Nema 1 enclosed units must be UL Listed. The continuous current rating of the reactor must be equal to or greater than the rms output current rating of the drive. Reactors must be copper wound with a UL class H (180 C) insulation system. They must be suitable for an ambient temperature of 45 C and a have a maximum temperature rise of 115 C. Their watts loss must be less than 1% of the rated load. Box lug type terminals must be provided on all reactors rated from 2 amps thru 400 amps. Higher current reactors may be supplied with copper tab type terminals. Reactor must be MTE Corporation type “RL” series.

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Motor Protection Filters

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Harmonic Filters

- ✓ **Effects of Harmonics**
- ✓ **IEEE-519**
- ✓ **Solutions**

Typical VFD Harmonics

Without using any filtering techniques

1 - 20 HP	> 100 %
25 - 40 HP	80 - 100 %
50 - 150 HP	60 - 80 %
200 HP and up	50 - 70 %

Typical VFD Harmonics

Depends on Input Line Impedance

Harmonic Number	INPUT IMPEDANCE						
	0.50%	1%	1.5%	2%	2.5%	3%	5%
5th	0.8	0.6	0.5	0.46	0.42	0.4	0.32
7th	0.6	0.37	0.3	0.22	0.2	0.16	0.12
11th	0.18	0.12	0.1	0.09	0.08	0.073	0.058
13th	0.1	0.075	0.06	0.058	0.05	0.049	0.039
17th	0.073	0.052	0.04	0.036	0.032	0.03	0.022
19th	0.06	0.042	0.03	0.028	0.025	0.022	0.008
% THD -I	102.5	72.2	59.6	52.3	47.6	44.13	34.96
Amps Increase	43%	23%	17%	13%	11%	9%	6%

Problems Caused by Harmonics

- Elevated RMS current
- Circuit Breaker Trips
- Nuisance Fuse Operation
- Reduced Equipment Life
  - Transformers, Conductors, Breakers, Switches
- Equipment Malfunctions
- High Frequency Currents
- Reduces Effective Power Factor

IEEE - 519

I_{SC}/I_L	< 11	$11 \le h < 17$	$17 \le h < 23$	$23 \le h < 35$	$35 \le h$	TDD
< 20	4.0	2.0	1.5	0.6	0.3	5.0
$20 < 50$	7.0	3.5	2.5	1.0	0.5	8.0
$50 < 100$	10.0	4.5	4.0	1.5	0.7	12.0
$100 < 1000$	12.0	5.5	5.0	2.0	1.0	15.0
> 1000	15.0	7.0	6.0	2.5	1.4	20.0

IEEE - 519

- **PCC = At Point of Metering**

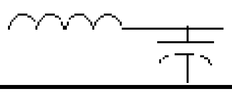
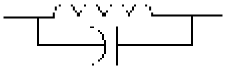
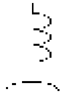
- **PCC = Point Where Non-Linear Load Meets Linear Loads**

IEEE - 519

- TDD = Magnitude of harmonic distortion as a percent of maximum demand current

- THD = Instantaneous value of harmonic distortion

Harmonic Filtering Techniques

TECHNIQUE	Low Pass (Broad Band) Harmonic Filter	Series Passive Harmonic Filter	Shunt Passive (Tuned) Harmonic Filter	Series Passive AC Input Reactor
INSTALLATION				
HARMONIC FREQUENCIES FILTERED	• All Frequencies Above Resonant Frequency	• Specific Tuned Frequency Example: 3rd Harmonic, 5th Harmonic	• Specific Tuned Frequency Example: 5th Harmonic, 7th Harmonic, 11th harmonic	• All harmonic frequencies, by varying amounts
ADVANTAGES	• Minimizes ALL harmonic frequencies	• High impedance to tuned frequency	• Low impedance to tuned frequency	• Low cost
	• Supplies all harmonic frequencies to load rather than from AC source	• Popular for 1-phase applications to minimize 3rd harmonic	• Supplies specific harmonic component to load rather than from AC source	• Improves True power factor
	• Does not introduce any system resonance	• Does not introduce any system resonance	• Quite effective for the specific tuned frequency	• Small size
	• Does not import harmonics from other sources	• Does not import harmonics from other sources	• Only required to carry harmonic current, not full load current	• Will not import harmonics from other non-linear loads
	• Does not require existing power system analysis	• Does not require existing power system analysis	• Improves displacement power factor	• Will not create system resonance
	• Improves displacement power factor	• Improves displacement power factor	• Improves True power factor	• Protects against power line disturbances
	• Improves True power factor	• Improves True power factor		
DISADVANTAGES	• Must handle the rated full load current	• Must handle the rated full load current	• Only filters a single (tuned) harmonic frequency	• Must handle the rated full load current
	• Can supply non-linear loads only	• Minimally effective other than tuned harmonic frequencies	• Can create system resonance	• Can only improve harmonic current distortion to 30-40% at best
		• Can supply non-linear loads only	• Can import harmonics form other non-linear loads	
			• Multiple filters required to satisfy typical desired harmonic limits	• Slightly reduces displacement power factor
			• Harmonic analysis required prior to adding this filter to the power system	

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Harmonic Mitigation Alternatives

5 % Line Reactor	30 - 35 % THID
5% Line Reactor + 3% DC Choke	25 - 30 % THID
5th Tuned Harmonic Trap	20 - 30 % THID
5th + 7th Tuned Harmonic Traps	12 - 20 % THID
12 - Pulse Drive (balanced line currents)	15% THID
18 - Pulse Drive (balanced line currents)	< 5 % THID
Broad Band Harmonic Filters	8 - 12 % THID

Shunt Filter (Traps) Disadvantages

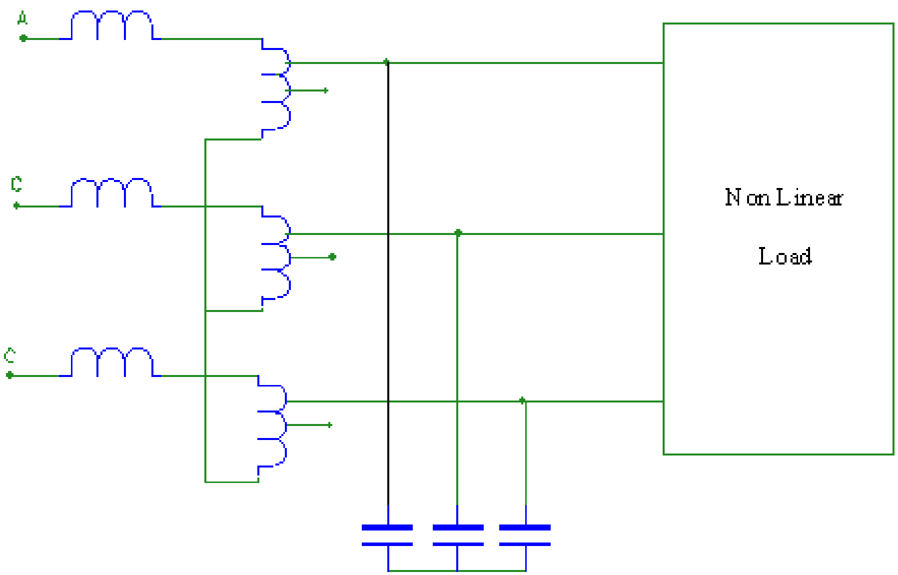
- System Resonance
- Import Harmonics
- Overvoltage at light load

Shunt Filter (Traps) Disadvantages

- Multiple Sections Required to Meet IEEE - 519
  - (5th, 7th, 11th)
- System Analysis Required

Broad Band Harmonic Filter

Broad Band Harmonic Filter



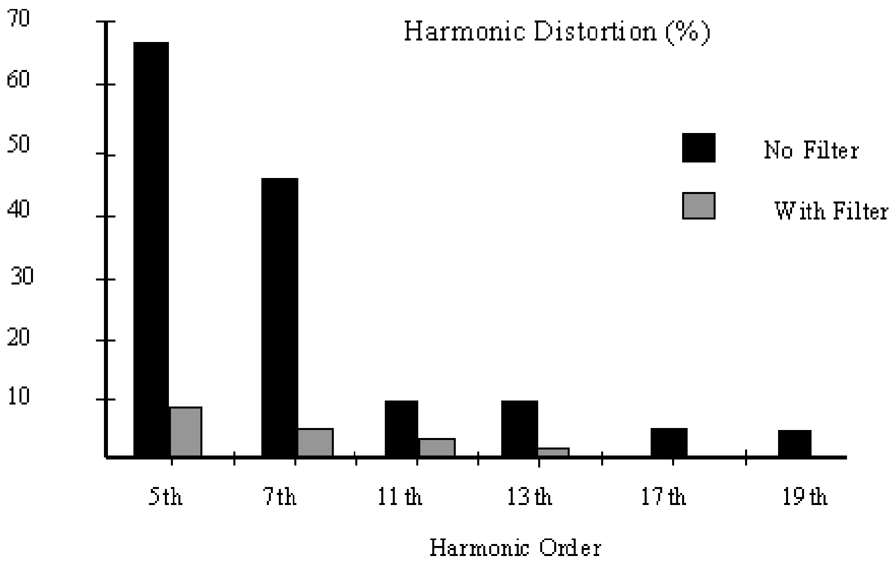
Broad Band Harmonic Filter

- Guarantees $\leq$ 12% THID at Input
  - $\leq$ 8% Available at Premium
- No System Analysis Required
- No System Resonance
- No Harmonics Imported
- Filters All Harmonic Frequencies

Where to Use Broad Band Harmonic Filters

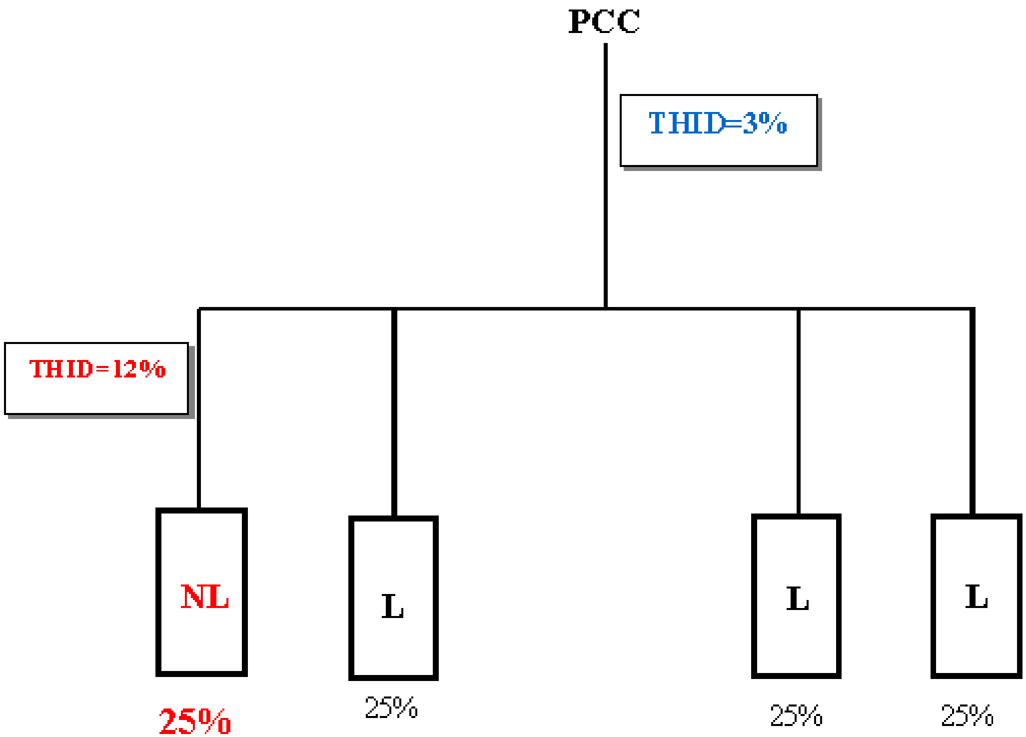
- **AC Variable Frequency Drives**
  - **Variable Torque Applications**
  - **6-Diode Input Rectifier Bridge**
  - **Fan & Pump Applications**
- **For Non-Linear Loads Only**

Broad Band Harmonic Filter

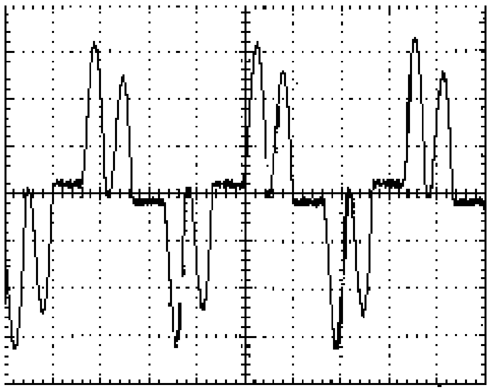


Actual Application Data - 10HP / 460 V

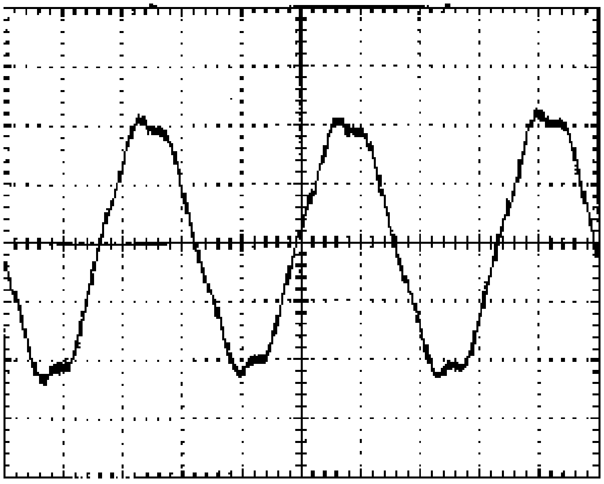
Linear Load Mitigation



Broad Band Harmonic Filter Performance



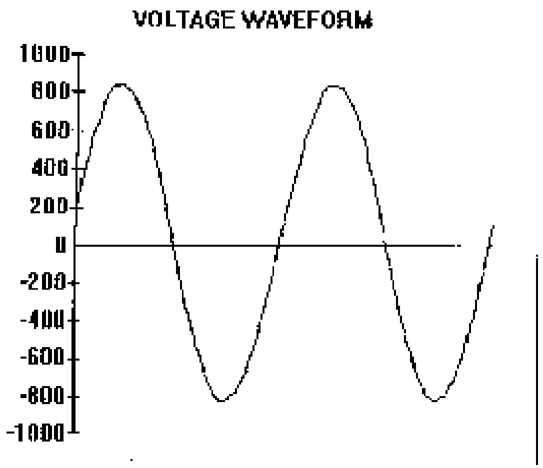
VFD Input Current Without Filter

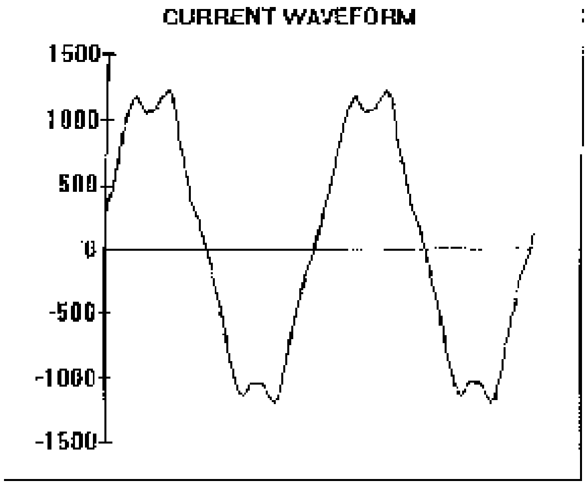


VFD Input Current With Filter (9.1% THID)

Actual Application Data - 10 HP / 460 Volts

Broad Band Harmonic Filter Performance





THVD = 1.6 %

THID = 9.8 %

Actual Application Data: 1000 Hp, 600 V

IEEE - 519 Solutions

Desired % THID at PCC (IEEE-519)	3% Line Reactor	5% Line Reactor	3% Line + 3% DC Reactors	5% Line + 3% DC Reactors	BBHF (12% Max)	BBHF (8% Max)
	Maximum VFD Load if all VFD's use same Harmonic Mitigation Method					
5	11	14	15	18	42	63
8	18	23	24	29	67	100
12	27	34	36	43	100	100
15	34	43	45	54	100	100
20	45	57	61	71	100	100

Harmonic Filter Costs

Solution	Expected THD - I	Cost of 150HP VFD + Solution
5% Line Reactor	25-35%	$15K
5th Harmonic Trap	15-30%	$20K-$21K
5th + 7th Traps	10-20%	$22K - $24K
12-Pulse Drive	* 15%	$22K
18 - Pulse Drive	* < 5%	$23K
Broad Band Filter	8 - 12%	$17K - $19K

* Based on balanced line voltages.

MTE Gives You...

- MTE guarantees ≤ 12% THID
- No adverse system interaction
- Best performance to cost ratio
- No system analysis required
- A global delivery system

Harmonic Filters

Each variable frequency drive (VFD) supplied for fan and pump or other variable torque loads must be supplied with a harmonic suppressor to reduce the total harmonic current distortion to 12% or less at the filter input terminals. The suppressor operation must be independent of and it must not interact with the power system or source impedances including power factor correction capacitors. The suppressor must not import harmonics from any other sources. The suppressor must not create a system resonance condition. The suppressor must not increase facility electrical system voltage under any loading conditions. The suppressor must improve true power factor to 90% minimum (lagging or leading). Leading power factor is acceptable provided that it does not cause the system voltage to be elevated. The watts loss of the suppressor must be no more than 4% of the load for which it is rated. The harmonic suppressor must be MTE Corporation type DBF Broad Band Harmonic Filter.

EC Declaration of Conformity

COMPANY: MTE CORPORATION

ADDRESS: W147 N9525 HELD DRIVE
MENOMONEE FALLS, WI 53051-1640
UNITED STATES OF AMERICA

PRODUCT: AC LINE/LOAD REACTOR (COMPONENTS)

The first two letters in the part numbers of covered products are "RL" with a format of RL-###### or RLX-####-###.

The above products are manufactured to meet applicable portions of industry standards EN 60076 (IEC 76), UL 506, UL 508, and CSA 22.2 No. 66-1988.

Thus meeting the requirements for the low voltage directive (73/23/EEC as amended by 93/68/EEC)

MTE Corporation
March 6, 1999

Bruce Schram
Engineering Manager

Protect Your Motor From Long VFD Output Circuits!

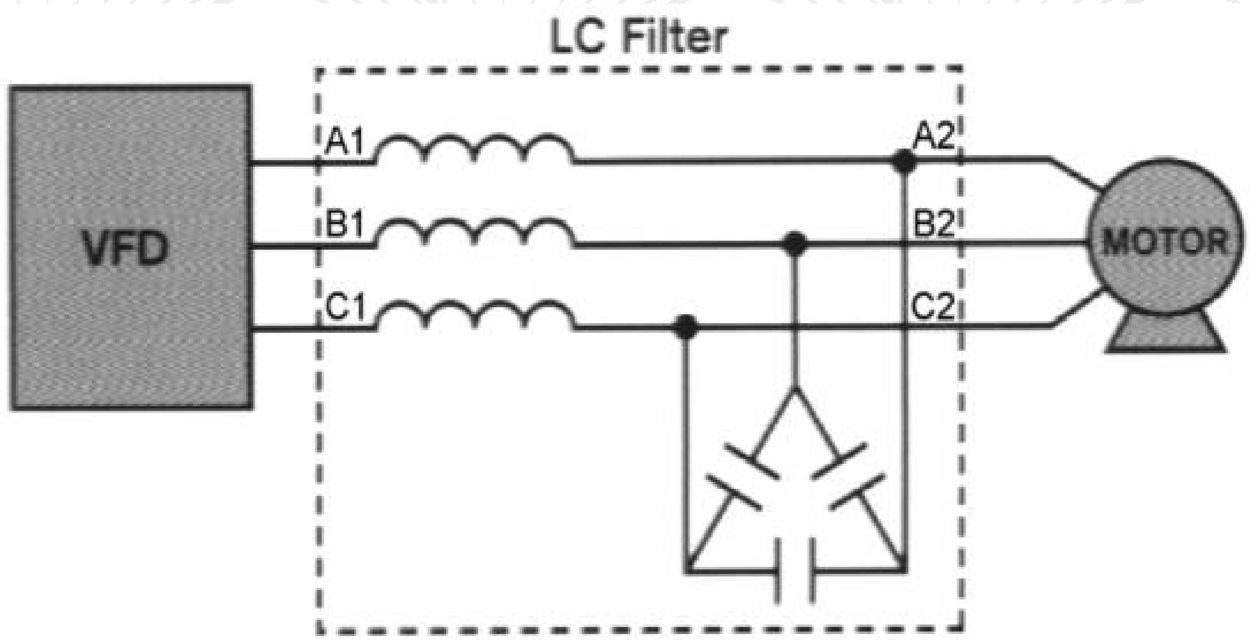
Guard your motor's insulation system against stress caused by high voltage peaks and dv/dt often experienced with use of a VFD at long distance from the motor.

Selection and Use of the MTE Motor Protection Filter
(LC Sine Wave Type)

Verify that the sine wave filter is compatible with your application:

- VFD switching (carrier) frequency set in range of 5kHz to 20kHz?
- VFD output frequency 60Hz or less?
- Ambient temperature 40°C or less?
- Altitude 1,000 meters or less?
- 480V (up to 600HP) or 600V (up to 20HP) supply?

If you can answer yes to the questions above, apply the appropriate standard MTE Motor Protection Filter. Select based on motor HP/voltage rating. The connection is shown below. **Please note that improper connection can cause damage to the components of filter or drive. Capacitor connections must be on the "motor side" of the reactor.**



Selection:

The filter model selection is based on the HP and Full Load Amp rating from the motor's nameplate. The Motor Protection Filter's fundamental current rating must be as close as possible to the motor FLA. The first three digits of the filter's catalog number indicate its fundamental current rating. Care should be taken in selection, as significant oversizing or undersizing of the filter may cause damage to the filter components.

The Motor Protection Filter design requires that the impedance of the motor load be within a certain value relative to the current rating of the filter. The filter must be selected to match the motor. If the filter is much larger than necessary, it will not be matched to the motor, and is misapplied.

Location:

Consider that the output filter is a heat source, and should be installed a suitable distance from combustible surfaces.

In some applications, the filter can produce high-frequency audible noise, so installation near workstations, living areas, or on ductwork should be avoided.

Installation of the output filter is typically near the VFD, but may be at the motor or anywhere on the output circuit. Locating the filter at the VFD is usually most convenient, and is the best location for protecting output circuit wiring and VFD output semiconductors.

Association Memberships

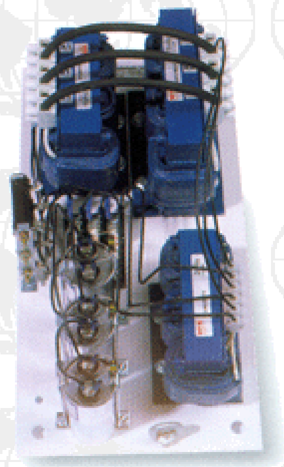
ASSOCIATION	MEMBERS
ASHRAE	MTE Corporation & John Houdek
IEEE Networking the World™	Various MTE Corporation Engineers
Rockwell Automation Encompass Americas Partner	MTE Corporation

NOTE: These links will open a browser window (you must have a connection to the internet to access the website).

New MTE Corporation Matrix™ Harmonic Filters Announced

Contact-. Mr. John Houdek, (262) 253-8200

New MTE Corporation Matrix™ Harmonic Filters
Offer Harmonics Reduction in 6-Pulse Rectifier Applications
At nearly half the cost of previous broad-band harmonic filtering technology



Menomonee Falls, WI - **Matrix™ Low Pass Harmonic Filters** from MTE Corporation substantially reduce harmonic current distortion and improve true power factor in a wide variety of six-pulse rectifier applications while offering dramatically lower cost, smaller size and greater energy efficiency than former broad band technology harmonic filters.

The Matrix™ Filter improves upon former broadband harmonic filtering techniques and broadens the range of suitable applications. Matrix™ Harmonic Filters can be applied on SCR rectifiers, including phase control and pre-charge front ends, as well as six-pulse rectifiers using AC line reactors or DC chokes.

The new filters minimize harmonic distortion in applications involving fans, pumps, water treatment facilities, HVAC systems, DC motor drives, AC motor drives, diode or SCR rectifiers, rectifier type welders, induction heating equipment, uninterruptible power supplies and elevators/controls.

Matrix™ Harmonic Filters provide guaranteed performance levels of either 12% or 8% total harmonic current distortion and can be used to meet IEEE-519 and other harmonic standards. Harmonic distortion levels are guaranteed at the input terminals to the filter from "no load" to "100% load". Harmonics will typically be lower upstream.

The new filters accomplish broadband harmonic filtering with about half the capacitance of former broadband filters. This minimizes leading current under light load conditions and improves compatibility with standby power generators.

The MTE Matrix™ Harmonic Filters perform equally well on virtually all types of six-pulse rectifiers, including six-diodes, 6 - SCRs, or 3 - diodes with 3 SCRs. They are suitable for use with both SCR pre-charge power supplies and full phase control front ends.

MTE Corporation offers a wide variety of power quality solutions designed to improve the reliability and performance of variable speed drive systems and to minimize interference with other sensitive electronic equipment.

MTE products are available and supported worldwide from factory offices/warehouses and through a network of Sales Representatives and Authorized Distributors.

Archived News Releases

- Milestone: 250th "Harmonic Suppressor" Sold
- European Expansion
- New Manufacturing Facility

Economical Solutions to Meet Harmonic Distortion Limits

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Abstract: The widespread adoption of variable frequency drive technology is allowing electricity to be utilized more efficiently throughout most of the world. Following right behind the adoption of drives is the establishment of harmonic distortion limits. This can cause confusion and may instill needless fear in people involved in the decision to apply variable frequency drives. While the drive utilizes electricity most efficiently, drives are also known to cause harmonic distortion on the power system. This paper suggests economical solutions for meeting harmonic distortion limits while improving the reliability of the facility power system. Various solutions are presented along with their typical performance characteristics. Included are guidelines for applying the various solutions, expected residual harmonic levels for the various solutions, as well as a simplified approach to system harmonic analysis.

I. INTRODUCTION

Electric utilities, consulting engineers and major production or process facilities throughout the world are readily adopting various harmonic distortion standards. Frequently, harmonic distortion limits are imposed on new electrical equipment which will be added to the power system. In continental Europe, EN 61800 may be referenced in new drive installations. In the USA, IEEE-519 is frequently imposed. In Australia, AS 2279 is the common standard, and In England, the British Standard G5/3 is the driving force behind harmonic distortion limitations.

II. POINT OF EVALUATION

The various standards may consider different points on the electrical system at which the measurement of harmonics will be considered. In some cases, it will be at the utility metering point or incoming transformer while in others the measurement point may be right at the actual piece of equipment being added. Typically, different harmonic limits are imposed depending on whether the measurement is taken at the equipment or at the facility power input source.

The point at which the harmonic limits are applied is typically referred to as the Point of Common Coupling (PCC). When the input transformer (primary) is the point of measurement, then the PCC refers to this point where the facility electrical system is common to the facilities of additional consumers. If there is distortion present on the electrical power system at this point, it may be experienced by the neighboring facilities as well.

In other cases, the PCC may be defined at a piece of equipment or on a particular mains bus in the facility. These loads have common electrical connection (through the bus) to other loads within the facility. If harmonic distortion appears at this PCC, then it will also be experienced by the other loads which are supplied by this bus.

III. HARMONIC CURRENT DISTORTION

Whenever loads draw current in a non-linear manner, such as that experienced with rectifier based equipment, harmonic distortion is commonly experienced. The amount of current distortion will depend on the size of this non-linear load in relation to the capacity of the electrical power source. Input circuit impedance helps to reduce the input current distortion. For this reason, many drive users add impedance to the drive in the form of a line reactor.

Typical levels of total harmonic current distortion (THID) for six pulse rectifiers are listed in Figure 1. The *% THID* is representative of drives which do not have any means of filtering included in the input circuit.

KW	% THID
≤ 15 KW	> 100 %
18 - 30 KW	80 - 100 %
37 - 112 KW	60 - 80 %
> 150 KW	50 - 70 %

Fig. 1

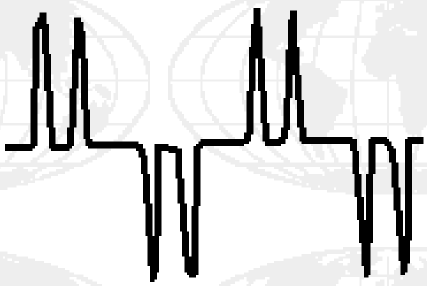

Fig. 2 Actual input current waveform for six pulse VFD without any filtering.

IV. AC INPUT LINE REACTORS

The input harmonic current distortion can be reduced significantly by the simple addition of input line reactance. The inductive reactance of an input line reactor allows 50hz or 60hz current to pass easily but presents considerably higher impedance to all of the harmonic frequencies. Harmonic currents are thus attenuated by the inductive reactance of the input reactor. *Figure 3* illustrates the expected harmonic current distortion for six pulse input rectifier type drives (VFD) having various amounts of total input reactance (inductive impedance).

Input Impedance	THID
< 1 %	> 75 %
2%	52%
3%	45%
4%	40%
5%	35%
8%	28%

Fig. 3

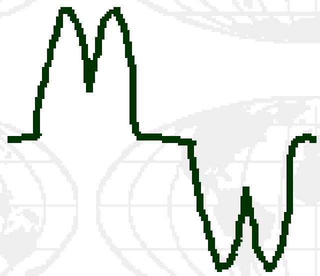

Fig. 4 Actual input current waveform for six pulse VFD with 3% line reactor.

Input impedance may consist of source impedance (upstream transformer), line reactor and / or DC link choke. The 8% data reflects the performance of a typical VFD when a combination of a 3% impedance DC link choke and a 5% impedance AC line reactor are used. It is easy to see how the simple addition of either a line reactor or equivalent DC link choke can have a significant effect on the input harmonic current distortion of a six pulse VFD. Reactors are by far, the most economical means of reducing input current distortion on a drive system.

The actual distortion at the main input (metering point) will vary depending on the system impedance and the distribution of loads (linear vs. non-linear). Figure 5 is a chart that indicates the expected current distortion levels at the PCC for various combinations of linear and non-linear loads. Add up the total motor and other linear loads plus VFD loads to determine the total load. Divide the VFD load by the total load. Look up this number in the % VFD load column and read the distortion level (at PCC) for the appropriate line reactor ahead of each drive. This will result in a conservative number because any additional source impedance will cause the actual distortion to be even lower.

It is important to note that whenever one is considering the impedance of a reactor, it is the effective impedance that does the work, not the rated impedance. Effective impedance is based on the actual fundamental current which is flowing and the actual inductance of the reactor.

Effective impedance (percent) =

$$\frac{\underline{L \text{ x } f \text{ x } 2 \text{ x pi x } 1.732 \text{ x Fundamental amps}} \text{ x } 100}{\text{Volts (line – to – line)}}$$

Figure 5 quantifies the expected levels of % THID at PCC for various non-linear load content (% non-linear load at PCC).

% VFD Load at PCC	3% Impedance at each VFD	5% Impedance at each VFD
10	4.4	3.5
20	9	7
30	13	11
40	18	14
50	22	18
60	27	21
70	31	25
80	35	28
90	40	32
100	44	35

Fig. 5

It is easy to predict the current distortion at the PCC when each VFD employs the same filtering technique (such as line reactors). If 5% impedance line reactors are installed on the input of each VFD, then the input current distortion would be ≤ 35% depending on the amount of source impedance (in addition to the line reactor). If the electrical load was entirely made up of VFDs, each having a 5% impedance line reactor, then the distortion at the PCC would simply be

35% THID x 100%VFD / 100% total load = 35% THID at the PCC.

Now if the same VFDs were only 20% of the total load at the PCC, then

35% THID x 20% VFD / 100% Total Load = 7% THID at PCC.

V. HARMONIC FILTERS

In some cases, reactors alone will not be capable of reducing the harmonic current distortion to the desired levels. In these cases, a more sophisticated filter will be required. The common choices include shunt connected, tuned harmonic filters (harmonic traps) and series connected low pass filters (broad band suppressors).

Harmonic traps have been used for nearly thirty years. They consist of a capacitor and an inductor which are tuned to a single harmonic frequency. Since they offer a very low impedance to that frequency, the specific (tuned) harmonic current is supplied to the drive by the filter rather than from the power source. If tuned harmonic filters (traps) are selected as the mitigation technique, then you may need multiple tuned filters to meet the distortion limits which are imposed.

When employing tuned harmonic filters, you will also need to take special precautions to prevent interference between the filter and the power system. A harmonic trap presents a low impedance path to a specific harmonic frequency regardless of its source. The trap cannot discern harmonics from one load versus another. Therefore, the trap tries to absorb all of that harmonic which may be present from all combined sources (non-linear loads) on the system. This can lead to premature filter failure.

Since harmonic trap type filters are connected in shunt with the power system, they cause a shift in the power system natural resonant frequency. If the new frequency is near any harmonic frequencies, then it is possible to experience an adverse resonant condition which can result in amplification of harmonics and capacitor or inductor failures. Whenever using harmonic trap type filters, one must always perform a complete system analysis. You must determine the total harmonics which will be absorbed by the filter, the present power system resonant frequency, and the expected system resonant frequency after the filter (trap) is installed. Field tuning of this filter may be required if adverse conditions are experienced.

VI. LOW PASS HARMONIC SUPPRESSORS

Low pass harmonic filters, also referred to as broad band harmonic suppressors, offer a non-invasive approach to harmonic mitigation. Rather than being tuned for a specific harmonic, they filter all harmonic frequencies, including the third harmonic. They are connected in series with the non-linear load with a large series connected impedance, therefore they don't create system resonance problems. No field tuning is required with the low pass filter.

Due to the presence of the large series impedance, it is extremely difficult for harmonics to enter the filter / drive from the power source. Rather they are supplied to the drive via the filter capacitor. For this reason, it is very easy to predict the distortion levels which will be achieved and to guarantee the results.

A low pass (broad band) harmonic filter can easily offer guaranteed harmonic current levels, right at the drive / filter input, as low as 8% to 12% THID. (To achieve 8% maximum current distortion one can typically select the broad band harmonic suppressor based on a HP / KW rating which is 25-30% larger than the total drive load to be supplied). In most cases, this results in less than 5% THID at the facility input transformer and meets most international standards.

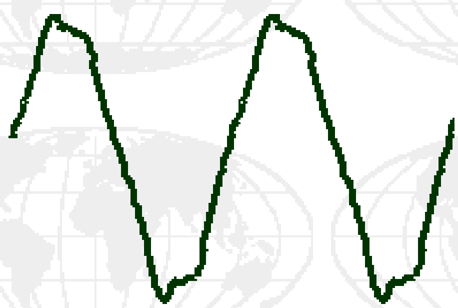

Fig. 6 Actual input current waveform for VFD fitted with Broad Band Harmonic Suppressor.

The low pass filter not only offers guaranteed results, it is also more economical than 12 or 18 pulse rectifier systems, active filters or in many cases even harmonic traps. They are intended for use with 6-pulse drives having a six diode input rectifier in variable torque applications. This typically means fan and pump applications. For the sake of economy, a single Broad Band Harmonic Suppressor may be used to supply several drives (VFDs). When operating at reduced load, the THID at the filter input will be even lower than the guaranteed full load values.

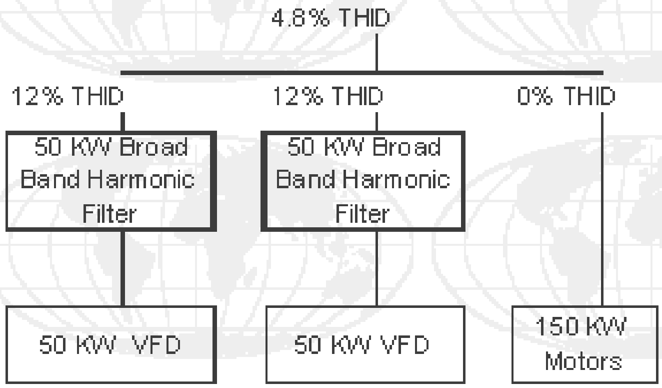

Fig. 7

Figure 7 demonstrates how 5% THID is accomplished at the utility PCC, or facility input transformer. It is easy to see that 12% THID guaranteed at the filter input, reduces to less than 5% at the PCC due to the presence of additional linear loads (motors).

The drives, in the example above, represent 100 KW of the total 250 KW load and have 12% or less current distortion. When the 150 KW motor is drawing full load current, we have the following:

100KW / 250 KW x 12%   = 4.8%

150KW / 250KW x 0%   = 0%

TOTAL Distortion at PCC   = 4.8%

It is now very simple to perform harmonic analysis on a power system, because we know the worst case levels of harmonic distortion whether we are employing a line reactor, combination of line reactor & DC link choke, or broad band harmonic suppressor. The simple analysis will work whether we are considering the facility input PCC or a PCC defined on a particular mains bus.

1. Add up the total load, at the PCC of your choice, using each of the various filtering techniques.
2. Determine the percentage of this type of load compared to the total load by dividing each of these group totals by the total load.
3. Multiply this result by the expected % THID for this particular filter technique (linear loads or motor loads = 0%, 5% line reactor = 35%, 5% line reactor & 3% DC link choke = 28%, broad band harmonic suppressor = 12% or broad band harmonic suppressor = 8%).
4. Add up all of these factors to determine the percent of total harmonic distortion at the PCC you selected.

Example:

100 KW has Broad Band Harmonic Suppressor and guarantees 12% THID,

150KW is motor loads with 0% THID.

100KW / 250KW x 12% = 4.8% and

150KW / 250KW x 0% = 0%. The sum total is 4.8% + 0% = 4.8% THID at this PCC.

VII. CONCLUSION

VFD users have many choices when it comes to harmonic filtering. Of course they may do nothing, or they may choose to employ one of the many techniques of filtering available. Each filtering technique offers specific benefits and has a different cost associated with it. Some may have the potential to interfere with the power system while others will not.

The simplest solutions to use are AC reactors, combination of AC & DC reactors and low pass filters. These solutions all offer very consistent results and will have no invasive effect on the electrical power system. AC reactors (5% impedance) can be expected to reduce input current harmonics to $\leq$ 35%, while the combination of 5% impedance AC reactor and 3% effective impedance DC link choke can be expected to reduce input current harmonics to $\leq$ 28%. A low pass harmonic filter sized directly to the load will reduce current harmonics to $\leq$ 12%, while a similar filter of 25-30% larger capacity will typically maintain harmonic current distortion at $\leq$ 8%.

The facility distribution system can be simplified down to a block diagram of various loads having similar distortion levels (because they employ similar filtering techniques). Once in this format, it is very easy to understand the harmonic current at each of the loads and at the various PCCs as well.

When harmonic filters are applied at the facility input transformer, the utility benefits from the harmonic reduction but the harmonic current will still be flowing on the facility conductors and mains.

For best overall results when using reactors or harmonic filters, be sure to install them as close as possible to the non-linear loads which they are filtering. When you minimize harmonics directly at their source you will be cleaning up the internal facility mains wiring. This will also reduce the burden on upstream electrical equipment such as circuit breakers, fuses, disconnect switches, conductors and transformers. The proper application of harmonic filtering techniques can extend equipment life and will often improve equipment reliability and facility productivity.

VIII. REFERENCES

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[3] Swamy, Mahesh M., PhD, ; Rossiter, Steven L.; Spencer, Michael C.; Richardson, Michael “Case Studies On Mitigating Harmonics In ASD Systems To Meet IEEE-519-1992 Standards”, IEEE Industry Application Society Proceedings October, 1994.