Medium Voltage AC Drive Topology

Comparisons & Feature-Benefits
Typical AC Inverter System

AC Inverter Technology
Up To 97% Efficiency, including transformers
AC Drive Topology:

A map-like diagram showing the elements of an AC drive and the relationships between them.

Two Basic AC Drive Topologies

• Current source drive: ENERGY STORAGE section between converter and inverter consists of an inductor.

• Voltage Source Drive: ENERGY STORAGE section between converter and inverter consists of capacitors.
Evolution of Power Devices Leads the pace of AC drive development
• The Common Threads:
  ✓ All AC Drives rectify AC to DC
  ✓ All AC Drives use switches to create AC from DC
• Drive topologies were created as power rectifiers and switches grew in ratings and capabilities.
• Each new or uprated device opens up new applications
• A quick look at the device development timeline is useful
Development Time Line of Power Semiconductors

**Transistor Devices**

- Bipolar Power Transistor (BPT)
- Low Voltage Insulated Gate Bipolar Transistor (LV IGBT)
- Medium Voltage Insulated Gate Bipolar Transistor (MV IGBT)
- Injection Enhanced Gate Transistor (IEGT)

**Thyristor Devices**

- Diode (D)
- Silicon Controlled Rectifier (SCR)
- Gate Turn Off Thyristor (GTO)
- Integrated Gate Commutated Thyristor (IGCT)
- Symmetrical Gate Commutated Thyristor (SGCT)
# Diode and Thyristor Families of Devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diode</td>
<td>![Diode Symbol]</td>
<td>Conducts positive current</td>
</tr>
<tr>
<td>Silicon Controlled Rectifier (SCR)</td>
<td>![SCR Symbol]</td>
<td>Gate current triggers the flow of positive current. After loss of gate signal, turns off the positive current at next zero cross over.</td>
</tr>
<tr>
<td>Gate Turn Off Thyristor (GTO)</td>
<td>![GTO Symbol]</td>
<td>Small positive gate signal turns on positive current, a large reverse gate turns off the positive current.</td>
</tr>
<tr>
<td>Integrated Gate Commutated Thyristor (IGCT)</td>
<td>![IGCT Symbol]</td>
<td>A GTO with electronics for gate control integrated onto a printed circuit wrapped around the device. Blocks voltage in one direction.</td>
</tr>
<tr>
<td>Symmetrical Gate Commutated Thyristor (SGCT)</td>
<td>![SGCT Symbol]</td>
<td>A GTO thyristor similar to the IGCT except that it blocks voltage in both directions.</td>
</tr>
</tbody>
</table>
### Transistor Family of Devices

<table>
<thead>
<tr>
<th>Device</th>
<th>Operation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bipolar Power Transistor (BPT)</td>
<td>![Waveform]</td>
<td>Controls the flow of positive current with current injected into its base.</td>
</tr>
<tr>
<td>Insulated Gate Bipolar Transistor (IGBT)</td>
<td>![Waveform]</td>
<td>A hybrid device with very high input resistance gate transistor providing current to turn it on.</td>
</tr>
<tr>
<td>Injection Enhanced Gate Transistor (IEGT)</td>
<td>![Waveform]</td>
<td>A high-power advanced form of the IGBT with a very low on-state voltage and even lower losses than the thyristor.</td>
</tr>
</tbody>
</table>
## Drive Power Device Application Comparison

<table>
<thead>
<tr>
<th>Device</th>
<th>Silicon Diode Rectifier</th>
<th>Thyristor [SCR]</th>
<th>GTO</th>
<th>Bipolar Transistor</th>
<th>Power Darlington Type</th>
<th>Insulated Gate Bipolar Transistor</th>
<th>Insulated Gate Bipolar Transistor</th>
<th>Integrated Gate Controlled Thyristor</th>
<th>Symmetrical Gate Controlled Thyristor</th>
<th>Injection Enhanced Gate Transistor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter Switch</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>AC - DC Conversion</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Inverter Circuit</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Inverter types</td>
<td>Current Source</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage Source</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Efficiency</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Medium-High</td>
<td>Medium-High</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Gate Control Signal</td>
<td>NA</td>
<td>Current</td>
<td>Current</td>
<td>Current</td>
<td>Voltage</td>
<td>Voltage</td>
<td>Current</td>
<td>Voltage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gate Current</td>
<td>NA</td>
<td>&lt; 2 amps</td>
<td>400-1000 amps</td>
<td>up to 10 amps</td>
<td>0.1 amps</td>
<td>&lt; 1 amp</td>
<td>4000 amps</td>
<td>4000 Amps</td>
<td>&lt; 1.5 A</td>
<td></td>
</tr>
<tr>
<td>Gate control component Count</td>
<td>NA</td>
<td>Medium</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Voltage Rating</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>to 1200 volts</td>
<td>to 4500 volts</td>
<td>to 6000 volts</td>
<td>to 6000 volts</td>
<td>to 4500 volts</td>
<td></td>
</tr>
<tr>
<td>Current Rating</td>
<td>6000 amps</td>
<td>5500 amps</td>
<td>1000 amps</td>
<td>500 amps</td>
<td>1000 amps</td>
<td>4000 amps</td>
<td>5000 amps</td>
<td>4000 amp</td>
<td>4000 amps</td>
<td></td>
</tr>
<tr>
<td>Switching Losses</td>
<td>NA</td>
<td>Medium</td>
<td>High</td>
<td>Medium</td>
<td>Low</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
<td>Medium</td>
<td>Low</td>
</tr>
<tr>
<td>Snubber Parts</td>
<td>NA</td>
<td>Few</td>
<td>Many</td>
<td>NA</td>
<td>Low</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>Low</td>
</tr>
<tr>
<td>Switching Speed</td>
<td>NA</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Very High</td>
<td>High</td>
<td>Medium</td>
<td>Medium</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>Life Cycle Point</td>
<td>Mature but current</td>
<td>Mature but current</td>
<td>Phasing out</td>
<td>Rarely used</td>
<td>Current &amp; Growing</td>
<td>Current &amp; Growing</td>
<td>Current</td>
<td>Current</td>
<td>Current &amp; Growing</td>
<td></td>
</tr>
</tbody>
</table>
**Comparison Areas**

- Gate power to turn device on & off
- External circuitry [firing & protection]
- Switching speed, switching losses
- On-state forward drop and losses
- Continuous current ratings
- Forward & reverse blocking voltage
- Physical mounting & thermal characteristics

**Impact**

- Number of control devices & system reliability
- System efficiency & cooling
- Number of power devices, & system reliability
- Packaging & system Size
Comparing Gate Power of Devices - 1

Switching of GTO
- Large Gate Current (800A)
  - Faster Switching Speed
  - Brief but Very Large Gate Current (4000A)

Switching of IGCT
- Voltage
- Current

I gate
Comparing Gate Power of Devices - 2

Switching of IGBT

Voltage

Current

Quick Switching Speed

Small Gate Power and Current (1.5A)

Switching of IEGT

Voltage

Current

Quick Switching Speed

Small Gate Power and Current (1.5A)
GTO Gate Driver & Cell Stack Equipment
GE GTO-IMD Example

- Liquid-cooled configuration
- Many discrete parts in firing and auxiliary parts
- Snubber network also shown
- Physically quite large
GCT Gate Driver Equipment

Covers on

Gate Power Supply
Integrated Gate Signal Unit
Isolation Transformer
GGT

4.5kV-4kA
GCT & Gate Driver Board

Covers off

4.5kV-4kA

36 Electrolytic caps
21 FET Switches

4.5kV-800 A
Typical IGBT & IGBT Gate Driver Circuit

**IGBT**
400 amp 3300 volt dual package
Larger ratings have 1/package

**Typical MV IGBT Dual Gate Driver**
Each board has 2 drivers, & fires 2 IGBT’s

Approximate Size:
4 inches x 4.5 inches
IEGT – Latest Generation Voltage Switched Power Device

- IEGT = Injection Enhanced Gate Transistor
- Ratings to 4000 volts, 4500 amps
- Press pack or single sided
- Lower forward drop than IGBT, meaning higher power density, more efficiency.
IEGT Gate Driver Equipment

Gate Drive Board

IEGT = Injection Enhanced Gate Transistor

IEGT = Injection Enhanced Gate Transistor

IEGT 4.5kV-4kA
Calculated Reliability of Gate Drivers
IEGT Voltage Fired vs GCT Current Fired

FITs
 Failures per Billion Hours

0 500 1000 1500 2000 2500 3000 3500

IGCT IEGT

- IC
- LED
- FILM CAPACITOR
- ELECTROLYTIC
- RESISTOR(1/4)
- RESISTOR(PWR)
- DIODE
- FET
- TRANSISTOR
Power Device Losses

Generally
Volts across device X Current Through Device = Power Lost in Device

Two Categories of Device Loss:

1. Losses During Turn-on & Turn-off –
   • Minimized by faster switching
   • Equals area under volt-amp product curve

2. Losses during conduction
   • Minimized by reducing device forward drop
   • Equals device forward volts x amps
Power Device Losses

- **Forward amps**
- **Volts across device**
- **Power loss in device**

- Open Circuit volts
- On-state volts
- Turn-on loss
- Conduction Losses
- Turn-off loss

- Power loss in device
# Power Device Switching Losses

**Current Switched [IGCT] vs Voltage Switched MV IGBT**

<table>
<thead>
<tr>
<th>DEVICE</th>
<th>IGCT 750 AMP</th>
<th>IGBT 800 AMP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Device rating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Turn On Joules Lost / pulse</td>
<td>2.15</td>
<td>1.92</td>
</tr>
<tr>
<td>Turn-Off Joules Lost / pulse</td>
<td>12</td>
<td>1.02</td>
</tr>
<tr>
<td>Total Switching Energy Joules Lost / Pulse</td>
<td>14.15</td>
<td>2.94</td>
</tr>
</tbody>
</table>

Almost 5:1 higher switching losses

IGCT vs MV IGBT!

IGCT Rated Amps = 750
SOURCE: Mitsubishi FGC1500-130DS

IGBT Rated Amps = 800
SOURCE: EUPEC FZ 800 R33 KF2
Power Device On-State Losses
IGCT vs MV IGBT Examples

**750 amp IGCT**
Forward v = 4.5 - 4.75

**800 amp MV IGBT**
Forward v = 3.35 - 4.25
Comparing Large Inverter Efficiencies:
IEGT vs IGCT / SGCT vs GTO

High Efficiency from light load to rated load

Note: IGBT drive efficiencies typically equivalent to IEGT
Power Switch Voltage and Current Ratings

Continuous current ratings AFFECTS Forward & reverse blocking voltage

• Higher device voltage ratings mean fewer devices are needed to match load voltage rating
• Higher current ratings mean fewer devices can be used without requiring paralleling
• Tradeoff: Using fewer, higher voltage-rated devices gives output waveform fewer levels with larger voltage change. For >4 kv drives, this requires large output filters.

• As of March 2003: GCT: 4500 A, 6kV  IGBT: 1200 A, 4500 V  IEGT: 4000 A, 4500 V

As of March 2003:
- GCT: 4500 A, 6kV
- IGBT: 1200 A, 4500 V
- IEGT: 4000 A, 4500 V

Graphs:
- 5 level 4000 volt Output
  - No sine filter needed
- 3 level 4000 volt Output
  - Large sine filter needed
Power Switching Devices
Final Comparisons & Conclusions

- **Current switched** devices [SGCT, IGCT] require many more parts in firing / gate control than voltage switched devices [IGBT, IEGT].
- **Voltage switched** devices [IGBT, IEGT] have MUCH lower switching losses than current switched.
- Conduction losses are nearly equal for equivalent volt & amp-rated device SGCT, IGCT vs IGBT, IEGT
- **Voltage switched** devices allow higher switching rates and can give better output waveforms
Comparisons of Major Drive Type Topologies
Comparing Topologies

• Current Source Drives
  ✓ LCI – Load Commutated Inverter
  ✓ GTO/SGCT Current Source Induction Motor Drive

• Voltage Source Drives
  ✓ LV IGBT “Paice” Multilevel PWM
  ✓ MV IGCT PWM – Diode or Active Source
  ✓ MV IGBT PWM – Integrated package
  ✓ MV IEGT PWM – Active or Diode Source
LCI – Current Source Load Commutated Inverter

<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Advantages</th>
<th>Drawbacks</th>
<th>Practical Power Range</th>
</tr>
</thead>
</table>
| Current source Load-Commutated Inverter   | • Low Parts Count  
• Full Regen is inherent  
• Rugged – ultra reliable  
• Economical High HP  
• N+1 SCR device redundancy possible                                           | • Requires a controlled front end  
• High motor current THD  
• Slow transient response  
• Narrow motor frequency range  
• Reduced Starting Torque  
• Limited starting performance  
• Poor PF at low motor speeds  
• High harmonics unless multiple channels used; filters may be needed.      | Above 6 MW  
Synchronous Motors Only                                                        |

**Example: GE-Innovation Series® LCI**

- **Current source Load-Commutated Inverter**
  - SCR = Silicon Controlled Rectifier, Thyristor

- **Advantages**
  - Low Parts Count
  - Full Regen is inherent
  - Rugged – ultra reliable
  - Economical High HP
  - N+1 SCR device redundancy possible

- **Drawbacks**
  - Requires a controlled front end
  - High motor current THD
  - Slow transient response
  - Narrow motor frequency range
  - Reduced Starting Torque
  - Limited starting performance
  - Poor PF at low motor speeds
  - High harmonics unless multiple channels used; filters may be needed.

- **Diagram**

- **Primarily being offered by:**
  - GE Toshiba, ABB, Siemens

- **Diagram Details**
  - Energy stored in Link Inductor
  - Alternate: Multi-pulse/ Multi-channel Converter
  - SCR = Silicon Controlled Rectifier, Thyristor
  - DC Link Inductor
  - Sync Motor
  - Volts
  - UTILITY
  - SCR

- **Diagram Description**
  - The diagram illustrates the LCI (Load Commutated Inverter) configuration and connections, including the utility, DC link inductor, SCR, and sync motor.

**Notes**

- Primarily being offered by GE Toshiba, ABB, Siemens.
- Energy stored in Link Inductor.
- Alternate: Multi-pulse/ Multi-channel Converter.
Alternate LCI Configurations

- **6-Pulse input**
  - 6-Pulse output

- **12-Pulse input**
  - 12-Pulse output

- **24-Pulse input**
  - 12-Pulse output
Current Source GTO / SGCT Induction Motor Drive

Example: GE-GTO IMD

<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Advantages</th>
<th>Drawbacks</th>
<th>Practical Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current Source GTO or SGCT PWM Inverter</td>
<td>• Low power device (GTO/SGCT) parts count</td>
<td>• Requires a controlled front end – extra complexity</td>
<td>2 - 15 MW</td>
</tr>
<tr>
<td>GTO = Gate Turn Off Thyristor</td>
<td>• Low motor THD</td>
<td>• Poor input power factor, with SCR front end</td>
<td>Primarily induction motor load</td>
</tr>
<tr>
<td>SGCT = Symmetrical Gate-Controlled Thyristor</td>
<td>• Low motor insulation stress when input isolation transformer is used</td>
<td>• Slow transient response</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Narrow speed range</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Potential resonance between motor &amp; caps</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Limited availability of power devices</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Complex firing circuit</td>
<td></td>
</tr>
</tbody>
</table>

Primarily being offered by: Allen Bradley
Current Source SGCT Induction Motor Drive
With “Isolation” Reactor in Place of Transformer

Energy stored in
Link Inductor
Voltage Source General Drive Arrangements

Diode Rectifier Converter Fed

Active Rectifier Converter Fed
PWM: Pulse Width Modulation

A method of varying voltage by changing the average “ON” time of switches between source and load.

Example Pulse-Width-Modulated [PWM] Waveform

Voltage: The Average of the time the Voltage is on Plus the time the Voltage is Off.

Current: The Motor tends to smooth the resulting current

EXAMPLE SIMULATED SINE WAVE PRODUCED BY 2-LEVEL PWM INVERTER
Example Two-Level Voltage Source Inverter
LV IGBT Multi-level Voltage Source PWM Inverter

Example: GE Innovation Series® Type H

<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Major Advantages</th>
<th>Major Limitations</th>
<th>Practical Power Range</th>
</tr>
</thead>
</table>
| Multi-level Voltage Source LV IGBT PWM Inverter | • Power Cell N+1 redundancy available  
• Low motor current THD  
• Fast transient response  
• Wide motor frequency range  
• No significant torque pulsations  
• High starting torque.  
• Multi-pulse converter for very low AC line harmonics  
• High true pf over all speeds | • No regen or DB possible  
• Large parts count – lowers base MTBF  
• N+1 redundancy adds parts and decreases MTBF  
• Large footprint in high HP  
• Electrolytic capacitors degrade with time and are sensitive to overvoltage | 0.5 - 7 MW  
Sync or Induction motor |
| LV IGBT = Low-voltage Insulated Gate Bipolar Transistor | | | |
Power Cell “N+1” Redundancy

- “N+1 redundancy” originated in LCI drive design, defined as having an extra SWITCHING DEVICE per leg, with no other added parts.

- One Robicon method re-defines “N+1” as including a complete extra cell transformer secondary & SCR bypass switch:
  - Cell must be intact and control 100% functional to work
  - Added parts work all the time and decrease drive component MTBF

- Traditionally, increased reliability comes from reducing parts count and conservative design.

---

**LCI drive**

N+1 requires 12 SCR’s

**LV IGBT MV Drive**

N+1 [3 extra power cells] adds
- 18 diode Rectifiers
- 12 LV IGBTs, 15 bypass SCRs
- 42 electrolytic Caps, Firing circuits + 3 added transf windings

---

**TYPICAL LV IGBT POWER MODULE FOR REDUNDANT USE**

- Diode Rectifier
- Fixed DC Bus
- ELECTROLYTIC CAPS
- Inverter (IGBT)
- BYPASS SCR
IGCT PWM Voltage Source Inverter

Example: GE-Innovation Series® SP IGCT Mill Drive

<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Major Advantages</th>
<th>Major Limitations</th>
<th>Practical Power Range</th>
</tr>
</thead>
</table>
| IGCT PWM Voltage Source Inverter | • Low power switch device count for voltage rating  
• Fast transient response & wide motor frequency range  
• High starting torque  
• High power levels with largest IGCT devices  
• Regen possible with active IGCT converter | • Complex high parts count firing circuit  
• 3-level output requires output sine filter.  
• Above 4 kV output requires output filter for low motor current distortion.  
• Potential for electrical and mechanical resonance between load and filter. | 0.5 – 4.8 MVA per inverter, air cooled  
4.8 – 9.6 MVA, dual channel |

Primarily being offered by: ABB
IGCT PWM Voltage Source Inverter
Details & Alternate Configurations

Alternate IGCT converter and 24-pulse diode converter

Typical Entry Level
12 pulse diode converter & IGCT PWM Drive

IGCT Active Converter

A

B

24 Pulse Diode Converter
<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Major Advantages</th>
<th>Major Limitations</th>
<th>Practical Power Range</th>
</tr>
</thead>
</table>
| Three / Five Level Voltage Source MV IGBT PWM Inverter | • Minimum parts count for voltage rating & waveform  
• Simple firing circuit.  
• High efficiency  
• Low motor current THD  
• Fast transient response  
• Wide motor frequency range  
• No significant torque pulsations  
• High starting torque.  
• Multi pulse converter for very low AC line harmonics  
• High true pf over all speeds | • No regeneration available  
• Fast rise time IGBT switching may require dv/dt output filter in some cases  
• Power Device redundancy not practical | 0.5 – 4.8 MVA per inverter, air cooled  
4.8 – 9.6 MVA, dual channel |

**Example: GE-Toshiba Dura-Bilt5i® MV**

**MV IGBT NPC Voltage Source Drive**

**Primarily being offered by:** GE-Toshiba, Siemens
MV IGBT NPC Voltage Source Drive Details

- Neutral Point Clamped [NPC] reduces voltage to ground
- 5 / 9 level waveform < 3% motor current distortion
- 24 pulse diode converter <2% line current distortion, better than IEEE 519 limits

Example 5/9 level motor voltage & current waveforms
### IEGT PWM Voltage Source Inverter

**Example: GE-Toshiba 8 MW T650**
IEGT drive with active IEGT Source

<table>
<thead>
<tr>
<th>Inverter Topology</th>
<th>Major Advantages</th>
<th>Major Limitations</th>
<th>Practical Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Level Voltage Source IEGT PWM Inverter</td>
<td>- Minimum power device count – 24 for complete 8 mw regen system&lt;br&gt;- Simple firing circuit [4:1 more reliable than IGCT] and very high system MTBF.&lt;br&gt;- Low motor current THD&lt;br&gt;- Fast transient response &amp; wide motor frequency range&lt;br&gt;- High starting torque with no significant torque pulsations&lt;br&gt;- Active front end for low harmonics, regeneration, unity or leading PF</td>
<td>- IEGT device limits allow 3300 volt motor output [European and Asian Standard]&lt;br&gt;- 3300 volts is not as common as 4160 volts in North American applications.</td>
<td>6 to 26 MW, water cooled, one or two channel&lt;br&gt;At 3300 volts&lt;br&gt;Sync or Induction Motor</td>
</tr>
</tbody>
</table>

- IEGT = Injection Enhanced Gate Transistor

---

**Primarily being offered by:**
GE-Toshiba

---

Energy stored in liquid filled caps
IEGT PWM Voltage Source Inverter & Active Converter
Circuit Details & Alternate Diode Converter Configuration

8 MW IEGT Inverter with active regen-capable source

IEGT PWM Voltage Source Inverter with Diode Converter

AC Input

Fixed DC Bus

Diode Rectifier

Induction Motor or sync Motor [req field exciter]

Transformer & Feed Reactor 20% Z

Sync Field [If Applic]
Global Office Locations:

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1501 Roanoke Blvd.
Salem VA, 24153 USA
TEL: +1-540-387-5741; FAX: +1-540-387-7060
www.getoshiba.com

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13-16 Mita 3 chome, Minato-ku Tokyo
108-0073 Japan
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