Medium Voltage Drives
Overview, Evolution & Application

Western Mining Electrical Association
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Bill Horvath, PE
TMGE Automation Systems
MV Drive Session Overview

- Provide links to more reference materials.
- Review the benefits of ASDs in motor starting and control
- Cover basic drive application
- Cover basic tradeoffs between MV & LV drives
- Review one recent mining conveyor MV drive application
- Trace the Evolution of MV drives & circuit configuration
  - Compare each historical and current major MV drive topology
  - Compare each drive topology's major strengths and weaknesses.
- Review the TMGE Dura-Bilt5i MV IGBT Drive as an example of current technology
MV Drive Materials -1

• **MV Drive Evolution** White Paper GEZ-S1006

• Engineering Reference Manual & CDROM, GET-S1009

• Obtain from TMGE General Industries www.tmge.com
More MV Drive Materials - 2

• Electronic MV Newsletter
  http://www.imakenews.com/getoshiba_mve-news/

• TM GE Automation Web Link:
  www.tmge.com
AC Motors & Control Overview

- Induction Motor Basic Characteristics
- Load Types
  - Starting and Running Torque-Speed Profiles
  - Typical Applications
- Starting and Running Control Methods
- Variable Frequency Drives
  - Low Voltage vs Medium Voltage
  - MV Drive Evolution
  - TMGE Automation Systems Dura-Bilt5i MV Overview
Induction Motor Speed-Torque Profile

Locked Rotor Tq

Pull Up Torque

Rated Torque

Sync Rpm = $120 \times \frac{x \text{ Freq.}}{\#\text{Poles}}$

Peak [Breakdown] Torque, BDT

Rated Slip RPM = Sync - Rated RPM

Rated RPM

Sync RPM
Motor Starting
Motor Starting
Factors That Apply

- Inrush Amps and Duration
- Motor Limit on Number of Starts Per Hour
- Motor Connected Inertia Limits
- Load Mechanical Issues
  - Pumps, Piping & Hydraulic issues
  - Coupling Stress
- Starting Torque vs Load Requirements
Full-Voltage Motor Starting

Single Motor, Single Starter

Multiple Motors, Single Starter

Full Voltage Amps & Torque vs Speed

Torque, Amps

Amps

Torque

Full Load

RPM >
Reduced -Voltage Motor Starting

1. **Frequency is** = line frequency
2. **Inrush current and torque are limited for a “soft” start, but no true speed or torque control is possible.**
Motor on AC Adjustable Speed Drive

1. Frequency and voltage are controlled.
2. Line current, motor voltage torque regulation provide true speed and torque control.
3. KEY: Process and energy use can be optimized.
Drive Ratings and Torques

- **Variable Torque** - ratings usually include 110 -115% OL rating for 60 seconds at rated Temp
Loads & Motor “Capability” Curves

Induction Motor Capabilities Under Variable Speed Operation

- Theoretical Motor Capability
- Actual Motor Capability

100% Load Point, NP RPM, Sine wave power

Constant Torque Load, Example 1

Constant Torque Load, Example 2
Pump & Fan “Affinity” Laws: 1-2-3

- 1 Flow Rate Varies 1st power of Speed [Proportional]
- 2 Pressure & Load Torque Varies as the 2nd power [square] of Speed
- 3 Horsepower at Motor Shaft varies as the 3rd power [cube] of Speed
“Fans” have variable torque loads. “Blowers” may have constant torque or variable torque loads.

- Load torque goes up as the square of the speed.
- Horsepower load goes up as the cube of the speed.

- Torque needed to run an Induced Draft fan increases significantly as gas temperature decreases.

- Fan Motor sizing greatly affected by across the line...
Important fundamental relationships

Fluid power = \( \text{Flow rate (gpm)} \times \text{Head (ft)} \times \text{specific gravity} \times \frac{3960}{3960} \)

AND

Fluid energy = Fluid power \times \text{operating time}

Reduce the run time
Reduce the flow rate
Reduce the head

\{ \text{Reduce energy use, cost} \}
## Variable Torque Drive Applications

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Multiple Motor Pumping Application
Drive Ratings and Torques

Constant Torque [CT] rating usually includes 150% - 250% OL rating for 60 seconds when at rated Temp.
Constant Torque –
Characterized as a load curve that looks like

- Theoretical Motor Capability
- Actual Motor Capability
- Variable Load [Pump, Fan]
- 100% Load Point, NP RPM, Sine wave power
- Constant Torque Load, Example 1
- Constant Torque Load, Example 2

RPM -->
Load Torque
Conveyor or Mill Loading

- **Breakaway Torque**

- **Conveyor Typical Demand**

- **Typical Induction Motor Characteristic on 60 Hz Power**

- **Frequency (FREQ)** - **Speed (SPEED)**
Conveyor or Mill Loading

VFD CONTROLLED MOTOR - ENOUGH TORQUE ACROSS THE RANGE

BREAKAWAY TORQUE

TORQUE

FREQ, SPEED

Conveyor typical demand

Typical Induction Motor Characteristic on 60 Hz power
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Crushing and Conveying Systems
Example MV Drive Mining Application

MINE-MOUTH TO PROCESSING PLANT CONVEYOR
Application Story – Long Conveyor

1. Underground Molybdenum Mine in Colorado had a 15 mile long train to take ore from mine tunnel to processing plant.

2. Train equipment became obsolete, unreliable.

3. Three segment conveyor at variable speed was winning concept to replace train.

4. Total length of conveyors over 15 miles! One section over 10 miles!
**Application Story – Long Conveyor**

**Electrical One Lines**

**A** 2250 HP PWM-3 w/ 1 2250 HP Motor
Basic Configuration for Pulleys 1, 2, 3

**B** 2000 HP PWM-3 w/ two 1000 HP Motors
Alternate for pulley 4

**C** 1000 HP PWM-3 w/ 1 1000 HP Motor
Basic configuration for Pulleys 4, 5, 6, 7
Application Story – Long Conveyor

Conveyor Mechanical Application Considerations

Stretch, Length, Belt weight, load weight, speed

Friction

Tension Ratios, Dynamic Response, Programmed Torque, Load Sharing
PC-2 UPHILL CONVEYOR with PWM Drives

PC-2 Conveyor
Plan View

Head end equip house
@ 9500 feet AMSL

1 x 2250 HP

2 x 2250 HP

1 x 2250 HP

2140 kVA
13,800/2400 V

13.8kV

PWM-3. 2250 HP

2250 HP

2.3 kV

A 2250 HP PWM-3 w/1 2250 HP Motor
Basic Configuration for Pulleys 1, 2, 3
PC-3 OVERLAND CONVEYOR with PWM-3 Drives

PC-3 Conveyor

Plan View

Tail end equip house
@ 9,500 feet AMSL

Head end equip house
@ 9,500 feet AMSL

1 x 1000 HP

6

5

1 x 2 x
1000 HP 1000 HP

900 kVA
13,800/2300 V

13.8kV

PWM-3
1000 HP

1000 HP

2.3 kV

C

1000 HP PWM-3 w/1 1000 HP Motor
Basic configuration for Pulleys 4, 5, 6, 7
PC-1 FEED CONVEYOR with PWM-3 Drives

Head end equip house @ 7,100 feet AMSL

PC-1 Conveyor Plan View

- 2 x 1000 HP
- 900 kW
- 13,800/2300 V
- 13.8kV

C 1000 HP PWM-3 w/ 1 1000 HP Motor
Basic configuration for Pulleys 4, 5, 6, 7
Application Story – Long Conveyor Challenges & Solutions

Motor Challenges
- High Starting Torque for PC3
- Two sizes: 1000 HP & 2250 HP each
- Wide speed range

Drive Challenges
- 24/7 Reliable
- Energy Efficient
- Low Maintenance
- High overload torques in winter on PC3

Control Challenges
- Precise, programmable torque for belt tension control
- Head-to-tail tension coordination for PC3
- Allow variable speed operation of any motor

Power Challenges
- Long power feeds
- Cable capacitance created resonance high order harmonics

Motor Solution
GE 2.3 kv induction motor separate cooling air by user

Drive And Control Solution
GE Innovation PWM 2300 volt 3-level, 18 pulse rectifiers. Utilized Innovation Series Controller for torque programming & PLC Ethernet interface.

Power Solution
3-level Inverter with IEEE 519 compliant 18 pulse converters and high frequency filters to eliminate cable resonance at 19th harmonic
Application Story – Long Conveyor

Customer Benefits

• Train system replacement with conveyor has proven to be very reliable.
• Variable speed operation on the conveyor resulted in added energy savings, reduced friction and belt wear.
• Biggest risks and failure potentials were avoided by careful design:
  ✓ Slippage and stretch of long strand 20 mile total length PC2 with 4 x 2250 HP at head end
  ✓ Tension control of up-and-down PC3 overland with many curves
All AC Drive Selection Factors

- Load type: CT, VT, CH, Regen or non-regen
- Physical Environment at drive location
- Power system compatibility
- Precision of control needed
- Overload ratings needed
- Operator control & digital communication needed

- Drive Output Voltage & Motor Application
Drive Output Voltage & Motor Application

*LV drives: defined as having output volts* $< 690$ volts

- Why Pick LV [$< 690v$] Drive & Motor?
- Why pick MV over LV?

Trends:

Some users select MV at $> 250$ HP
Many users select MV over 500 HP.
Drive Output Voltage & Motor Application

• **Why Pick LV [<690v] Drive & Motor?**
  – LV drives are lower cost / HP than MV
  – Reduces some safety & MV training concerns
  – HP range is small enough
  – Individual preference

• **Why pick MV [>690v] Drive & Motor over LV?**
  – Lower cost wiring, smaller cables
  – Lower power system harmonic impact
  – High HP LV require dual winding motors
  – Individual preference

• **Trend:** Some users select MV at >250 HP
  Many users select MV over 500 HP.
MV vs LV AC Drives: Cost Factors of Various Configurations

- MV drive $ / HP decreases with HP
- Harmonic content can be important:
  - MV data is 24 pulse TMGE Automation Systems DB5i MV
  - LV data is GE-Fuji AF300 P11
- Installed cost must be considered
Safety, Training & MV Drives

- Different level of training and personnel for MV vs LV equipment
- Different procedures MV vs LV
- Local maintenance staff may not be “comfortable” with MV equipment
- MV drive include many safety features:
  - Optical control isolation: feedbacks and firing
  - Electrical and mechanical interlocks & isolator switches
  - Bolt on covers, warning labels
MV vs LV Drives: Some Conclusions

- For drives > 1000 HP, MV makes sense.
- For long cable runs, MV makes sense.
- For drives < 500 HP, LV makes sense.
- If low system harmonics are required, LV filter or multi-pulse expense can favor MV over LV.
- In the range 500 to 1000 HP the various application & installation factors apply.

*Final choice may boil down to user preference.*
MV Drive Evolution

History,
Topology Comparisons,
& Future Trends
Typical AC Inverter System

AC Inverter Technology
Up To 97% Efficiency, including transformers
• 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)

Diode (D)
Silicon Controlled Rectifier (SCR)
Gate Turn Off Thyristor (GTO)
Integrated Gate Committed Thyristor (IGCT)
Symmetrical Gate Commutated Thyristor (SGCT)

Thyristor Devices
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

GCT

4.5kV-4kA
GCT & Gate Driver Board
Covers off

36 Electrolytic caps
21 FET Switches
Typical IGBT & IGBT Gate Driver Circuit

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

**Approximate Size:**
4 inches x 4.5 inches

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

[Image of IGBT module]

[Image of Dual Gate Driver]

2 in, 50 mm
IEGT Gate Driver Equipment

IEGT = Injection Enhanced Gate Transistor

IEGT 4.5kV-4kA

Gate Drive Board
Calculated Reliability of Gate Drivers
IEGT Voltage Fired vs GCT Current Fired

FITs
Failures per Billion Hours

IGCT
IEGT

IC
LED
FILM CAPACITOR
ELECTROLYTIC
RESISTOR(1/4)
RESISTOR(PWR)
DIODE
FET
TRANSISTOR
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
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.
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
Current Source Drives
**LCI – Current Source Load Commutated Inverter**

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

<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 Load-Commutated Inverter</td>
<td>• Low Parts Count • Full Regen is inherent • Rugged – ultra reliable • Economical High HP • N+1 SCR device redundancy possible</td>
<td>• 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.</td>
<td>Above 6 MW Synchronous Motors Only</td>
</tr>
</tbody>
</table>

**SCR = Silicon Controlled Rectifier, Thyristor**

Alternate: Multi-pulse/ Multi-channel Converter

Energy stored in Link Inductor

**Primarily being offered by:**
**TMGE, ABB, Siemens**
Current Source GTO / SGCT Induction Motor Drive

Example: GE-GTO IMD Induction Motor Drive

### Inverter Topology
- **Current Source GTO or SGCT PWM Inverter**
  - GTO = Gate Turn Off Thyristor
  - SGCT = Symmetrical Gate-Controlled Thyristor

### Advantages
- Low power device (GTO/SGCT) parts count
- Low motor THD
- Low motor insulation stress when input isolation transformer is used

### Drawbacks
- Requires a controlled front end – extra complexity
- Poor input power factor, with SCR front end
- Slow transient response
- Narrow speed range
- Potential resonance between motor & caps
- Limited availability of power devices
- Complex firing circuit

### Practical Power Range
- 2 - 15 MW
  - Primarily induction motor load

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 Drives
Voltage Source General Drive Arrangements

Diode Rectifier Converter Fed

Active Rectifier Converter Fed

Alternate: Multi-pulse/ Multi-channel Converter
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 Two-Level Voltage Source Inverter

3 Phase Diode Bridge

AC Incoming Line

Cap Bank

DC Bus Rectified Power

PWM Motor Volts

Motor Amps

Rectified 3-Phase

Cap Bank
**LV IGBT Multi-level Voltage Source PWM Inverter**

**Example: GE Innovation Series® Type H**

### Inverter Topology
- Multi-level Voltage Source LV IGBT PWM Inverter
- LV IGBT = Low-voltage Insulated Gate Bipolar Transistor

### Major Advantages
- 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

### Major Limitations
- 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 are sensitive to over temp & overvoltage

### Practical Power Range
- 0.5 – 10 MW
- Sync or Induction motor

**Primarily being offered by:** Robicon, Toshiba Japan
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

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**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
IGCT PWM Voltage Source Inverter

Example: GE-Innovation Series® SP IGCT Mill Drive

**Inverter Topology**

<table>
<thead>
<tr>
<th>IGCT PWM Voltage Source Inverter</th>
<th>Major Advantages</th>
<th>Major Limitations</th>
<th>Practical Power Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three Level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Low power switch device count for voltage rating</td>
<td>- Complex high parts count firing circuit</td>
<td>0.5 – 4.8 MVA per inverter, air cooled</td>
</tr>
<tr>
<td></td>
<td>- Fast transient response &amp; wide motor frequency range</td>
<td>- 3-level output above 3.3 kV requires output filter for low motor current distortion.</td>
<td>4.8 – 9.6 MVA, dual channel</td>
</tr>
<tr>
<td></td>
<td>- High starting torque</td>
<td>- Potential for electrical and mechanical resonance between load and filter.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- High power levels with largest IGCT devices</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Regen possible with active IGCT converter</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Primarily being offered by: TM GE, ABB*
**MV IGBT NPC Voltage Source Drive**

Example: TMGE Automation Systems
Dura-Bilt5i® MV

<table>
<thead>
<tr>
<th>Inverter Topology</th>
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<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  
Sync or Induction Motors |

**Primarily being offered by:**
TMGE Automation Systems, 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
LV IGBT NPC Voltage Source Drive

Example: TMGE Automation Systems TMdrive 30

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<thead>
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<th>Major Limitations</th>
<th>Practical Power Range</th>
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</table>
| Three Level Voltage Source LV IGBT PWM Inverter | • With High reliability design and component selection, measured MTBF of > 50 years is possible.  
• Simple firing circuit.  
• High efficiency  
• Low motor current THD  
• Fast transient response  
• No significant torque pulsations  
• High starting torque.  
• Active Front End for full regen, Harmonic, and PF control. | • Power Device redundancy not practical  
• 1250 volt rating limits max power | 0.5 – 10 MVA using up to 4 bridges, air cooled  
Sync or Induction Motors |

Energy stored in high reliability electrolytic caps

Primarily being offered by: TMGE Automation Systems
MV IGBT NPC Voltage Source Drive Details

- Neutral Point Clamped [NPC] reduces voltage to ground
- 3 level waveform ~ 3% motor current distortion
- Active PWM front end better than IEEE 519 guideline limits

Simulated Inverter Voltage Waveforms of 3 level NPC PWM
**IEGT PWM Voltage Source Inverter**

**Example:** TMGE Automation Systems 8 MW TM-70 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 At 3300 volts Sync or Induction Motor</td>
</tr>
</tbody>
</table>

Primarily being offered by: TMGE Automation Systems

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

Transformer & Feed Reactor 20% Z

Induction Motor or sync Motor [req field exciter]
A Modern MV Drive Example:

TMGE Automation Systems

Dura-Bilt5i® MV
Dura-Bilt5i MV Overview

- An AC Fed Medium Voltage Drive Featuring:
  - Compact/compartmentalized design
  - Integral incoming fused disconnect
  - Integral converter transformer
  - 24 pulse IEEE 519 compliant ac to dc converter
  - Advanced user interface and system features
Covering a Broad Range of Medium Voltage Drive Applications

- **4000 Series**: 400 – 10,000 HP [300 – 7500 kW]
- **3000 Series**: 300 – 8500 HP [225 – 6340 kW]
- **2000 Series**: 200 – 5000 HP [150 – 3730 kW]
Very Compact

300-900 HP 3.3 & 4kV Outline

No rear access required

24" fan top to ceiling for airflow clearance

Left Side / End View

43.4 [1102]

43.4 [1102]

300-900 HP Dura-Bilt5i MV Inverter, 3000 & 4000 series

EST WT: 7,500 LBS 3,402 KG
Dura-Bilt5i MV
3300 - 4160 Volt
Detailed One-Line Diagram

- Main Power: 7.2 kV class or below
- Sensing PT’s 120 output
- Integral 12 winding Transformer
- Integral Disconnect Option
- Integral Lightning Arrestor
- Auxiliary & Control Power: 460 std., others available
- Standard E.S. Shield
- Hall CT Current Feedback
- Optional redundant fans shown dotted
- 24-P Pulse Source
- 24-P Source Assembly
- Voltage Detection Module
- Optical Link Module
- Control power feed option
- Conventional Fan
- Optional DV/DT Filter
- Incoming Power Compartment: ACL M1, M2
- Optional DV/DT Filter
- Dura-Bilt5i MV Control
Power System and Motor Friendly

Current Distortion: THD < 3%,
Voltage Distortion: THD < 6%

Line Current Distortion < 3%

Requires No Special Motor Thermal Rating

Operating Conditions: Full Speed, 95% Load

NOTE: Utility current trace displaced in time for clarity
A Look Inside . . .

Compartmentalized Design...

- Separate cooling for converter and inverter
- Control and power separated
- Voltage levels separated
- Only front access required

Typical Dura-Bilt5i MV 1850 kVA Drive
Incoming Power Compartment

- Integral ac reactor for charging and protection of dc bus components
- Built-in 3-phase fused disconnect, interlocked with cubicle door that can be padlocked in the open position
- Built-in 3-phase MV contactor interlocked with disconnect
- Integral lightning arresters for transient and surge protection
- Dedicated wireways support bottom or top incoming cabling
- Fused potential transformers
Transformer and Converter Compartment

DC cables to inverter compartment minimizes connections; this speeds and simplifies installation.

24-pulse rectification gives power quality better than IEEE 519 recommended limits.

Transformer secondaries fused with blown fuse indicators.

Forced air cooled with dedicated fan. [Optional redundant fan with auto throw-over available]

Washable filters can be changed while drive is operational.
Drive Control Compartment

- Separate disconnect for control power
- Optional controls for drive by-pass or other auxiliary functions
- Process input-output [I/O] control board
- Microprocessor control boards for drive sequencing and motor speed/torque control
- Communication board supporting Profibus, ISBus, DeviceNet™ and Tosline S20
Inverter Compartment

- Easy access roll-out inverter phase modules
- Inverter module consists of:
  - MV IGBT’s and heat sinks
  - Liquid-filled capacitors
  - Snubbers
  - Gating power supplies
  - Gate driver board
- Air cooled heat plate cooling system
  - High efficiency, low fan noise
  - Low device temperature rises and temperature cycling
  - Optional redundant fan with auto throw-over available
High Efficiency Plate Heat Exchanger for IGBTs

How it works

- Devices are mounted to side of plates
- Current flow generates heat in devices
- With only a few degrees of temperature rise, coolant is vaporized within the plate
- Vapor rises to the top condensing unit passages
- Heat is removed by airflow over fine fins, which liquefies coolant
- Coolant returns to base of chill plate for next cycle
High Efficiency Heat Pipe Exchanger for IGBTs

Advantages

• Liquid-cooled performance is achieved with air-cooled simplicity!

• Low IGBT-to-plate thermal resistance keeps IGBTs cool

• Minimized temperature fluctuations during operation maximize IGBT life up to 10x

• Sealed system is maintenance free

• Like the proven GE Innovation Series heat pipe design, but even more effective, with a larger active surface
Inside a Typical Power IGBT

This example: 400 amp, 1700 Volt.

- Inside the package, many individual devices paralleled with bonding leads.
- Thermal cycling from wide load cycle can cause fatigue failure of bonds due to expansion and contraction.
- Heat plate, like liquid cooling, keeps mounting plate surface more even during load cycles.
- Minimized temperature fluctuations during operation maximize IGBT life up to 10x.
By-Pass Contactor Compartment

Requires optional additional cubicle integrated into drive line up
Contactors are interlocked to allow drive by-pass and connect motor across the power lines
Cubicle extension houses both input and output contactors

Allows full speed motor operation from utility power if drive is not available.
Dura-Bilt5i MV Display Unit

Drive Status
Graphic screen displays key variables in bar chart format with additional status icons

Status Indicators
Give quick indication of drive operation, without requiring separate panel lamps

Control System Toolbox Interface
10-100 Mbps Ethernet can be multi-drop networked - access to GE 24-7 on-site monitoring

Parameter Editing
Intuitive menu interface for parameter editing

Signal Monitor
Analog signals for test instrumentation

Local Drive Control
Dedicated keys for local control of the drive for commissioning and maintenance activities
Integrated Trend Window
- Drag and drop variables
- Real time trending or archiving to buffer for historical trending
- Auto scaling
- Zoom in/out function
- Different views by using variable hide feature
- Analyze specific time with cross hair
- Frequency-based analysis of trend with fast Fourier transform function

Easy to Understand Data Structure:
- Drive parameters and variables in tree structure

Animated Block Diagrams

Same Toolbox as all GE System Drives and Many Exciters!
Summary & Conclusions

• ASDs offer superior motor control
• MV Drives can make sense at even modest HP levels
• MV Drives have come a long way
• MV drives using MV IGBTs have simplest control
• MV Drive Reliability needs to be built in, not added on
Thanks!

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