Medium Voltage Drives in Industrial Applications

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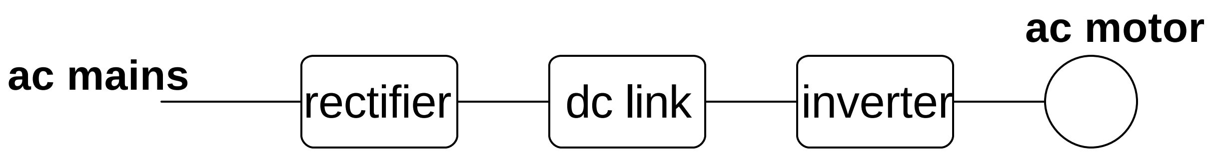
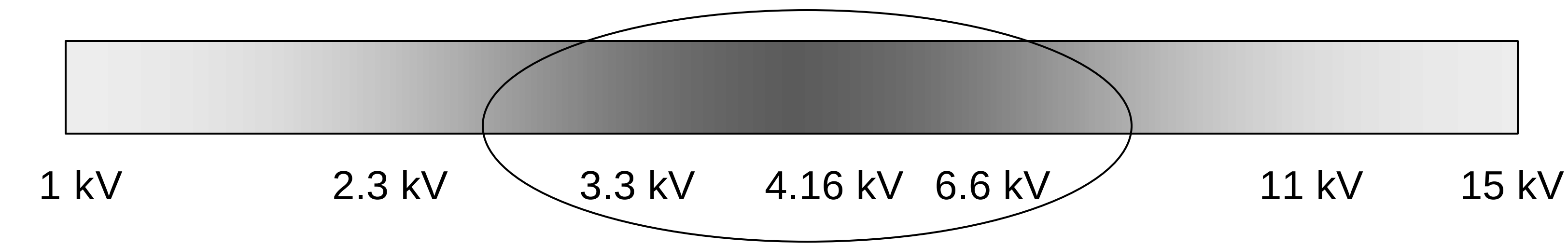
Outline

- Introduction
- Medium Voltage Drive Topologies
  - A Brief Comparison
- Power Semiconductors
- Influence of the Semiconductor on Drives
- Influence of Topology on Power System
- A Hypothetical Drive for the Future
- Conclusion

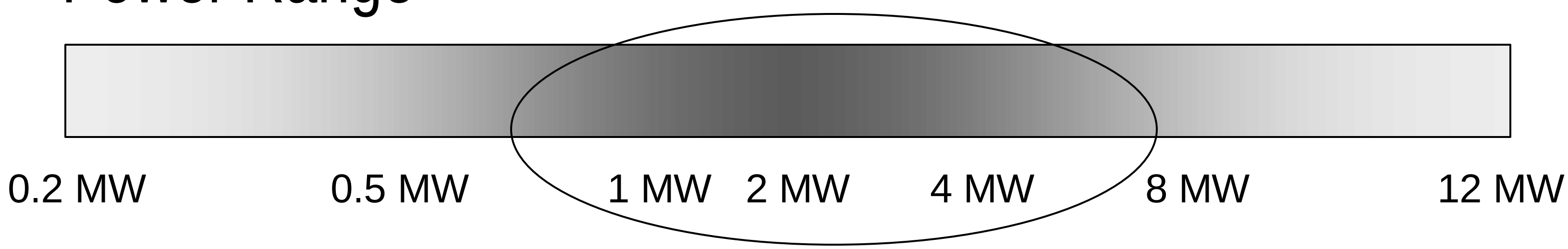
Medium Voltage Drive Introduction



- Voltage range



- Power Range



Target Industries / Applications

Petrochemical
Pipeline pumps
Gas compressors
Brine pumps
Mixers / extruders
Electrical submersible pumps
Induced Draft Fans
Boiler feed water pumps

Forest Products
Fan pumps
Induced draft fans
Boiler feed water pumps
Pulpers
Refiners
Kiln drives
Line shafts

Mining & Metals
Slurry pumps
Ventilation fans
De-scaling pumps
Conveyors
Baghouse fans
Cyclone feed pumps

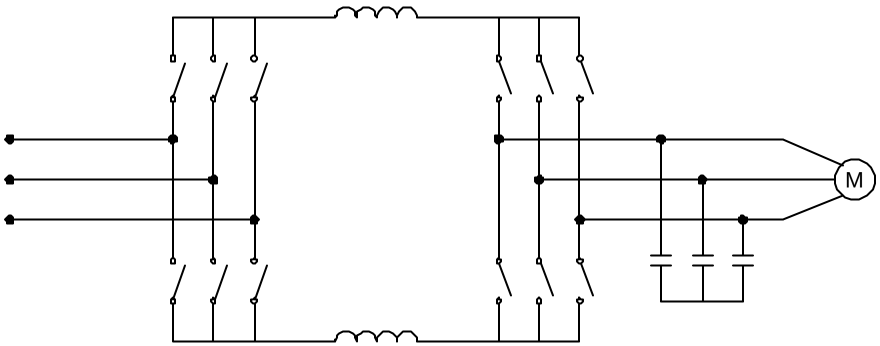
Cement
Kiln induced draft fans
Forced draft fans
Cooler baghouse fans
Preheat tower fans
Raw mill induced draft fans
Kiln gas fans
Cooler exhaust fans
Seperator fans
Baghouse fans

Water / Waste Water
Raw sewage pumps
Bio-roughing tower pumps
Treatment pumps
Freshwater pumps

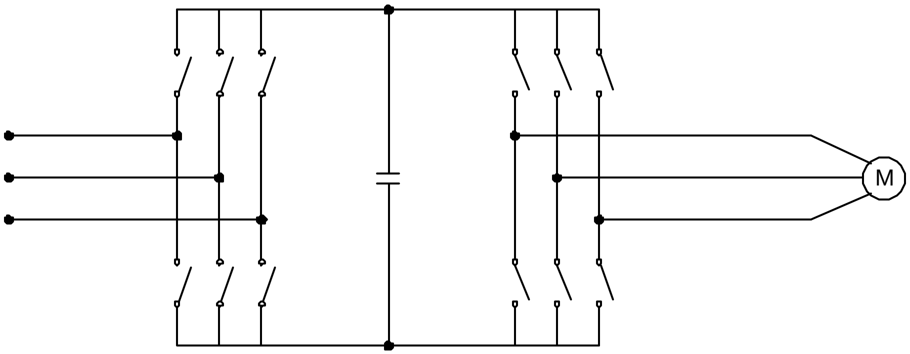
Miscellaneous
Test stands
Wind tunnels
Agitators
Rubber mixers

Electric Power
Feed water pumps
Induced draft fans
Forced draft fans
Baghouse fans
Effluent pumps
Compressors

Medium Voltage Basic Topologies

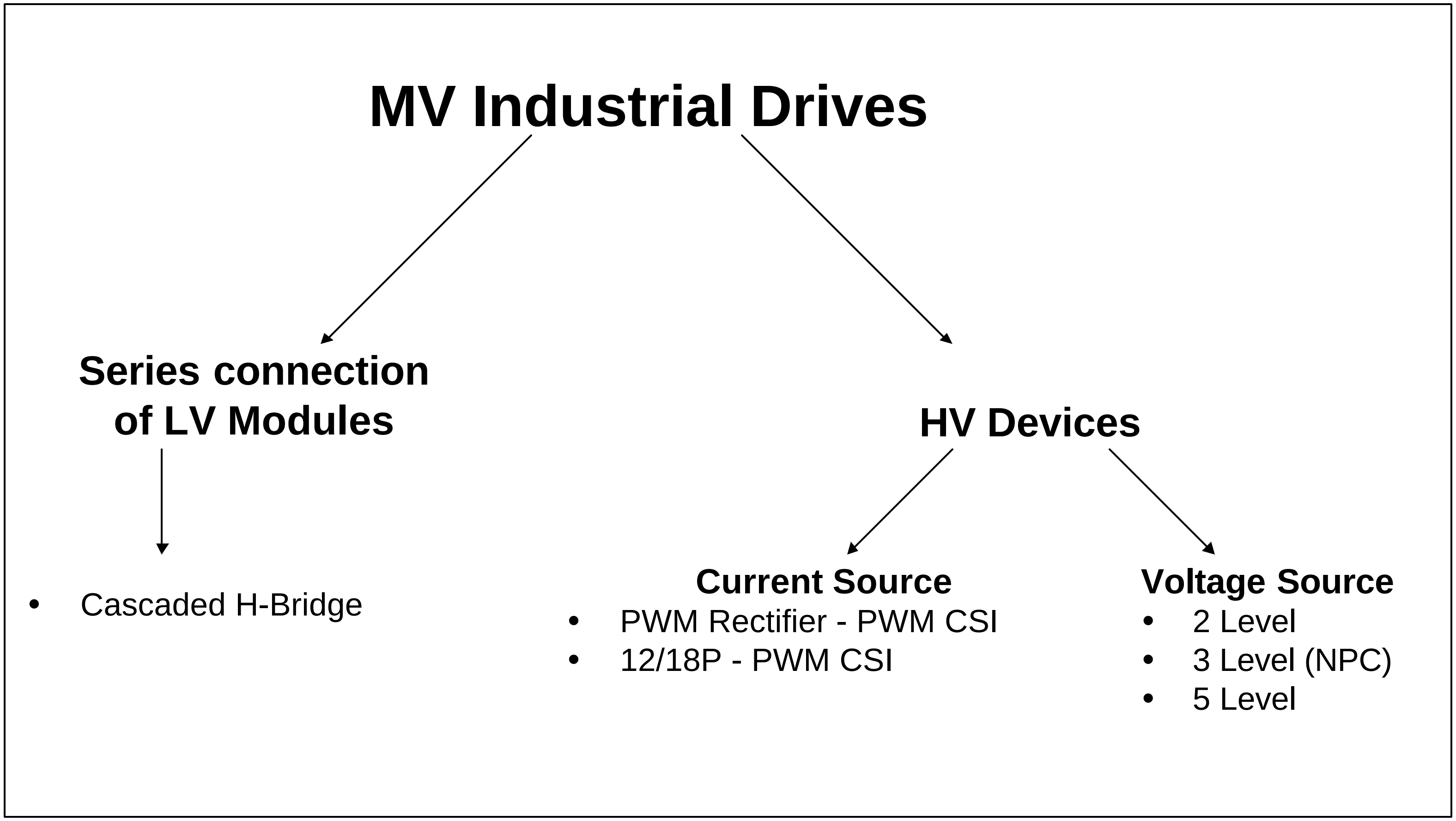


Current Source Inverter

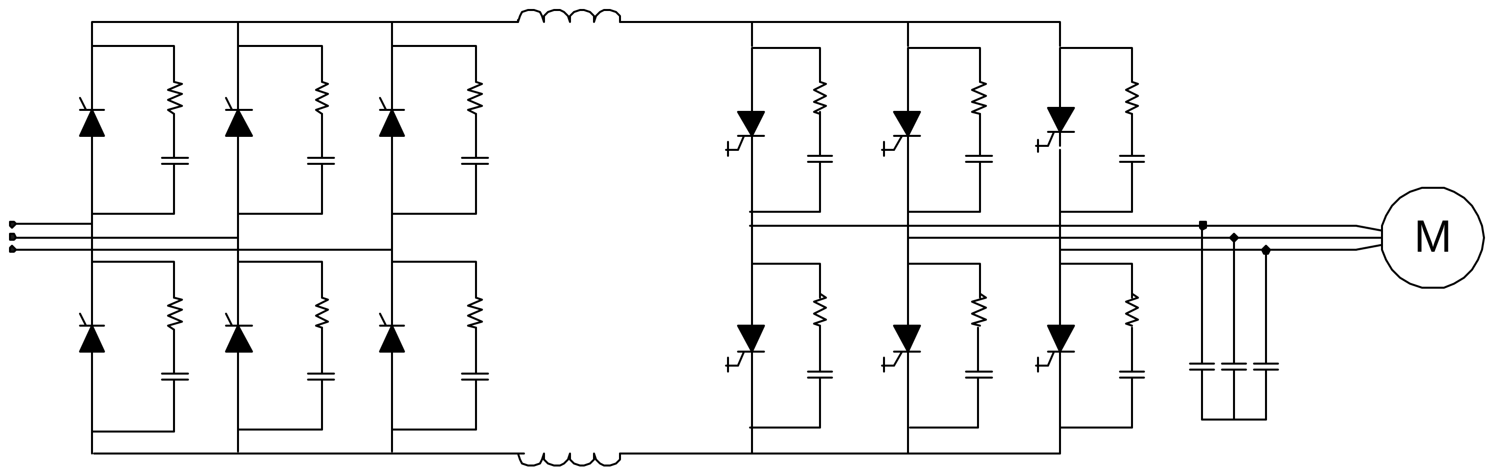


Voltage Source Inverter

Medium Voltage Topology Summary

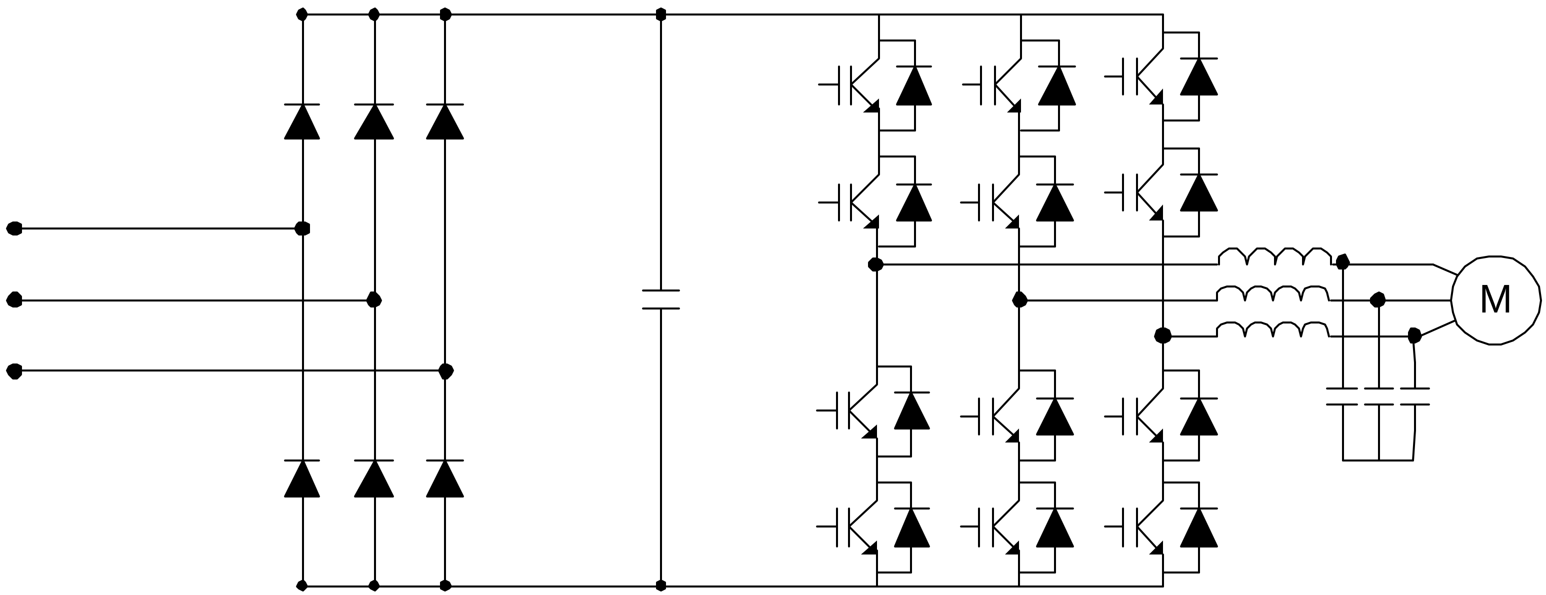


Current Source Inverter



- Inverter GCT based
- PWM Rectifier (AFE) GCT based
  - 6, 12, 18, or 24 pulse phase controlled thyristor
- Converter voltage capability increased by placing devices in series

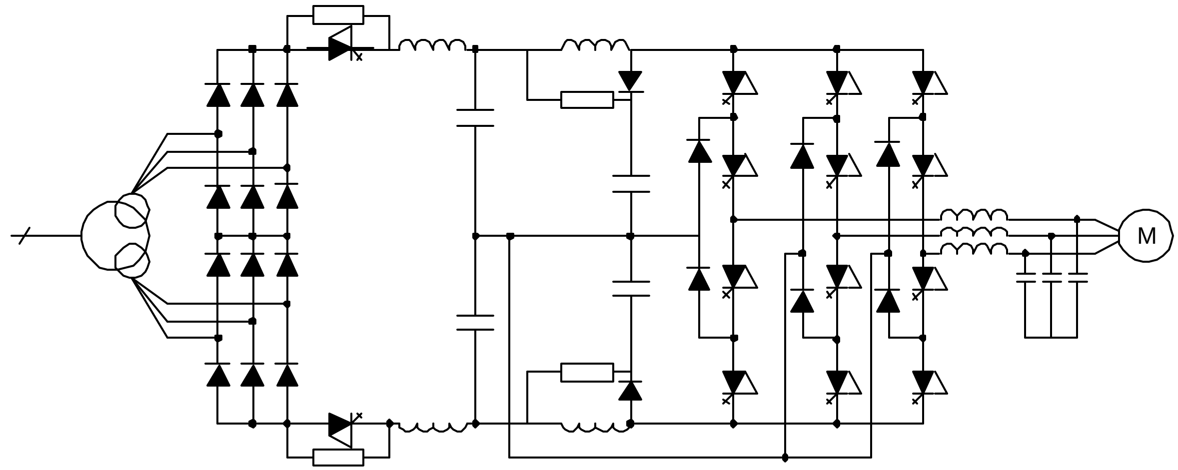
2 Level Voltage Inverter

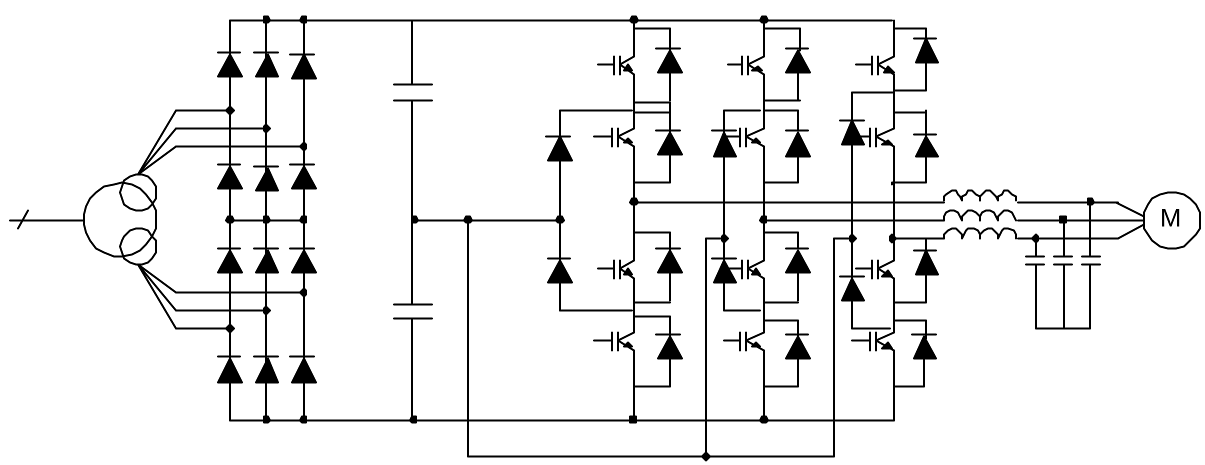


- Inverter IGBT based
- 6, 12, 18, or 24 pulse diode rectifier
  - PWM Rectifier (AFE)
- Converter voltage capability increased by placing devices in series

3 Level Voltage Inverter

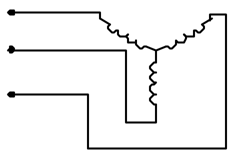
- Inverter GCT or IGBT based
- 12, or 24 pulse diode rectifiers
  - PWM Rectifier (AFE) with GCTs or IGBTs
- Converter voltage capability is 4.16 kV. For greater voltage series devices are required doubling number of devices in the inverter

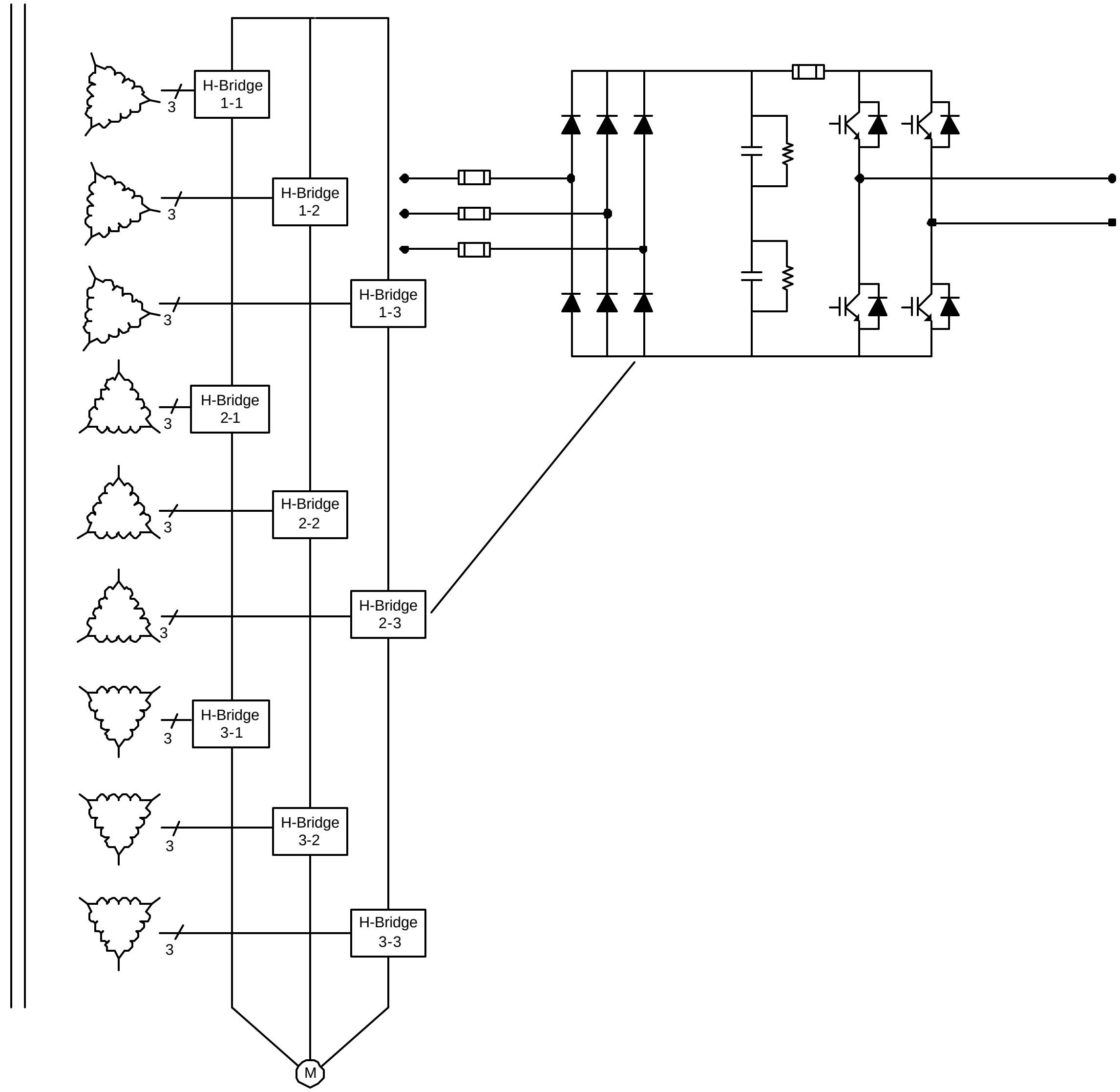




Cascaded H Bridge with LV IGBTs

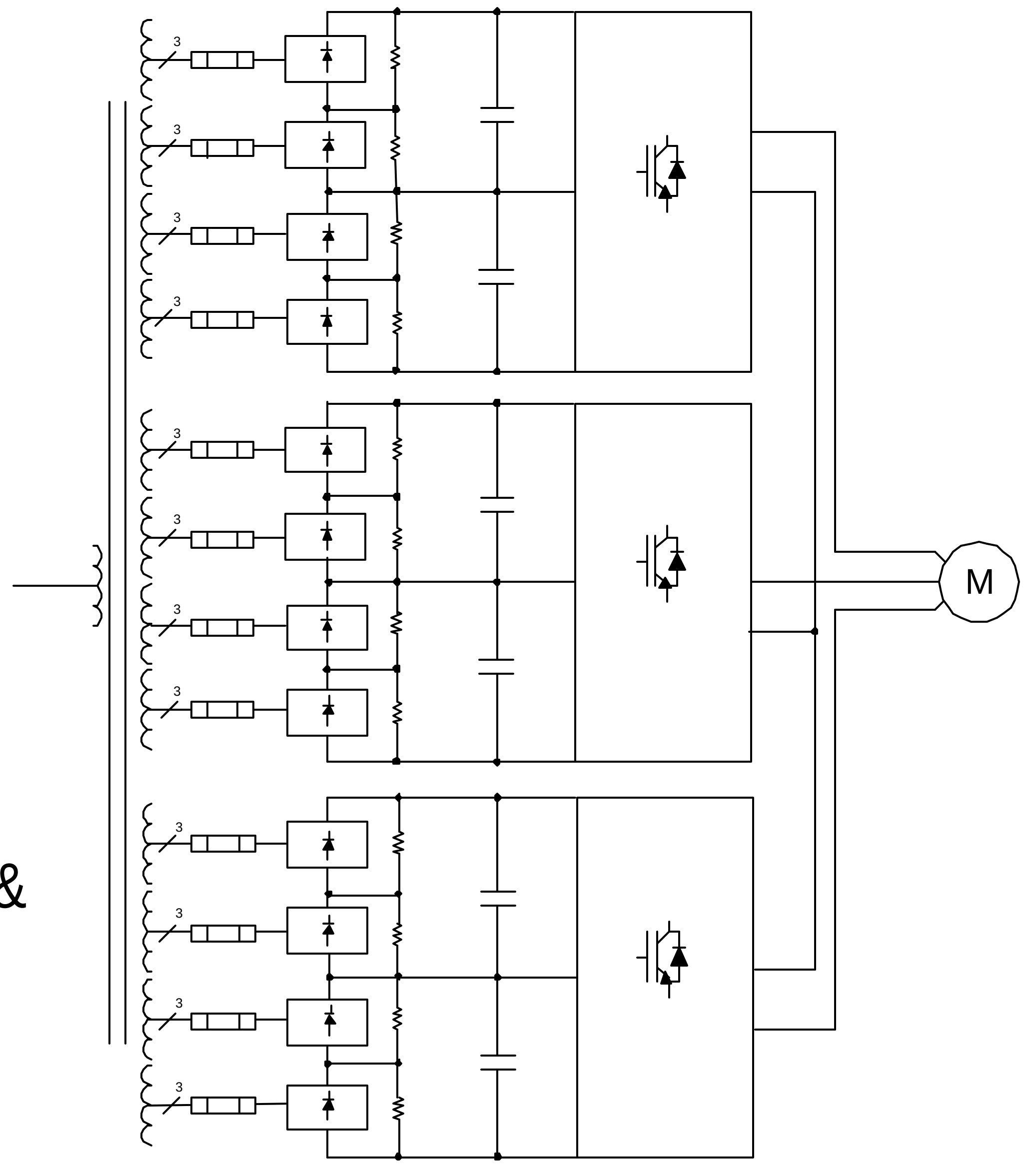
- Inverter LV IGBT based
- Diode 6 pulse rectifiers fed from a minimum of 9 windings
- Converter voltage capability is increased by adding a set of 3 secondary windings and H-Bridge modules



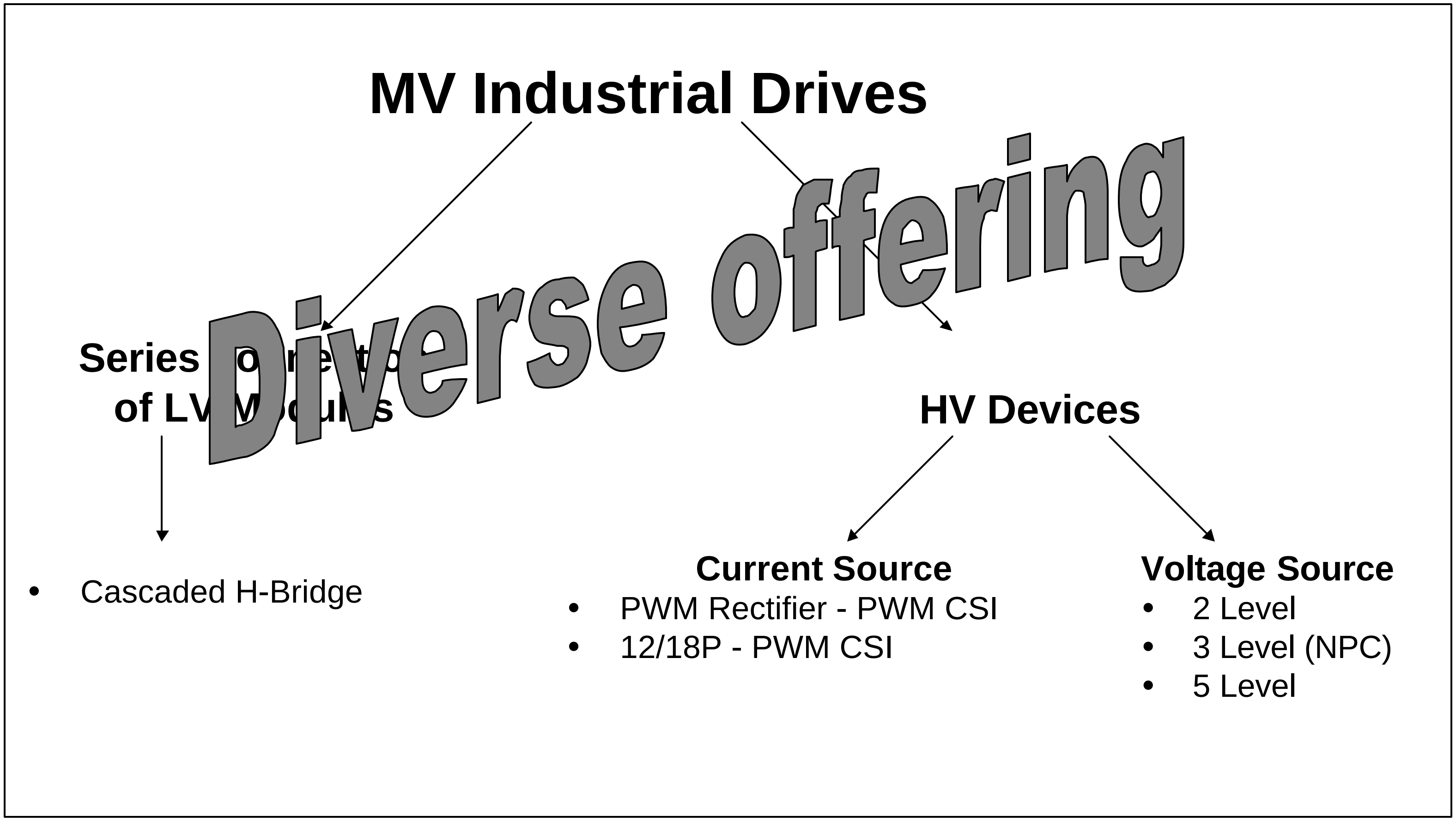


Cascaded H Bridge with HV IGBTs

- Inverter HV IGBT based
- Diode 6 pulse rectifiers fed from a minimum of 12 windings
- Converter voltage capability is increased by greater secondary winding voltage and higher voltage Diodes & IGBTs

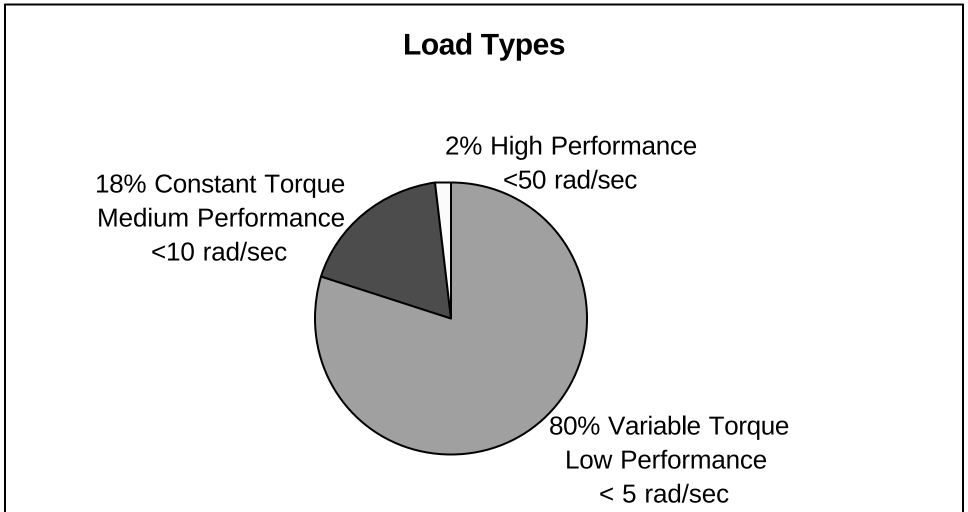


Medium Voltage Topology Summary



Indicates the technology is still evolving !

Performance Comparison



Typical Performance Criteria Values

	Speed Regulation		Speed Regulator	Speed Range	VFD	Regeneration
	Open Loop	Close loop	Bandwidth		Efficiency	
CSIPWM-GTO	0.5%	0.1%	< 10 rad/s	0-75 Hz	>97	Inherent
CSIPWM-SGCT	0.5%	<0.1%	< 20 rad/s	0-75 Hz	>97	Inherent
3Level-IGCT	0.5%	0.01%	Approx. 50 rad/s	0-66Hz	>97	With PWM rectifier
3Level-IGBT	0.5%	0.01%	Approx. 50 rad/s	150Hz at 4 kV 66 Hz at 6.6 kV	>97	With PWM rectifier
Series H-Bridge	0.5%	0.1%	Unknown	0-120 Hz	>97	Not available

Component Count

- Numerous reasons for reduction in complexity of system and component count
  - general increase in reliability
  - possibly reduce the number of spare parts required
  - possibly eliminate the need for costly entire cell replacement
- Ideally reduce complexity with the elimination of the multi winding transformer
  - presently only the PWMCSI is known to achieve this

Component Count

Rectifier Component Count for Transformerless 4160 V, 750kW drive IEEE519-1992

	PWMCSI-GTO Not Available	PWMCSI-SGCT	2-Level IGBT Not Available	3-Level IGCT Not Available	3-Level IGBT Not Available	Series H Bridge Not Available
Rectifier Semi-Conductors	-	12- 6.5 kV SGCTs	-	-	-	-
Rectifier Snubber	-	12 RC	-	-	-	-

Component Count Cont’d

Rectifier Component Count for 4160 V, 750kW drive with isolation transformer meeting IEEE519-1992 Isc/Il<20

	PWMCSI-GTO 18p	**PWMCSI-SGCT 18p**	**2-Level IGBT 18p**	**3-Level IGCT 24p**	**3-Level IGBT 24p**	**Series H Bridge 24p**
Transformer	1 primary 3 secondaries	1 primary 3 secondaries	1 primary 3 secondaries	1 primary 4 secondaries	1 primary 4 secondaries	1 primary 12 secondaries
Rectifier Semi-Conductors	18 thyristors	18 thyristors	18 diodes	24 diodes	24 diodes	72 diodes
Rectifier Snubber	18 RC	18 RC	Not required	Not required	Not required	Not required

Component Count Cont'd

DC Link & Inverter Component Count for 4160 V, 750kW

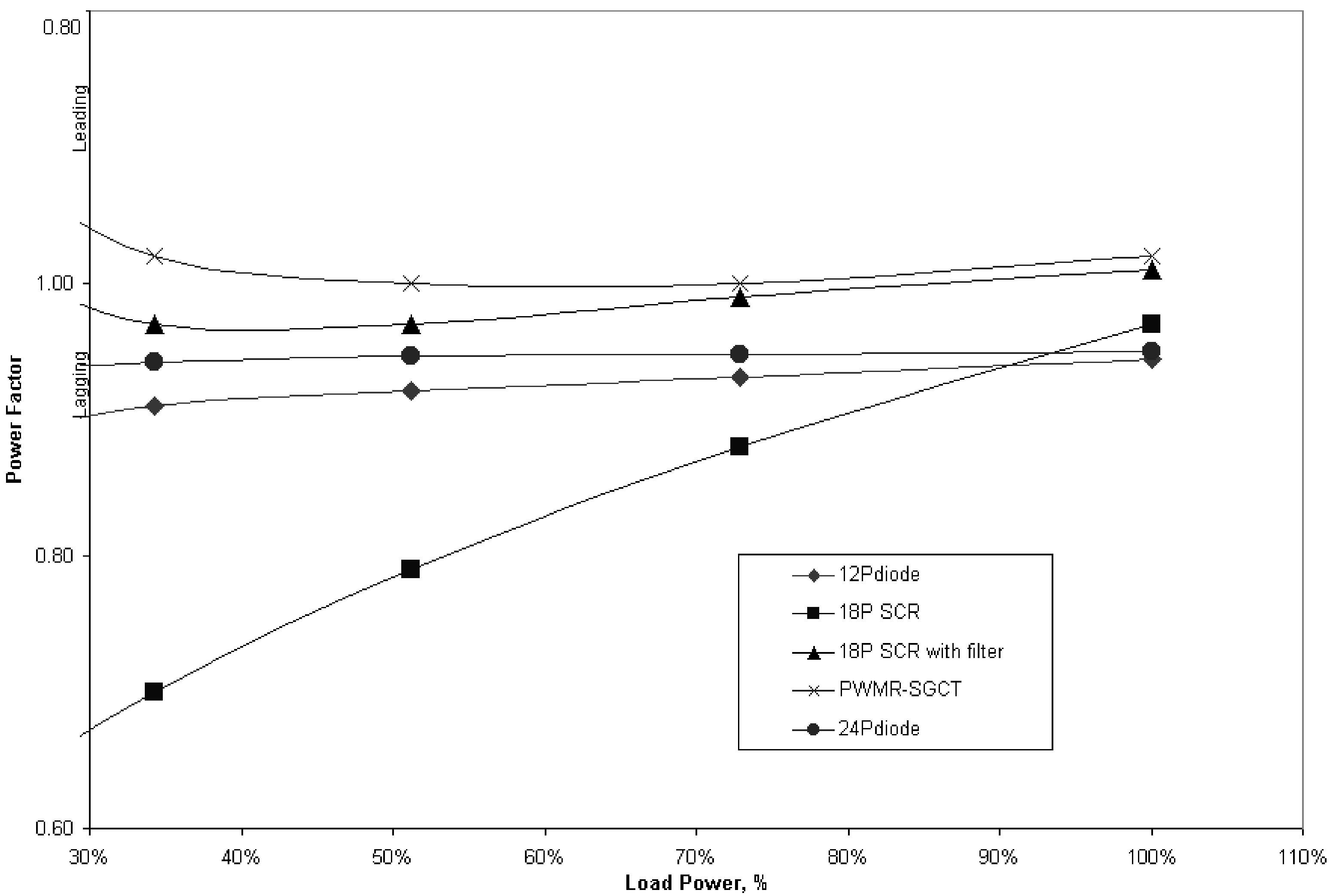
	PWMCSI-GTO 18p	**PWMCSI-SGCT 18p**	**2-Level IGBT 18p**	**3-Level IGCT 24 p**	**3-Level IGBT 24p**	**Series H Bridge 24p**
Charging circuitry	Not required	Not required	1	1	1	1 per cell
DC link	1 , 0.6 per unit inductor	1, 0.4 per unit inductor	Oil Film, 4-0.5pu	Oil Film, 4-0.5pu	Oil Film, 4- 0.5pu	180 electrolytic capacitors @ 6300uF
DC link Voltage sharing networks	Not Required	Not Required	Internal to capacitors	Internal to capacitors	Internal to capacitors	36 sharing resistors
DC Link Fusing	Not required	Not required	Normally not required	Yes or IGCTs	Normally not required	Normally not required
Inverter Semiconductors	12-6500 V GTOs	12 6500 V SGCTs	24-3300 V IGBTs	12-5500V IGCTs	24-3300 V IGBTs	48-1400V IGBTs
Neutral Point Clamping network	Not Required	Not Required	Not Required	6-diodes	6-diodes or 12-3300 V IGBTs	Not Required
Snubber for inverter	12-RCD	12-RC	Not Required	Clamp snubber	May not be required depends on layout	Not Required
Output filter	0.4-0.6 per unit capacitor	0.25-0.35 per unit capacitor	LC output filter (fres=5-6pu)	LC output filter (fres=7-8pu)	LC output filter (fres=7-8pu)	Not Implemented
			L =0.1 pu C= 0.3 pu	L=0.1 pu C=0.2 pu	L=0.1pu C=0.2pu	

Loss & Efficiency Estimation

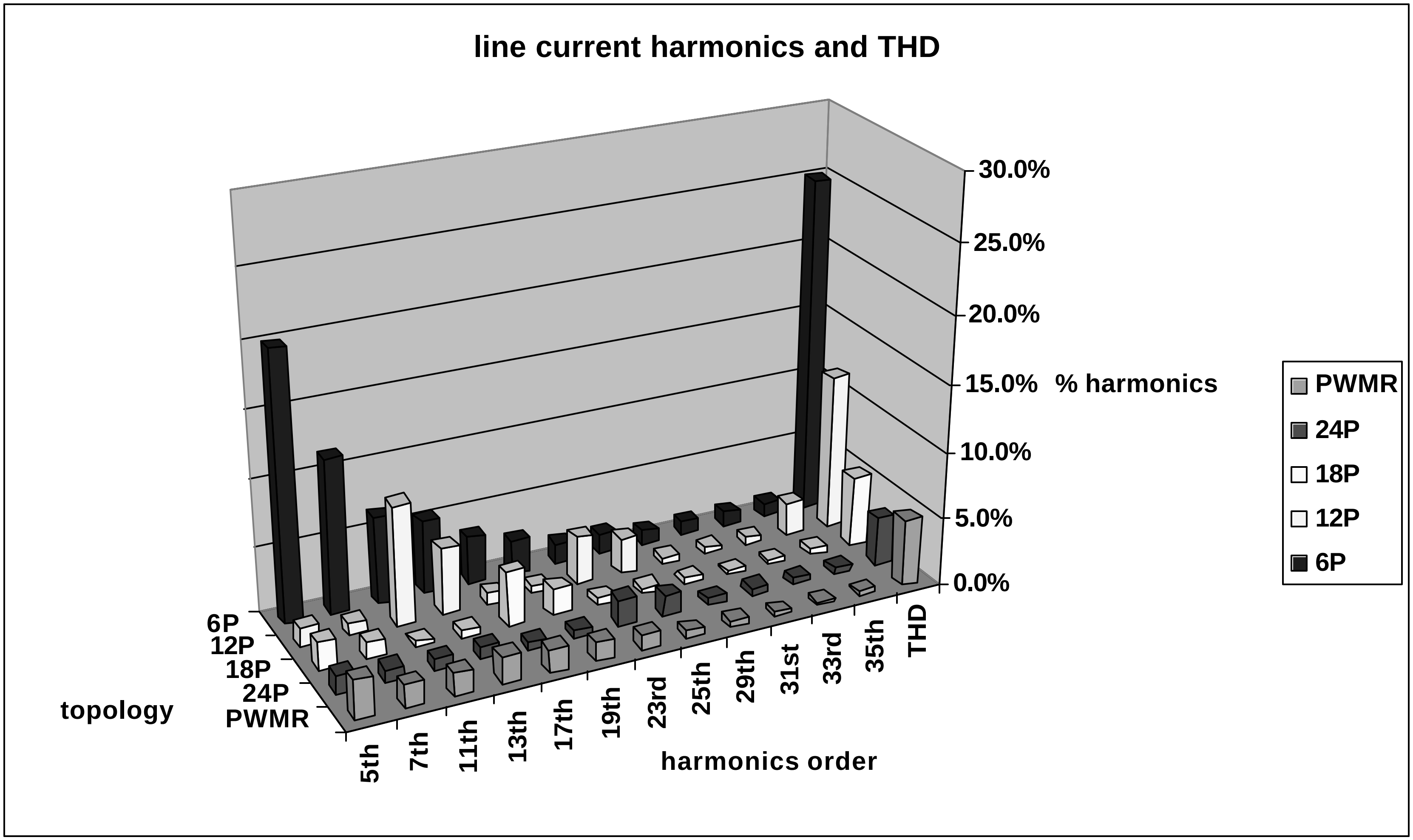
- System efficiency greatly affected by :
  - semiconductor, control algorithms, fsw, selection of passive components
- Literature has numerous comparisons between the IGBT and IGCT
- All manufactures indicate a drive efficiency of >97%
  - some do not include ancillary components
    - fans, power supplies, etc..
  - Which manufacturer is more correct ?
    - difficult and challenging question for the end user to answer

Simulation Results for Input Power Factor vs Load Power for Different Rectifier Options

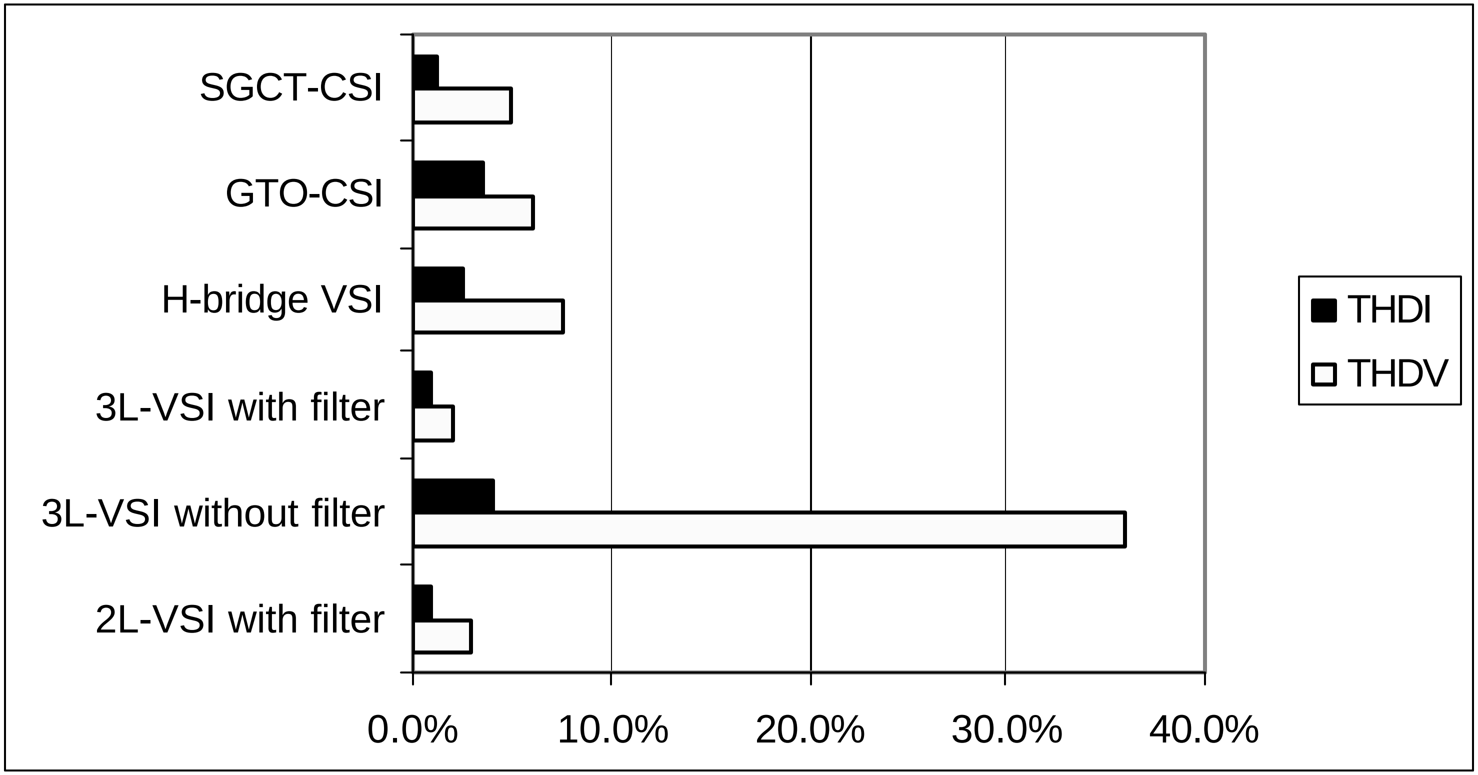
(Variable Torque Load)



Power System Impact
Input Harmonic Performance



Output Impact
Motor Voltage and Current Harmonics



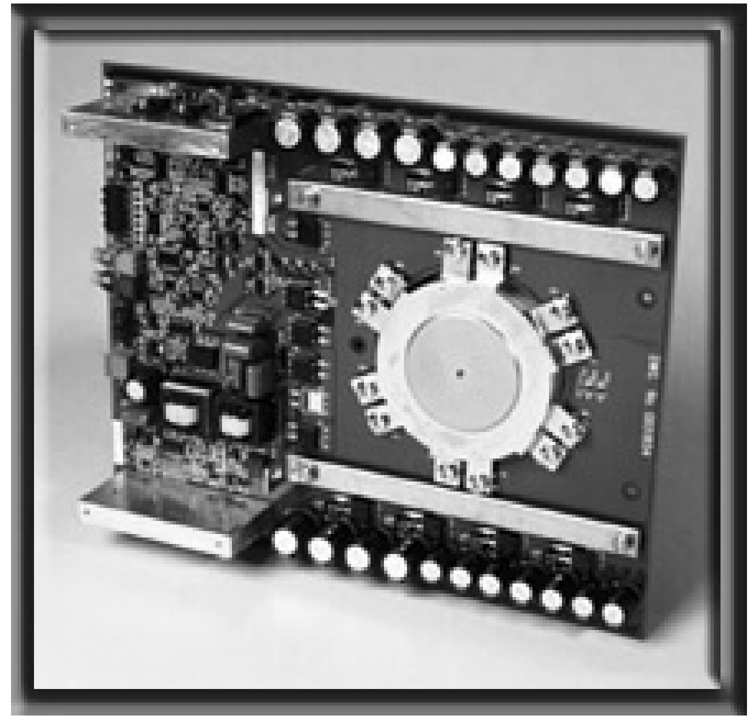
Power Semiconductor Devices in MV Drives

- Wide variety of devices are used
  - Low voltage devices
    - IGBTs up to 1700 V
  - High voltage devices 3.3 kV to 6.5 kV
    - GCTs (symmetric, asymmetric, reverse conducting)
    - IGBTs
    - State of the art IGBTs 6500 V , 600 A
    - State of the art GCT   6500 V, 6000A
      - 10 kV devices have been demonstrated
- New device technology (e.g. SiC) would have a significant impact in consolidating the offerings or perhaps enabling a new MV topology

Device technology has yet to force a standard topology as in low voltage drives.

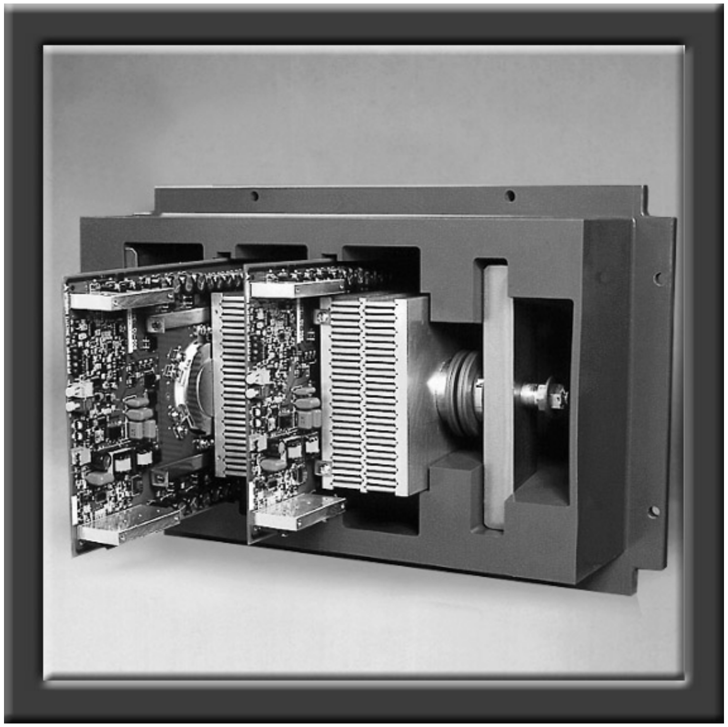
Symmetrical Gate Commutated Thyristor (SGCT)

- Modified GTO with integrated gate drive
- Gate drive close to the device creates low inductance path
  - more efficient and uniform gating
- Low conduction & switching losses
- Low failure rate
  - 100 failures per billion hours operation
- Double sided cooling
- Non rupture failure mode

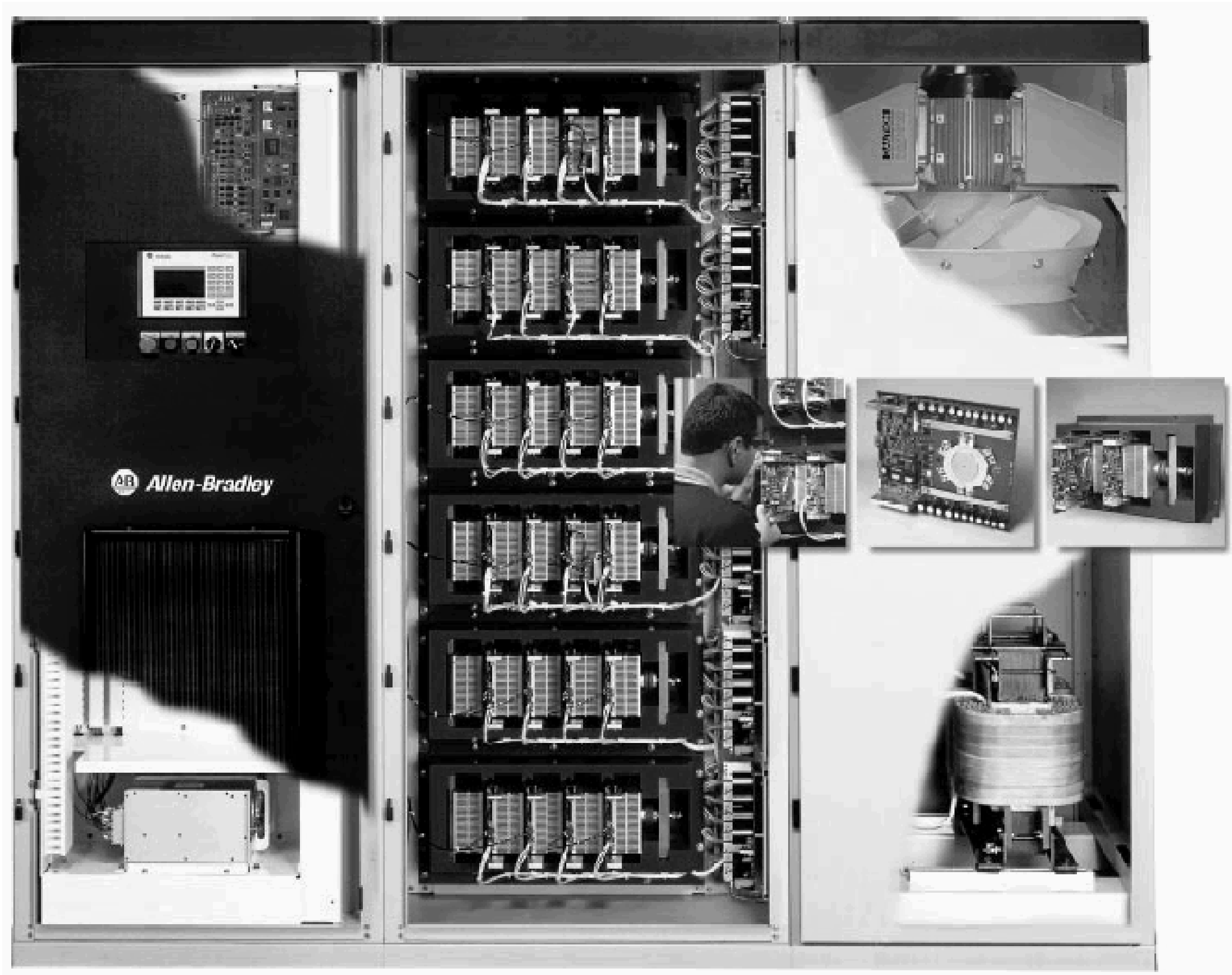


Patented* Power Cage

- Houses main power components
- Compact, modular package
- Common design for rectifier & inverter modules



4160 Volt PWM Rectifier

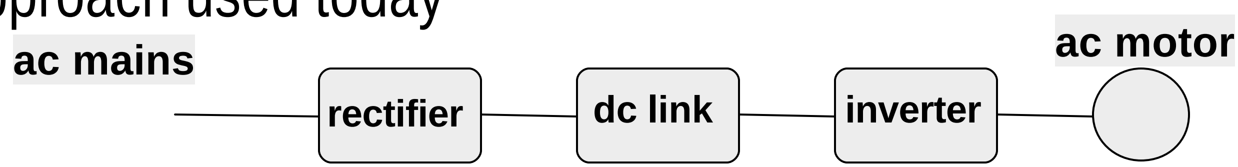


Conclusions

- There is a diverse approach by industry
- Each of the topologies presented meet the performance requirements of a majority of the applications in industry
- Higher voltage semiconductors inherently reduce overall component count and system complexity
  - can eliminate the isolation transformer on CSI PWM rectifiers
- Higher voltage semiconductor costs have an advantage over low voltage devices. The (S)(I)GCT technology is presently very cost effective
- IEEE519 can be met with 18, 24, and PWM rectifiers
- The power factor for CSI PWM rectifiers can be held close to unity throughout the load range

A Medium Voltage Drive for the Future

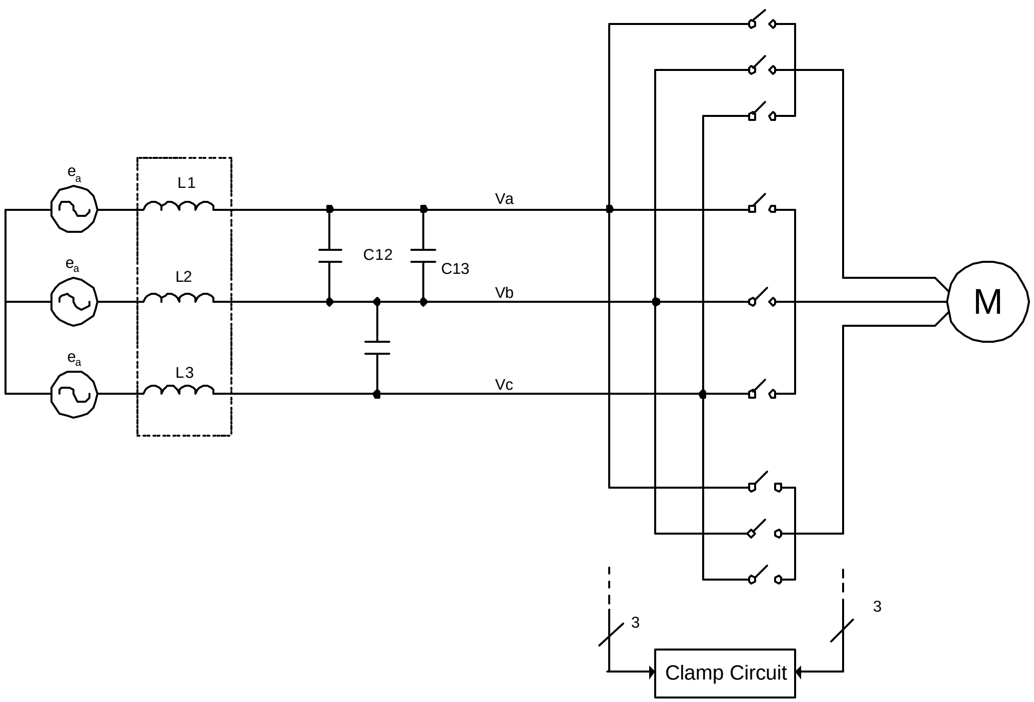
- What should we expect from this future drive?
  - Competitive pricing
  - Greater ease of installation, operation and maintenance
  - Greater reliability
- We should expect to continue to see (for the next 3 to 5 years) MV drives with ‘standard’ stages of rectification, DC energy storage and inversion
  - It is unlikely that a different methodology will displace the ‘traditional’ approach used today



We must strive for greater simplicity and functionality!

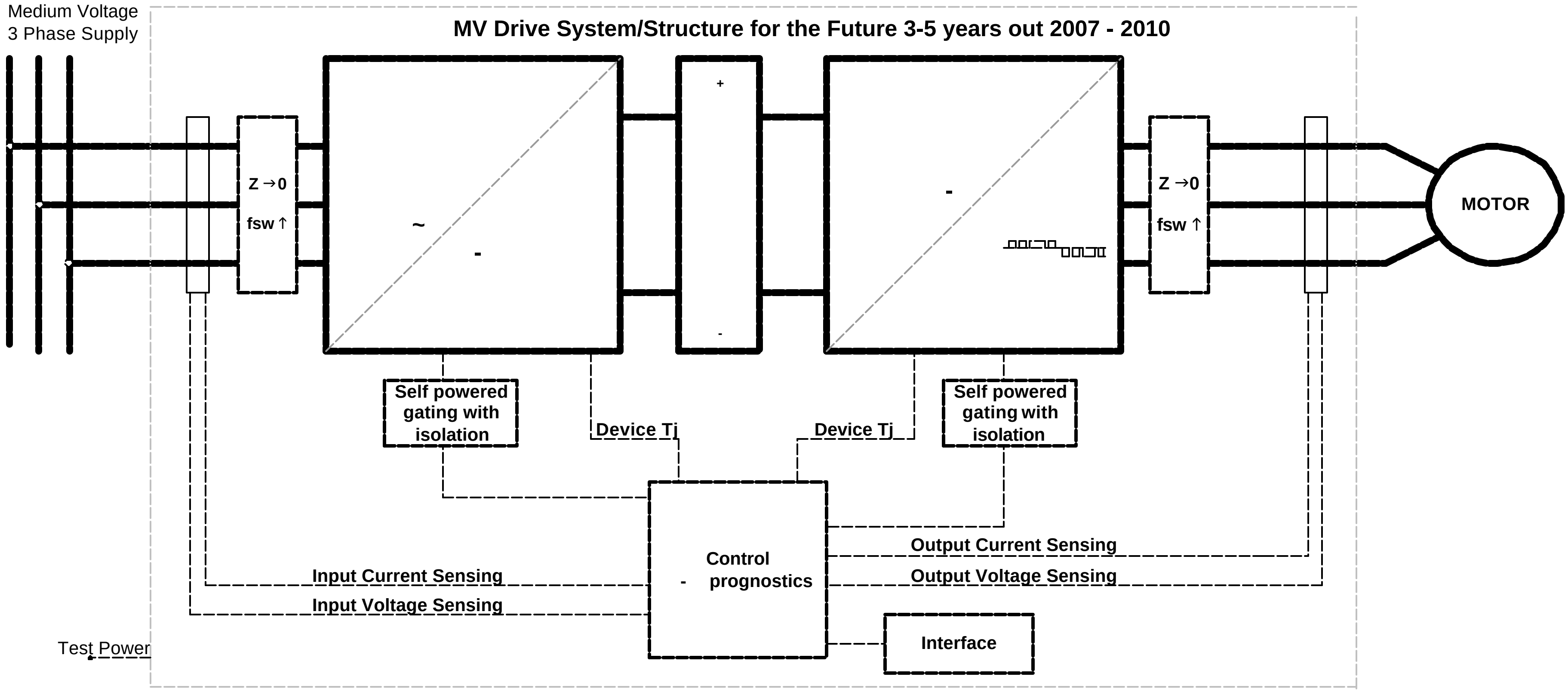
Possible Alternative Device

- Bi-directional device
  - Using RB-IGBT technology can lead to the matrix converter



It remains to be seen if this is commercially viable at low voltage!

The Drive Layout



Input

- 3 cables in
- Standard cables
- Line current/ voltage meet standards/ guidelines

Rectifier

- Active rectifier
  - Control power factor to near unity
  - Provide active damping/clamping for oscillations/ transients
  - Regenerative
- 6-device structure
- Line impedance, not necessarily transformer

DC Link

- Single to few components designed for the life of drive
- Optimize/ minimize stage

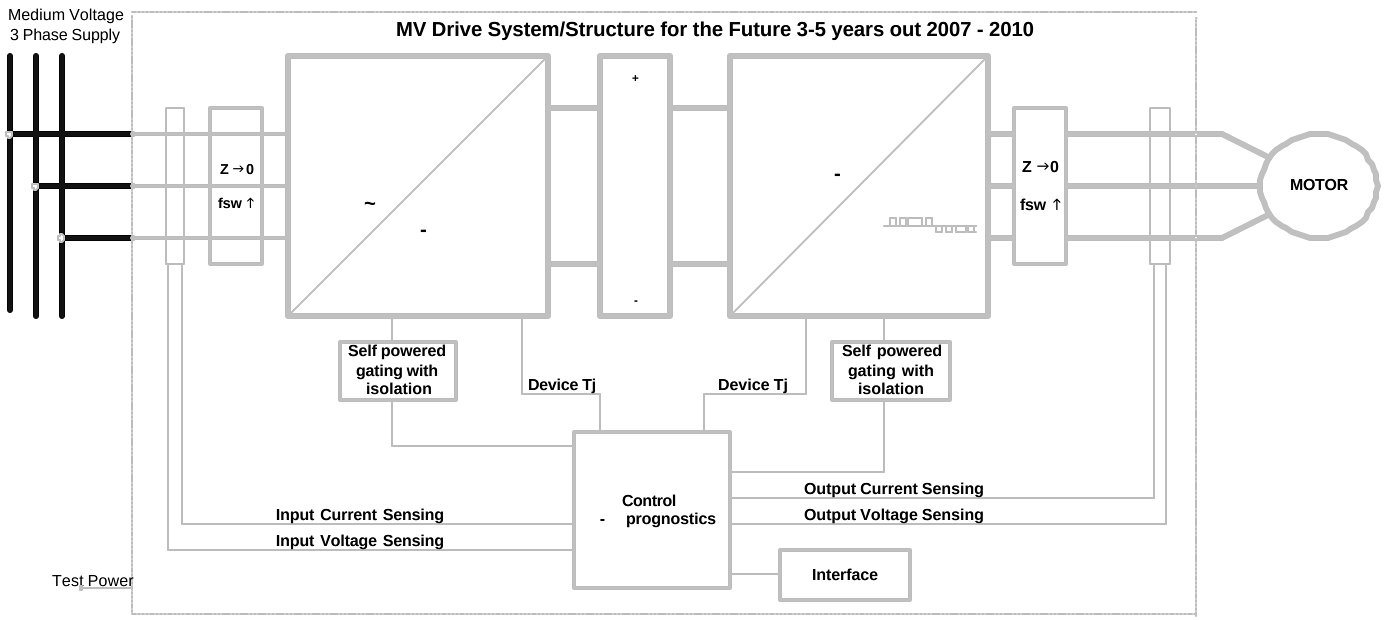
Inverter

- Active Inverter
  - Provide low THD to motor
  - Provide damping/clamping for oscillations/transients
- 6 device structure
- Mitigate neutral to ground voltage

Output

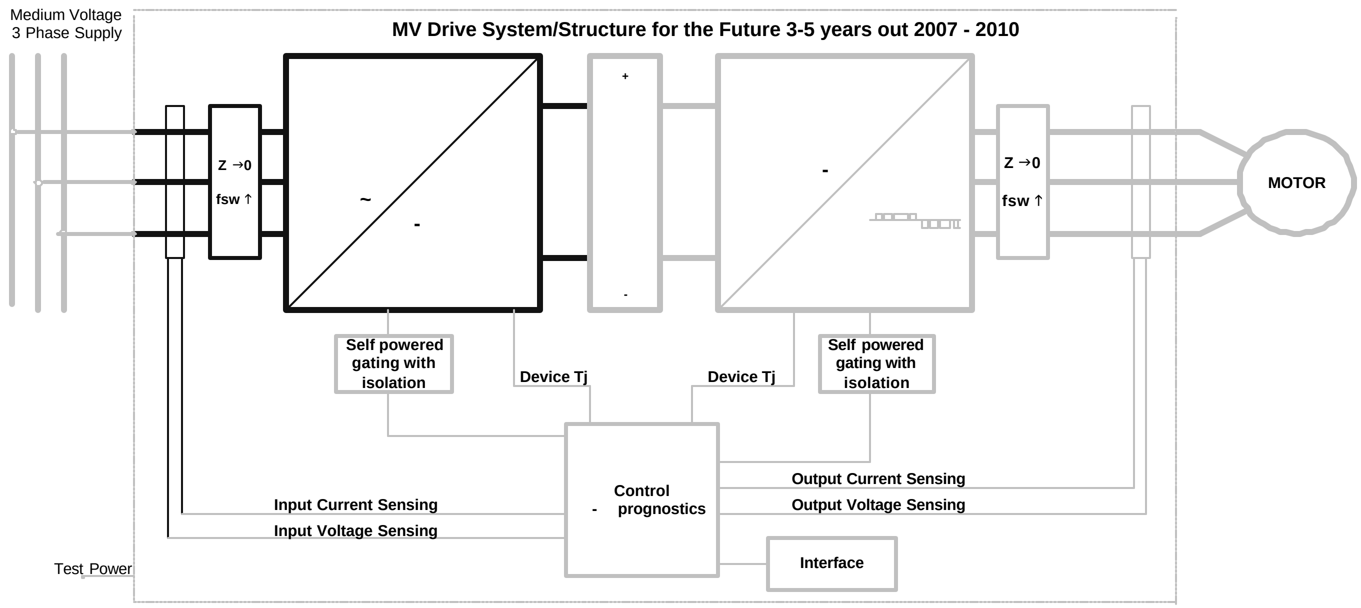
- 3 cables out
- Standard cables
- Motor current/voltage facilitate standard motor design
- Cable length limited only due to voltage drop

Input



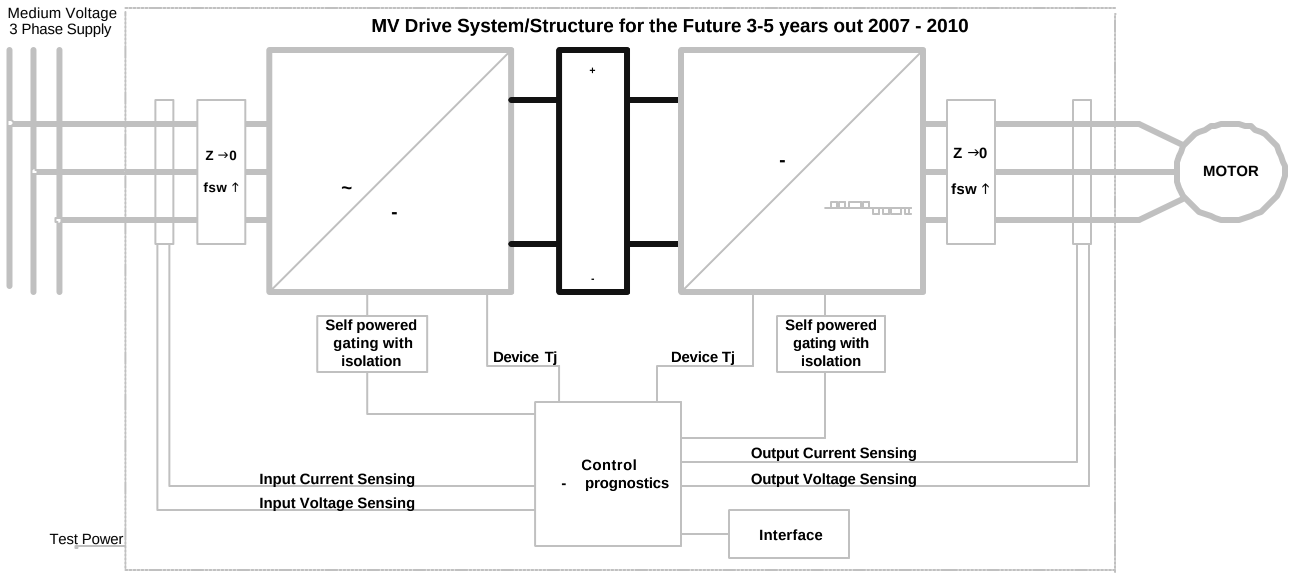
- 3 cables in to drive
- Cables are to be standard
- Line current/voltage meet harmonic standard/guide lines
- Input impedance should be minimal with out the need to isolate the drive from the power system (no transformer)

Rectifier



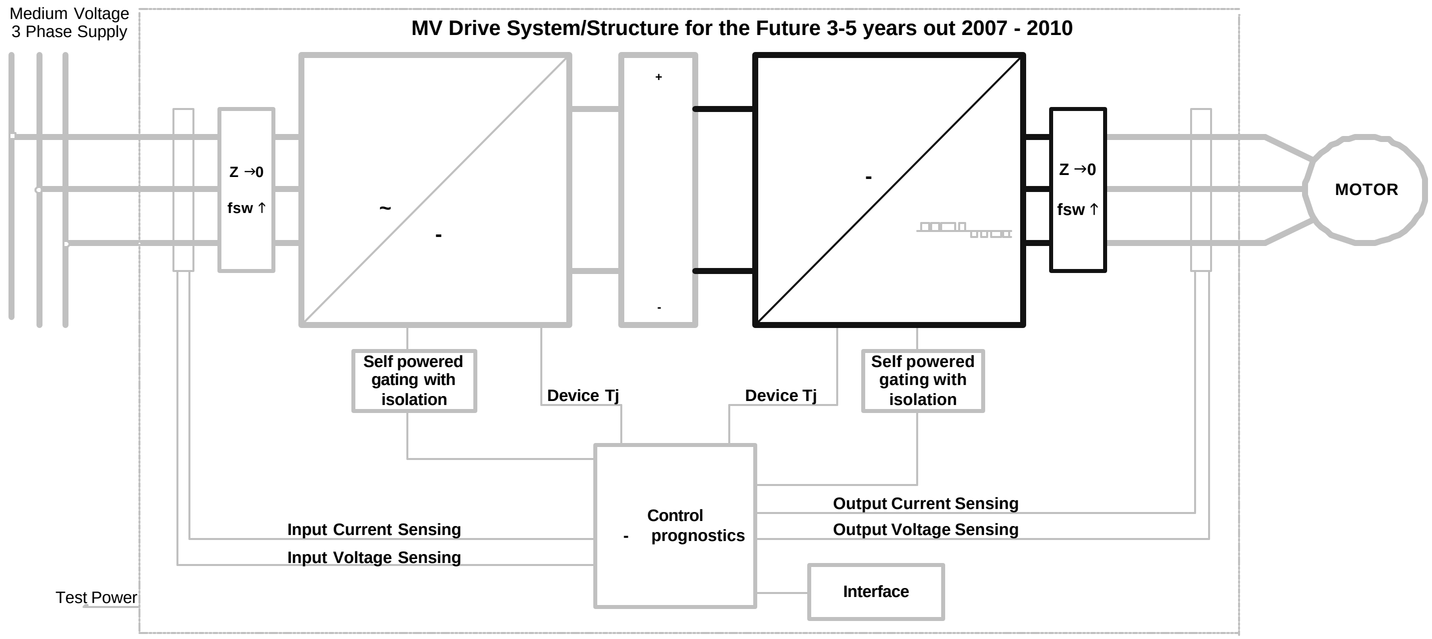
- ‘Active’ line converter providing:
  - Harmonic mitigation
  - Power factor near unity through the load range
  - Capable of damping/clamping any system oscillation or transient
  - Regeneration
- 6 device line converter for voltages in the 4.16 kV to 6.6 kV
- Device would be self-powered identical to that used in the inverter

DC Link Energy Storage



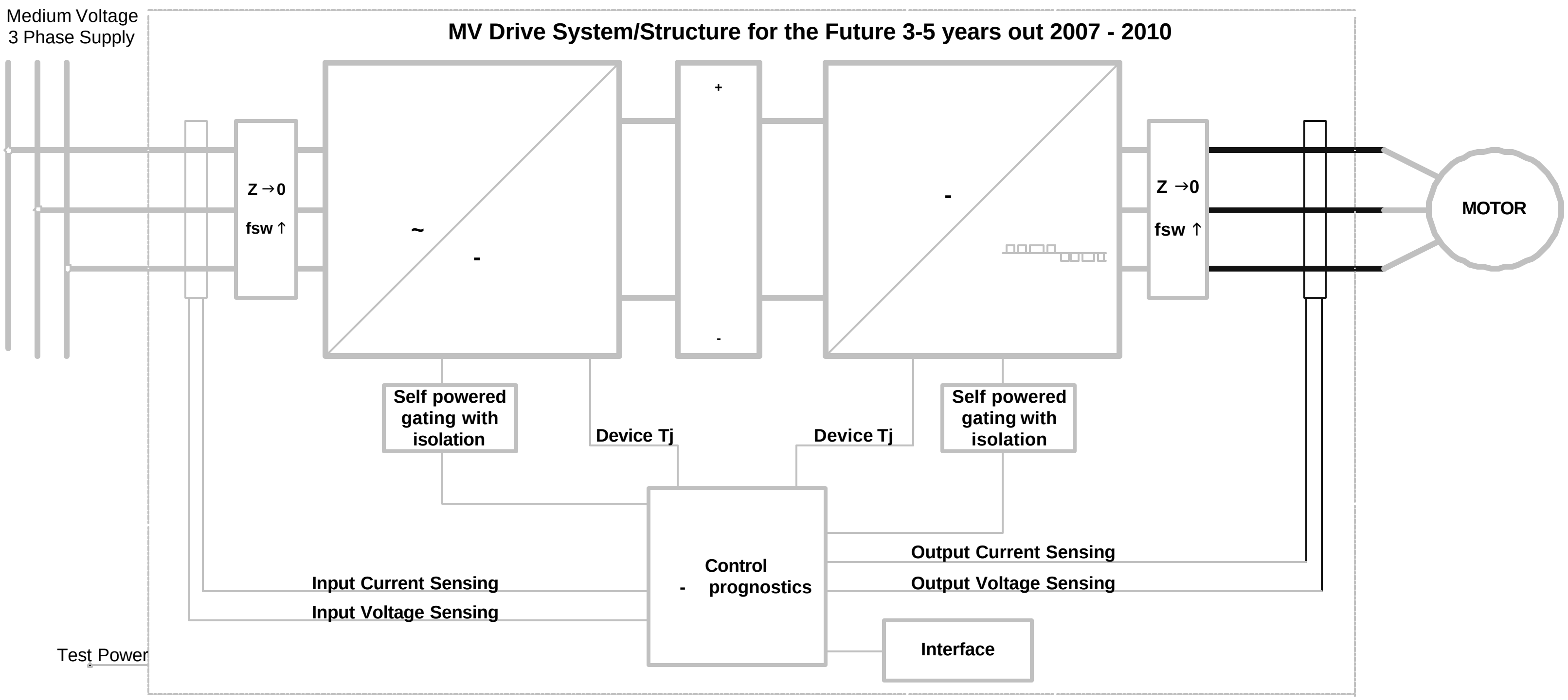
- Consist of a single to a few parts designed for life of the drive system
- No snubber or clamp assisting the operation of the converter devices

Inverter



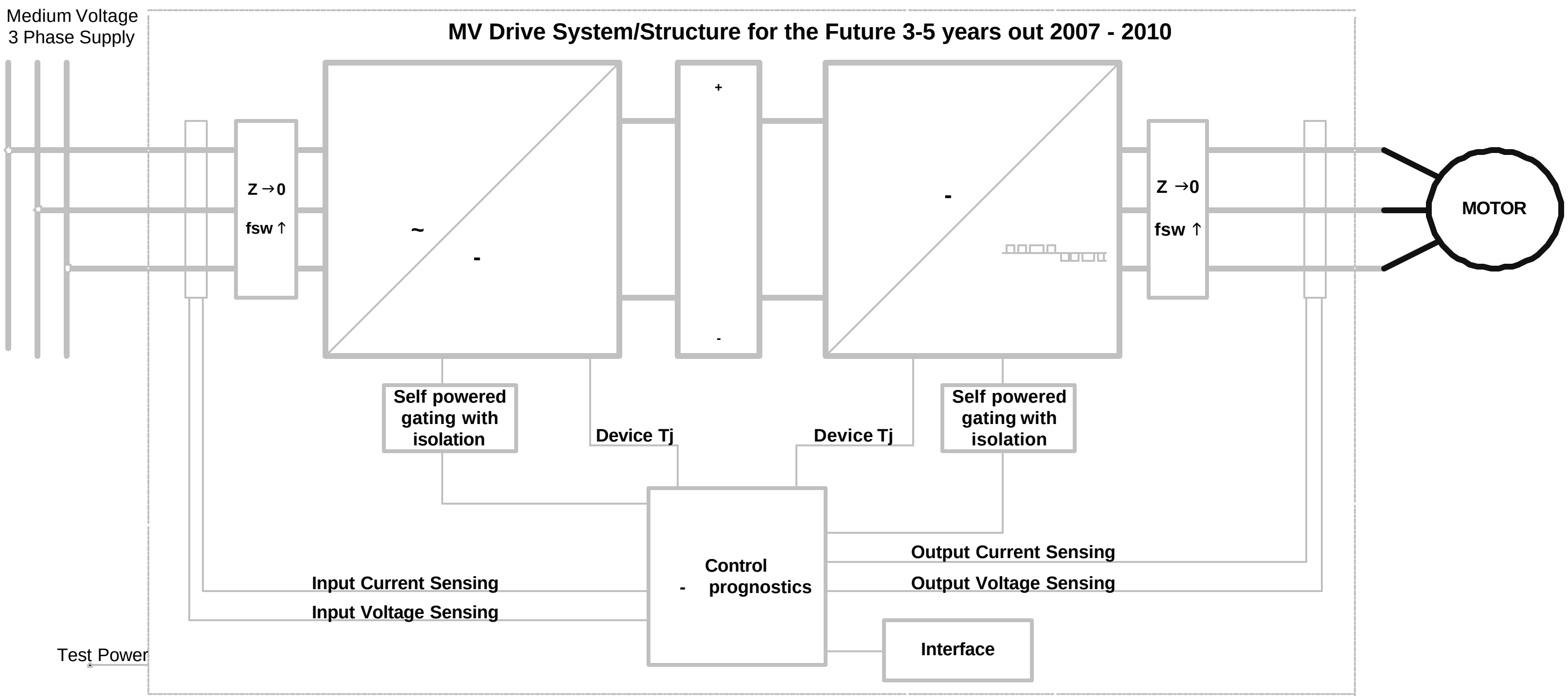
- 6 device machine converter for voltages in the 4.16 kV to 6.6 kV
- Device would be self-powered identical to that used in the rectifier
- Output voltage and current would be near sinusoidal eliminating issues with dv/dt, and wave reflection due to cable length
- Actively damp / clamp oscillations or transients
- Mitigate neutral to ground voltage concerns on the motor

Output



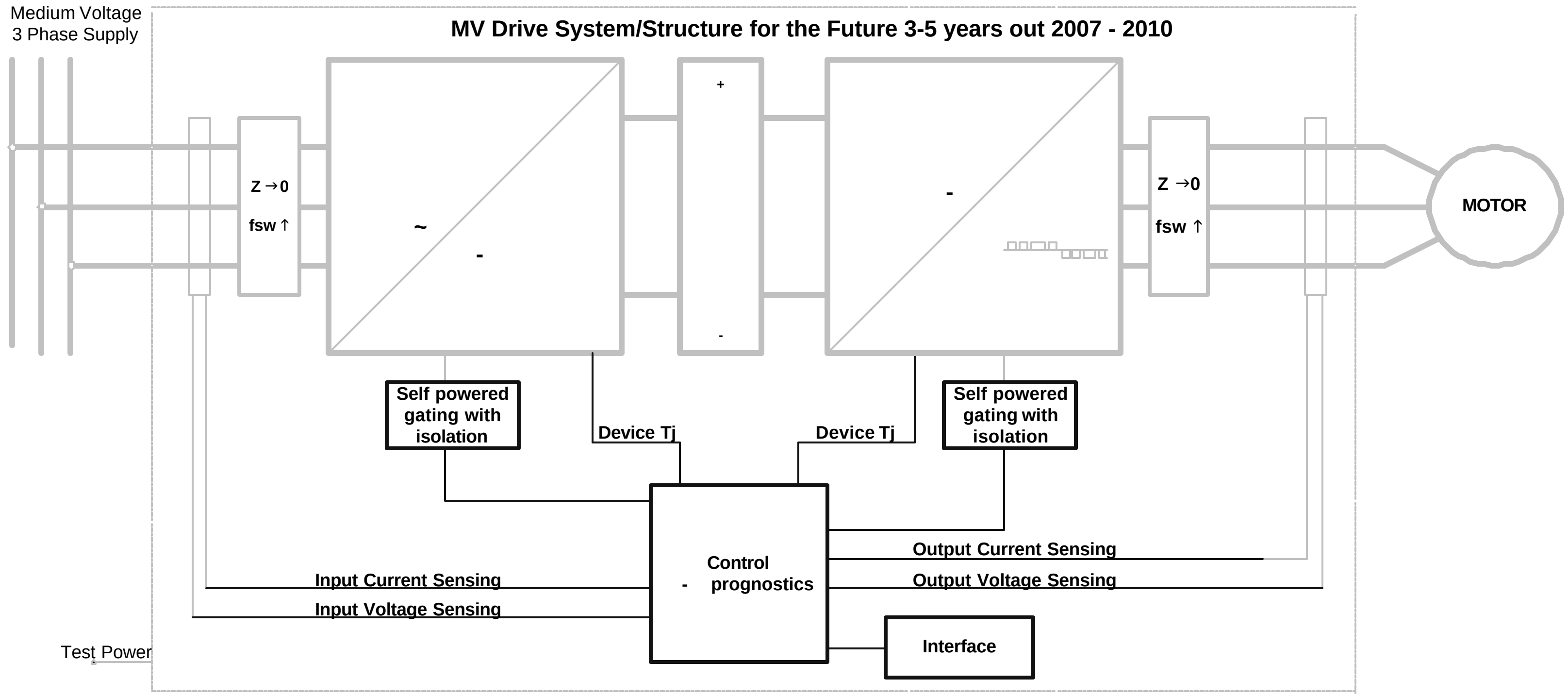
- 3 cables from the output of the drive to the motor
- The output voltage/current waveforms allow for the use of standard motor designs
- Cable length from drive to the motor is ‘unlimited’

Motor



- The inverter waveform quality would result in **no** need for:
  - Inverter duty designs
  - Added insulation due to neutral to ground offset voltage
  - De-rating of existing standard machines while running on MV drives

Control



- Software based algorithms characterizing systems will decline in favor of adaptive controllers making knowledge of the system less critical
- More prognostic capability which will reduce the potential for unexpected down time

Conclusion

- A summary of the MV topologies has been given
- A summary of the power semiconductors and their influence on topologies described
- A hypothetical drive for the near term described
- A significant advancement in power device technology will be the key to greater simplicity and functionality