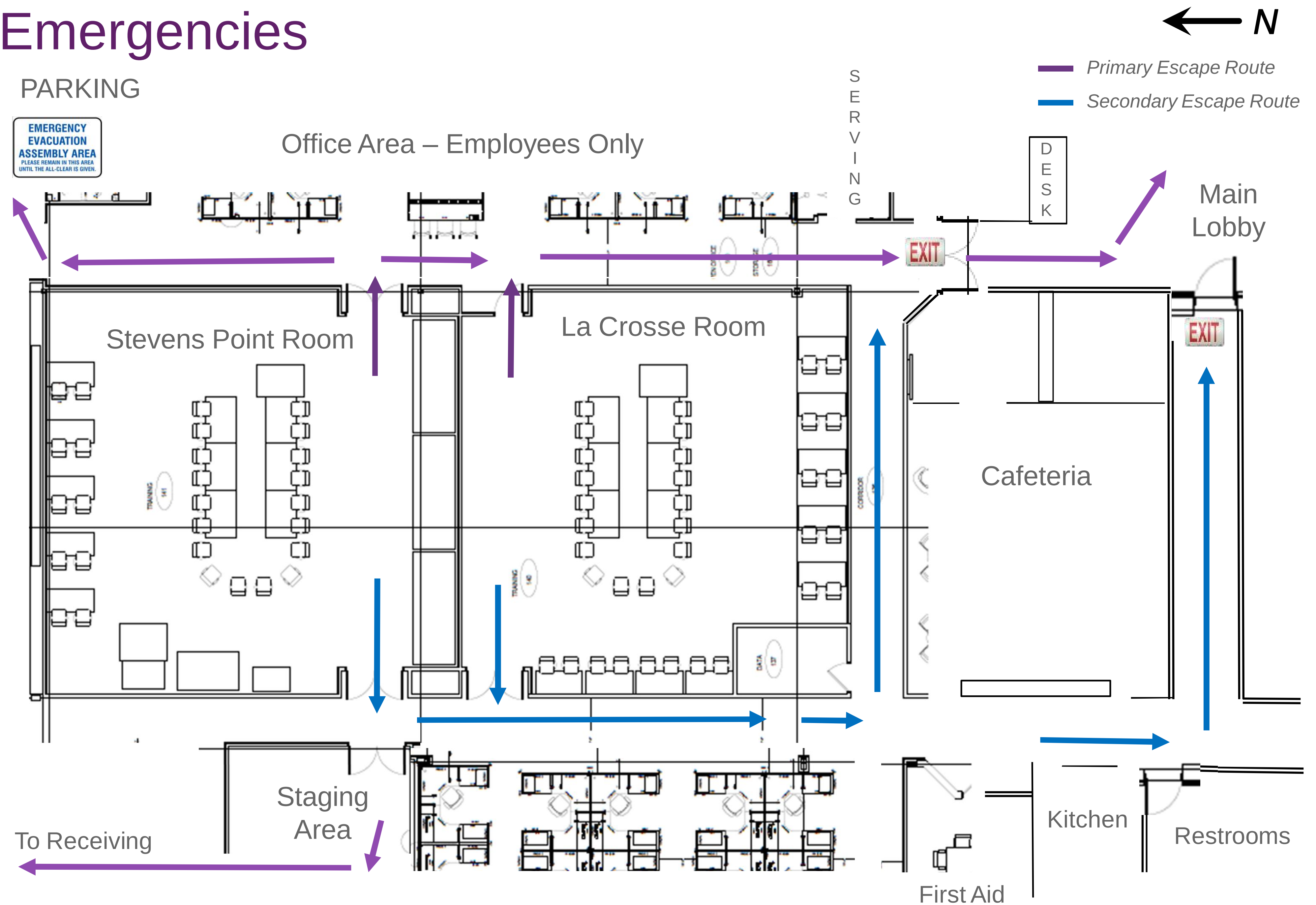
Welcome to ABB

Thank You for Joining Us!
Things you need to know

- Emergency: Dial **31-911** and notify Front Desk at **31-3214**
  - On-site First-Aid room / Sharps disposal / Blood-borne pathogens
- Tornado (stay in or move to the classrooms)
  - Shelter areas - Lowest level, interior room without windows
  - Close doors and stay in the room
  - Wait for all-clear announcement before returning

- Fire (Evacuate to Assembly Area in Parking Lot)
  - Go to nearest exit (see next slide) – “Buddy System”
  - Walk to the southwest “Emergency Evacuation Assembly Area”
  - Wait for all-clear announcement before returning

Emergencies



Thank You for Joining Us!
Ground Rules

- Respect:
  - For each other, the equipment, the facility, and ABB
- No Smoking / Tobacco use indoors:
  - Smoking permitted in designated areas only
- No Cell Phone/Texting during classroom time:
  - Set phones to silence please
- Participate:
  - This is not a spectator sport
  - Ask questions, answer questions
- Learn something:
  - New Knowledge, Skills, and Attitudes to help do your job better
- HAVE FUN and enjoy your stay!

AGENDA

START	END	TOPIC	PRESENTER	LOCATION
8:00	8:15	WELCOME/KICK-OFF	SCOTT KINOWSKI	STEVENS POINT
8:15	9:00	LV/MV DRIVES 101	RICK HOADLEY	STEVENS POINT
9:00	9:45	HARMONICS 101	JEF FELL	STEVENS POINT
9:45	10:00	BREAK	ALL	
10:00	10:45	MOTOR TECHNOLOGY UPDATE	BRENT McMANIS	STEVENS POINT
10:45	11:30	EV CHARGING	HEATHER FLANAGAN	STEVENS POINT
11:30	12:00	STATCOM/ENERGY STORAGE	MICHELLE MEYER	STEVENS POINT
12:00	12:15	MOVE TO ALE HOUSE	ALL	
12:15	2:00	LUNCH & BRAINY BUNCH	JACK CAMPBELL	ALEHOUSE

START	END	TOPIC	PRESENTER	LOCATION
8:15	8:30	WELCOME/KICK-OFF	JACK CAMPBELL	LA CROSSE
8:30	9:15	MOTOR TECHNOLOGY UPDATE	BRENT McMANIS	LA CROSSE
9:15	10:00	LV/MV DRIVES 101	RICK HOADLEY	LA CROSSE
10:00	10:15	BREAK	ALL	
10:15	11:00	HARMONICS 101	JEFF FELL	LA CROSSE
11:00	11:30	STATCOM/ENERGY STORAGE	MICHELLE MEYER	LA CROSSE
11:30	12:15	EV CHARGING	H. FLANAGAN	LA CROSSE
12:15	12:30	SWITCH TO NB ALE HOUSE	ALL	
12:30	2:00	LUNCH & BRAINY BUNCH	JACK CAMPBELL	ALEHOUSE

Power and productivity
for a better world™

July 2014

North America Region Overview

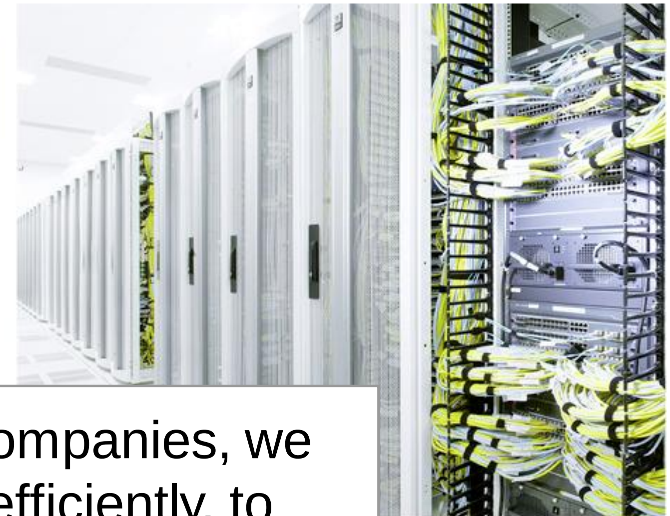
Power and productivity
for a better world™

A leader in power and automation technologies
Facts about ABB in North America

- Largest installed base of ABB power transmission and distribution equipment
- One of company's largest markets for products, systems and services
  - Discrete Automation and Motion
  - Low Voltage Products
  - Power Products
  - Process Automation
  - Power Systems
- Region headquarters in Cary, North Carolina
- More than 30,000 employees working in Canada, Mexico and the United States
- Five major operational areas: Manufacturing, Assembly, Service, Sales and Engineering, Research & Development

Power and productivity for a better world
ABB's vision





As one of the world's leading engineering companies, we help our customers to use electrical power efficiently, to increase industrial productivity and to lower environmental impact in a sustainable way.

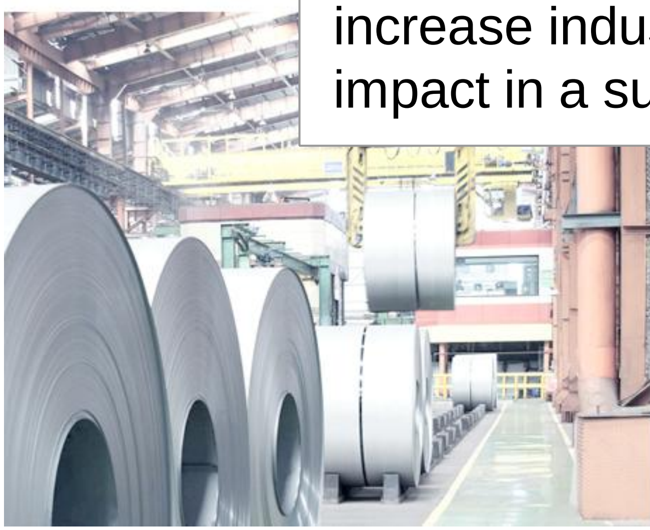
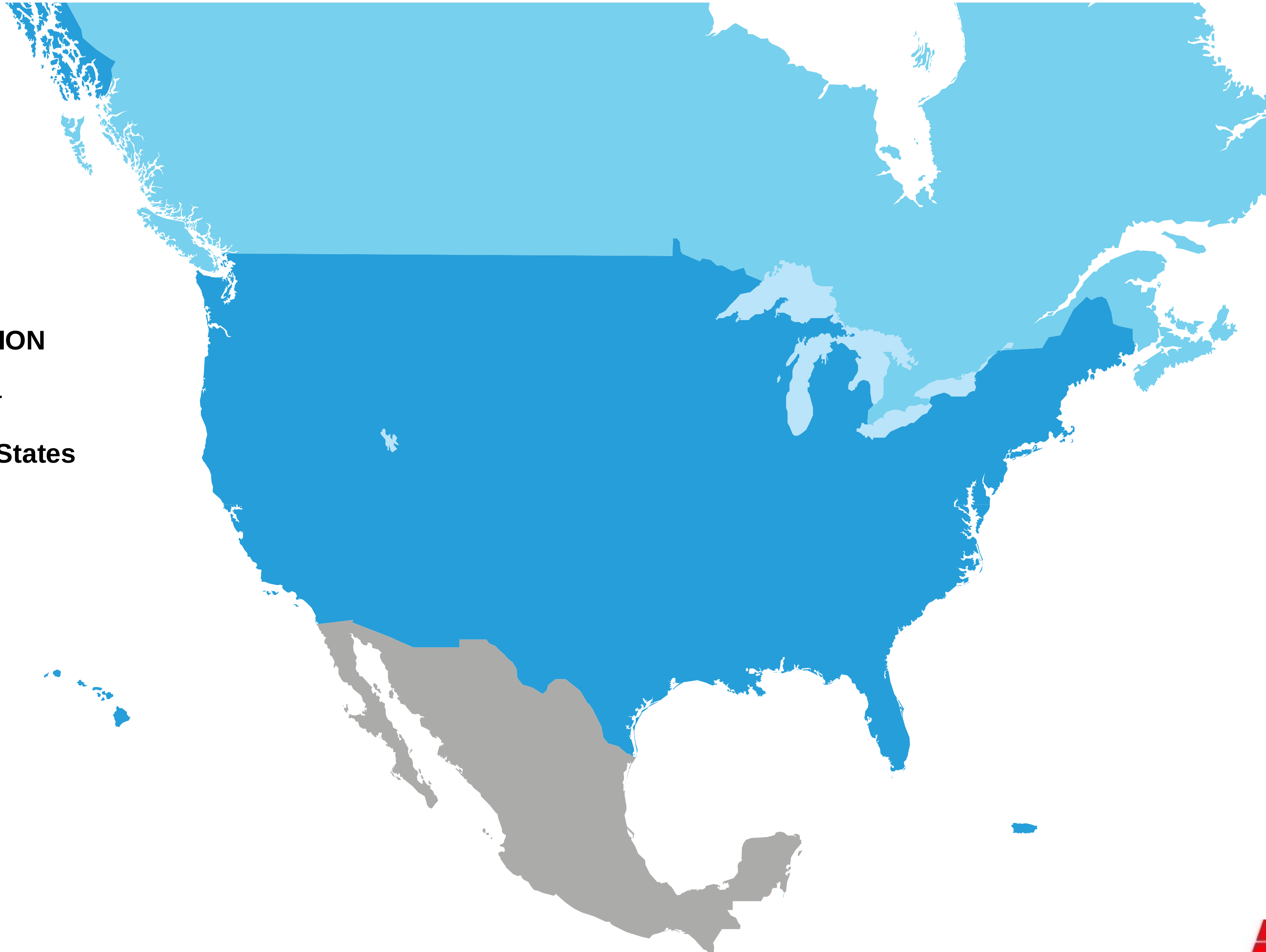


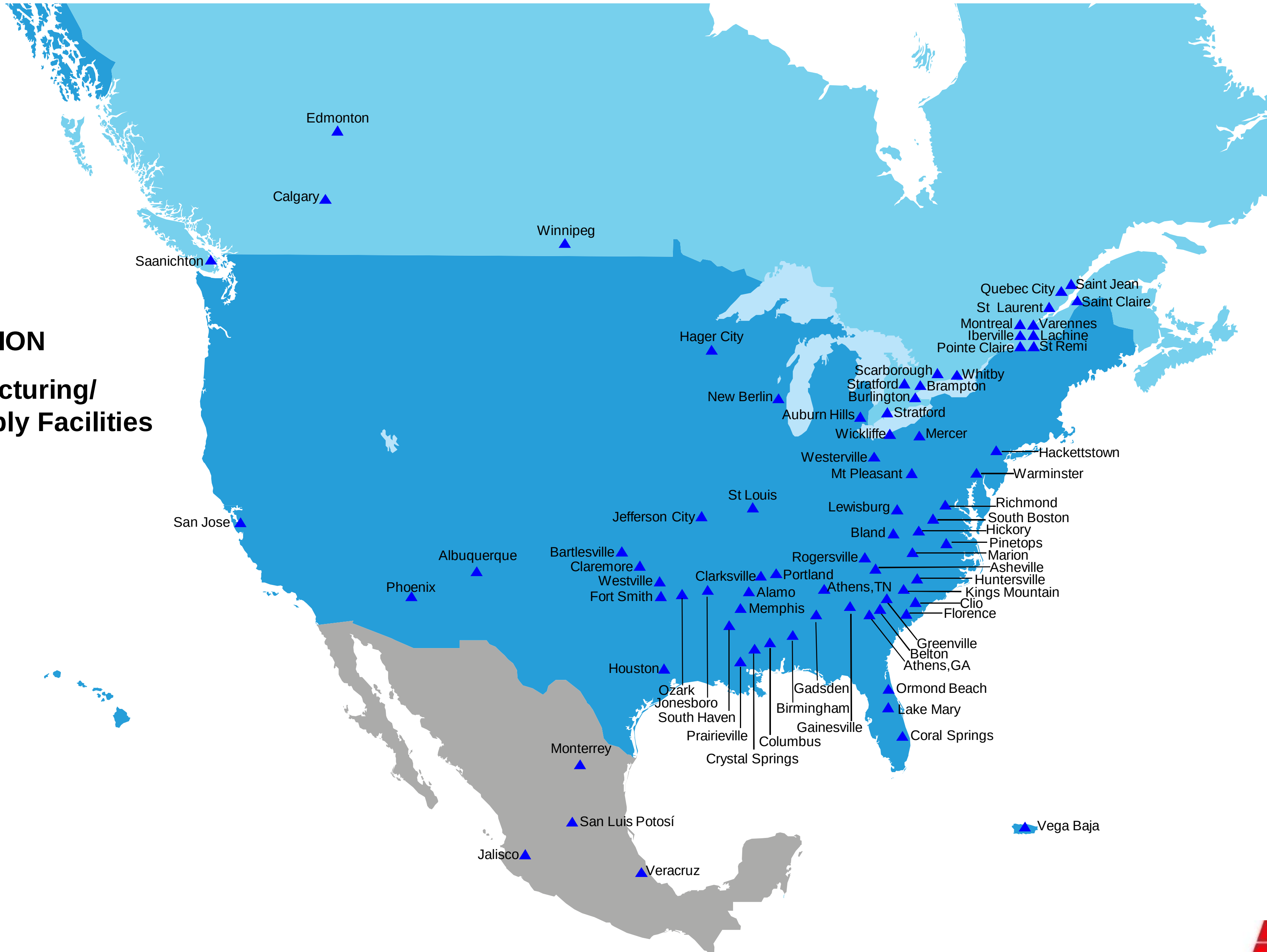
ABB North America Footprint



NAM REGION

- **Canada**
- **Mexico**
- **United States**

ABB North America Footprint



NAM REGION

▲ **Manufacturing/ Assembly Facilities**

ABB North America Footprint

NAM REGION

Service/ Distribution Centers

ABB

ABB North America Footprint

NAM REGION

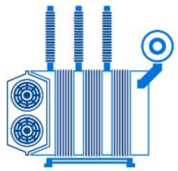
- Region Headquarters
- Country Headquarters
- Engineering/ Research & Development/ Major Offices

ABB North America Footprint

NAM REGION

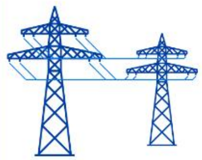
Combined Locations

How ABB is organized
Five divisions



Power Products

5,163 employees



Power Systems

2,443 employees

Discrete Automation and Motion

9,584 employees

Low Voltage Products

9,056 employees

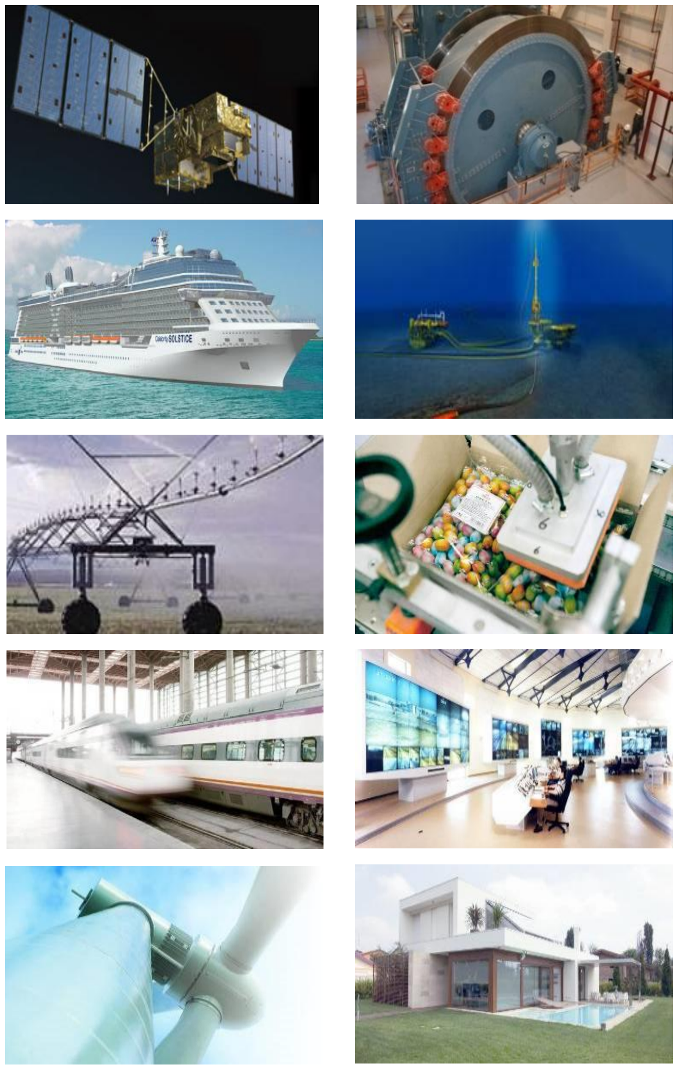
Process Automation

3,038 employees

ABB's portfolio covers:

- Electricals, automation, controls and instrumentation for power generation and industrial processes and commercial installations
- Power transmission
- Transformers
- Distribution solutions
- Low-voltage products
- Medium-voltage products
- High-voltage products
- Robots and robot systems

Power and automation are all around us
You will find ABB technology…



Orbiting the earth and working beneath it,

Crossing oceans and on the sea bed,

In the fields that grow our crops, and packing the food we eat,

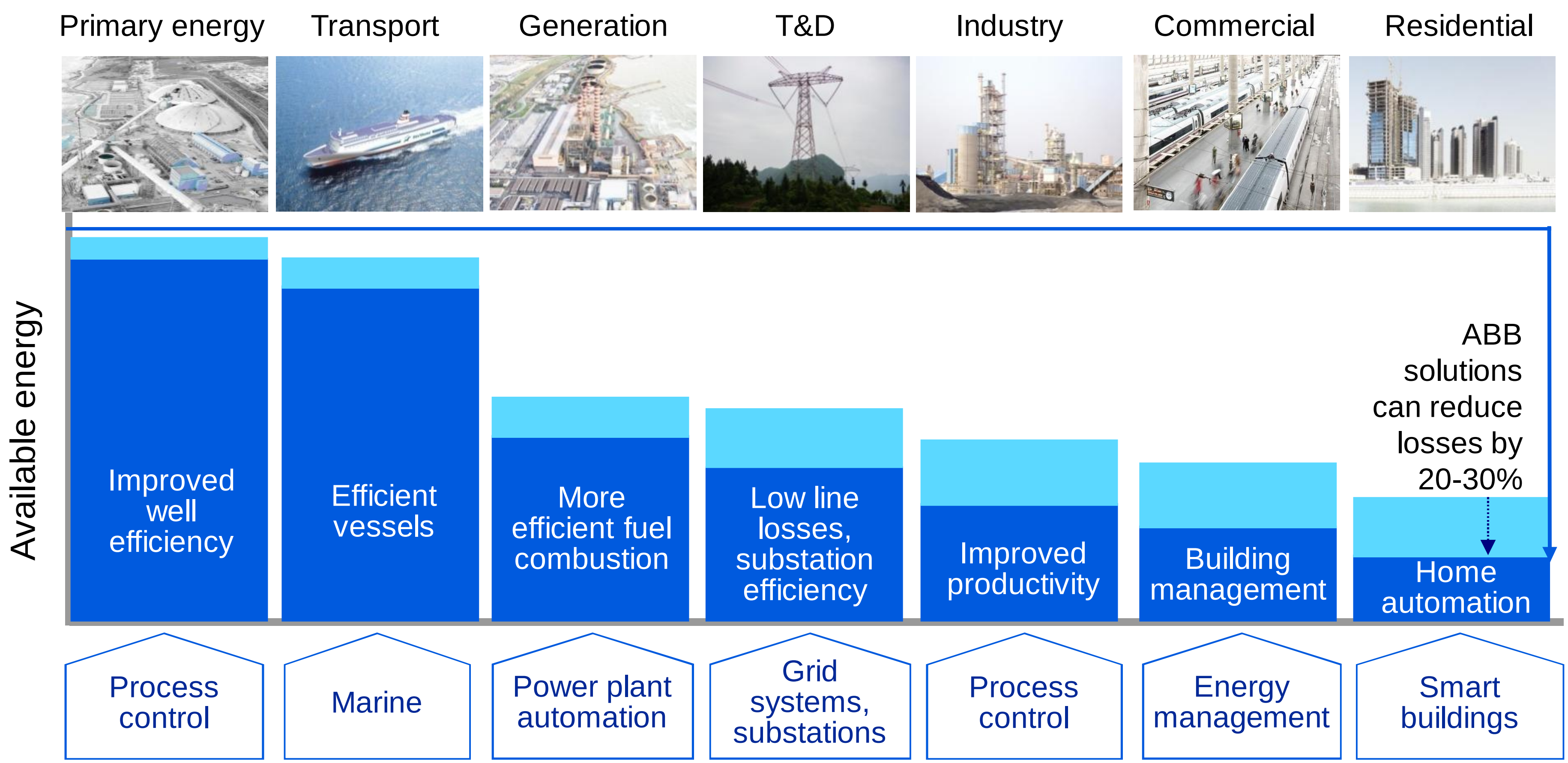
On the trains we ride, and in the facilities that process our water,

In the plants that generate our power, and throughout our homes and workplaces.

ABB Achievements

- Zayed Future Energy Prize (2014)
- Top 100 Global Innovators – Thomson Reuters (2013)
- Top 50 Disruptive Companies – MIT (2013)
- America's Safest Companies (8 honored) – EHS Today (2012)
- World's Most Ethical Companies – Ethisphere Institutes (2013)
- Top 50 Employers for Women Engineers – Woman Engineer Mag. (2013)
- World-class performer, Dow Jones Sustainability Index (2010-2013)
- Red Dot award for industrial design – Azipod® Controller (2013)
- Member, Smart Cities Council (2013)
- Pioneer Award: EV charging – Green Parking Council (2013)
- Two "Engineers' Choice Awards"– Control Engineering (2013)
- Founding member, Research Triangle Cleantech Cluster

ABB in the “sweet spot” of energy efficiency



80% of energy is lost along the value chain

Renewable energy
Key growth driver for both power and automation

- Generation and transmission solutions for:
  - Hydro
  - Wind
  - Solar
  - Wave
- ABB is the world's biggest supplier of electrical equipment and services to the wind industry
- ABB has connected 230 GW of renewable energy to the grid
- ABB delivered the automation systems and electrical equipment to Europe's first large-scale 100 MW solar plant in Spain

Automation & Power World
ABB's largest customer event has expanded

Now a multi-dimensional customer engagement platform delivering content in three ways

- **Online education series** – SmartStream digital conferences held twice annually for customer segments
- **Conversation series** – SmartSquad of ABB experts meeting with customers at key industry events
- **Conference & exhibition series**
  - North America event held biennially – March 2015 in Houston, Texas
  - APW Mexico event – August 2014 in Santa Fe, Mexico
  - Conference – Ideas, information, hands-on technical and educational training, customer case studies, business forum, and panel discussions
  - Technology & Solution Center – SmartBar, SmartSquad, Latest technology from ABB, Software pavilion, Technology partners
- More information at www.abb.com/apw

Overview

Divisions
North America Region

Power Products

Key deliverables

- Power technology products for HV and MV applications
  - Transformers: power, distribution, traction, others
  - Switchgear and other equipment
  - Range of power capacitors
  - Distribution automation products and systems
- Power products services
  - Transformer repair, refurbishment, spare parts, maintenance
  - Switchgear / breaker refurbishments, spare parts, maintenance

Markets served

- Utilities, industrials, OEMs, EPCs, distributors

Power Systems

Key deliverables

- Electrical, automation, control and instrumentation for power generation
- HVDC, FACTS, substation automation
  - Increased transmission capacity
  - Power quality and reliability
- Smart grid technologies, network management and market systems
- Power systems services
  - Consulting and system studies
  - Turnkey electrical power substations
  - Repair, retrofit, refurbishment
  - Software and hardware upgrades
  - Asset management and diagnostics

Markets served

- Utilities, industrials, OEMs, EPCs, channel partners

Discrete Automation and Motion

Discrete automation

Products and integrated automation solutions, incl. PLC, robots, drives and motors for discrete automation in industry, and infrastructure

Industrial motion

Movement and control in industrial applications. Motors, drives, generators, and mechanical power transmission for industry, utilities, infrastructure and transport

Renewables

Generators, converters, inverters, drives, motors, controls, packages, and applications for renewable power generation

Power control and quality

Control of power supply and ensuring power quality for industrial, utility, and infrastructure applications

Transport

Fast charging of electric vehicles, components for rail rolling stock and rail infrastructure, drives and motors for heavy electric vehicles

Product packages and engineered applications

Life-cycle services

World-class operations

Low Voltage Products

Key deliverables

- Breakers and Switches
- Wiring accessories
- Control products
- Enclosures and DIN-rails
- LV systems
- Machine safety
- Services

Markets served

- OEMs, distributors, wholesalers and installers
- Systems integrators and panel builders
- End-users within building automation, transportation, power utility, process industries and manufacturing industries

Process Automation

Key deliverables

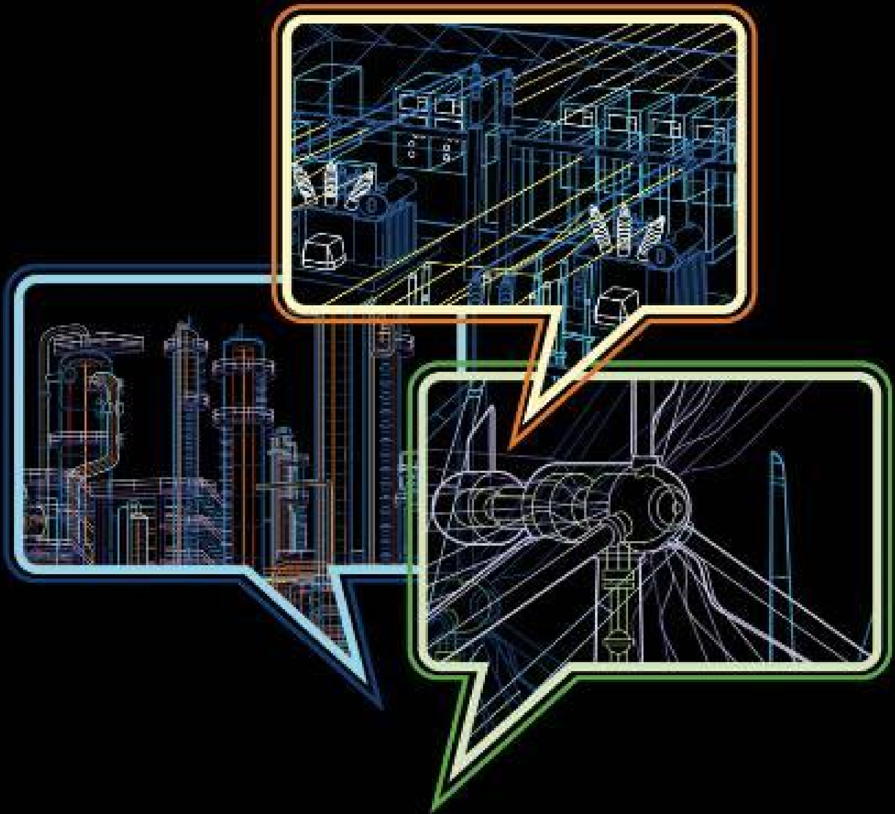
- Solutions and products for process control, safety, energy and information management systems
- Industry-specific process solutions
- Services: consulting, full service and life cycle including remote optimization services
- Flawless project execution due to excellent project management and engineering services
- Process instrumentation and analytics
- Process analyzers: gas chromatograph, FTIR, and continuous gas analyzers

Markets served

- Food and beverage; life sciences; marine and cranes; metals; minerals; oil, gas, petrochemical; printing; pulp and paper; specialty chemicals; turbo charging

Power and productivity
for a better world™

ABB



R Hoadley, 22 July 2014

LV and MV Drives 101

LV and MV Drives 101

Speaker name:	Rick Hoadley
Speaker title:	Principle Consulting Applications Engineer
	Medium Voltage Drives
Company name:	ABB
Location:	New Berlin, WI

Agenda
LV and MV Drives 101

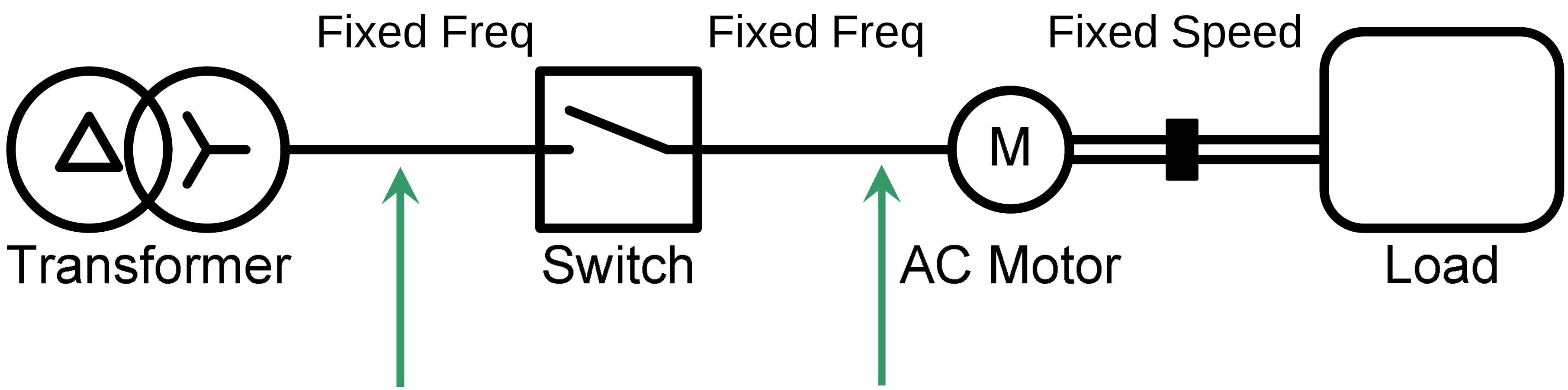
What is a VFD?
- Goals
- Motors
- Method

Line Side Requirements
- Harmonics
- Power Factor
- Ground Configurations

Motor Side Challenges
- NEMA MG-1
- Topologies
- Reflected Waves

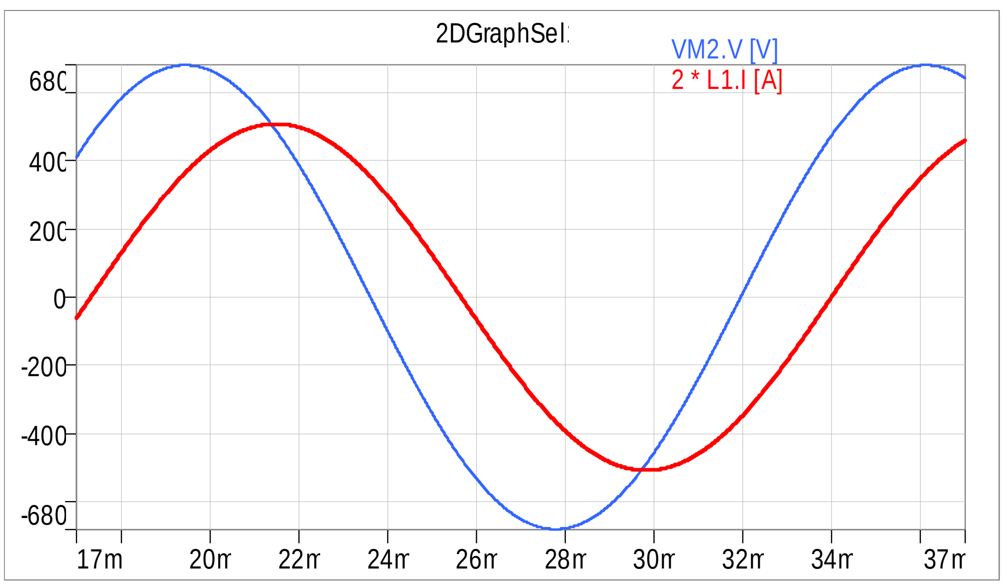
Drive Protection
- PQ Events
- Over-Voltage
- Over-Current

This is a Non-Drive System

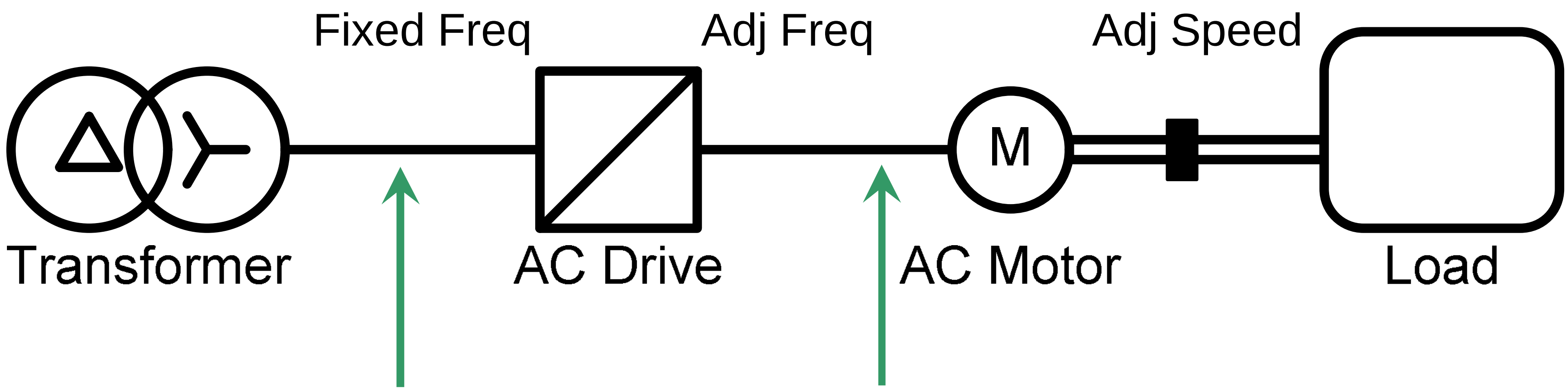


Line Side: Sinusoidal Voltage

Motor Side: Sinusoidal Current

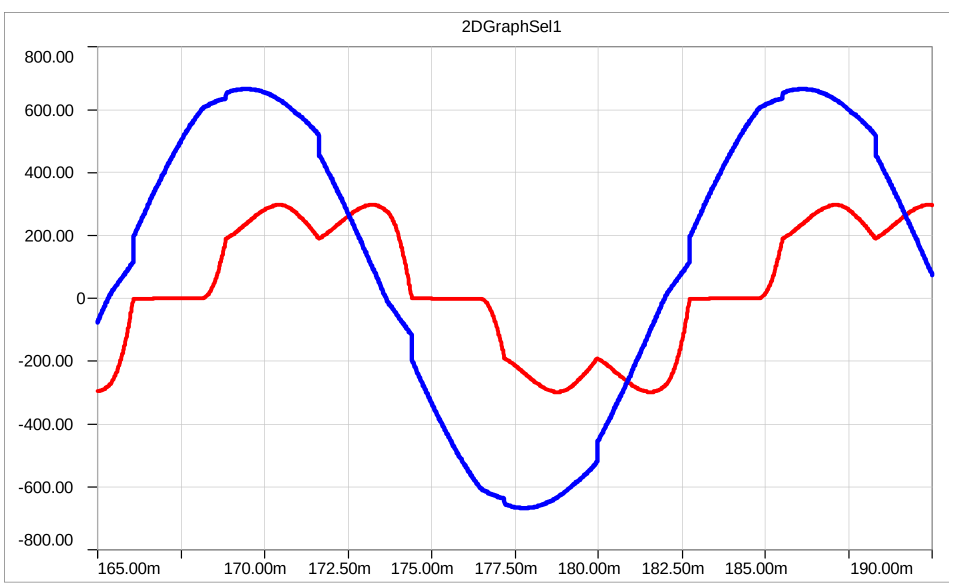


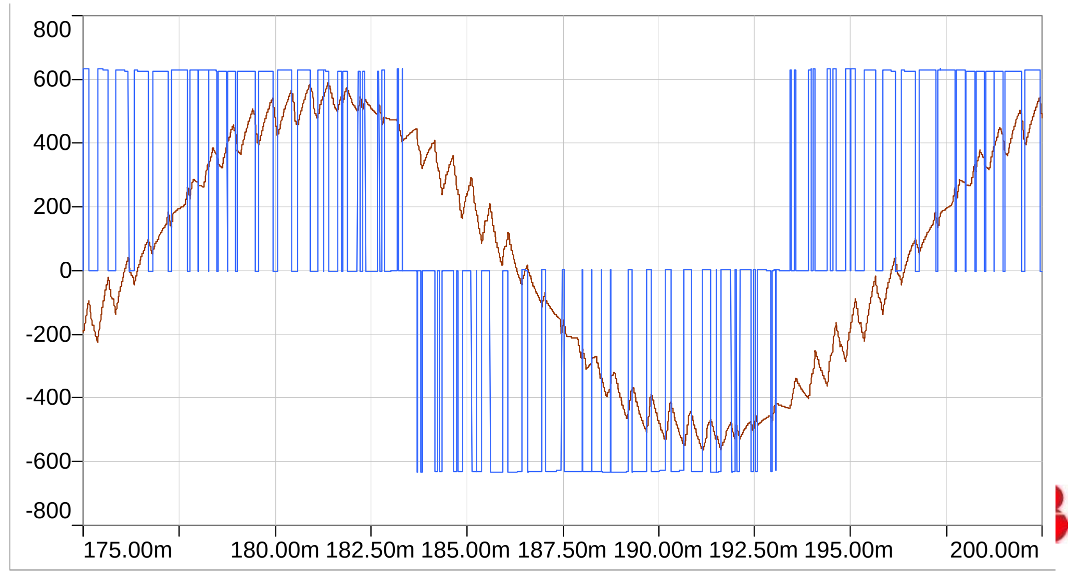
This is a Drive System



Line Side: Current Pulses

Motor Side: Voltage Pulses

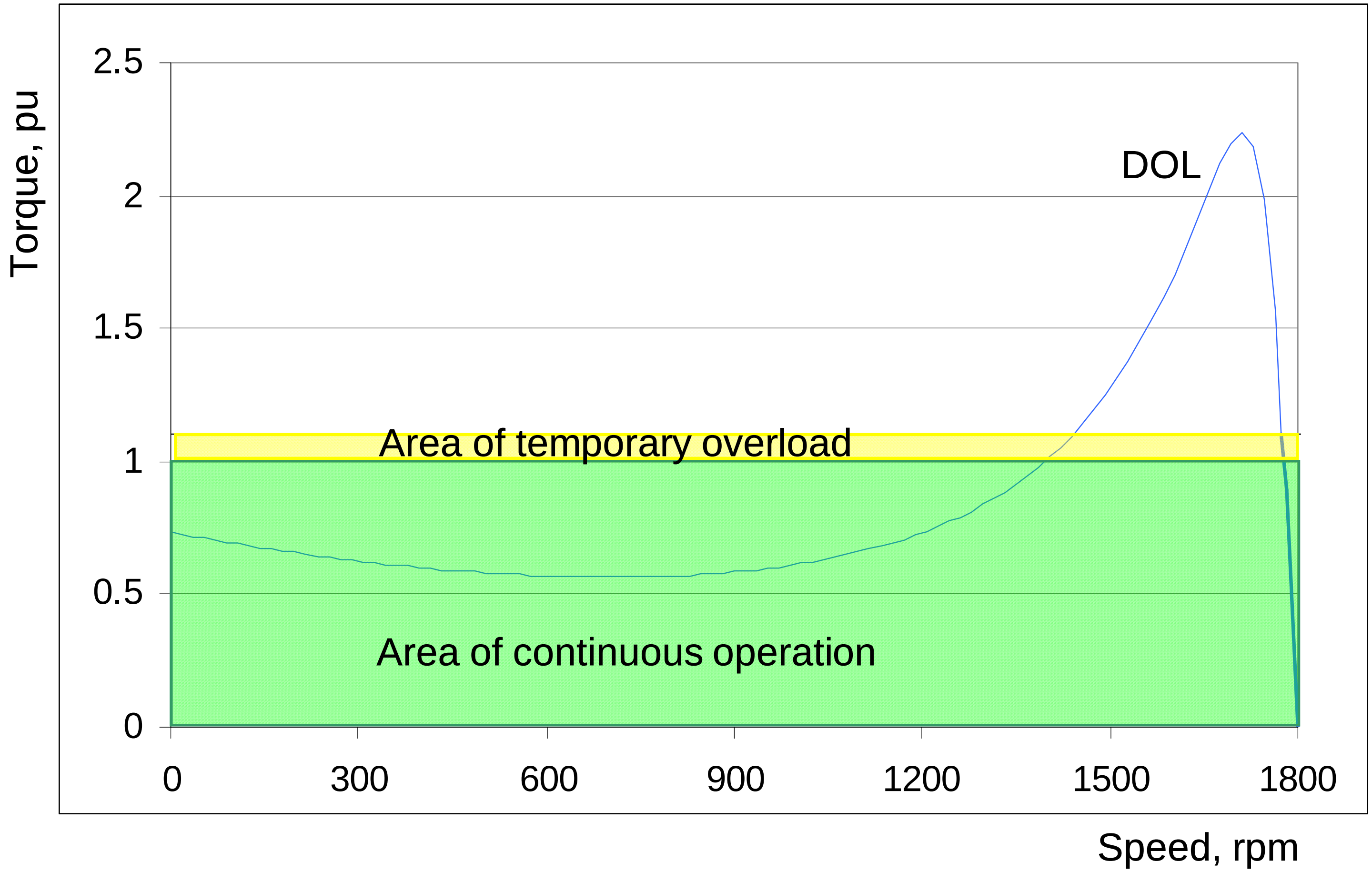




Why are AC drives used?

Why Use a VFD?

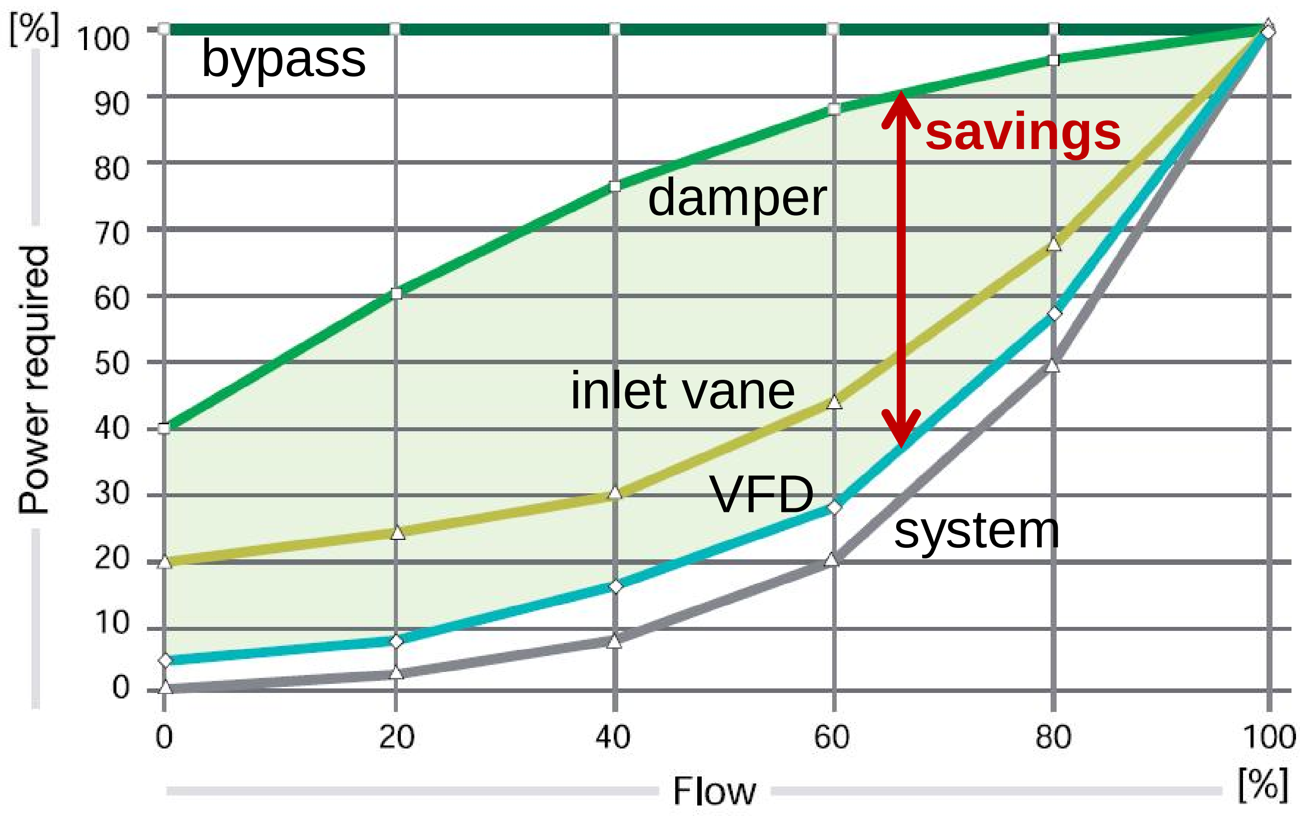
Large Operating Speed and Torque Area



Why Use a VFD?

Power Savings = **Cost Savings** with Fans and Pumps

0.5 to 1.5 year payback !



Why Use a VFD?

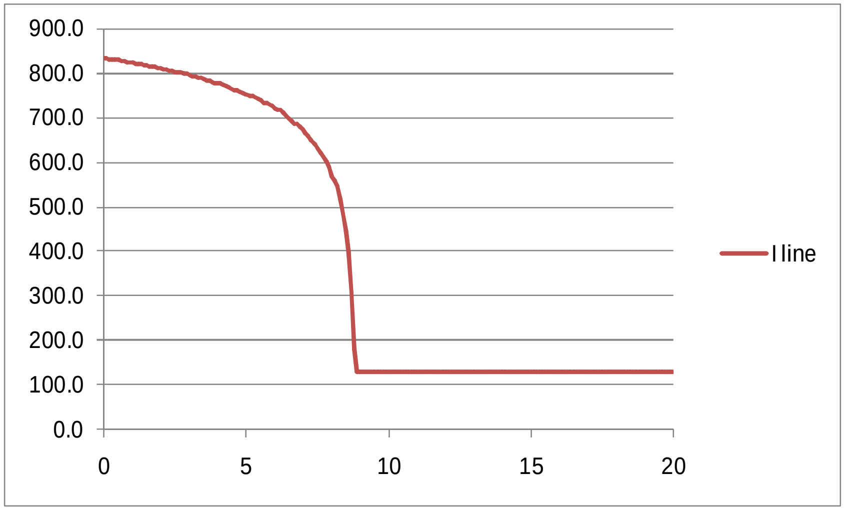
Adjustable speed to **Optimize Process**

Reduce production losses

Why Use a VFD?

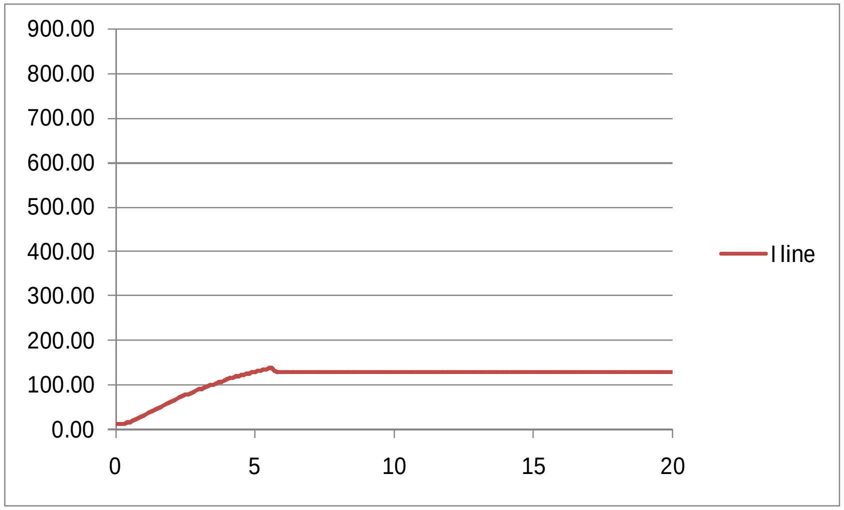
Elimination of 6x Inrush Current for **Soft Starting**

DOL Start



Line Current, A vs Time, s

VFD Start

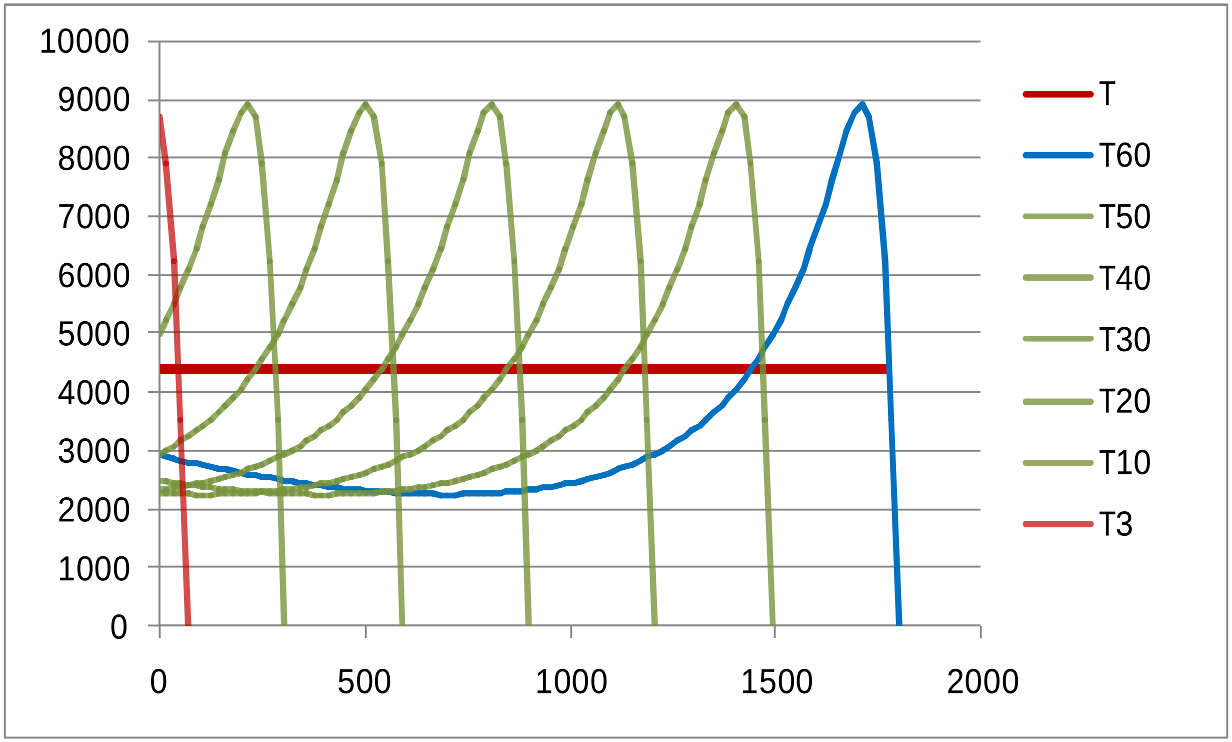


Line Current, A vs Time, s

Can have multiple starts per hour!

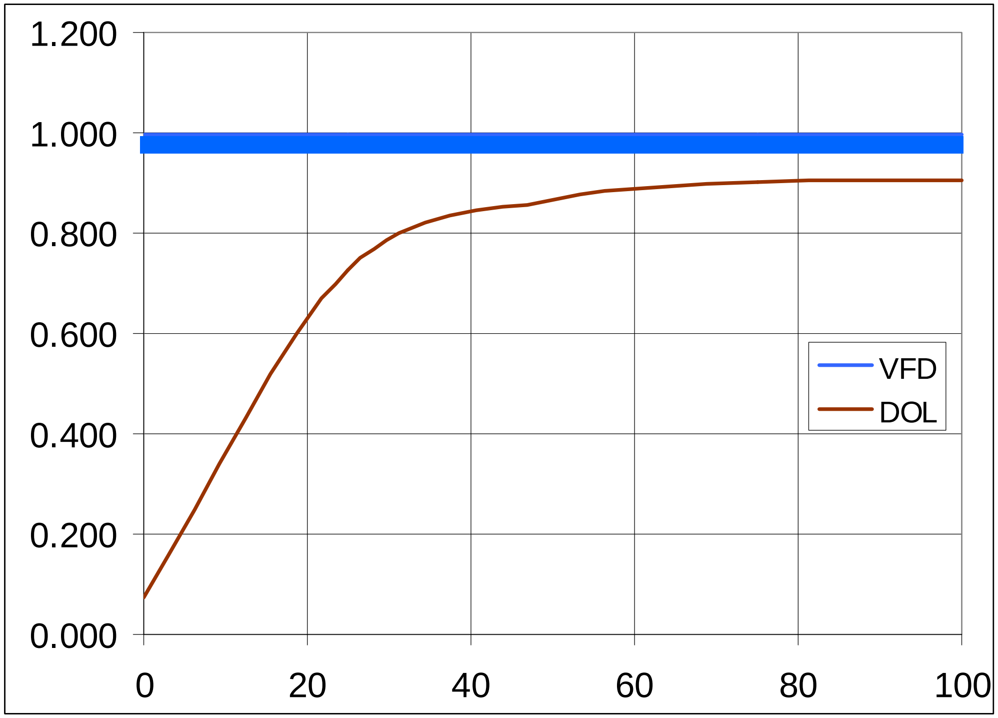
Why Use a VFD?

Greater **Starting Torque**



Why Use a VFD?

Operate at or close to **Unity PF** throughout Load Range



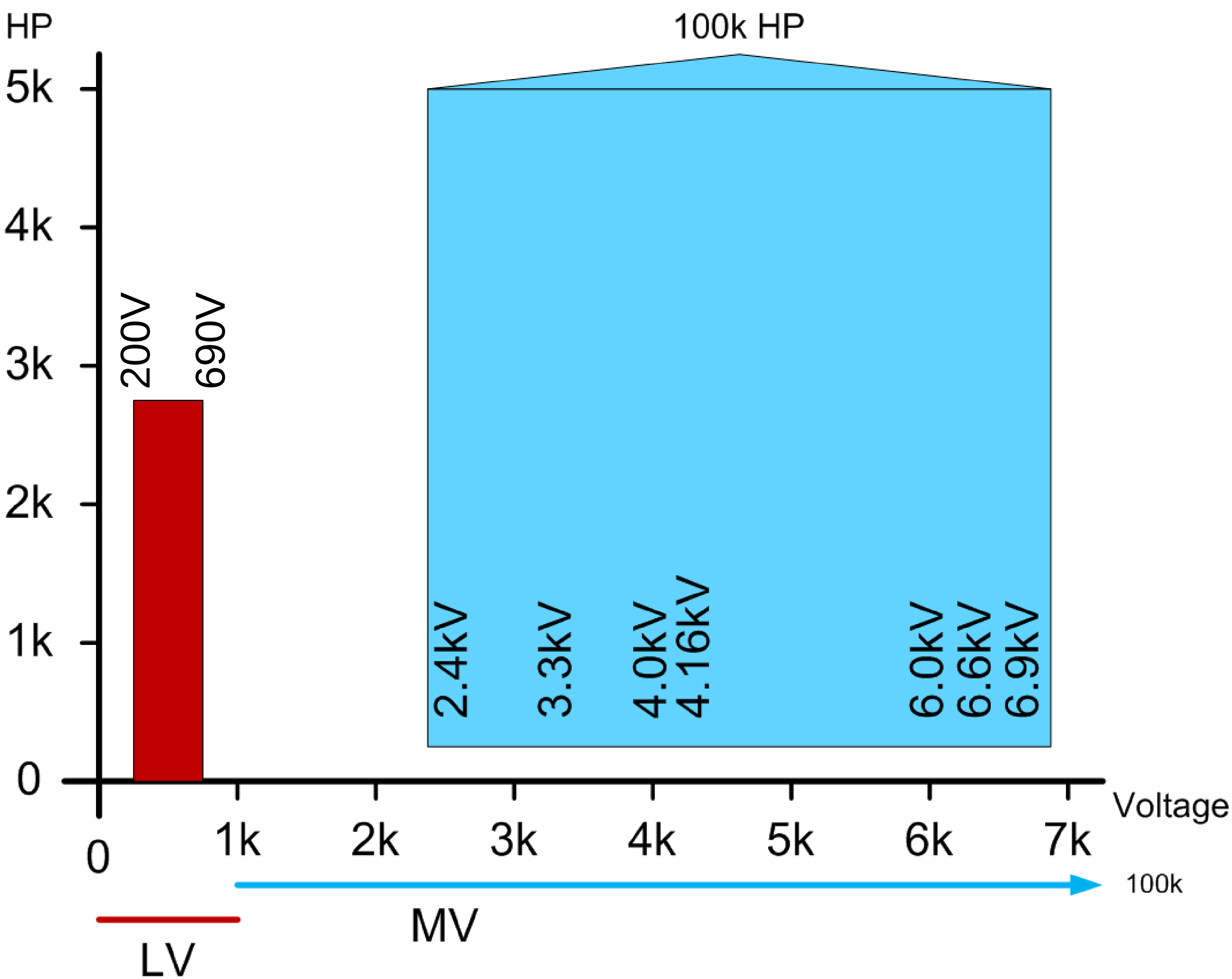
Why Use a VFD?

Adjustable Torque Limit to prevent damage to equipment

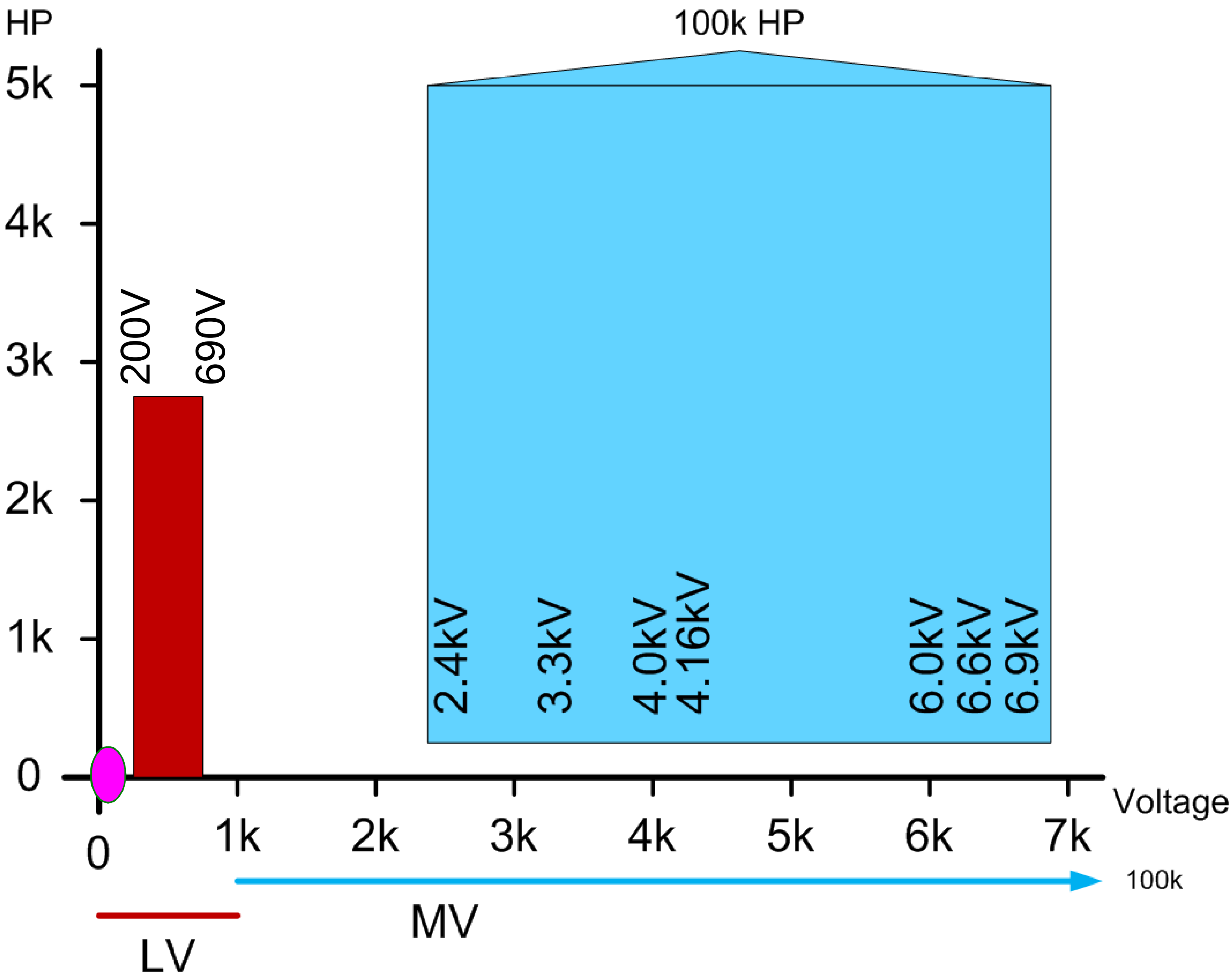
- No mechanical jerk, smooth acceleration

What is LV and MV?

What is LV and MV?



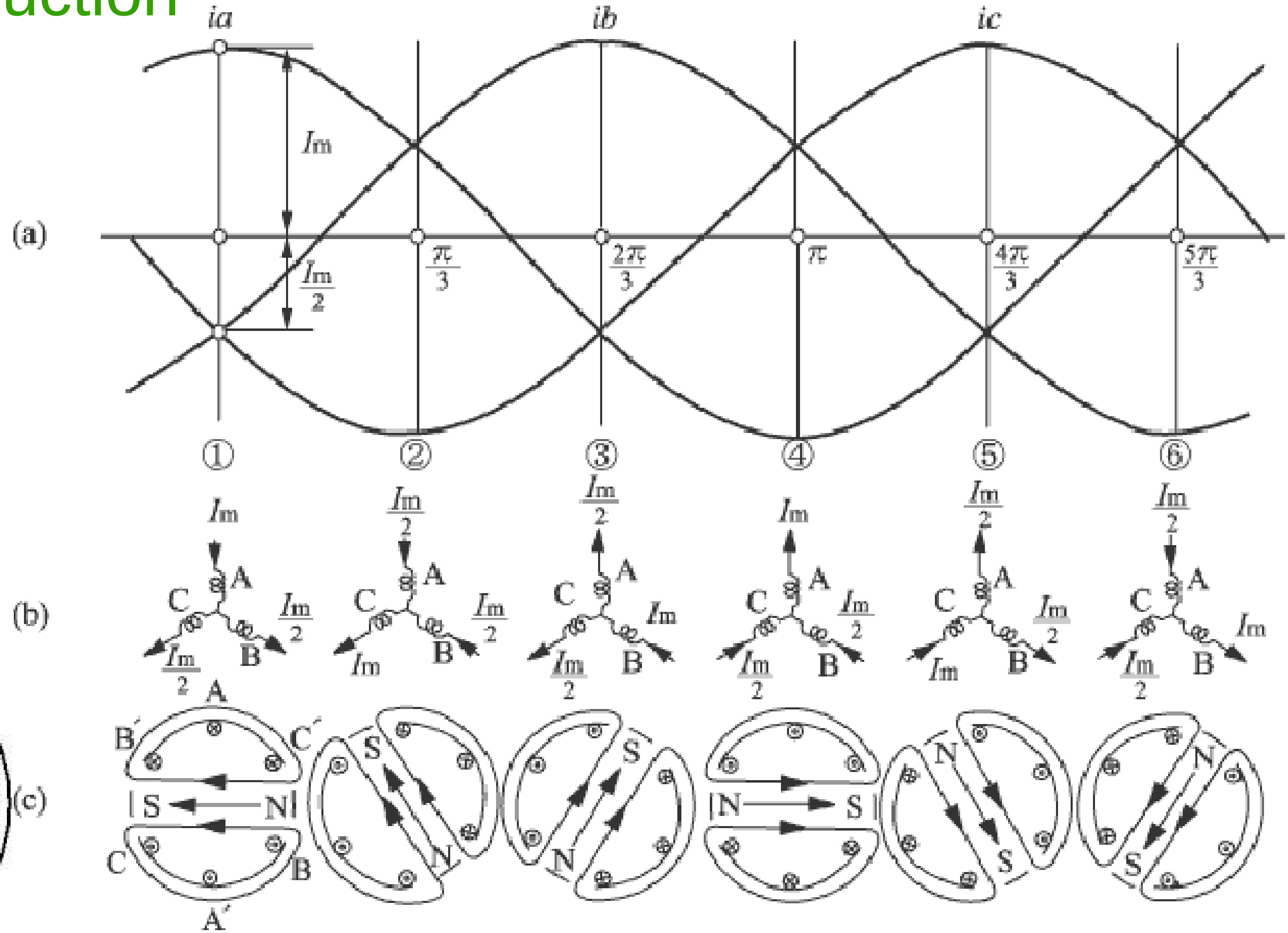
What is LV and MV?

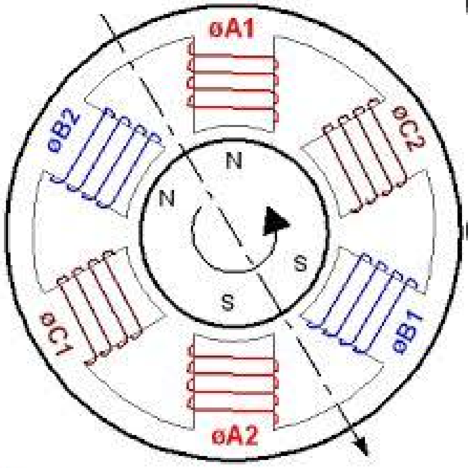


How do you change the speed of an AC motor?

How do you change motor speed?

Motor construction





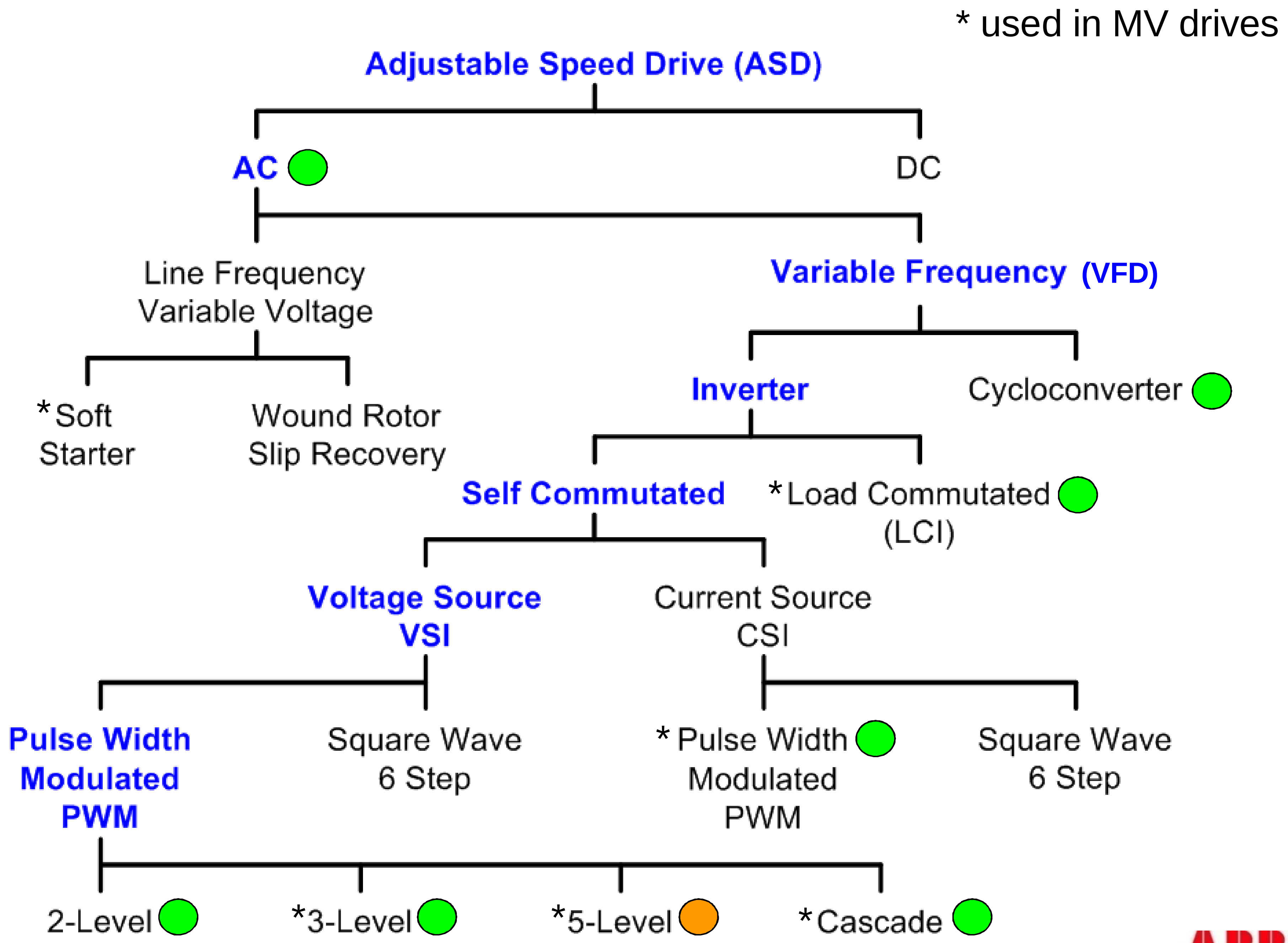
ABB

How do you change motor speed?
Motor equations

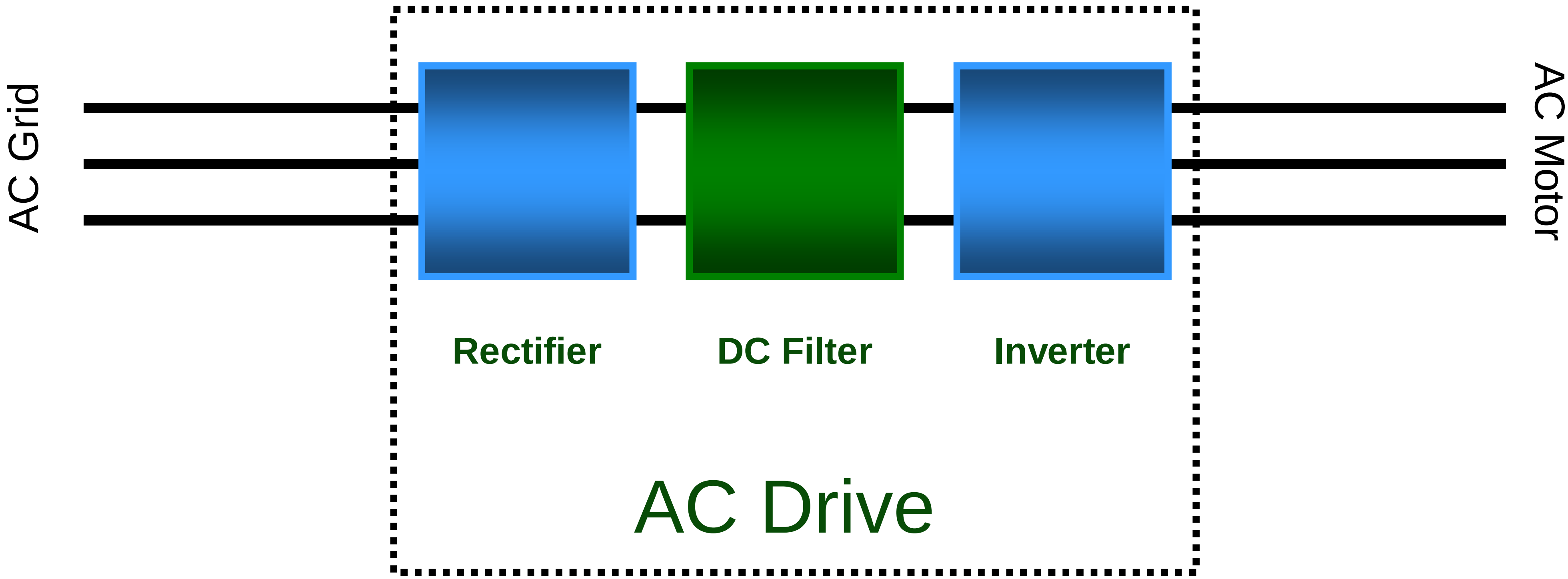
- Input
  - $S_{in} = FLA \times kV \times \sqrt{3}$ [kVA] FLA = Full load amps
  - $S_{in} = P_{in}/PF_M$ [kVA] PF_M = Motor power factor
  - $P_{in} = S_{in} \times PF_M$ [kW]
  - $P_{in} = P_{out}/\eta_M$ [kW] η_M = Motor efficiency
- Losses
  - $P_{loss} = P_{in} - P_{out}$
- Efficiency
  - $\eta_M = P_{out}/P_{in}$
- **Speed** (synchronous)
  - $n = 120 \times f / p$ [rpm] f = Frequency, Hz; p = Number of poles (2,4,6, …)

How do you make variable frequency AC?

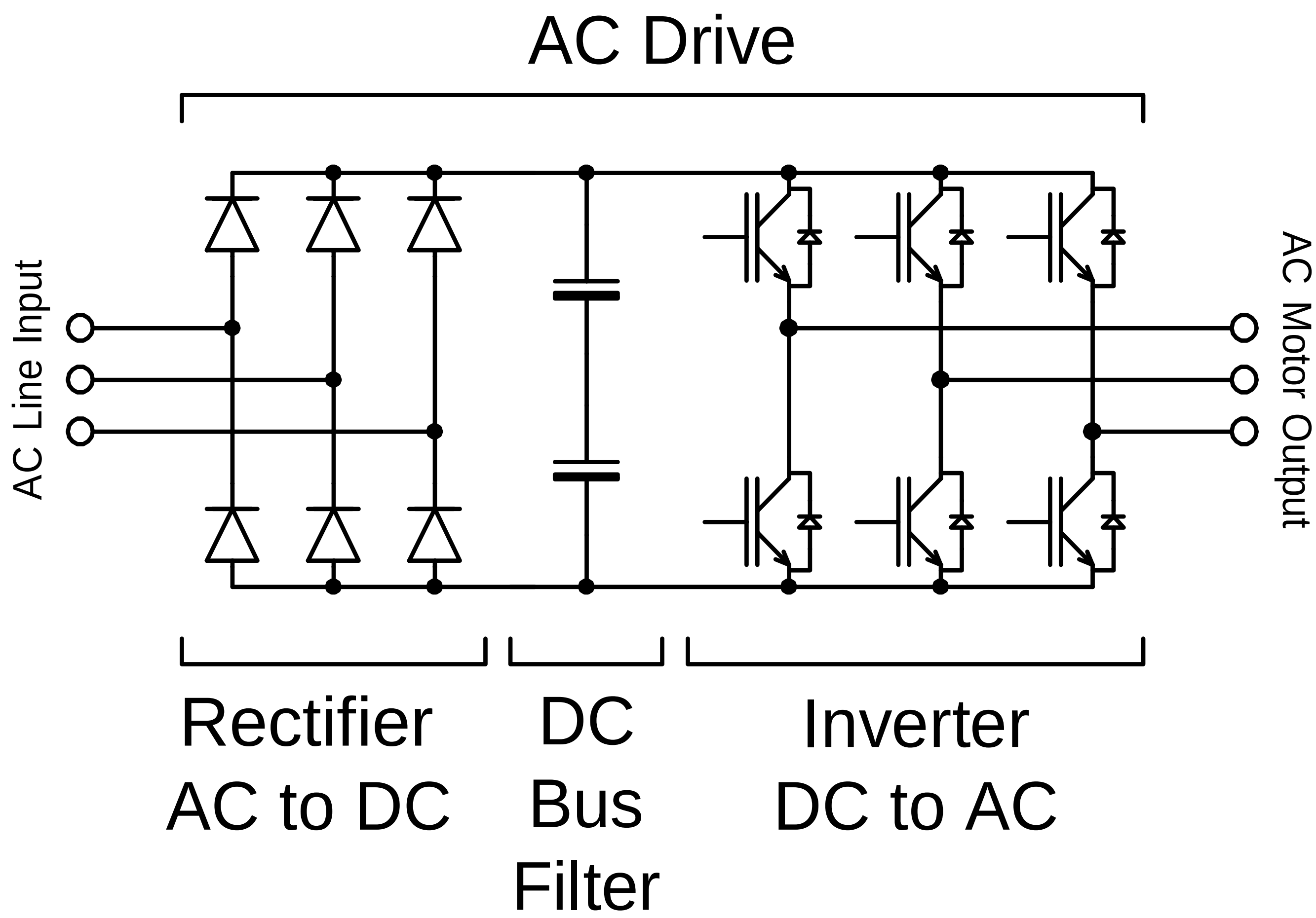
AC Drive Classifications



General Block Diagram of a Basic AC Drive



Basic AC Drive Topology
6-Pulse



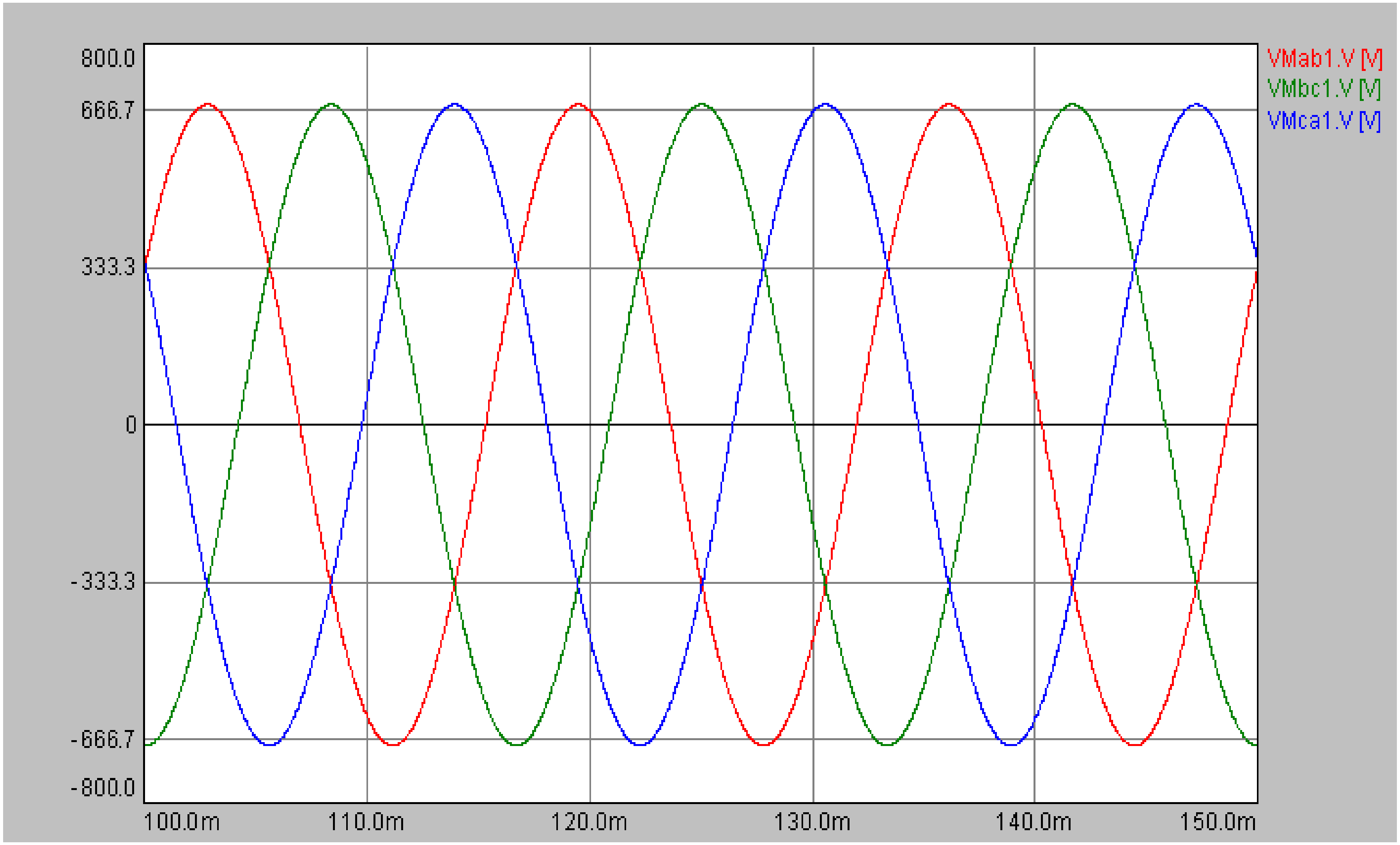
Fixed AC Voltage
Fixed AC Frequency

Fixed DC Voltage

Adjustable AC Voltage
Adjustable AC Frequency

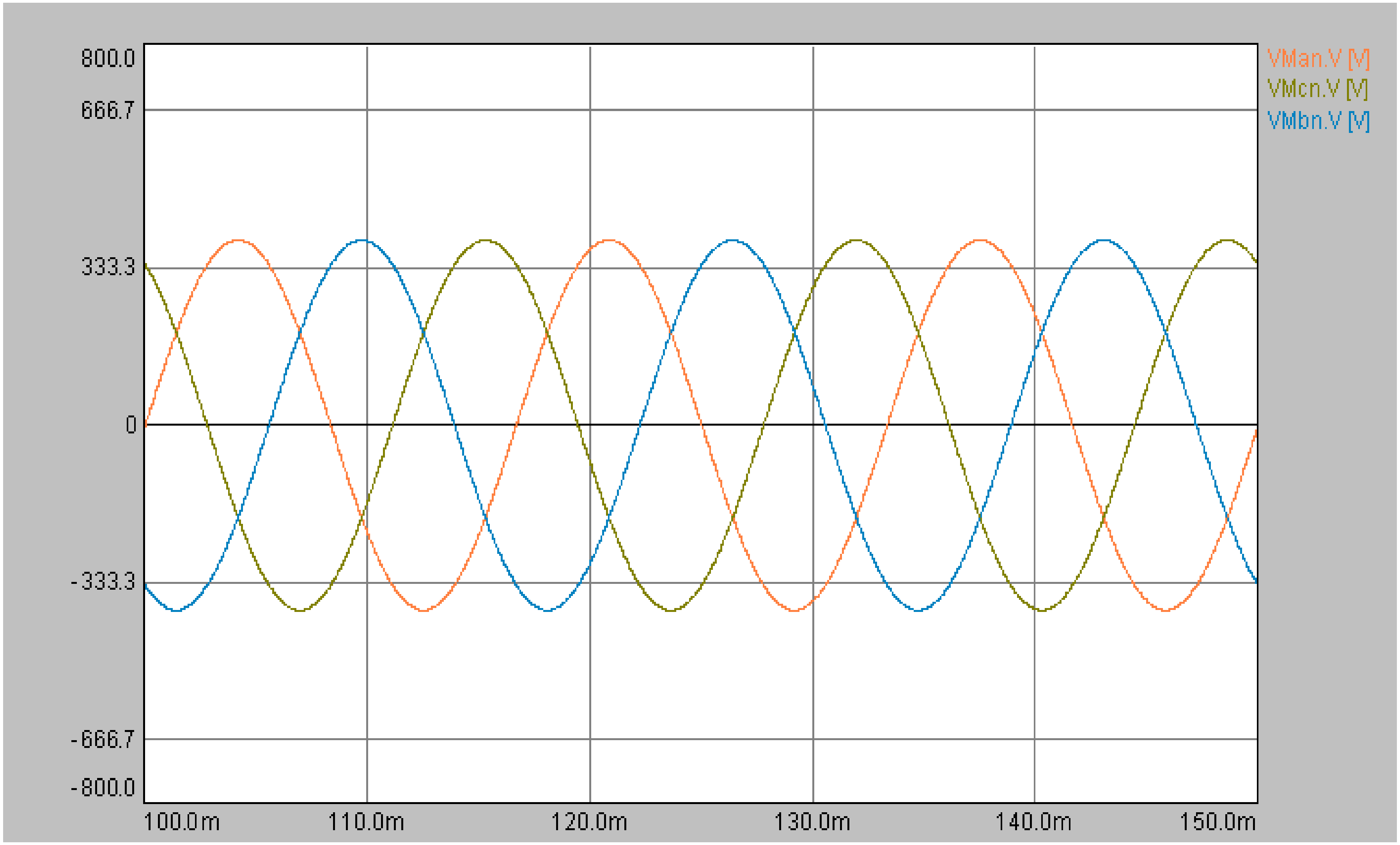
What We'd Like to See -

480Vac / 4160Vac line-to-line



An Ideal Supply Voltage

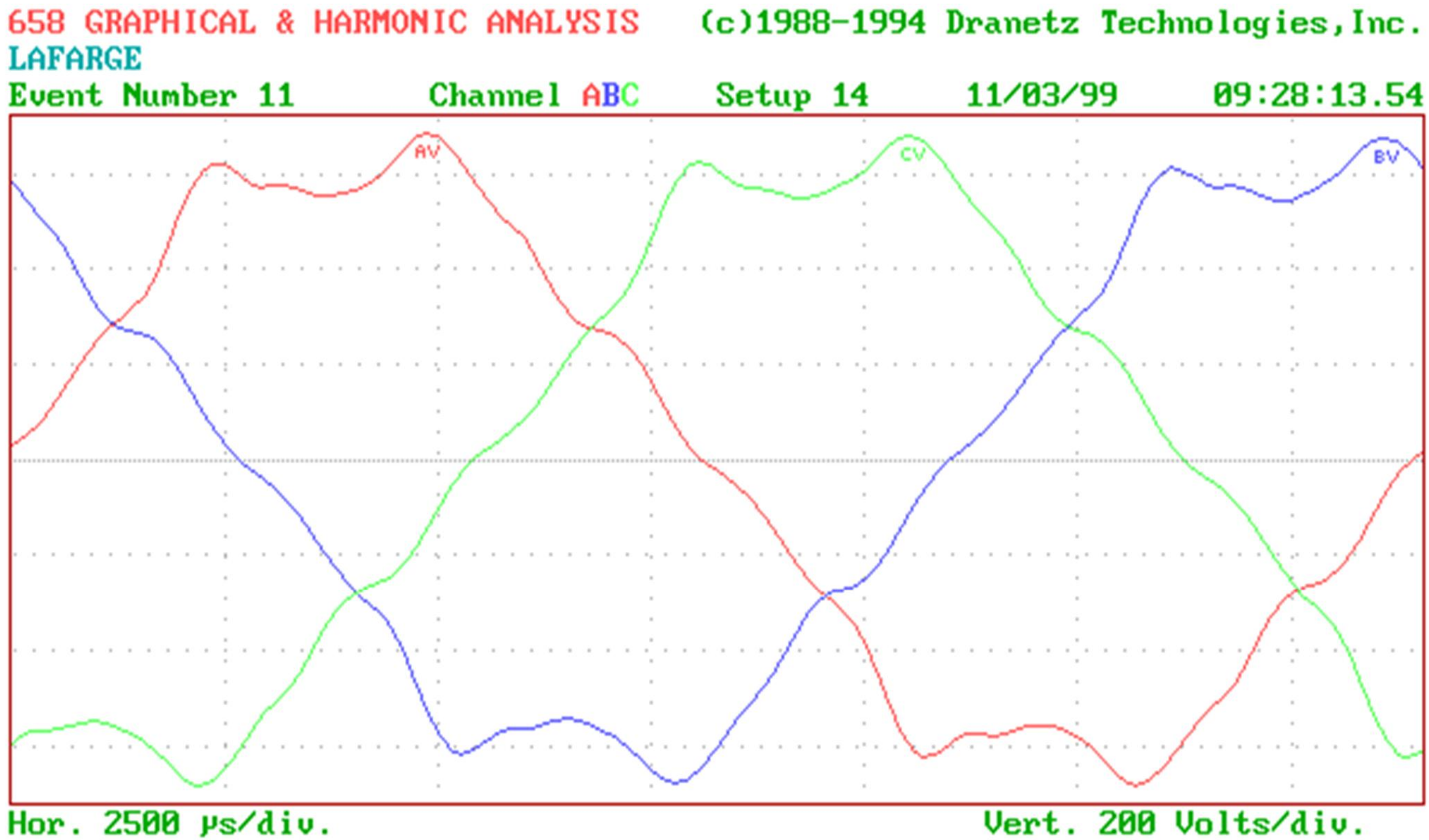
277Vac / 2400Vac line-to-neutral



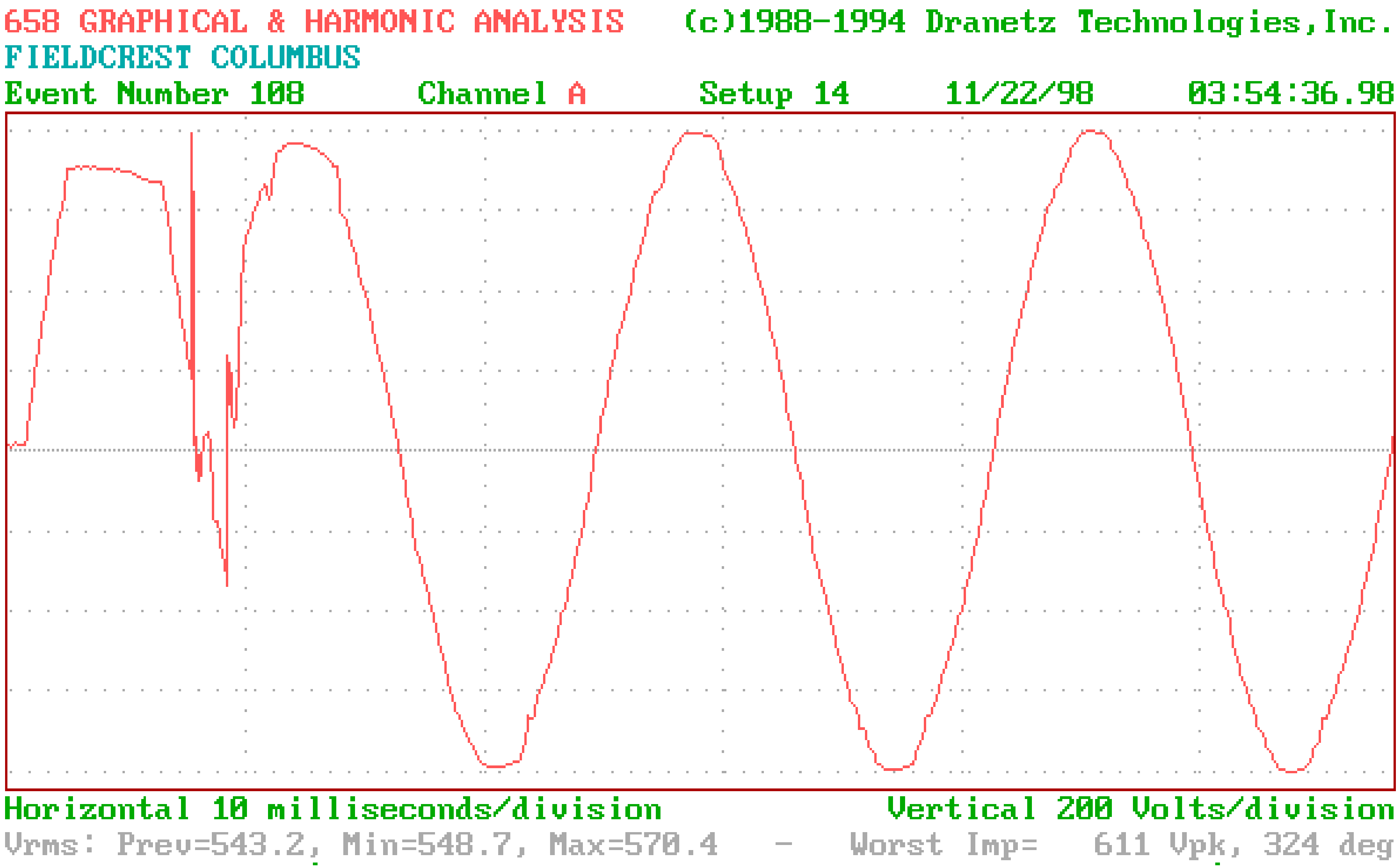
Common Power Quality Problems

- **Too High**
  - Switching in PF caps
  - DC drive transients
  - Switching off inductive loads
- **Too Low**
  - Voltage sags
  - Voltage notches
  - Voltage flat-topping
- **Nothing's There**
  - Voltage interruptions

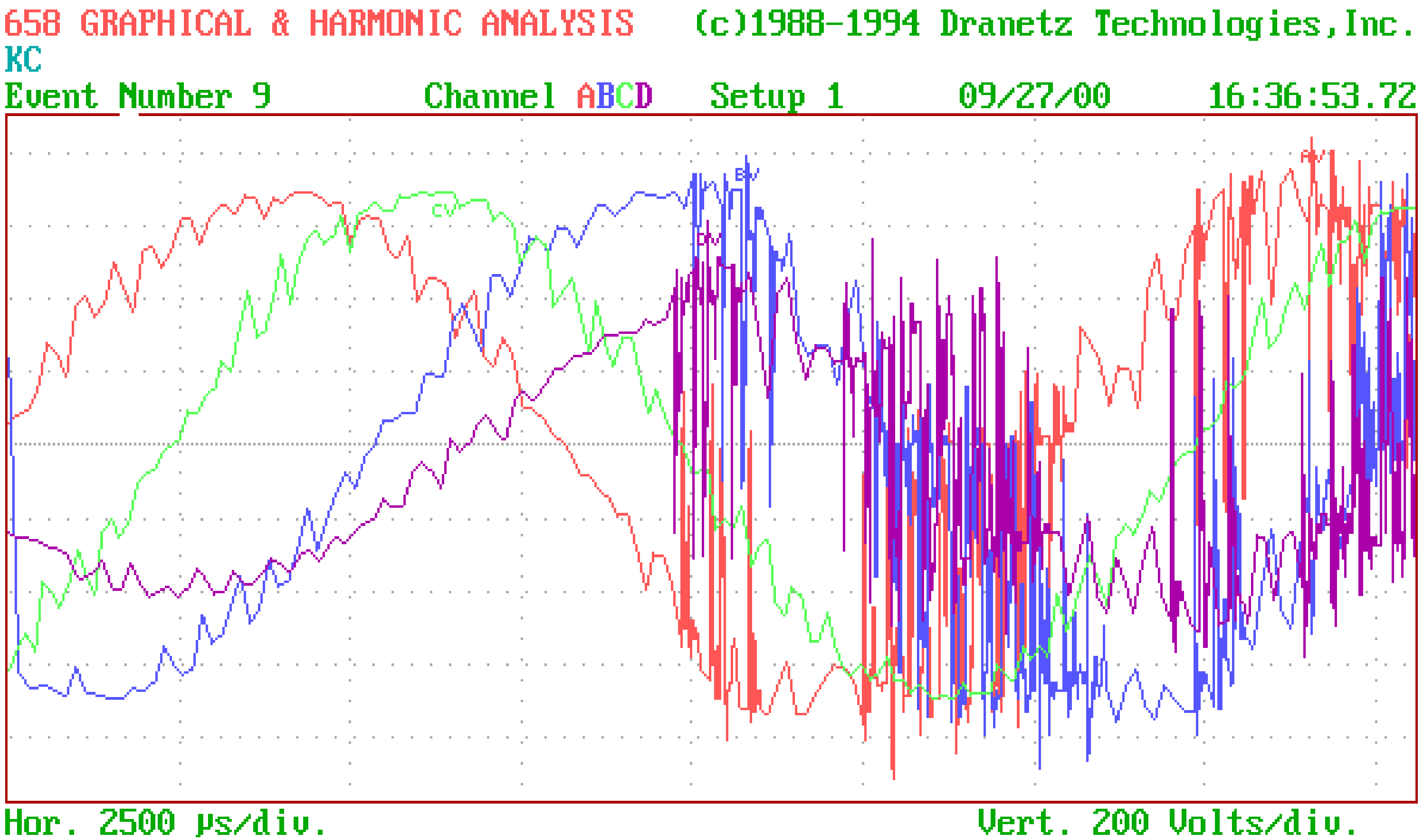
What have we seen?



Transfer Switch

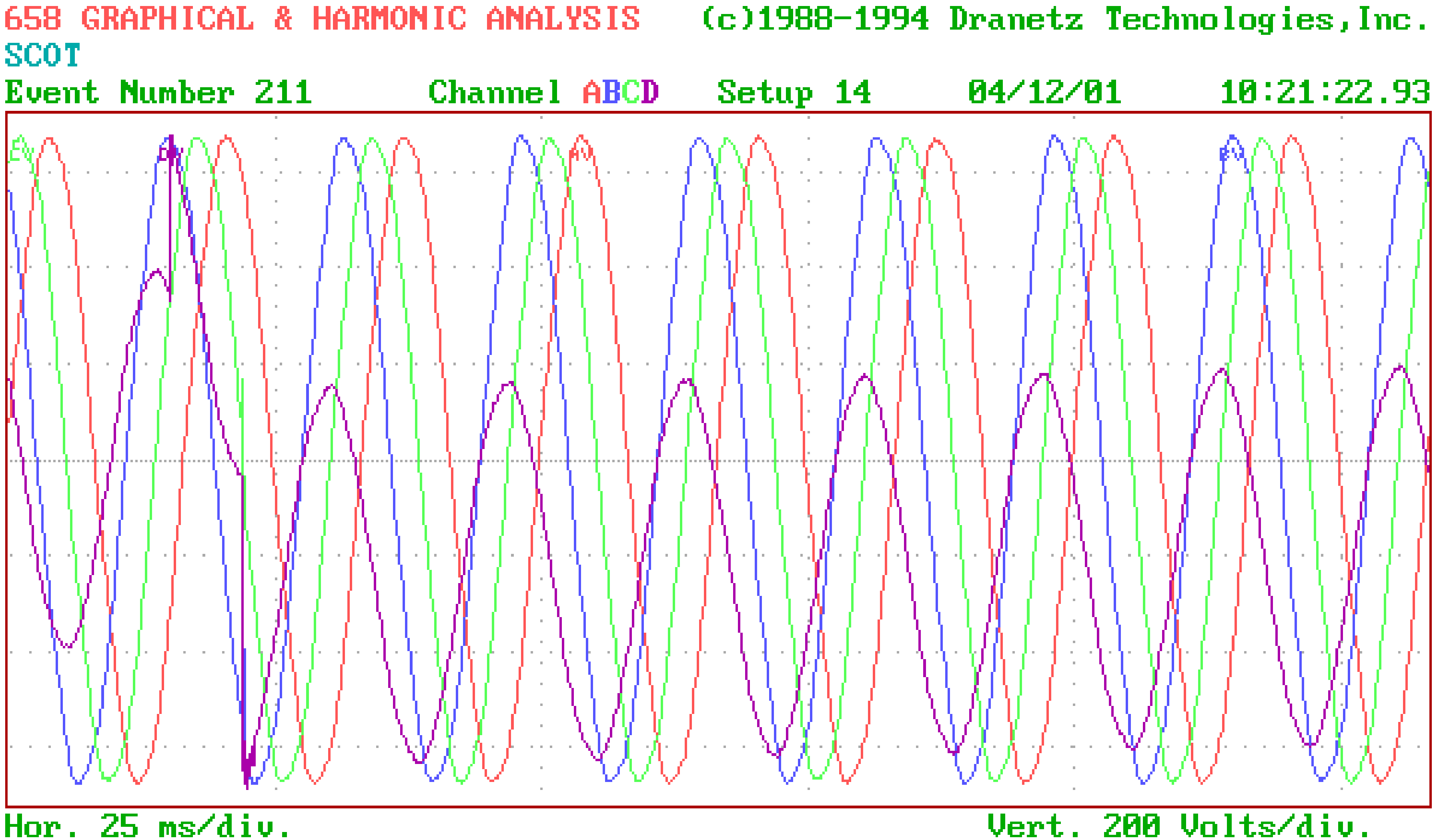


Voltage Modulation – AFE w/ Blown Fuse

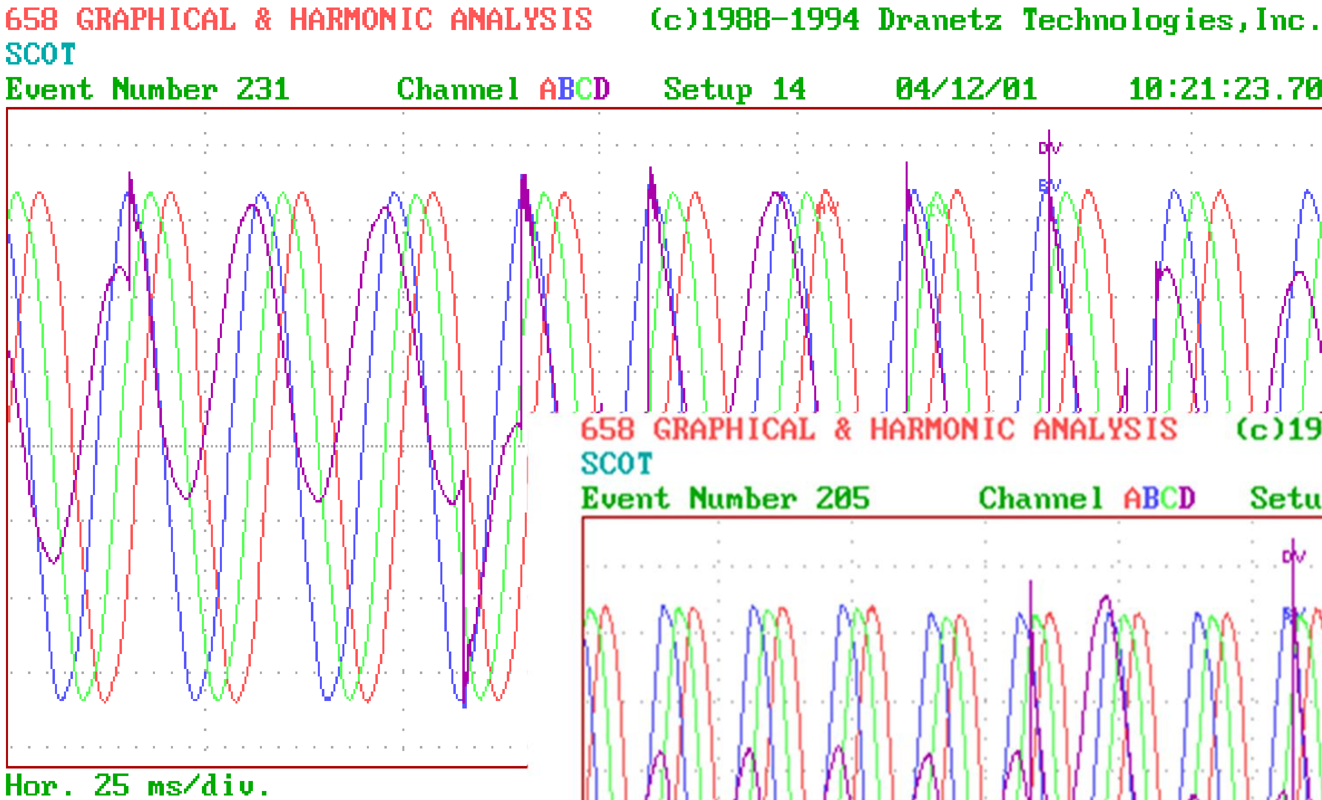


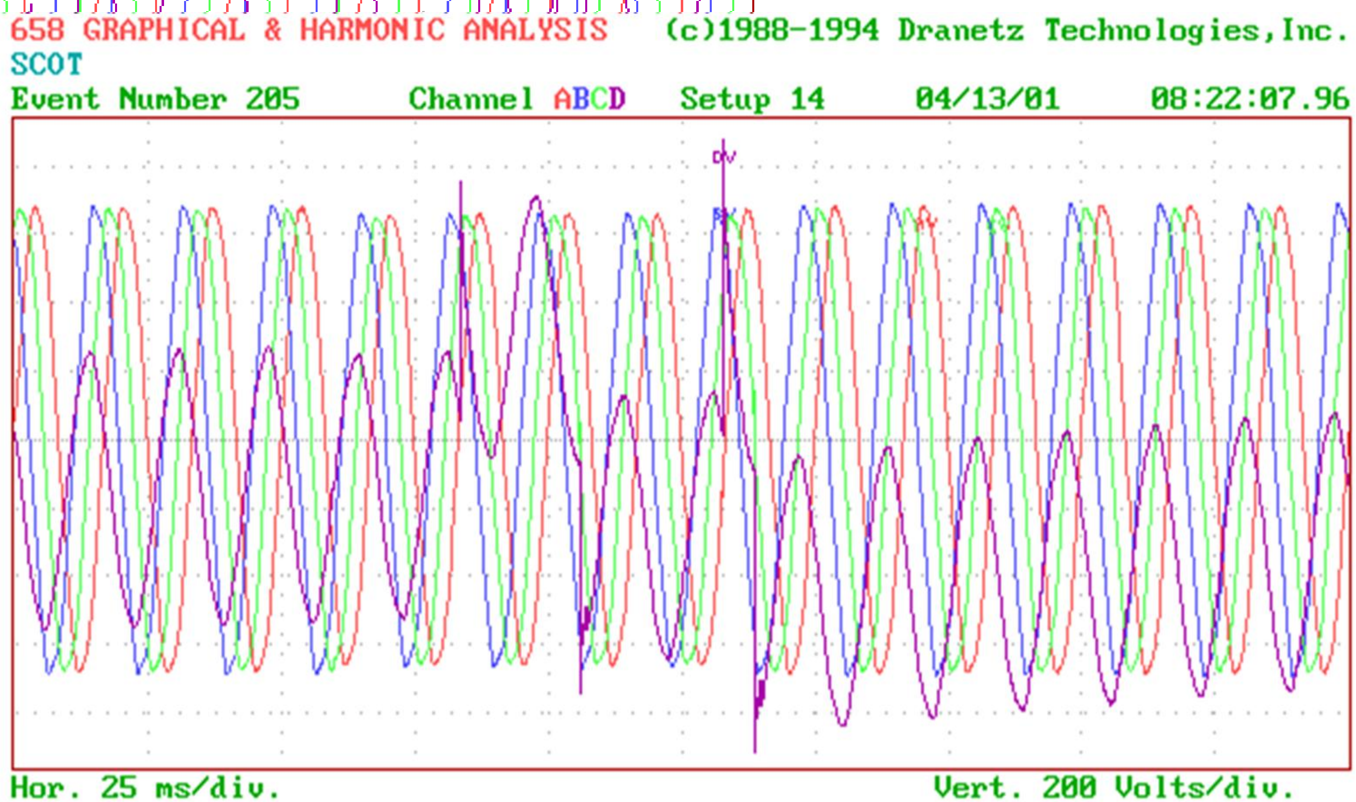
ABB

Example of Load with Ground Fault

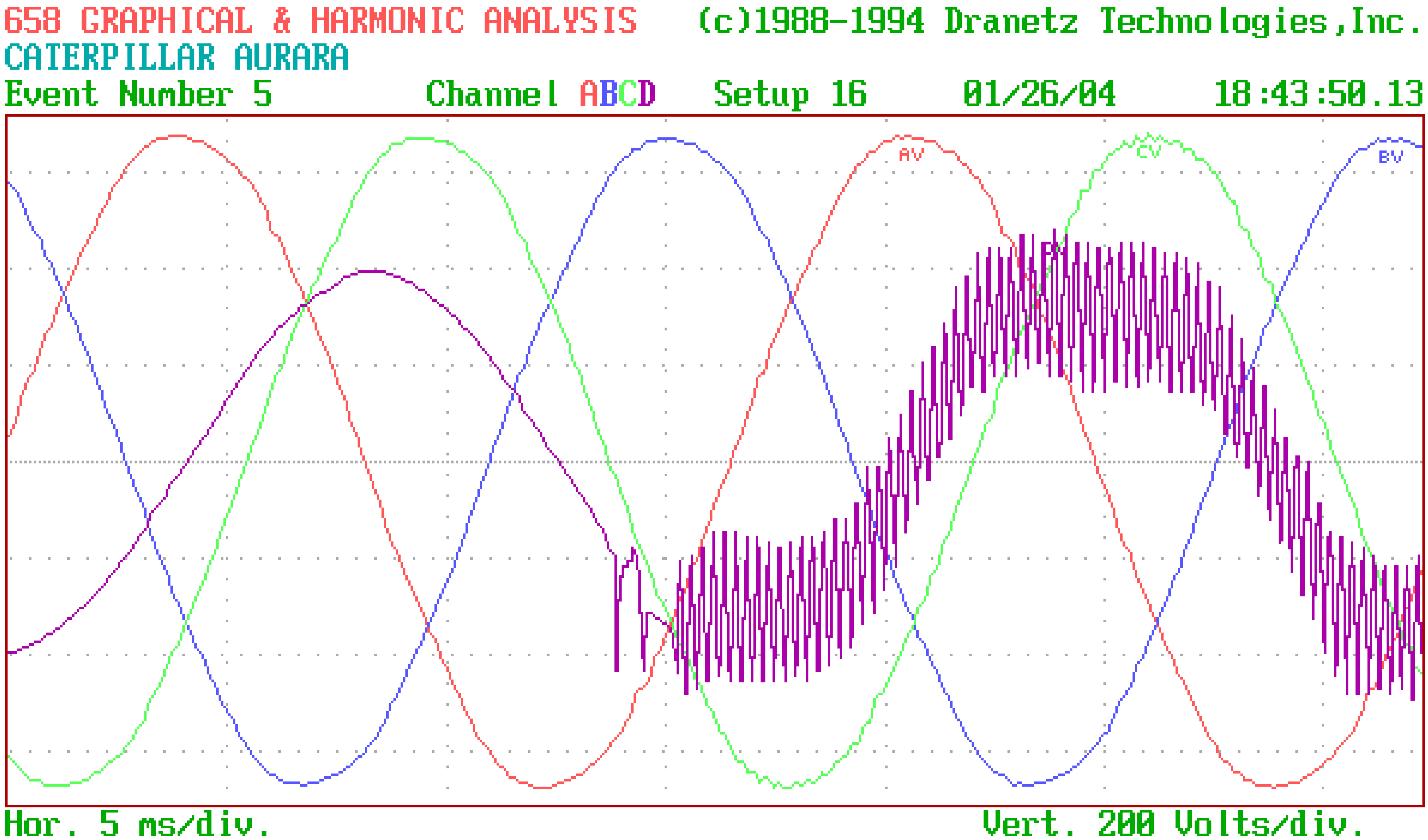


Ungrounded Supply

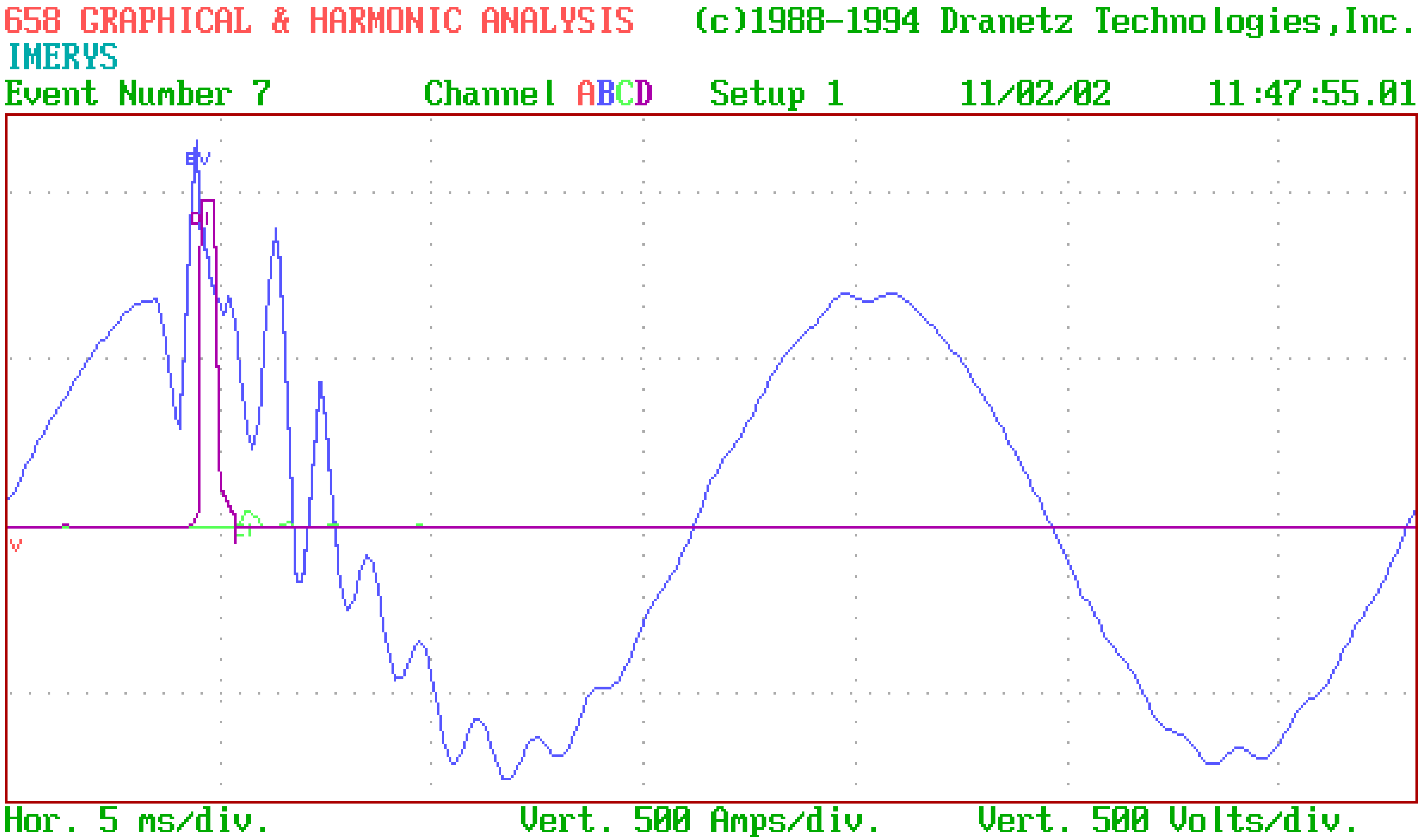




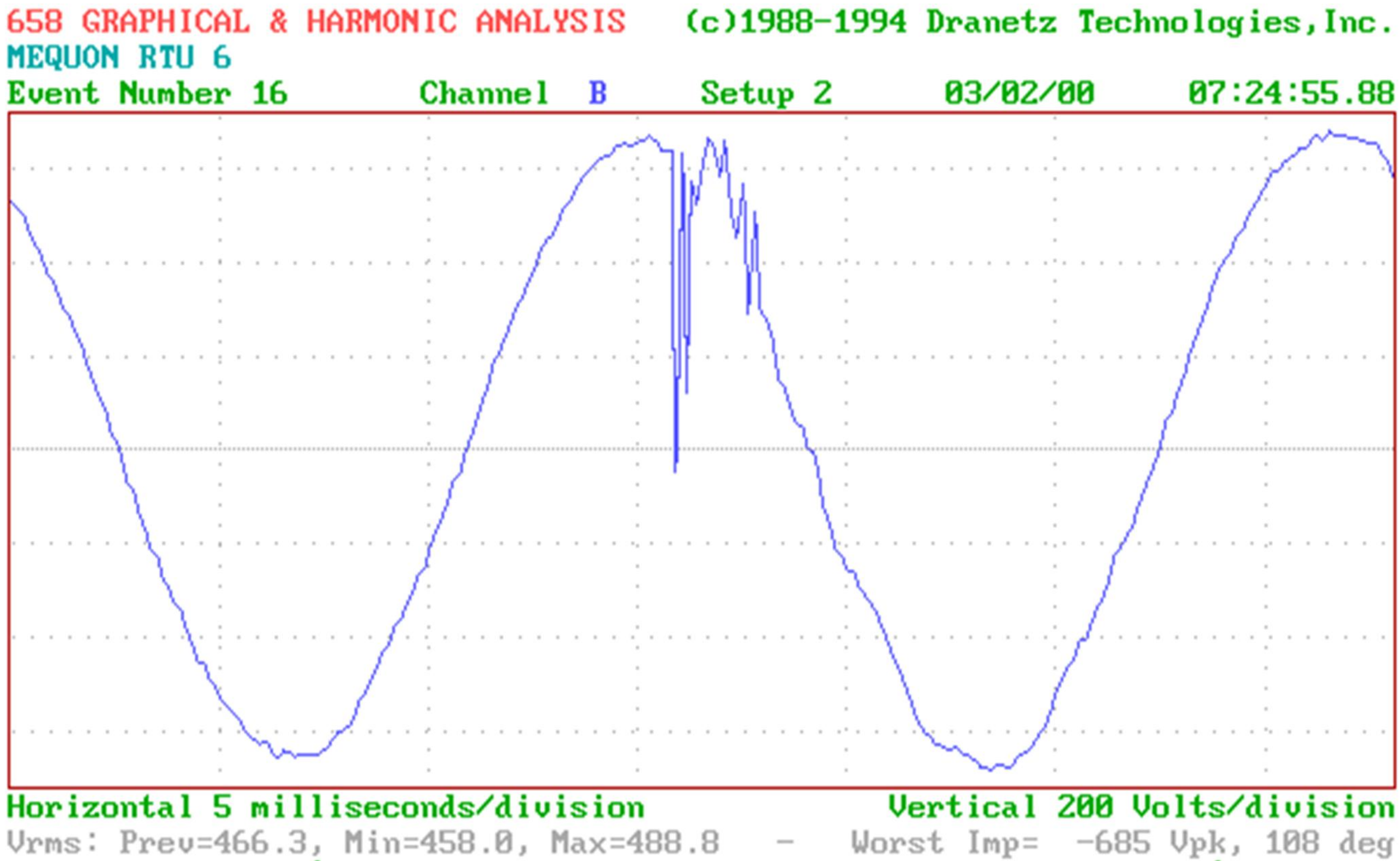
Example of Load with Ground Fault



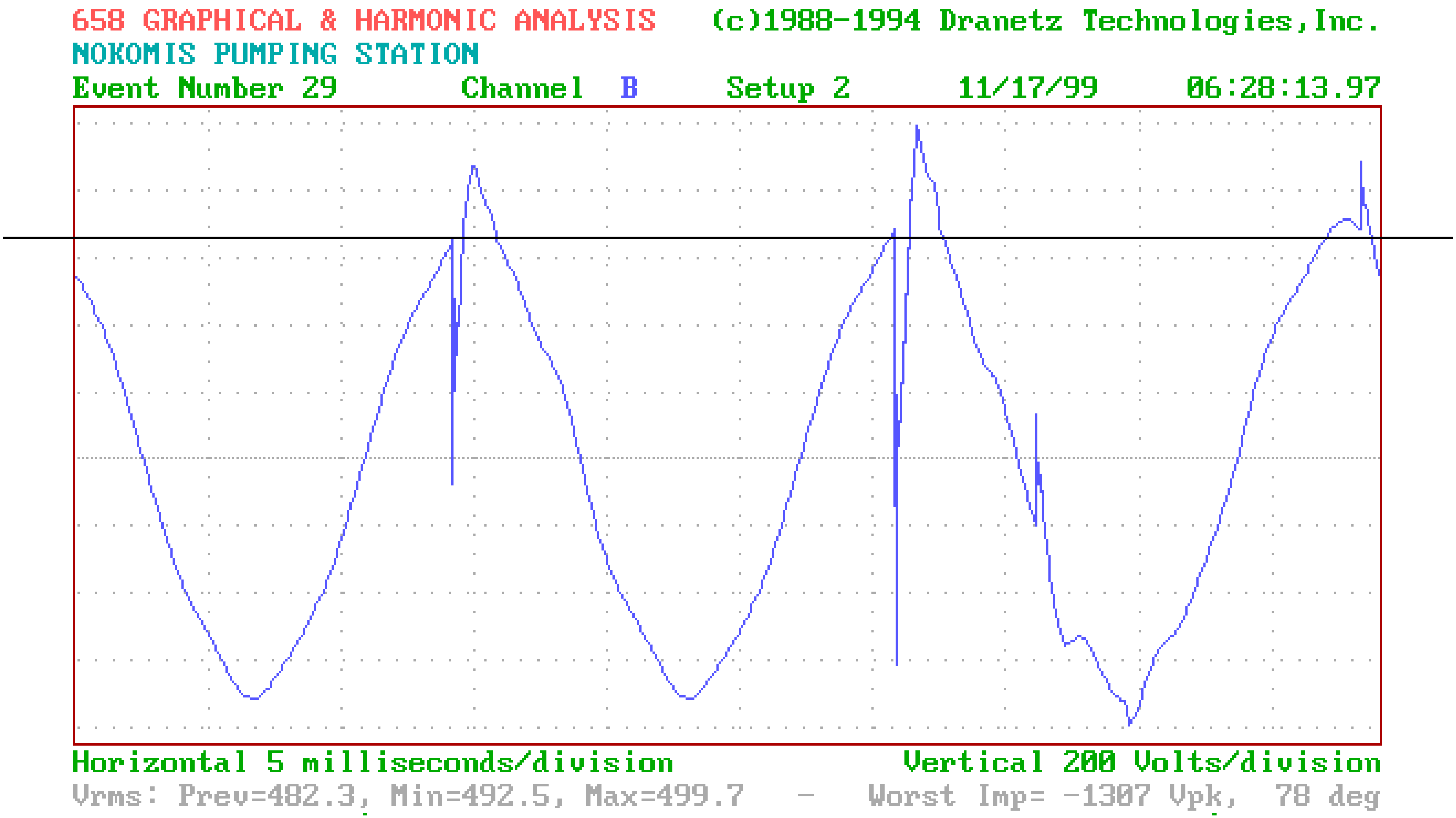
PF Cap Insertion



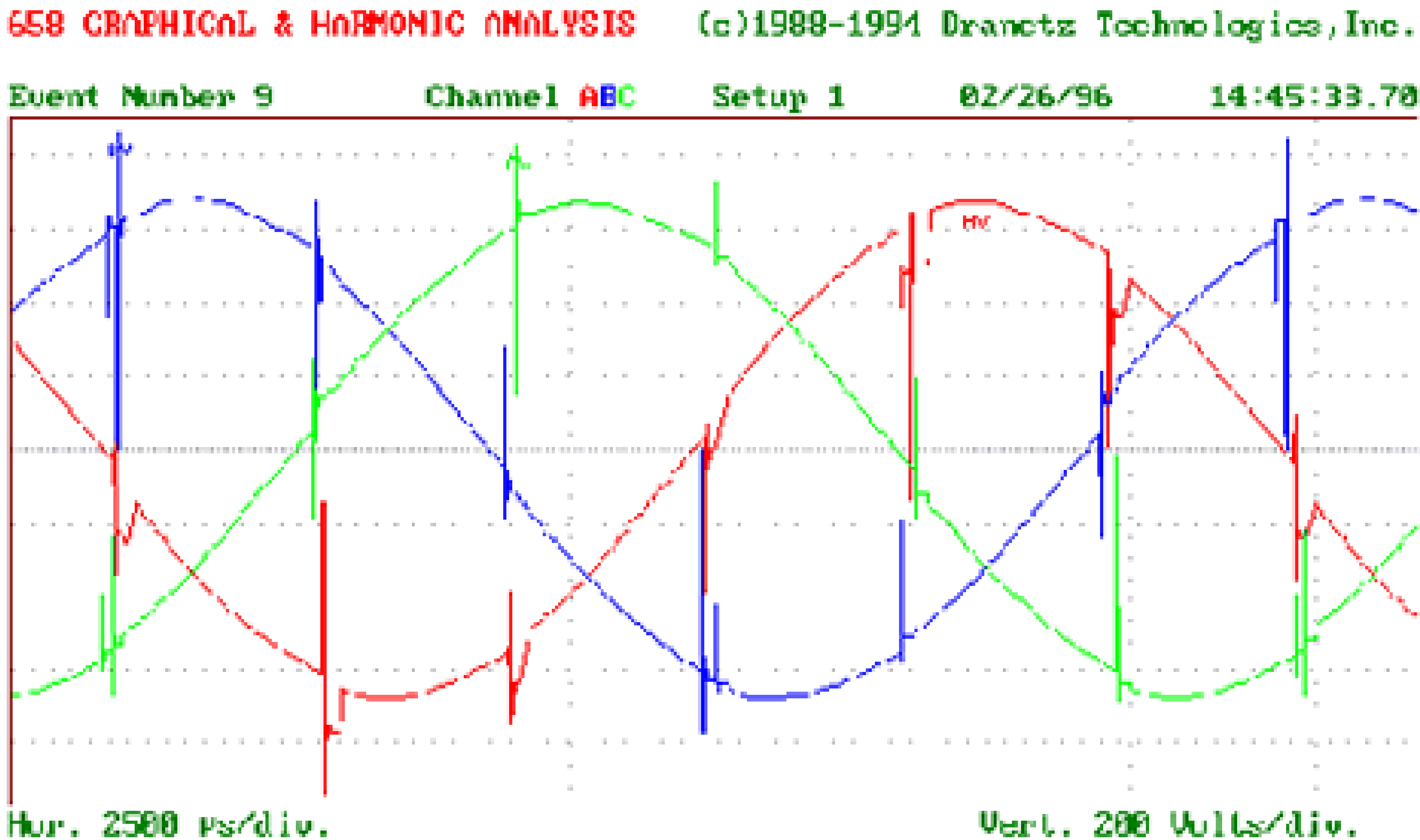
PF Cap Insertion



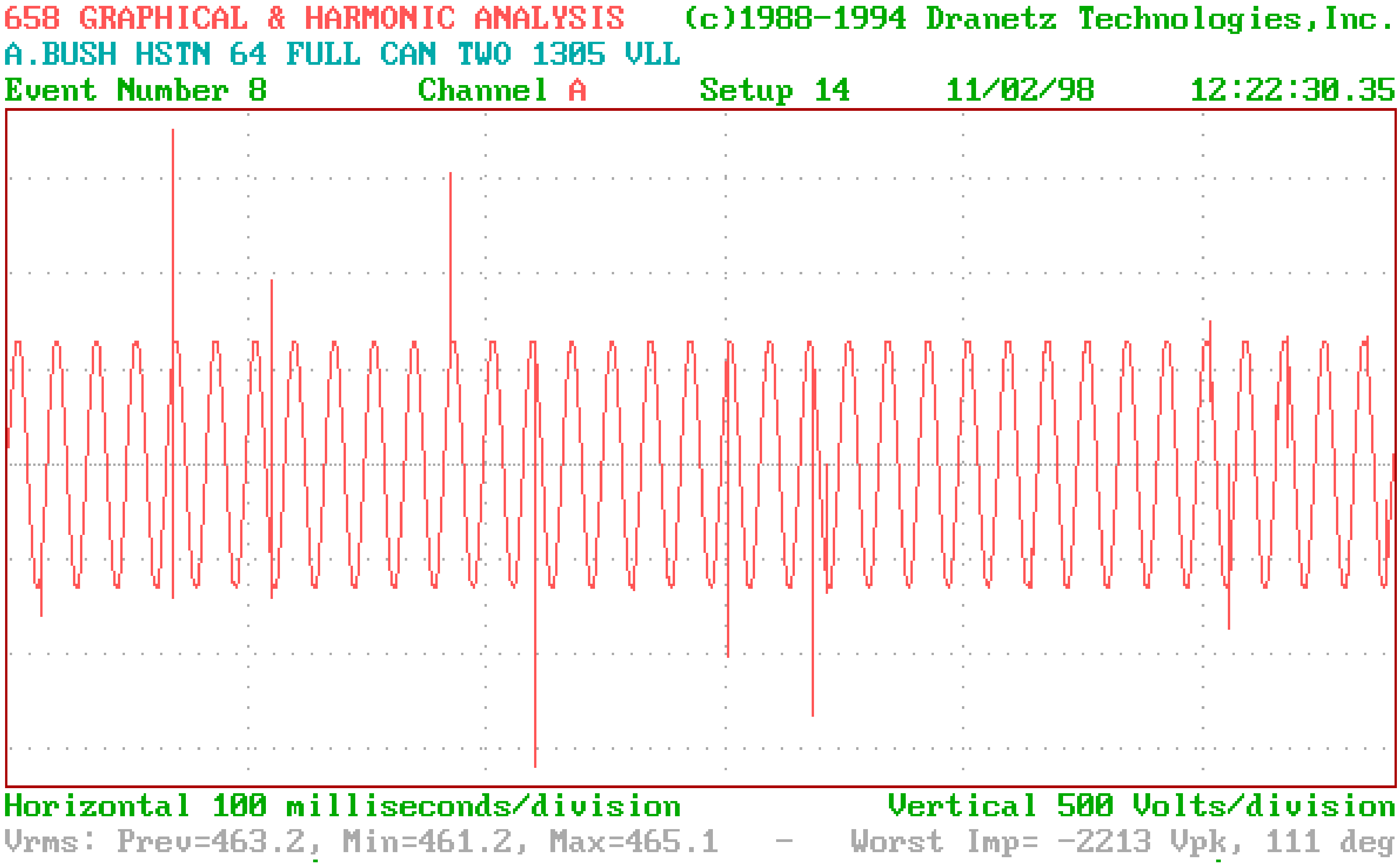
Severe Distortion



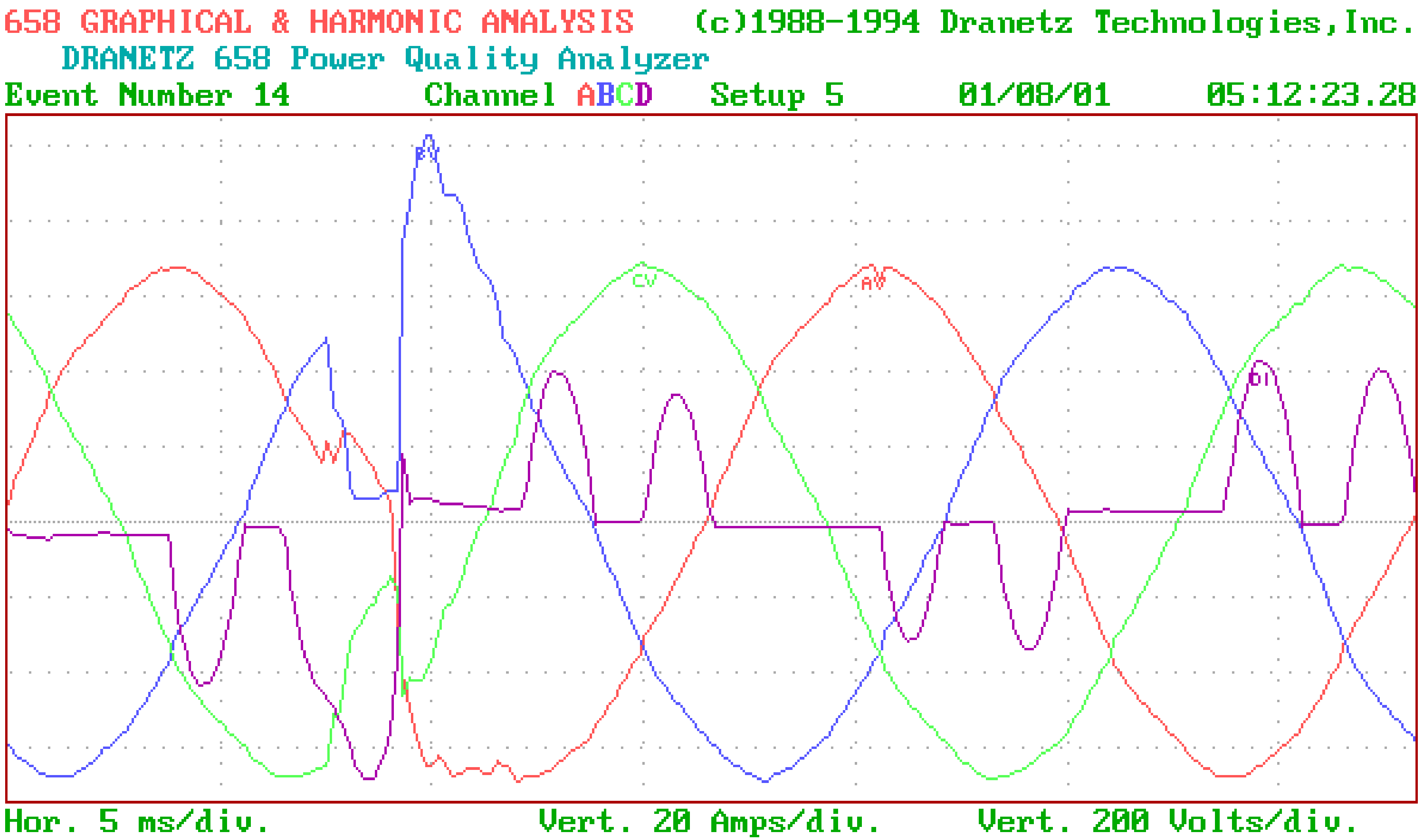
Line-Notching from DC Drive



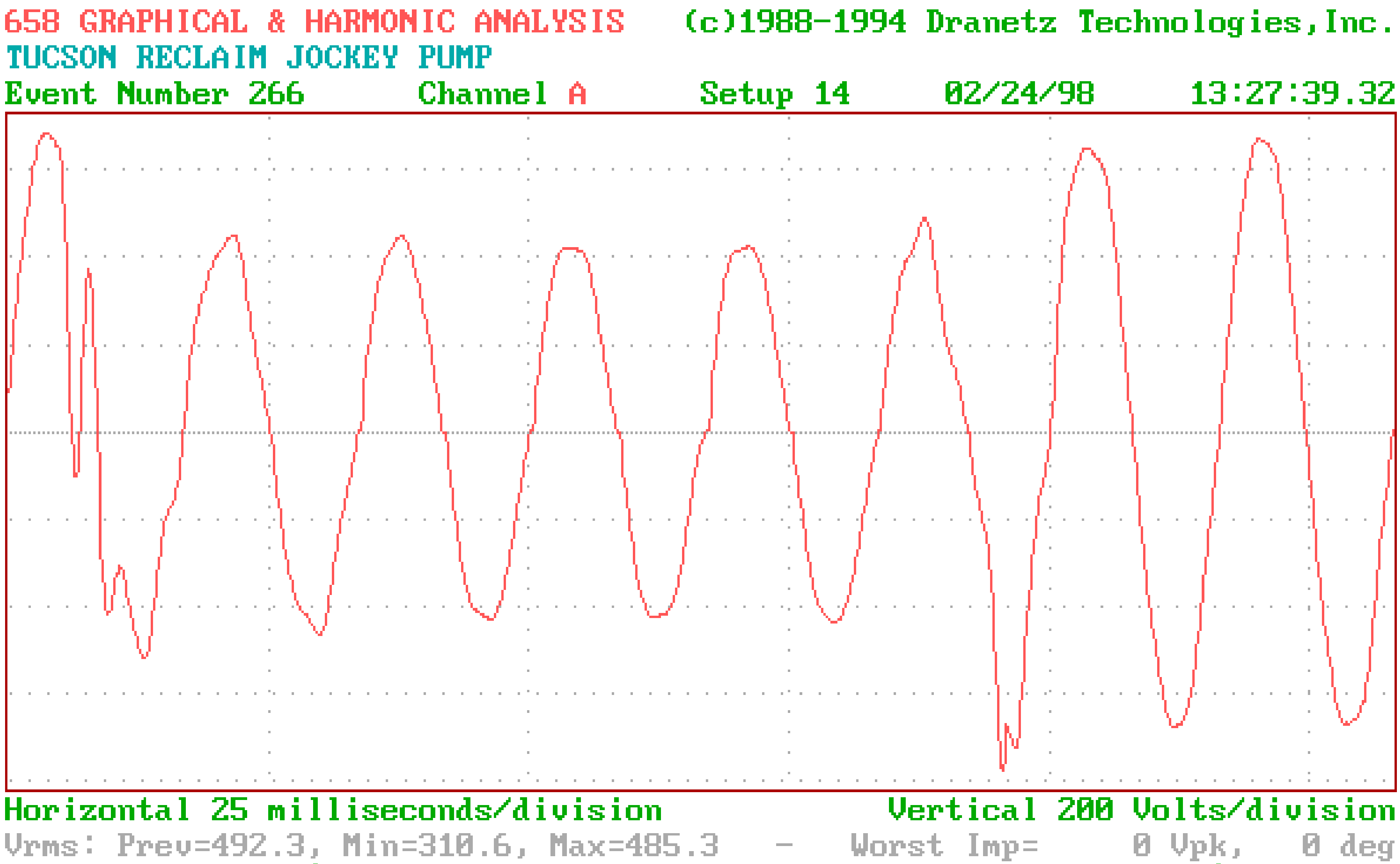
Voltage Transients – Inductive Load Switching?



Single Notch



Voltage Sag



658 GRAPHICAL & HARMONIC ANALYSIS (c)1988-1994 Dranetz Technologies,Inc.
TUCSON RECLAIM JOCKEY PUMP
Event Number 266 Channel A Setup 14 02/24/98 13:27:39.32
Horizontal 25 milliseconds/division Vertical 200 Volts/division
Vrms: Prev=492.3, Min=310.6, Max=485.3 - Worst Imp= 0 Vpk, 0 deg

Voltage Interruption

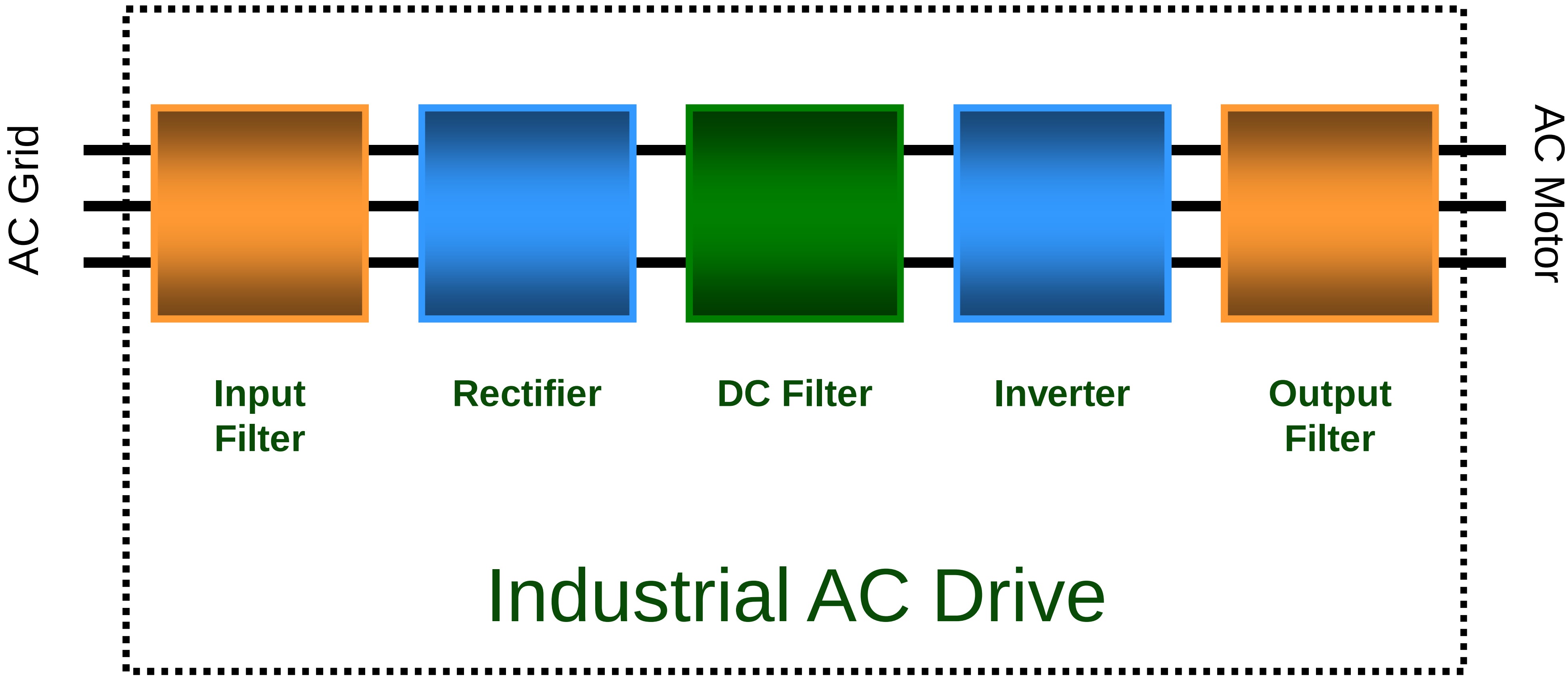
658 GRAPHICAL & HARMONIC ANALYSIS (c)1988-1994 Dranetz Technologies,Inc.
FIELDCREST COLUMBUS
Event Number 22 Channel A Setup 14 11/20/98 06:46:43.51

Horizontal 25 milliseconds/division Vertical 200 Volts/division
Vrms: Prev=452.2, Min=431.7, Max=453.8 - Worst Imp= 0 Vpk, 0 deg

Analysis Rules-of-Thumb

- **Rule #1 = measurements and plots**
  - Don’t rely on meter measurements alone
  - Obtain waveform plots in addition to measurements
- **Rule #2 = each phase to everything else**
  - Take Voltage measurements and plots each line-to-line
  - Take Voltage measurements and plots each line-to-neutral
  - Take Voltage measurements and plots neutral-to-ground
  - Take Current measurements and plots in each line and neutral
  - Not just line-to-ground and not just line-to-line: BOTH

General Block Diagram of an Industrial AC Drive



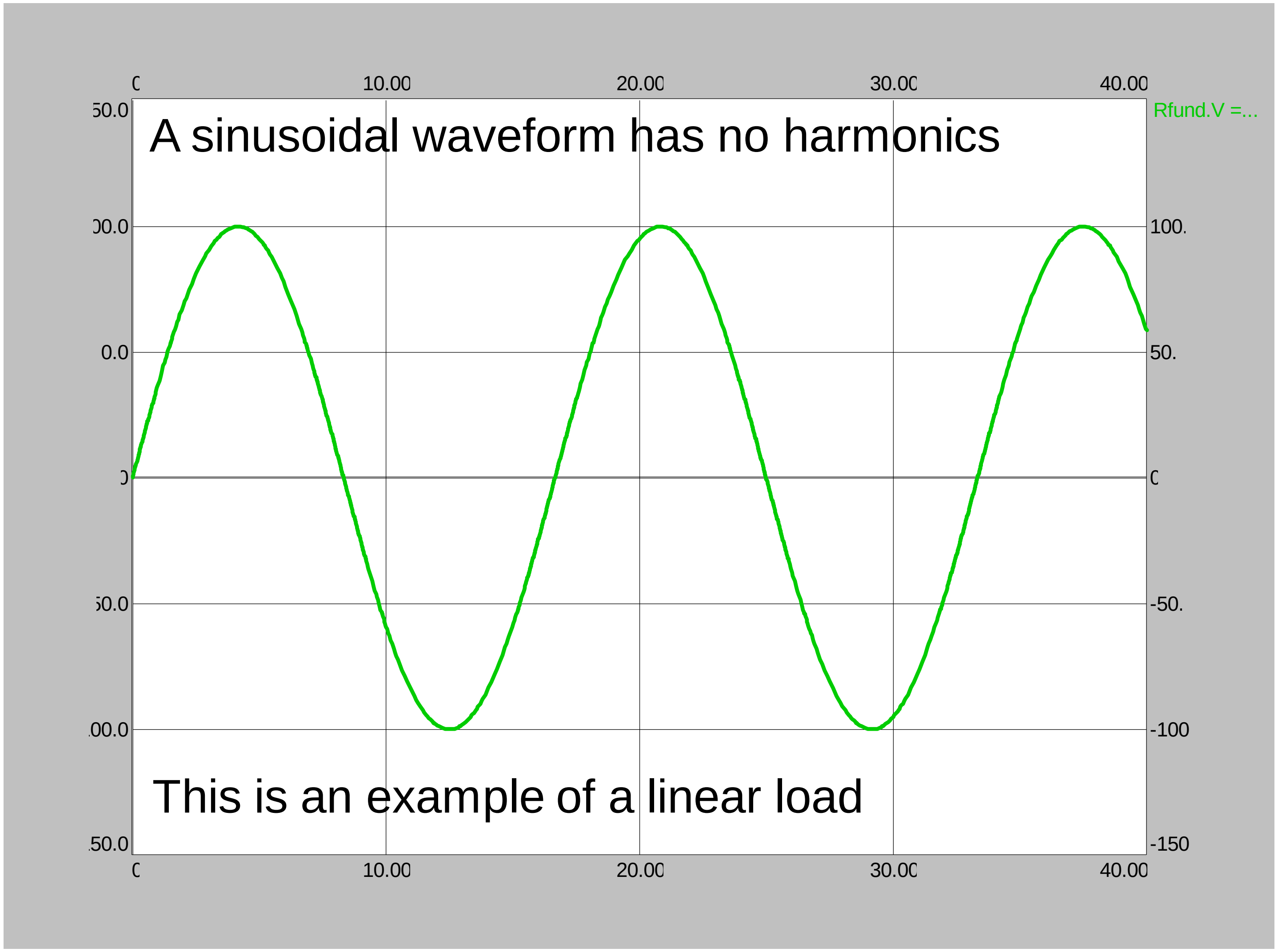
What’s Unique to High Power Drives?

- Higher Power
  - Usually major part of operation at a plant
  - Reliability is critical
    - More internal monitoring
    - Greater protective features
  - Line side
    - Transformer is expensive
      - Protection is critical
    - Line harmonics can be significant
  - Motor side
    - Motor is expensive
      - Protection is critical
      - Reflected Waves

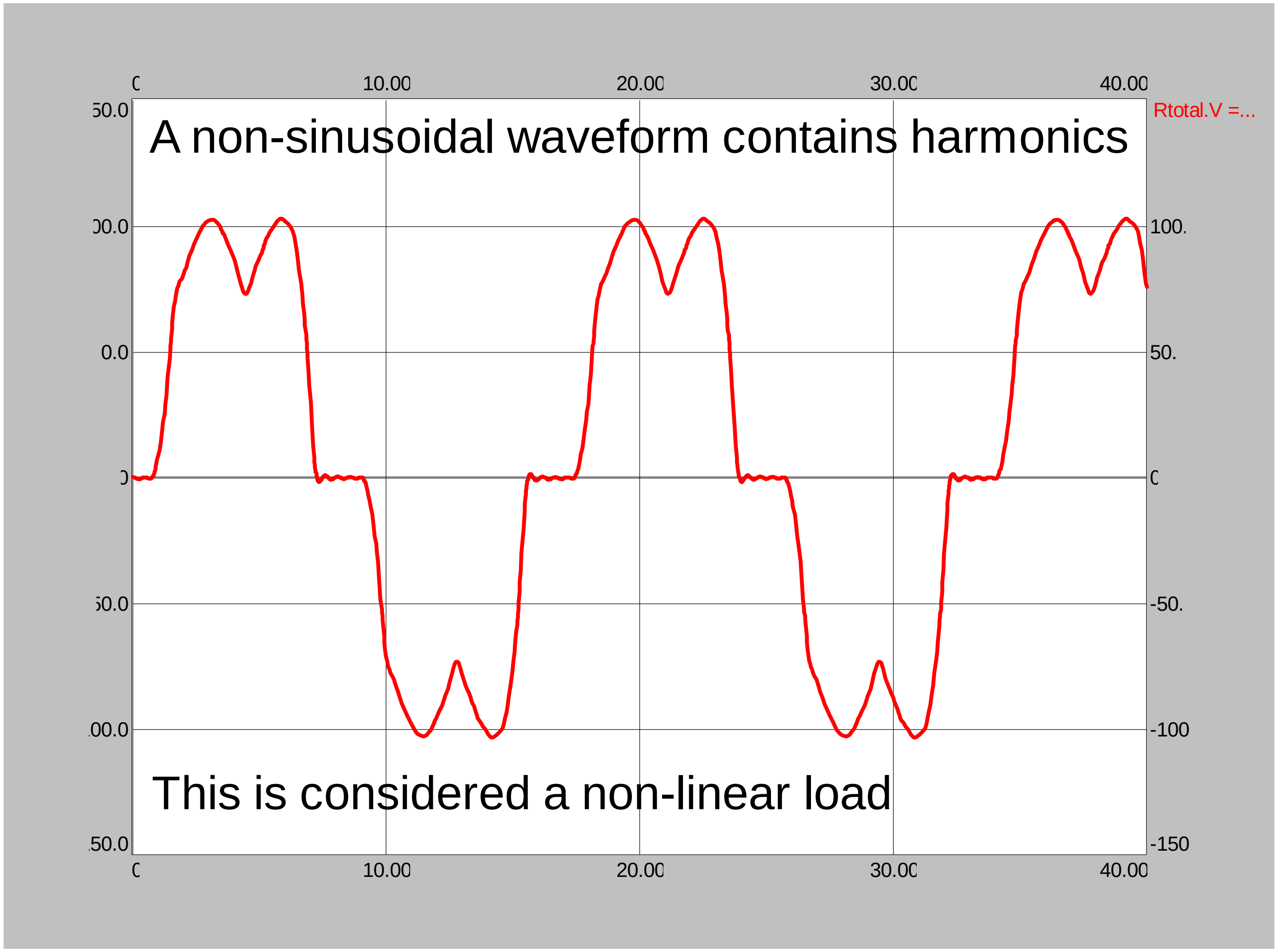
Line Side Requirements

- Harmonics
- Power Factor
- Grounding Configuration

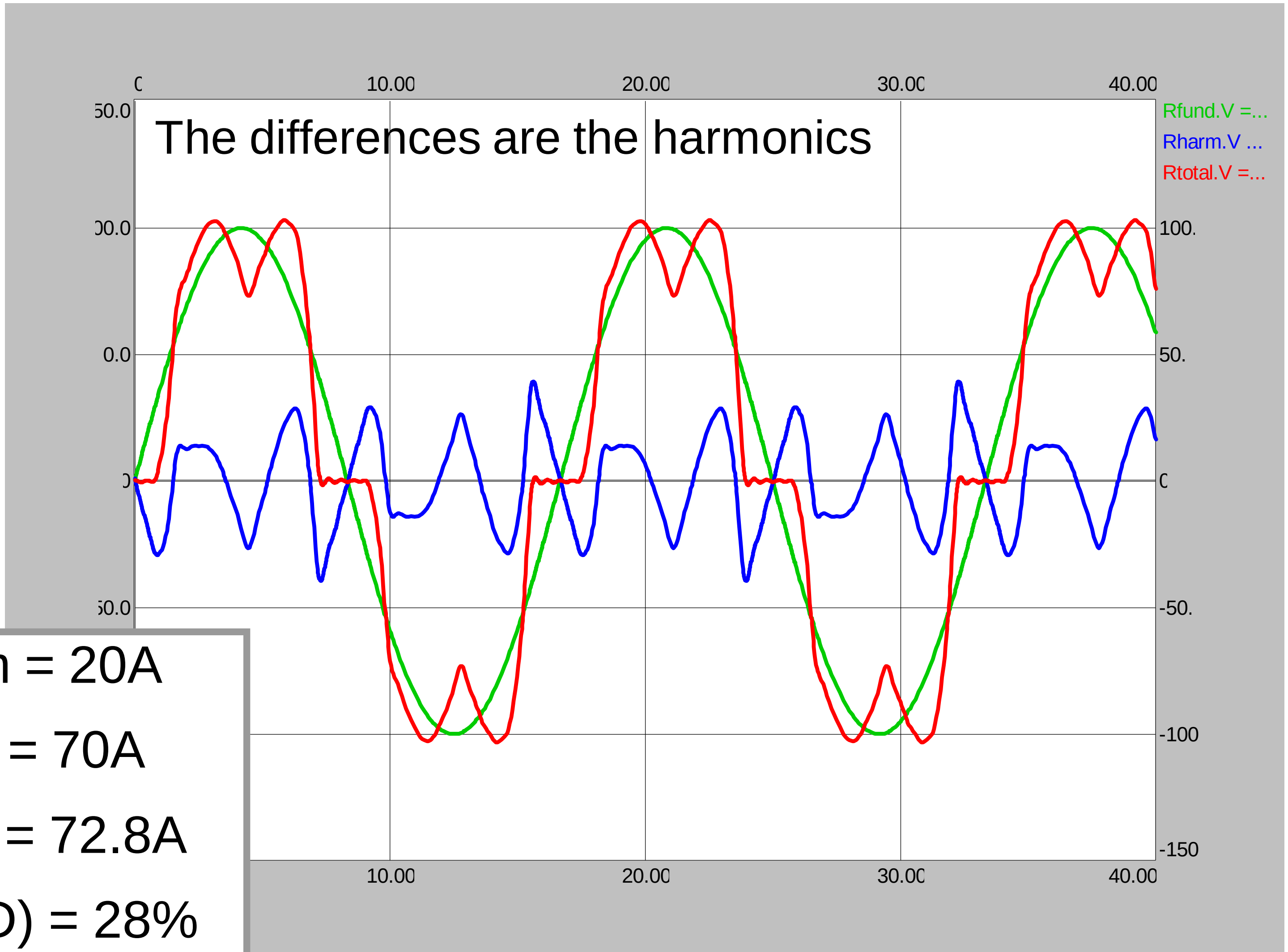
What are Harmonics?



What are Harmonics?



Total, Fundamental, Harmonic Current



Iharm = 20A

Ifund = 70A

Itotal = 72.8A

I(THD) = 28%

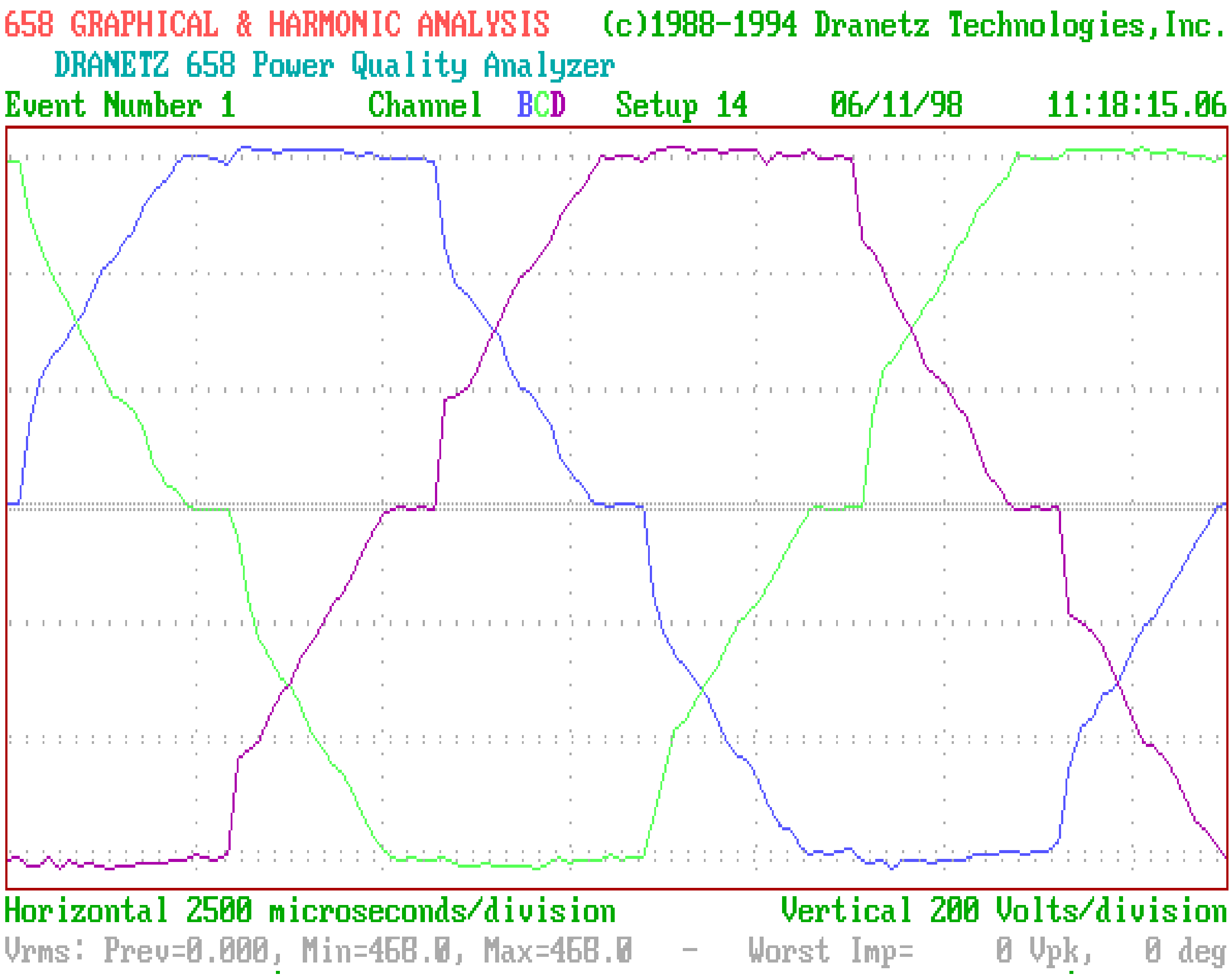
Root Cause of Problems with Other Equipment

Current Harmonics

create

Voltage Distortion

Flat-Topping the Voltage



What are the IEEE 519-1992 standards?

Harmonic Voltage Limits	Table 10.2
Low-Voltage Systems	
Application	Maximum THD (%)
Special Applications - hospitals and airports	3.0%
General System	5.0%
Dedicated System - exclusively converter load	10.0%

Current distortion Limits for General Distribution Systems (120V through 69,000V)						
Maximum Harmonic Current Distortion in Percent of Iload						
Isc/Iload	<11	11<=**h**<17	17<=**h**<23	23<=**h**<35	35<=**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						
						Table 10.3
Isc=maximum short circuit current at PCC						
Iload=maximum demand load current (fundamental frequency component) at PCC						

What are the IEEE 519-1992 standards?

Harmonic Voltage Limits	Table 11.1
Medium-Voltage Systems (≤69kV)	
Voltage Distortion	Maximum THD (%)
Individual Harmonic Distortion	3.0%
Total Harmonic Distortion	5.0%

Current distortion Limits for General Distribution Systems (120V through 69,000V)						
Maximum Harmonic Current Distortion in Percent of Iload						
Isc/Iload	<11	11<=**h**<17	17<=**h**<23	23<=**h**<35	35<=**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						
						Table 10.3
Isc=maximum short circuit current at PCC						
Iload=maximum demand load current (fundamental frequency component) at PCC						

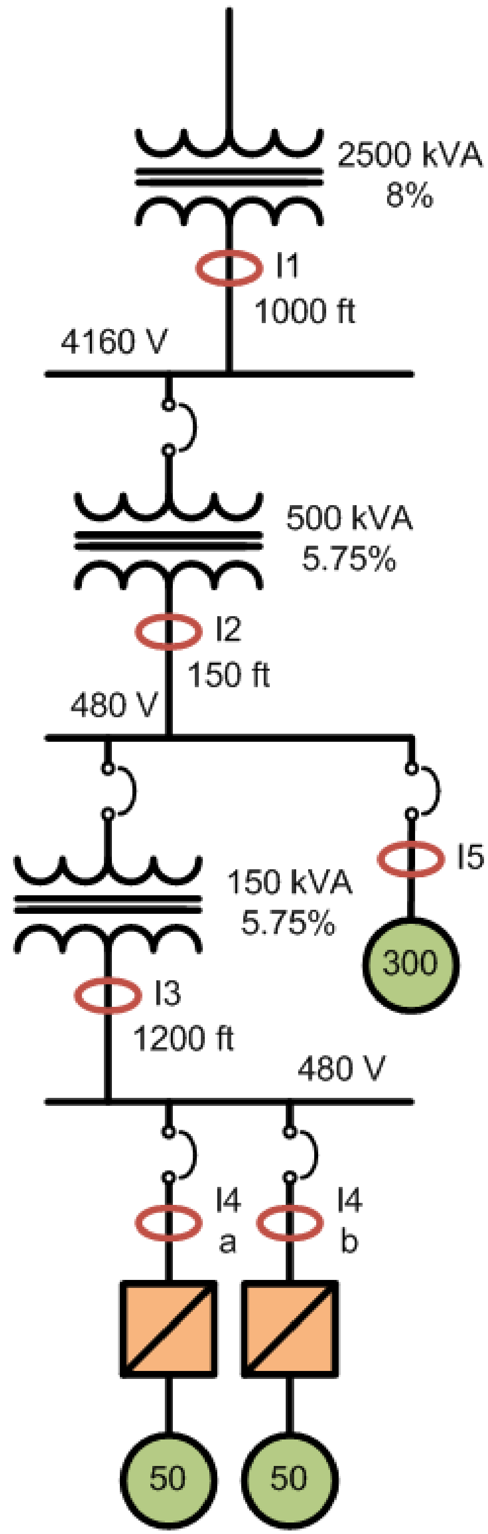
Where is the PCC?

For an Harmonic Study:

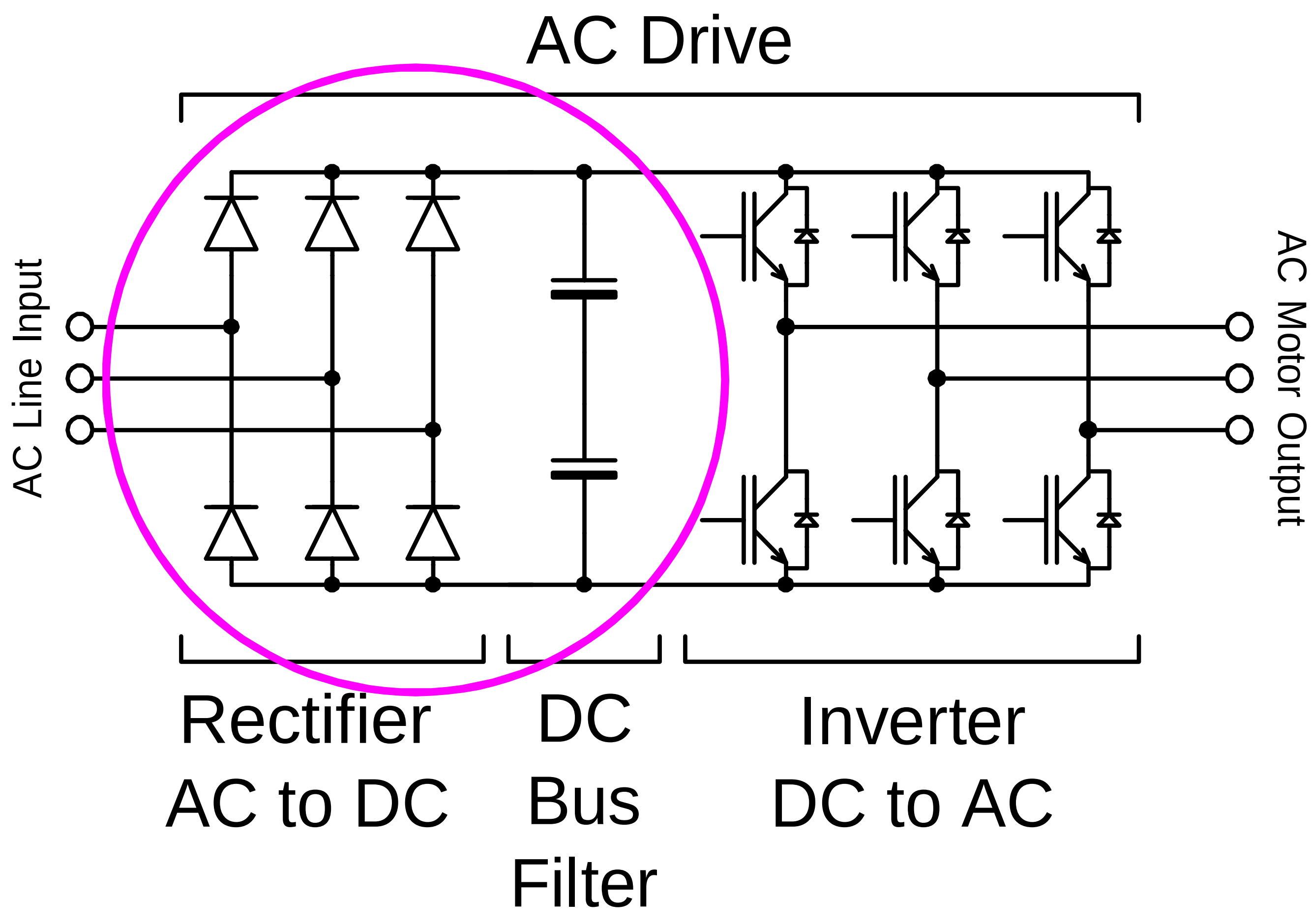
Need to calculate and measure the voltage and current magnitudes and distortion at each of the 6 locations (PCCs) noted.

Need to know types of loads, max loads and impedances.

Need to know if there are back-up generators, too.

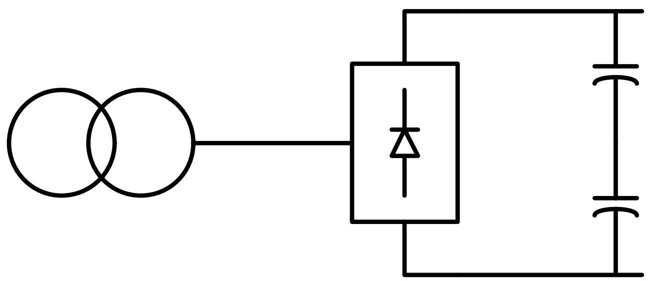


Basic AC Drive Topology
6-Pulse Rectifier

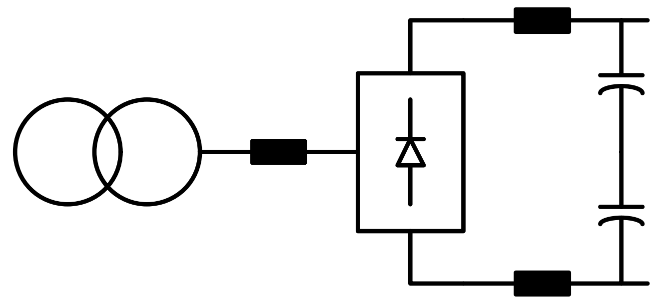


Line Current Harmonic Mitigation Methods

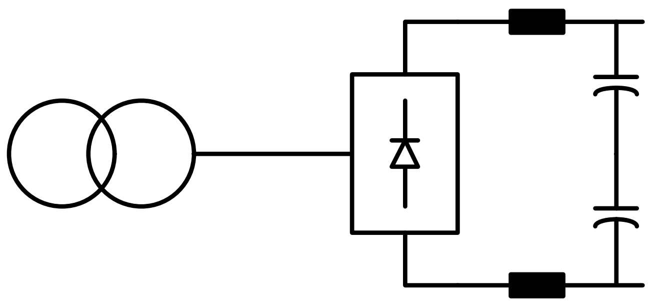
6-Pulse (120°/2 = 60°)



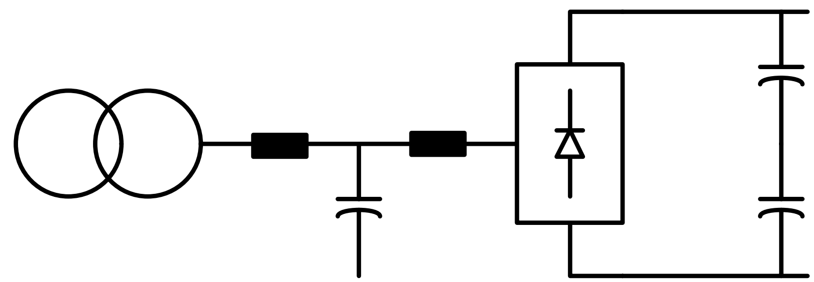
Basic Converter



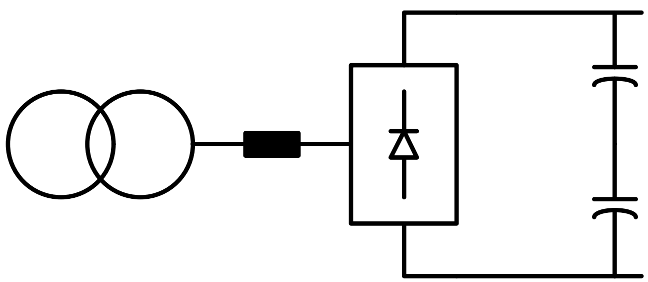
Link Choke and Reactor



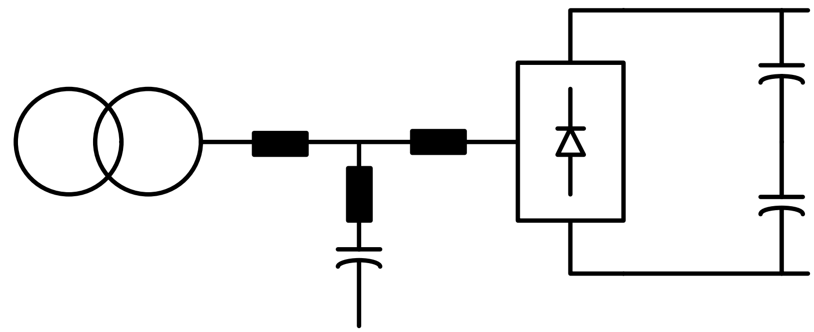
DC Link Chokes



Passive Harmonic Filter

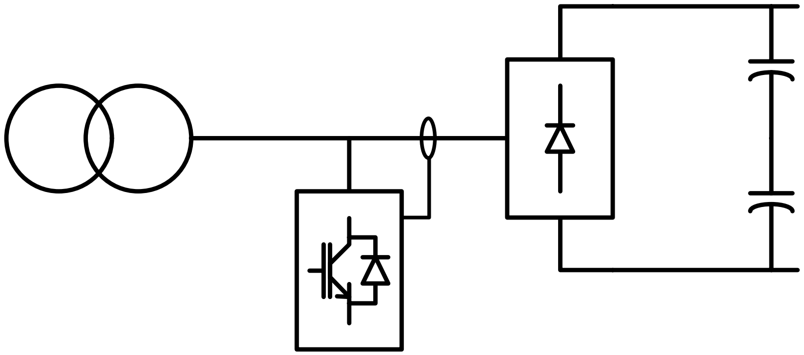


AC Line Reactor



Passive Notch Filter

Line Current Harmonic Mitigation Methods
6-Pulse

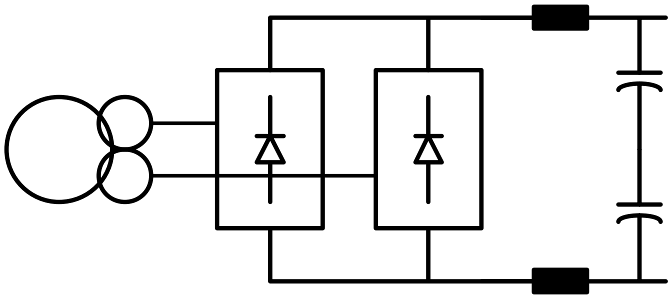


Active Harmonic Filter

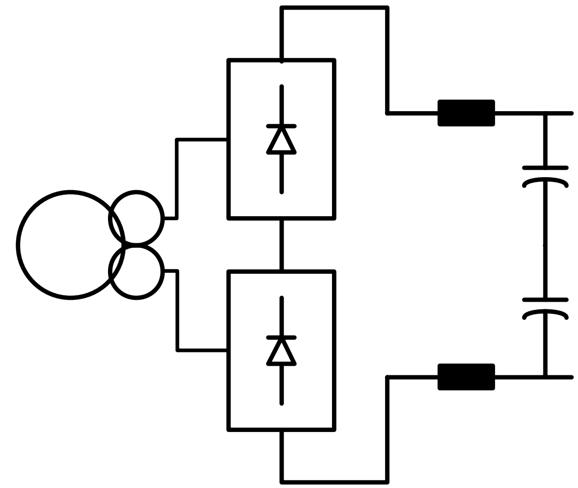
Line Current Harmonic Mitigation Methods

12-Pulse (30°)

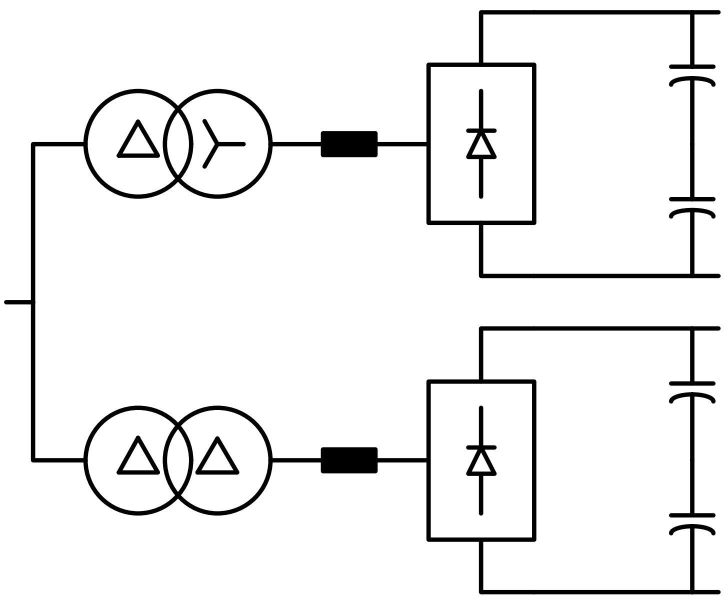
* Used in MV drives



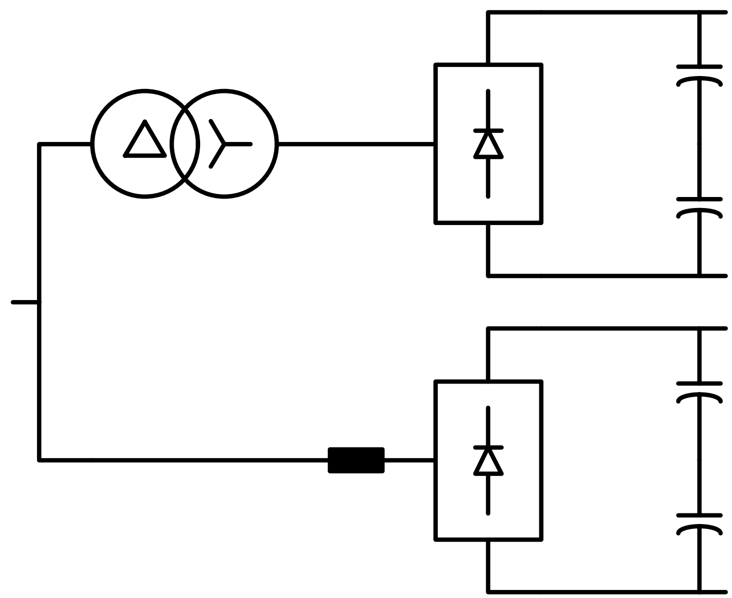
Parallel Bridges



*Series Bridges



Pseudo 12-Pulse

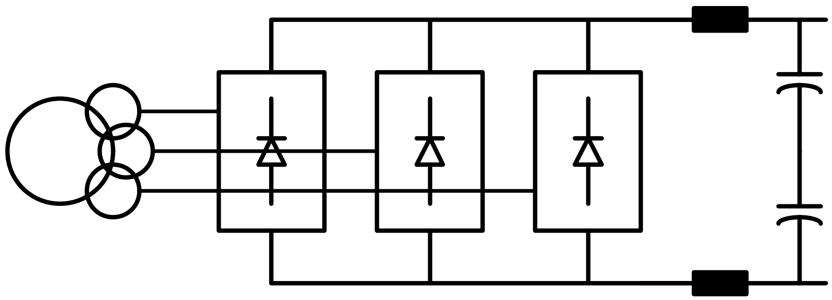


Poor-Man’s 12-Pulse

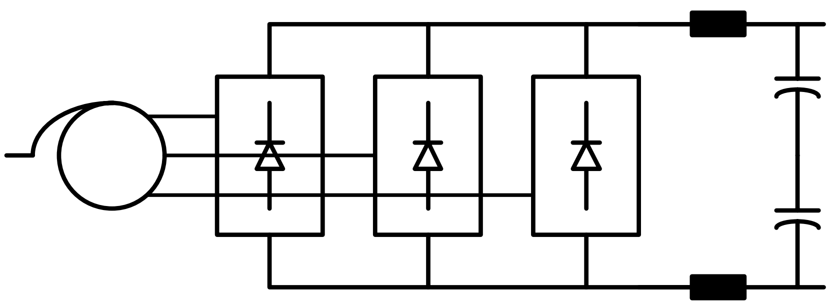
Line Current Harmonic Mitigation Methods

18-Pulse (20°)

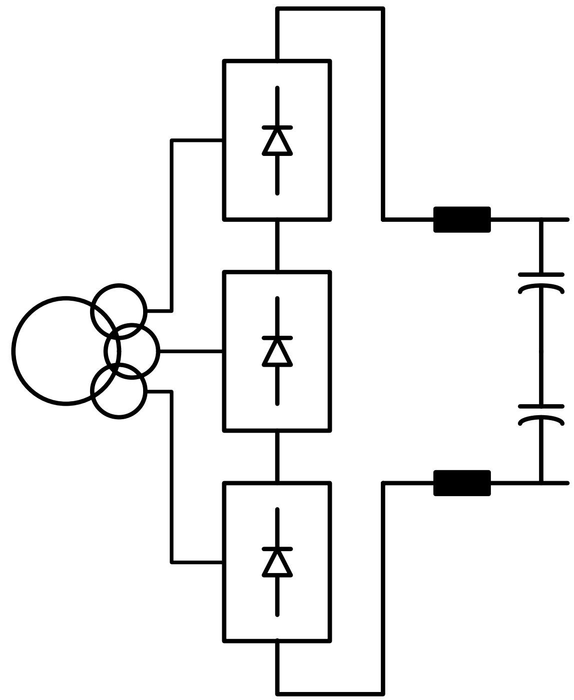
* Used in MV drives



Parallel Bridges



Auto-Transformer with Parallel Bridges

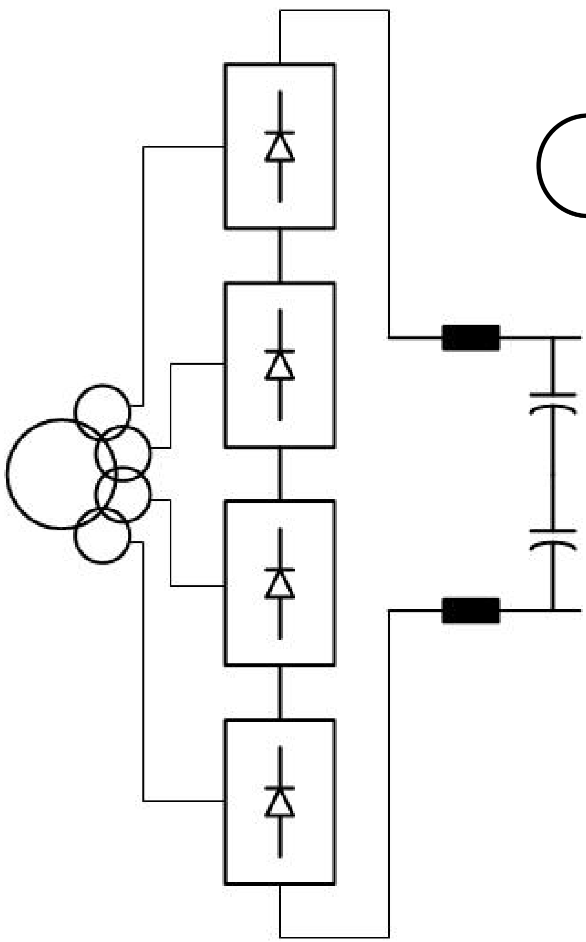


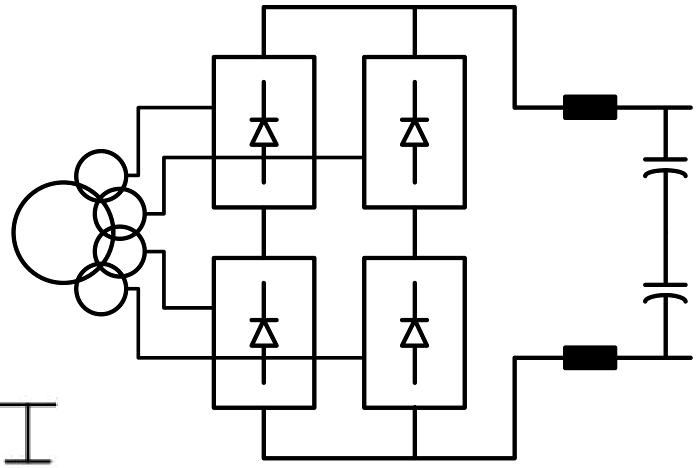
*Series Bridges

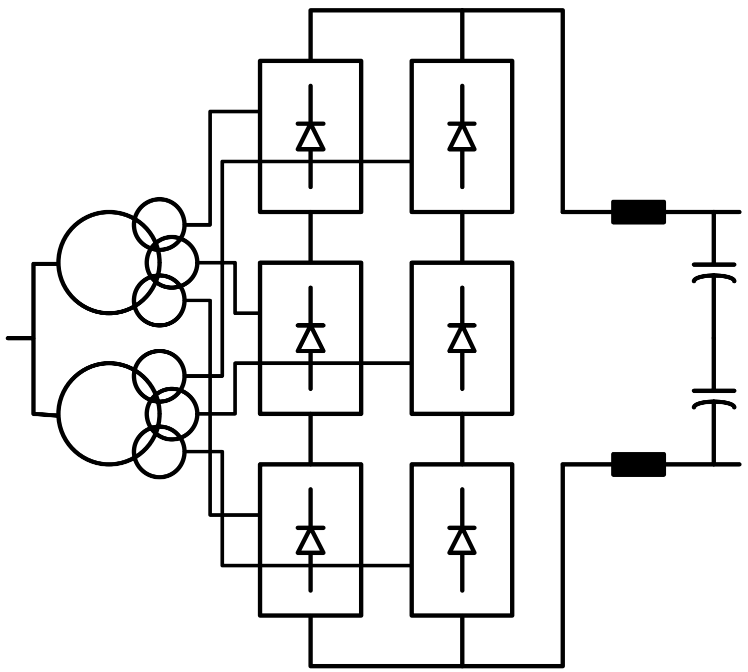
Line Current Harmonic Mitigation Methods

24-Pulse (15°), 36-Pulse (10°)

* Used in MV drives



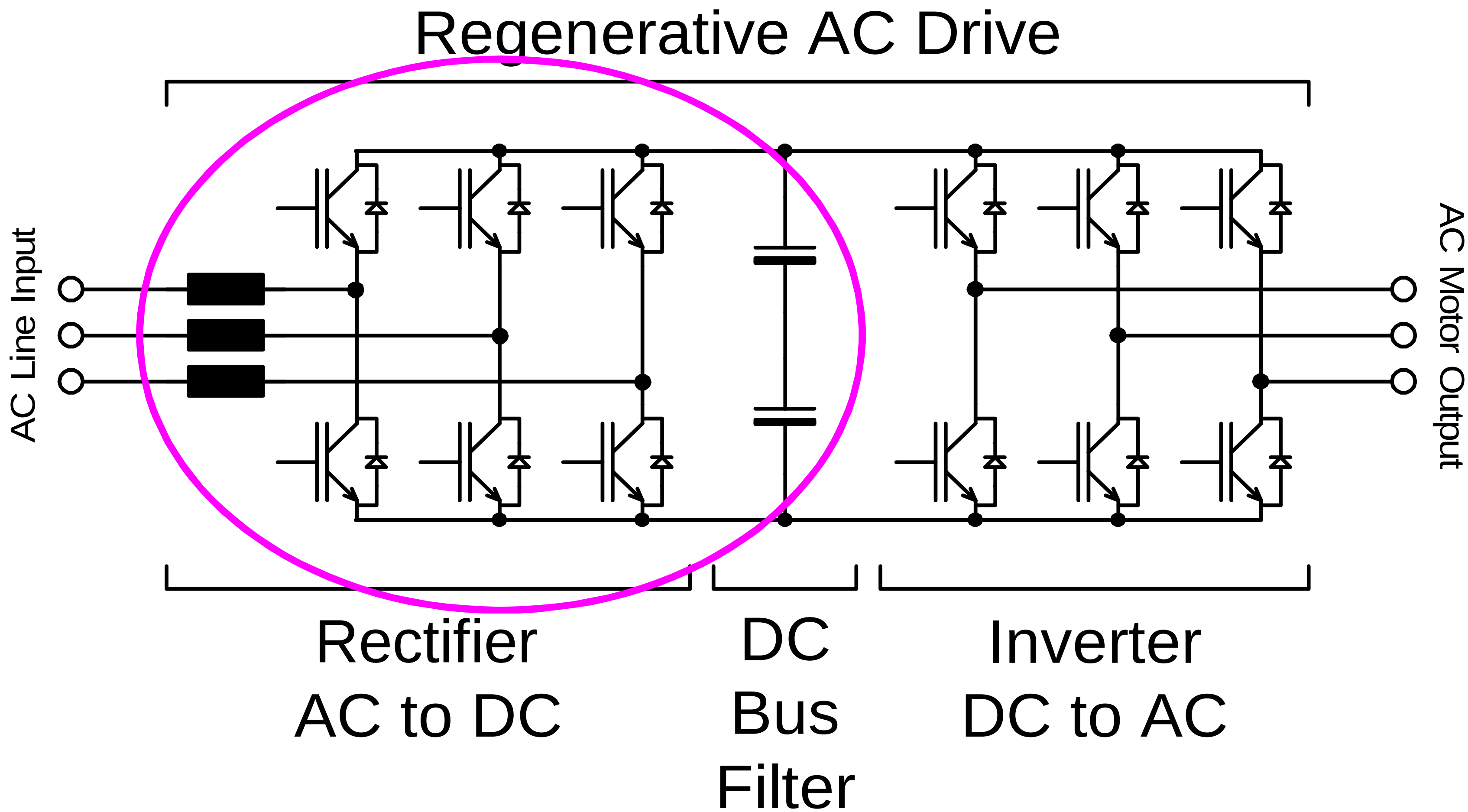




*Series / Parallel Bridges, 36P

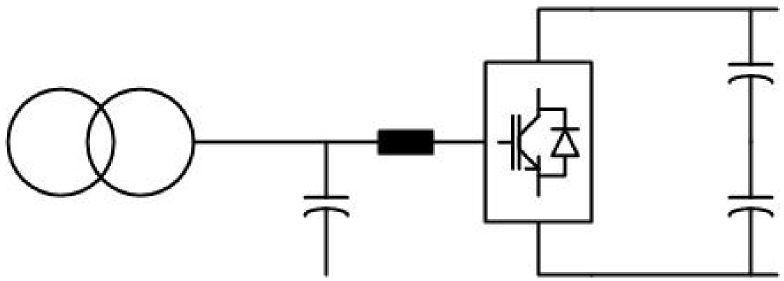
*Series or Series / Parallel Bridges, 24P

Line Current Harmonic Mitigation Methods
Active Front End (AFE)

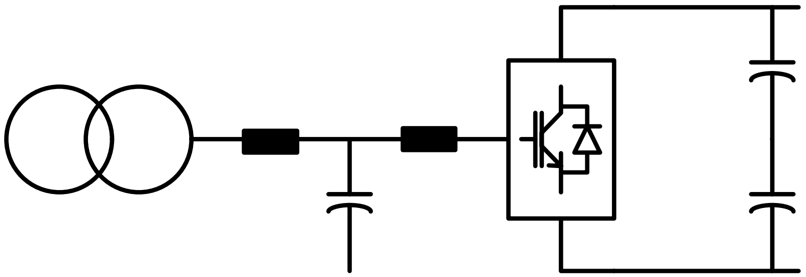


Line Current Harmonic Mitigation Methods
Active Front End (AFE)

* Used in MV drives



AFE with Isolation Transformer



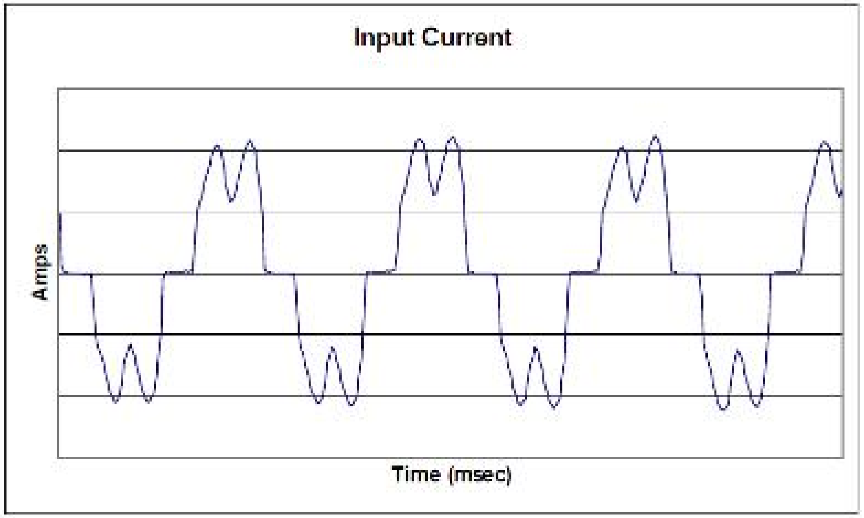
*AFE with LCL Filter

NOTE: The AFE can be 2-Level, 3-Level, 5-Level

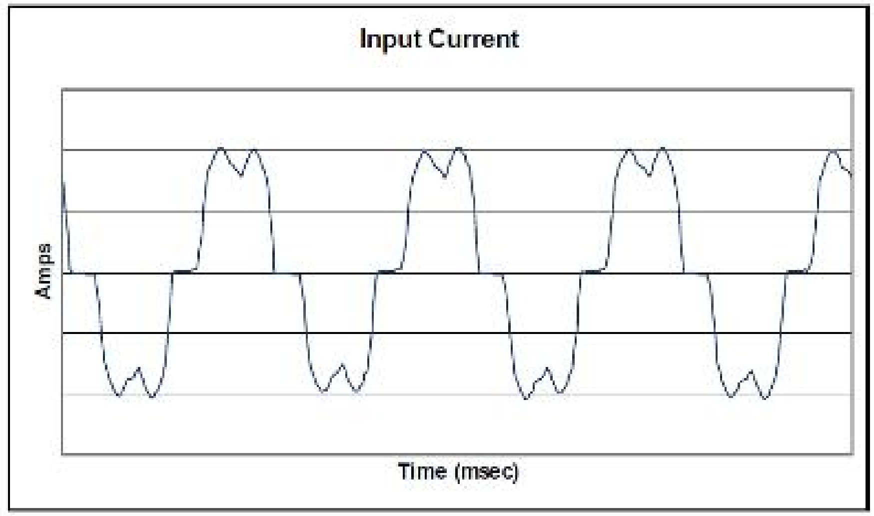
(more on this later)

The Goal of Harmonic Mitigation

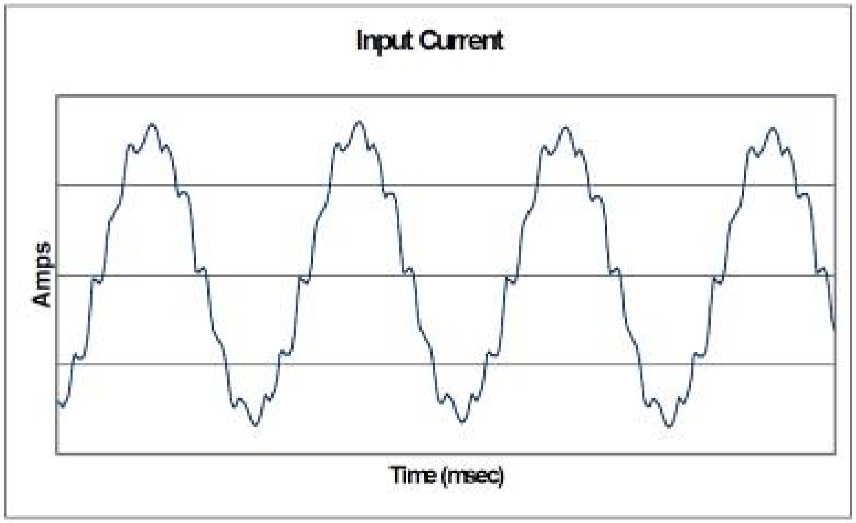
6-Pulse: 32% Ithd



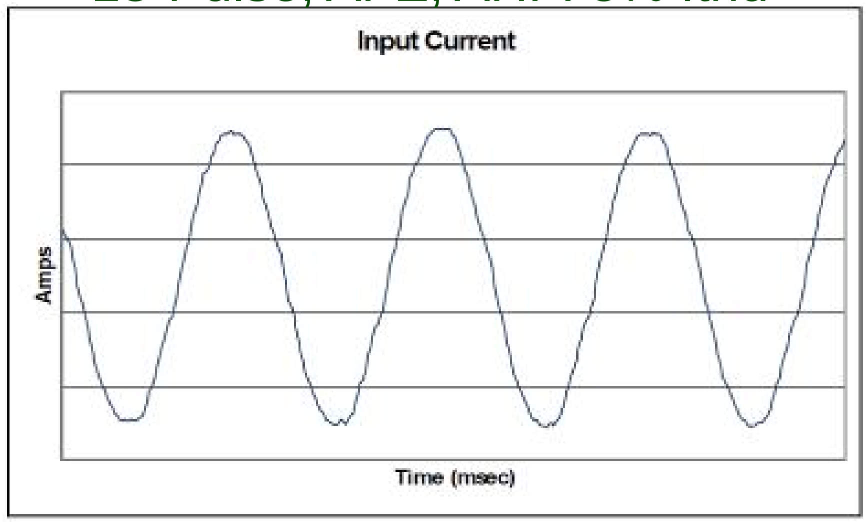
6-Pulse with 5% Line Reactor: 25% Ithd



12-Pulse: 10% Ithd



18-Pulse, AFE, AHF: 5% Ithd



Line Current Harmonic Mitigation Methods
Harmonic Content

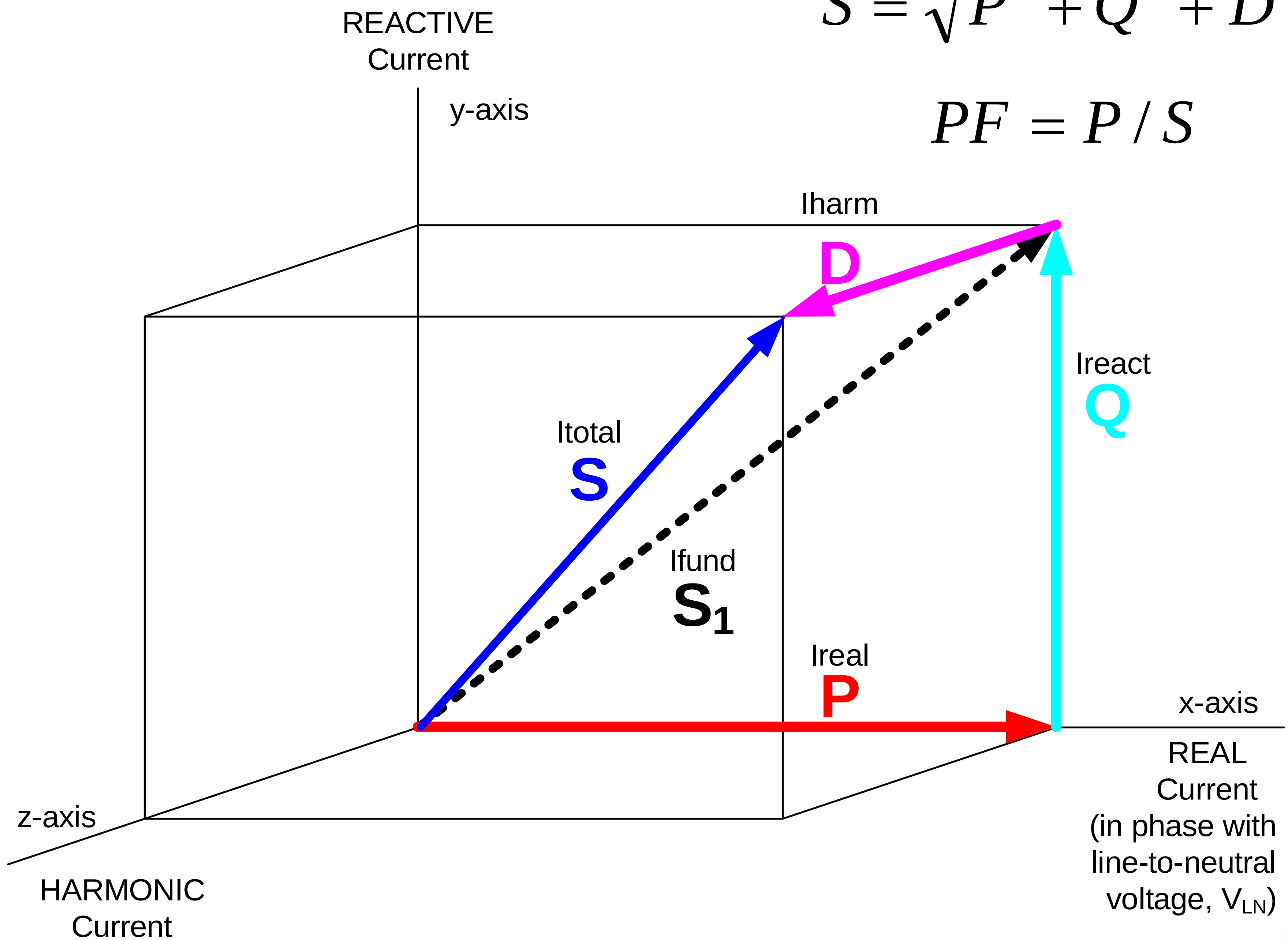
Multi-Pulse	XFMR	Ithd	PF
▪ 6 Pulse	std xfmr	30-120%	0.90
▪ 12 Pulse	6 phase shift xfmr	10-15%	0.92
▪ 18 Pulse	9 phase shift xfmr	5-6%	0.95
▪ 24 Pulse	12 phase shift xfmr	4-5%	0.96
▪ 36 Pulse	18 phase shift xfmr	3-4%	0.96
Active Front End (AFE)			
▪ AFE	std xfmr	4-5%	1.0
Current Source PWM			
▪ CSI, LCI	std xfmr	5-6%	0 – 1.0 lead

ABB

Power Cube

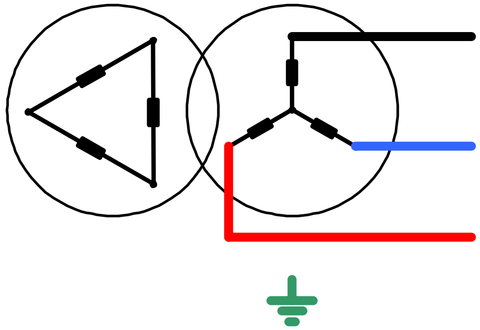
$$S = \sqrt{P^2 + Q^2 + D^2}$$

$$PF = P / S$$

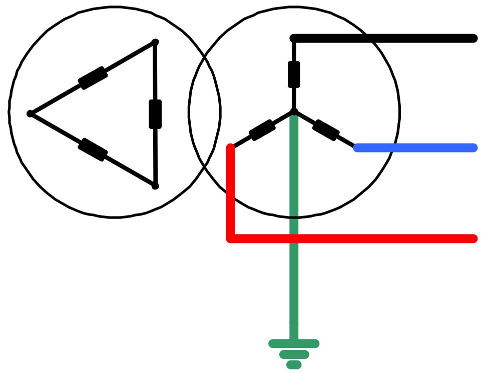


Grounding Configurations

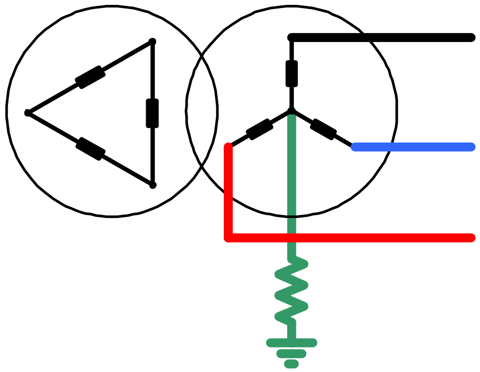
- **Floating** secondary



- Solidly **grounded** secondary



- Low **resistance** grounded secondary
  - LV – 10, 50, 100A
  - MV – 200, 400A



Motor Side Challenges

- NEMA MG-1
- Topologies
- Reflected Wave

MG 1-2006, Rev 1, Part 30

Section IV
PERFORMANCE STANDARDS APPLYING TO ALL MACHINES
Part 30
APPLICATION CONSIDERATIONS FOR CONSTANT SPEED MOTORS USED ON A SINUSOIDAL BUS WITH HARMONIC CONTENT AND GENERAL PURPOSE MOTORS USED WITH ADJUSTABLE-VOLTAGE OR ADJUSTABLE-FREQUENCY CONTROLS OR BOTH

30.0 SCOPE

The information in this Section applies to 60 Hz NEMA Designs A and B squirrel-cage motors covered by Part 12 and to motors covered by Part 20 rated 5000 horsepower or less at 7200 volts or less, when used on a sinusoidal bus with harmonic content, or when used with adjustable-voltage or adjustable-frequency controls, or both.

NEMA Designs C and D motors and motors larger than 5000 horsepower and voltages greater than 7200 volts are excluded from this section and the manufacturer should be consulted regarding their application.

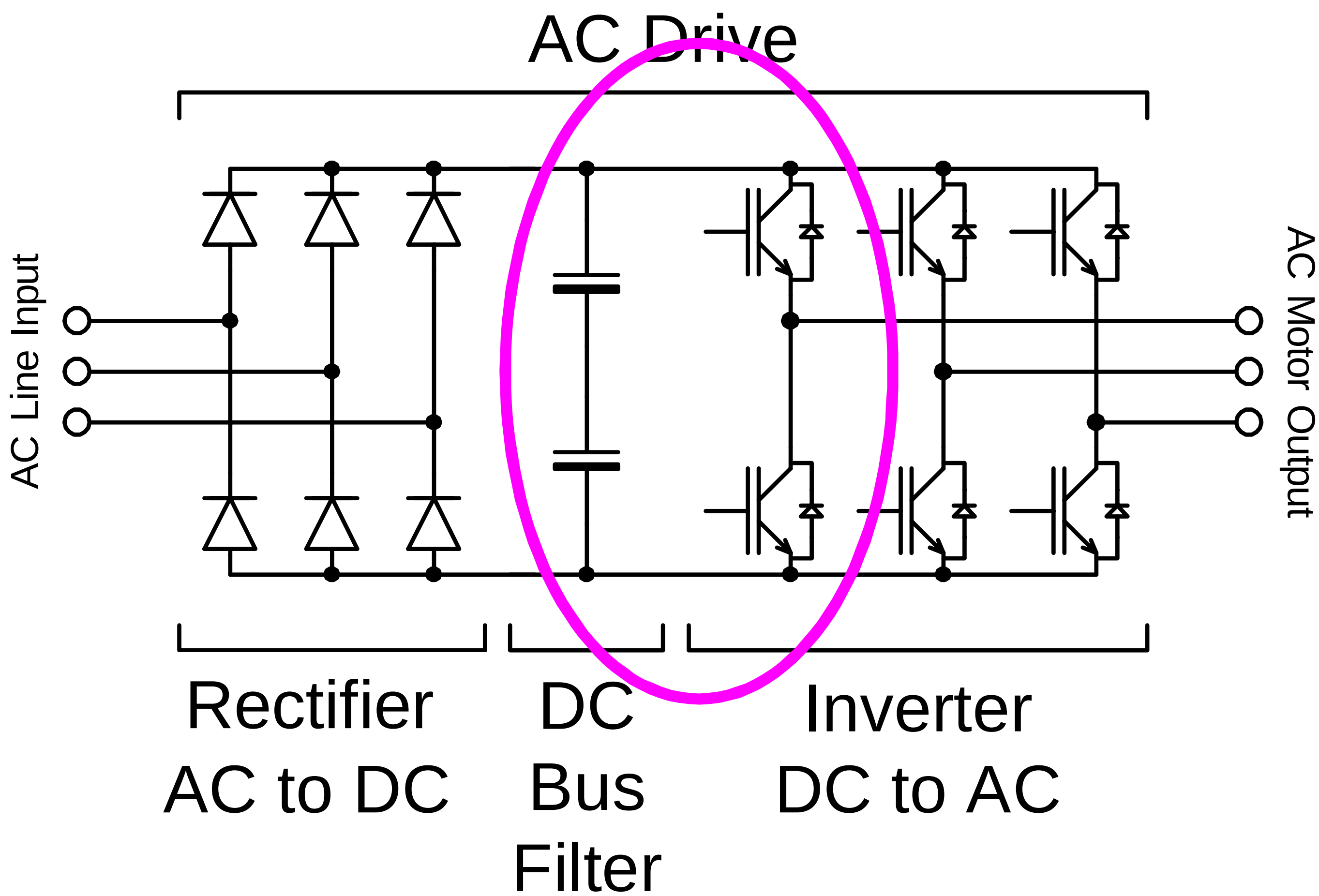
For motors intended for use in hazardous (classified) locations refer to 30.2.2.10.

ABB

Topologies

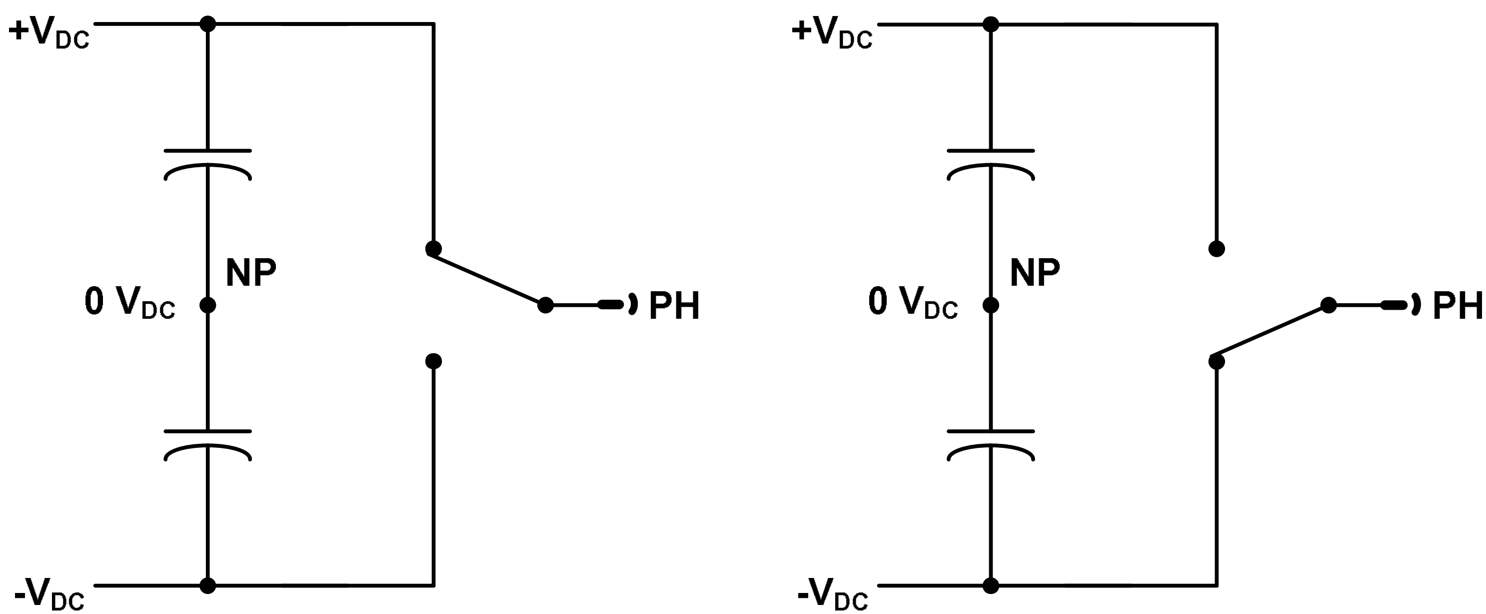
- Reflected Wave Reduction
  - 2-Level
  - 3-Level
  - 5-Level
  - Cascaded H-Bridge
- CSI, LCI
- CCV
- Matrix

Basic AC Drive Topology
2-Level Inverter Topology



The n-level VSI topology
2-Level

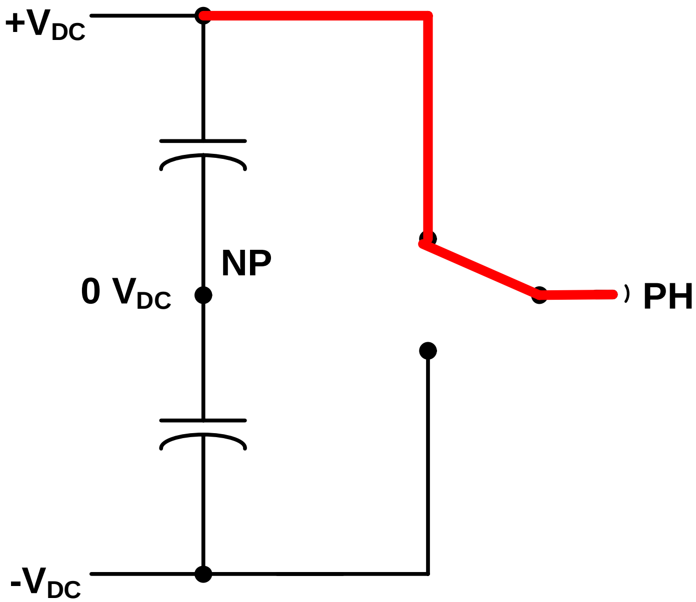
- 2-Level VSI
- Phase output voltages

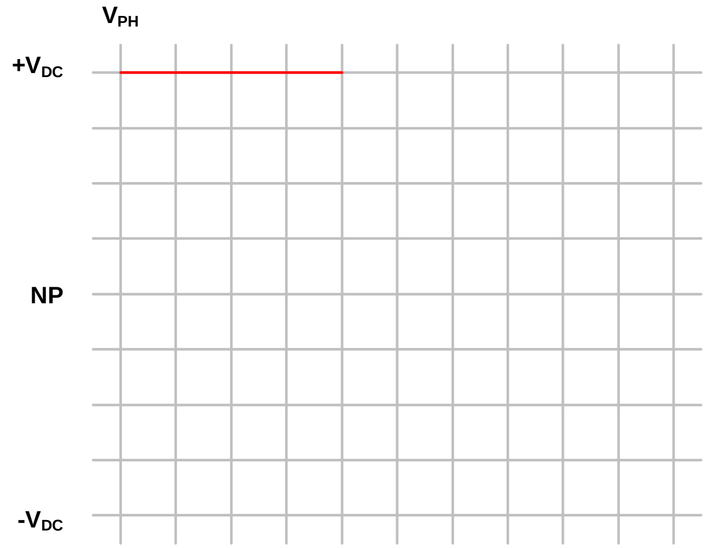


ABB

The n-level VSI topology
2-Level

- 2-Level VSI
- Phase output voltages

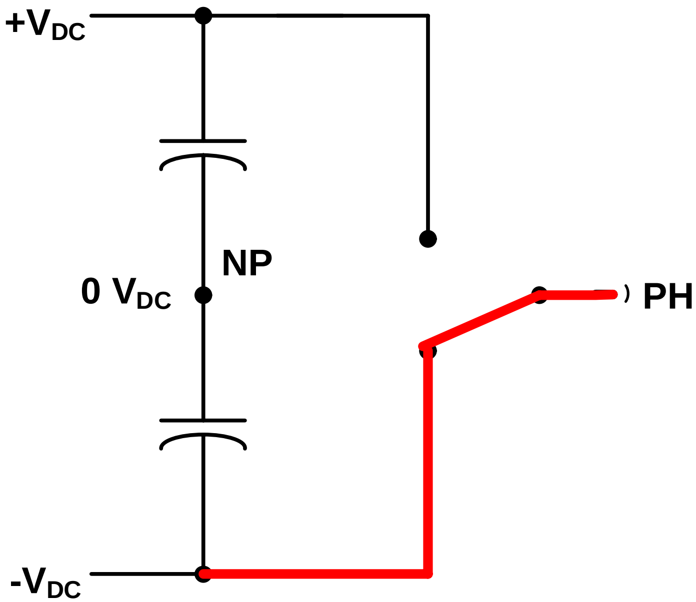


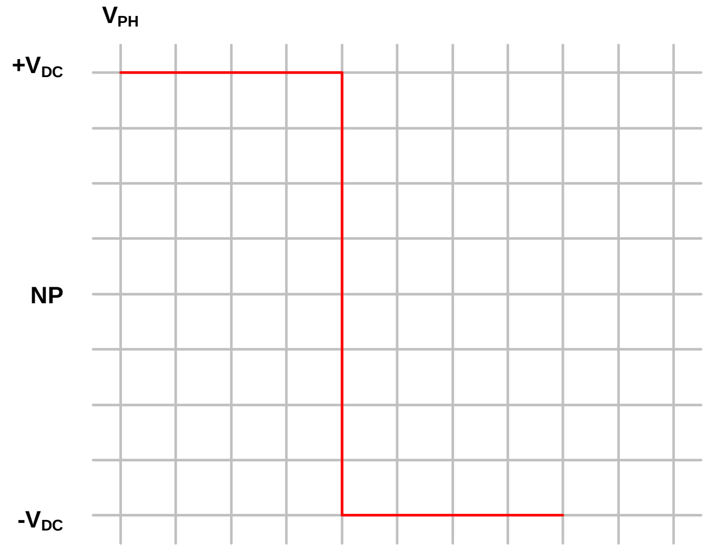


ABB

The n-level VSI topology
2-Level

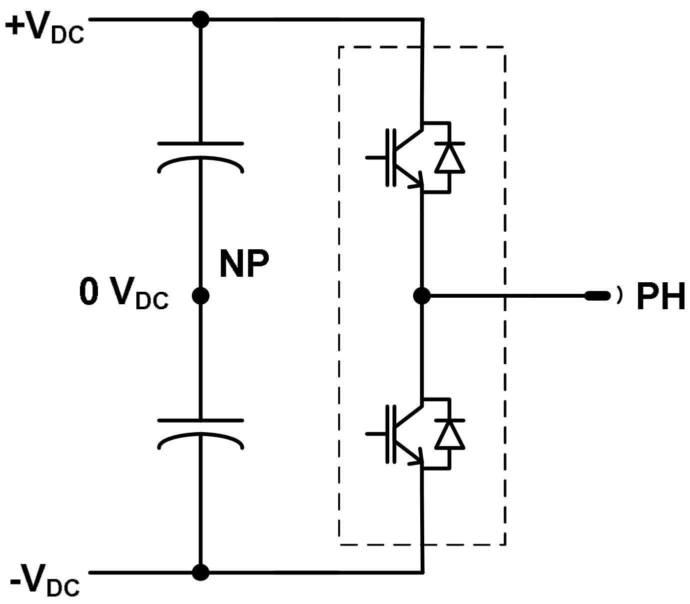
- 2-Level VSI
- Phase output voltages





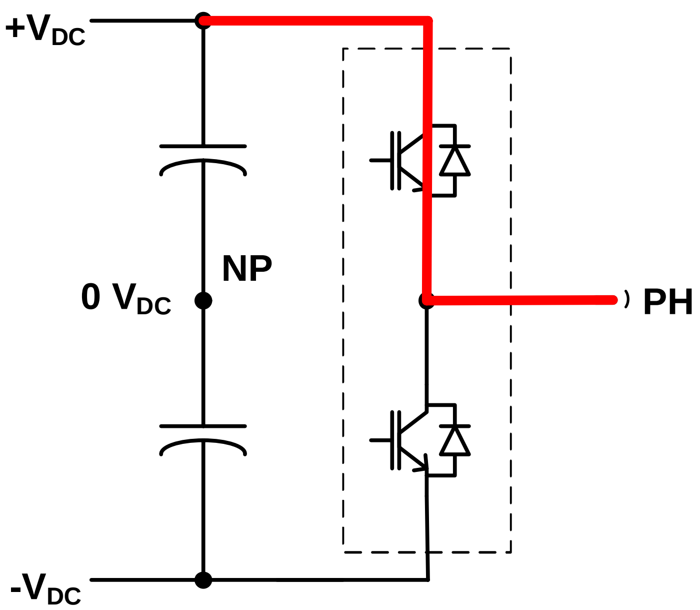
The n-level VSI topology
2-Level

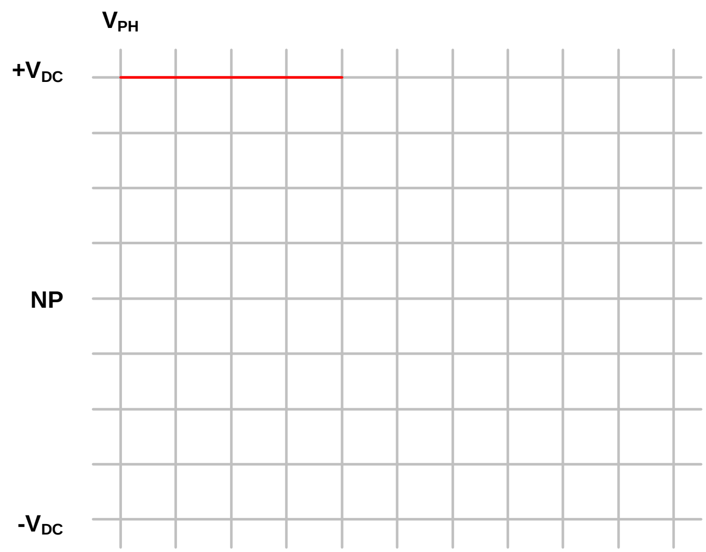
- 2-Level VSI
- Phase output voltages



The n-level VSI topology
2-Level

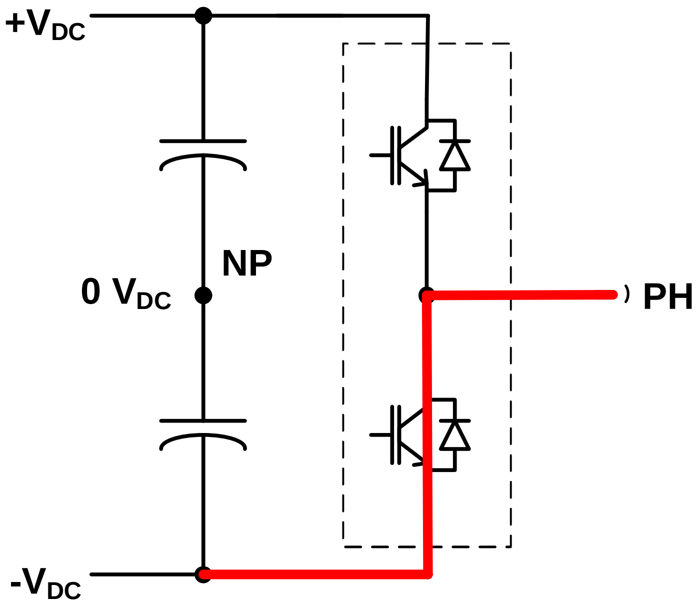
- 2-Level VSI
- Phase output voltages

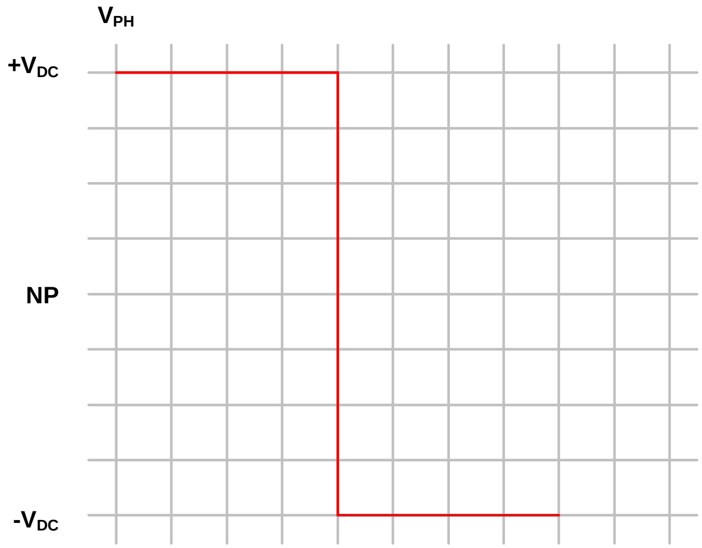




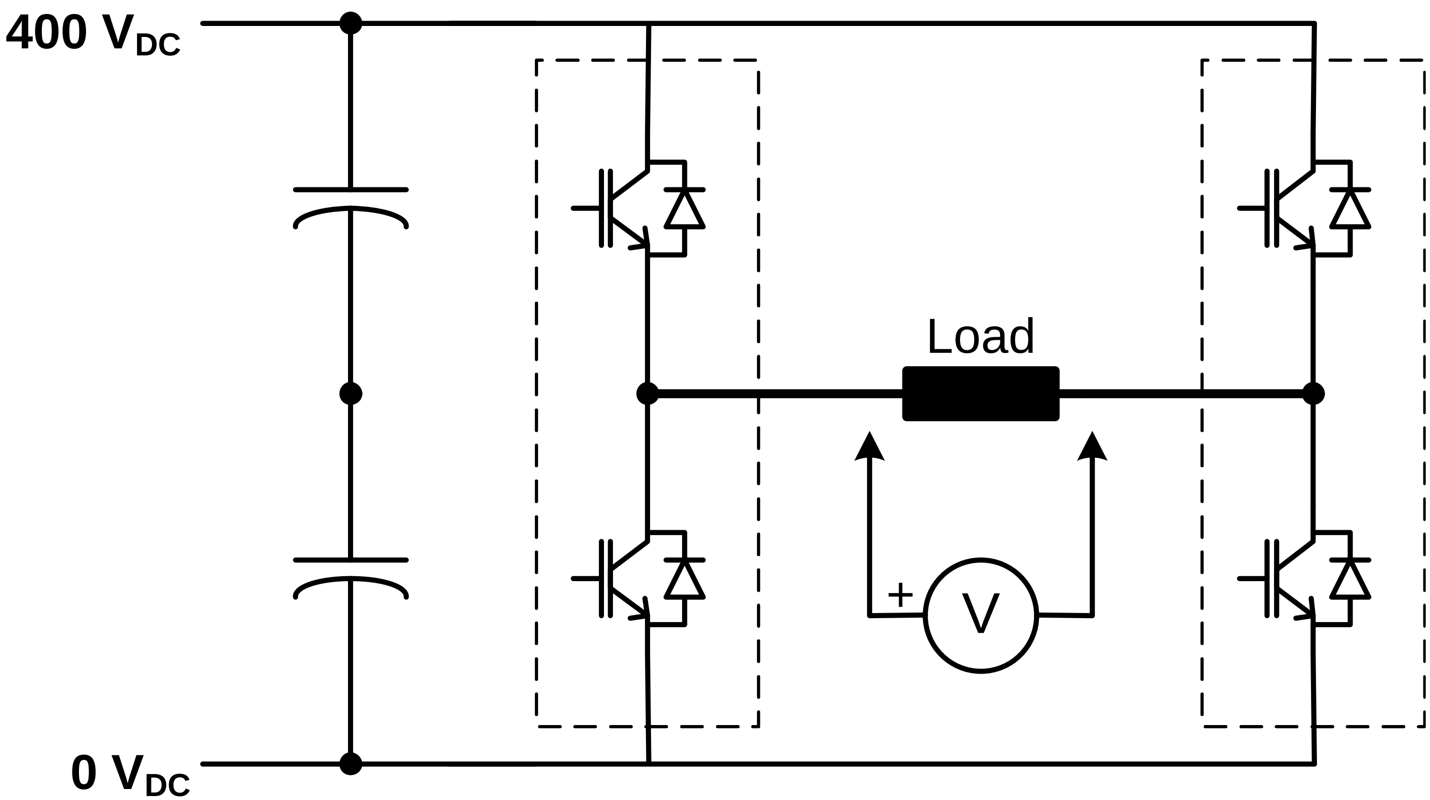
The n-level VSI topology
2-Level

- 2-Level VSI
- Phase output voltages

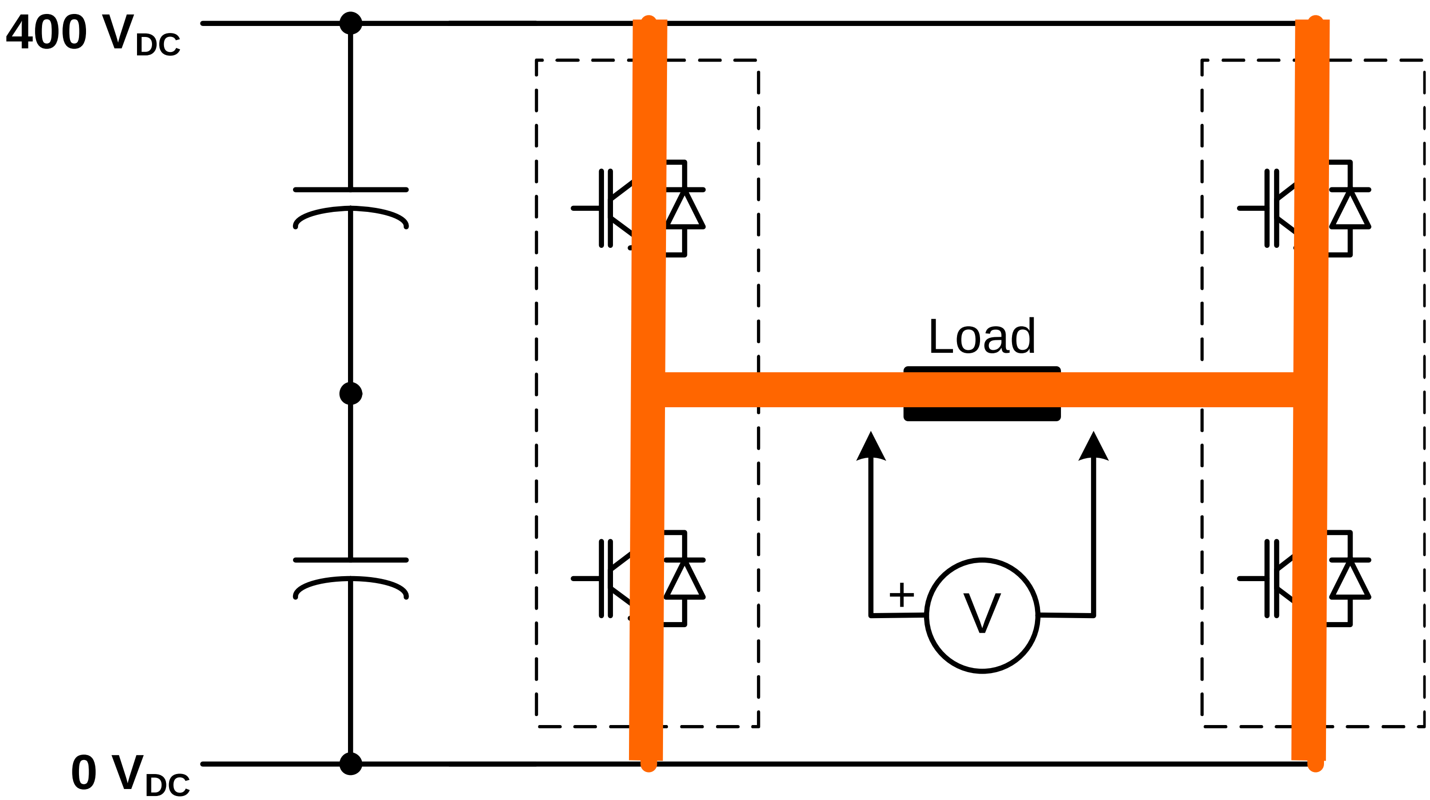




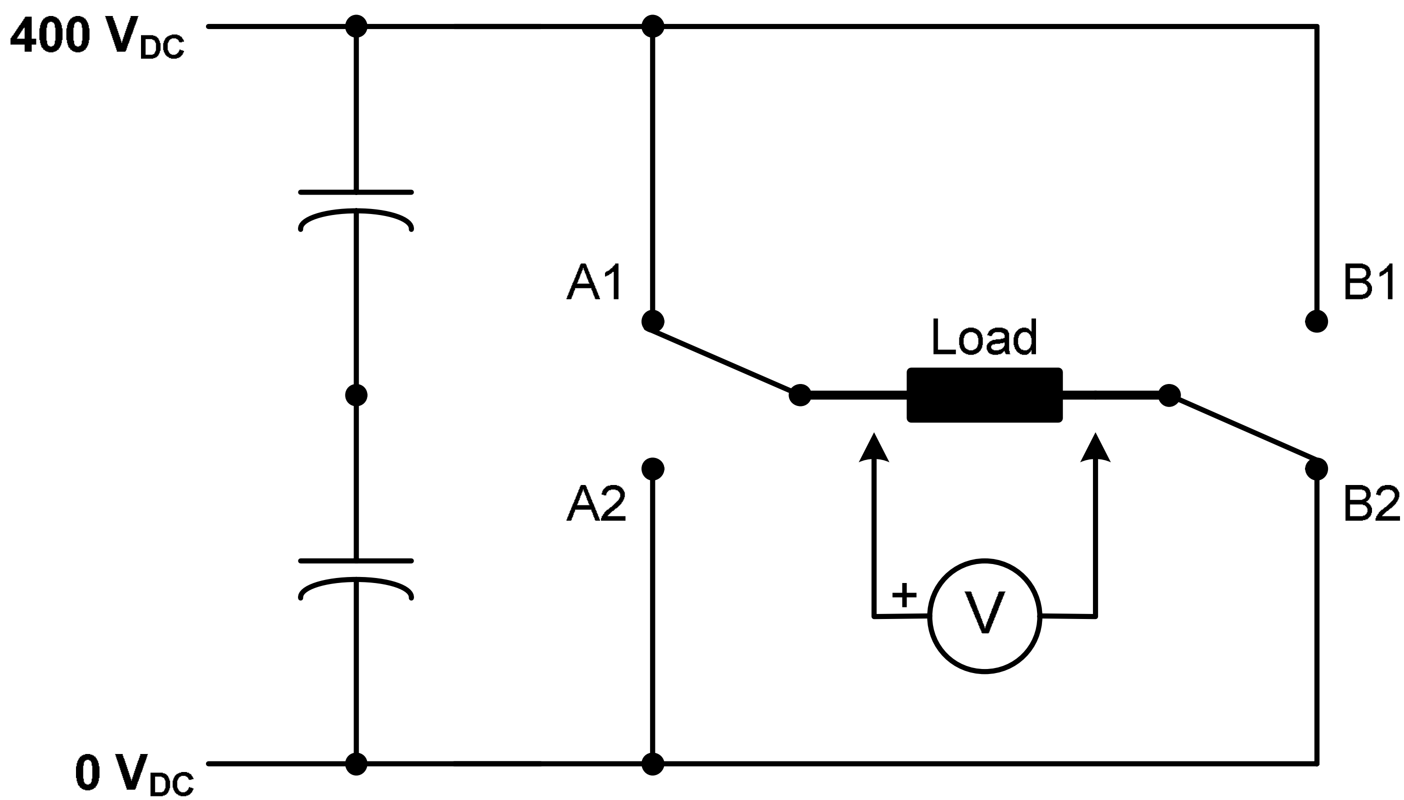
The n-level VSI topology
H-Bridge



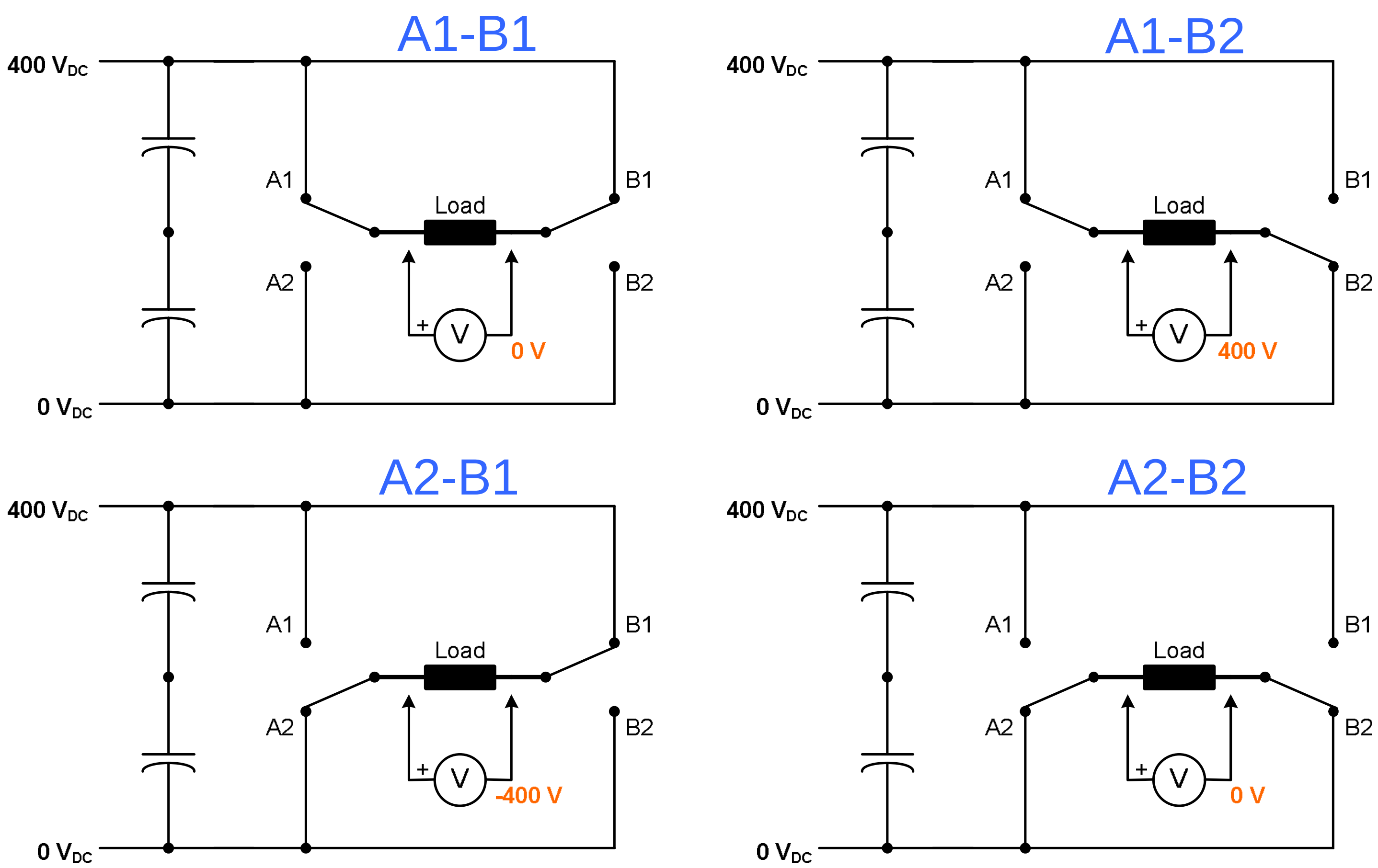
The n-level VSI topology
H-Bridge



The n-level VSI topology
H-Bridge



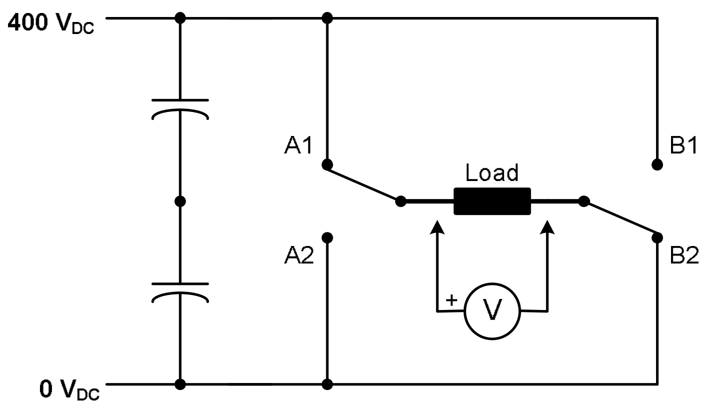
The n-level VSI topology
H-Bridge

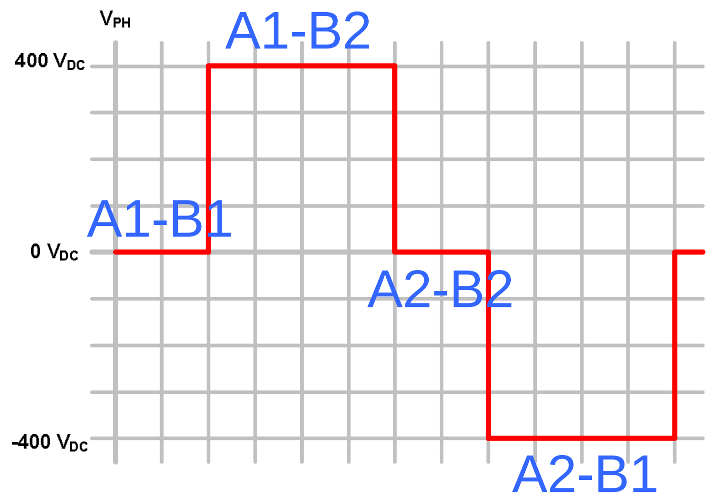


The n-level VSI topology
H-Bridge

- 2-Level VSI
- Phase output voltages

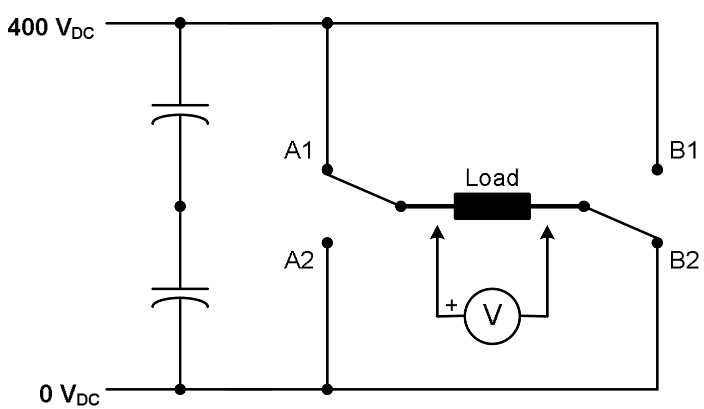
	B1	B2
A1	0	400
A2	-400	0





The n-level VSI topology
H-Bridge

- 2-Level VSI
- Phase output voltages



	B1	B2
A1	0	400
A2	-400	0

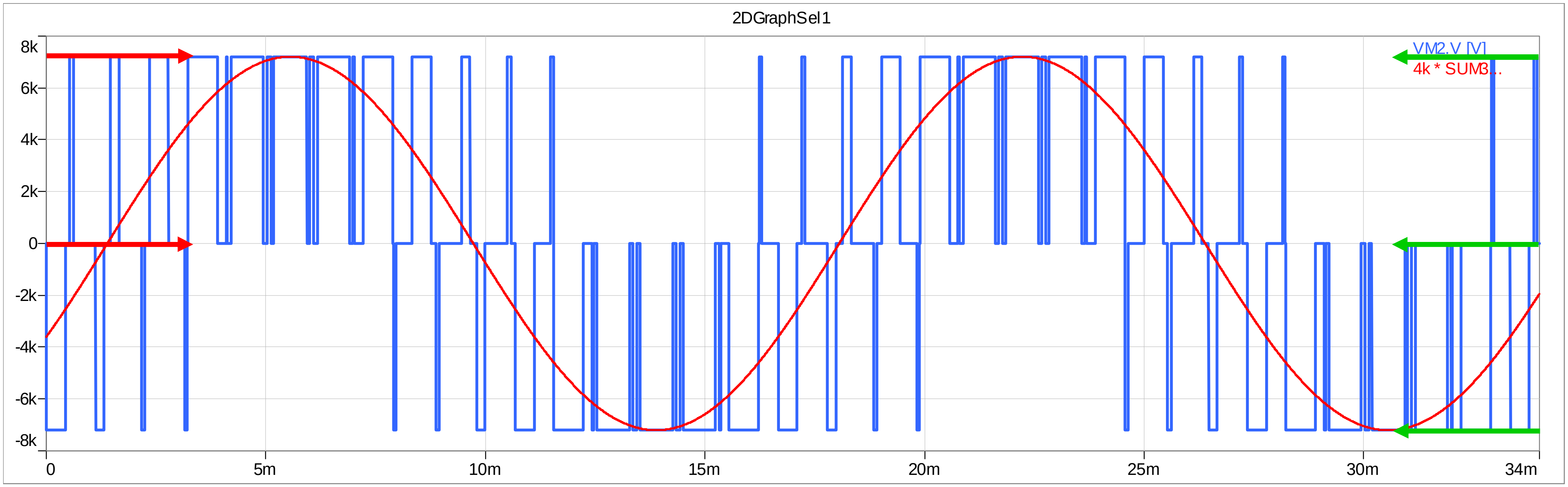
Number of Levels, n

2

Number of Voltage steps, line-to-line, 2n-1

3

2-Level Waveform, Line-to-Line

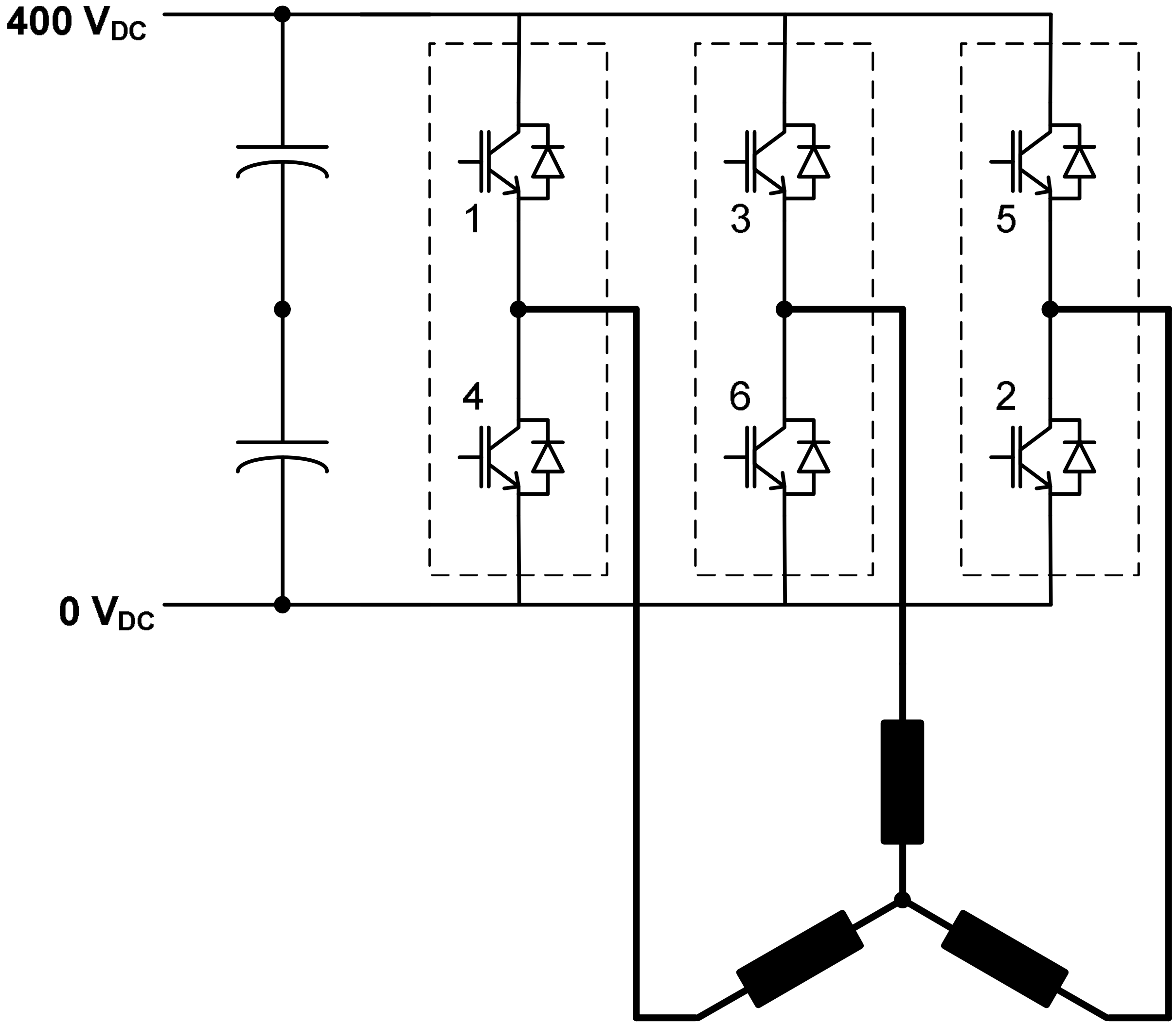


2-Levels

3-Steps

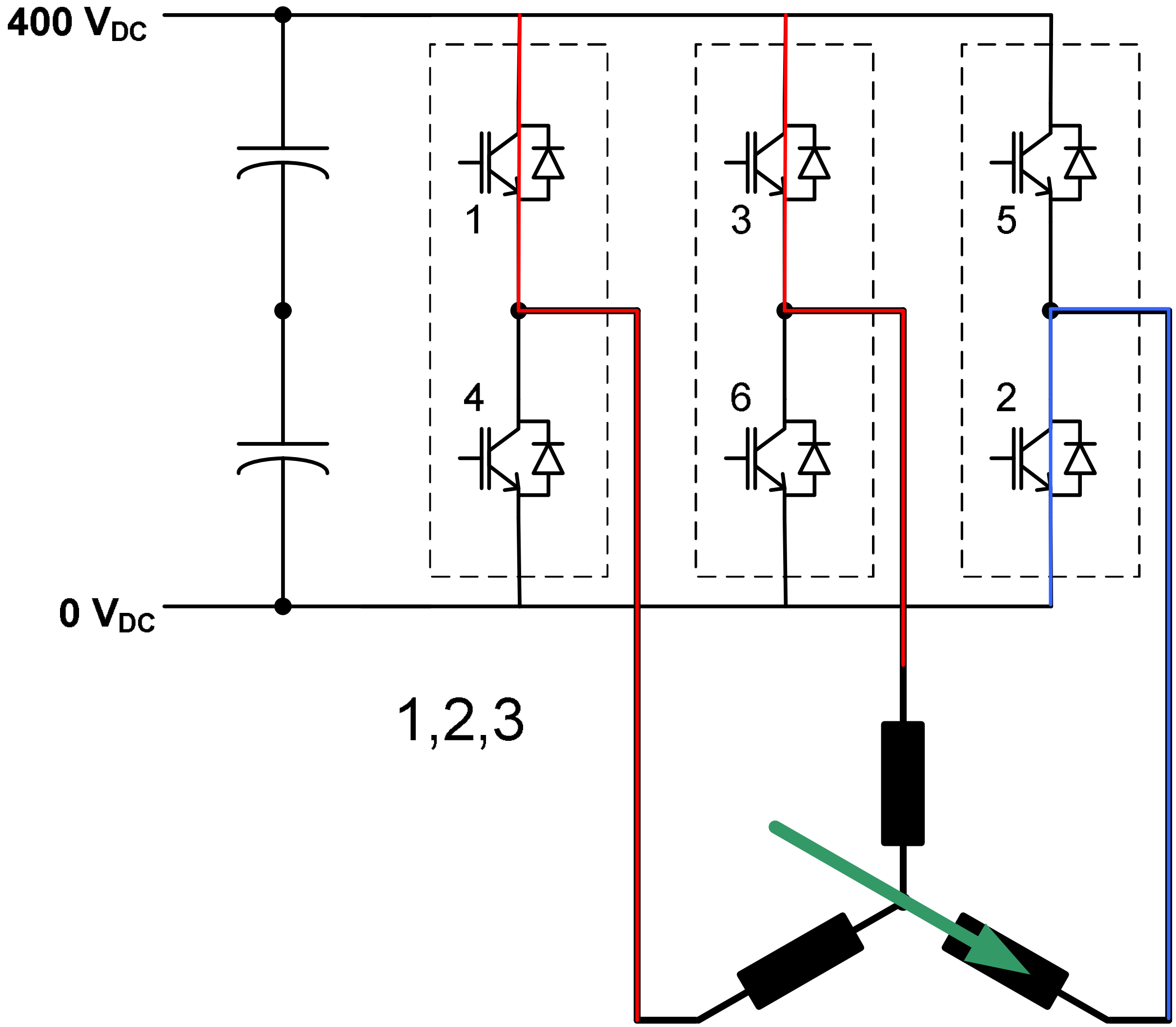
Basic Inverter
2-Level

3 Phase Bridge Configuration



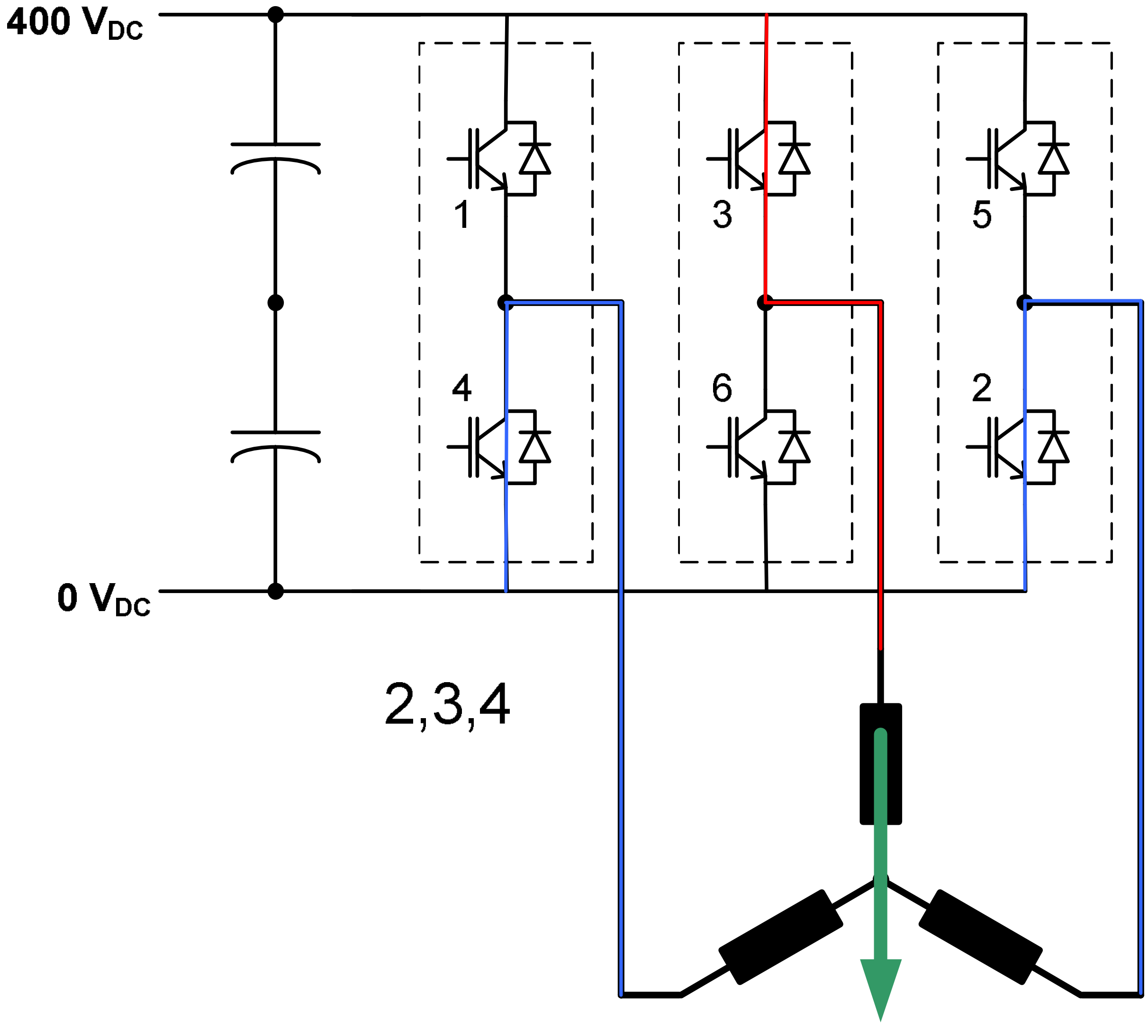
Basic Inverter
2-Level

3 Phase Bridge Configuration



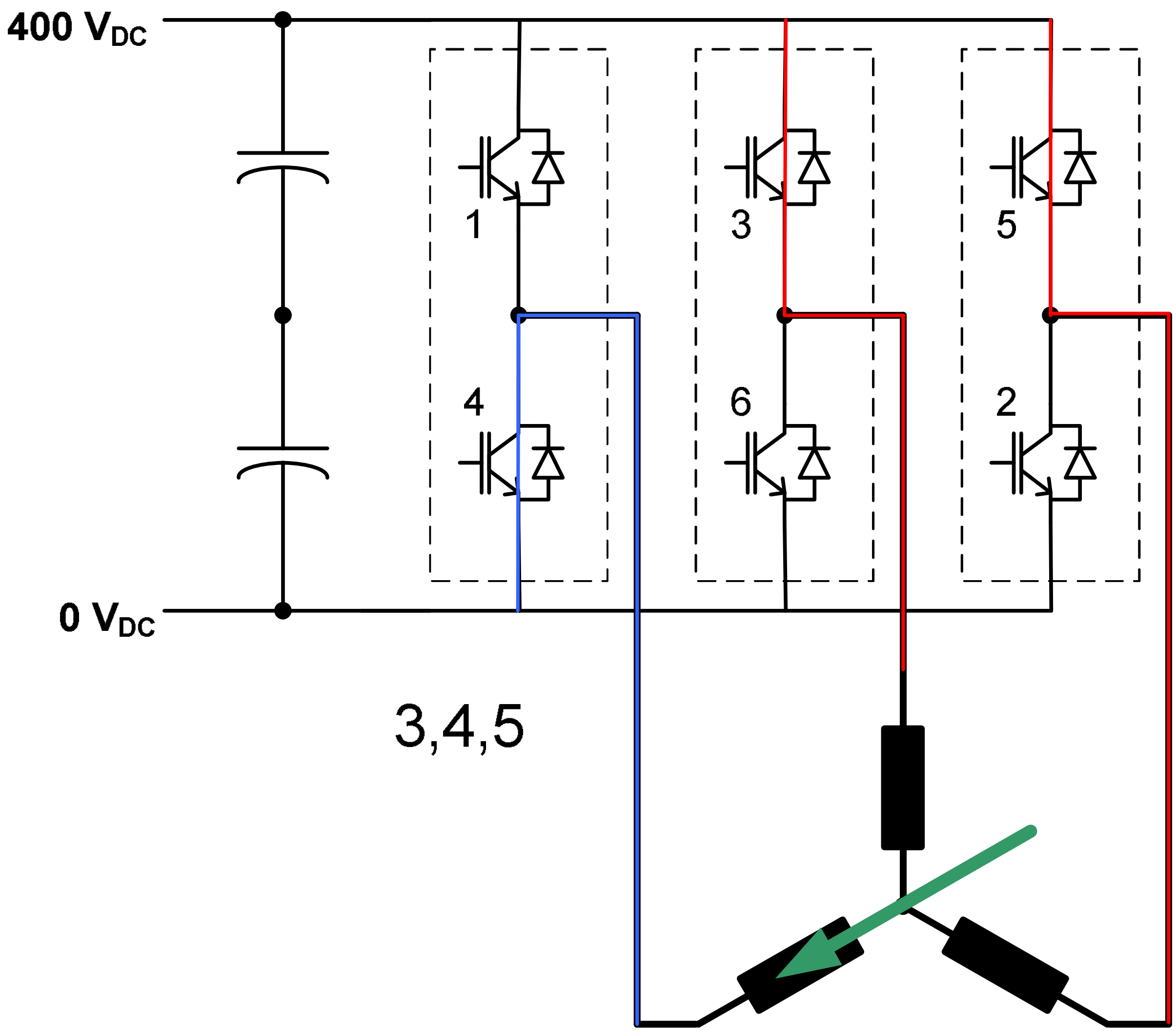
Basic Inverter
2-Level

3 Phase Bridge Configuration



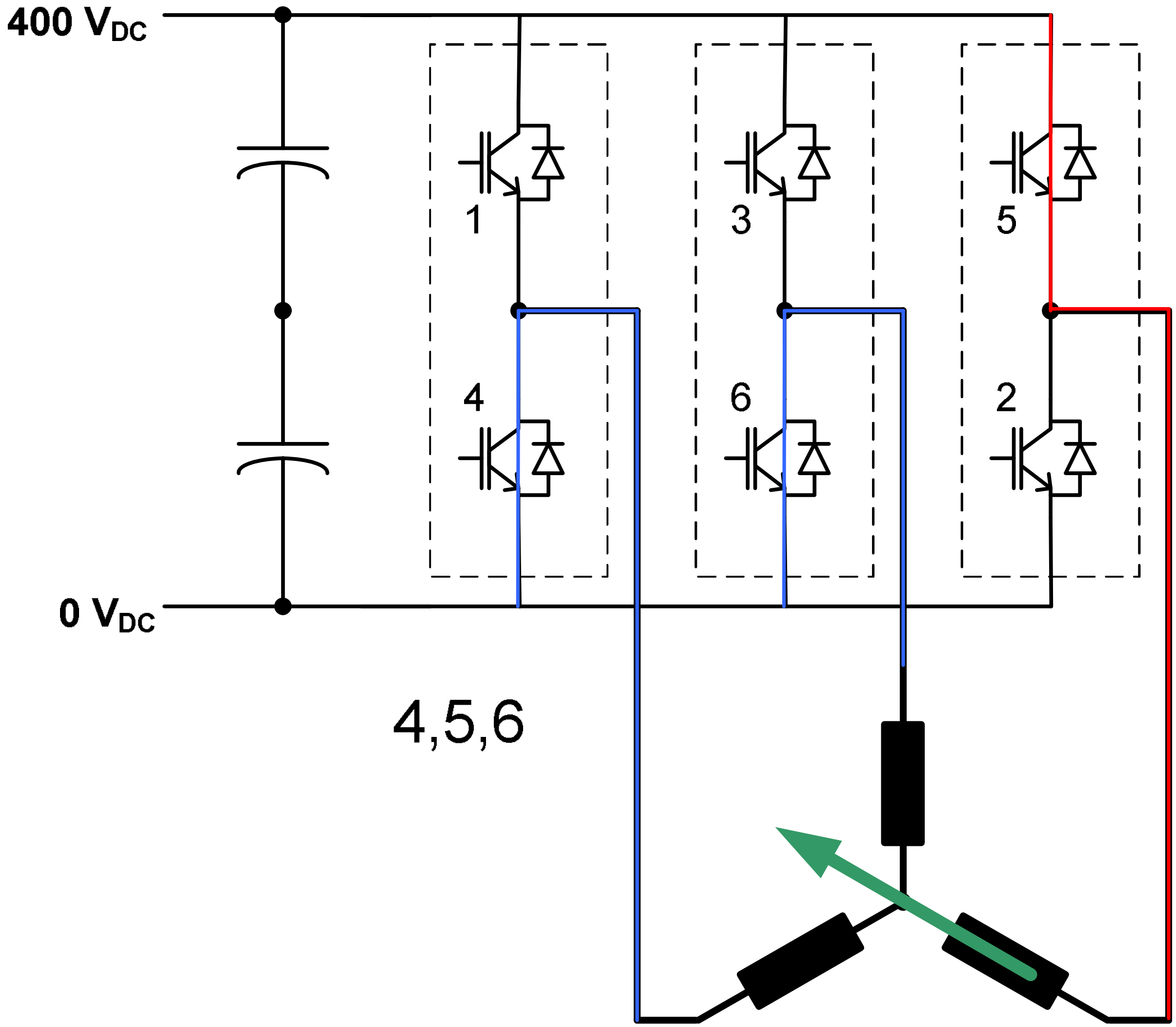
Basic Inverter
2-Level

3 Phase Bridge Configuration



Basic Inverter
2-Level

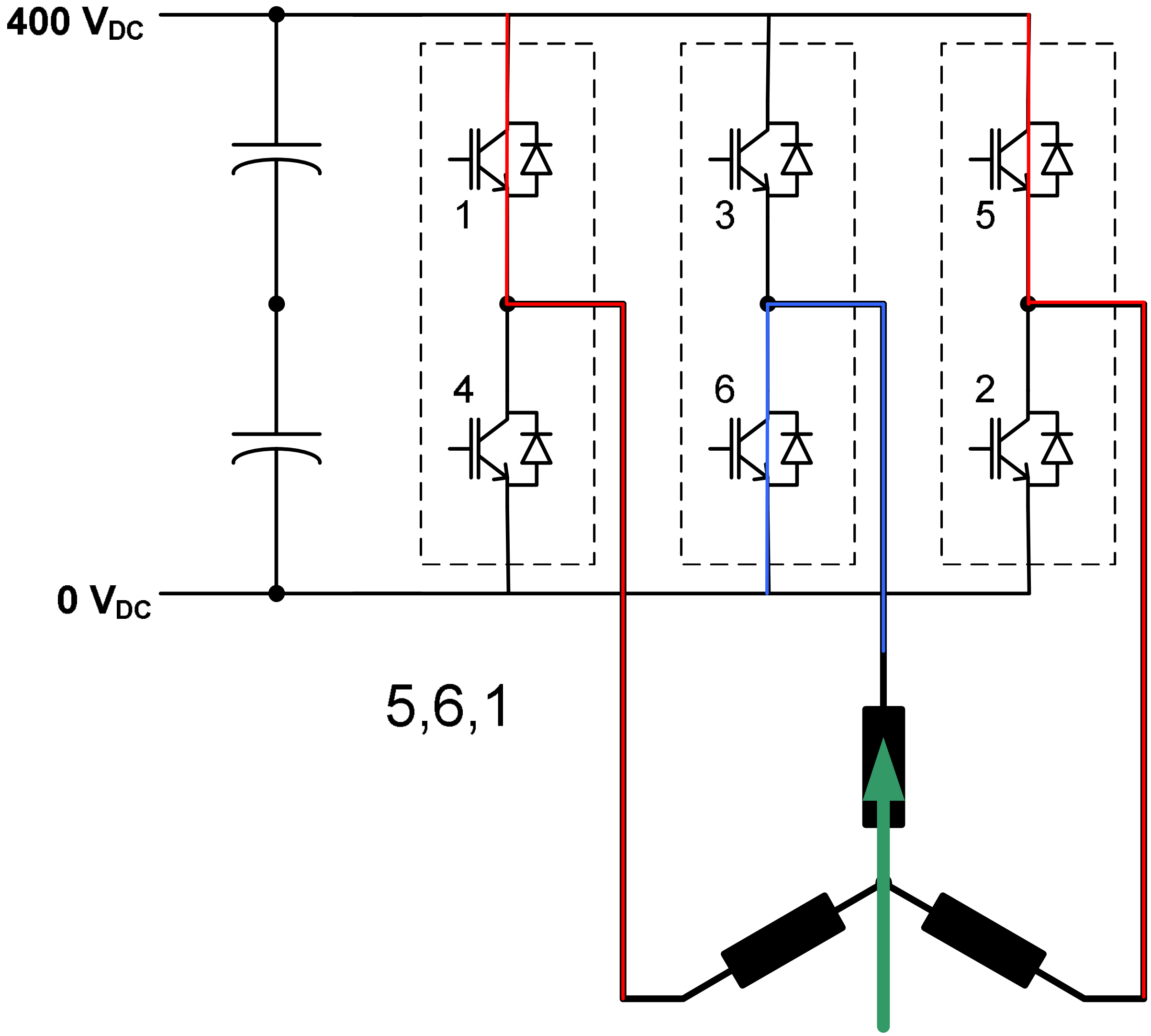
3 Phase Bridge Configuration



ABB

Basic Inverter
2-Level

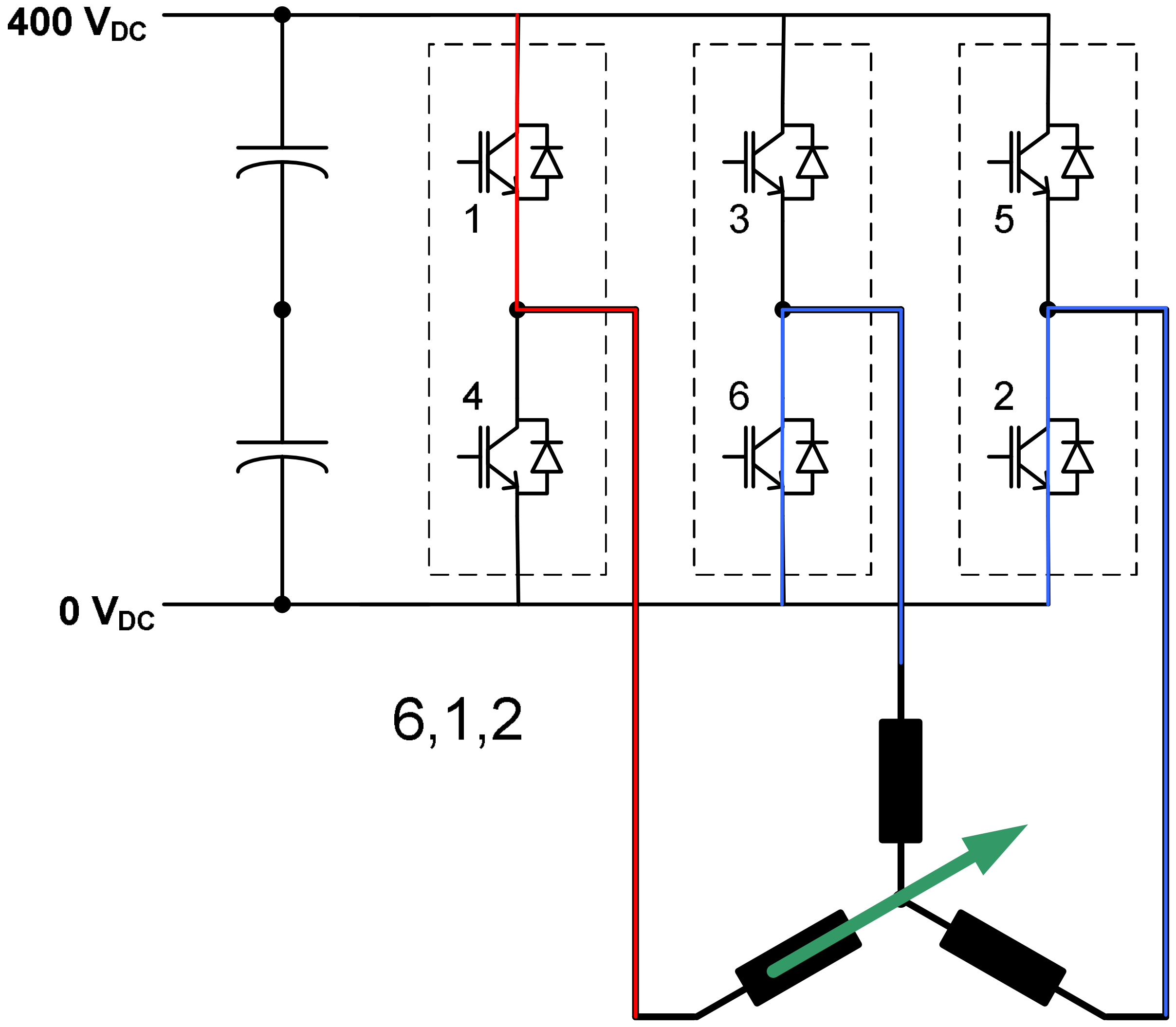
3 Phase Bridge Configuration



ABB

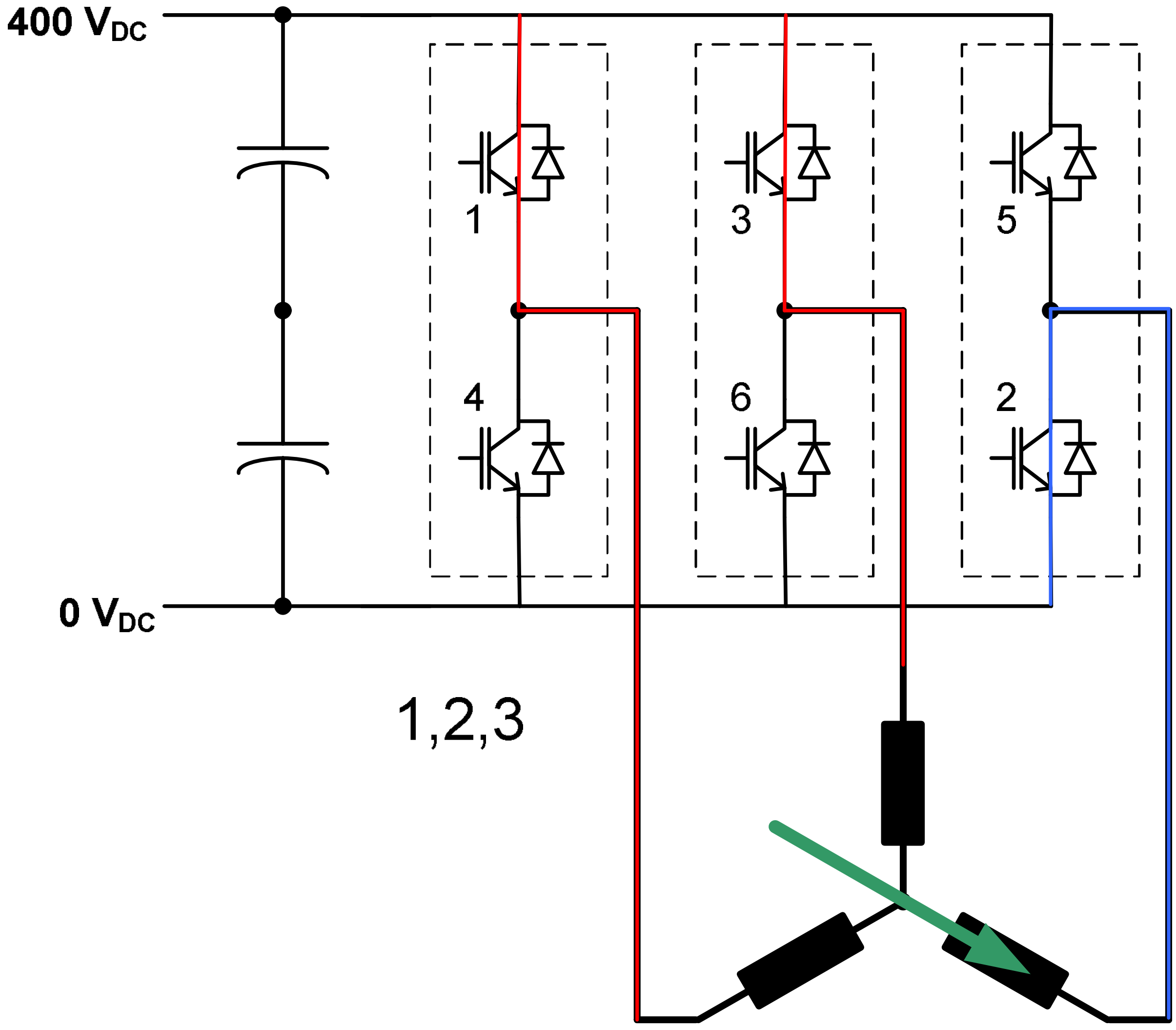
Basic Inverter
2-Level

3 Phase Bridge Configuration



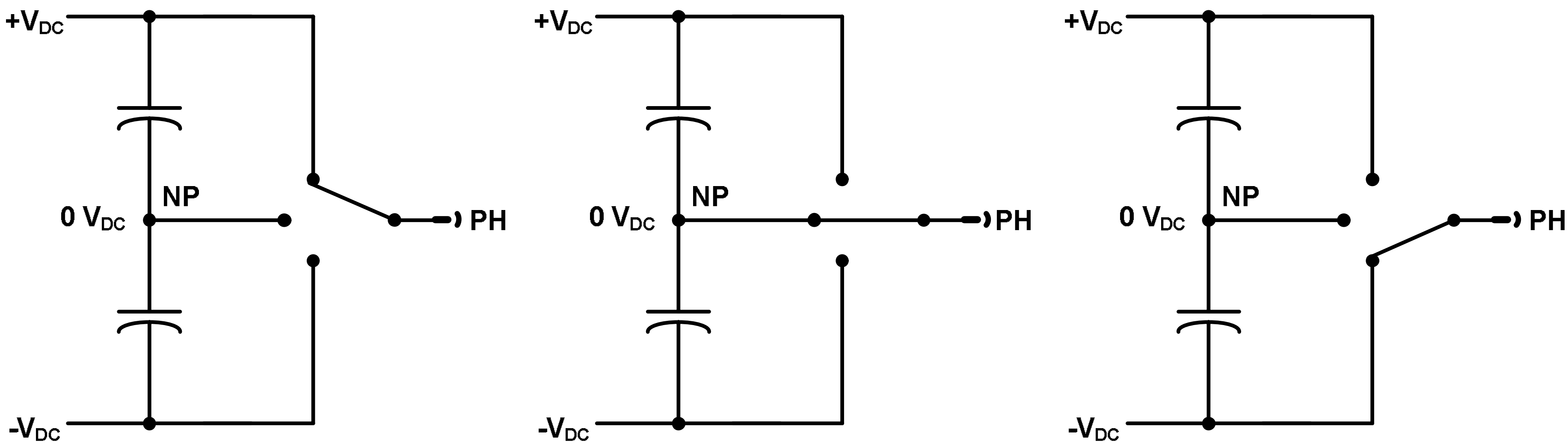
Basic Inverter
2-Level

3 Phase Bridge Configuration



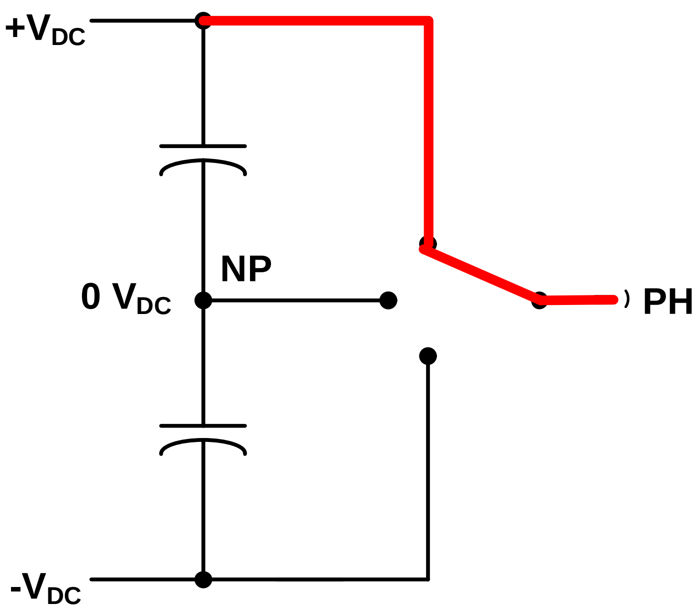
The n-level VSI topology
3-Level

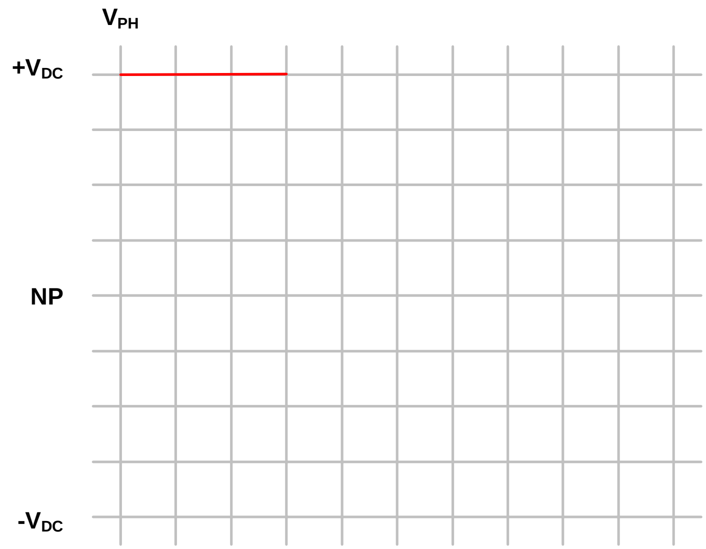
- 3-Level NPC VSI
- Phase output voltages



The n-level VSI topology
3-Level

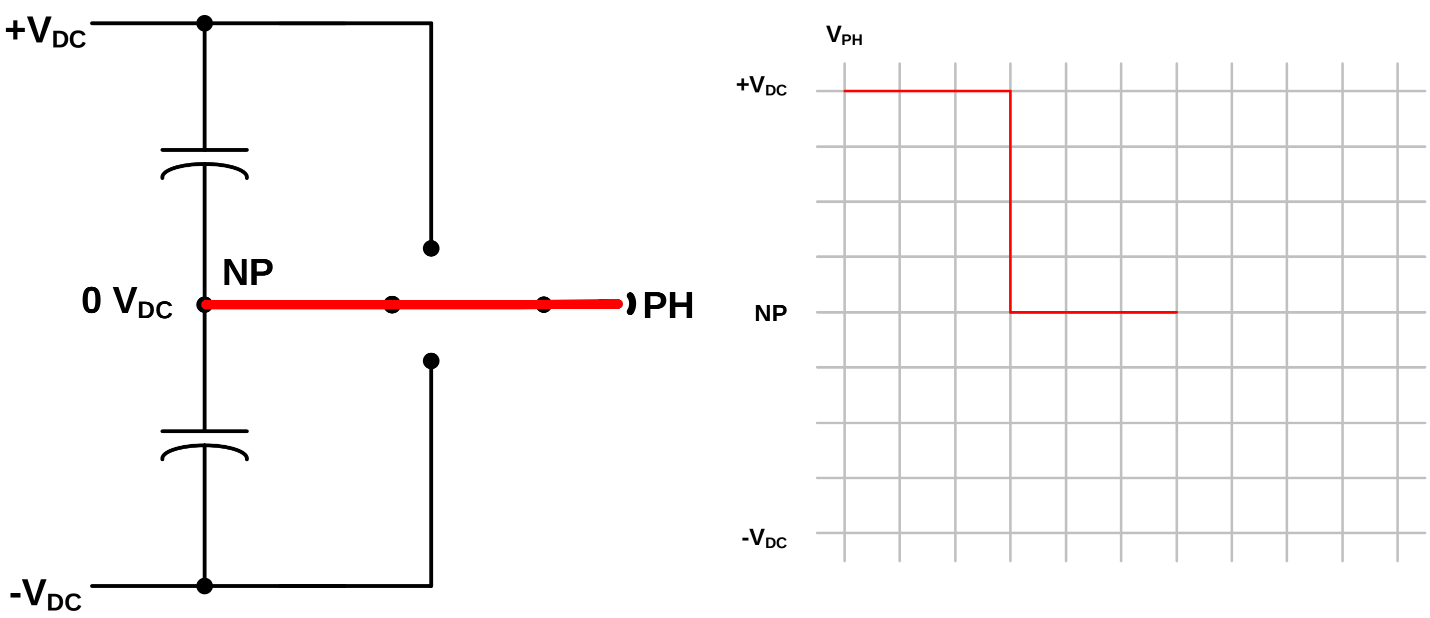
- 3-Level NPC VSI
- Phase output voltages





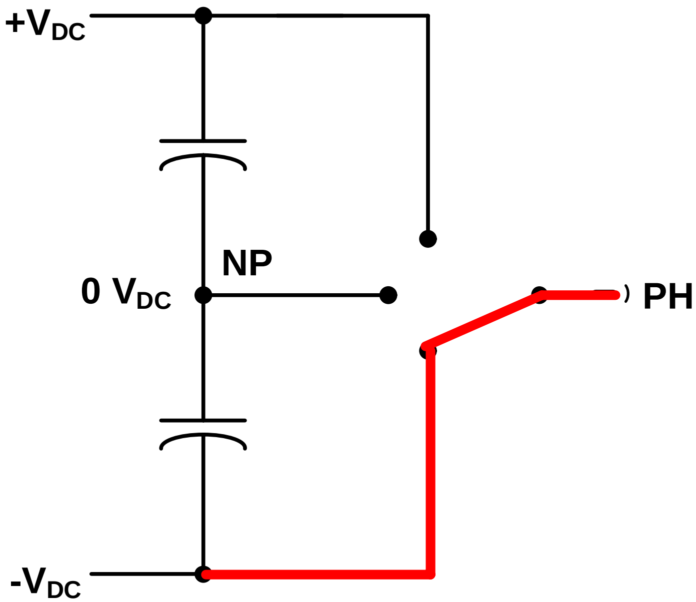
The n-level VSI topology
3-Level

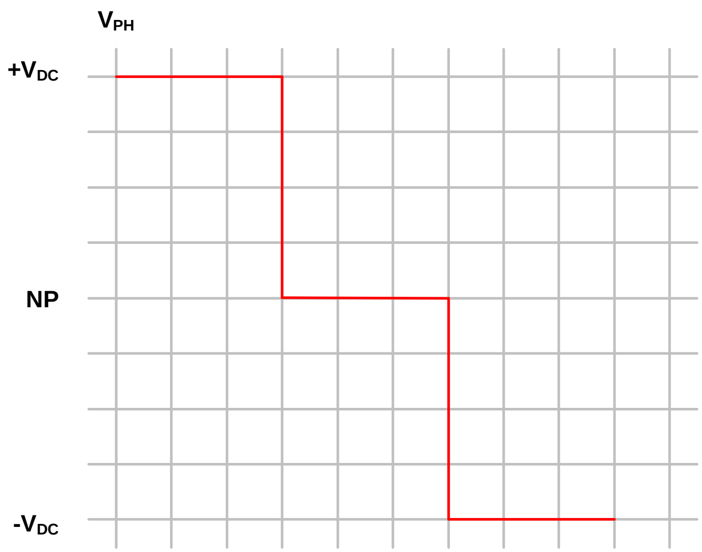
- 3-Level NPC VSI
- Phase output voltages



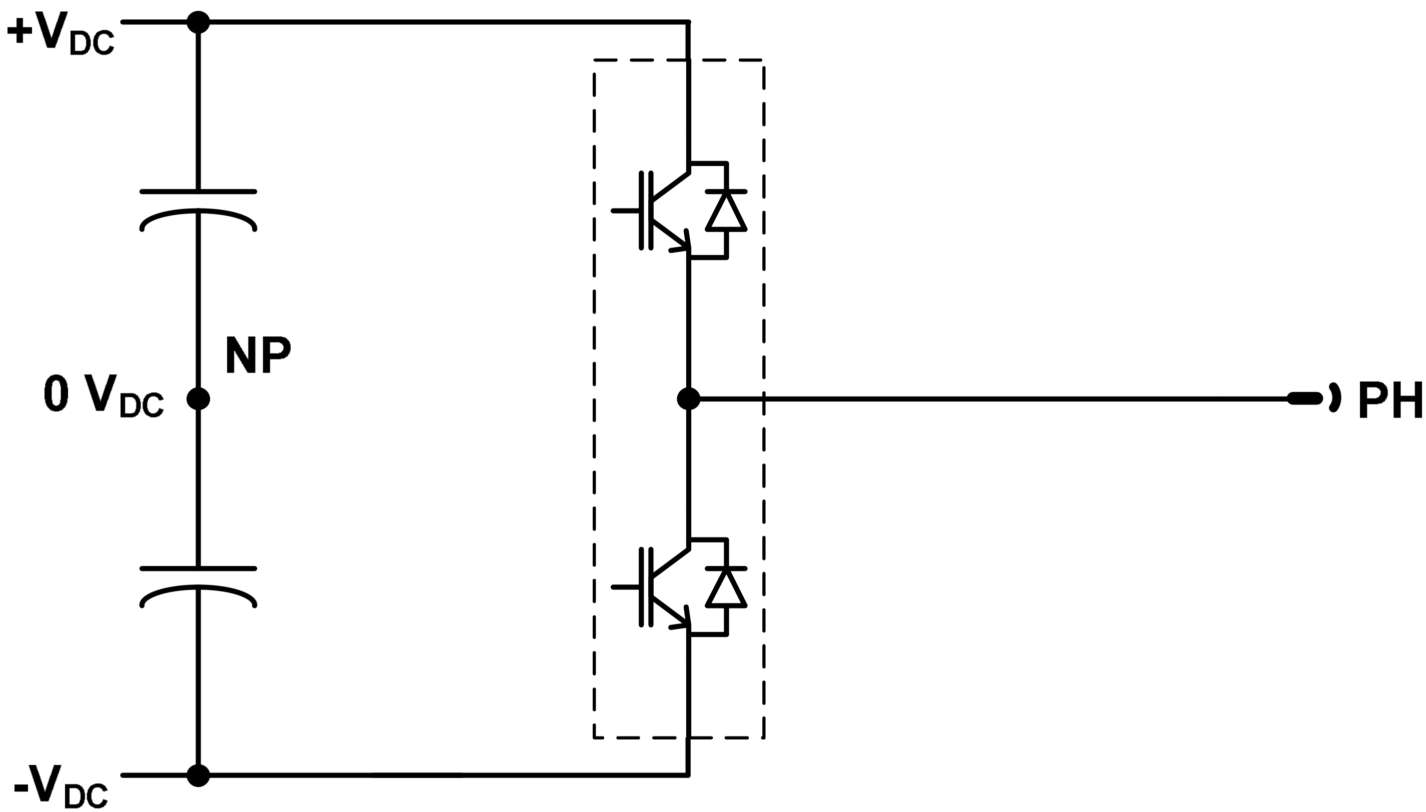
The n-level VSI topology
3-Level

- 3-Level NPC VSI
- Phase output voltages



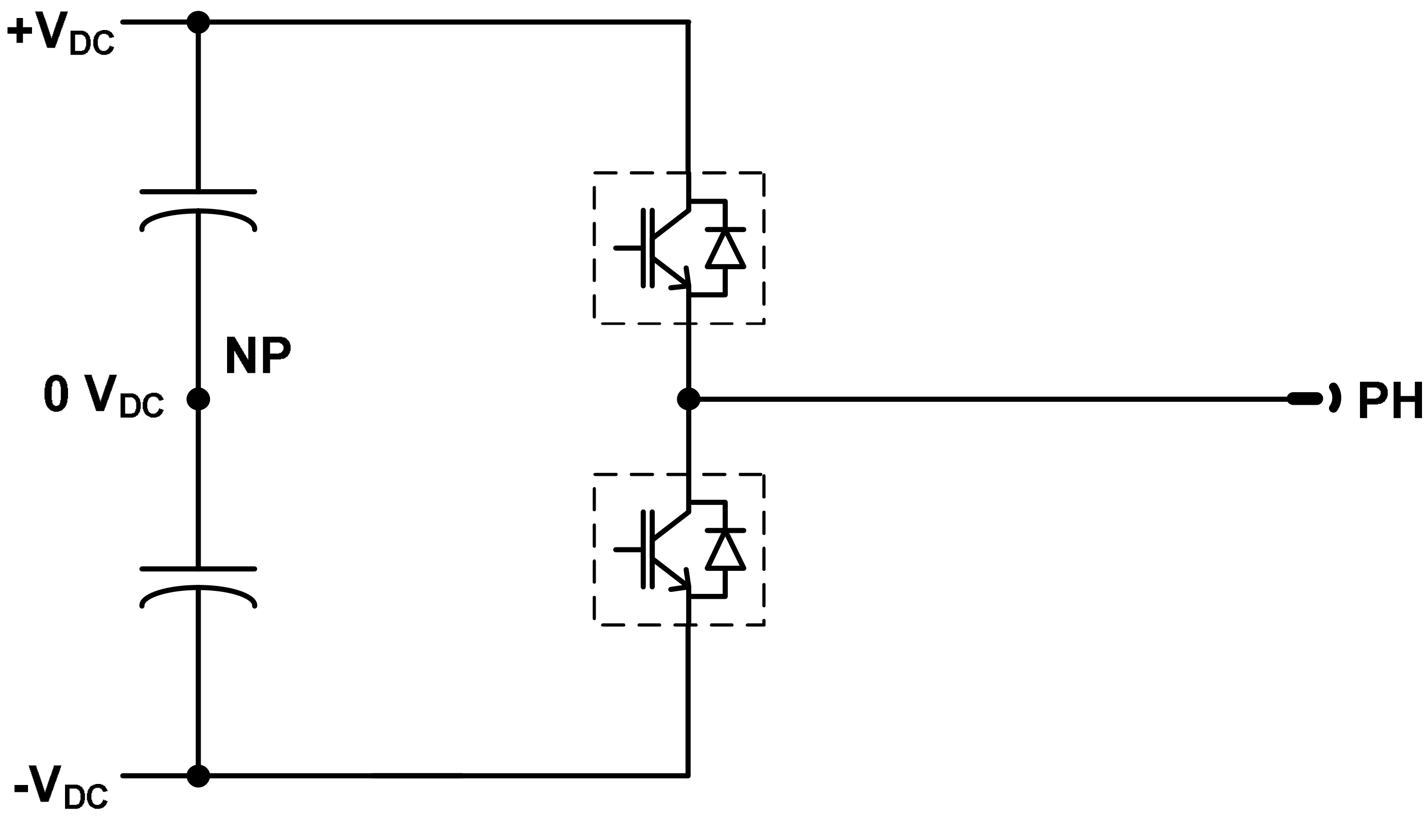


The n-level VSI topology
Going from 2-Level to 3-Level



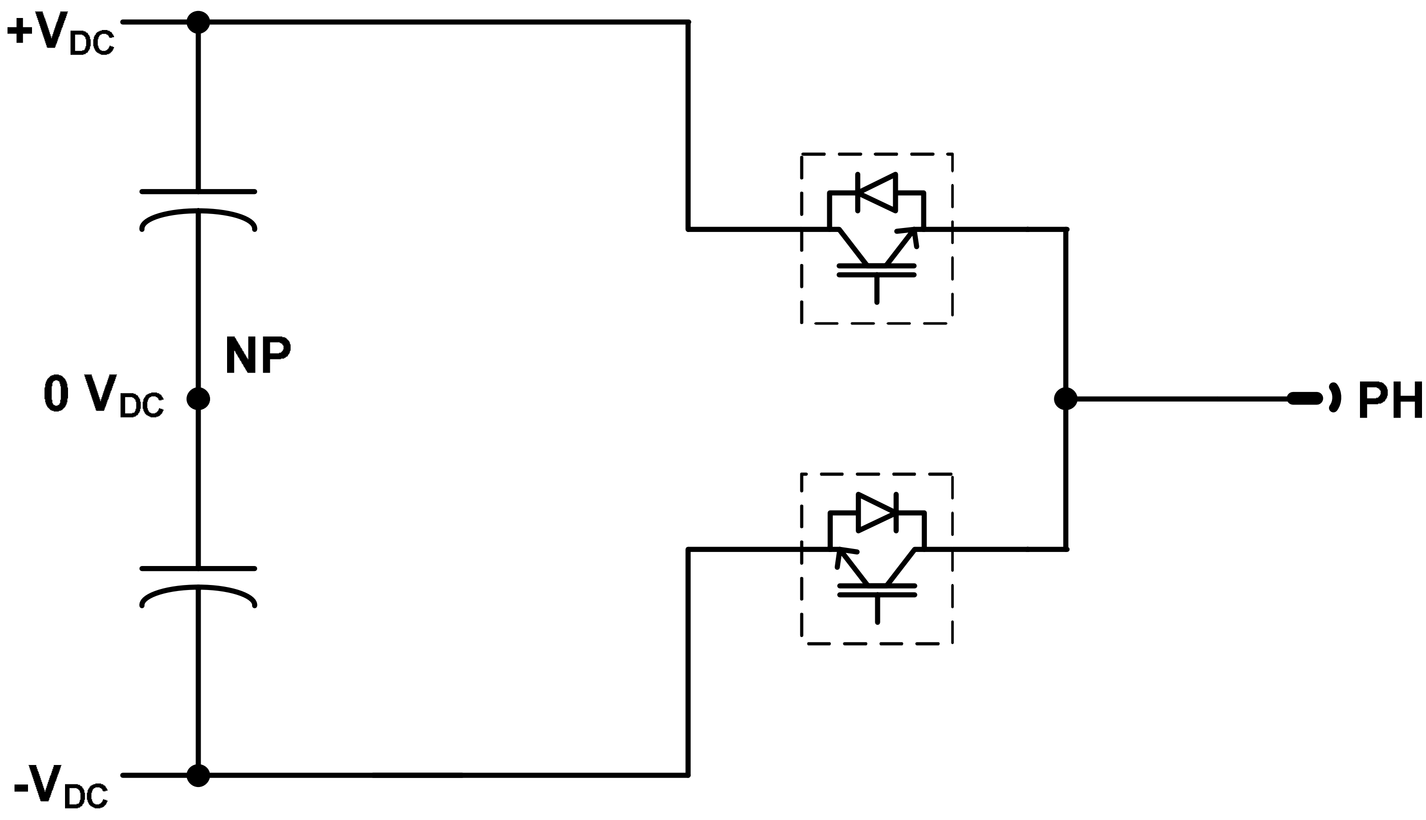
ABB

The n-level VSI topology
Going from 2-Level to 3-Level

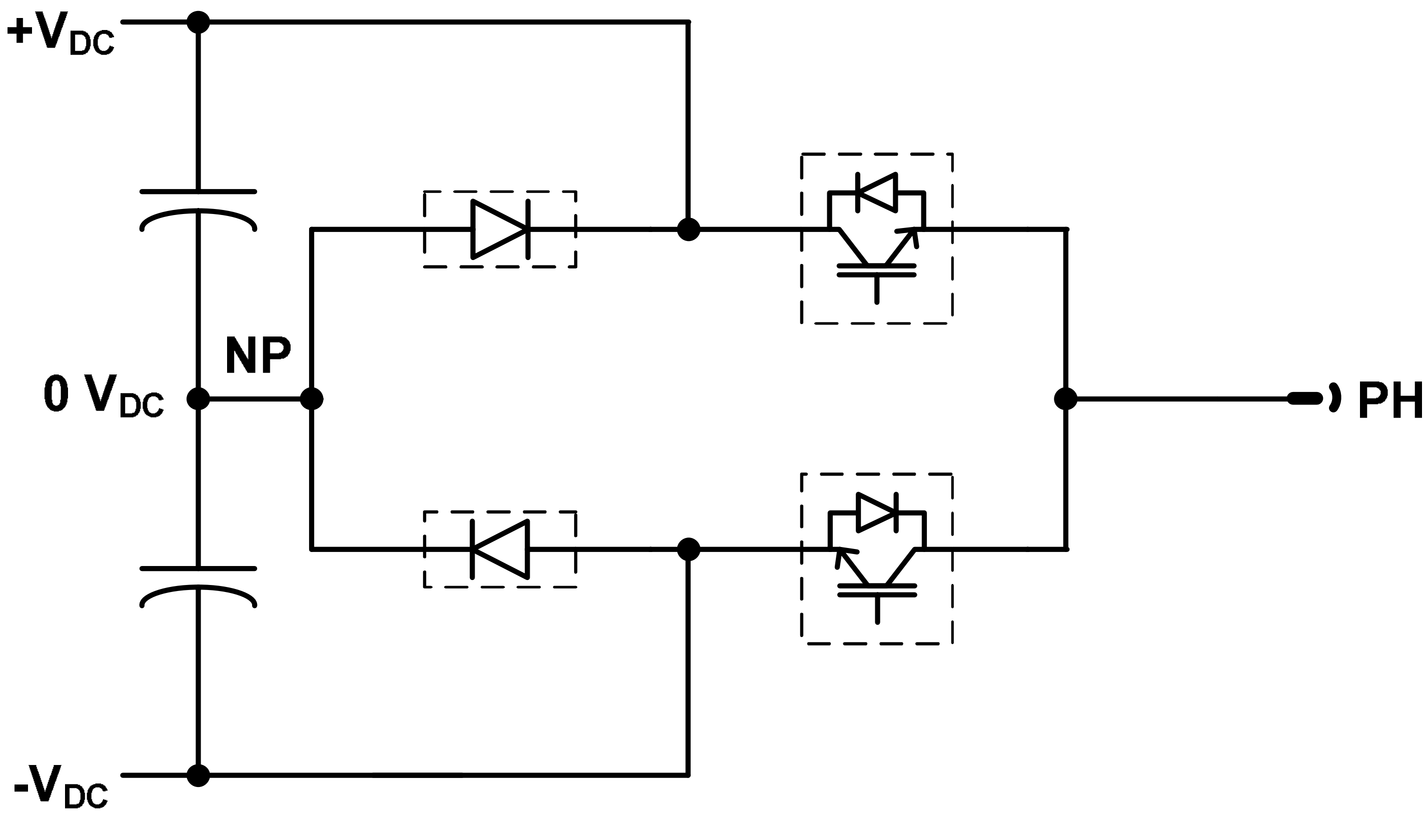


The n-level VSI topology

Going from 2-Level to 3-Level

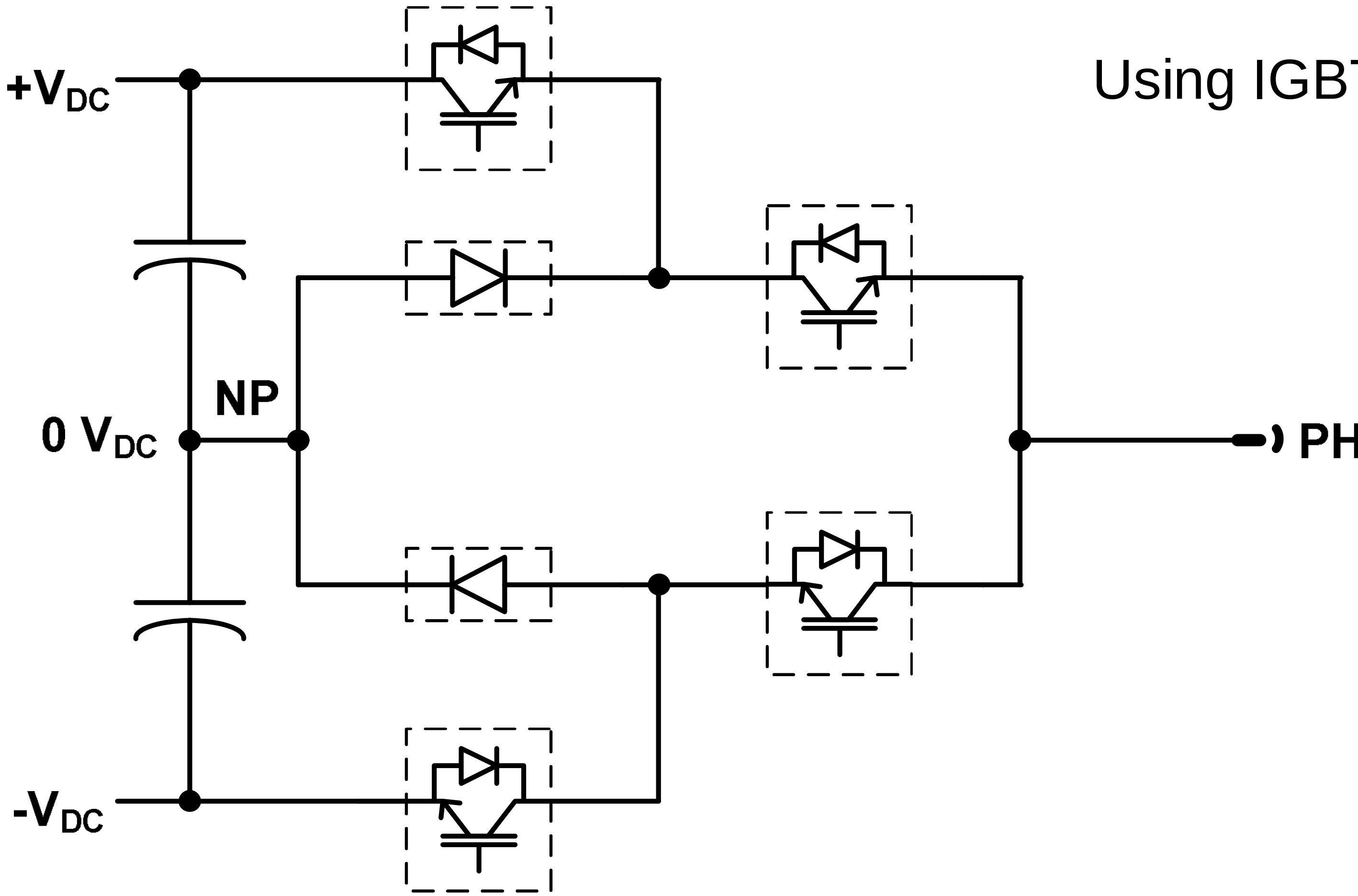


The n-level VSI topology
Going from 2-Level to 3-Level



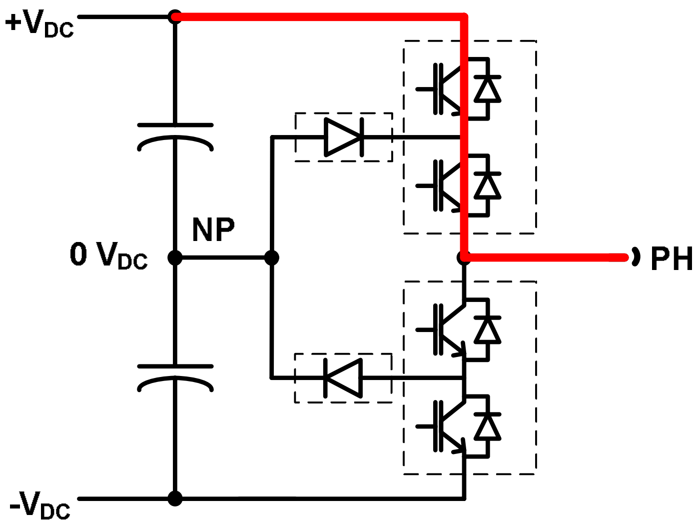
The n-level VSI topology
3-Level

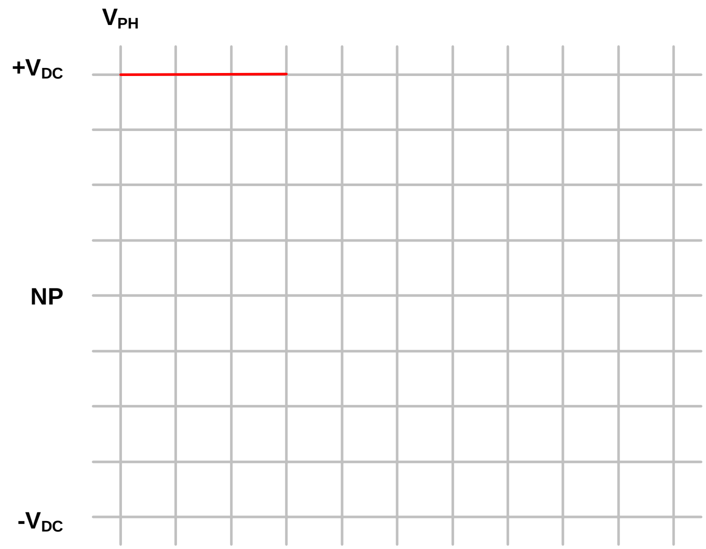
Using IGBTs



The n-level VSI topology
3-Level

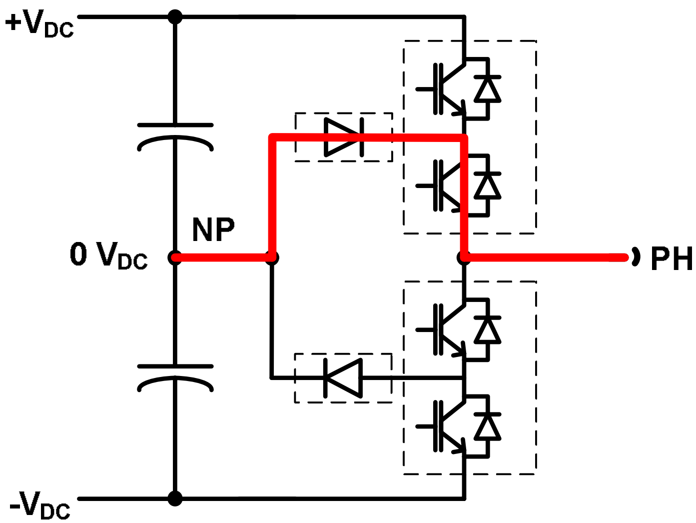
- 3-Level NPC VSI
- Phase output voltages

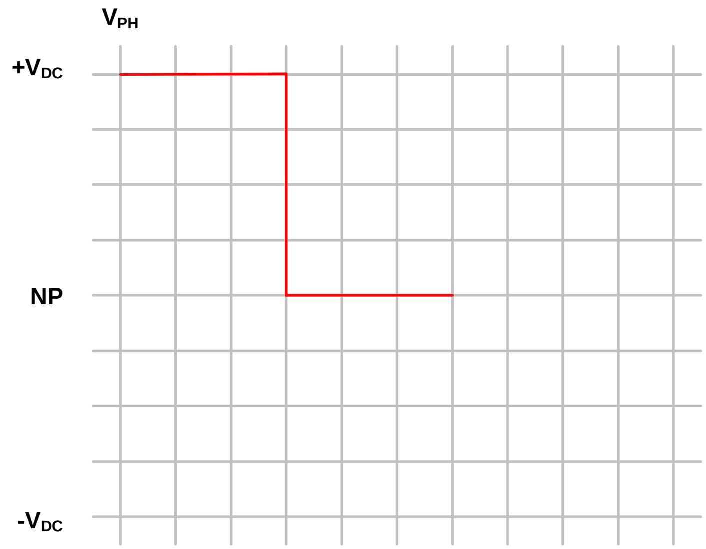




The n-level VSI topology
3-Level

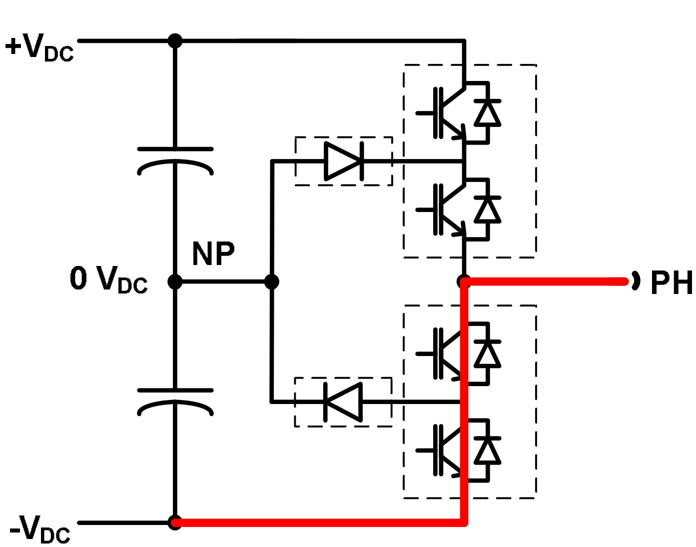
- 3-Level NPC VSI
- Phase output voltages

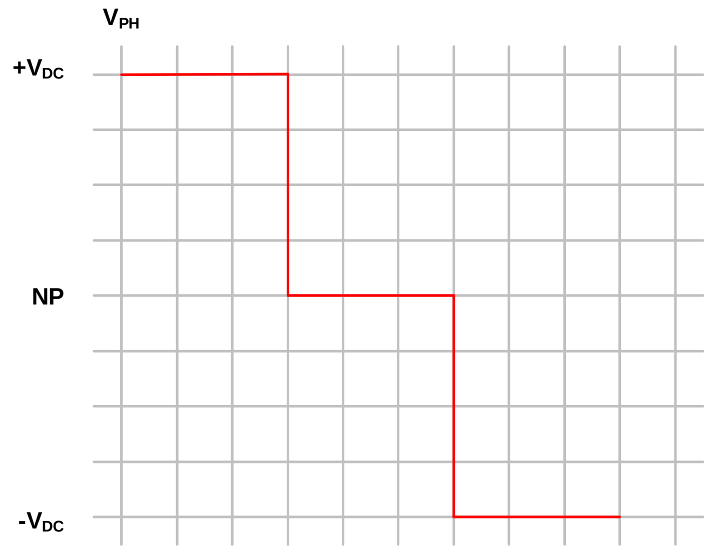




The n-level VSI topology
3-Level

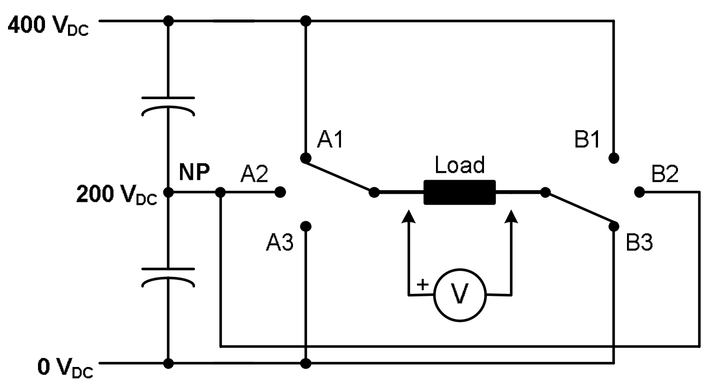
- 3-Level NPC VSI
- Phase output voltages





The n-level VSI topology
3-Level

- 3-Level NPC VSI
- Phase output voltages



	B1	B2	B3
A1	0	200	400
A2	-200	0	200
A3	-400	-200	0

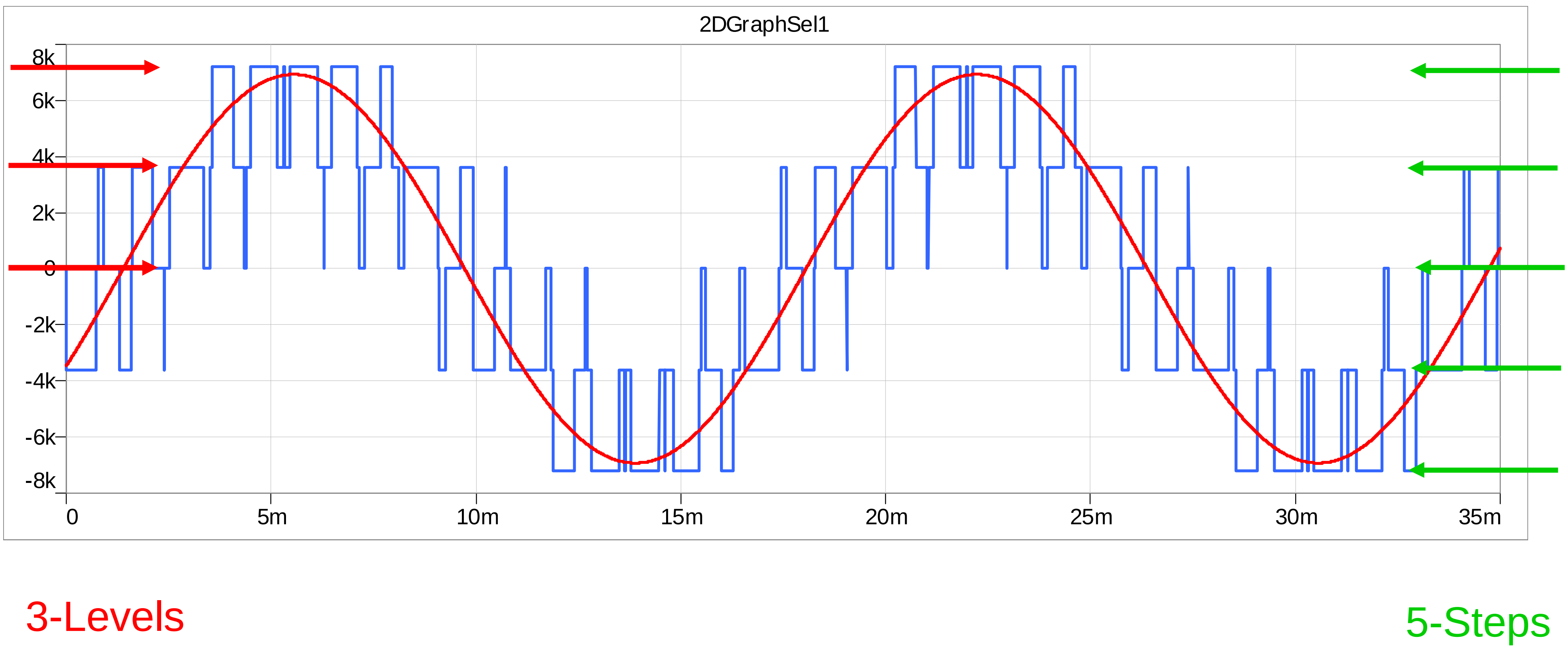
Number of Levels, n

3

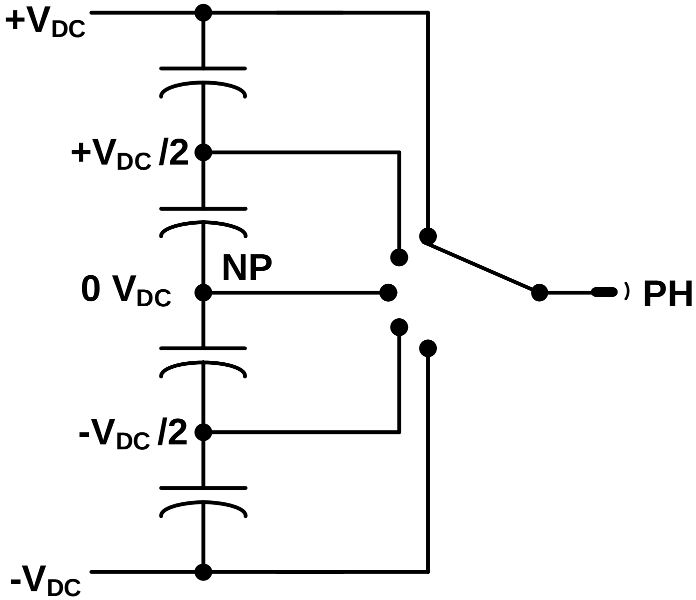
Number of Voltage steps, line-to-line, 2n-1

5

3-Level Waveform, Line-to-Line

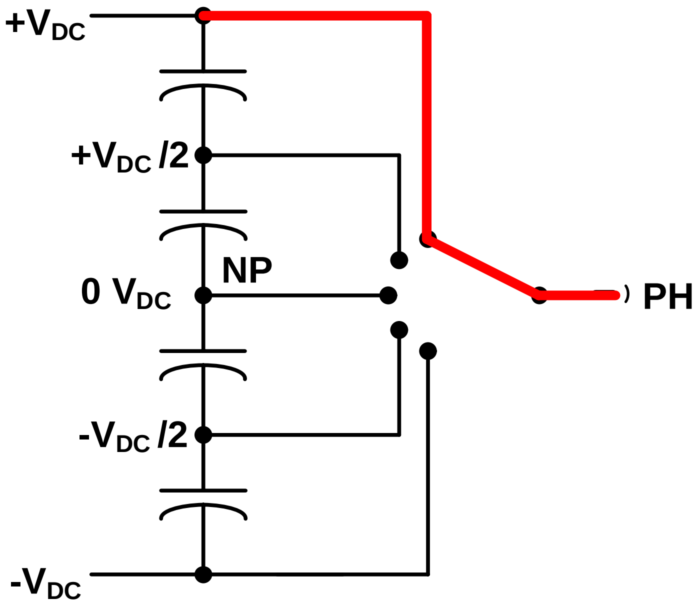


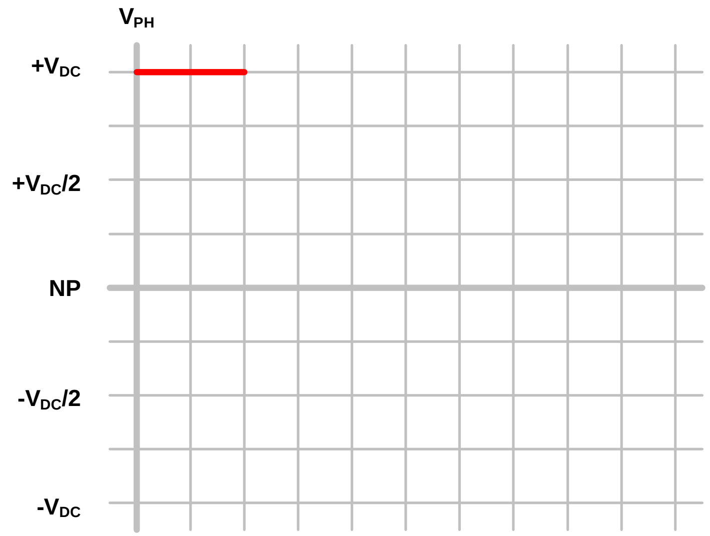
The n-level VSI topology
5-Level



The n-level VSI topology
5-Level

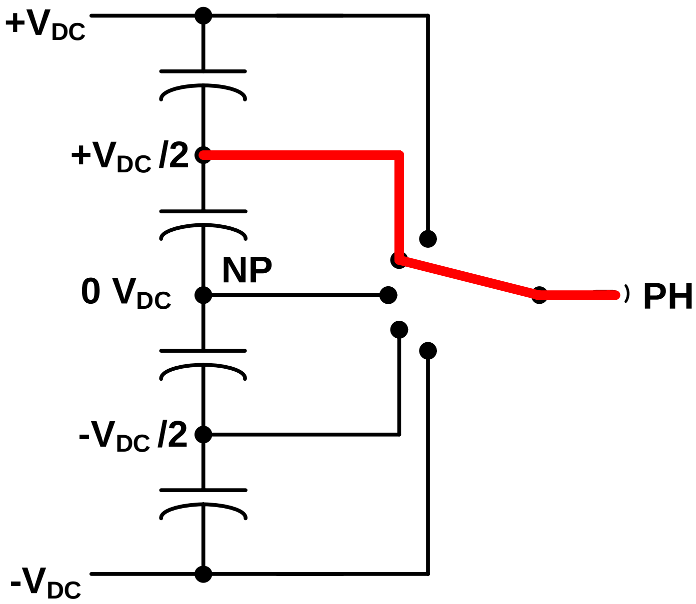
- 5-Level ANPC VSI
- Phase output voltages

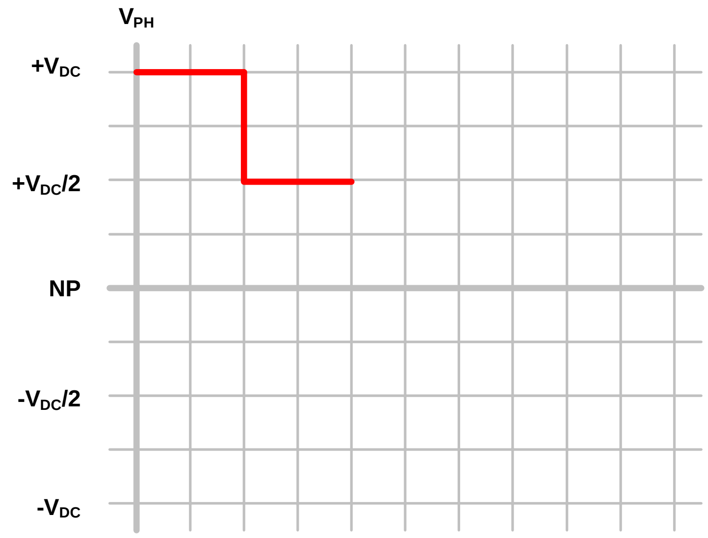




The n-level VSI topology
5-Level

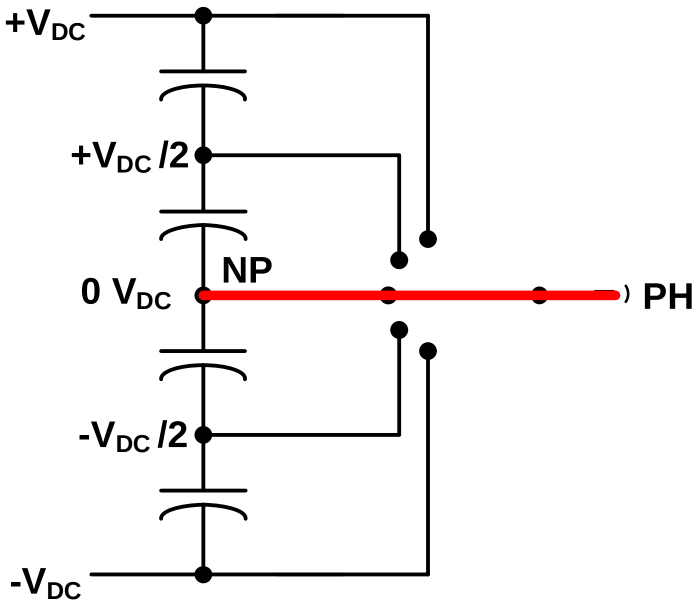
- 5-Level ANPC VSI
- Phase output voltages

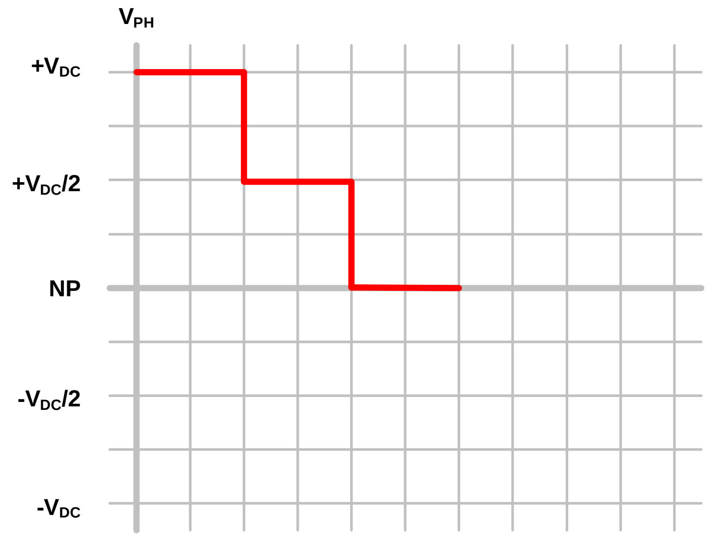




The n-level VSI topology
5-Level

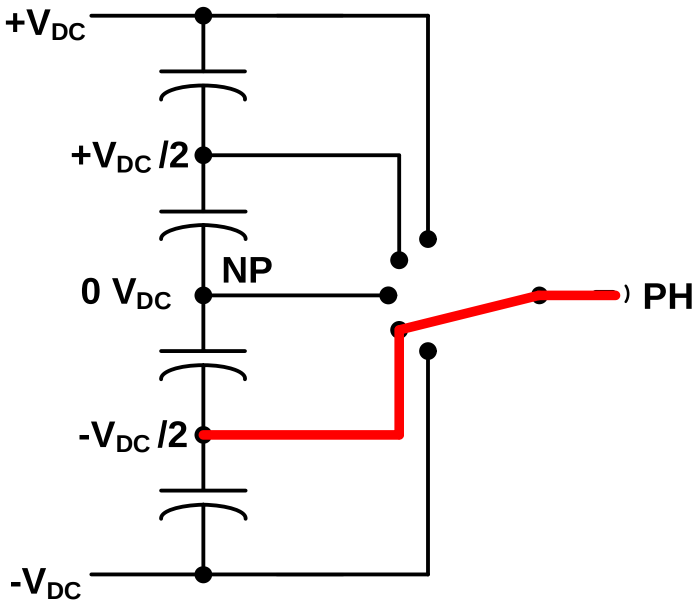
- 5-Level ANPC VSI
- Phase output voltages

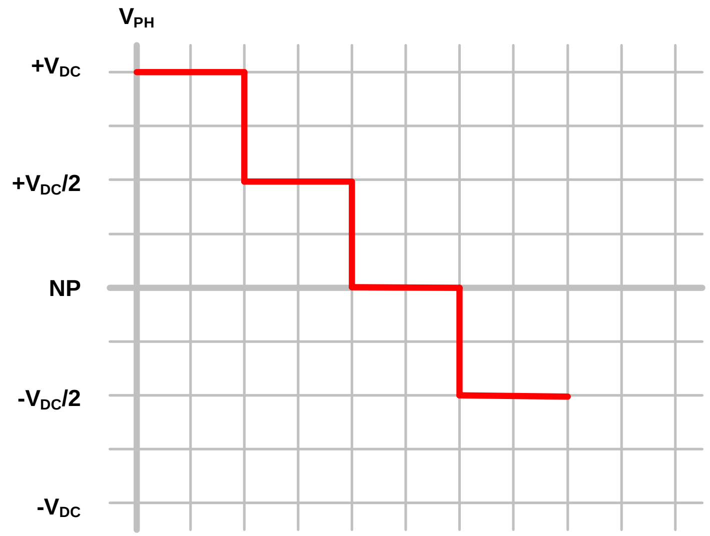




The n-level VSI topology
5-Level

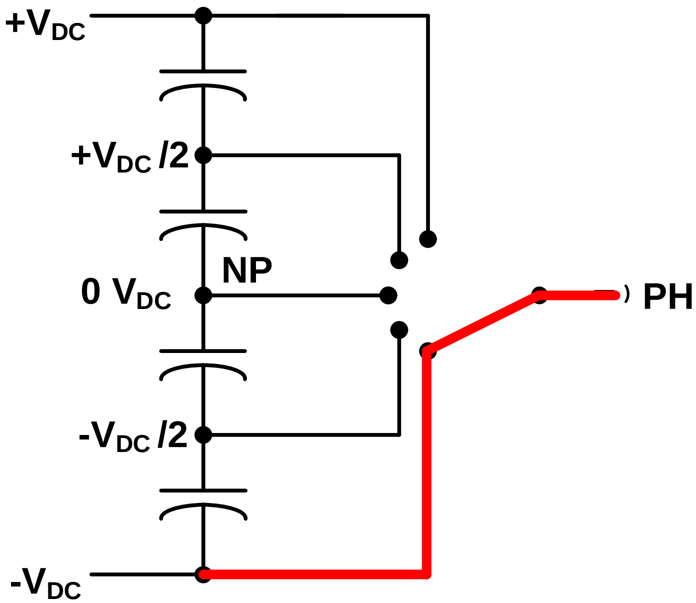
- 5-Level ANPC VSI
- Phase output voltages

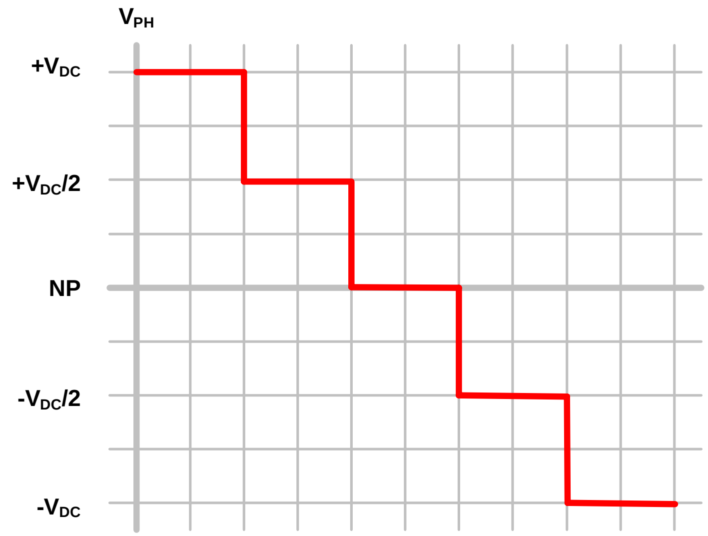




The n-level VSI topology
5-Level

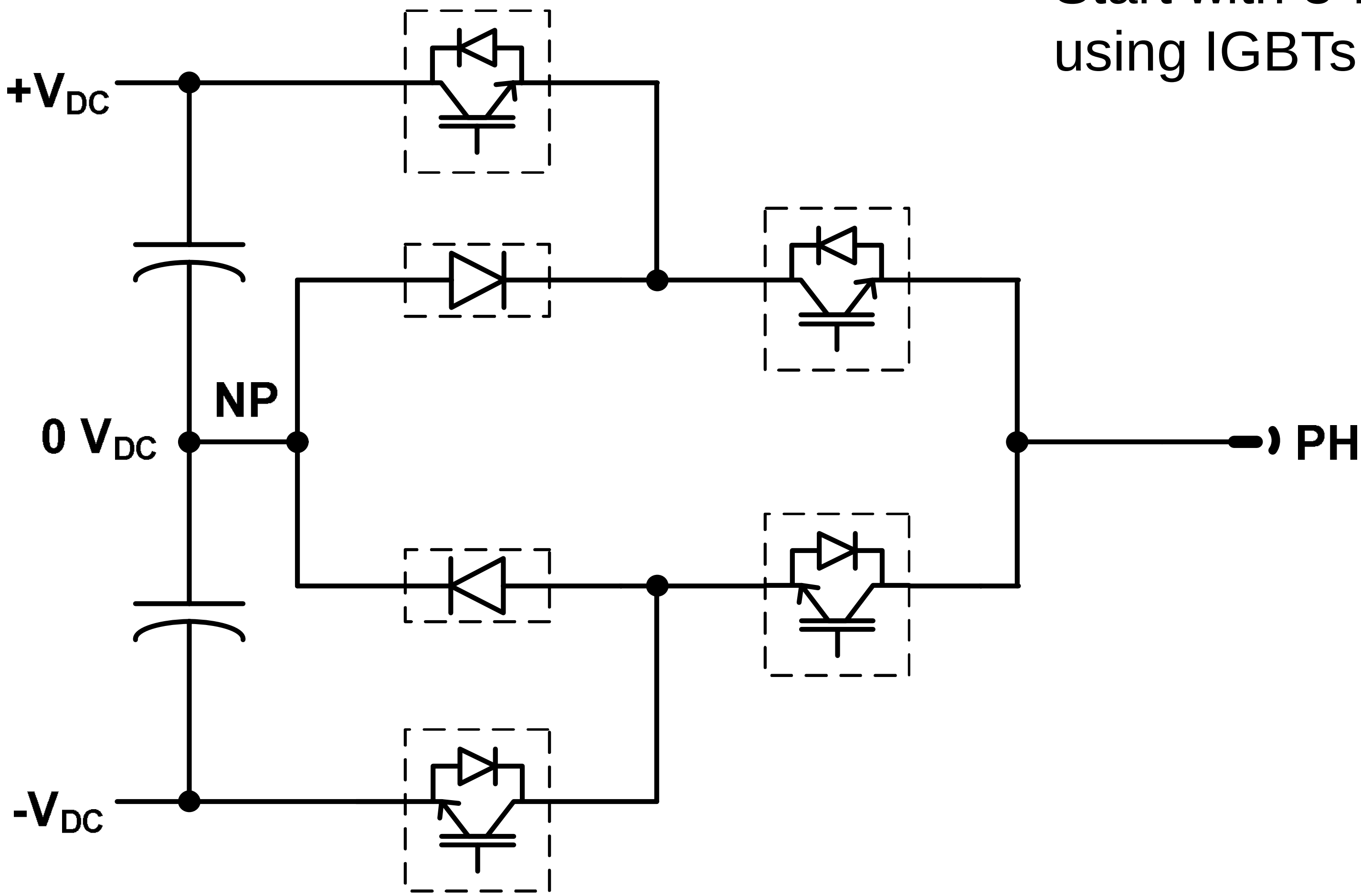
- 5-Level ANPC VSI
- Phase output voltages





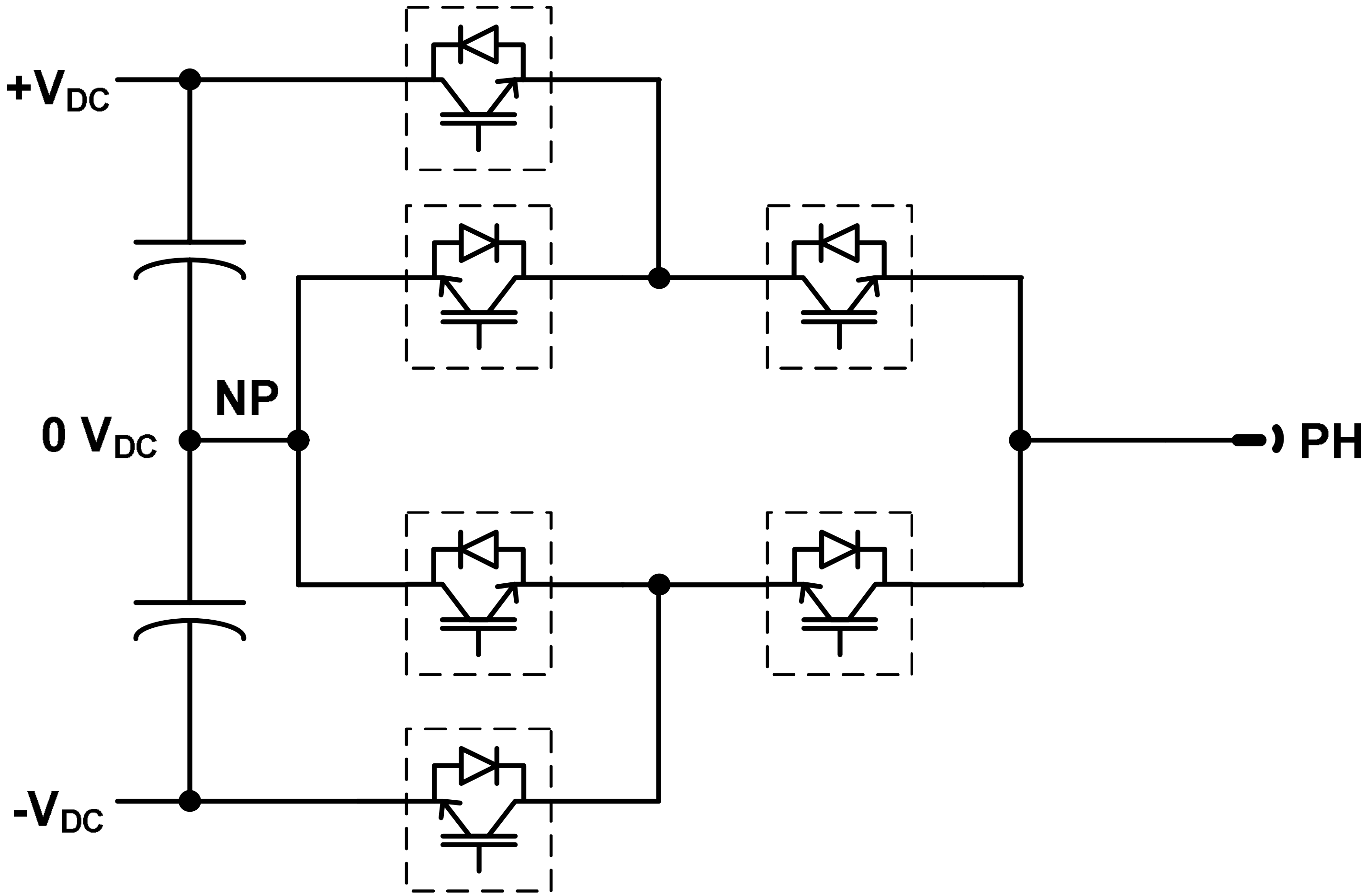
The n-level VSI topology
Going from 3-Level to 5-Level

Start with 3-Level
using IGBTs

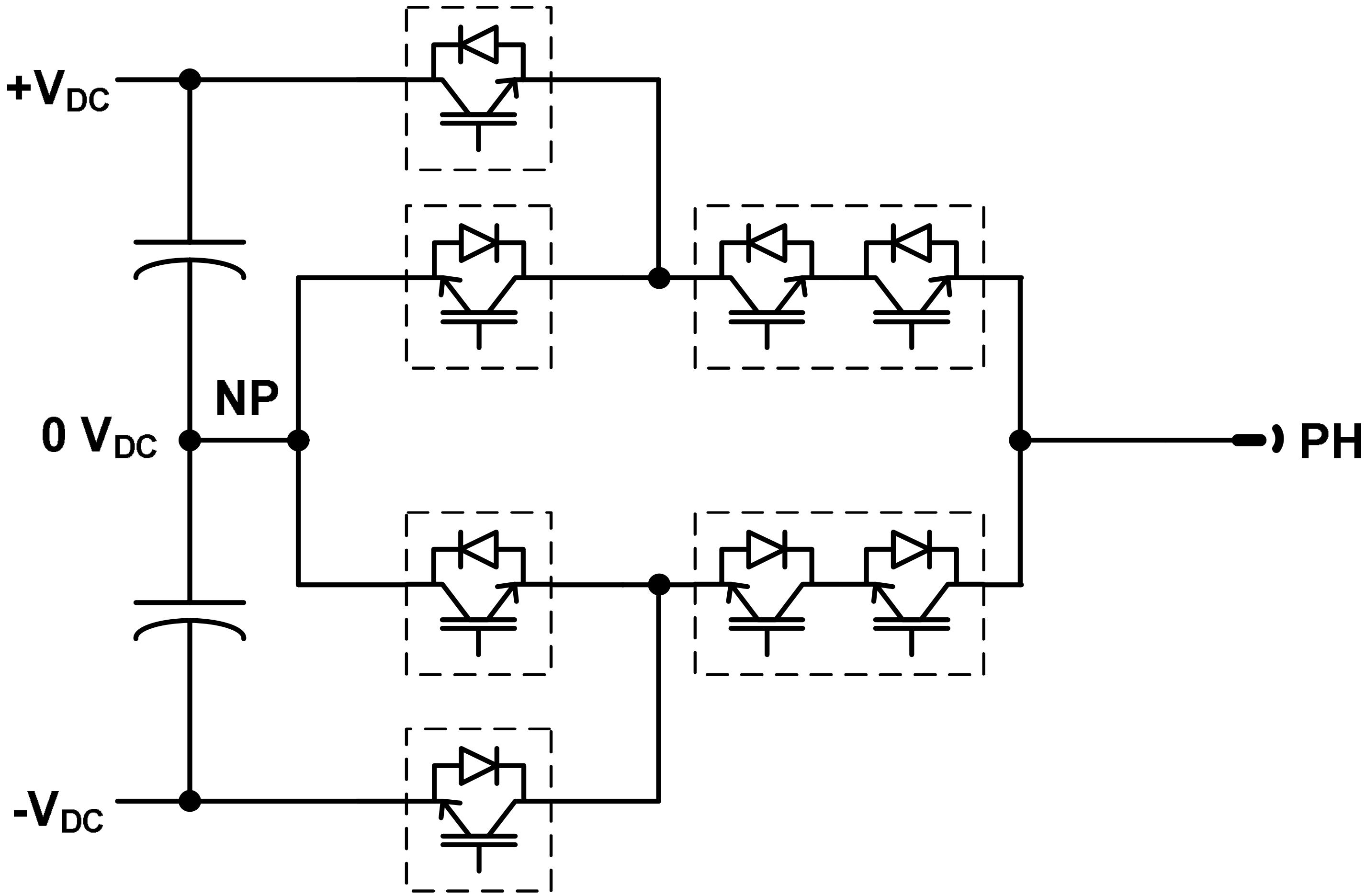


The n-level VSI topology

Going from 3-Level to 5-Level



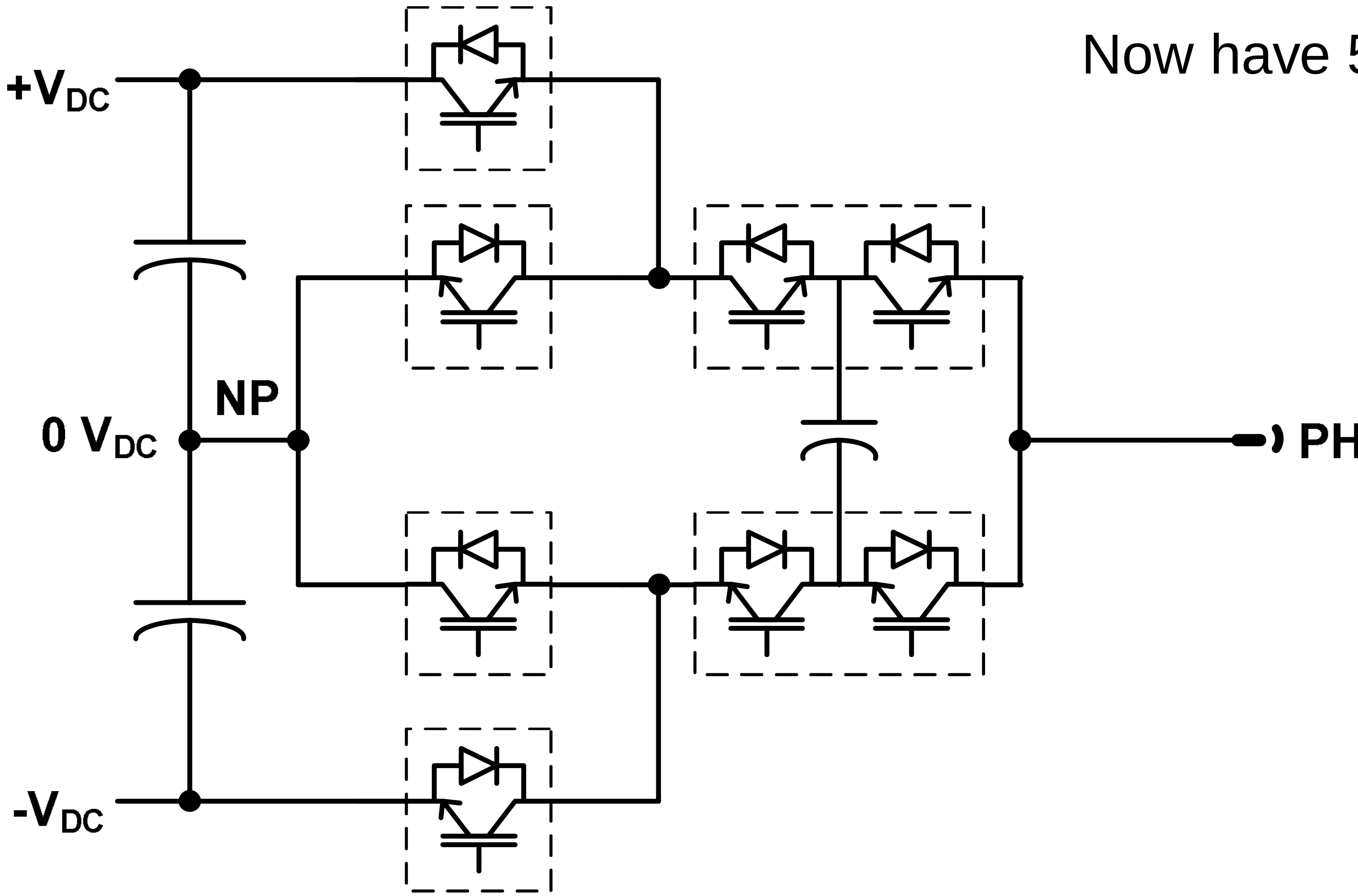
The n-level VSI topology
Going from 3-Level to 5-Level



The n-level VSI topology
Going from 3-Level to 5-Level

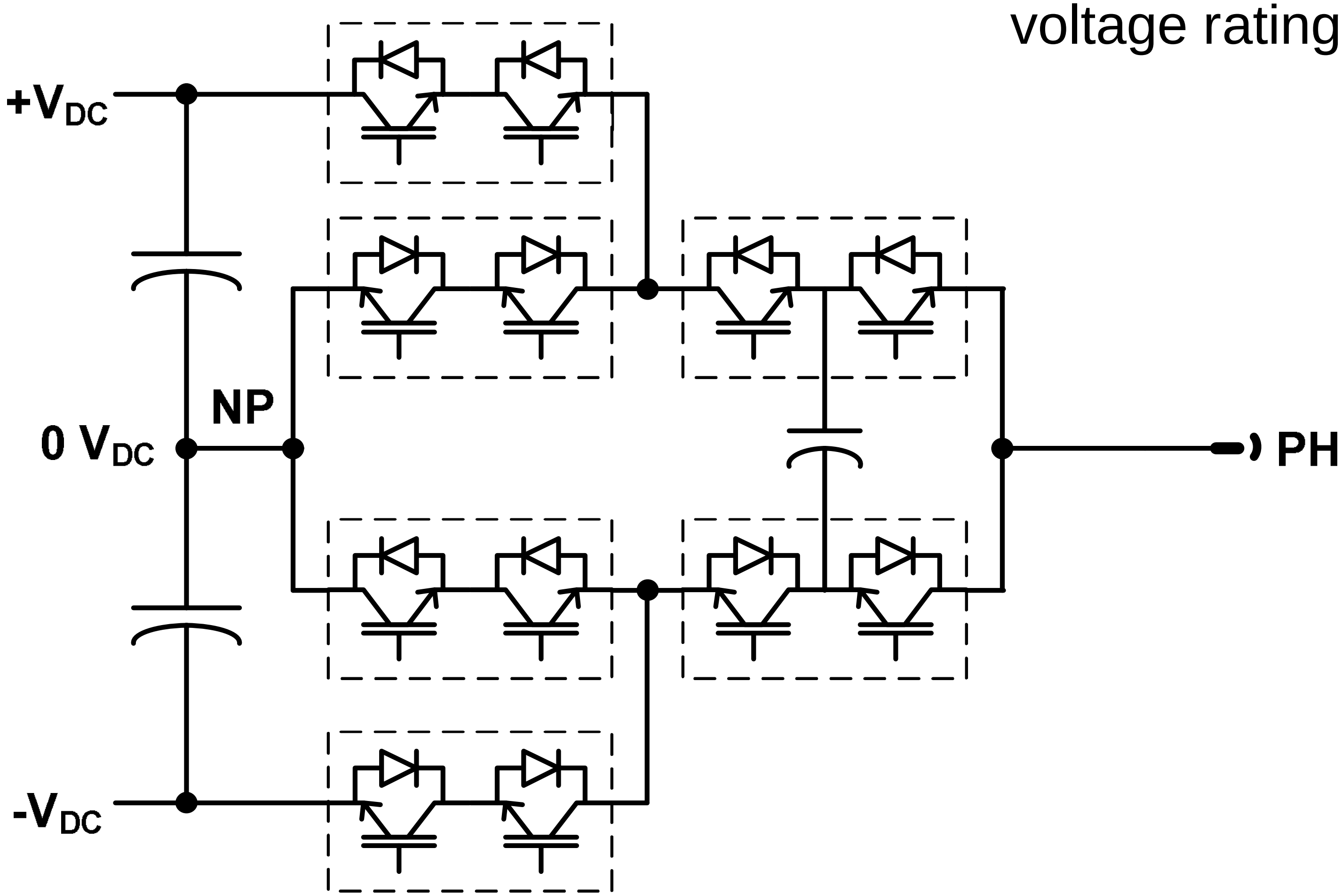
Added cap at Vdc/2

Now have 5-Level



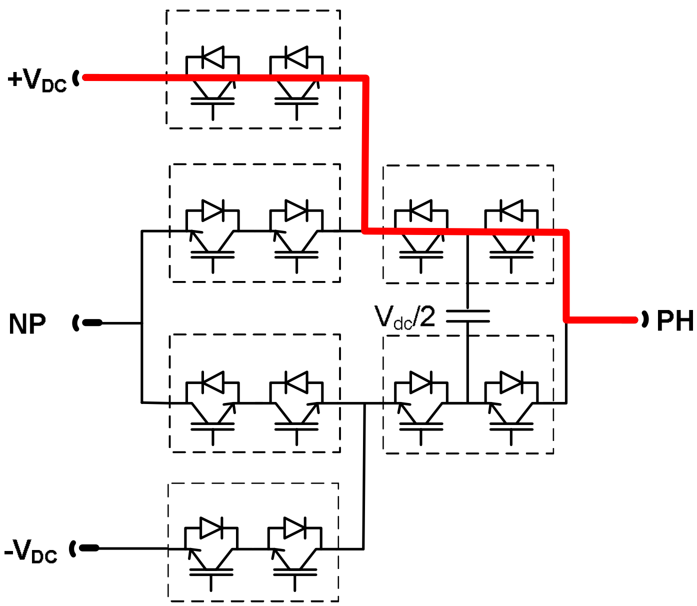
The n-level VSI topology
Going from 3-Level to 5-Level

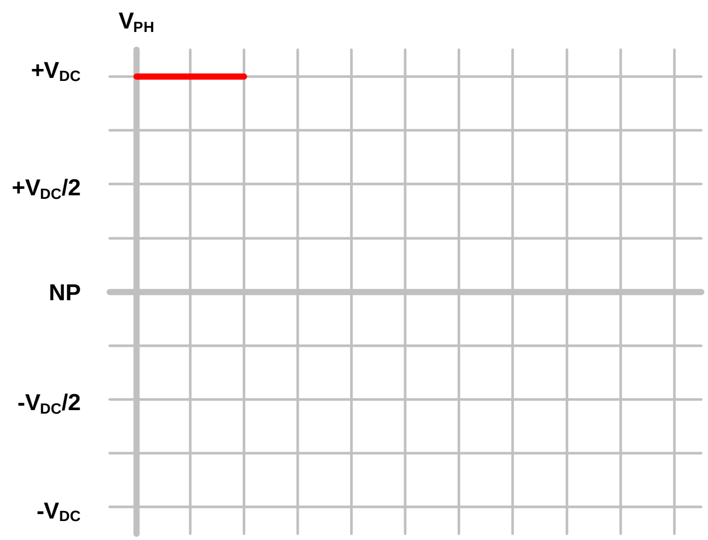
Double up IGBTs for voltage rating



The n-level VSI topology
5-Level

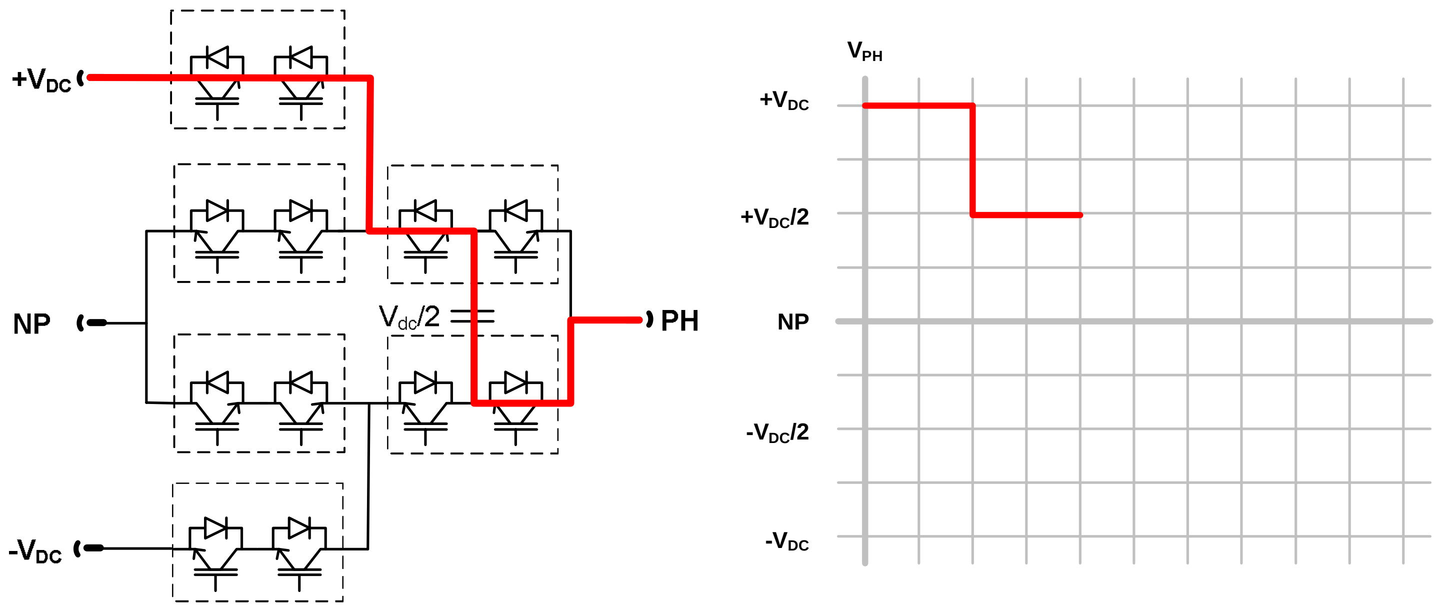
- 5-Level ANPC VSI
- Phase output voltages





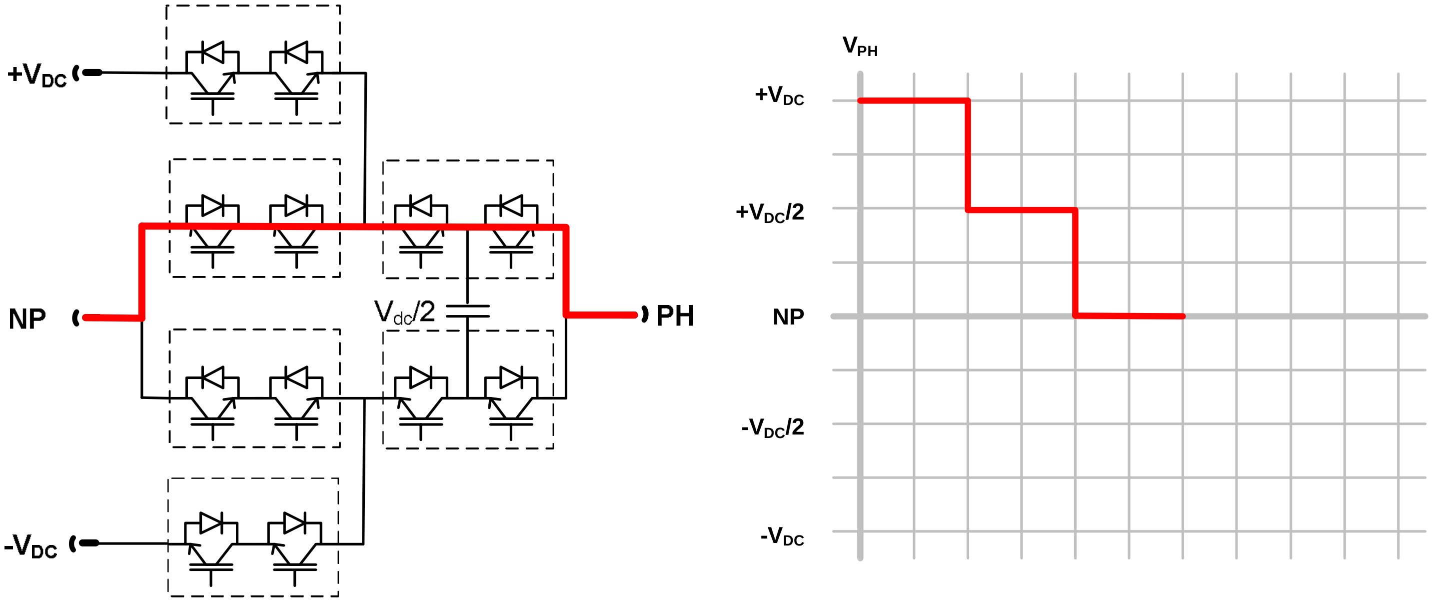
The n-level VSI topology
5-Level

- 5-Level ANPC VSI
- Phase output voltages



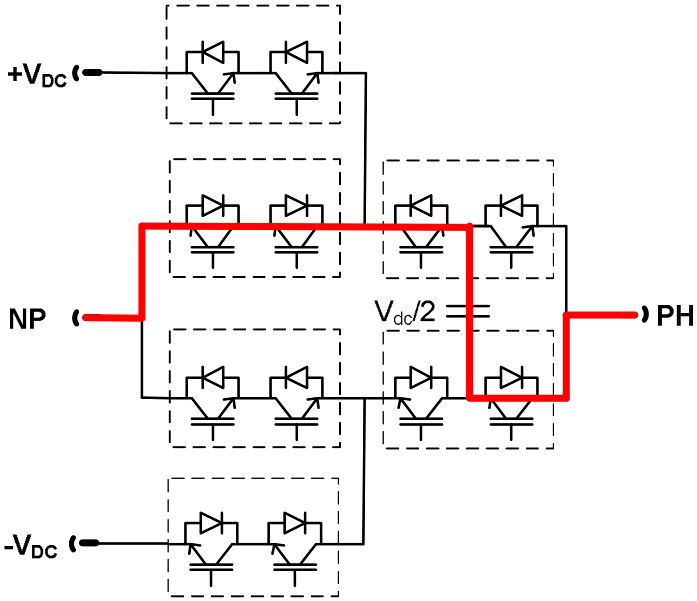
The n-level VSI topology
5-Level

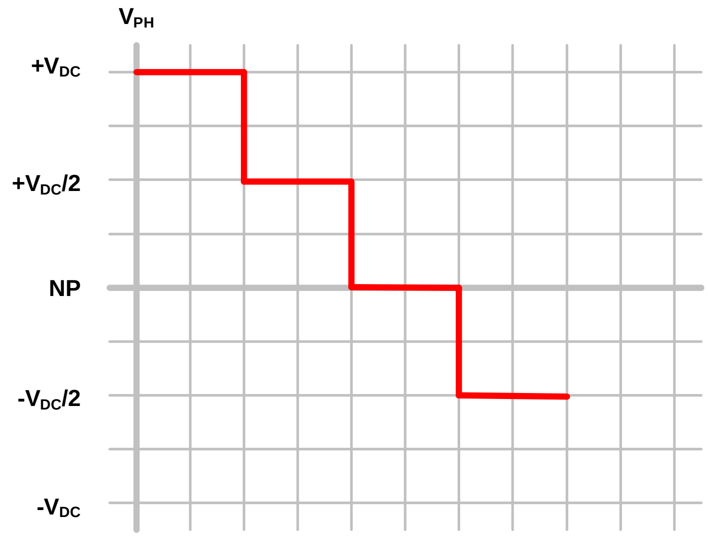
- 5-Level ANPC VSI
- Phase output voltages



The n-level VSI topology
5-Level

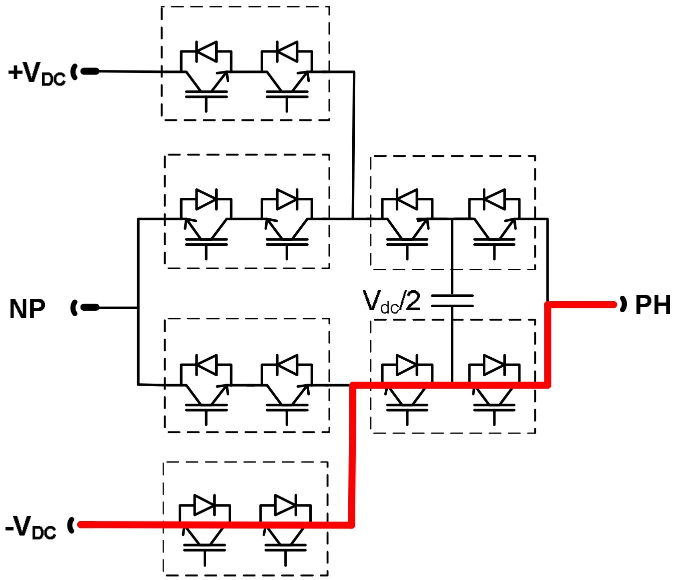
- 5-Level ANPC VSI
- Phase output voltages

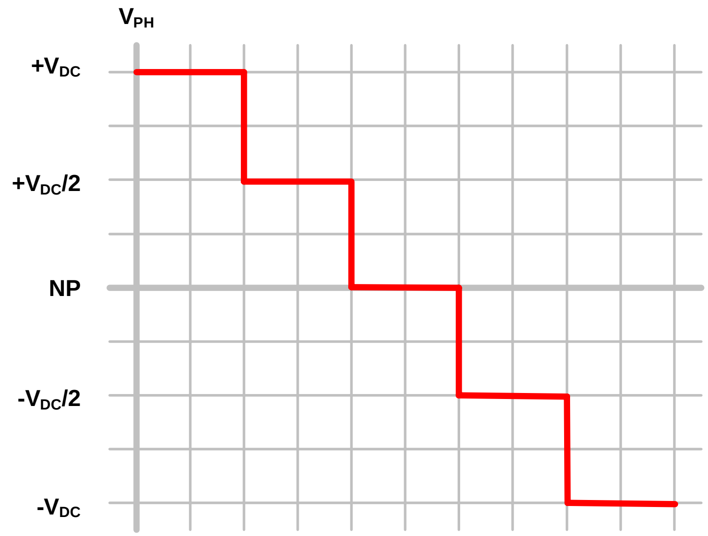




The n-level VSI topology
5-Level

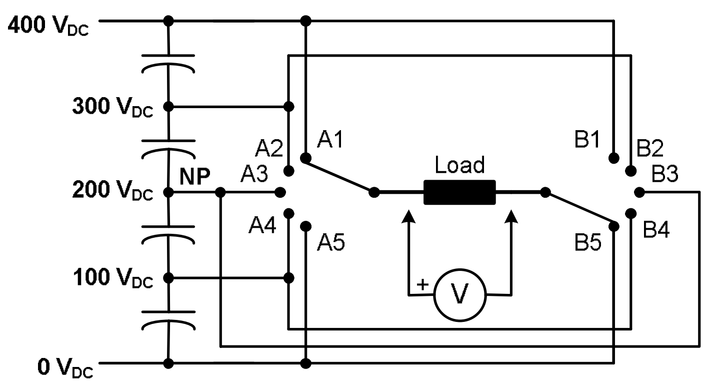
- 5-Level ANPC VSI
- Phase output voltages





The n-level VSI topology
5-Level

- 5-Level ANPC VSI
- Phase output voltages



	B1	B2	B3	B4	B5
A1	0	100	200	300	400
A2	-100	0	100	200	300
A3	-200	-100	0	100	200
A4	-300	-200	-100	0	100
A5	-400	-300	-200	-100	0

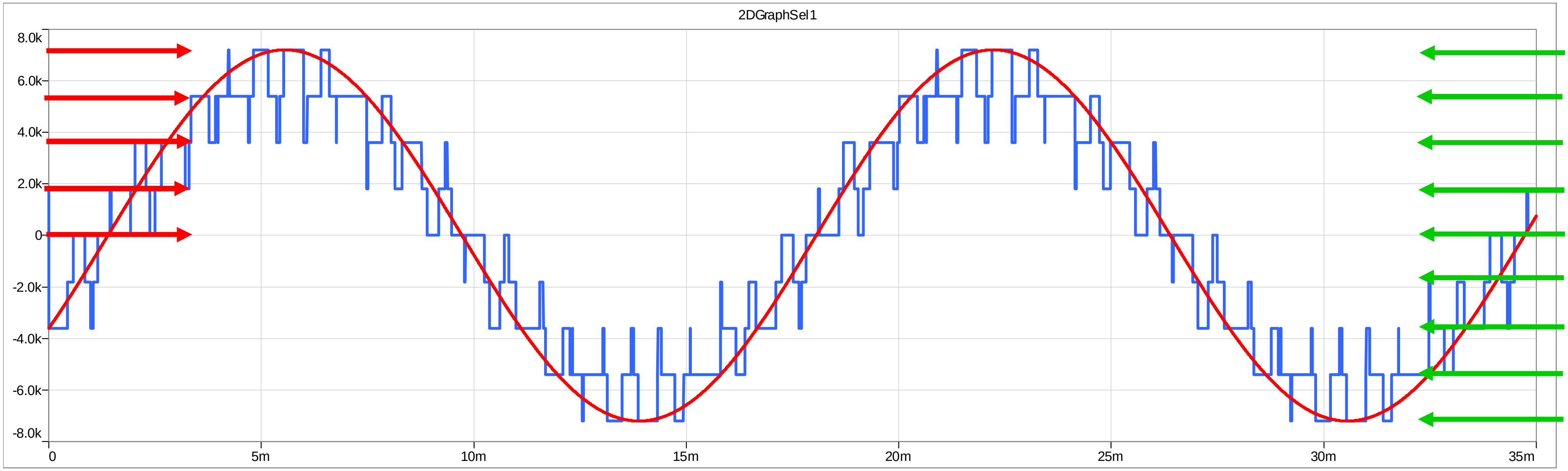
Number of Levels, n

5

Number of Voltage steps, line-to-line, 2n-1

9

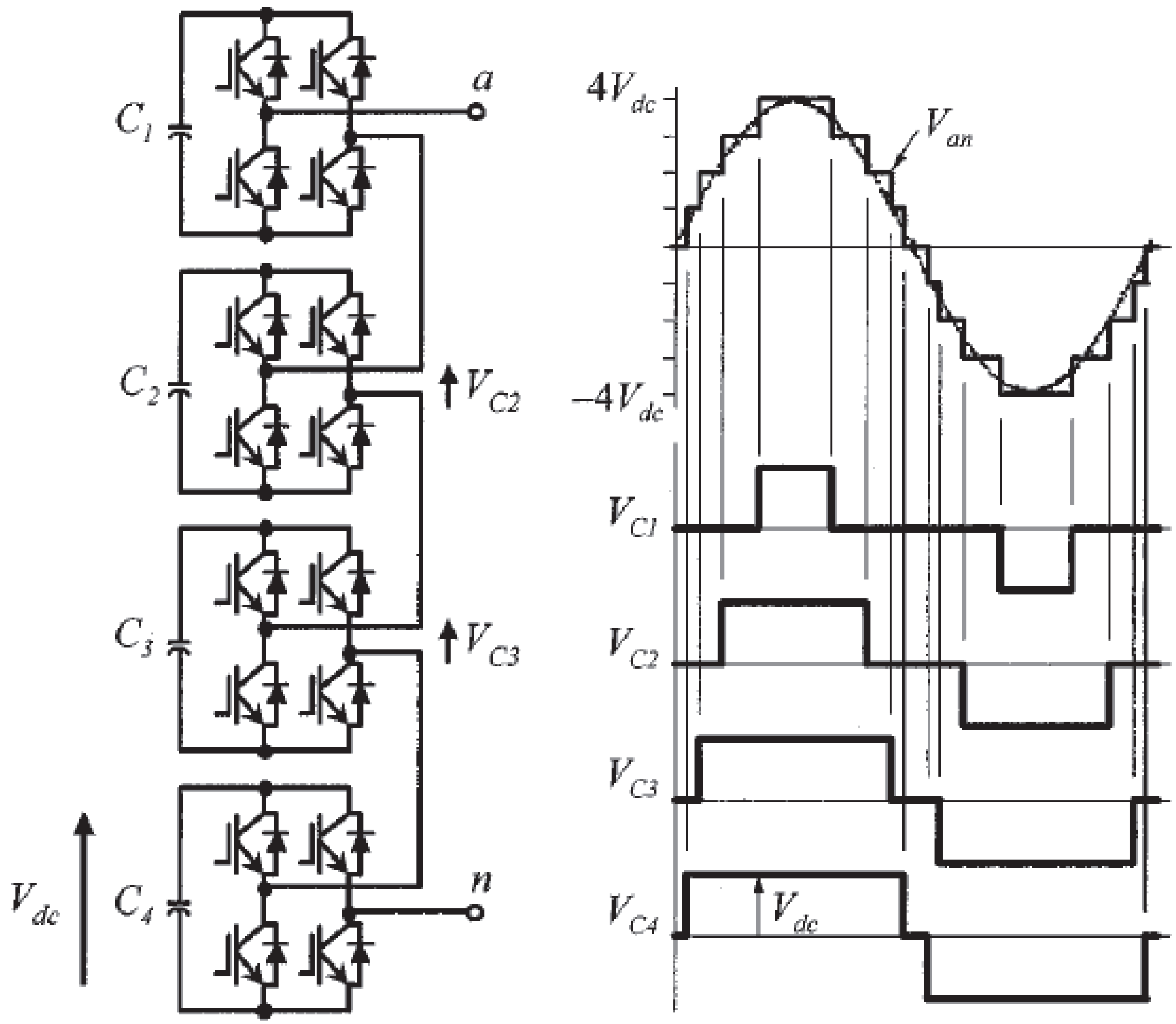
5-Level Waveform, Line-to-Line



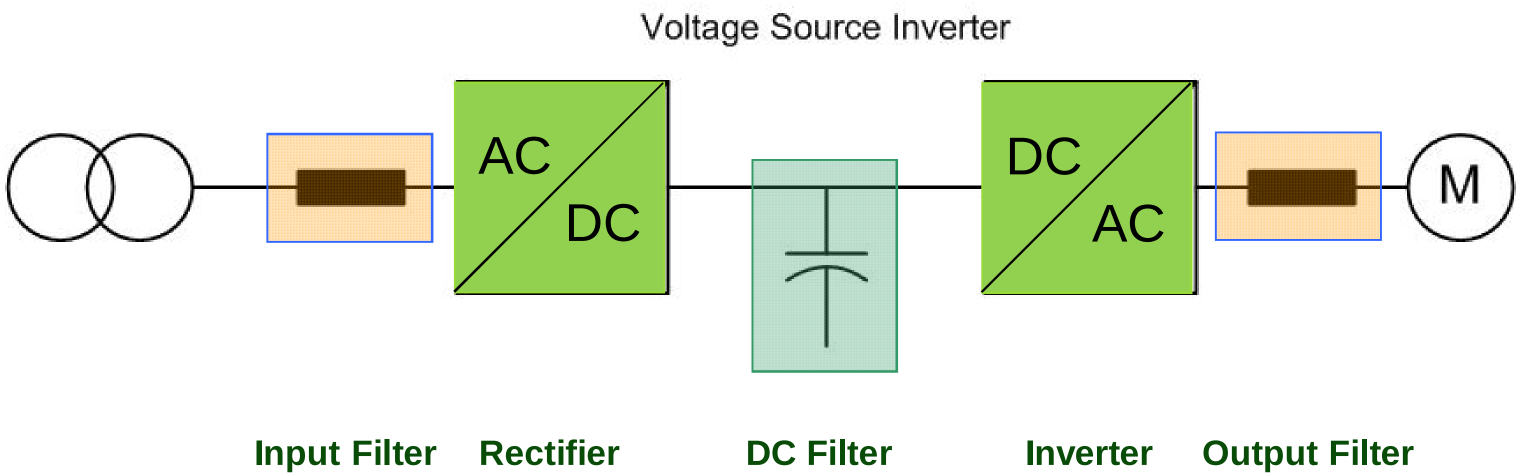
5-Levels

9-Steps

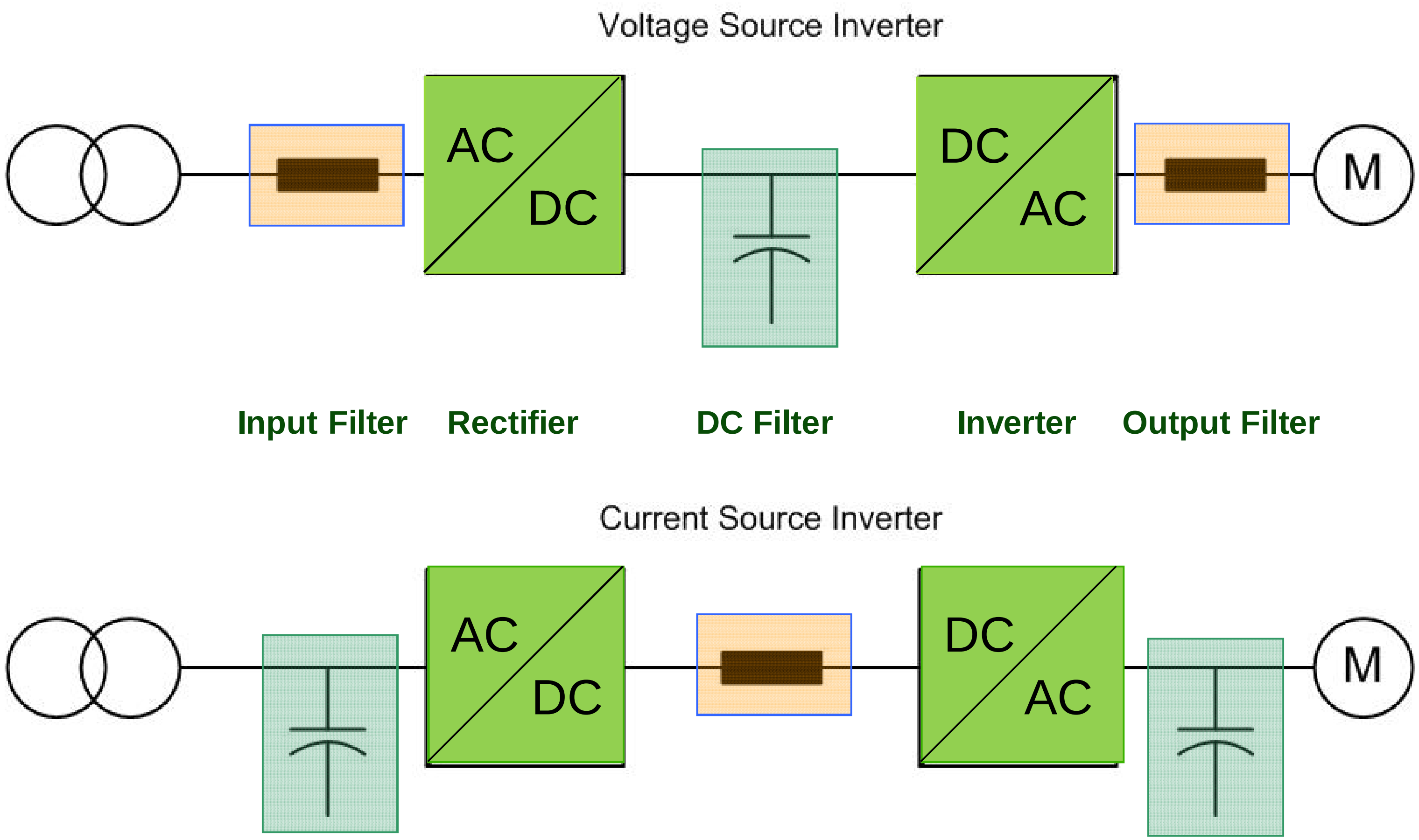
Cascaded H-Bridge



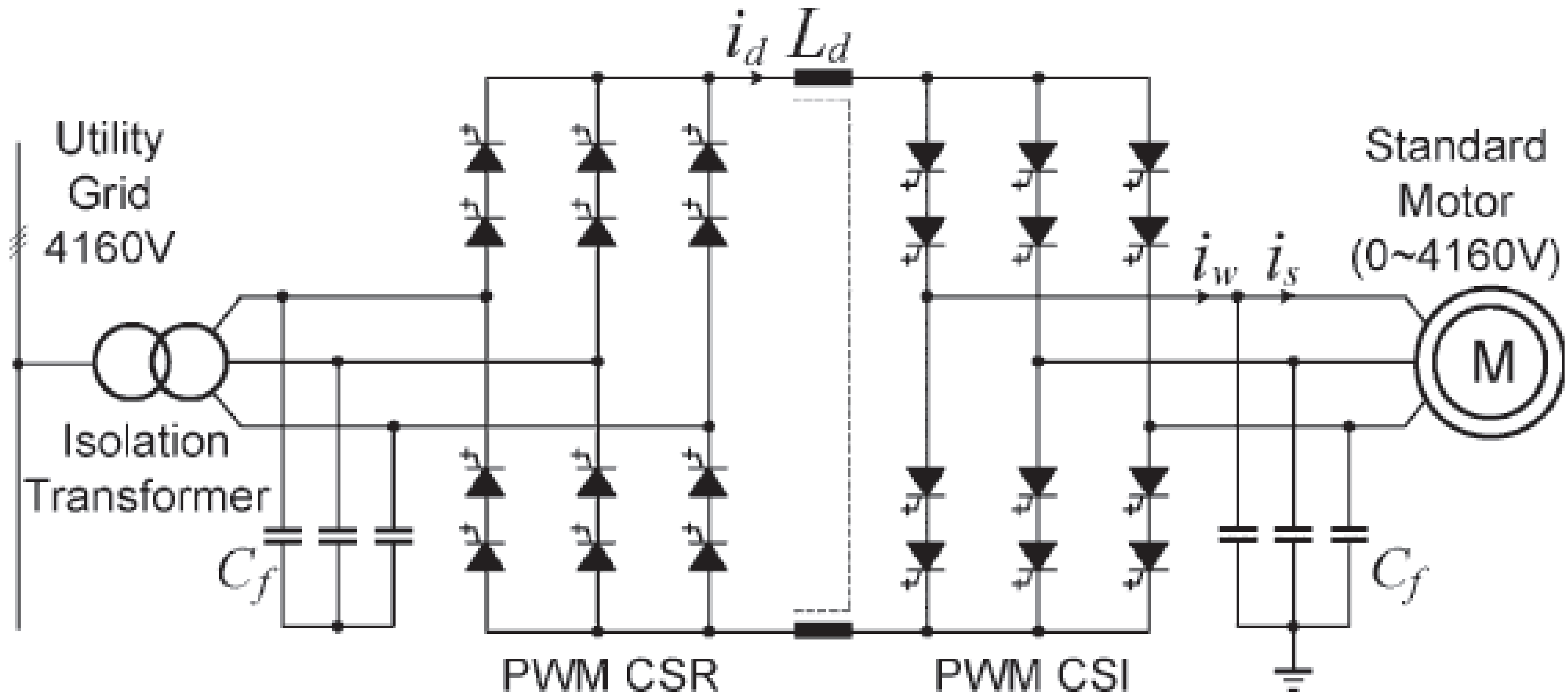
How are VSI and CSI similar?



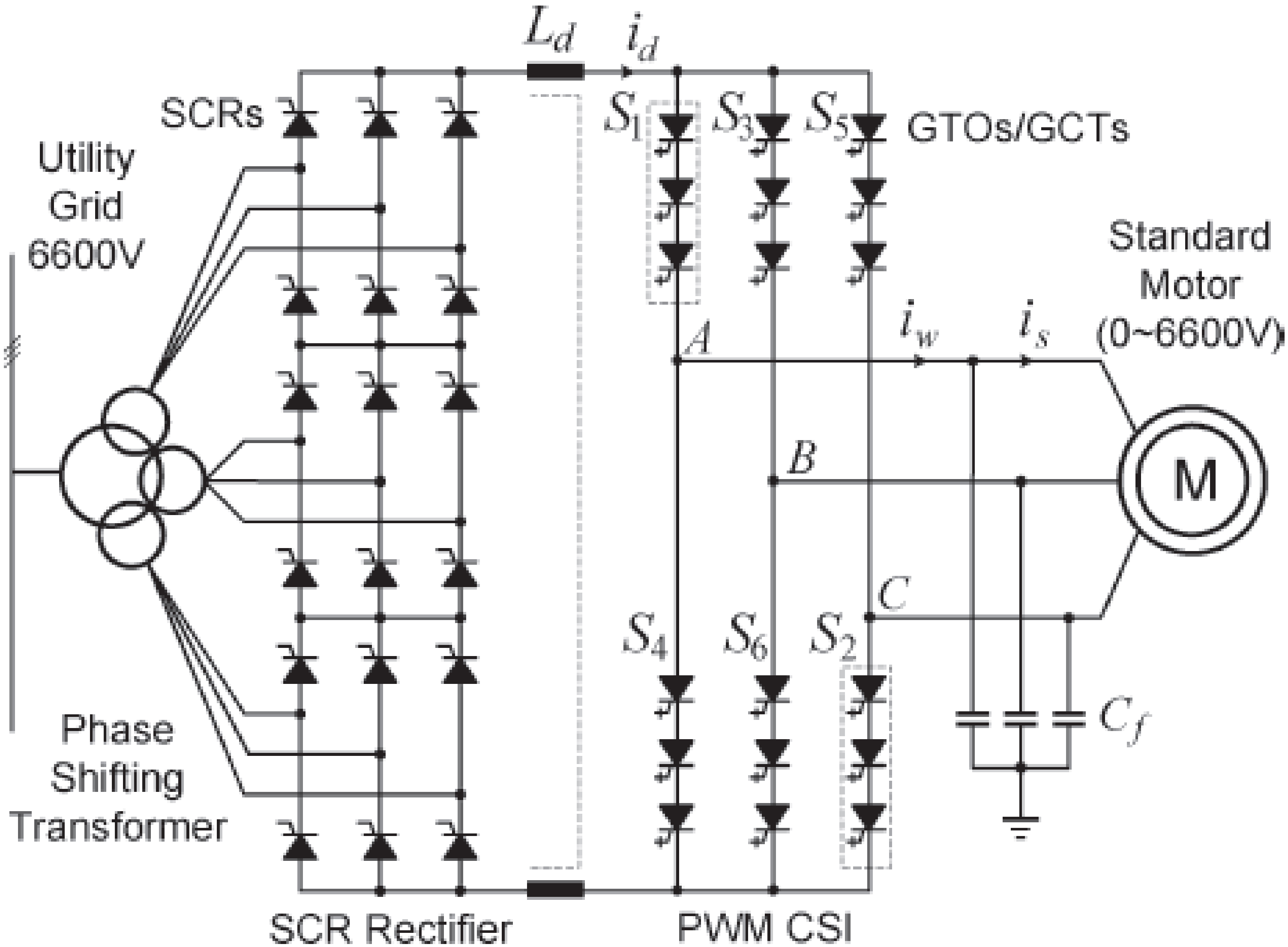
How are VSI and CSI similar?



CSI, PWM Converter, Isolated

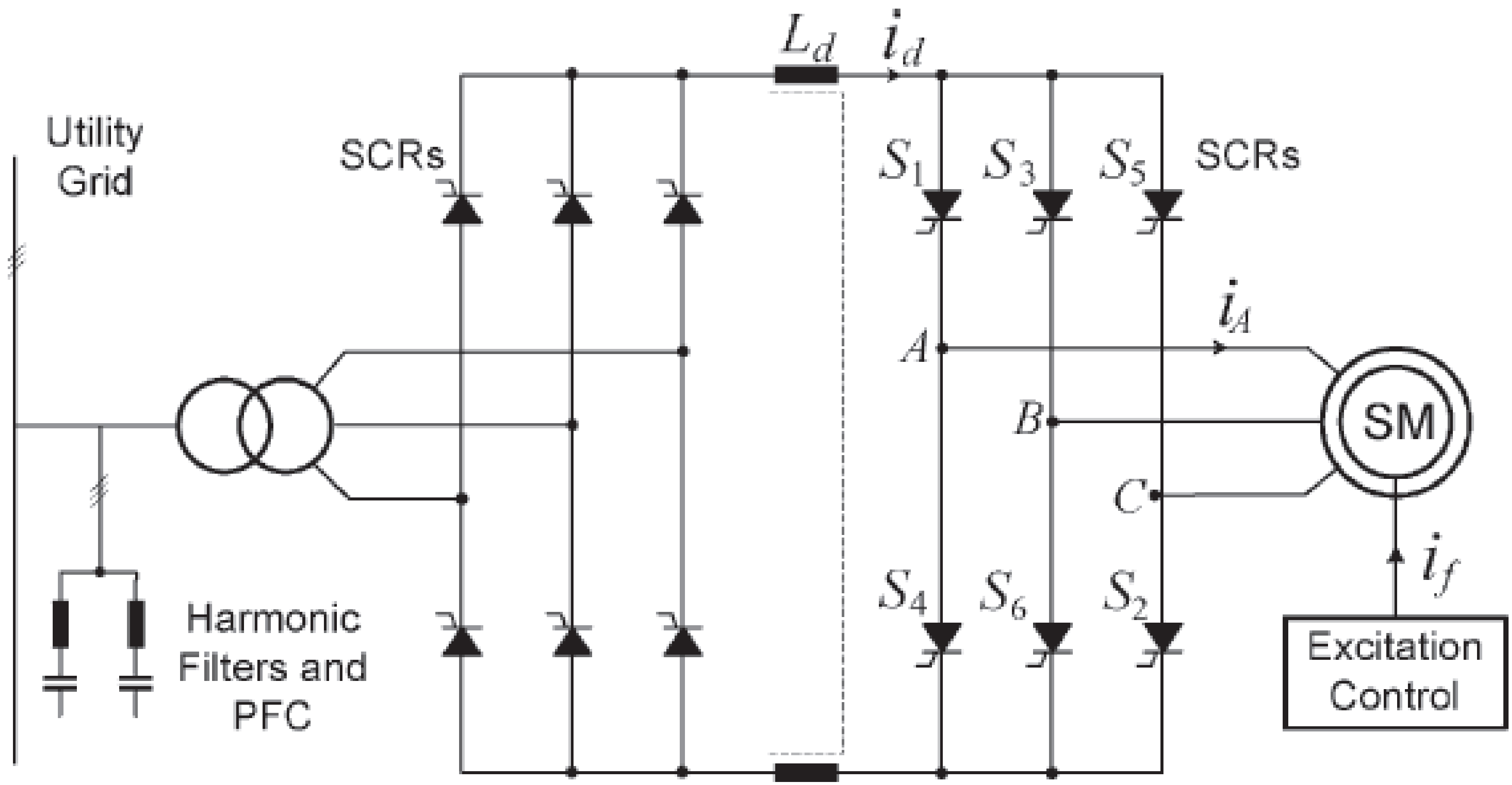


CSI, 18P Converter, Isolated

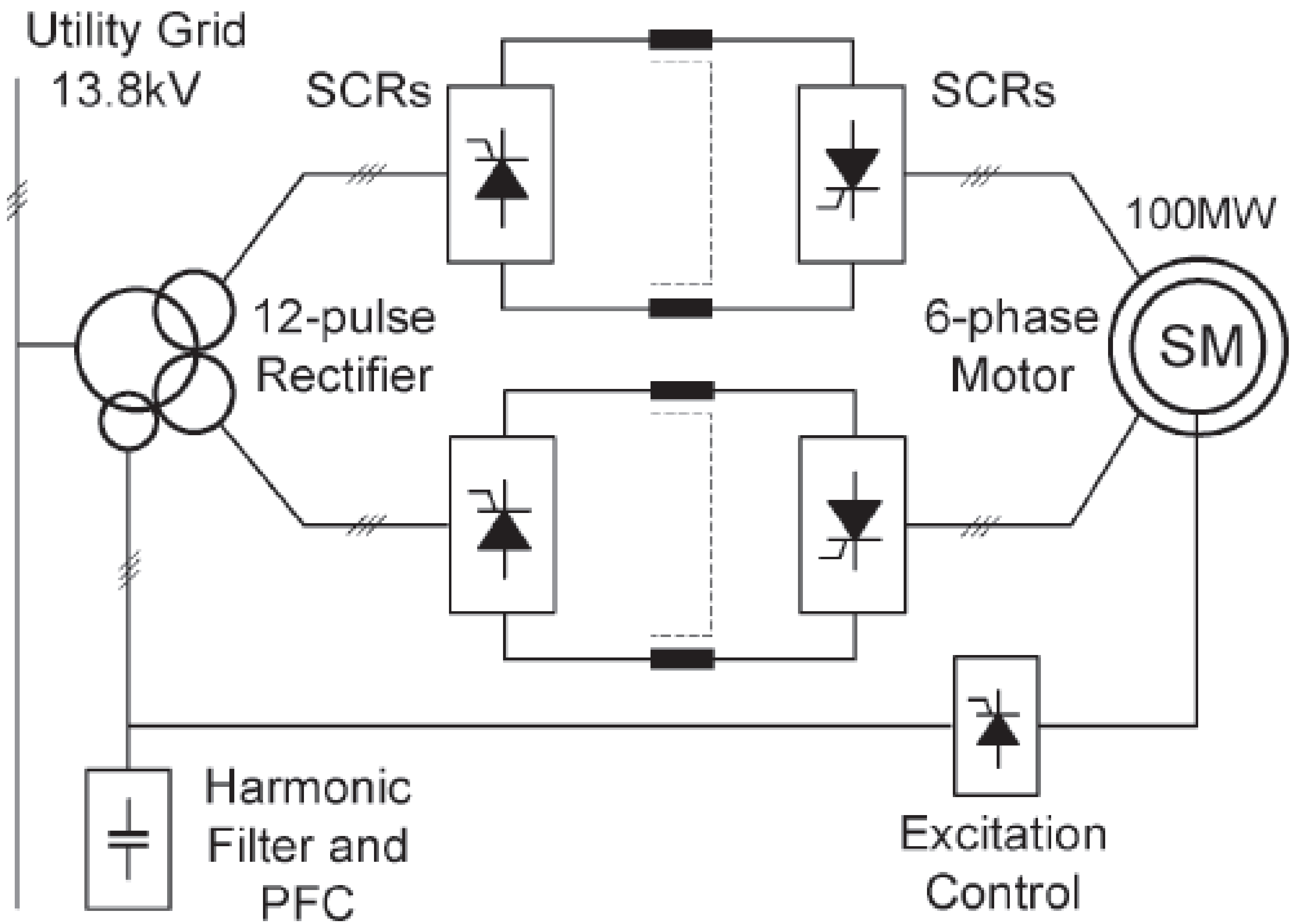


LCI, PWM Converter, Isolated

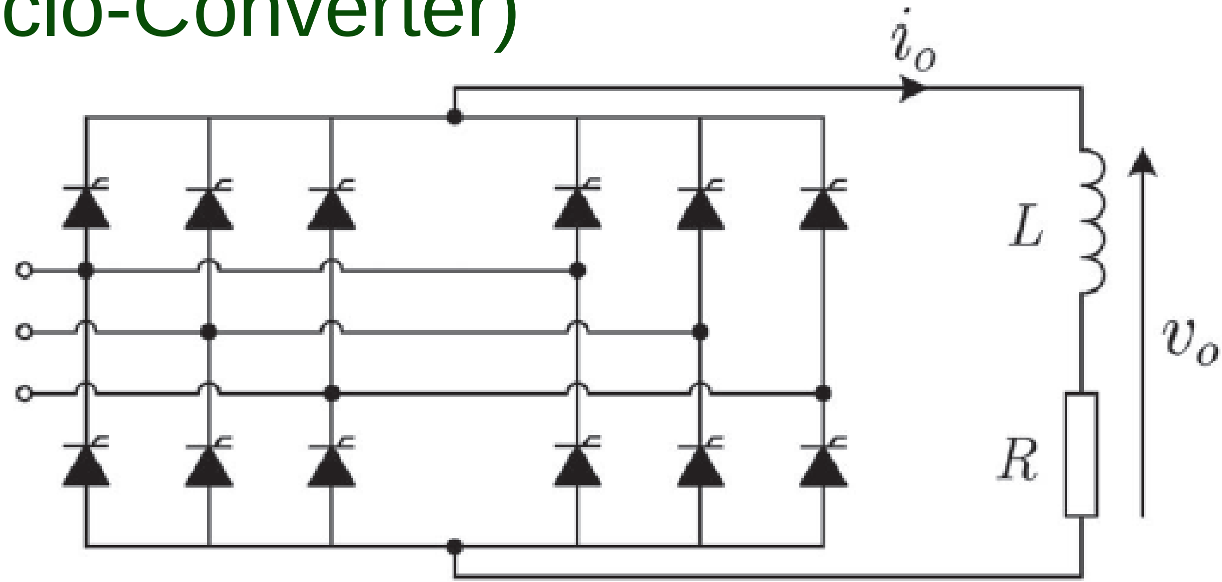
Load Commutated Inverter



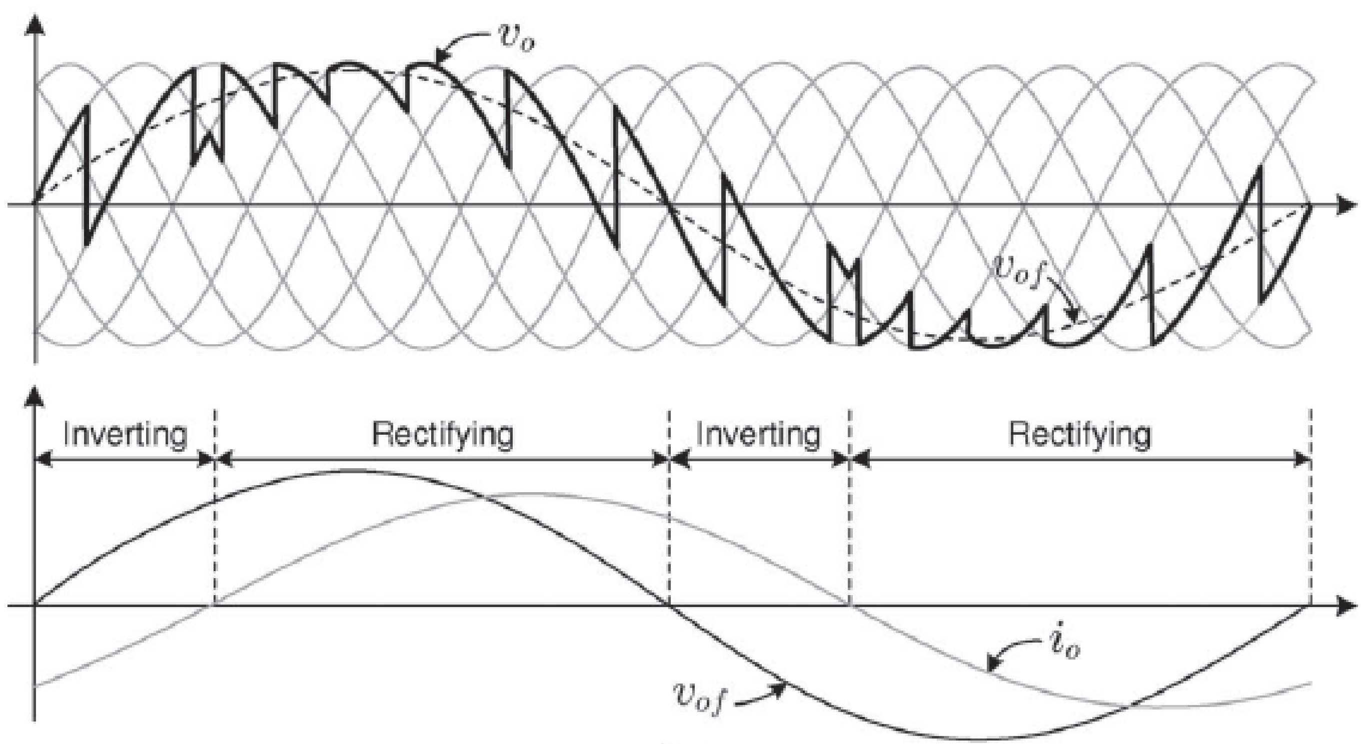
LCI, 12P Converter, Isolated



6P CCV (Cyclo-Converter)

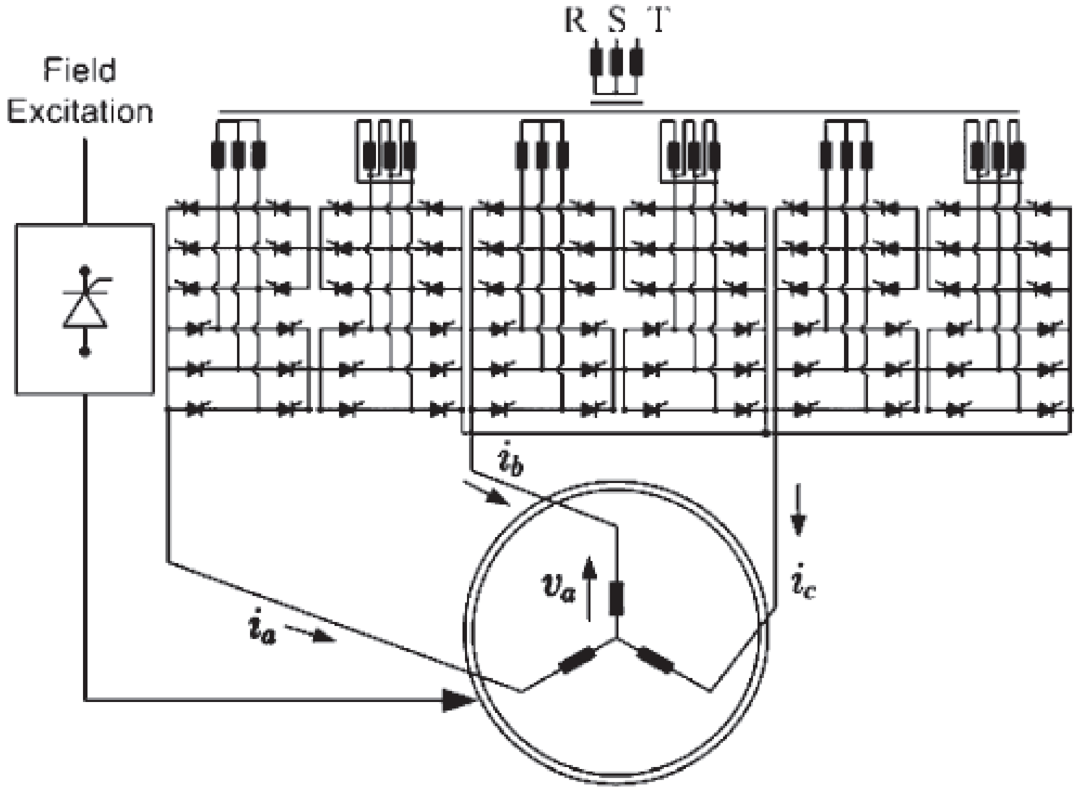


(a)

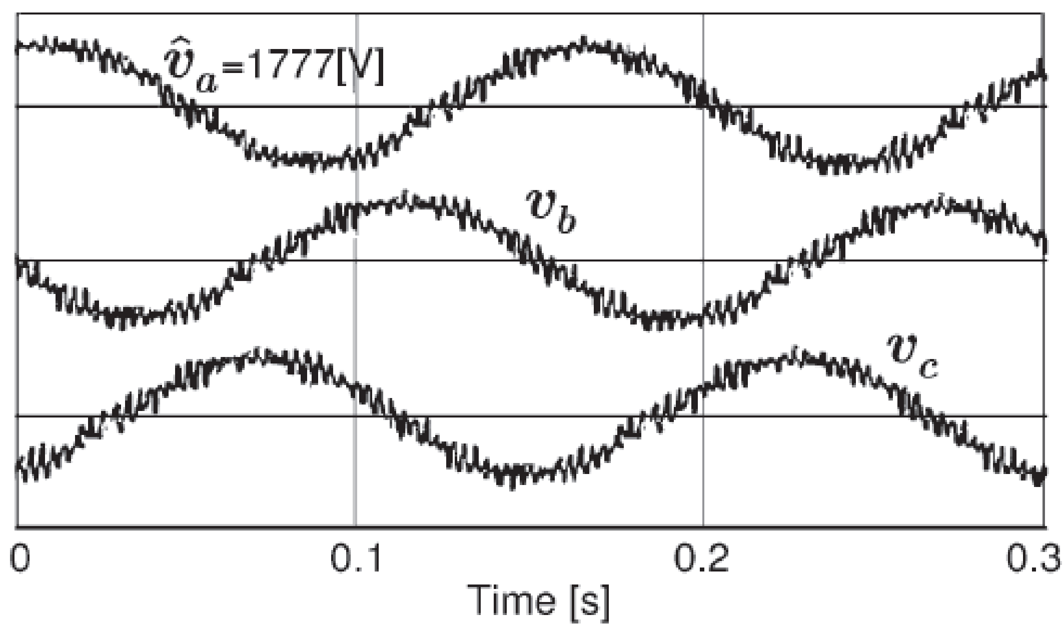


(b)

12P CCV


R S T
Field
Excitation
i_b
v_a
i_c
i_a

(a)

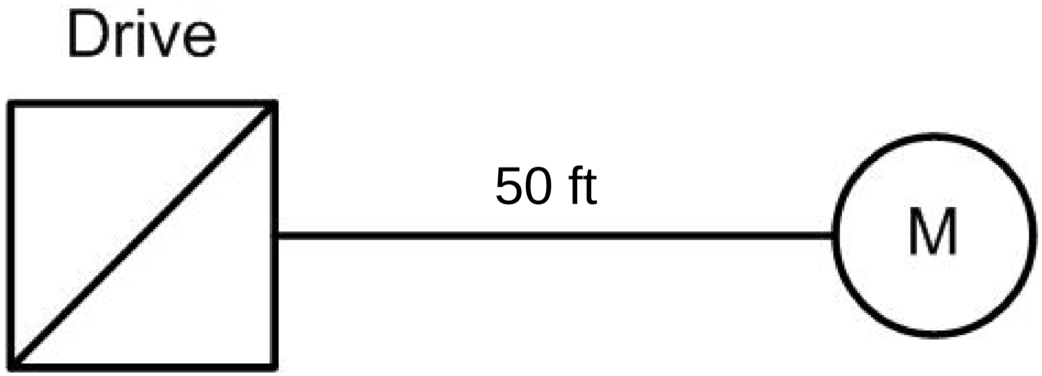

$\hat{v}_a$=1777[V]
v_b
v_c
0
0.1
0.2
0.3
Time [s]

(b)

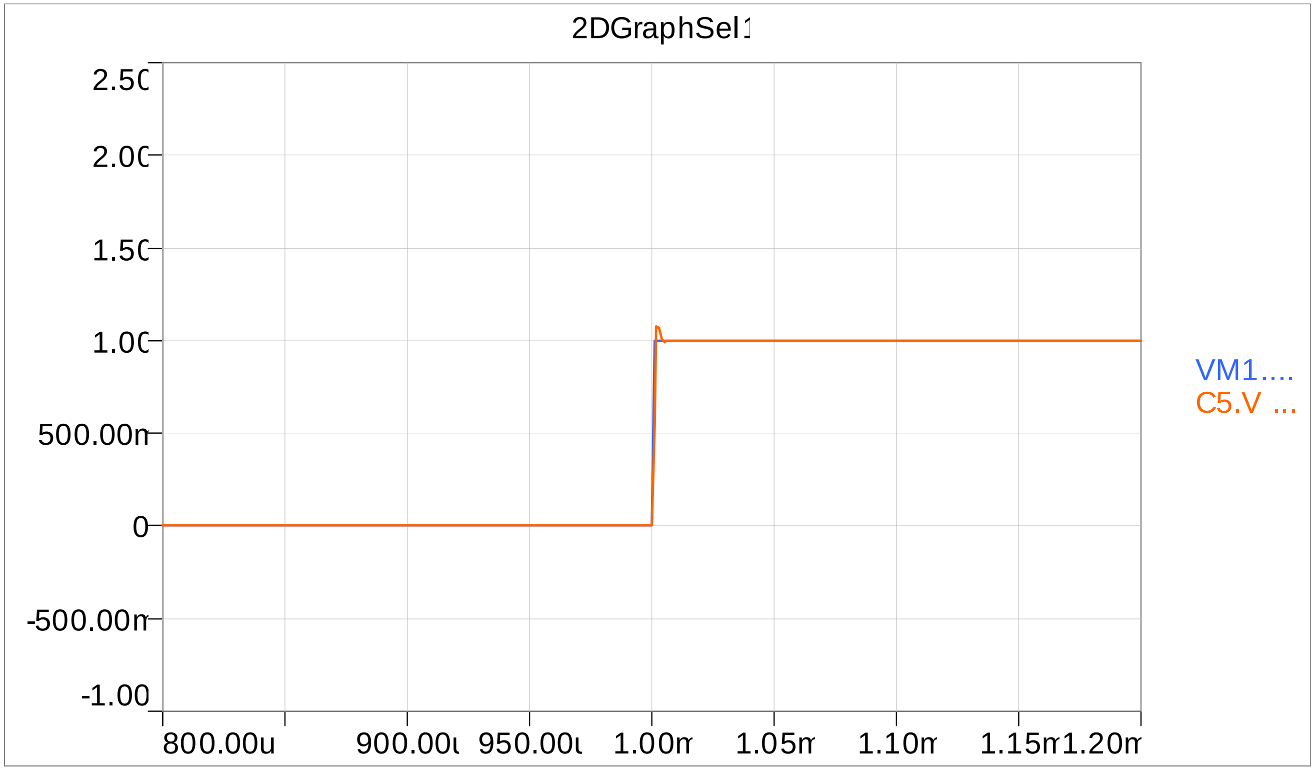
Reflected Waves

- Affected by:
  - Length of cable between drive and motor
  - Rate of rise of voltage (dV/dt)
  - Voltage step size
  - Pulse width

short

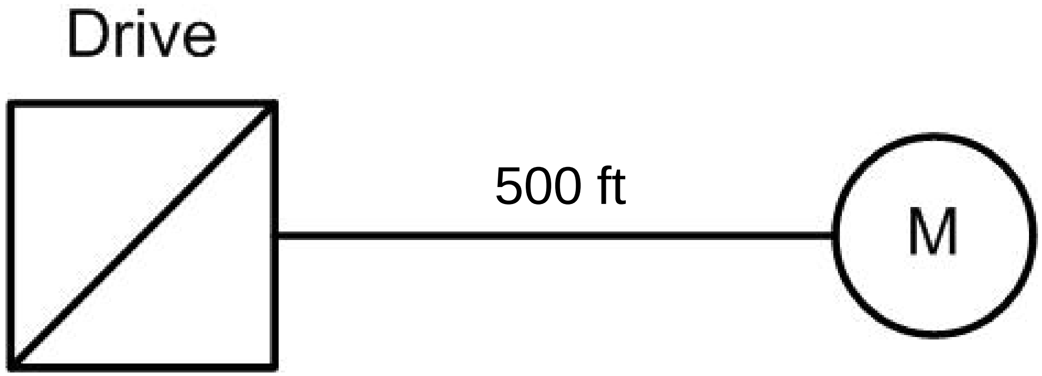


Drive
50 ft
M

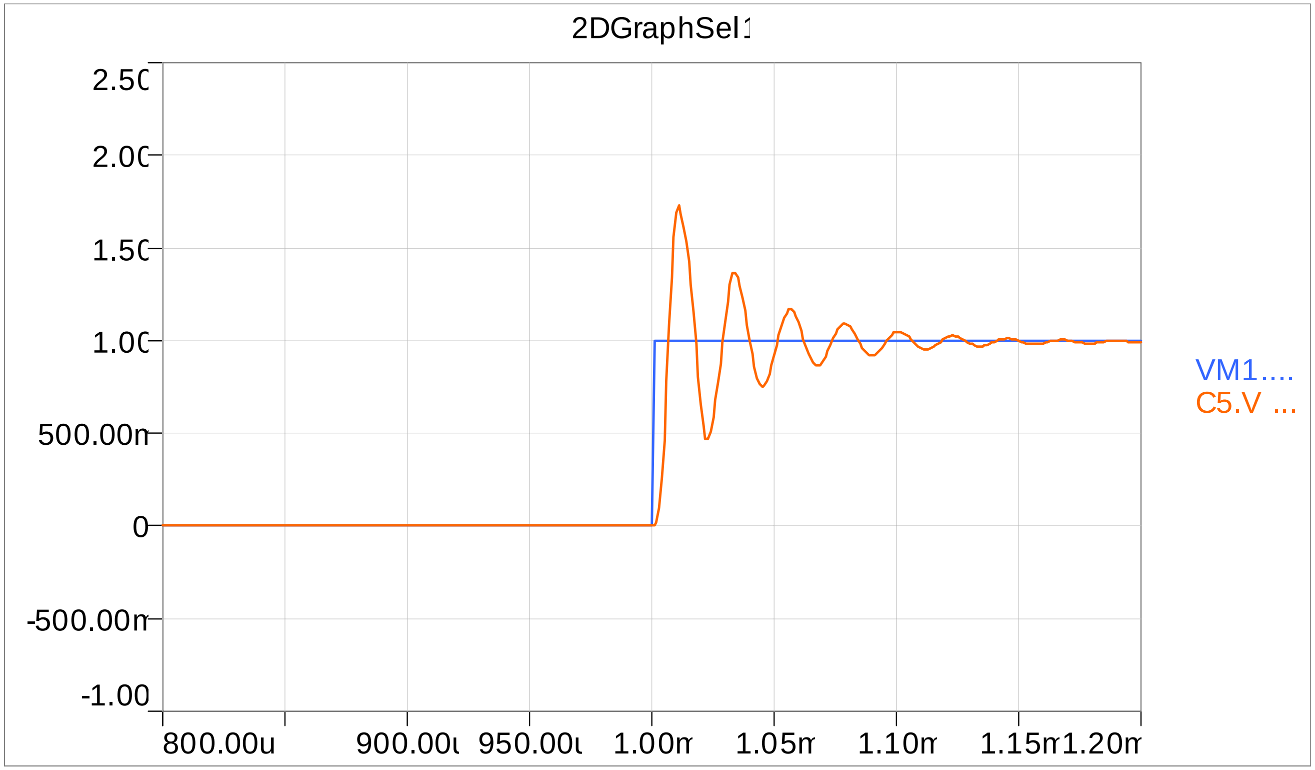


2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

longer

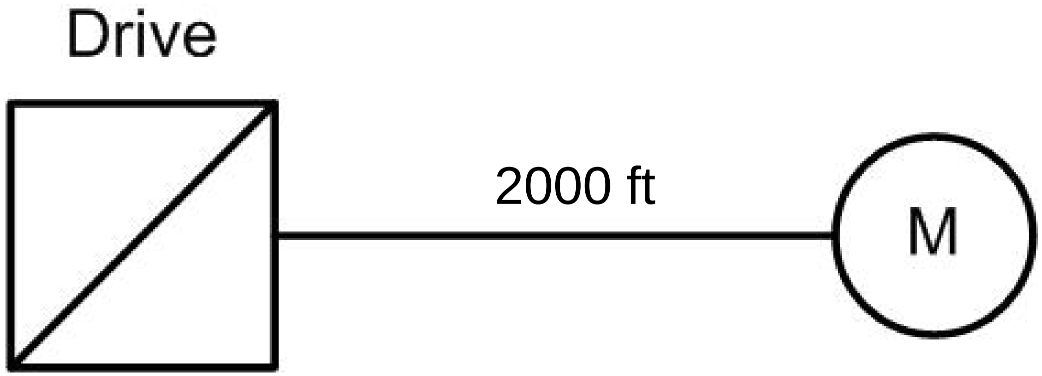


Drive
500 ft
M

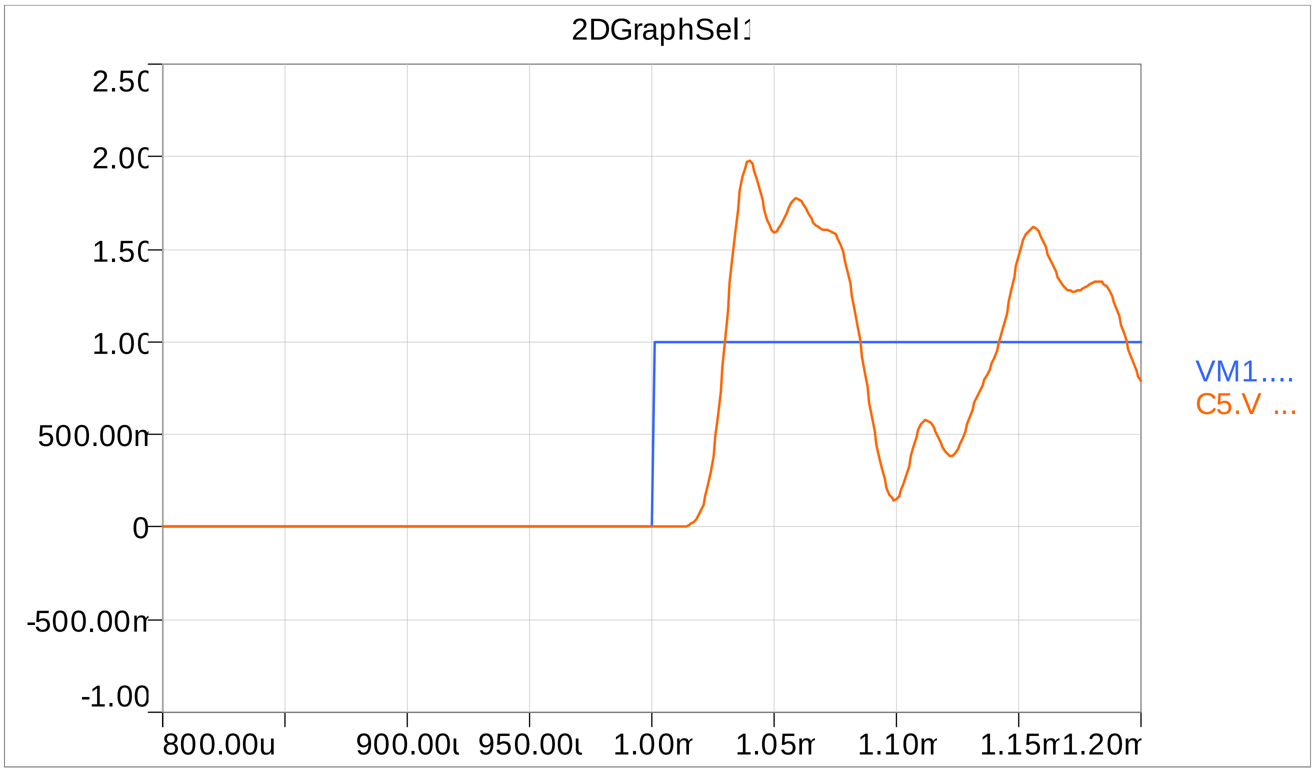


2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

longest



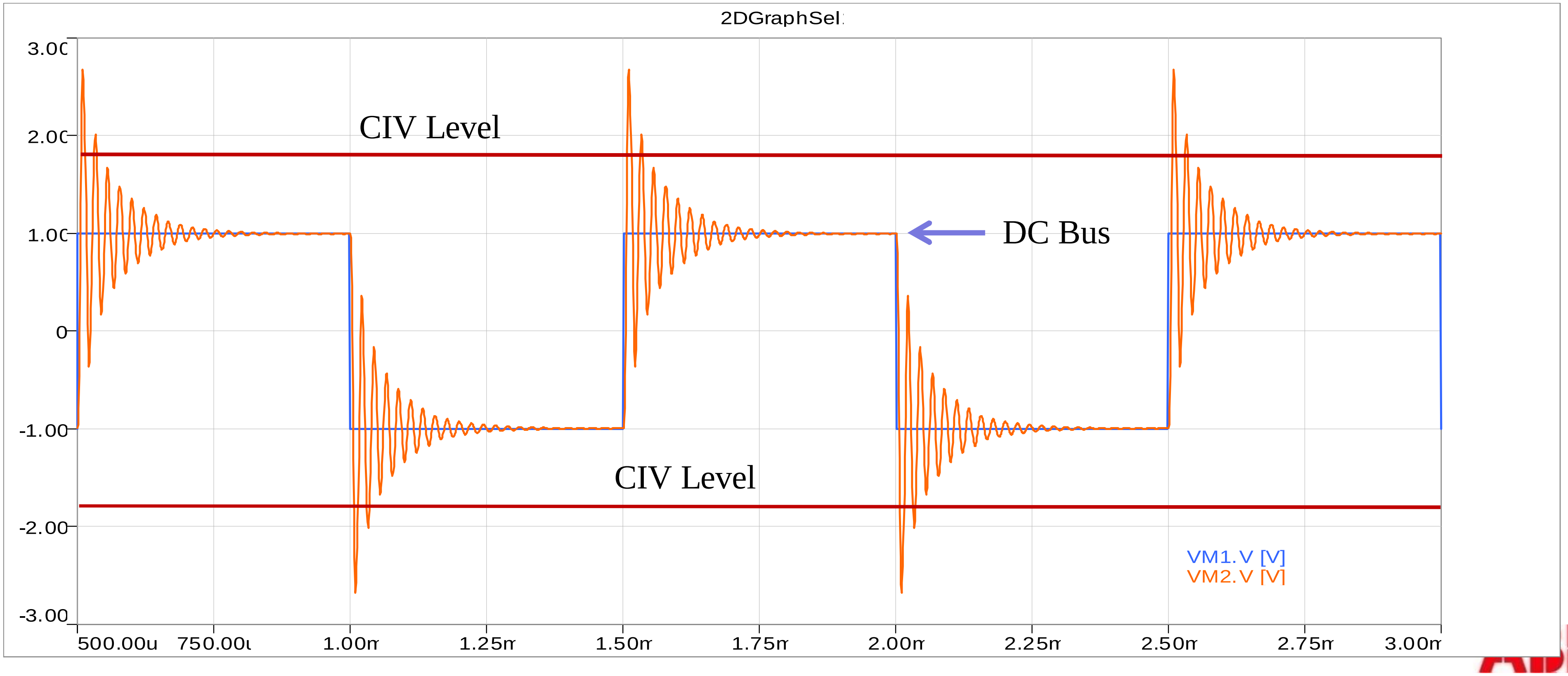
Drive
2000 ft
M



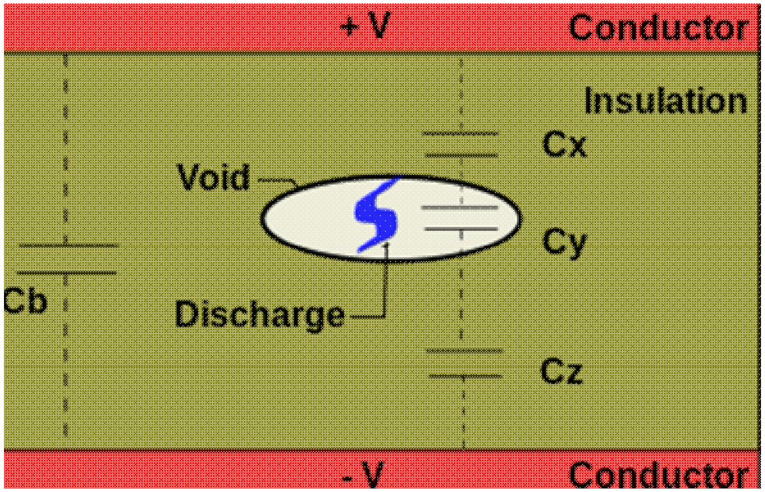
2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

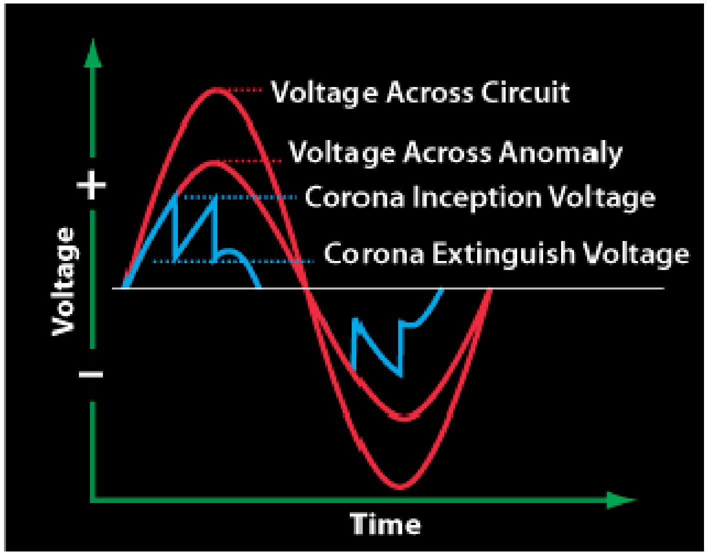
When does PD (Corona) occur?

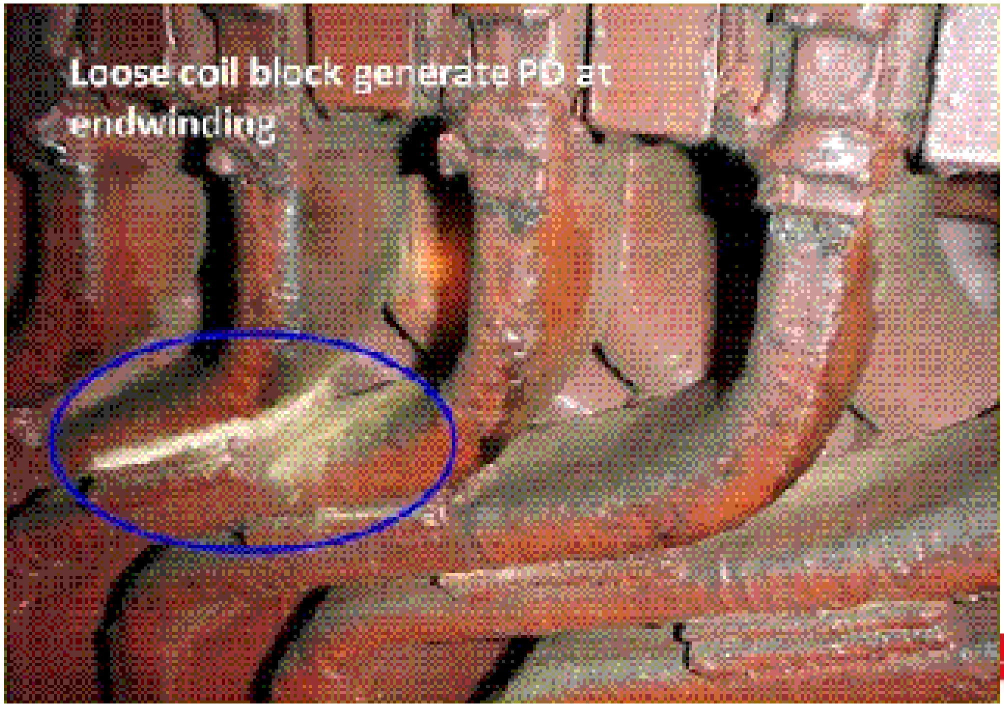
- Reflected wave produces voltage peaks at the motor terminals
- Terminal voltage in excess of the insulation system CIV level will begin the PD / CORONA process
- Excessive voltage causes partial discharges / corona that attacks insulation materials



Partial Discharge

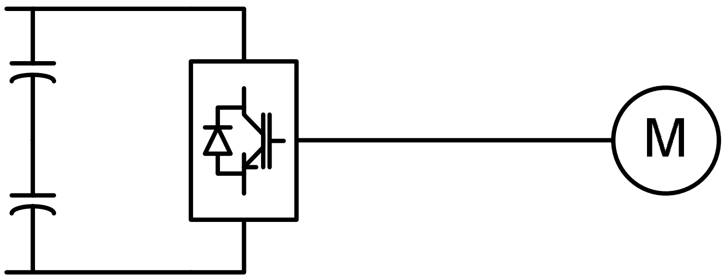




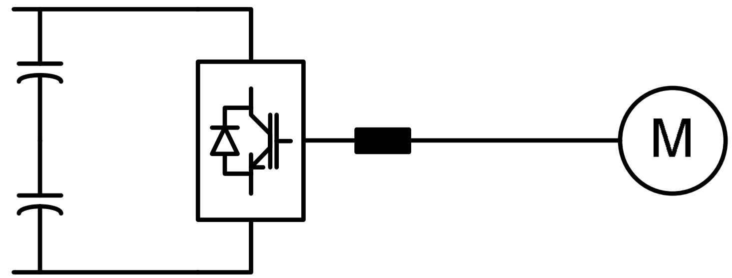


How can we reduce the dV/dt?
Filtering

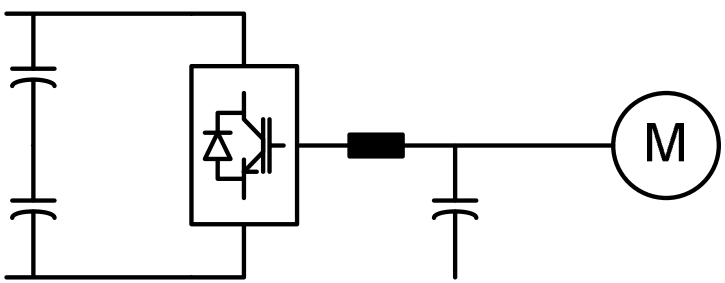
* Used in MV drives



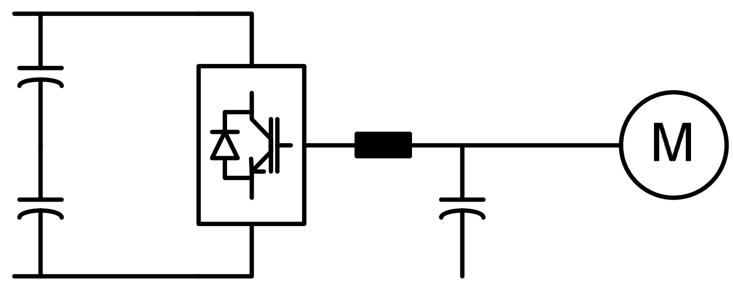
Basic Inverter and Motor



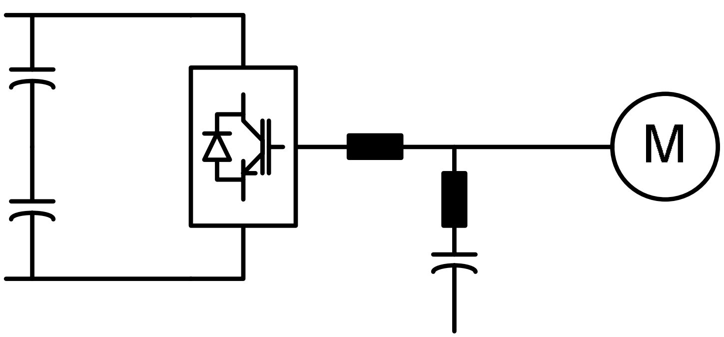
Output Load Reactor



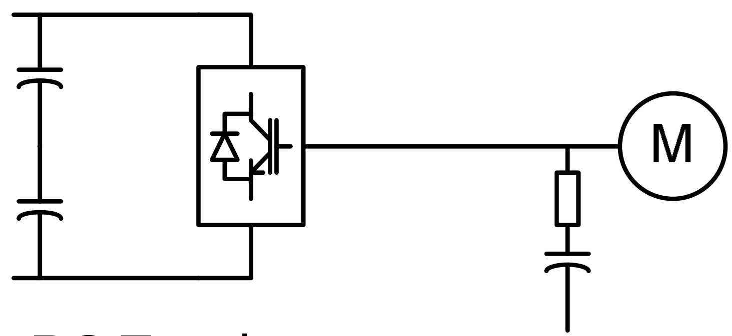
*dV/dt Filter



*Broadband Sinewave Filter

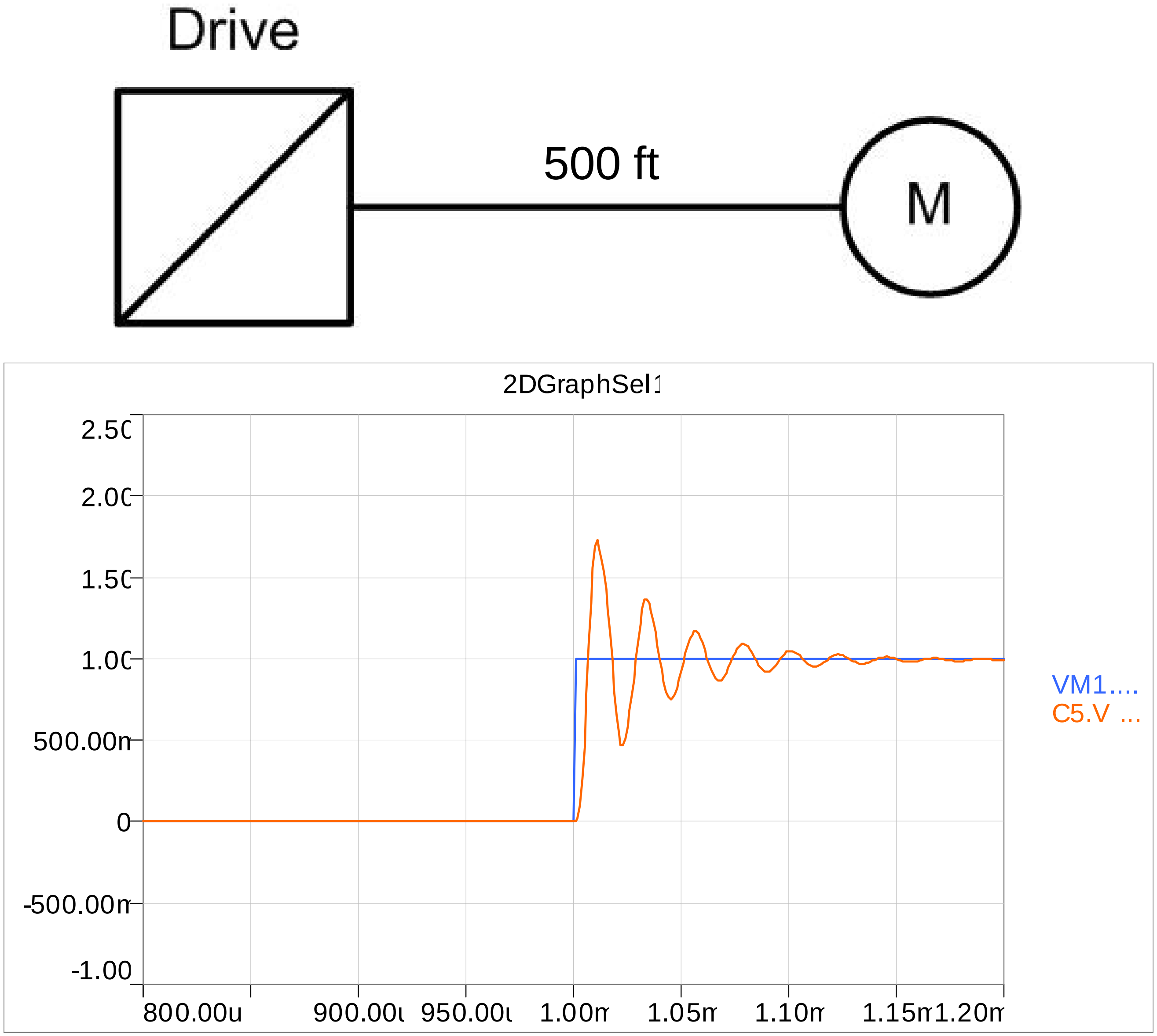


Sinewave Filter



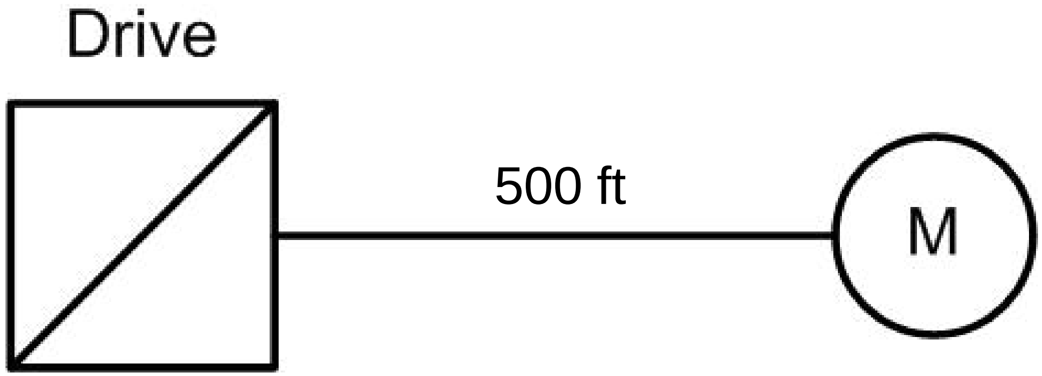
RC Terminator

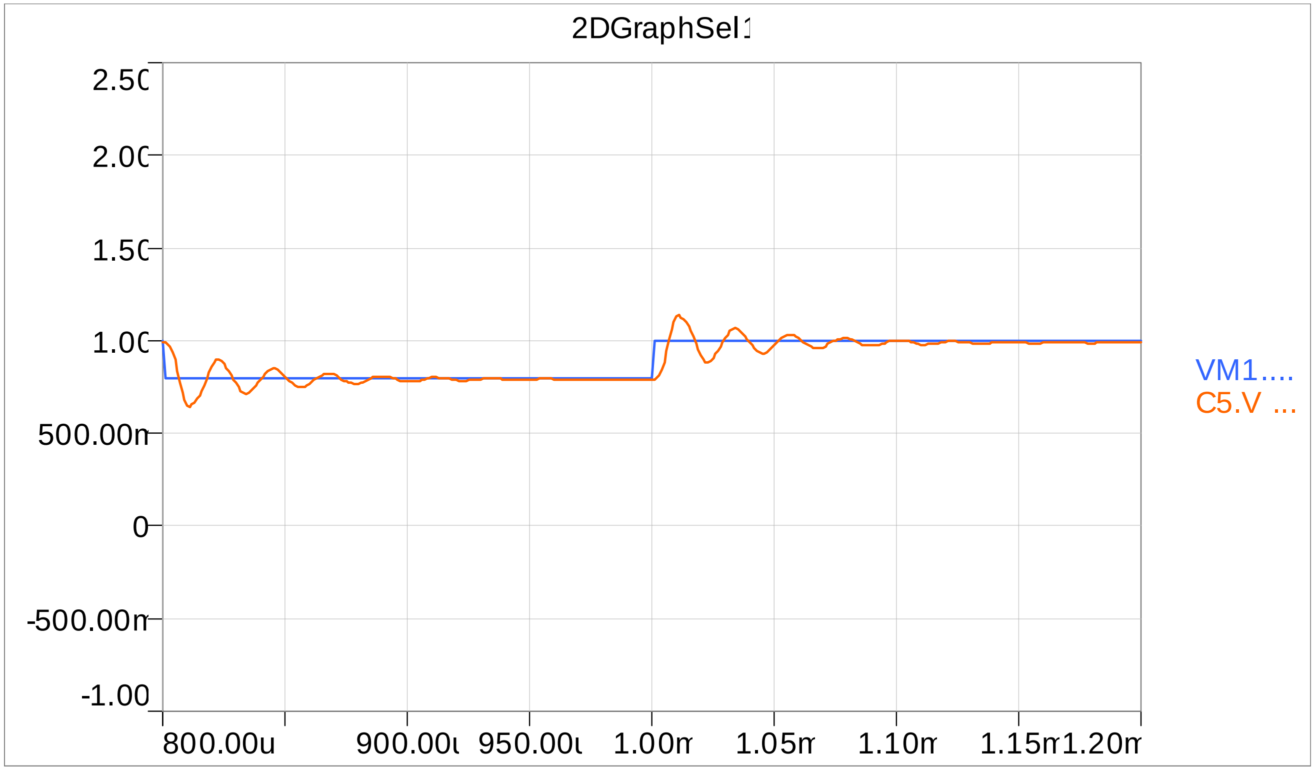
Step size of 100%



Vpk is about 1.7x the Voltage step size

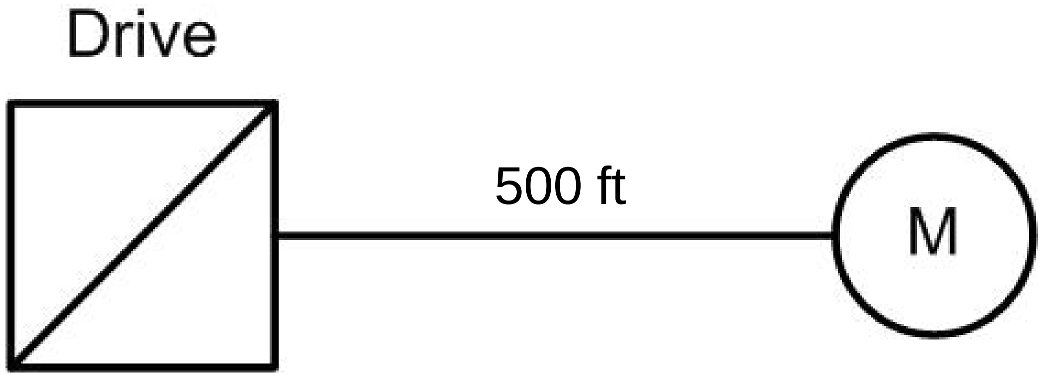
Step size of 20%

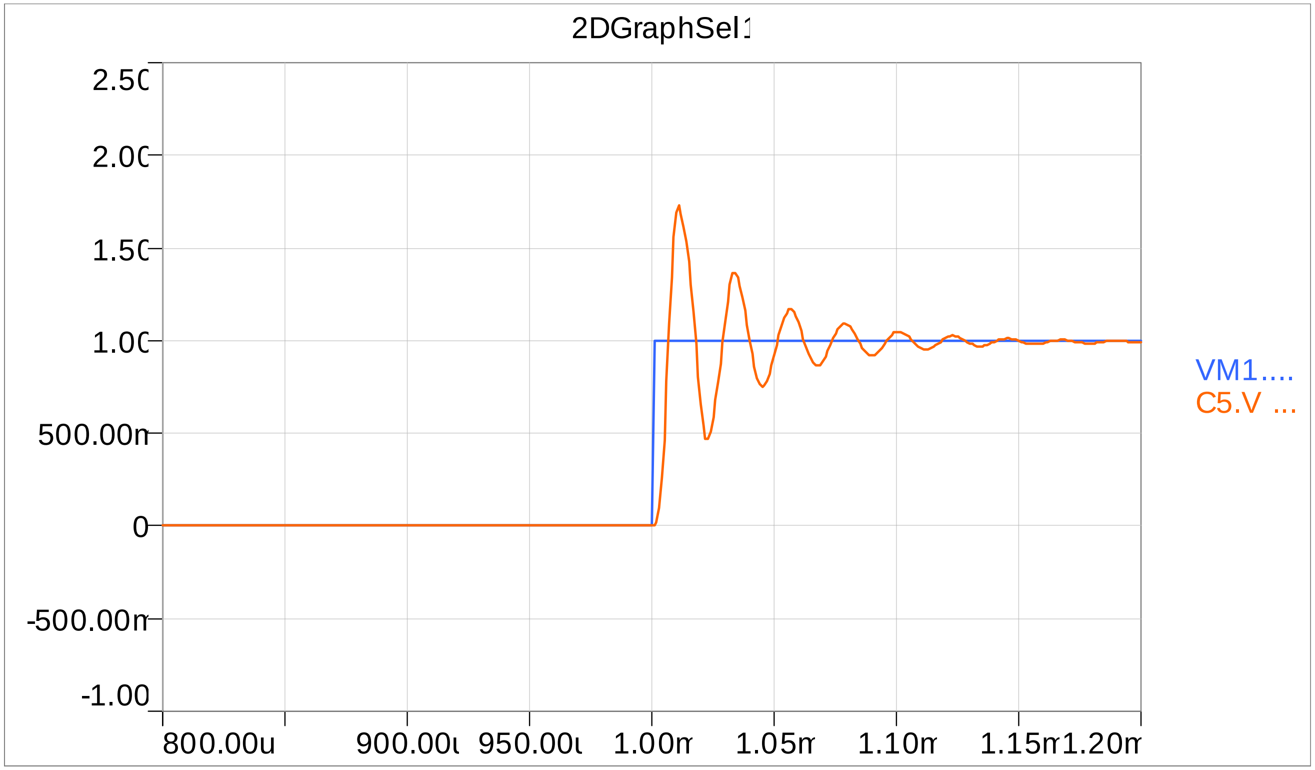




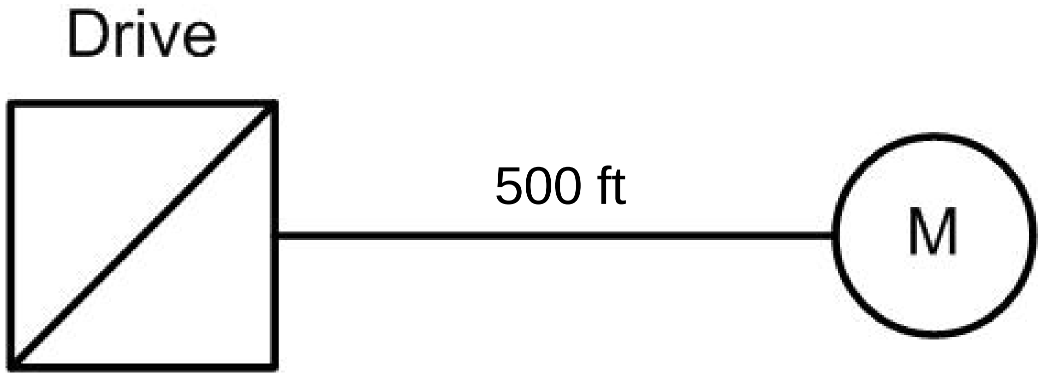
Have small voltage steps

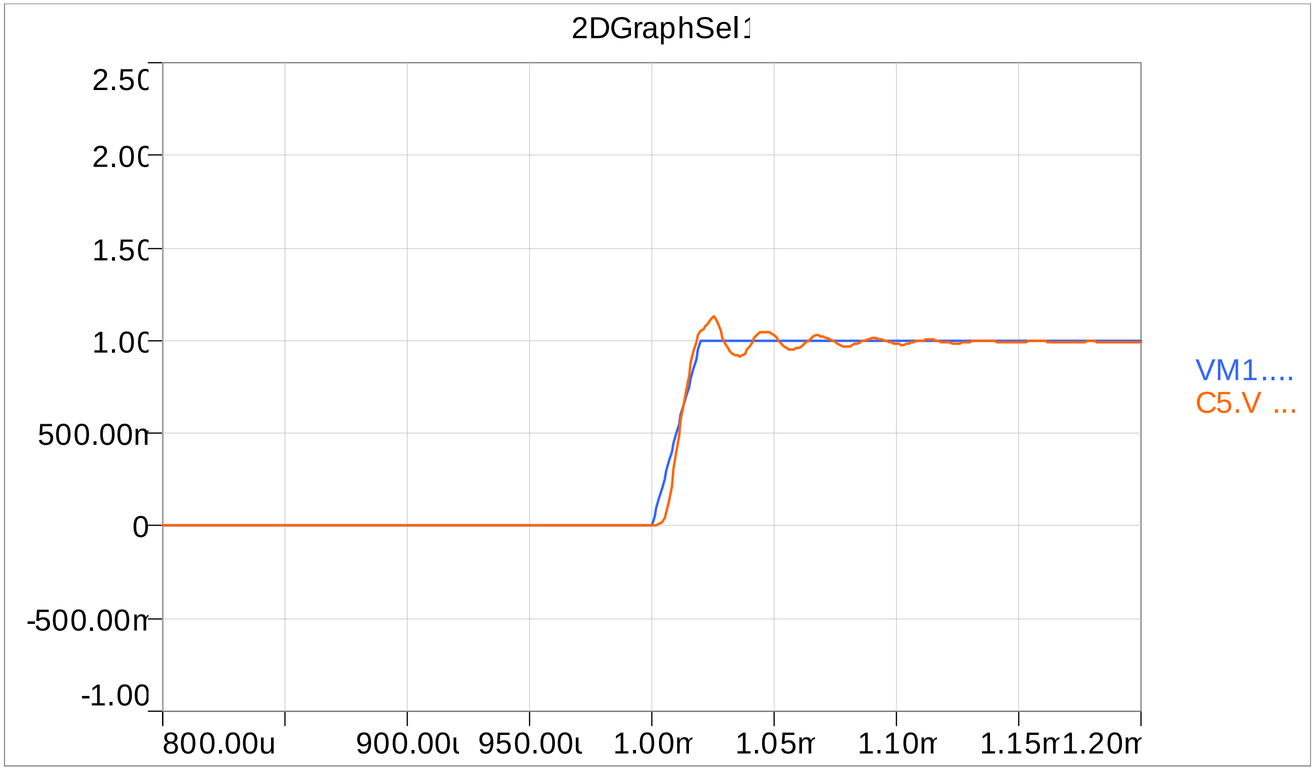
dV/dt = 10,000 V/us



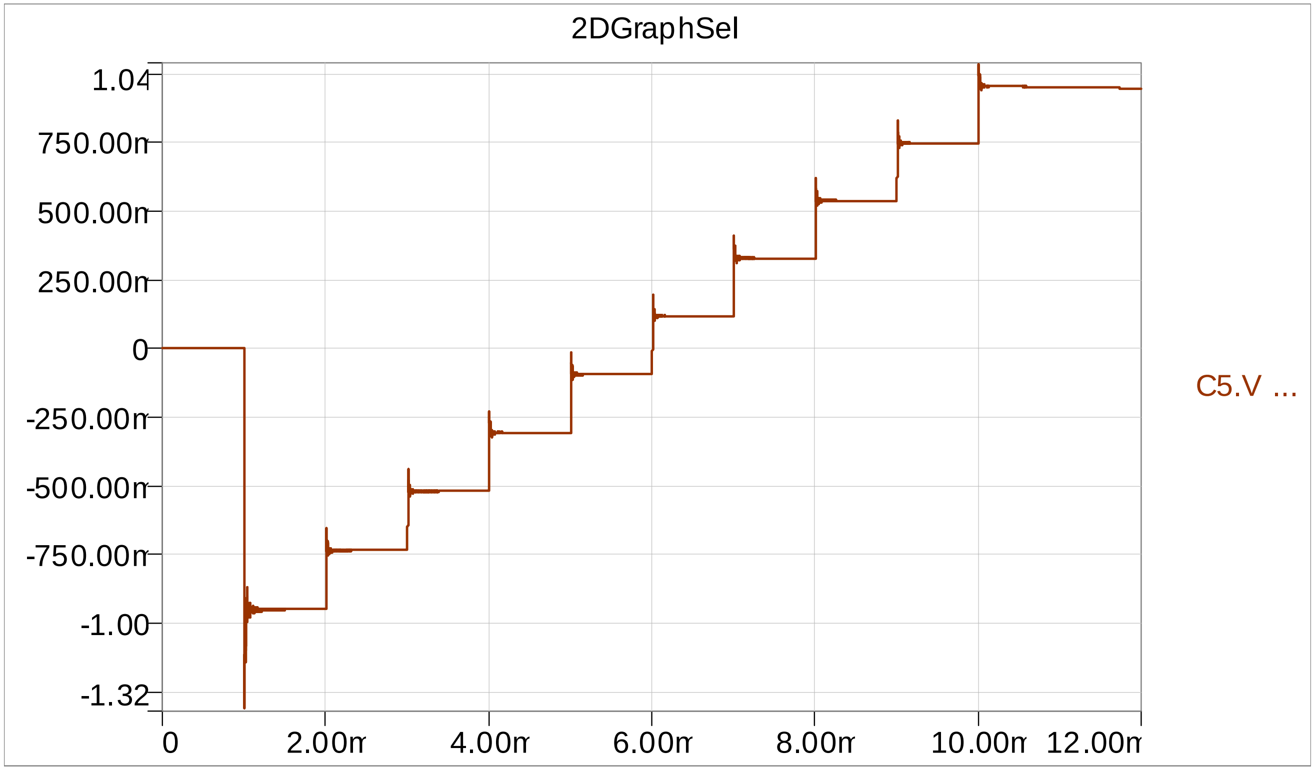


dV/dt = 500 V/us

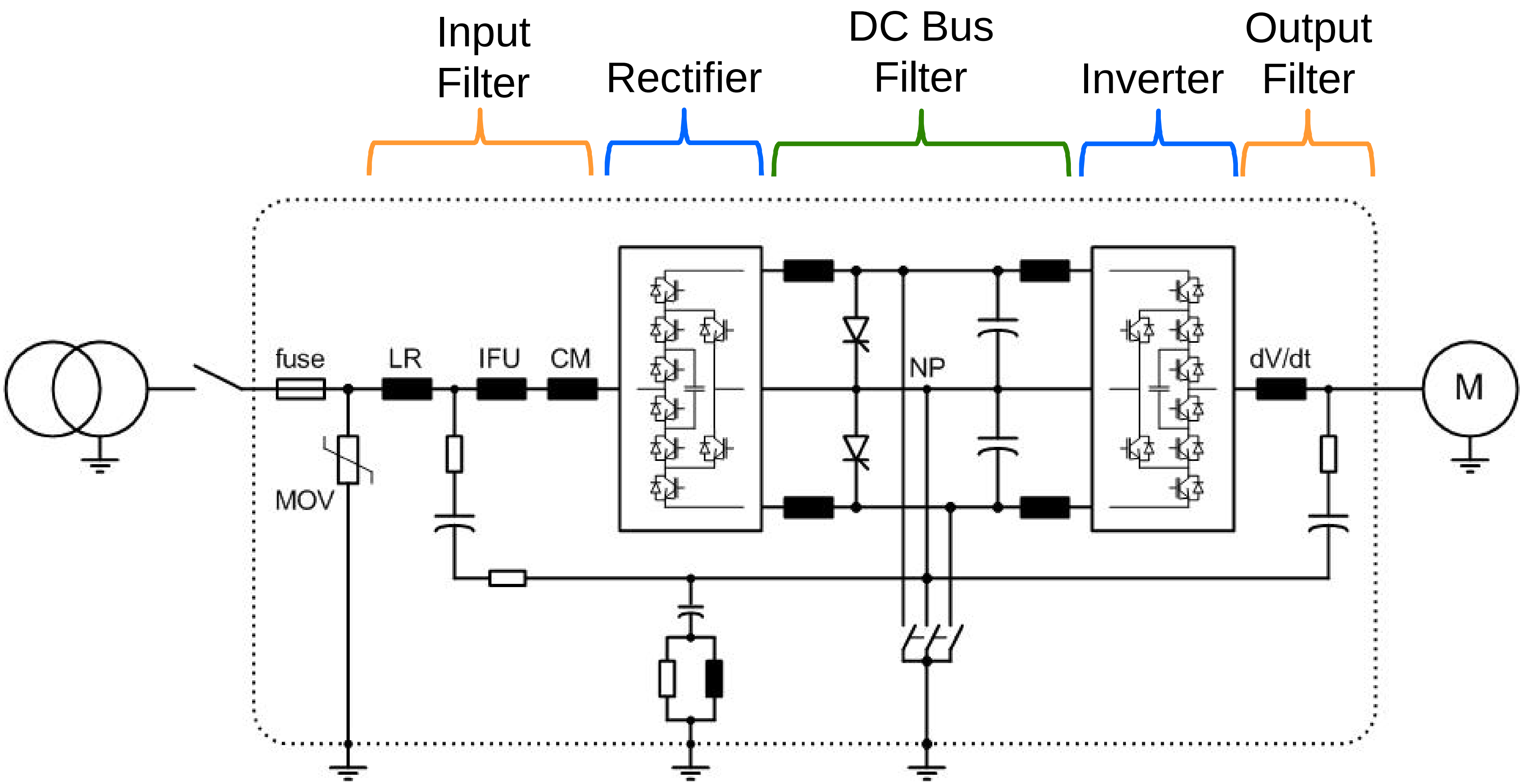

Drive
500 ft
M


2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

Multi-Step Approach, low dV/dt

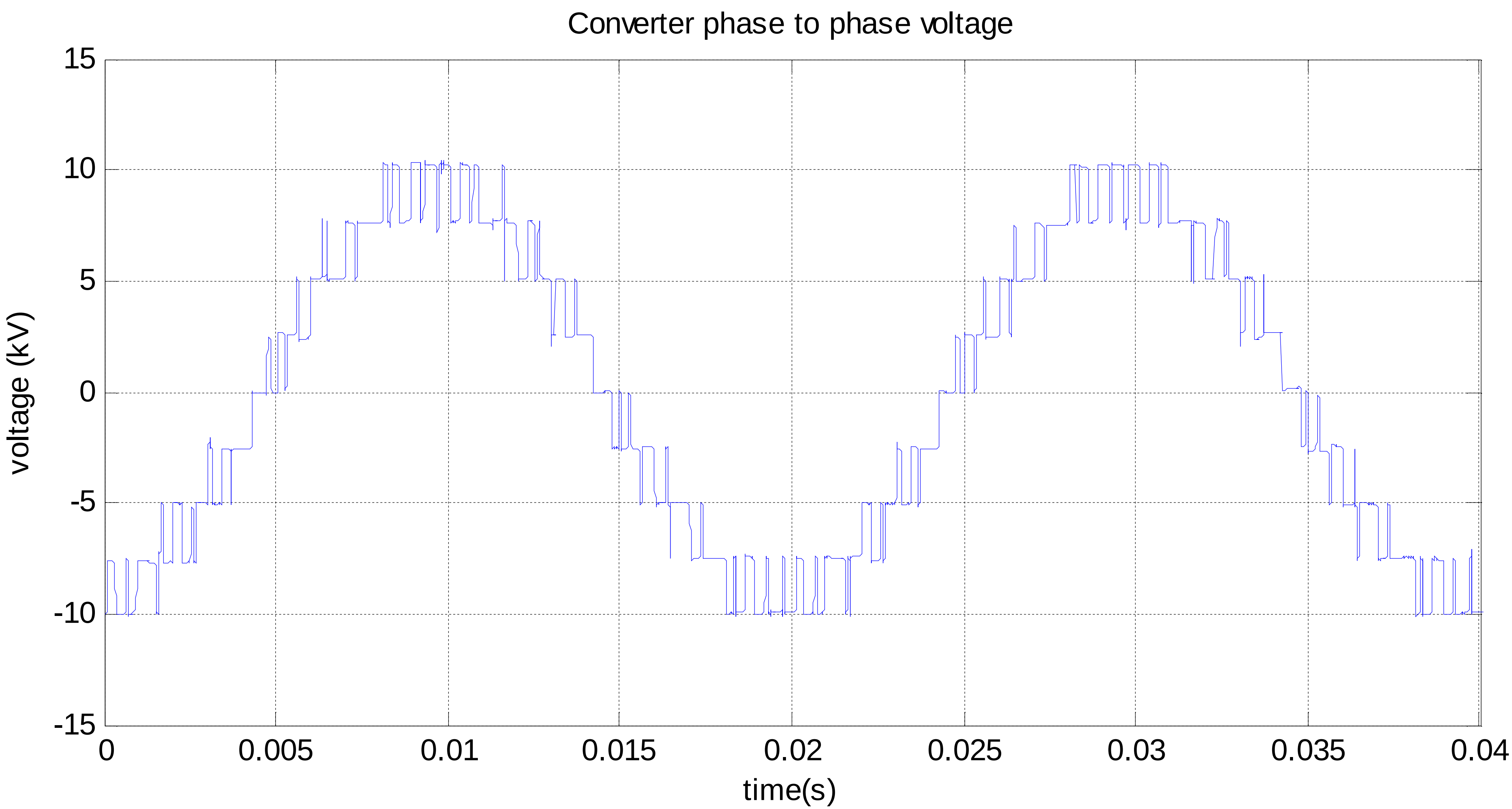


Implementation in a MV Drive



The n-level VSI topology

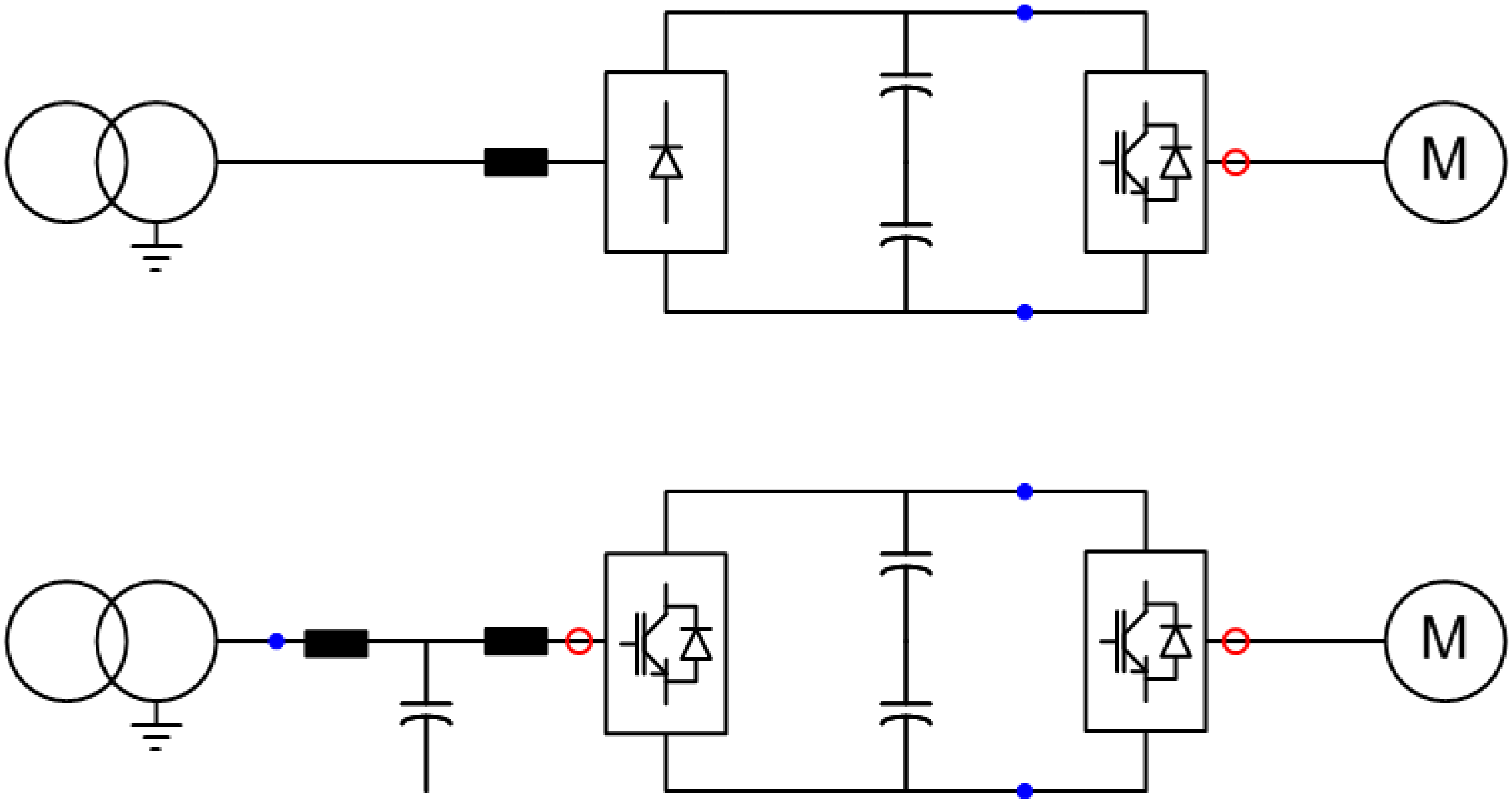
5-Level phase-to-phase voltage levels



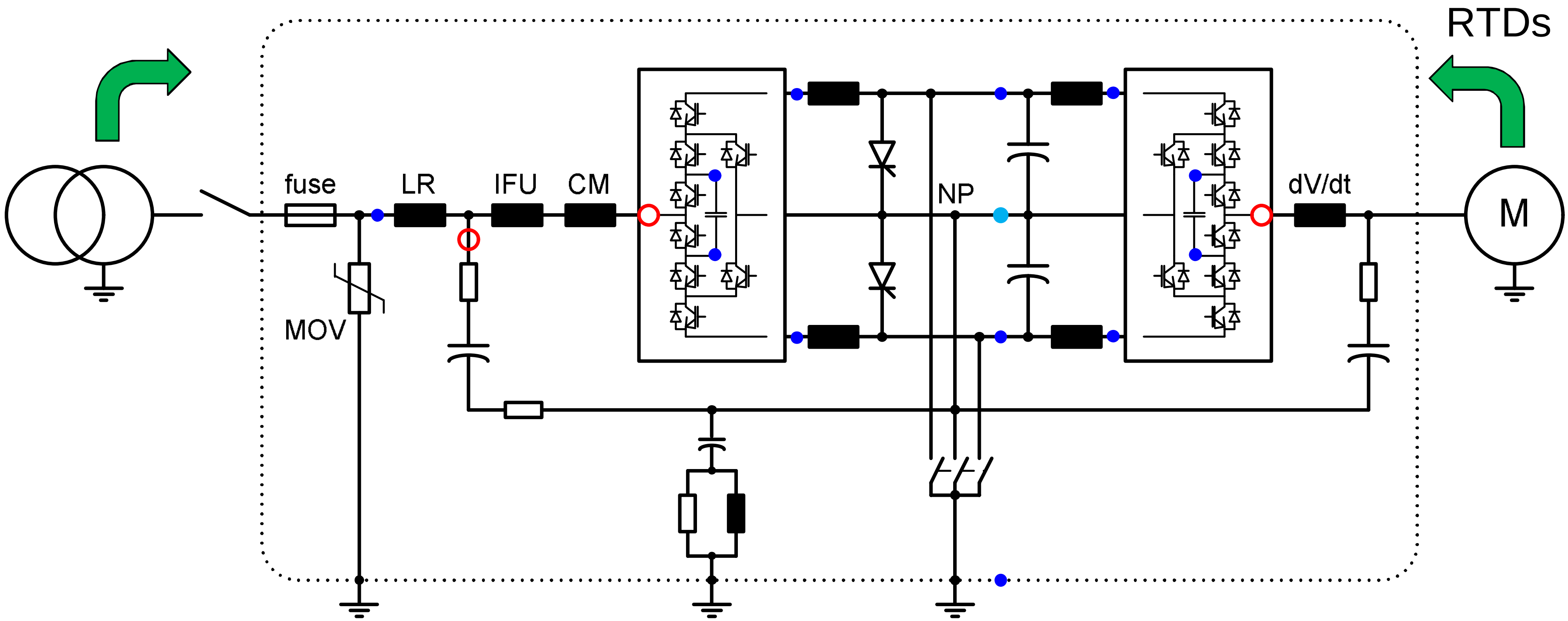
Protection

- PQ Events
- Over-Voltage
- Over-Current

Drive Self Monitoring – LV Drive



Drive Self Monitoring – MV Drive



Operation and Protection Concept

- Try to keep operating
- If unable to due to external issues
  - Alarm, but don't stop
  - Trip
- If catastrophic failure
  - Limit collateral damage
  - Minimal MTTR (mean time to repair)
- Look-out for its motor and transformer, too!
  - Like a big brother or sister

LV Low Harmonic Drives
Active front end drives, what do they look like?

Wall-mounted low harmonic drive ACS800-U11/U31

10 – 125 HP

Cabinet-built low harmonic drive ACS800-17/37

75 - 2800 HP

MV Low Harmonic Drives
Active front end drives, what do they look like?

MV Drives

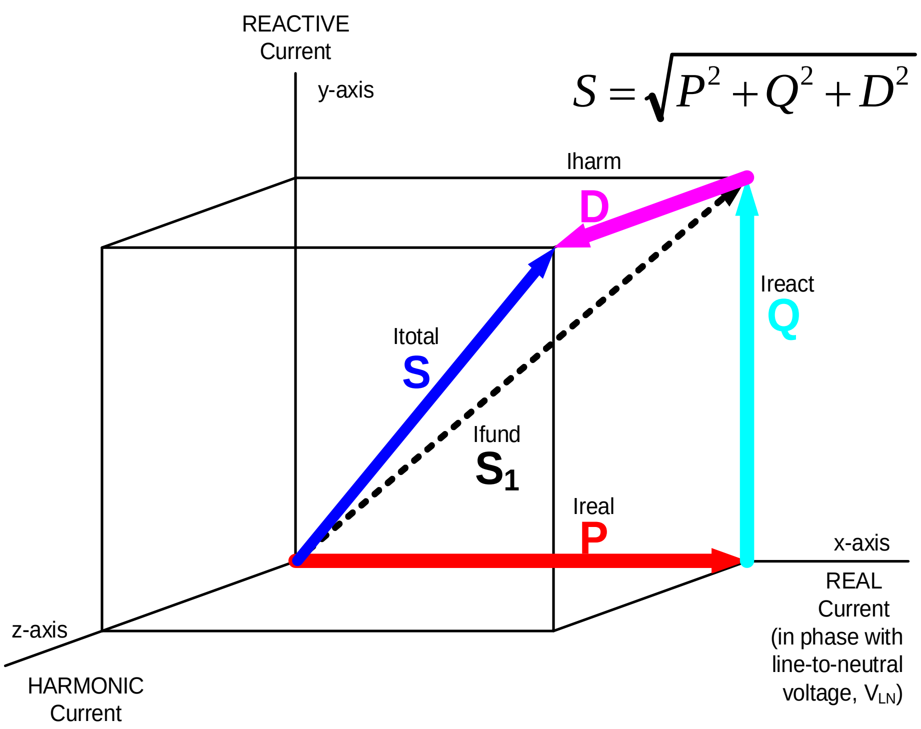
ACS 2000 4kV - 6.9kV

300 – 3,000 HP

ACS 6000 2.3kV, 3.3kV

4,000 – 31,000 HP

Questions?



Rick Hoadley
ABB, New Berlin, WI
(262) 408-1589
Rick.L.Hoadley@us.abb.com

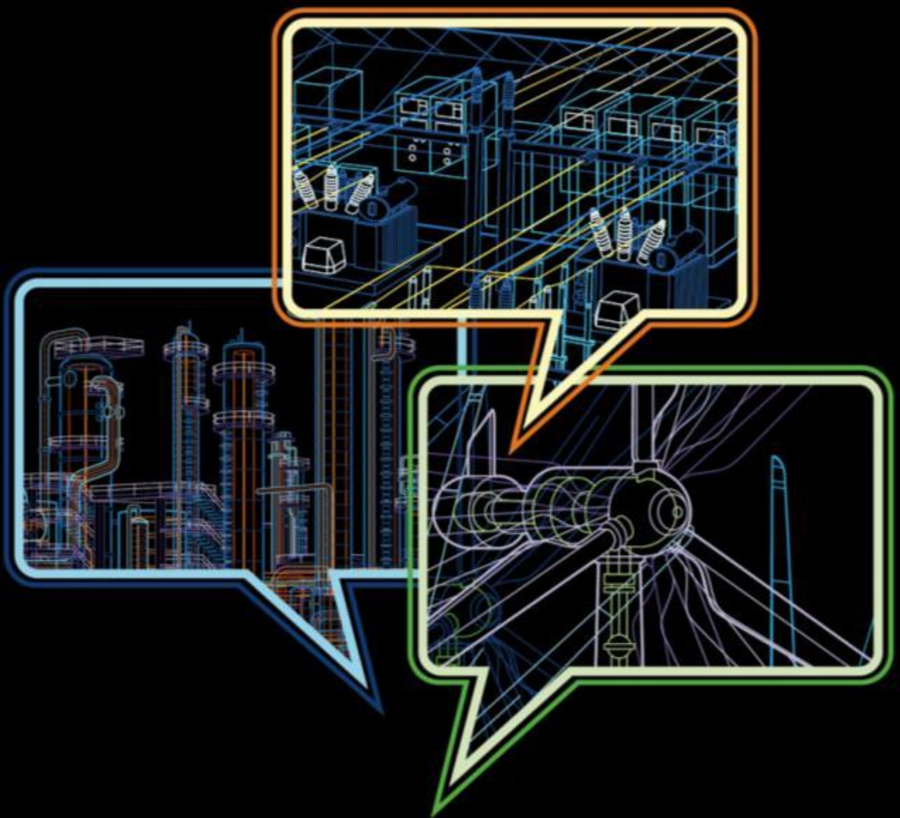
ABB

Power and productivity
for a better world™

ABB

ABB

Harmonics 101 What are they, why do I care, and how do I solve them?



Drive Harmonic Solutions

Speaker name:	Jeff Fell
Speaker title:	Sr. Application Engineer
Company name:	ABB, Inc. (LV Drives)
Location:	New Berlin, WI

Table of Contents

Harmonics –

What are they?

What are the problems?

How much is too much?

What can I do?

What kinds of Power Quality Issues are there?

- Sag
- Dip
- Brown-out
- Under-voltage
- Droop
- Surge
- Swell
- Over-voltage
- Harmonics
- Sub-harmonics
- Interruption
- Outage
- Black-out
- Flicker
- Single-phasing
- Transient
- Spike
- Impulse
- Notch
- Glitch

What kinds of Power Quality Issues are there?

- Sag
- Dip
- Brown-out
- Under-voltage
- Droop

Not Enough

- Surge
- Swell
- Over-voltage

Too Much

- Harmonics
- Sub-harmonics

Odd Stuff

- Interruption
- Outage
- Black-out
- Flicker
- Single-phasing

Nothing's There

- Transient
- Spike
- Impulse
- Notch
- Glitch

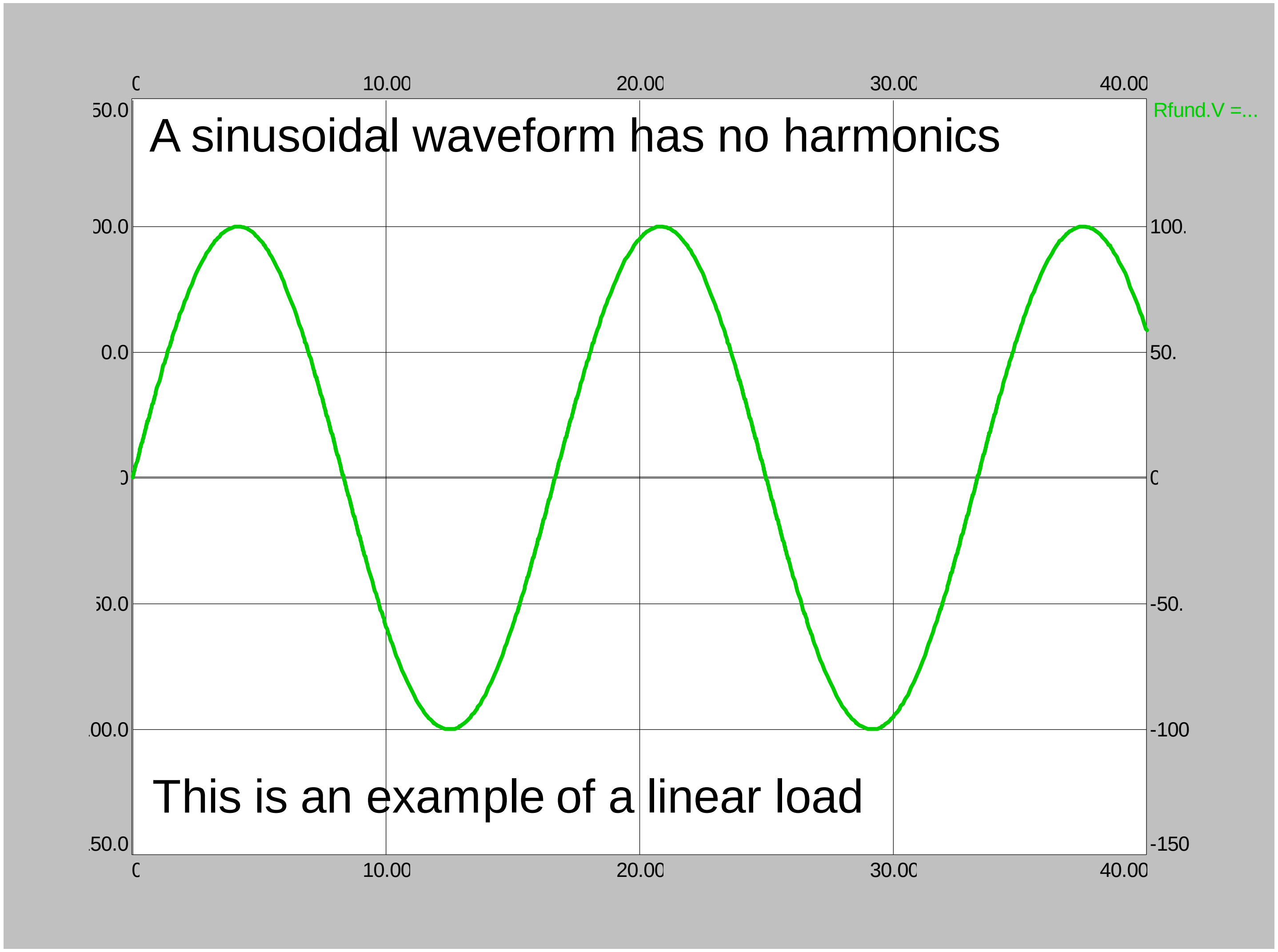
Watch Out !

- "Something weird"

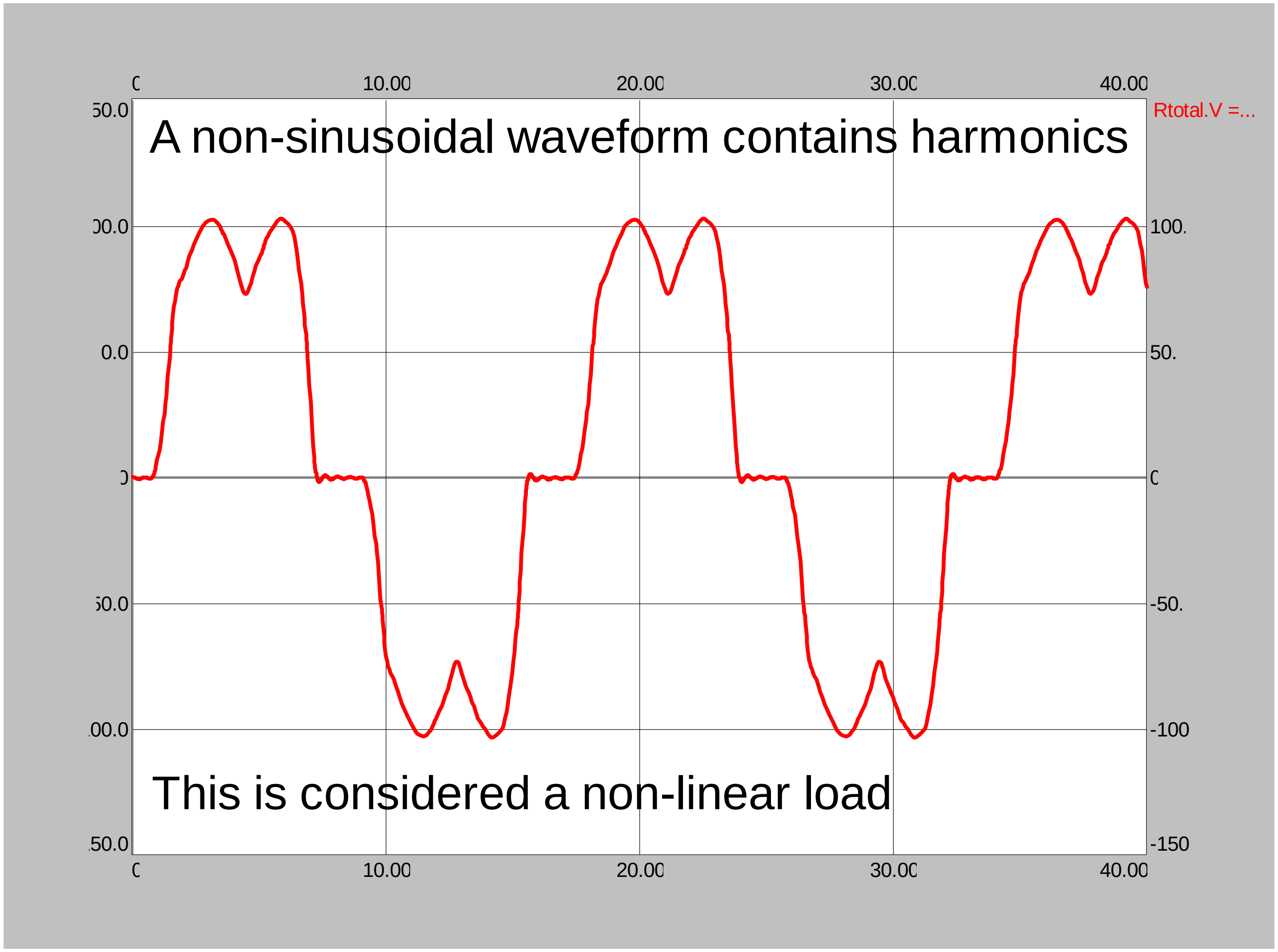
?

ABB

What are Harmonics?



What are Harmonics?



Harmonics — What?
Basic concept

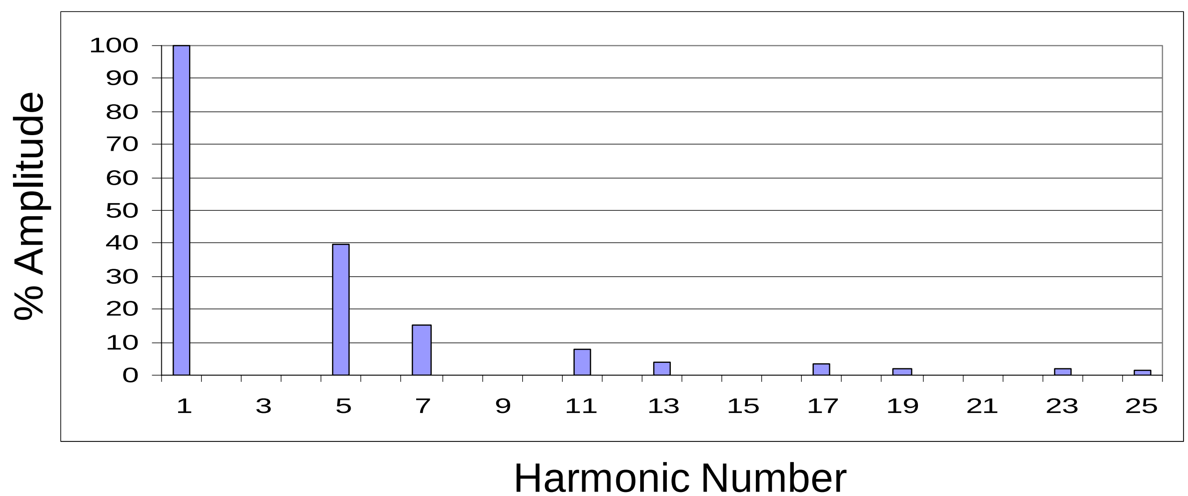
- Harmonics are associated with non-linear loads which draw non-sinusoidal currents from a essentially sinusoidal voltage source (i.e. load current doesn't look like applied voltage):
  - Non-incandescent lighting
  - Computers
  - Uninterruptible power supplies
  - Telecommunications equipment
  - Copy machines
  - Battery chargers
  - Any device with a solid state AC to DC power converter
  - Adjustable speed drives

Analysis

Frequency, Amplitude, Phase Angle

- Harmonics are simply integer multiples of the fundamental **frequency**
  - for example, if 60Hz is the fundamental (sometimes referred to as the 1st harmonic), then the 2nd harmonic is 120Hz, the 3rd harmonic is 180Hz, etc.

- Any non-sinusoidal waveform can be created by the addition of harmonics at various **amplitudes** and **phase angles**

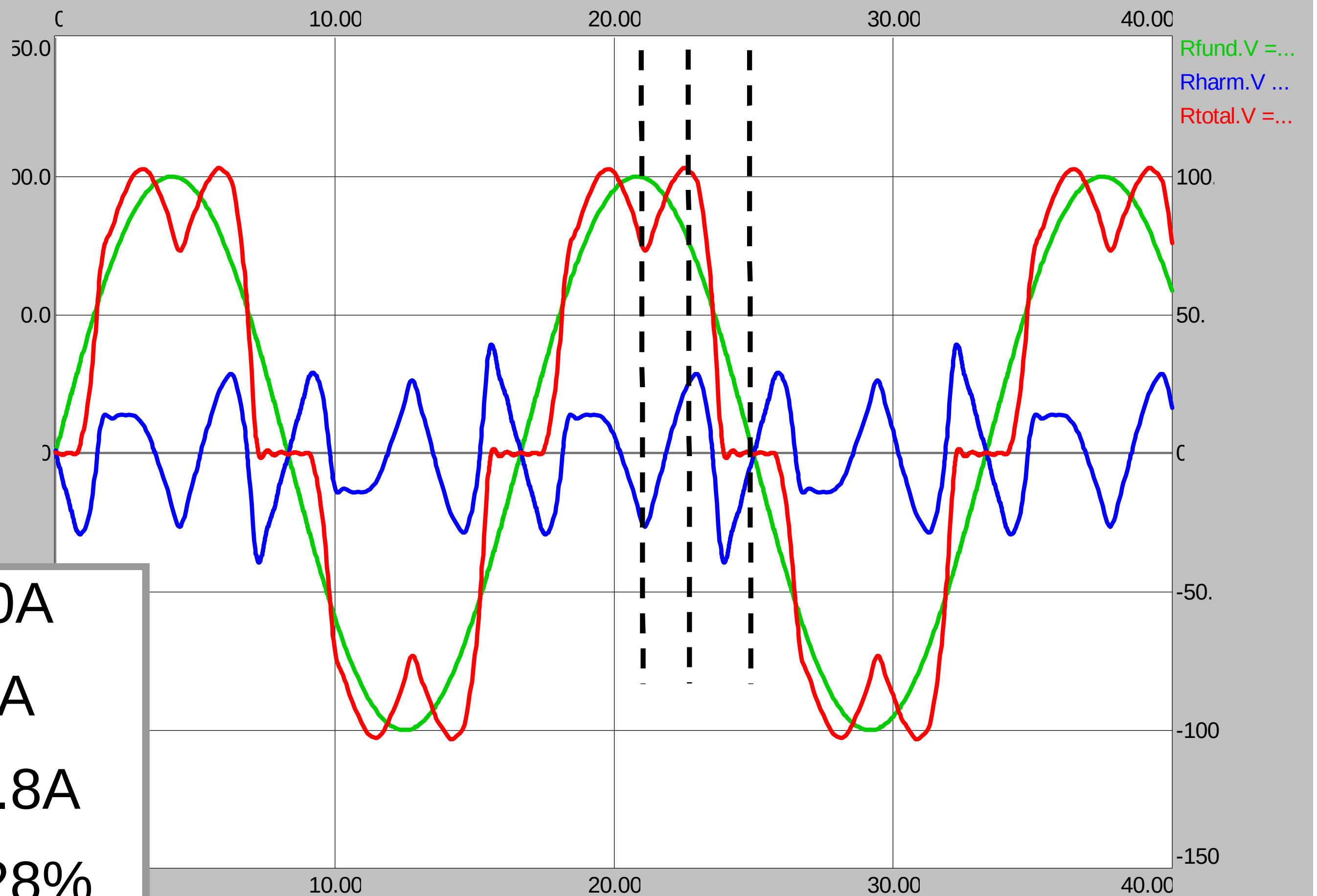


Analysis
Frequency, Amplitude, Phase Angle

Waveforms: Itotal = Ifund + Iharm

RMS: Itotal = sqrt (Ifund^2 + Iharm^2)

The differences are the harmonics



Iharm = 20A

Ifund = 70A

Itotal = 72.8A

I(THD) = 28%

What Is I(THD)?

I(THD) = Iharm / Ifund

So, Iharm = I(THD) * Ifund

I(THD) is a ratio between two numbers,
it does not stand alone!

We can decrease I(THD)
by either decreasing Iharm or increasing Ifund

Root Cause of Problems with Other Equipment

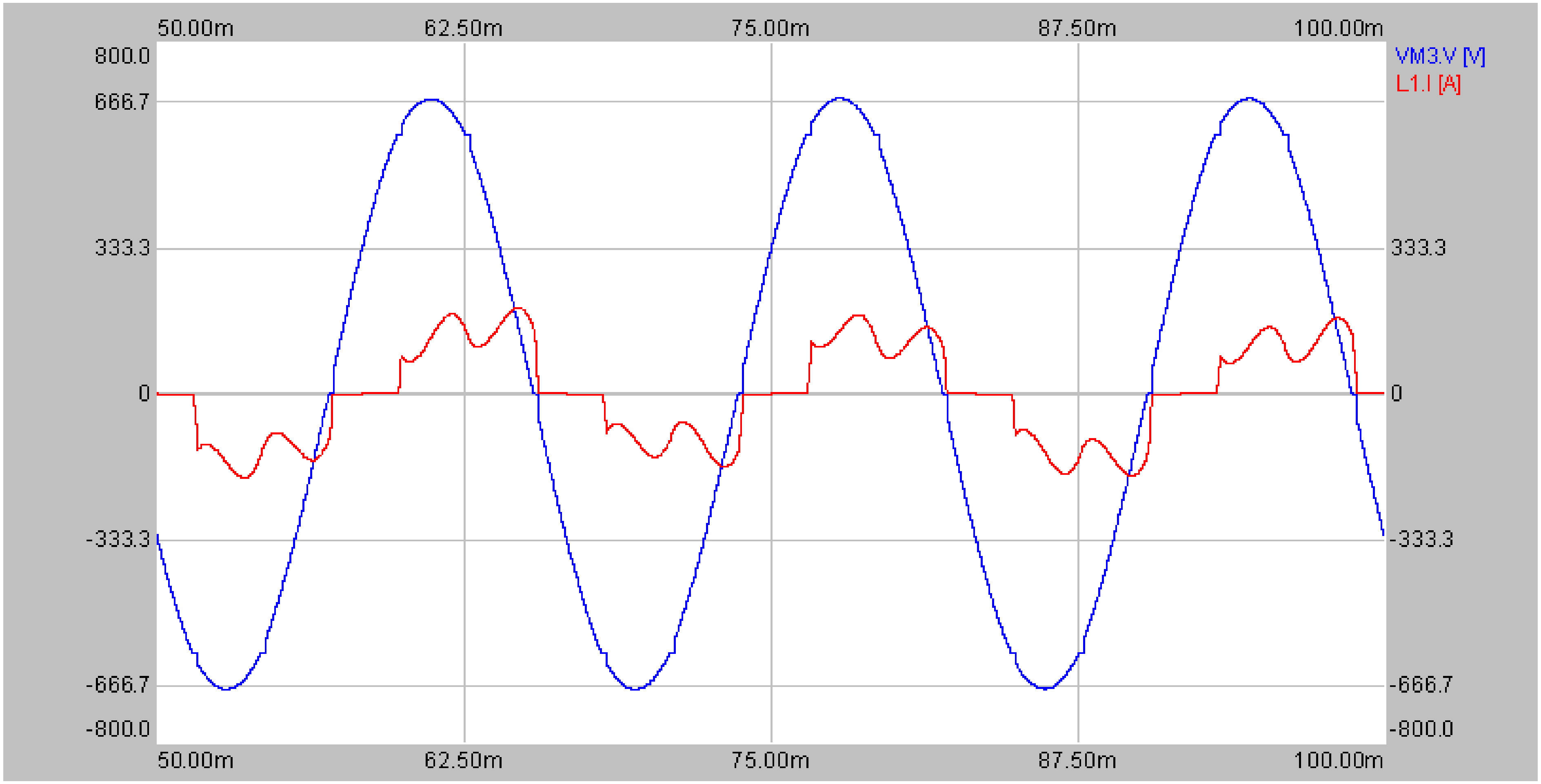
Current Harmonics

create

Voltage Distortion

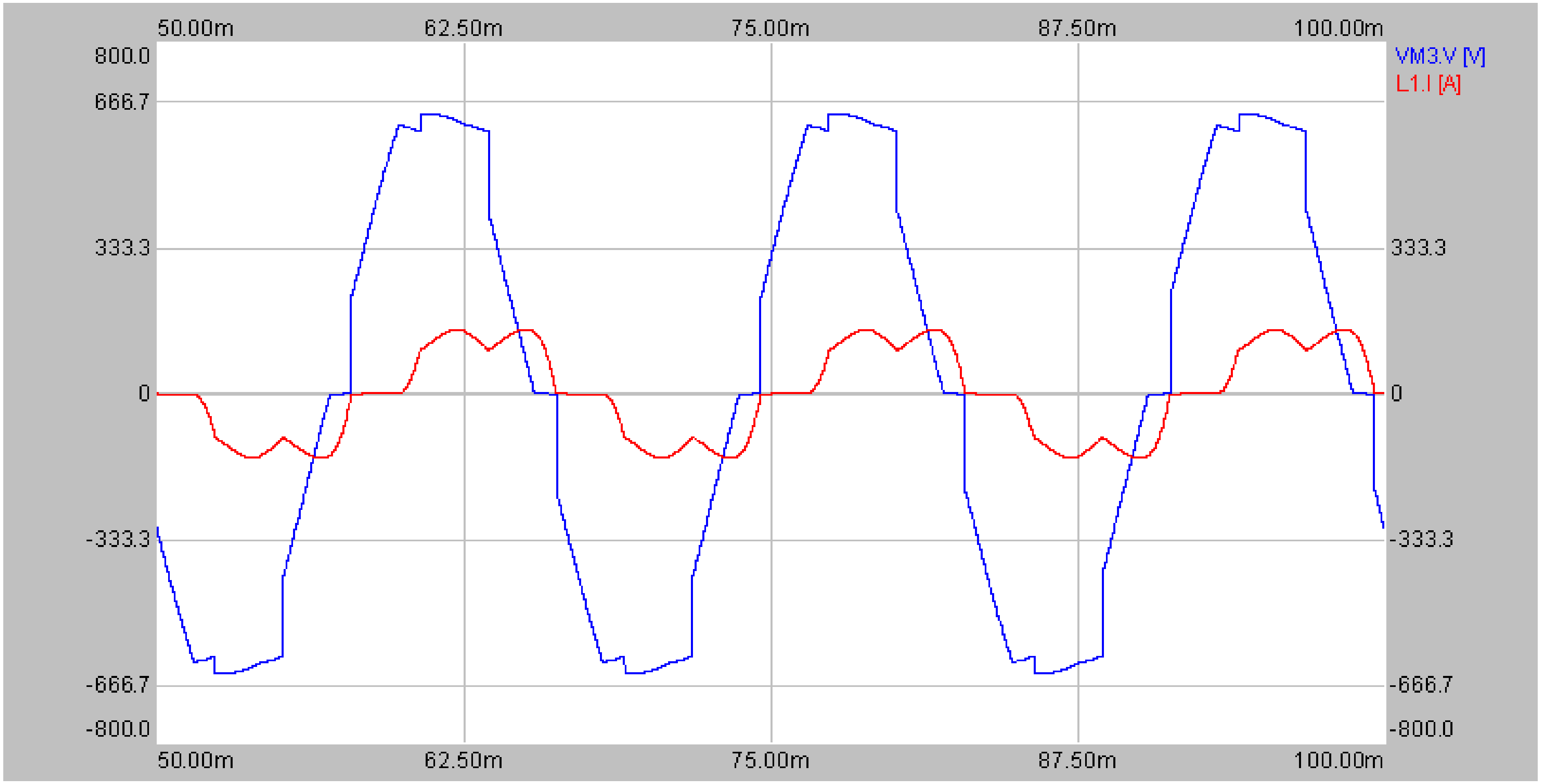
ABB

1500kVA, 75hp



Ithd = 37% Vthd = 0.9%

75kVA, 75hp



Ithd = 29%   Vthd = 9.3%

What other problems do they cause?

- Increased Utility current requirement
  - **Inability to expand or utilize equipment**
  - **Larger wire size needed = increased installation costs**
- Component overheating
  - **Distribution transformers, generators & wires**
- Reduced Utility power factor
  - **Increase in utility costs**
- Equipment malfunction
  - **Due to multiple or loss of zero crossing**
  - **Due to voltage distortion such as flat topping**
- Excitation of Power System Resonance's creating over-voltage's
  - **If PFCC in system**

How much is too much?

IEEE Std 519-1992

IEEE Std 519-1992

(Revision of IEEE Std 519-1981)

IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems

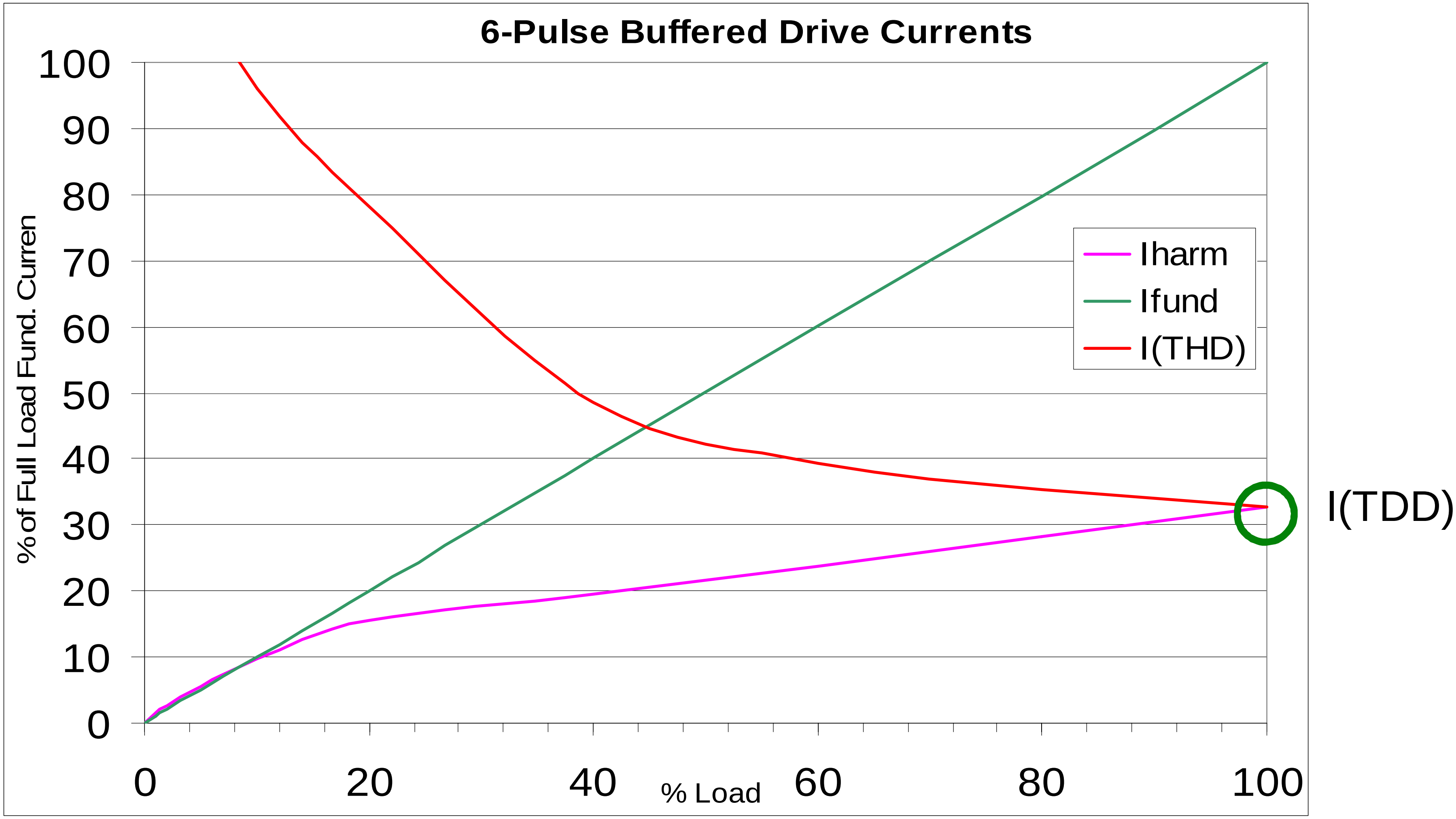
What are the IEEE 519-1992 standards?

Harmonic Voltage Limits	Table 10.2
Low-Voltage Systems	
Application	Maximum THD (%)
Special Applications - hospitals and airports	3.0%
General System	5.0%
Dedicated System - exclusively converter load	10.0%

Current distortion Limits for General Distribution Systems (120V through 69,000V)						
Maximum Harmonic Current Distortion in Percent of Iload						
Isc/Iload	<11	11<=**h**<17	17<=**h**<23	23<=**h**<35	35<=**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						
						Table 10.3
Isc=maximum short circuit current at PCC						
Iload=maximum demand load current (fundamental frequency component) at PCC						

Rsc = Isc / Iload

How does motor load affect I(THD)?



NOTES:

I(THD) = Iharm / Ifund

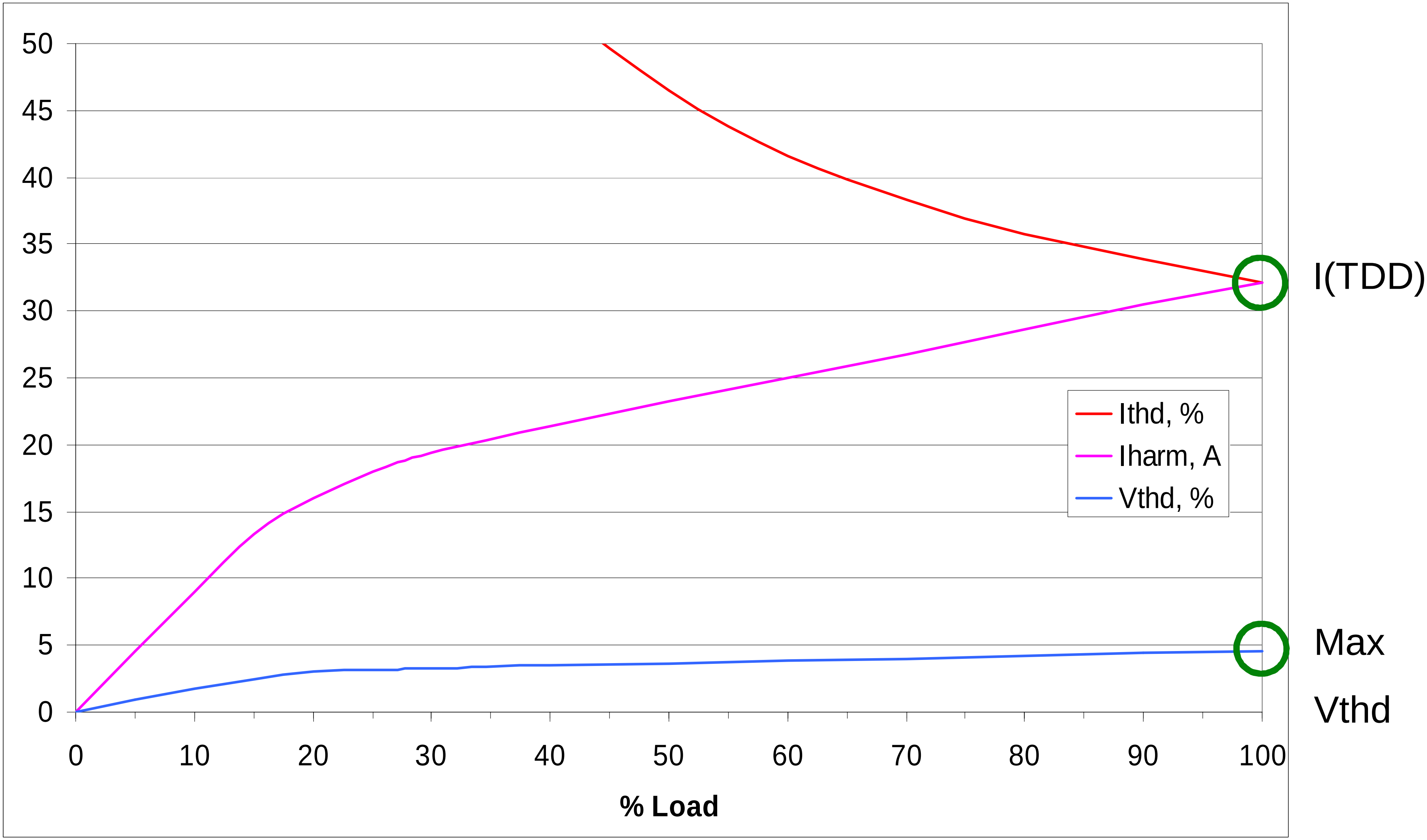
I(THD) **increases** as load decreases

Ifund **decreases** as load decreases

Iharm **decreases** as load decreases

(drive is at full speed)

Vthd vs Load, What is Worst Case?



100hp drive on 250kVA xfmr, 6%

The Goal of IEEE 519

Thou

Shalt Not

Mess Up

Thy

Neighbor's

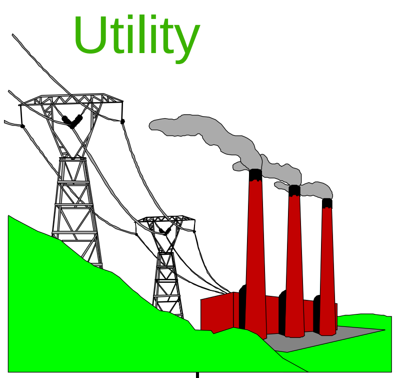
Line Voltage

IEEE 519-1992: PCC Definition

- PCC: Point of Common Coupling
  - Defined at the point in a power one-line where other customers are connected or could be connected (metering location)
  - Defined at the point where linear and non-linear loads join together
  - Industry often misapplies & misinterprets the intent of the standard
    - Asks that equipment manufacturers meet the current distortion limits at the equipment input terminals
    - May also define specific current distortion limits which contradict the limits in Table 10.3

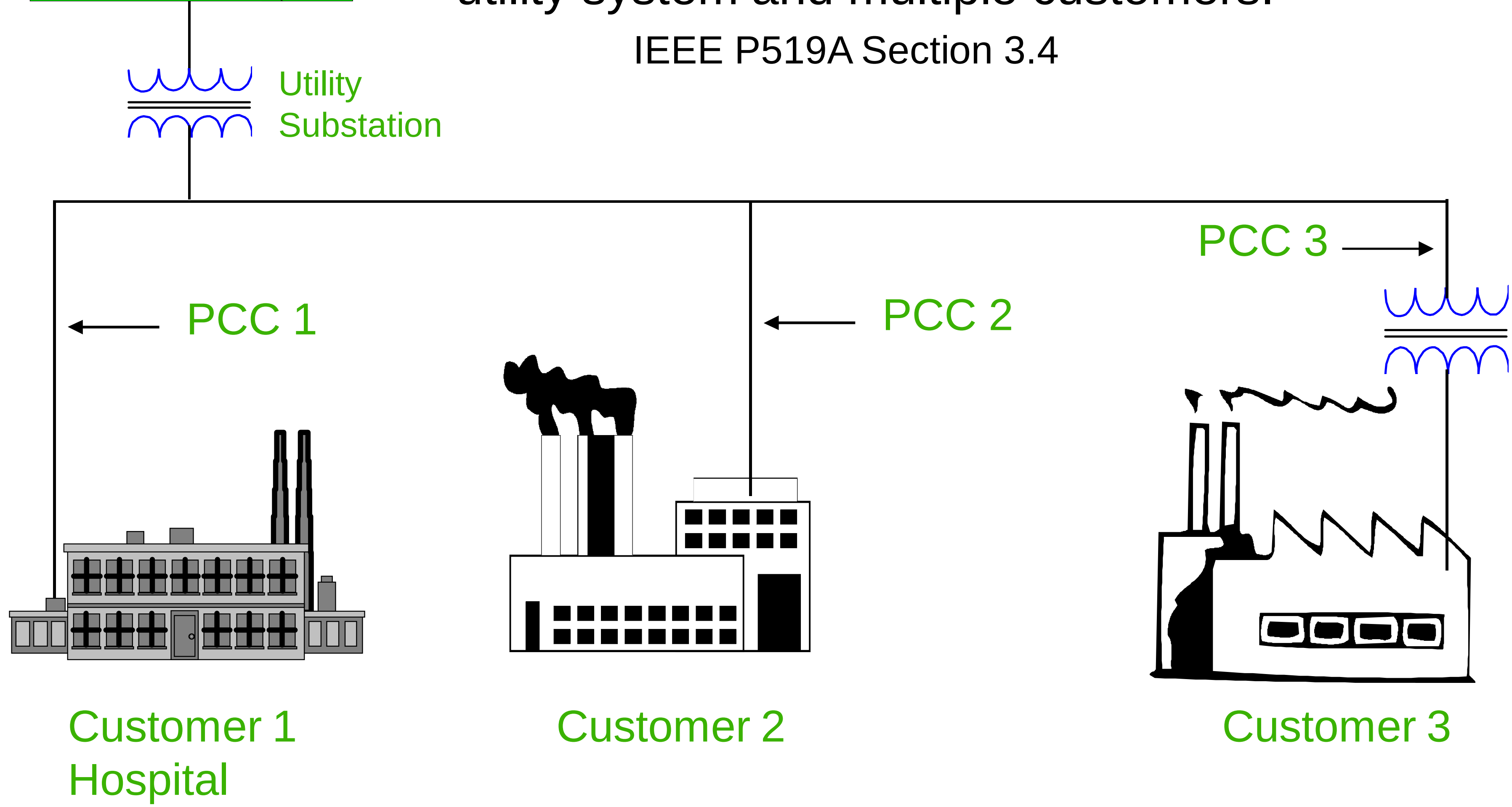
ABB

Where to Apply the PCC?



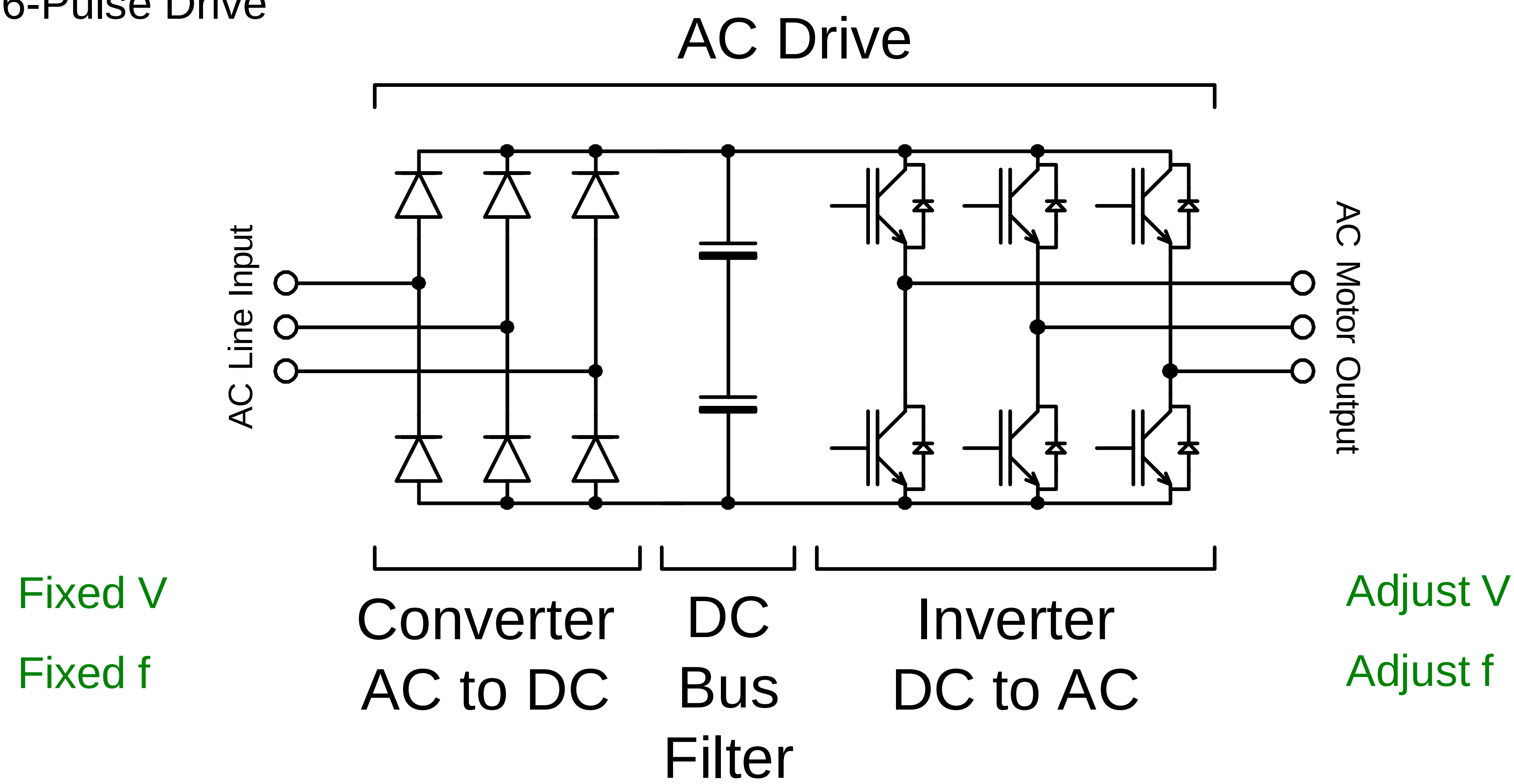
"Current limits in IEEE 519-1992 were meant to be applied at the Point of Common Coupling (PCC) between the utility system and multiple customers."

IEEE P519A Section 3.4

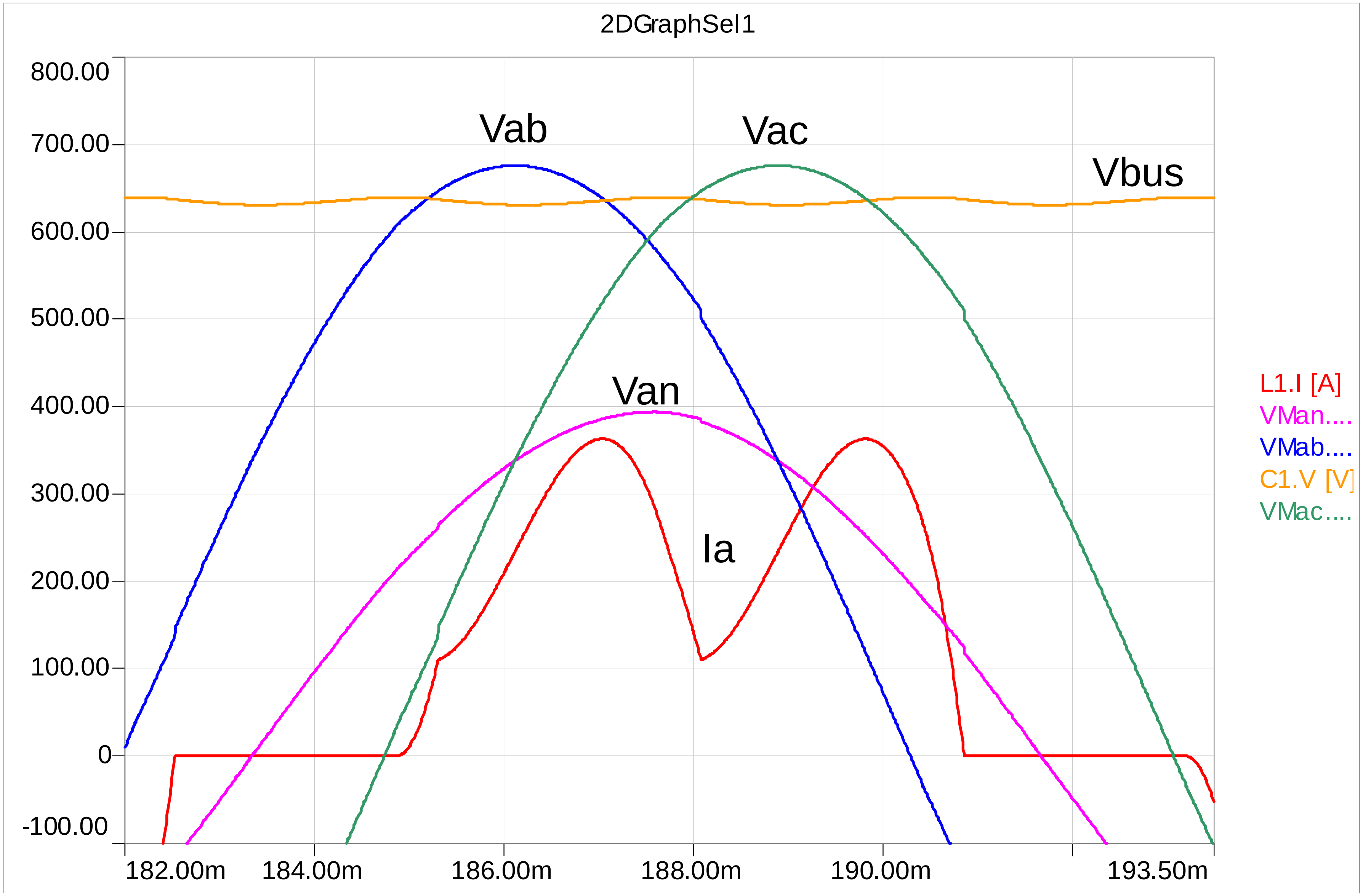


Why does a drive produce harmonics?
Converting AC to DC

6-Pulse Drive



Why does a drive produce harmonics?
Converting AC to DC



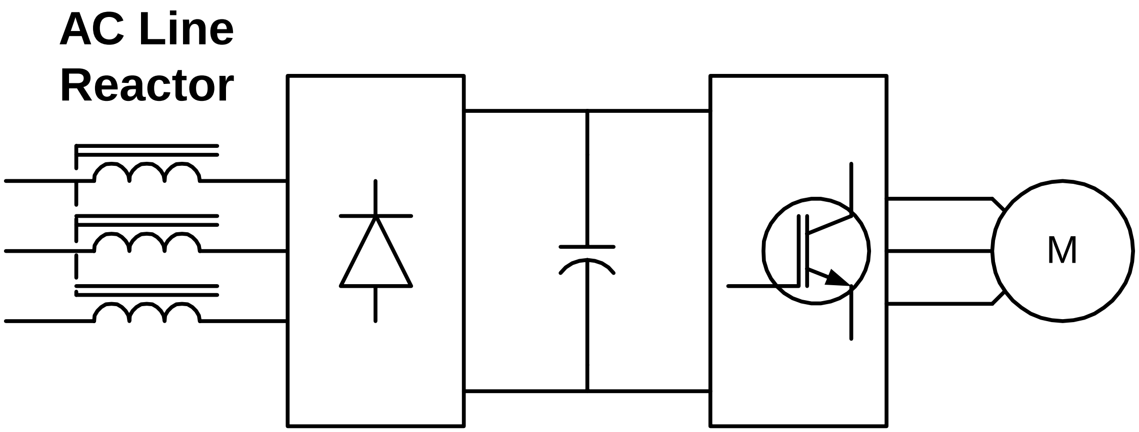
Harmonics — What can I do?
Possible solutions

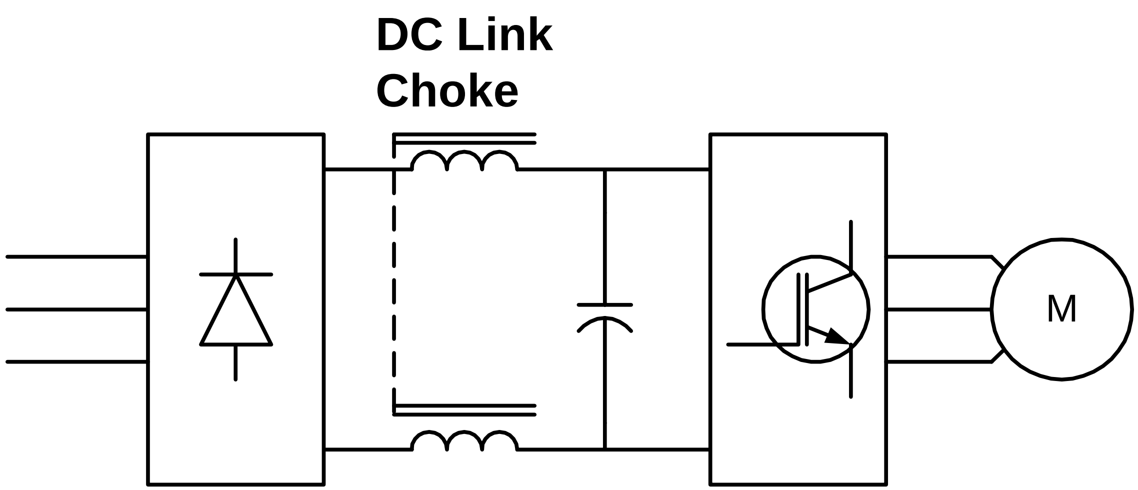
- Reactors or Chokes
  - AC Line Reactor
  - DC Link Choke
  - Swinging Choke
- Drive Isolation Transformer
- Passive Filters
  - Passive or Trap Harmonic Filter
- High Pulse Count Rectification
  - Harmonic Cancelation
  - 12, 18, 24, 36 Pulse or Poor Man’s 12-pulse
- Active Methods
  - Drive Active Front End (AFE, ULH or Regen)
  - Stand Alone (Active Harmonic Filter)

Harmonics — What can I do?
Reactors (chokes)

- Simplest and least expensive harmonic reduction technique
- May be included in base drive package
- Often meet harmonic needs provided drive load is a small portion of total connected load
- May be implemented with AC line reactors or with DC link reactors
  - AC line reactors provide better input protection
  - DC link reactors provide better output voltage regulation
  - Both types provide similar harmonic benefits
- “Swinging” choke design provides enhanced light load harmonic performance

Harmonics — What can I do?
AC Line Reactor or DC Link Choke



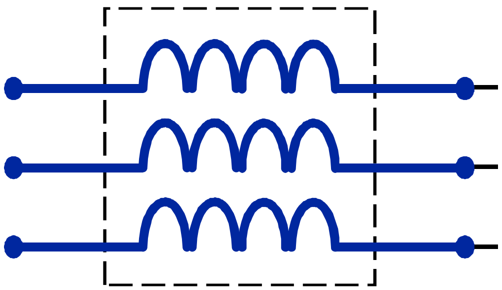


- Different design techniques
- Equal harmonic reduction for same normalized % reactance
- Typical full load THD (current) at drive input terminals reduced to 28% to 46% Ithd

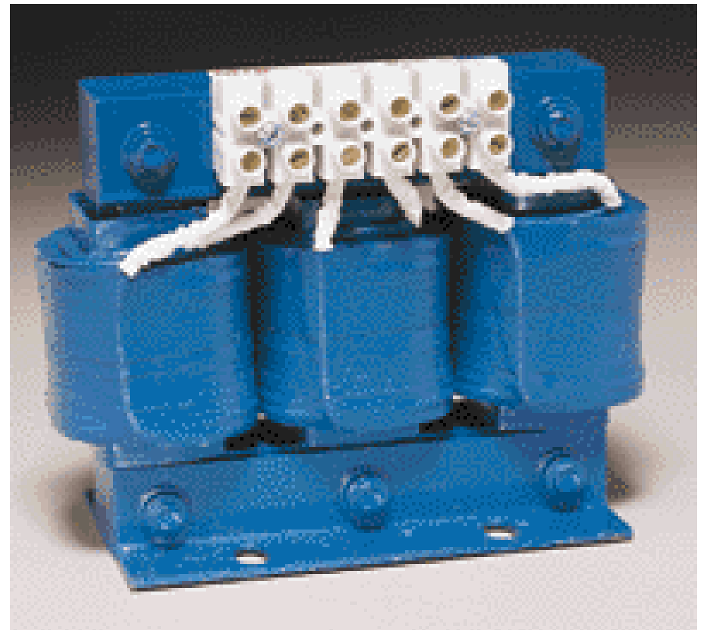
Existence not position is what is most important

AC Line Reactor

AC Line



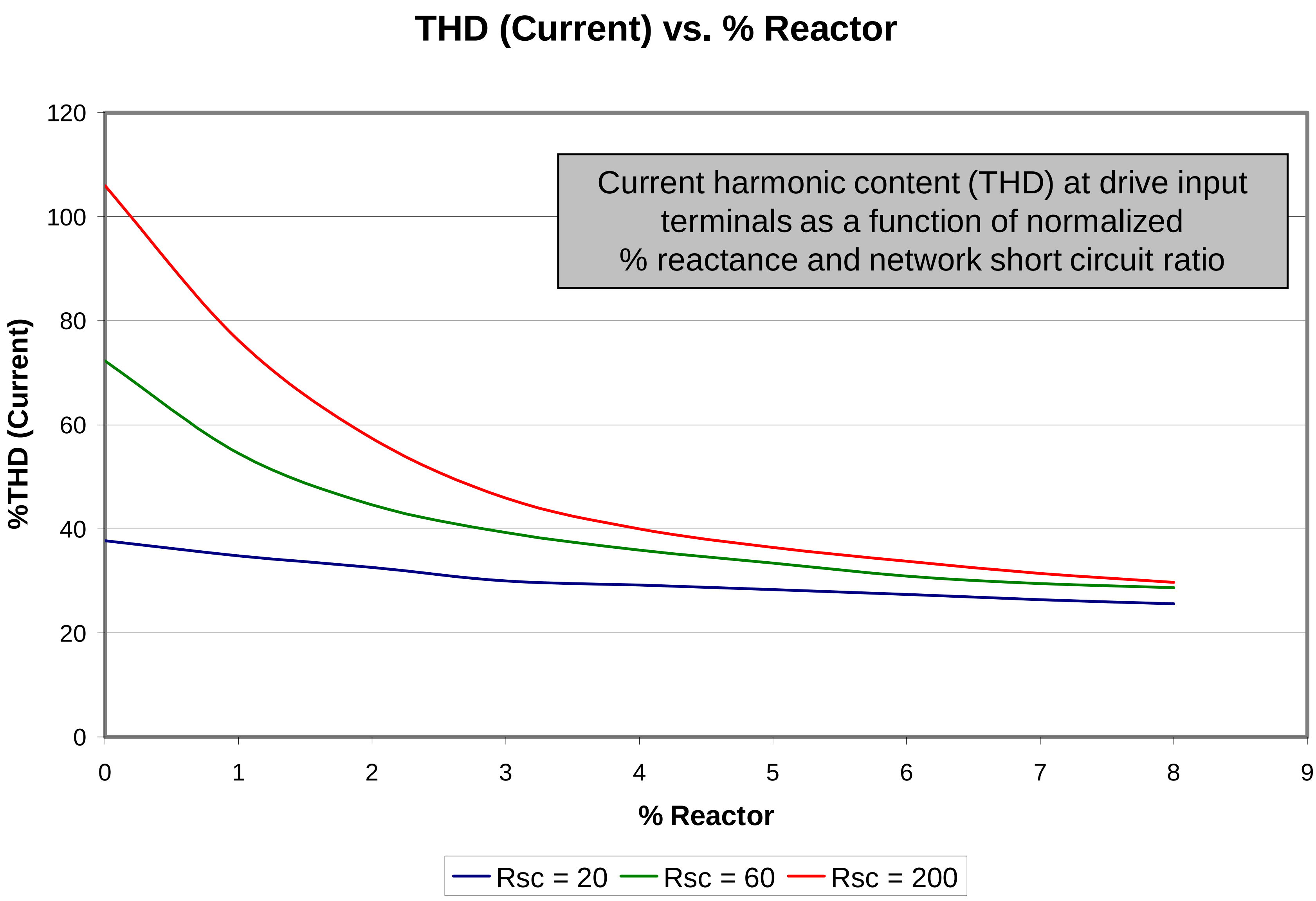
VFD



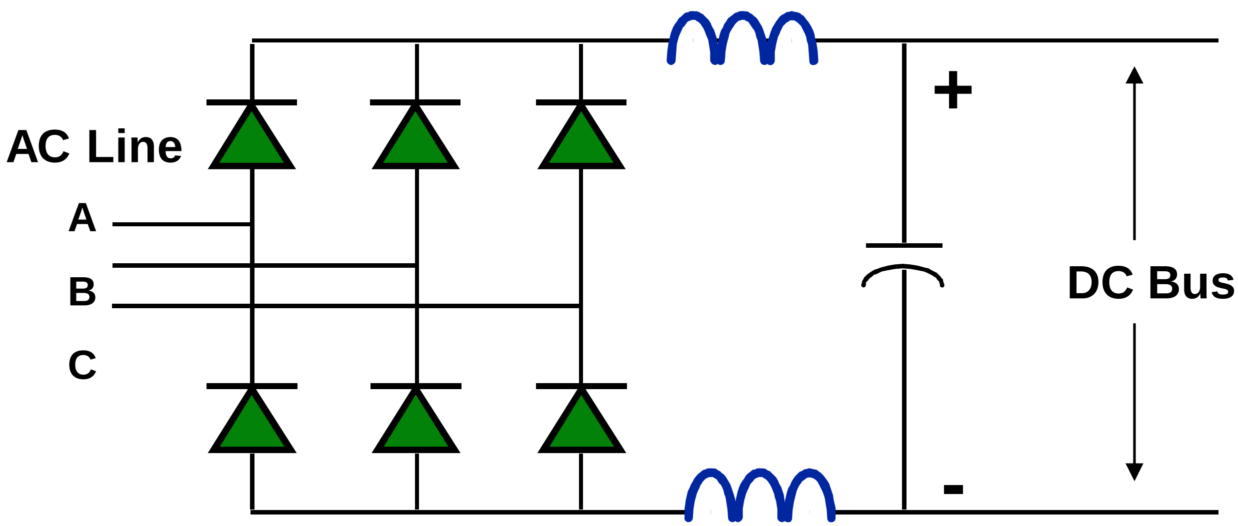
Source: *MTE, Corp.*

3 Separate Windings On An Iron Core

Harmonics — What can I do?
Reactor effectiveness



DC Link Choke



Source: *MTE, Corp.*

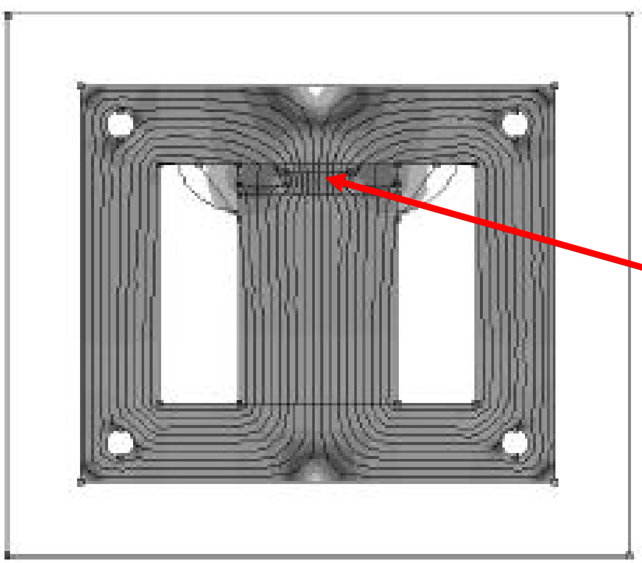
2 Windings On An Iron Core

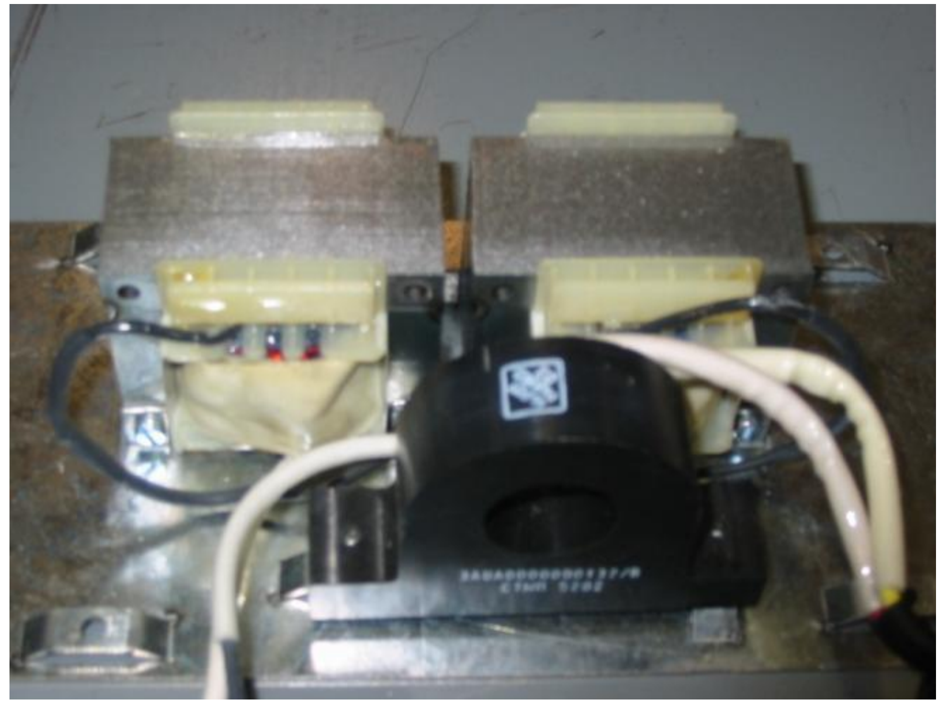
Between Diode Bridge and DC Bus Capacitors

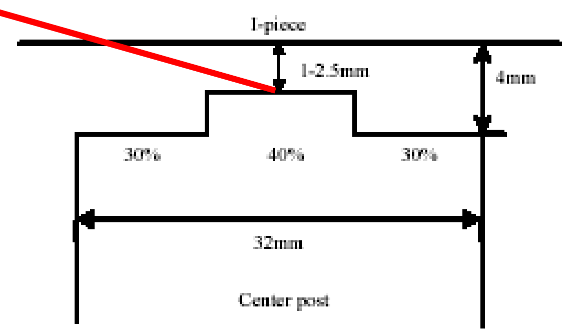
DC Link Choke in the ACS550

New "Swinging" DC Link Choke USF

- Patent Pending
- Designed to reduce harmonics at full and partial loads
- Perfect for Variable Torque Centrifugal Loads
- Equivalent to **5%** line reactor





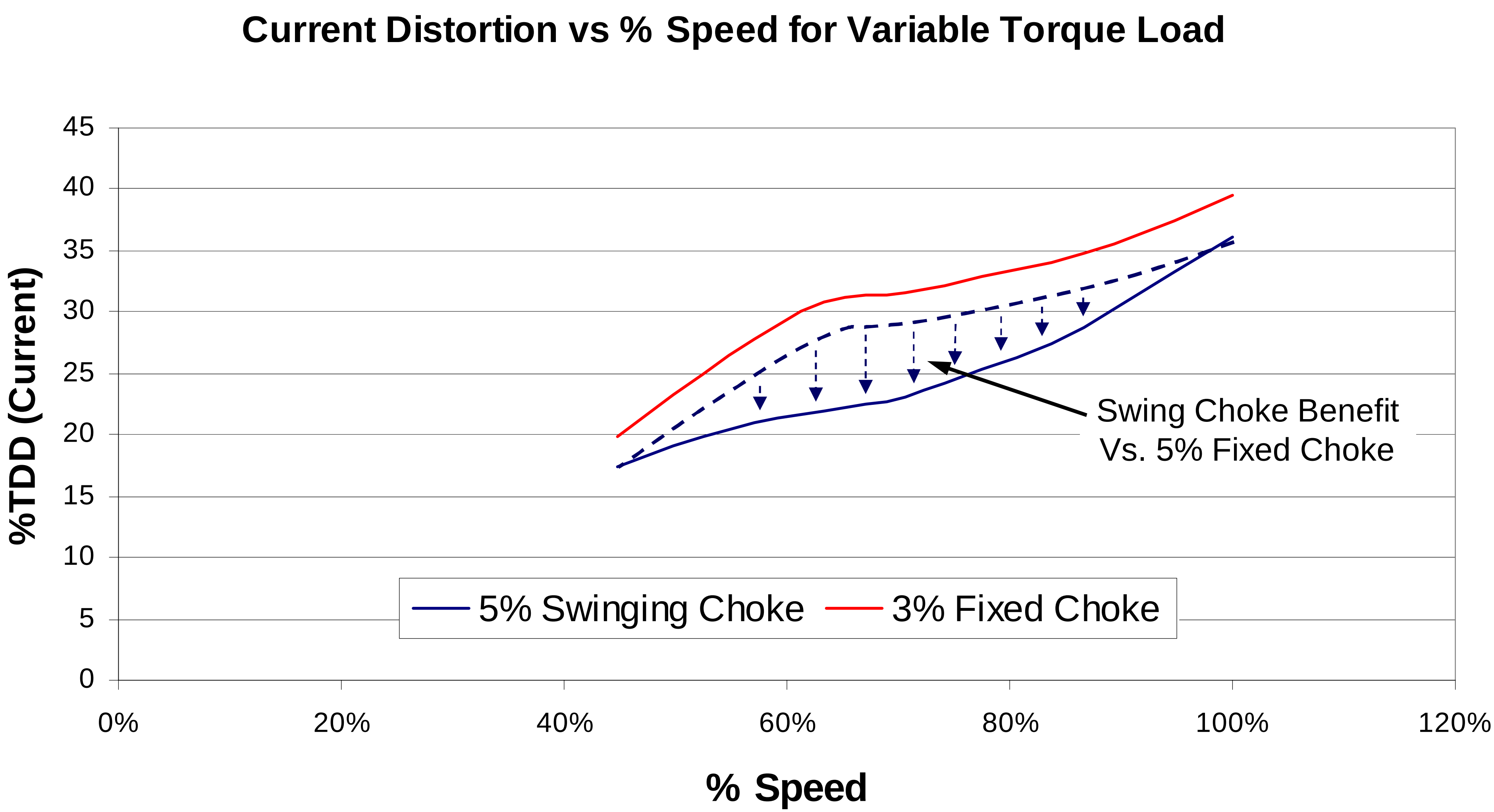


More inductance per volume/weight

ABB

Harmonics — What can I do?

Swinging choke vs. fixed choke

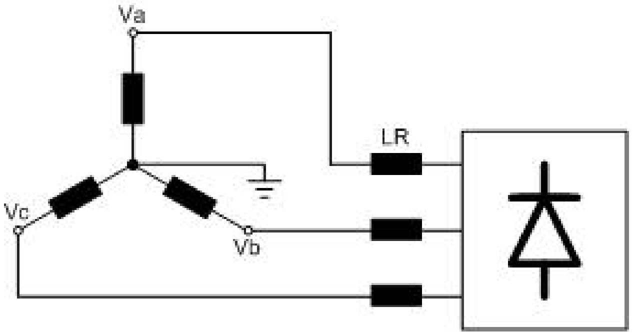


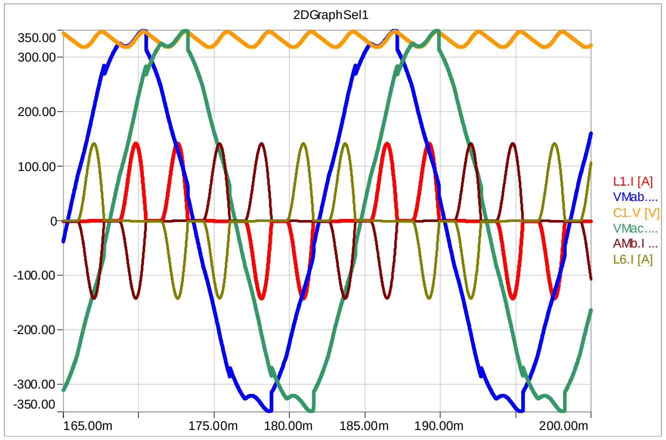
How else can Line Reactors and Link Chokes help?

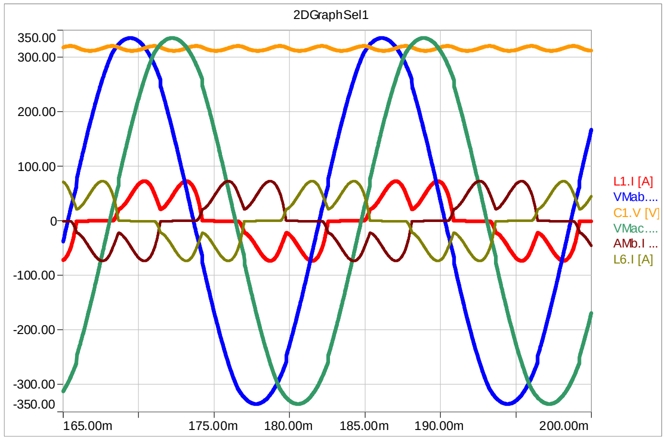
No LR or LC

With LR and LC

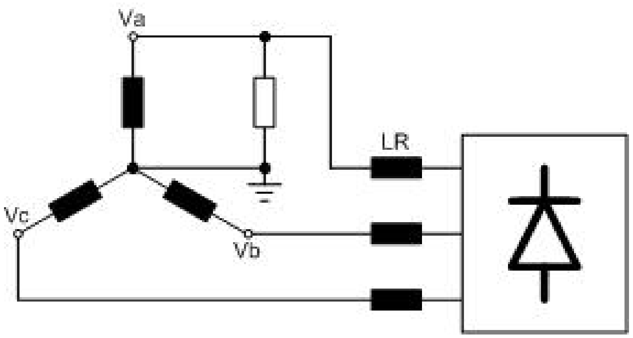
Low Impedance Source

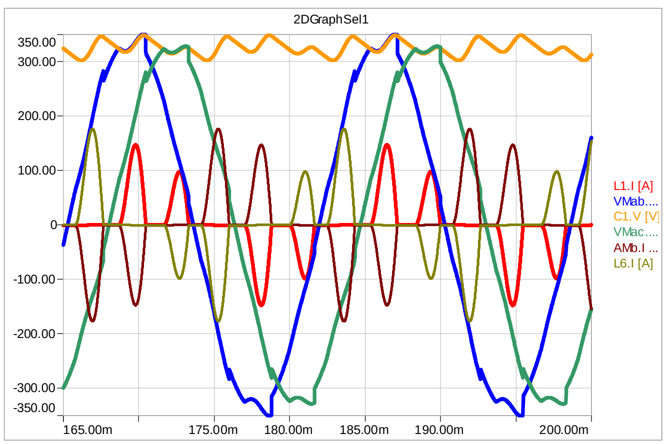


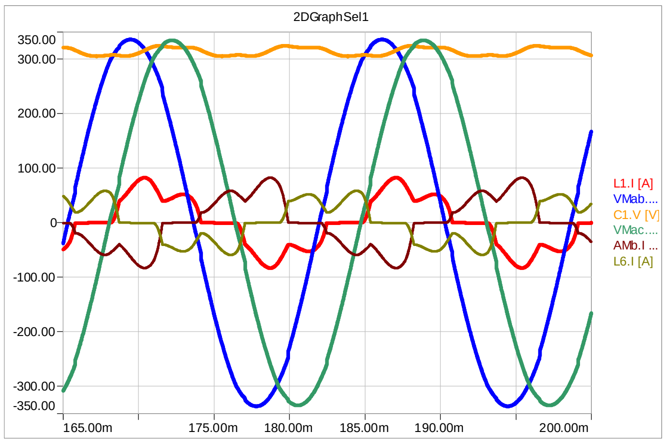




Unbalanced Lines





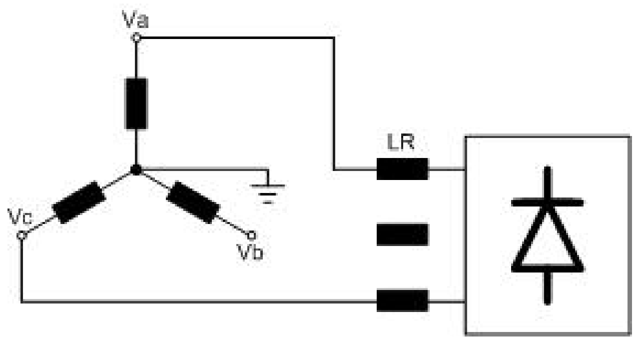


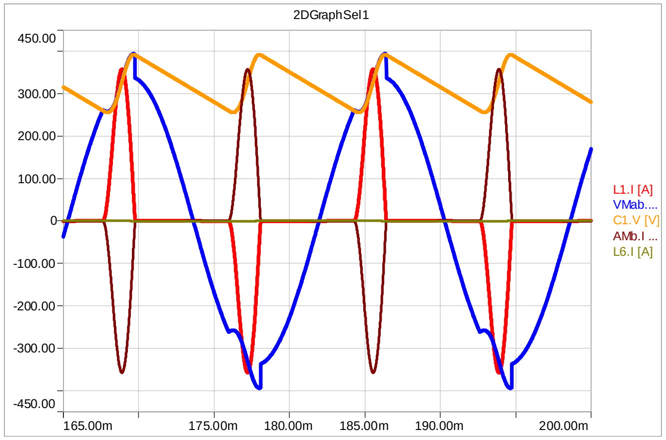
How else can Line Reactors and Link Chokes help?

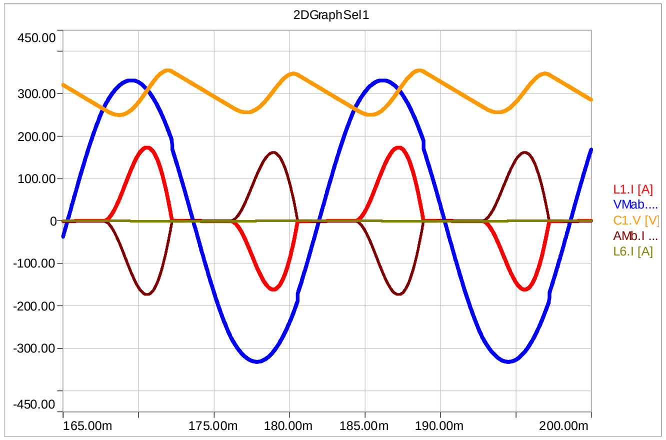
No LR or LC

With LR and LC

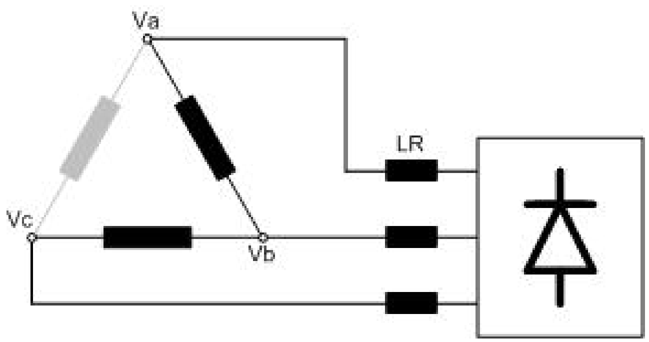
Single Phase

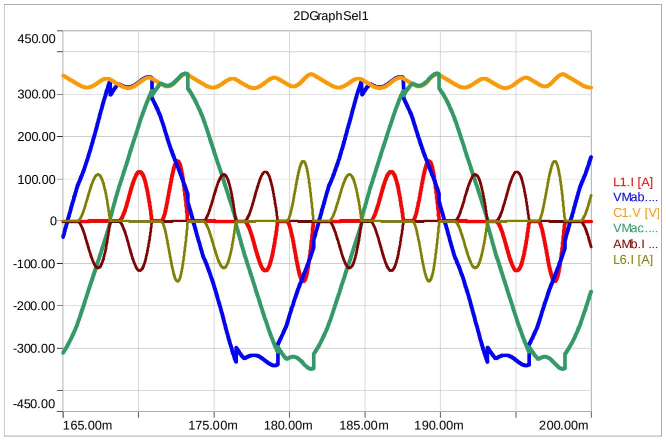


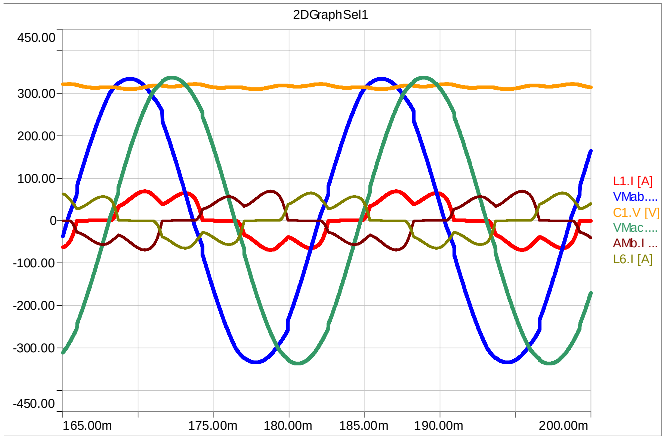




Open Delta Source

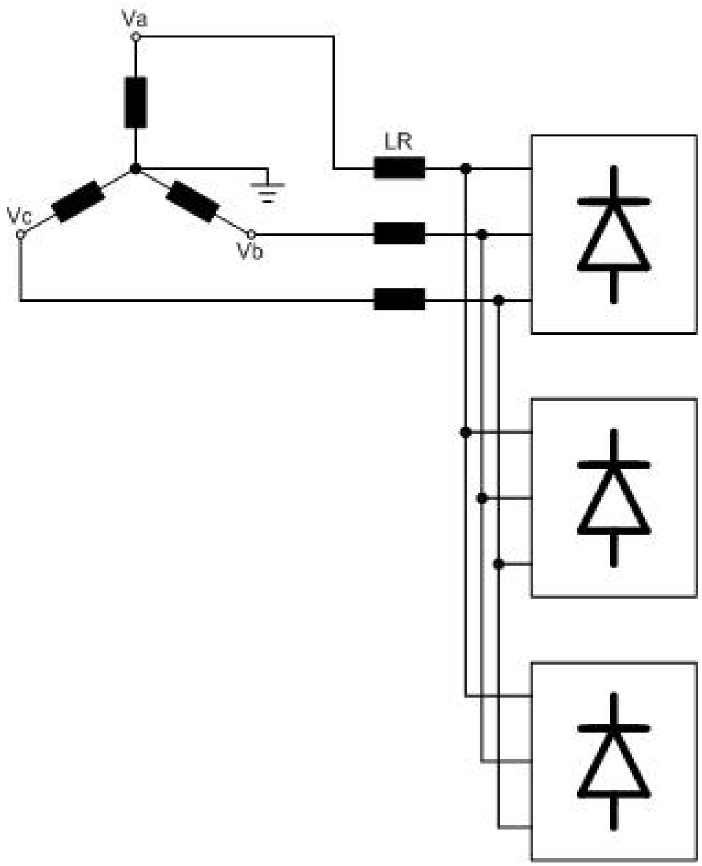






How else can Line Reactors and Link Chokes help?

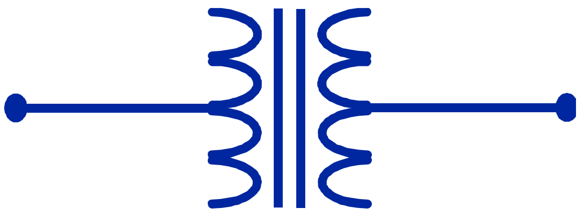
Multiple Unbuffered Drives



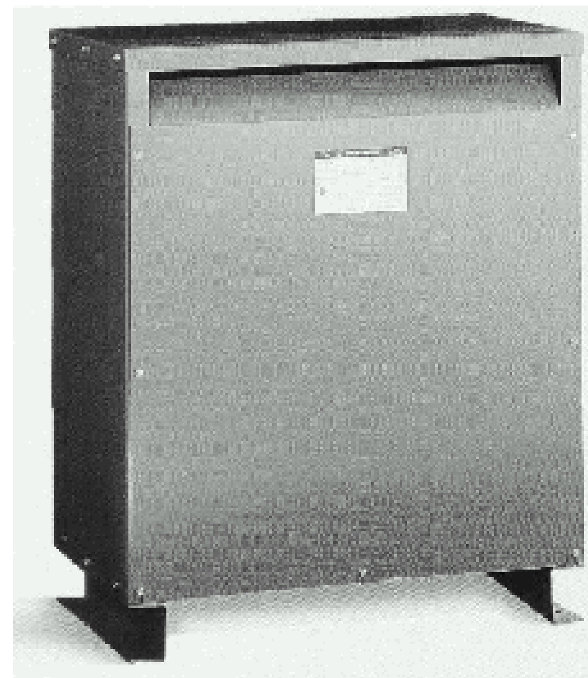
- Rule of Thumb
  - Three drives
    - 3% line reactor sized for total
  - Five drives
    - 5% line reactor sized for total
  - Reduces installation costs

Drive Isolation Transformer

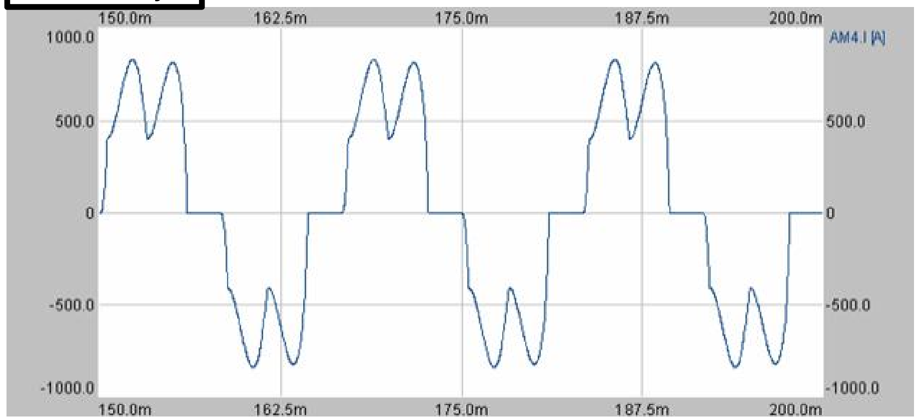
AC Line

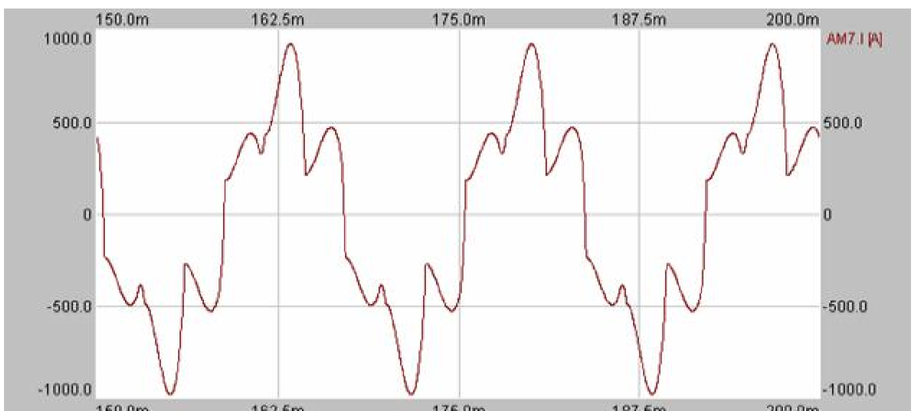


VFD



Secondary





Primary

- 1:1 Delta/Wye Wound Transformer Offers Other Power Quality Benefits
- Delta primary: same harmonics and amplitudes as above but at different angles. The same THD!!!

ABB

Line Reactor or Isolation Transformer

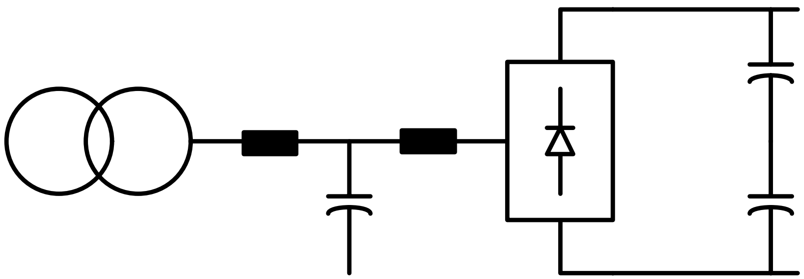
Benefits

- Reduces harmonic currents
- Reduces Drive input currents
- Suppresses voltage transients
- Compensates for unbalanced line voltage
- Highly reliable (passive solution)
- Transformer only
  - Electrically isolates Drive from distribution system
  - Provides neutral connection for delta system
  - Provides voltage matching
  - Reduces transfer of common & differential mode impulses

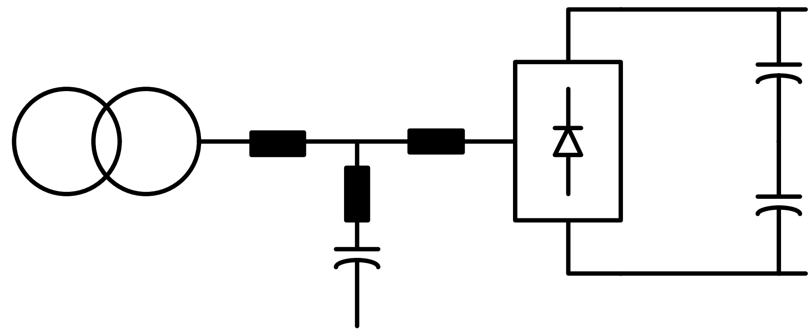
Disadvantages

- Line Reactor
  - Voltage Drop at full power
  - Adds heat to room
- Transformer
  - Expensive - 250% more than reactor solution
  - Size - Separate Floor Mount 400% or more larger than reactor solution
  - Consumes power - draws magnetizing current even with Drive off
  - Adds heat to room

Line Current Harmonic Mitigation Methods
6-Pulse Filters



Passive or Trap Harmonic Filter



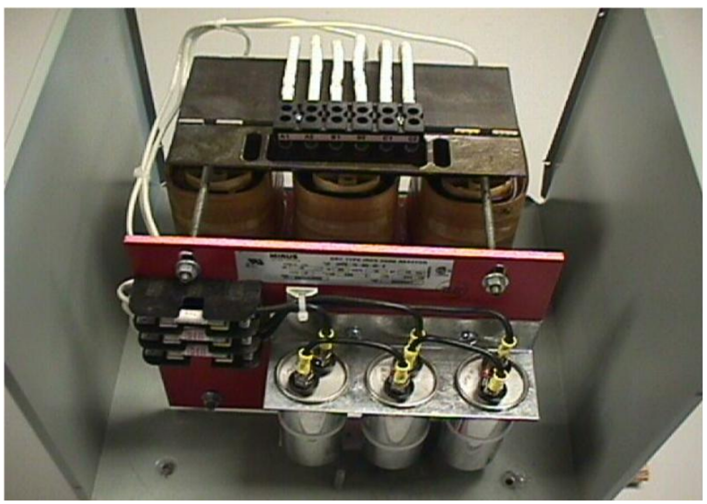
Passive Notch Filter

- May feed multiple drives
- Improves power factor (may go leading)
- Typical full load THD (current) at filter input terminals (line side) 10% → 14%
- Performance reduced by line imbalance

Passive Filters

Two Types to discuss

- Tuned trap filter
- Broad band filter

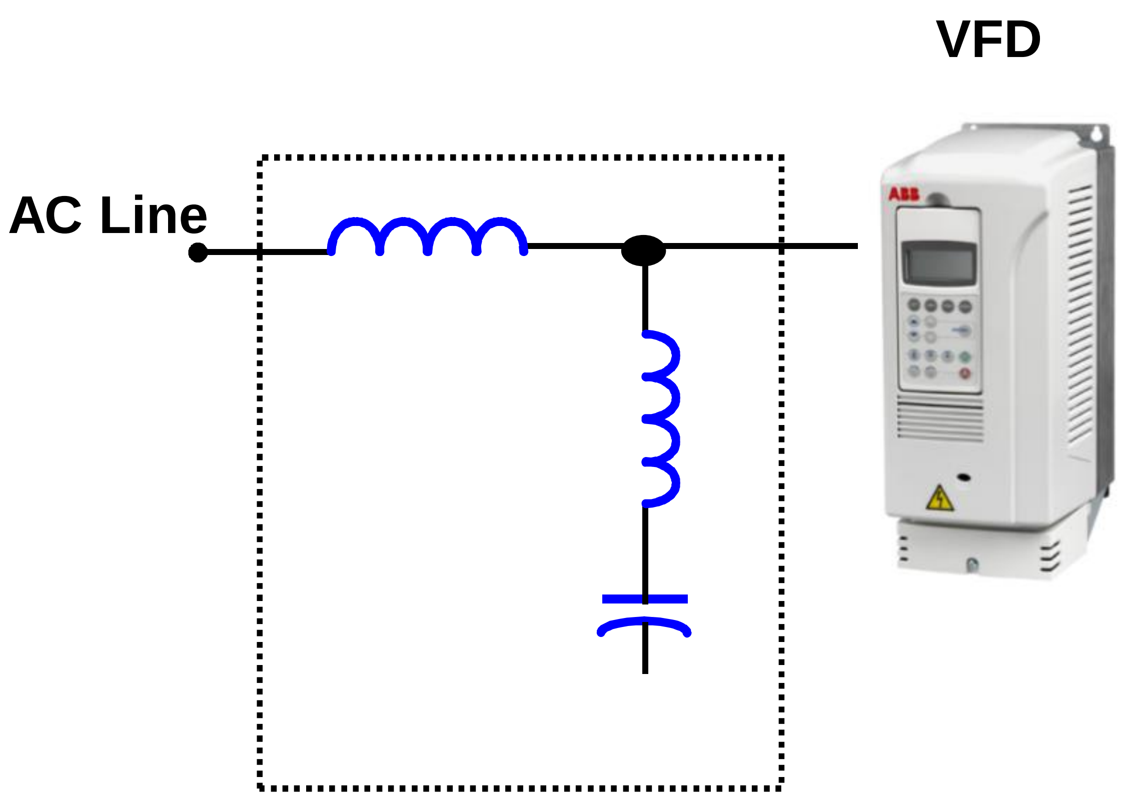


Source: *Mirus*

Source: *MTE*

Source: *TCI*

Passive Filters - Tuned Trap Filter



Source: *TCI*

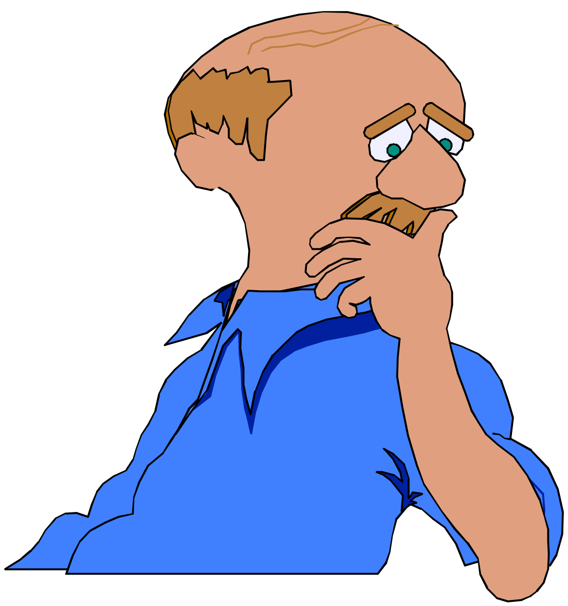
Reactors and capacitors selected

to provide source for 5th harmonic or 7th harmonic

Tuned Trap Filter

Benefits

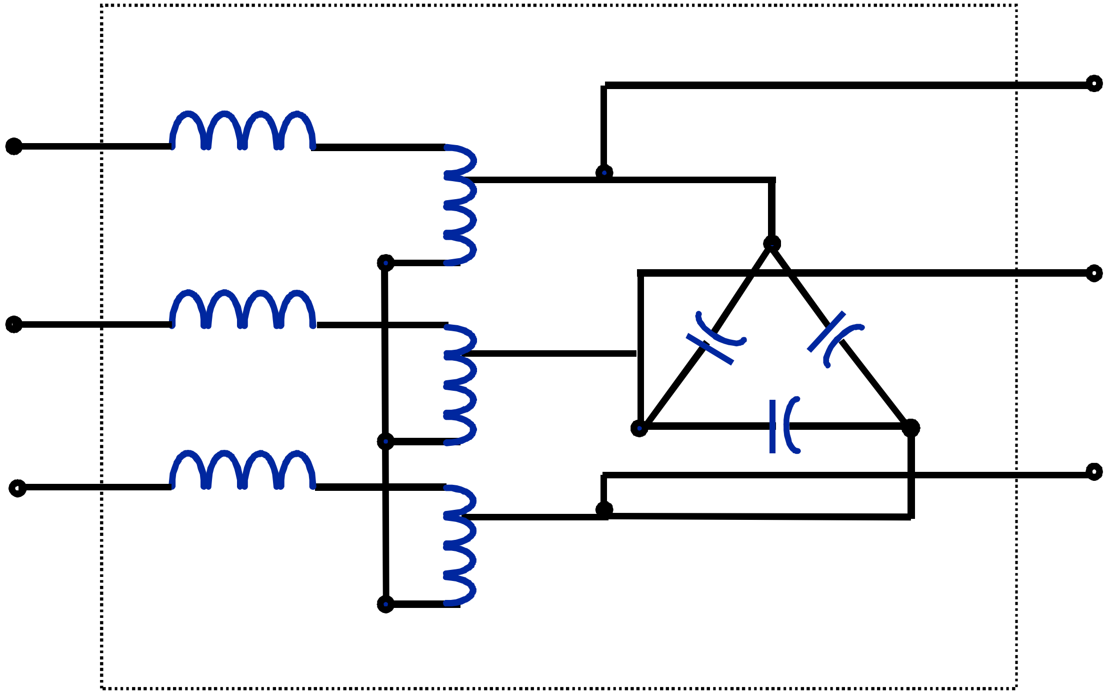
- Source for harmonic currents
- Reduces total harmonic distortion



Disadvantages

- Can import harmonics
- Should perform system analysis or field measurements
- Expensive - each filter (stage) designed for one specific harmonic frequency
- Size - consists of at least one reactor and capacitor network
- Not always a permanent solution; could change as distribution system grows
- System responsibility?

Passive Filters - Broad Band Filter



Series Reactor, Auto Transformer, and Shunt Capacitor Network

Source: *MTE, Corp.*

Source: *Mirus*

Broad Band Filter

Benefits

- Reduces harmonic currents
- Will not import system harmonic currents
- Suppresses voltage transients
- Reduces input line current
- Available in all horsepower sizes

Disadvantages

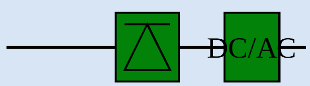
- More expensive than line reactors and isolation transformers
- Larger than line reactors and isolation transformers
- Large no-load currents

High Pulse Count Rectification

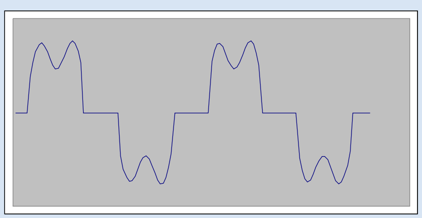
Circuits and characteristics

Performance →

6-pulse Rectifier

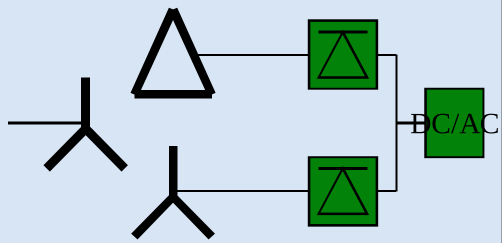


Transformer not required;
Simple cabling

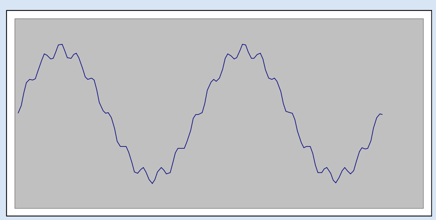


Current distorted
I_{THD} 35% to 46%
(3% reactor)

12-pulse Rectifier

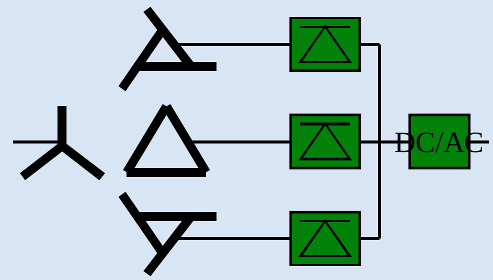


Transformer required;
More cabling, more space, more weight

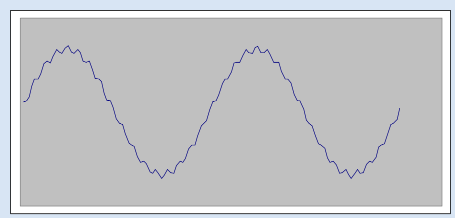


Current slightly distorted
I_{THD} 8% to 12%

18-pulse Rectifier



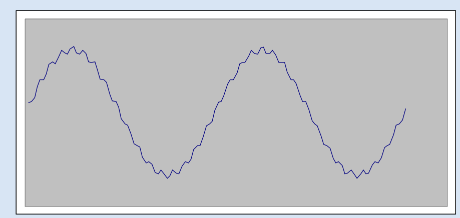
Transformer required;
Complex cabling, increased space and weight over a 12 pulse



Current wave form good
I_{THD} 4% to 6%

AFE, ULH or Regen Drive

Transformer Not required;
Simple cabling, space and weight same as a 6 pulse



Current wave form good
I_{THD} 4% to 6%

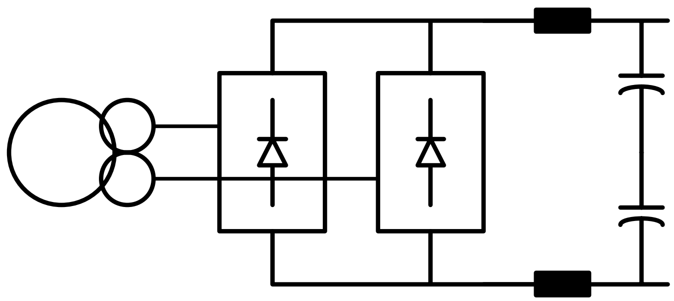
AFE= Active Front End

Line Current Harmonic Mitigation Methods
High Pulse Count Rectification

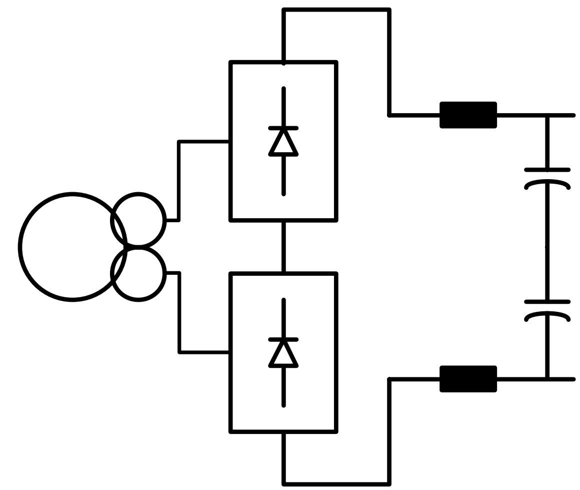
- Configurations are either 12, 18, 24 or 36 pulse
- Phase shifting transformer is required
- Additional drive input bridges are needed
- Typical full load THD (current) at transformer primary
  - 8% → 12% (12 pulse), 4% → 6% (18 pulse)
  - 4% → 5% (24 pulse), 3% → 4% (36 pulse)
- Performance may be significantly reduced by line imbalance (voltage or phase)
- Excellent choice if stepdown transformer is already required.
  - Often the case with MV Drive

ABB

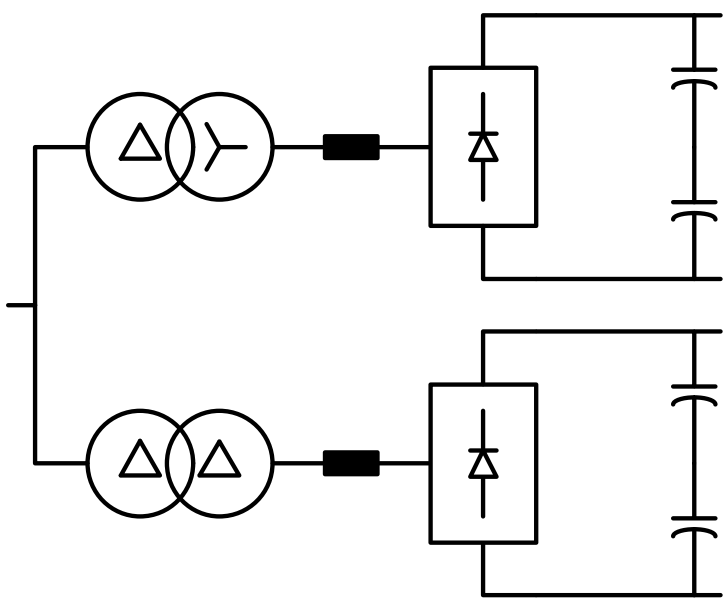
Line Current Harmonic Mitigation Methods
12-Pulse



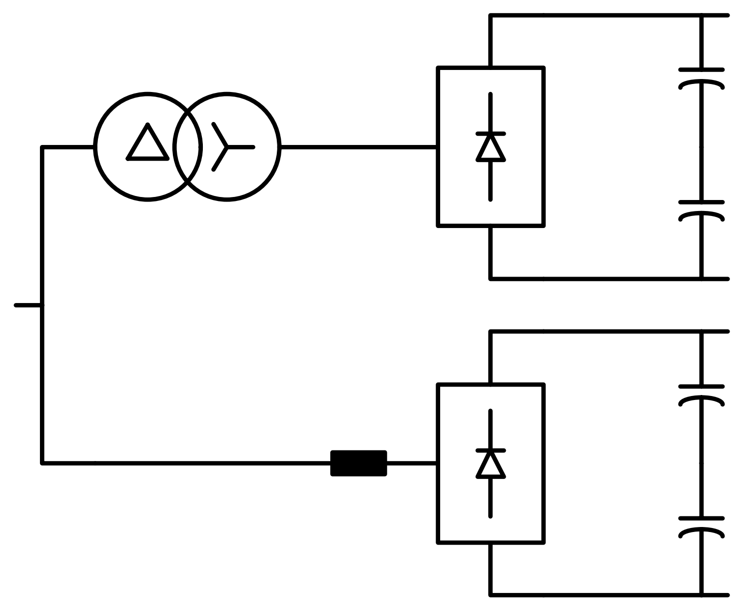
Parallel Bridges



*Series Bridges



Pseudo 12-Pulse

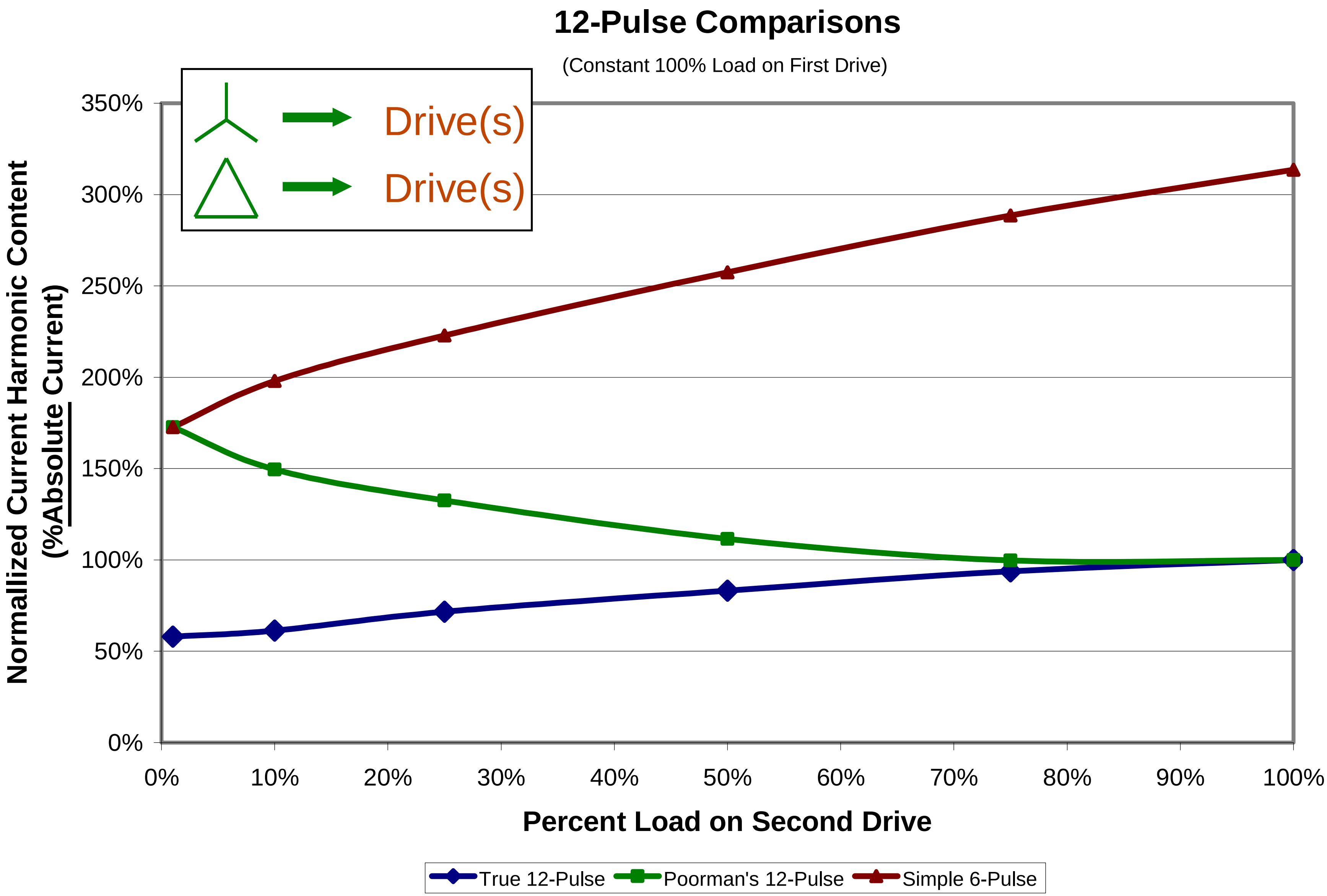


Poor-Man's 12-Pulse

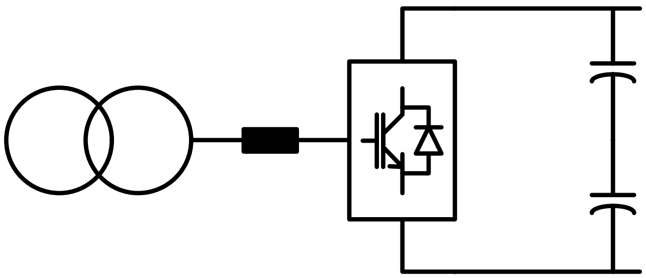
* Used in MV drives

Harmonics — What can I do?

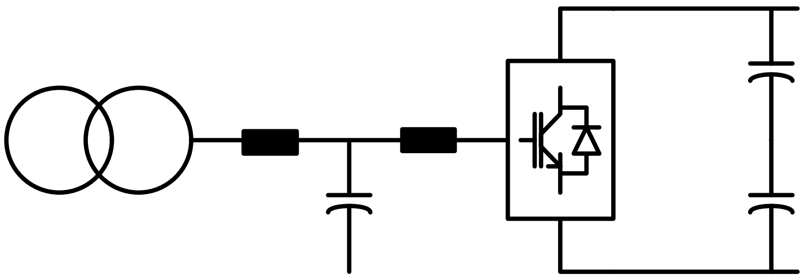
What about poor man's 12-pulse?



Line Current Harmonic Mitigation Methods
Active Front End (AFE), ULH or Regen



AFE with Isolation Transformer

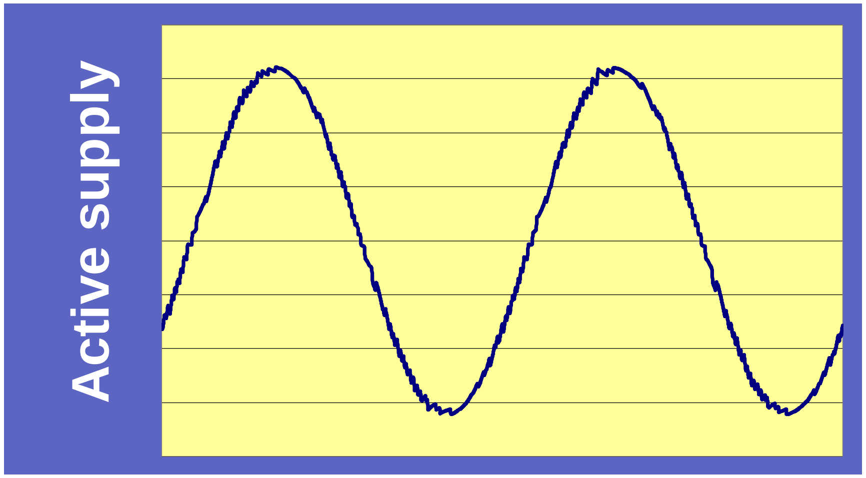


*AFE with LCL Filter

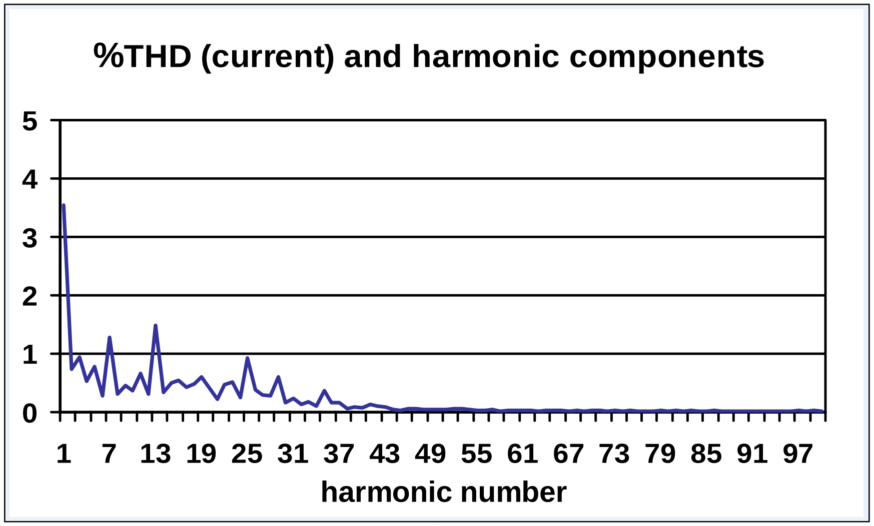
* Used in Low Voltage and MV drives

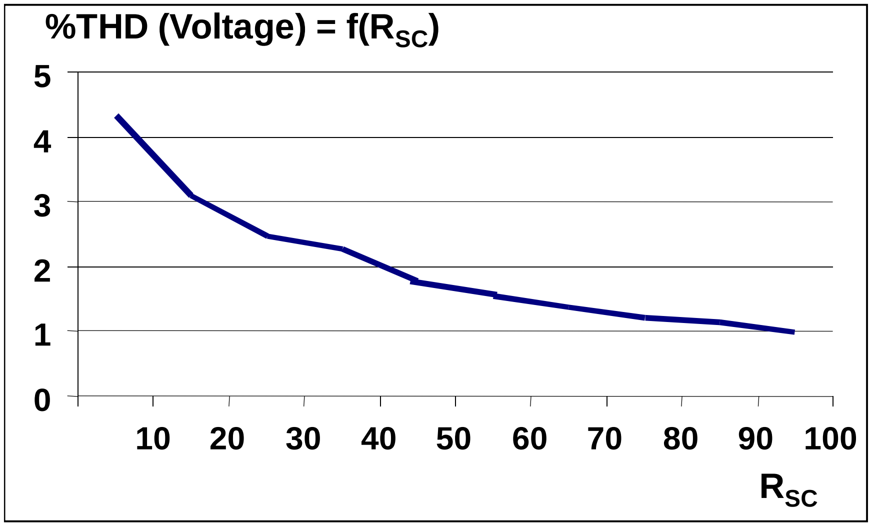
ABB

Harmonics — What can I do?
Active front end - impressive performance



- Meets IEEE 519
- Near sinusoidal line current
- Total current distortion meets IEEE TDD (rated load)
- Total voltage distortion less than 5.0%
- Out of the box Unity Power Factor!





Harmonics — What can I do?
Active front end drives, what do they look like?

Wall-mounted low harmonic drive ACS800-U11/U31

10 – 125 HP

Cabinet-built low harmonic drive ACS800-17/37

75 - 2800 HP

Harmonics — What can I do?
Active front end drives, what do they look like?

MV Drive, ACS 2000 4kV

300 - 3000 HP

Active Front End

Benefits

- Most effective solution
- Unity power factor
- Standard Drive Product
- No dedicated transformer required
- Lower transformer losses compensates overall efficiency
- Harmonic performance robust against supply input imbalances
- Reduces size of back-up generator
- **Only solution that can boost the DC Bus voltage (up to 15%) when motor requires it**

Disadvantages

- More costly than reactor and passive filter solutions
- Size - larger foot print - more equipment to package
- Active solution, therefore dependent on reliability of electronics

Harmonics — What can I do?
Harmonic reduction summary

Performance
Complexity
Cost

Typical Results

Technique	Current THD
No mitigation	70-120%
3% Line Reactors or DC Link Choke	40-50%
5% Line Reactors or DC Link Choke	25-40%
12-Pulse Rectifier	10-15%
Passive Harmonic Filter	8-12%
18-Pulse Rectifier	4-6%
Active Front End or Active Harmonic Filter	3-5%

–

+

Remember -

Take measurements at MAXIMUM load.
THD = harmonics / fundamental

Power and productivity
for a better world™

ABB

BALDOR®

A MEMBER OF THE ABB GROUP

Motor Technology Update

Brent McManis, P.E.
Industry Engineering Manager
Baldor Electric: A Member of the ABB Group

Motor Technology Update

- Motor Efficiency Background/Rules/Regulation
- Motor Technology
  - Induction
  - Laminated Frame
  - Permanent Magnet
  - Line Start PM
  - Synchronous Reluctance

BALDOR
A MEMBER OF THE ABB GROUP

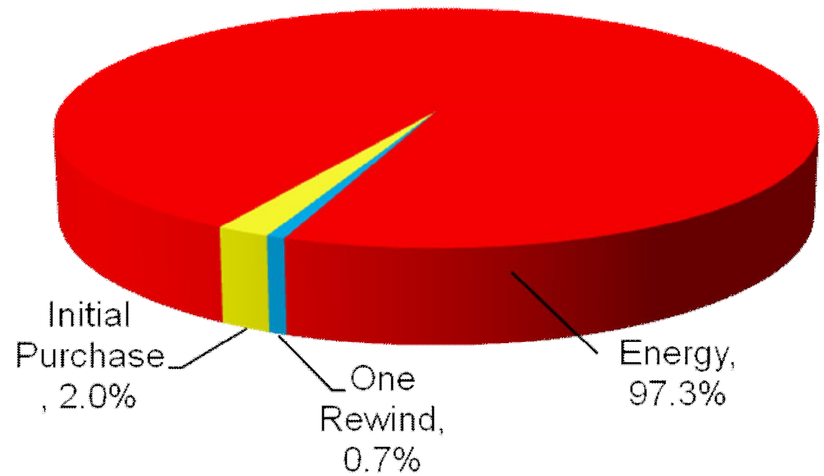
Motor Technology Update

Motor Efficiency Background/Rules/Regulation

BALDOR
A MEMBER OF THE ABB GROUP

Energy Efficiency Driving New Motor Technologies

- **Almost 30% of all electricity generated in the United States is used to run electric motors.[1]**
- **For industrial companies, electric motor-driven systems consume 63% of the electricity used. [1]**
- **The cost of electricity to run an electric motor represents over 97% of its lifetime cost.**



Lifetime Cost of a Motor

[1] **Department of Energy - Market Opportunities Assessment 2002**

Energy Cost

- Cost of 100 hp motor around $5000
- Energy cost is about $0.07/kW-hr
- Cost to run the motor for one day

100 hp * 0.746 kW/hp * 0.07 $/kW-hr * 24 hrs =

$125/day

# of days for energy cost = purchase price?

40 Days!

Induction Motors

- Workhorse of Industrial and Commercial Applications
- Motor efficiency regulated by US DOE, Canada - NRCan, EU
  - EPAct effective 1997
  - EISA effective 2010
  - Integral Motor Rule effective May 2016
  - Small Motor Rule effective Mar 2015
  - EU at IE2 effective Jun 2011
  - EU at IE3 for 7.5-370 kW effective 2015
  - EU at IE3 for 0.75 – 370 kW effective 2017

BALDOR
A MEMBER OF THE ABB GROUP

NEMA, IE ….?

NEMA MG-1		IE-60034-10
EPACT Efficiency	Table 12-11	IE-2
NEMA Premium Efficiency	Table 12-12	IE-3
Super Premium Efficiency (proposed)	TBD	IE-4

NEMA Efficiency Bands

- NEMA Efficiency Bands
  - Actual efficiency varies from motor to motor in a particular design
  - Full load efficiency from a single design is not a unique efficiency, but rather a band
  - NEMA has defined logical series of NOMINAL efficiencies. NEMA MG-1 table 12-10
  - To move to higher band requires an approximate 10% reduction in motor LOSS
  - Motor nameplate will have Nominal efficiency marking that shall not be greater than average efficiency of large population of motors.

Nominal Efficiency
91.0
90.2
89.5
88.5
87.5
86.5
85.5
84.0
82.5
81.5
80.0
78.5
77.0
75.5
74.0
72.0
70.0
68.0
66.0
64.0
62.0
59.5
57.5
55.0
52.5

New: Integral HP Motor Rule

- Replaces Energy Independence & Security Act of 2007
- Expected to take effect 24 months after Final Rule (~May 2016)
- Most motors will be covered at Premium Efficiency levels (IE3)

Compare IHP Rule to EISA

Motor Type	EISA	New Integral HP Rule
1-200 HP Subtype I	Premium Efficient NEMA MG 1, Table 12-12	Premium Efficient NEMA MG 1, Table 12-12
1-200 HP Subtype II	Energy Efficient NEMA MG 1, Table 12-11	Premium Efficient NEMA MG 1, Table 12-12
201-500 HP	Energy Efficient NEMA MG 1, Table 12-11	Premium Efficient NEMA MG 1, Table 12-12
56 Frame Enclosed	Exempt	Premium Efficient NEMA MG 1, Table 12-12
Custom Configurations	Exempt	Premium Efficient NEMA MG 1, Table 12-12
1-200 HP Fire Pump Motors	Energy Efficient NEMA MG 1, Table 12-11	Energy Efficient NEMA MG 1, Table 12-11

BALDOR
A MEMBER OF THE ABB GROUP

Motors covered under IHP Rule

The motors regulated under expanded scope meet the following nine characteristics:

1. Is a single speed motor,
2. Is rated for continuous duty
3. Squirrel cage rotor
4. 3-Phase line power,
5. Has 2-, 4-, 6-, or 8-pole configuration,
6. Is rated 600 volts or less,
7. Has a three or four-digit NEMA frame size (or IEC metric equivalent) or an enclosed 56 NEMA frame size (or IEC metric equivalent),
8. 1 – 500 HP
9. NEMA design A, B or C or IEC design N or H electric motor

BALDOR
A MEMBER OF THE ABB GROUP

Motors added previously not covered by EISA

- What is covered:
  - NEMA Design A motors from 201-500 HP
  - Electric motors with moisture-resistant windings, sealed or encapsulated windings
  - Partial electric motors
  - Totally-enclosed non-ventilated (TENV) electric motors
  - Immersible electric motors
  - Integral brake electric motors
  - Non-integral electric brake motors
  - Electric motors with non-standard endshields or flanges
  - Electric motors with non-standard base or mounting feet
  - Electric motors with special shafts
  - Vertical hollow shaft electric motors
  - Vertical medium and high thrust solid shaft electric motors
  - Electric motors with sleeve bearings
  - Electric motors with thrust bearings

BALDOR
A MEMBER OF THE ABB GROUP

Motors not covered under IHP rule

- What is not covered:
  - Single phase motors (Small Motor Rule)
  - DC motors
  - Two digit frames (42 – 48)
  - Multi-speed motors
  - Medium voltage motors
  - TEAO motors
  - Submersible motors
  - Water-cooled motors
  - Intermittent duty motors
  - Stator-rotor sets
  - Design D motors

What the New Rule Means

- Motors manufacturers must begin building compliant motors by 1 Jun 2016.
- Existing inventory may be sold or used

BALDOR
A MEMBER OF THE ABB GROUP

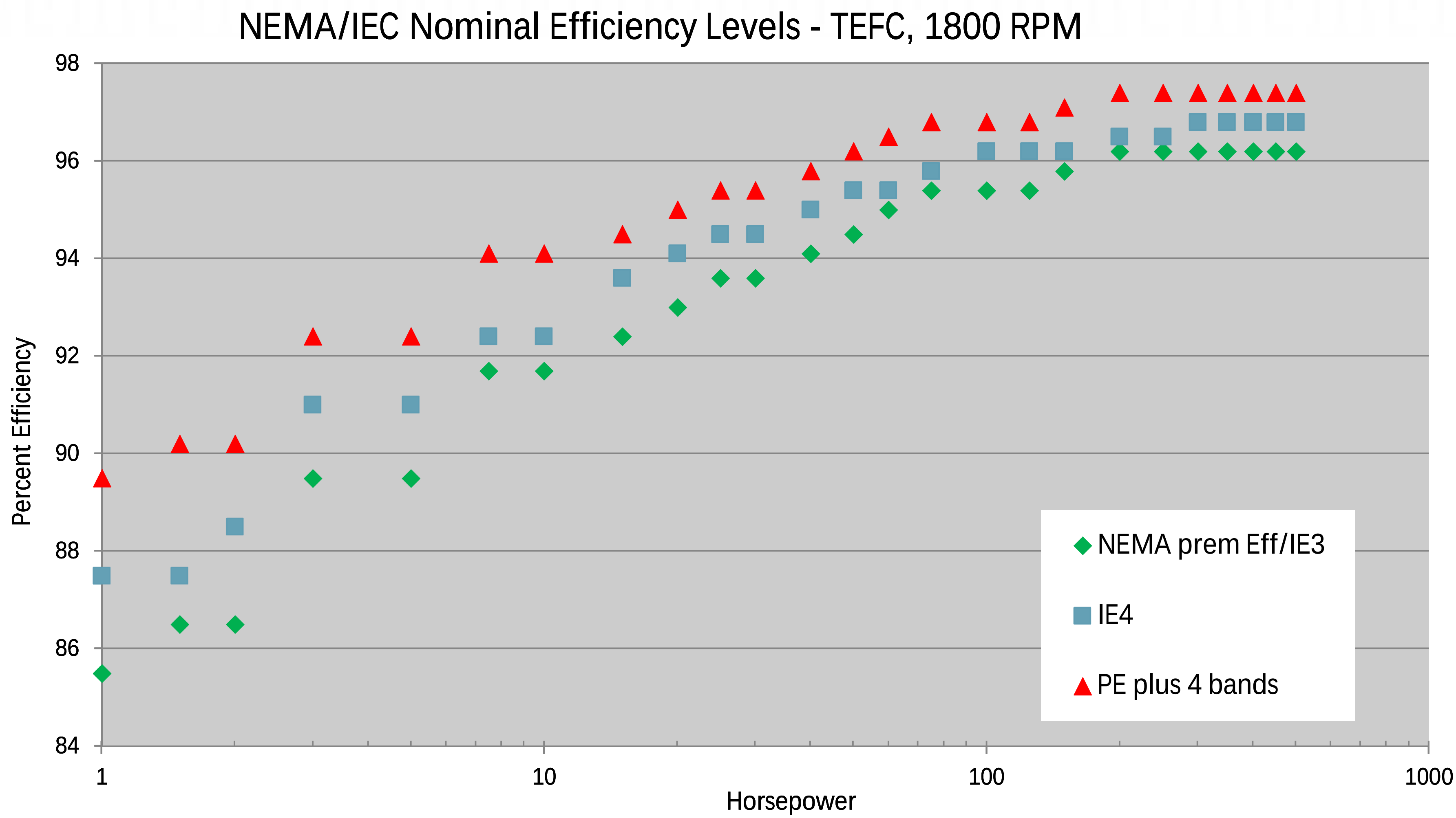
New: Small Motor Rule

- Passed in 2010
- Covers ¼ - 3 HP 2, 4, 6 pole
- Open Drip Proof – General Purpose only
- 42, 48 , 56 Frame
- Both Single and Three Phase
- Specific DOE Average Efficiency Assignments (Not NEMA nominal)
- Effective March 9, 2015

Improving Motor Efficiency:

- Add more material
  - Longer core length
  - Slots more full of winding copper
- If you want a 10% reduction in loss, add 10% more material
- Reduce fan size (trade off motor runs hotter)
- Maxed out on ability to increase efficiency above NEMA Premium® efficiency
- Efficiencies beyond NEMA Premium® (IE3) will require different technologies to stay in standard frame size.

Motor Efficiency Levels



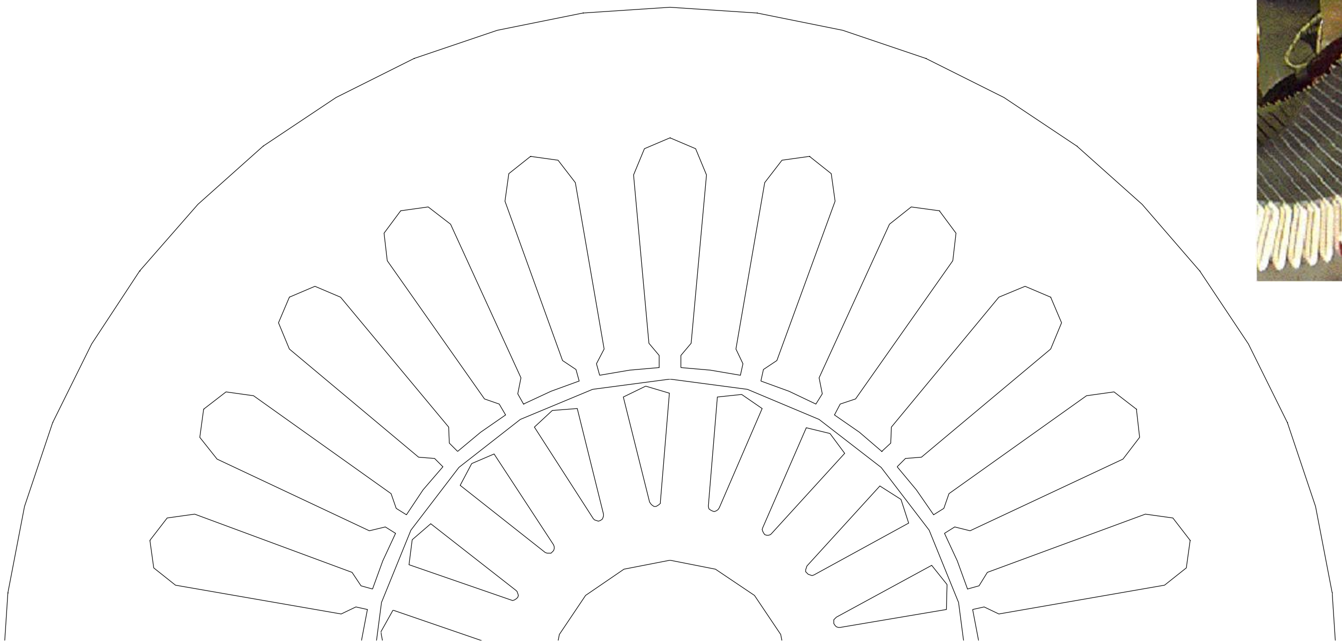
BALDOR
A MEMBER OF THE ABB GROUP

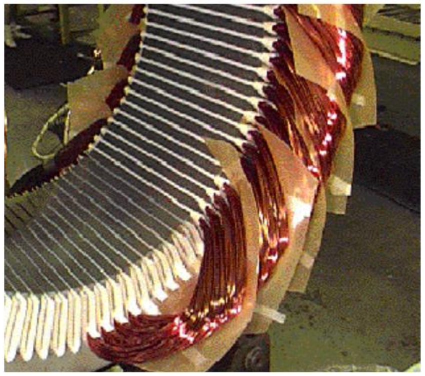
Motor Efficiency Levels

- How do we get to IE4 and beyond?

Current Technology: Induction Motors

- Distributed stator lamination slots and winding
- Stator is pressed into cast iron motor frame
- Squirrel cage rotor (cast or fabricated) with Al or Cu.

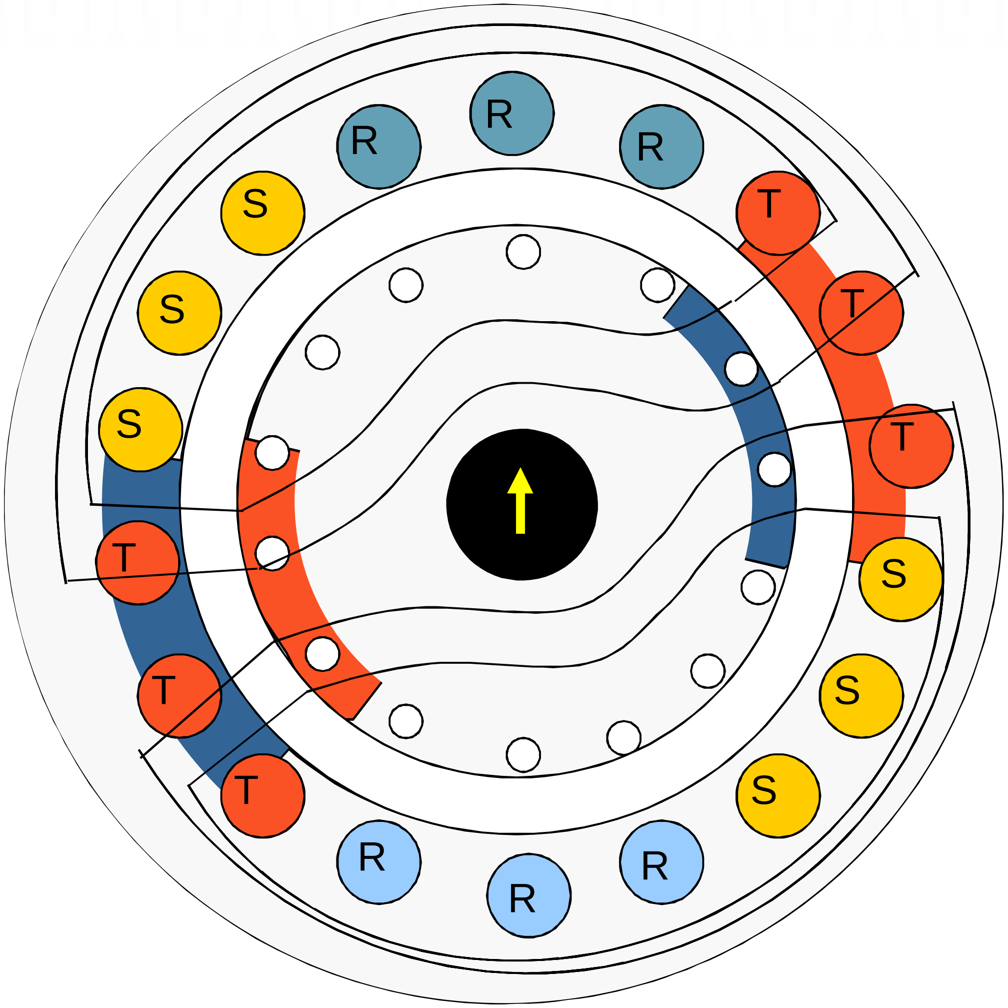




BALDOR
A MEMBER OF THE ABB GROUP

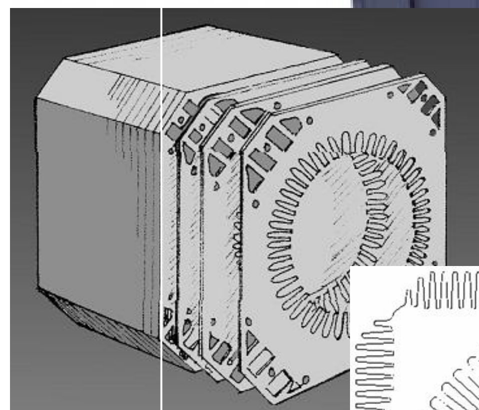
Induction Motors

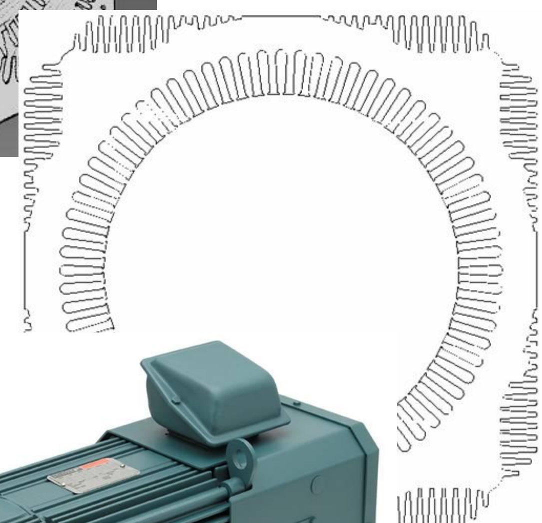
- Rotor "Slip" results in rotor loss



BALDOR
A MEMBER OF THE ABB GROUP

Laminated Frame Motors

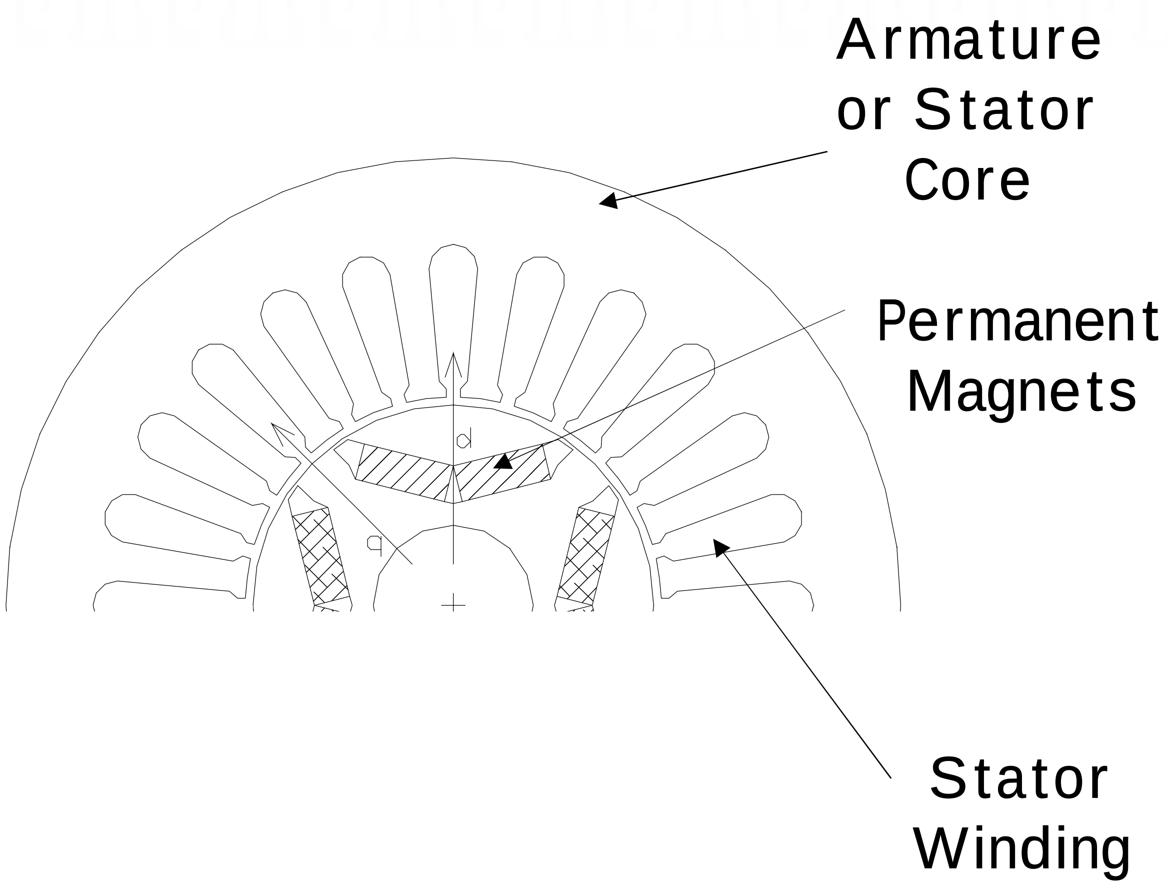




- Developed in the 1980’s to replace DC with AC Induction Motor
- Benefits of Laminated Frame
  - No cast frame
  - Channels for cooling air
  - Power dense
- Finned Laminated Frame
  - Developed in 2005
  - TEFC, TENV, TEBC
  - FOCUS ON POWER DENSITY
  - Up to 30% Increase in rating
  - Platform for Permanent Magnet Rotor

Interior Permanent Magnet (PM) AC Motors

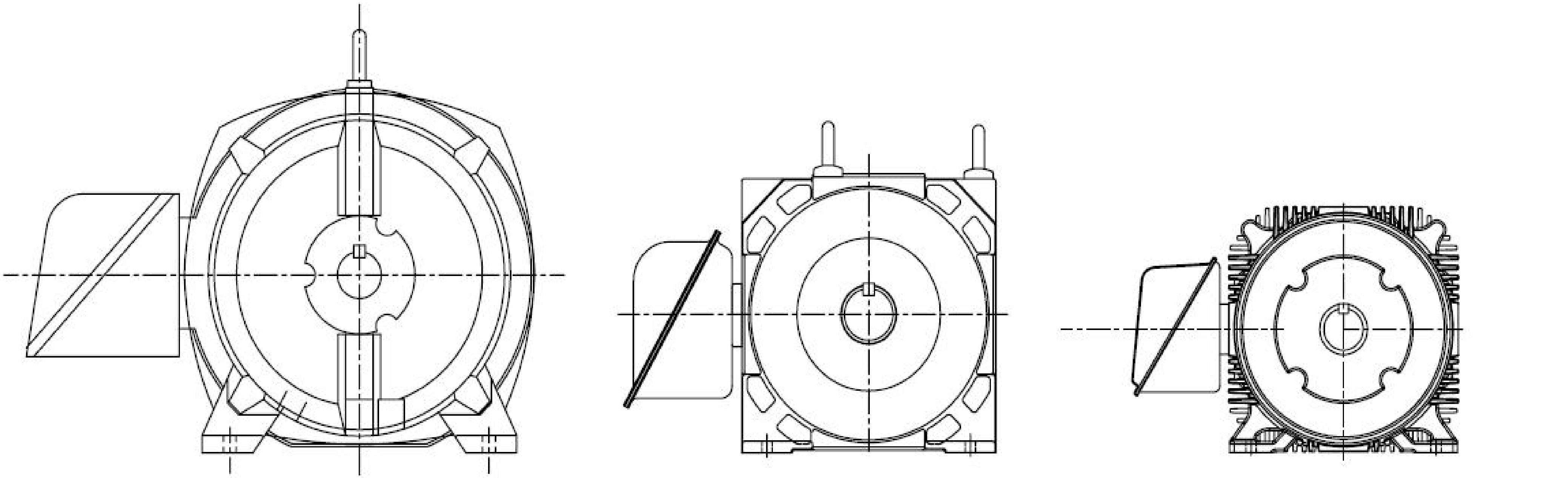
- Typical Interior Magnet PM AC Motor cross section
- Rotor field from permanent magnets
- No Slip (synchronous)
- Very low rotor losses
- Requires VFD



PM Motor comparison to IM

Frame Type	NEMA Cast Iron		Laminated Steel
Rotor Type	Induction		Interior PM
Enclosure	TEFC	TEFC	TEBC
HP @ 1750 RPM	20	100	100
Frame Size	256T	405T	FL2586
lbs/HP	16.25	11.60	5.32
F.L. Amps	25.5	115	103.5
F.L. Power Factor	78.9%	86.4%	93.4%
kW Losses	1.116	4.381	2.4
F.L. Efficiency	93.0%	94.5%	96.9%
Rotor Inertia	2.42 lb-ft²	26.1 lb-ft²	4.9 lb-ft²
Temp Rise	80 C	80 C	77.6 C

Shaft Height Comparison



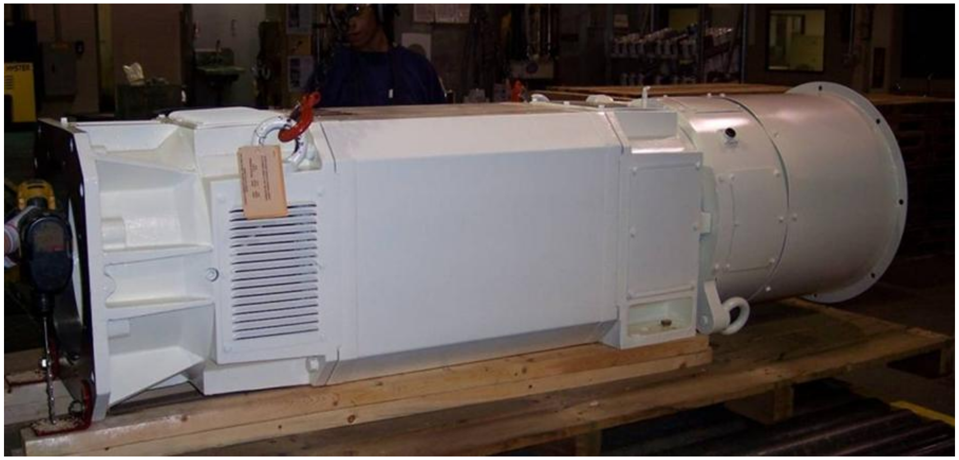
Application Specific PM Developments

- Cooling Tower – Direct Drive Fan
  - Higher Reliability
  - Lower Operating Cost
  - Lower Environmental Impact

BALDOR
A MEMBER OF THE ABB GROUP

Application Specific PM Developments

- Mining Equipment



BALDOR
A MEMBER OF THE ABB GROUP

Application Specific PM Developments

- Blower for theme park ride
  - Compact Design
  - Higher Reliability
  - High Response

NOW OPEN
Cars
LAND

BALDOR
A MEMBER OF THE ABB GROUP

Application Specific PM Developments

- Drill Rig Top drive motor

Application Specific PM Developments

- Top drive motor
  - Greater Power Density
  - Higher Reliability
  - Lower Cost

BALDOR
A MEMBER OF THE ABB GROUP

Application Specific PM Developments

- Top drive motor
  - Higher Power within a fixed envelope
  - Low Noise
  - Higher Reliability
  - Certification
    - Ex e

BALDOR
A MEMBER OF THE ABB GROUP

Application Specific Developments

- Vertical PM motor w/ Planetary Gearset for Low Speed High Volume Pumping
  - Replaces Slow Speed High Pole Count Motors

- Single reduction planetary gear
- 8:1 Reduction
- 5,000,000 in-lbs output torque

BALDOR
A MEMBER OF THE ABB GROUP

PM Motors, the next generation

- Past development as focused on power density and meeting specific application needs
- Optimizing efficiency has not been primary goal
- PM designs require VFD with special control firmware
- What if application doesn't need VFD?
- Can we use this technology to get to the next efficiency levels (IE4)?

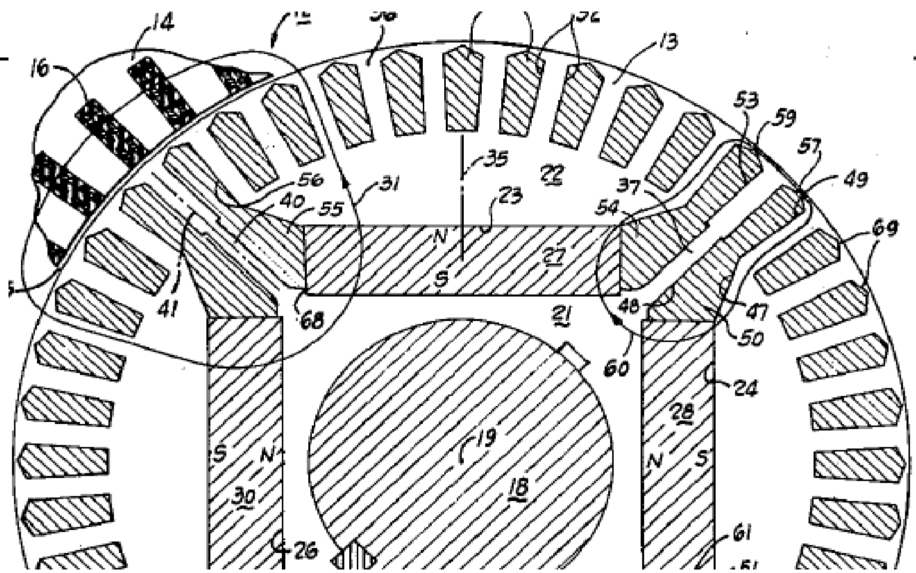
PM Motors, the "New Approach"

PM Motor that can start as a normal induction motor

"Line Start"; "Across the line"; "DOL"

United States Patent [19] [11] **4,139,790**

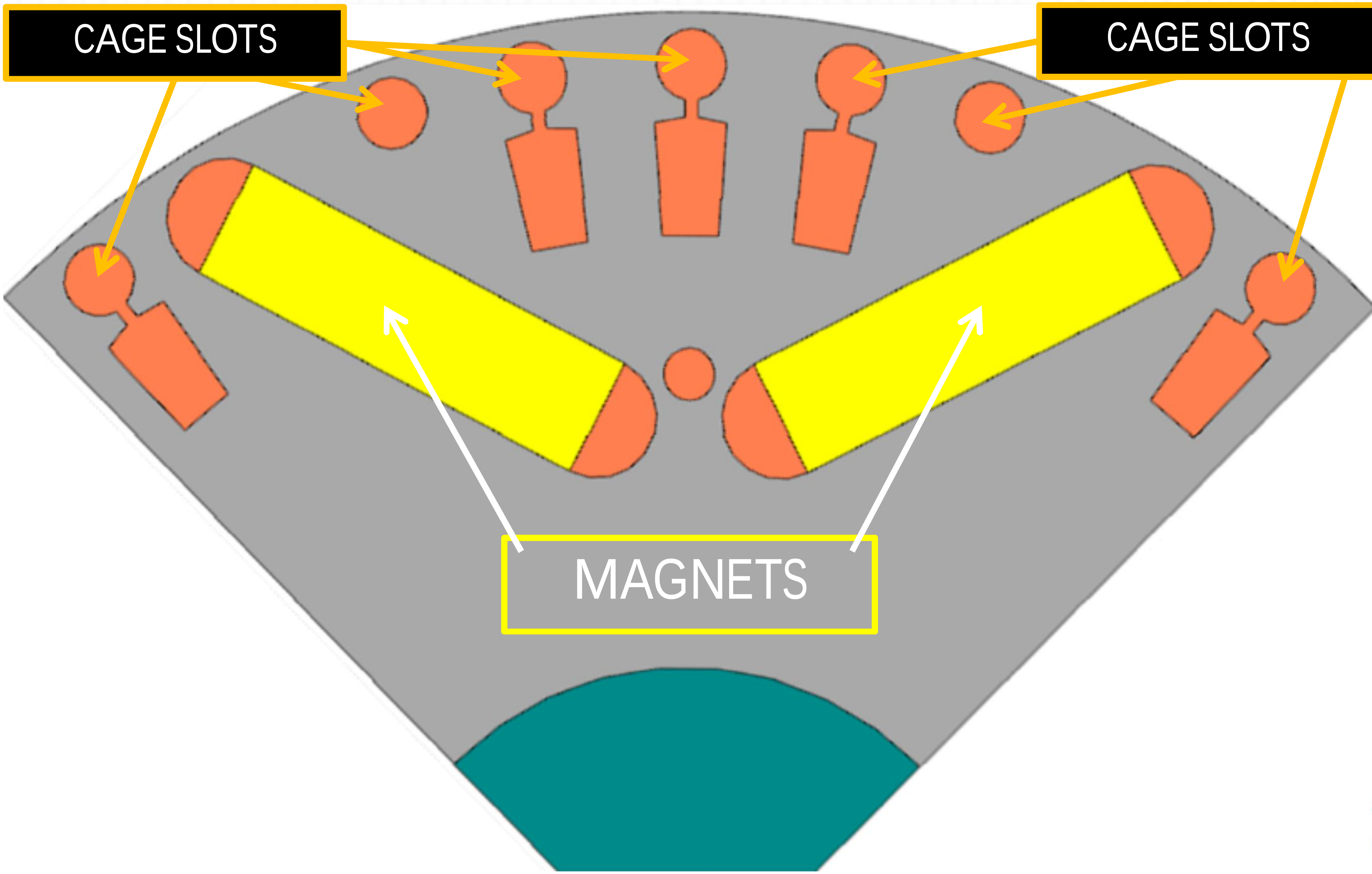
Steen [45] **Feb. 13, 1979**



BALDOR

A MEMBER OF THE ABB GROUP

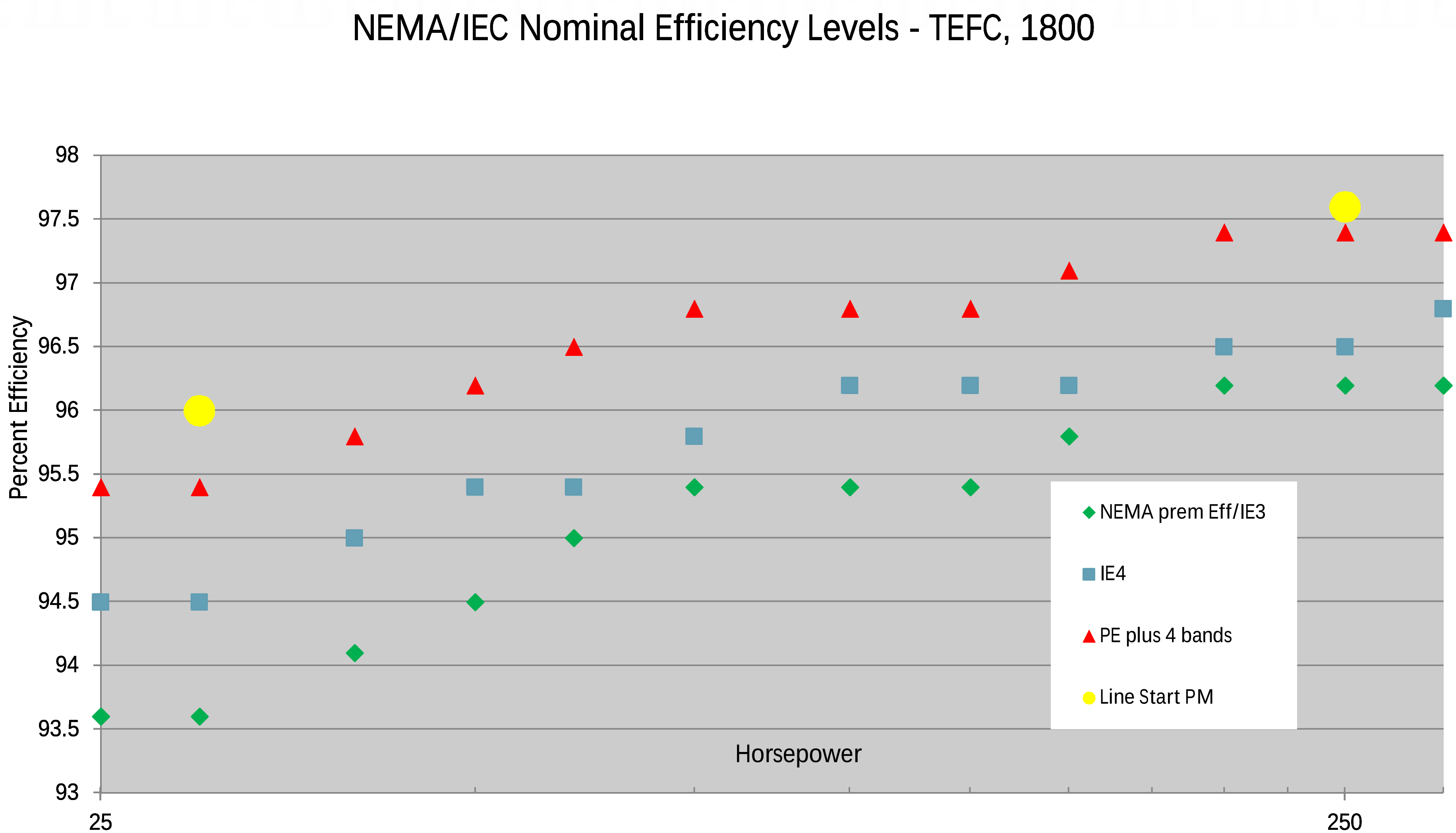
Line Start PM Motors



Line Start PM Motors

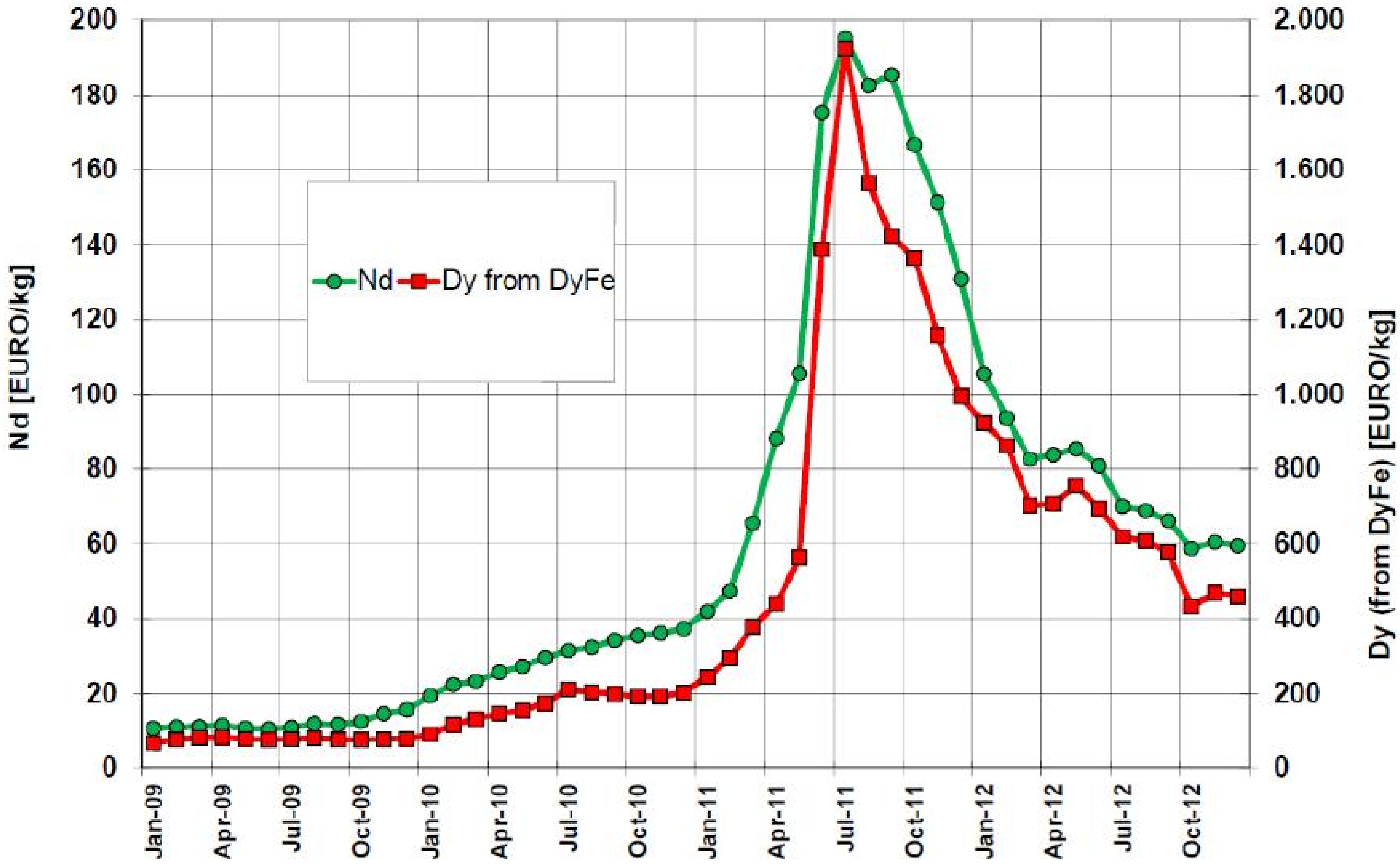
- Steady State Demonstrated Performance at 30 - 250 HP
  - Proof-of-Concept motors and prototypes designed, built, and tested from 30 – 250 HP
  - Test rigs were built to accurately measure the efficiency
  - Test rigs were built to assess the starting and synchronization capabilities

Line Start PM Motor Efficiency



BALDOR
A MEMBER OF THE ABB GROUP

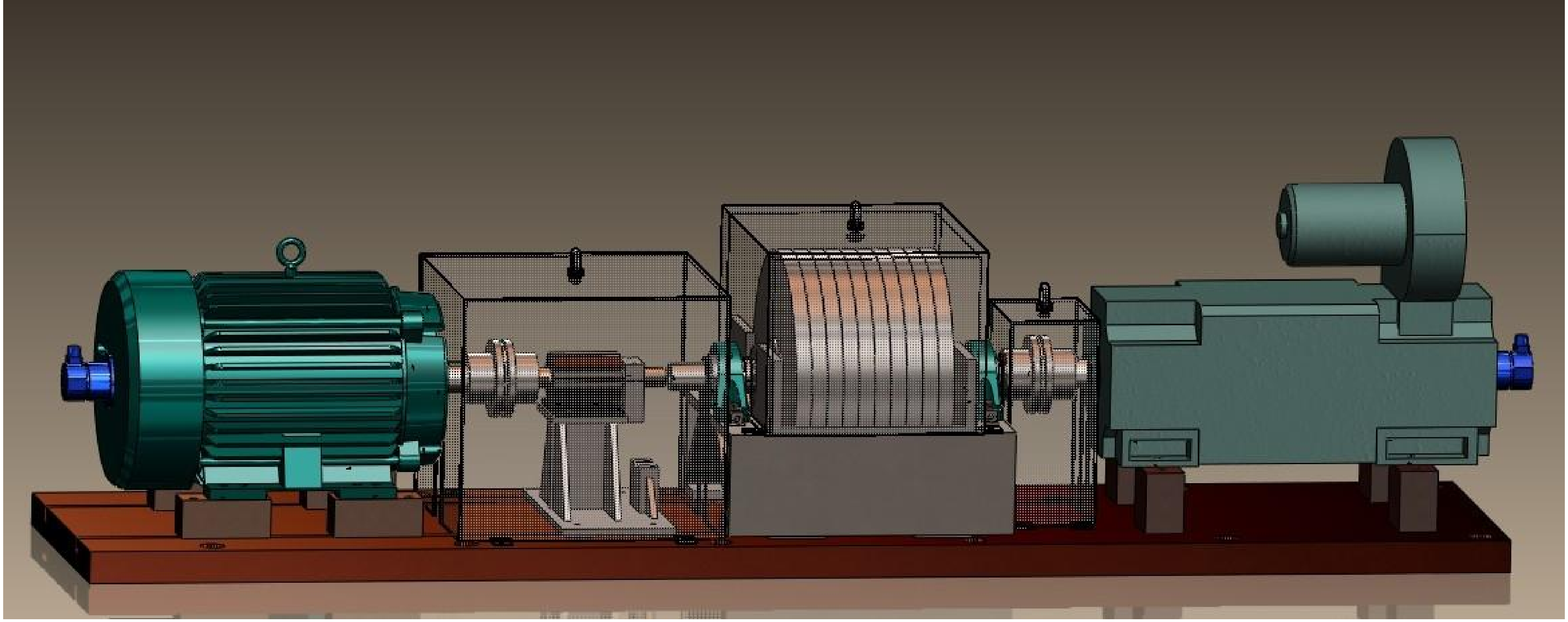
Line Start PM - Too good to be true?



BALDOR
A MEMBER OF THE ABB GROUP

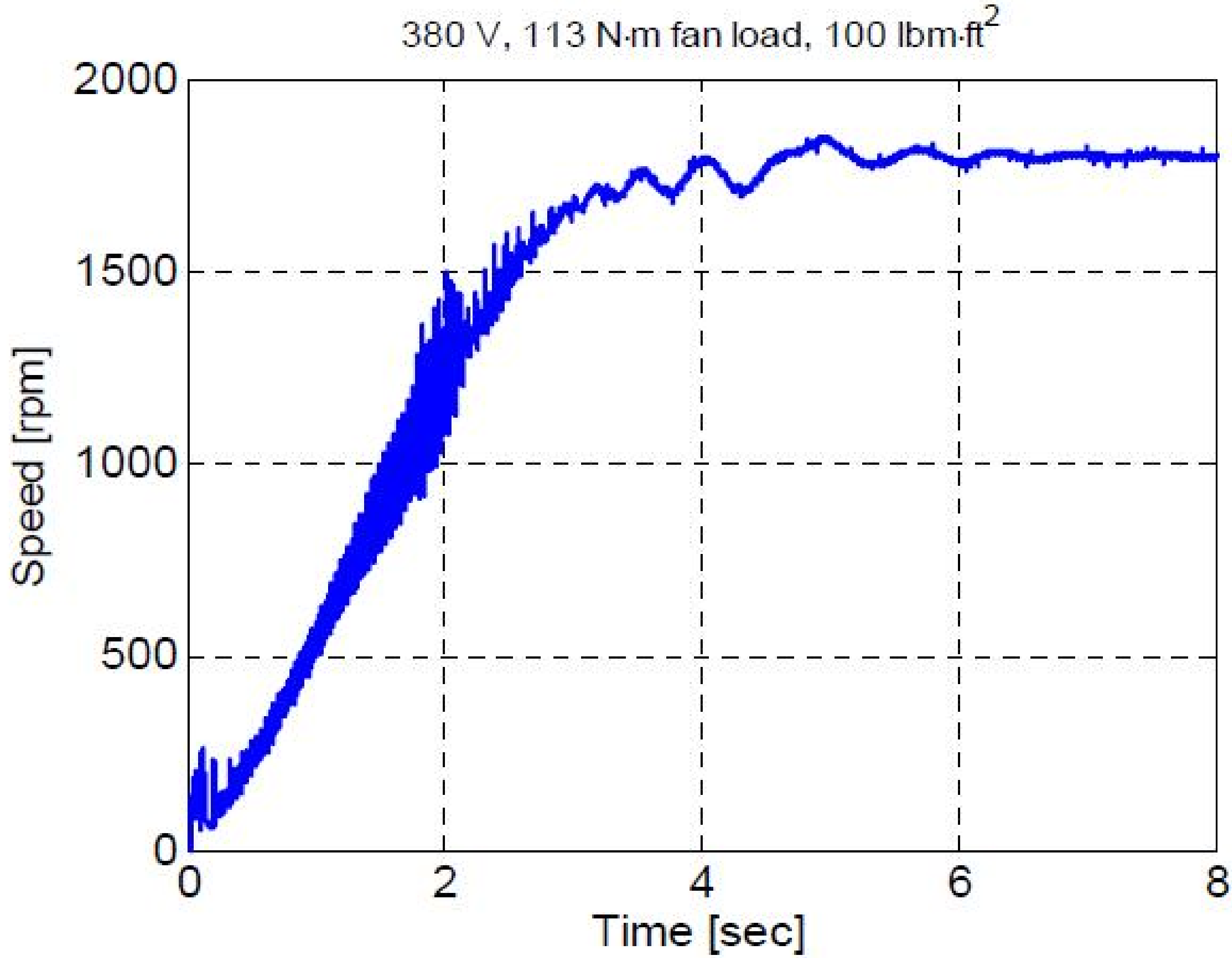
Line Start PM – Too good to be true?

Starting Performance – Test Rig



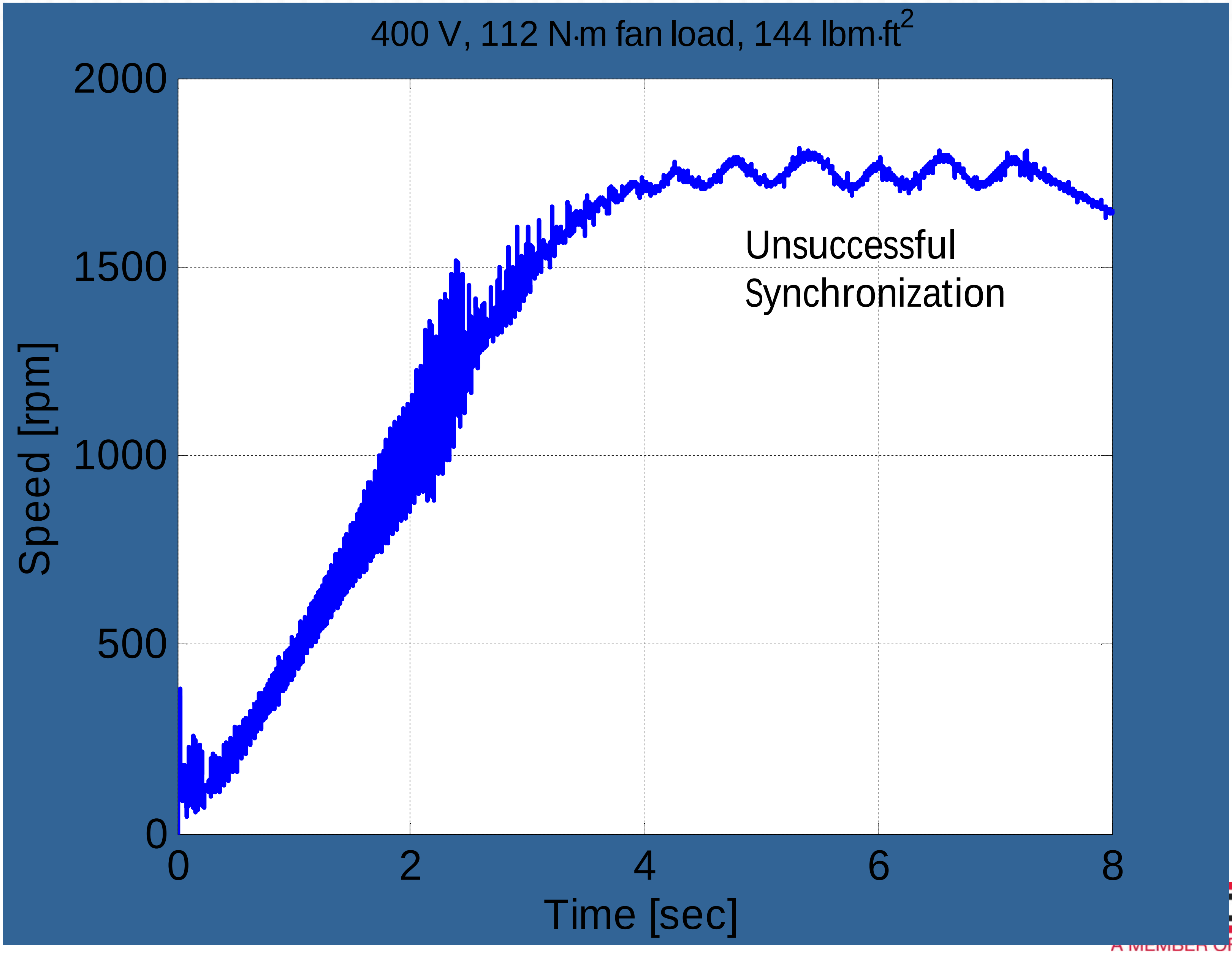
BALDOR
A MEMBER OF THE ABB GROUP

Line Start PM – Starting Performance



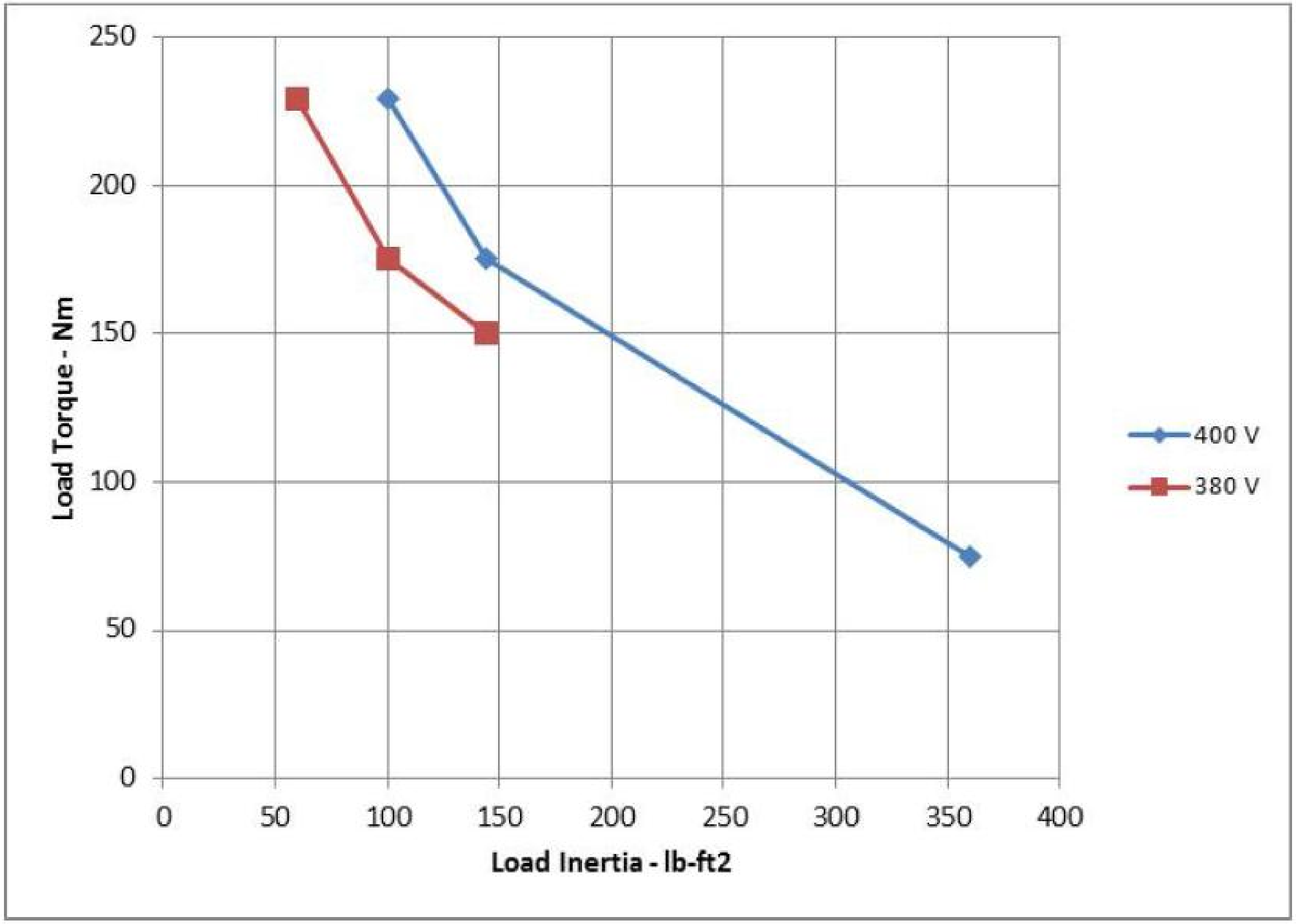
BALDOR
A MEMBER OF THE ABB GROUP

Line Start PM – Starting Performance



Line Start PM – Starting Performance

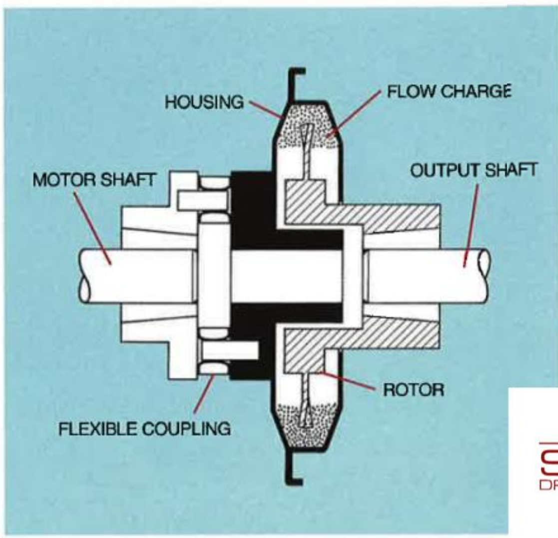
Motors can synchronize in the range of 20x their own inertia or about 25% of the equivalent NEMA <u>induction</u> motor load wk^2



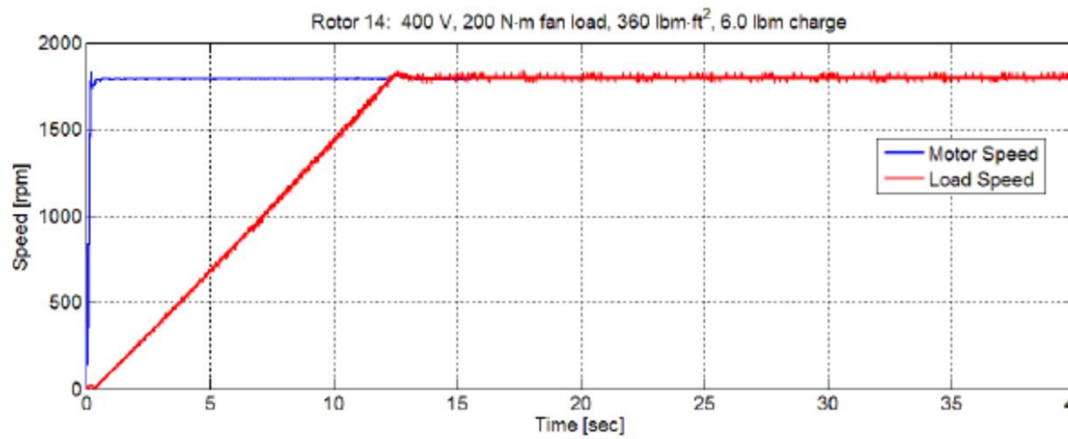
BALDOR
MEMBER OF THE ABB GROUP

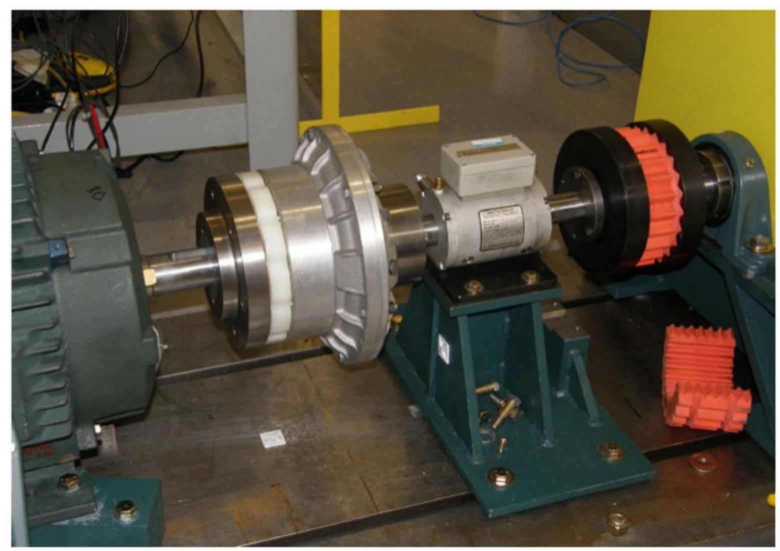
Line Start PM – Starting Performance

- For high inertia loads, soft start options are available



FLEXIDYNE Couplings





Line Start PM – Conclusions

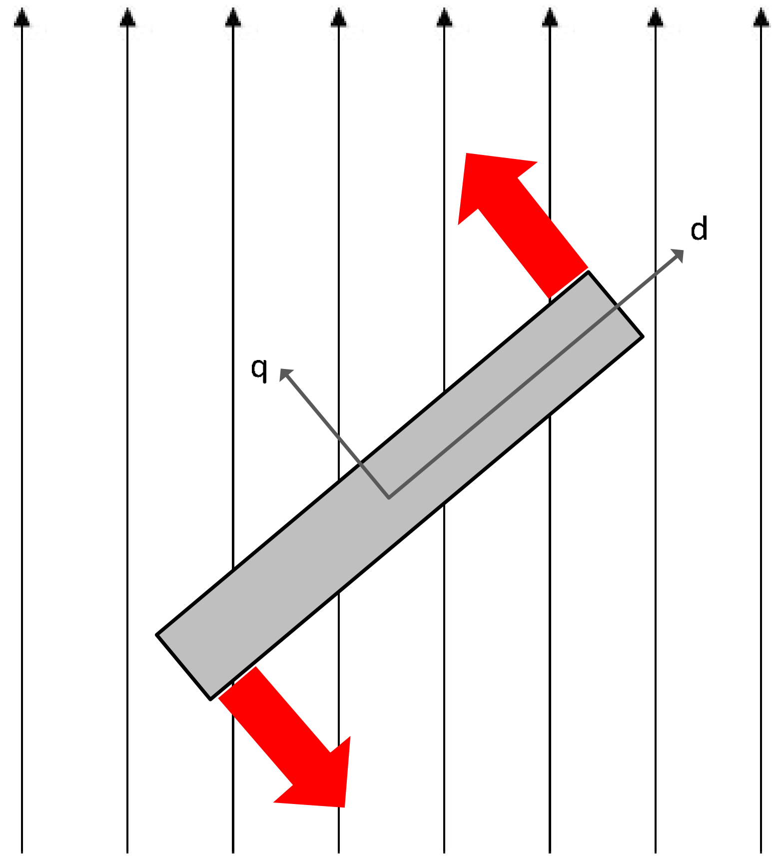
- Demonstrated efficiencies jumped beyond IE4 levels with 4 – 8 NEMA efficiency band improvements beyond NEMA Premium / IE3
- LSPM Motors enable leaps in energy efficiency
- Power factors also higher than induction motors
- Ability to run on simple inverters (V/Hz or “scalar mode”)
- Capability to start most (but not all loads)
- Torque pulsations during starting
- Dependent on high strength magnets
- Potential for magnet costs to drive costs up
- Need to account for lack of slip in applications

“New” Technology - Synchronous Reluctance

- Not a new idea (1923)
- No suitable starting method available (VFD)
- Initial work with technology could not demonstrate superior torque performance
- Advances in drive technology and design have overcome initial obstacles

BALDOR
A MEMBER OF THE ABB GROUP

Synchronous Reluctance

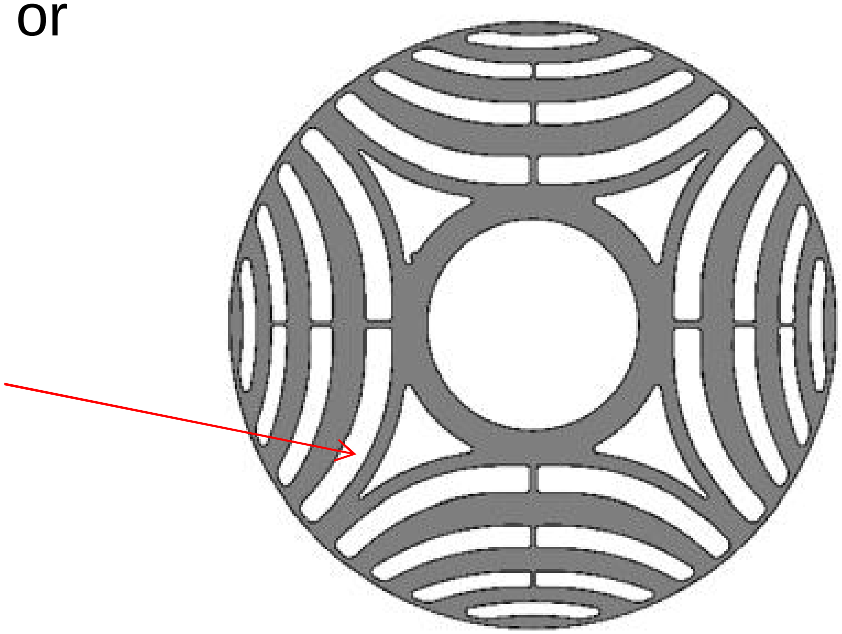


- Magnetic Reluctance is the magnetic equivalence to resistance
- Rotor consist of one direction of least possible reluctance (d) and a perpendicular direction (q) with a high reluctance
- Torque is produced as the rotor attempts to align it's magnetically conducting direction with the field.

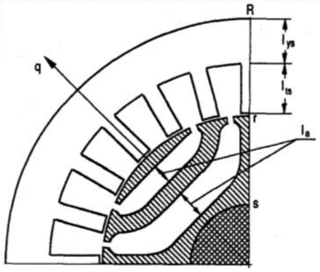
BALDOR
A MEMBER OF THE ABB GROUP

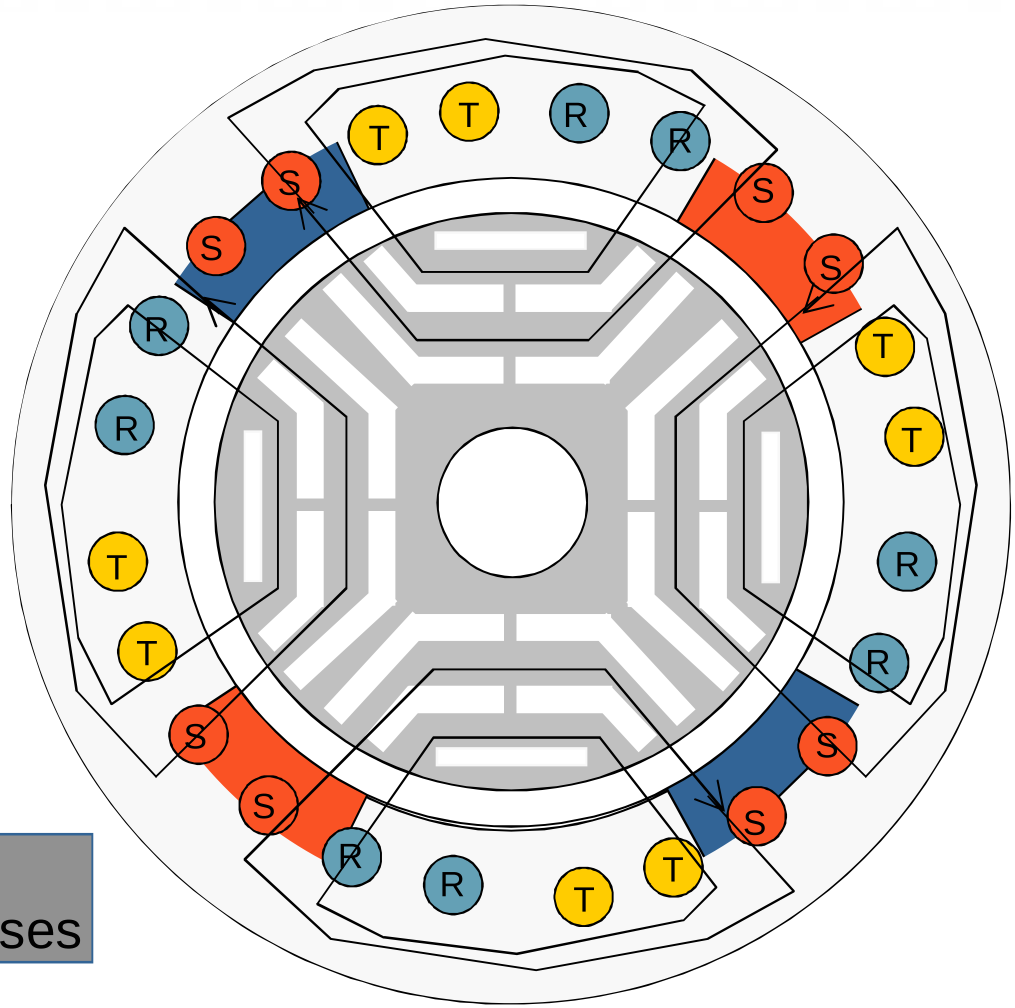
Synchronous Reluctance

- Distributed, symmetric stator lamination and winding (same as induction motor)
- Rotor is simple design, no magnets or cage.
- Designed to create areas of high reluctance



Synchronous Reluctance

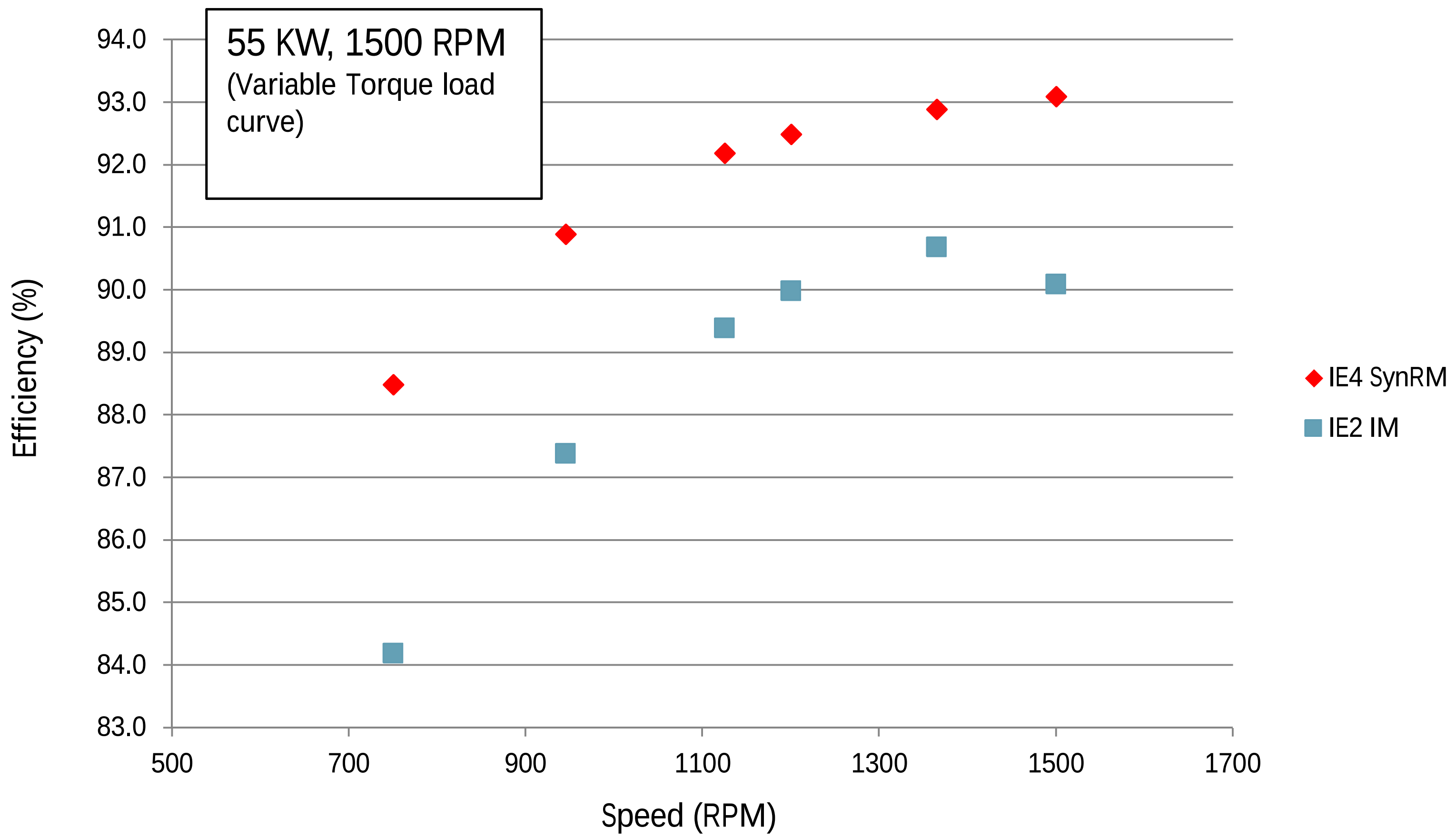




Elimination of
resistive rotor losses

Synchronous Reluctance - Performance

- Comparison testing of "packaged" SynR motor/drive w/ IEC IE2 Induction motor/drive as function of speed.

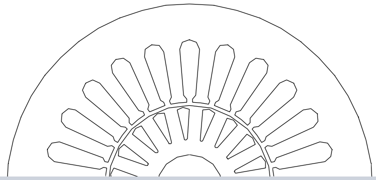
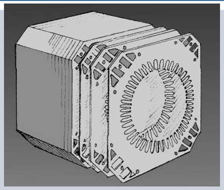
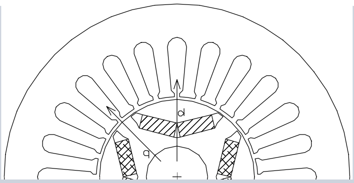
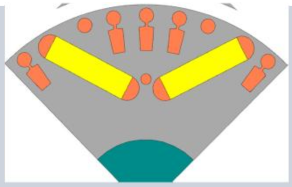
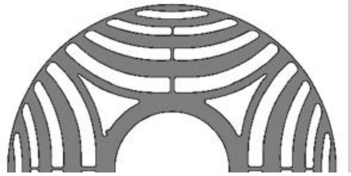


BALDOR
A MEMBER OF THE ABB GROUP

Synchronous Reluctance – Conclusions

- Demonstrated efficiencies up to IE 4 levels
- Simple rotor construction (no magnets or cages)
- Low temperature operation (no rotor losses)
- Low rotor inertia
- Technology can be optimized for power density or efficiency
- Requires a VFD (no line start)
- Power factor worse than IM or PM (may need bigger drive/cabling)

New Motor Technology Comparison

Induction	Lam. Frame IM	Lam. Frame IPM	Line Start PM	SyncR
				

BALDOR
A MEMBER OF THE ABB GROUP

Motor Technology Update

- Advances in motor designs, technology and materials are enabling motor manufacturers to push motor efficiencies beyond current IE3, induction motor capabilities.
- Line Start Permanent Magnet and Synchronous Reluctance are two "emerging" technologies that could be beneficial to the pump and fan industries.

- QUESTIONS?

Heather Flanagan, ABB Inc. July 22, 2014

Electric Vehicle Charging Infrastructure

Why is ABB in EV business?
Technology, market, electrification

PDM (Charger, converter)

Inverter

Motor

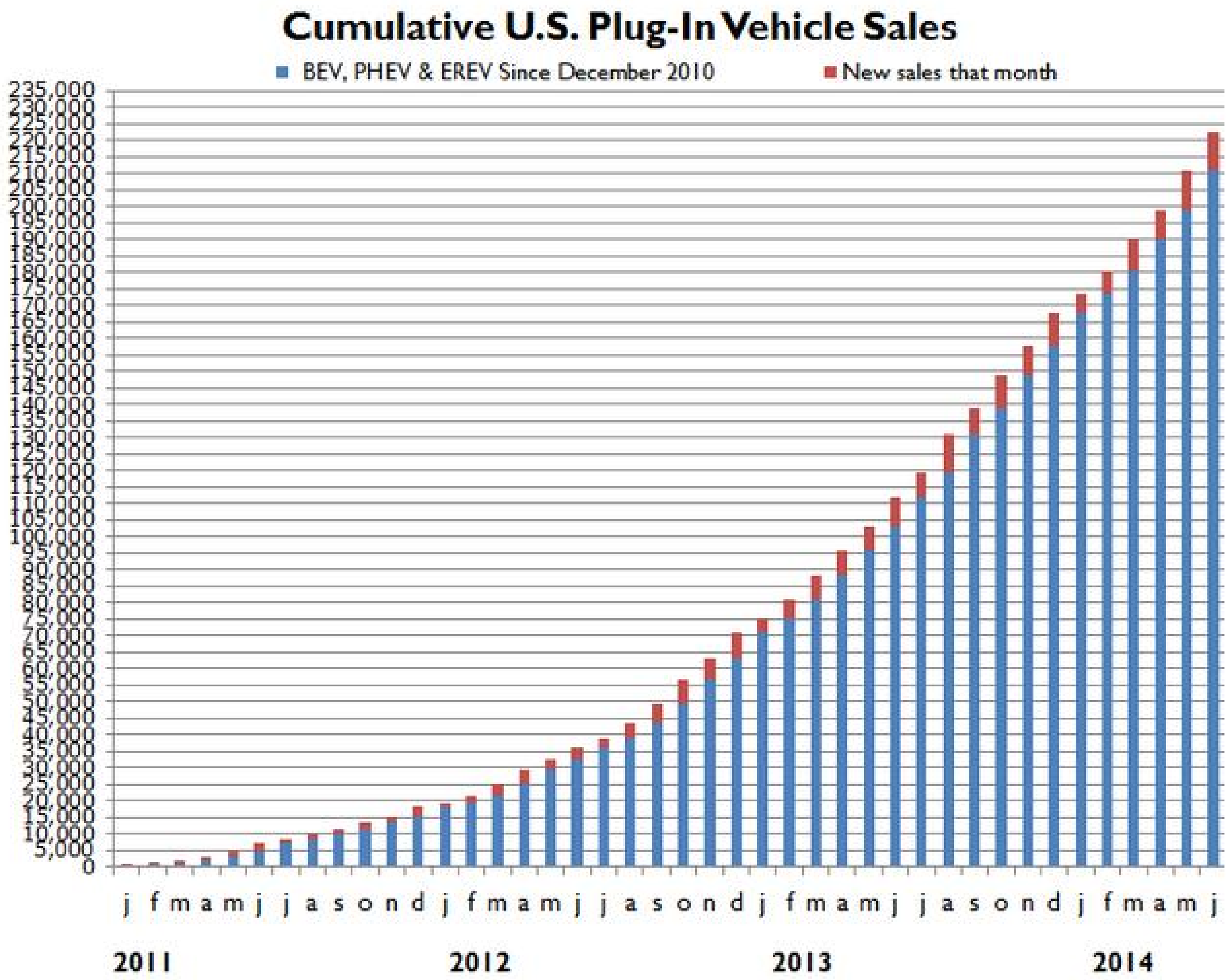
Nissan Leaf ePowertrain

- Charging equipment technology:
    - Power electronics / power conversion competency
- Transportation segment
    - ABB has dominant electrical transportation history – rail infrastructure / marine propulsion
- Electrification value proposition
    - Energy efficiency, reduced emissions, low maintenance, low noise, longer life

Plug-In Vehicle Sales
+220,000 cars now need charging

Source:
Electric Drive Transportation Association

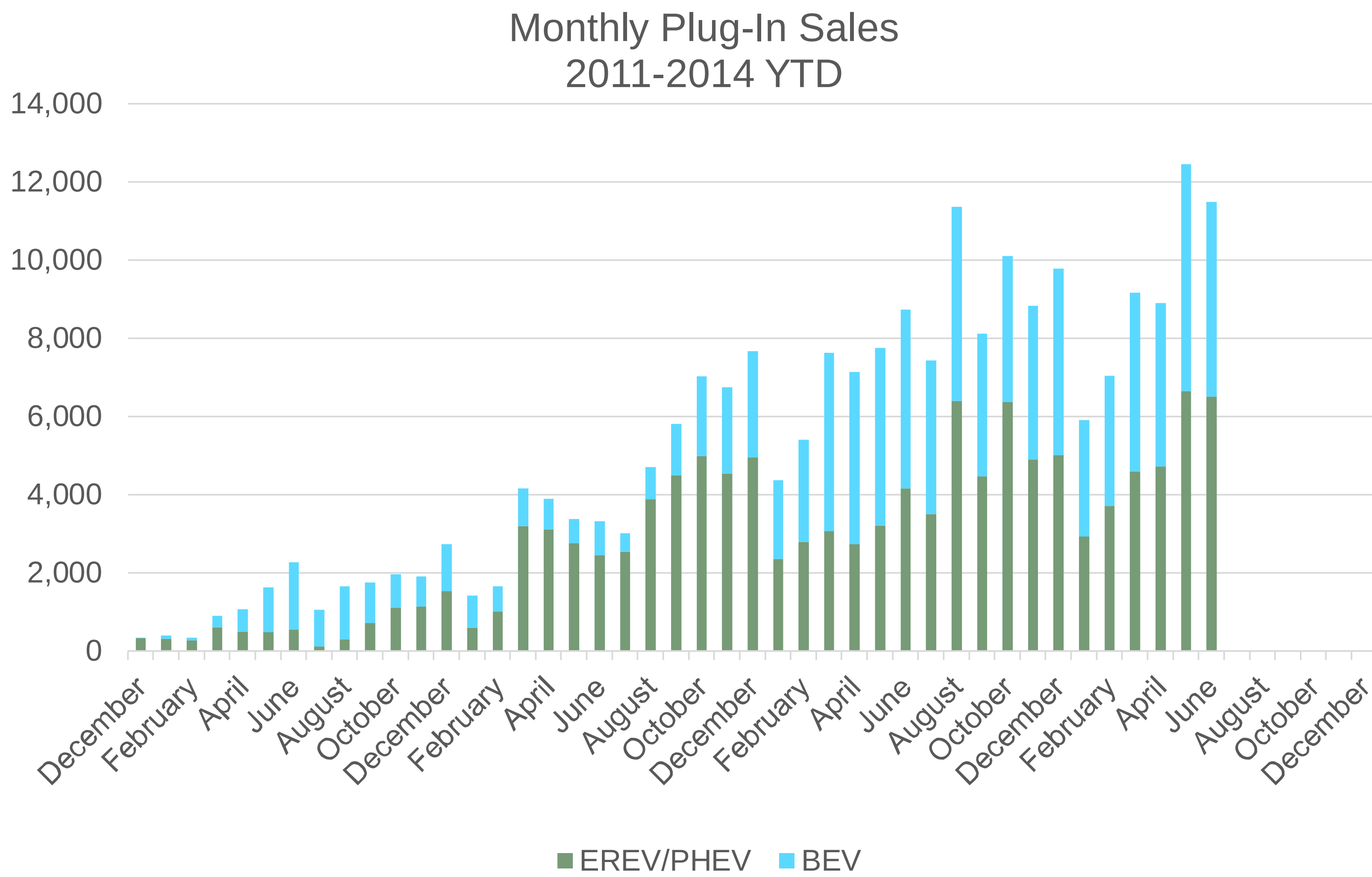
Rate of plug-in adoption higher than the original gas engine automobile and hybrids a decade ago.



Plug-In Vehicle Sales
Growth curve is strong

Source:
Electric Drive Transportation Association

Rate of plug-in adoption higher than the original gas engine automobile and hybrids a decade ago.



Charging
Equipment types

Type	Voltage	Charging time		Estimated cost of unit
		Battery EV (larger battery)	Plug in Hybrid (smaller battery)	
Level 1 Charger	120 volts	12-18 hours	6-8 hours	$0 - $1000
Level 2 Charger	240 volts	4-6 hours	2-4 hours	$400 - $10,000
DC Fast Charger	480 volts	15-60 minutes	n/a*	$25,000 - $50,000

*Current PHEV models do not fast charge, but vehicle landscape is quickly evolving, may become more common

ABB

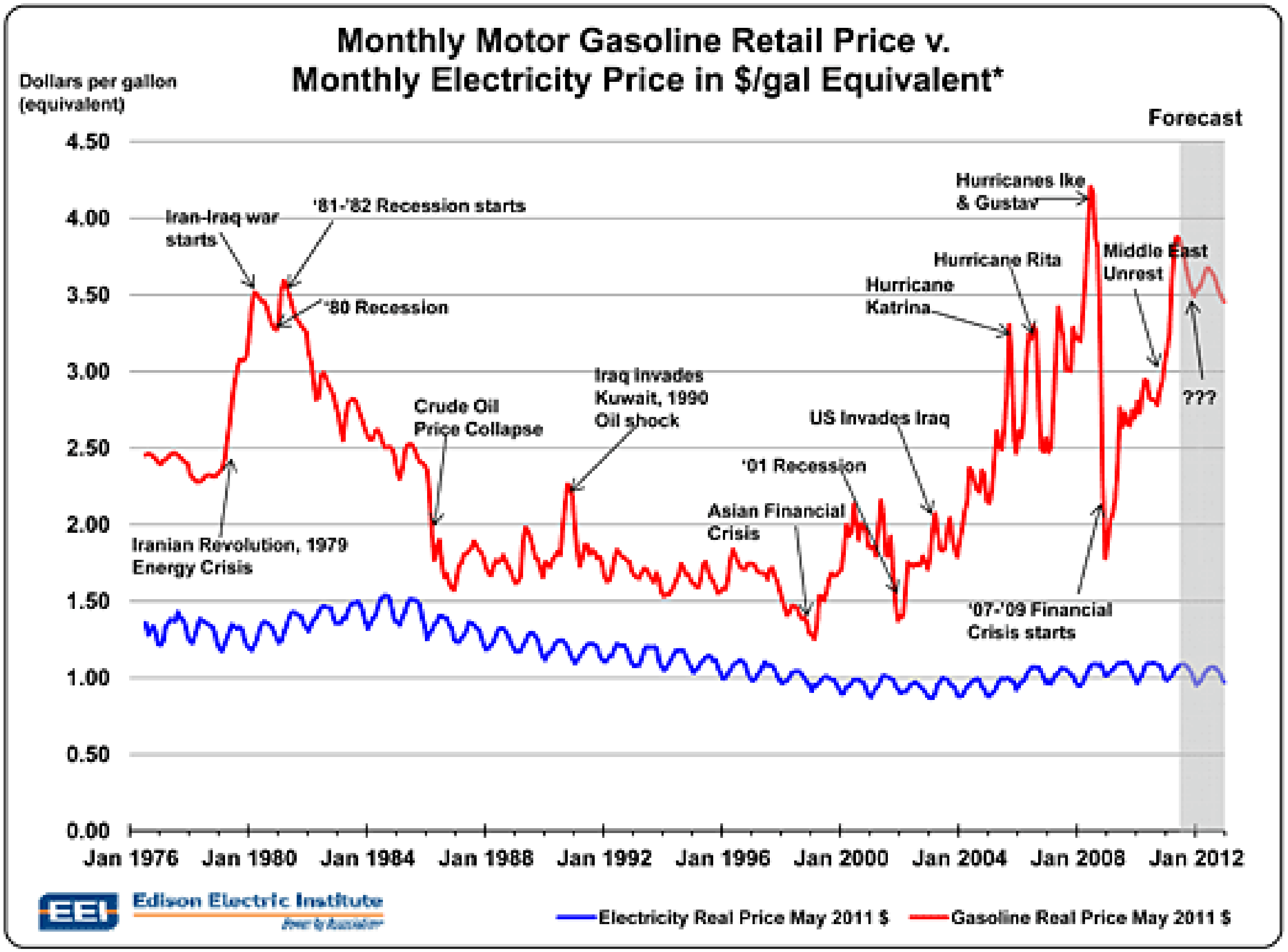
Charging
Cost to charge vs gas fuel

Type	Voltage	Location		Comparable gas cost on 40 miles of range
		Home	Public	
Level 1 Charger	120 volts	$1 - $1.50	Generally free if offered	$6
Level 2 Charger	240 volts	$1 - $1.50	Free to $5	
DC Fast Charger	480 volts	n/a	Commonly free to $5	

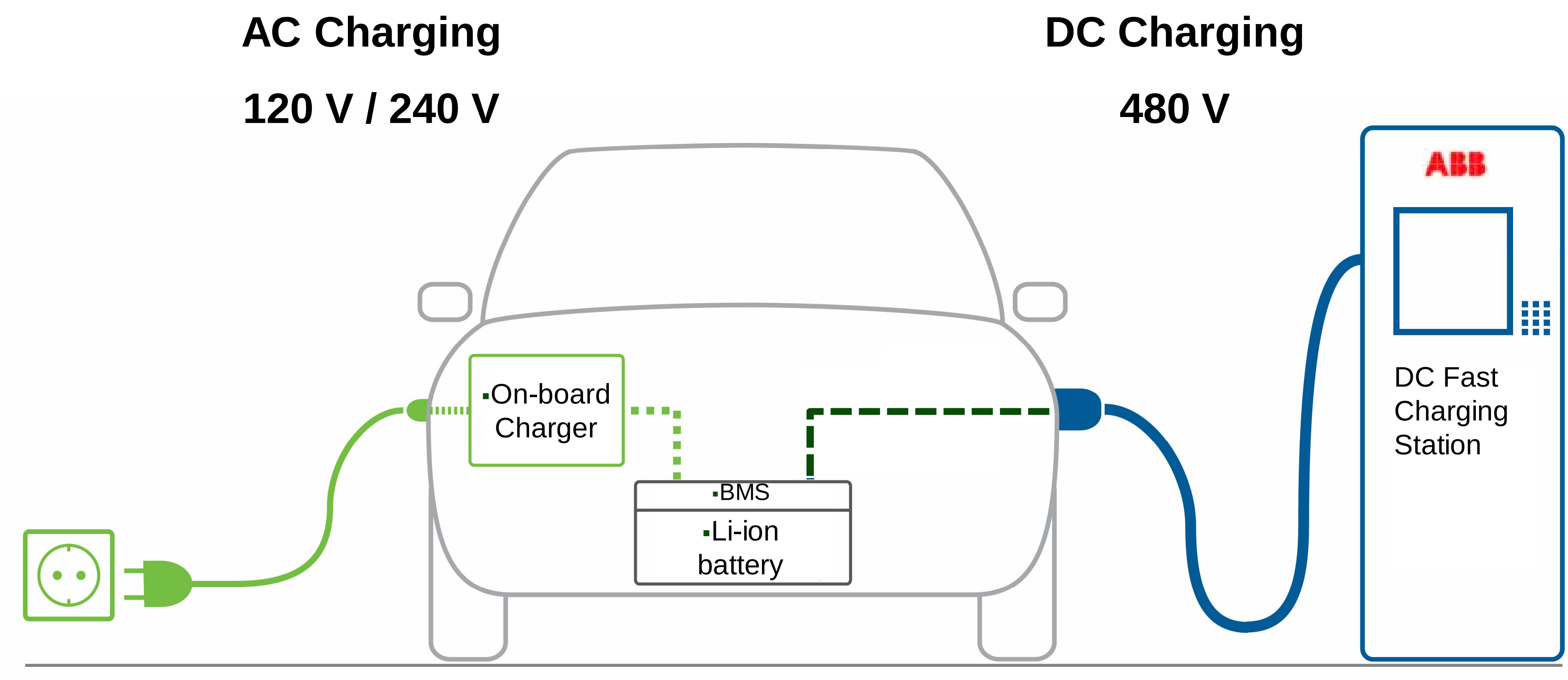
Assumptions:
Average miles per day: 40
Electricity rate: .12 cents/kWh
Gas vehicle 25 mpg, $3.75/gallon

ABB

Energy comparison, gas vs electric
Relative cost/stability of transportation energy



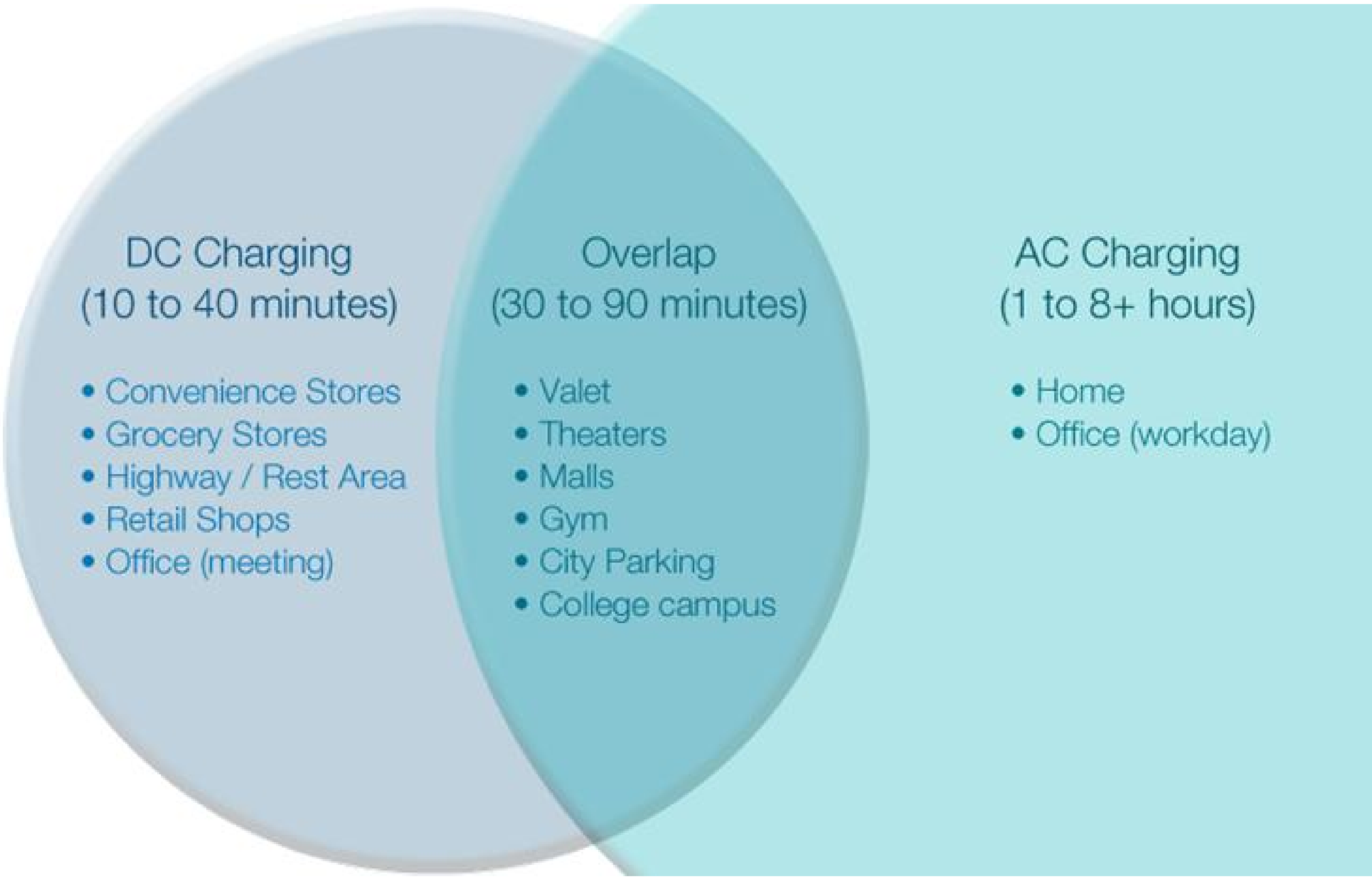
Charging
AC vs. DC Charging



Every vehicle needs to have it's own onboard equipment

Infrastructure investment is shared with hundreds of users

Fitting the EV driver's lifestyle
Parking Use Cases – DC vs AC charging

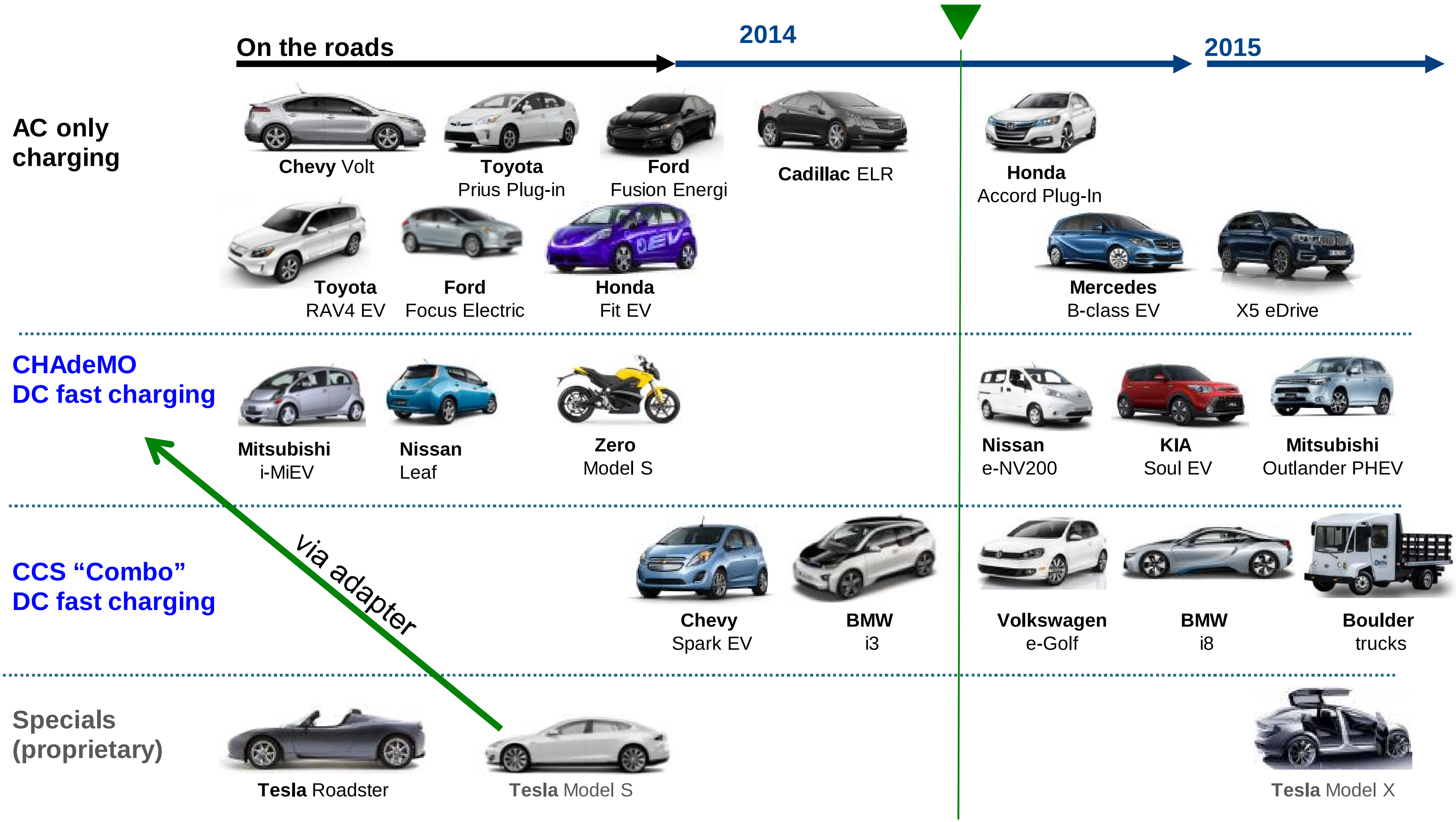


Charging standards
Hardware and communications

SAE J1772 AC	CHAdeMO	SAE J1772 CCS (Combo)
AC; < 19.2 kW	DC; < 62.5 kW	DC; < 90 kW
Typical 3.3, 6.6 kW	Typical 20-50 kW	20-50 kW
4-8 Hour Charge	15-60 min. Charge	15-60 min. Charge
		
"Universal"	KIA, NISSAN, MITSUBISHI MOTORS, ZERO MOTORCYCLES, SUBARU, TESLA*, TOYOTA	GM, BMW, VW, PORSCHE, Mercedes-Benz, Ford

ABB

EV model landscape
Plug-in models by charging standard



ABB

What's prompting DC fast charging interest and growth?

- More EV's on the road: demand increase and regional concentrations
- Battery packs continue to grow and gain energy density (while cost of batteries is decreasing – Li-ion 50% less than 5 years ago)
- DC charging enables range
  - Drivers want fast energy
  - Cold weather considerations (battery range)
- Vehicle OEMs are fully engaged – private incentives
- Public incentives at start – less so now (EVSE credits ended)
- Standards established
  - CHAdeMO, CCS Combo – multi-standard units now available, from ABB!

Public EV Charging
Billing models – EVSE market evolving

1. **Free.** Incentive to park/shop. Less common than it used to be... like early days of internet service

2. **Membership model** – such as a monthly fee to belong to a network

3. **Flat fee per session** - simple, but inefficient use of a valued charging station and parking location.

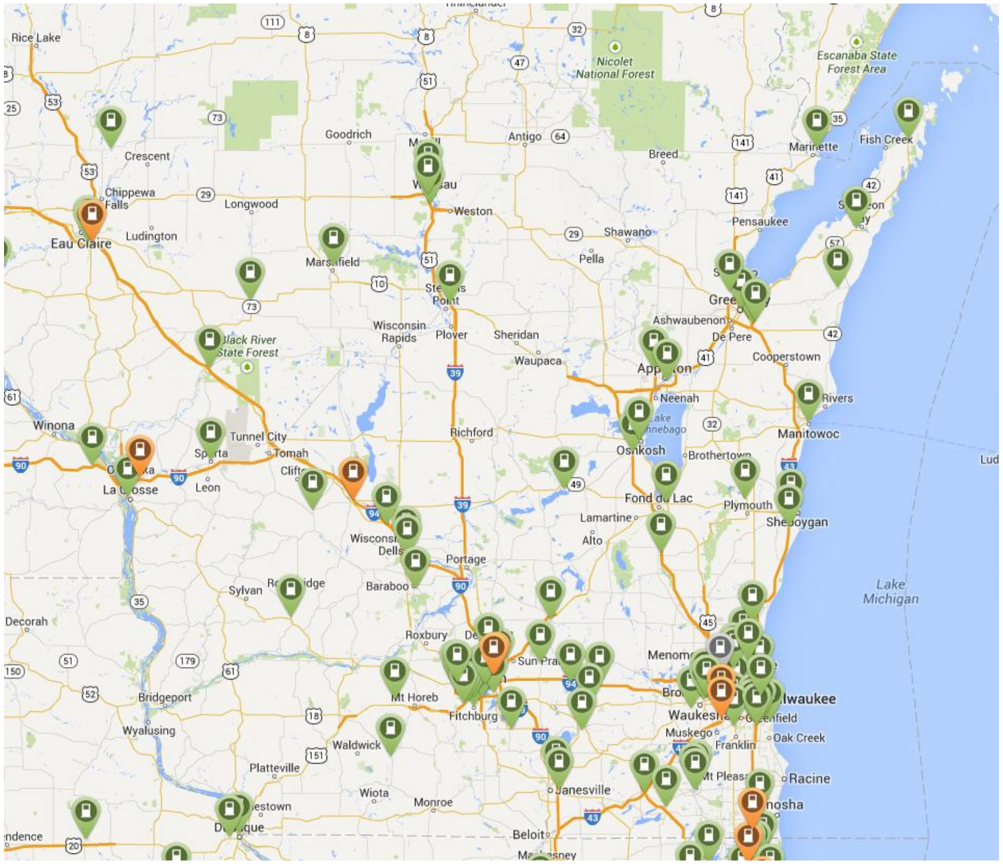
3. **Bill per kWh** (most like the gas model, as paying by the gallon). Motivates drivers to only charge as they need

4. **Bill by time.** Moves cars along faster, keeps vehicles from squatting at popular charging locations.

5. **Bill by time escalating**, i.e. billing rate of $2.50 for the first 10 minutes and $0.50 for each additional minute.

Charging stations

Where are they in Wisconsin?



Sites and apps:

www.plugshare.com

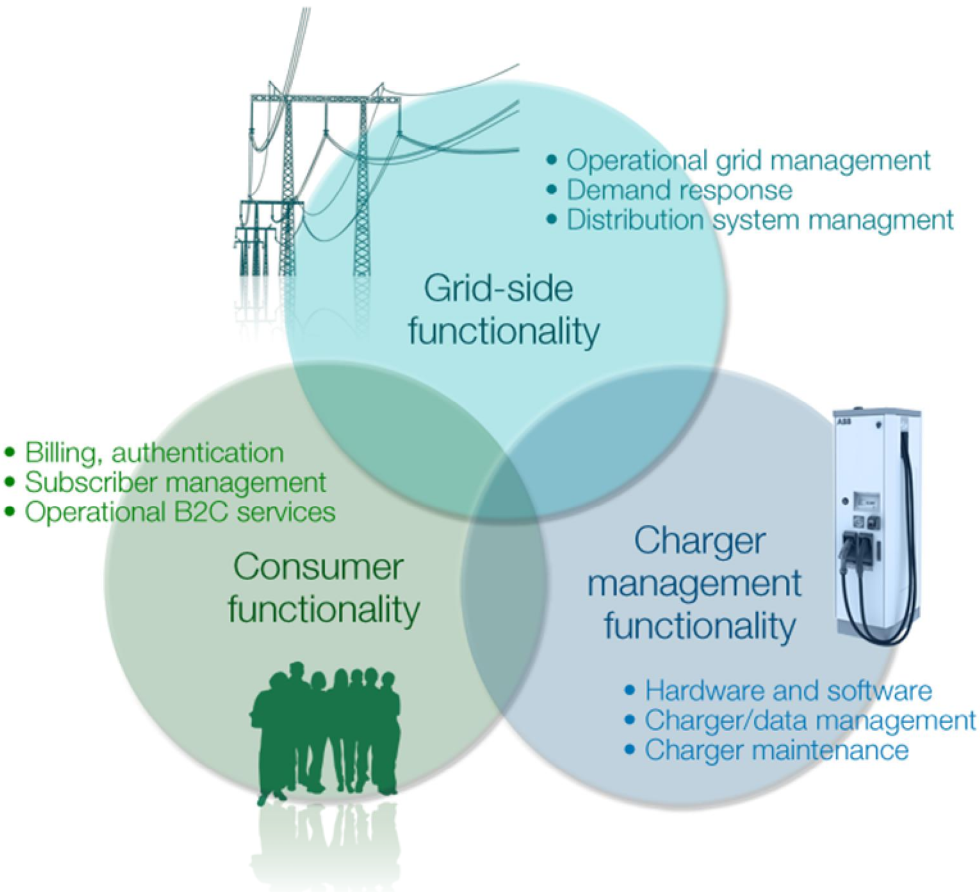
(site and app)

DOE:

http://www.afdc.energy.gov/fuels/electricity_locations.html

http://openchargemap.org/site

Grid impact
So far, so good – and what lies ahead



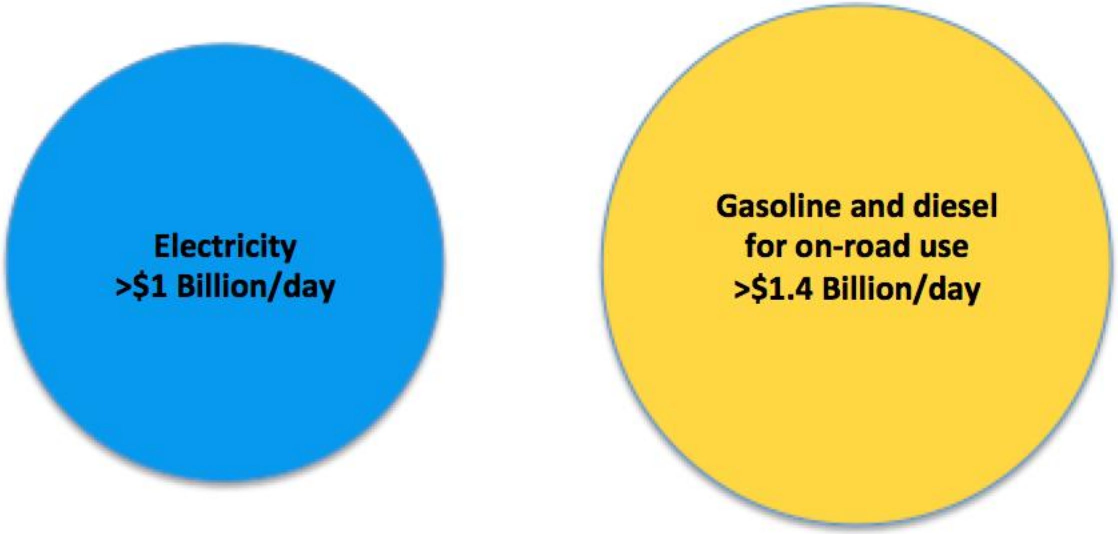
- Time-of-use EV pricing programs and overnight charging habits showing off-peak behavior working, smoothing demand
  - Opower (western US)
  - SCE (SoCal region)
  - PSR Analytics (Austin region)
- Big data:
  - Equipment capability - charger power management intelligence
  - Utility capability - demand response technology
- V2G models – distributed energy storage (aggregated EVs offering peak load leveling)

US Daily Energy Use
A revenue opportunity for utilities

Source: Energy Trends Insider, July 14, 2014

Article: The Greatest Growth Opportunity for Electric Companies: Devour Oil’s Market

Daily U.S. Consumer Energy Spending



- http://www.energytrendsinsider.com/2014/07/14/the-greatest-growth-opportunity-for-electric-companies-devour-oils-market
- http://www.navigantresearch.com/blog/plug-in-vehicles-for-utilities-more-opportunities-than-challenges
- http://cleantechnica.com/2014/02/13/utility-companies-welcome-evs

ABB

Useful Resources
Web links

EDTA (Electric Drive Transportation Association - http://www.electricdrive.org

Alternative Fuel Data Center (AFDC) - http://www.afdc.energy.gov

Charged EV Magazine - http://chargedevs.com

PlugShare.com - http://www.plugshare.com

Union of Concerned Scientists - http://www.ucsusa.org

InsideEVs - http://insideevs.com

FleetCarma - http://www.fleetcarma.com

Clean Cities - http://www1.eere.energy.gov/cleancities

DoE Workplace Charging Challenge - www.electricvehicles.energy.gov

ABB Inc. - http://www.abb.com/evcharging

Sign up for ABB EVCI eNews:

https://ja147.infusionsoft.com/app/form/evciwebsignup

ABB

Contact information

Heather Flanagan
Marketing Communications Manager, EV Charging Infrastructure - Americas
ABB Inc.
Innovation Campus – Wauwatosa, WI
262.395-1773
heather.flanagan@us.abb.com
www.abb.com/evcharging

Sign up for ABB EVCI eNews:

https://ja147.infusionsoft.com/app/form/evciwebsignup

Power and productivity
for a better world™

ABB

2014

Advanced Technologies
Power Electronics for the Grid

Power Quality Issues on the Network

Voltage Sags

- **Cause:** Fault on feeder or connecting large loads such as motors
- **Effects**: Tripping of VSD's, PC's, switchgear, high motor current, over-current protection tripping

Transients

- **Cause:** Lightening, storms, down power lines, capacitor switching
- **Effects**: Electronic equipment failure, overvoltage tripping, voltage breakdown

Neutral-ground voltages

- **Cause:** Poor electrical wiring and grounding
- **Effects**: device malfunction

Harmonics

- **Cause:** Use of power electronics (VSDs, SMPS, high efficiency lamps, etc)
- **Effects**: motor, transformer, neutral conductor overheating, instrument and PLC malfunctioning

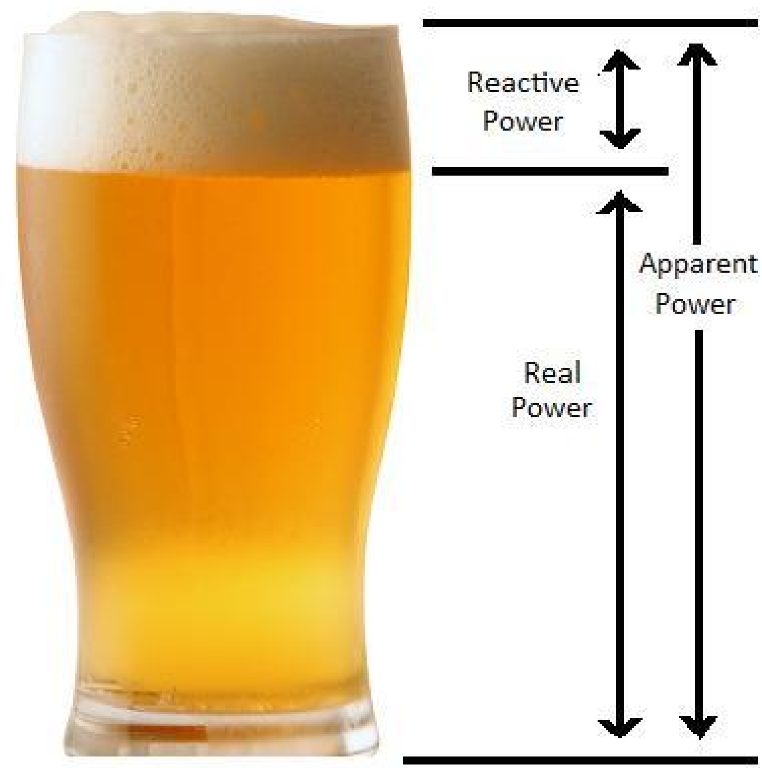
Fluctuations

- **Cause:** Cyclical loads, cranes, welding, arc furnaces
- **Effects**: visible lighting flicker and damage to electronic equipment

ABB

What is Reactive Power and Why is It Important

- Refers to the circulating power in the grid that does no useful work
- Transformers, power lines, other electric equipment are all contributors to reactive power
- The variation in reactive power can have severe impact on the system voltage levels
- If not kept in balance , reactive power can increased losses and lead to excessive voltage sags an poor power factor
- Precise reactive power control can help enhance power quality



Blackout of 2003

via

The New York Times

Experts now think that on Aug. 14, northern Ohio had a severe shortage of reactive power, which ultimately caused the power plant and transmission line failures that set the blackout in motion. Demand for reactive power was unusually high because of a large volume of long-distance transmissions streaming through Ohio to areas, including Canada, that needed to import power to meet local demand. But the supply of reactive power was low because some plants were out of service and, possibly, because other plants were not producing enough of it.

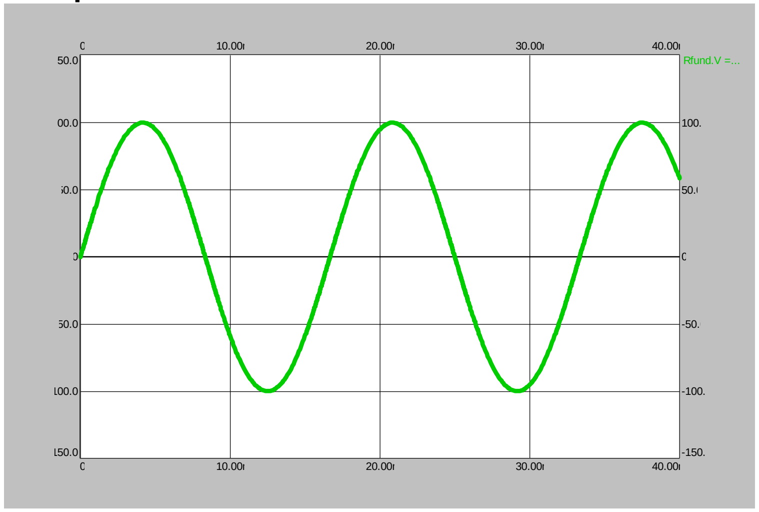
- *Source: NYTimes (September 23, 2003)*

ABB

Other Power Quality Concerns
Harmonics & non-linear loads

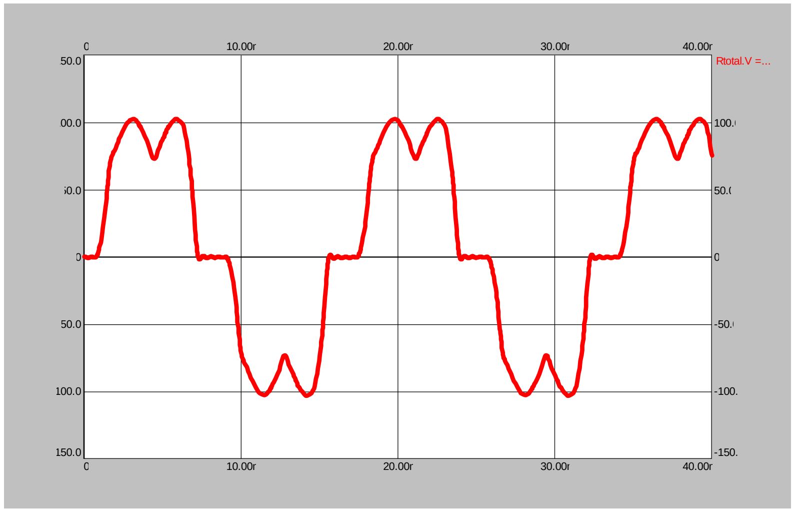
Linear Loads

- When equipment draws current from the supply that is proportional to the applied voltage
- Examples of linear loads include resistive heaters and incandescent lamps



Non-linear Loads

- Loads which draw current from the supply that is dissimilar in shape to the applied voltage
- Examples include discharge lighting, computers and variable speed drives (power electronics)



Consequences of Harmonics

- Increased Utility current requirement
  - Less flexible system with limited ability to expand
  - Larger wires which means added costs
- Component overheating
  - Distribution transformers, generators & wires
- Reduced Utility power factor
- Equipment malfunction

- IEEE 519-1992 standards

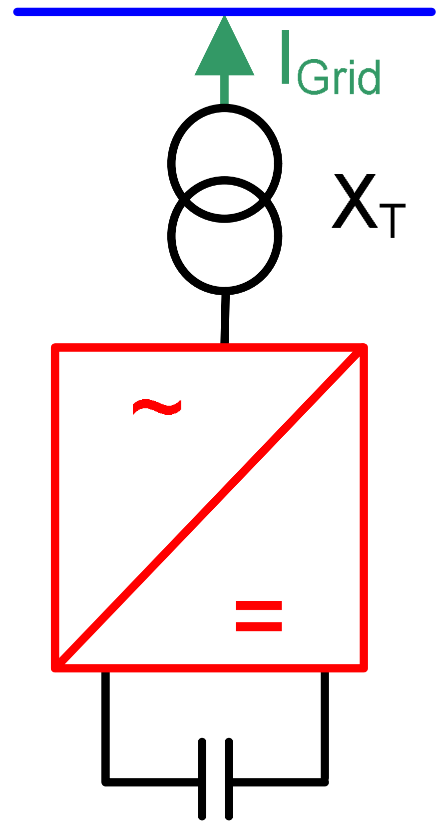
Harmonic Voltage Limits	Table 10.2
Low-Voltage Systems	
Application	Maximum THD (%)
Special Applications - hospitals and airports	3.0%
General System	5.0%
Dedicated System - exclusively converter load	10.0%

Current distortion Limits for General Distribution Systems (120V through 69,000V)						
Maximum Harmonic Current Distortion in Percent of Iload						
Isc/Iload	<11	11<=h<17	17<=h<23	23<=h<35	35<=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						
						Table 10.3
Isc=maximum short circuit current at PCC						
Iload=maximum demand load current (fundamental frequency component) at PCC						

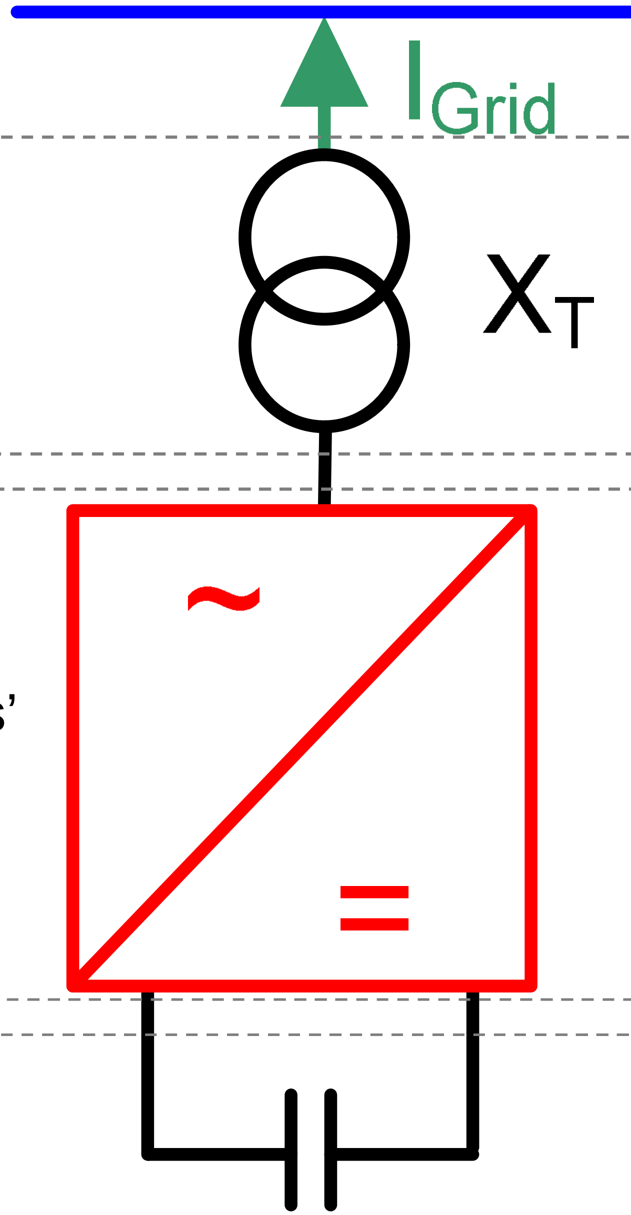
ABB

Dynamic reactive power control
What is a STATCOM?

- A member of the Flexible Alternating Current Transmission Systems (FACTS) family of devices used on alternating current electricity transmission networks
- Is a power electronic based device (also referred to as a voltage-source converter)
- Acts as either a source or sink of reactive AC power to an electricity network for purpose of controlling voltage or power factor



STATCOM – Major Components



AC Step-Up Transformer

- From 480 V to MV

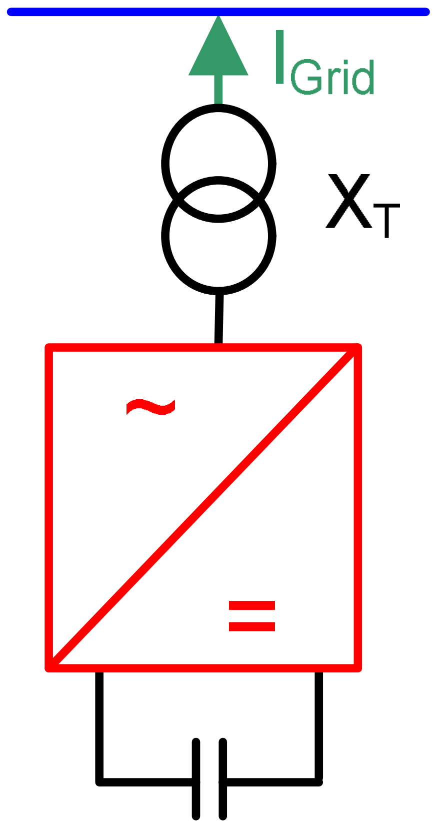
Power Converters

- IGBT power electronic ‘switches’
- Controls and Aux Power

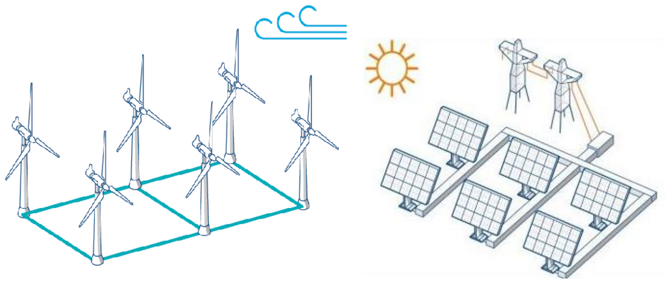
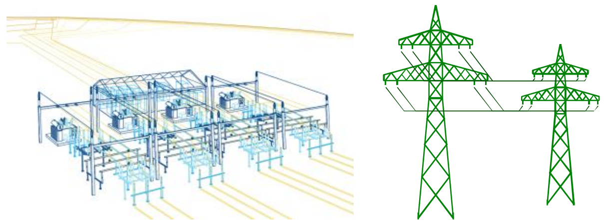
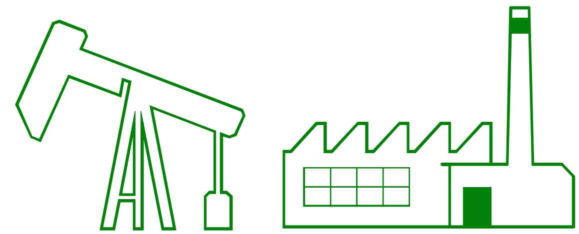
DC Bus

STATCOM Capabilities
Why use a STATCOM?

- **Dynamic VARs:** Delivers continuously variable reactive current
- **Speed of Response**: Rapidly delivers reactive current on a sub-cycle basis.
- **Performance at Low Voltages:** Is a current injection device. Reactive power decreases linearly with voltage (impedance based system's reactive power decreases with voltage squared)
- **Programmable and Versatile:** A STATCOM operates as a self-sufficient voltage or power factor regulator, and contains highly programmable control systems with optional features such as capacitor and reactor bank control, droops, deadbands, etc.



ABB's VArPro^{TM} STATCOM
Voltage control and reactive power management

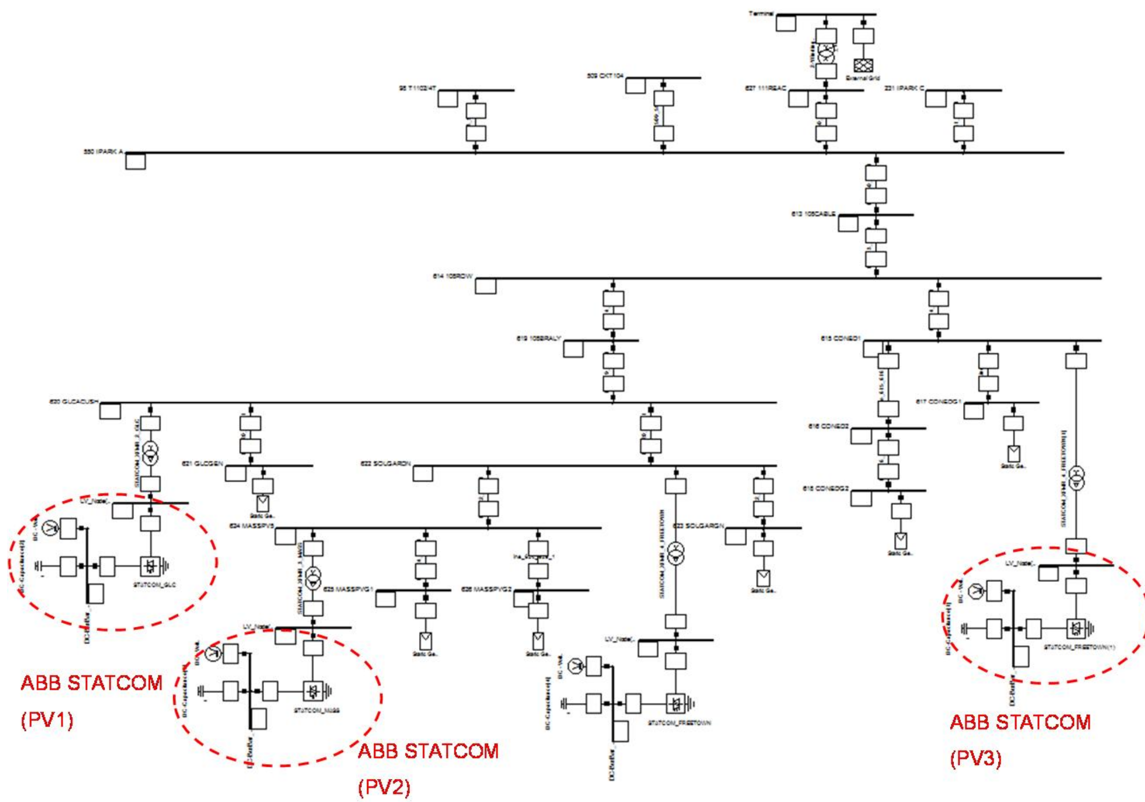
Renewables	Utilities	Industrial
		
▪ Enables grid code compliance in wind and solar plants	▪ Utility grid compensation for fluctuating loads, particularly in remote locations	▪ Industrial grid support and power quality enhancement
		

Application: Distributed Generation Solar PV
10.5 MW PV Facility in Eastern U.S.

- A collection of distributed PV facilities (DG) on the distribution network
- The surrounding grid was shown to have voltage variations caused by the PV fluctuations
- Needed to regulate the voltage at the feeder and substation to make sure it was within acceptable limits

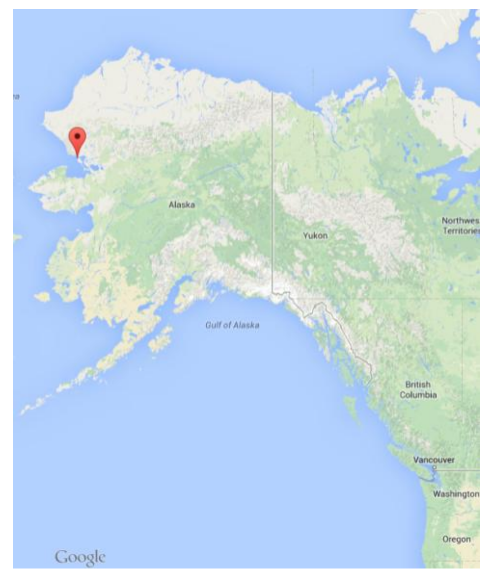
Application: Distributed Generation Solar PV
VArPro STATCOM solution applied

- ABB installed a standard 1.3 MVAr air-cooled statcom enclosure
- Included a 1.3 MVA padmount liquid-filled transformer designed for operation on a 13.2 kV network
- Solution included entire plant control



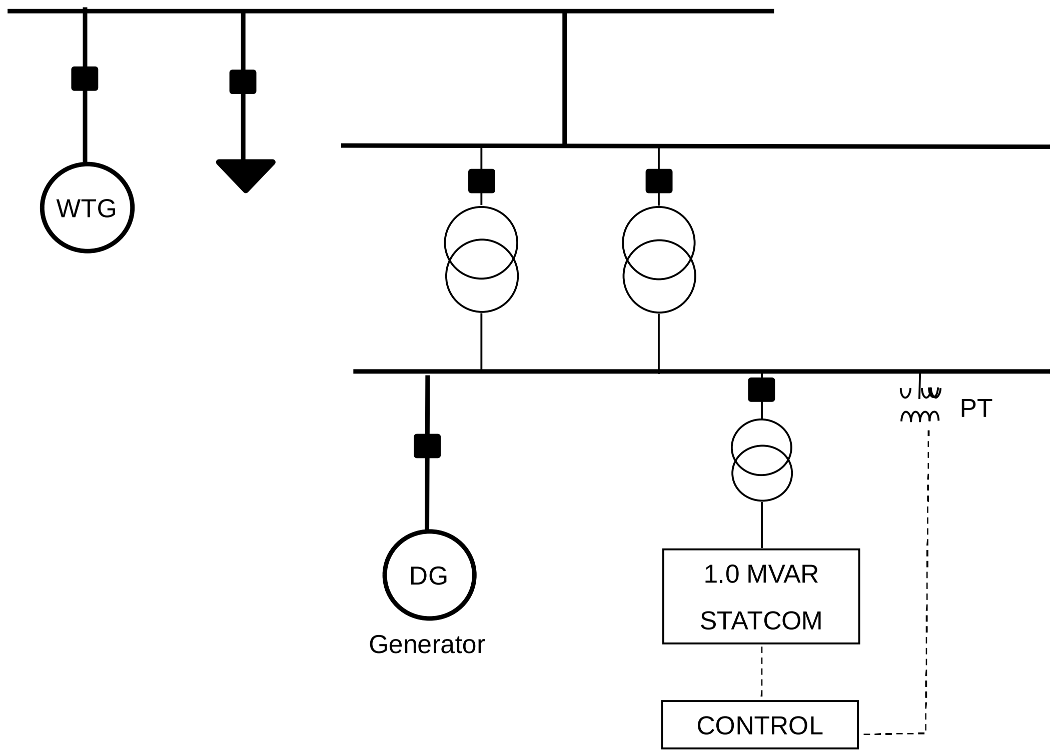
Application: Voltage Support for Micro-grid
Micro-grid in Northern Alaska

- An Alaskan village on a wind/diesel micro-grid 30 miles above the arctic circle required dynamic voltage regulation
- Terrain consisting of tundra and permafrost with little infrastructure in place
- The diesel generator was used to provide reactive power regardless of active power output



Application: Voltage Support for Micro-grid
VArPro STATCOM solution applied

- ABB supplied a 1 MVAr STATCOM unit with transformer
- Included plant control
- This alleviated the diesel generator, reducing stress to the micro-grid and saving fuel costs

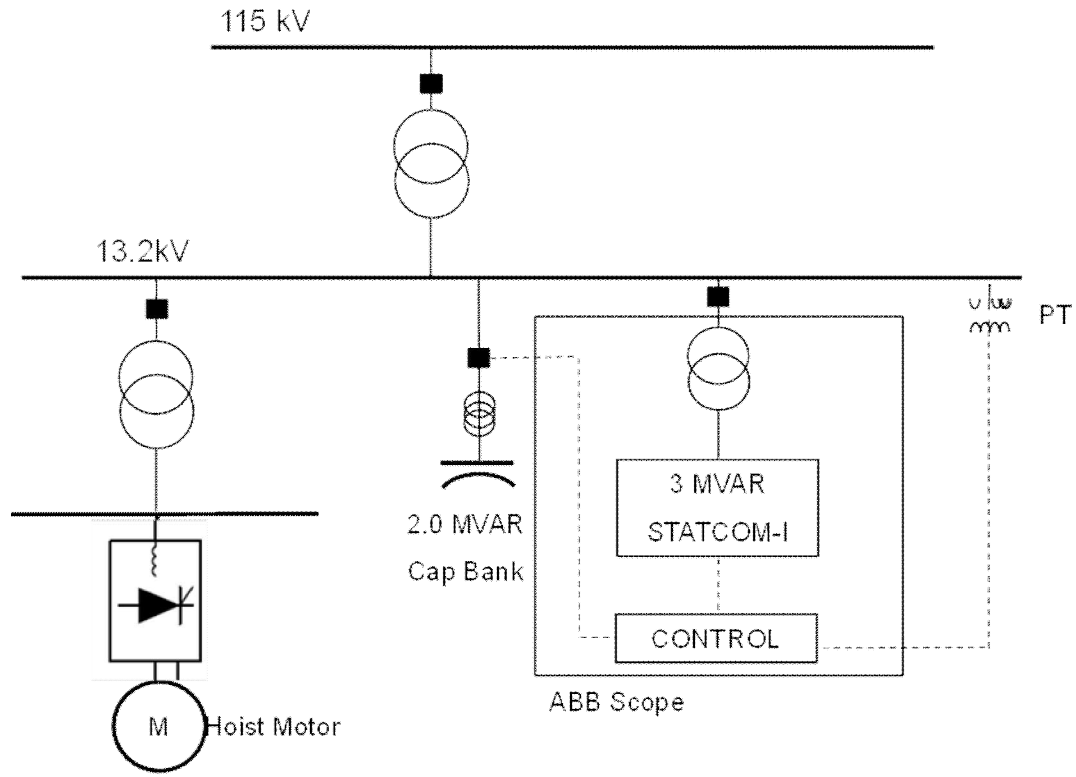


Application: Mining facility looking to expand
Required voltage & Power Factor Regulation

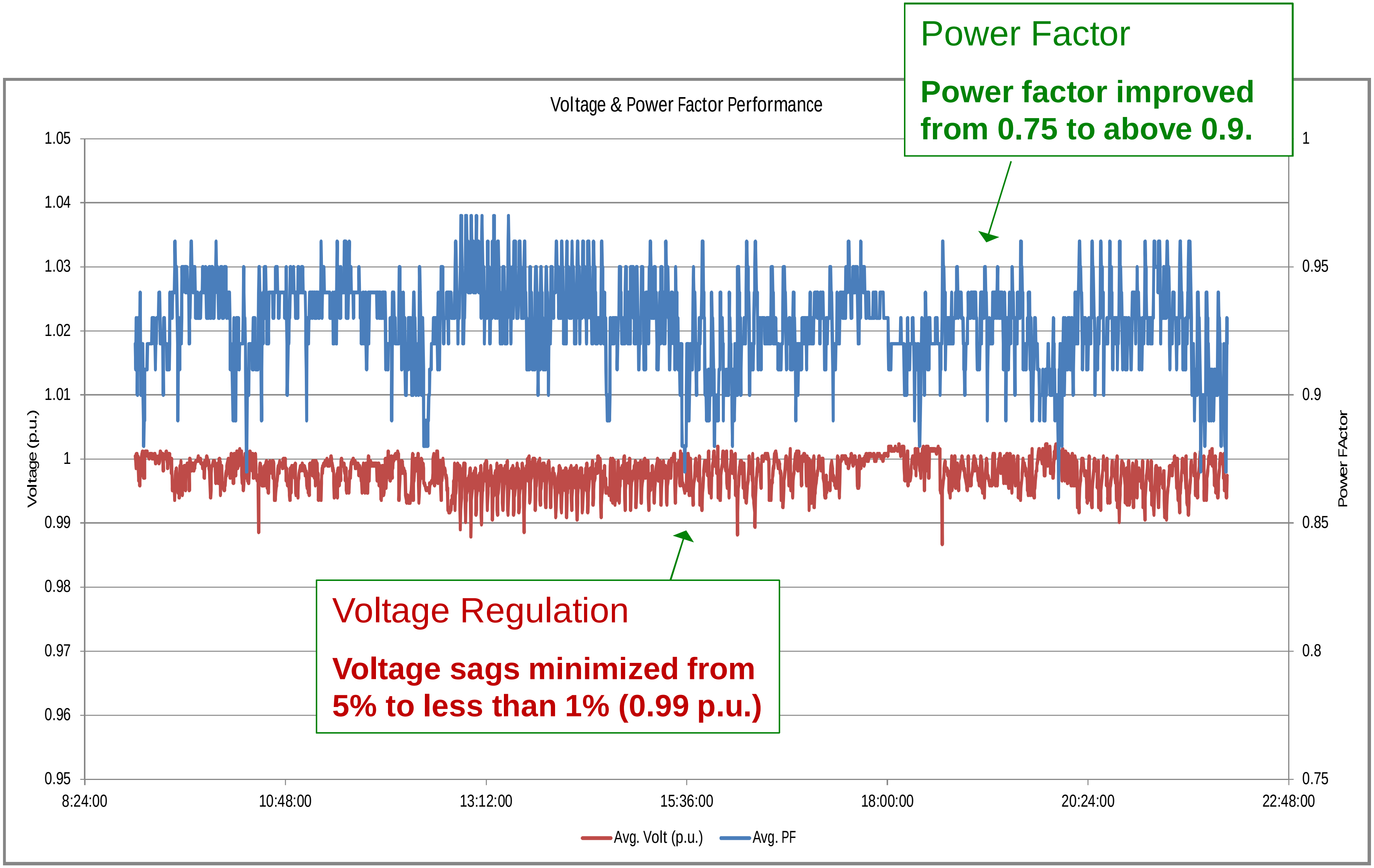
- A precious minerals mine wanted to expand production
- This expansion required to increase their power load to 20 MVA with 8 MW located at a new substation
- Grid operator required the mine to take corrective actions such as providing voltage regulation during the operation of their hoist motor
- In addition to voltage issues, the mine was being heavily penalized due to poor power factor and harmonic performance

Application: Mining facility with power quality issues
VArPro STATCOM solution applied

- A 3.0 MVAr ABB STATCOM provides dynamic voltage regulation.
- Combined with a 2.0 MVAr notch filter bank
- The statcom system improved power factor above PF = 0.9.
- Plant Control



Application: Mining facility with power quality issues
VArPro STATCOM solution applied



Power and productivity
for a better world™

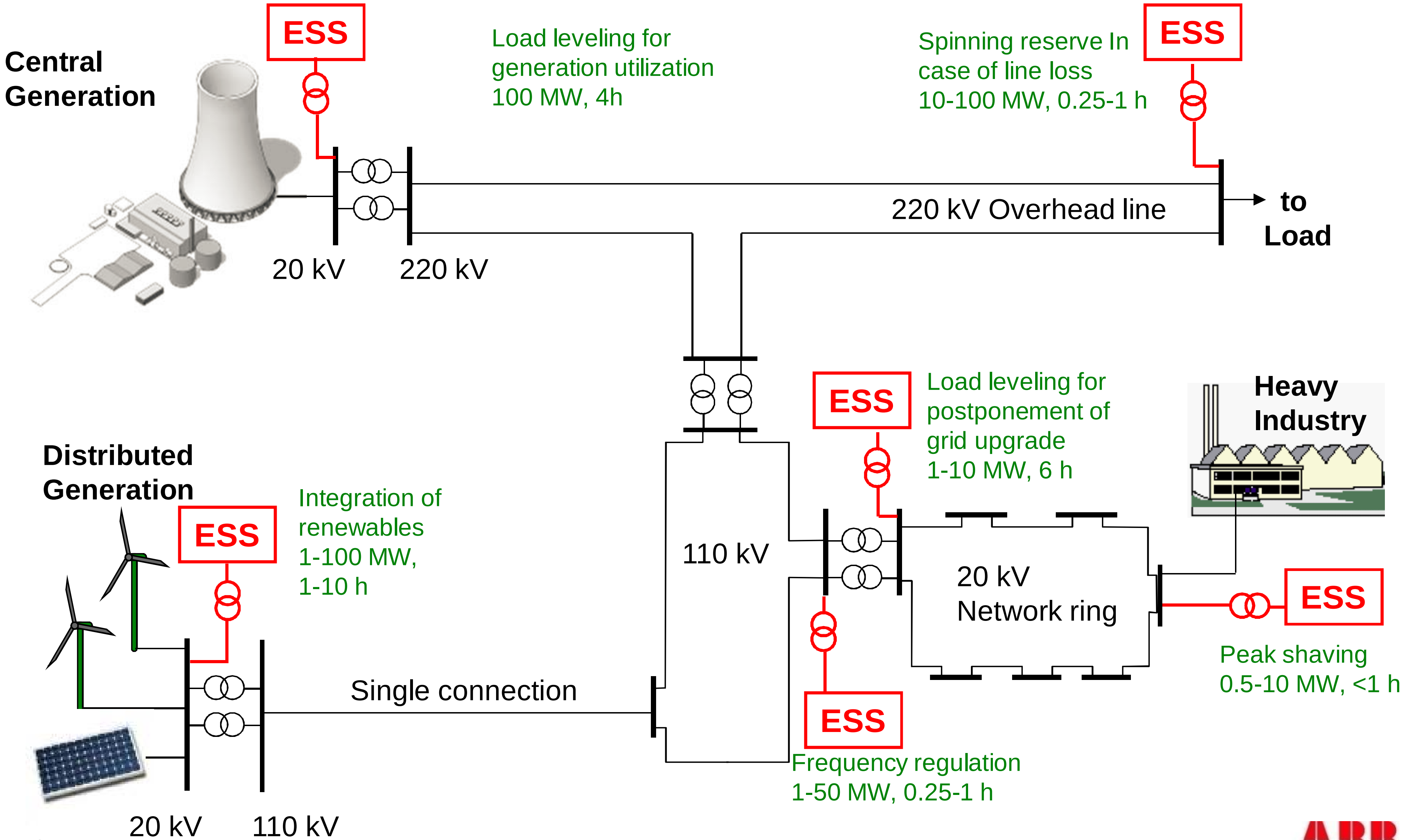
ABB

2014

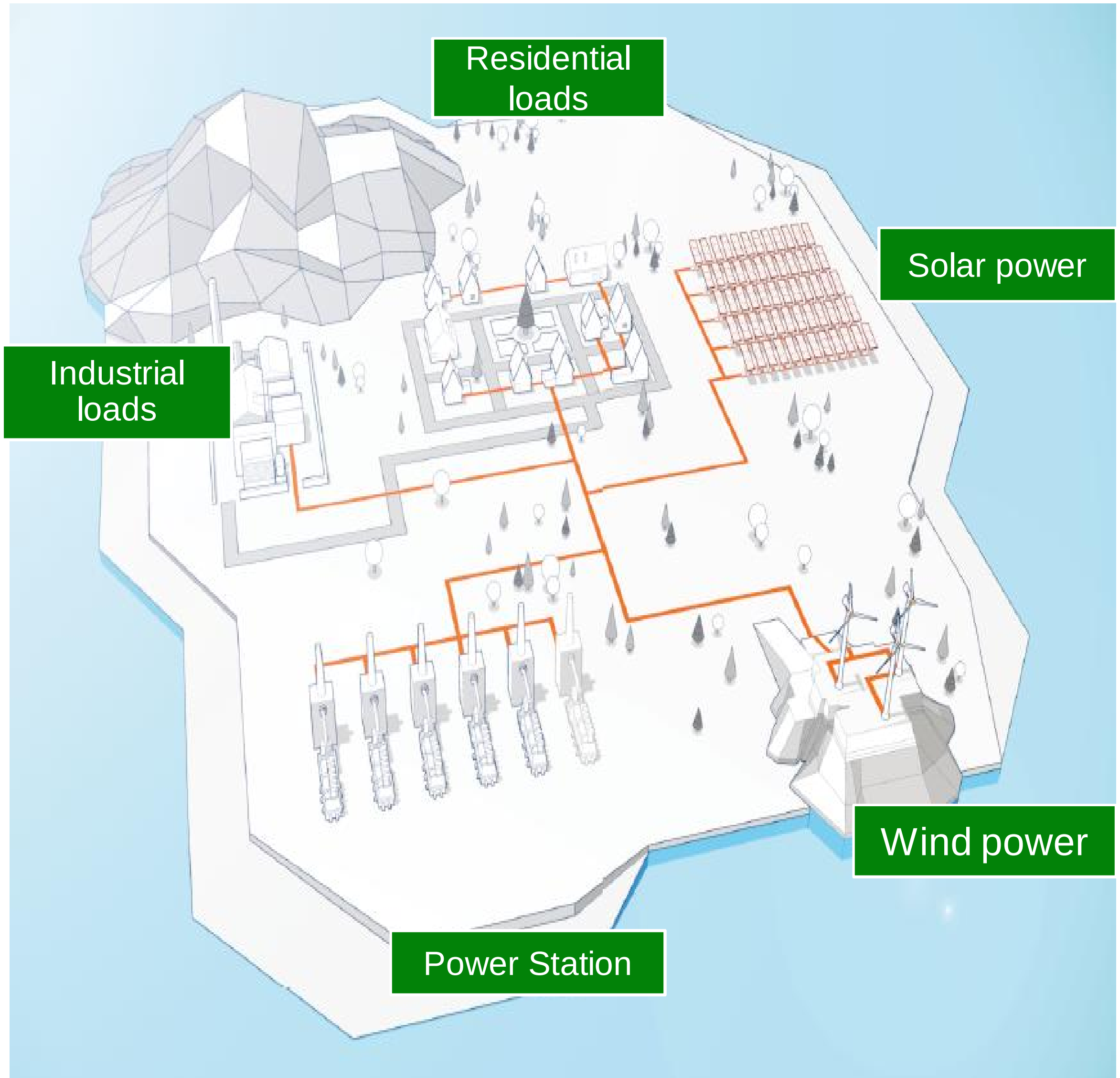
Advanced Technologies
Energy Storage Power Conversion

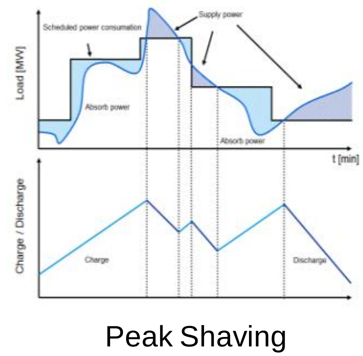
Power and productivity
for a better world™ ABB

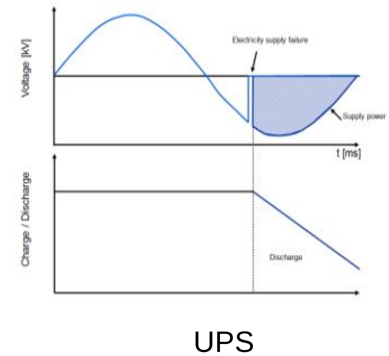
Energy Storage Applications
Energy Storage needed throughout the grid

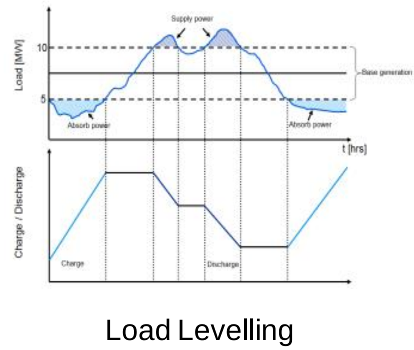


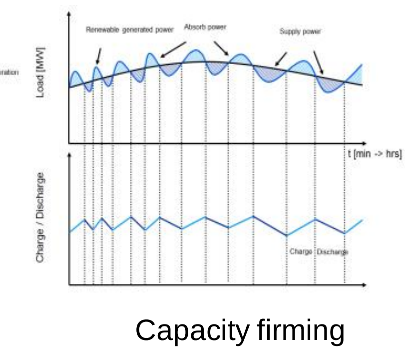
EssPro™ Energy Storage Solutions
Applications & Benefits

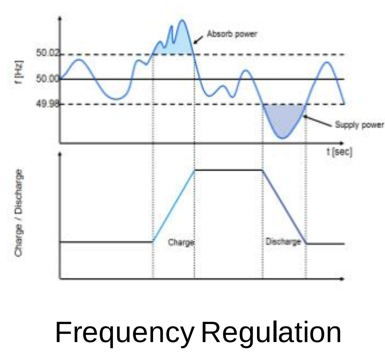


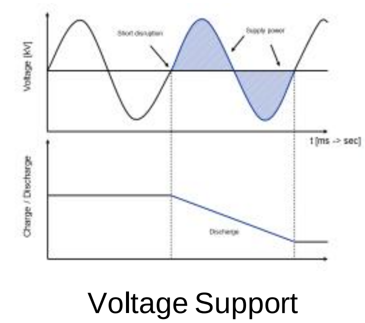




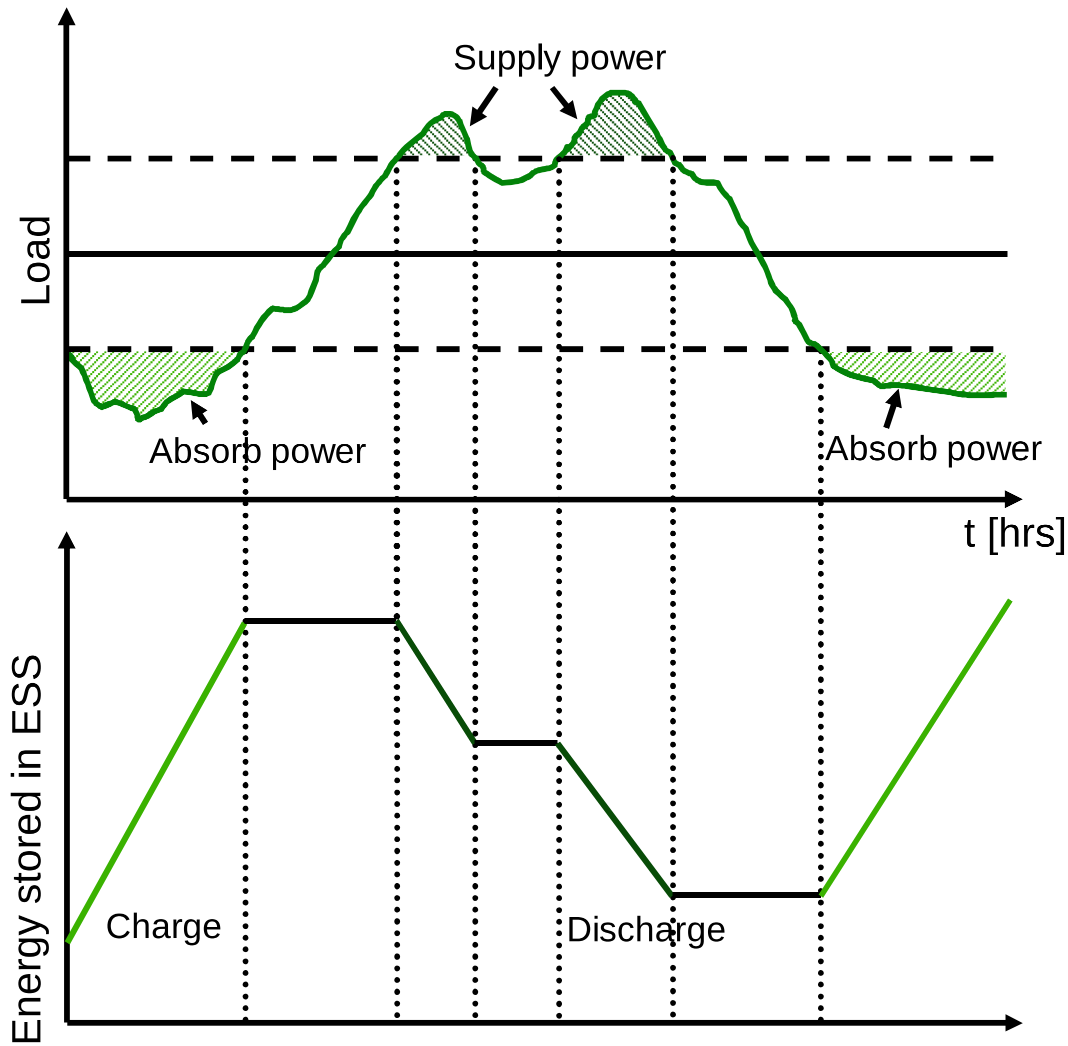






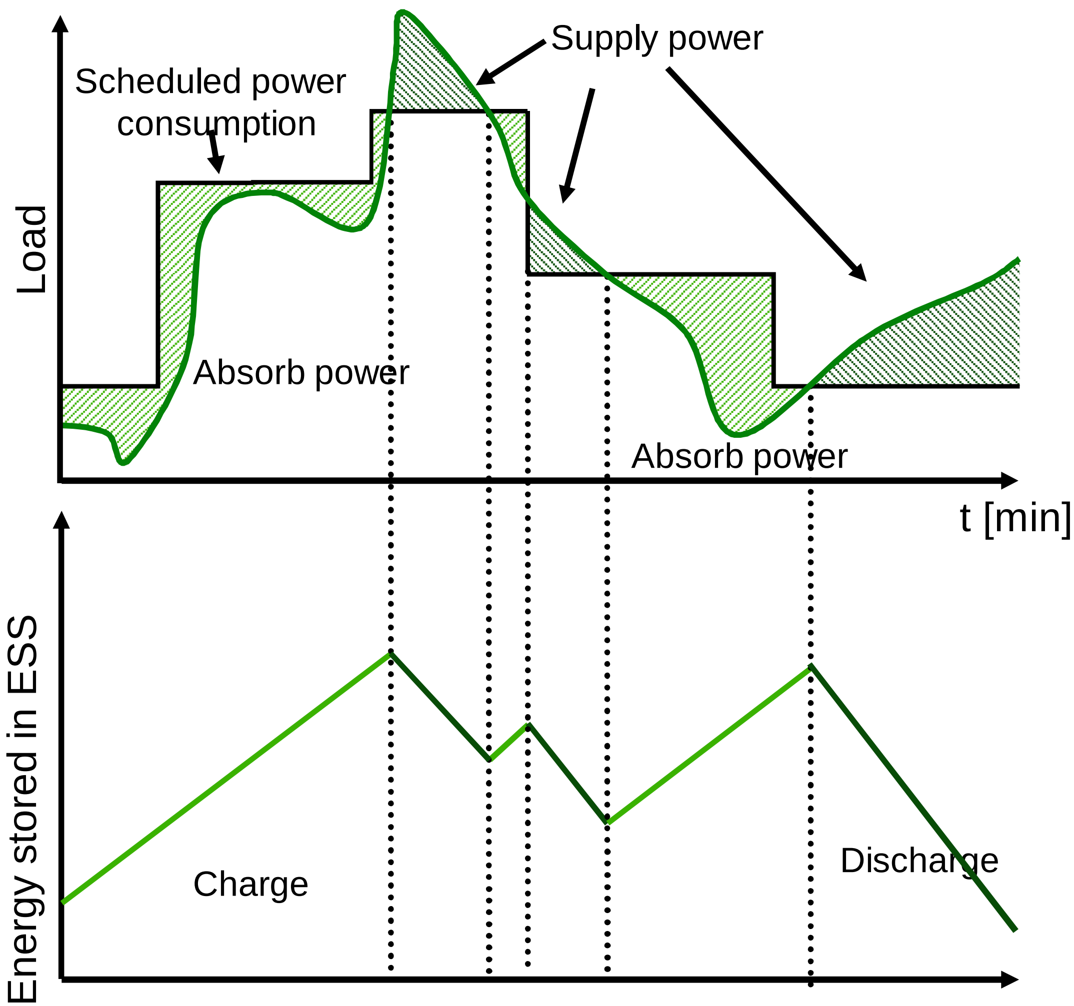


Applications
Load shifting / Arbitrage



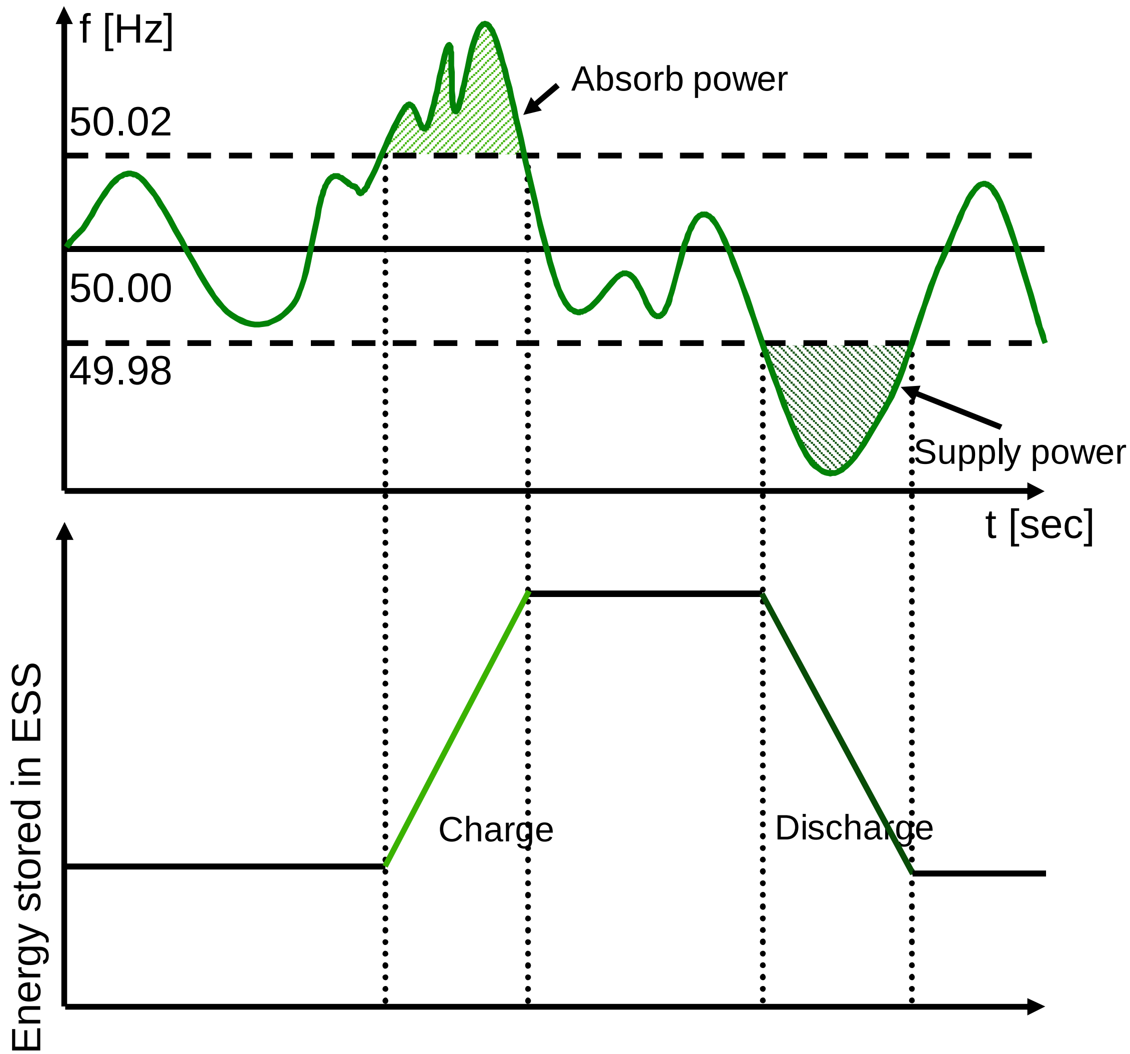
- Load shifting is capturing access energy and reusing it at a later point in time
- Can be used for energy arbitrage which involves charging when energy prices are low and discharging when energy prices are high
- Storage can also provide similar time-shift use to store excess energy production from renewable energy resources which otherwise would be curtailed

Applications
Peak-Shaving for "Behind the Meter"



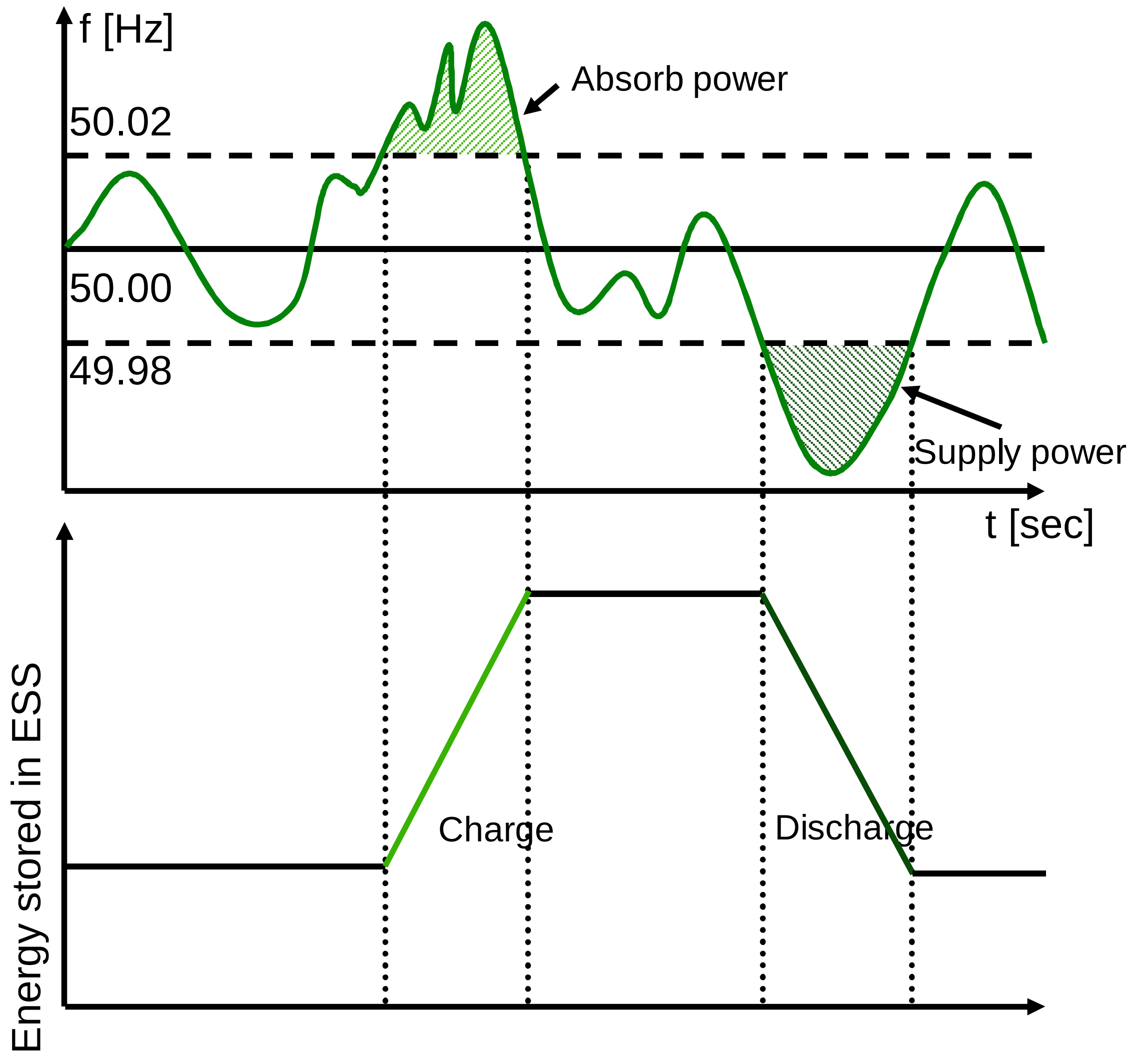
- Peak shaving is similar to load leveling, but used for the purpose of reducing individual electricity consumer's peak demand
- Consumers are charged when their electricity consumption reaches its highest peak (peak demand charges)
- Consumers can charge during periods where energy storage is at its lowest and then discharge during periods of peak demand
- Saves money for both the consumer and the utility

Applications
Frequency regulation



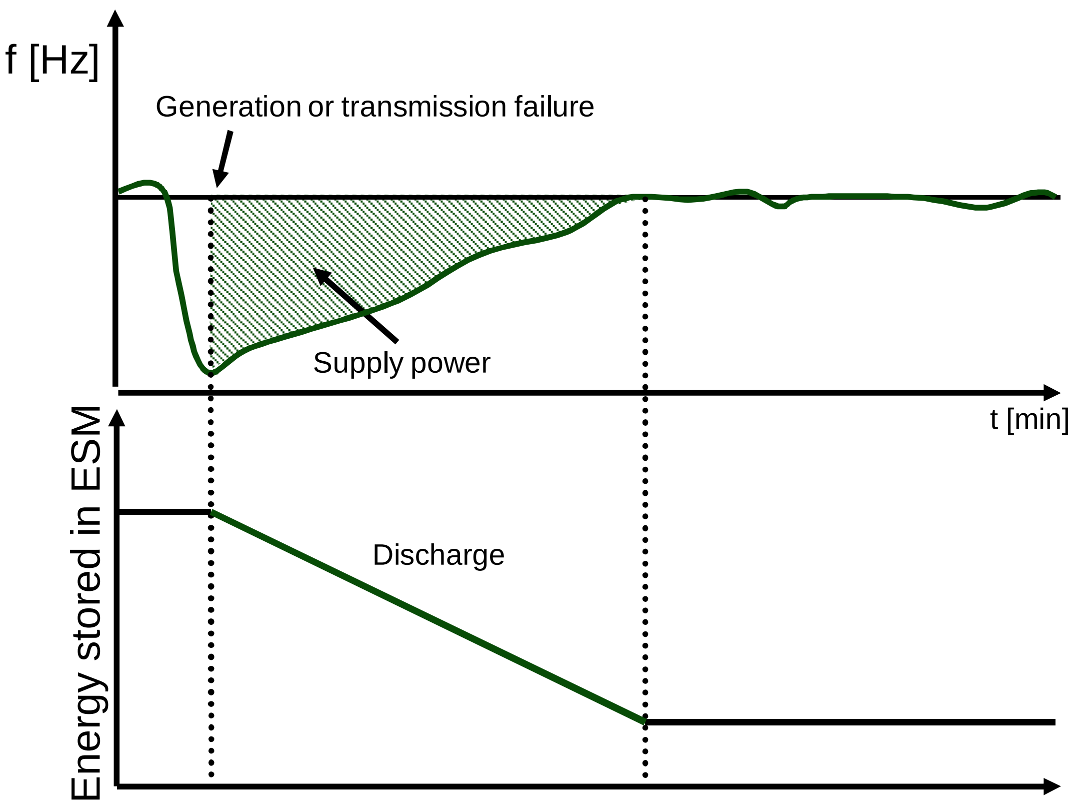
- Need to reconcile momentary differences caused by fluctuations in generation and loads
- Regulation is used for damping of that difference
- Storage is ideal solution to regulate frequency due to its rapid response time and emission-free operation

Applications
Capacity Firming



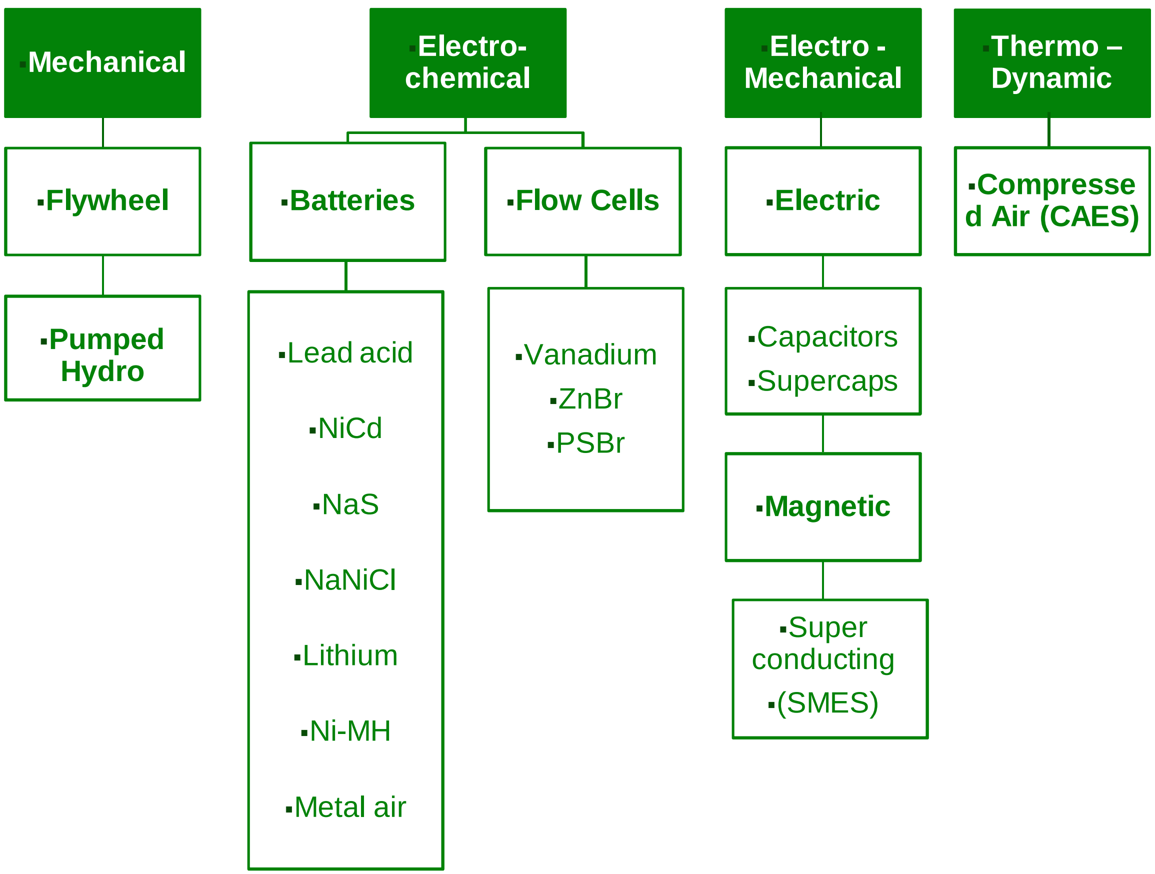
- The variable, intermittent power output from a renewable power generation plant, such as wind or solar, can be maintained at a committed level for a period of time
- The energy storage system can smooth the output and controls the ramp rate (MW/min) to eliminate rapid voltage and power swings on the electrical grid

Applications
Spinning Reserves



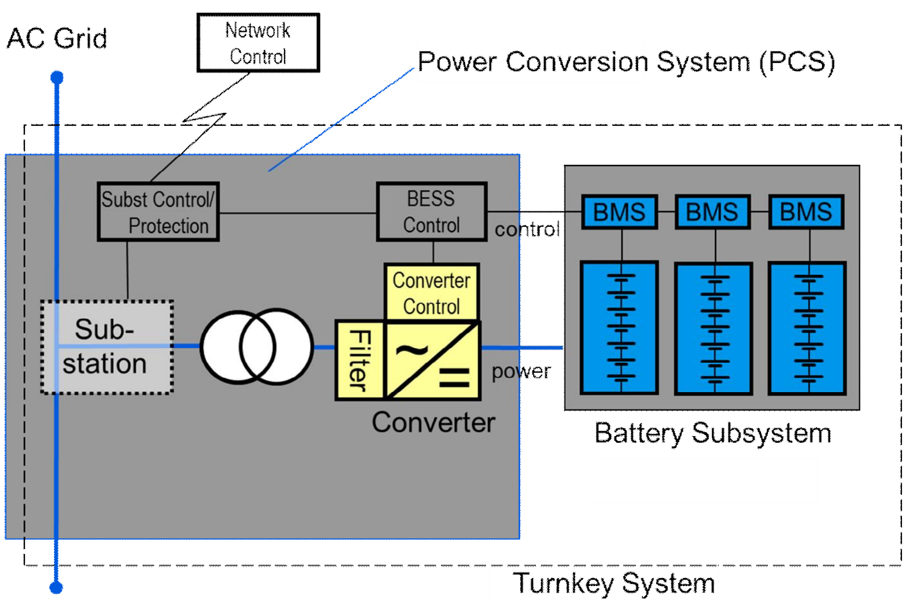
- Utilities keep generation capacity on reserve that can be accessed quickly if there is a disruption to the power supply
- These are usually older generators that are already synchronized with the grid and operating at low capacity
- Energy storage can

Power Conversion
Various Types of Methods of Storing Energy



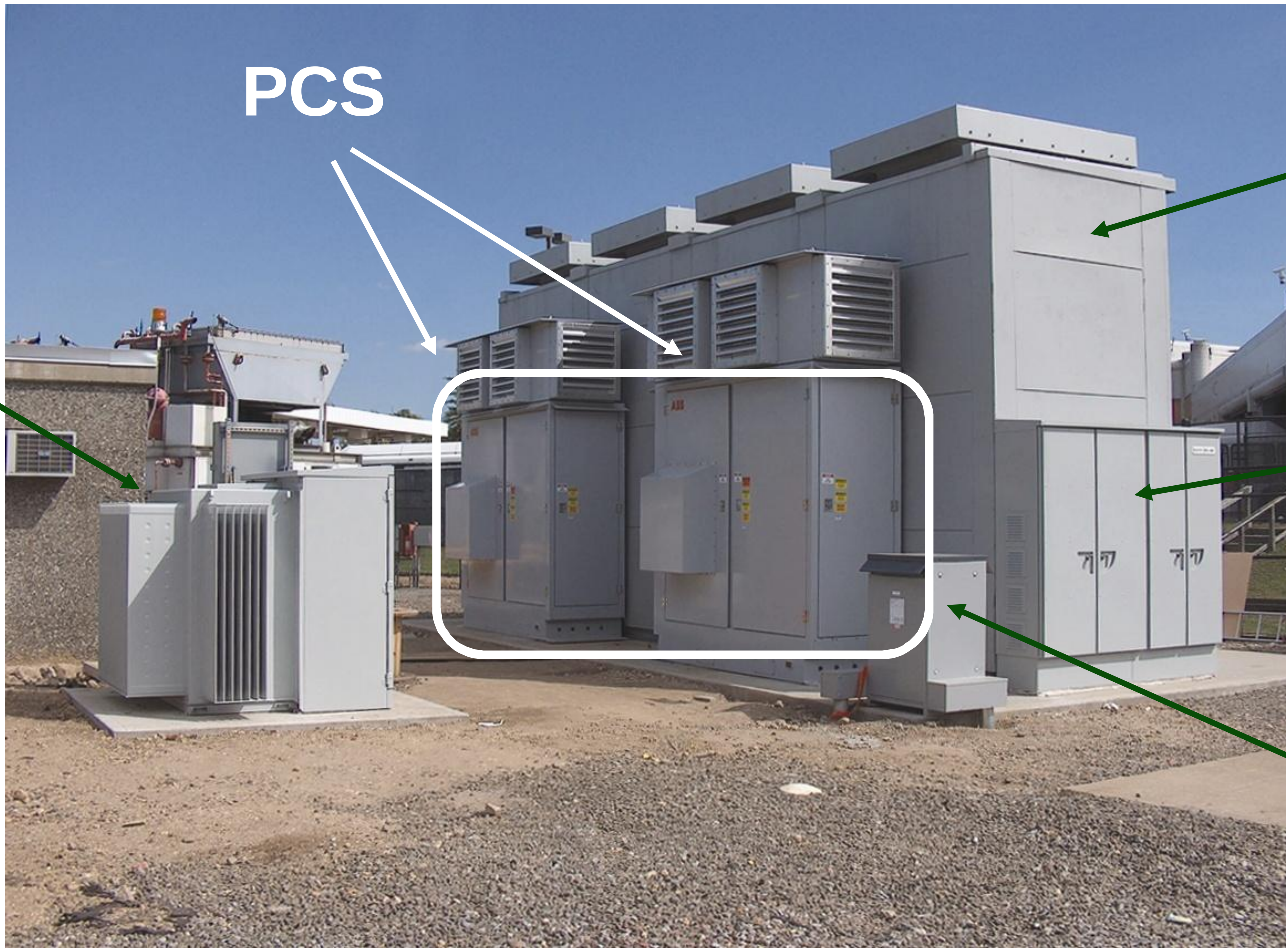
- They all work!!!!
- Variables to Consider
  - Power vs Energy
  - Discharge / Charge Rates (C-rates)
  - Efficiency (round trip)
  - Depths of Discharge vs cycle life
  - Footprint / Packaging
  - Cost

Power Conversion
Definition of Energy Storage System (ESS)



- A solution for storing energy for use at a later time
- Store energy and supply it to loads as a primary or supplemental source
- ESS contains
  - Inverters that rectify AC energy into DC to store in the batteries
  - Then invert DC energy into AC energy
  - AC power is connected to the electrical network at low or medium Voltage

Power Conversion System for Energy Storage
Battery Energy Storage Layout



1MW / 6.5MWHr

ABB's EssPro^{TM} Power Conversion System
System Sizes from 50 kW to 50 MW

Indoor Units

Outdoor Enclosures

Outdoor System Solutions

EssPro™ Grid Substation

▪ System Integrators – complete portfolio

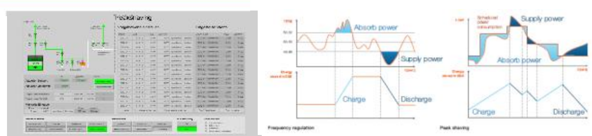
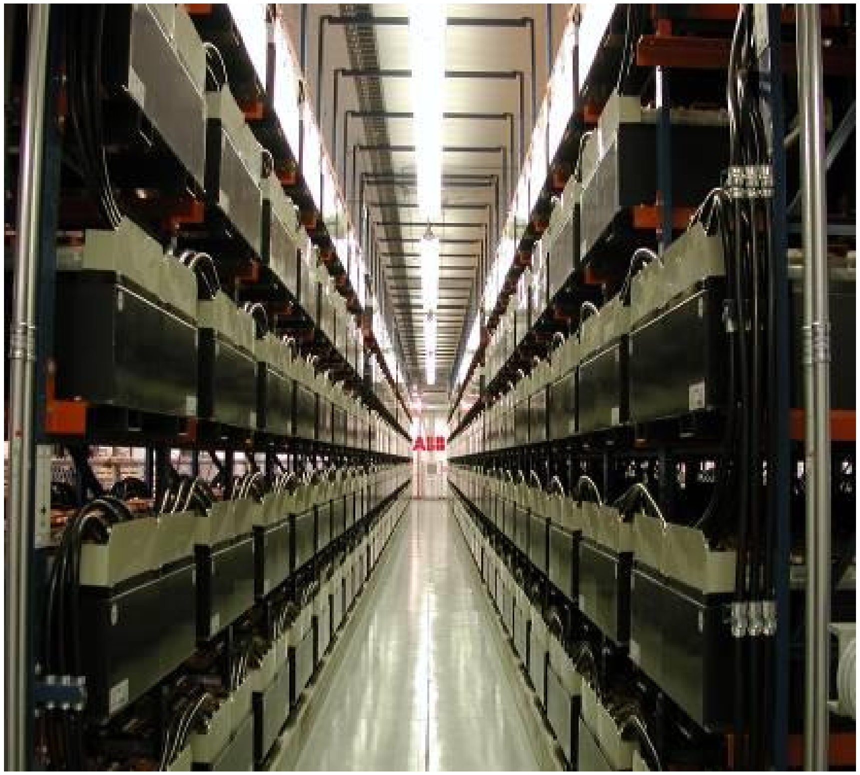
System Components		
Converters		Wide range of leading edge converters systems
Batteries		Optimal battery technology for every application
Control systems & algorithms		Integrated EssPro Grid control system enables manual and automatic operation
Protection equipment		State-of-the-art protection systems for AC and DC equipment.
Transformers and switchgear		LV, MV, & HV switchgear ensures safe and reliable grid connection. Full range of transformers for any local standard
Modular and scalable		Scalable & flexible systems facilitate easy and safe operation

ABB Energy Storage Experience
GVEA, Fairbanks, Alaska



- *27 MW / 15 minutes*
- *46 MW / 5 minutes*

- **Customer needs**
  - Spinning reserve
- **Project Details**
  - Ni-Cd Batteries
  - Installed in 2003
- **ABB Scope**
  - ABB PCS to supply power long enough for local generation to come online.
  - BESS system to operate in cold ambient temperatures.

ABB Energy Storage Experience
EKZ, Switzerland (installed 2012)

▪ 1 MW PCS

- **Customer needs**
  - Dynamic Control
  - Peak shaving
  - Frequency regulation
  - Demonstrate Islanding
- **Project Details**
  - Li-ion batteries
- **ABB Scope**
  - Delivery of a complete energy storage system for demonstration purposes
  - 1 MW, 250kWh BESS
  - 1 MW PCS100 ESS converter housed in a outdoor cabinet

EKZ; Zürich, Switzerland

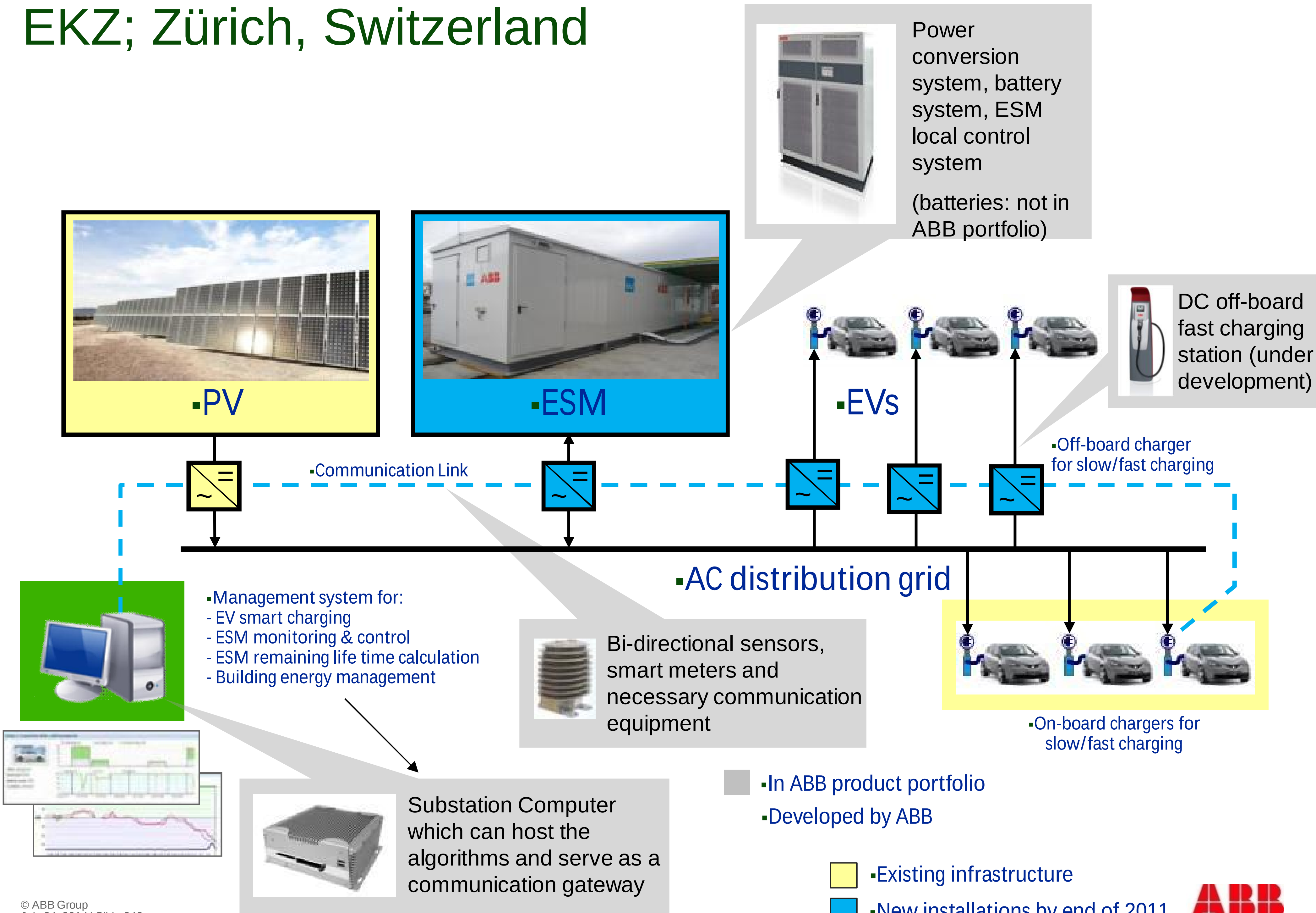


ABB Energy Storage Experience
United States Utility

▪ *500 kW / 1.5MWHr*

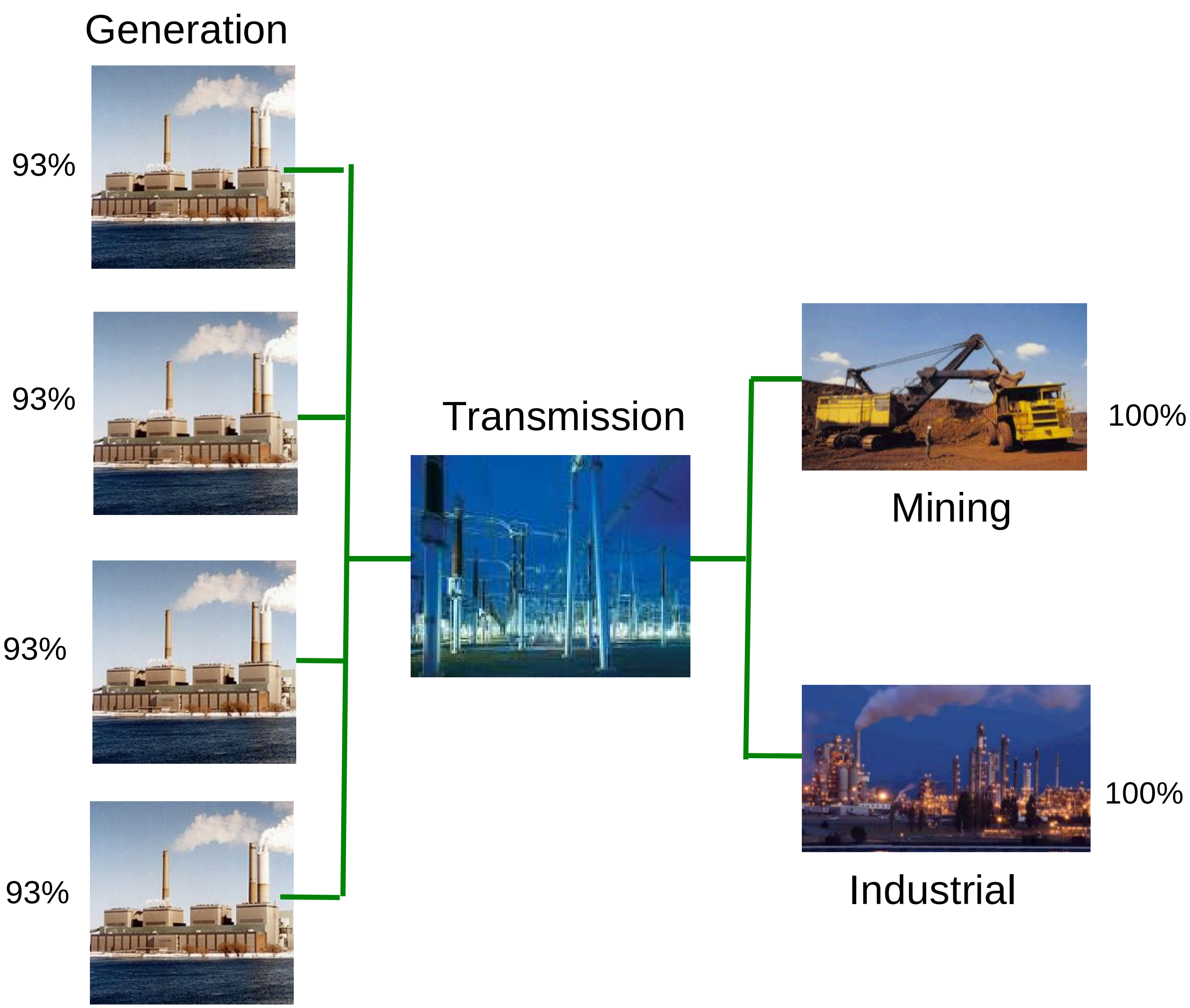
- **Customer needs**
  - Demand Reduction
  - PV Integration (Firming)
- **Project Details**
  - Li-Ion Battery Supplier
  - Installed in 2012
- **ABB Scope**
  - Supplied 500 kW PCS, including inverters, Circuit Breakers, isolation transformer, disconnect switch and metering cabinet
  - Ongoing development of Control Algorithms with US Utility and University in the area.

ABB Energy Storage Experience
20 MW Energy Storage System in Chile

▪*20 MW / 5MHr*

- **Customer needs**
  - Spinning Reserve
  - Frequency Regulation
- **Project Details**
  - Li-Ion Batteries
  - Installed in 2011
- **ABB Scope**
  - 5 x 4 MW PCS Containers
  - Each containing Inverters, circuit breakers, step up transformers, control, MV Disconnect Switch

ABB Energy Storage Experience
20 MW Energy Storage System in Chile



- To help maintain grid stability and increase efficiency SING
- The SING stem operator (CDEC) request 7% spinning reserve which is divided into:
  - 3% Frequency Regulation
  - 4% Critical Contingency Service
  - 20% Customers Load Shedding

ABB Energy Storage Experience
Saft / Hawaii Projects

- *Saft IM20E Container*
- *100 kW / 240 kWHr*

- **Customer needs**
  - Site #1 – West Health Civic Center
    - 100 kW / 240 kWh BESS
    - Demand Reduction
    - Load Shifting / PV Integration
  - Site #2 - Koyo Bottling Company
    - 100 kW / 240 kWh BESS
    - Voltage Support
    - Demand Reduction
- **Project Details**
  - Li-ion Batteries
  - Installed in 2012
- **ABB Scope**
  - Indoor 100kW PCS including inverters, dc contactors, ac circuit breakers, control and isolation transformer
  - Dynamic Control Algorithms

ABB Energy Storage Experience
LG Chem & SCE (8 MW / 9 MVA PCS)

▪8 MW / 32 MWHr Tehachapi Storage Project

- **Customer needs**
  - DOE Smart Grid Program
  - ARRA funds
- **Project Details**
  - Li-ion batteries
  - Installed in 2013
- **ABB Scope**
  - (2) x 4 MW / 4.5 MVA PCS100 for BESS
  - EssPro Vantage Controller
  - DC Bus and Protection Circuit Breakers
  - Mini-PCS System (100kW Indoor) w/ Site Energy Control
  - System Models, RTDS and Simulations
  - Commissioning, Training and Installation Supervision

Power and productivity
for a better world™

ABB

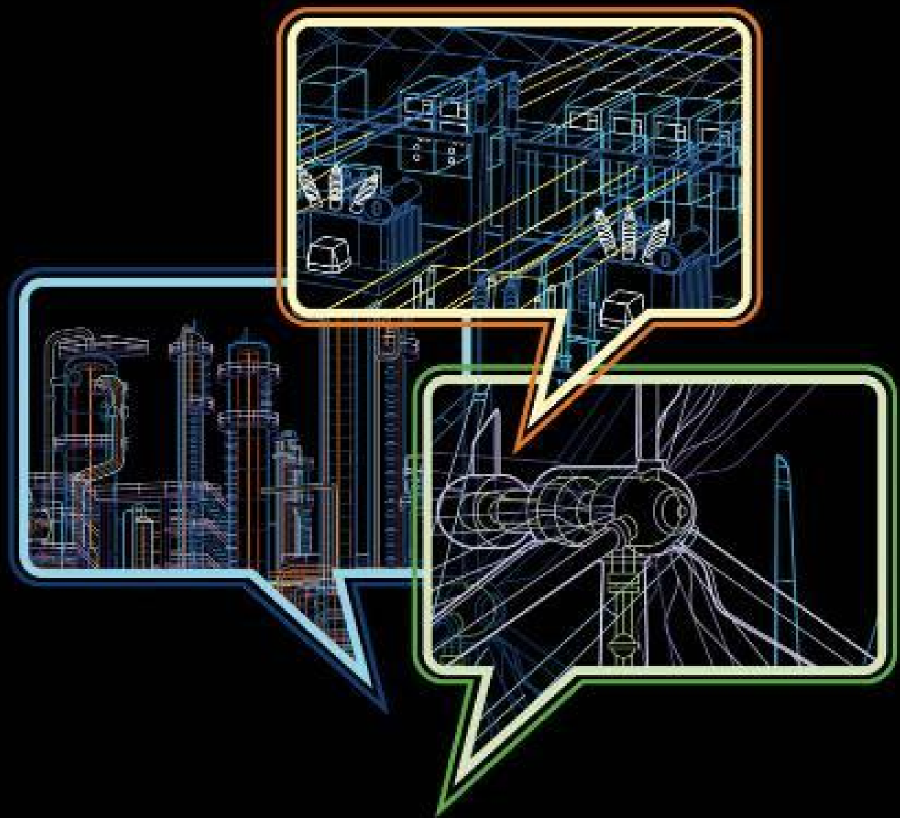


ABB Contact Information

ABB Discrete Automation and Motion
Contact Information

LV/MV Drives 101
Rick Hoadley
Principle Consulting Engineer
262-408-1589
rick.l.hoadley@us.abb.com

Harmonics 101
Jeff Fell
Sr. Application Engineer
262-785-3591
jeff.m.fell@us.abb.com

Electric Vehicles
Heather Flanagan
Marketing Comm. Mgr. - EV
262-395-1773
heather.flanagan@us.abb.com

Motor Technology Update
Brent McManis
Industry Engineering Mgr.
864-281-2234
brent.mcmanis@baldor.abb.com

STATCOM / Energy Storage
Michelle Meyer
Product Marketing Mgr. - Power Systems
262-395-2124
michelle.meyer@us.abb.com

ABB/Baldor District Office
Scott Kinowski
Outside Sales Mgr.
262-661-9356

ABB Discrete Automation and Motion
Contact Information

ABB Inc.
Discrete Automation & Motion
16250 W. Glendale Drive
New Berlin, WI 53151
www.abb.com

Drives and Controls
www.abb.us/drives

Motors and Generators
www.abb.us/motors&generators

Power Conversion
www.abb.us/evcharging
www.abb.us/powerelectronics

ABB Automation & Power World 2015
March 2-5 ● Houston, Texas

Why attend?

Connect.

Meet and network with thousands of technology experts.

Learn.

Choose from hundreds of workshops, customer case studies, panel discussions and hands-on technical training courses…many offering CEUs and PDHs.

Succeed.

Take back information and ideas that you can use immediately to improve your business.

Save the date for this must attend event
Visit www.abb.com/apw for information and updates