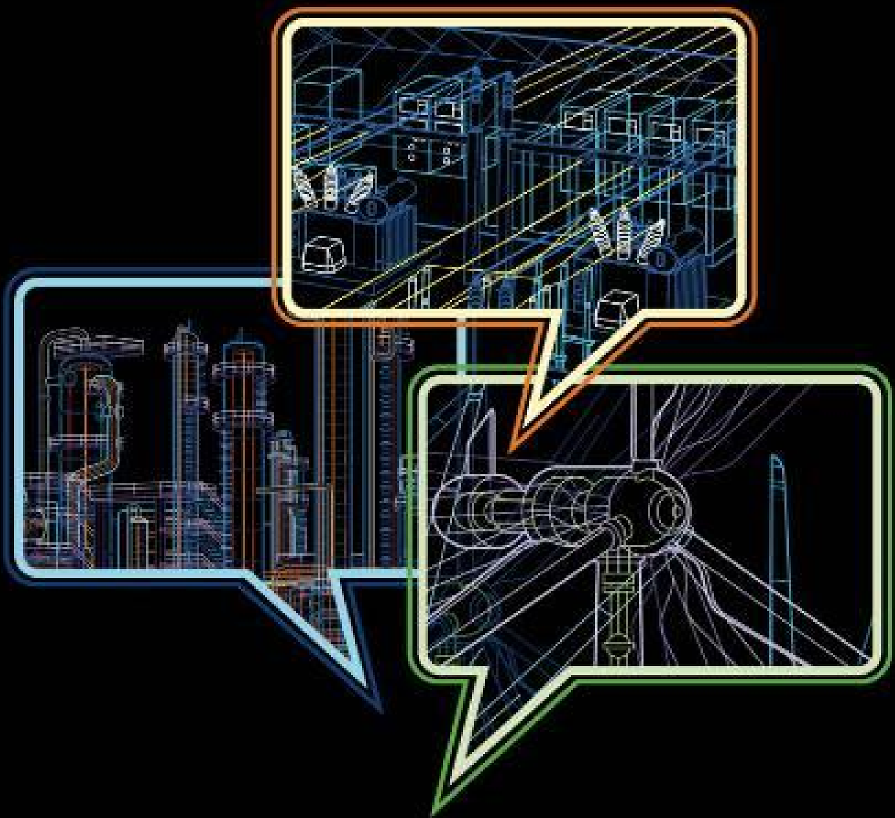


R Hoadley, 22 July 2014

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

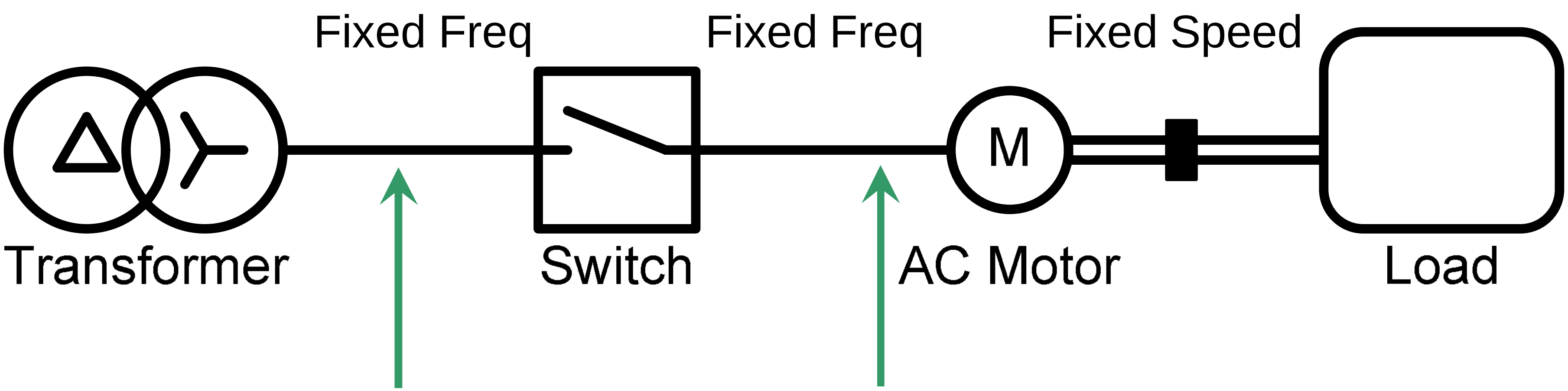
Motor Side Challenges

- NEMA MG-1
- Topologies
- Reflected Waves

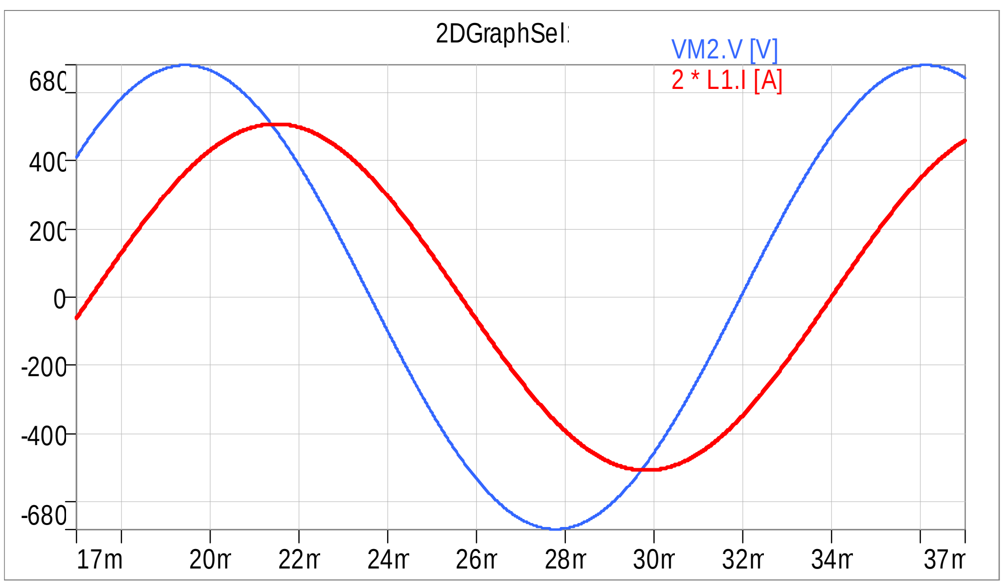
Drive Protection

- PQ Events
- Over-Voltage
- Over-Current

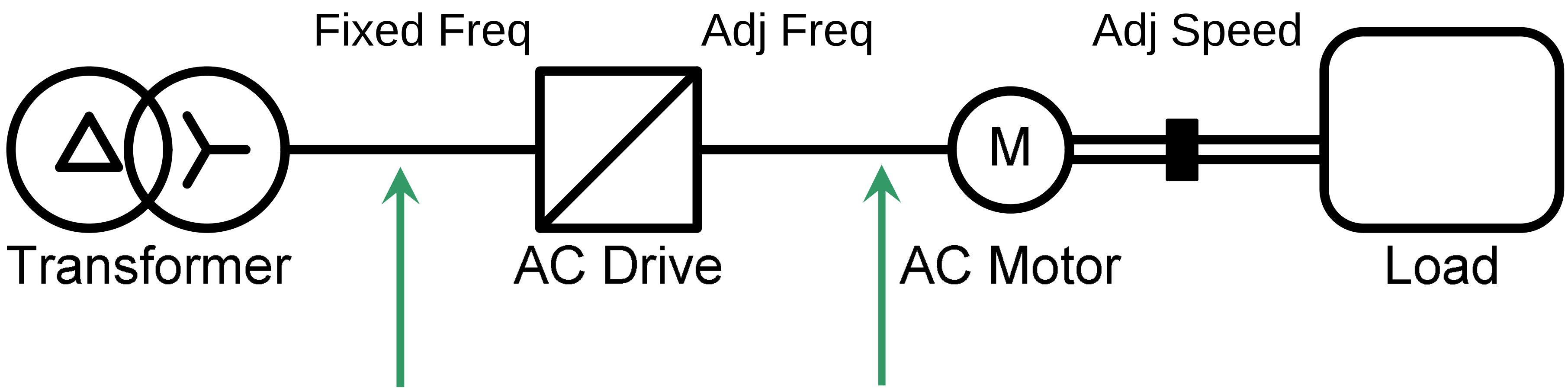
This is a Non-Drive System



Line Side: Sinusoidal Voltage   Motor Side: Sinusoidal Current

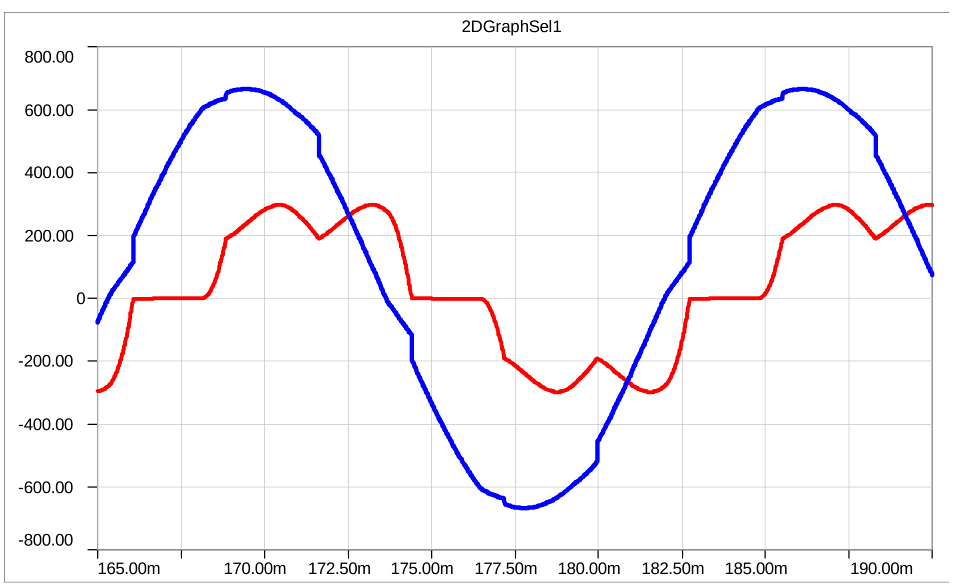


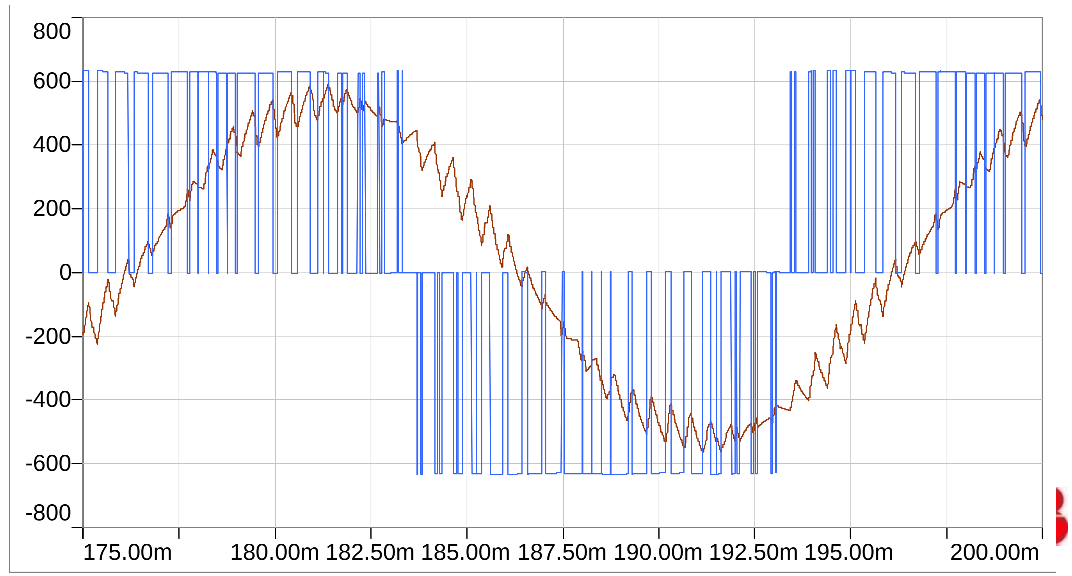
This is a Drive System



Line Side: Current Pulses

Motor Side: Voltage Pulses

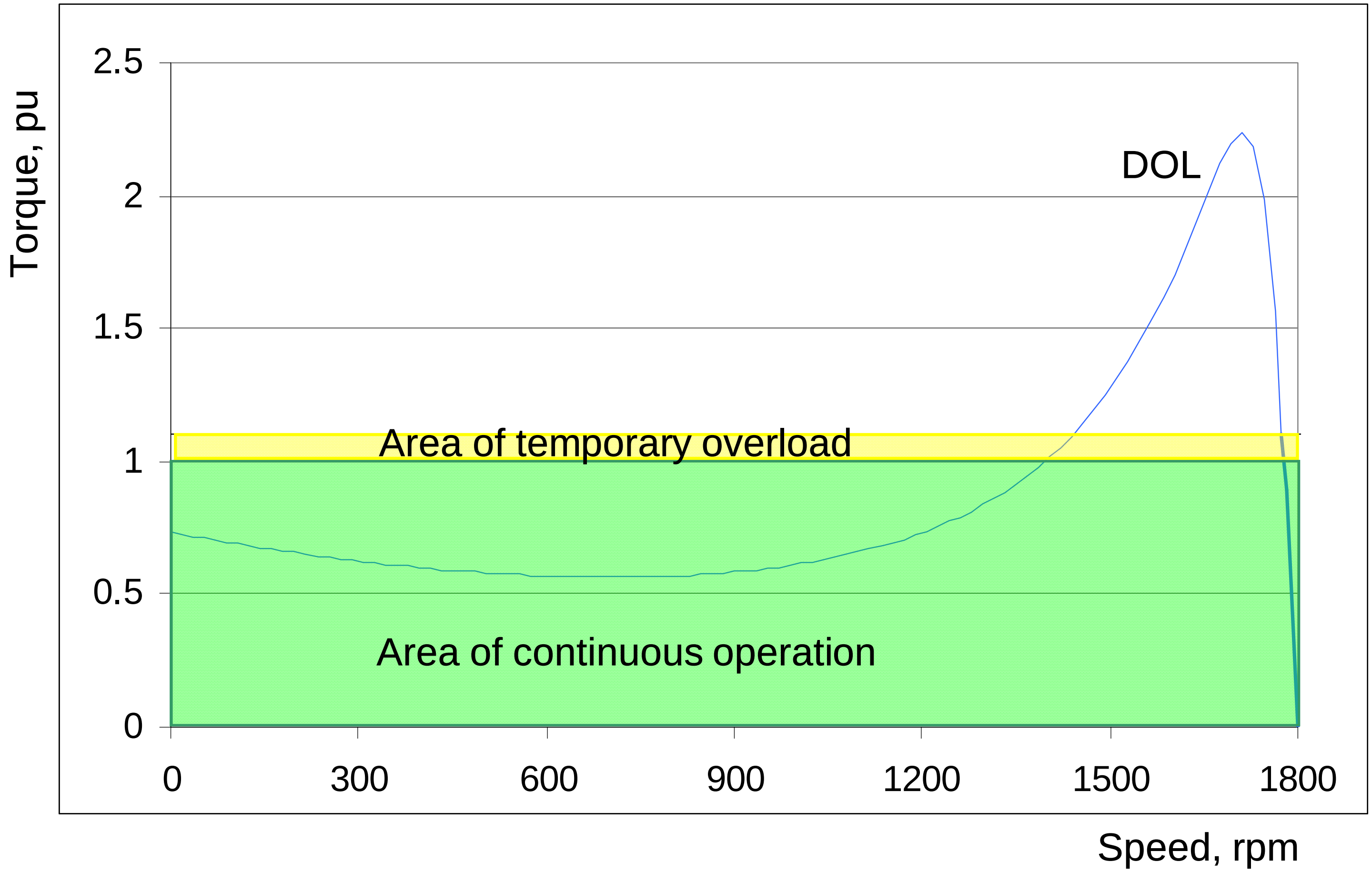




Why are AC drives used?

Why Use a VFD?

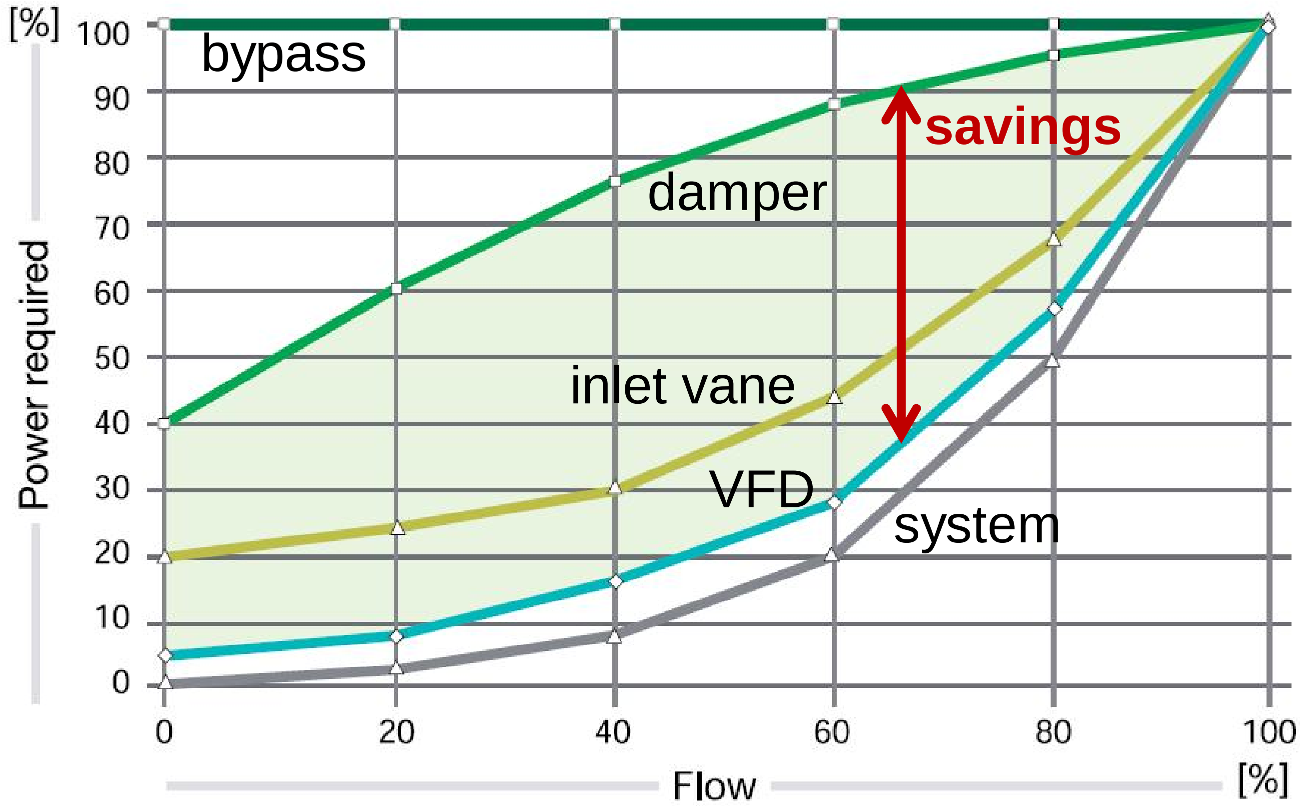
Large Operating Speed and Torque Area



Why Use a VFD?

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

0.5 to 1.5 year payback !



Why Use a VFD?

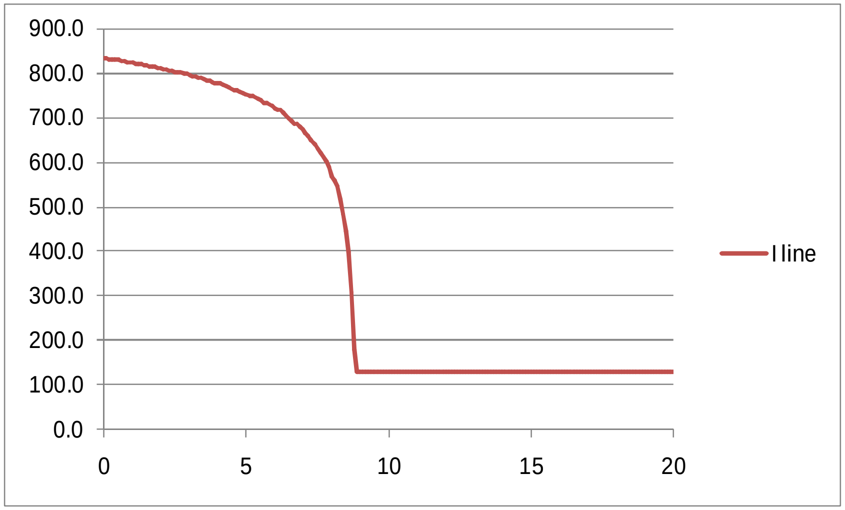
Adjustable speed to **Optimize Process**

Reduce production losses

Why Use a VFD?

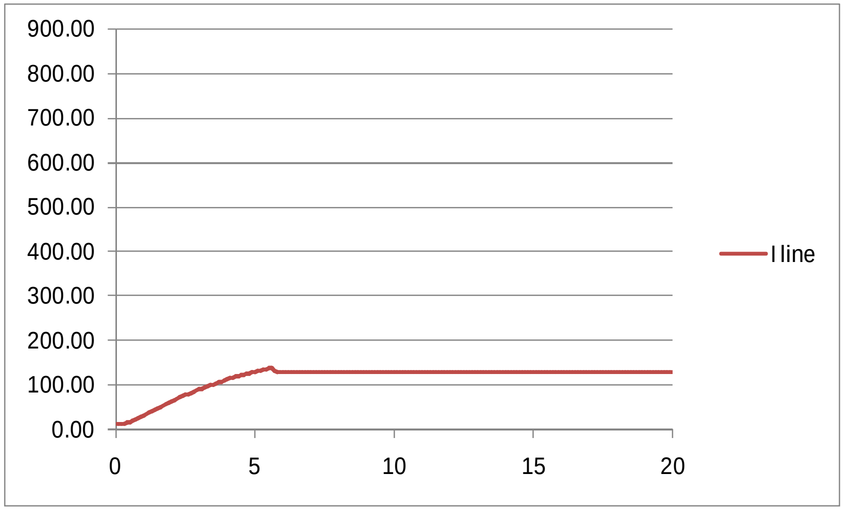
Elimination of 6x Inrush Current for **Soft Starting**

DOL Start



Line Current, A vs Time, s

VFD Start

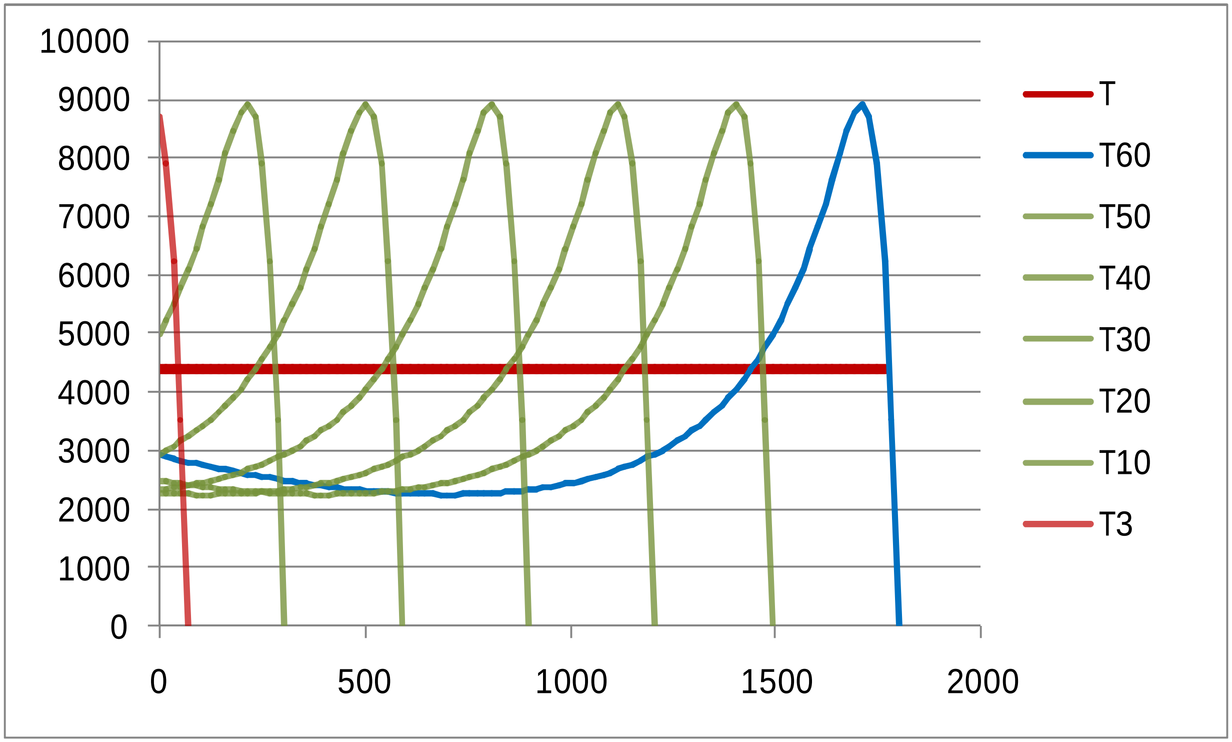


Line Current, A vs Time, s

Can have multiple starts per hour!

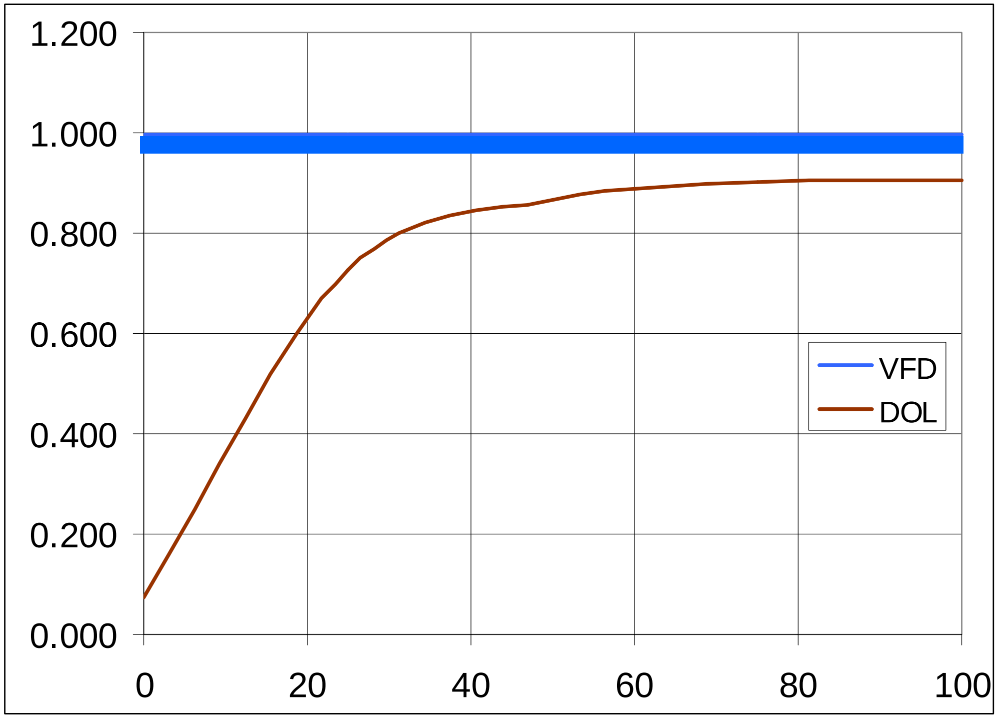
Why Use a VFD?

Greater **Starting Torque**



Why Use a VFD?

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



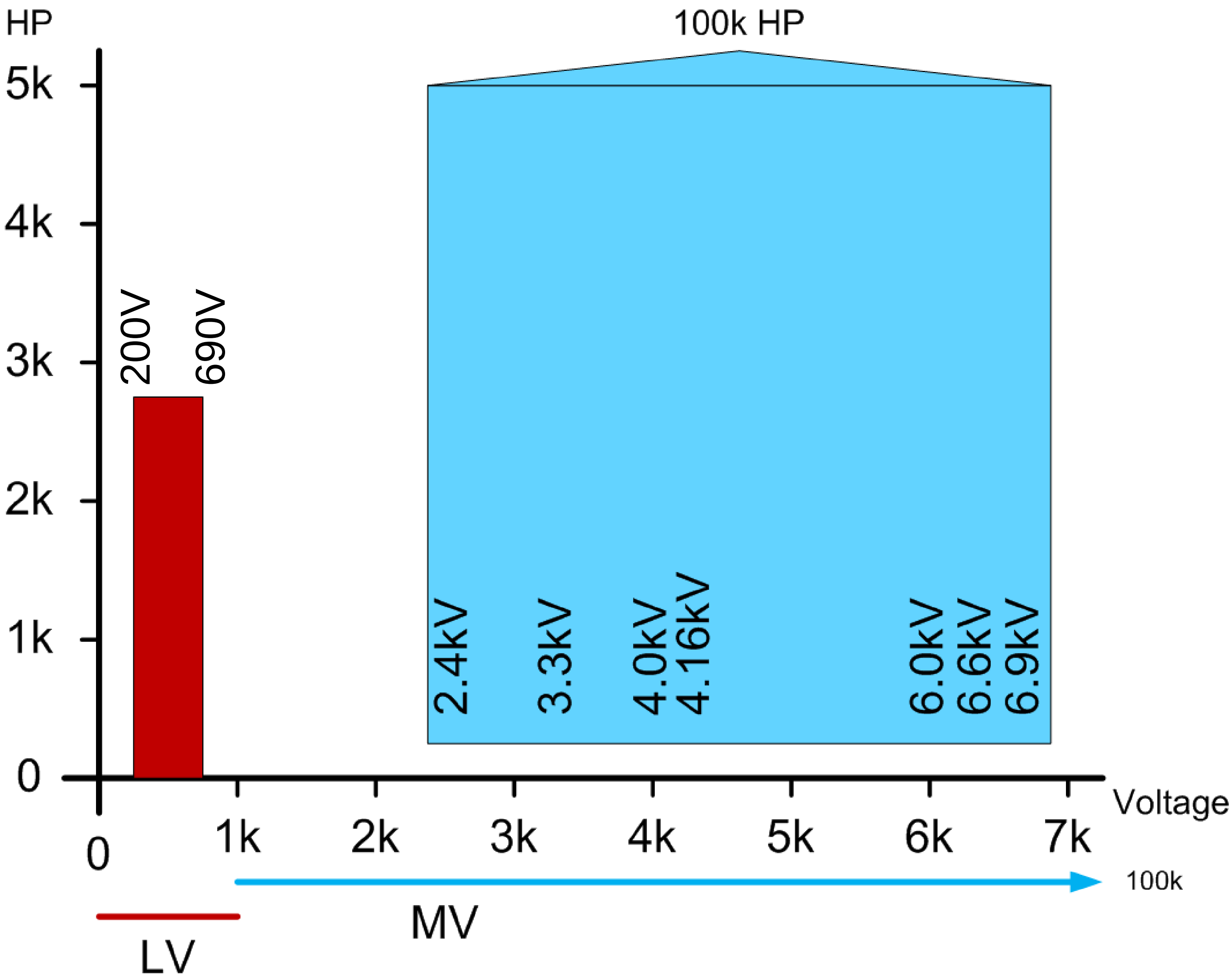
Why Use a VFD?

Adjustable Torque Limit to prevent damage to equipment

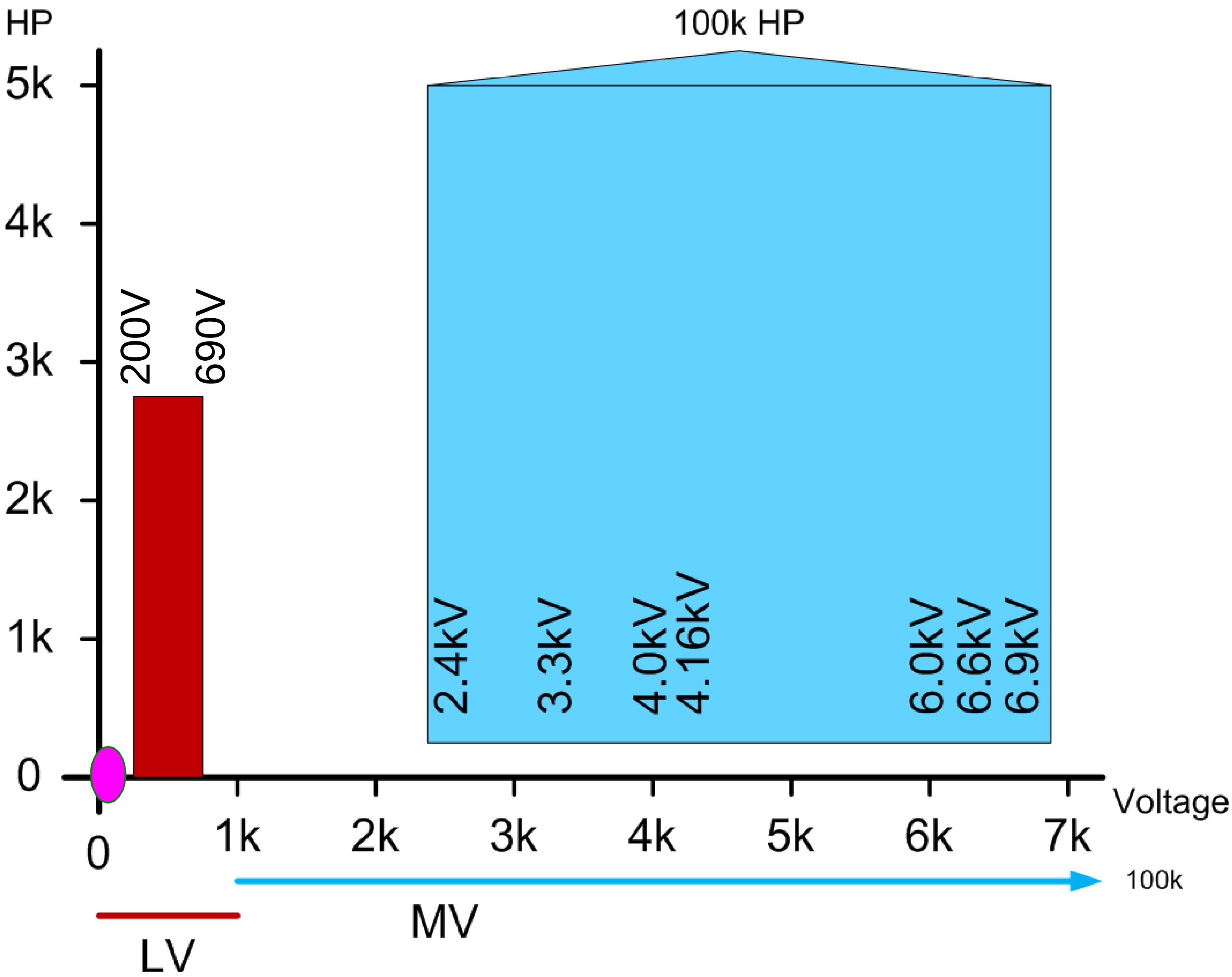
No mechanical jerk, smooth acceleration

What is LV and MV?

What is LV and MV?

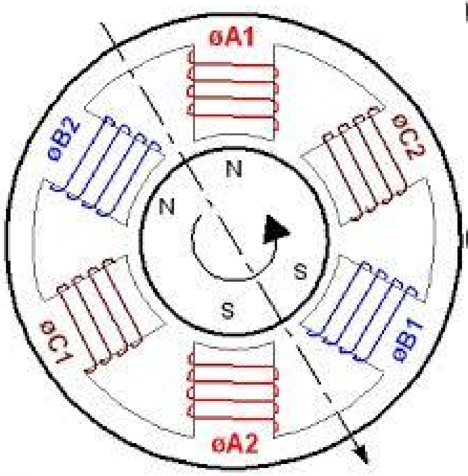


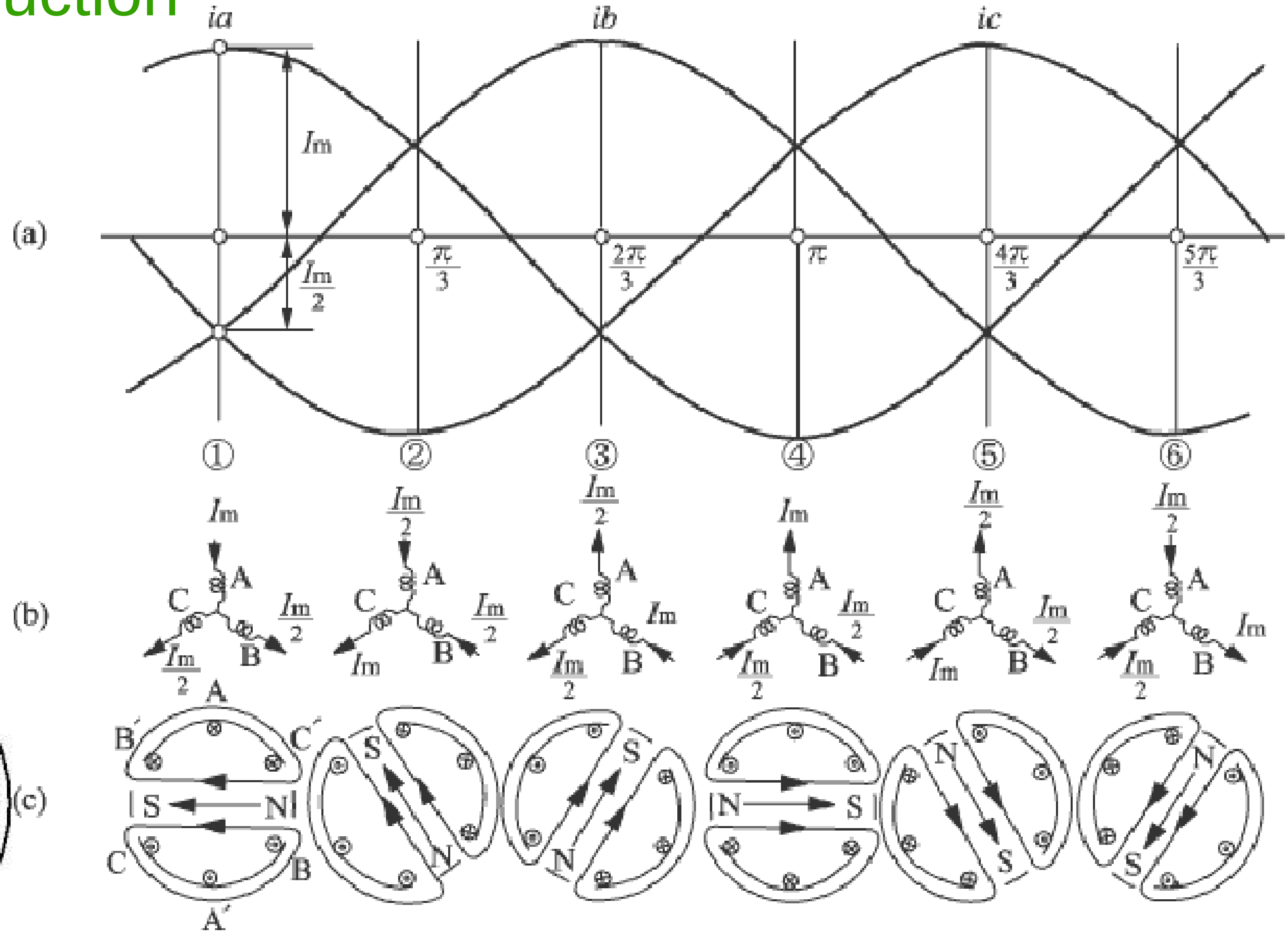
What is LV and MV?



How do you change the speed of an AC motor?

How do you change motor speed?
Motor construction





How do you change motor speed?
Motor equations

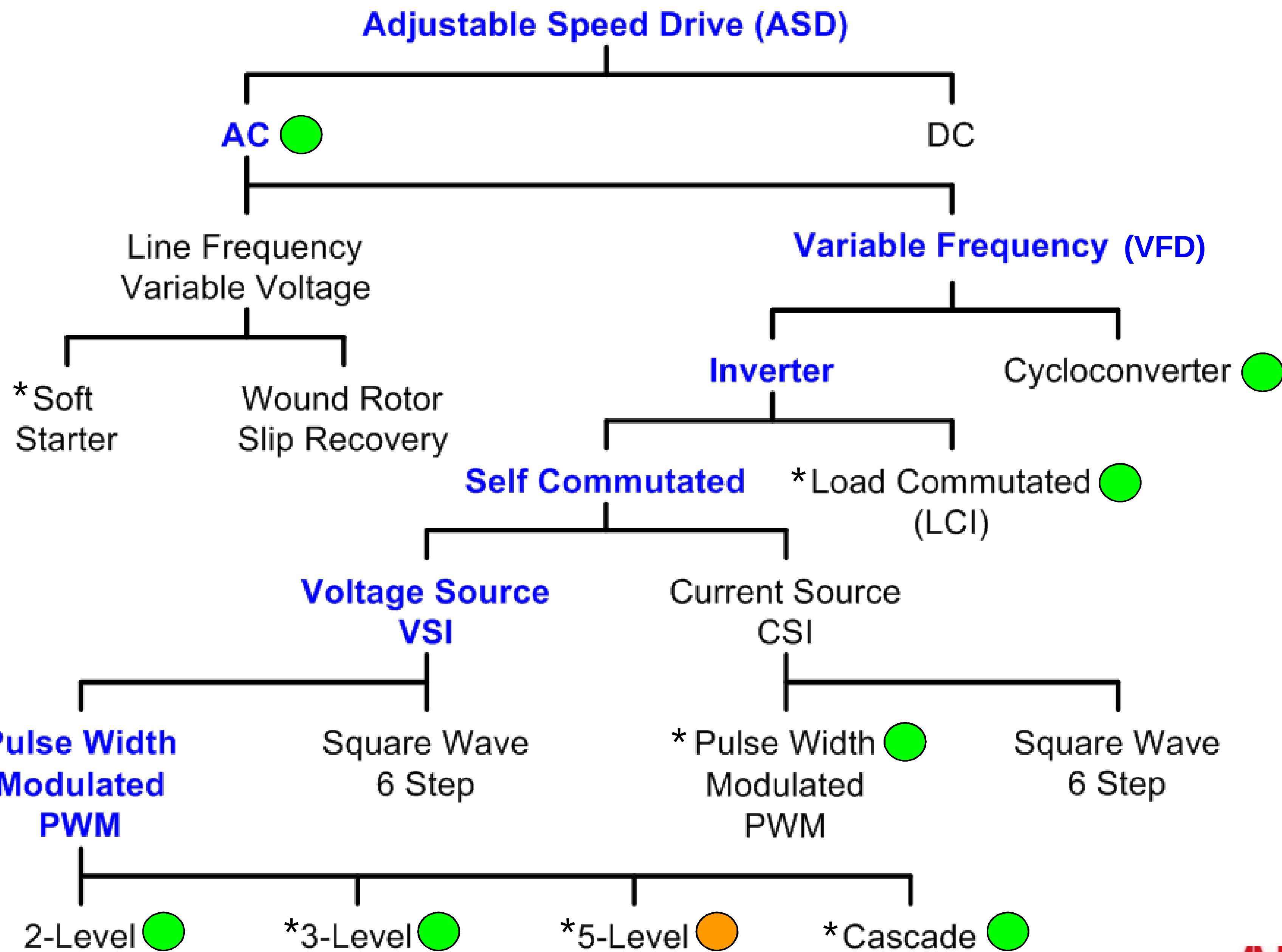
- Input
  - $S_{in} = FLA \times kV \times \sqrt{3}$ [kVA] — FLA = Full load amps
  - $S_{in} = P_{in}/PF_M$ [kVA] — PF_M = Motor power factor
  - $P_{in} = S_{in} \times PF_M$ [kW]
  - $P_{in} = P_{out}/\eta_M$ [kW] — η_M = Motor efficiency
- Losses
  - $P_{loss} = P_{in} - P_{out}$
- Efficiency
  - $\eta_M = P_{out}/P_{in}$
- **Speed** (synchronous)
  - $\boldsymbol{n = 120 \times f\ /p}$ [rpm]

f = Frequency, Hz
p = Number of poles (2,4,6, …)

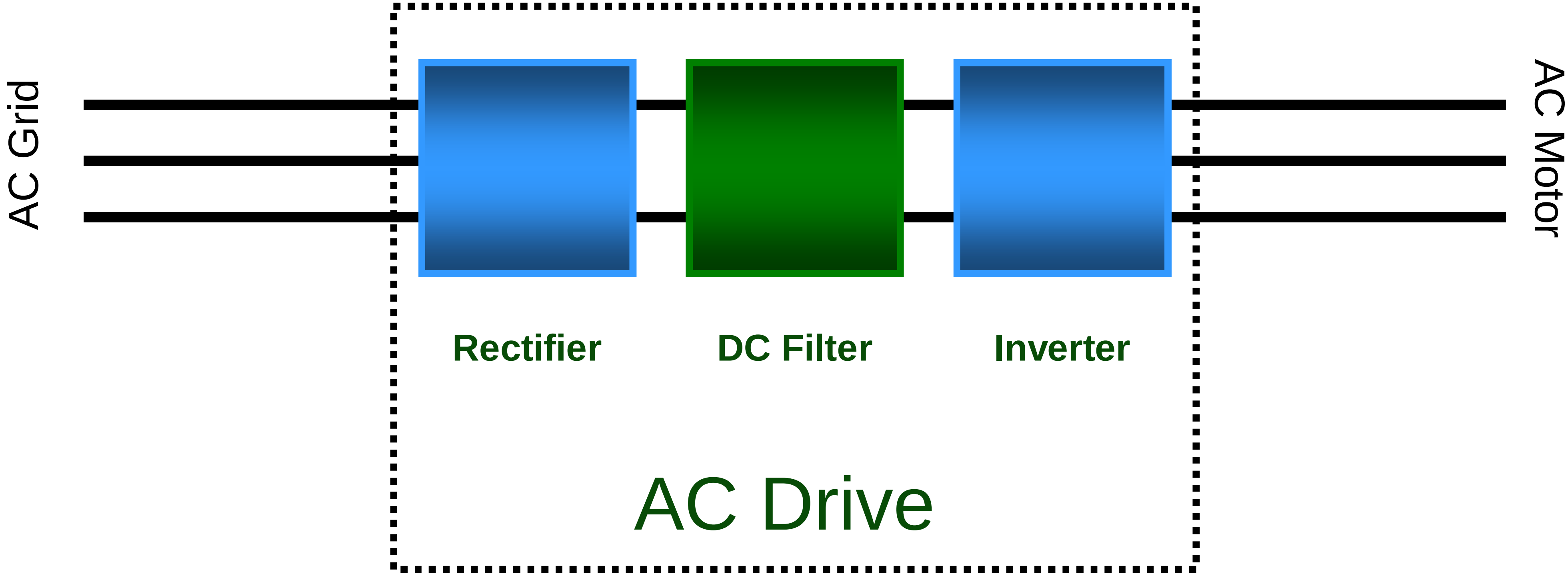
How do you make variable frequency AC?

AC Drive Classifications

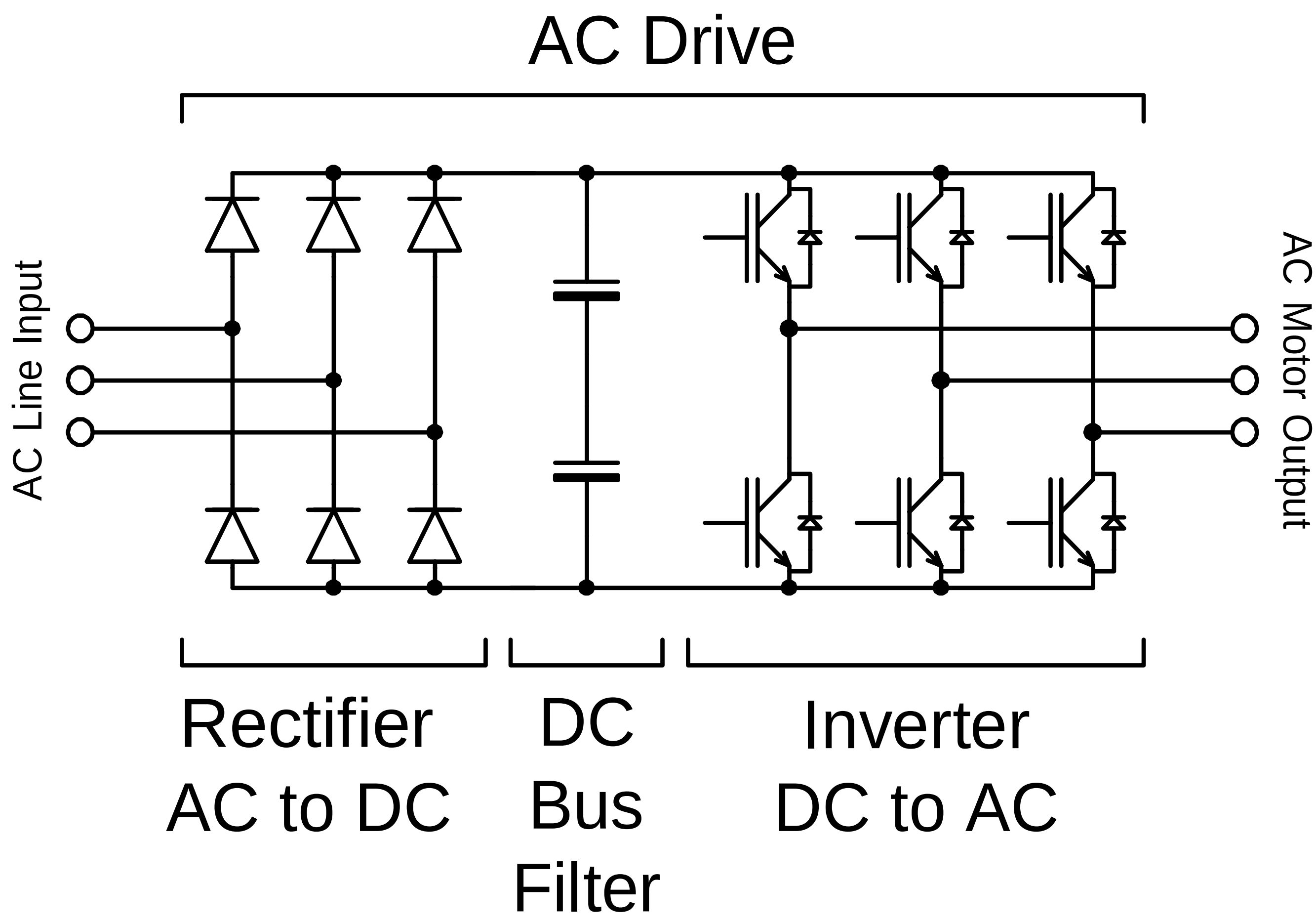
* used in MV drives



General Block Diagram of a Basic AC Drive



Basic AC Drive Topology
6-Pulse



Fixed AC Voltage
Fixed AC Frequency

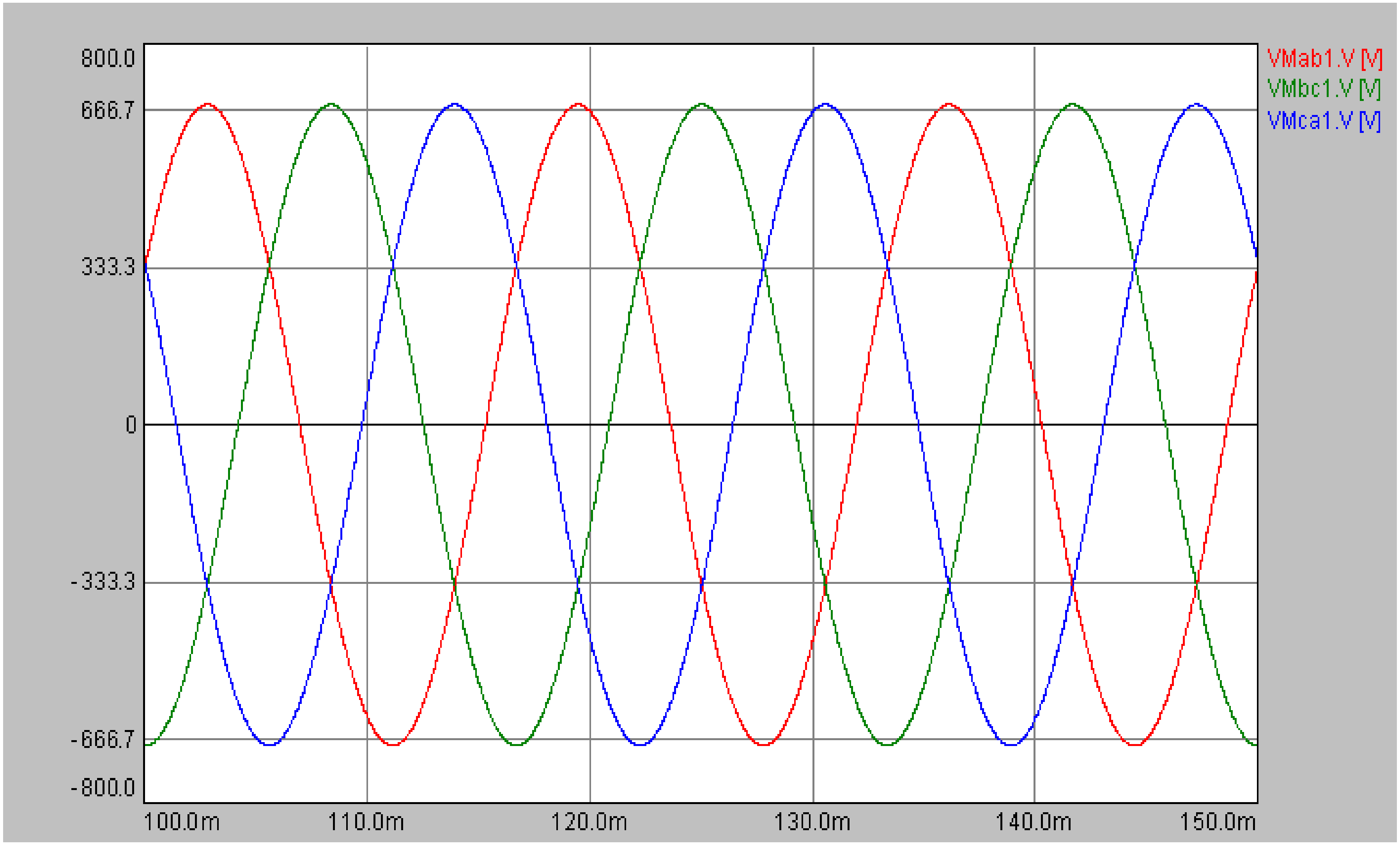
Fixed DC Voltage

Adjustable AC Voltage
Adjustable AC Frequency

ABB

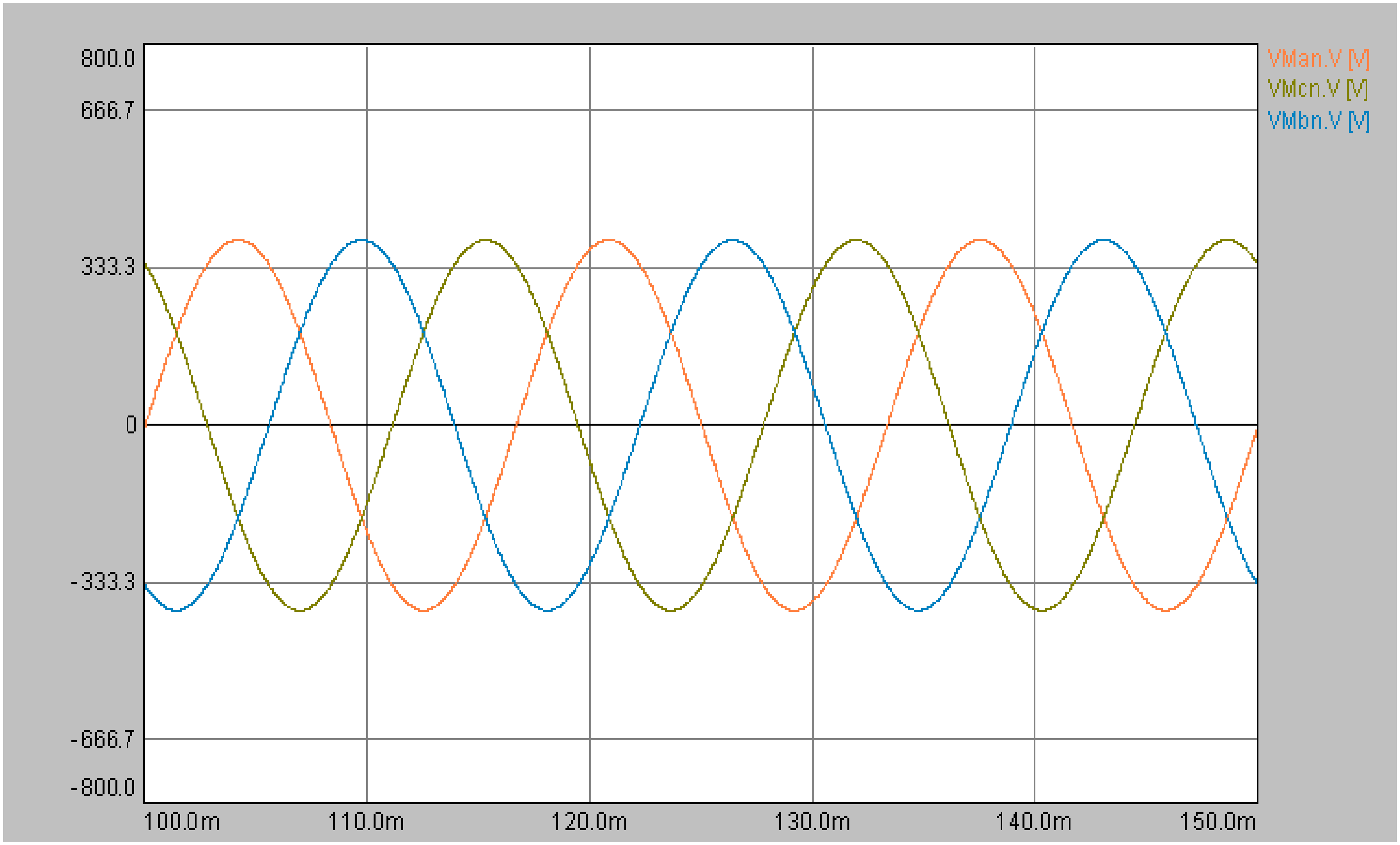
What We'd Like to See -

480Vac / 4160Vac line-to-line



An Ideal Supply Voltage

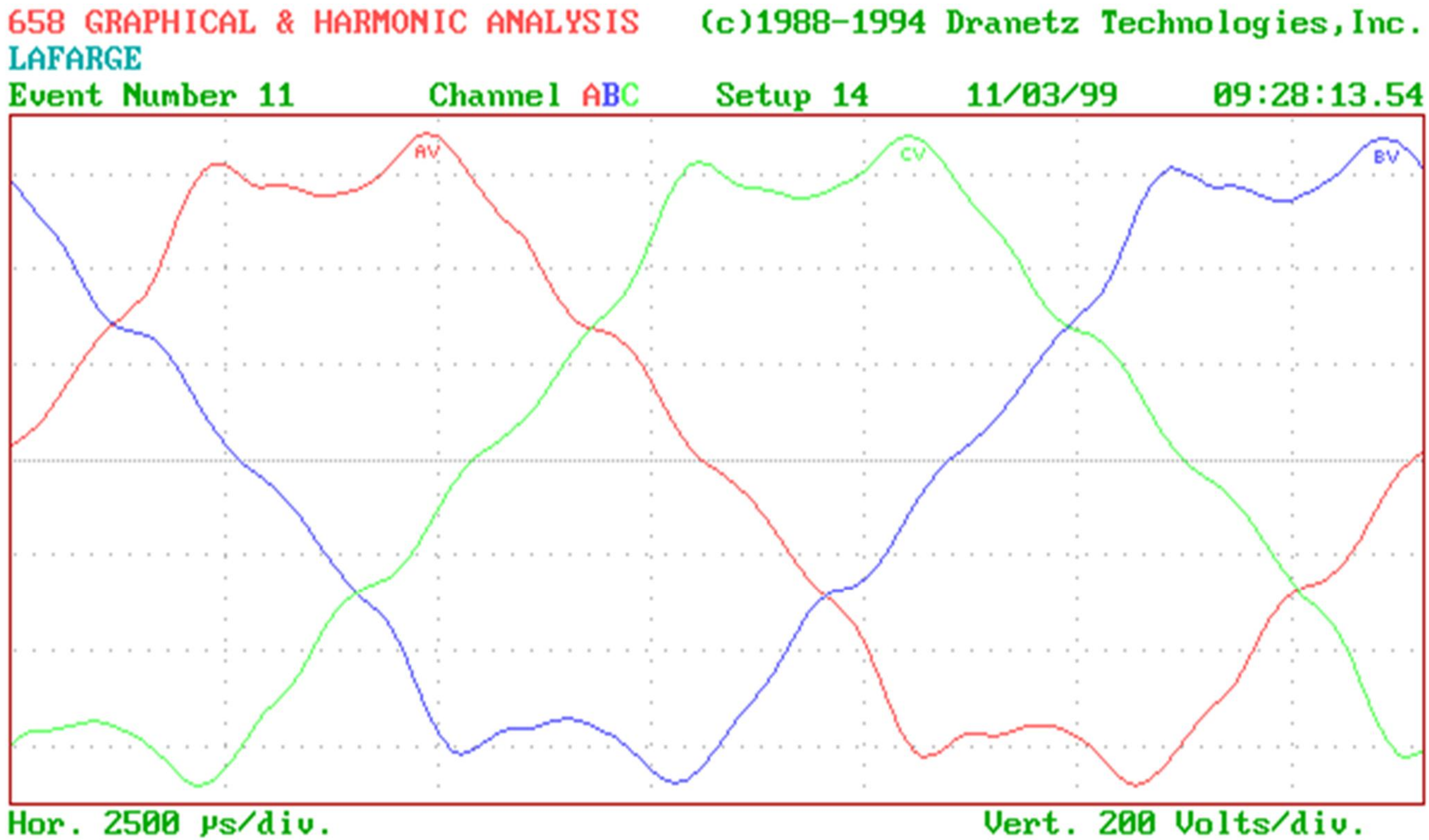
277Vac / 2400Vac line-to-neutral



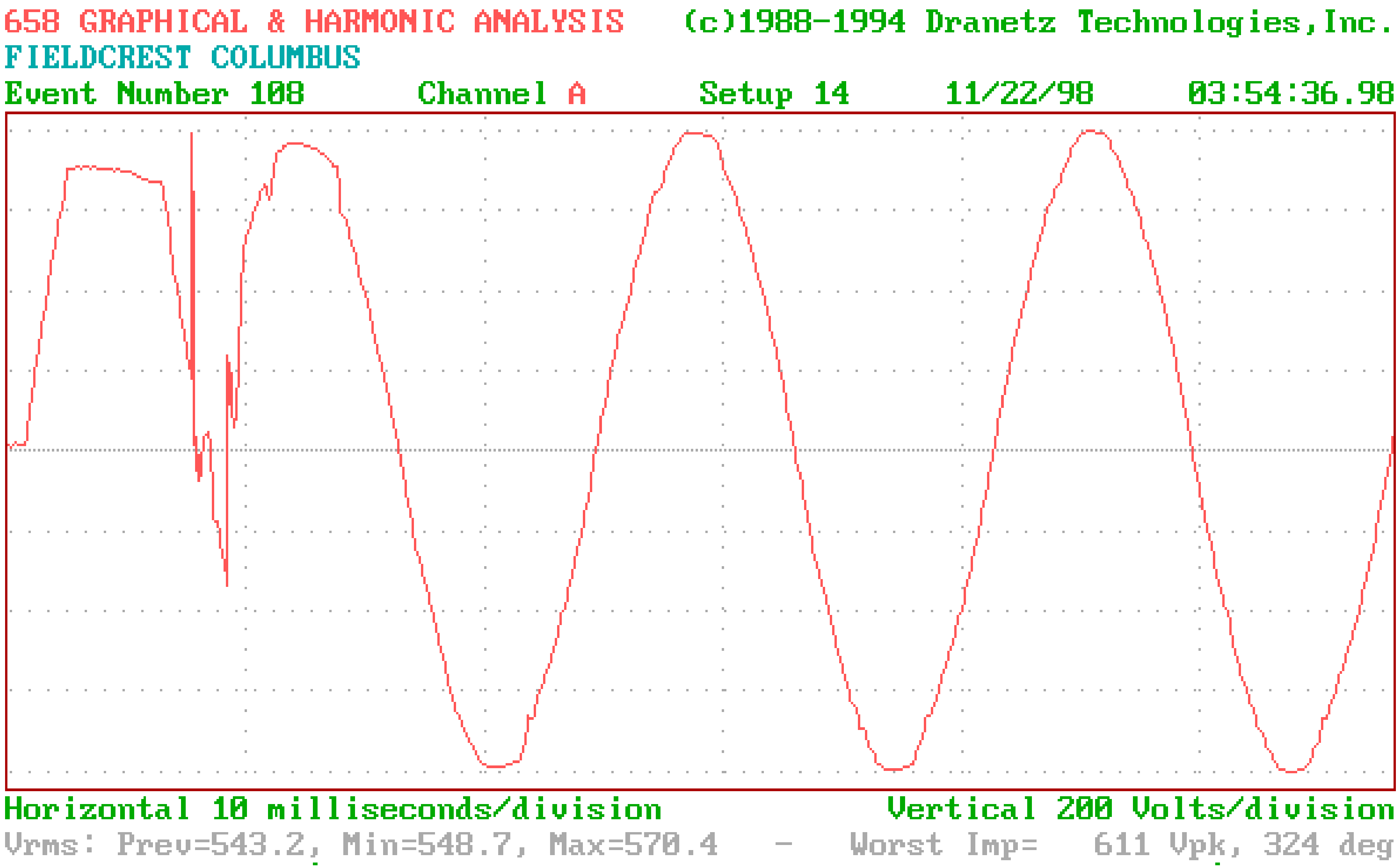
Common Power Quality Problems

- **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

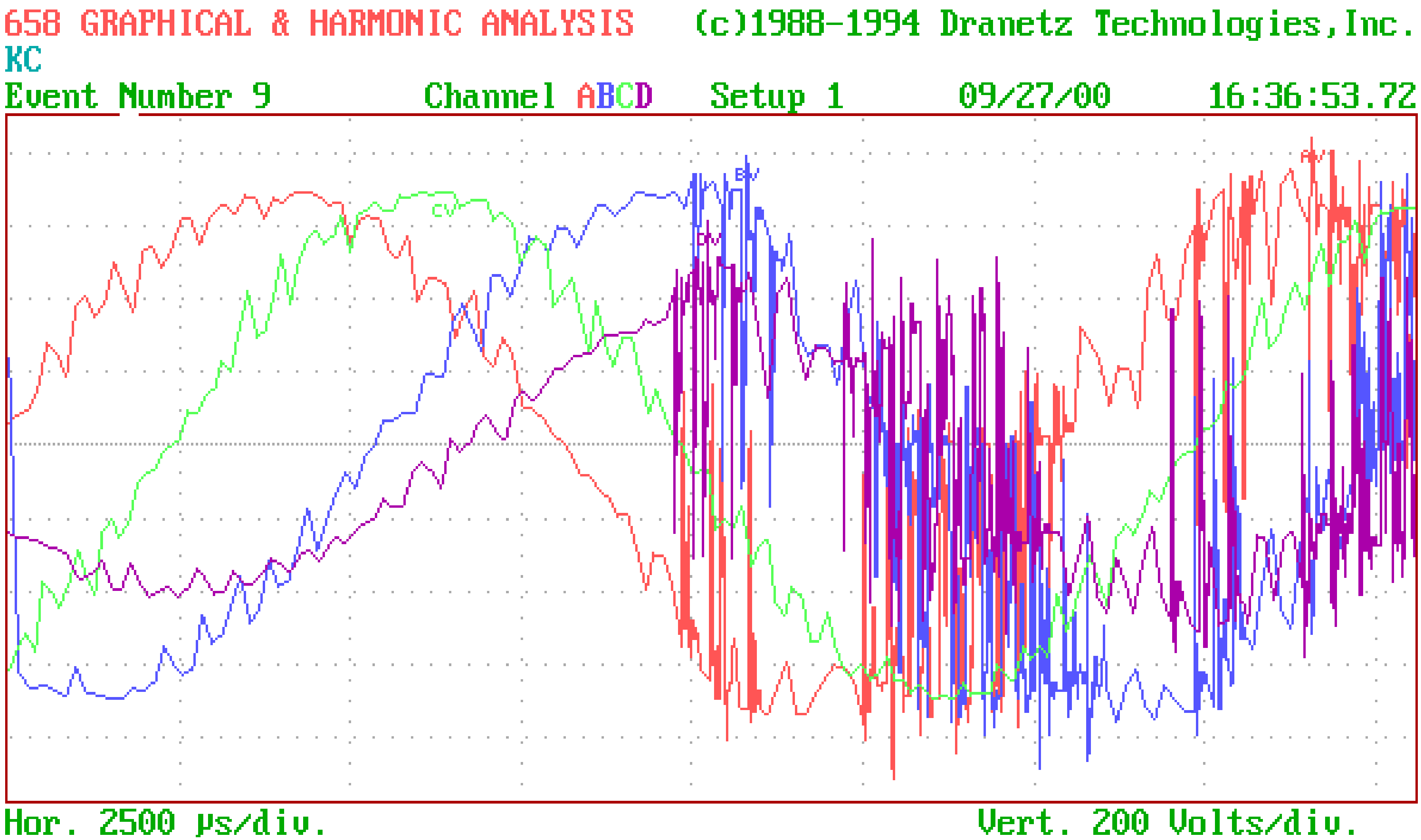
What have we seen?



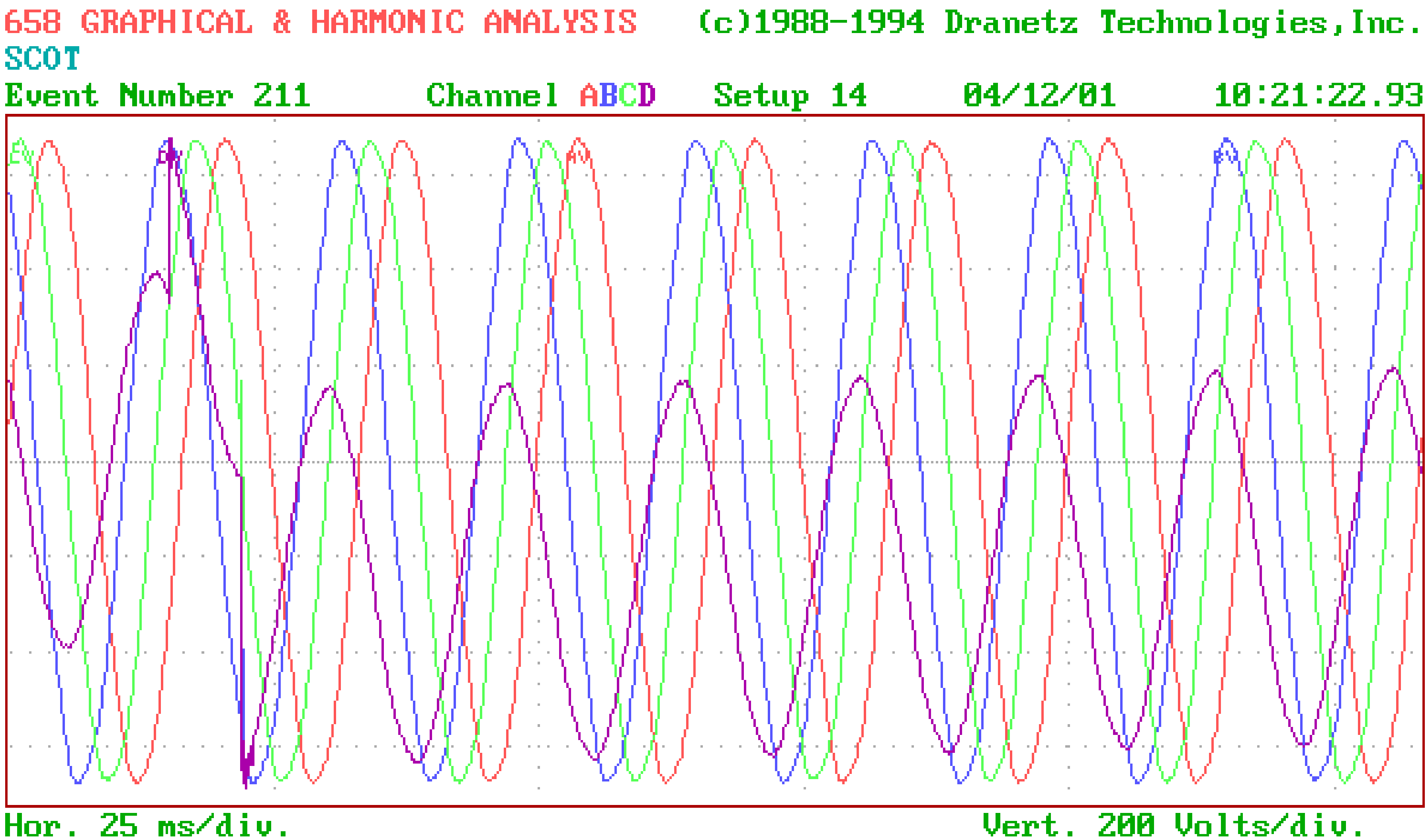
Transfer Switch



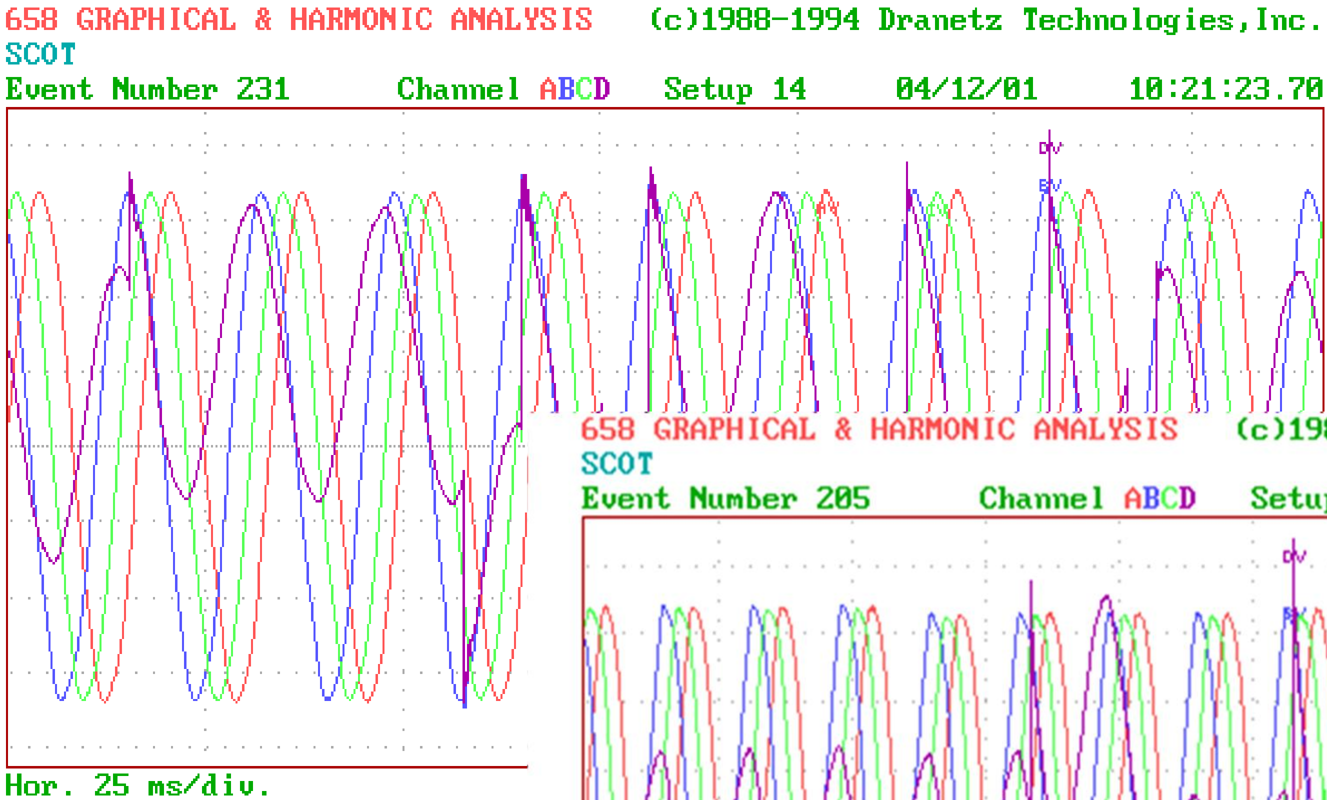
Voltage Modulation – AFE w/ Blown Fuse

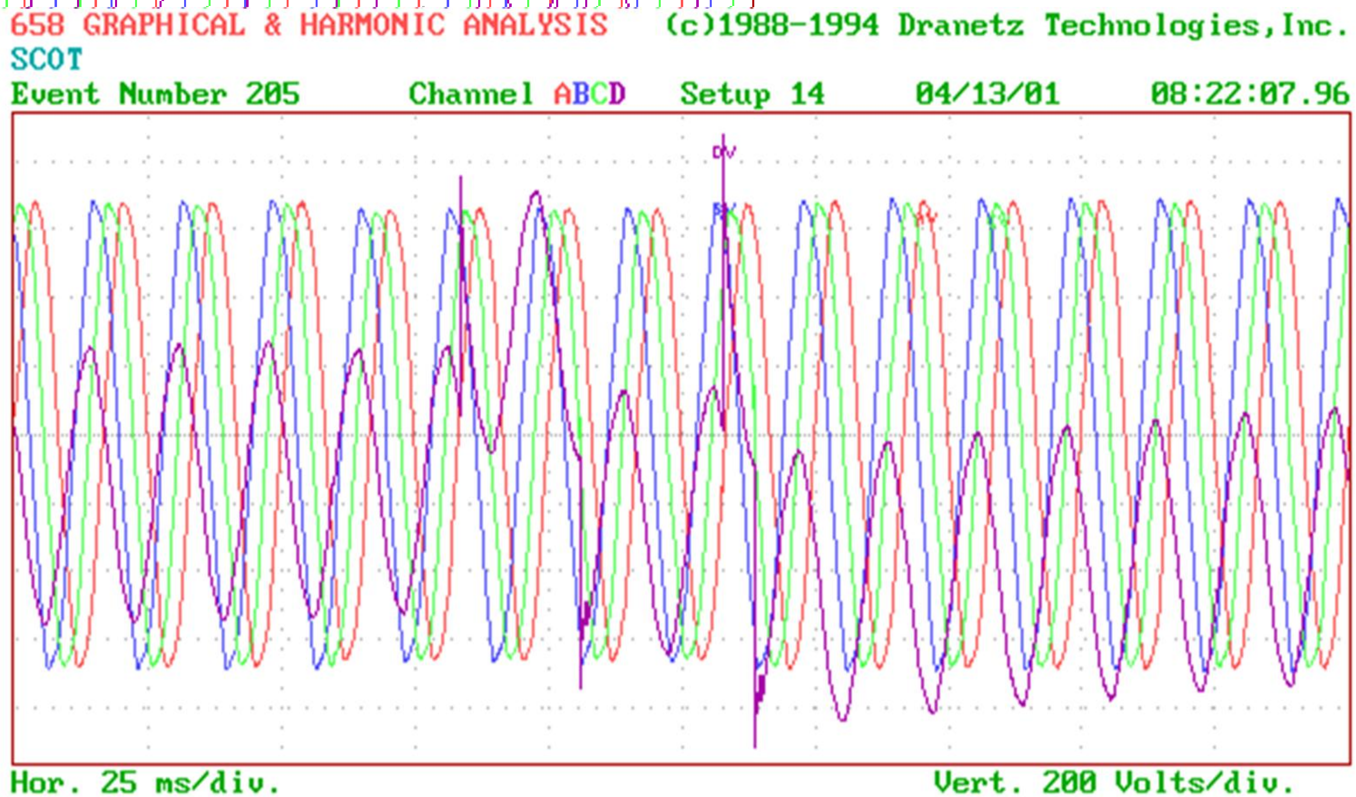


Example of Load with Ground Fault

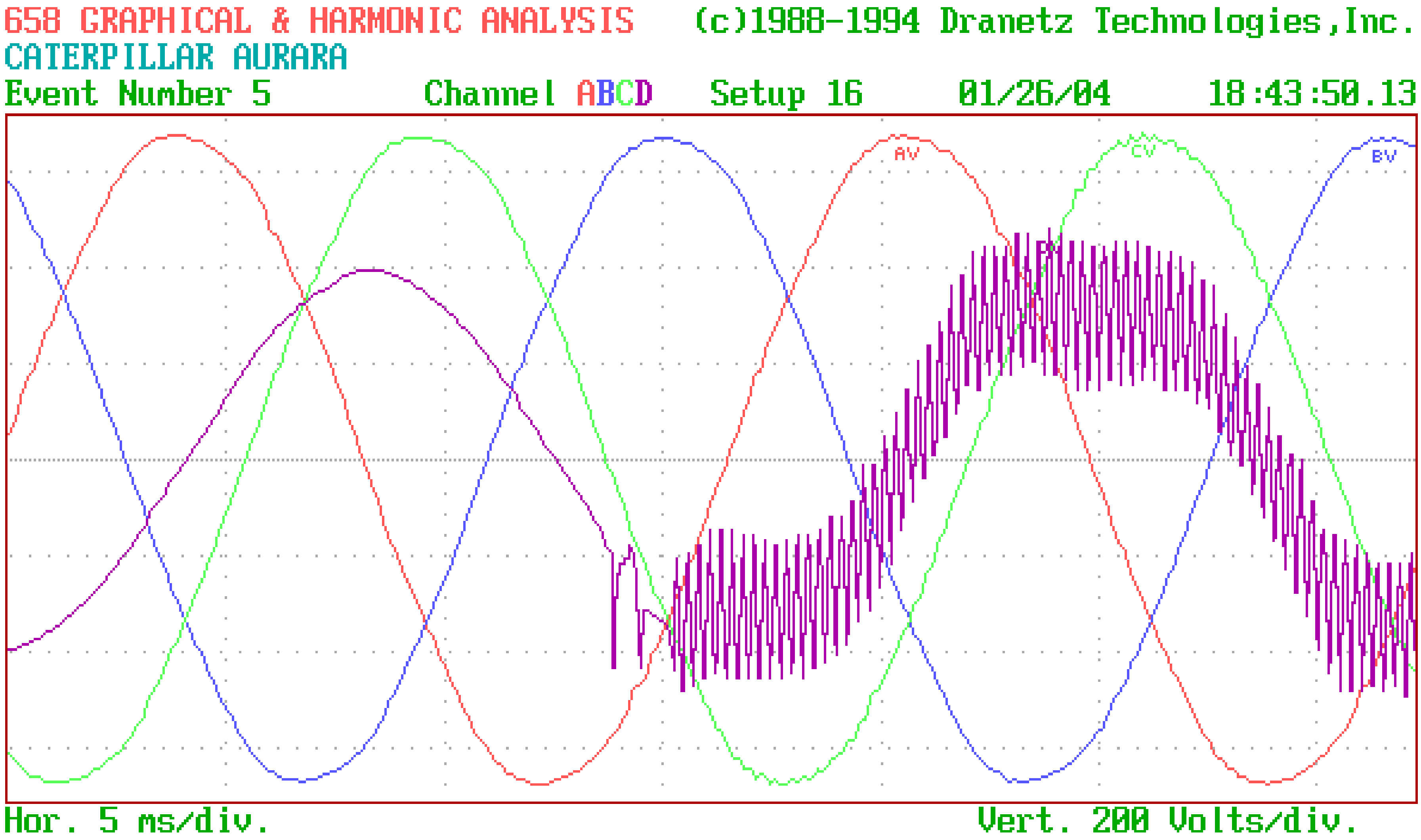


Ungrounded Supply

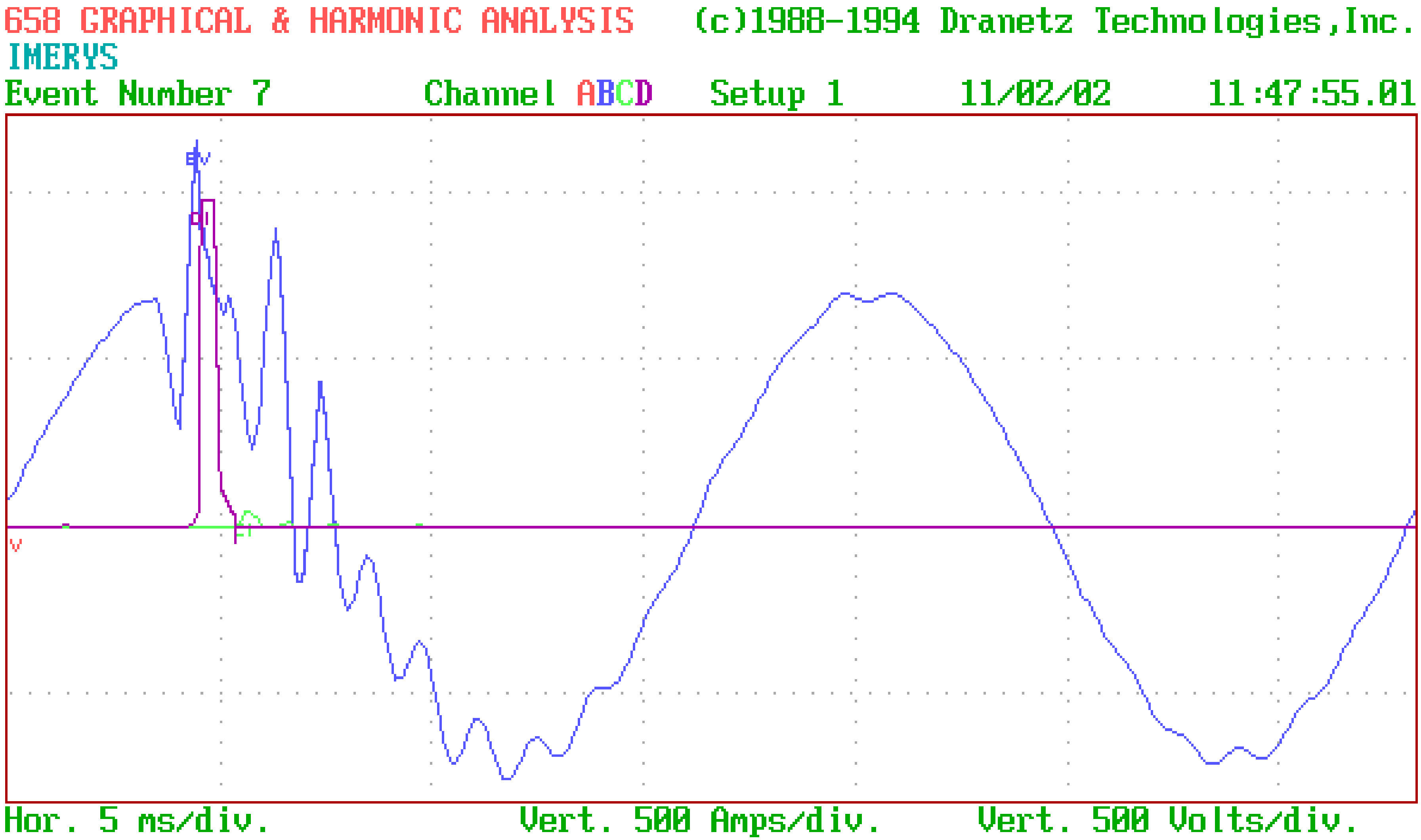




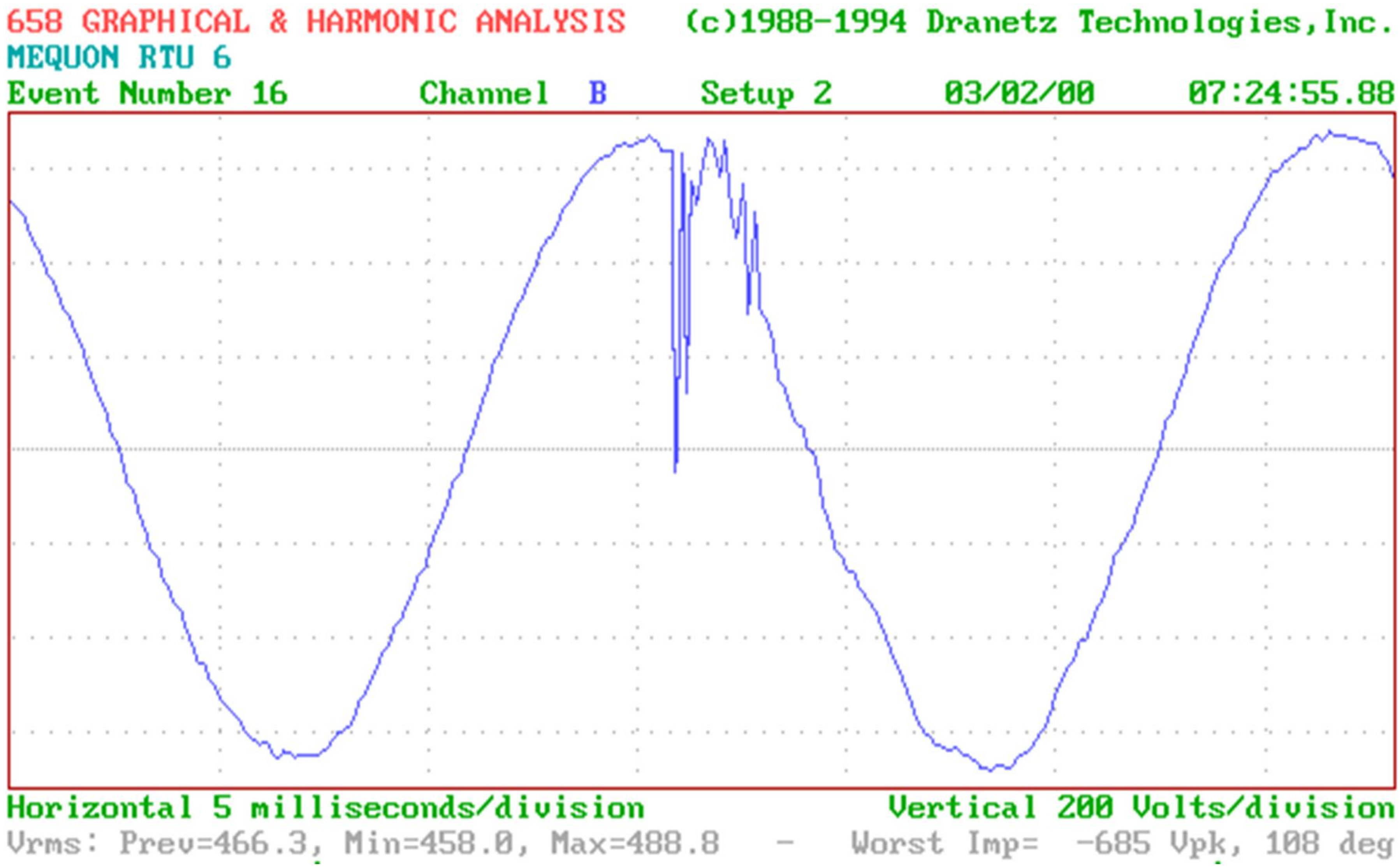
Example of Load with Ground Fault



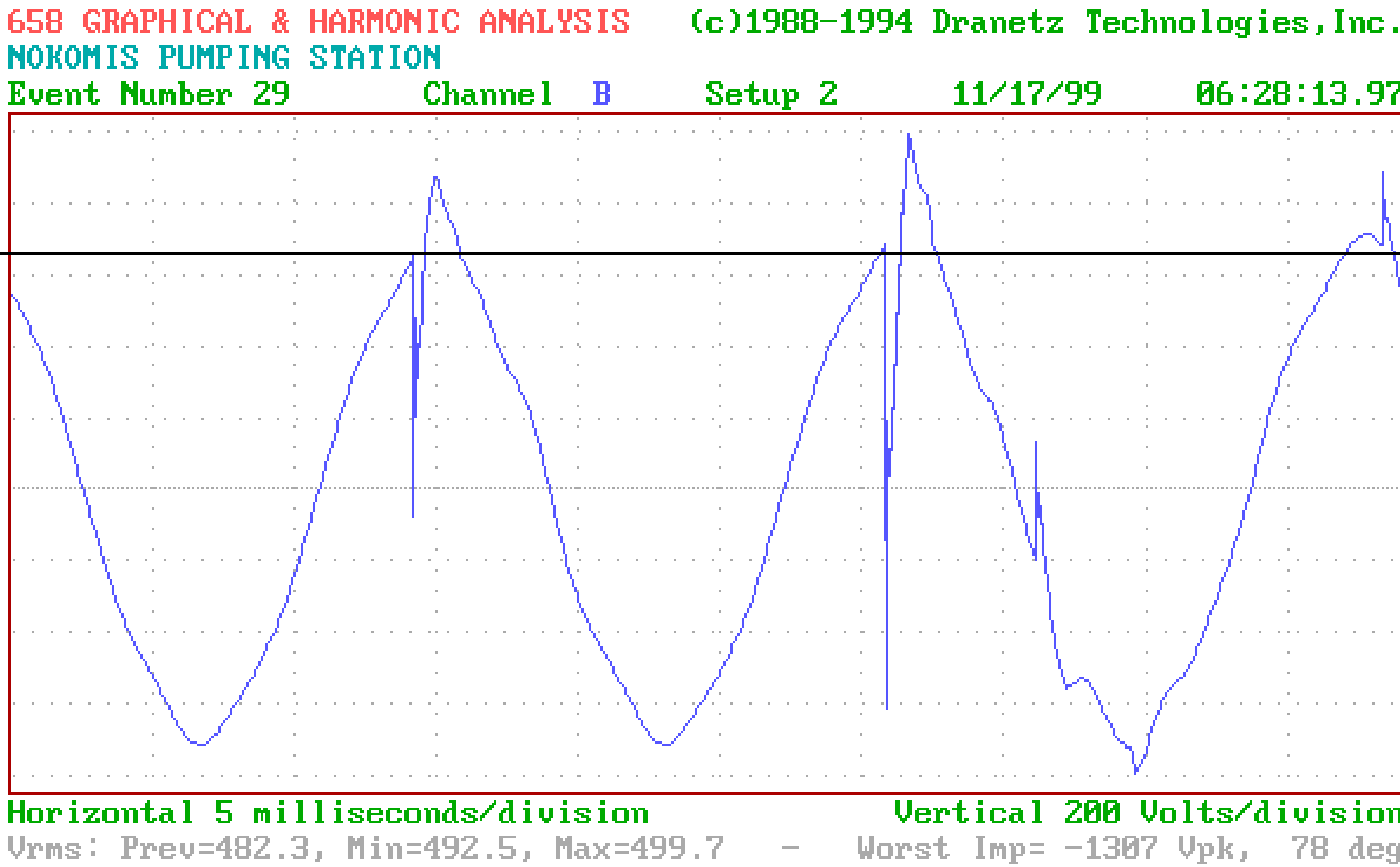
PF Cap Insertion



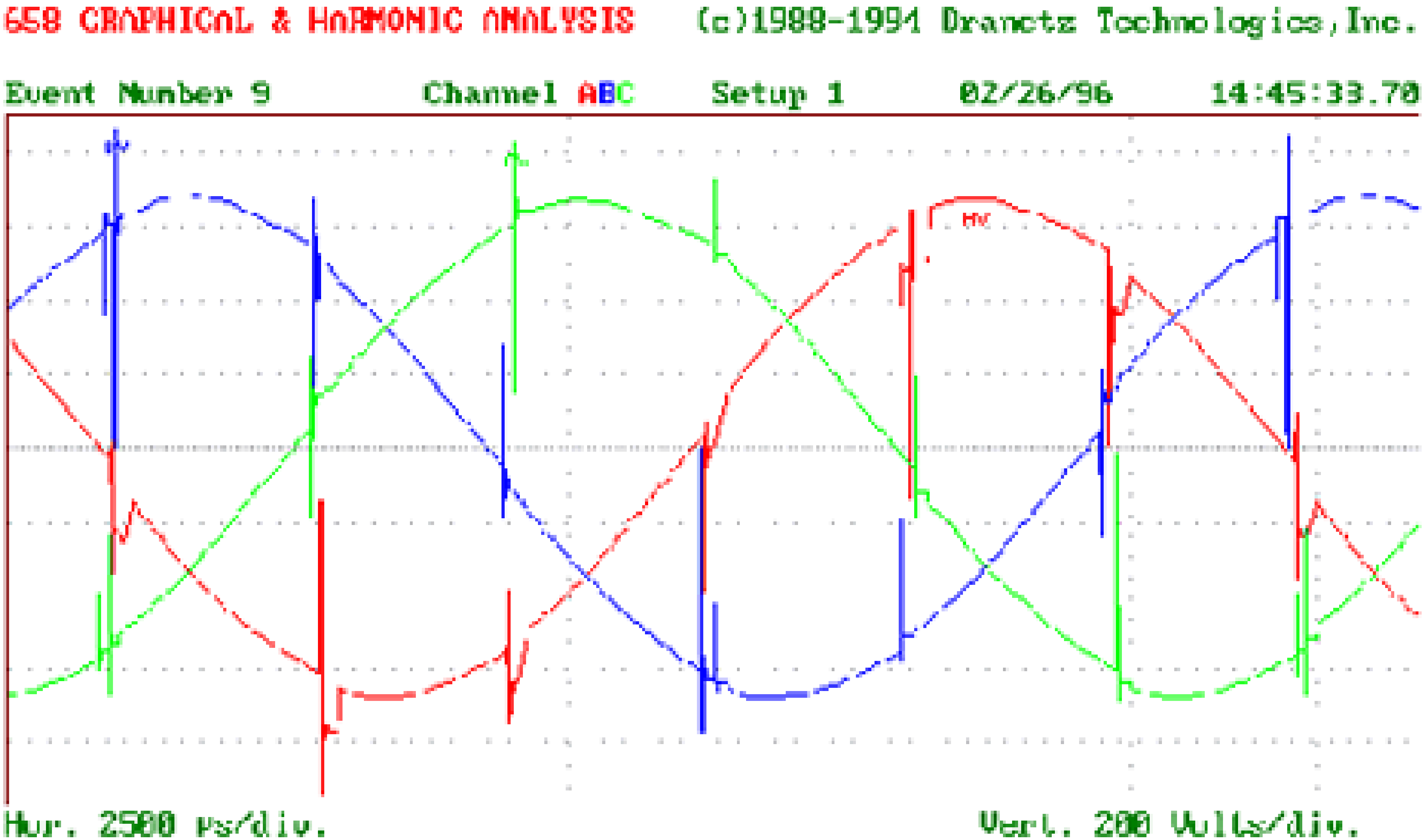
PF Cap Insertion



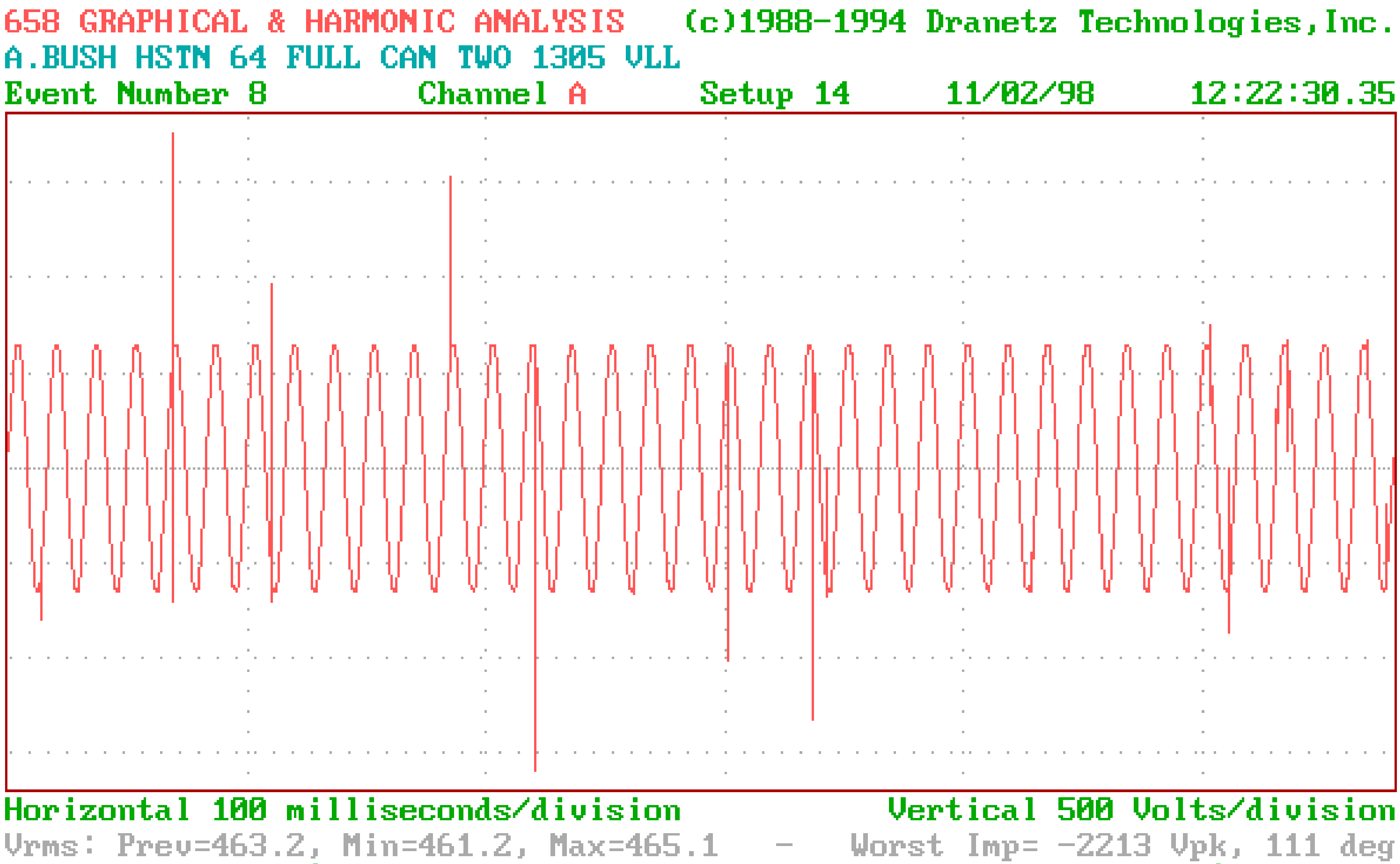
Severe Distortion



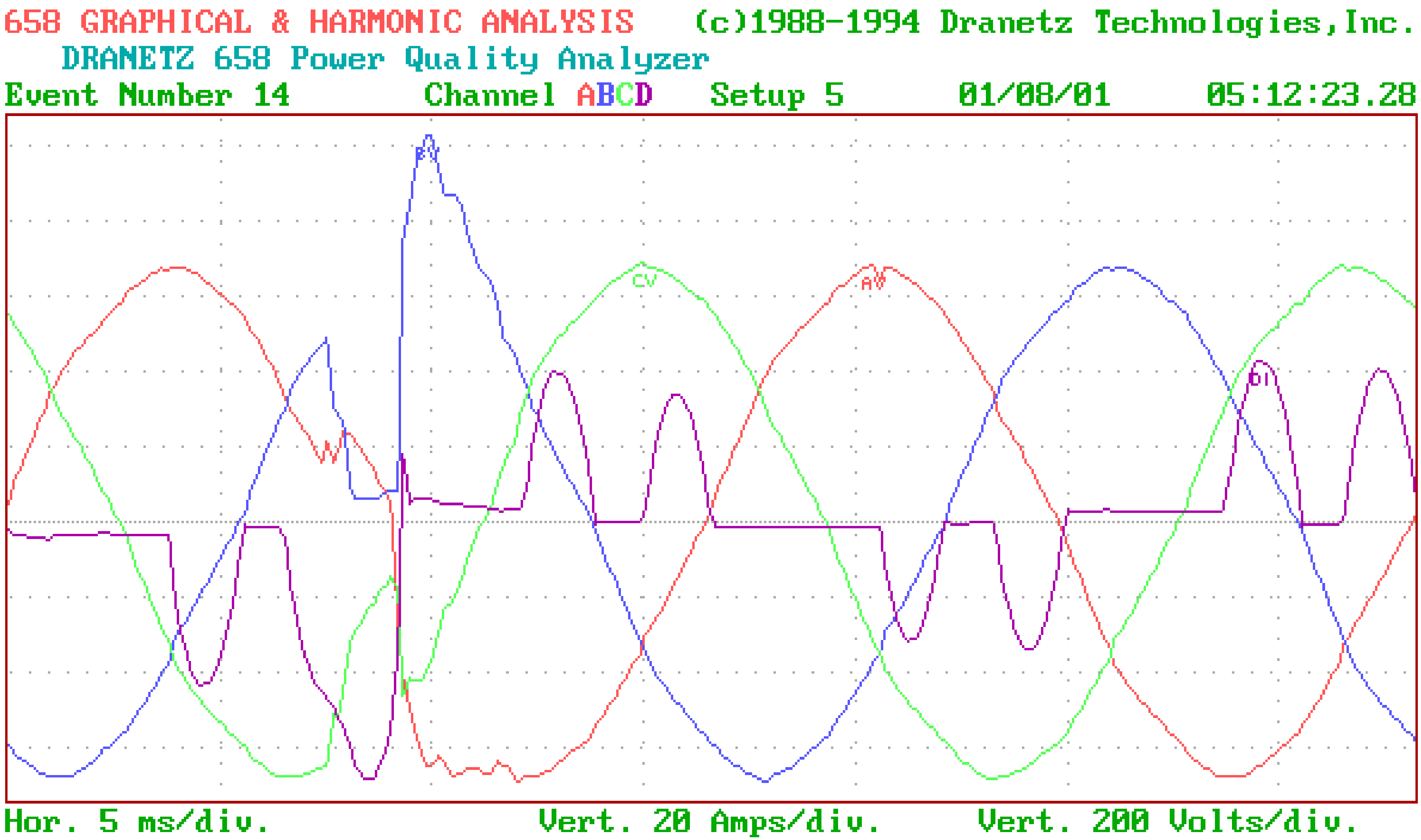
Line-Notching from DC Drive



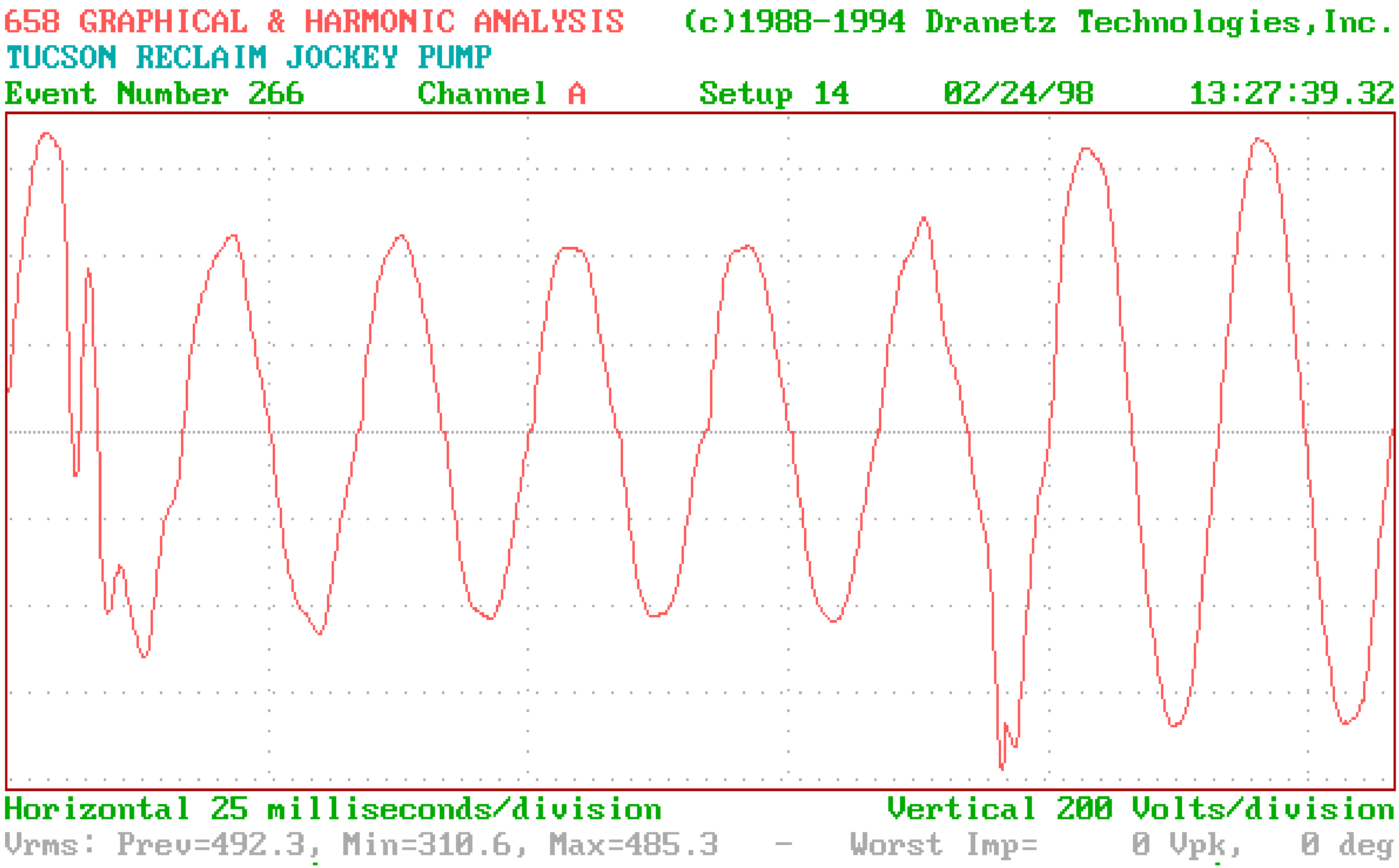
Voltage Transients – Inductive Load Switching?



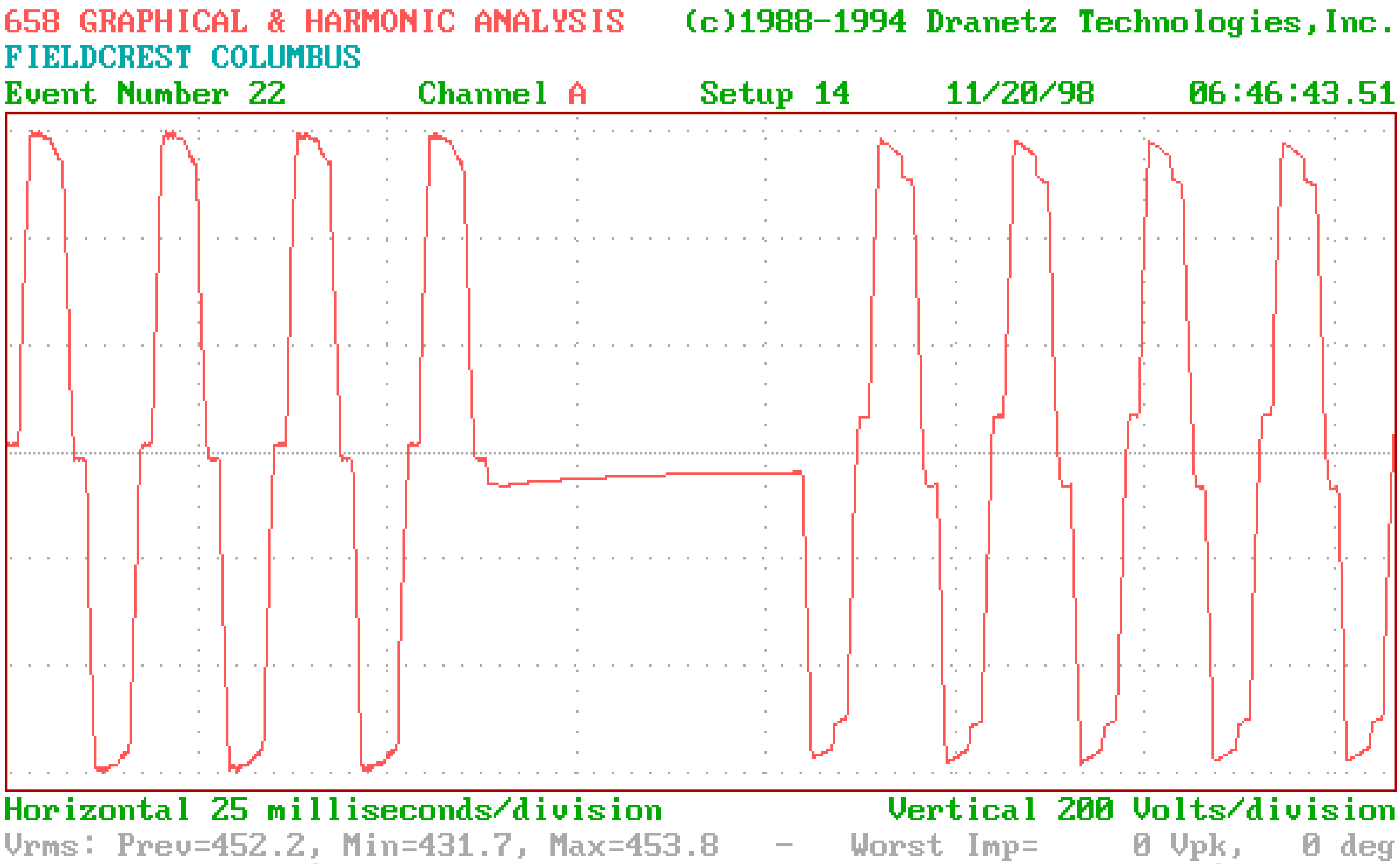
Single Notch



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

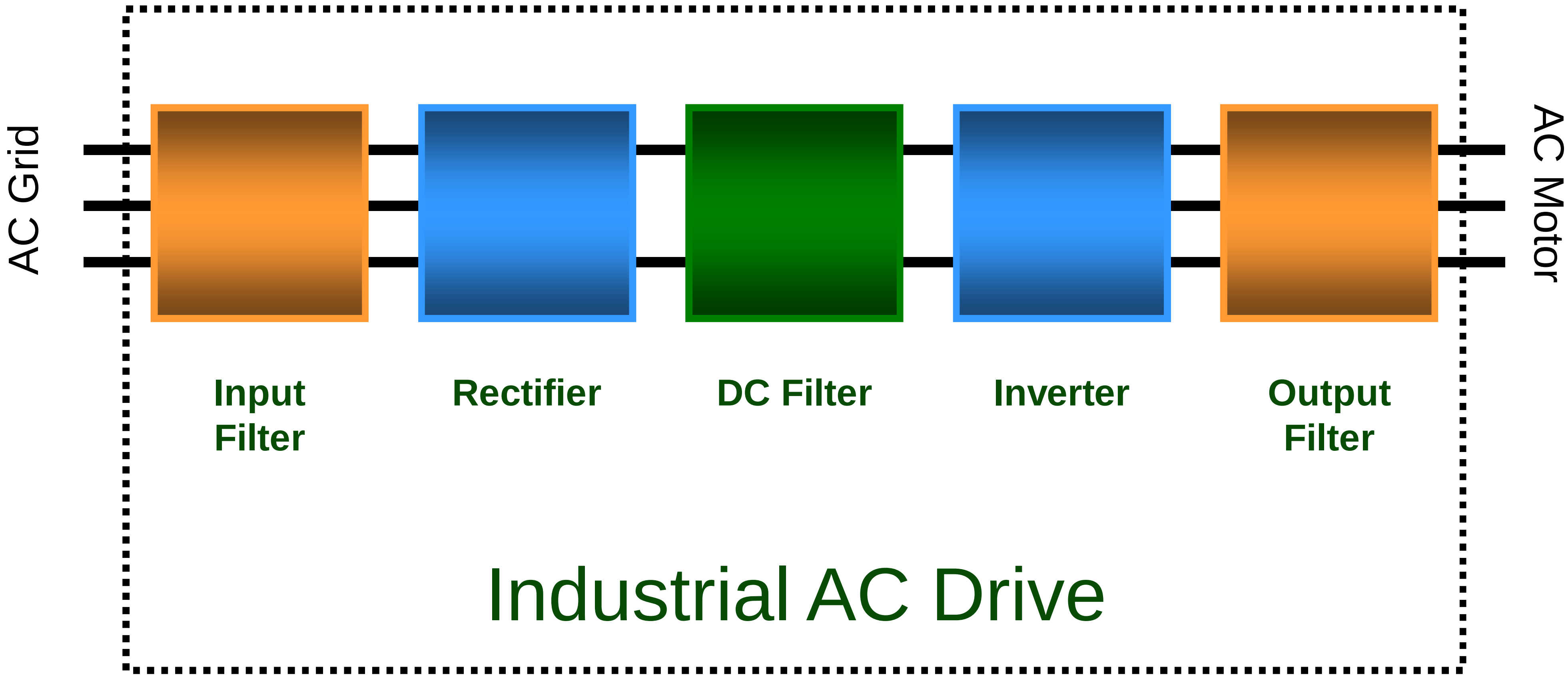
Voltage Interruption



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



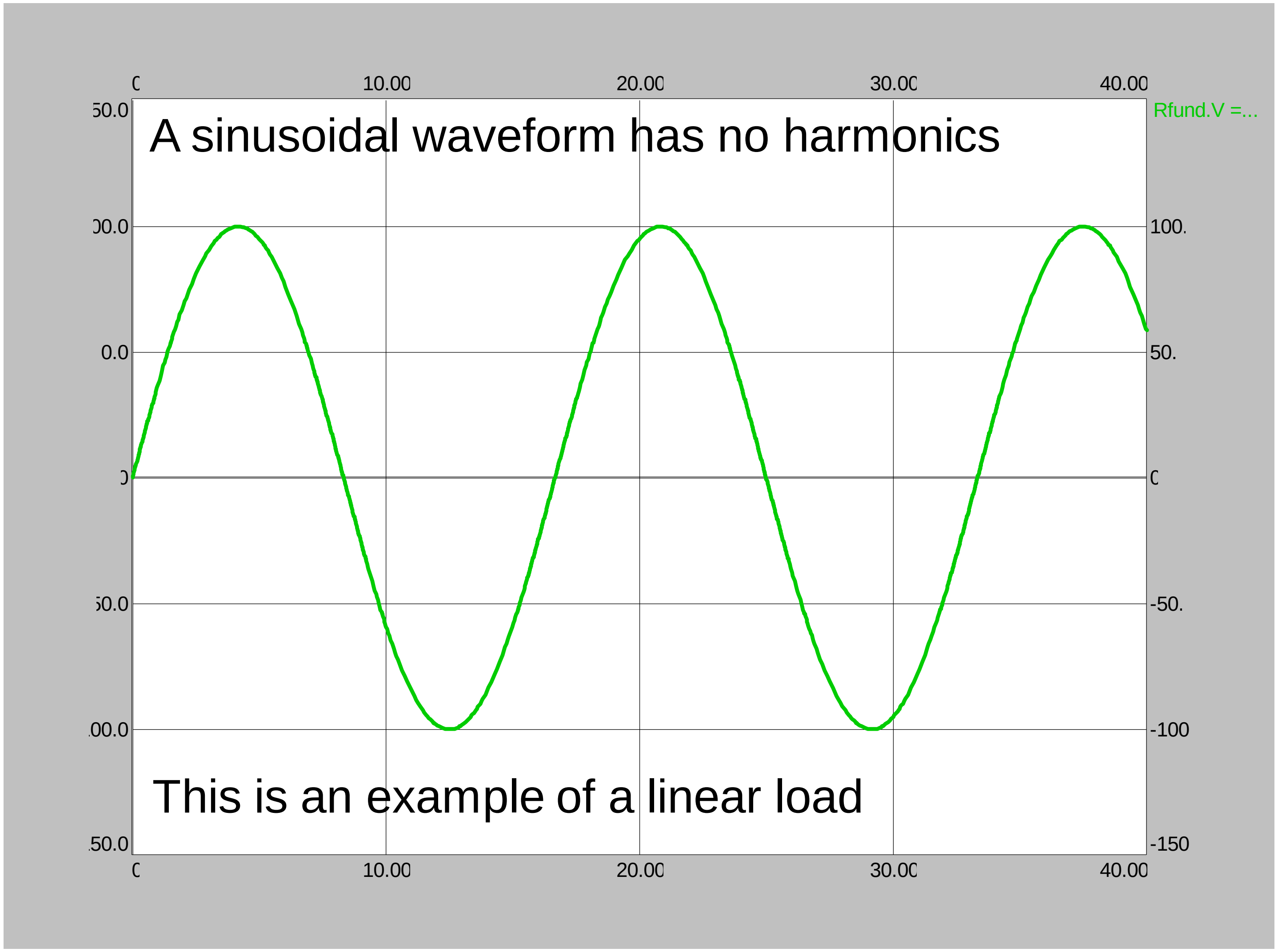
What's Unique to High Power Drives?

- 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

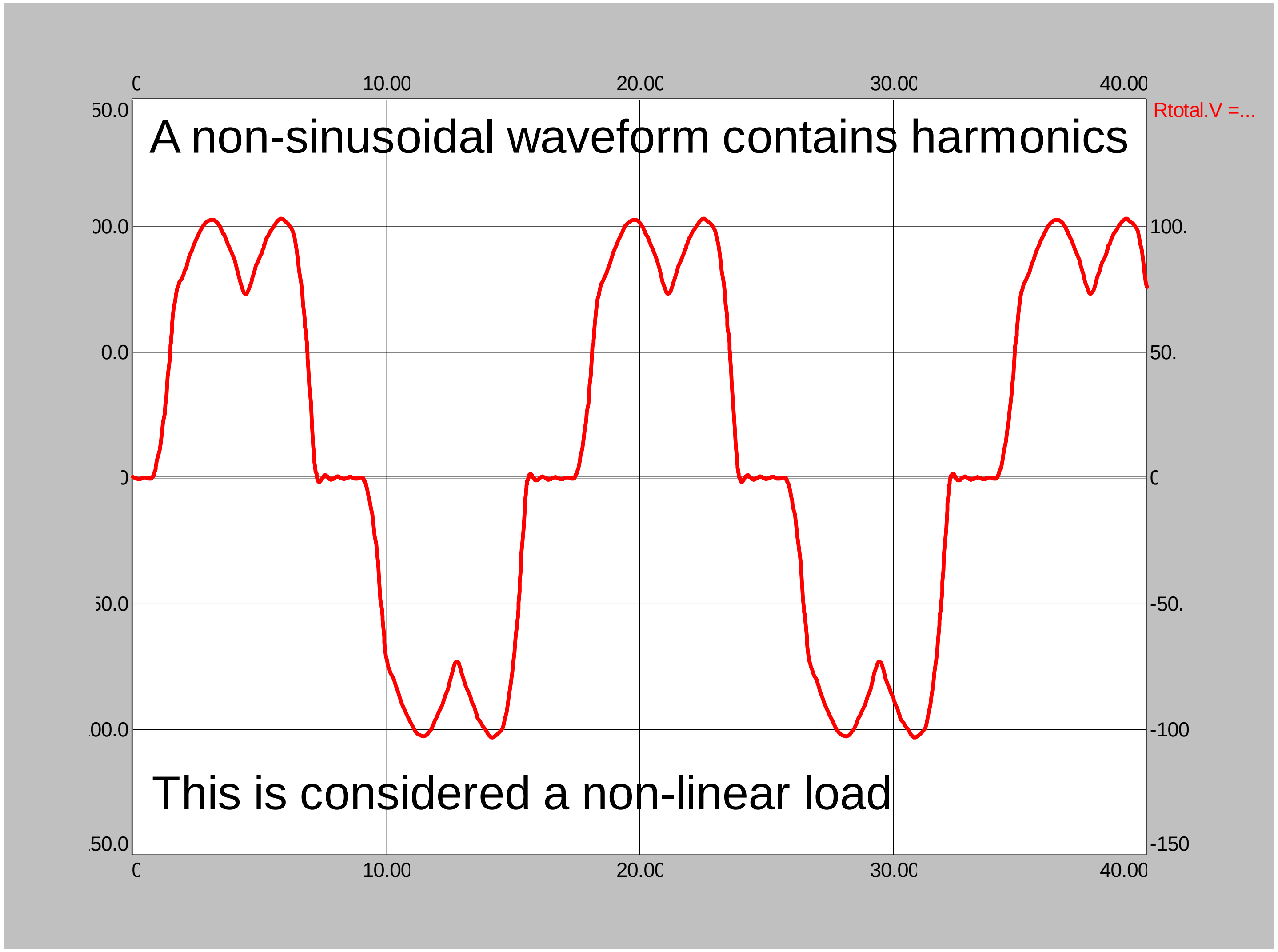
Line Side Requirements

- Harmonics
- Power Factor
- Grounding Configuration

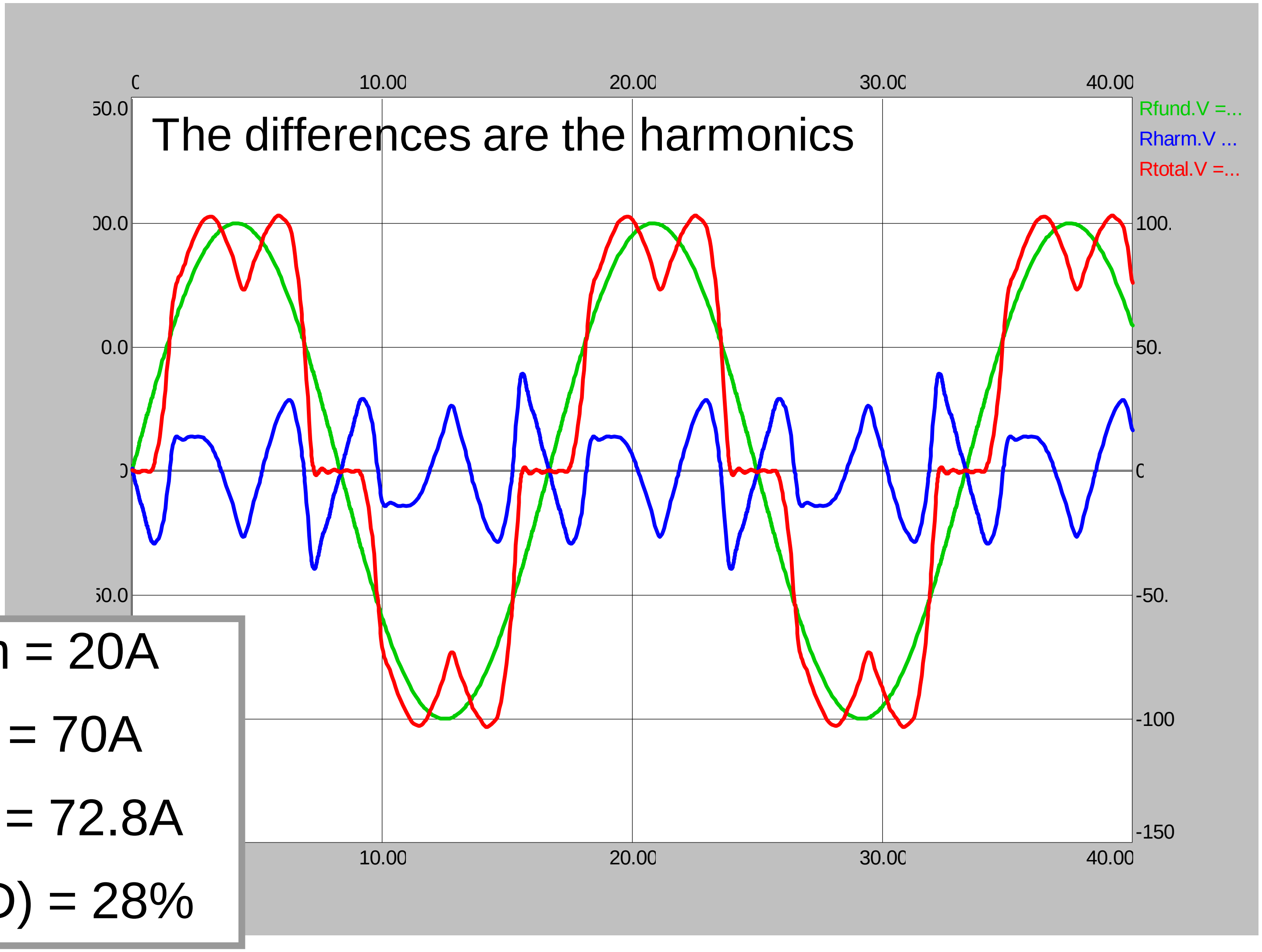
What are Harmonics?



What are Harmonics?



Total, Fundamental, Harmonic Current



Iharm = 20A

Ifund = 70A

Itotal = 72.8A

I(THD) = 28%

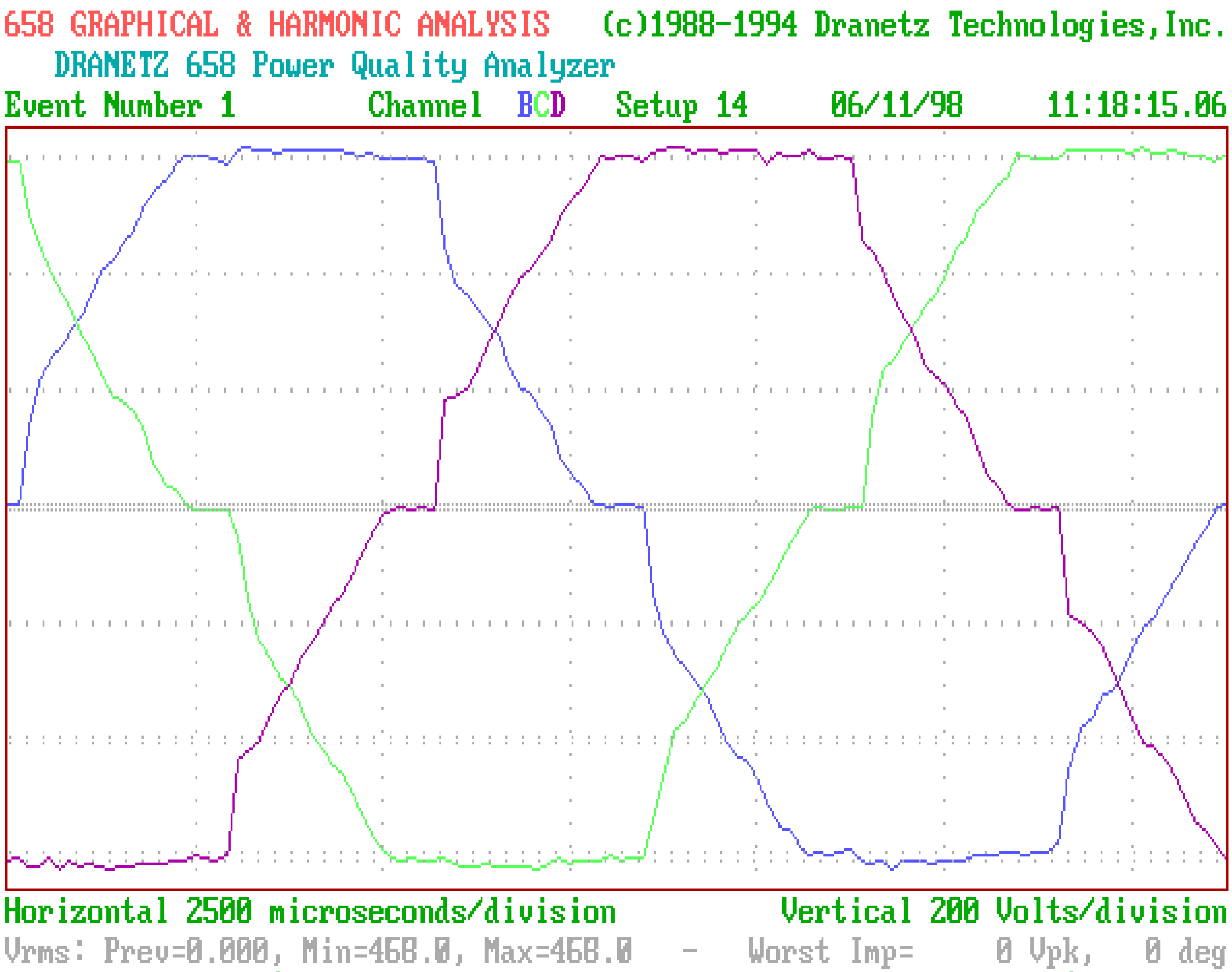
Root Cause of Problems with Other Equipment

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						

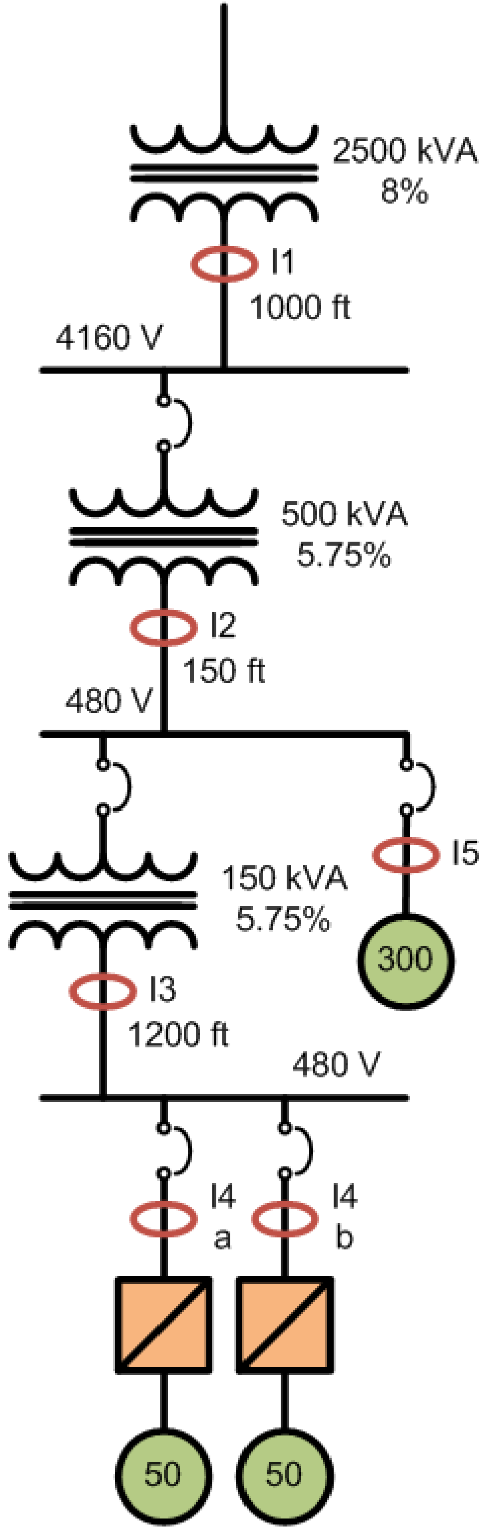
Where is the PCC?

For an Harmonic Study:

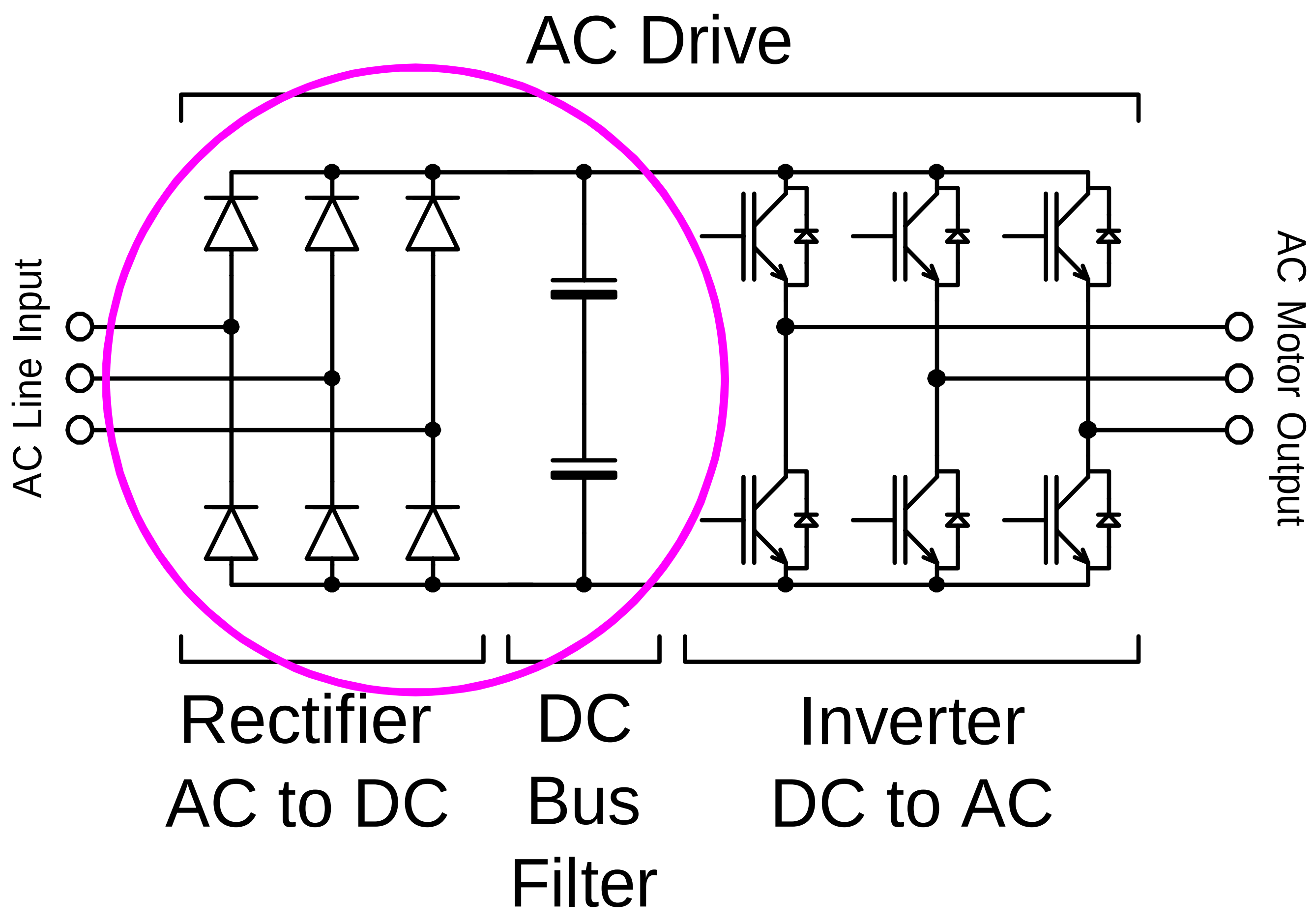
Need to calculate and measure the voltage and current magnitudes and distortion at each of the 6 locations (PCCs) noted.

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

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

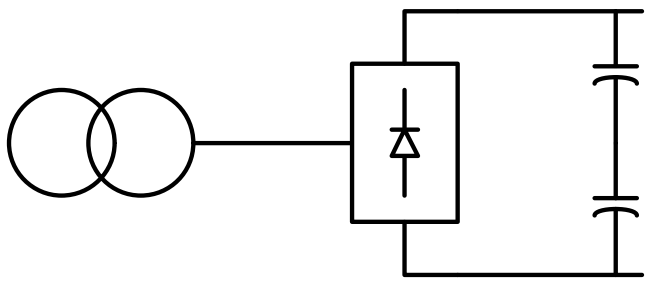


Basic AC Drive Topology
6-Pulse Rectifier

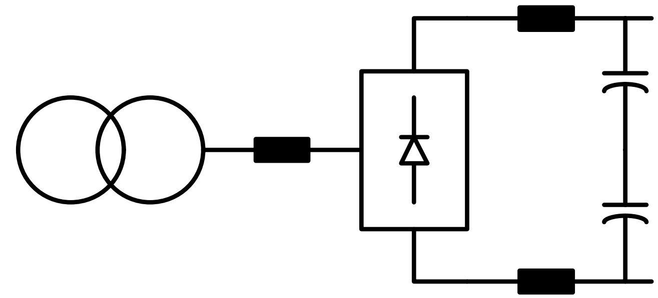


Line Current Harmonic Mitigation Methods

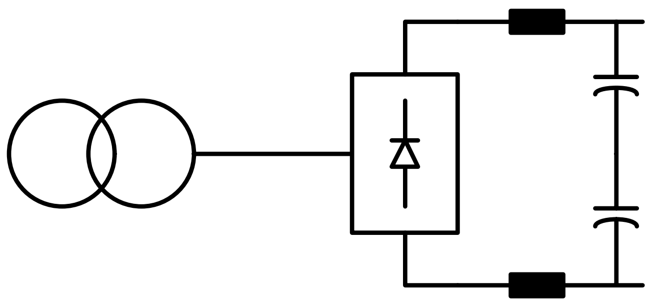
6-Pulse (120°/2 = 60°)



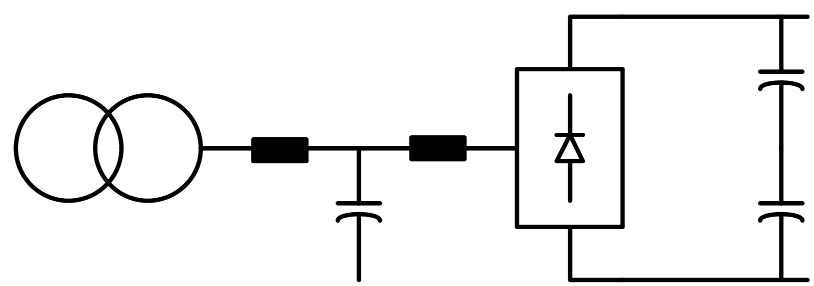
Basic Converter



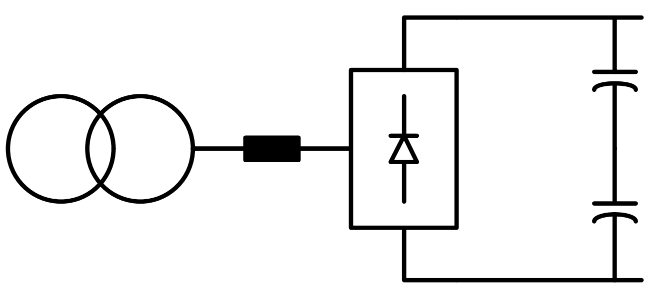
Link Choke and Reactor



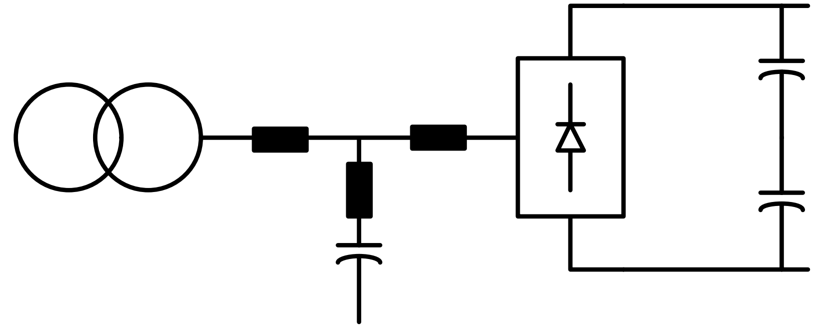
DC Link Chokes



Passive Harmonic Filter

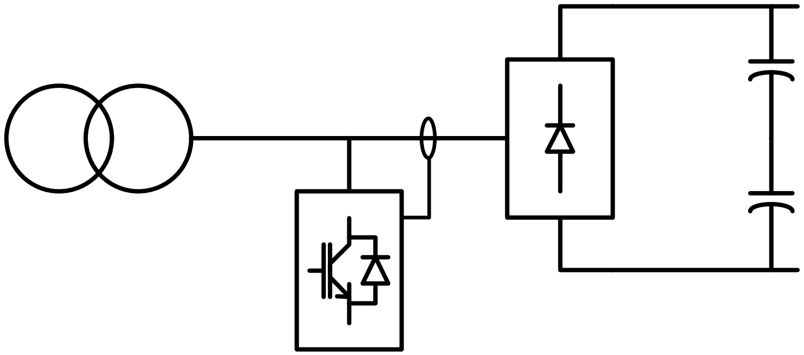


AC Line Reactor



Passive Notch Filter

Line Current Harmonic Mitigation Methods
6-Pulse

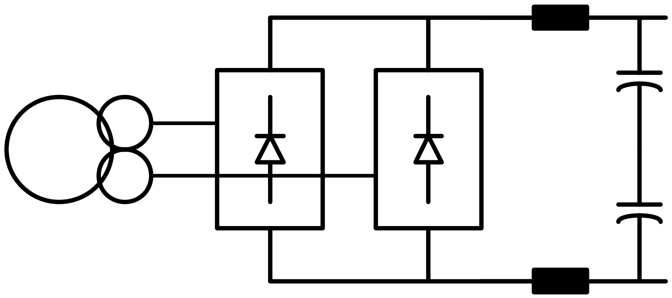


Active Harmonic Filter

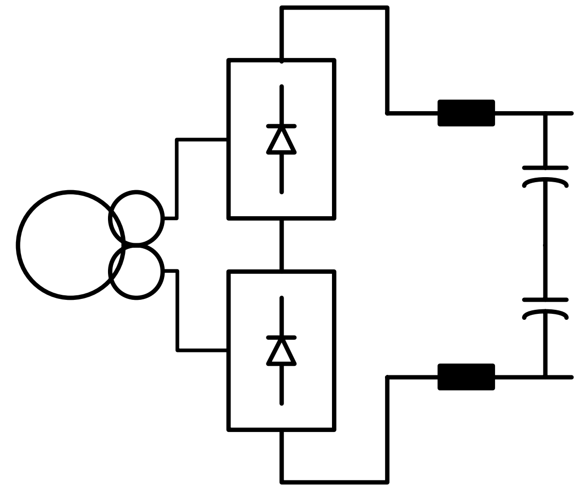
Line Current Harmonic Mitigation Methods

12-Pulse (30°)

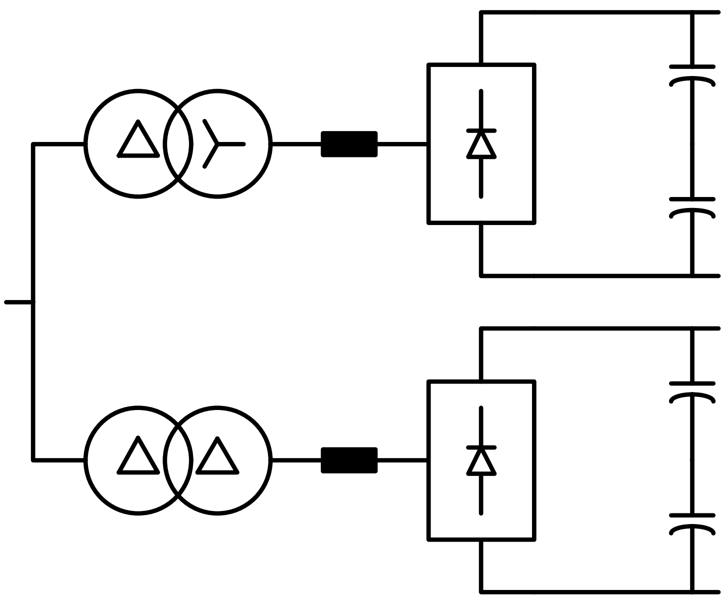
* Used in MV drives



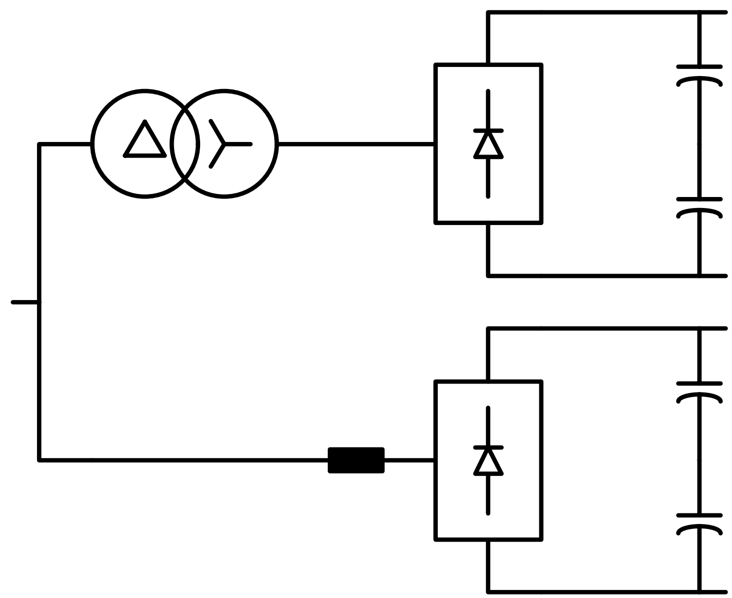
Parallel Bridges



*Series Bridges



Pseudo 12-Pulse

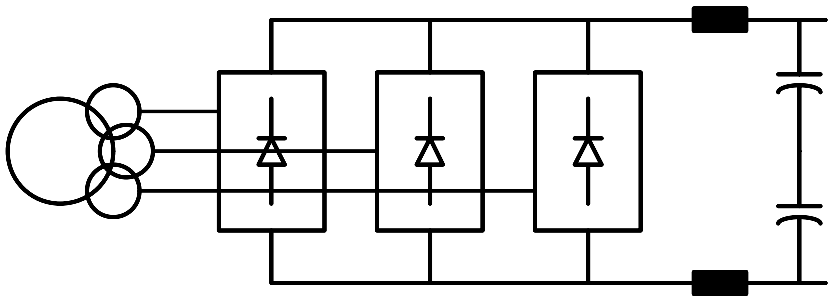


Poor-Man's 12-Pulse

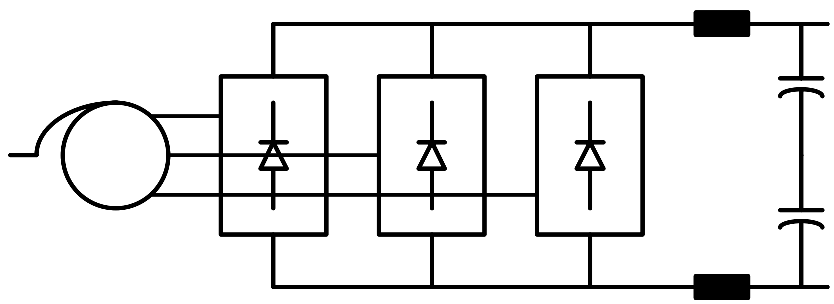
Line Current Harmonic Mitigation Methods

18-Pulse (20°)

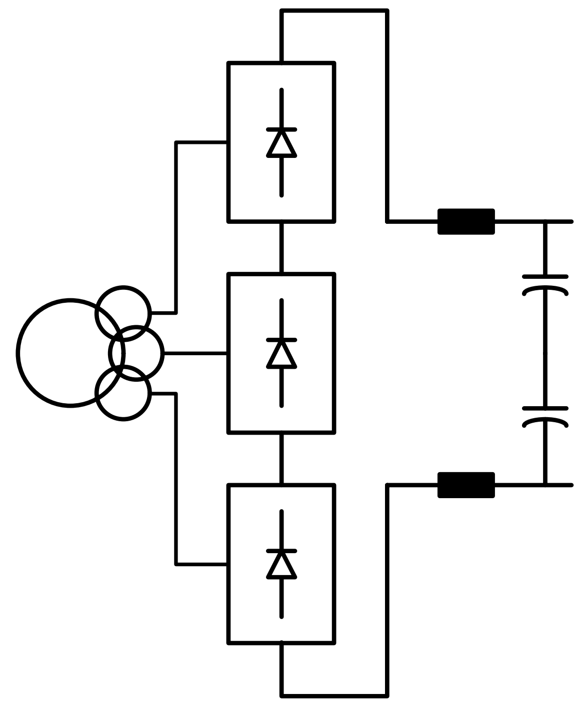
* Used in MV drives



Parallel Bridges



Auto-Transformer with Parallel Bridges

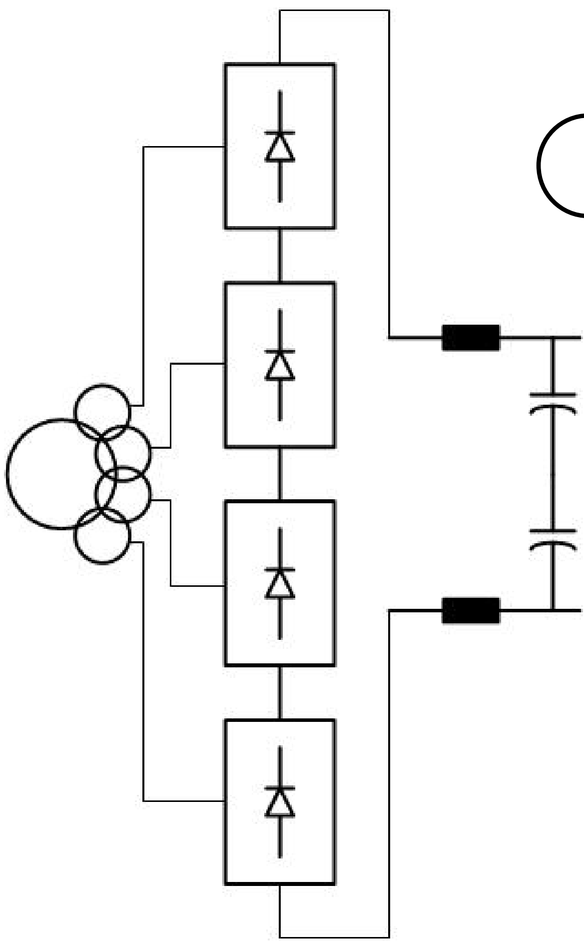


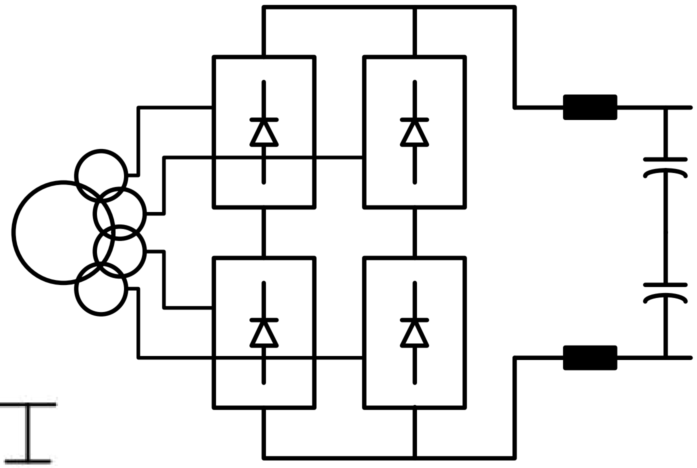
*Series Bridges

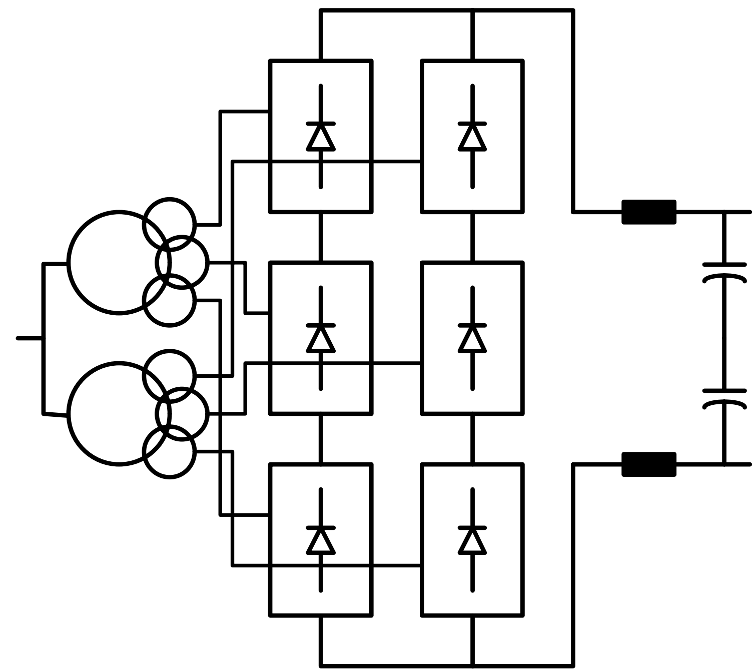
Line Current Harmonic Mitigation Methods

24-Pulse (15°), 36-Pulse (10°)

* Used in MV drives



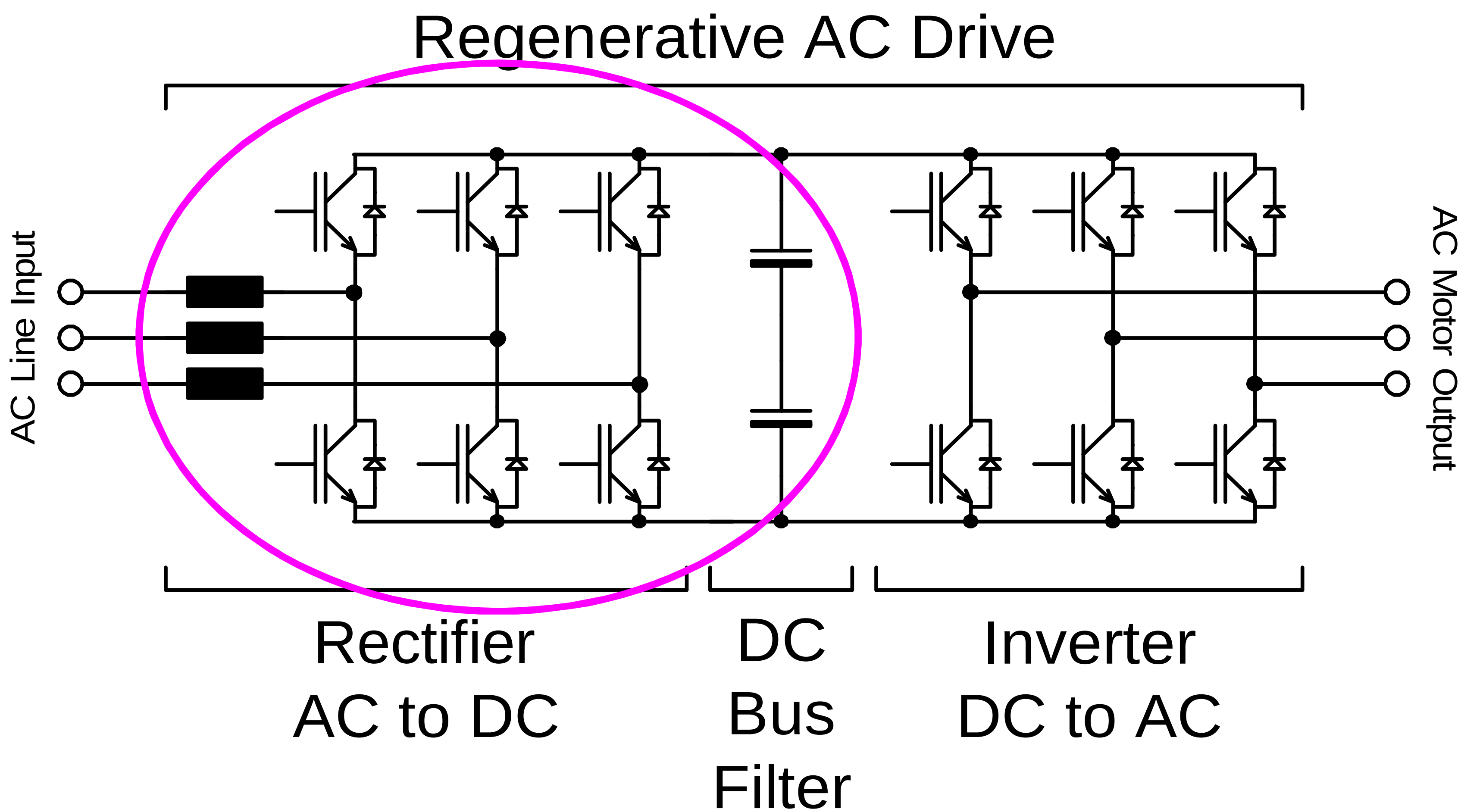




*Series / Parallel Bridges, 36P

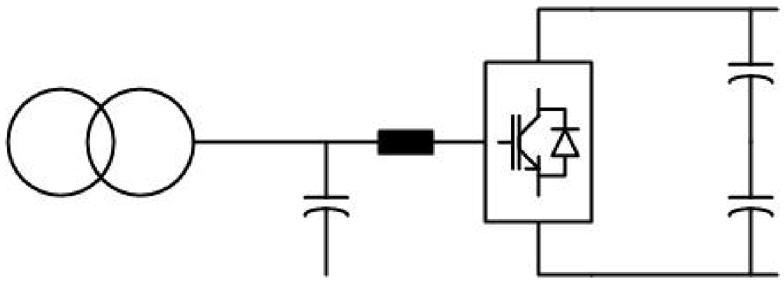
*Series or Series / Parallel Bridges, 24P

Line Current Harmonic Mitigation Methods
Active Front End (AFE)

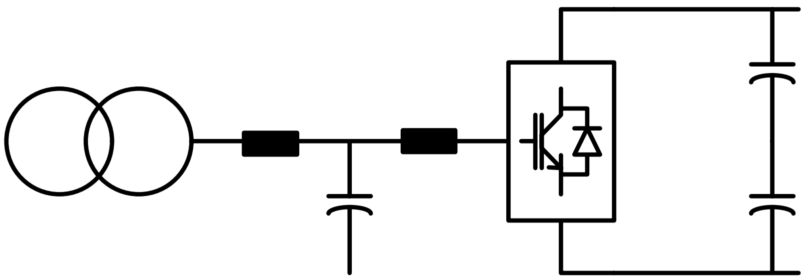


Line Current Harmonic Mitigation Methods
Active Front End (AFE)

* Used in MV drives



AFE with Isolation Transformer



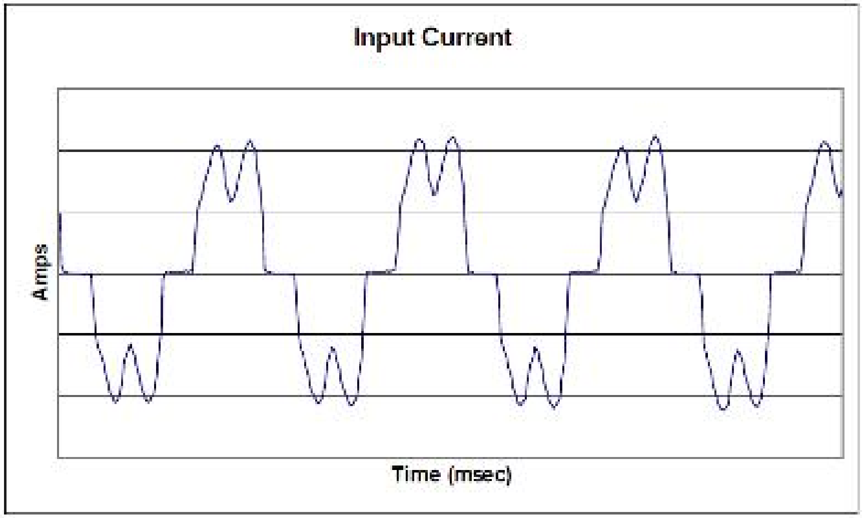
*AFE with LCL Filter

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

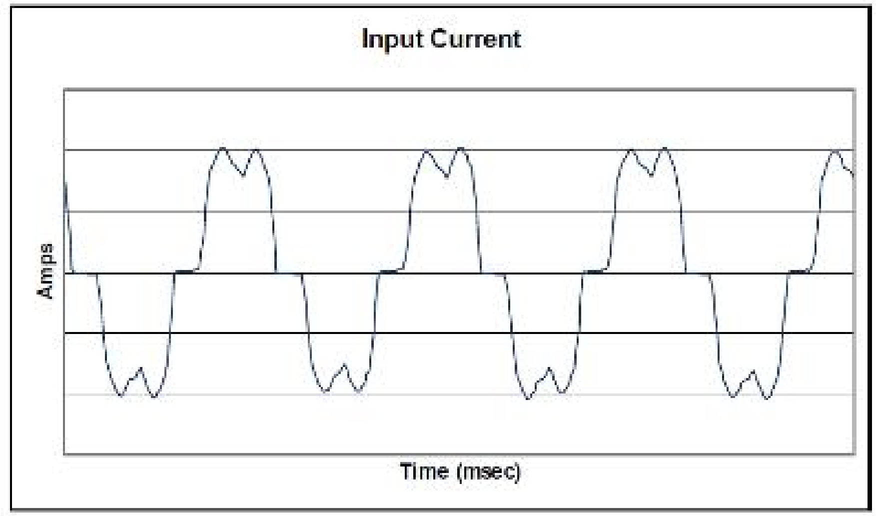
(more on this later)

The Goal of Harmonic Mitigation

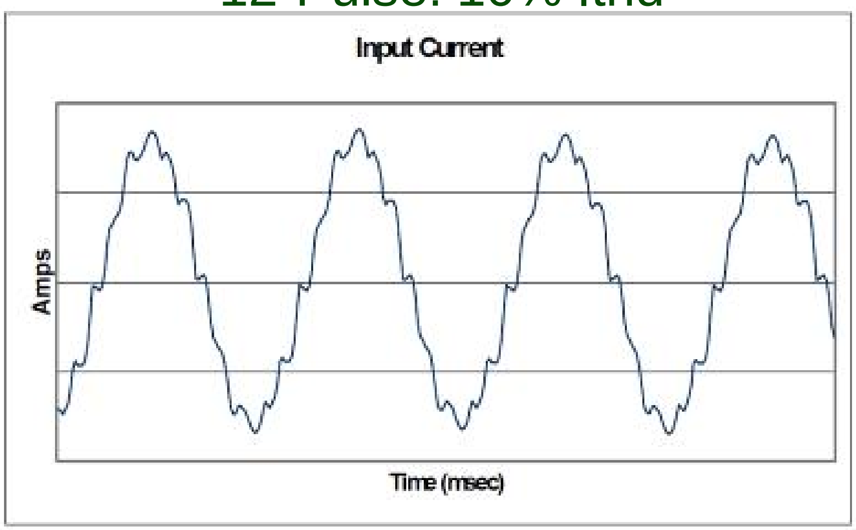
6-Pulse: 32% Ithd



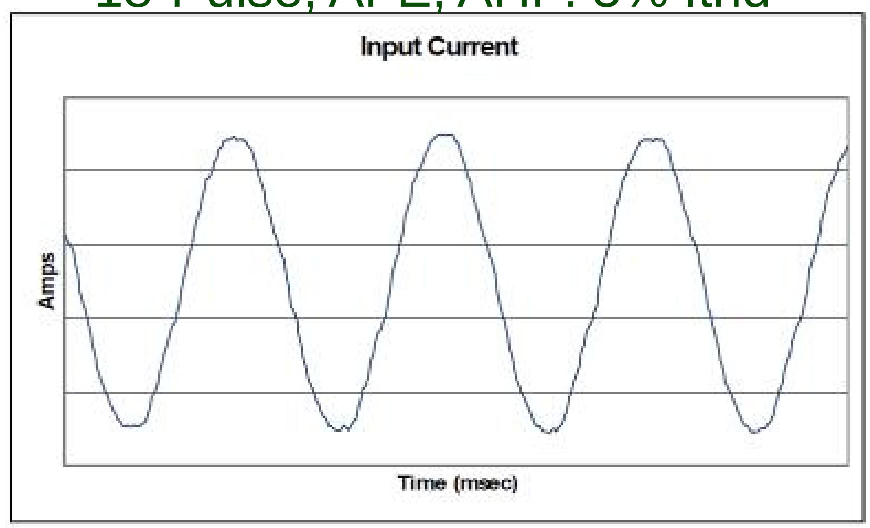
6-Pulse with 5% Line Reactor: 25% Ithd



12-Pulse: 10% Ithd



18-Pulse, AFE, AHF: 5% Ithd



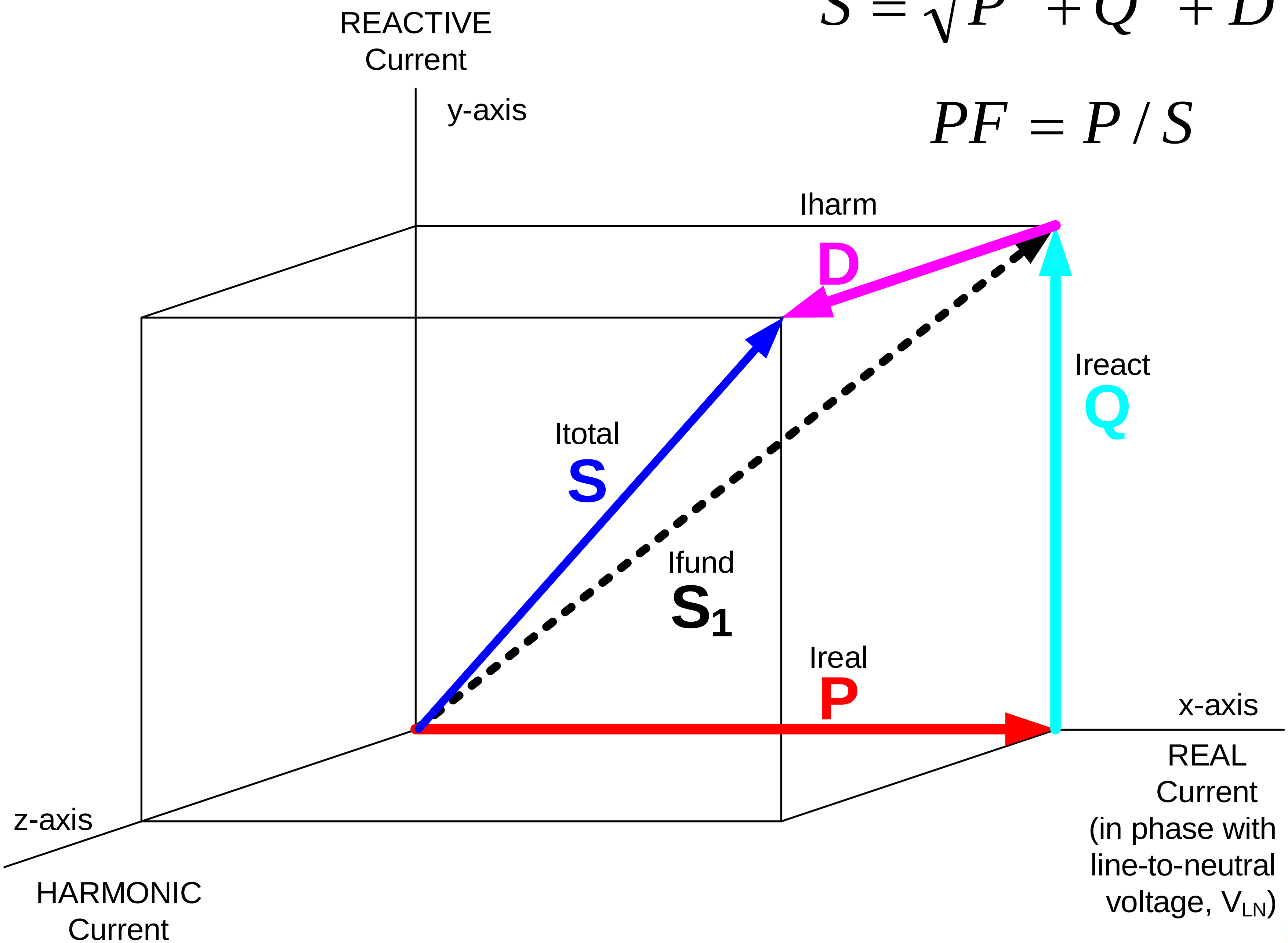
Line Current Harmonic Mitigation Methods
Harmonic Content

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

Power Cube

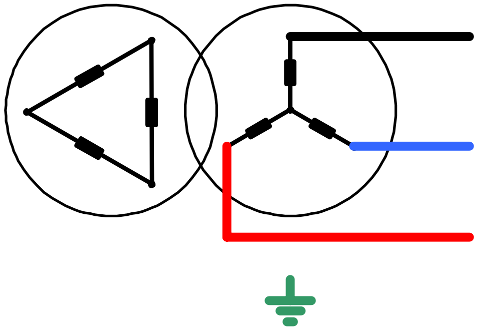
$$S = \sqrt{P^2 + Q^2 + D^2}$$

$$PF = P / S$$

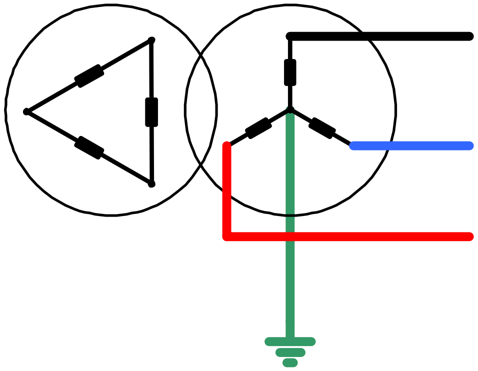


Grounding Configurations

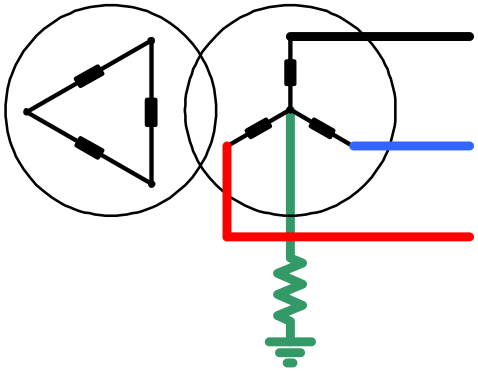
- **Floating** secondary



- 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.

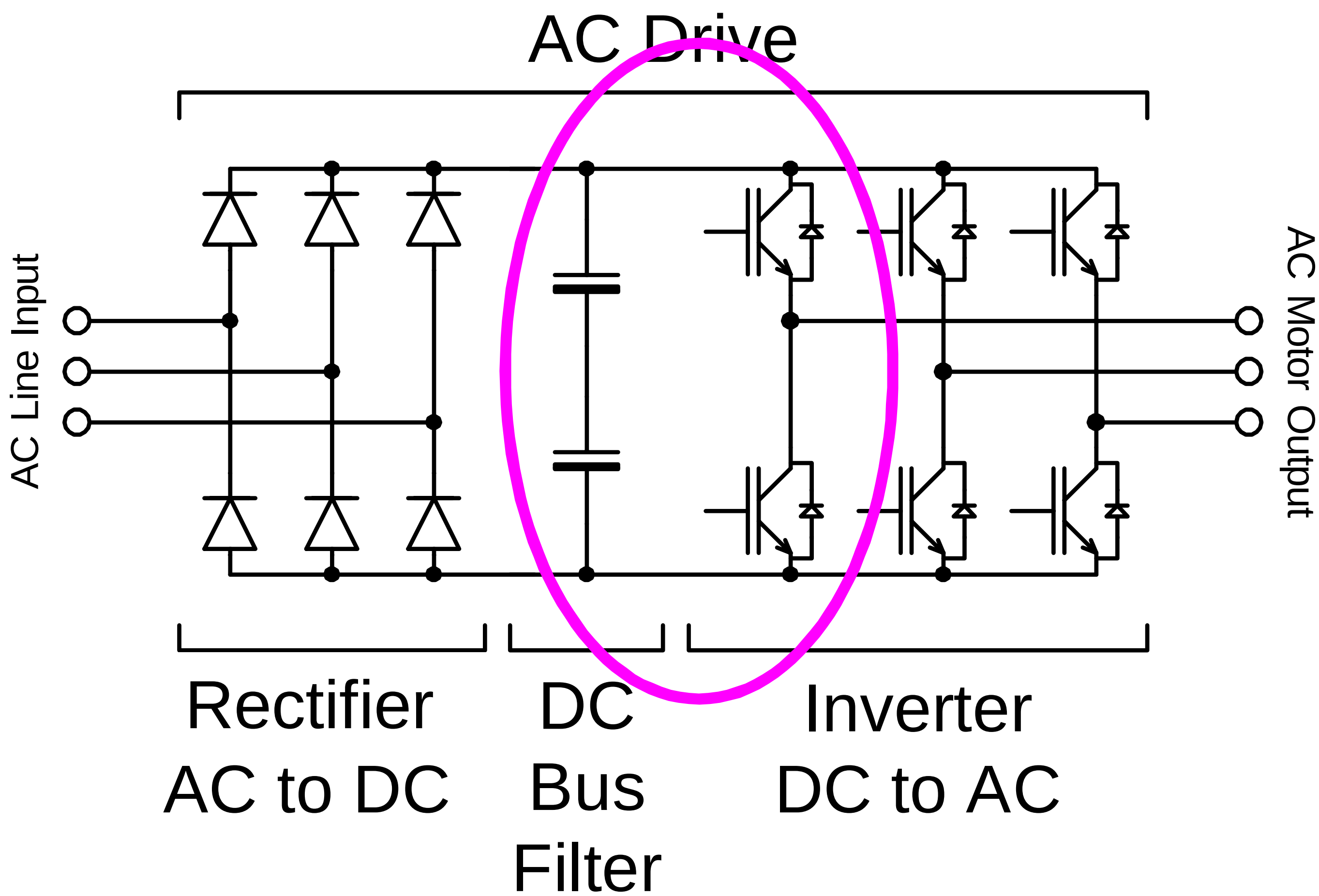
NEMA Designs C and D motors and motors larger than 5000 horsepower and voltages greater than 7200 volts are excluded from this section and the manufacturer should be consulted regarding their application.

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

Topologies

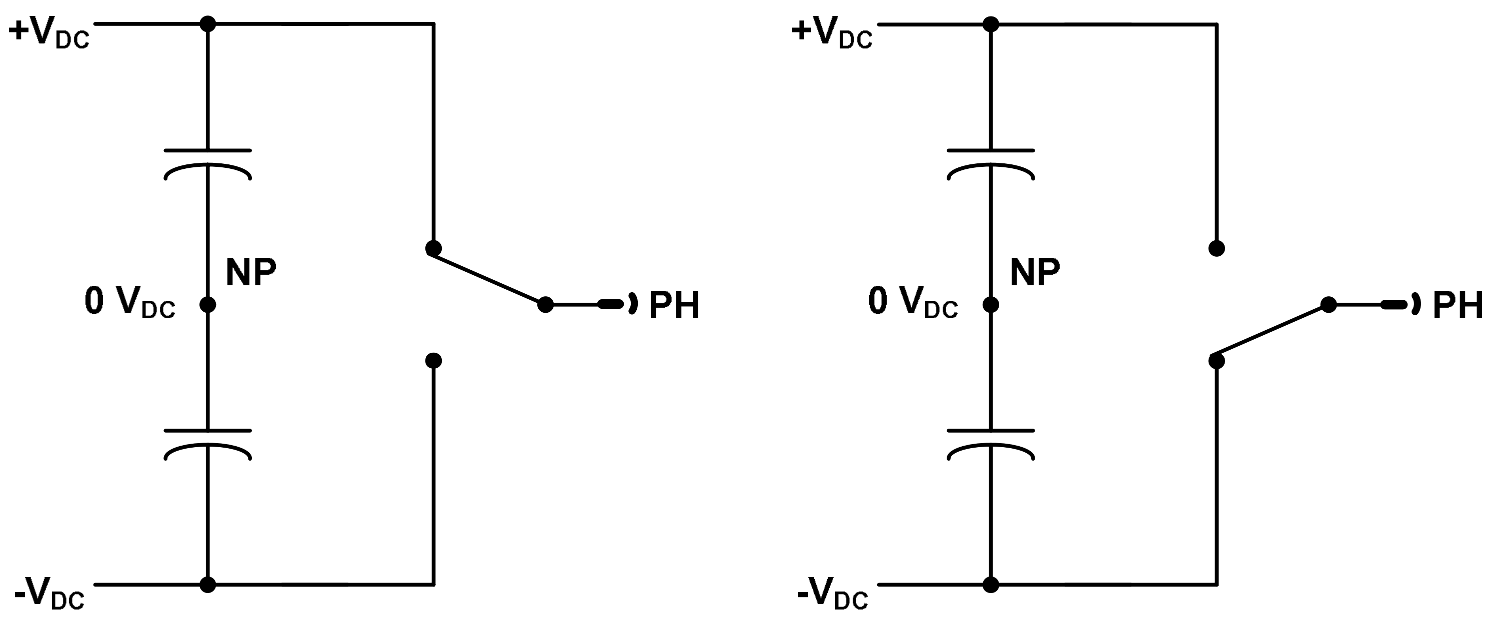
- Reflected Wave Reduction
  - 2-Level
  - 3-Level
  - 5-Level
  - Cascaded H-Bridge
- CSI, LCI
- CCV
- Matrix

Basic AC Drive Topology
2-Level Inverter Topology



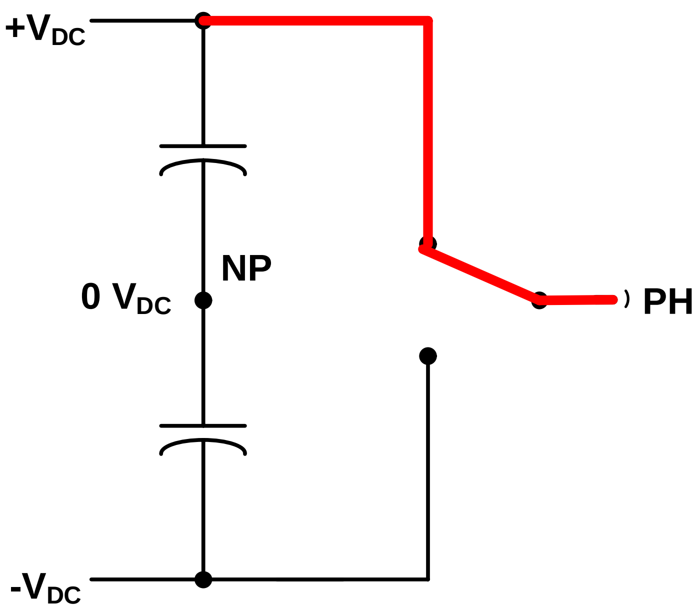
The n-level VSI topology
2-Level

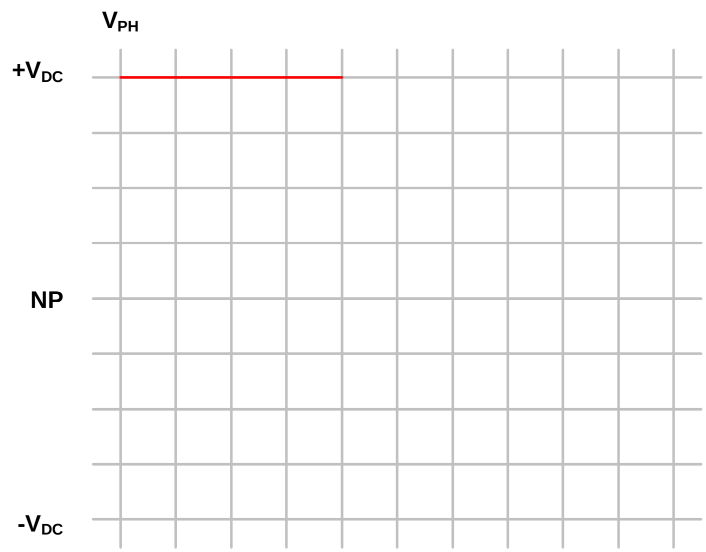
- 2-Level VSI
- Phase output voltages



The n-level VSI topology
2-Level

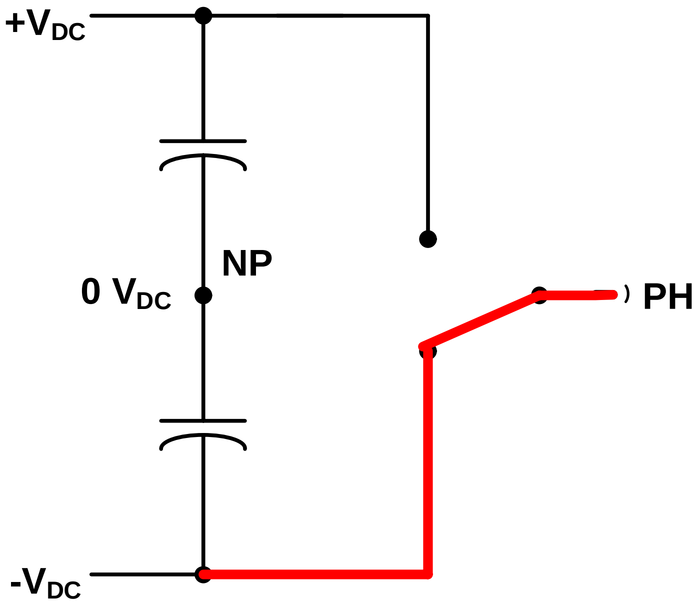
- 2-Level VSI
- Phase output voltages

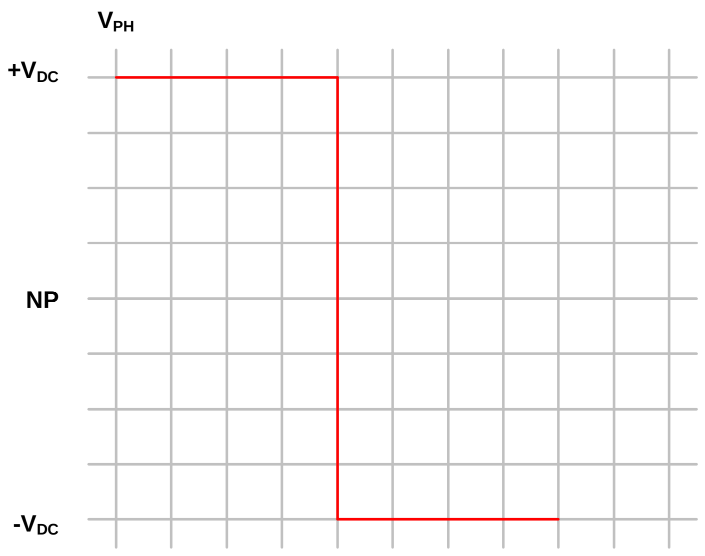




The n-level VSI topology
2-Level

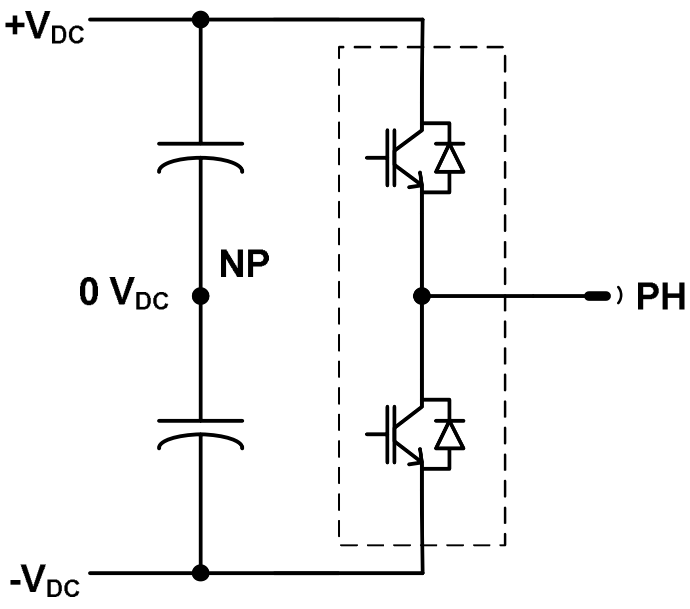
- 2-Level VSI
- Phase output voltages





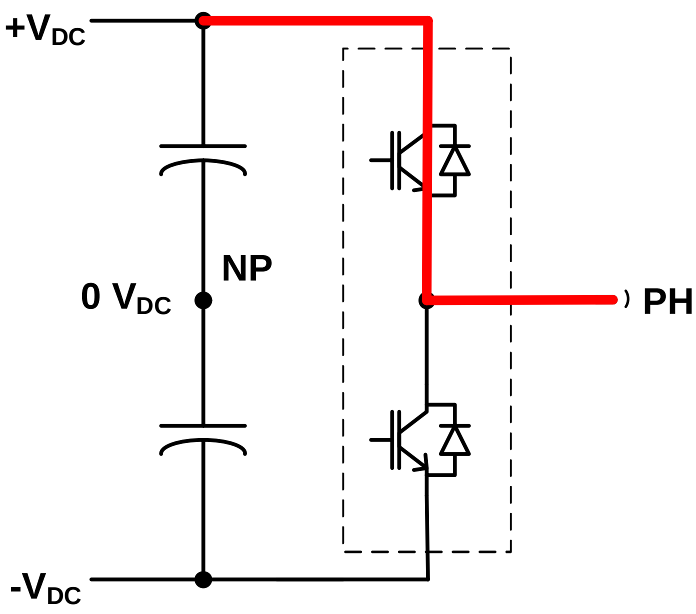
The n-level VSI topology
2-Level

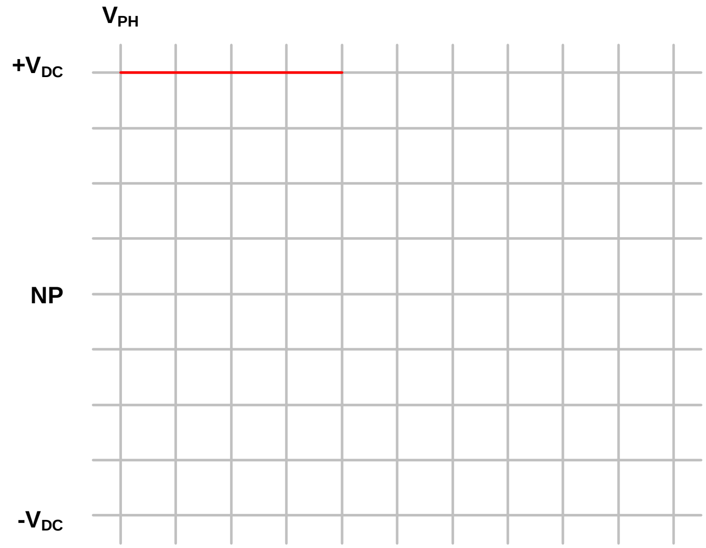
- 2-Level VSI
- Phase output voltages



The n-level VSI topology
2-Level

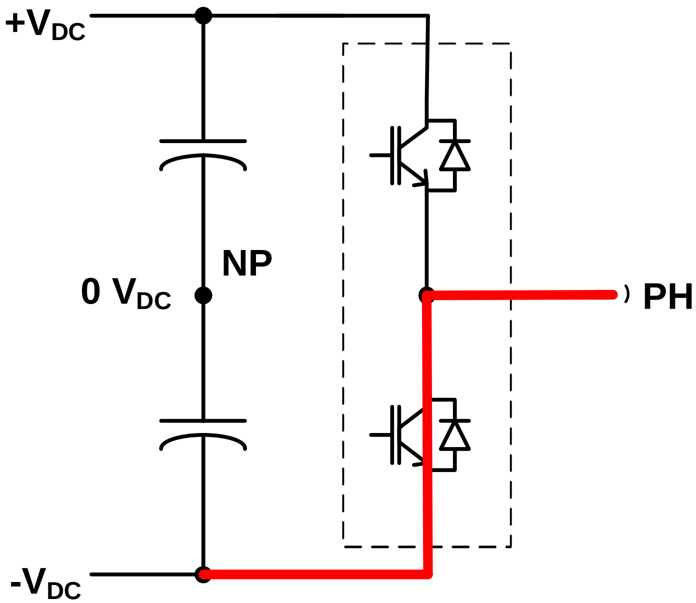
- 2-Level VSI
- Phase output voltages

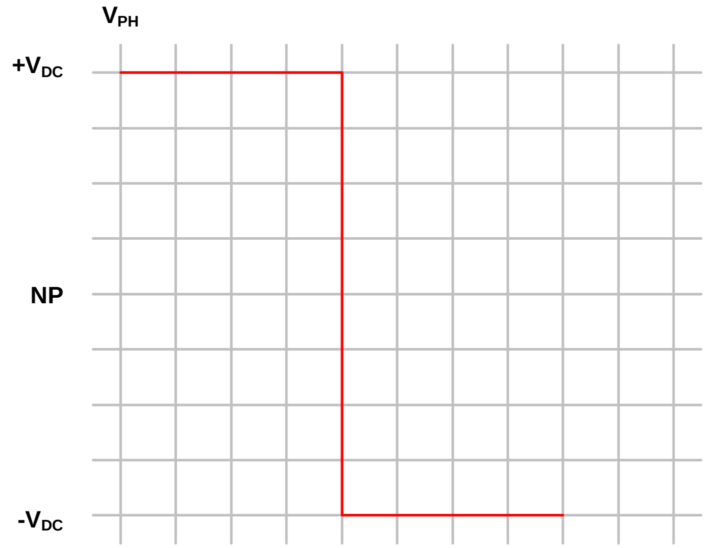




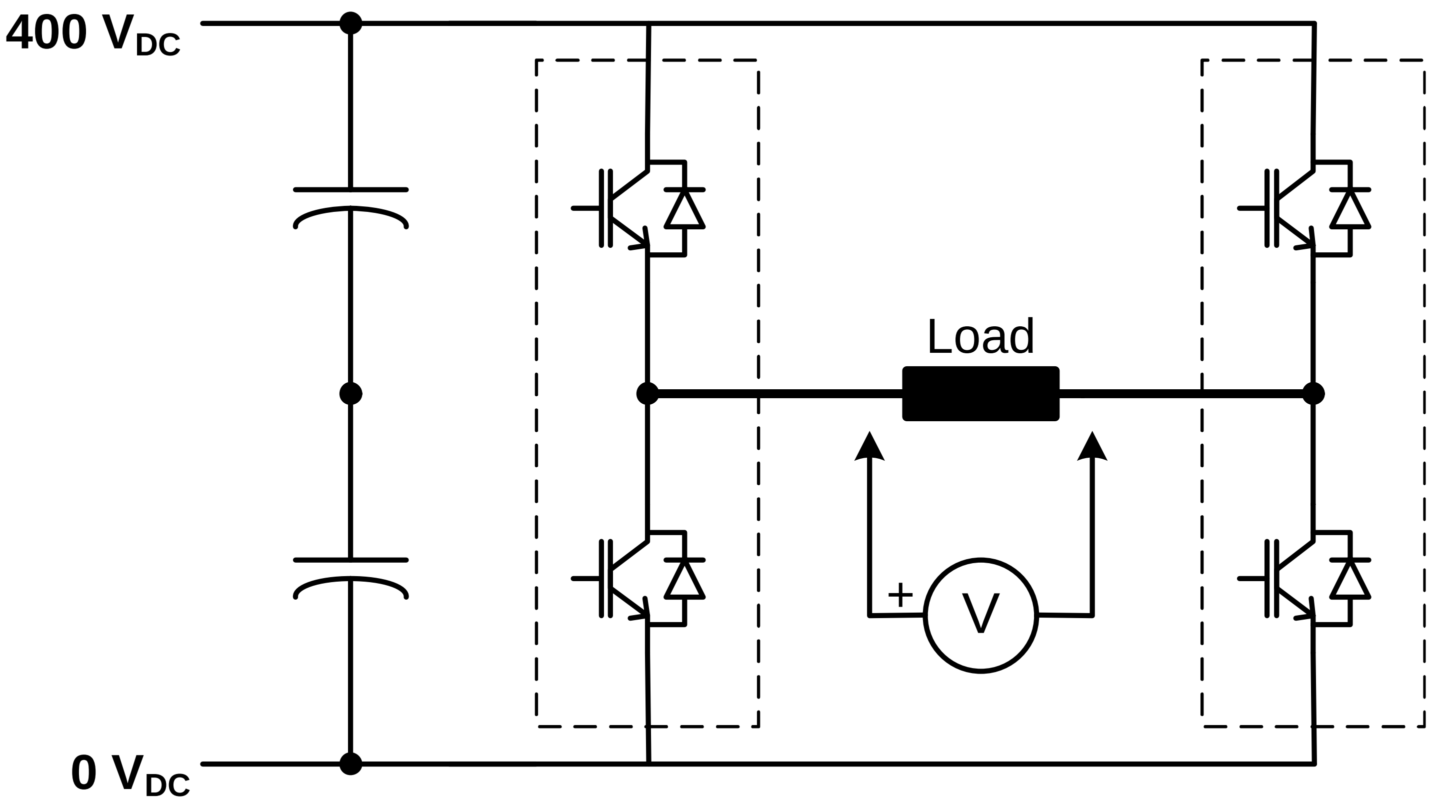
The n-level VSI topology
2-Level

- 2-Level VSI
- Phase output voltages

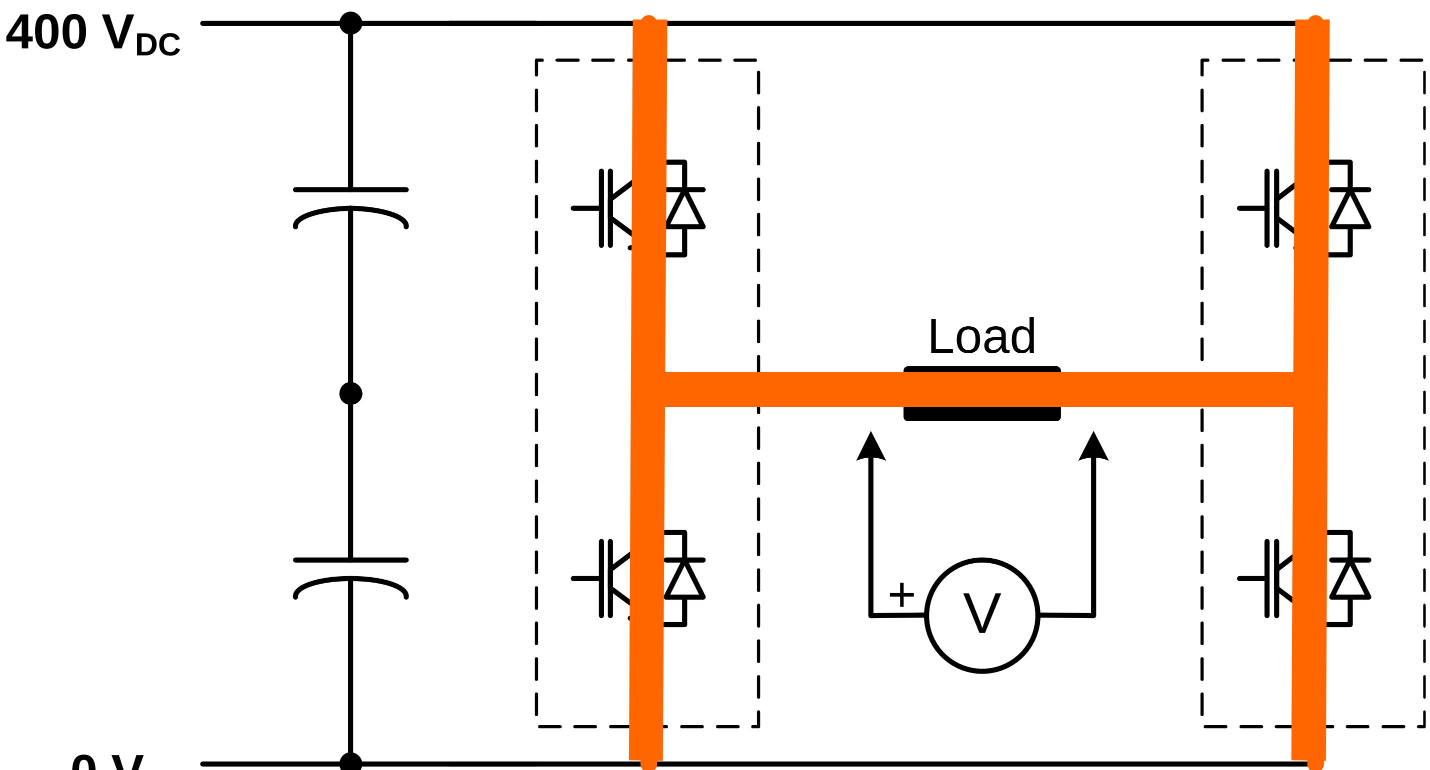




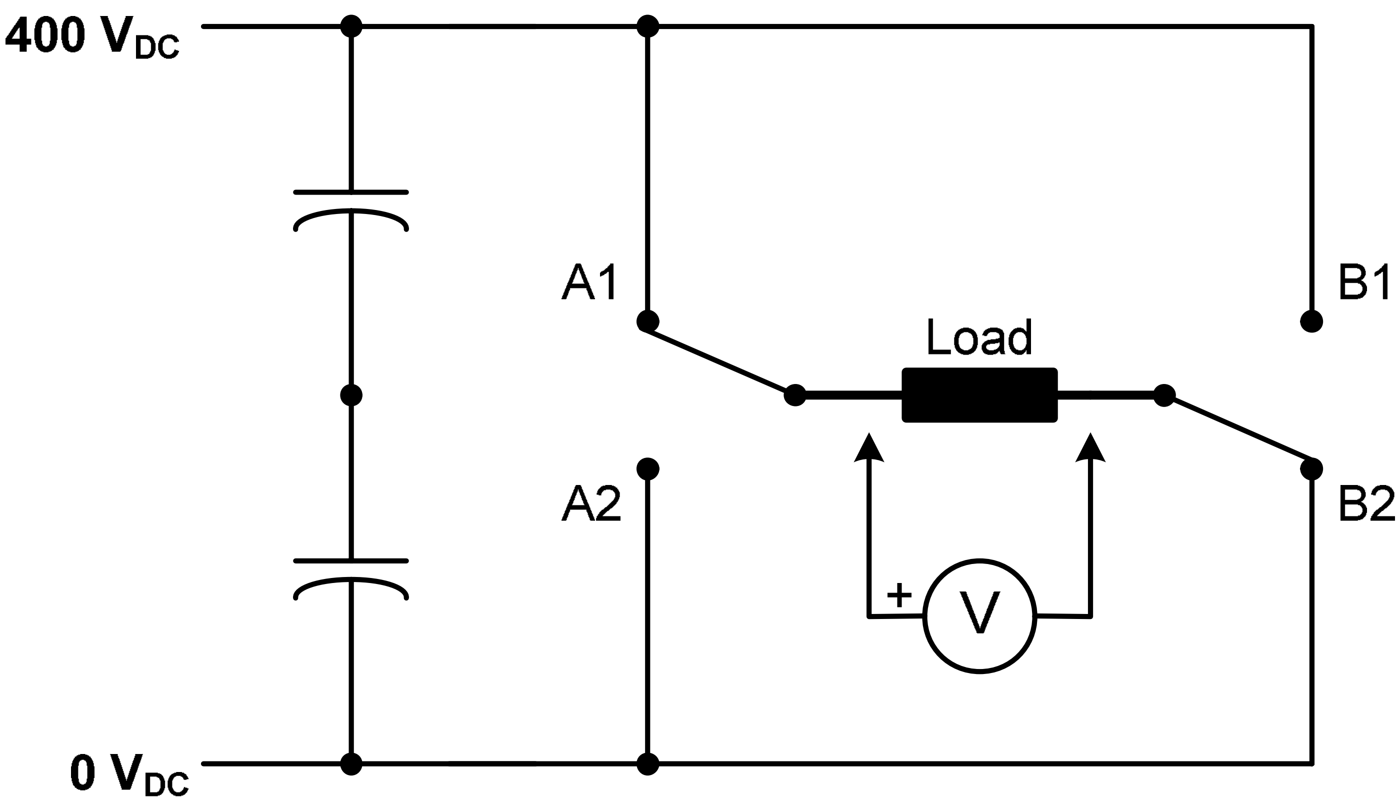
The n-level VSI topology
H-Bridge



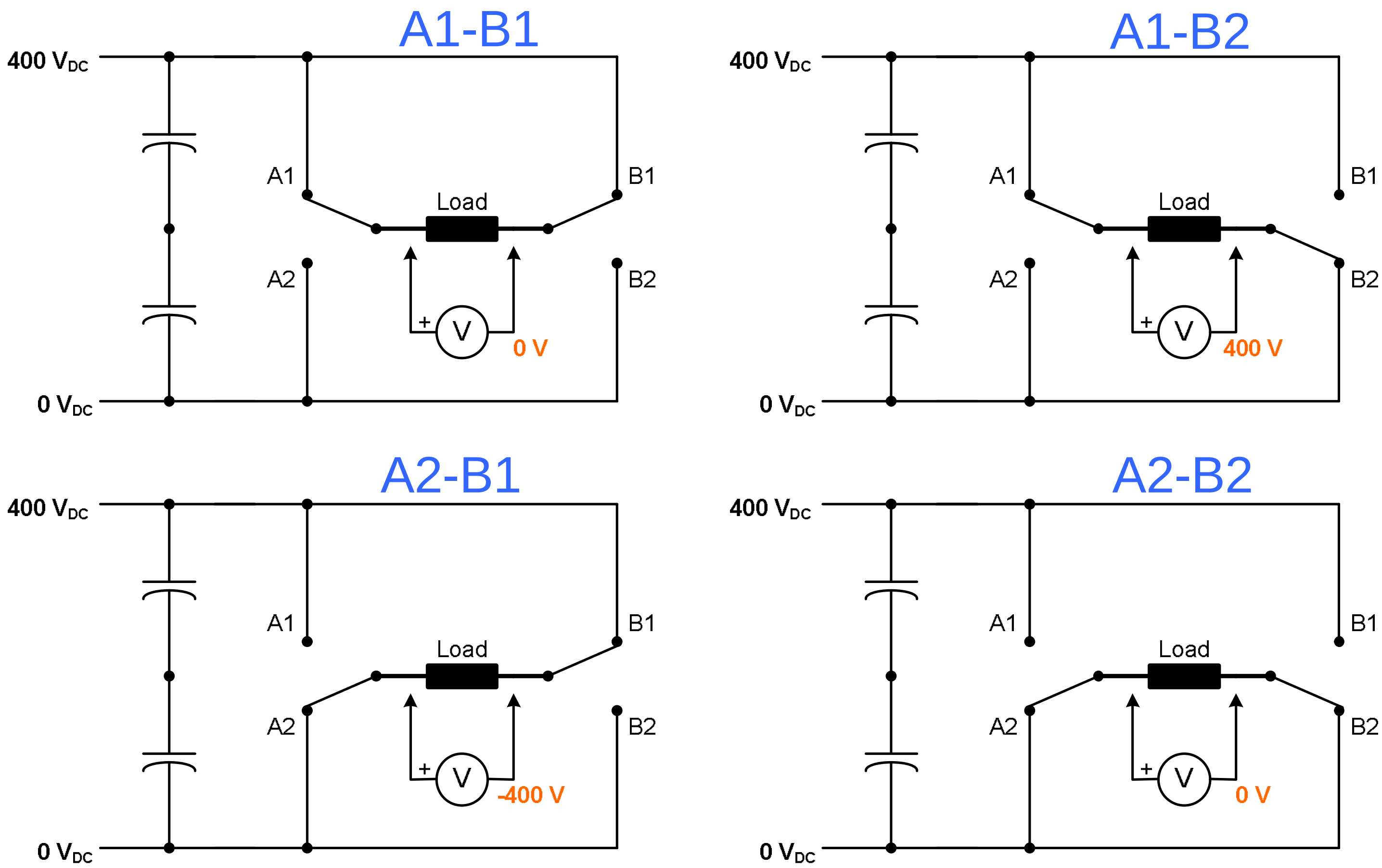
The n-level VSI topology
H-Bridge



The n-level VSI topology
H-Bridge



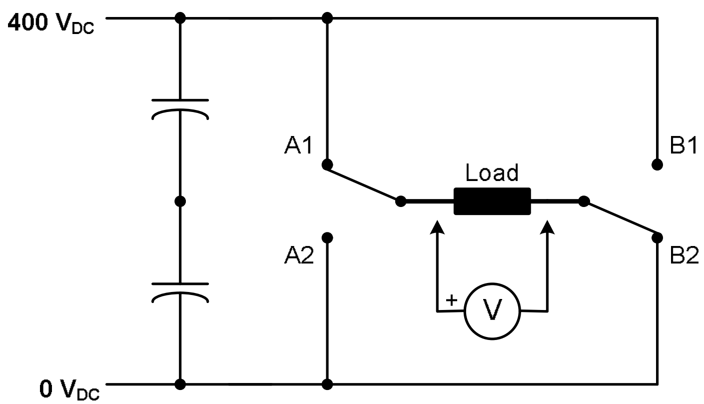
The n-level VSI topology
H-Bridge

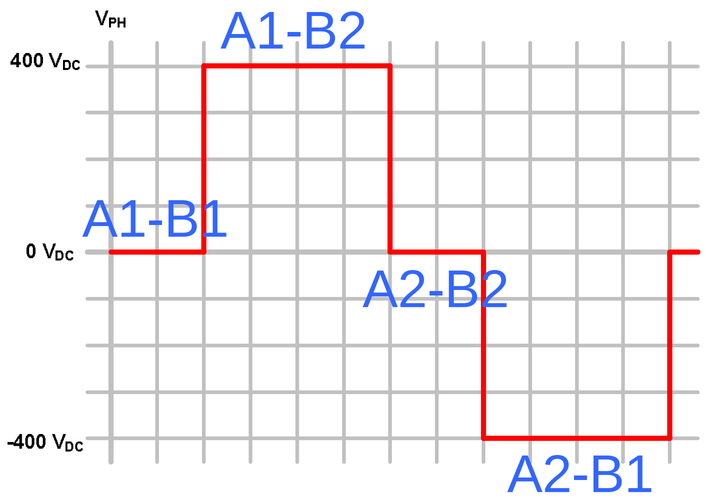


The n-level VSI topology
H-Bridge

- 2-Level VSI
- Phase output voltages

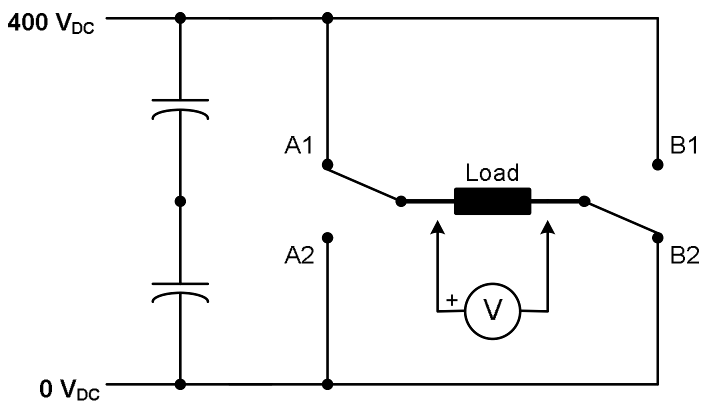
	B1	B2
A1	0	400
A2	-400	0





The n-level VSI topology
H-Bridge

- 2-Level VSI
- Phase output voltages



	B1	B2
A1	0	400
A2	-400	0

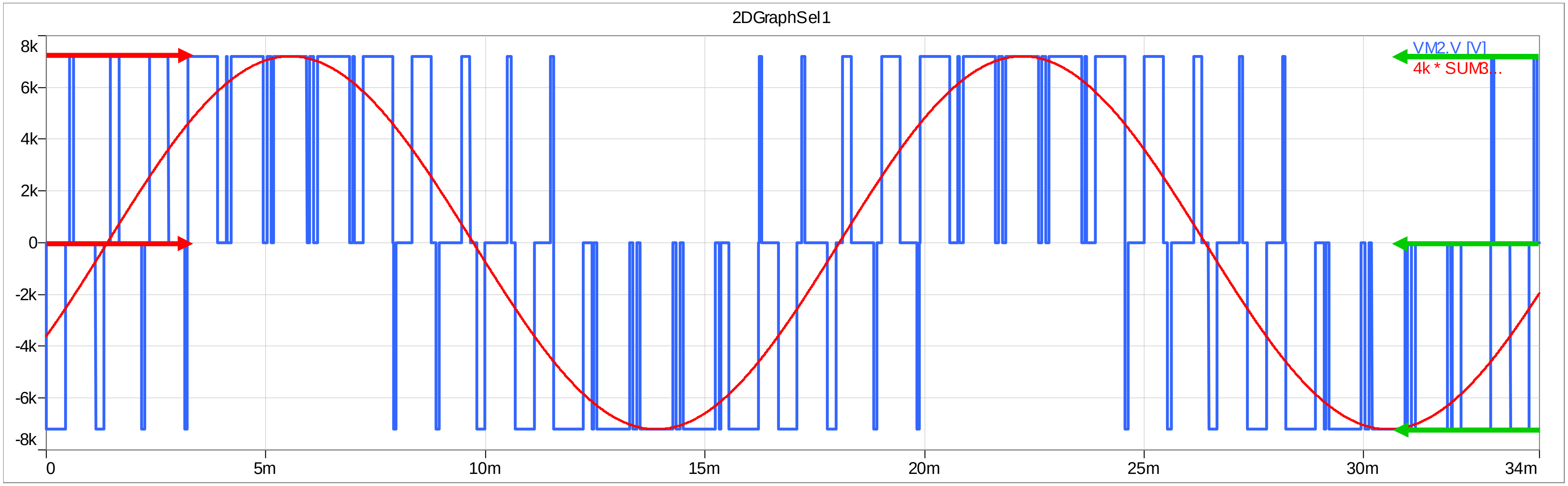
Number of Levels, n

2

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

3

2-Level Waveform, Line-to-Line

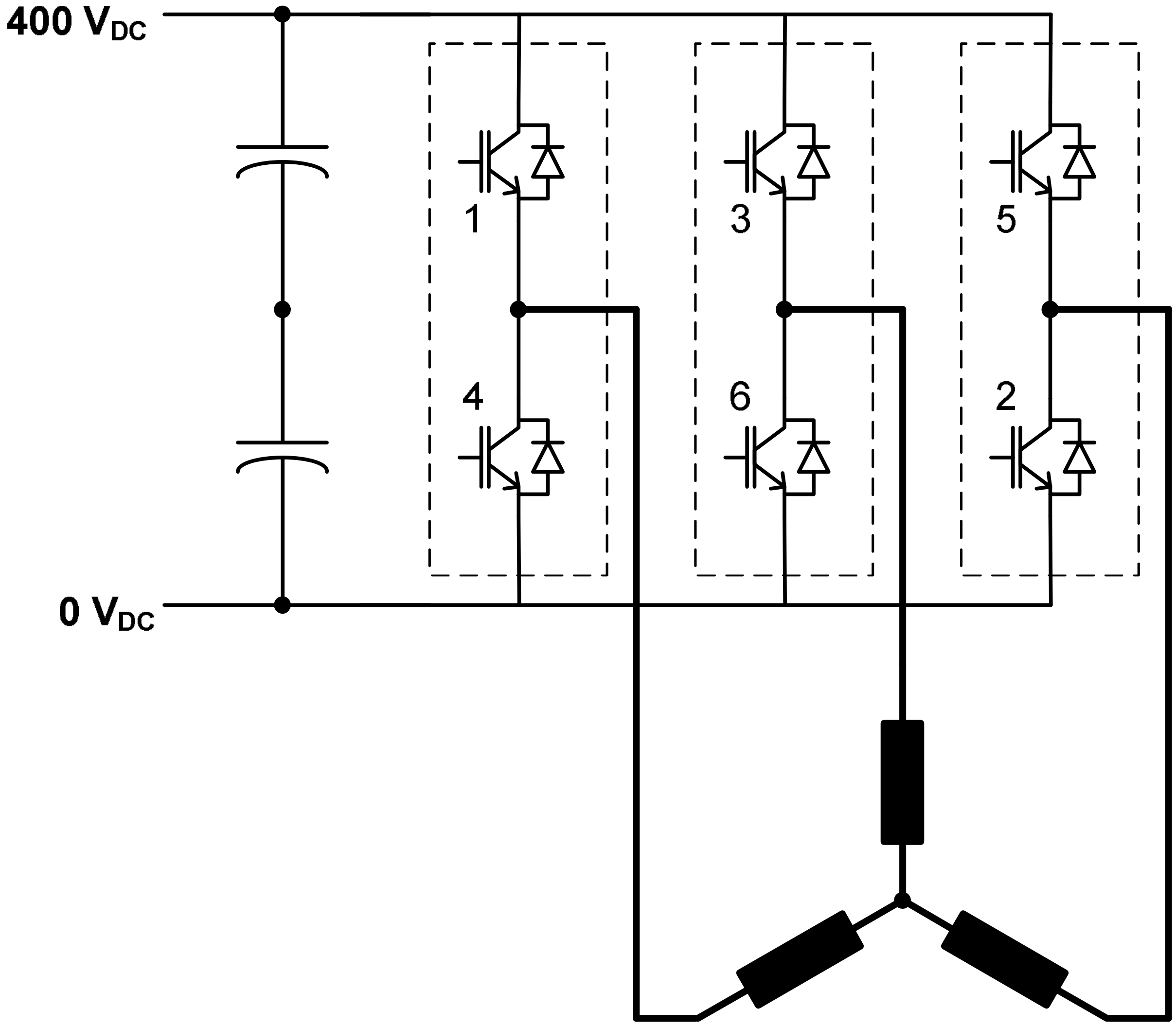


2-Levels

3-Steps

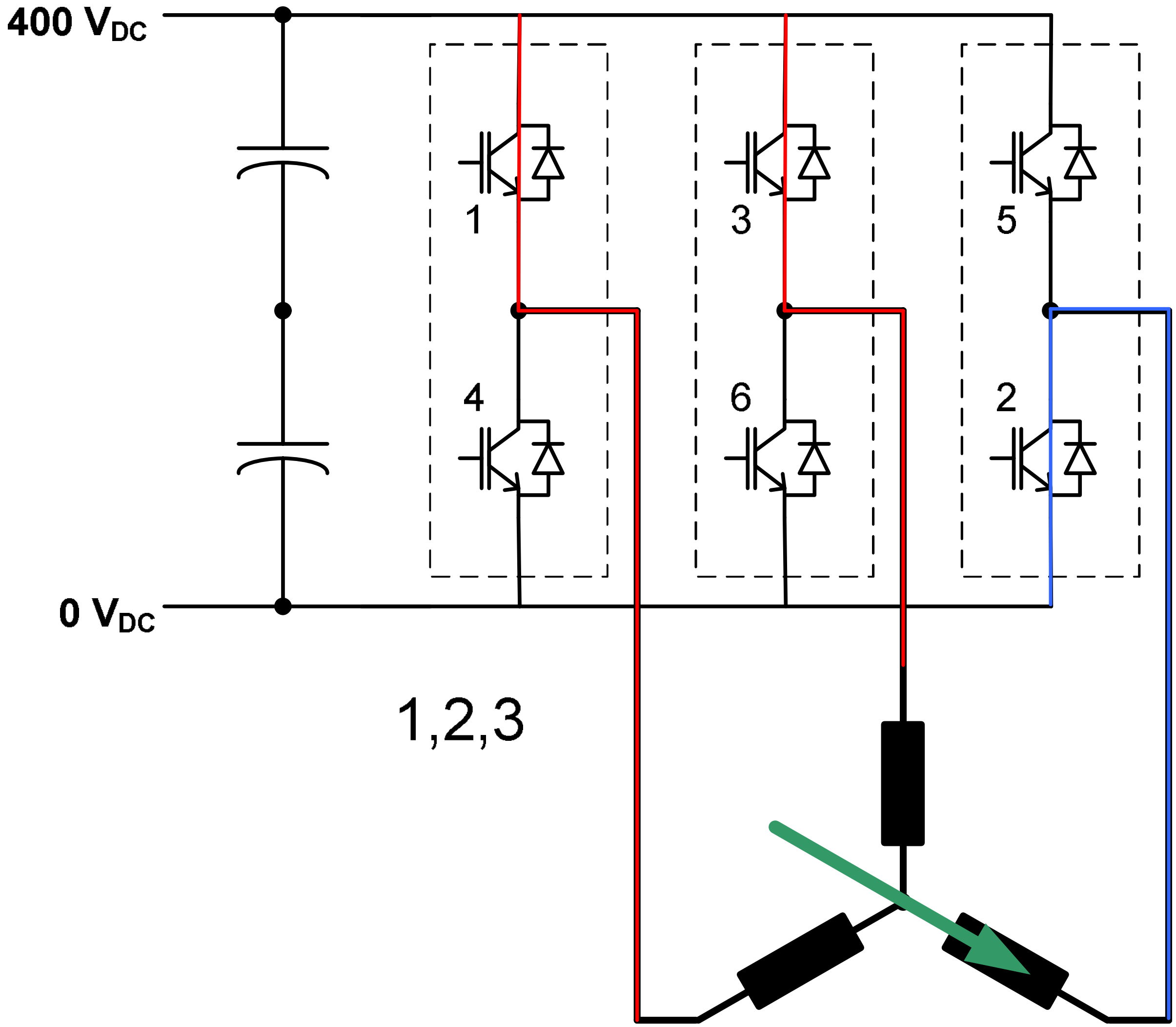
Basic Inverter
2-Level

3 Phase Bridge Configuration



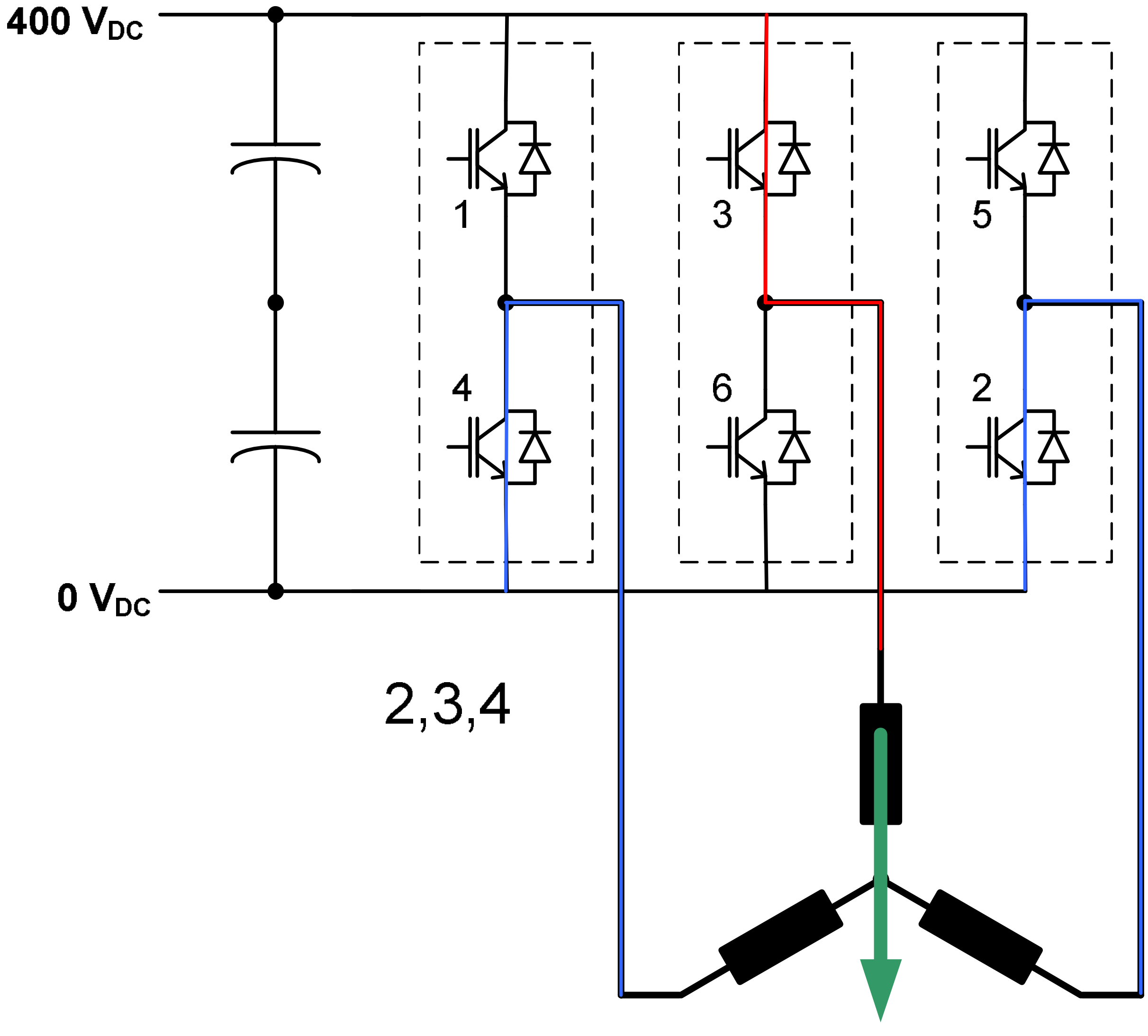
Basic Inverter
2-Level

3 Phase Bridge Configuration



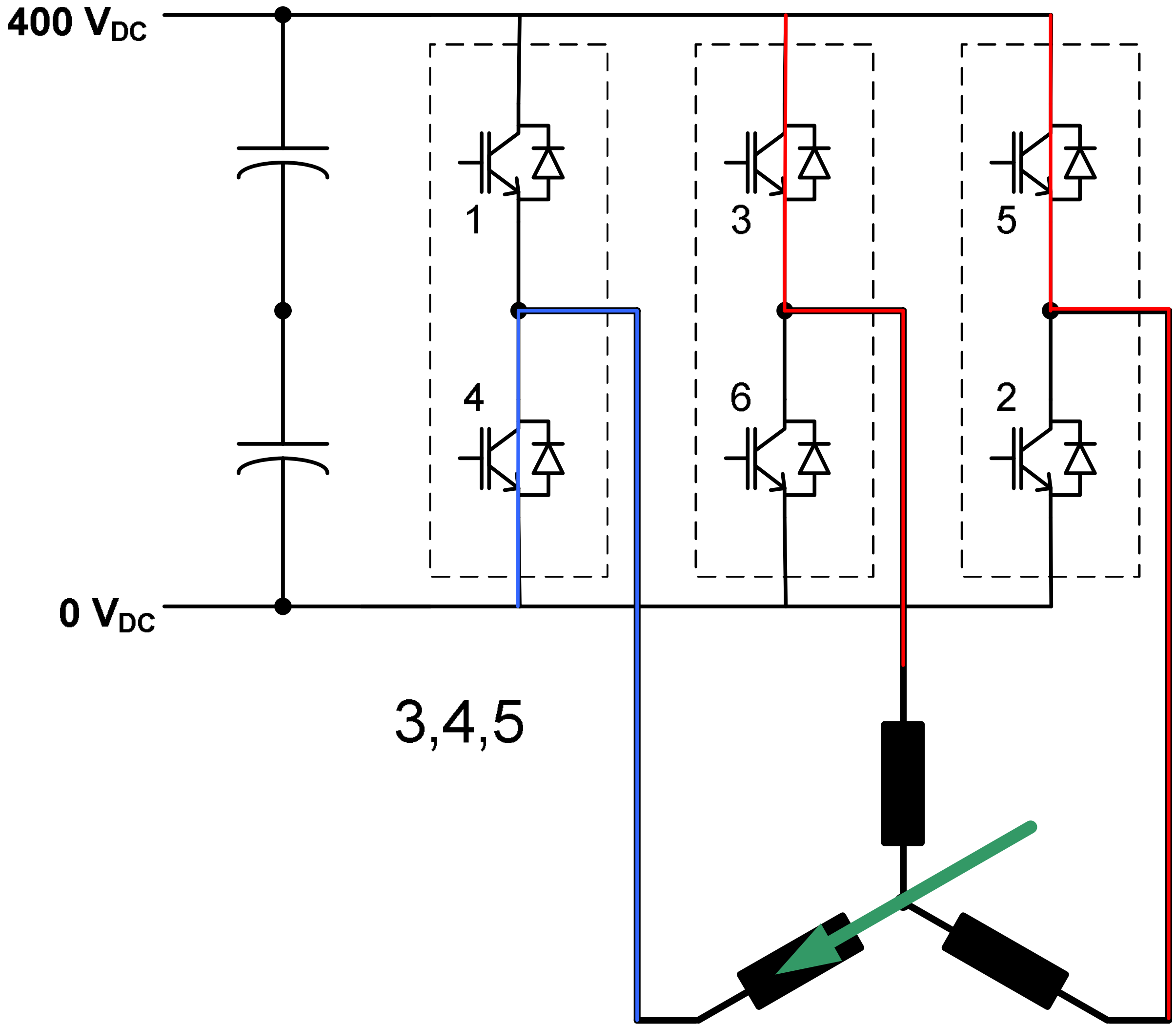
Basic Inverter
2-Level

3 Phase Bridge Configuration



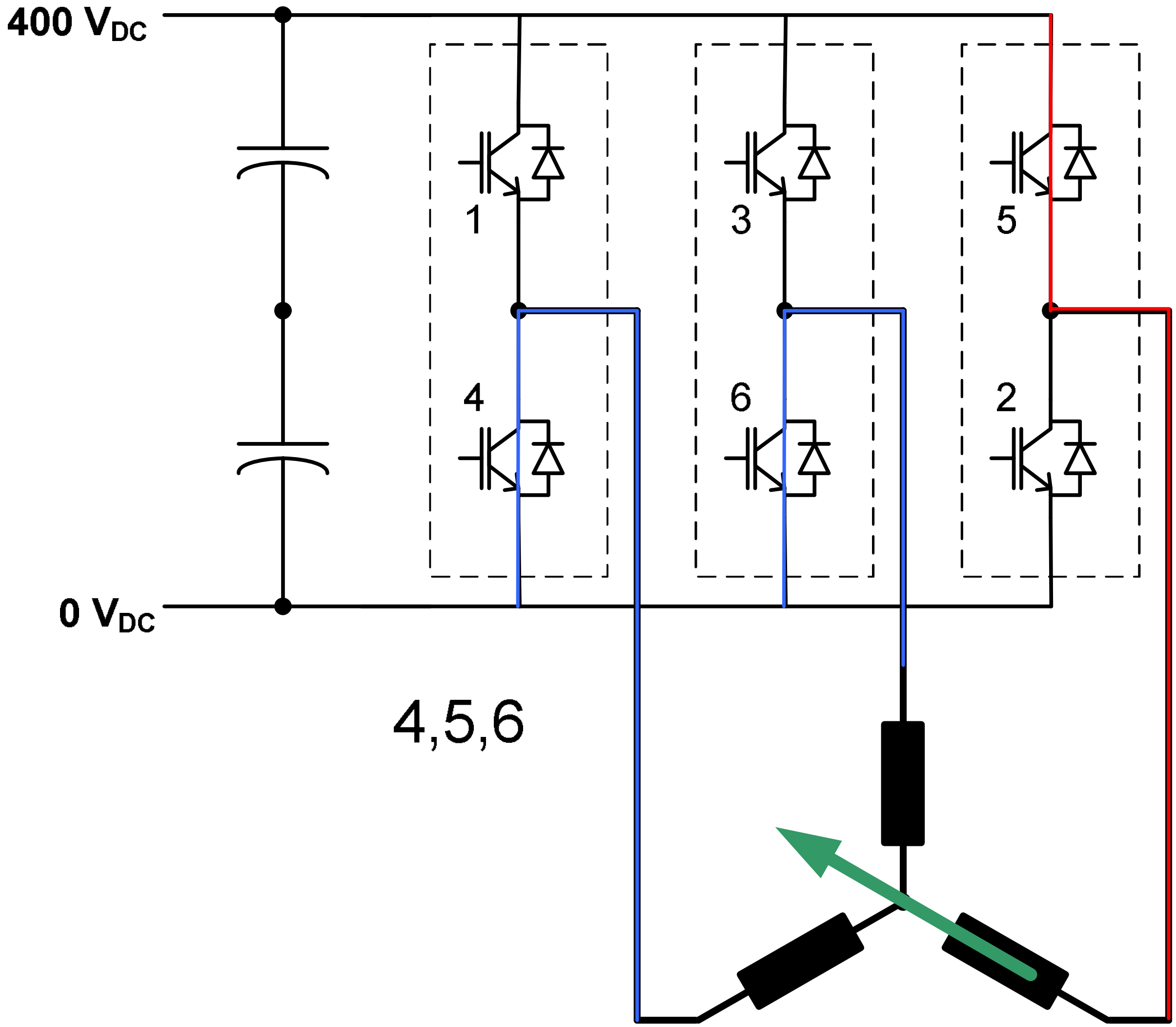
Basic Inverter
2-Level

3 Phase Bridge Configuration



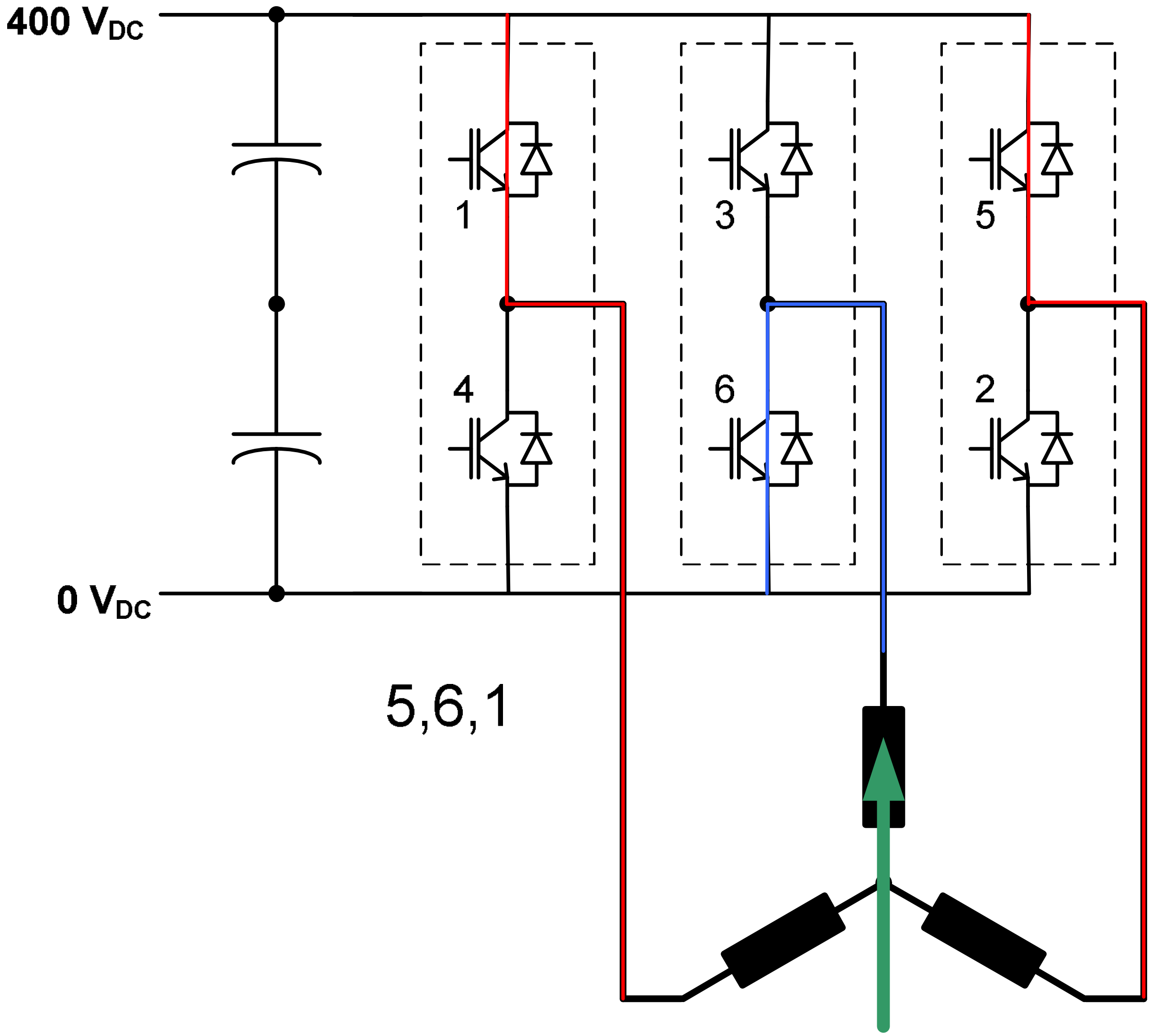
Basic Inverter
2-Level

3 Phase Bridge Configuration



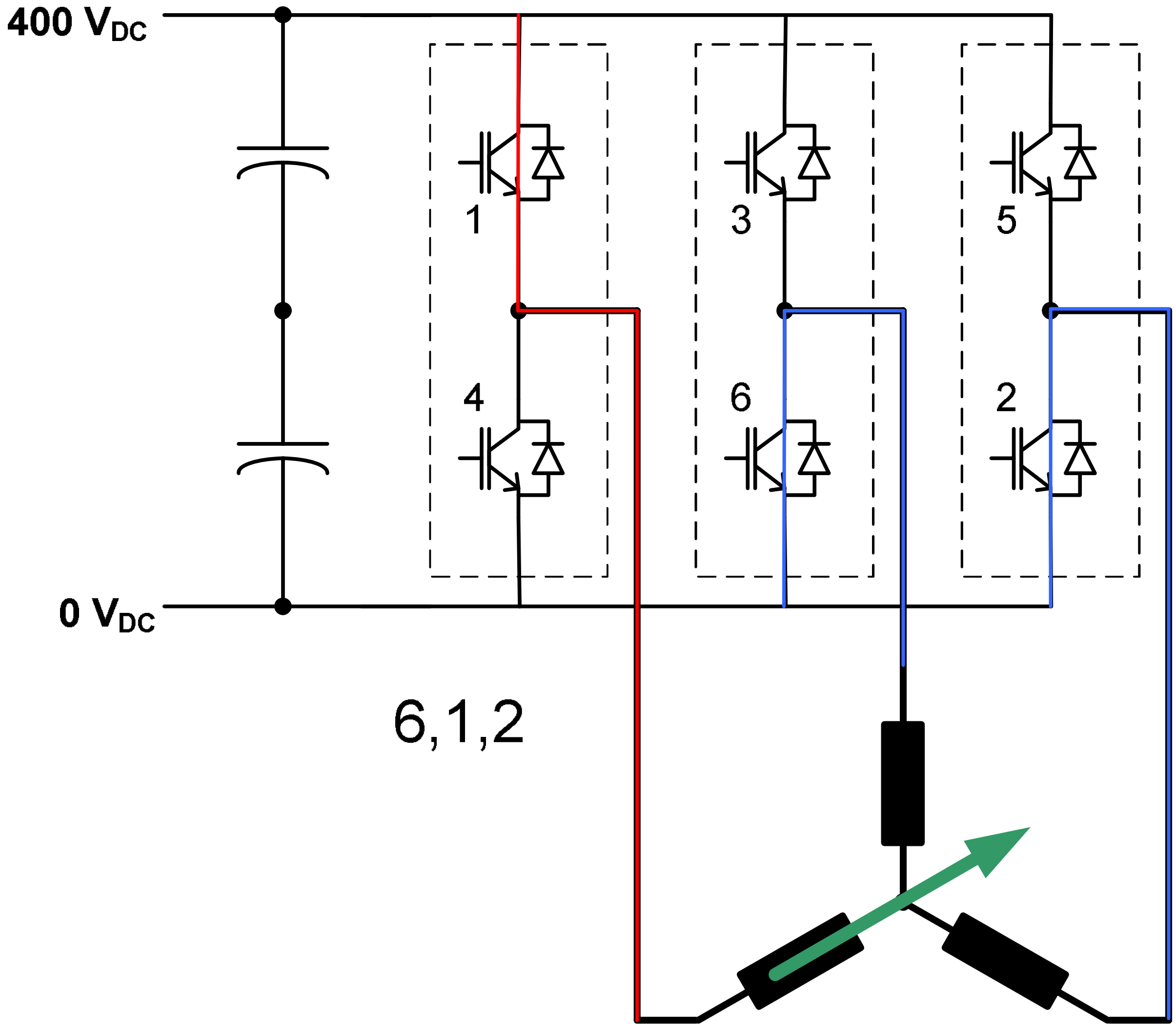
Basic Inverter
2-Level

3 Phase Bridge Configuration



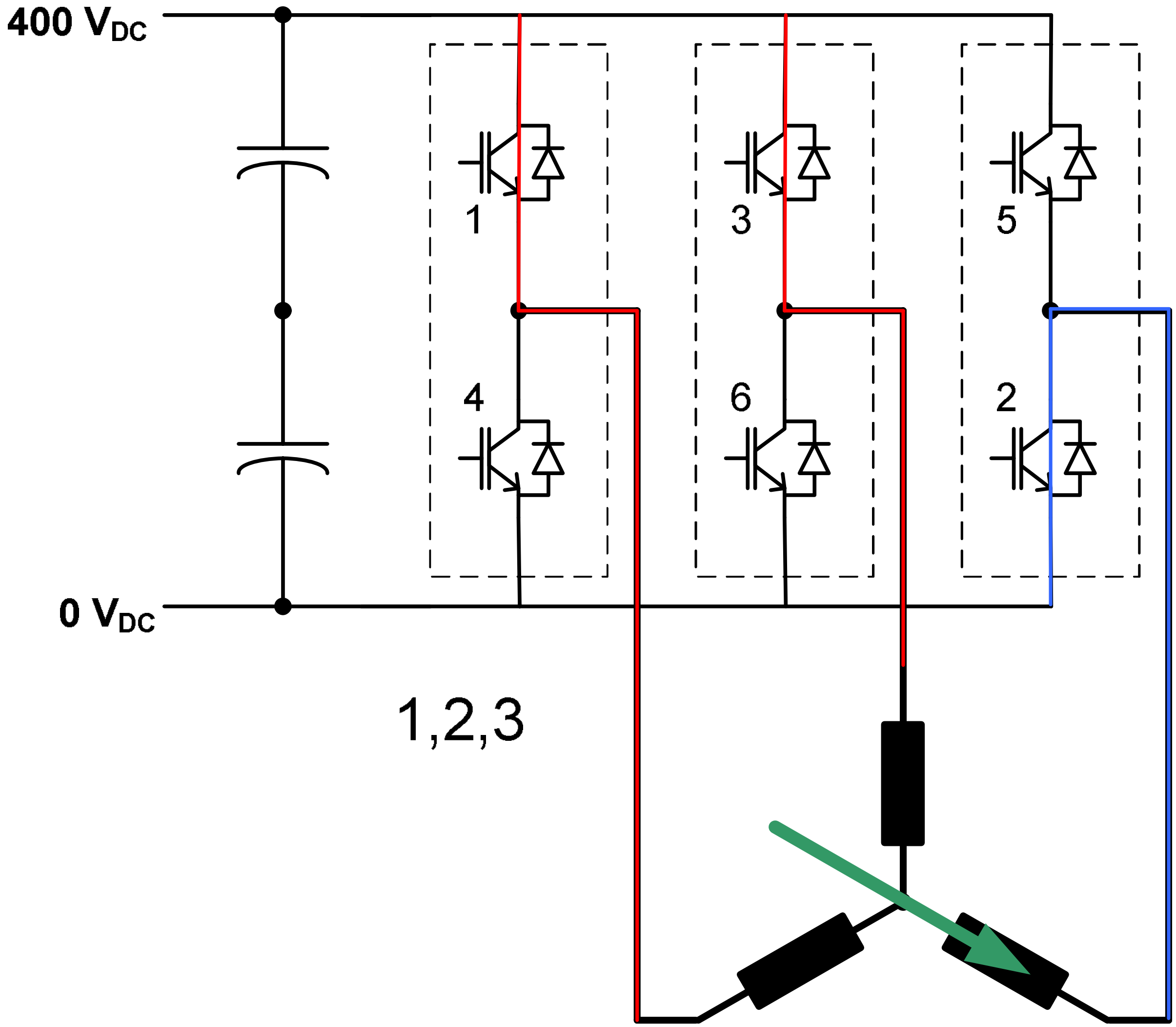
Basic Inverter
2-Level

3 Phase Bridge Configuration



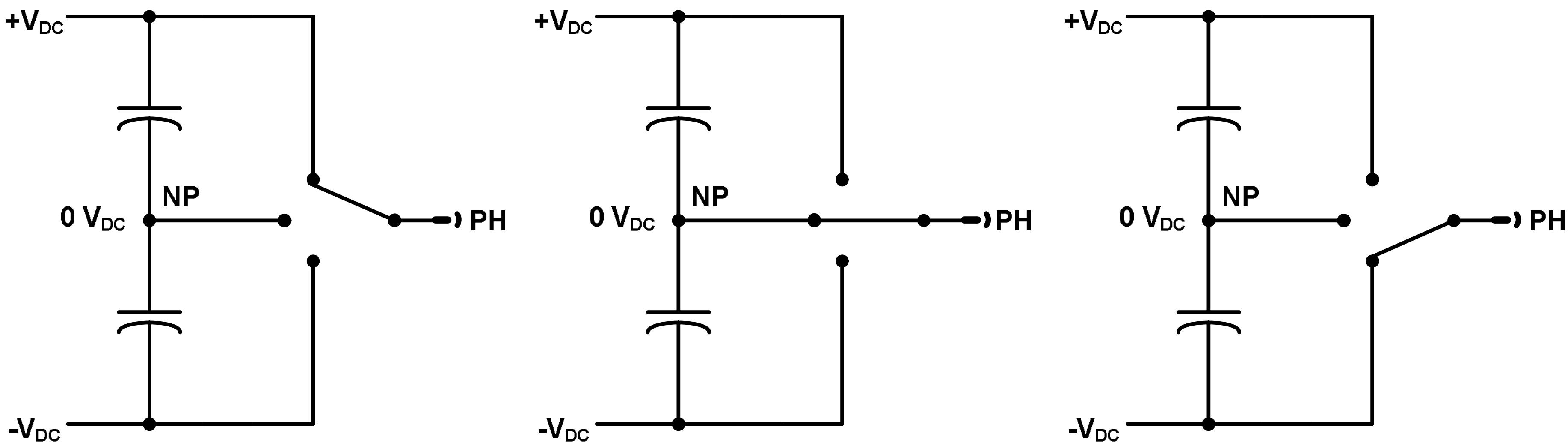
Basic Inverter
2-Level

3 Phase Bridge Configuration



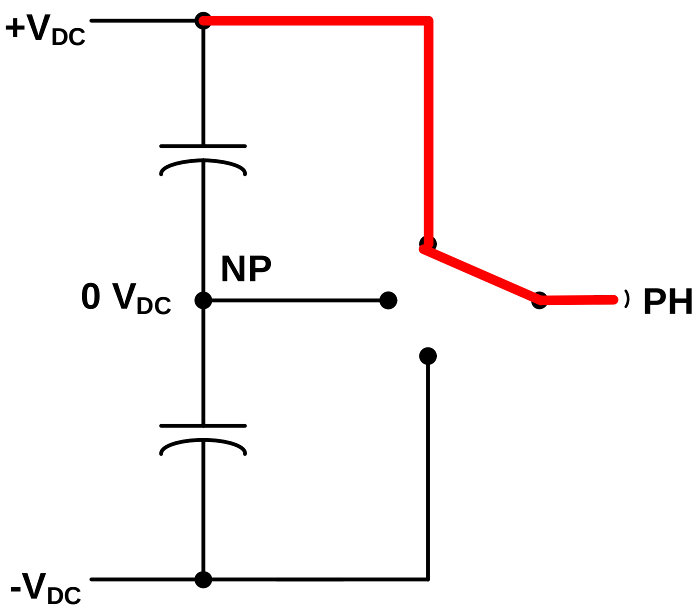
The n-level VSI topology
3-Level

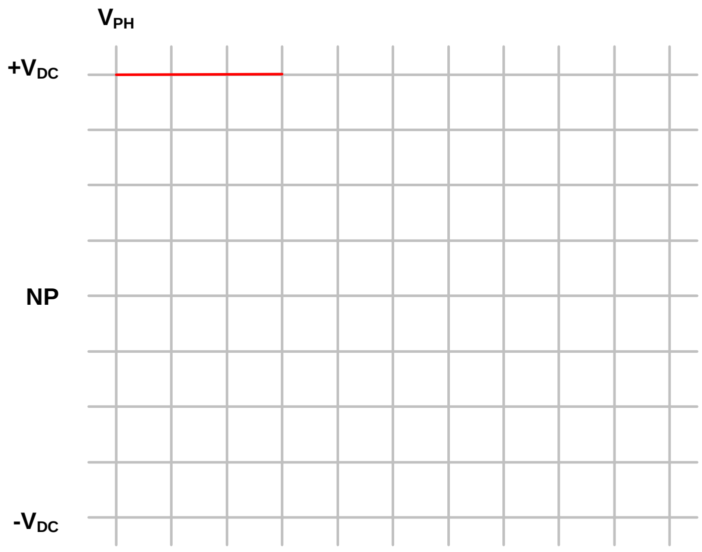
- 3-Level NPC VSI
- Phase output voltages



The n-level VSI topology
3-Level

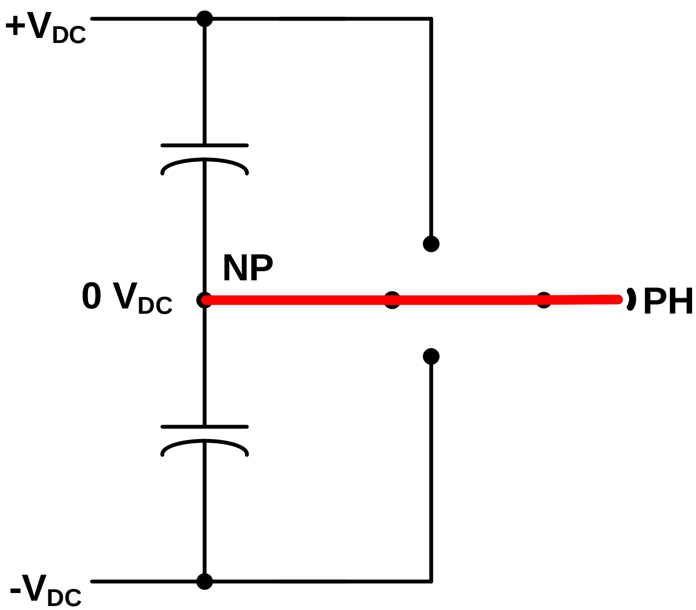
- 3-Level NPC VSI
- Phase output voltages

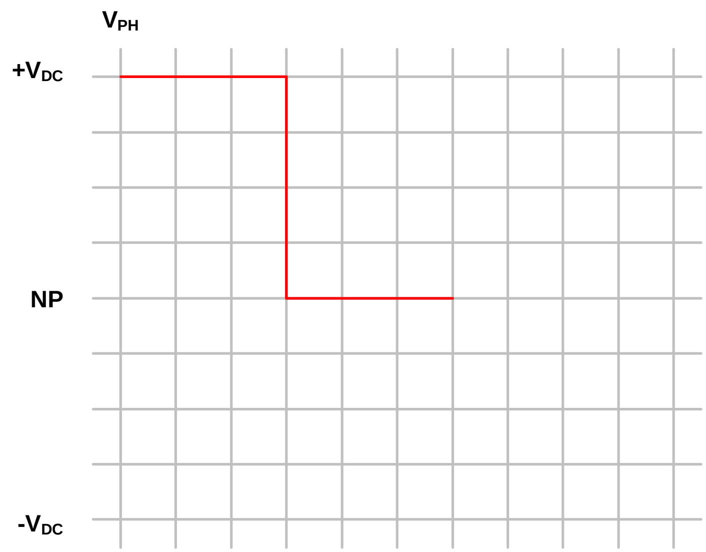




The n-level VSI topology
3-Level

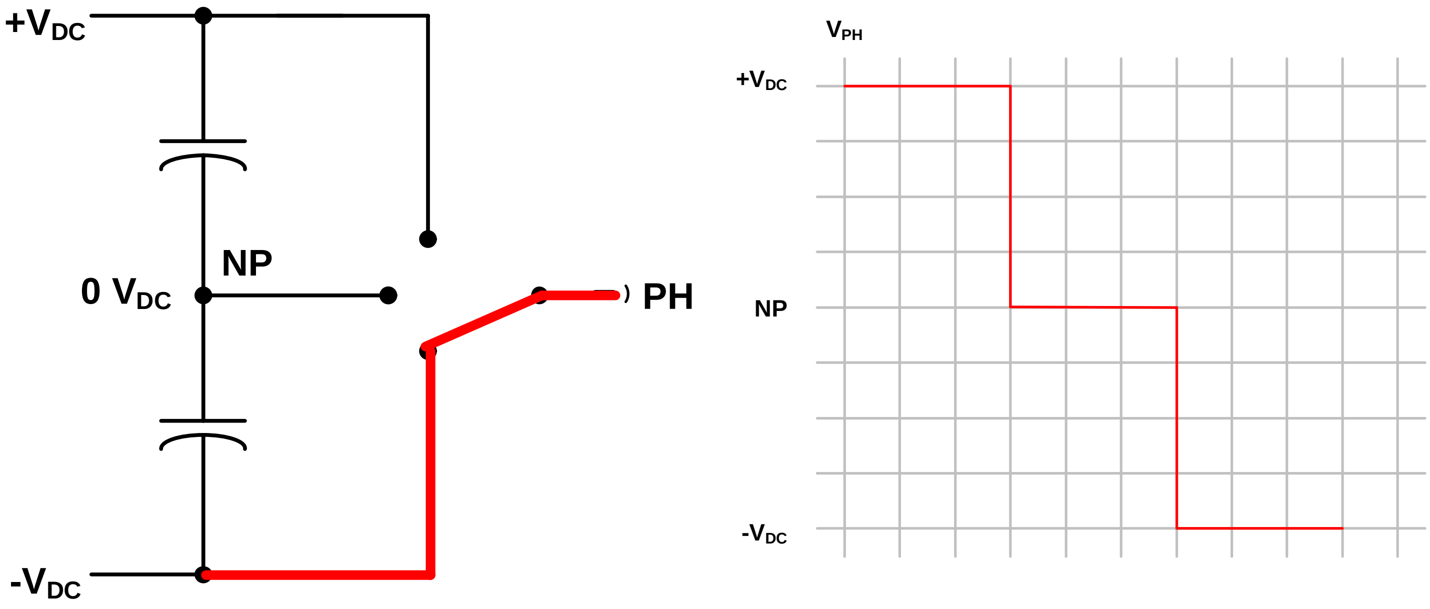
- 3-Level NPC VSI
- Phase output voltages



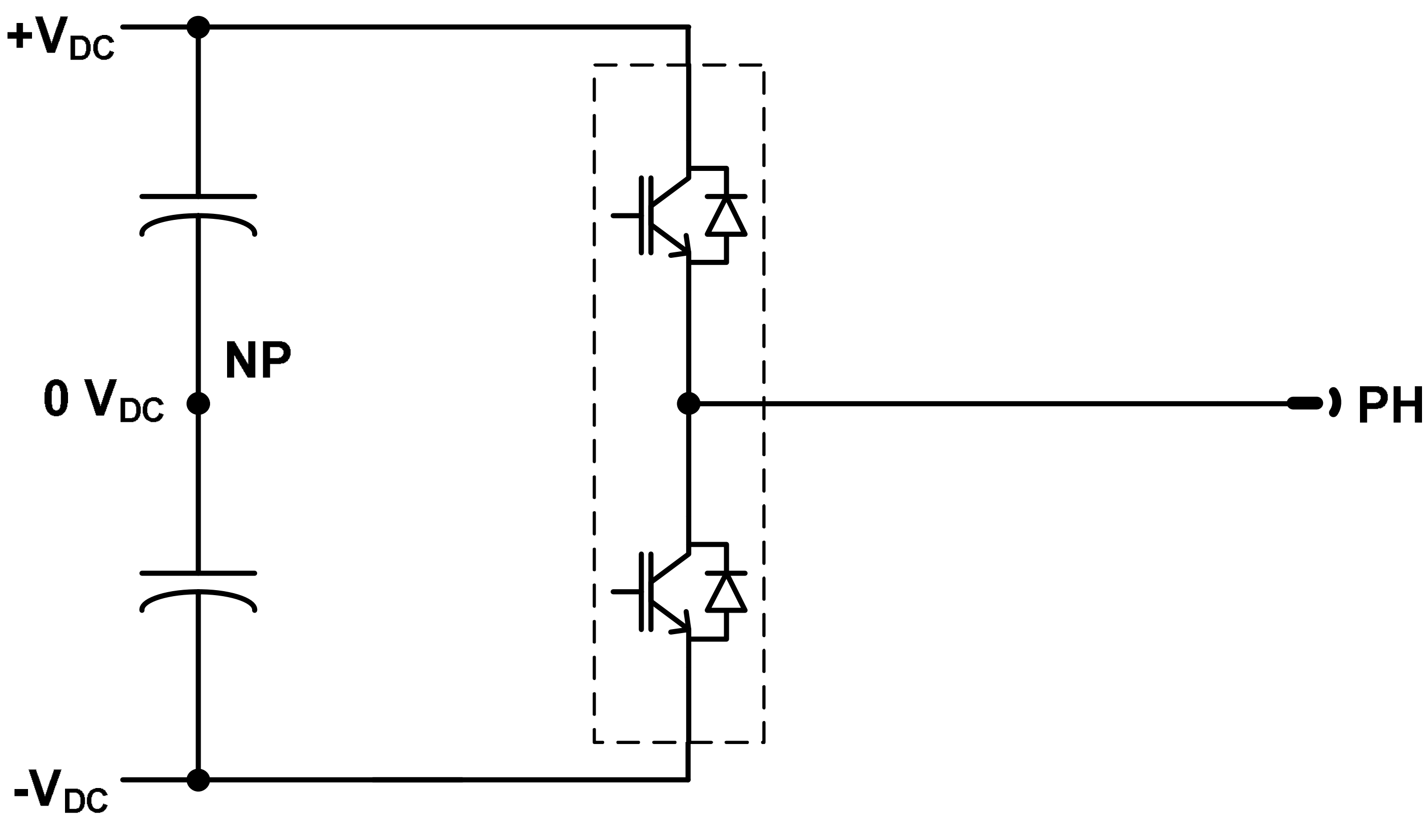


The n-level VSI topology
3-Level

- 3-Level NPC VSI
- Phase output voltages

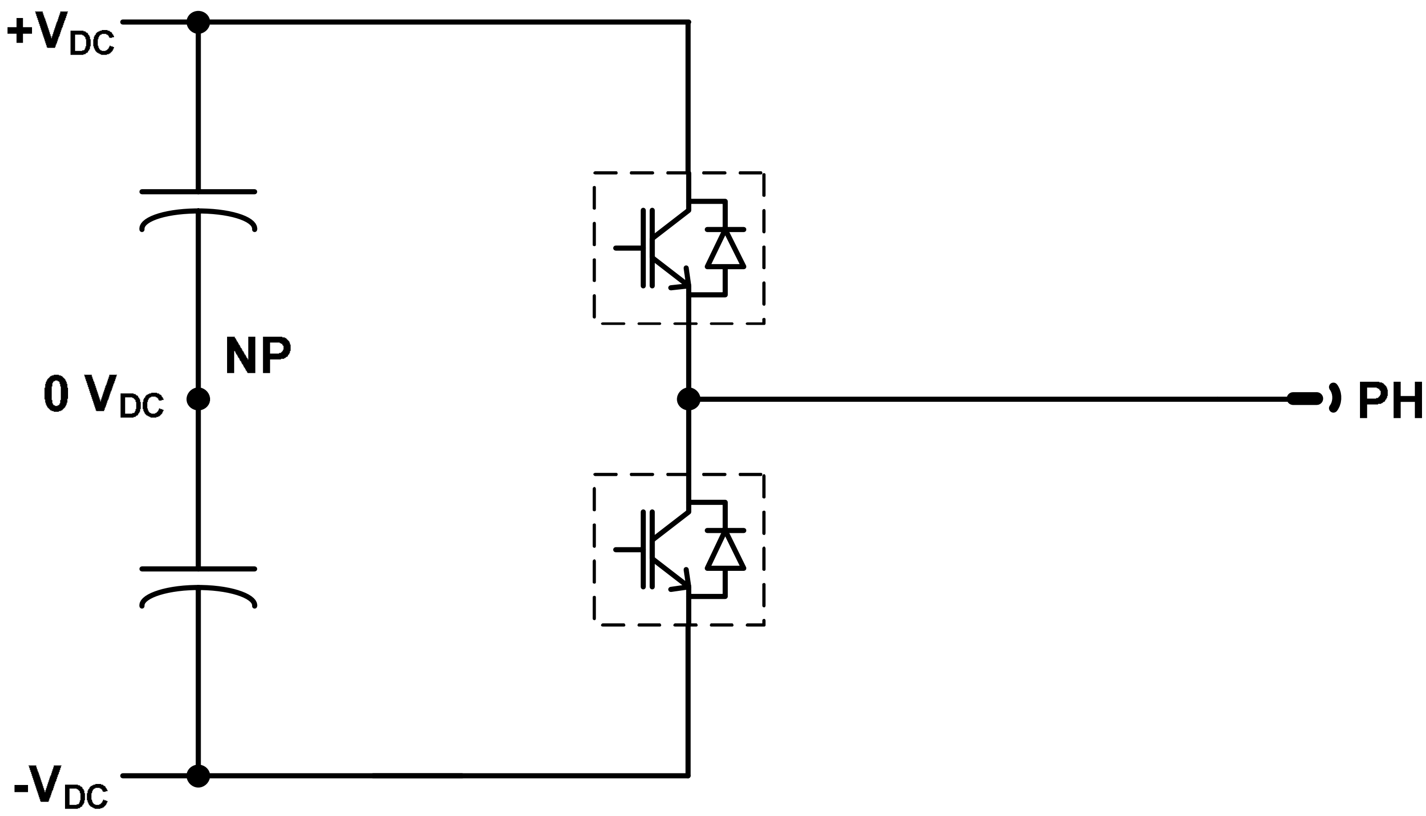


The n-level VSI topology
Going from 2-Level to 3-Level

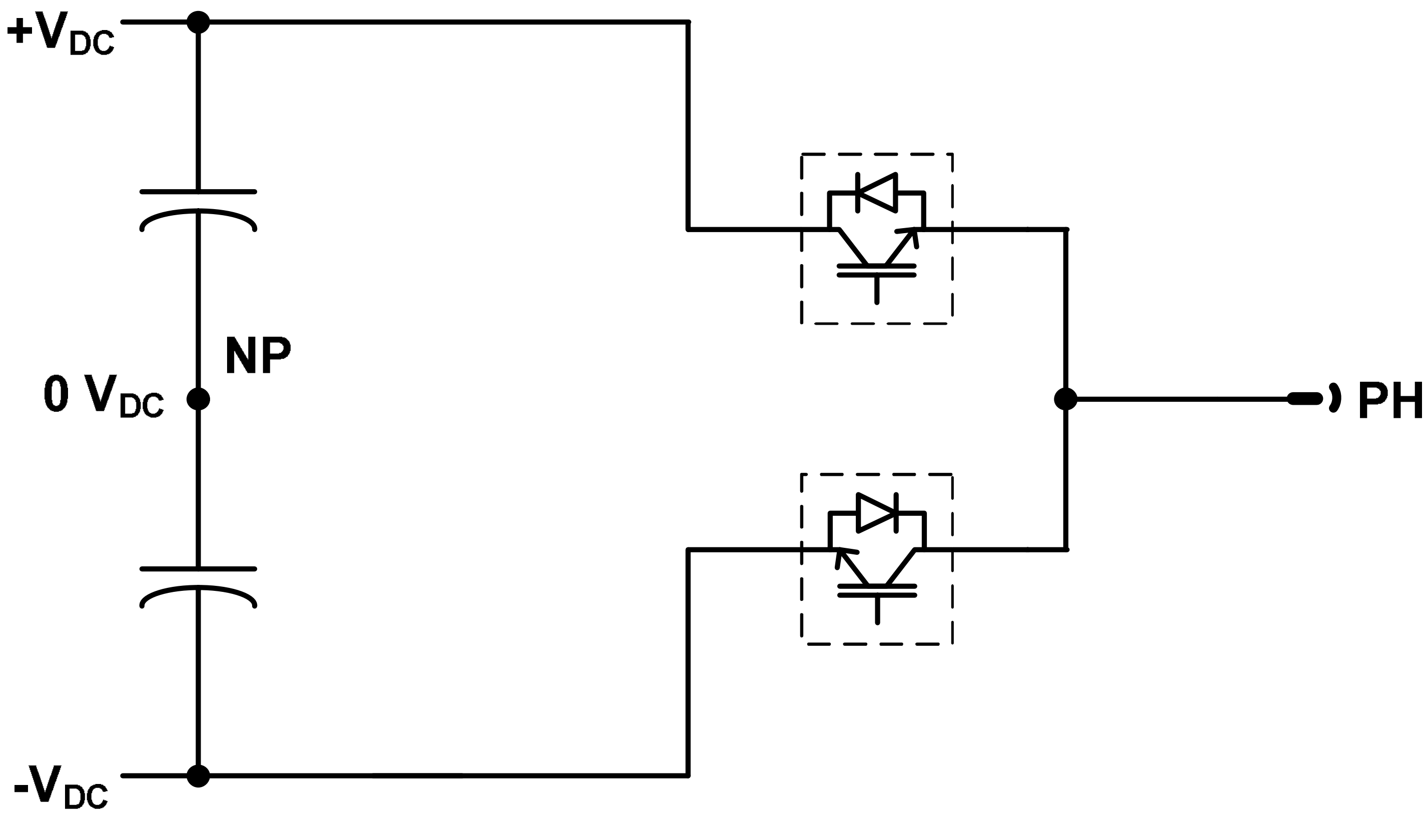


The n-level VSI topology

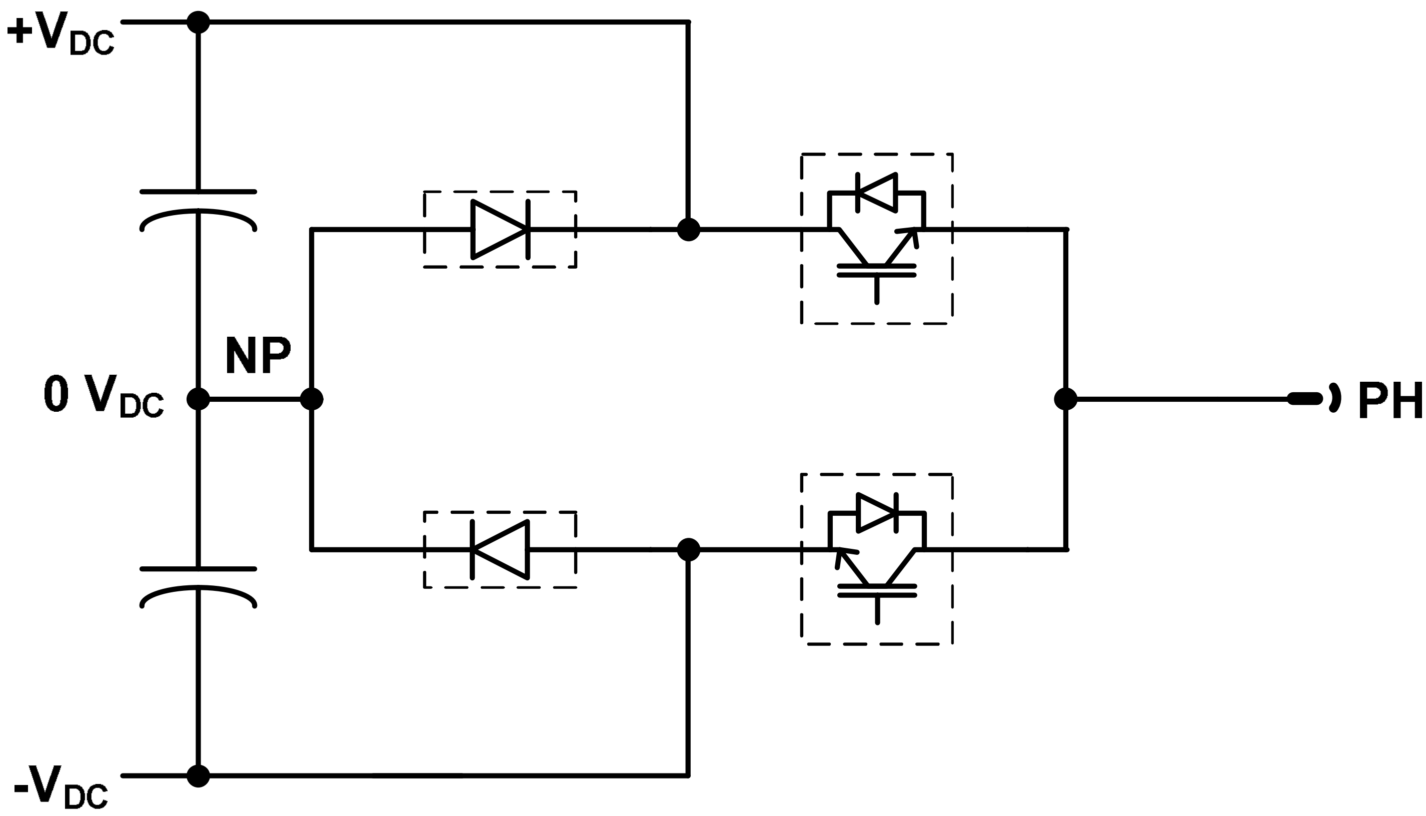
Going from 2-Level to 3-Level



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

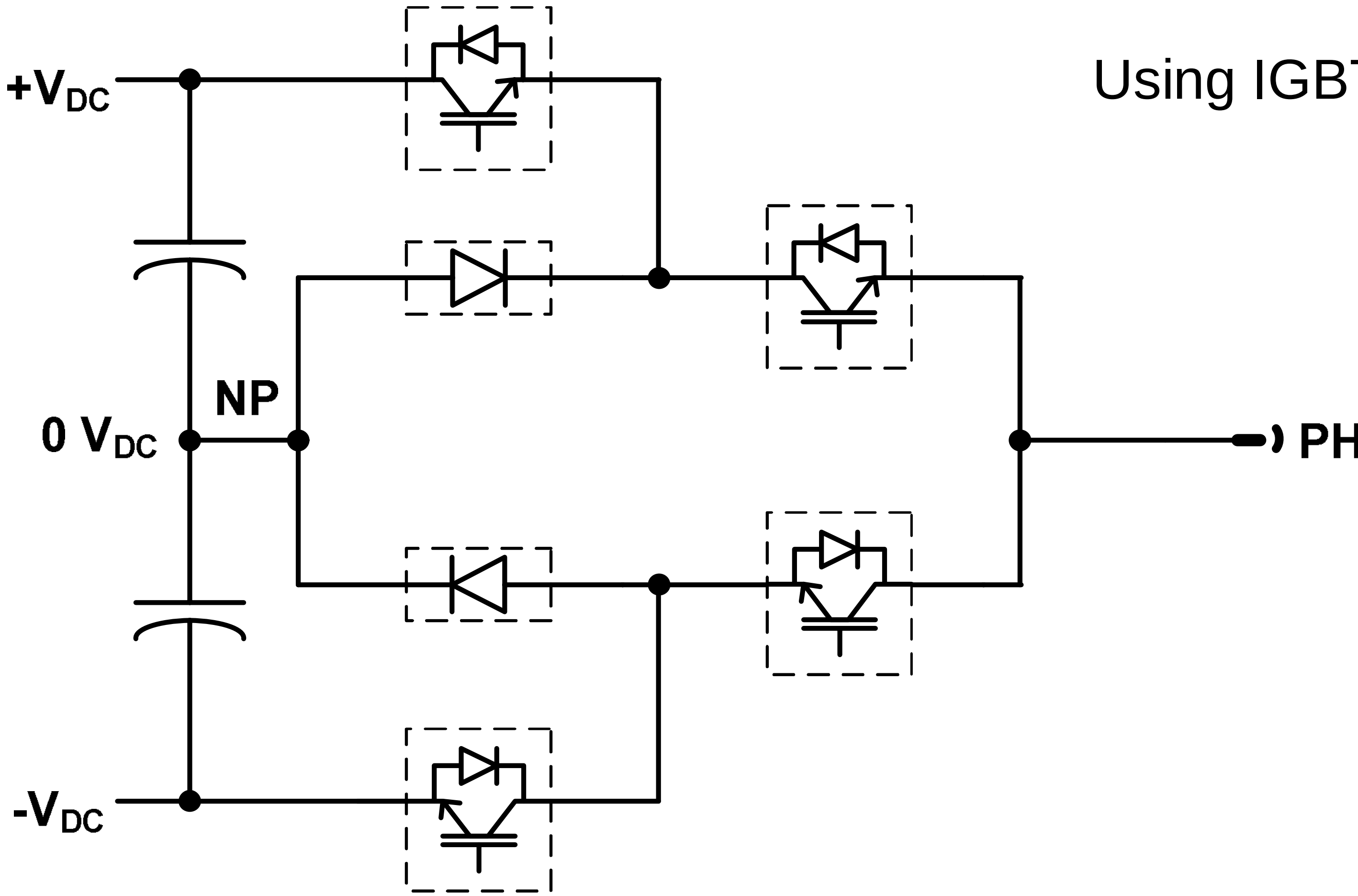


The n-level VSI topology
Going from 2-Level to 3-Level



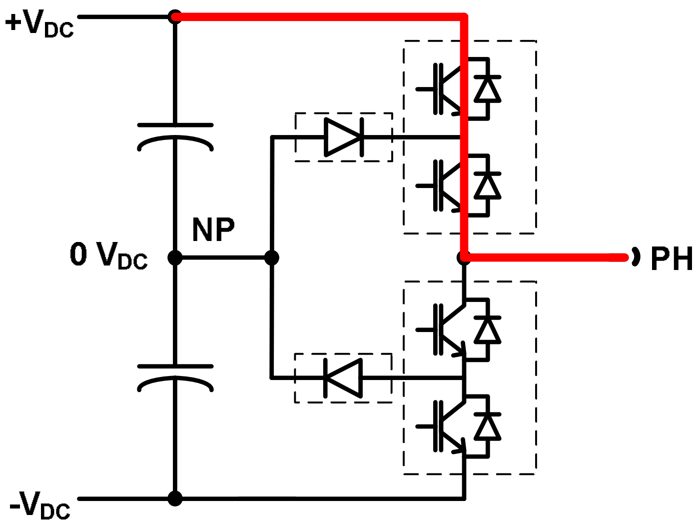
The n-level VSI topology
3-Level

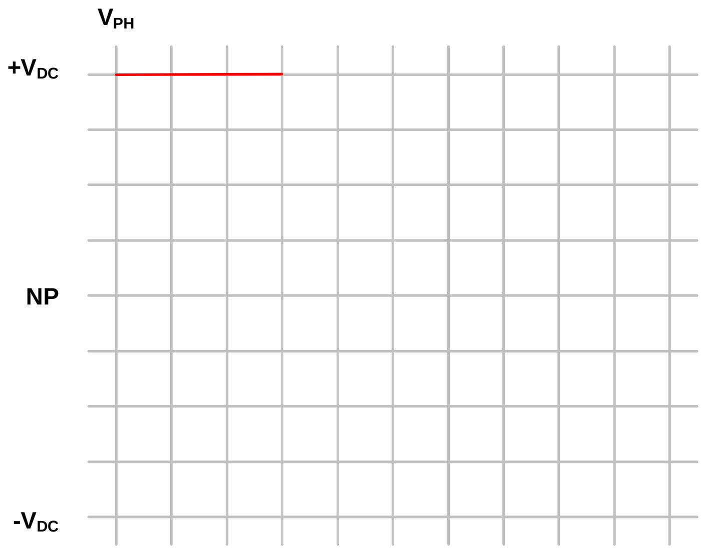
Using IGBTs



The n-level VSI topology
3-Level

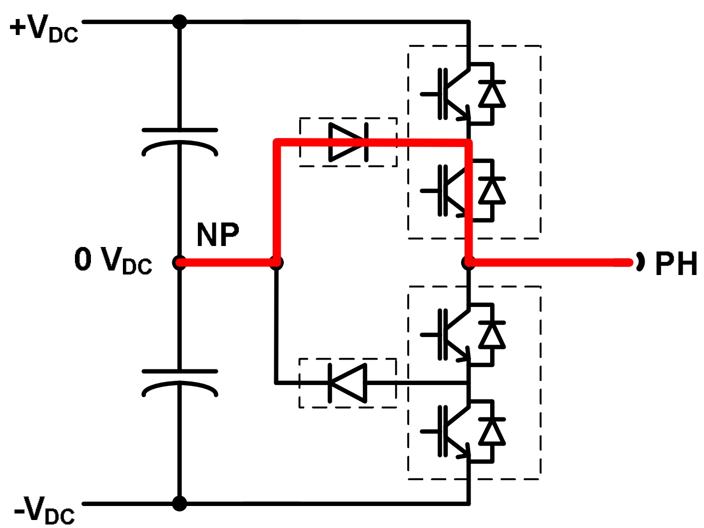
- 3-Level NPC VSI
- Phase output voltages

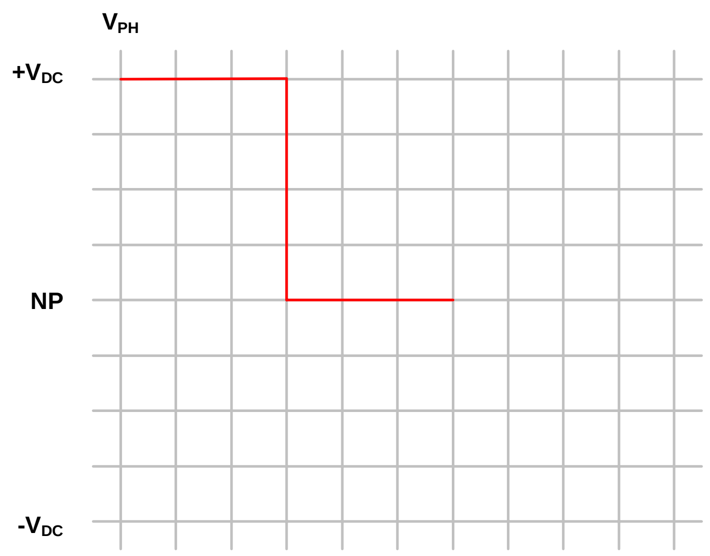




The n-level VSI topology
3-Level

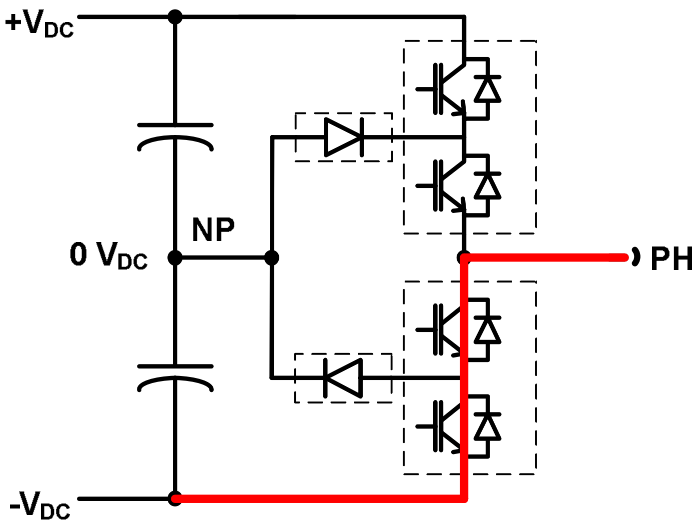
- 3-Level NPC VSI
- Phase output voltages

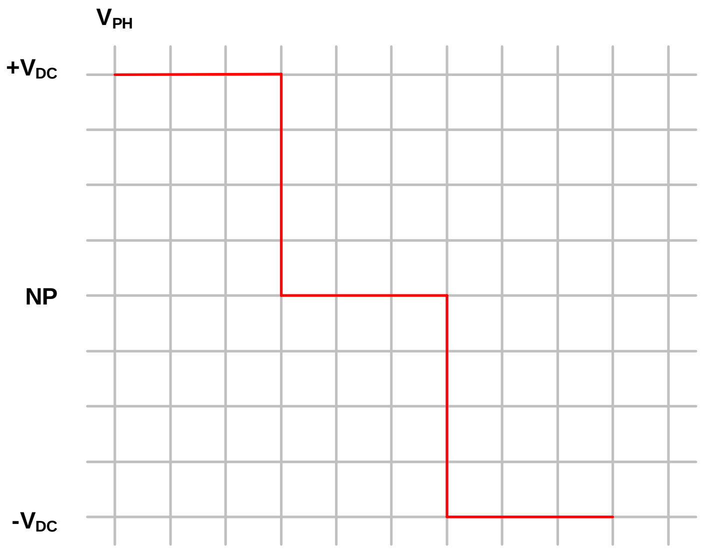




The n-level VSI topology
3-Level

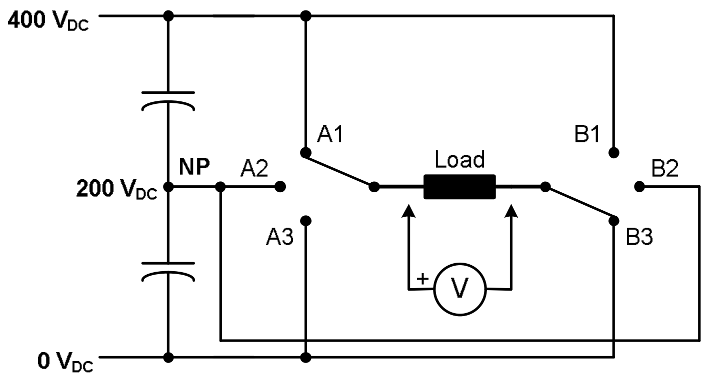
- 3-Level NPC VSI
- Phase output voltages





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

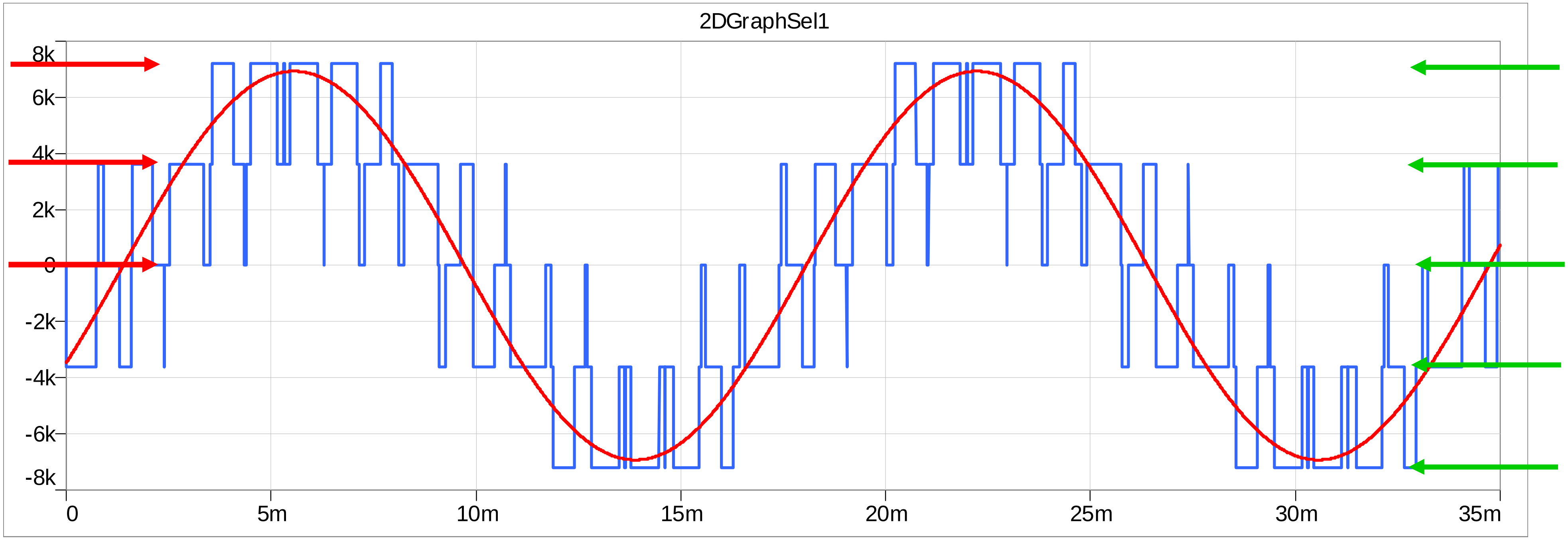
Number of Levels, n

3

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

5

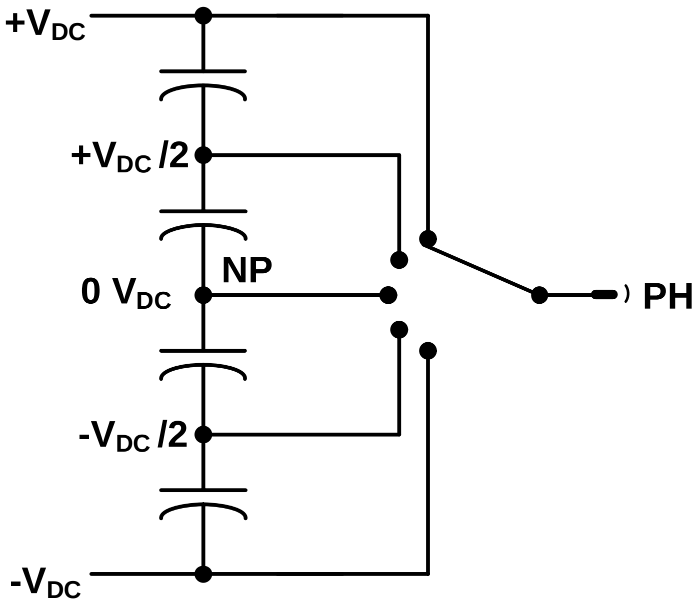
3-Level Waveform, Line-to-Line



3-Levels

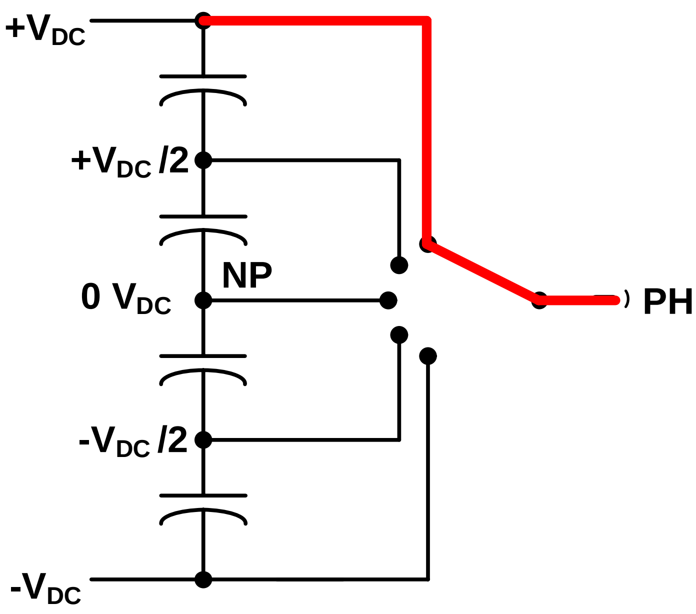
5-Steps

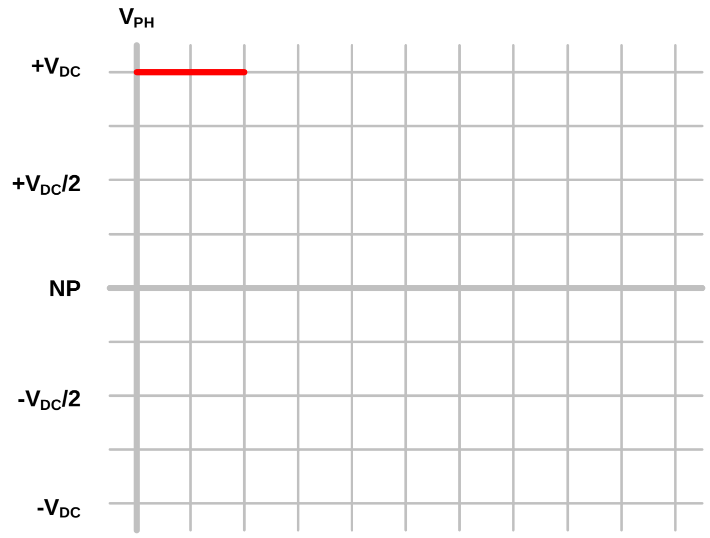
The n-level VSI topology
5-Level



The n-level VSI topology
5-Level

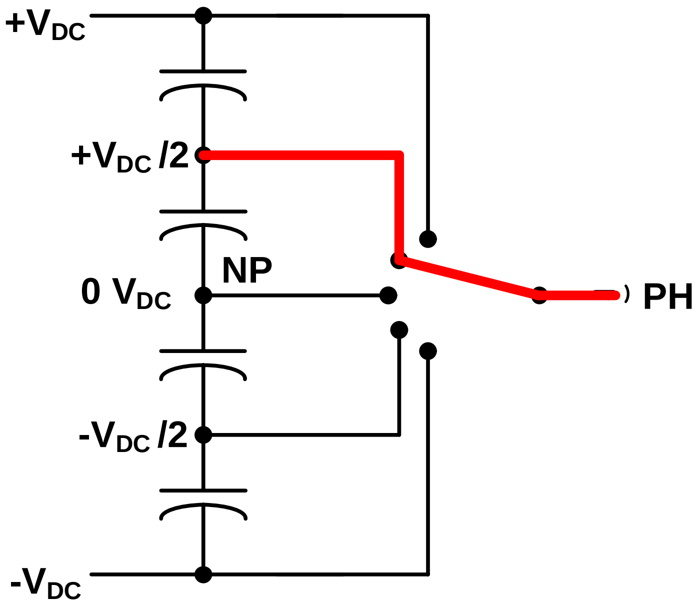
- 5-Level ANPC VSI
- Phase output voltages

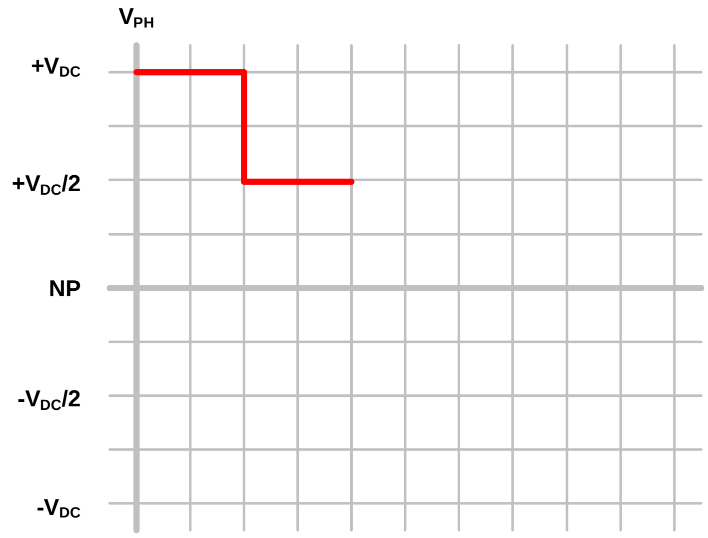




The n-level VSI topology
5-Level

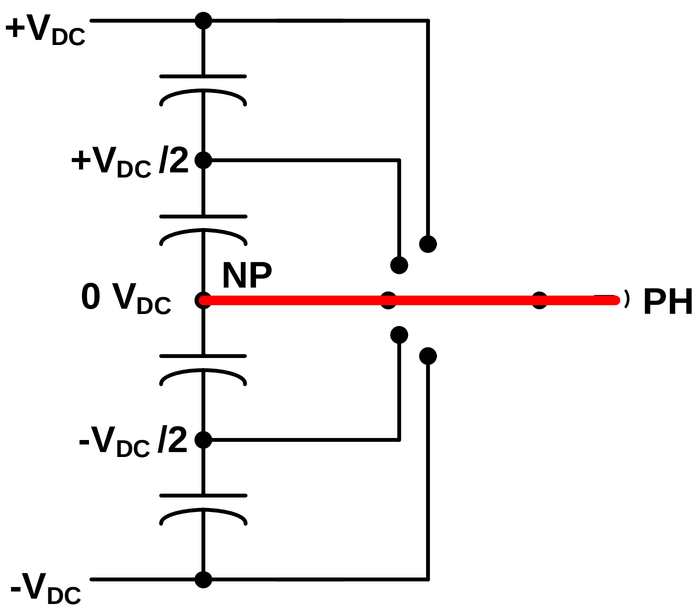
- 5-Level ANPC VSI
- Phase output voltages

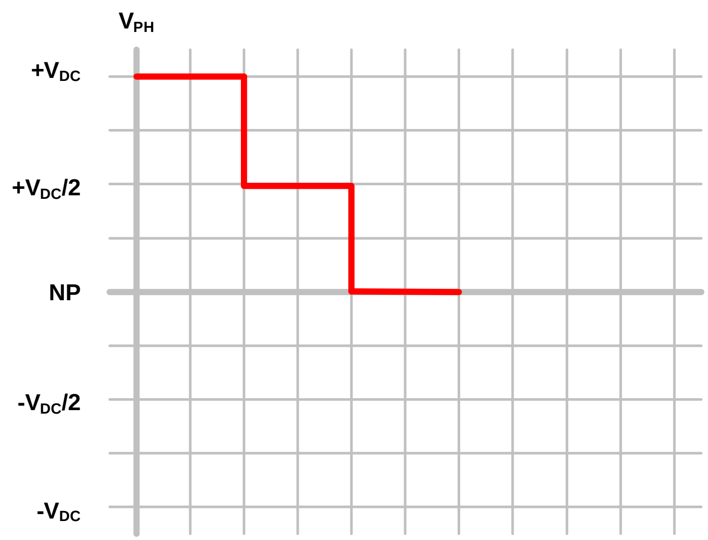




The n-level VSI topology
5-Level

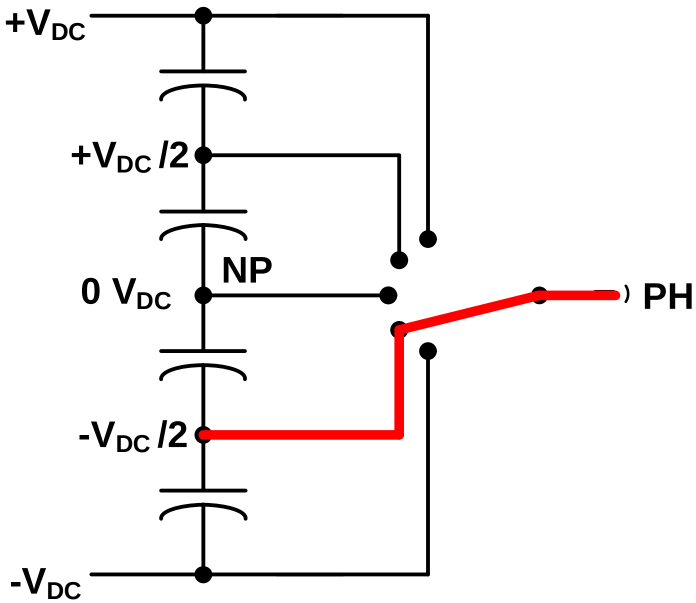
- 5-Level ANPC VSI
- Phase output voltages

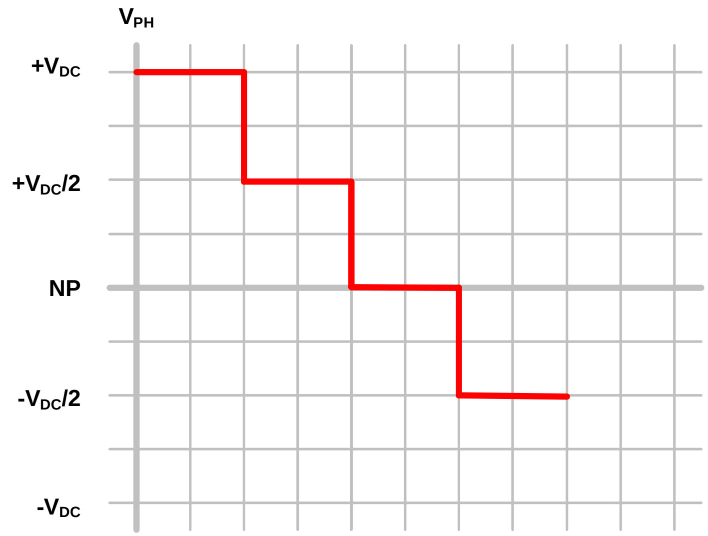




The n-level VSI topology
5-Level

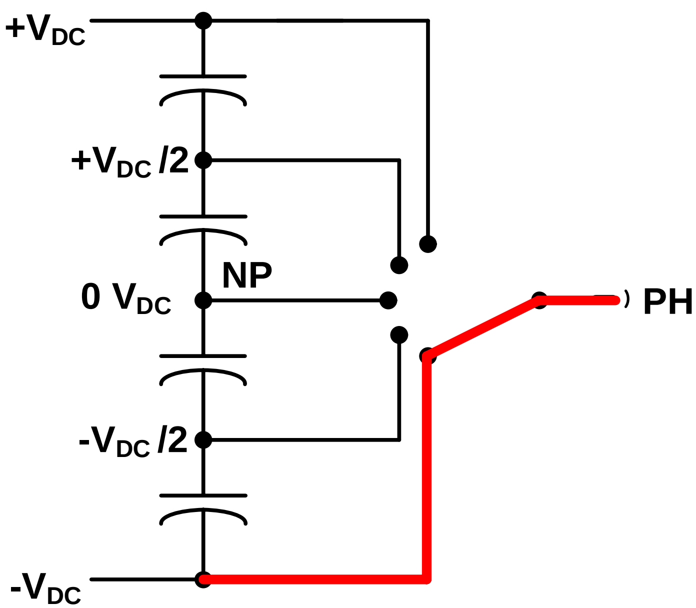
- 5-Level ANPC VSI
- Phase output voltages

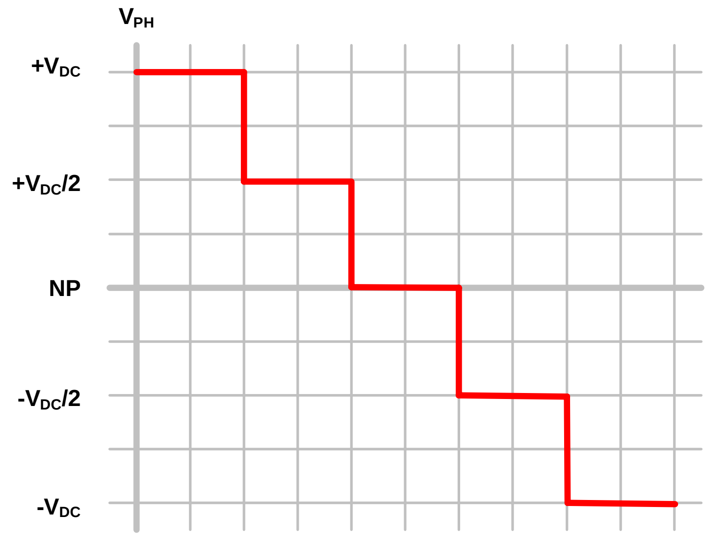




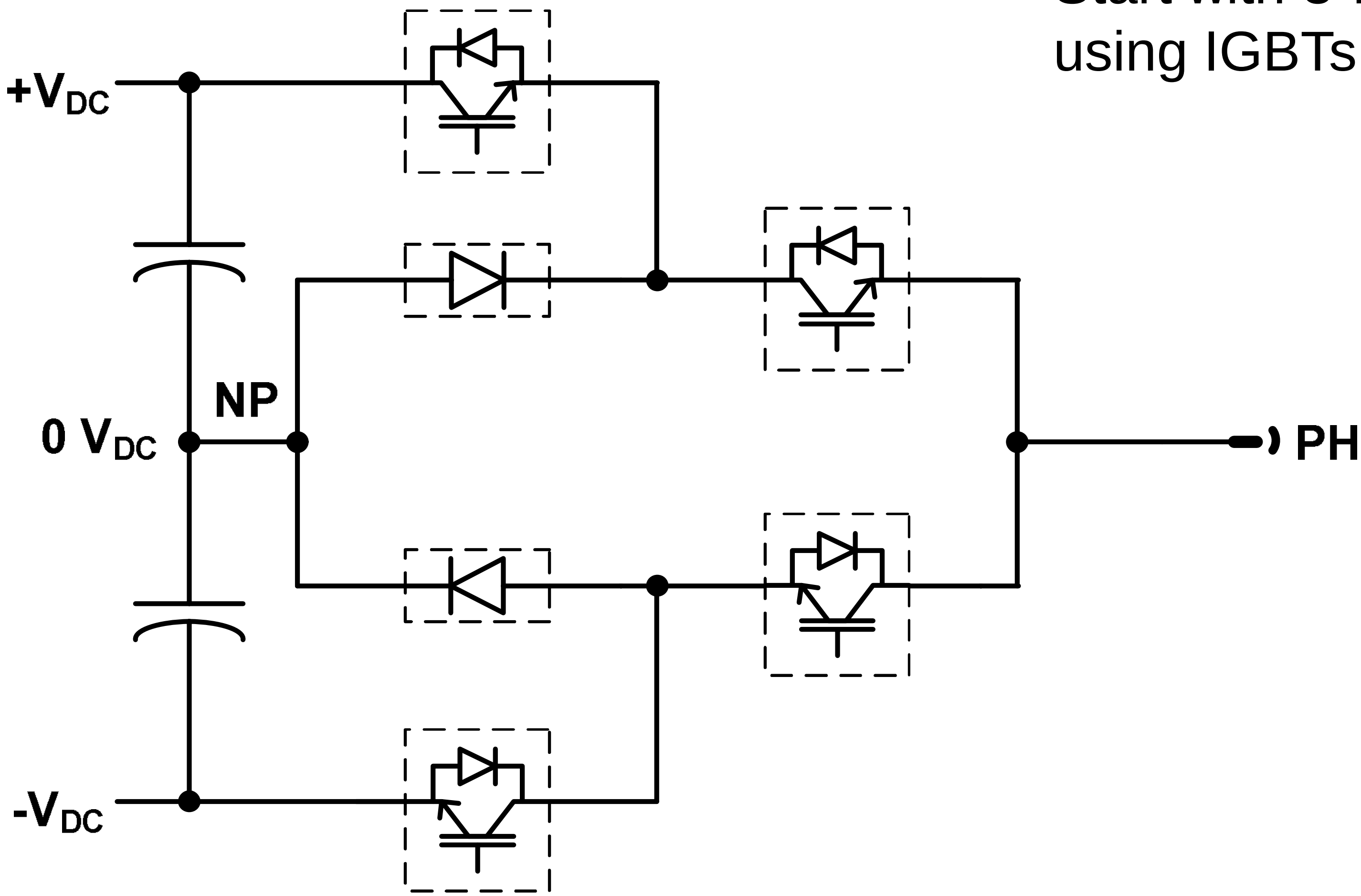
The n-level VSI topology
5-Level

- 5-Level ANPC VSI
- Phase output voltages





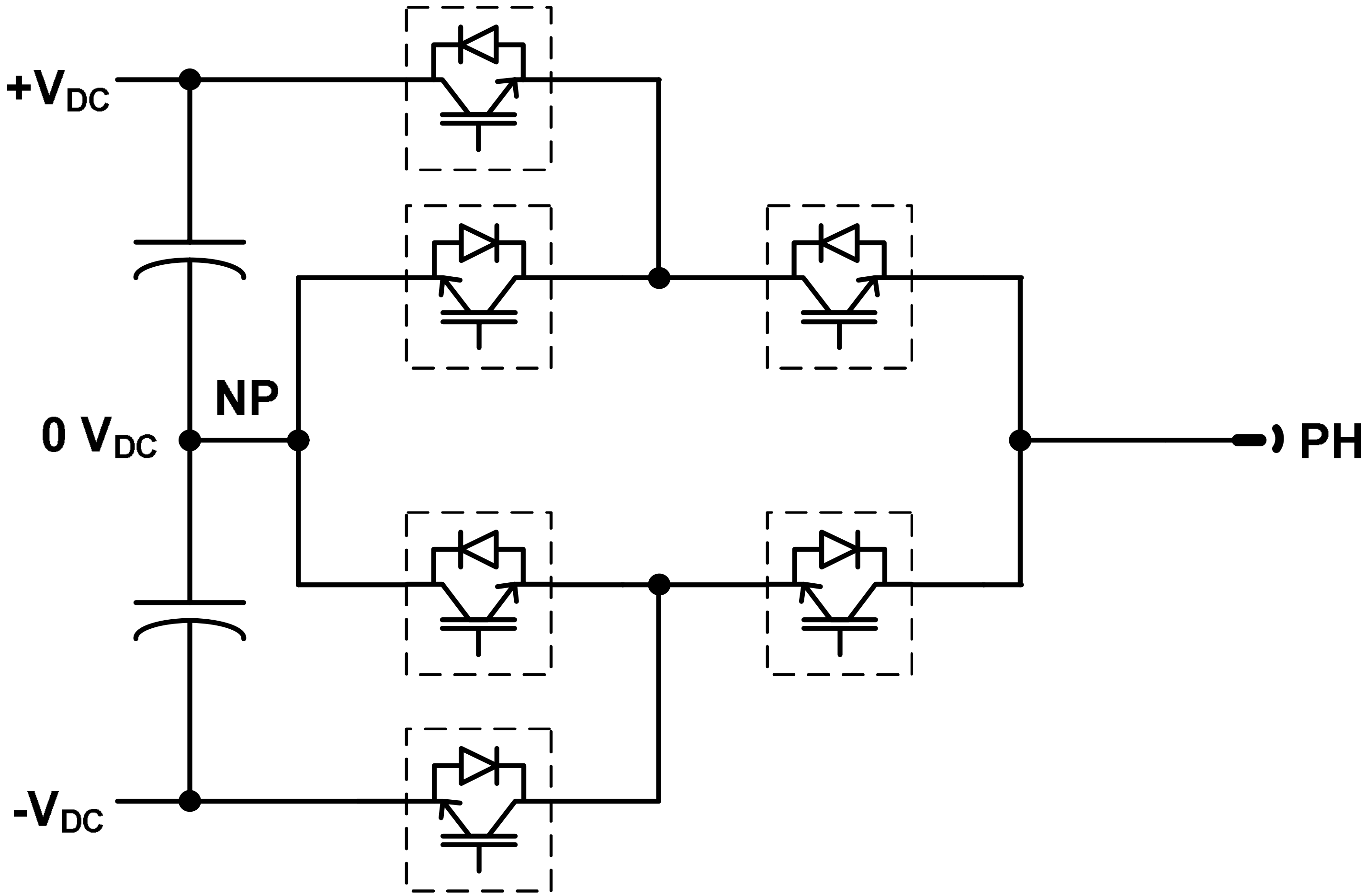
The n-level VSI topology
Going from 3-Level to 5-Level



Start with 3-Level using IGBTs

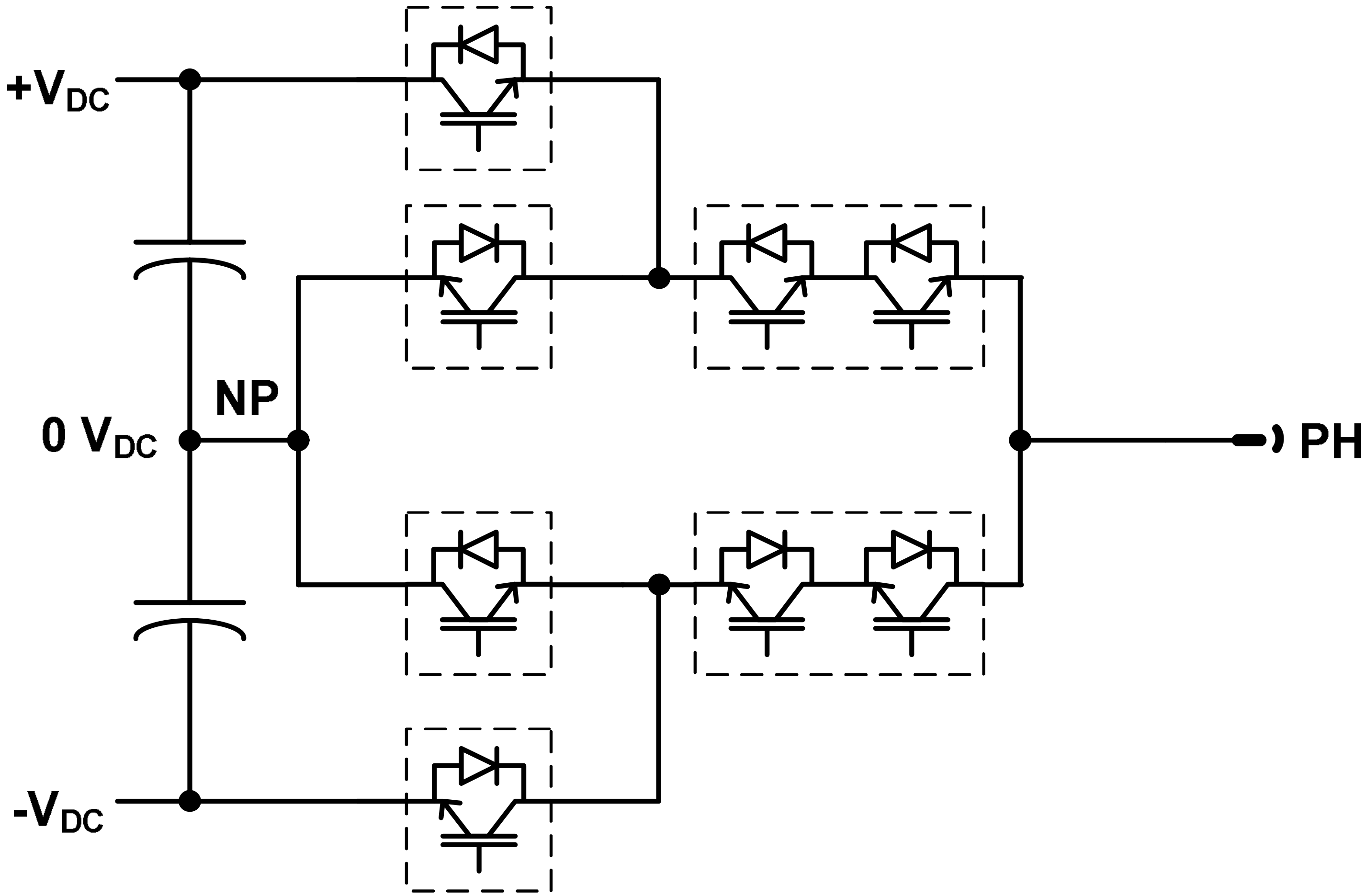
The n-level VSI topology

Going from 3-Level to 5-Level



The n-level VSI topology

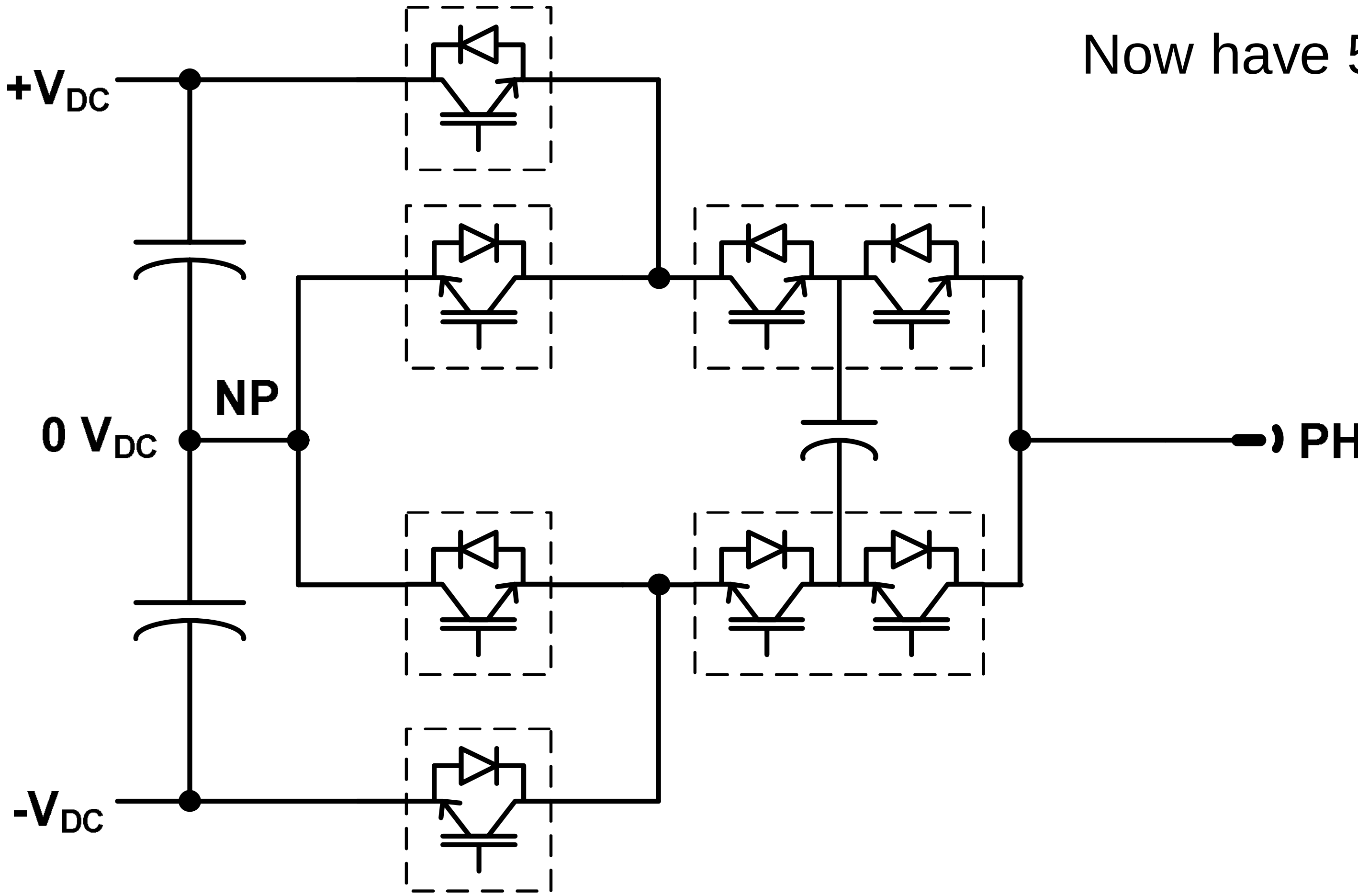
Going from 3-Level to 5-Level



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

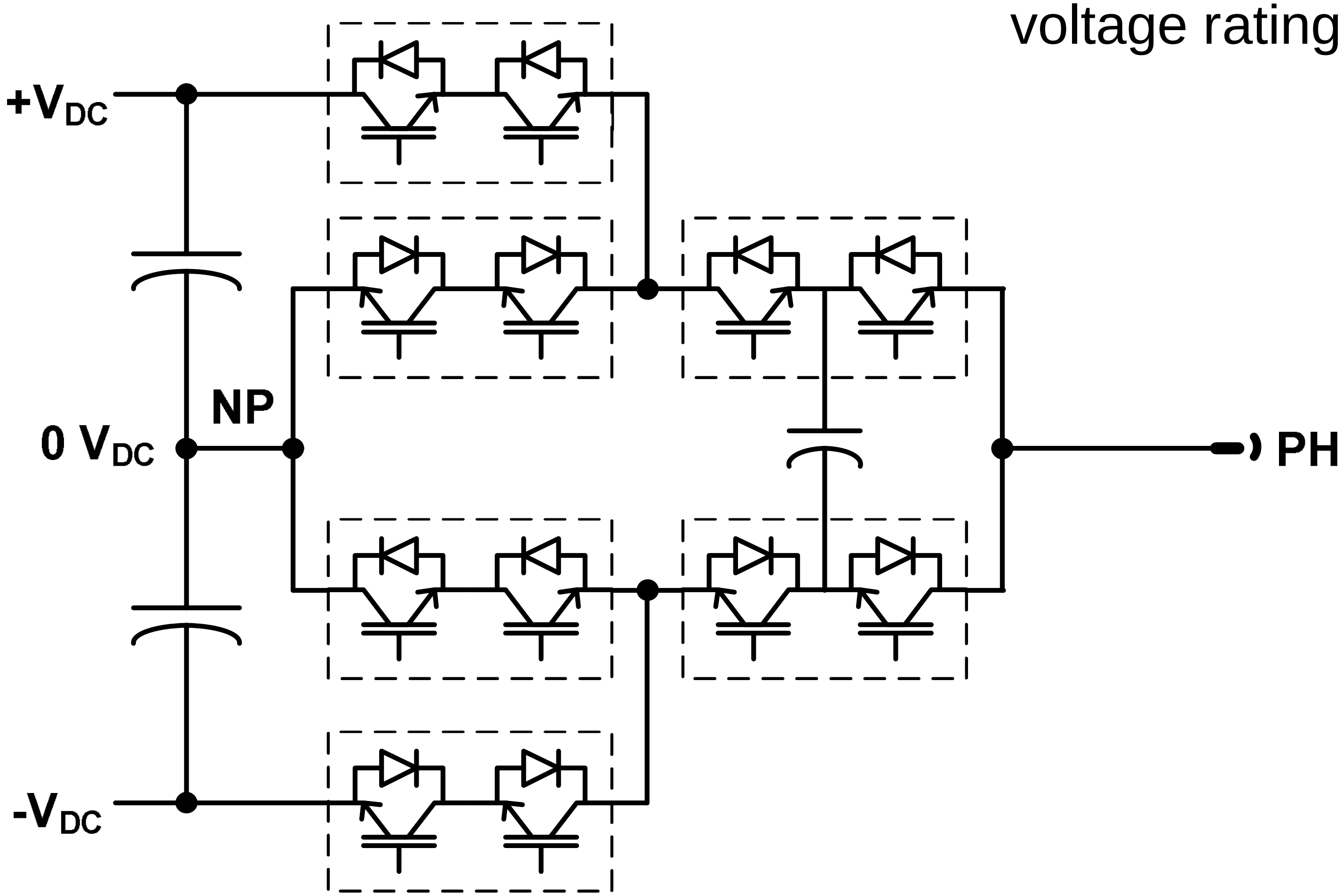
Added cap at Vdc/2

Now have 5-Level



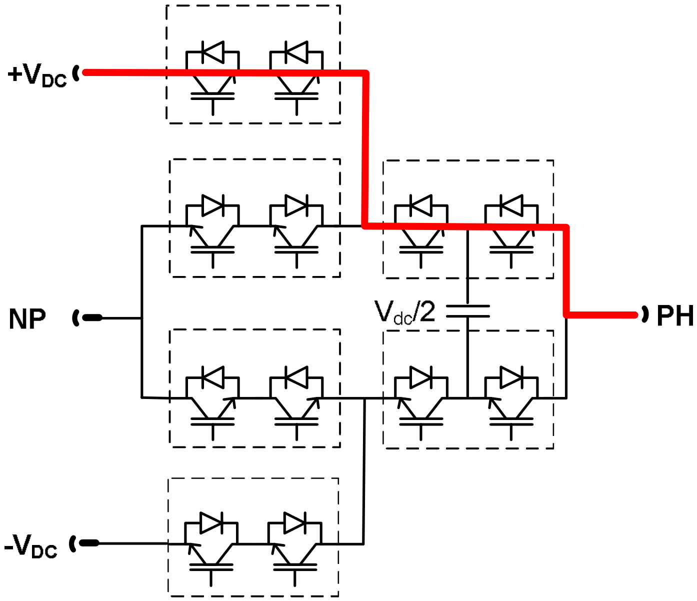
The n-level VSI topology
Going from 3-Level to 5-Level

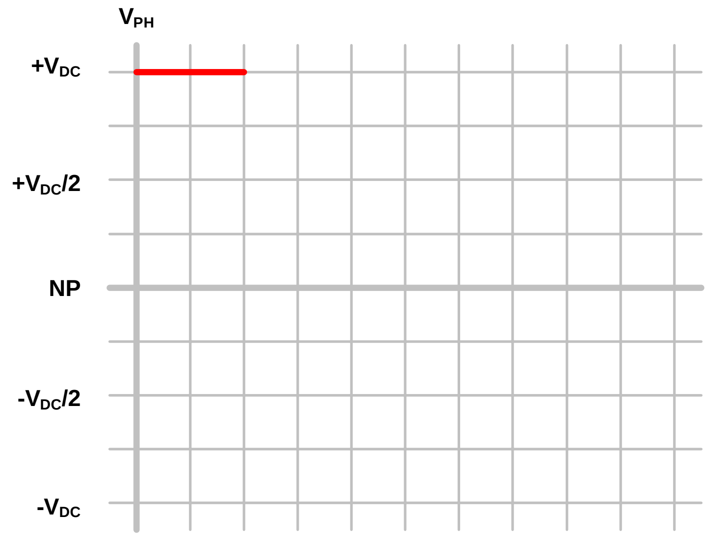
Double up IGBTs for voltage rating



The n-level VSI topology
5-Level

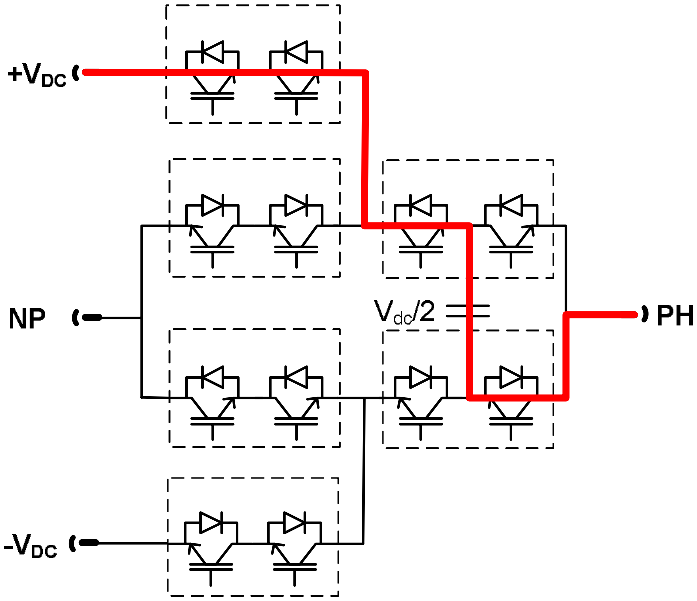
- 5-Level ANPC VSI
- Phase output voltages

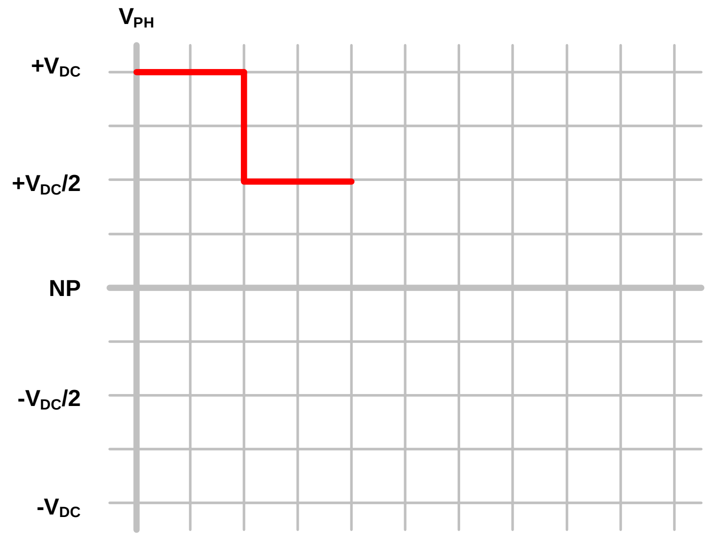




The n-level VSI topology
5-Level

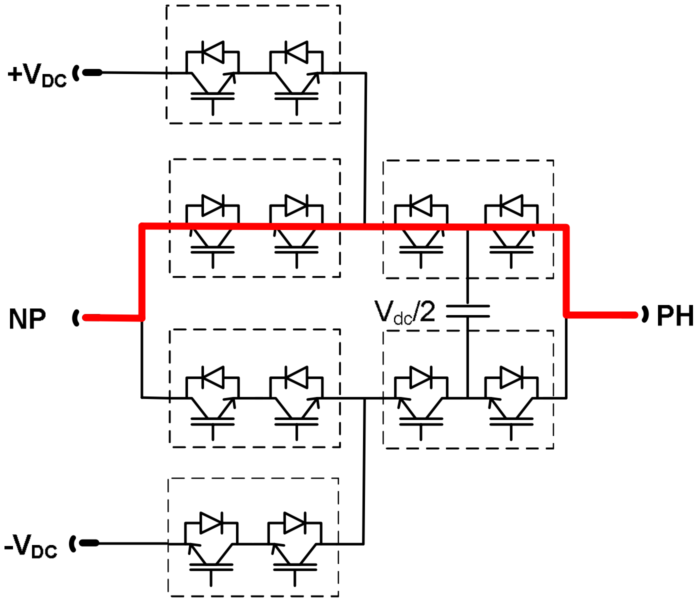
- 5-Level ANPC VSI
- Phase output voltages

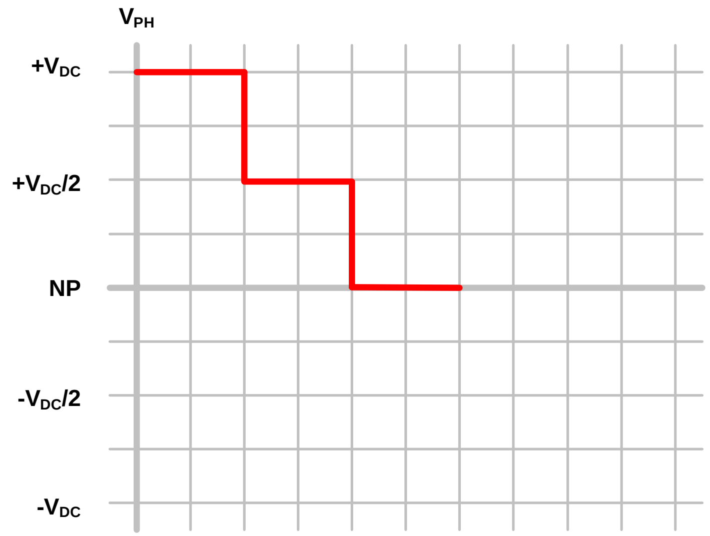




The n-level VSI topology
5-Level

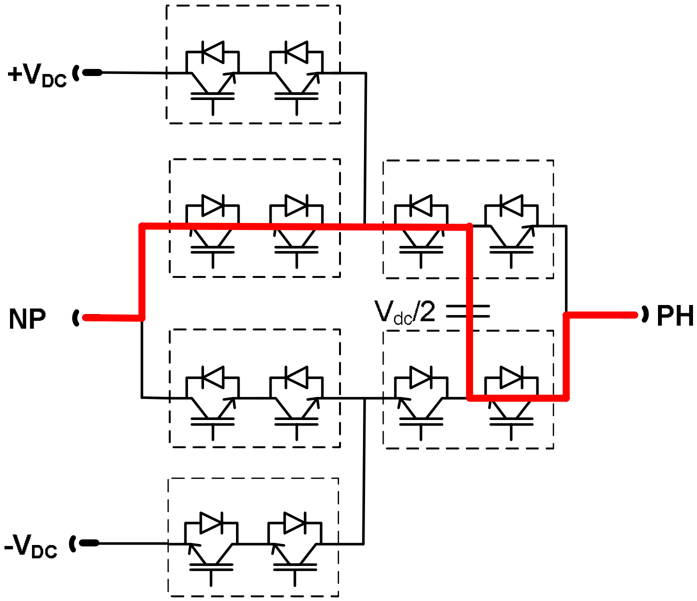
- 5-Level ANPC VSI
- Phase output voltages

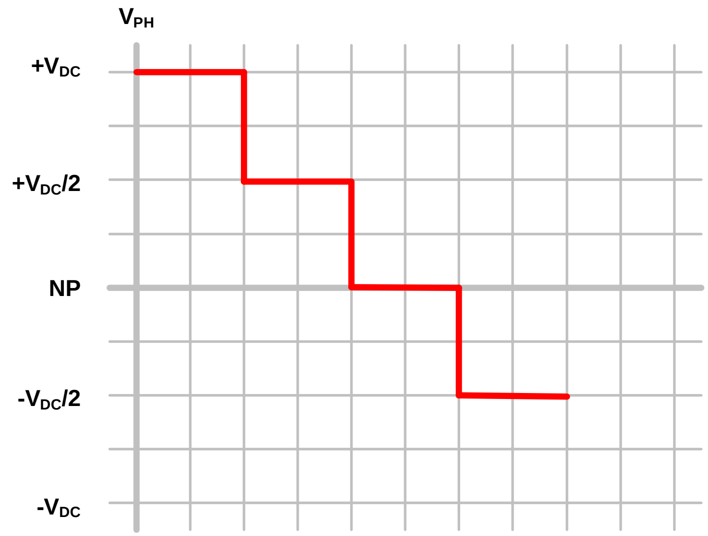




The n-level VSI topology
5-Level

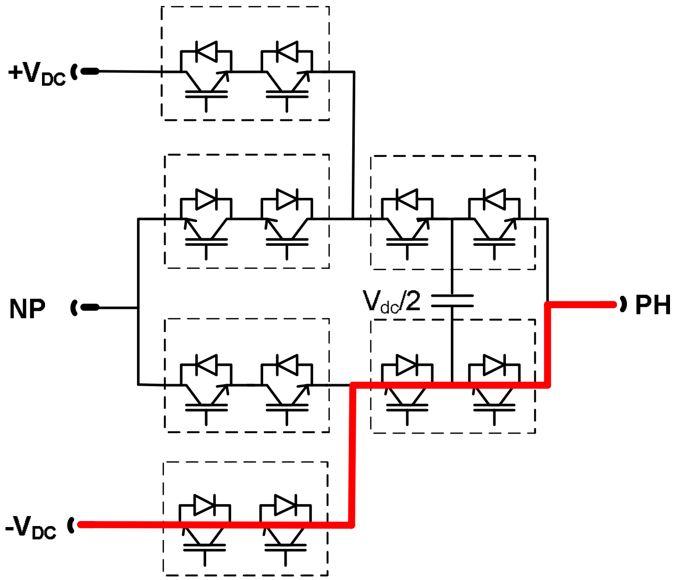
- 5-Level ANPC VSI
- Phase output voltages

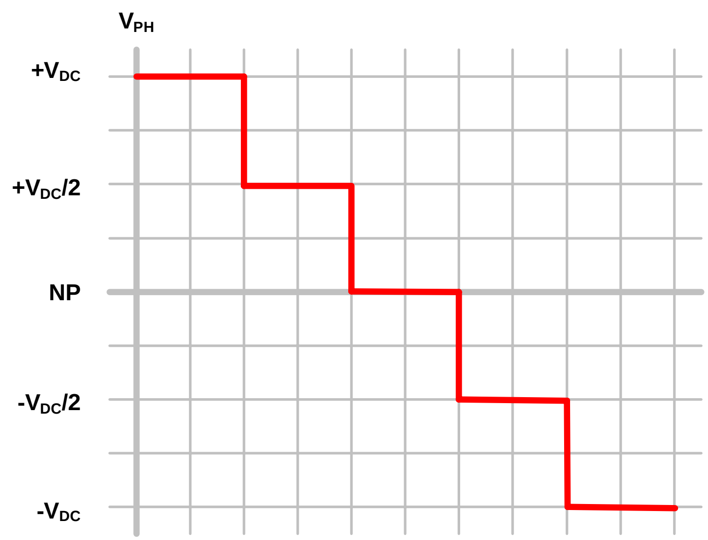




The n-level VSI topology
5-Level

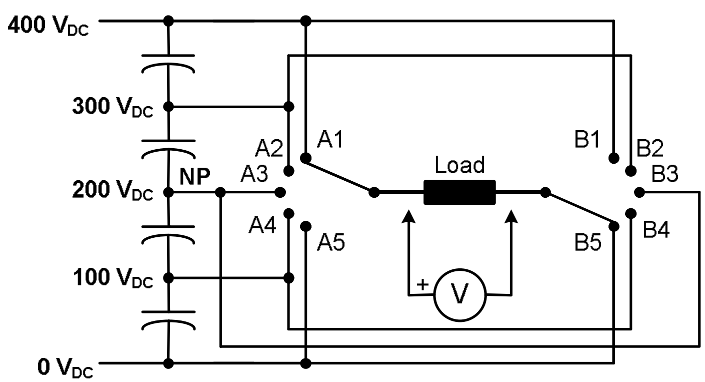
- 5-Level ANPC VSI
- Phase output voltages





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

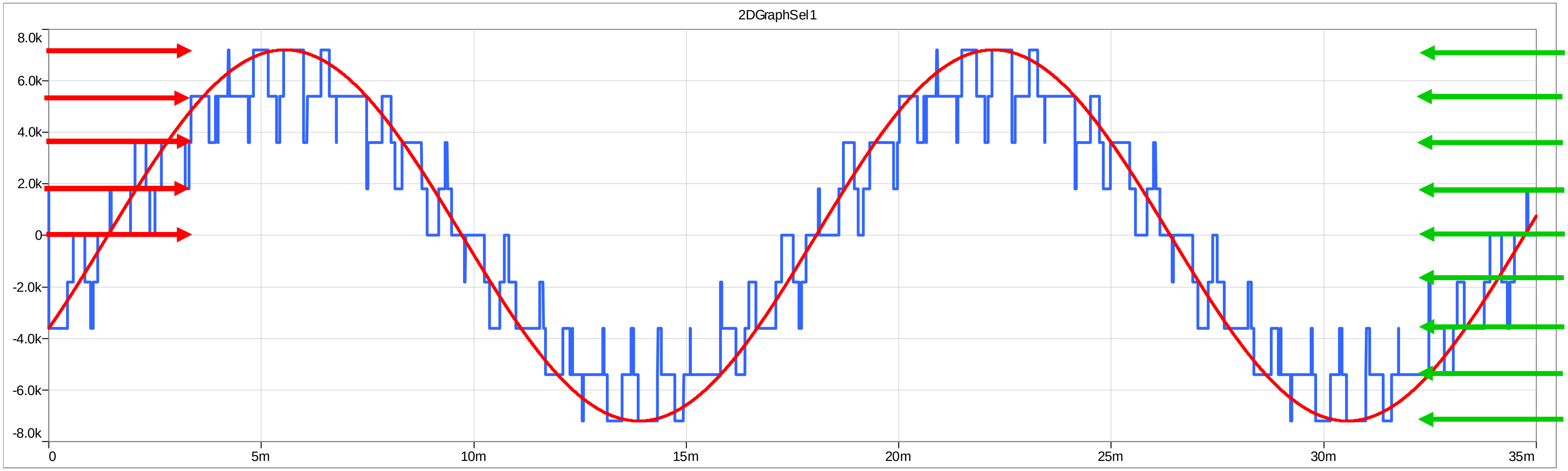
Number of Levels, n

5

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

9

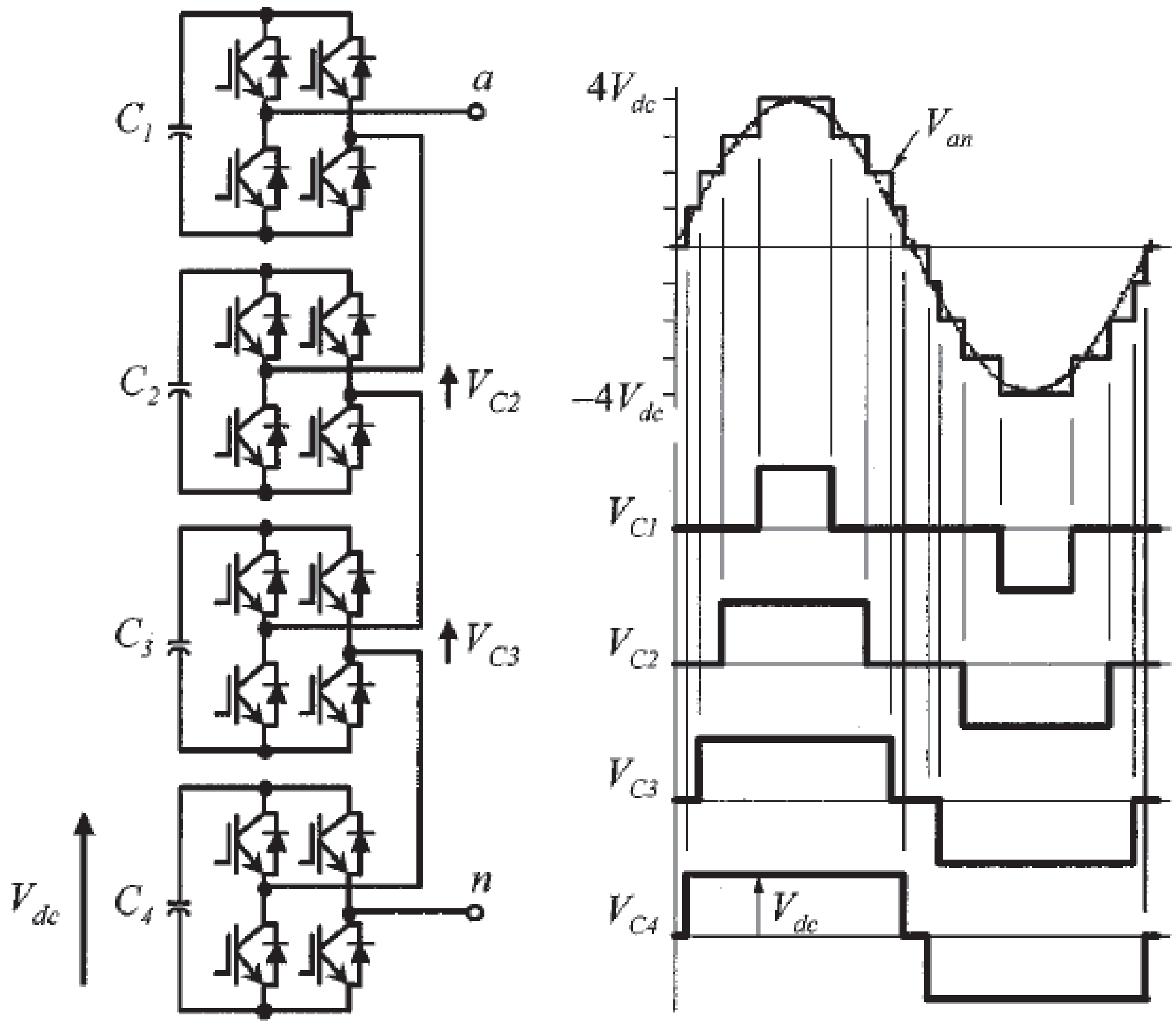
5-Level Waveform, Line-to-Line



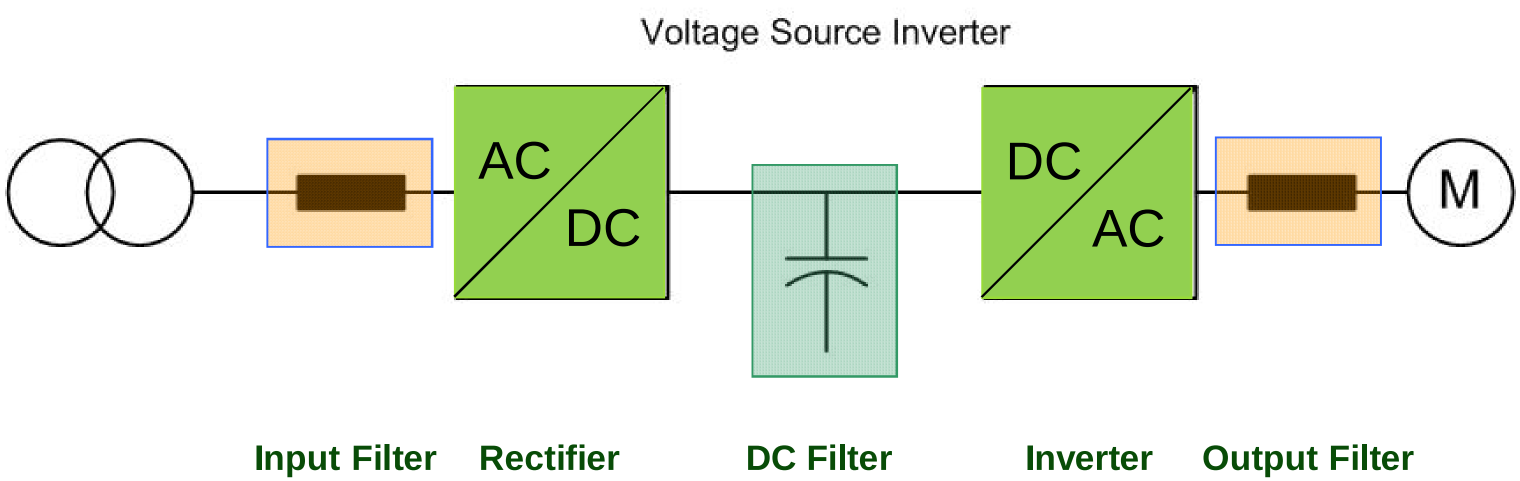
5-Levels

9-Steps

Cascaded H-Bridge

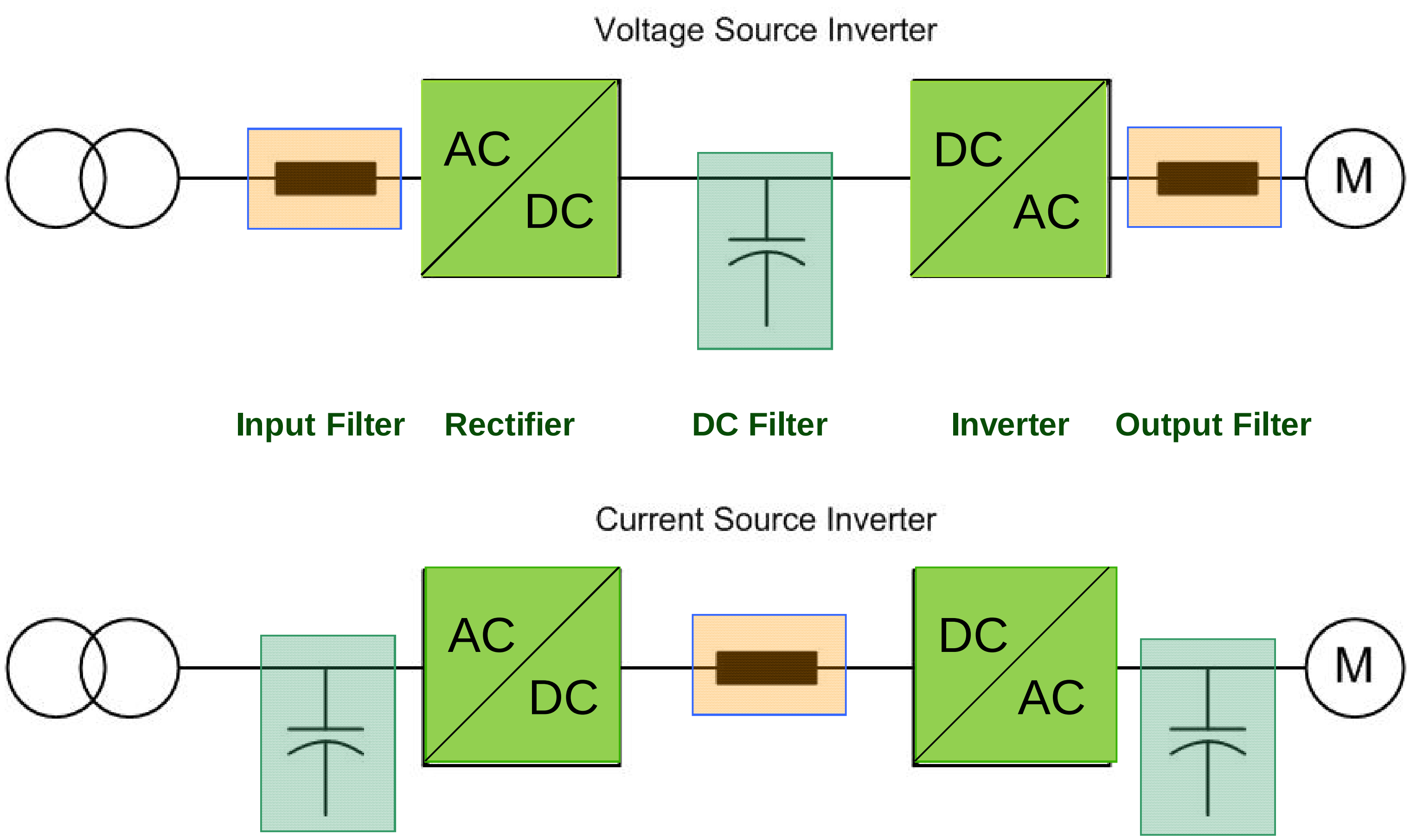


How are VSI and CSI similar?

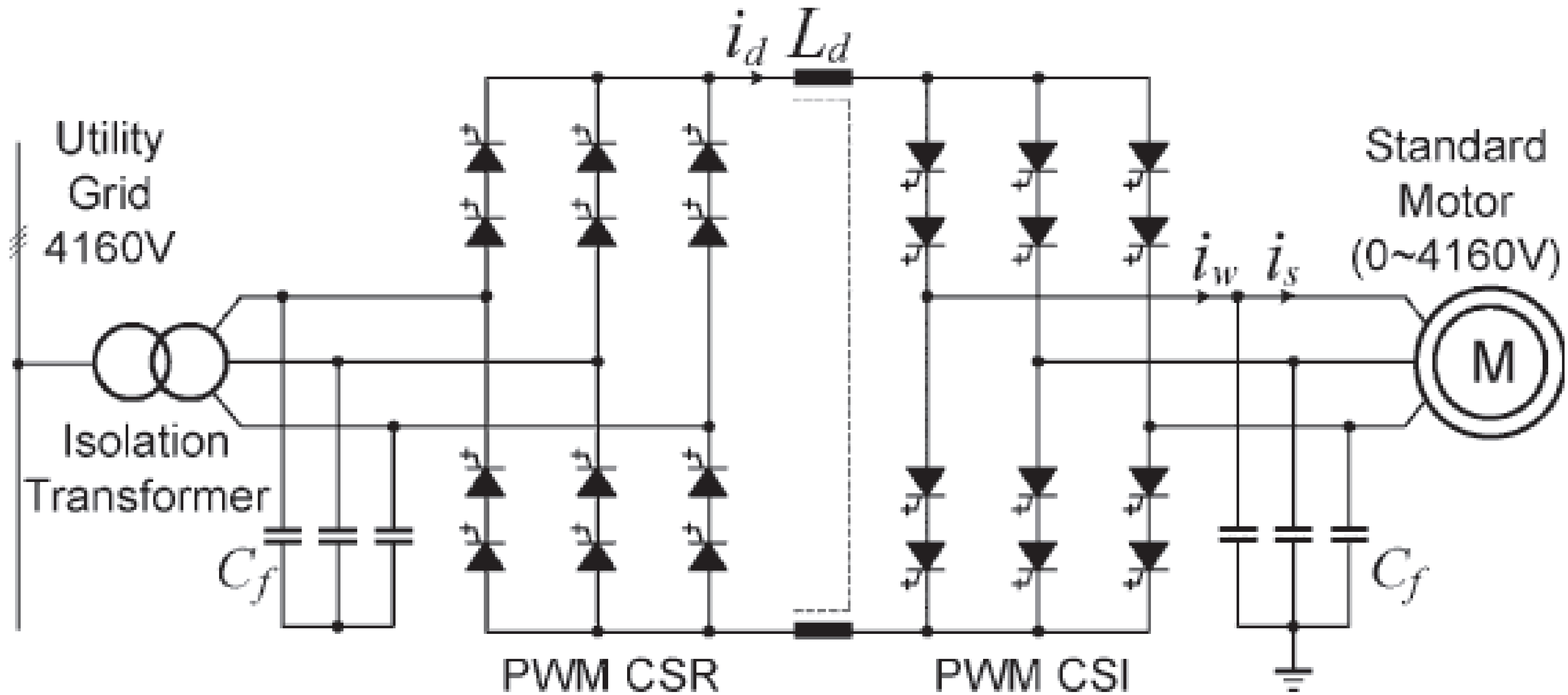


ABB

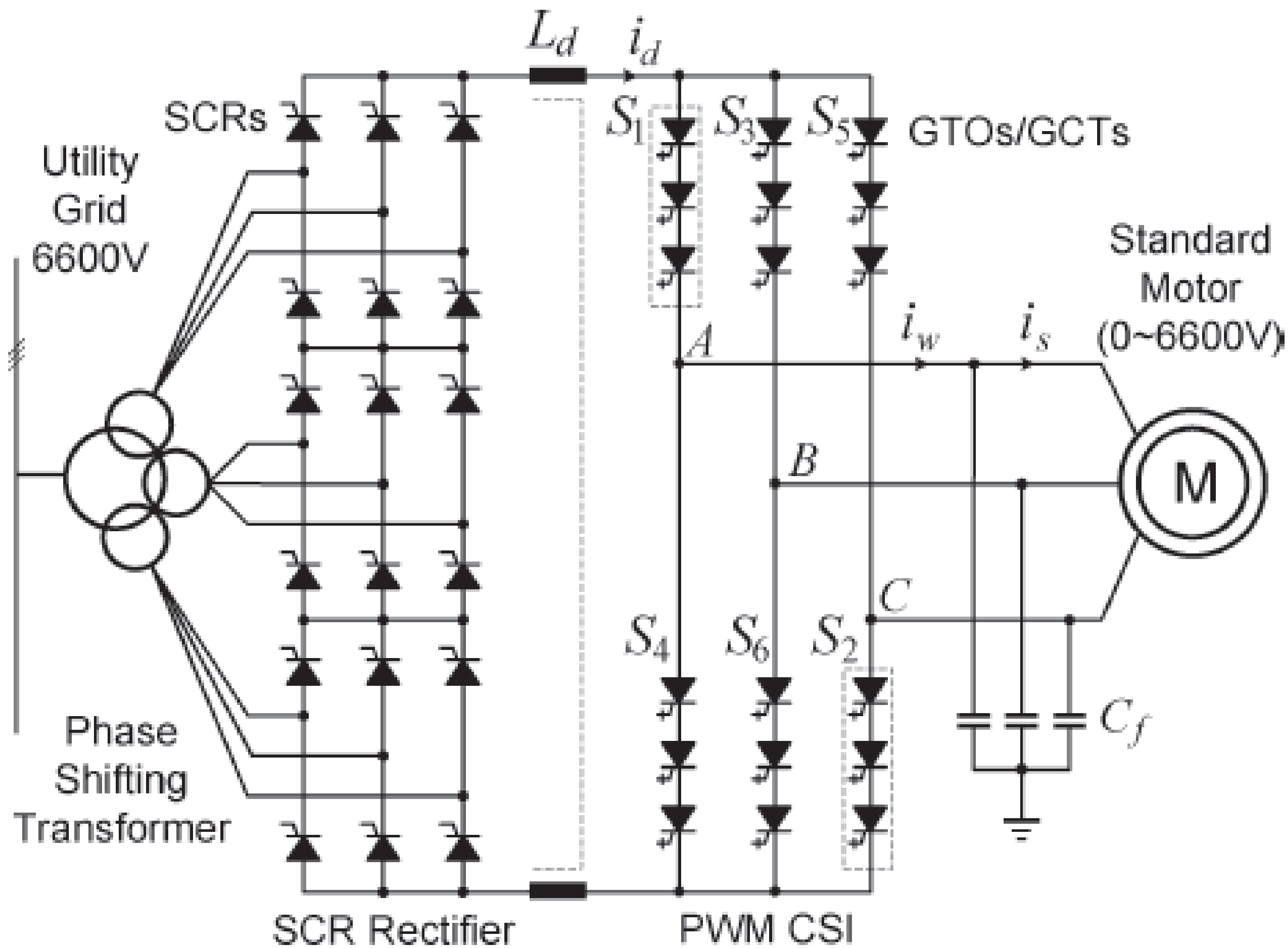
How are VSI and CSI similar?



CSI, PWM Converter, Isolated

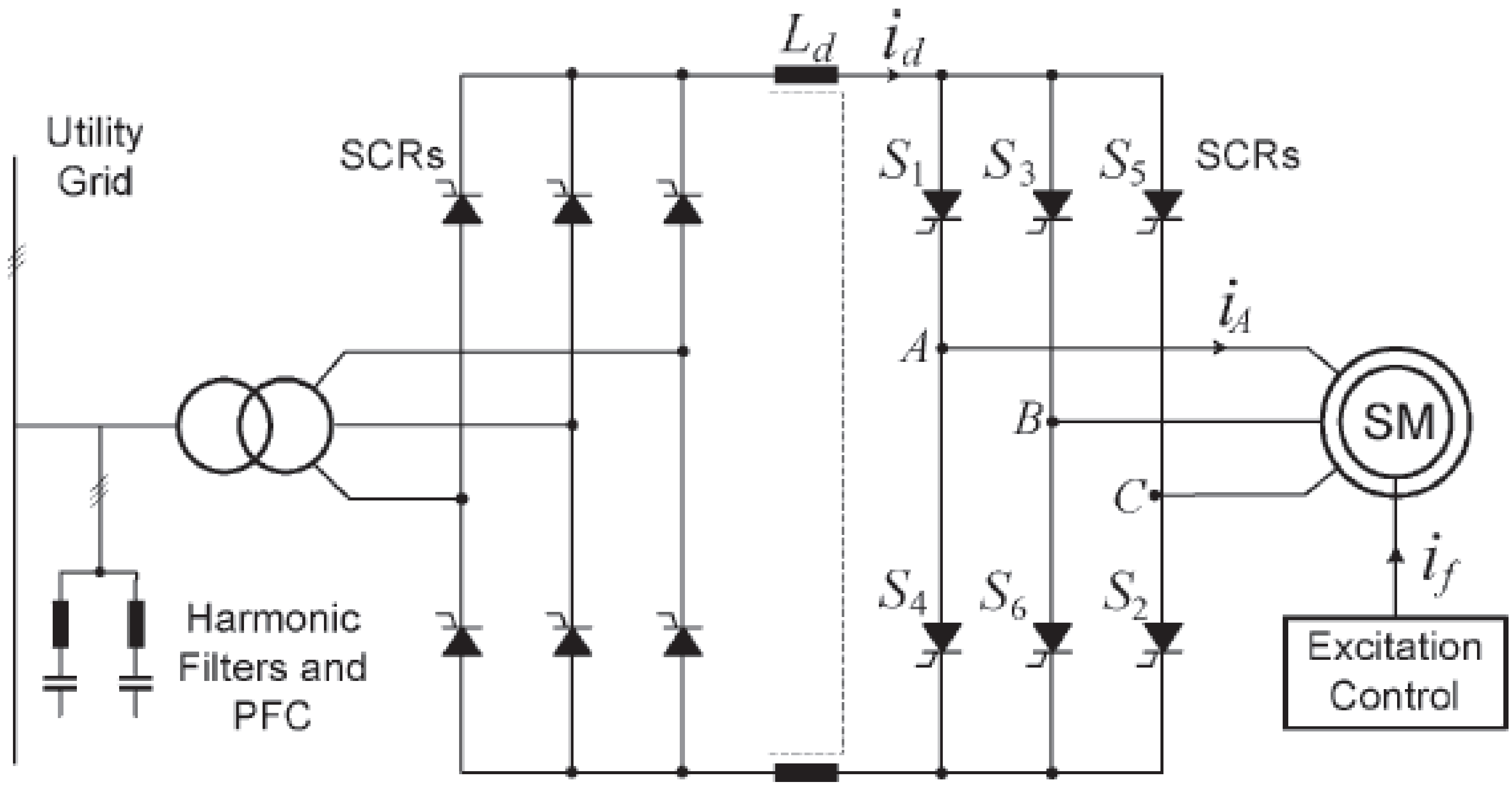


CSI, 18P Converter, Isolated

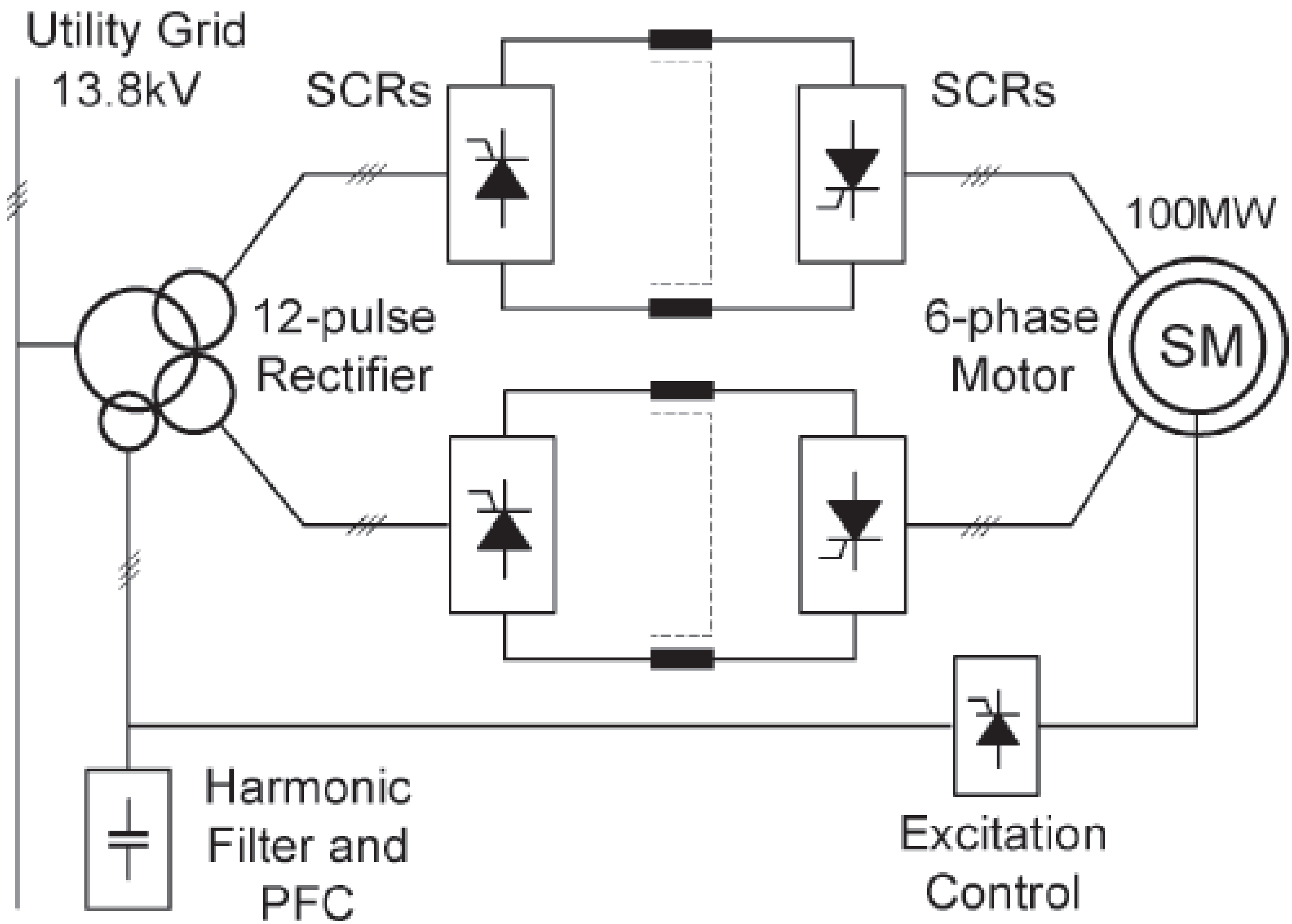


LCI, PWM Converter, Isolated

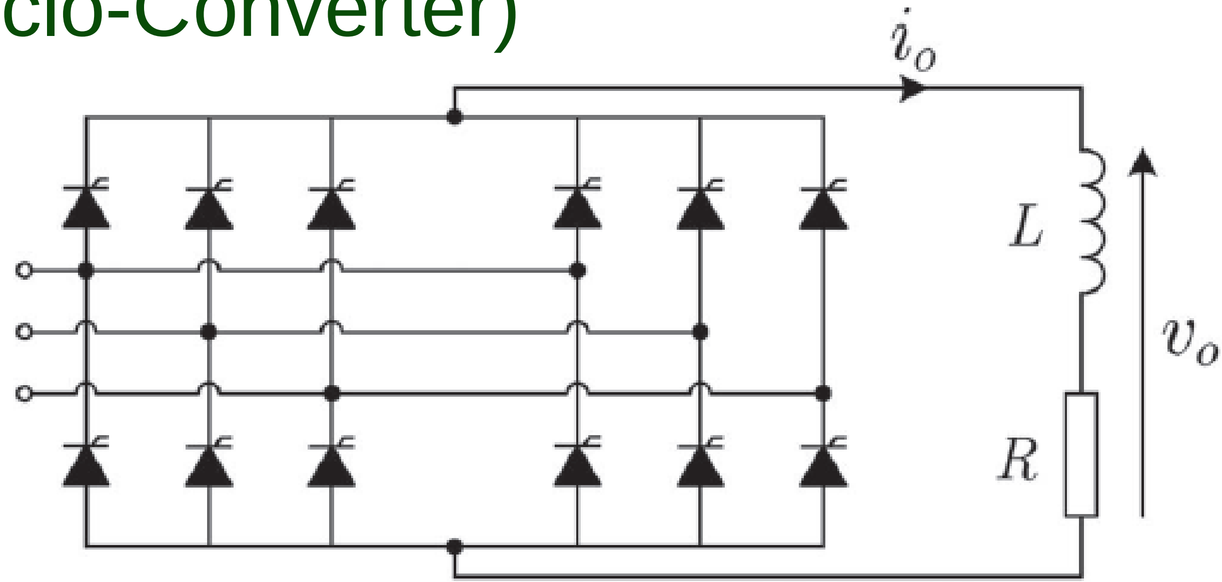
Load Commutated Inverter



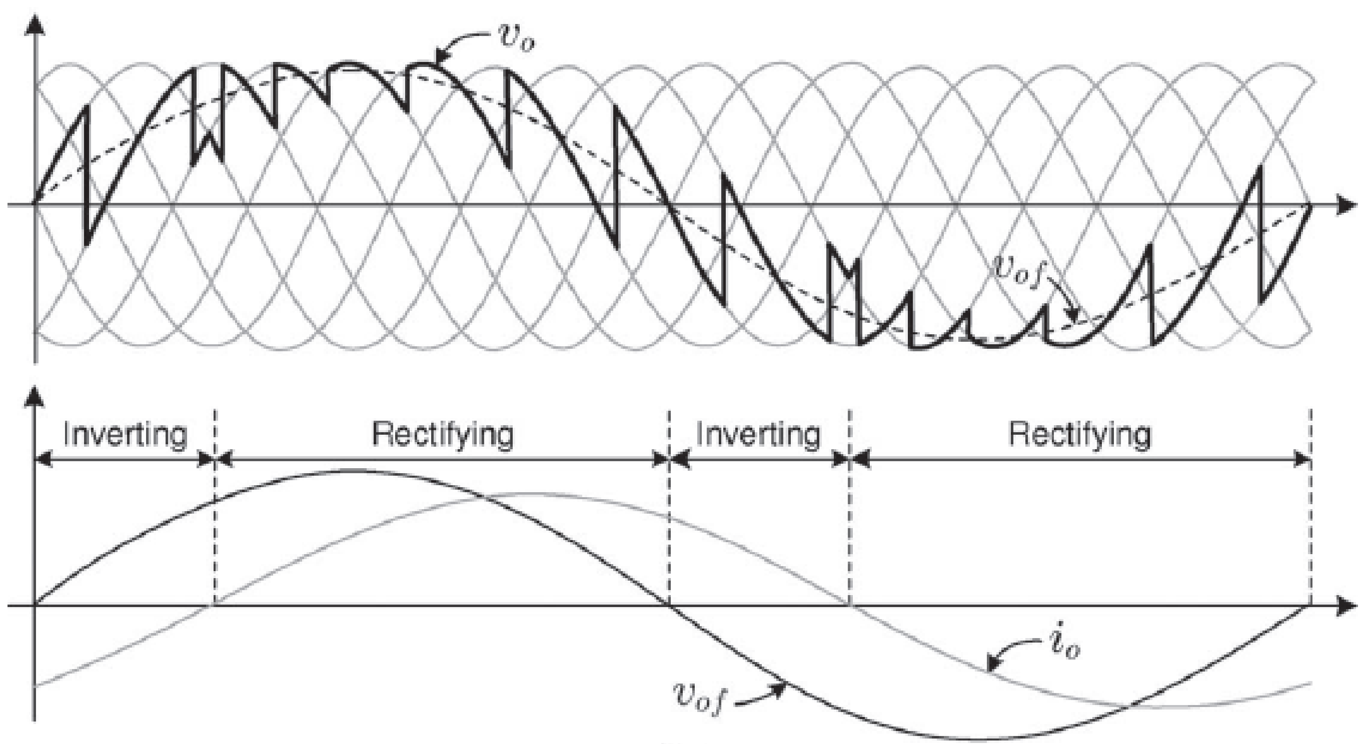
LCI, 12P Converter, Isolated



6P CCV (Cyclo-Converter)

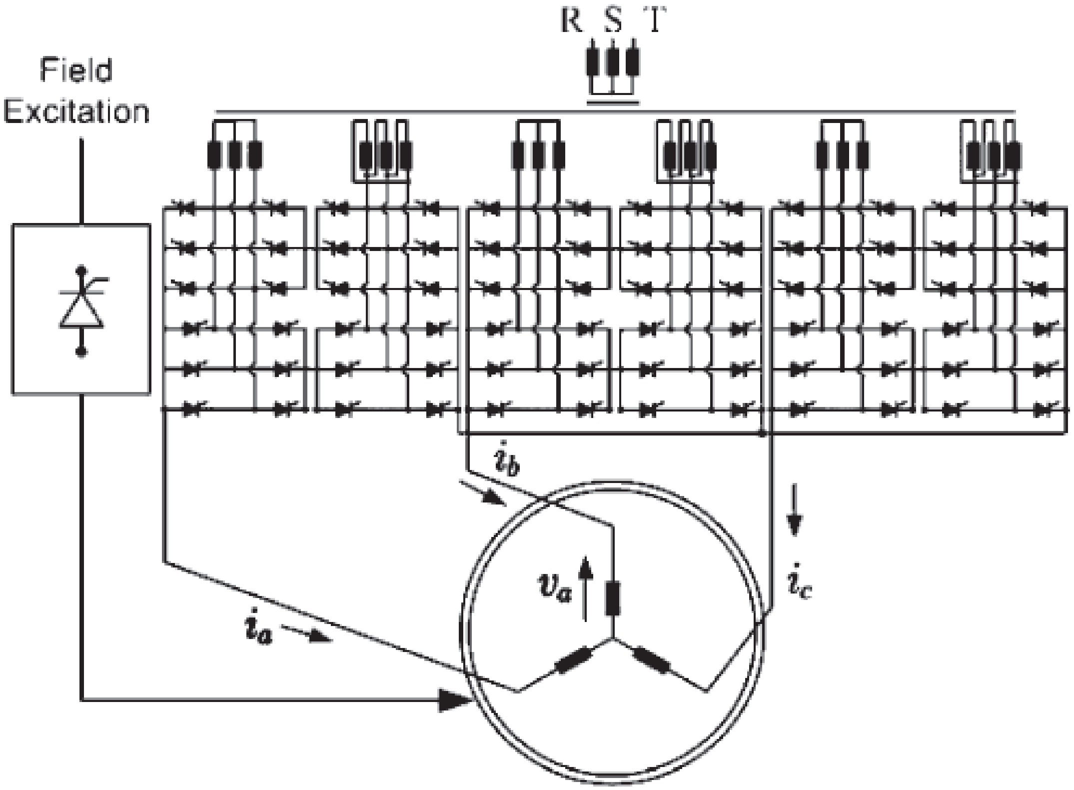


(a)

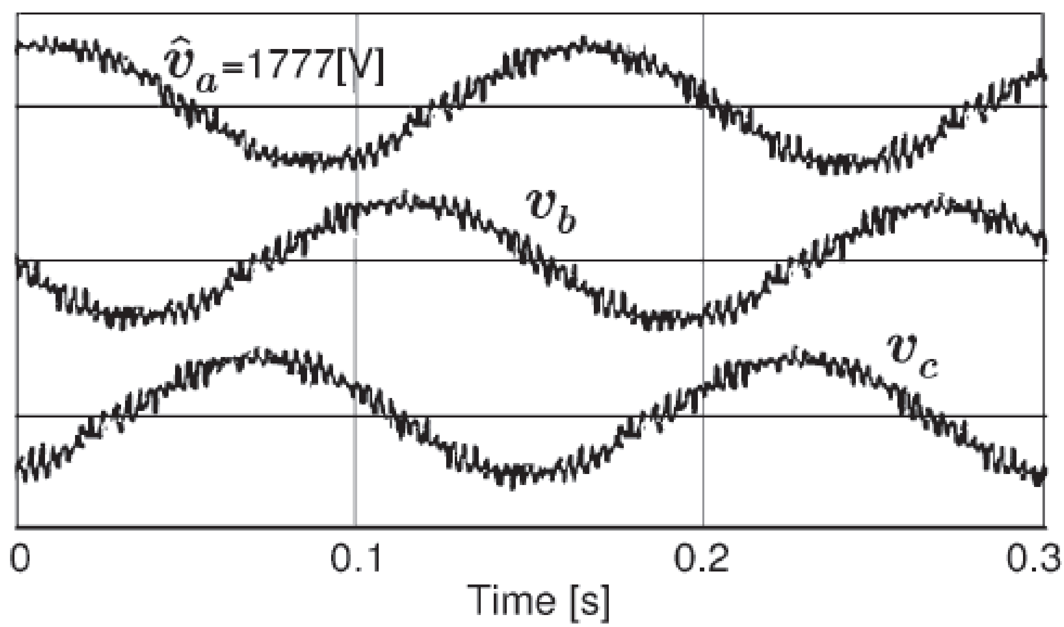


(b)

12P CCV


R S T
Field
Excitation
i_b
i_c
v_a
i_a

(a)

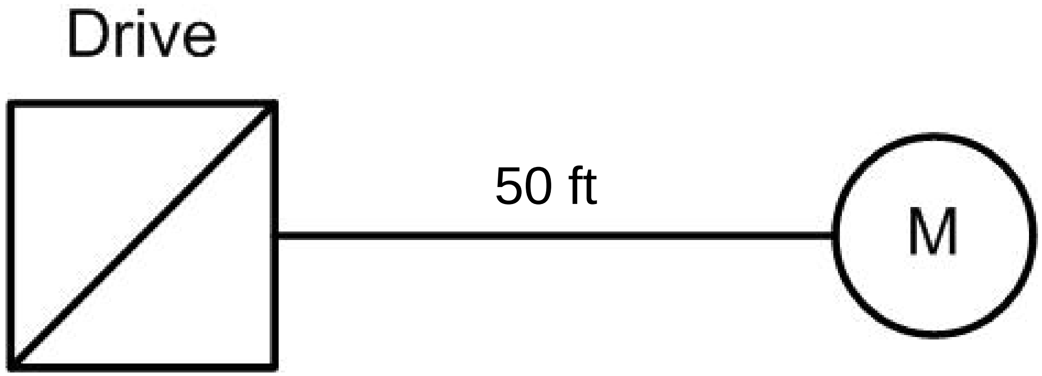

$\hat{v}_a$=1777[V]
v_b
v_c
0
0.1
0.2
0.3
Time [s]

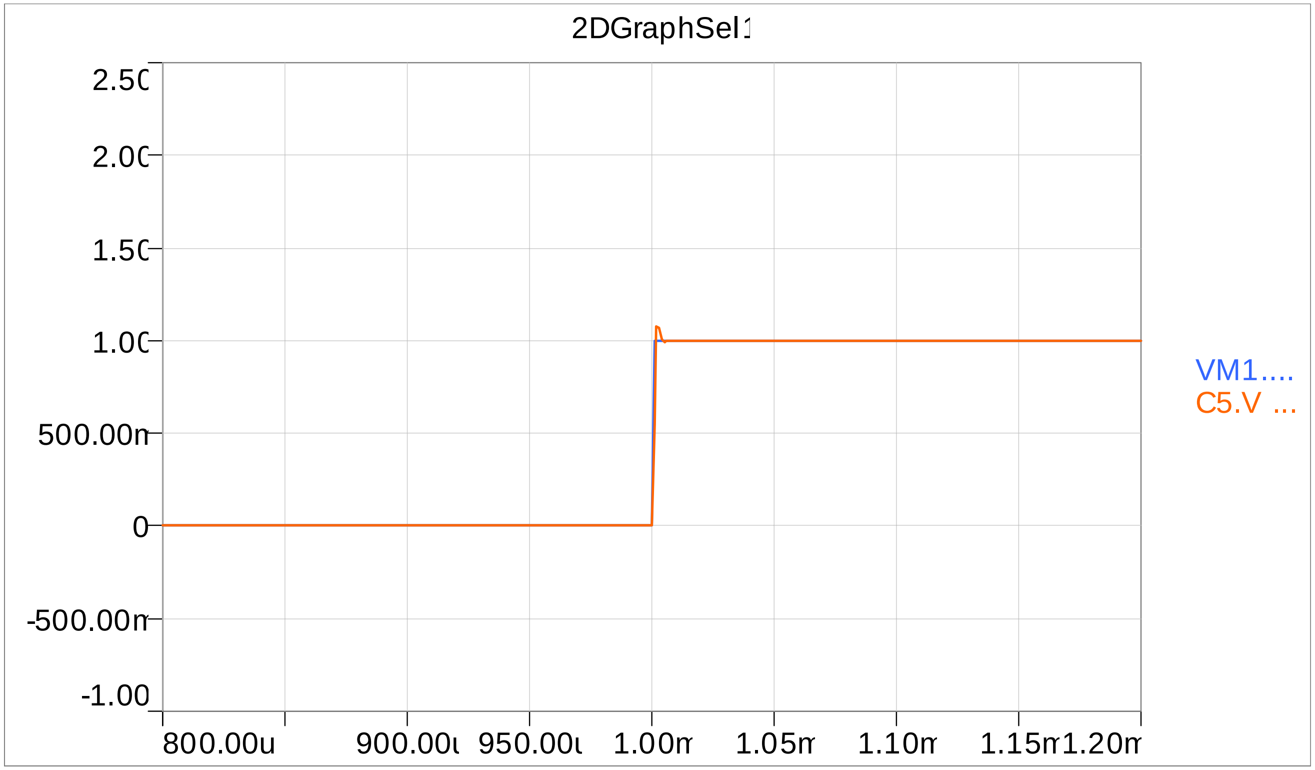
(b)

Reflected Waves

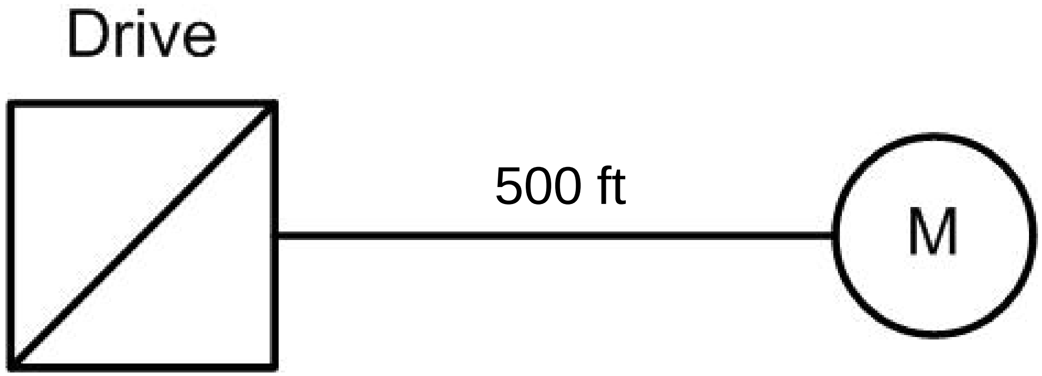
- Affected by:
  - Length of cable between drive and motor
  - Rate of rise of voltage (dV/dt)
  - Voltage step size
  - Pulse width

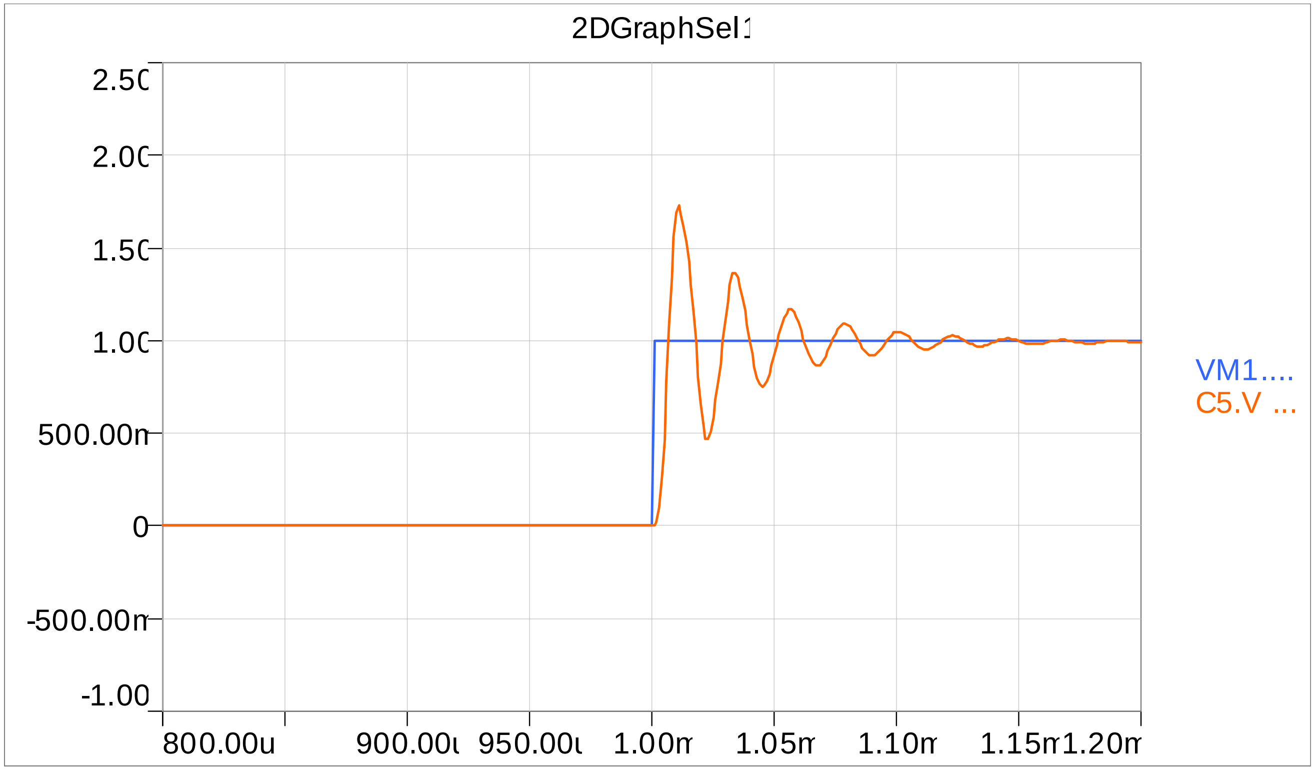
short


Drive
50 ft
M

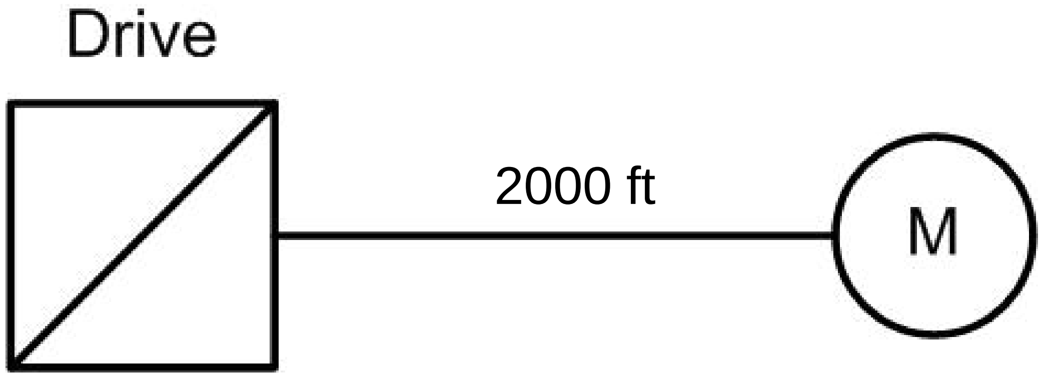

2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

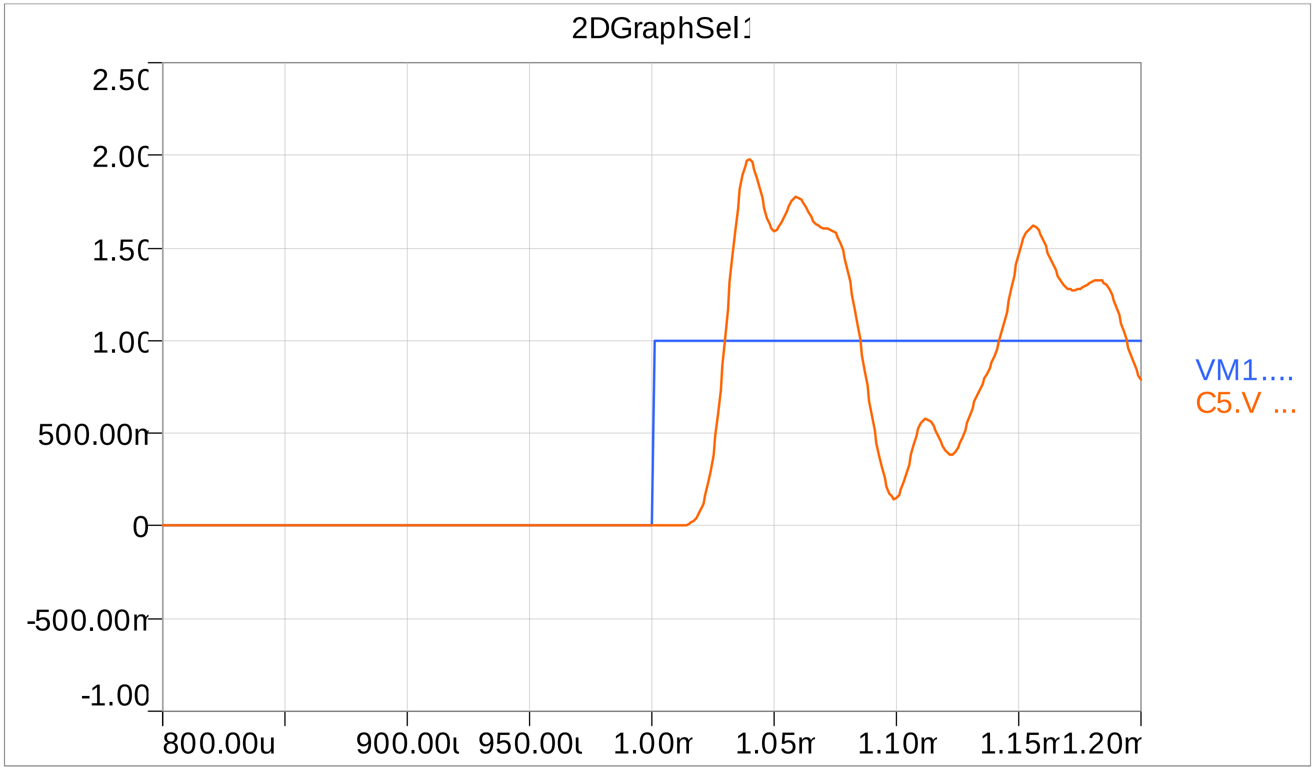
longer


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 ...

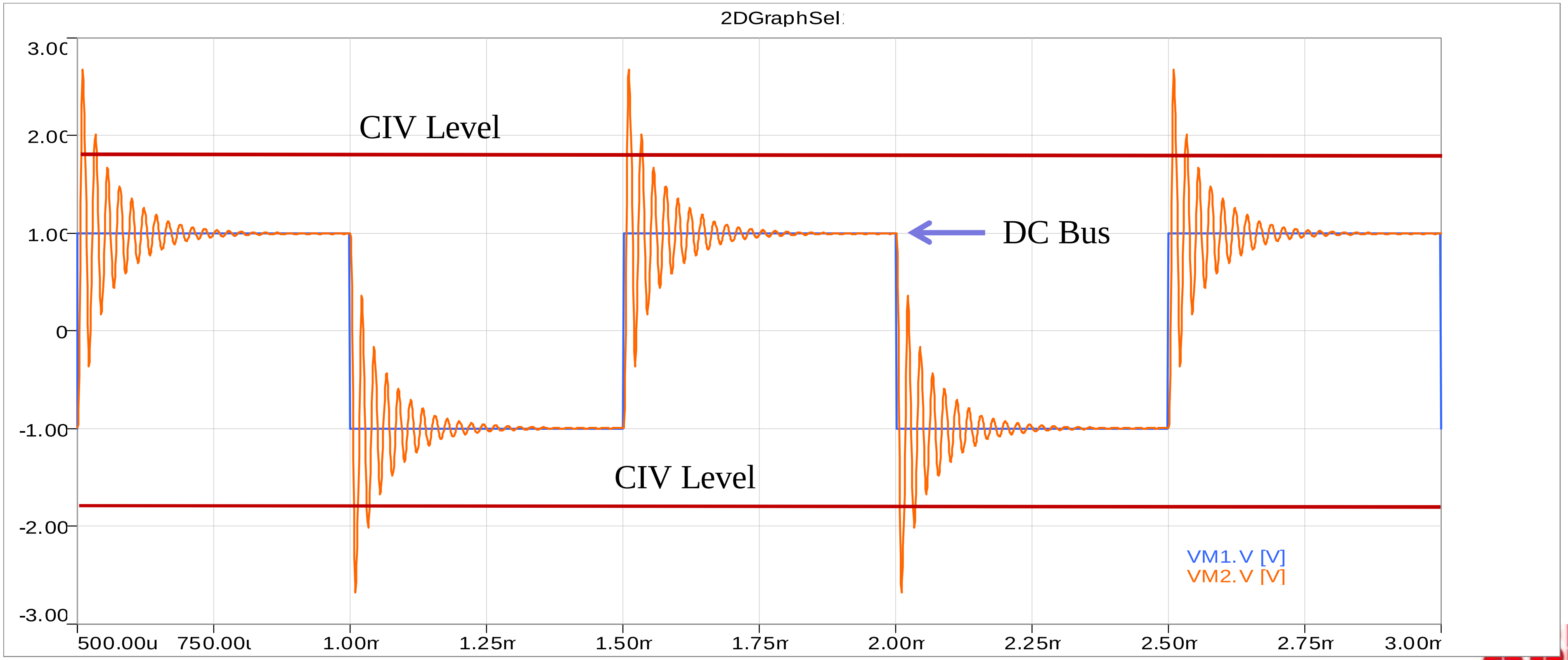
longest


Drive
2000 ft
M

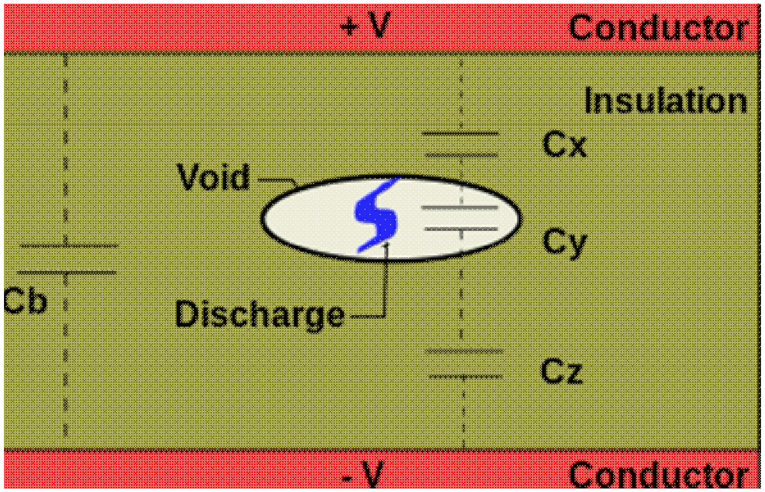

2DGraphSel1
2.50
2.00
1.50
1.00
500.00m
0
-500.00m
-1.00
800.00u
900.00u
950.00u
1.00m
1.05m
1.10m
1.15m
1.20m
VM1....
C5.V ...

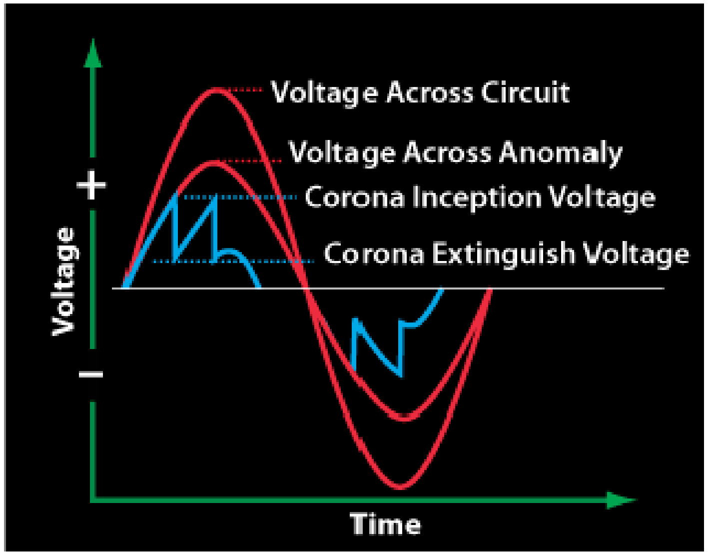
When does PD (Corona) occur?

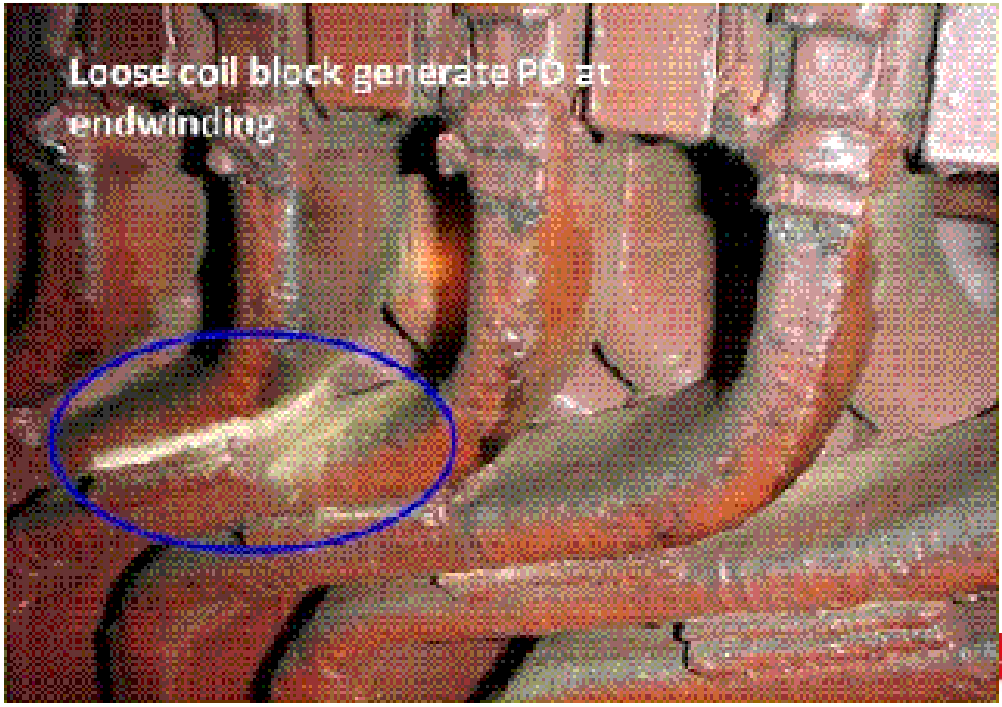
- Reflected wave produces voltage peaks at the motor terminals
- Terminal voltage in excess of the insulation system CIV level will begin the PD / CORONA process
- Excessive voltage causes partial discharges / corona that attacks insulation materials



Partial Discharge

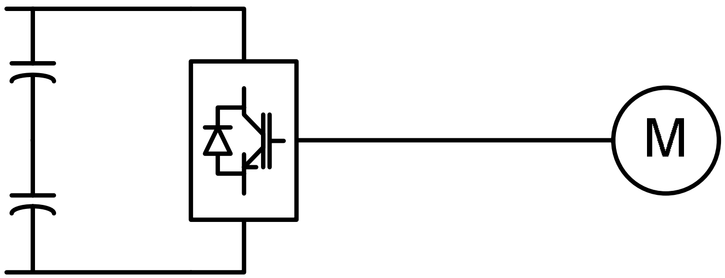




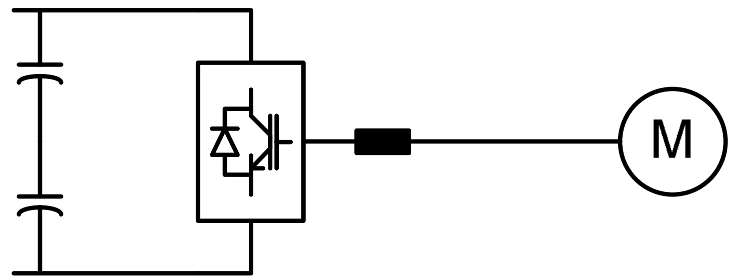


How can we reduce the dV/dt?
Filtering

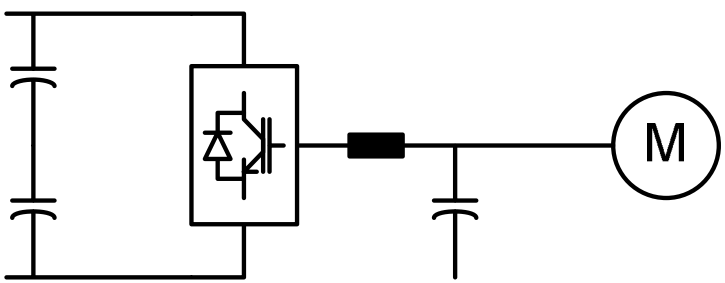
* Used in MV drives



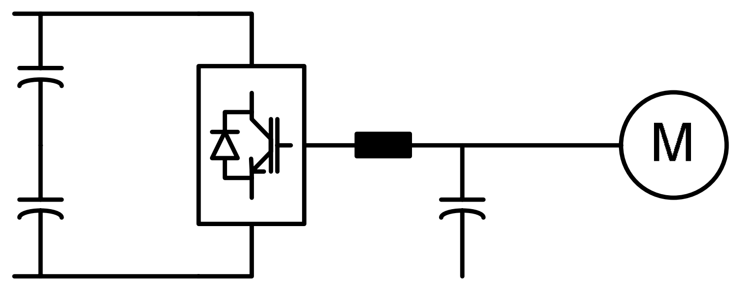
Basic Inverter and Motor



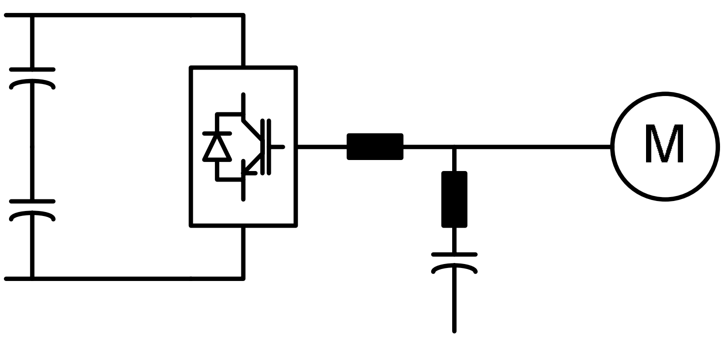
Output Load Reactor



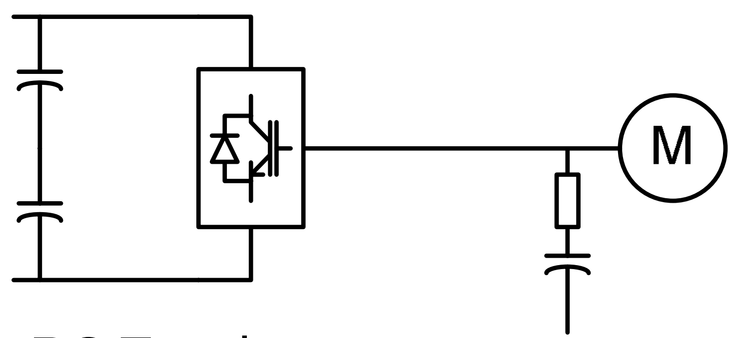
*dV/dt Filter



*Broadband Sinewave Filter

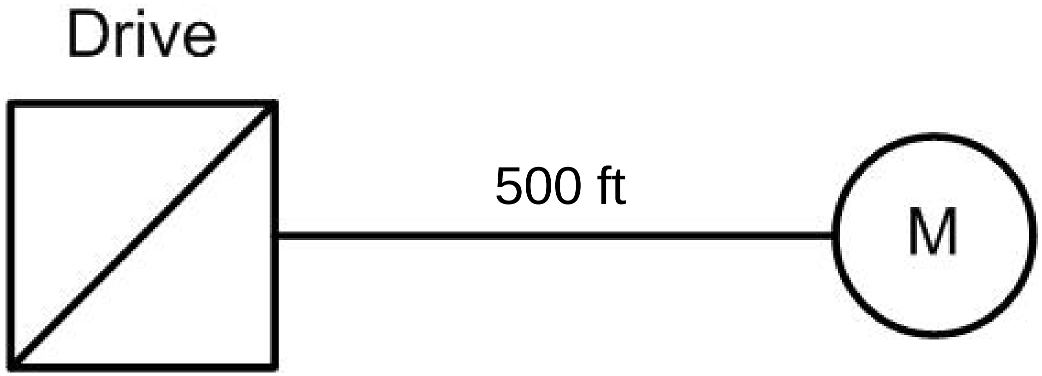


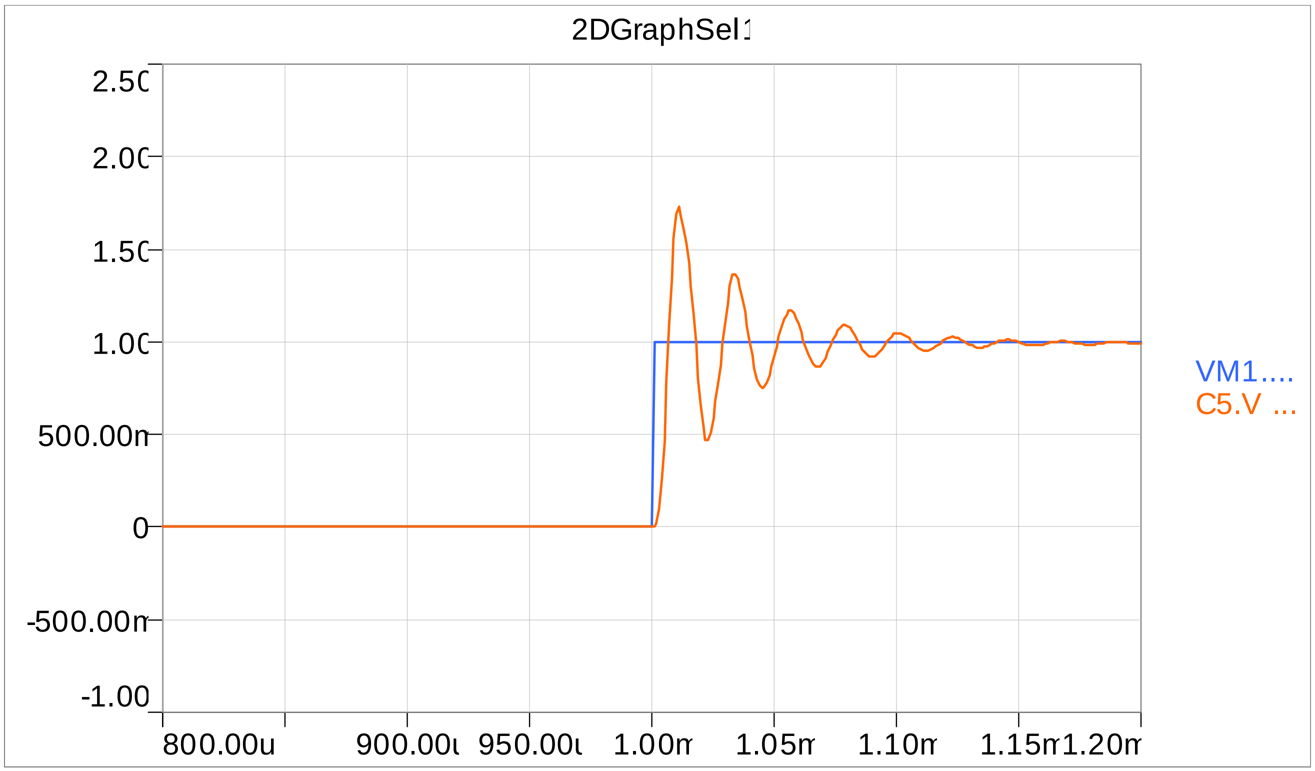
Sinewave Filter



RC Terminator

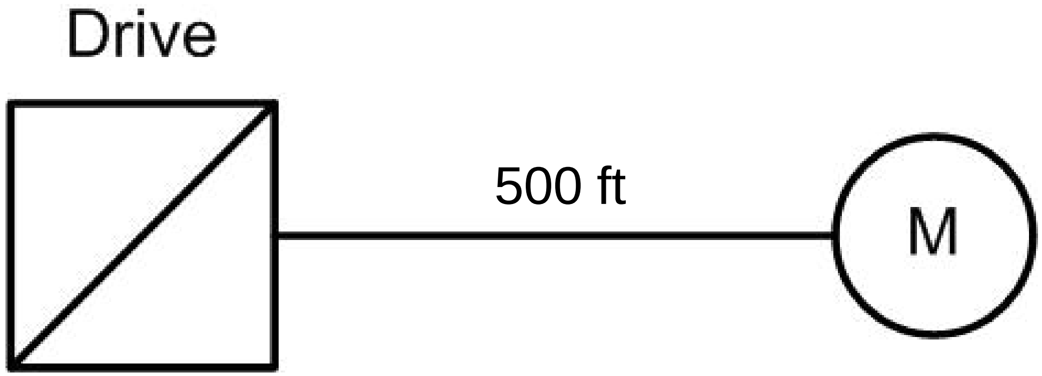
Step size of 100%

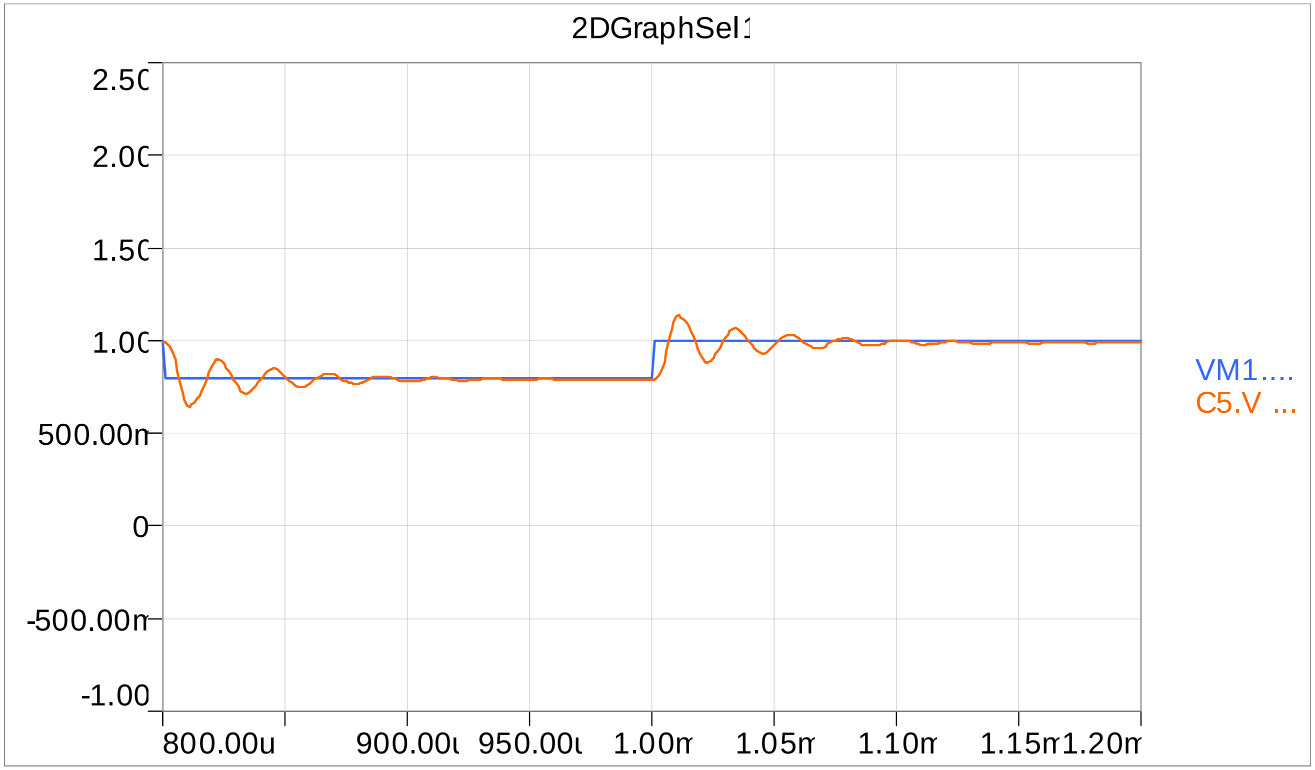




Vpk is about 1.7x the Voltage step size

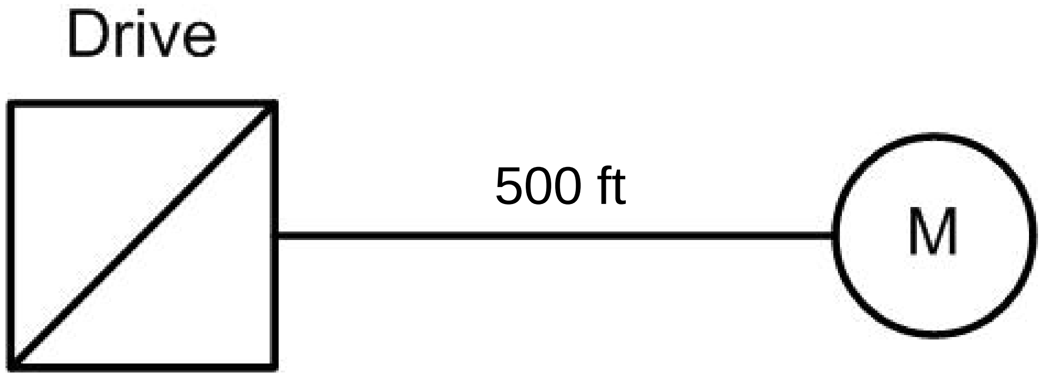
Step size of 20%

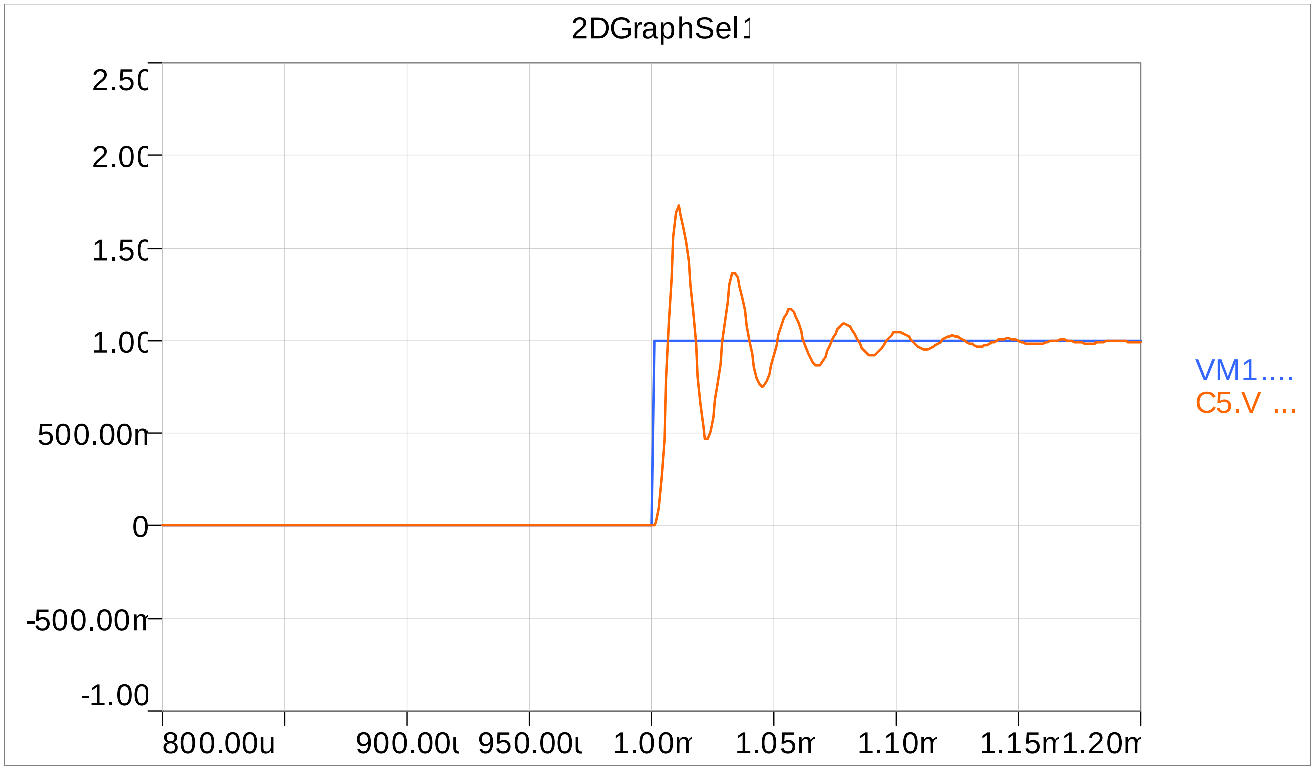




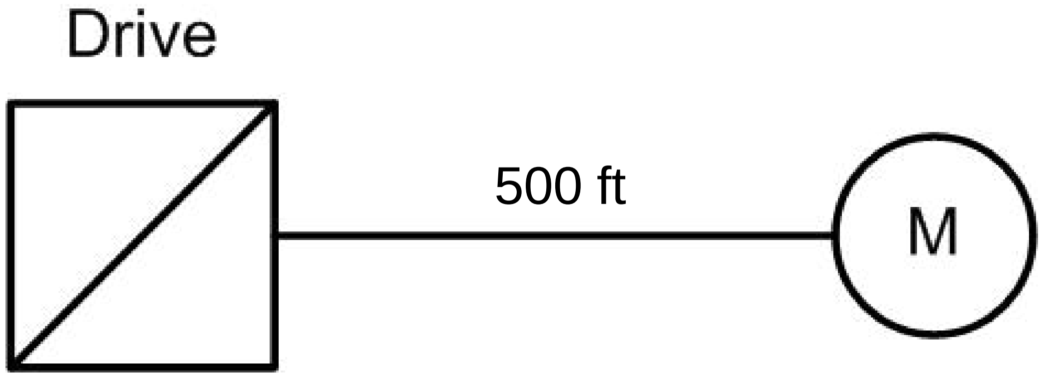
Have small voltage steps

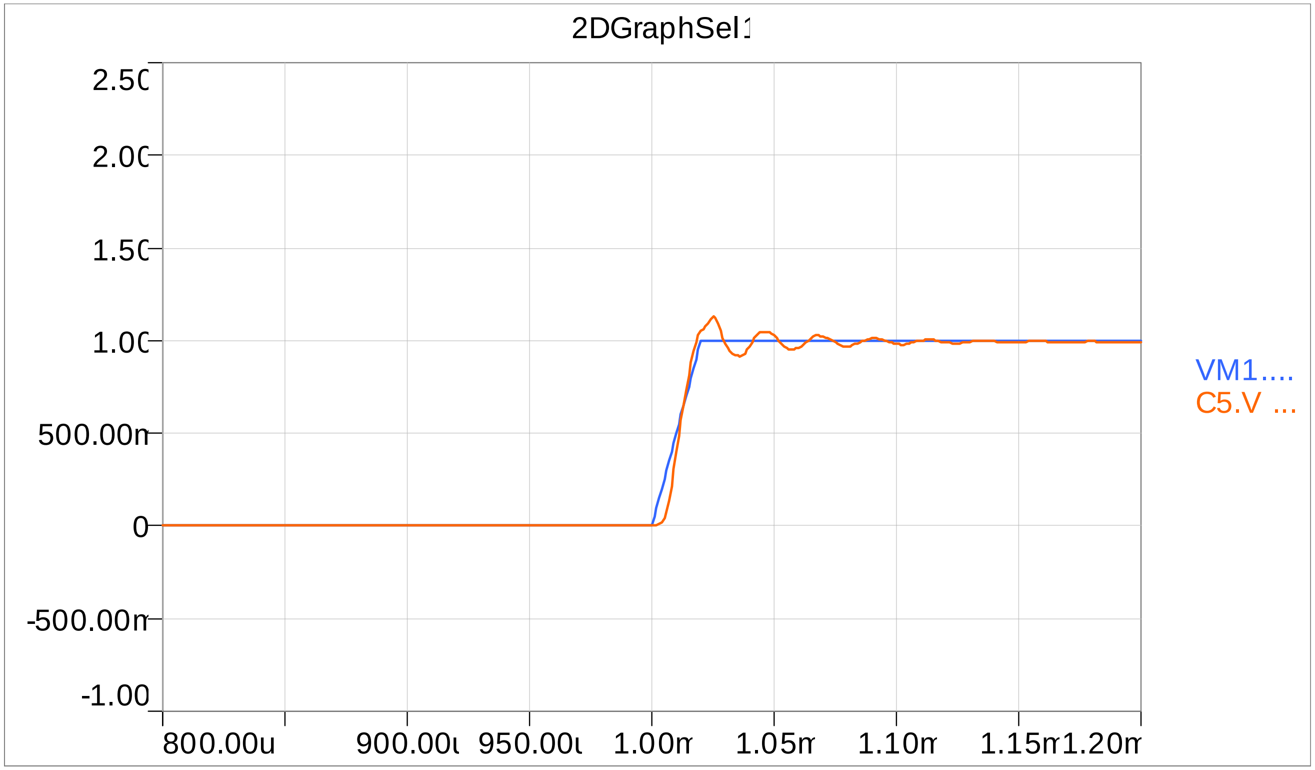
dV/dt = 10,000 V/us



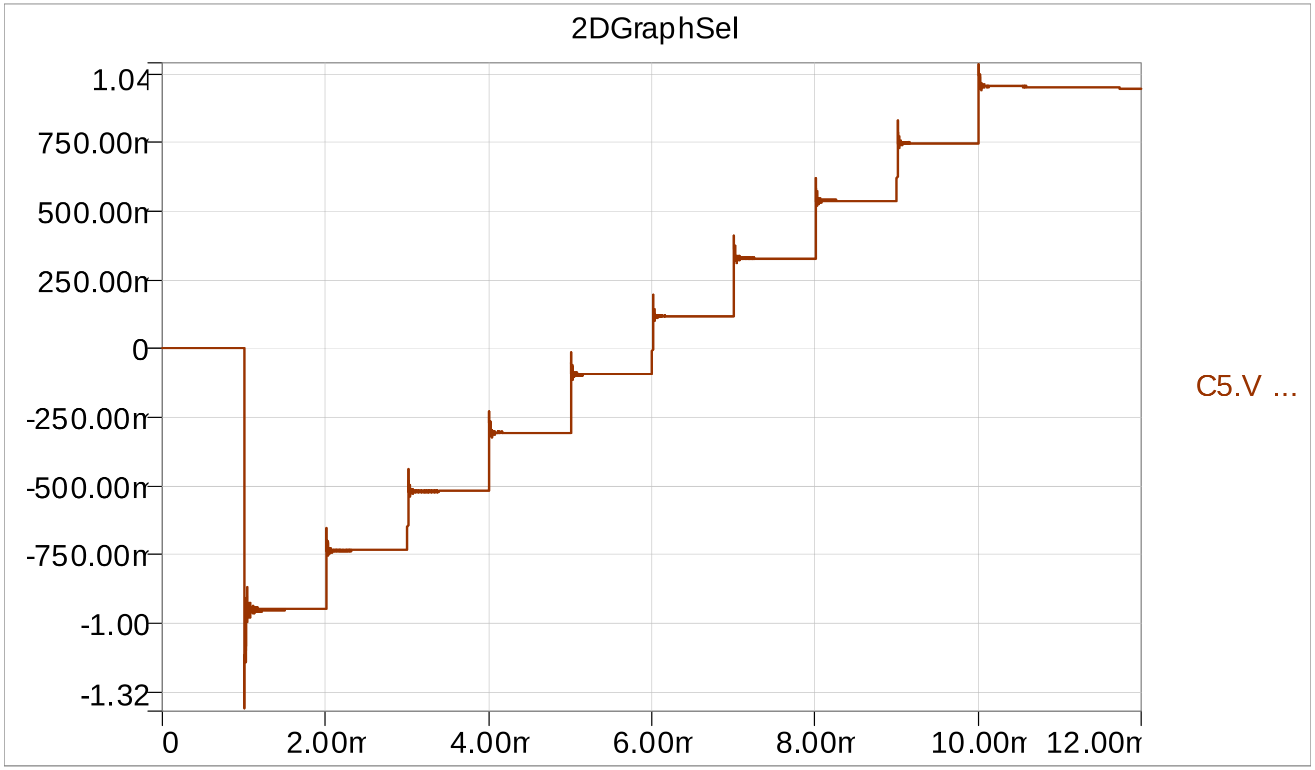


dV/dt = 500 V/us

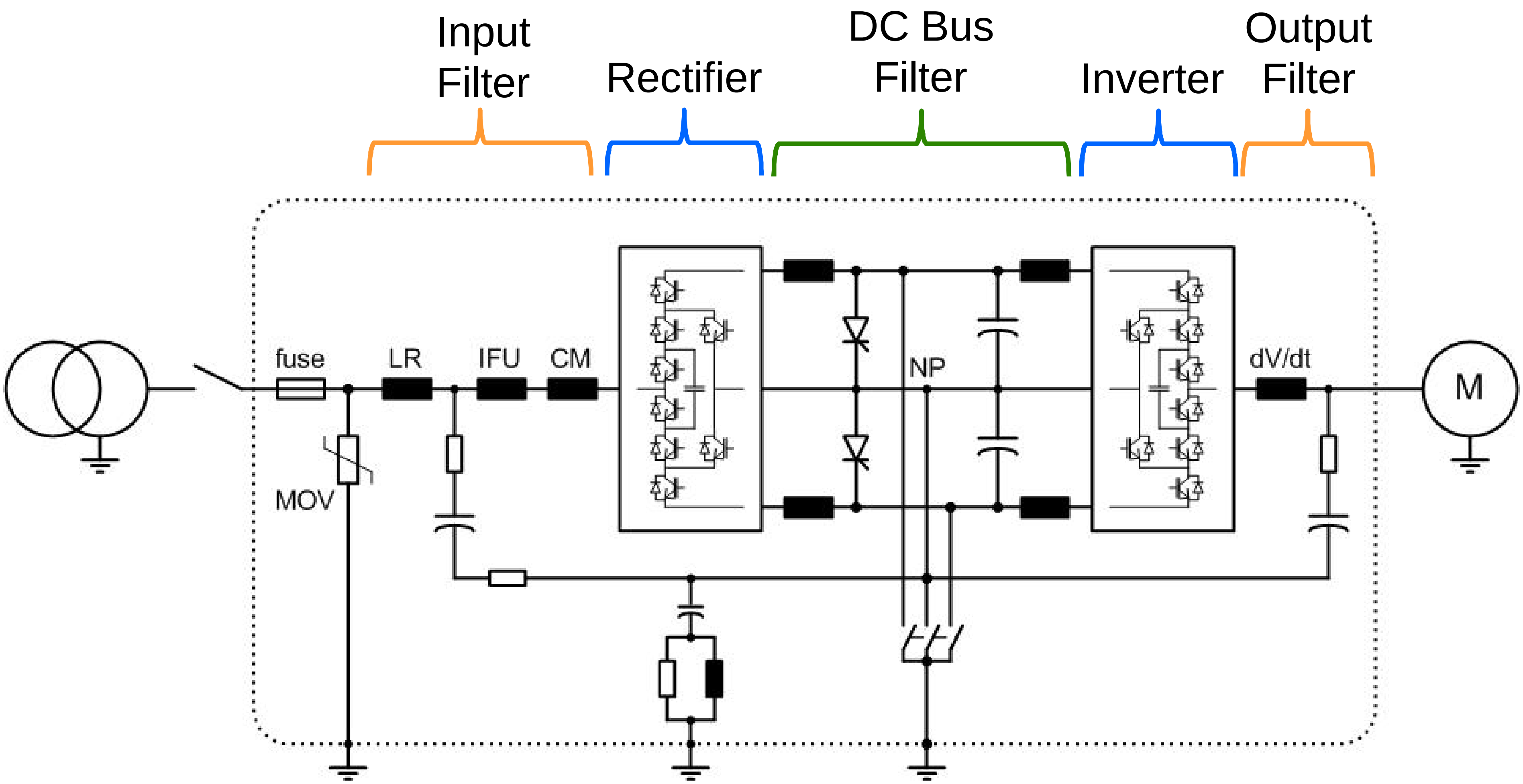

Drive
500 ft
M


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 ...

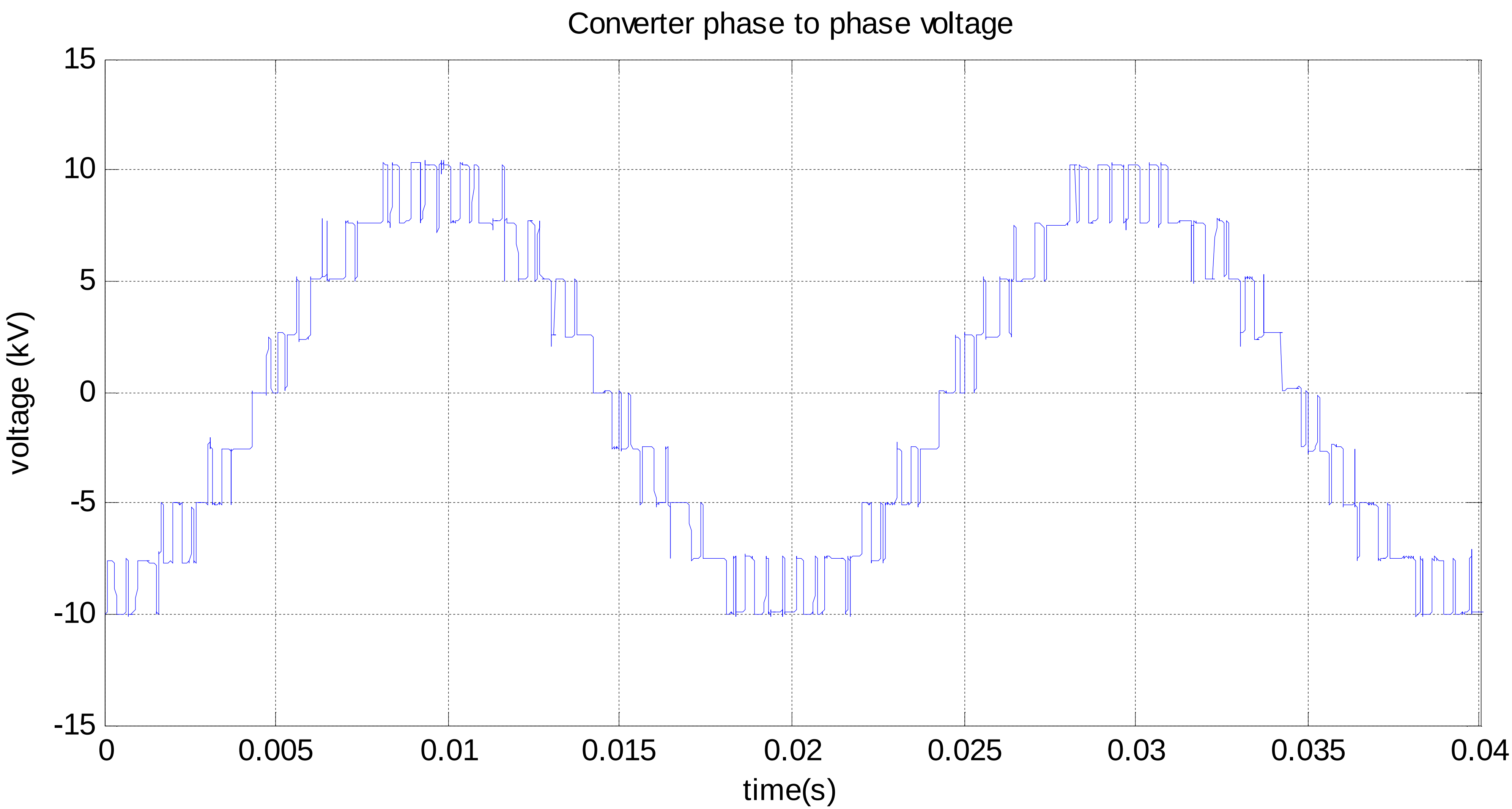
Multi-Step Approach, low dV/dt



Implementation in a MV Drive



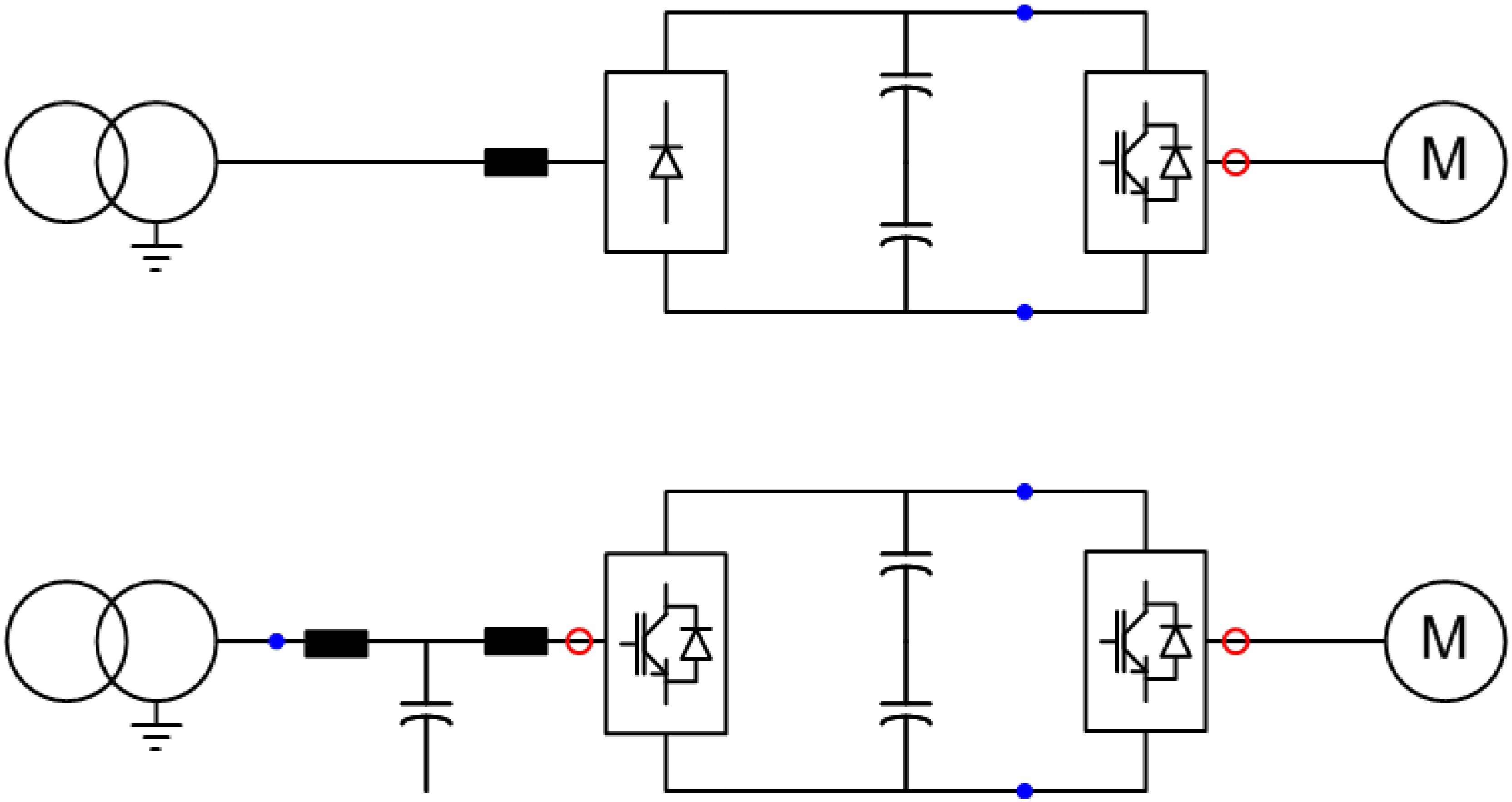
The n-level VSI topology
5-Level phase-to-phase voltage levels



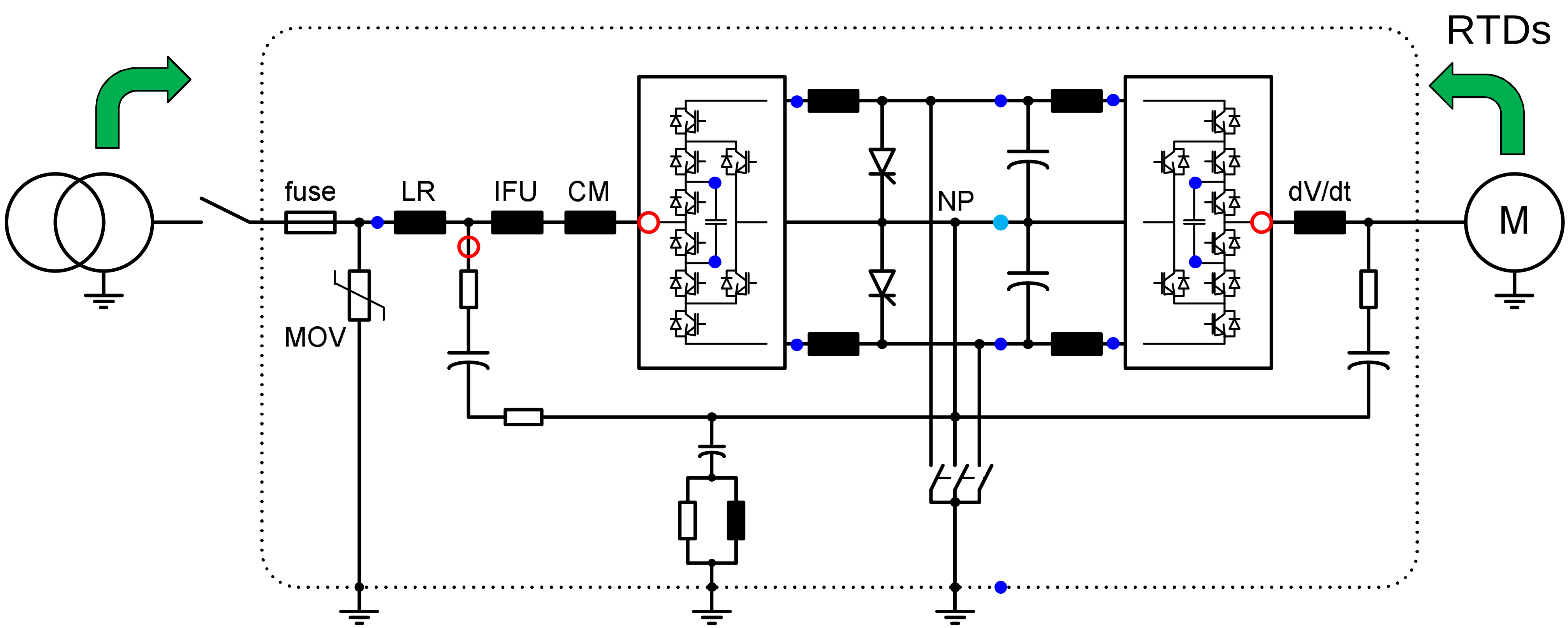
Protection

- 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

ABB

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

MV Drives

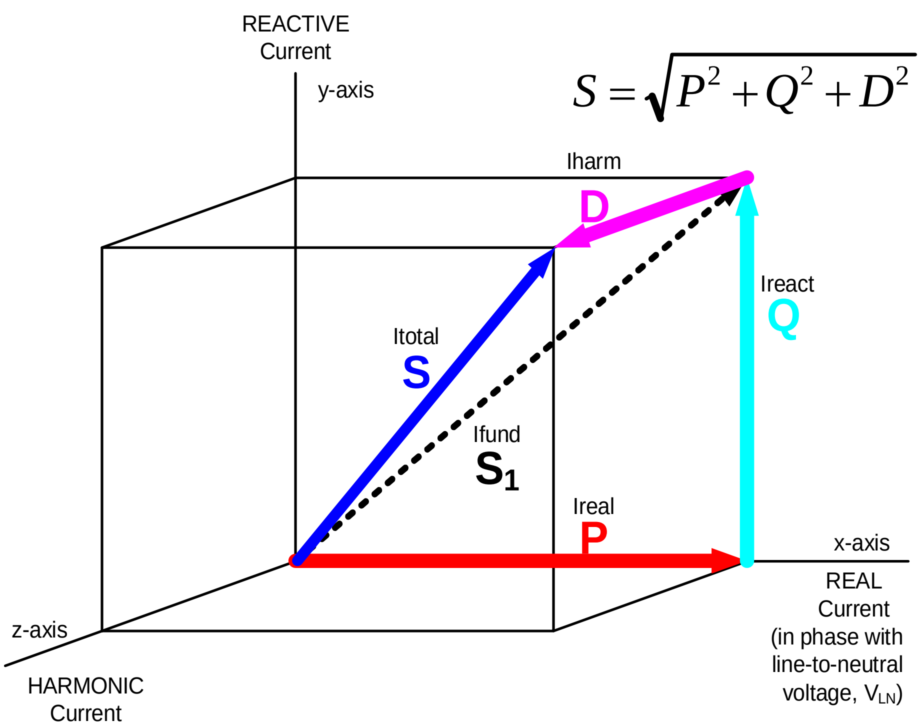
ACS 2000 4kV - 6.9kV

300 – 3,000 HP

ACS 6000 2.3kV, 3.3kV

4,000 – 31,000 HP

Questions?



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