

TeckChin & TeongWah, DMDR/Drives Seminar, 24-25 Sept 2014

Managing harmonics distortion with AC Drives

Power and productivity
for a better world™

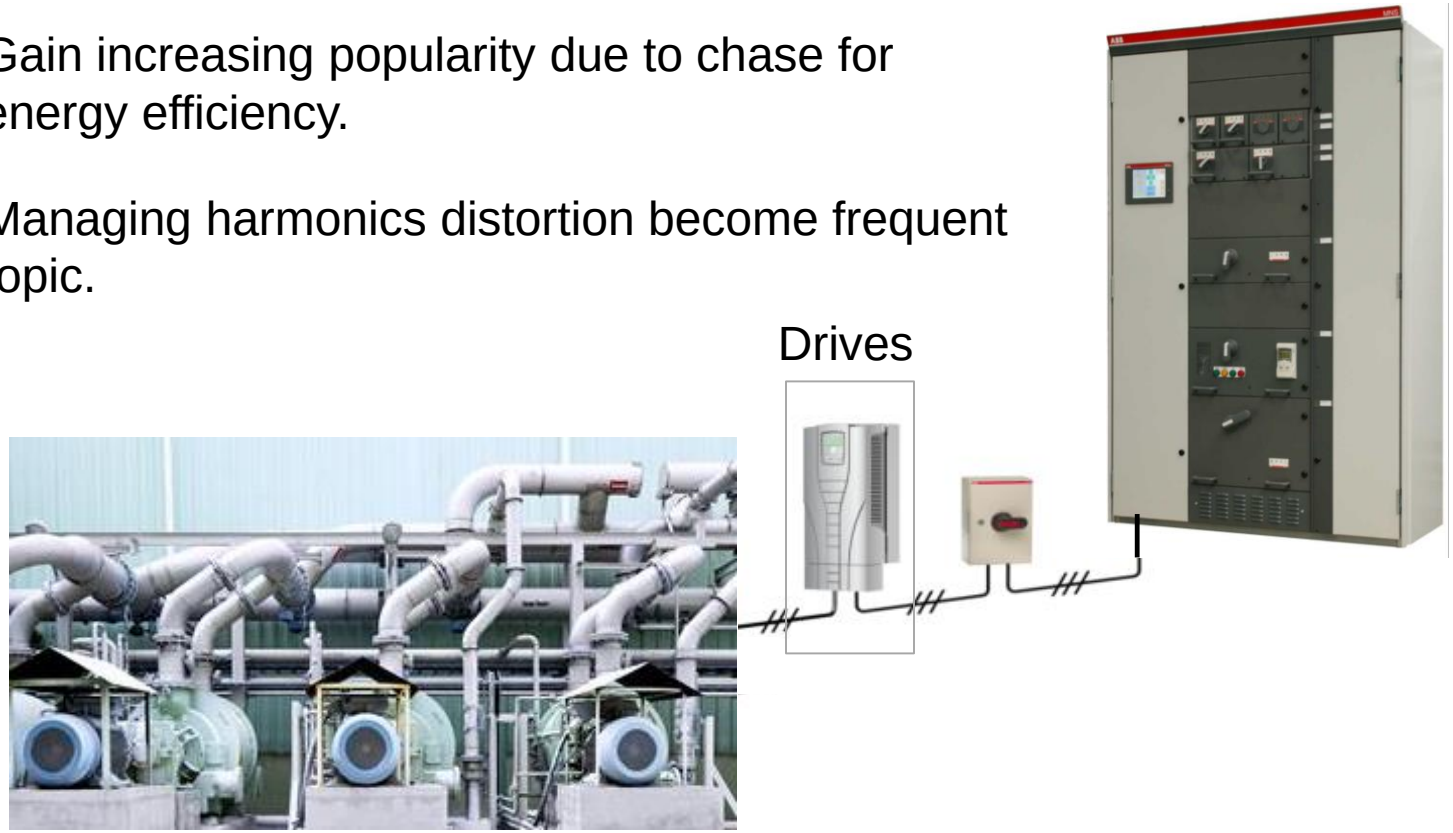
Contents

- Introduction
- AC Drives and current harmonics distortion
- Effects of harmonics
- Evaluation of harmonics
- What are the available solutions?
- How to choose the best solution?
- Case study

© ABB Group

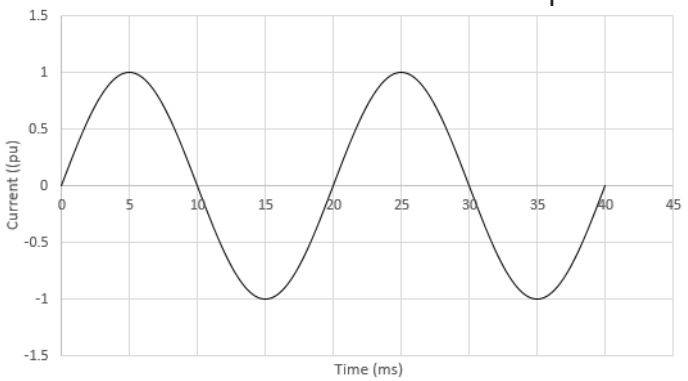
Introduction
AC Drives

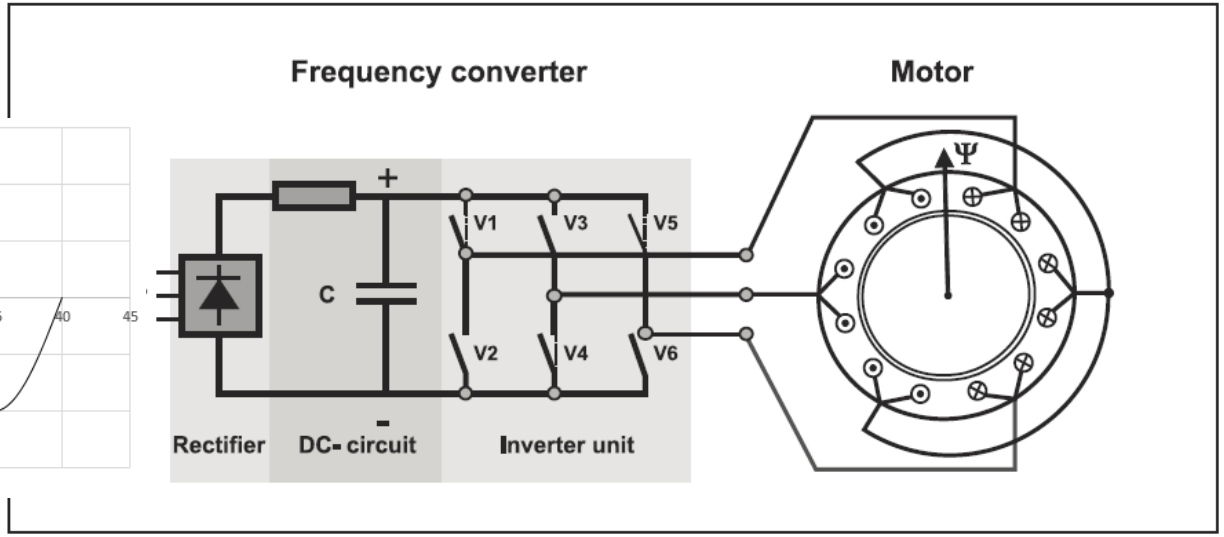
- AC drive is used to control the speed and torque of an AC induction motor.
- Gain increasing popularity due to chase for energy efficiency.
- Managing harmonics distortion become frequent topic.



© ABB Group

AC Drives and current harmonics distortion
Typical six-pulse Drives

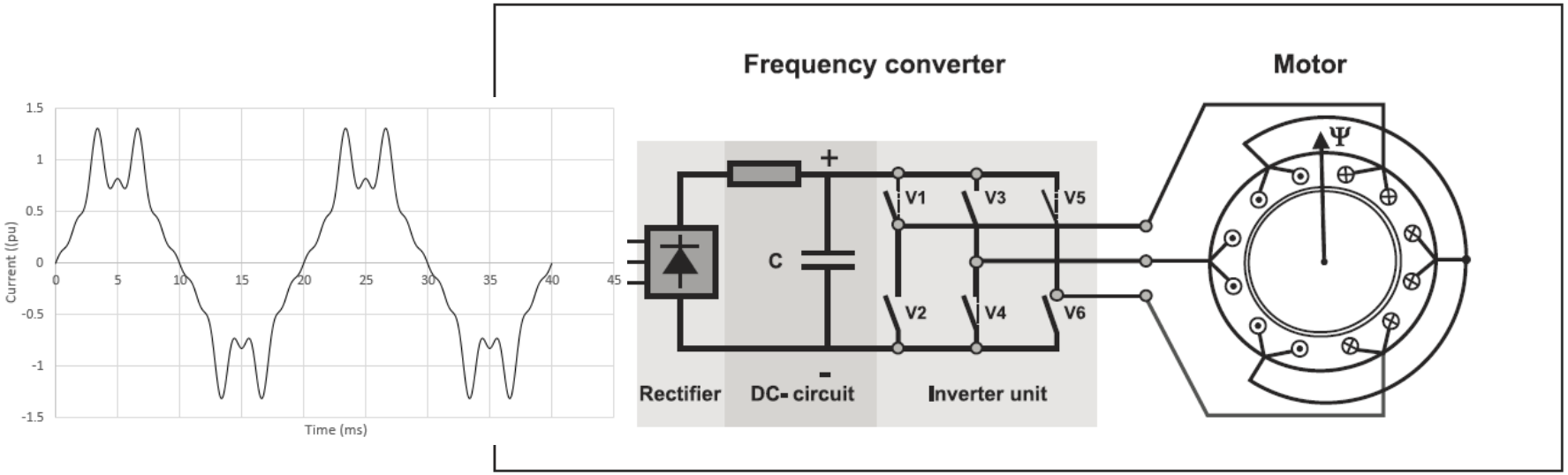




© ABB Group

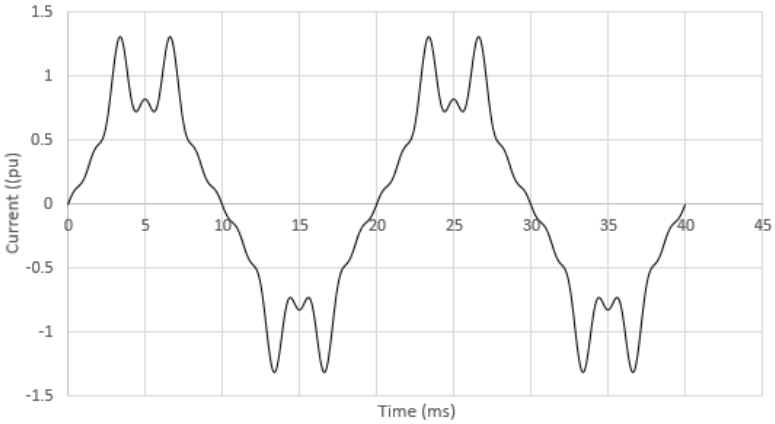
AC Drives and current harmonics distortion
Typical six-pulse Drives

- Conversion from AC to DC by rectifier, result in current waveform that is distorted.
- Distorted current waveform consists of multiples of the network frequency.
- E.g. for six-pulse drives, 5^{th} and 7^{th} harmonics are dominant.



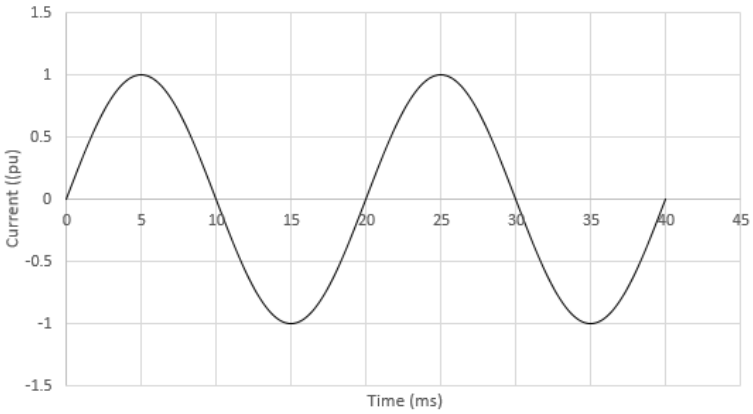
© ABB Group

AC Drives and current harmonics distortion
Typical six-pulse Drives

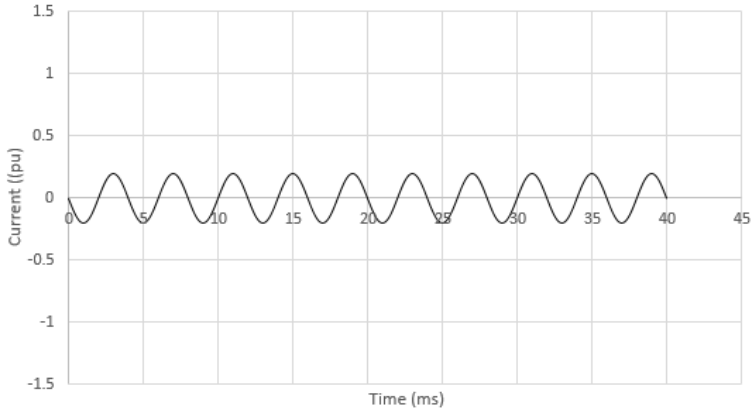


=

Distorted Current Waveform



+



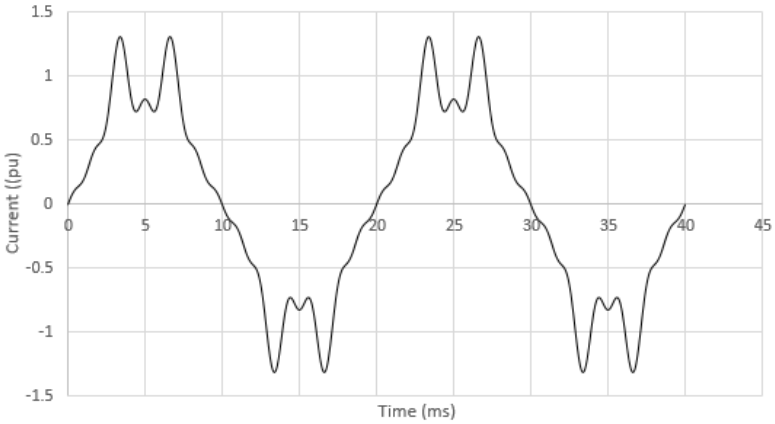
+

Fundamental waveform (50Hz)

5th harmonics (250Hz)

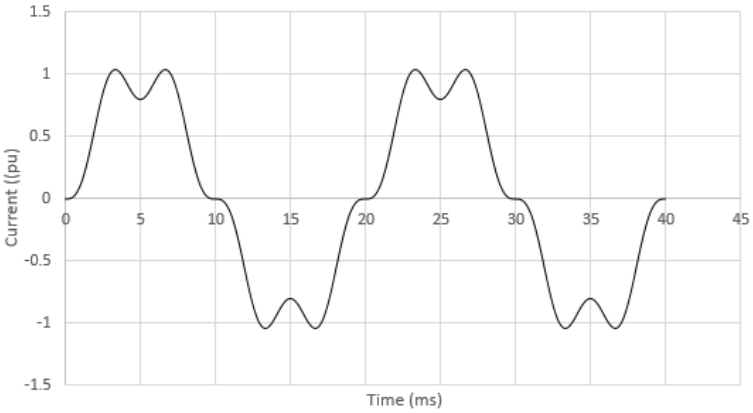
© ABB Group

AC Drives and current harmonics distortion
Typical six-pulse Drives

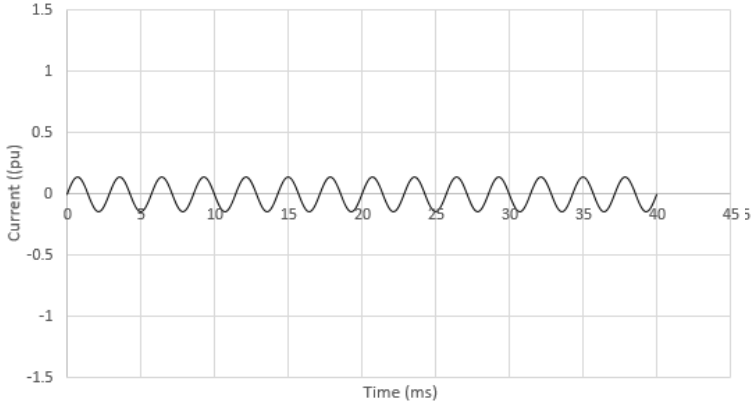


=

Distorted Current Waveform



+



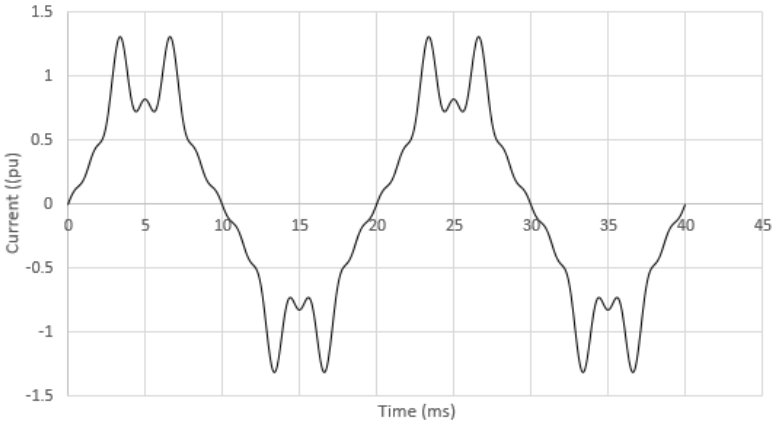
+

Fundamental + 5th harmonics waveform

7th harmonics (350Hz)

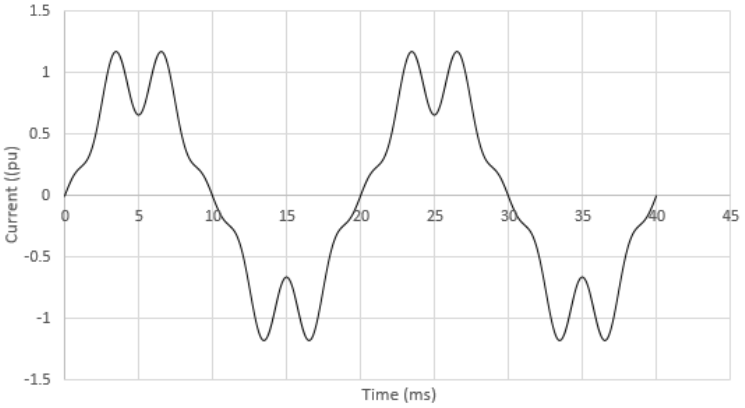
© ABB Group

AC Drives and current harmonics distortion
Typical six-pulse Drives



=

Distorted Current Waveform



+

9^{th} ,11^{th}, 17^{th}, 19^{th} … harmonics

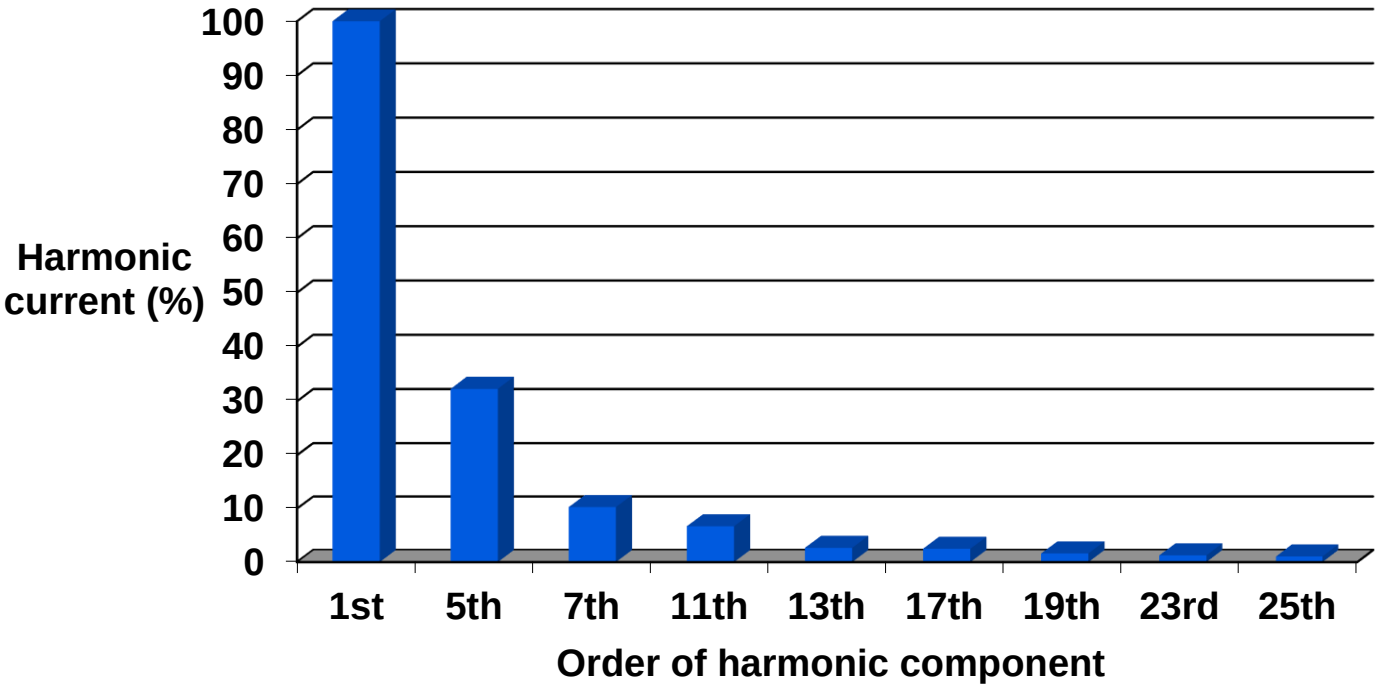
(6n +/- 1) th harmonics,
n = 1,2,3,…

Fundamental + 5^{th} & 7^{th} harmonics waveform

© ABB Group

AC Drives and current harmonics distortion
Typical six-pulse Drives

- If we take root-mean-square (rms) of each harmonics, and divided by the fundamental rms, we will be able to obtain harmonics spectrum as per below:



© ABB Group

AC Drives and current harmonics distortion
Total harmonics distortion (THD)

- If we again take sum of root-mean-square (rms) of all harmonics, and divided by the fundamental rms, we will be able to obtain total harmonics distortion (THD) as per below:

$$THD = \frac{\sqrt{\sum_{h=2}^{\infty} I_h^{\,2}}}{I_1}$$

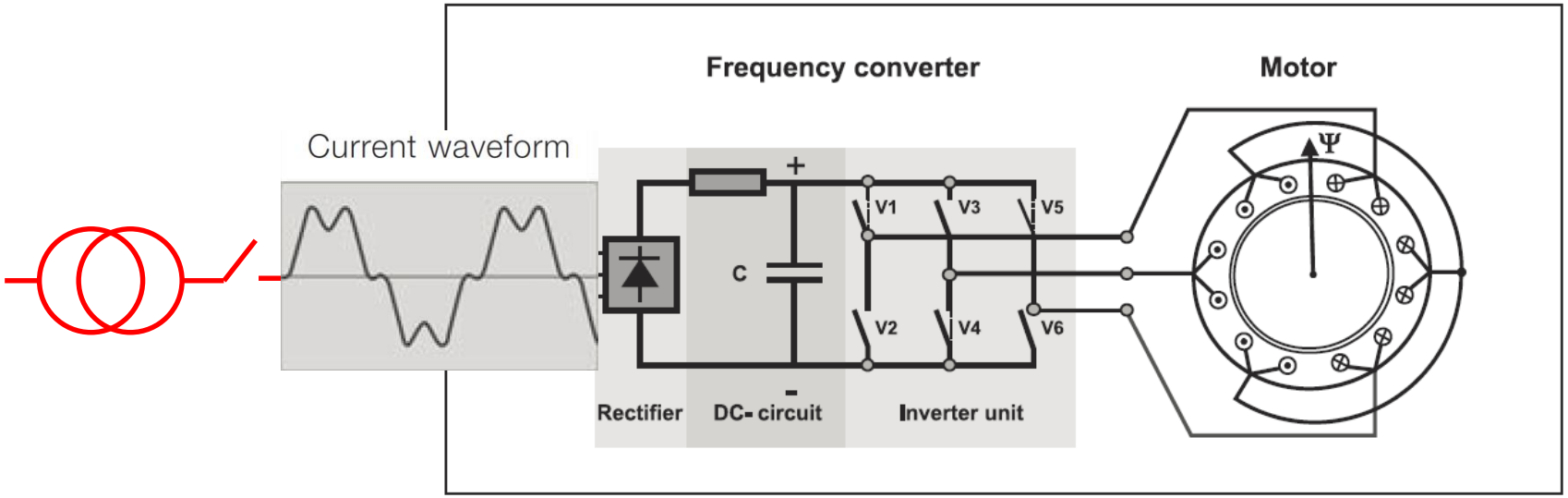
$$THD = \frac{\sqrt{32.28^2 + 10.28^2 + 6.69^2 + 2.65^2 + 2.48^2 + 1.60^2 + 1.24^2 + 1.04^2}}{100}$$

$$THD = 34.80\%$$

© ABB Group

Effects of harmonics

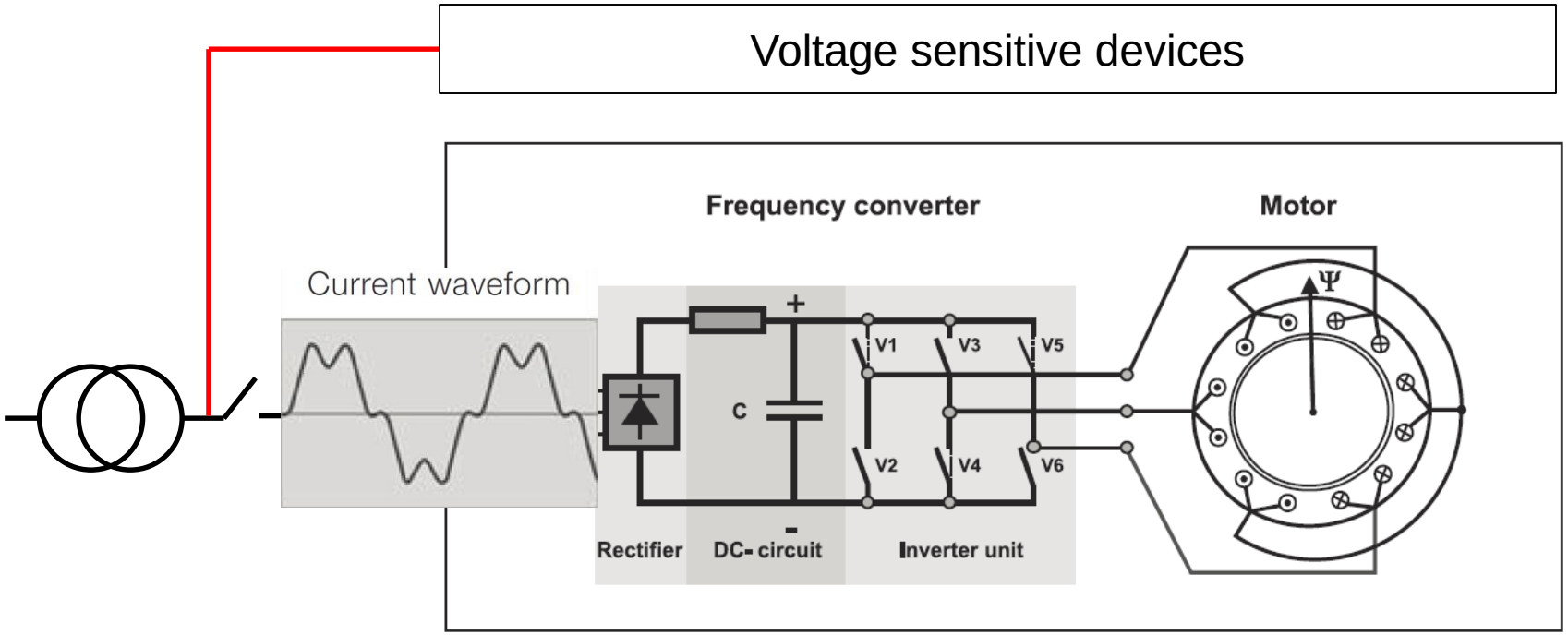
- From example, typical six-pulse drives consist of 34.80% of current harmonics, with high frequency (250Hz, 350Hz, 550Hz, etc)
- May cause overheating of devices connected in series with AC Drives such as transformers
- Oversized transformer or K-rated transformer required for proper operation



© ABB Group

Effects of harmonics

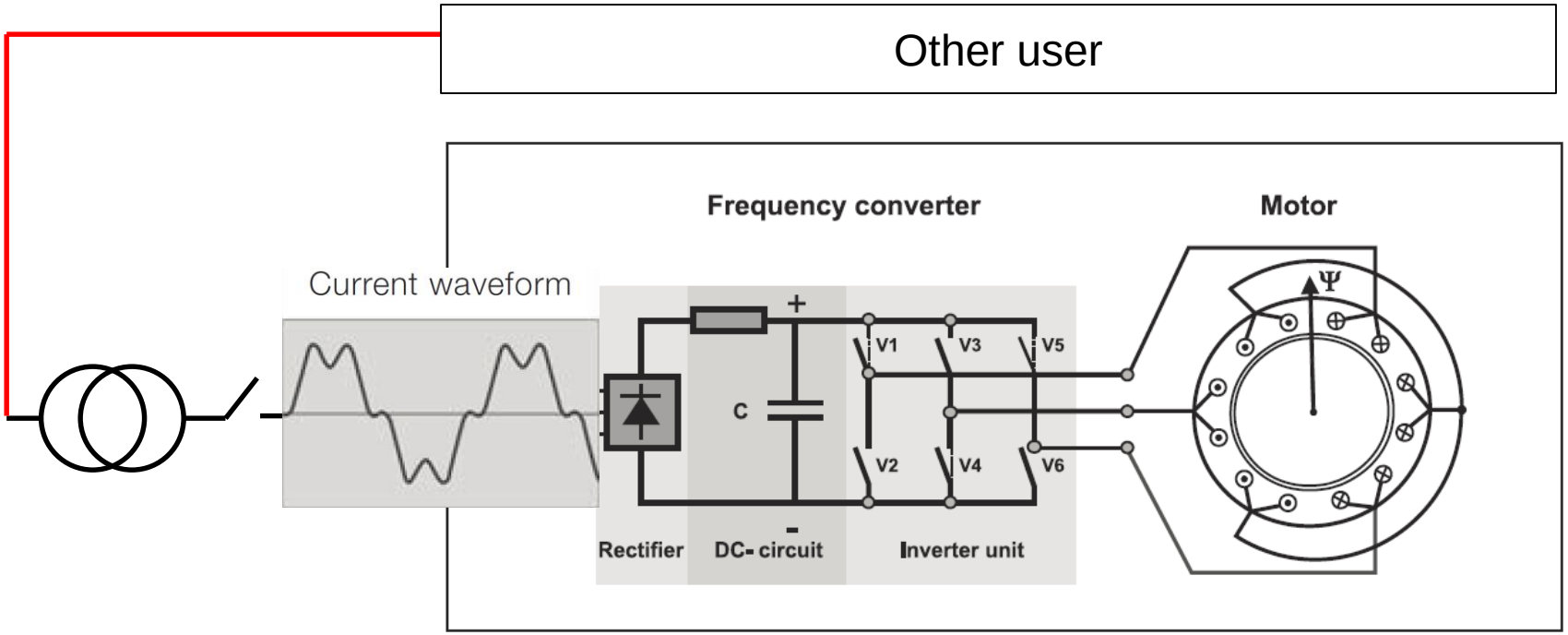
- Produce distorted voltage waveform and trip devices connected in parallel with AC Drives



© ABB Group

Effects of harmonics

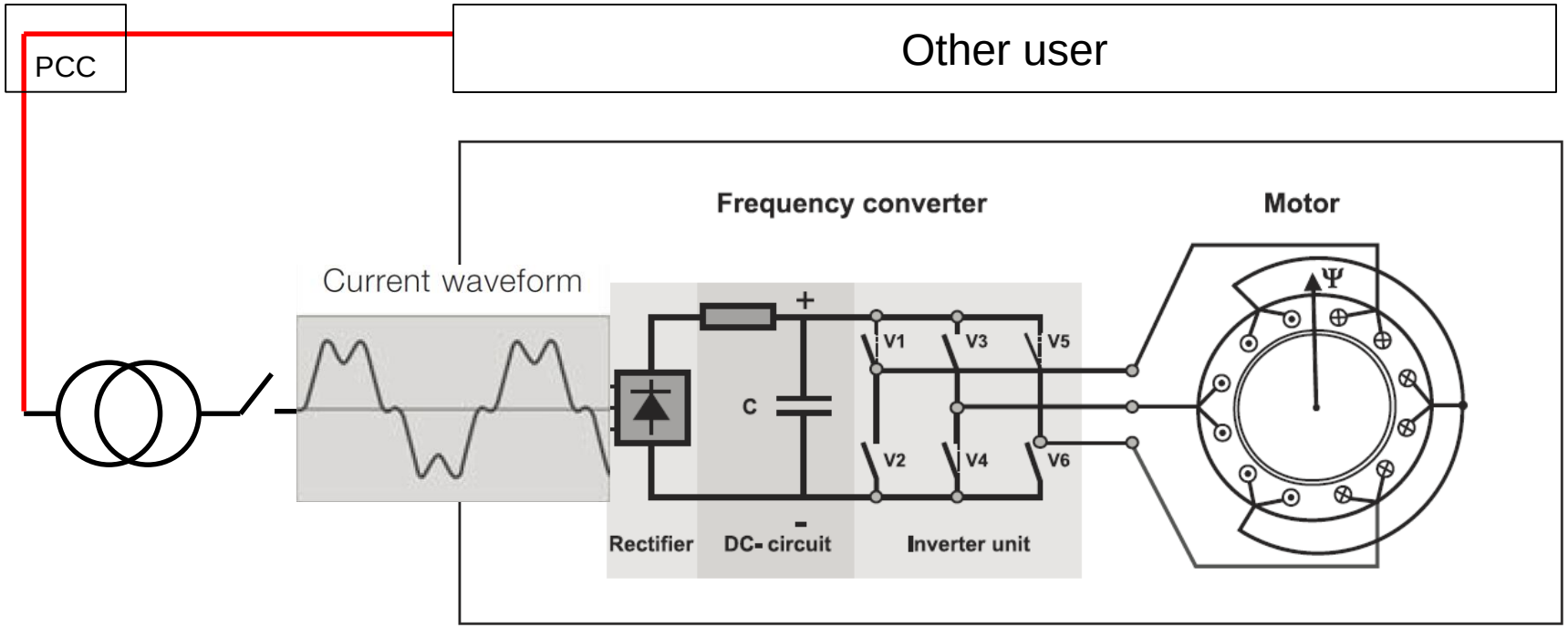
- Due to network impedance, distorted current waveform causes main voltage waveform to be distorted and affects other users



© ABB Group

Evaluation of harmonics
IEEE-519 1992

- Prevent one customer from harming another.
- PCC - Point of Common Coupling. The closest point on the utility side of the customer's service where another utility customer is or could be supplied.



© ABB Group

Evaluation of harmonics
IEEE-519 1992 – Voltage harmonics

- Table 10.2 from IEEE 519-1992, for bus voltage 69kV and below, voltage harmonics (THDv) at PCC must not be more than 5%

Voltage Distortion Limits

Bus Voltage at PCC	Individual Voltage Distortion (%)	Total Voltage Distortion THD (%)
69 kV and below	3.0	5.0
69.001 kV through 161 kV	1.5	2.5
161.001 kV and above	1.0	1.5
NOTE: High-voltage systems can have up to 2.0% THD where the cause is an HVDC terminal that will attenuate by the time it is tapped for a user.		

© ABB Group

Evaluation of harmonics
IEEE-519 1992 – Current harmonics

Current Distortion Limits for General Distribution Systems
(120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<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.						
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						

- Table 10.3 from IEEE 519-1992, maximum current harmonics distortion limit (TDD) are based on ratio of available short circuit current (I_{SC}) to total load current (I_L)

© ABB Group

Evaluation of harmonics
IEEE-519 1992 – Current harmonics

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<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.						
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						

- The higher the ratio, allowable TDD is higher. I.e. weaker system (low I_{SC}) or high load (high I_L) are subject to stricter limit.

© ABB Group

Evaluation of harmonics
IEEE-519 1992 – Current harmonics

Current Distortion Limits for General Distribution Systems (120 V Through 69000 V)

Maximum Harmonic Current Distortion in Percent of I_L						
Individual Harmonic Order (Odd Harmonics)						
I_{SC}/I_L	<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.						
Current distortions that result in a dc offset, e.g. half-wave converters, are not allowed.						
* All power generation equipment is limited to these values of current distortion, regardless of actual I_{sc}/I_L.						

- Instead of THDi, TDD is used in IEEE 519-1992 to prevent user from being unfairly penalized during periods of light load

© ABB Group

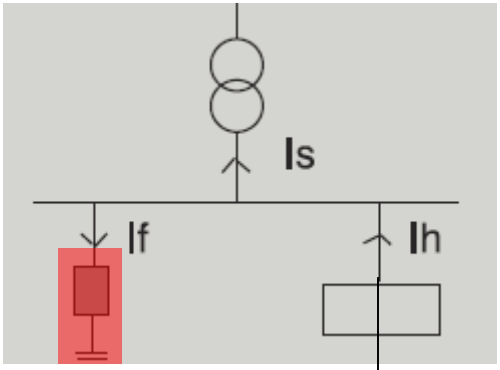
What are the available solutions?

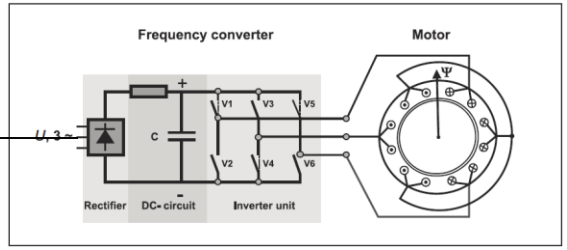
- Two ways to approach harmonics
- External filtering equipment
  - Passive filter
  - Active harmonics filter
- AC Drives design
  - AC or DC reactors (chokes)
  - 12, 24, or 36 pulse input bridge
  - Insulated-gate bipolar transistor (IGBT) input bridge

© ABB Group

What are the available solutions?
Passive filter

- Consists of an inductor in series with a capacitor bank
- Tuned to specified frequency
- Above the tuned frequency the harmonics are absorbed but below that frequency they may be amplified
- Cheap solution but could introduces resonances

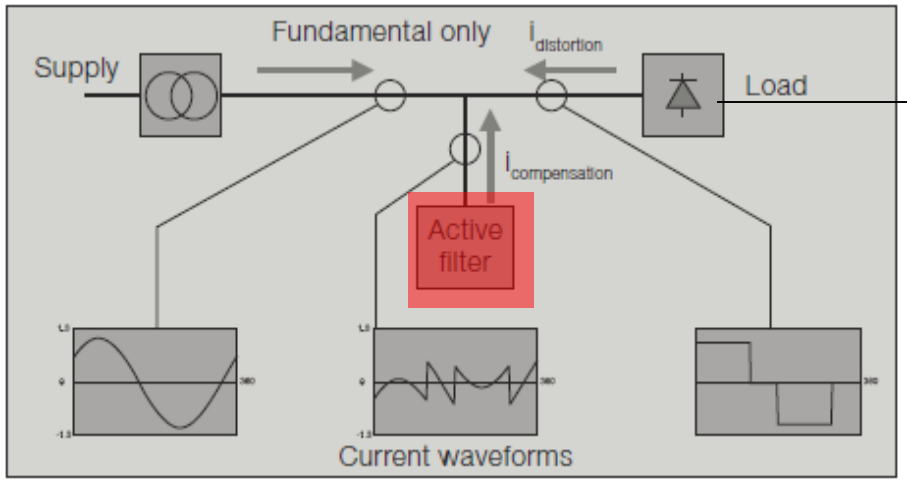


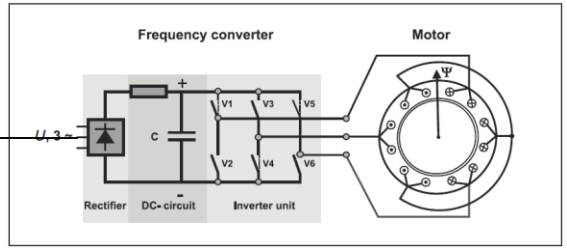


© ABB Group

What are the available solutions?
Active harmonics filter

- Compensates the harmonics by generating the same harmonic components in opposite phase
- Most suited to multiple small drives

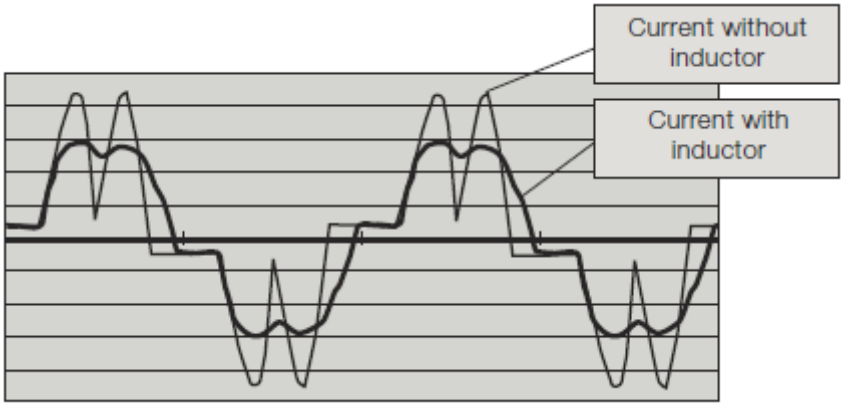


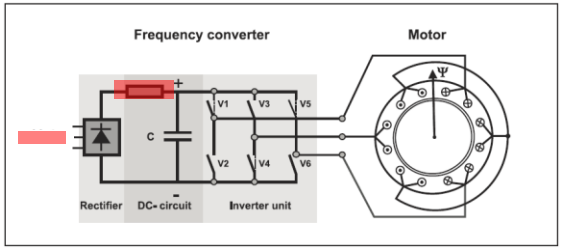


© ABB Group

What are the available solutions?
AC or DC reactors (chokes)

- Reactor at the AC or DC side of rectifier
- Bigger the size of reactor, lower the current harmonics
- Most commonly used method to mitigate THDi to 20-30%
- Adopted by most AC Drives manufacturer

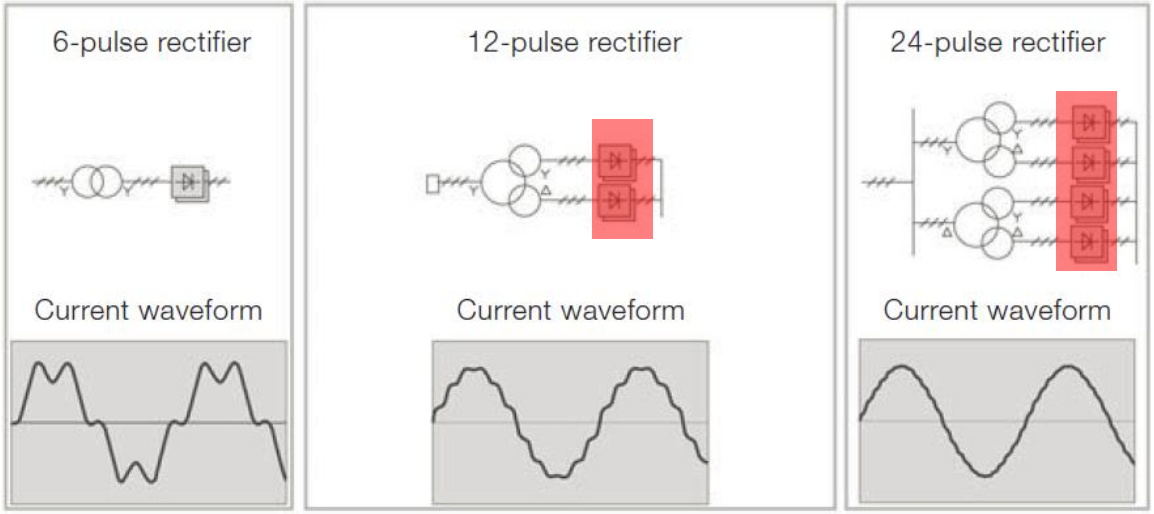


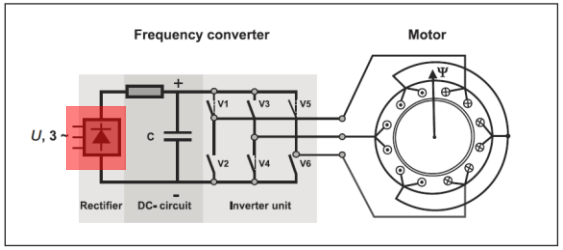


© ABB Group

What are the available solutions?
12, 24, or 36 pulse input bridge

- Larger number of pulses, lower the current harmonics
- Most economical solution for high power AC drives

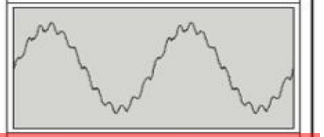


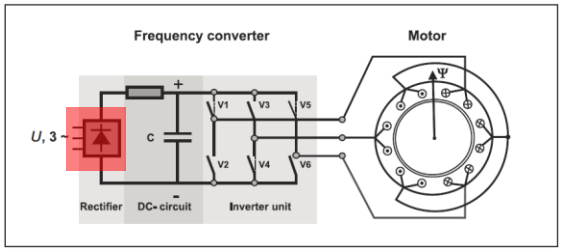


© ABB Group

What are the available solutions?
Insulated-gate bipolar transistor (IGBT) input bridge

- Nearly sinusoidal supply current with low harmonic content
- Able to generate reactive power (near unity power factor)

Supply type	Current TDH (%)	Current waveform
6-pulse rectifier	30	
12-pulse rectifier	10	
IGBT supply unit	4	



© ABB Group

How to choose the best solution?

Criteria	AC/DC Choke	12,24 pulse rectifier	Passive filter	Active filter	IGBT input bridge low harmonics drives
THDi	~30%	~3 to 15%	~5%	<5%	<5%
Simplicity	Simple and inherited in most AC Drives	Complex site cabling	Risk of resonance and capacitor overheat	Additional equipment to maintain	Simplest form of harmonics mitigation
Compactness	Most compact mode of mitigation	Occupy most space due to additional transformer	Requires additional space and proper cooling	Additional space for AHF cubicle	Compact solution without external components
Efficiency	~97%	~98%	~95%	~97%	~97%
Remarks	Limited THDi mitigation capability Further mitigation may not be necessary if AC Drives load is relatively small (<10%) compared to other linear load	Expensive and complex solution for low power AC Drives Most economical solution for high power AC Drives	Cheapest solution for low power AC Drives, but prone to resonance	Normally used with groups of low power AC Drives, or to mitigate existing harmonics.	Cost effective solution Able to generate reactive power

© ABB Group

Case study
4 x 250kW AC Drives

- The line up:
- 2 x 250kW AC Drives = IGBT input bridge low harmonics Drives
- 2 x 250kW AC Drives = 6-pulse Drives with DC choke
- 1 x 270A active filter

© ABB Group

Case study
4 x 250kW AC Drives

- The test:

22kV/415V 2MVA Transformer		Test A			Test B			Test C		
		Amp	THDI%	THDV%	Amp	THDI%	THDV%	Amp	THDI%	THDV%
LV MCC	kW	Status(On/ OFF)	Running kW	Running Amps	Status(On/ OFF)	Running kW	Running Amps	Status(On/ OFF)	Running kW	Running Amps
6-pulse drives with DC choke	250.0	ON			OFF			ON		
6-pulse drives with DC choke	250.0	ON			OFF			ON		
IGBT input bridge low harmonics drives	250.0	ON			ON			OFF		
IGBT input bridge low harmonics drives	250.0	ON			ON			OFF		

- Test A : All drives are running at 240kW each
- Test B : Only 2 x 250kW IGBT input bridge low harmonics drives are running at 240kW each
- Test C : Only 2 x 250kW 6-pulse drives are running at 240kW each

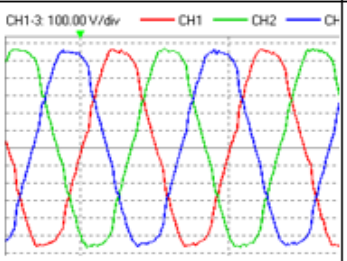
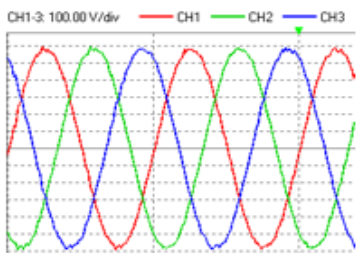
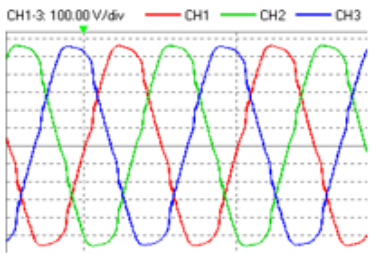
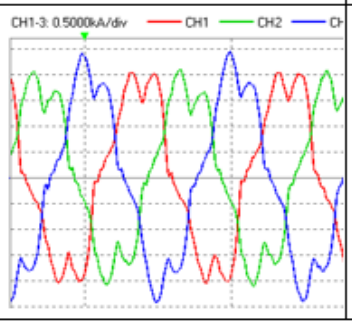
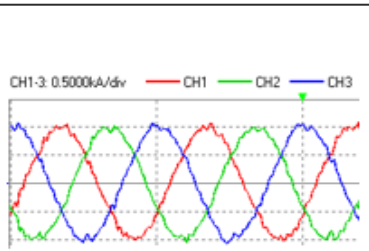
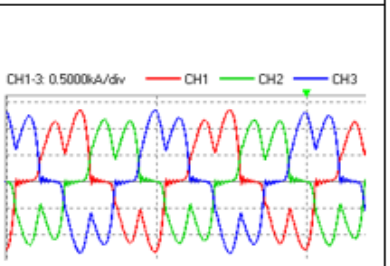
© ABB Group

Case study
4 x 250kW AC Drives

- The results: Only Test B pass IEEE-519 1992 standard

	Test A			Test B			Test C		
	Amp	THDI%	THDV%	Amp	THDI%	THDV%	Amp	THDI%	THDV%
22kV/415V 2MVA Transformer	1421	18.9	5	705	4	1.5	777	29	5.25

LV MCC	kW	Status(On/ OFF)	Running kW	Running Amps	Status(On/ OFF)	Running kW	Running Amps	Status(On/ OFF)	Running kW	Running Amps
6-pulse drives with DC choke	250.0	ON	240	374	OFF	0	0	ON	240	374
6-pulse drives with DC choke	250.0	ON	240	375	OFF	0	0	ON	240	374
IGBT input bridge low harmonics drives	250.0	ON	243	345	ON	242	340	OFF	0	0
IGBT input bridge low harmonics drives	250.0	ON	240	341	ON	239	337	OFF	0	0

	Test A	Test B	Test C
Voltage waveform			
Current waveform			

© ABB Group

Power and productivity
for a better world™

