ESS2016
Energy Sustainability Symposium
Unveiling the technology

Power Quality of Modern Electricity System

By Mo Wei

Consultant Sales Dept.



富士電機グループ

Agenda

- Power Quality Considerations
- Reactive Energy and Power Factor
- Ways to Improve System Power Factor
- Harmonic Origins and Impacts
- System Harmonic Estimation
- Harmonic Solutions

Power Quality

- **Except for Completed Failure, No Close Attention to Supplied Power**
  - Non-sensitive loads: lighting, motors
- **Electronics Age**
  - Sensitive loads: stringent power requirements
  - Susceptible to power disturbances
- **Healthy Power Needed**

Fuji Electric
Innovating Energy Technology

Power Quality Impacts

- **Poor Power Efficiency**
  - Increase power loss
- **System Oversize**
  - Equipment upsize
- **Poor Productivity**
  - Inefficient power utilization
- **Harm/Damage Power Equipment**
- **Affect Performance of Distribution System**

Fuji Electric
Innovating Energy Technology

Power Quality Related Problems

Power Disturbances

- Voltage/Current fluctuations
- Voltage/Current unbalance



Power Factor

- Effectiveness of power usage

Harmonics

- Non-linear loads
- Integer-multiple of fundamental frequency components

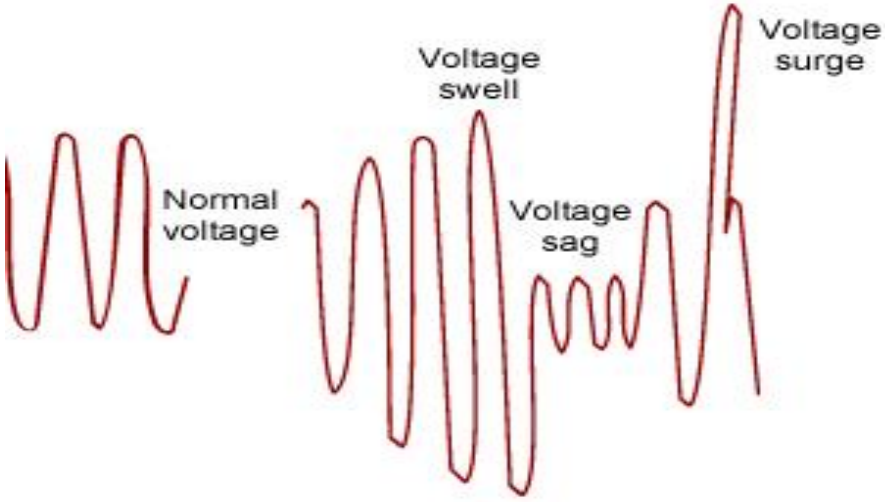
Power Disturbances

Steady State

- Long term over-voltage
- Long term under-voltage
- Frequent power noise (RFI, EMI)
- Consistent system harmonics

Intermittent

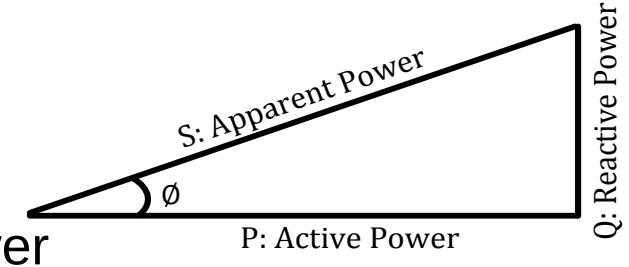
- Voltage/Current sag
- Voltage/Current swell
- Impulse, transient spikes, interruptions



Power Factor Characteristics (1)

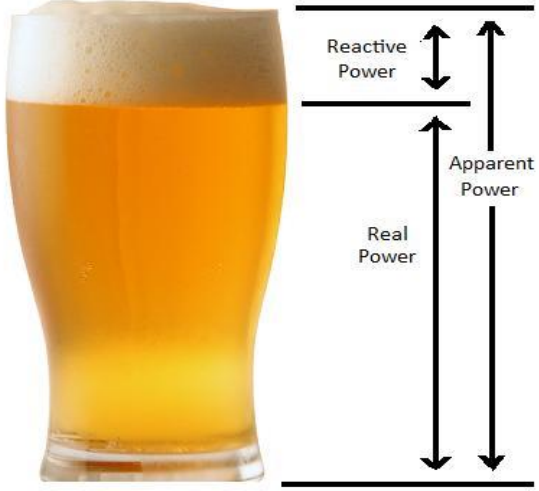
➢ Apparent Power: S = P + jQ

- Useful power: active power
- Electrostatically stored energy: reactive power
- Reactive power by inductive loads and capacitive loads



➢ Reactive Power: Q

- Absorbed by transformer/motor to build up working magnetic field
- Re-inject back into electrical system
- Wont draw power itself, but increase I^2R



Fuji Electric
Innovating Energy Technology

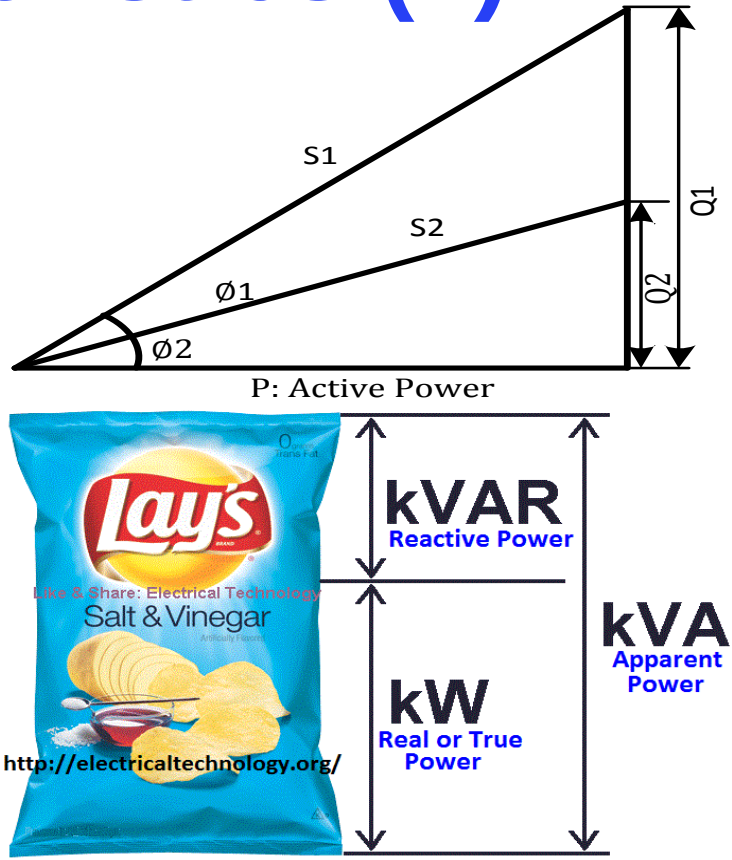
Power Factor Characteristics (2)

Power Factor

- $PF = \frac{P}{S} = \frac{kW}{kVA} = \cos(\emptyset)$

Practical Power Factor Value

- Case 1: P = 120kW, PF = 0.6
- $I = \frac{S}{\sqrt{3}V} = \frac{P/PF}{\sqrt{3}V} = 289A$
- Case 2: P = 120kW, PF = 0.85
- $I = \frac{S}{\sqrt{3}V} = \frac{P/PF}{\sqrt{3}V} = 204A$
- **29%** current reduction, Reduce I^2R ,IZ



Improve Power Factor

Benefits

- Reduce transformer, cable, breaker size
- Reduce voltage drop
- Reduce power loss



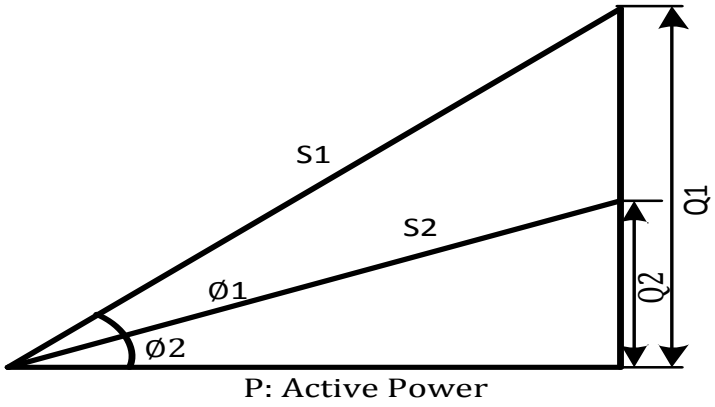
Method to Improve Power Factor

- Capacitor bank, Synchronous Motor, VSD

$$Qc = Q1 - Q2 = S1 * \sin(\emptyset 1) - S2 * \sin(\emptyset 2)$$

$$= S1 * \sqrt{1 - PF_1^2} \text{-} S2 * \sqrt{1 - PF_2^2}$$

- Installed at main switchboard
- Installed at individual sector

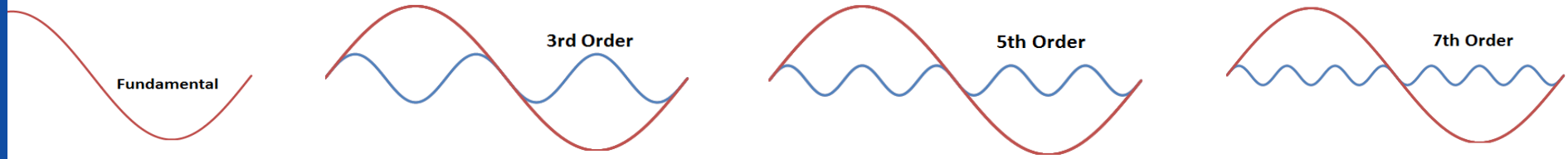


Fuji Electric
Innovating Energy Technology

Understand of Harmonics

Definition:

"A harmonic is a component of a periodic wave having a frequency that is an integral multiple of the fundamental power line frequency".



In Fourier Series Form

- Breakdown of THD into individual harmonics
- Show the amount of harmonics as percentage of fundamental

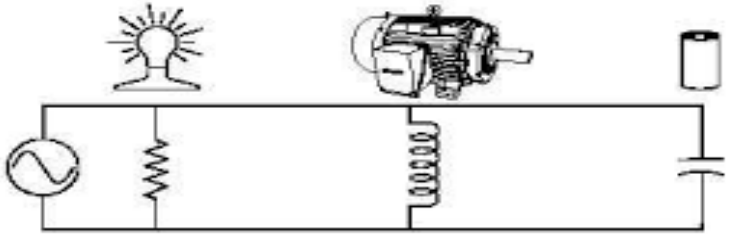
$$s_N(x) = \overbrace{a_0}^{A_0}/2 + \sum_{n=1}^{N}\left(\overbrace{a_n}^{A_n\sin(\phi_n)}\cos(\tfrac{2\pi nx}{P}) + \overbrace{b_n}^{A_n\cos(\phi_n)}\sin(\tfrac{2\pi nx}{P})\right)$$

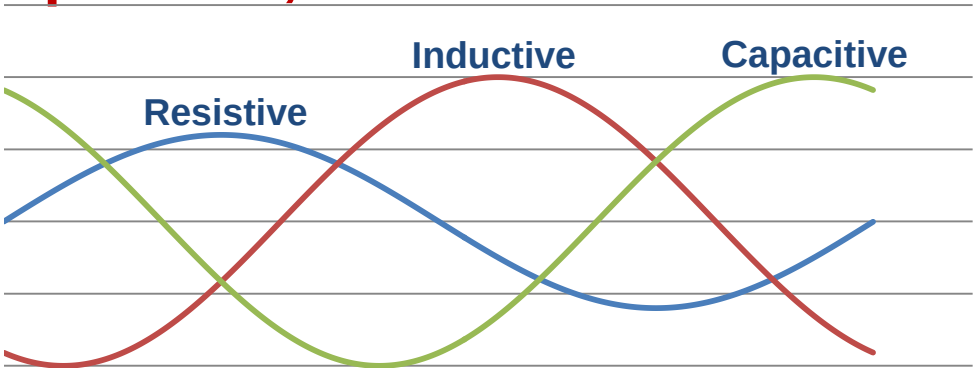
$$= \sum_{n=-N}^{N} c_n \cdot e^{i\frac{2\pi nx}{P}},$$



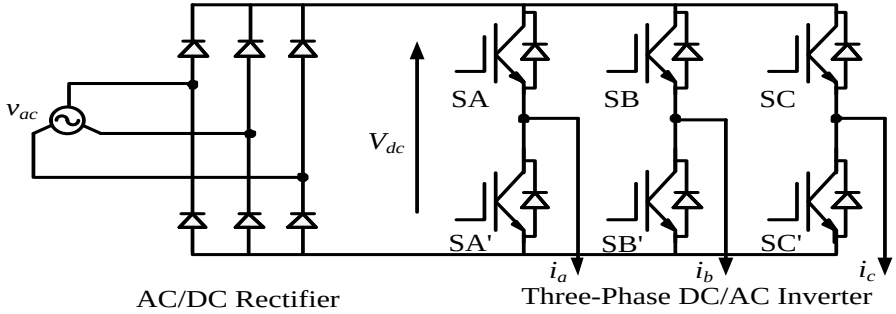
Harmonic Origins

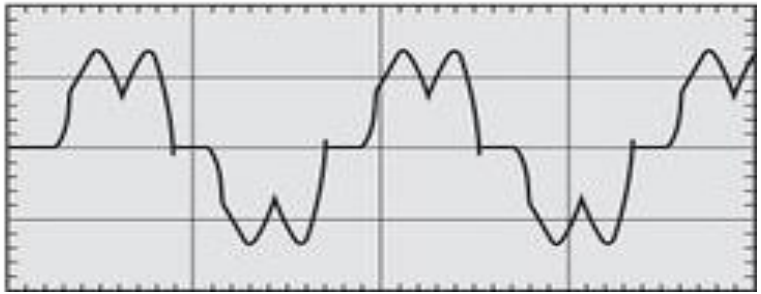
- **Traditional: Inductive, Capacitive, Resistive Loads**





- **Non-Linear Loads since 1980s**

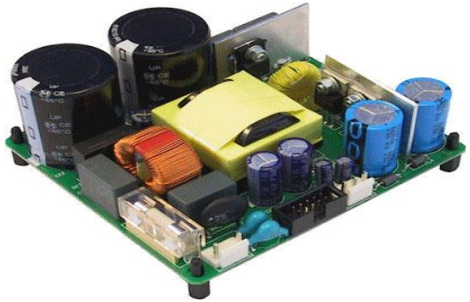


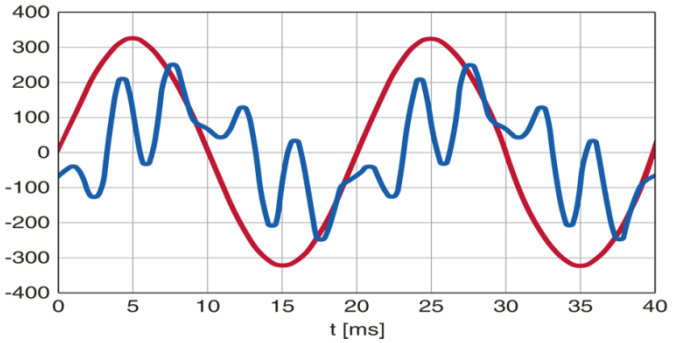


Fuji Electric
Innovating Energy Technology

Harmonic Causes

- **Invisible Electrical “Pollution” that Effects Electrical Networks.**



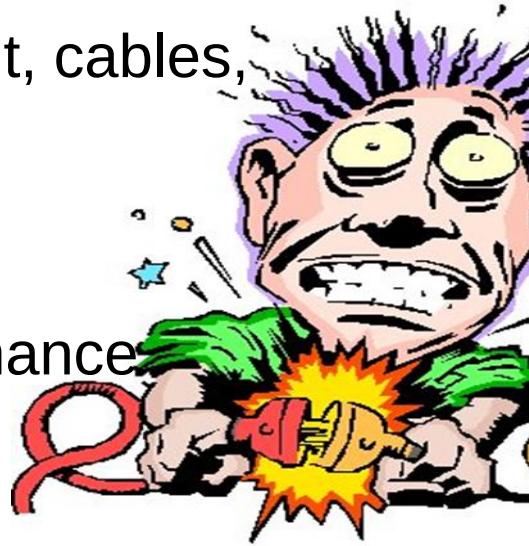


- **Harmonic Causes**
  - Welding machines, arc furnaces, induction furnaces
  - Personal computers and servers
  - Fluorescent light with electronic ballast, photocopy machine
  - Air conditioning units
  - Variable speed drives, battery charger etc.

Fuji Electric
Innovating Energy Technology

Harmonic Impacts (1)

- Overheating of electrical distribution equipment, cables, transformers, standby generators, etc.
- $Xc = \frac{1}{wC} = \frac{1}{2\pi fC}$
- Circulating currents caused by harmonic resonance
- $fs = \frac{1}{2\pi\sqrt{LC}}$, where $X_L = X_C$
- Equipment malfunctions due to excessive voltage distortion
- Increased internal energy losses in connected equipment, causing component failure and shortened life span



Harmonic Impacts (2)

- False tripping of branch circuit breakers
- Metering errors
- Fires in wiring and distribution systems
- Generator failures
- Crest factors and related problems
- Lower system power factor, resulting in penalties on monthly utility bills



Harmonic Analysis - Fundamental

➢ Harmonic Expression

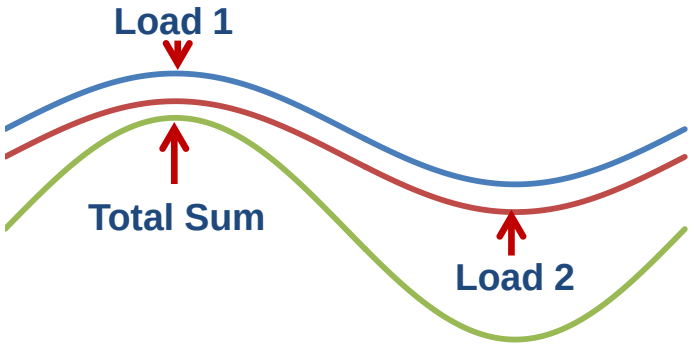
$$y(t) = \sum_{h=1}^{h=\infty} Y_h \sqrt{2} \sin(hwt - \emptyset_h)$$

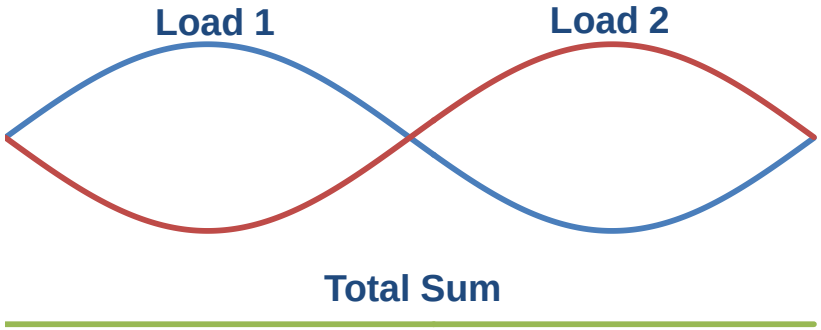
➢ Total Harmonic Voltage Distortion

$$THD_v = \sqrt{\sum_{h=2}^{h=\infty} \left(\frac{V_h}{V_1}\right)^2} = \sqrt{\frac{(V_2)^2 + (V_3)^2 + \cdots + (V_H)^2}{(V_1)^2}}$$

Summation of Two Non-linear Loads

➢ Sum-up of Total Harmonic Current Distortion



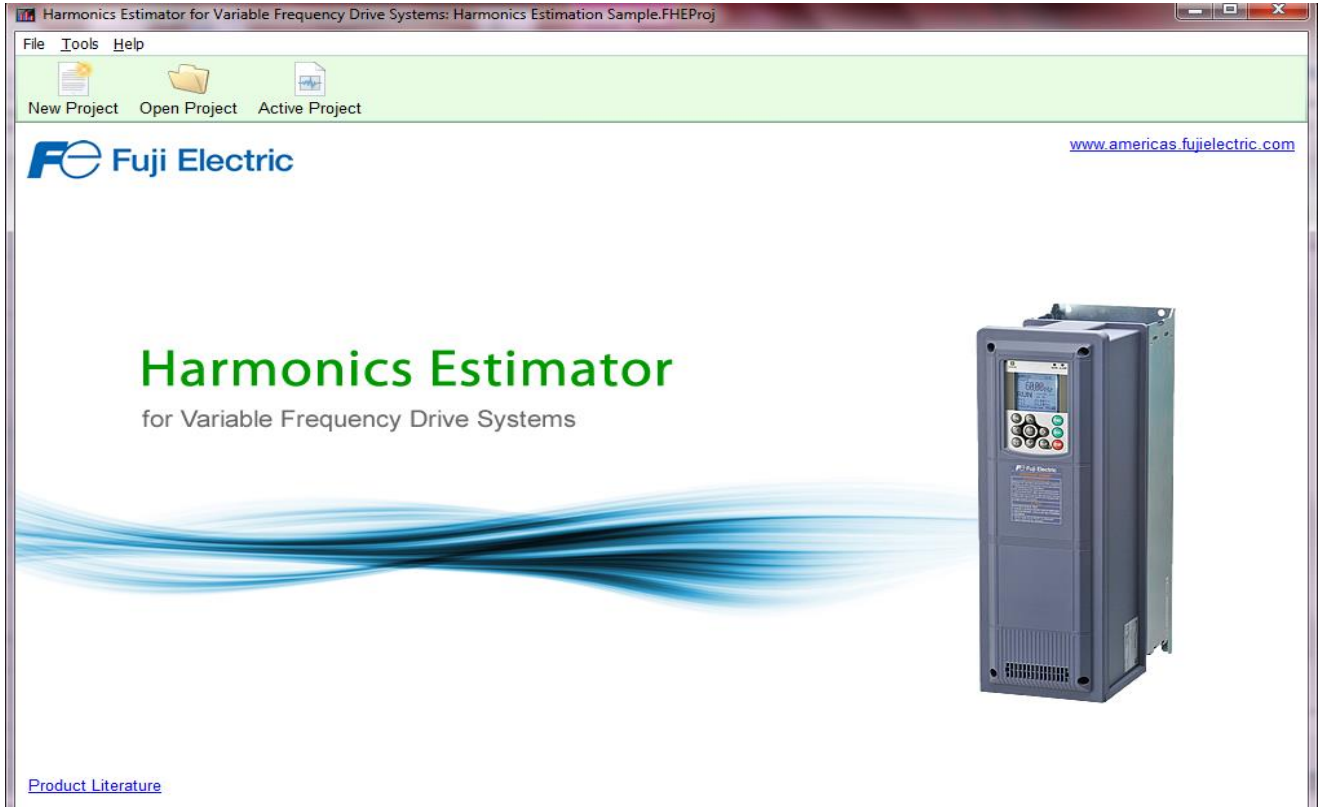


$$I_{RMS} = (I_1 + I_1')\sqrt{1 + THD_i^2}$$

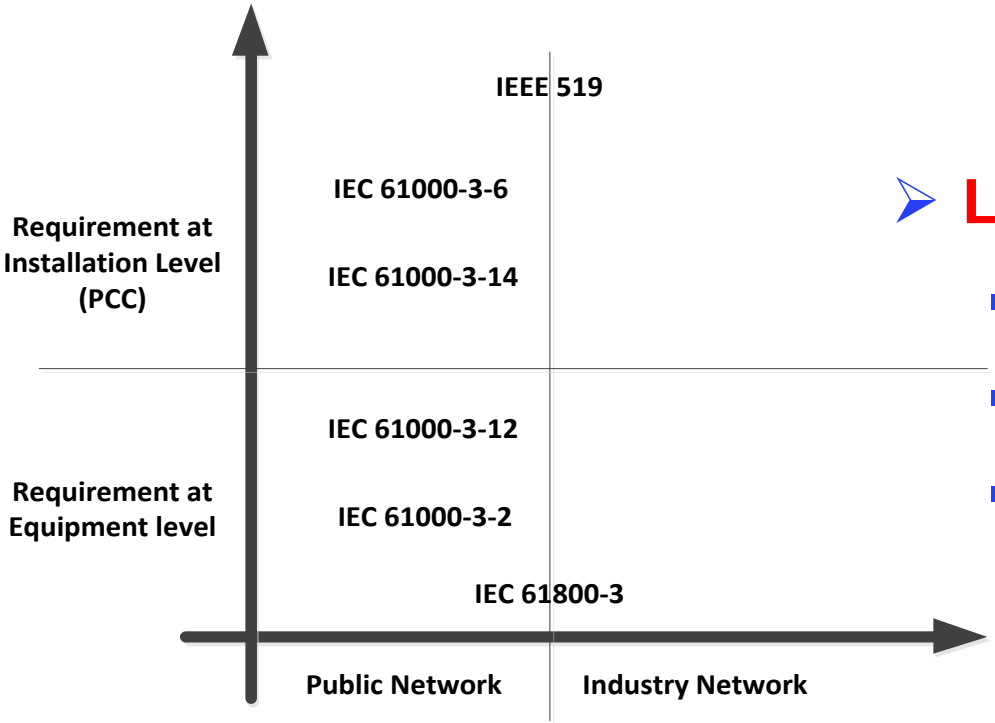
$$I_{RMS} = (I_1 + I_1')\sqrt{1 + (I_2 + I_2')^2 + (I_3 + I_3')^2 + \cdots + (I_H + I_H')^2} \approx$$

$$(I_1 + I_1')\sqrt{1 + a(I_2)^2 + a(I_3)^2 + \cdots + a(I_H)^2} = (I_1 + I_1')\sqrt{1 + aTHD_i^2}$$

Harmonics Estimation Tool



Harmonics Emission Standards



- **Limits Established**
  - Total harmonic voltage distortion
  - Total current distortion
  - Individual harmonic current

Fuji Electric
Innovating Energy Technology

IEEE 519 Regulations

Harmonic Voltage Limits	Table 10.2
Low-Voltage Systems	
Application	Maximum THDv (%)
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						
Isc=maximum short circuit current at PCC **I**load=maximum demand load current (fundamental frequency component) at PCC						

Fuji Electric
Innovating Energy Technology

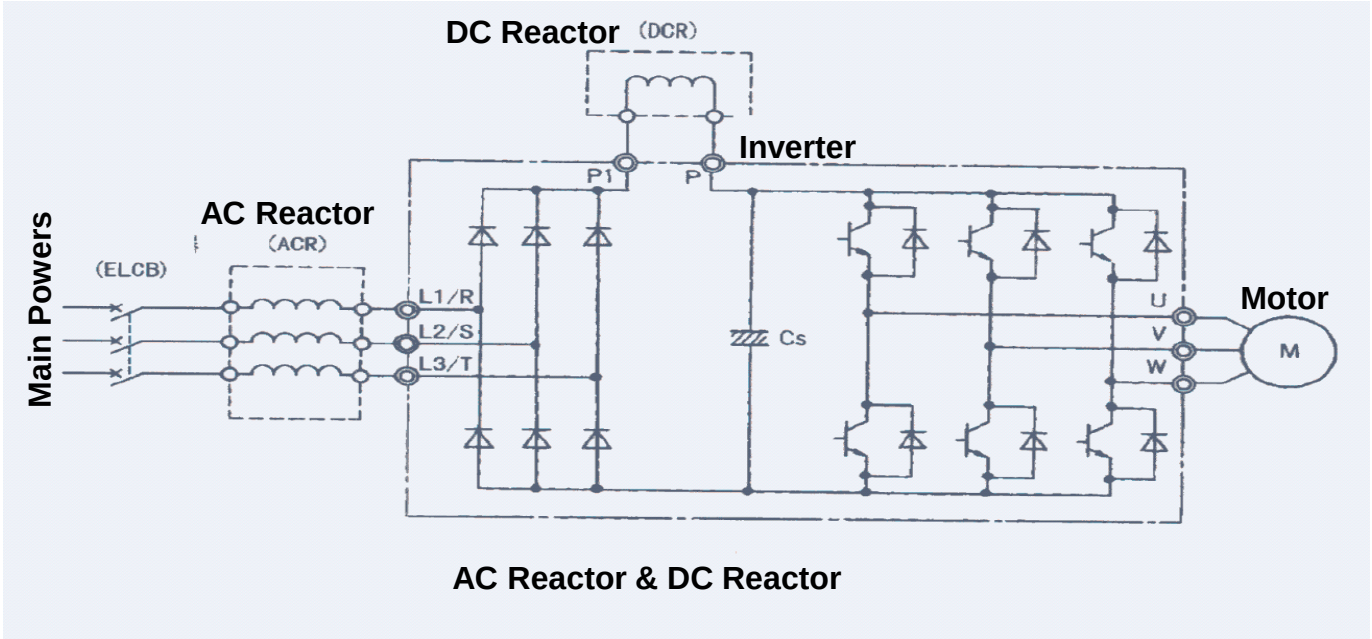
IEC 61000-3-1

Current distortion Limits for General Distribution Systems (120V through 69,000V)					
Maximum Harmonic Current Distortion in Percent of Iload					
Isc/Iload	5th	7th	11th	13th	THDi (%)
33-66	10.7	7.2	3.1	2.0	13.0
66-120	14.0	9.0	5.0	3.0	16.0
120-250	19.0	12.0	7.0	4.0	22.0
250-350	19.0	20.0	12.0	7.0	37.0
>350	19.0	25.0	15.0	10.0	48.0
Even harmonics are limited to 25% of the odd harmonic limits above					
Isc=maximum short circuit current at PCC Iload=maximum demand load current (fundamental frequency component) at PCC					

Fuji Electric
Innovating Energy Technology

Available Solutions

- AC-line Reactor/DC-line Choke

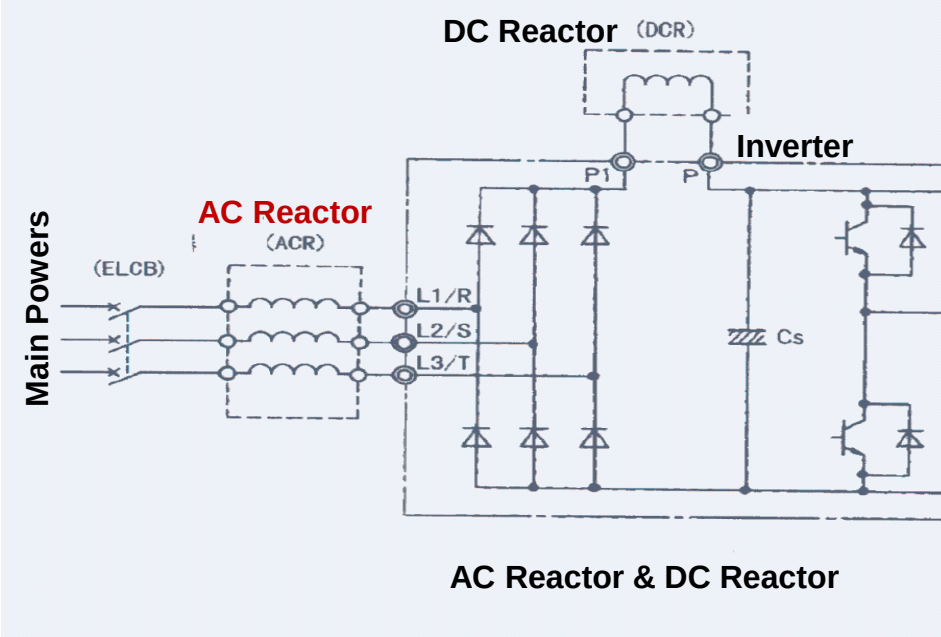


AC Reactor & DC Reactor

AC Reactor

AC Reactor

- Put at drive input
- Mitigate harmonics
- Buffer for surges and transients
- Disadvantage: voltage drop
- THDi can be reduced to 32% from 88%

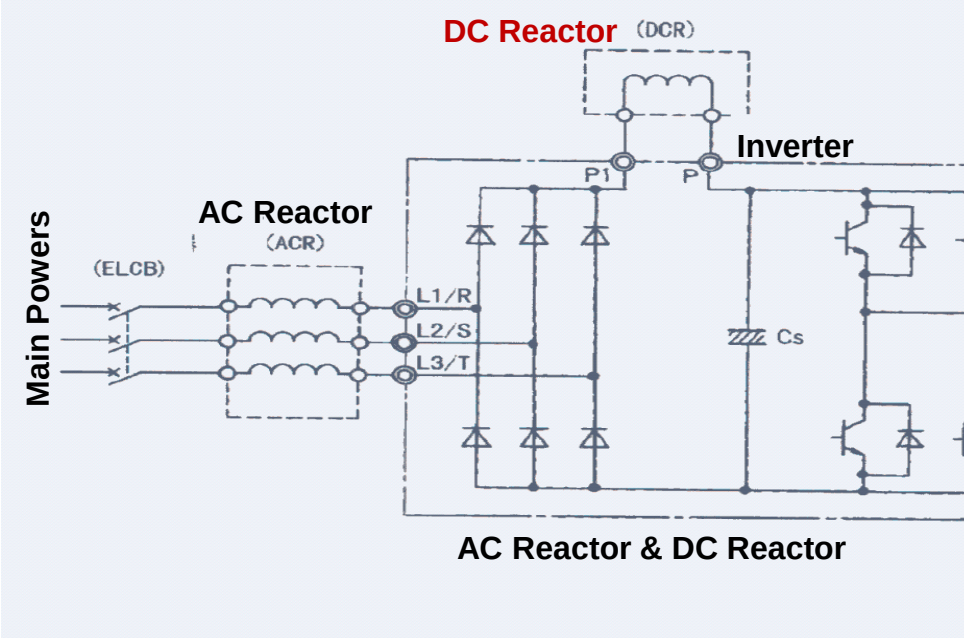


AC Reactor & DC Reactor

DC Reactor

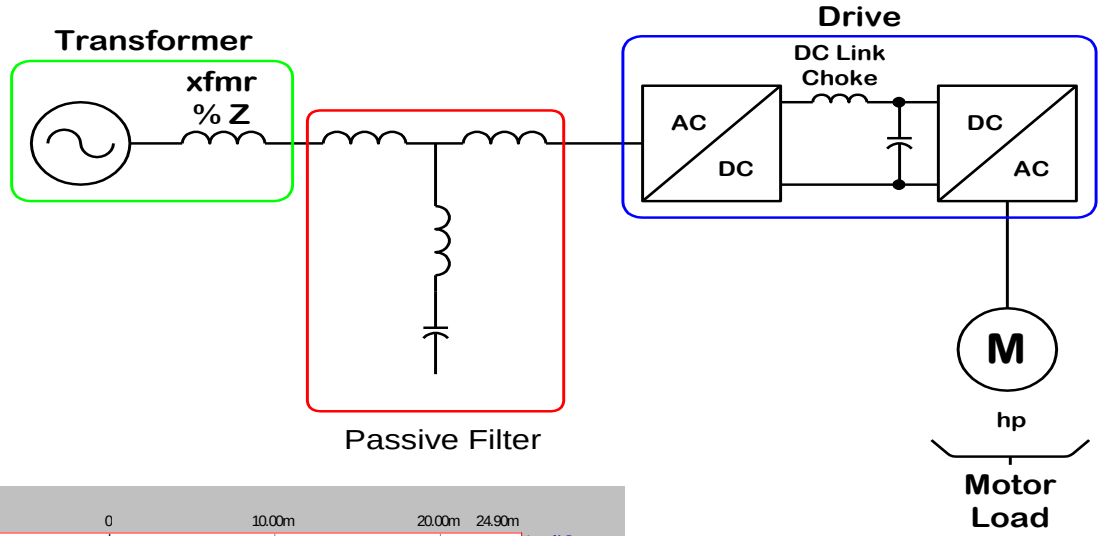
➢DC Reactor

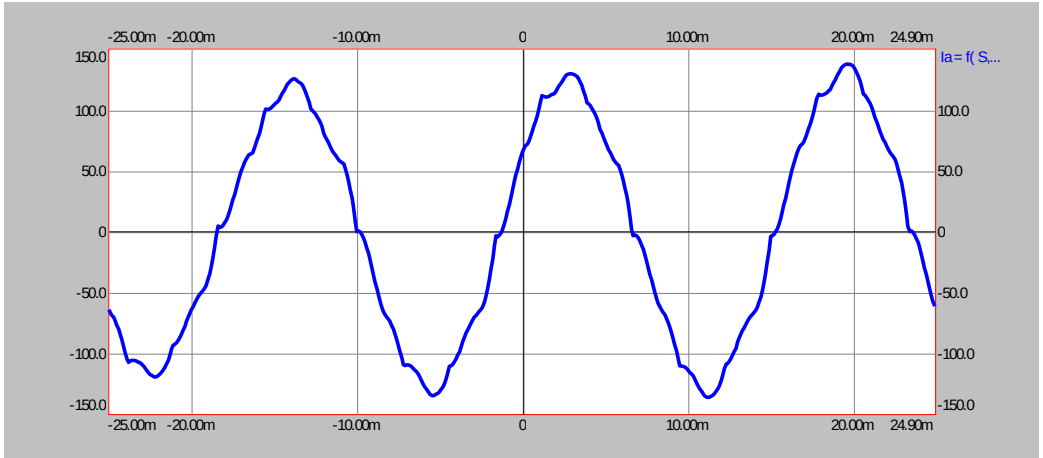
- Between rectifier and DC bus
- Mitigate harmonics
- Smaller than AC reactor
- Minimum voltage drop
- Protect from current surge
- THDi can be reduced to 38%



Passive Harmonic Filter

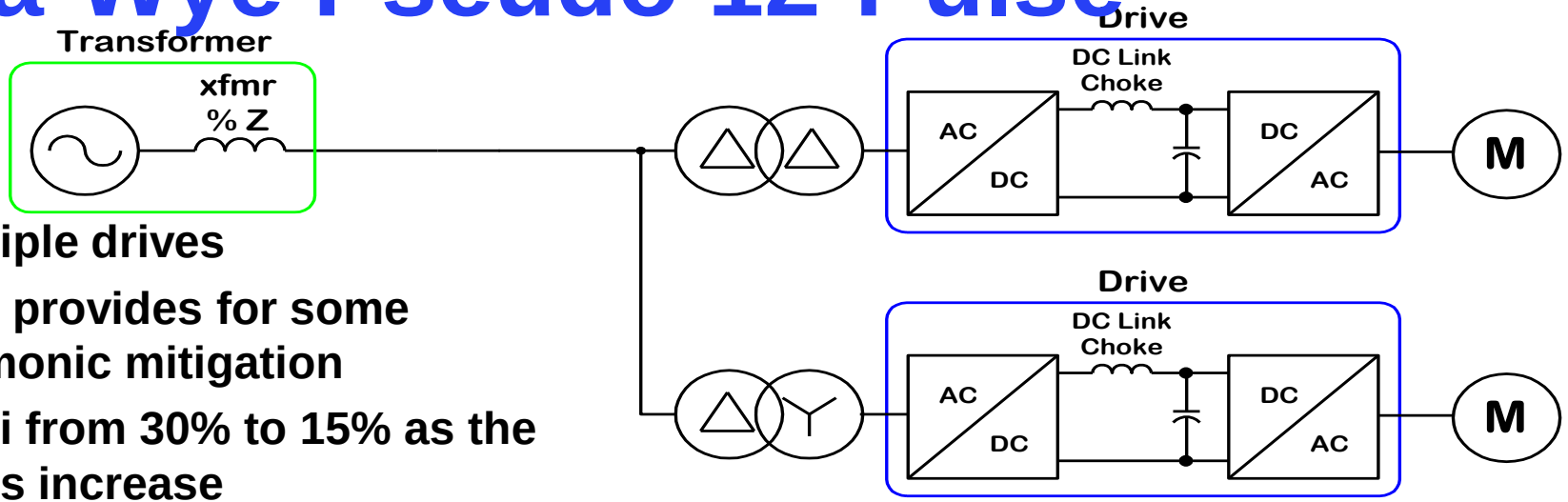
- LRC filter between source and inverter
- Typical THDi is suppressed to 5 to 8%
- Commonly used cost effective solutions





Fuji Electric
Innovating Energy Technology

Delta-Wye Pseudo 12-Pulse



- Multiple drives
- This provides for some harmonic mitigation
- THDi from 30% to 15% as the loads increase

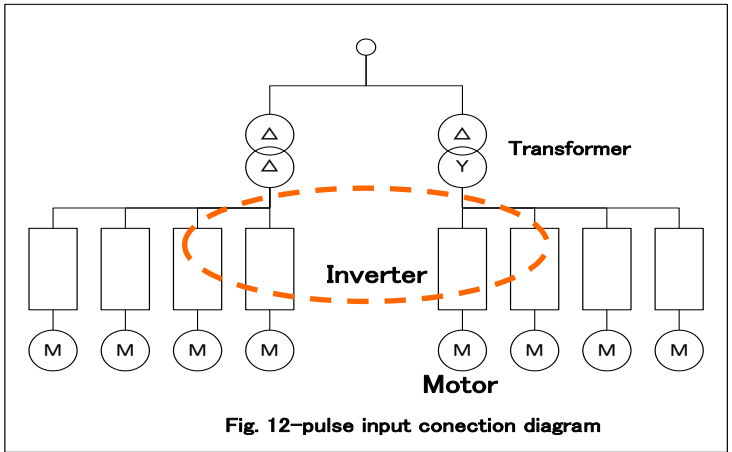
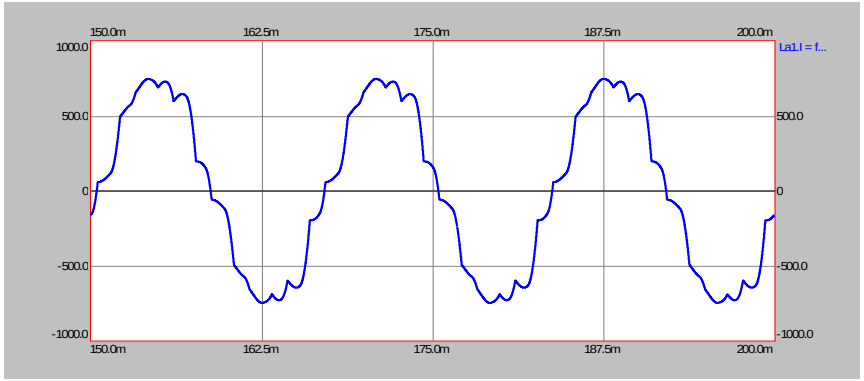


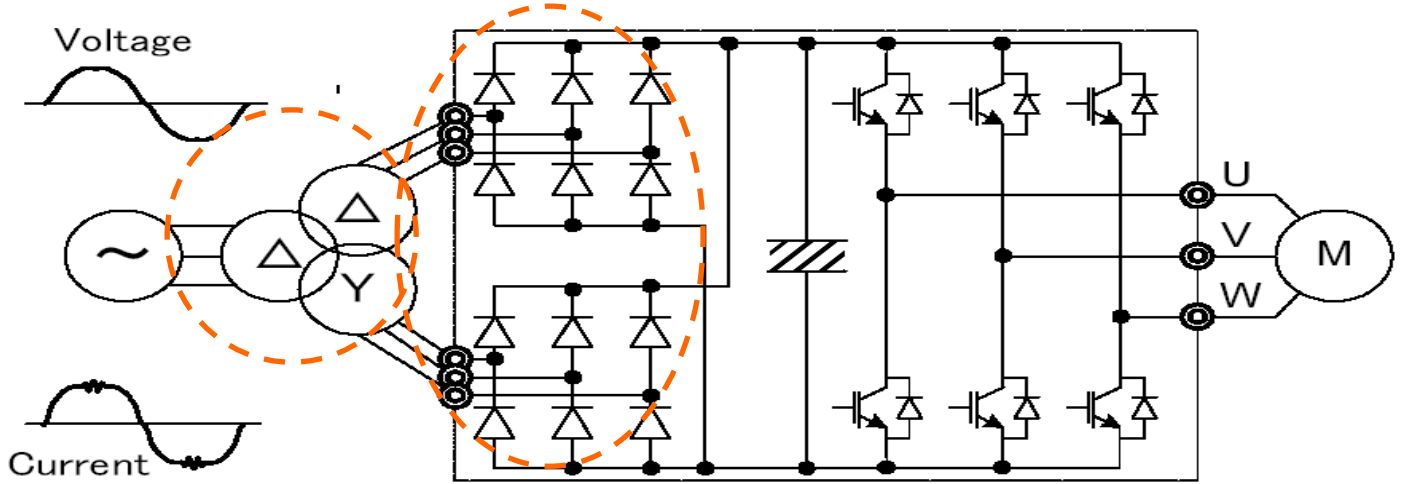
Fig. 12–pulse input conection diagram



Fuji Electric
Innovating Energy Technology

12-Pulse Solutions for Harmonics

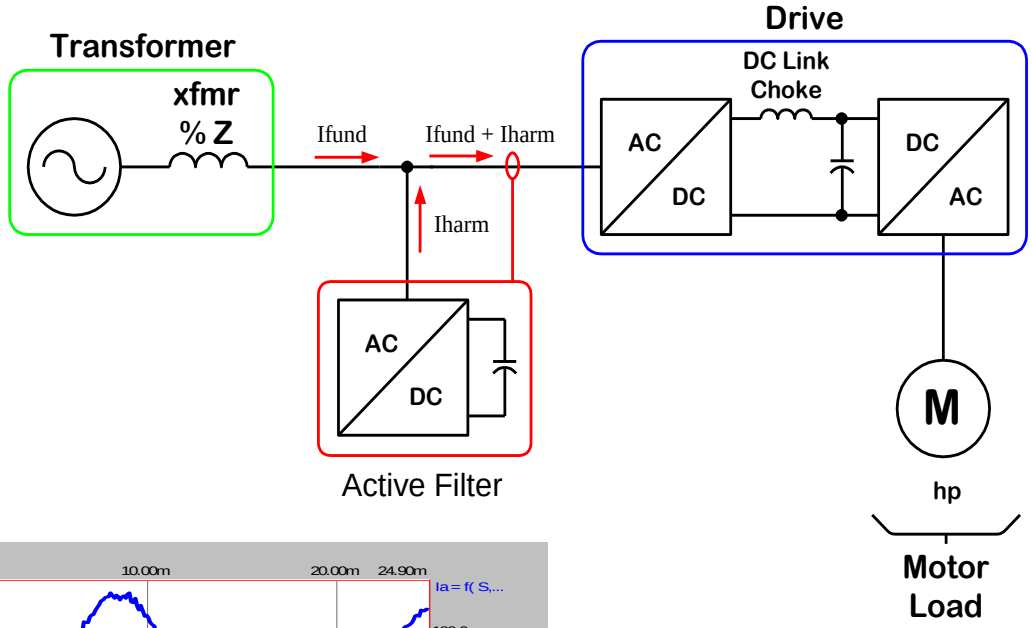
- Using 12-pulse input rectifier
- Need three-winding phase shift transformer
- THD level is 10 to 12%

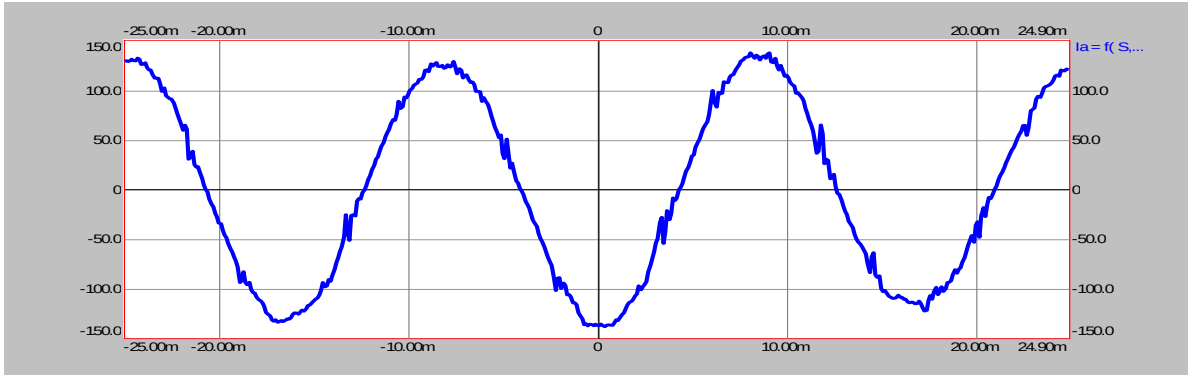


Fuji Electric
Innovating Energy Technology

Active Harmonic Filter

- Installed at incoming
- Active filter monitor harmonic level
- Generate opposition harmonics
- Typical I(THD) of 3 to 6%

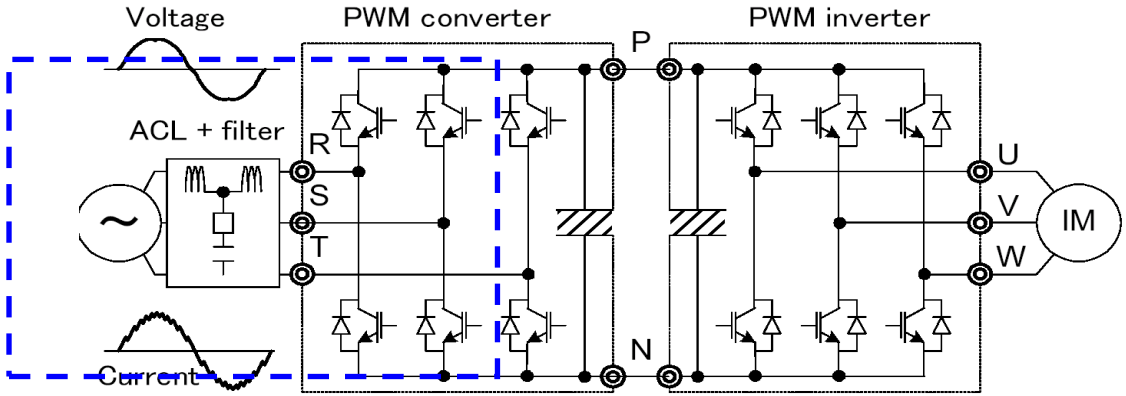


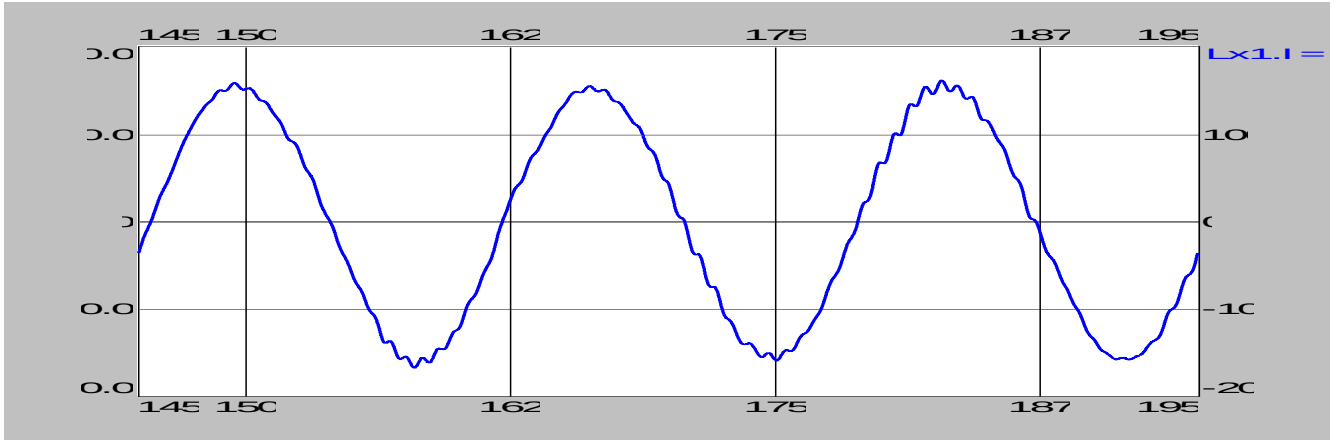


Fuji Electric
Innovating Energy Technology

Active FrontEnd PWM converter

- Using the PWM converter
- Modulation control of rectifier
- Bi-directional power flow capability
- THD level is less than 3%



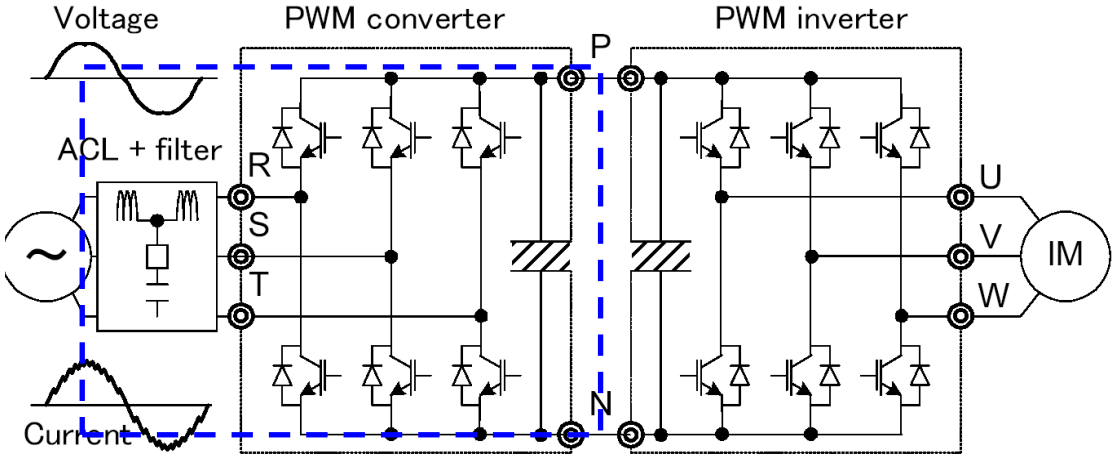


Fuji Electric
Innovating Energy Technology

PWM Converter



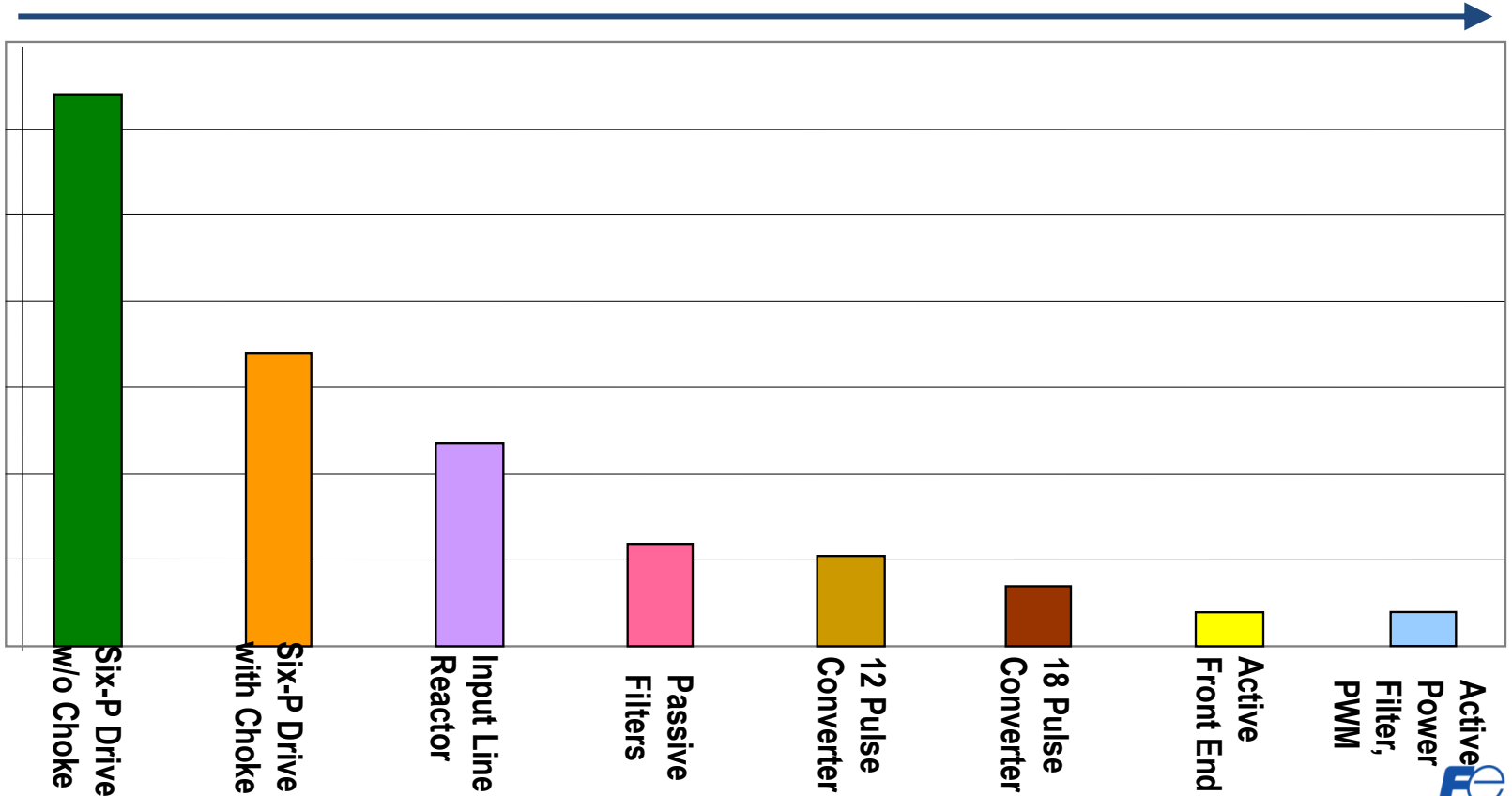




Fuji Electric
Innovating Energy Technology

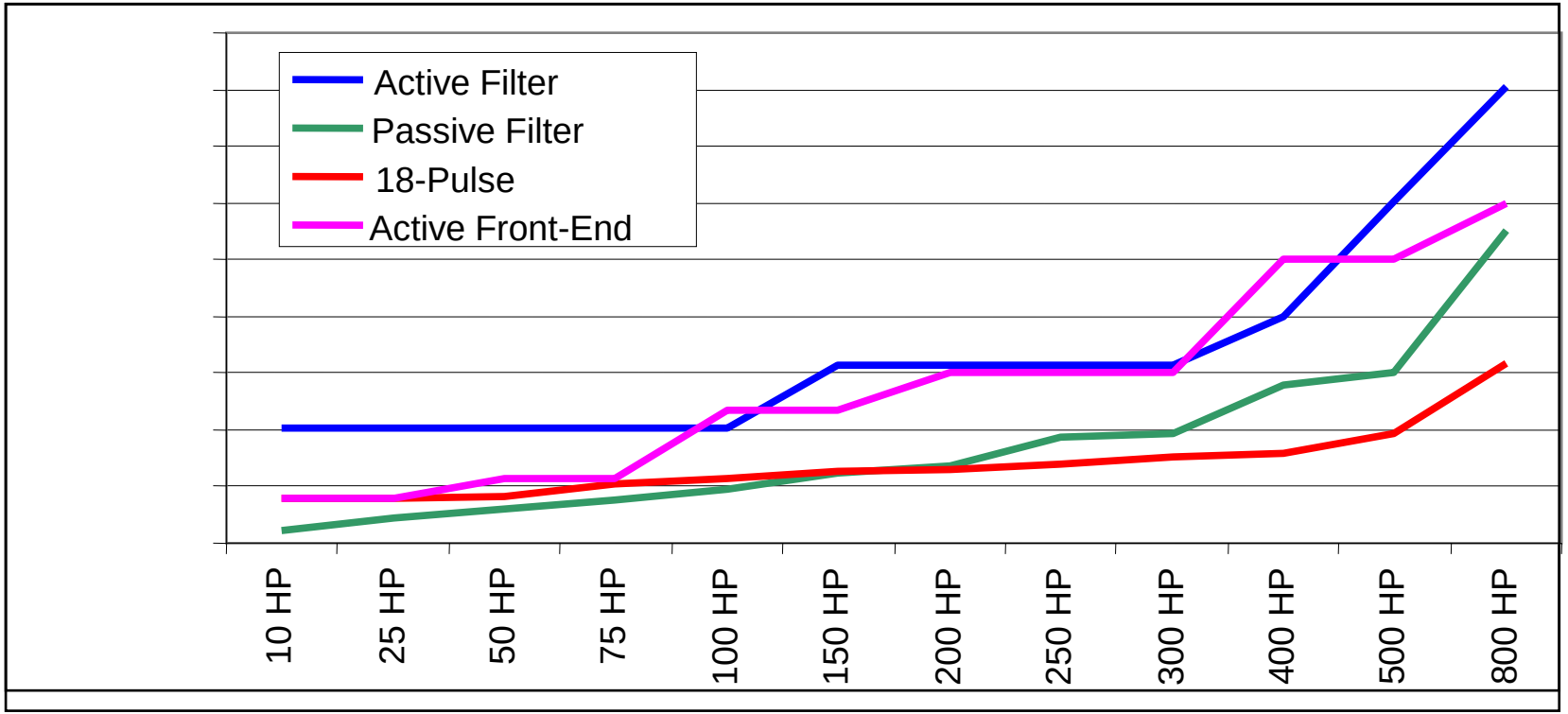
Harmonic Mitigation Solution

Less Harmonic Distortion



Fuji Electric
Innovating Energy Technology

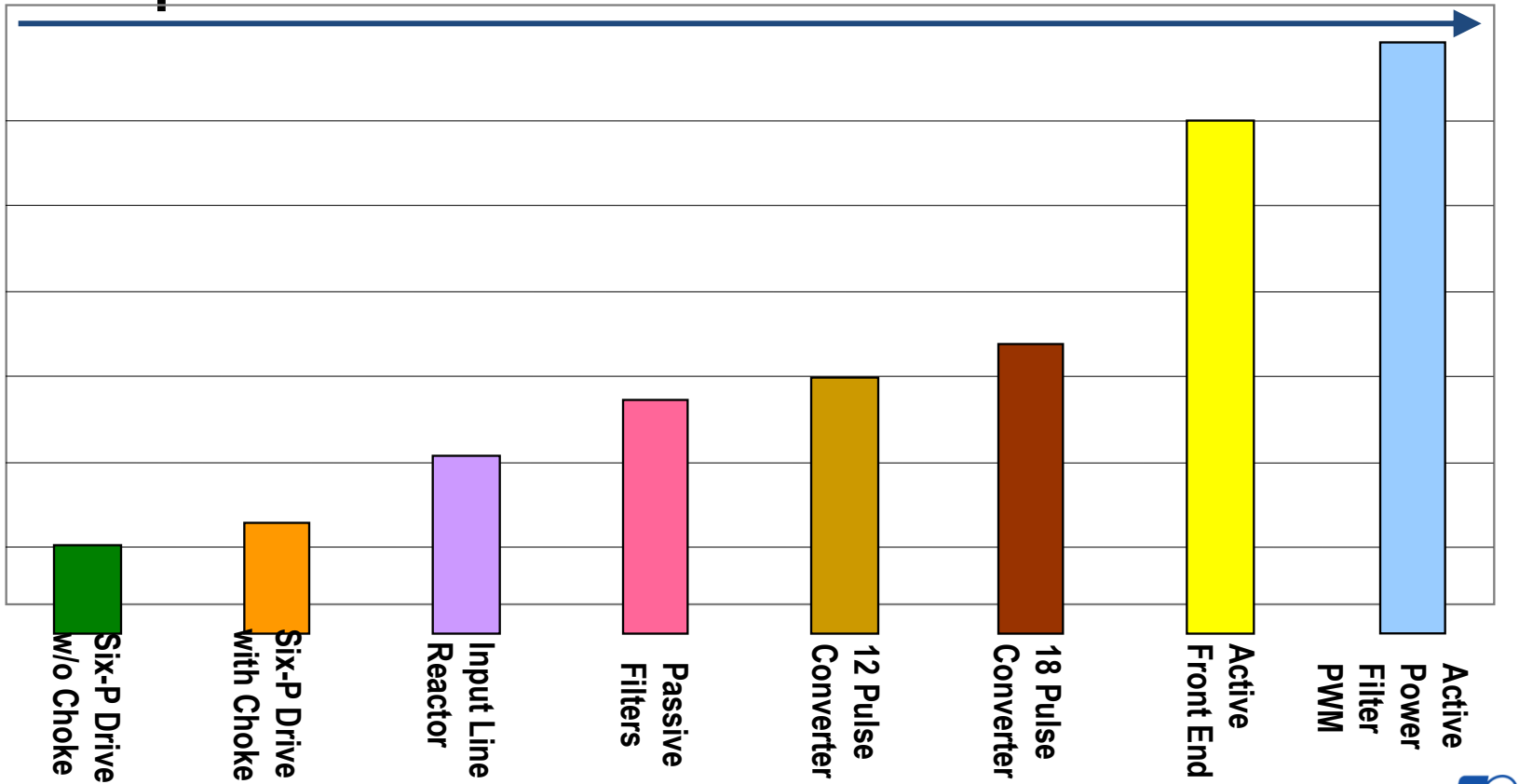
Harmonic Mitigation Solution Costs



Fuji Electric
Innovating Energy Technology

Harmonic Mitigation Solution Sizes

Footprint Size



Fuji Electric
Innovating Energy Technology

Fuji Electric
Innovating Energy Technology

Further contribution to the global community

The Possibilities Are Endless



Hand over to the future

At Fuji Electric
we believe we can do our part in energy conservation and help reducing impact to the mother earth by using environmental friendly component for a better future.



High quality products through a quality assurance system that conforms to the ISO9001 Standard

Fuji Electric
Innovating Energy Technology

Mo Wei

wei-mo@fujielectric.com



Fuji Electric Solutions

Want a little more performance in your work and workplace?

The advanced technology of
Fuji Electric holds the key to
a lot more efficiency.

Find out more →

www.fujielectric.com

Thank you