INTERNATIONAL JOURNAL OF SCIENTIFIC RESEARCH IN ENGINEERING AND MANAGEMENT (IJSREM)
VOLUME: 06 ISSUE: 12 | DECEMBER - 2022 IMPACT FACTOR: 7.185 ISSN: 2582-3930

# Power Factor Correction and Harmonic Control in Industries

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***Abstract*—Due to rising electricity prices, wastage of electrical energy needs to be reduced through countering the electric pollution in the circuit. Power factor correction and harmonics control is necessary in industries. Power factor correction can be done through placing capacitors in parallel in the circuit. Power factor of nearly 1 is the most efficient. Harmonics can be controlled with the help of linear reactors. In this paper we will discuss about the power factor correctors and linear reactors for harmonic attenuation.**

***Keywords—Power factor, linear reactor, harmonics, power quality.***

## I. INTRODUCTION

In recent times, where industries are moving towards automation, maximum capability out of machine plays a drastic role for increasing efficiency. Machine is judged according to its efficiency and selected accordingly. The efficiency of a machine is the ratio of output power received to the input power given to the machine.

Due to various losses the ratio of output power is always less than the input power but for higher efficiencies this ratio must be as high as possible. Today, as the natural resources are depleting at lightning speed it becomes very necessary to utilize higher percentage of power by reducing the losses to minimum.

The power dissipation occurs due to the presence of reactive power in the system due to the inductive nature of various loads. For inductive loads power factor improvement is necessary for obtaining maximum potential out of a machine.

Energy management is becoming a very critical issue in today's workplace and environment as the electricity rates continue to increase.

Problems caused by low power factor:

i. Large KVA rating of equipment
ii. Greater conductor size
iii. Large copper losses ($I^2R$)
iv. Poor voltage regulation

This research paper explains how power factor is related to energy efficiency in industries and methods available for correction of power factor to reduce the harmonics

## II. ELECTRICAL POWER

Electrical power is the rate at which electrical energy is consumed or dissipated to any other form. There are various types of power which come across when a machine works. These are classified as:

### A. Active power

It is the amount of Power actually consumed

in an electrical circuit. It is the product of current and voltage when current is in phase with the voltage.

Active power = voltage × current (in-phase with the voltage)

Active power(P) = V I cos ϕ

Units: Watts

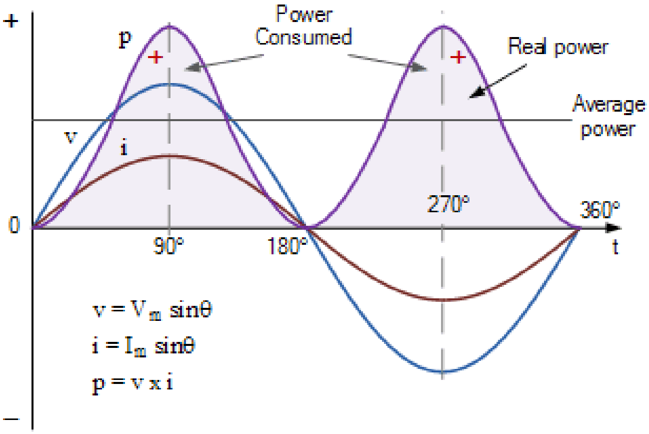


**Fig. 1**: Power as a product of current and voltage

### B. Reactive power

When L or C is present in an AC, energy is required to build up magnetic field around L or electrostatic field in C, this energy comes from the source. However, power consumed in inductor or capacitor is zero because all the power received from the source in a quarter cycle is returned to the source in next quarter cycle. This power oscillates back and forth is called reactive power. It does not perform any useful work in the circuit.

Reactive power = voltage × current 90º out of phase with voltage

Reactive power(Q) = V × I sin ϕ

Units: volt-ampere reactive (VAR)

### C. Complex power

Complex power is the electrical power in form of complex numbers. It consists of real and imaginary part. Real part represents the active power whereas imaginary part represents the reactive power.

S = P + jQ

Where P = Active power & Q = Reactive power

Also, $S = V_{rms} I^*_{rms}$

Units: Volt-Ampere (VA)

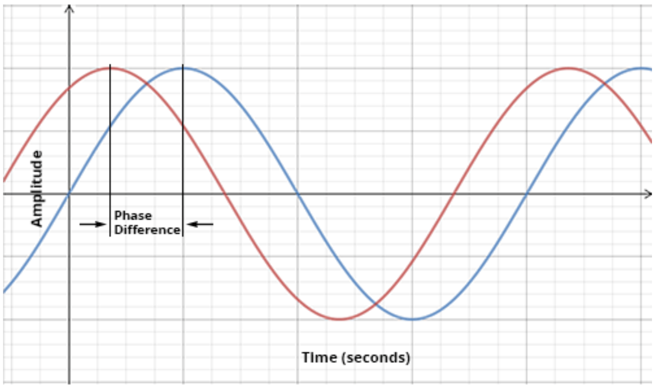


Fig. 2: Power as a product of current and voltage with current lagging voltage by phase difference ϕ

Phase difference (ϕ) = $\tan^{-1}\frac{P}{Q}$

Practically, the load consists of both active and reactive components. The active component consumes the power whereas reactive component determines the circuit characteristics i.e. inductive circuit or capacitive circuit.

### D. Apparent power

It is the magnitude of complex power or total power available in the circuit.

$|S| = I^2Z$

Where, $Z = \sqrt{R^2 + (XL - XC)}2$

Units: Volt-Ampere (VA)

### E. Power Triangle

It is the relation between apparent power, active power and reactive power [1].

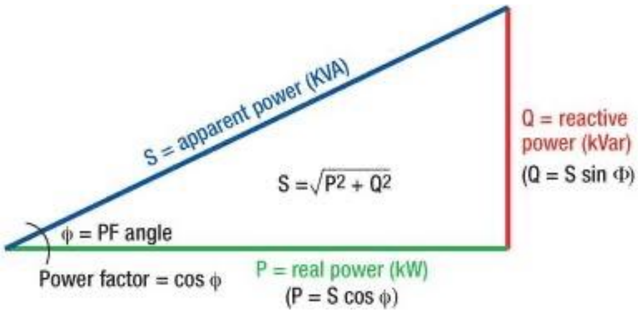


Fig. 3: Scaler representation of power triangle

## III. POWER FACTOR

Power factor of a system is defined as the ratio of the real power absorbed by system to the apparent power flowing in the system.
It is also defined as the cosine of angle between current and voltage.

P.F = Cos ϕ = $\frac{Kw}{KVA}$

Significance: The apparent power drawn by circuit has two components
1) True power
2) Reactive power
True power component should be as large as possible because it is a factor of useful work done in the circuit, for this reactive power should be minimum. As seen in Fig. 3 smaller the phase angle (ϕ) smaller is the reactive power hence, greater is the power factor (cos ϕ)
Thus when, ϕ = 0 (cos ϕ = 1), the reactive power component is zero and real power is equal to apparent power.
Thus, power factor is a measure of circuit's effectiveness in utilizing the apparent power drawn by it.
Greater the power factor of a circuit, greater is its ability to utilize the apparent power.
A 0.5 PF (50%PF) means a circuit will utilize only 50% of the apparent power.

## IV. POWER FACTOR CORRECTION

In industries, most amount of load is inductive in nature, therefore low power factor results due to the presence of high reactive power due to which current is lagging in nature.
For compensation, capacitive load is to be introduced to the fact that, both capacitive reactance and inductive reactance have a phase difference of 180º.

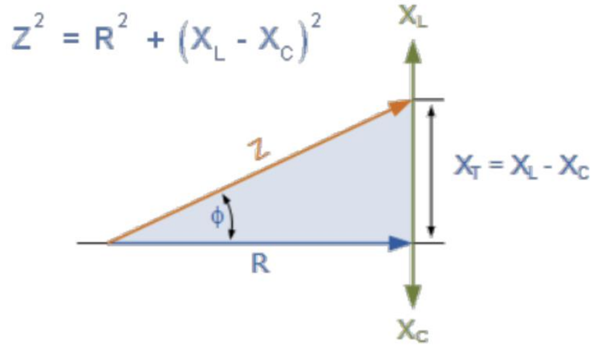


Fig. 4: Impedance triangle

Therefore, Z = $\sqrt{R^2 + (XL - XC)}2$

*A. Power factor correction using capacitors for industries*

As, most of the industrial loads are inductive, therefore they take lagging current which decreases the PF.
For power factor improvement, Static capacitor are installed in vicinity of large inductive loads in parallel with them.
These capacitors provide leading current which compensates the lagging inductive component of load current [2].

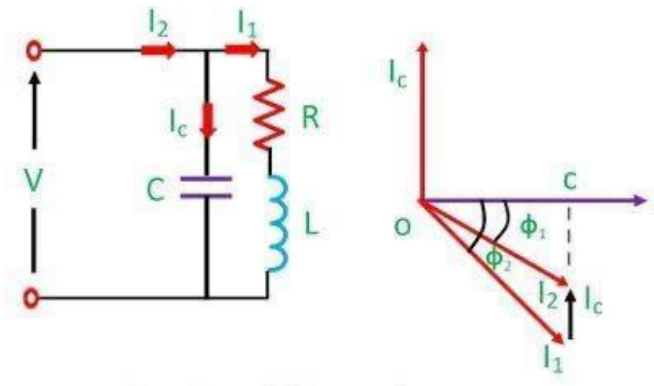


Fig. 5: Current and phasor diagram

The capacitor is connected in parallel with load.
It can be said that capacitors are source of local reactive power which supplies the reactive power in circuit therefore the main reactive power gets reduced.
Magnetic reversal in AC circuit due to phase difference occurs 50 times/sec.
A capacitor helps to improve the power factor by storing the magnetic reversal energy.

*B. Selection of capacitors:*

The sizing of capacitors is necessary for proper power factor correction.

KVAR = P (Tan $\phi_1$ – Tan $\phi_2$)

Where, $\phi_1 = \text{Cos}^{-1} \phi_1$ = Original power factor

$\phi_2 = \text{Cos}^{-1}\phi_2$ = Desired power factor

The voltage rating of a capacitor is usually the same as or little higher than the system voltage.

- As per Non-linear loads:

| Sr.no. | % Non-linear load | Type of Capacitor |
|---|---|---|
| 1. | <=10% | Standard duty |
| 2. | Upto15% | Heavy duty |
| 3. | Upto20% | Super heavy duty |
| 4. | Upto25% | Capacitor + reactor (detuned) |

- As per construction:

| Type of Capacitor | Material |
|---|---|
| Standard duty | Resin filled/Resin coated -Dry |
| Heavy duty | Resin filled/Resin coated -Dry, oil, gas |

Dielectric material: Metalized polypropylene (MPP)

Fig. 6: Cylindrical type capacitor

VOLUME: 06 ISSUE: 12 | DECEMBER - 2022 IMPACT FACTOR: 7.185 ISSN: 2582-3930

Fig. 7: Rectangular type capacitor

## V. HARMONIC ANALYSIS

The increase in non-linear loads has led to harmonic distortion in electrical distribution systems.
The deviations from the sinusoidal waveform of current and voltage due to the presence of non-linear loads in the system are called harmonics
Harmonic distortion is the ratio of harmonics to fundamental when a pure sinusoidal waveform is reconstructed [3].

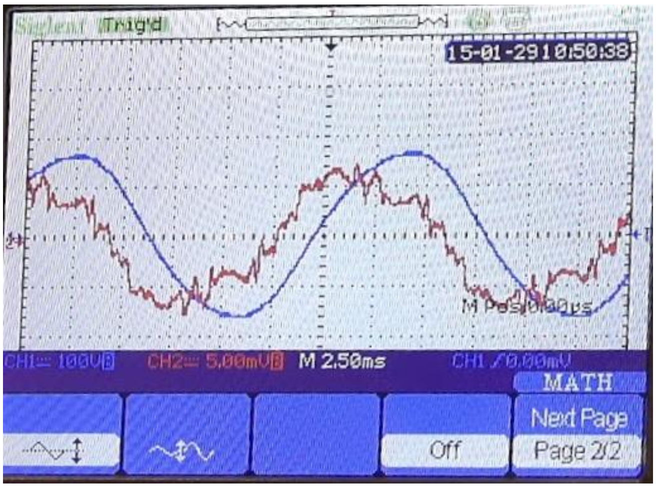


Fig. 8: Harmonic distortion in current wave.

### A. Non-linear loads

Most of the industrial load is non-linear i.e with current consuming characteristics that do not follow the same fundamental shape as the applied voltage waveform.

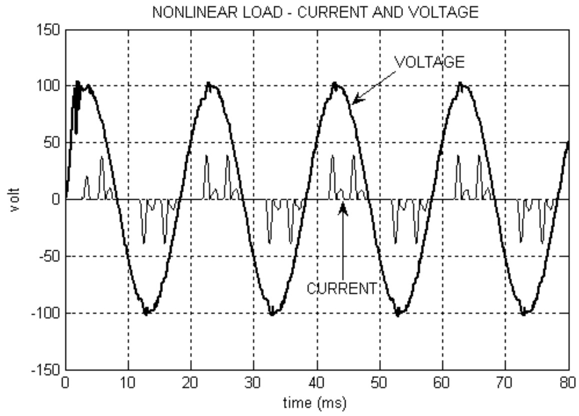


Fig. 9: Fundamental wave due to harmonics

This is due to harmonics that come from load.
This sinusoidal current contains harmonic currents that interact with the impedance of power distribution system to create voltage distortion that can effect load connected to it [4].

Non-linear load types:

a) DC drives
b) Variable frequency drives
c) Programmable controllers
d) Personal computers
e) Uninterruptible power supplies (UPSs)

### B. Co-related problems with harmonics

Unwanted currents and overheating are caused due to current harmonics.
Mis-operation of equipment are due to voltage harmonics.

Problems:

- Mis-operation and equipment failure
- Economic considerations (losses /inefficiency)
- Failure of power factor correction equipment.
- Electrical usage increases.
- Higher maintenance cost
- Power quality problems
- Utility penalties.

Unmanaged harmonics can increase motor temperature by 10 to maintain output. This side effect can reduce the life of motor by 50%.

### C. Total harmonic distortion (THD)

Harmonics have frequencies that are integer multiples of their waveform fundamental frequency.

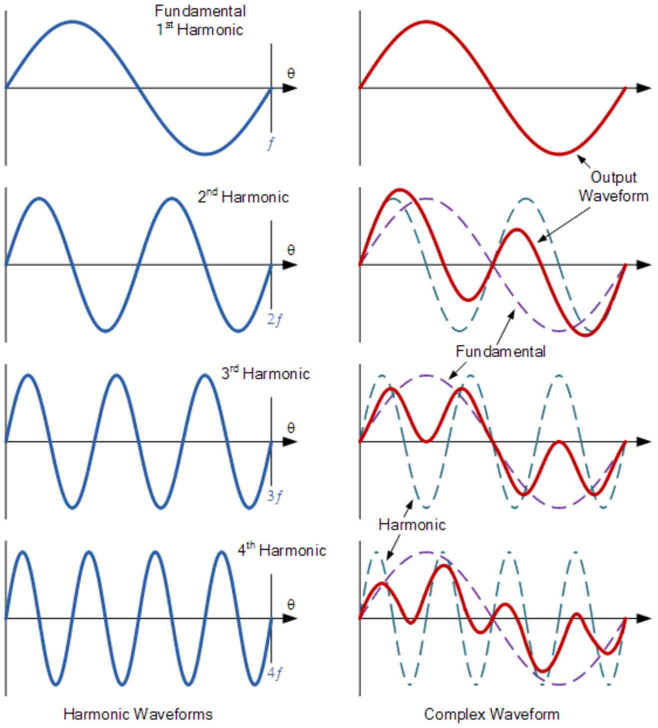


Fig. 10: Representation of 2nd, 3rd and 4th harmonic.

For example, given a 50Hz fundamental frequency, the 2nd harmonic have frequency 100Hz like-wise, 3rd harmonic is 150Hz, 4th harmonic is 200Hz respectively[5].
Thus, harmonic distortion can be defined as degree to which a waveform deviates from its fundamental frequency as a result of summation of all these harmonics.

Total harmonic distortion is defined as the summation of all harmonic components of voltage and current waveforms compared with fundamental components.

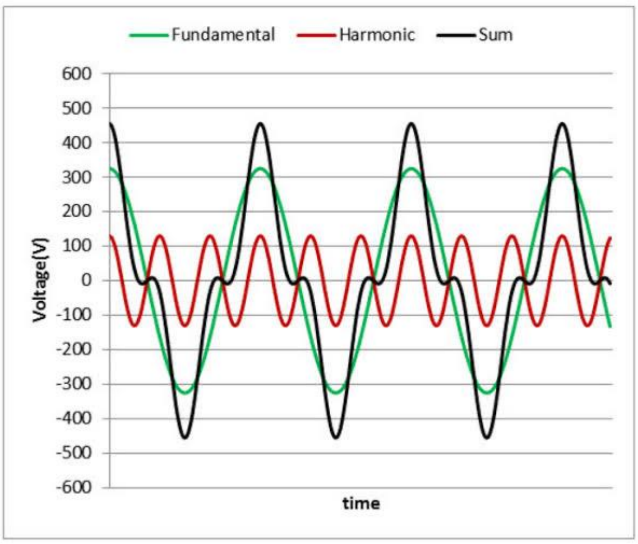


Fig. 11: Total harmonic distortion representation.

$$THD_F = \frac{\sqrt{V_2^2 + V_3^2 + V_4^2 \dots}}{V_1}$$

$V_n$ = RMS voltage of $n^{th}$ harmonic.

The end result is percentage comparing the harmonic components with fundamental components of signal. Higher the percentage, more is the distortion [6].

*D. Harmonic correction*

Harmonic in the system adds to the total apparent power of the system (KVA). Therefore, the power factor of the system is brought down. This does not effect on power bill but the important part is we draw more KVA so cables draw more Amps thus more heating of cable takes place.

- Line Reactor:

A three-phase line reactor is an inductor wired in series between two points in a power system.
The line reactor provides additional circuit inductance which is used to derive the line resistance.


Fig. 12: Line Reactor

Line reactor work as an impedance between the power source and Variable frequency drive as a result slow down harmonics and disturbances.
Line reactor not only protect variable frequency drives but also protect motor from disturbances such as transient, voltage spikes and surges.

*E. Classification of line reactor*

- Standard duty reactors:

Designed for voltages with low THD voltage like $V_3 = 0.5\%$ and $V_5 = V_7 = 3.5\%$.

Application: small scale industries.

- Heavy duty reactors:

Designed for voltage with THD voltages like $V_3 = 0.5\%$ and $V_5 = V_7 = 5\%$.

Application: medium scale industries (textile and automobile)

- Super heavy-duty reactors:

Designed for voltage with very high THD voltage like $V_5 = 0.5\%$, $V_5 = 9\%$, $V_7 = 6.5\%$, $V_{11} = 4.5\%$.

Application: large scale industries like steel, cement industries with a high percentage of nonlinear loads.

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