Harmonics and its impacts on power factor – Distortion Power Factor

Defining Power Factor

Power factor is usually identified as the cosine of angle between the voltage sine wave and the current sine wave. For a better understanding, it can be seen as the efficiency of electricity consumption. Similar to the efficiency of a machine, it can be defined as the ratio of output power rendered by the machine to the machine input power. Hence, it is the ratio of True power (kW) to Apparent Power (kVA).

$$\boldsymbol{Power\ Factor(PF) = \frac{kW}{kVA}}$$

However, it is not the only power factor present in the system. Depending on which value of voltage and current we consider, there are different types of power factors:

1. Displacement PF –The power factor which is due to the phase shift between voltage and current at the fundamental frequency is known as displacement power factor.

$$\boldsymbol{Displacement\ PF = \frac{P}{V_1 I_1}}$$

2. Distortion PF –The power factor which includes the effect of harmonics present in the system is called distortion power factor.

$$\boldsymbol{Distortion\ PF = \frac{1}{\sqrt{1 + \%iTHD^2}}}$$

3. True PF – It is defined as the ratio of average power to apparent power.
   Both the above power factors together combine to form the True power factor.

   True PF = Displacement PF x Distortion PF

$$\boldsymbol{True\ PF = \frac{P}{V_{rms}\ I_{rms}}}$$

Different types, different implications

Understanding the various types of power factor is very important because all three have different implications.

When we talk about power factor correction by means of capacitors, we are referring to improvement of only the displacement power factor, which consequently improves the true power factor. Capacitors act like an alternate "source" of reactive power and hence by decreasing the "inductiveness" of the system, they reduce the lag between the current and voltage phase, thus improving the power factor. But it is important to note that these voltage and current waves are with respect to the fundamental component i.e. 50 Hz. There might be some cases where even after installing capacitors at site, the power factor doesn't improve.

Here distortion power factor comes into picture.

Under normal load conditions,

$$kVA = \frac{\text{kW}}{\text{PF}}$$

Here, the system current is the rms current at 50 Hz.

For pure sinusoidal cases (systems without Harmonics),

$PF_{true} = PF_{disp} = \cos \phi$

where ϕ is the angle between voltage and current wave

In case of a system with Non Linear loads, when the system is polluted by harmonics, the rms current increases as seen by the following formula –

$$I = I_1\sqrt{1 + iTHD^2}$$

Increase in rms current consequently leads to increase in kVA demand. But the kW output of the system would remain the same.

Following the formula $VA = \frac{\text{kW}}{\text{PF}}$,

If kVA demand increases with kW remaining constant, power factor has to decrease. This decrease in power factor due to the presence of harmonics can be attributed to the **'distortion power factor'**.

Here true power factor becomes a product of displacement and distortion power factor.

True PF = Displacement PF x Distortion PF

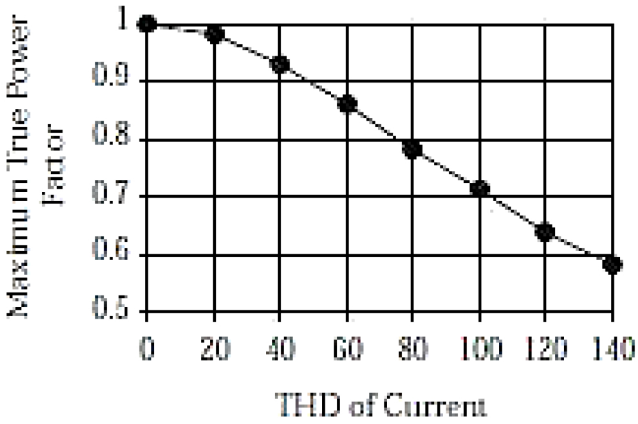
Hence, even if the displacement PF is corrected up to unity, the true PF will still remain low because of poor distortion PF.

Mathematically, distortion PF can be calculated as:

$$PF_{dist} = \frac{1}{\sqrt{1+iTHD^2}} = \frac{I_{rms(1)}}{I_{rms}}$$

where $I_{rms(1)}$ is the rms value of the fundamental current and I_{rms} is the rms value of total current.

Harmonic levels are measured as Total Harmonic Distortion (THD). Higher THD implies lower distortion PF. The graph below depicts the impact of THD levels on the true power factor of non linear loads.



The following table shows how different types of power factor vary with THD.

THD-I	Displacement PF (assumed to be compensated by equivalent Capacitors)	Distortion PF	True PF
5%	0.999	0.999	0.998
30%	0.999	0.958	0.957
40%	0.999	0.929	0.928

Capacitors don't do any good in correcting distortion power factor. In harmonic rich environment, using capacitors can even be detrimental to the installation as it can lead to harmonic resonance and harmonic amplification. Hence, in such cases, we need to use detuned reactors along with capacitors to avoid amplification.

APFC panels with detuned filters can effectively increase the displacement PF to unity. But the distortion PF will still remain low due to the presence of harmonics in the system. And hence, the true power factor will remain low, as seen in the above table. Thus, to improve distortion PF, Active Harmonic Filter should be used to mitigate harmonics.

The smart choice

For improving true power factor, correction of both displacement and distortion power factor is required. Capacitors are the means for improving solely the displacement power factor. But we can't overlook the repercussions of using capacitors alone in systems with high harmonics. In a harmonics rich environment, Active Harmonic Filter must be used to improve distortion PF. Hence, for true power factor correction, hybrid filter (capacitor-reactor combination with AHF) is the smart choice.