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3. Why do non-linear loads have low power factors and why is it important to have a high power factor?

Power factor is a measure of how effectively a specific load consumes electricity to produce work. The higher the power factor, the more work produced for a given voltage and current. Figure 3-1 shows the power vector relationships for both linear and non-linear loads. Power factor is always measured as the ratio between real power in kilowatts (kW) and apparent power in kilovoltamperes (kVA).

For linear loads, the apparent power in kVA ($S = V \cdot I$) is the vector sum of the reactive power in kVAR (Q) and the real power in kW (P). The power factor is $P/S = \cos\Phi$, where Φ is the angle between S and P. This angle is the same as the displacement angle between the voltage and the current for linear loads. For a given amount of current, increasing the displacement angle will increase Q, decrease P, and lower the PF. Inductive loads such as induction motors cause their current to lag the voltage, capacitors cause their current to lead the voltage, and purely resistive loads draw their current in-phase with the voltage. For circuits with strictly linear loads (a rare situation) simple capacitor banks may be added to the system to improve a lagging power factor due to induction motors or other lagging loads.

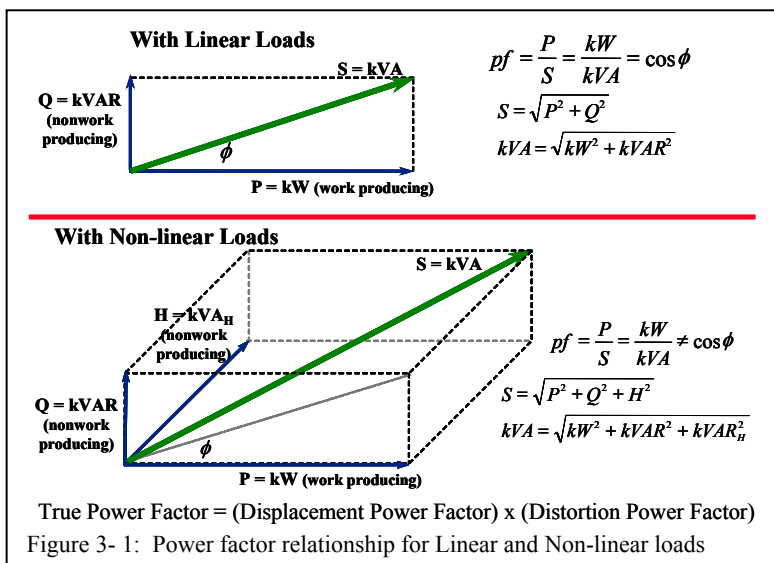


Figure 3- 1: Power factor relationship for Linear and Non-linear loads

For non-linear loads, the harmonic currents they draw produce no useful work and therefore are reactive in nature. The power vector relationship becomes 3 dimensional with distortion reactive power, H, combining with both Q and P to produce the apparent power which the power system must deliver. Power factor remains the ratio of kW to kVA but the kVA now has a harmonic component as well. True power factor becomes the combination of displacement power factor and distortion power factor. For most typical non-linear loads, the displacement power factor will be near unity. True power factor however, is normally very low because of the distortion component. For example, the displacement power factor of a personal computer will be near unity but its total power factor is often in the 0.65 – 0.7 range. The best way to improve a poor power factor caused by non-linear loads is to remove the harmonic currents.

Most Utilities charge their customers for energy supplied in kilowatt-hours during the billing period plus a demand charge for that period. The demand charge is based upon the peak load during the period. The demand charge is applied by the utility because it must provide equipment large enough for the peak kVA demand even though the customer's power demand may be much lower. If the power factor during the peak period (usually a 10 minute sliding window) is lower than required by the utility (usually 0.9 or 0.95), the utility may also apply a low PF penalty charge as part of the demand charge portion of the bill.

Suppose the peak demand was 800kW with apparent power consumption of 1000kVA (a PF of 0.8). If a power factor penalty was applied at 0.9, the Utility would charge the customer as if his demand was 0.9 x 1000kVA = 900kW even though his peak was really 800kW, a penalty of 100kW. Improving the power factor to 0.85 at 1000kVA demand would lower the penalty to just 50kW. For power factors of 0.9 to 1.0, there would be no penalty and the demand charge would be based upon the actual peak kW. The demand charge is often a substantial part of the customer's overall power bill, so it is worthwhile to maintain good power factor during peak loading and reducing the harmonic current as drawn by the loads can help achieve this.

References:

1. Roger C. Dugan, *Electrical Power Systems Quality*, McGraw-Hill, New York NY, 1996, pp. 130-133
2. H. Rissik, *The Fundamental Theory of Arc Convertors*, Chapman and Hall, London, 1939, pp 85-97