Power Factor, Correction and Optimal Value of This Factor in The Power Network

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Abstract

Power factor is an expression of energy efficiency. It is usually expressed as a percentage—and the lower the percentage, the less efficient power usage is.

Power factor (PF) is the ratio of working power, measured in kilowatts (kW), to apparent power, measured in kilovolt amperes (kVA). Apparent power, also known as demand, is the measure of the amount of power used to run machinery and equipment during a certain period. It is found by multiplying (kVA = V x A). The result is expressed as kVA units.

Power factor (pf), is the cosine of the phase shift between voltage and current, it is also found as the cosine of the load impedance angle. The main purpose of this study

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is to find the best method to correct the power factor in order to obtain economic, environmental and quality benefits from it. etc., as well as finding the optimal level of its value. The importance of studying the power factor is related to the many benefits that its correction offers us. First, we found out theoretically what the power factor is, its relations with active, reactive and complex power, then we found the way to correct it in order to get this optimal value. At the end we presented all the conclusions and results.

Key words: *Active power, reactive power, apparent power, complex power, power factor, power factor correction.*

Introduction

Electric power in alternating current circuits consists of three components: active power (P), reactive power (Q) and apparent power (S).

Active power (P), is the power that an electrical device consumes. So, circuits, devices or electrical loads use active power to work. Active power is measured in *watts, kilowatts or megawatts* (W,KW or MW). Real power produces the mechanical power in an engine – eg. in a packaging environment, or conveyor power moving materials through the factory. It is otherwise called real power or real power (Circuit Globe).

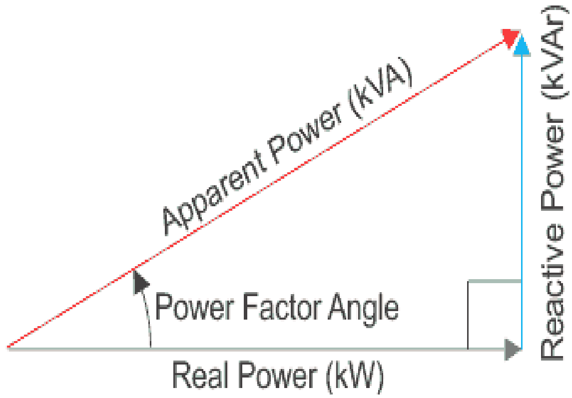
Reactive power (Q), doesn't do any real work. The power that flows before and after, which means it moves in both directions in a circuit or opposes itself, is called reactive power (Circuit Globe). Reactive power moves from source to load and back, from load to source. The transfer of this power is done without loss Reactive power is measured in , ,,(VAR,KVAR OR MVAR) (Circuit Globe)

Apparent power (S) is the product of the effective value of the voltage and the effective value of the current. This power is so named because of the power analogy that is calculated as voltage x current in DC circuits. Apparent power is measured in *voltamper, kilovoltamper, or megavoltamper* (VA, KVA or MVA) (Circuit Globe)

Power factor (pf), is the cosine of the phase shift between voltage and current. It is also found to be as the cosine of the full load resistance angle. Power factor is expressed as the ratio of active power (P) to apparent power (S). power factor is a quantity that takes values from 0 to 1.

The zero value is encountered for purely inductive or purely capacitive loads. A power factor value of 1 is encountered for pure resistive loads (Circuit Globe), (Alexander, Ch. & Sadiku,M. 2009).

FIGURE 1. Power factor triangle



Purpose of the work

The presented thesis is a small contribution to the ongoing studies being done on power factor utilization and regulation. Various methods have been used to adjust the power factor, the most used of which is the addition of capacitors. The purpose in choosing this topic is that the power factor can be used to have benefits such as: economic, environmental, voltage wave quality, cable losses, etc.

This paper analyzes the results obtained from studies made by well-known and interested engineers and analysts on power factor. Some of the materials are based on various books or engineering websites that have addressed the topic of power factor.

By studying the different methods of adjusting the power factor, I tried to determine the optimal level of the power factor in order to get optimal benefits from it. By studying different methods of adjusting the power factor we can distinguish which of these methods is the most suitable and most used in different working conditions.

Adding capacitors is the most economical way to improve the power factor of a facility. Capacitors serve as the main current generator to counteract the residual reactive current in the system.

Maintaining a high-power factor in a system will give us direct savings. As the power factor of the system is improved, the overall current flow will decrease, allowing additional loads to be added and served by the existing system.

FIGURE 2. Explanation of reactive and real energy

If equipment such as transformers, cables and generators are thermally overloaded, improving the power factor is the most economical way to reduce the current and eliminate the overload condition.

Based on what was said above, the finding to use the adjustment of the power factor will come as a result of numerous studies, which comparing them will give us a satisfactory result.

So, from what we said above and from what we will see below, we will understand that adjusting the power factor is a process of great interest to us. Electrical engineers must continue to study and improve the power factor to have economic benefits, in terms of quality of the voltage wave as well as environmental benefits.

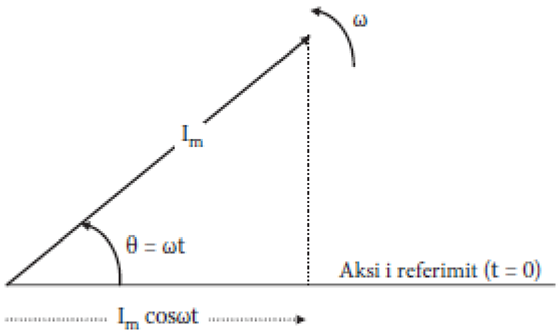
The power triangle

Electrical engineers have made constant efforts to determine the power that an electrical device consumes. To determine this power, it is necessary to determine the complex power, which gives us information on the nature of the load. (Circuit Globe), (Alexander & Sadiku, 2009).

The instantaneous value of the current passing through an element of the electrical circuit is $\mathbf{i(t) = Im\ cos\omega t}$. This quantity is represented as a vector of length Im rotating in the complex plane with angular velocity (frequency) ω rad/sec as shown in the Figure below. The instantaneous value of i(t) at any time t is **Im cosωt**, which is the projection onto the horizontal axis. It varies between +Im and –Im, going to zero twice at ωt = 90° and 270° each cycle. Since the actual value of i(t) depends on the phase angle of the rotating vector, this vector is called phase (Patel, 2011).

In general, the voltage and current phasors have a phase difference between their maximum values, that is, the maximum values can appear at different moments of time. The voltage and current phasor shown in Figure 1 has a phase difference θ, the maximum value of the current lags in phase by the angle θ to the voltage. Two phasors of the same frequency with a phase shift θ between their maxima will have the same phase shift θ between their zeros. The waveform above V and I imply that these quantities vary sinusoidally with respect to time. (Patel, 2011)

FIGURE 3. Phasor representing alternating current.



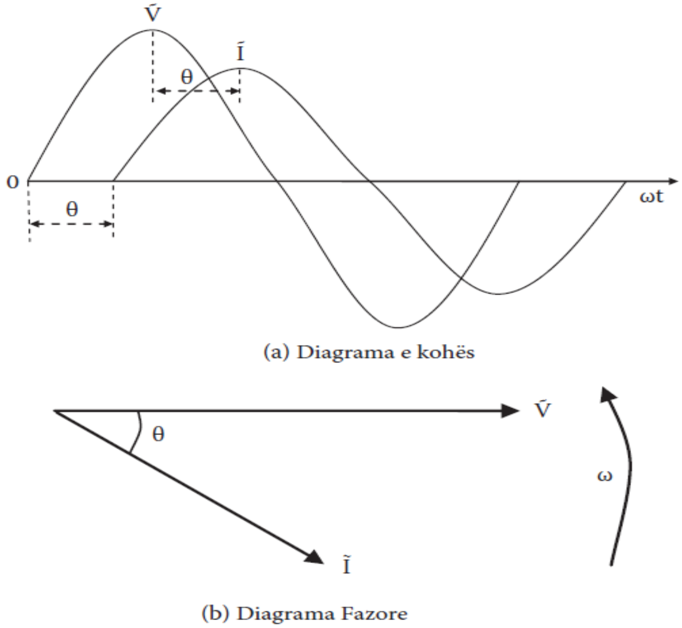
For average power, we know that when voltage and current are out of phase they produce less average power than when their peaks appear at the same time. If *V* and *I* are in phase (θ = 0), their product is always positive even when V and I are negative throughout the half cycle. However, when , the instantaneous power is negative when either V or I is negative and the other is positive. If positive power means power flowing from the source to the load, then negative power means power flowing back to the source as energy stored in the inductive or capacitive load. The average power in such cases is less than the maximum power that V and I can produce if they are in phase. The average power of the voltage V and the current I with phase delay against the voltage with the phase angle θ is given by the time average for one cycle with period T, so,

$$P_{mes} = \frac{1}{T}\int_0^T V_m\, cos(\omega t) \cdot I_m\, cos(\omega t - \theta) dt = \frac{V_m I_m}{2} cos\,\theta = V_{ef} I_{ef}\, cos\,\theta \quad (1)$$

If the voltage and current are in phase with $\theta = 0^\circ$, they will produce the maximum possible power equal to $V_{ef} \times I_{ef}$.

When they are out of phase they produce less average power. The reduction factor $cos\,\theta$ is called the power factor (pf). It is clear that, $pf = 1.0$ (unit) when $\theta = 0^\circ$, and $pf = 0$when $\theta = 90^\circ$. (Patel, 2011)

FIGURE 4. Two sinusoidal phasors (vectors) staggered by the angle θ.



Power factor improvement

The most economical way to improve the power factor of a facility is by adding utility power capacitors. It is important to understand the utility rate structure to determine the return on investment to improve power factor. (Meyers & Prado, 2016) (Small Business)

Maintaining a high-power factor in a facility will provide direct savings. In addition to reducing the power factor penalties imposed by some utilities, there may be other economic factors that, when considered as a whole, may lead to adding power factor correction capacitors that provide a justifiable return on investment. Other savings such as reduced distribution losses, improved voltage reduction and increased current-carrying capacity are less obvious but true nonetheless. In addition, there are other indirect benefits such as a result of more efficient equipment performance or lower carbon emissions, to be considered. (Meyers & Prado, 2016) (Small Business)

As the power factor of the system is improved, the overall current flow will decrease - allowing additional loads to be added and served by the existing system. In case of equipment, such as transformers, cables and generators, can be thermally overloaded, improving the power factor can be the most economical way to reduce the current and eliminate the overload condition. (Small Business)

Incorporating power factor correction capacitors into new construction or facility expansions can theoretically reduce project cost by reducing the size of transformers, cables, buses, and switches.

In practice, however, damping ratings are a function of full-load equipment values, and size reductions may be excluded by electrical codes. (Islami, 2017) (Small Business)

What is power factor correction?

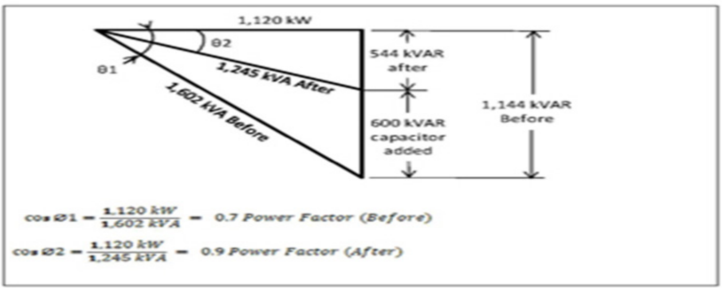
Power factor correction is a technique of increasing the power factor of a power supply. Switching power supplies without power factor correction draws the current in short, high-magnitude pulses. These impulses can be attenuated using active or passive techniques. This reduces the actual and apparent input RMS power, thereby increasing the power factor. (Islami, 2017)

Power factor correction shapes the input current to maximize the real power from the AC supply. Ideally, electrical equipment should present a load that emulates a pure resistance, meaning that the reactive power will be zero. And the current and voltage waves would be the same sine wave and in phase with each other.

The power generating company must produce more power to meet the demand for useful power and what is lost. This means more capital investment in generation, transmission, distribution and control. The costs are passed on to the consumer in addition to contributing to global warming. (Meyers & Prado, 2016)

Power factor correction tries to push the power factor of the electrical system, such as the power supply, towards 1, and although it does not achieve this, it gets as close as 0.95 which is acceptable for most applications. (Islami, 2017)

FIGURE 5. Energy triangle in relation to power factor.



Power factor correction methods

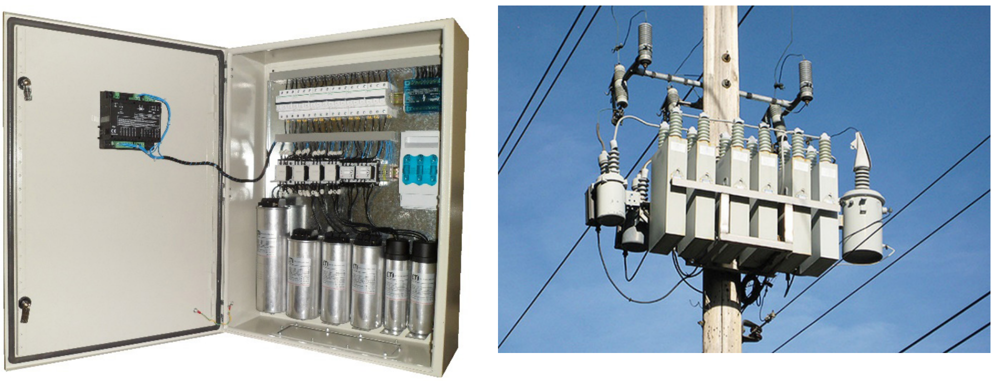
Fixed capacitor location schemes include:

1. Combining the required number of capacitors in the main bus. This will eliminate the power factor penalty but will not reduce losses in the facility. Capacitors located in this location are more sensitive to harmonic resonance.
2. Distribute capacitors in motor control centers and sub-panels proportional to the average load. This will generally improve losses, although it is not an optimal solution.
3. Distribute the capacitors using the motor sizes and NEMA tables as a guide. This solution does not reflect the need for more released capacity if that is a goal. Capacitors sized for small loads are often proportionally much more expensive than larger fixed capacitors, mainly due to installation costs.

Improving the power factor in electrical systems requires the installation of capacitor banks which act as a source of reactive power. In the low voltage system compensation can be provided by:

1. Capacitors with constant capacity
2. Capacitor battery which automatically adjusts the demand for reactive energy, i.e. the automatic change of capacity.

FIGURE 6. Banks of capacitors



Correction of the power factor in the economic aspect, (example)

A company absorbs active and reactive energy according to table 1:

TABLE 1. Active and Reactive energy consumption of company

MONTH	ACTIVE POWER	REACTIVE POWER	AVERAGE POWER FACTOR	HOURS OPERATED	ACTIVE POWER	Q_C=P(tangΘ-0.484)
January	7221	6119	0.76	160	0.76	16.4
February	8664	5802	0.83	160	0.83	10.0
MARCH	5306	3858	0.81	160	0.81	8.1
APRIL	8312	6375	0.79	160	0.79	14.7
May	5000	3948	0.78	160	0.78	9.5
JUNE	9896	8966	0.74	160	0.74	26.1
JULY	10800	10001	0.73	160	0.73	29.8
August	9170	8910	0.72	160	0.72	27.9
September	5339	4558	0.76	160	0.76	12.3
OCTOBER	7560	6119	0.78	160	0.78	15.4
NOVEMBER	9700	8870	0.74	160	0.74	26.1
December	6778	5879	0.76	160	0.76	16.2
TOTAL	93746	79405				

We start by calculating 0.484 as the tangent corresponding to a cosΘ=0.9.

If an automatically controlled capacitor bank for power factor correction with Qc = 30 kvar, against a total installation cost per year cc of €25 / kvar, gains a total cost of €750. The saving for the consumer, without considring the payment and financial payments, will be:

$$\mathbf{C_{EQ} - C_{QC} = 1370€ - 750€ = 620€}$$

As we can see from the example above, the installation of a bank of capacitors automatically controlled for the correction of the power factor of power there will be a considerable saving, a saving which is far greater than the cost of installing the capacitor bank.

Benefits of power factor improvement

1. *Reduction of cable size.* The table below shows the increase in cable cross-section for reducing the power factor from 1 to 0.4 for the same transmitted active power.
2. *Reduction of losses (P, kW) in the cable (conductor).* Losses in the cable are proportional to the current squared. Reducing the current in the conductor by 10% for example, the losses will be reduced to about 20%.
3. *Reduction of voltage drop.* A lower power factor causes a higher current flow for a given load. As the current increases, the voltage drop across the conductors increases, which can result in a lower voltage across the device. With an improved power factor, the voltage drop across the driver is reduced, improving the voltage across the device.
4. *Increasing the capacity of transformers, lines, etc..* By improving the power factor, the load current fed by the transformer will decrease which will make it possible to increase the load on it.
5. *Reducing carbon footprints.* By reducing the demand load on your power system through power factor correction, your utility is putting less strain on the power grid, reducing its carbon footprint. With the passage of over time, this reduced demand on the electricity grid can account for hundreds of tons of reduced carbon output, all thanks to improved electrical efficiency of your power system through power factor correction.
6. *Losses of use of the energy system.* Although the financial return from conductor loss reduction alone is rarely sufficient to justify the installation of capacitors, it is sometimes an attractive additional benefit, especially in older plants with long outlets or in field pumping operations. System driver losses are proportional to the square of the current and, since the current is reduced in direct proportion to the improvement in power factor, the losses are inversely proportional to the square of the power factor.
7. *Cost savings.* Most electric utility companies charge for peak demand measured based on the highest recorded demand in kilowatts (KW meters), or a percentage of the highest recorded demand in KVA (KVA meters), whichever is greater. If the power factor is low, the percentage of measured KVA will be significantly greater than the required KW. Improving the power factor through power factor correction will lower the load demand, helping to reduce your electricity bill.

Conclusions

- From the analysis done for adjusting the power factor, we see that adding capacitors is the most economical way to improve the power factor.
- Different power factor correction techniques give us the opportunity to solve the optimal type of power factor correction technique for different networks with different voltage levels.
- Reducing the size of the cable is a benefit obtained by adjusting the power factor.
- Another benefit of power factor regulation is the reduction of cable losses as they are proportional to the squared current.
- The reduction of the voltage drops which is obtained by adjusting the power factor by means of capacitors reduces the reactive component.
- By adjusting the power factor, we can increase the capacity of transformers and lines as the load current fed by the transformer will decrease increasing the load on it.
- Another benefit is the environmental benefit as power factor adjustment because of more efficient equipment performance or lower carbon emissions, to be considered.
- All the above-mentioned benefits result in three main benefits where they are all included. Economic benefits, voltage wave quality benefits and environmental benefits.

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