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Power factor Benefits and ModellingUsing Magnetizing Current andProducing Currents

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ABSTRACT
This paper discusses the Sinusoidal Power Factor model, which is used in the electrical networks to get high efficiency and a low cost. There are several reasons that are very beneficial for improving the power factor. Some of these are economical and others are technical. For the technical reasons, power factor correction can help to reduce the voltage drop that is produced in underground cables or overhead lines at the transmission or distribution level. Also, it can reduce the load on electrical equipment which provides more capacity for equipment and can result in less copper loss. The economical side for power factor correction is represented by the reduction of the consumed power by compensating the reactive power and the decline of electric bills that are paid by customers. The excessive reactive power can be used in suppling inductive loads such air-condition and huge motors in factories.
This paper will discuss the calculation of power factor model using the two current types magnetizing and producing currents.

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I. INTRODUCTION

It is hard to explain the meaning of the term 'power factor' when using the relationship between the sinusoidal wave of voltage and current sine any correlation is difficult to demonstrate. However, the effect of the 'power factor' and the usage of capacitors can be demonstrated by studying the alternating current passing through the circuits.

The current supplied to any type of load can be helpful to understand the power factor by discussing the two current types i.e. magnetizing and producing currents. The magnetizing current is responsible for generating the magnetic flux for the operation of inductive loads such as motors and transformers. The produced power of the magnetizing current is the reactive power and can be measured in Kvar.

Current Model

The power producing current is needed to perform operations related to resistive loads such as heaters. The resultant power for this type can measured in Kw [1], the current components can be represented by the phasor diagram whilst using the voltage as reference which has been illustrated in the figure below

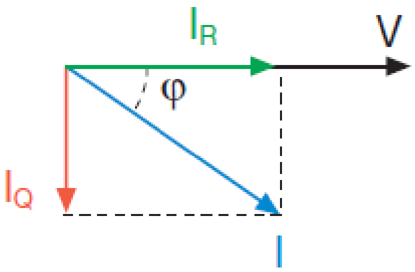

Figure 1: Phasor diagram of Power factor [2]

The above figure indicates the power current is located horizontally in phase with the voltage. Also it can be seen from the figure the magnetizing current is perpendicular to the voltage.
The total current can be calculated using the formula below:

$$I_t = \sqrt{\text{power current}^2 + \text{magnitizing current}^2}$$

Using the vector properties, it is possible to convert the current vector with its angle to two vectors and represent the X-components.
Then,

$$I_t = \sqrt{(I\cos\varphi)^2 + (I\sin\varphi)^2}$$

and the second represents the Y-component. By multiplying the X and Y components by the voltage it is possible to acquire the active and reactive power respectively:

$$\text{Apperant power} = \sqrt{\text{active power}^2 + \text{reactive power}^2}[3]$$

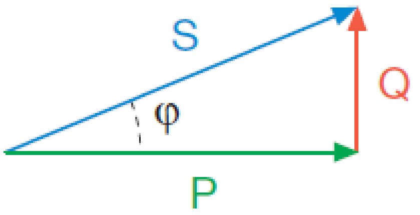

Figure 2: Power triangle[2]

This figure indicate the relationship between types of power

The first thing which must be established is the power factor in the circuits, this is represented by the amount of active power (real) which is measured in K watt or M watt to the amount of apparent power which is measured in KVA or MVA [4].

The value power factor is essential for any electric network because it is the indicator for the quality of the system. As mentioned above there are three types of power i.e. active, reactive and apparent power. Active power is responsible for the current and voltage used. It can be stated the power factor is the ratio of active power to the apparent power which can be present in intervals of 0 and 1, within real networks it is equal to 0.8 to 0.98 [5].

In AC networks there are two types of power. The first is real power that is responsible for making lamps and heaters work whereas the reactive power is done by loads which do not consume real power (these loads can be either capacitors or inductors). Also reactive power has a negative or positive sign which relates to the kind of load, for example if it has a positive load, this indicates an inductive load and if it has a negative sign this indicates a capacitive load [6].

Reactive power is used in any AC circuit and is essential for understanding how circuits work. It is hardly mentioned in physics books. Furthermore, this type of power is difficult to explain because of using imaginary numbers in mathematics and that made electrical engineers use certain phenomenon in AC circuits to explain it [7].

Power Factor Benefits

Reasons for low power factor [8, 9]: There are many reasons that result in low power and it can effect on the efficiency of the network and economic issue and they are:

1- Using motors such as induction and synchronous specially at factories
2- The machines for connecting metals
3- Heaters working by electricity
4- Lights having fluorescent

Advantages of power factor correction: Correcting power factor of any electrical network in either transmission or distribution can be beneficial in many aspects including the following:

1- Minimizes the consumed power because of the good energy quality, thus reducing the environmental impact because there is a reduction in the fuel used in generating electricity [10].
2- Power factor correction can decrease the consumer's electrical bill [10]. This is evident in European models, which allow consumers to use less amounts of reactive power. Using less reactive power can be achieved using capacitors. The electric bills can be decreased by keeping the amount of reactive power from exceeding the limit given by the electric provider. This can be represented by the following formula:

$$\tan\varphi = \frac{\text{Q Kvarh}}{\text{P KWh}}$$

This formulate can be used to understand the related costs of in cases having free reactive power. Where tan φ is less than 0.4, which means the percent of reactive energy to active energy, is less than 40%. These figures are common in winter sessions with high daily loads. On the other hand when tan φ becomes greater than 0.4, this indicates the usage of reactive energy is more than 40% which is still charged at the same tariff rate. In such a scenario the cost of reactive energy can be given as follows

$$\text{Kvarh} = \text{Kwh}(\tan\varphi > 0.4)$$

Where during the time of prevention:

- KWh is the consumed active energy
- KWh tanφ is the total reactive energy
- 0.4 KWh is the non-charged used reactive energy

The value of power factor can be known by the value of tan φ, for instance when tan φ is equal to 0.4, the power factor is 0.93. This means customers will not be charged extra because of the reactive energy if the power factor is kept the same.[11]

Equipment and appliances		cos φ	tan φ
Common induction motor	loaded at 0%	0.17	5.80
	25%	0.55	1.52
	50%	0.73	0.94
	75%	0.80	0.75
	100%	0.85	0.62
Incandescent lamps		1.0	0
Fluorescent lamps (uncompensated)		0.5	1.73
Fluorescent lamps (compensated)		0.93	0.39
Discharge lamps		0.4 to 0.6	2.29 to 1.33
Ovens using resistance elements		1.0	0
Induction heating ovens (compensated)		0.85	0.62
Dielectric type heating ovens		0.85	0.62
Resistance-type soldering machines		0.8 to 0.9	0.75 to 0.48
Fixed 1-phase arc-welding set		0.5	1.73
Arc-welding motor-generating set		0.7 to 0.9	1.02 to 0.48
Arc-welding transformer-rectifier set		0.7 to 0.8	1.02 to 0.75
Arc furnace		0.8	0.75

Figure 3: The values for cos φ and tan φ for the common equipment [11]

3- Minimizing bills is economically beneficial to customers but this requires several considerations including the cost, repair, installing, and controlling of power factor compensation devices. Customers should be aware of capacitor losses in the network because this causes higher energy consumption [11].

4- The correction can provide more reactive power to the supply which can be used to feed additional loads in the network [10].

5- Minimize the copper losses in elements of distribution networks such as transformers and cables [10]. The main factors for the copper loss are the value of conductor resistance and the squared current passing through the conductor. The current can reduced by increasing the power factor value whilst keeping the same value of transferred active power through the network. As the current value decreases the losses will eventually reduce, this can be shown in the formulas below [2]:

(The losses in 3 phase circuits can calculated by the formula)

$$P = 3RI^2 = \frac{R(P^2+Q^2)}{V_{Line}}[2]$$

$$I = \frac{S}{\sqrt{3}\,V_{line}} = \frac{\sqrt{P^2+Q^2}}{\sqrt{3}\,V_{line}} \rightarrow 3I^2 = \frac{P^2+Q^2}{V_{line}^2}[2]$$

Where:

- I is the current crossing the conductor
- R is the resistance value of the conductor
- S is the apparent power needed for the electric load
- P is the active power needed for the load
- Q is the reactive power needed for the load
- V_L is the rated voltage of main source

The relationship between the reduction of losses and the new and old power factor values can be expressed mathematically as follows:

$$P_1 = \frac{R(P^2+Q^2)}{V_{Line}^2} = \frac{R\times S^2}{V_{Line}^2} = \frac{R}{V_{Line}^2} \times \frac{P^2}{(\cos\varphi)^2} \text{ and } P_2 = \frac{R}{V_{Line}^2} \times \frac{P^2}{(\cos\varphi)^2}[2]$$

Then,

$$\Delta P = P_1\left[1 - \left(\frac{\cos\varphi_1}{\cos\varphi_2}\right)^2\right][2]$$

Where,

- P_1 is the power loss before the power factor improvement
- $\cos\varphi_1$ is the power factor value before the improvement
- $\cos\varphi_2$ is the power factor value after the improvement

		cosφ1						
		0.4	0.5	0.6	0.7	0.8	0.9	0.95
Δp%	from cosφ1 to 0.9	80.2	69.1	55.6	39.5	20.9	-	-
	from cosφ1 to 0.95	82.3	72.3	60.1	45.7	29.1	10.2	-

Figure 4: The effect for improving the power factor can help to reduce the losses [2]

Help to reduce the voltage drop in power cables [10]. It is possible to calculate the voltage drop in a 3 phase circuit using the formula below:

$$\Delta V = \sqrt{3}\, I\,(R\cos\varphi + X\sin\varphi) = \frac{P}{U_n}(R + Xtg\varphi)[2]$$

Where:

- R is the resistance of the line
- X is the reactance of the line
- P is the active power carried
- I is the current
- U_n is the rated voltage

It is likely to control the voltage drop through the lines by maximizing the power factor value to the same active power transferred; this is shown in the figures below. It can be seen that the when angle between the voltage and the current becomes smaller for the same active power, this results in a lower voltage drop which indicates there is no reactive power [2]. The following figure shows the voltage drop on the transmission line without power factor correction:

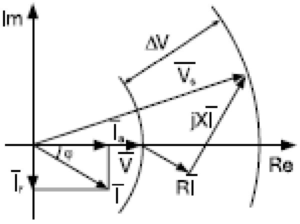

Figure 5: Voltage drop in the line without power factor correction [2]

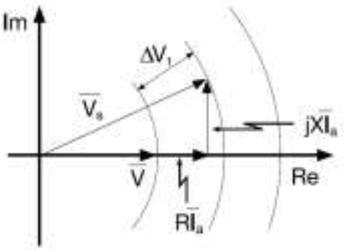

Figure 6: The figure below shows the voltage drop with resistive load:[2]

6- It can help to decrease the load in electrical devices such as cables [10]. When loads are reduced on cables, this can minimize their cross sectional area. This can be achieved by improving the power factor, which reduces the current carried by the cables.

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