

Power Factor(Pf) Analysis and Suggestive Methodology for Improvement of Pf



Engineering

KEYWORDS : Power factor, Power factor analysis, power waveforms, improvement of PF, requirement of improvement of PF, methods of PF improvement.

Manish Kumar Agrawal

B Tech, 3RD Year, Electrical Engineering, VSS UNIVERSITY OF TECHNOLOGY, BURLA, Odisha

Sukhamaya Swain

AXIS BANK LTD, Odisha

ABSTRACT

The ideal voltage and current waveform of supply to the users is sinusoidal but in actual practice it is not possible. So the calculation of the PF is different from the traditional way. Power transmission and distribution system has a particular limit of carrying current. It depends on users that how that power is being utilized. The amount of extra power that is drawn by the load depends on the PF of the load. In electrical installation with low PF, significant cost savings can be made through the application of PF correction. Improving of PF can reduce power cost, release electrical capacity of the system, raise the voltage level and reduce system losses.

II-Introduction:-

During recent years, increasing attention has been paid to minimize the energy cost and inefficiency in electricity generation, transmission and distribution. When designing a compensation scheme, one should attempt to achieve the most economical solution in which the saving achieved in the equipment cost is significantly greater than the procurement cost of the reactive power. Different systems are available to produce reactive energy and improve the power factor: Particularly, shunt capacitors at the nearest point to the loads is a well-established approach to improve the power factor. Shunt capacitors are attractive because they are economical and easy to maintain. Not only that, but also they have no moving parts, unlike some other devices used for the same purpose.

III- Present state of affairs:-

III(a)-Logical analysis:-

“Power factor is a measure of the degree to which a given load matches that of a pure resistive load.”

PF=1 If load appears as R (purely resistive) , PF=0 If load appears as L or C (purely reactive), For R-L circuit PF is between 0 & 1 (lagging), For R-C circuit PF is between 0 & 1 (leading).

III(b)-Mathematical analysis:-Power factor is the ratio between the KW (kilo watts) and KVA (kilo volt amperes) drawn by electrical load where,

KW- real power

KVA-apparent power=RMS voltage*RMS current

It is a measure of how effectively the current is being converted into useful work output and more particularly is a good indicator of the effect of the load current on the efficiency of the supply system. All current flow will cause losses in the transmission & distribution system e.g.; a load with PF of 1 results in the most efficient loading of the supply and load with PF of 0.5 will result with much high losses in the system.

Consider a pure resistance is connected across an alternating voltage source of sinusoidal wave form and current in phase with voltage as shown (fig 1). Now we shall make the graph for V*I (power) by multiplying each point of current wave with corresponding point in voltage wave(fig 2).fig.1. voltage, current and power characteristics of resistive load (from MATLAB by author)

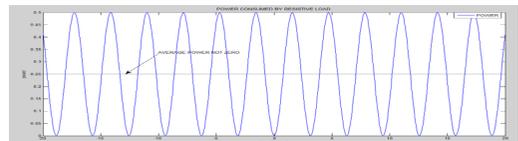
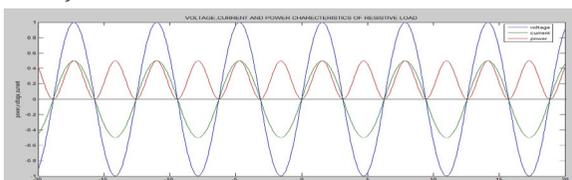
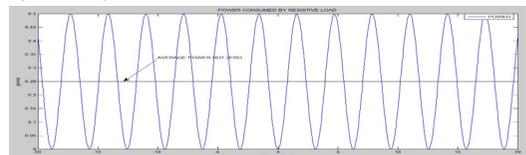


fig.2- power characteristics of resistive load (from MATLAB by author)



Here we can see that no negative components are there in the power graph and the frequency is double that of the voltage and current frequency.

Average power consumed by this circuit is $P_{avg} = \frac{V_m * I_m}{2}$
 V_m = maximum voltage
 I_m = maximum current

The above same method was repeated for pure inductive and pure capacitive circuits and the power wave forms were drawn as shown(fig3,fig 4,fig 5,fig 6). In both the cases the power waves have both positive and negative components and the average power consumed are zero $P_{avg} = 0$.

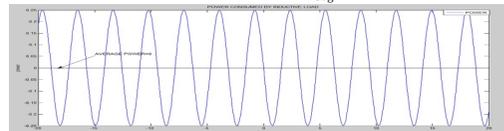


fig.3. voltage, current and power characteristics of inductive load (from MATLAB by author)

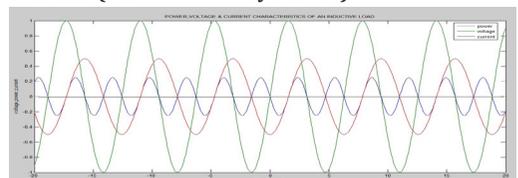


fig.4. power characteristics of resistive load (from MATLAB by author)

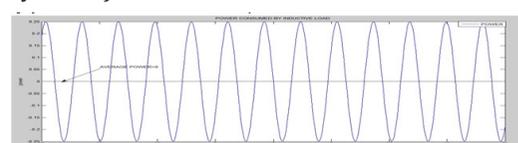


fig.5. voltage, current and power characteristics of capacitive load (from MATLAB by author)

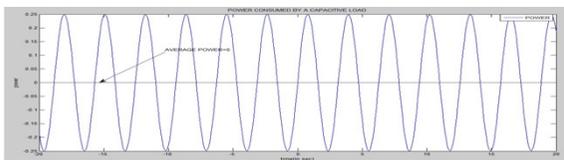


fig.6. power characteristics of resistive load (from MATLAB by author)

Now let us study the circuits containing both R and L and draw the respective graphs(fig7,fig 8). We have added a resistance in a pure inductive circuit, the phase difference will decrease from a pure inductive circuit. As the value of resistance increases the phase difference decreases (fig 9(a)(b)).

Note:-when we increase the value of resistance the power graph shifts upward. When the value of resistance is much larger than inductance than inductance then the power graph contains no negative part, negative part of power graph means some power is being put back to the source so it is called reactive power. The average power that actually goes to the load is called active power.

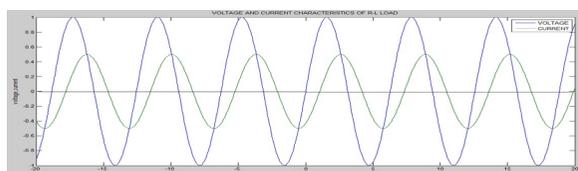


fig.7. voltage, current and characteristics of R-L load (from MATLAB by author)

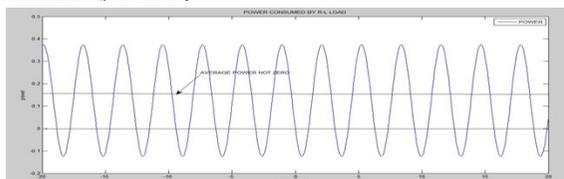


fig.8. power characteristics of resistive load (from MATLAB by author)

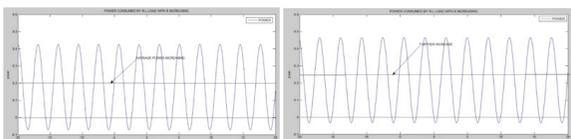


fig.9(a),(b)- power characteristics of R-L load with increasing R (from MATLAB by author)

All the above experiments are repeated for R-C circuits and corresponding graphs are drawn as shown (fig 10,fig 11,fig 12(a)(b)).

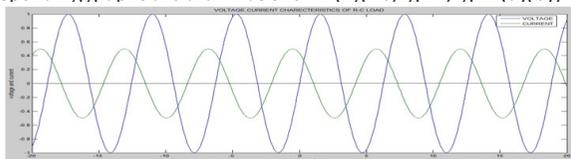


fig.10. voltage, current characteristics of R-C load (from MATLAB by author)

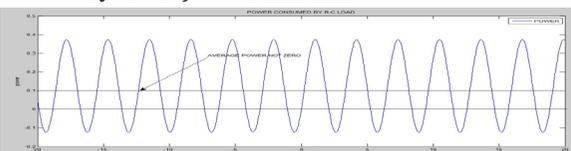


fig.11.power characteristics of R-C load (from MATLAB by author)

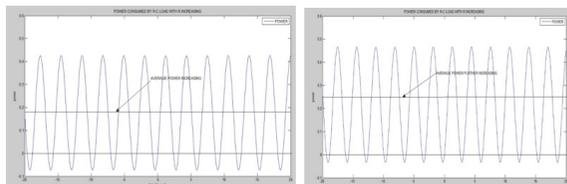


fig.12(a)(b)- power characteristics of R-C load with increasing R (from MATLAB by author)

Note:- in both the above cases average powers are not zero.

III(c)-Measuring power factor(for any wave shape of voltage and current):-To calculate the power factor of a load, always compare it with an equivalent pure resistive load.

Compare a R-L circuit with an equivalent resistive load with same amplitudes of voltage and current. Both the power graphs are drawn and average powers are calculated. We can see that R-L circuit has a low average power than R circuit for the same voltage and current amplitude (fig 13(a)(b)).

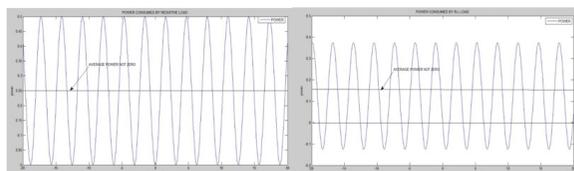


fig.13(a).power consumed by resistive load with same voltage & current amplitude of R-L load,(b)power consumed by R-L load (from MATLAB by author)

$$\text{POWER FACTOR} = \frac{P_{\text{LOAD}}}{P_R}$$

P_{LOAD} = average power of any given load

P_R = average power of a resistive load (for same voltage and current waveform and magnitude)

Note:- as power is an average quantity the above equation is valid for any voltage and current wave shape.

IV-Some causes for low PF:-

IV(a)-Due to induction machines:-Current which is drawn by the induction motor from supply that is made up of resistive components and inductive components. The resistive components are load current&loss current and the inductive components are leakage current&magnetizing current.

The current due to leakage reactance is dependent on the total current drawn by the motor, but the magnetizing current is independent of the load on the motor. The magnetizing will typically be between 20%-60% of rated full load current of the motor. The magnetizing current is the current that establishes the flux in the iron and is very necessary if the motor is going to operate. The magnetizing current does not actually contribute to the actual power output of the motor: It is the catalyst that allows the motor to work properly. The magnetizing current and the leakage reactance can be considered passenger components of the current that will not affect the power drawn by the motor but will contribute to power dissipated in supply and distribution system.

Take for example motor with a current draw of 100A and PF= 0.75. The resistive component of the current is 75A and this is what KWH meter measures. The higher current will result in an increase in distribution losses of $100 \times 100 / 75 \times 75 = 1.77$ or 78% increase in the supply losses.

Note: - In the interest of reducing the losses in the distribution system power factor correction is added to neutralize a portion of magnetizing current of load.

IV(b)-Due to Harmonics:-A switch mode power supply (SMPS) when viewed as an AC load is neither capacitive nor inductive, but nonlinear. A switch mode supply conducts current in short pulses or spikes that are in phase with the line voltage. The product of "volt*ampere" is considerably high than the real power consumed, and thus the PF is much less than 1.

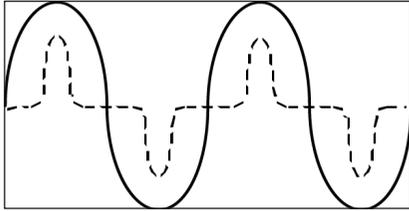


fig.14

V-Requirement of power factor correction:-Poor load current phase angle is generally the result of an inductive load such as an induction motor, power transformer, lighting ballasts, welder or induction furnace and now a days use of induction cooker in houses.

For the 60 watt incandescent lamps:

- *Customer pays for 60 watts of power
- *Utility generates 60 watts ÷ 1.0 PF = 60 VA

For the 15 watt medium-based compact fluorescent lamp, electronic ballast, normal power factor:

- *Customer pays for 15 watts of power.
- *Utility generates 15 watts ÷ 0.6 PF = 25 VA

For the 15 watt medium-based compact fluorescent lamp, electronic ballast, high power factor:

- *Customer pays for 15 watts of power
- *Utility generates 15 watts ÷ 0.95 PF = 15.8 VA

For the 13 watt medium-based compact fluorescent lamp, magnetic adapter unit:

- *Customer pays for 16 watts of power
- *Utility generates 16 watts ÷ 0.25 PF = 64 VA

VI-Methods of Power Factor Correction:-Capacitors connected at each starter and controlled by each starter is known as "Static Power Factor Correction" while capacitors connected at a distribution board and controlled independently from the individual starters is known as "Bulk Correction".

Capacitance required in KVAR = Average Maximum demand * Average PF * {tan (cos⁻¹(present PF) – tan (cos⁻¹preferred PF)}

VI(a)-Bulk Correction-The Power factor of the total current supplied to the distribution board is monitored by a controller which then switches capacitor banks in a fashion to maintain a power factor better than a preset limit. (Typically 0.95) Ideally, the power factor should be as close to unity (Power factor of "1") as possible. There is no problem with bulk correction operating at unity.

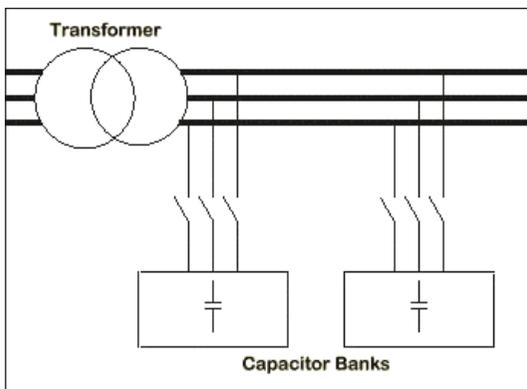


fig.15

VI(b)-Static Correction- The large proportion of the inductive current on the supply is due to the magnetizing current of induction machines, it is easy to correct each individual motor by connecting the correction capacitors to the motor starters. Capacitive current should be less than the inductive magnetizing current of the induction motor. In some cases of installations the correction capacitors are connected directly in parallel with the motor windings. When the motor is off-line, the capacitors are also off-line. This removes the requirement for any expensive power factor monitoring and control equipment. In this situation, the capacitors remain connected to the motor terminals as the motor slows down. An induction motor, while connected to the supply, is driven by a rotating magnetic field in the stator which induces current into the rotor. When the motor is disconnected from the supply, there is for a period of time, a residual magnetic field associated with the rotor. As the motor decelerates, it generates voltage out its terminals at a frequency which is proportional to its speed. A resonant circuit is being formed between capacitor and motor inductance. If the motor is critically corrected, (corrected to a power factor of 1.0) the inductive reactance equals the capacitive reactance at the line frequency and therefore the resonant frequency is equal to the line frequency. If the motor is over corrected, the resonant frequency will be below the line frequency. If the frequency of the voltage generated by the decelerating motor passes through the resonant frequency of the corrected motor, there will be high currents and voltages around the motor/capacitor circuit (Capacitors and motor may be damaged). It is important that motors are never over corrected or critically corrected when static correction is employed. Static power factor correction should provide capacitive current equal to 80% of the magnetizing current, which is essentially the no load current of the motor. The magnetizing current for induction motors can vary considerably. Typically, magnetizing currents for large two pole machines can be as low as 20% of the rated current of the motor while smaller low speed motors can have a magnetizing current as high as 60% of the rated full load current of the motor. It is not practical to use a "Standard table" for the correction of induction motors giving optimum correction on all motors. Tables result in under correction on most motors but can result in over correction in some cases. It is dangerous to base correction on the full load characteristics of the motor as in some cases, motors can exhibit a high leakage reactance and correction to 0.95 at full load will result in over correction under no load, or disconnected conditions.

Contactor is applied to control both the motor and the capacitors. It is better practice to use two contactors, one for the motor and one for the capacitors. Where one contactor is employed, it should be up sized for the capacitive load. The use of a second contactor eliminates the problems of resonance between the motor and the capacitors.

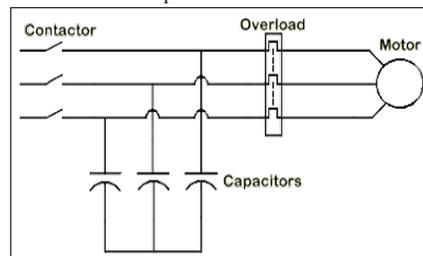


fig.16(a)

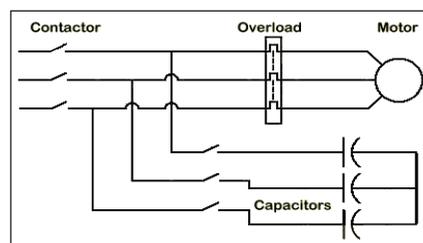


fig.16(b)

VI(c)-Supply harmonics-Higher current flow in the capacitors due to harmonics because the impedance of the capacitors goes down as the frequency goes up (impedance of capacitor is inversely proportional to frequency). Heating effect is increased due to more current flow and the life time is decreased. The harmonics are caused by many non-linear loads, the variable speed controllers and switch-mode power supplies (SMPS) are the major causes of harmonics. Harmonic voltages can be reduced by the use of a harmonic compensator, which is essentially a large inverter that cancels out the harmonics. This is an expensive option. Passive harmonic filters comprising resistors, inductors and capacitors can also be used to reduce harmonic voltages. This is also an expensive exercise. In order to reduce the damage caused to the capacitors by the harmonic currents, it is becoming common today to install detuning reactors in series with the power factor correction capacitors. These reactors are designed to make the correction circuit inductive to the higher frequency harmonics. Typically, a reactor would be designed to create a resonant circuit with the capacitors above the third harmonic, but sometimes it is below. Adding the inductance in series with the capacitors will reduce their effective capacitance at the supply frequency. Reducing the resonant or tuned frequency will reduce the effective capacitance further. The object is to make the circuit look as inductive as possible at the 5th harmonic and higher, but as capacitive as possible at the fundamental frequency. Detuning reactors will also reduce the chance of the tuned circuit formed by the capacitors and the inductive supply being resonant on a supply harmonic frequency, thereby reducing damage due to supply resonance amplifying harmonic voltages caused by nonlinear loads.

VII- latest techniques and futuristic perspective:-Research is going on the field of placement & size of capacitor to ensure minimum losses and minimum cost of capacitors and to improve voltage profile. The placement of capacitors in the distribution network using Harmony search algorithm, Bee colony based approach, particle swarm optimization algorithm, multi-level ant colony algorithm and with nonlinear loads & distributed generation using genetic algorithm are some of the techniques on which research is going on. The final expectation from this is enhancement of the overall system stability index and potential achievement of maximum net saving.

VIII- Conclusion:- In this paper we discuss the possible way to calculate the P_F of any waveform by taking the average of the power waveforms of the load circuit and comparing it with equivalent resistive circuit. We discussed the problems due to low PF and the profit of amendments to low PF. The possible and most effective ways of amendments are suggested. Capacitor used must be of suitable type and long-term rating for the supply voltage. We should be aware of possible stored charge in a capacitor and a suitable bleed resistor should be fitted.

REFERENCE

- [1] J B GUPTA, A Course In Electrical Power, ISBN- 8188458538. | [2] J B GUPTA, Theory And Performance Of Electrical Machines , ISBN- 8185749159. | [3] Sirjini R, Mohamed H ,2010. Optimal capacitor placement in a radial distribution system using Harmonic search algorithm. 10(23):2998-3006, ISSN-1812-5654 | [4] TaherSayed Abbas, HasaniMohammad,Karimian Ali 2010, A novel method for optimal capacitor placement and sizing in distribution systems with nonlinear loads and DG using GA, 16(2011) 851-862. | [5] El-FerganyAttia A, AbdelazizAlmoataz Y 2013, Capacitor placement for net saving maximum and system stability enhancement in distribution network using artificial bee colony based approach , 54(2014)235-243. | [6] Dr L UMANAND (IISc Bangalore), A video lecture of NPTEL on Basic Electrical Technology, http://www.youtube.com/watch?v=7S22cj_aF9M | [7] Leading Edge Design Group - NH - Jay Boucher from Leading Edge Design Group explains the theory behind power factor correction. <http://www.youtube.com/watch?v=dPFKcUxbNuQ> | [8] Berman Mel, Improving power quality and power factor correction, | <http://www.newark.com/pdfs/techarticles/lambda/IPQPFC.pdf> | [9] FAQ0002-0297.OSRAM SYLVANIA, National Customer Support Center | http://ceolas.net/Docs/Sylvania_on_CFL_Power_Factor.pdf | [10] ABB Power Factor Correction Capacitors on Galco TV. | <http://www.youtube.com/watch?v=YA4WjrYaZ8> | [11] <http://www.energymanagertraining.com/Journal/Power%20Factor%20Improvement.pdf> | [12] www.abb.com/~/abb_1hsm954331-01-capacitors_and_filters_en.pdf