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The Economics of Power Factor Improvement

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Abstract: Power factor (PF) is defined as the ratio of active power to apparent power, so the mount of the active power from the total apparent power depends on power factor. Electricity companies exerting big efforts to explore ways to reduce costs, and one area that is drawing interest is power factor improvement (PFI). This paper discusses the saving in money due to PFI for the consumers and the economical advantages for the electricity companies, as well as the factors affecting this, such as PFI methods, harmonics and billing practices of the electrical utility. Kassala distribution net-work is taken as case study. The saving in money and economical effect of PFI are determined. The results show the big saving in money and other economical benefits due to PCI.

Keywords: power factor, reactive power, capacitor, harmonics, electricity billing

I. INTRODUCTION

It is clear that in all electrical equipment the active power is useful only, whereas the reactive power does not make any useful contribution but it causes additional voltage drops and power losses which appear in the form of heat [3].

PFI is one of the most important topics in electrical engineering, since it subscribes in reducing the power losses and voltage drop. Recently big efforts are done to decrease the energy cost and increase the efficiency in electrical power generation, transmission and distribution system. The basic method for PFI depends on reactive power compensators. When designing the compensating devices, it is too important to achieve the most economical solutions, so that the total cost of the devices should not be greater than the effect of the reactive power due to un- improved power factor [1]. PFI has also other advantages such as reducing power losses and improving terminal voltage drop in a power system, as well as reduction of total current and sizing of cables in power distribution systems[1].

Some of electrical loads and equipments produce harmonics, such as (power electronic devices, generators, motors, welders and florescent lamps). As a result harmonic study should be done in conjunction with PFI capacitors. Many researches are done in power factor improvement economics. Temitope A, Ayodele S.A, Kehinde O, and Mufuto A.S discussed the economic and industrial application of Power Factor Improvement [1].

Muhamed Umran presented study and analysis for the effect of power factor correction Al- Najaf cement plant [3]. Energy efficiency improvement depending on power factor improvement, are presented in [4] and [5]. Ahmed Faheem Zobaa, Mohamed Mamdouh Abdel Aziz, proposed the most economical power factor correction according to tariff structures in Egypt [7].

II. ELECTRICAL POWER

Electrical power is given by;

$$S = V*I \quad (1)$$

S: The apparent power measured in VA
V: The voltage
I: The current

The apparent power which is measured by (VA), is divided into active power (P) and reactive power (Q). Active power is the power that converted to other type of energy and measured by watt.

$$\therefore S = P + JQ \quad (2)$$

The mount of total system reactive power depends on the power factor, it increases when the power factor drops. As a result the active power will decrease [2].

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III. ADVANTAGES OF PFI

In addition to the economic advantages PFI has the following technical advantages:-

- Decreasing the terminal voltage drop at the transmission and distribution systems.
- Decreasing the copper losses at transmission lines, distribution systems, generators and transformers.
- Decreasing the MVA demand for large electrical power consumers.
- Decreasing the load current, hence reducing the cables sizes.
- Improving the plants efficiency.
- Reducing overloading of cables, transformers, switchgears and alternators [1].
- Good operation of the electric machines, since that these electric machines can be dimensioned for a lower power, but still provide the same active power [6].
- Reducing carbon footprint, due to the reduction in power system demand charge [4].

IV. PFI METHODS

To improve the PF to a value near to unity, capacitor banks are installed in parallel with the load at various locations in the distribution system. The aim is to create an equal amount of leading PF in the system to match the lagging PF of the load which is mostly inductive. In practice, it is so difficult to get 100 percent of PF, because loads are switched on and off at random times, but utilities routinely maintain an overall power factor of approximately 99 percent. To accomplish this, capacitor banks are switched automatically to compensate for changing load conditions. In addition, static capacitors are used for PFI. These devices are similar to conventional oil-filled, high-voltage capacitors. The PFI capacitors are connected in parallel with the utility lines as close as practical to the low PF loads. The main problem of static PFI capacitors is that they cannot be adjusted for changing power factor conditions. Remotely operated relays can be used, however, to switch capacitor banks in and out of the circuit as needed. On the other hand, synchronous condensers can be adjusted to provide varying capacitance to improve for varying PF loads. The capacitive effect of a synchronous condenser is changed by varying the dc excitation voltage applied to the rotor of the device [2].

The first step in improving for low PF using capacitors is to determine the existing situation at a given facility.
The capacitors rating required in a given application can be determined either by using tables prepared for PFI or calculating the capacitors rating through some steps. Installation options include:
- Individual capacitors placed at each machine
- A group or bank installation for an entire area of the plant
- A combination of the two approaches

Figure 1 shows a simple circuit with shunt capacitor compensation applied at the load as well as current and voltage phasor diagrams.

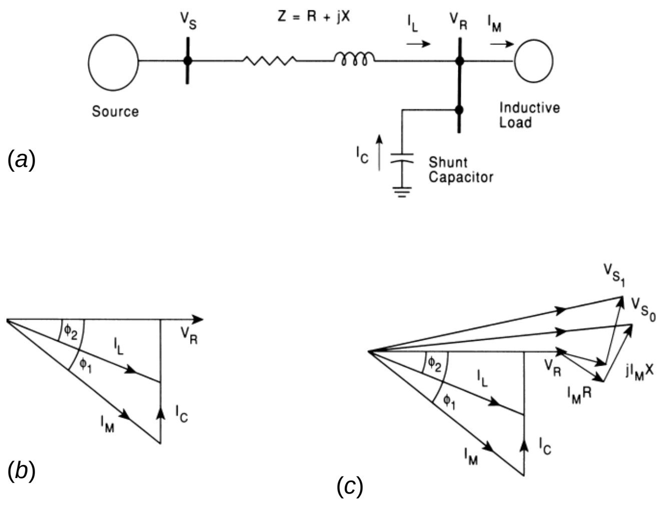

Figure (1): Shunt capacitor compensation: (a) schematic diagram; (b) current phasor diagram; (c) voltage phasor diagram.

The line current I_L is the sum of the motor load current I_M and the capacitor current I_C [2].

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V. EFFECT OF HARMONICS ON PFI

When rectifier loads that generate harmonic load current are the cause of a low PF condition, the addition of PFI capacitors will not necessarily provide the desired improvement. The capacitors, in some cases, may actually raise the line current and fail to improve the power factor. Harmonic currents generally are most apparent in the neutral of three-phase circuits. When adding capacitors for PFI, it is too important to avoid any unwanted voltage resonances that might be excited by harmonic load currents [2]. The high current absorbed by the capacitors increases the losses and the result is excessive heat and the damage in final [3].

VI. ECONOMIC ADVANTAGE OF PFI

Electricity utilities usually pass on the costs of operating low PF loads to the customers. PF can be billed as one, or a combination, of the following:

- A penalty for PF below a predetermined value or a credit for PF above a predetermined value.
- An increasing penalty for decreasing PF.
- A charge on monthly consumed reactive power.
- A straight charge for the maximum value of KVA used during the month.

In general, the contractual clauses of electricity supply require the payment of the reactive energy absorbed when the PF is low. The cost that the consumer incurs on an annual basis when drawing a reactive energy exceeding the value corresponding to a PF equal to 0.9 can be expressed as follows.

$$C_{EQ} = (E_Q - 0{,}5 * E_p) * C \qquad (3)$$

Where:
C_{EQ}: Is the cost of the reactive energy per year in SDG.
E_Q : Is the reactive energy consumed per year in kVArh;
Ep: Is the active energy consumed per year in kWh;
$(E_Q - 0.5 * Ep)$: Is the amount of reactive energy to be paid;
C: Is the unit cost of the reactive energy in SDG / kVArh.

Consumer savings is given by:

$$C_{EQ} – C_{Qc} = (E_Q - 0{,}5 * E_p) * C – (Qc * C_C) \qquad (4)$$

Where:

C_{Qc} : Is the yearly cost in SDG to get a PF equal to 0.9;
Qc : Is the power of the capacitor bank necessary to have a PF of 0.9 in kVAr;
C_C : is the yearly installation cost of the capacitor bank in SDG / kVAr [5].

VII. CASE STUDY AND DISCUSSION OF RESULTS

The study is applied to Kassala Distribution Net-work, which consists of main substation feeding two substations. Each substation contains two transformers with rating of 20 MVA for each. The study is done at each substation with rating of 40 MVA and total connected load of 33.5 MW.

The cost of the consumed reactive energy per year in SDG without PFI has been calculated using equation (3) as follows:
$C_{EQ} = (298.9*10^6 - 0{,}5 * 289.4*10^6) * 0.8 = 123.4 *10^6$

If a bank of automatic controlled capacitors for PFI for one substation with rating of 20 MVAr, compared to a total installation cost of 360 SDG / kVAr, a total cost of $7.2*10^6$ SDG is obtained.

Consumer savings, regardless of depreciation and financial costs for one substation can be found using equation (4) as follows:

$C_{EQ} – C_{QC} = 123* 10^6 – 7.2 * 10^6 = 115.2 * 10^6$ SDG.

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The results show that operating with a low overall PF, increases the transformer apparent power out- put for the same load as indicted in figure (2). And this increases the total loss. Never the less impose a need for bigger sizes of cable which increases the cost.

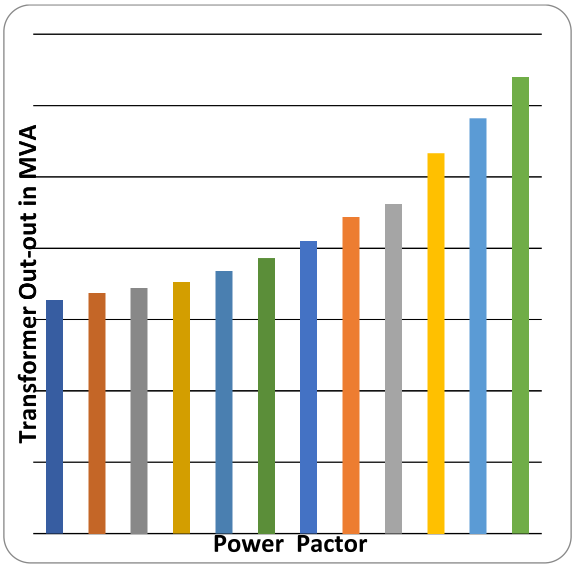

Figure (2): Increase of Transformer out-put Due to PF decrease

VIII. CONCLUSION

Inductive loads (such as transformers, electric motors, discharge lamps) implement more than 70 % of the total power system loads. These loads need the current to produce magnetic fields which creates the required work. This causes absorption of reactive power which leads to power factor decrease.

As it is mentioned above, utility companies impose indirect costs for low PF operation. Because operating with a low overall PF, reduces the amount of useful electrical energy available inside the plant at the distribution transformer due to increase of absorbed reactive power. Although central improvement provides displacement in PF at the point of common coupling, reactive power flow still reduced.

The results show that Pfi has many benefits to the consumers and electricity utility. For the consumers the total consumption bill is clearly reduced. For the utility less cable sizes can be used. For Kassala distribution net-work the total load is closed to the substations rating, so any drop of power factor will impose installation of another transformer.

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