International Journal of Electrical Engineering.
ISSN 0974-2158 Volume 4, Number 8 (2011), pp. 913-922

http://www.irphouse.com

A Method of Finding Capacitor Value for Power Factor Improvement

Gagari Deb, Partha Sarathi Saha and Prasenjit Das

Dept. of Electrical Engineering, Tripura University(A Central University)
Suryamaninagar, Agartala,Tripura-799003, India
E-mail: gagarideb@yahoo.com

Abstract

In recent years, increasing attention has been paid to minimize the energy cost and inefficiency in electricity generation, transmission and distribution. This paper presents an approach in order to determine the size of capacitor in power system to minimize investment cost and energy loss and for improving power factor. The distribution system has been designed Using Lab view software. Different components of Lab View Software are used for calculation of the rating of capacitor bank required installing in the proposed system. Power factor correction is one of the techniques recently applied to the electric distribution system. In this paper the power factor of the circuit without the use of capacitor bank has been assumed .Then to improve the power factor to a desired value the size of the capacitor bank required to compensate the load reactive power has been calculated. The results of the developed circuit are compared with the manual calculations. Shunt capacitor banks are used to improve the quality of the electrical supply and the efficient operation of the power system. Shunt capacitor banks are relatively inexpensive and can be easily installed anywhere on the network. Finally, loss reduction and power factor improvement economically justified the use of this method.

Introduction

Electricity in large quantities is required to supply in electric power systems. Electricity is produced in generating stations, commonly called power plants. Electric power can be easily and efficiently transported to locations far from production centers and converted into desired forms (e.g. mechanical, thermal, light, or chemical).Development and complexity of distribution system result in several problems such as loss increase and voltage drop. With respect to existing loads in distribution systems, voltage profile drops along these systems below acceptable operating limits. So loss reduction is an important aspect of power system. On the other hand due to use of harmonic producing devices in distribution systems, THD increases. So, location and sizing of capacitor are done in order to satisfy THD constraint [1].

The causes for high losses and poor voltage regulation in the distribution and sub transmission system are:

1. Low power factor on the consumer installations.
2. Long and over loaded L.T lines.
3. Distribution transformers' centers located away from the load centers.
4. Long and overloaded 11kV and sub transmission lines.
5. Poor voltage regulation on 11 kV and sub transmission lines.
6. Under loading of distribution transformers.
7. Absence of shunt compensation in the sub transmission and distribution system.

The system improvement has to be planned properly with the following objectives in mind:

1. To reduce losses in the distribution and sub transmission system.
2. To improve the voltage regulation so as to bring it within the prescribed limit.
3. To improve the power factor in the sub transmission system and distribution system so as to get optimum utilization of transmission and distribution"capacities [2].

Reactive power is not used to do work, but is needed to operate equipment. Many industrial loads are inductive such as motors, transformers etc. The current drawn by an inductive load consist of magnetization current and power producing current. The magnetization current is required to sustain the electromagnetic field in a device and creates reactive power. An inductive load draws current that lags the voltage, in that the current follows the voltage waveform. The amount of lag is the electrical displacement angle between current and voltage. 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 reactive power [3].

Power factor correction circuit is an auxiliary circuit attached to original system's circuit to improve power factor into the system. In a.c distribution system Power factor correction circuit consist of capacitor bank that would normally be switched on or off depending on the reactive demand from the load [4].

Shunt capacitors are used for loss reduction, voltage profile improvement and power factor correction. The internal discharge device is a resistor that reduces the unit residual voltage to 50V or less in 5 minute [5].

In the 80's, several methods such as mixed integer nonlinear programming were suggested by Grainger and Baran Wu. In the 90's, algorithms like neural network were introduced for solving capacitor placement problem. Fuzzy dynamic programming was used by Chin for optimum shunt capacitor allocation by explaining real power loss and voltage deviation. Genetic algorithm is also an important method in this area which was used in capacitor selection for radial distribution system by Sundharajan and Pahwa. Particle swarm optimization algorithm is based on metaphor of social interaction, searches a space by adjusting the trajectories of moving points in multi dimensional space and used for the optimization of continues and discrete non linear problems [1].

This paper presents several aspects that must be taken into consideration at conception and exploitation level of a power system. In order to ensure most favorable conditions for a supply system from engineering and economical standpoint it is important to have power factor as close to unity as possible. In this paper the optimal sizing of capacitor required for the improved power factor is calculated by designing the power system in Lab view software.

Power Factor

Definition of Power Factor

Electrical equipment having a resistance R and a reactance L will draw from the supply an apparent power S in terms of kVA which comprises a component of active power P and a component of reactive power Q, which is not involved in the transfer of energy. S is the vectorial sum of P and Q. The angle Ø between the vectors of the active power and the apparent power is the phase displacement angle. Power factor (COS Ø) is the ratio between the active power (kW) and the apparent power (kVA) drawn by electrical load.

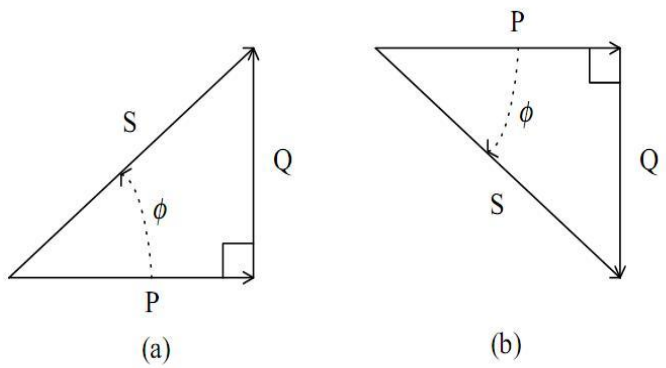

Figure 1: Power triangles with (a) lagging power factor and (b) leading power factor.

Where,
Ø = Phase angle
P = Active power (kW)
R = Reactive power (kVAR)
S = Apparent power (kVA)

This is known as the power factor of the load and is dependent upon the type of equipment in use. A large proportion of electrical machinery used in industry has inherently low power factor, which means that the generating stations have to generate much more current than is theoretically required. In addition transformers and cables must obviously carry this extra current. Voltage drop will be high due to high current. Generating efficiency will be low. Size of cables should be increased to carry high current.

To obtain the best possible economic advantage from electric power, both the generating station and consumer's plant should be operated at the highest possible efficiency. To achieve this event it is essential to maintain a good power factor throughout the system.

Most loads on electrical distribution system fall one of the three categories resistive, inductive or capacitive. Most of the loads are inductive. Typical examples of this include transformers, fluorescent lighting and AC induction motors. The operating power from the distribution system is composed of both active (working) and reactive (non-working) element.

All current will cause losses in the supply and distribution system. A load with a power factor of 1.0 result in the most efficient loading of the supply and a load with a power factor of 0.5 will result in much higher losses in the supply system.

Since capacitors are supplying only reactive power to a system, their power factor is always leading. Apparent power derives largely from the inductive loads in the installation, the higher the inductive loads connected, the lower the power factor.

Moreover a poor power factor can be result of either a significant phase difference between the voltage and current at the load terminals or it can be due to a high harmonic content or distorted or discontinuous current waveform. A distorted current waveform can be the result of a rectifier, variable speed drive, switched mode power supply, discharge lighting or other electronic load [6].

Problems of Low Power factor

When the overall power factor of a generating station's load is low, the system is insufficient and the cost of electricity correspondingly high. Disadvantages of low power factor are:

1. Because of flowing high current to full load power due to low power factor, line losses increase and then running cost increase.
2. Install capacity is more necessary for generators because of increasing losses due to over excitation.
3. The rating of transformers, switch gear and transmission and distribution lines have to more install. So, capital cost and fixed charges increase.
4. Higher line losses, lower voltage regulation.

A poor power factor due to an inductive load can be improved by the addition of power factor correction, but a poor power factor due to a distorted current wave form requires a change in equipment design or expensive harmonic filters to gain an appreciable improvement [6].

Improvement of System Power Factor

The use of static capacitors for the improvement of system power factor is the most economical solution for industry of today when considering the following factors:

1. Reliability of the equipment to be installed
2. Probable life
3. Capital cost
4. Maintenance cost
5. Running cost
6. Space available

Capacitors have no moving parts, initial cost is low, upkeep costs are minimal and they are compact, reliable and highly efficient and can be installed basically three possibilities to correct loads individually in groups or centrally.

By installing capacitors to improve power factor could save money on electricity bill. Additional potential benefits include:

1. Reduction of heating losses in transformer
2. Stabilized voltage levels
3. Increase in capacity of existing system and equipment
4. Improved profitability [6].

Use of Shunt Capacitor in Power Factor Improvement

Shunt capacitors can be used on the distribution system to improve the voltage regulation of the system. The shunt capacitors if connected to utilization equipment and switched on in accordance with the load, reduce the voltage drop in the distribution system and thus help in obtaining better voltage regulation. If the utilization equipment draws a current which is fairly constant, the voltage regulation by the shunt capacitor is more effective.

Shunt capacitors installed on a distribution system reduce energy losses in every part of the system between capacitors and generators. The use of shunt capacitors improves the voltage regulation of the system.

The size of shunt capacitor banks varies from individual units of 5 to 25 kVA connected to the secondary or primary circuits of a distribution system to a bank of capacitors of large-size kVA connected to the bus of substation at the primary voltage side [2].

The capacitor units are made up of individual capacitor elements arranged in series/parallel connected groups within a steel enclosure. Capacitors connected in parallel make a group and series connected groups form a capacitor bank. Capacitor units are available in a variety of voltage ratings and sizes. When a capacitor bank unit fails, other capacitors in the same parallel group contain some amount of charge. This charge will drain off as a high frequency transient current that flows through the failed capacitor unit and its fuse. The fuse holder and the failed capacitor unit should withstand this discharge transient [5].

The degree of compensation being decided by an economic point of view between the capitalized cost of compensator and the capitalized cost of reactive power from supply system over a period of time. In practice a compensator such as a bank of capacitors can be divided into parallel sections, each switched separately, so that discrete changes in the compensating reactive power may be made according to the requirements of load.

Reasons for the application of shunt capacitor units are because of:

1. Increase voltage level at the load.
2. Improves voltage regulation if the capacitor units are properly switched.
3. Reduces I^2R power loss in the system because of reduction in current.
4. Reduces I^2X loss in the system because of reduction in current.
5. Increases power factor of the source generator.
6. Decreases kVA loading on the source generator and circuits to relieve an overloaded condition or release capacity for additional load growth.
7. By reducing kVA loading on the source generators additional kilowatt loading may be placed on the generation if turbine capacity is available.
8. To reduce demand power purchasing.
9. Reduces investment in system facilities per kilowatt of load supplied [2].

Power Factor Correction

To correct the lagging power factor, capacitor banks can be used. Assuming that a motor load has a power triangle as shown in Figure 2, and its existing power factor is $\cos\varphi$ lagging. If a desired power factor is $\cos\varphi_{new}$ lagging, then the new power triangle can be obtained. With power factor corrected, the net reactive power supplied by the source is reduced to its new value, namely,

$$Q_{new} = P \tan\varphi_{new}$$

The size of the capacitor bank required, Q_{cap}, to compensate the load reactive power to its new value can be calculated as:

$$Q_{cap} = P (\tan\varphi - \tan\varphi_{new})$$

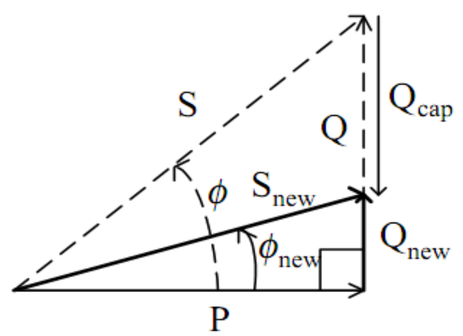

Figure 2: Power triangles before and after power factor correction

Since the reactive power generated by a single-phase capacitor bank is

$$Q_{cap} = V^2/X_c = \omega CV^2$$

Therefore, the corresponding capacitance of the capacitor bank can be obtained by

$$C= Q_{cap}/\omega V^2$$

Where $\omega = 2\pi f$, f = frequency.

Distribution System Modeling

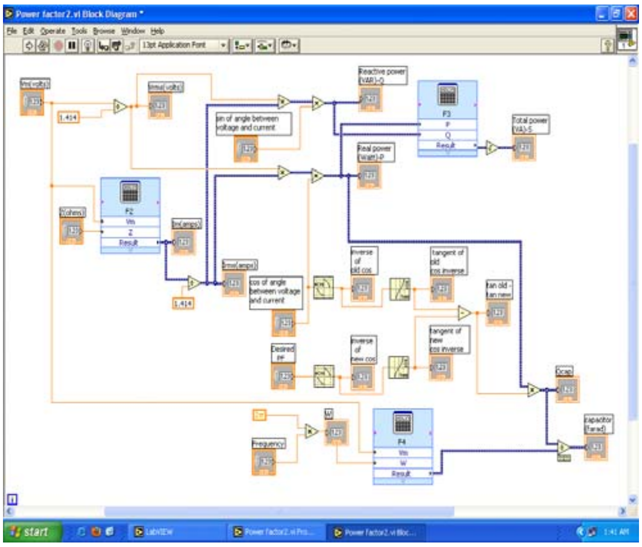

Figure 3: Circuit description.

Two Numeric properties Dialog Boxes are used to assign the parameters Vm (Volts) and Z (Ohms). In the first Divider one input is Vm and another input is 1.414 which is given through Numeric Constant Properties Dialog Box to find Vrms = Vm/1.41. In the first Formula Box two inputs are Vm and Z. and the formula used is Im = Vm/Z. Im is again divided with 1.414 for finding Irms. Irms and Vrms are multiplied by using multiplier. The values of Sin $Ø_1$ and Cos $Ø_1$ are given by Numeric properties Dialog Boxes. Then Real power and Reactive power are calculated using the formulas $P = V_{rms}I_{rms}\text{Cos } Ø_1$and $Q = V_{rms}I_{rms}\text{Sin } Ø_1$ respectively. In the second Formula Box two inputs are real power, P and reactive power, Q and the formula used is $S^2 = P^2 + Q^2$.In the output of second Formula Box root over box is used to calculate the Total Power, S from S^2 . From the value of cos$Ø_1$ the value of tan$Ø_1$ is calculated. The desired power factor is given by Numeric properties Dialog Box which is cos$Ø_2$and from that value tan$Ø_2$ is obtained. After this operation tan$Ø_2$ is subtracted from tan$Ø_1$. From these values the size of the capacitor bank required is calculated using the formula, $Q_{cap} = P\ (\tan Ø_1 - \tan Ø_2)$.In the third Formula Box two inputs are Vm and ω. The value of ω is calculated by multiplying frequency, f with 2π. The value of frequency, f is given by Numeric properties Dialog Box and 2π is given through Numeric Constant Properties Dialog Box. The formula used in Formula Box 4 is $V_m{}^2$ *W. Now the value of capacitor needed is calculated by dividing Q_{cap} with the output of Formula Box 3 that is $V_m{}^2$ *W.

Result and Discussion

The input parameters Vm, Z, frequency, desired power factor, cosØ and SinØ are given to find the values of active power, reactive power, total power, Q_{cap} and C. The results can be seen in the front panel of Lab View software.

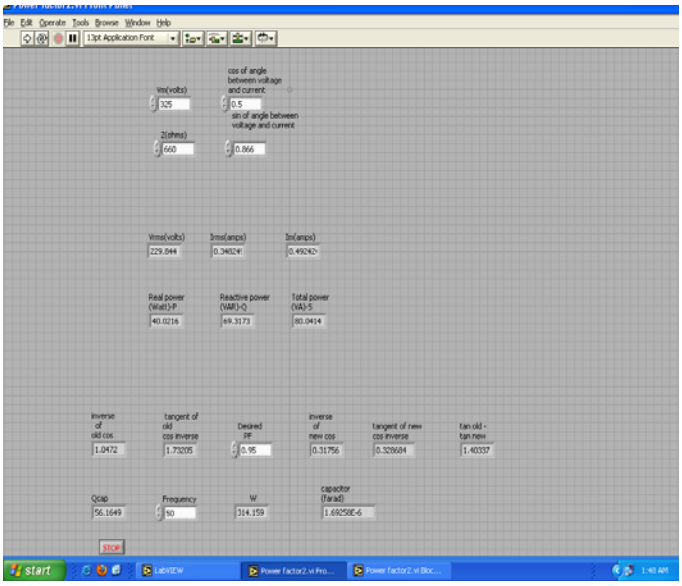

Figure 4: Front Panel.

The results can be verified from the following calculation:

$Vm = 325$ V
$Z = 660\ \Omega$
$f = 50$ Hz

Desired power factor = 0.95

$\cos Ø_1 = 0.5$
$\sin Ø_1 = 0.866$
$Ø_1 = 1.0472$ radian
$\tan Ø_1 = 1.73205$
$Vrms = Vm / 1.414$
$= 325 / 1.414$
$= 229.844$ V
$Im = Vm / Z$
$= 325 / 660$
$= 0.49242$ A
$Irms = Im / 1.414$
$= 0.49242 / 1.414$
$= 0.34824$ A
P (Real Power) $= Vrms*I_{rms}* \cos Ø_1$
$= 229.844*0.34824*0.5$
$= 40.02$ Watt

Q (Reactive Power) = $V_{rms}*I_{rms}*\sin Ø_1$
= 229.844*0.34824*0.866
= 69.31 VAR
S (Total Power) = $\sqrt{(P^2+Q^2)}$
= $\sqrt{(40.02^2 + 69.31^2)}$
= 80.03 VA

Now the power factor of the system will be improved to 0.95.
$\cos Ø_2 = 0.95$

So, $Ø_2 = 0.31756$ radian
$\tan Ø_2 = 0.328684$
$Q_{cap} = P (\tan Ø_1 - \tan Ø_2)$
= 40.02 (1.73205 - 0.328684)
= 56.16 VAR
$\omega = 2\pi f$
= 2 X 3.14 X 50
=314.159 rad/ sec

Now the capacitor C = Qcap/ω*Vm^2
= 56.16 / 314.159 X 325^2
= 1.692×10^{-6} Farad

Conclusion

By using this circuit the value of capacitor for desired power factor before experimenting it in real time can be calculated. Since the power bill is based on the usage of the active power – kilo-watt-hour (kWH) while the power system equipment is built to handle the apparent power, the power company may charge a higher rate for loads drawing below a certain power factor, for instance, 0.95.By spending some money on power factor correction equipment customer can save money on electricity bill due to low power factor.

References

[1] B. Mirzaeian Dehkordi, M. Moallem,S. J Rezazadeh, O. Amanifar,M. Keivanfard, N. Sayadi, L. Kermani,"Optimal Capacitor Placement and Sizing in Tabriz Electric Power Distribution System Using Loss Sensitivity Factors and Particle Swarm Optimization (PSO) ," International Journal on Technical and Physical Problems of Engineering (IJTPE),ISSN 2077-3528, Issue 7, vol. 3, Number 2 , pp.54-59, June 2011.

[2] Khin Trar Trar Soe, " Design and Economics of Reactive Power Control in Distribution Substation, " World Academy of Science, Engineering and Technology, 48-2008, pp 416-421.

[3] Osama A Al-Naseem, Ahmad Kh. Adi, “Impact of Power Factor Crrection on the Electrical Distribution Network of Kuwait – A Case Study,” The Online Journal on Power and Energy Engineering (OJPEE), Vol. 2 – No. 1, pp 173-176.

[4] Taufik, A. Hernadi, R. Rudianto, M. Anwari, “Performance Study of Power Factor Correction Circuits,” Proceedings of the International Conference on Electrical Energy and Informatics, Institut Teknologi Bandung, Indonesia, ISBN 978-979-16338-0-2, June 17-19, 2007, pp 419-422.

[5] Gustavo Brunello, Dr Bogdan Kasztenny, Craig Wester, “Shunt Capacitor Bank Fandamentals and Protection,” 2003 Conference for Protective Relay Engineers – Texas A & M University, April 8 – 10, 2003, College Station. (TX), pp 1-17

[6] Miss Khin Trar Trar Soe, “Design and Calculation of Capacitor Banks for Power Factor Correction in Distribution Substation,” proceedings of the 1st International Conference of the IET Brunei Darussalam Network, 26 – 27 May, 2008.