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# Reactive Power Compenstation in Distribution System in terms of Power Loss Economics

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**Abstract: This article gives the complete information about the Reactive Power compensation given to the distribution system for reducing the Power Losses. In this article, a case study of MPPKVVCL, Jabalpur, India substation of 8MVA at 33/.4 kV data is taken with shunt capacitor bank and without shunt capacitor bank at peak hours is consider. It is seen from load curve that with the switch in of shunt capacitor bank, current of about 10- 12 Ampere is dropped in 11 kV line. This drop of current reduces the burden on the devices of the 11 kV feeder. Also current saved is used for other customers for providing Electrical Power. Further MATLAB simulation is done to show the current drop in 11 kV feeder line with the inclusion of shunt capacitor bank. Also, Annuity is used for Economic analysis for understanding the lifecycle cost saving with the inclusion of shunt capacitor bank is calculated. Nonetheless, this methodology can be used for any configuration knowing the actual saving with the inclusion of shunt capacitor in the distribution system.**

**Keywords: Power Distribution Economics, Annuity, Shunt Capacitor Bank, Reactive Power, Compensation, Matlab Simulation.**

## I. INTRODUCTION

With the partial deregulation of distribution system in developing country, there is competition among different utilities to become efficient or in other words to reduce their overall expenses. This reduction of costs reflects on reduction of tariff. It is seen that the reactive power is related to the magnetic field energy required in transformer, power lines motors, other loads etc. Reactive power energies the Magnetic field. The operating power from distribution system is composed of both active and reactive elements. From the different load curve data, MW/MVAr varies from 3 to 15 times [1]. It particularly increases in peak hours. Also generation and control of reactive power is important to maintain whole system reliability and reduction of losses [2]. The system voltage collapse due to lack of global control of reactive power flow [4] during crucial contingencies is emerging as a great problem. The system of northern grid has collapsed many times dunging last few years due to lack of reactive power in the region. The distribution lines consume reactive power ($I^2R$) depending on the series reactance and load current. The series reactance of line is proportional to the conductor self inductance, which decreases as the spacing between conductor decreases. Poor power factor caused by lack of proper compensation costs our community in increased electricity charges and unnecessary effect in the system and poor power quality. In this article, thoroughly study of reactive power compensation is done on distribution system with the help of case study. Capacitor Bank and Reactors devices with mechanical time control switch can be connected in parallel to the distribution network to supply the type of reactive power or current needed to counteract the out of phase component of current required by the inductive load to eliminate or reduce to an acceptable limit the voltage regulation [3]. Further, Economic analysis is done for lifecycle cost saving by providing reactive power compensation to the distribution system. Nonetheless, this methodology can be applied to any distribution system to reduce the overall expenses of entire system.

## II. ECONOMIC ADVANTAGES OF POWER FACTOR CORRECTION

Power factor correction in non-linear loads:

**Passive PFC:** The simplest way to control the harmonic current is to use a filter: it is possible to design a filter that passes current only at line frequency (50 Hz in case of India). This filter reduces the harmonic current, which means that the non-linear device now looks like a linear load. At this point the power factor can be brought to near unity, using capacitors or inductors as required. This filter requires large-value high-current inductors, however, which are bulky and expensive. A passive PFC requires an inductor larger than the inductor in an active PFC, but costs less. This is a simple way of correcting the nonlinearity of a load by using capacitor banks. It is not as effective as active PFC. Passive PFCs are typically more power efficient than active PFCs. Efficiency is not to be confused with the PFC, though many computer hardware reviews conflate them. A passive PFC on a switching computer PSU has a typical power efficiency of around 96%, while an active PFC has a typical efficiency of about 94%.

**Active PFC:** An "active power factor corrector" (active PFC) is a power electronic system that changes the wave shape of current drawn by a load to improve the power factor. The purpose is to make the load circuitry that is power factor corrected appear purely resistive (apparent power equal to real power). In this case, the voltage and current are in phase and the reactive power consumption is zero. This enables the most efficient delivery of electrical power from the power company to the consumer. Some types of active PFC are: i. Boost, ii. Buck, iii. Buck-boost.

**Solutions to improve power factor problems and reduce harmonics distortion:**
To achieve improve power factor is to use power factor correction switch connected at the near load terminals.

**Importance of power factor in distribution system:**
Power factors below 1.0 require a utility to generate more than the minimum volt-amperes necessary to supply the real power (watts). This increases generation and transmission costs. For example, if the load power factor were as low as 0.7, the apparent power would be 1.4 times the real power used by the load. Line current in the circuit would also be 1.4 times the current required at 1.0 power factor, so the losses in the circuit would be doubled (since they are proportional to the square of the current). Alternatively all components of the system such as generators, conductors, transformers, and switchgear would be increased in size (and cost) to carry the extra current. Utilities typically charge additional costs to customers who have a power factor below some limit, which is typically 0.9 to 0.95. Engineers are often interested in the power factor of a load as one of the factors that affect the efficiency of power transmission. With the rising cost of energy and concerns over the efficient delivery of power, active PFC has become more common in consumer electronics.

**Technical advantages of power factor correction:**
By correcting the power factor of an installation supplying locally the necessary reactive power, at the same level of required output power, it is possible to reduce the current value and consequently the total power absorbed on the load side; this implies numerous advantages, among which a better utilization of electrical machines (generators and transformers) and of electrical lines (transmission and distribution lines).

**Better utilization of electrical machines:**
Generators and transformers are sized according to the apparent power S. At the same active power P, the smaller the reactive power Q to be delivered, the smaller the apparent power. Thus, by improving the power factor of the installation, these machines can be sized for a lower apparent power, but still deliver the same active power.

**Better utilization of electrical lines:**
Power factor correction allows obtaining advantages also for cable sizing. In fact, as previously said, at the same output power, by increasing the power factor the current diminishes. This reduction in current can be such as to allow the choice of conductors with lower cross sectional area.

**Reduction of losses:**
The power losses of an electric conductor depend on the resistance of the conductor itself and on the square of the current flowing through it; since, with the same value of transmitted active power, the higher the power factor the lower the current, it follows that when the power factor rises, the losses in the conductor on the supply side of the point where the power factor correction has been carried out will decrease. Power supply authorities apply a tariff system which imposes penalties on the drawing of energy with a monthly average power factor lower than 0.9. The contracts applied are different from country to country and can vary also according to the typology of costumer: as a consequence, the following remarks are to be considered as a mere didactic and indicative information aimed at showing the economic saving which can be obtained thanks to the power factor correction. Generally speaking, the power supply contractual clauses require the payment of the absorbed reactive energy when the power factor is included in the range from 0.7 and 0.9, whereas nothing is due if it is higher than 0.9. For power factor is less than 0.7 power supply authorities can oblige. Consumers to carry out power factor correction. It is to be noted that having a monthly average power factor higher than or equal to 0.9 means requesting from the network a reactive energy lower than or equal to 50% of the active energy: Therefore no penalties are applied if the requirements for reactive energy do not exceed 50% of the active one. The cost that the consumer bears on a yearly base when drawing a reactive energy exceeding that corresponding to a power factor equal to 0.9.

**General Advantage of Power Factor:**
i. Decreased monthly energy costs, ii. Efficient electrical system, iii. Reduced loading on transformers, iv. Reduced loading on distribution lines, v. Reduced voltage drops, vi. Reduced wear and tear on electrical equipment, vii. Increased load handling capability of the plants electrical system.

**Disadvantage of Low Power Factor:**
i. Increased energy costs, ii. Overloaded transformers, iii. Overloaded distribution lines, iv. Resulting in voltage drops and needless wear and tear on electrical equipment, v. Reduced load handling capability of the plants electrical system.

### III. REACTIVE POWER CONTROL WITH SWITCHED SHUNT CAPACITORS

Shunt capacitors inject reactive power to the system according to [9]

$$Q_c = Q_{rat}\, U_c$$

Where, $Q$ is the reactive power injected by the capacitor in MVar, $Q_{rat}$ is the MVar rating of the capacitor, $U_c$ is the voltage in pu (relative to the capacitor voltage rating). The reactive power injected by the capacitor will compensate the reactive power demand and thereby boost the voltage. For example, consider that in Figure 1 a shunt capacitor injecting reactive power $Q$ is connected to the load bus. The voltage drop on the feeder can then be approximated as

$$\Delta U \approx \frac{R_{LN} P_L + X_{LN}(Q_L - Q_C)}{U_2}$$

Which indicates that the capacitor reduces the voltage drop. Further, when the capacitor properly compensates the reactive power demand, the capacitor will decrease the feeder current. These will in turn decrease the feeder losses $P_{Loss}$.

$$I = \frac{\sqrt{P_L^2 + (Q_L - Q_C)^2}}{U_2}$$

$$P_{Loss} = I^2 R_{LN}$$

In order to properly compensate the reactive power demand that changes from minimum to maximum and to be switched off at the load minimum. When the load varies during the day, the switched capacitors should be properly controlled. Different conventional controls can be used to control switched capacitors, such as time, voltage and reactive power. Time controlled capacitors are especially applicable on feeders with typical daily load profiles in a long term, where the time of the switching-on and off of the shunt capacitor can be predicted. The main disadvantage of this control is that the control has no flexibility to respond to load fluctuation caused by weather, holidays, etc. voltage controlled capacitors are most appropriate when the primary role of the capacitor is for voltage support and regulation [3]. Reactive power controlled capacitors are effective when the capacitor is intended to minimize the reactive power flow.

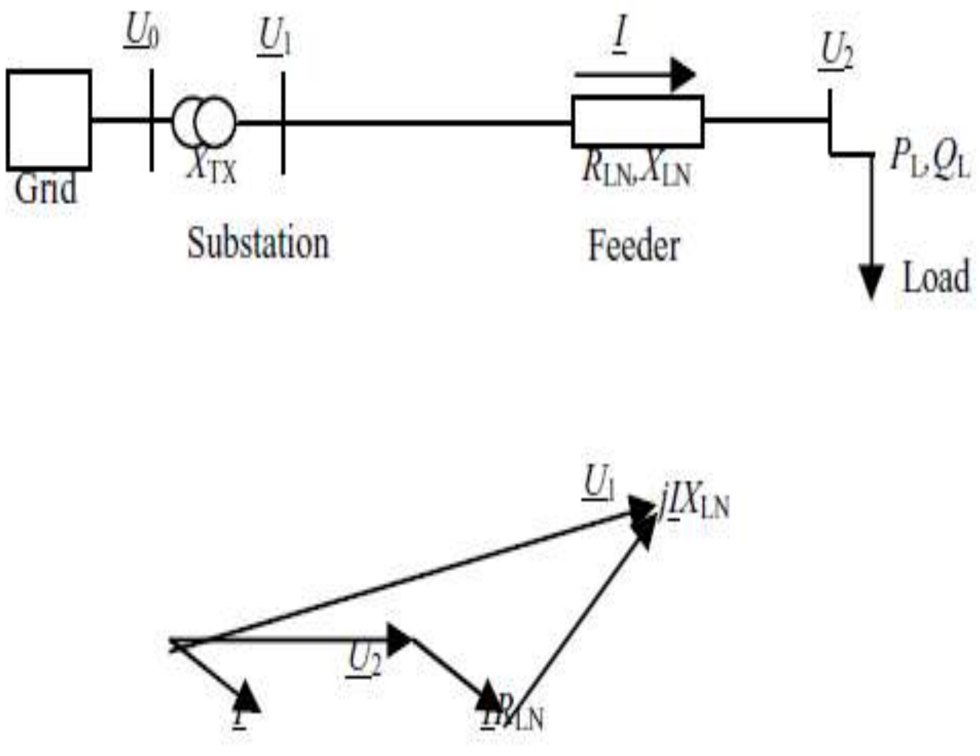


**Fig. 1** One line diagram and corresponding phasor diagram for an illustration of the voltage drop in a distribution system

## Calculation of the size of capacitor banks.

The source is Y connected and the line Voltage is 11kv,

Phase Voltage, $V_{ph} = \frac{11kV}{\sqrt{3}} = 6.35\ V$

Capacitor bank rating $Q_c = 600$ kvar.

Capacitor bank rating per phase $Q_{cph} = \frac{600\ kvar}{3} = 200kvar$.

Impedance of capacitance per Phase,

$$X_{Cph} = \frac{V^2_{ph}}{Q_{cph}} = \frac{(6.35kv)^2}{200kvar} = 201.61\Omega$$

$$Xcph = \frac{1}{2\pi \times f \times C} \Rightarrow C = 15.78\mu F,$$

Where f= 50 Hz, is the power system frequency.

Assuming severest conditions of switching the value of L in Henry is given by

$$L = \frac{1}{(2\pi \times f)^2 \times C} = 0.64\ H.$$

$$\text{Inrush Current} = \sqrt{2} \times 6.35 \times 10^3 \times \sqrt{\frac{15.78 \times 10^{-6}}{0.64}} = 44.59\ \text{amps}.$$

Line $X_L$: Aerial line with Conductor of size $100mm^2$

Length of line = 5m.

Line $X_L = 0.5\ \Omega / km$.

Total Line $X_L$ is $0.005 \times 0.5 = 0.0025\ \Omega$.

## IV. CASE STUDY

### A. *Matlab Simulation of Feeder*

The power factor correction obtained by using power factor correction switches banks (shunt capacitor) to generate locally the reactive energy necessary for the transfer of electrical useful power, allows a better and more rational technical-economical management of the plants. The system is capable of correcting power factor up to unity or adjusting it according to user desire. The proposed system is characterized by, no generation of harmonics, and reduction of distribution losses. Simulation results are reported and proved to be in good agreement with the relevant experimental results. Below show the case study of distribution feeder of 11 kV line where capacitor is switched in and provide the reactive power compensation. Transformer of the 3 phase, 8 MVA, 33/11 kV of primary distribution is used. Fig. 2 shows the simulation of 11kV feeder line in which capacitor is connected with the help of Circuit breaker. Fig. 3 shows the simulation with compensation.

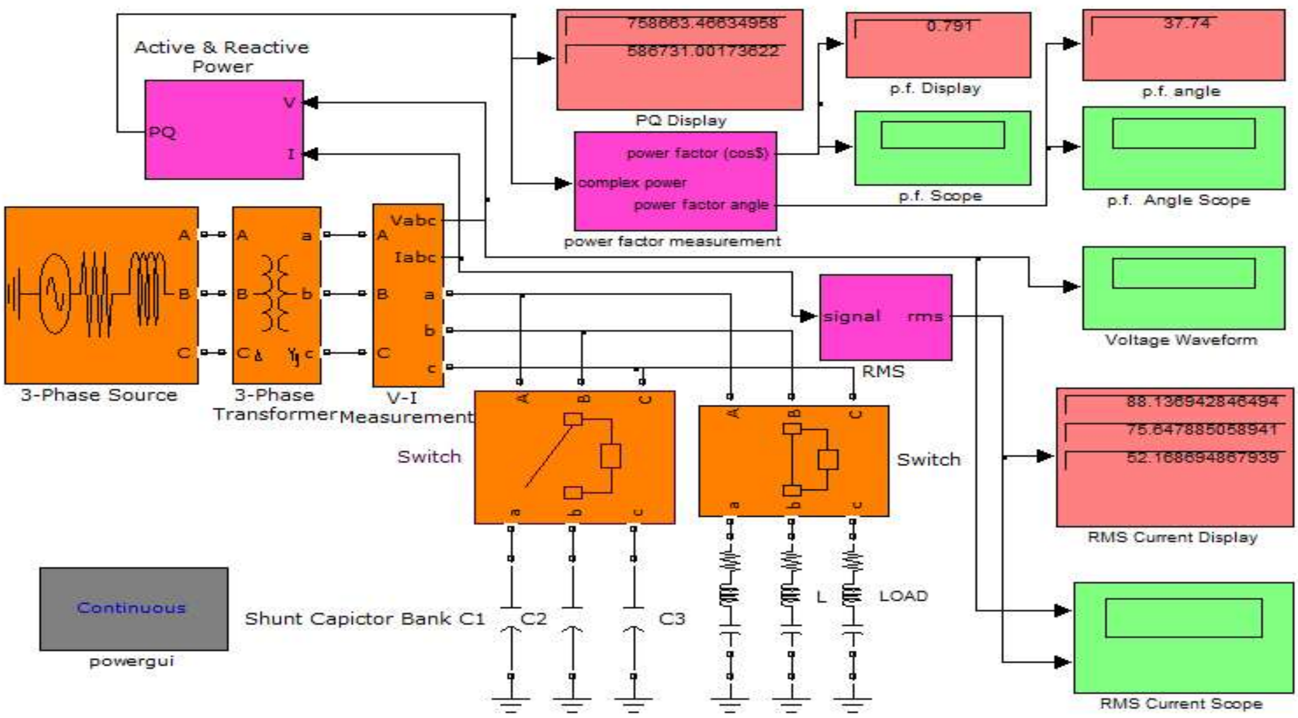


**Fig. 2** shows the Uncompensated Feeder of 11 kV line.

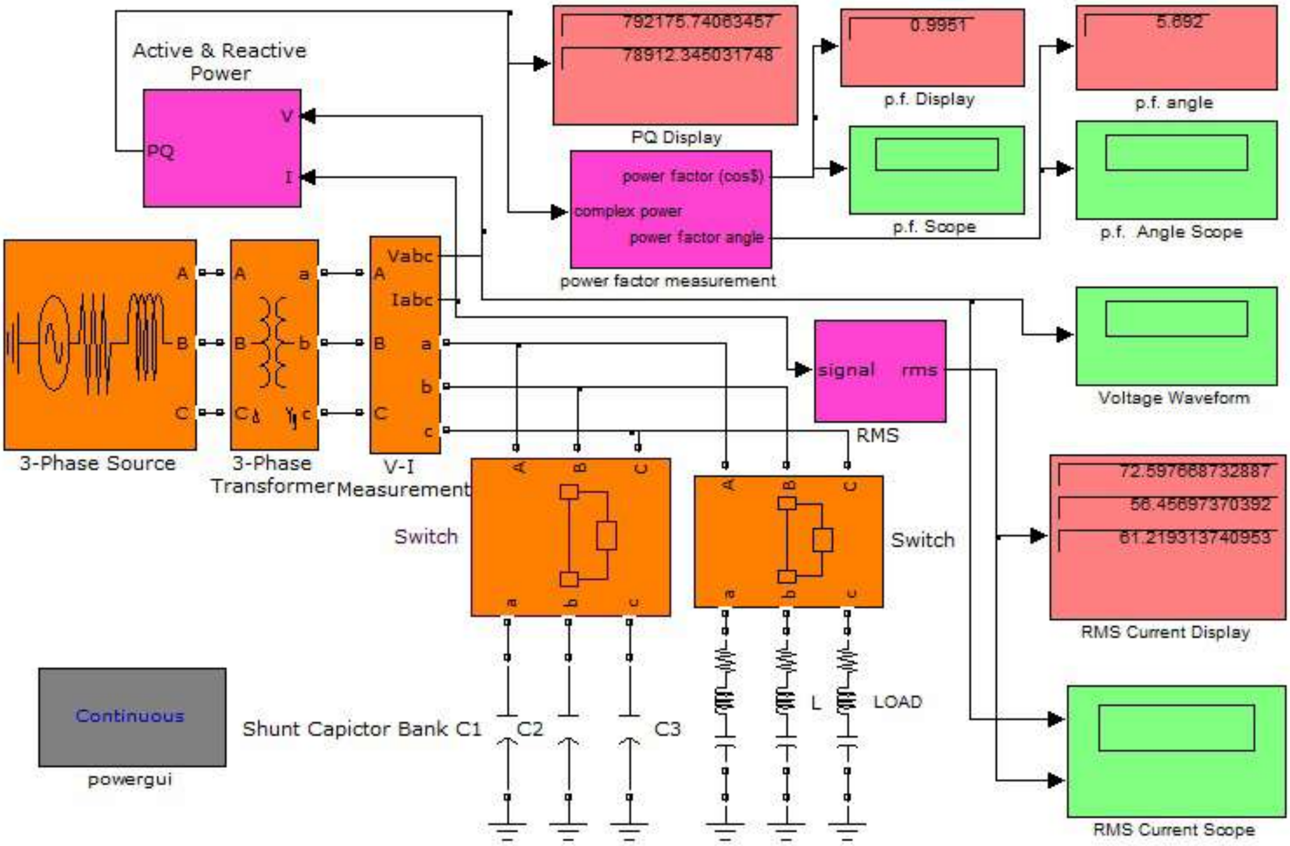


**Fig. 3** shows the Shunt Capacitance Compensated Feeder of 11 kV line.

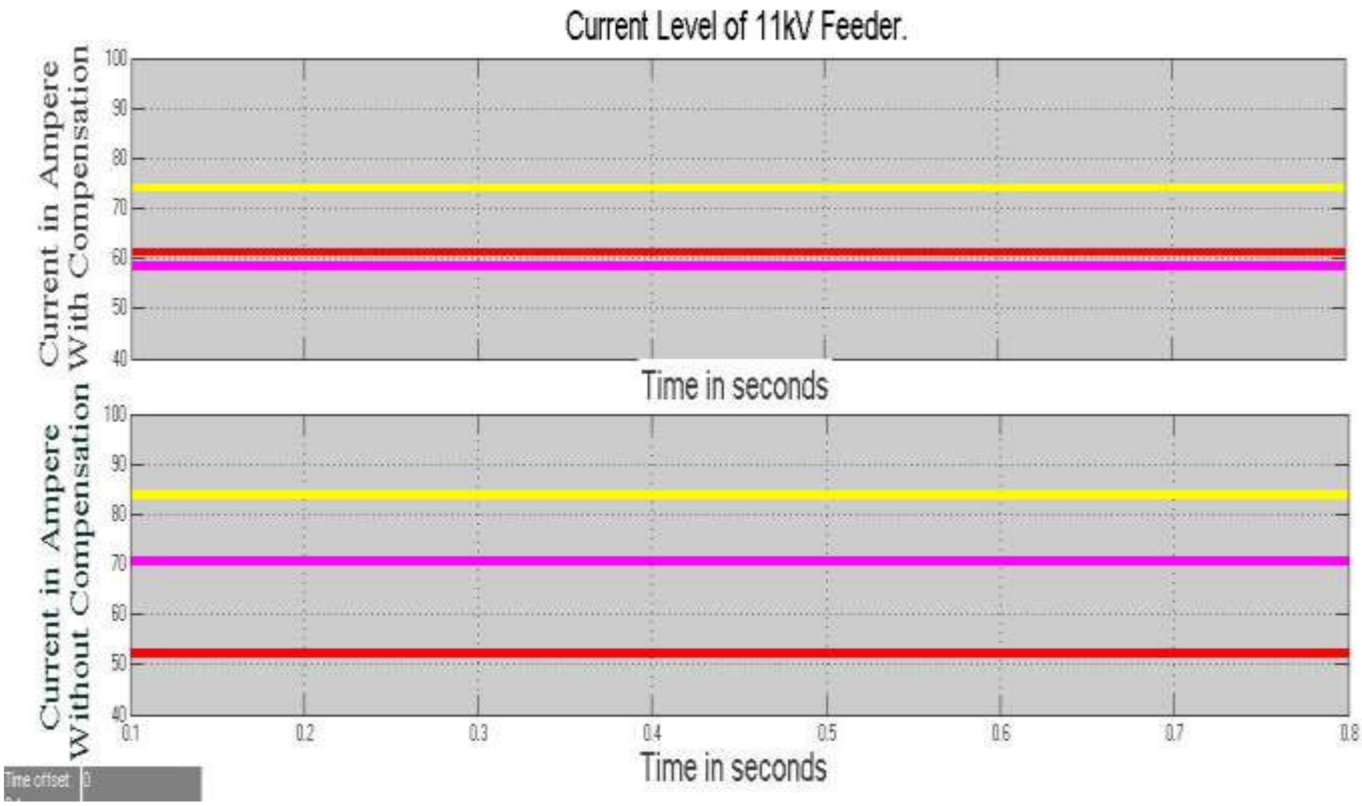


**Fig.** 4 RMS current Waveform of 11 kV feeder with Shunt Capacitor bank connected (above), and without Shunt Capacitor bank (below).

**TABLE I** Current Rating of Feeder with 1.2 MVAr compensation

| 11 kV Feeder | Current Rating(A) Without Compensation | Current Rating(A) With compensation | (%) Difference in Current |
|---|---|---|---|
| Phase 1 | 83.88 | 74.19 | 9.69 |
| Phase 2 | 70.59 | 58.50 | 12.09 |
| Phase 3 (Without Shunt Compensation) | 52.50 | 61.21 | -8.71 |

It is seen from Figure 4 and Table I that with the injection of capacitive reactive power of 1.2 MVA to phase 1 and phase 2 brings down the feeder current of approx. 10 Ampere. It is also seen in practical that approx. 10 ampere difference of current with the inclusion of shunt capacitor bank in the system. Also power factor goes up from 0.8295 to 0.995.

### *B. Economic Analysis of Power Losses*

The economical assessment of the power losses plays a significant role in the overall cost evaluation during the operational life of a distribution line [5]. Money is the most liquid economic resource and it has earning capacity at any time. The cost of money or price of money is interest rate. Due to the interest rate the value of a sum of money is different at different time which is called time value of money [6]. A rupee in hand today is worth more than a rupee to be received in the future since if you have it now, you can invest it and earn the interest [7]. The time value of money is the most important mathematics of finance and it is used in different areas of business. Time value of money concept is used to make different financial, economic and accounting decisions of the business. The main variables of time value of money are the sum of money, interest rate and time period. Time value of money is divided into present value and future value. The sum of money may be cost of asset, amount of loan, salaries, rent, tax and so on. The interest rate may be rate of return, cost of capital, opportunity cost and so on [8]. Time may be day, month, quarter, half year, year and so forth. Present value is also known as discounted value or current value or initial value. Present value is the current or discounted value of future cash flow(s) represented by Double round bracket throughout in this Article. Cash flow may be single or lump sum, even (annually) uneven (random and growing). The present time is denoted by zero and the future times are denoted by 1,2,3,4,……………..∞. The cash flow statement along with time period is known as cash flow time lines. Cash flow time lines are used to help visualize what is happening in time value of money problems.
Lifecycle = 40 (years); Real rate of interest (discount rate) = 5%; energy saving cost = Rs 3.20.

**TABLE II.** Power Saving of Distribution Feeder of 11 kV

| 11 kV Feeder | Power Losses Saving (KW) | Annual Energy Saving Cost (KW) | Annual Energy Saving in Rupees in Million(AESC) |
|---|---|---|---|
| Phase 1 | 184.61 | 1,617,183.6 | 5.17 |
| Phase 2 | 230.34 | 2,017,778.4 | 6.45 |
| Phase 3 (Without Shunt Compensation) | -165.94 | (-)1,453,634.4 | (-) 4.65 |

Therefore Annual Energy Saving Cost (AESC) = actual loss (KiloWatt) × 365 × 24 & discounted values (Ordinary Annuity) is given by:

$$\big((E)\big) = \frac{(1+i)^n - 1}{i(1+i)^n} \text{ (AESC) [7].}$$

Where i = 5% & n = 40 years therefore calculating, we have ((E)) = **88.70, 110.66, and (-) 79.77** Million rupees for three different phases of 11 kV feeder. It is seen from calculation that around Rs. 10 Crore is saved from entire service life of substation by using shunt capacitor bank. Also it is seen that device used in the substation have low power rating because of lower value of current. One another benefit of using shunt capacitor bank is extra current which is lost without using of capacitor, can be used to provide the electricity to other consumer.

**TABLE III** Power Saving of Distribution Feeder in Million Rupees (discounted)

| 11 kV Feeder | Power Saving in Million Rupees ((E)) |
|---|---|
| Phase 1 | 88.70 |
| Phase 2 | 110.66 |
| Phase 3 (Without Shunt Compensation) | (-) 79.77 |

## V. CONCLUSION

In this paper shunt capacitors is connected to prevent low power factor during peak load conditions. The capacitors Banks are usually switched during peak power flow periods and reduce the steady power transfer capacity to the line during this period. High speed mechanical switches capable of connecting the capacitor banks to the network are available for operator directed steady state voltage control. The reduction in max load during Peak loading period implies capacity release on the network, this means additional revenue for the utility company and more homes will be provided with electricity. Secondly the removal of the running cost of these generators from the production line of the industries will reduce the production cost of the goods produced; the resultant effect will be a reduction in the production cost of such goods, and the multiplying effect on the reductions of price of goods and services provided by such industries. It is seen from calculation that around Rs. 10 Crore (present value) is saved from entire service life of substation by using shunt capacitor bank. This is very large amount of saving, application of Decision Making theory clearly indicate connection of shunt capacitor bank to substation where power factor is low due to presence of inductive load. Another aspect of inclusion of shunt capacitor is reduction of burden on the devices of substation.

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