ISSN 2249 5460
Available online at www.internationaleJournals.com

International Journal of Mathematical Sciences, Technology And Humanities
www.InternationaleJournals.com

International eJournals

International Journal of Mathematical Sciences, Technology and Humanities 31 (2012) 302 – 312

REDUCTION OF REAL POWER LOSS AND IMPROVEMENT OF VOLTAGE PROFILE IN DISTRIBUTION SYSTEM BY OPTIMUM LOCATION OF SHUNT CAPACITOR

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Abstract

This paper presents reduction of real power loss and improvement of voltage profile in distribution system by optimum location of shunt capacitor. To show the effectiveness of the capacitor placement, the method is tested on single feeder distribution system (Chandur Village Feeder, Karnataka). It is observed that by placement of the shunt capacitor in the system there is improvement in the voltage profile of the system, also there is reduction in total real power loss as well as reactive power loss of the system thus resulting in total energy loss saving.

Keywords: Node Voltage, Radial Distribution System (RDS), Real Power Loss and Voltage Profile

1. Introduction

The electrical energy produced at the generating station is conveyed to the consumers through a network of transmission and distribution systems. According to scheme of connection, the distribution system may be classified as (a) radial system (b) ring main system (c) interconnected system. In radial distribution system, separate feeders radiate from a single sub-station and feed the distribution at one end only. This system being the simplest distribution system and having the lowest cost is commonly used for distribution purposes. All distribution of electrical energy is done by constant voltage system. Now that computers and other sensitive electronic equipments are ubiquitous in the offices, manufacturing and personal environments, a reliable high-quality electrical power supply is a necessity. Power quality would not be a problem if a perfect power supply was always available, always within voltage and frequency tolerances, with a pure, noise free sinusoidal wave shape. Unfortunately this is usually never the case, as there are various factors that change the voltage profile of the system. In this paper an attempt is made to improve the voltage profile of the system by placement of capacitor at the node that is having minimum voltage.

2. Literature Review

A new algorithm [1] is formulated for enhancement of voltage stability by network reconfiguration. This proposed method can be applied for efficient operation for online systems; since any change in loads does not need any change to be made in the algorithm and the optimum or near optimum switching configuration can be easily found without much effort. A novel algorithm [2] based on Fuzzy adaptation of Evolutionary Programming (FEP) to optimally reconfigure RDS to achieve the best voltage profile and minimal KW losses are developed in this paper. The fuzzy EP technique is found particularly suitable for solving Optimization problems with discontinuous solution space and multiple objectives when the global optimum is desired. Electric utilities are increasingly interested in maximizing the utilization of existing network equipment. Optimal management of reactive power dispatch will help achieve this goal. Shunt capacitors and reactors are installed at appropriate locations in large electric power systems to improve voltage profile for various loads and generator schedules, to improve system security and to minimize losses [3], [4] & [5]. In three phase ac systems, most of the loads are lagging power-factor in nature, which need reactive power resulting in reduction in ac terminal voltage, low efficiency and poor utilization of the ac network. A three phase advanced static compensator (STATCOM) [6] is used to compensate reactive power either for regulating ac supply voltage at a constant value or for unity power-factor and balancing of unbalanced reactive loads. The installation of shunt capacitors on radial distribution systems is essential for power flow control, improving system stability, power factor correction, voltage profile management and losses minimization. Two new heuristics techniques for reactive power compensation in radial distribution feeders have been developed [7] to obtain the optimal capacitor allocation according to available standard sizes of capacitor. A newly developed evolutionary technique particle swarm optimization (PSO) is used to find the optimum location and sizing of the shunt compensation devices in transmission systems to improve the voltage stability of the system while maintaining acceptable voltage profile. The load flow algorithm developed in has been used to analyze the system voltage profile before and after capacitor placement. In rural power systems, the automatic voltage regulators help to reduce energy losses and to improve the energy quality of electric utilities, compensating the voltage drops through distribution lines.

3. Method of Improving Voltage Profile of Radial Distribution Systems (RDS)

Reconfiguring the radial distribution system is one of the most commonly used methods to improve the voltage profile of the RDS. Network reconfiguration is performed by altering the topological structure of distribution feeders. Optimal placement of shunt capacitors in radial distribution system also helps in improving the voltage.

4. Load Flow Analysis
4.1 Circuit Model

Proposed algorithm is based on basic system analysis method and circuit theory. The purpose of it is to develop a new calculation model that requires less computer memory and is computationally fast for radial distribution networks. In this section, a circuit model of a radial Distribution system is presented. While developing the circuit model it is assumed that the radial distribution system is balanced and can be represented as a single line diagram as shown in Figure 1. Line shunt capacitance at distribution voltage level is negligibly small.

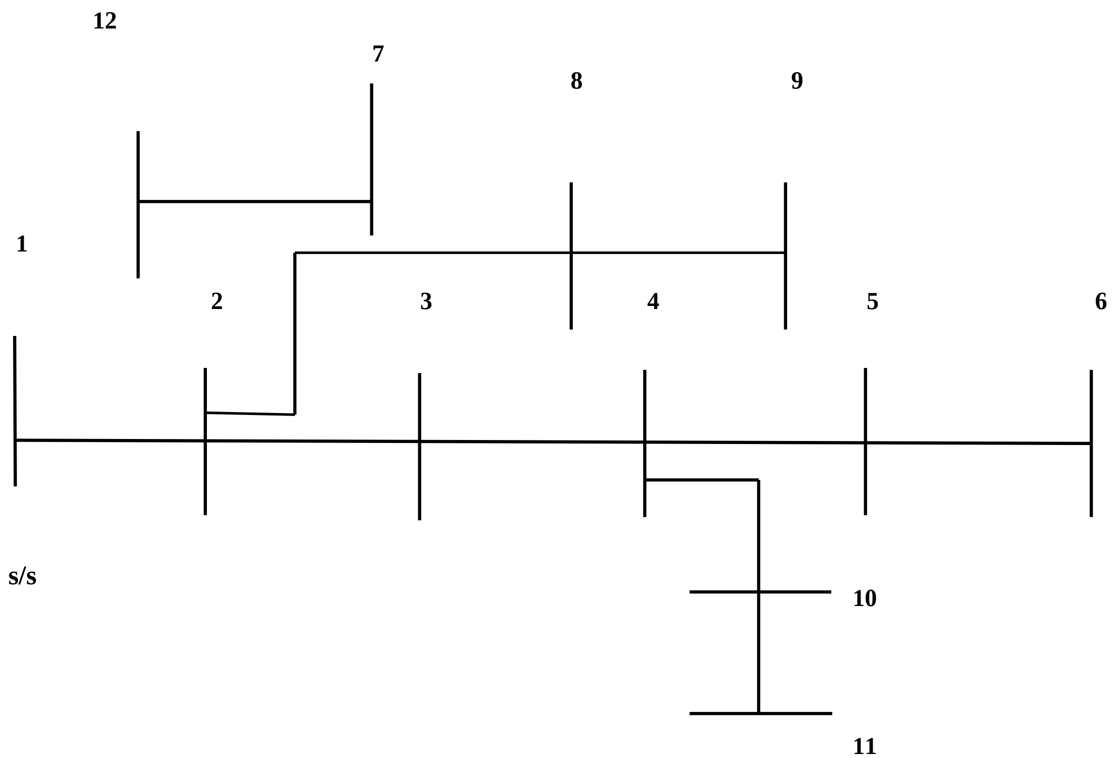


Figure 1. Sample Radial Distribution System

4.2. Mathematical Model of Radial Distribution System

A mathematical model of radial distribution system is derived from Figure 2.

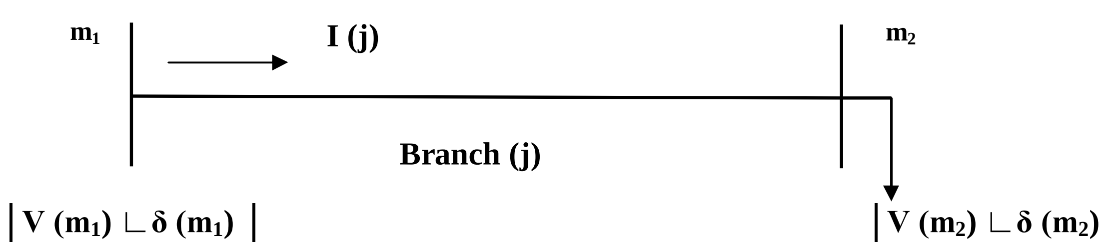


Figure2. Electrical Equivalent of a Branch

$$I(j) = \frac{|V(m_1) \angle \delta(m_1)| - |V(m_2) \angle \delta(m_2)|}{Z(j)} \quad (1)$$

and $P(m_2) - j\,Q(m_2) = V^*(m_2) \times I(j)$ (2)

Where Z (j) = R (j) + X (j), m_1 and m_2 are the sending end and receiving end nodes respectively. $P(m_2)$ = sum of the real power loads of all the nodes beyond node m_2 plus real power load of the node m_2 itself plus the sum of the real power losses of all the branches beyond node m_2. Q (m_2) = sum of the reactive power loads of all the nodes beyond node m_2 plus reactive power load of the node n2 itself plus the sum of the reactive power losses of all the branches beyond node m_2.
I (j) = current flowing through branch j.
$|V(i)|$ = voltage magnitude of the i^{th} node
ä (m_2) = voltage angle of the node m_2.
ä (m_1) voltage angle of the node m_1
R (jj) = resistance of the branch j.
X (jj) = reactance of the branch j.
From equation (1) and (2) we get

$$|V(m_2)| = \sqrt{\{B(j) - A(j)\}} \quad (3)$$

Where, $A(j) = \frac{\{P(m_2)*R(j)+Q(m_2)*X(j) - 0.5*|V(m1)|^2\}}{}$ (4)

$$B(j) = \sqrt{\{A^2(j) - [Z^2(j)*(P^2(m2) + Q^2(m2))]\}} \quad (5)$$

$$LP(j) = \frac{R(j)*(P^2(m_2) + Q^2(m_2))}{|V(m_2)|^2} \quad (6)$$

$$LQ(j) = \frac{X(j)*(P^2(m_2) + Q^2(m_2))}{|V(m_2)|^2} \quad (7)$$

LP (j) = real power loss in the branch j

LQ (j) = reactive power loss in the branch j.

5. Minimization of Real Power Loss and Improvement in Voltage Profile of DS by Placing Shunt Capacitor

Consider a single source radial distribution system with b branches and nb nodes. Let a capacitor C be placed at bus 'm' and á be a set of branches connected between the source and capacitor buses. The capacitor draws a reactive current Ic and for radial network it changes only the reactive components of current of branch set á. The current of other branches (ª á) is unaffected by the capacitor. Thus the new reactive current I_{ri}^{new} of the i^{th} branch is given by

$$I_{ri}^{new} = I_{ri} + D_i I_c \quad (8)$$

Where D_i= 1; if branch i Є α
= 0; otherwise

Here I_{ri} is the reactive current of the i^{th} branch in the original system obtained from the load flow solution.

$$I_{Li} = \frac{[P_{Li} - j Q_{Li}]}{V_i^*} \qquad i = 2, 3, 4\ldots\ldots..NB \quad (9)$$

For the purpose of explanation consider branch 5 of Figure.1. Current through branch 5 is given by I5 = (IL) 6 where (IL) 6 is the load current of the load connected to node 6. Now consider branch 4. Total number of nodes beyond branch 4 is two and these two nodes are 5 and 6 respectively. Therefore current through branch 4 is I4 = IL5 + IL6 Similarly consider branch 3. Total number of nodes beyond branch 3 is five and these nodes are4, 5,6,10 and 11 respectively. Hence current through branch 3 is I3 = IL4 + IL5 + IL6 + IL10 + IL11. Thus from above we will get the branch current in the form

$$I_B = I_a + jI_b \quad (10)$$

Where, I_a= Real part of branch current.
I_b=Imaginary part of branch current.
$I_b = I_{ri}$

The Loss P_{LrCom} associated with the reactive component of branch current in the compensated system (when capacitor is used).

$$P_{Lr}^{Com} = \sum_{i=1}^{b} (I_{ri} + D_i I_c)^2 \quad (11)$$

$$P_{Lr}^{Com} = \sum (I_{ri}^2 + D_i 2 I_c^2 + 2 I_{ri} I_c D_i) R_i$$

The Loss Saving 'S' is the difference between P_{LrCom} and $P_{Lr.}$

$$P_{Lr} = \sum_{i=1}^{b} I_{ri}^2 R_i \quad (12)$$

$$S = \sum_{i=1}^{b} I_{ri}^2 R_i - \sum_{i=1}^{b} (I_{ri}^2 + D_i 2 I_c^2 + 2 I_{ri} I_c D_i) R_i$$

$$S=-\sum_{i=1}^{b} (I_{ri}^{2}+D_i 2 I_c^{2}+2I_{ri}I_cD_i)R_i \quad (13)$$

The capacitor current I_c that provides the maximum loss saving can be obtained from

$$\frac{\partial S}{\partial I_c} = -2\sum_{i=1}^{b}(D_i^{2}I_c+I_{ri}D_i)R_i \quad (14)$$

Thus the capacitor current for the maximum loss saving can be obtained from equating the above eqn (7) to zero;

$$\sum_{i=1}^{b} D_i^{2}I_cR_i = -\sum_{i=1}^{b} I_{ri}D_iR_i \quad (15)$$

$$I_c= -\sum_{i=1}^{b} I_{ri\,i}R_i \Big/ \sum_{i=1}^{b}D_i^{2}R_i$$

The corresponding capacitor size is Qc = Vm*Ic Here, Vm is the voltage magnitude of the capacitor bus m where this capacitor is to be connected obtained from load flow studies. This capacitor is connected to that node which is having minimum voltage.

5.1 Algorithm

1. Run the load flow program and find the value of (i) Voltages at all nodes (ii) total real power loss (iii) total reactive power loss.
2. Using these voltages and power at all nodes calculate the branch current.
3. Find the reactive component of all branches current.
4. Using this reactive current find the capacitor current at the nodes at which capacitor is to be connected.
5. Find the capacitor value in Kvar using equation (9).
6. Compare this value with the standard value given in table and select the standard value which is nearest to this
   Calculated capacitor value.

Table-1: Available three-phase capacitor sizes and cost

Size (KVAR)	150	300	450	600	900	1200
Cost(Rs.)	750	975	1140	1320	1650	2040

7. Connect this capacitor at that particular node where the voltage is minimum.
8. Therefore load at that particular node (PL+j(QL-QC)) will change which in turn will change the values of Aj and Bj and hence the value of voltage at that particular node will change which in turn will change the value of total real power loss and total reactive power loss.

9. Run the load flow program again and now compute the new values of voltage, total real power loss and total reactive power loss.

Bus code From-	Line Length (Km)	Impedance R+jX (ohm\Km\ckt)	Line Voltag	Thermal Rating

6. Case Study

To show the effectiveness of the proposed method is tested on single feeder real distribution system (Chandur Village Feeder) is shown in Figure 3. The system data is as given in Table 2, 3 & 4.

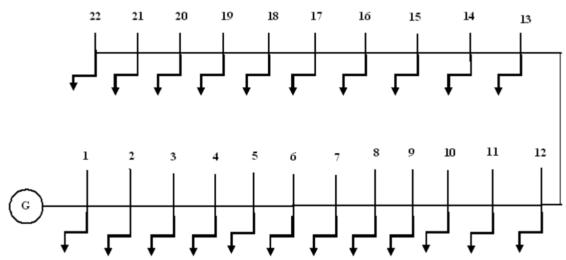


Fig. 3 Single Line Diagram of Chandur Village Feeder

Table 2. Bus Data

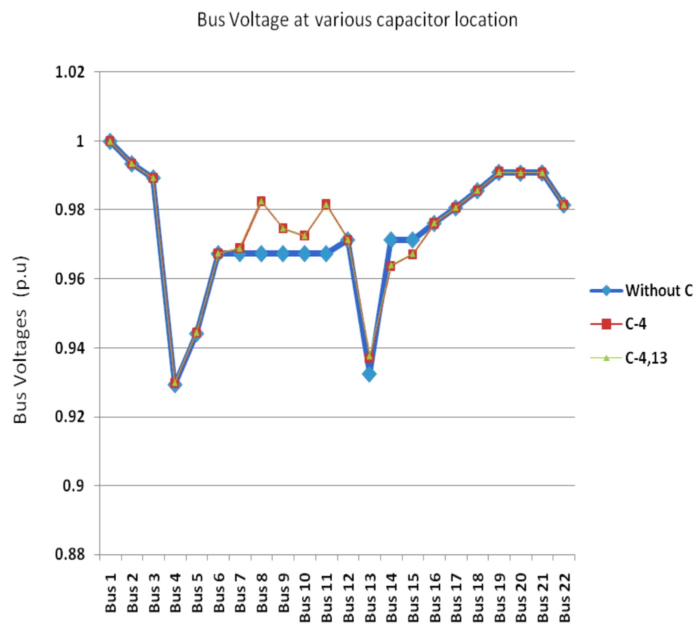
Bus No	Bus Name	Nominal Voltage (KV)
1	Gen. Bus	11
2	Bus 2	11
3	Bus 3	11
4	Bus 4	11
5	Bus 5	11
6	Bus 6	11
7	Bus 7	11
8	Bus 8	11
9	Bus 9	11
10	Bus 10	11
11	Bus 11	11
12	Bus 12	11
13	Bus 13	11
14	Bus 14	11
15	Bus 15	11
16	Bus 16	11
17	Bus 17	11
18	Bus 18	11
19	Bus 19	11
20	Bus 20	11
21	Bus 21	11
22	Bus 22	11

Table 3. Load Data

S. No	Bus Name	Load (KVA)	P.f
1	Gen	-------	-------
2	Bus 2	88	0.8
3	Bus 3	100	0.8
4	Bus 4	891	0.8
5	Bus 5	278	0.8
6	Bus 6	63	0.8
7	Bus 7	200	0.8
8	Bus 8	25	0.8
9	Bus 9	225	0.8
10	Bus 10	200	0.8
11	Bus 11	63	0.8
12	Bus 12	263	0.8
13	Bus 13	663	0.8
14	Bus 14	63	0.8
15	Bus 15	200	0.8
16	Bus 16	100	0.8
17	Bus 17	100	0.8
18	Bus 18	63	0.8
19	Bus 19	25	0.8
20	Bus 20	63	0.8
21	Bus 21	63	0.8
22	Bus 22	63	0.8

To			e (KV)	(MVA)
1-2	5.000	0.822+j0.138	11	2.762
2-3	0.850	0.822+j0.138	11	2.762
3-4	0.430	0.822+j0.138	11	2.762
4-5	0.500	0.822+j0.138	11	2.762
5-6	0.460	0.822+j0.138	11	2.762
6-7	0.600	0.822+j0.138	11	2.762
7-8	0.610	0.822+j0.138	11	2.762
8-9	0.240	0.822+j0.138	11	2.762
9-10	0.200	0.822+j0.138	11	2.762
10-11	0.180	0.822+j0.138	11	2.762
11-12	0.700	0.822+j0.138	11	2.762
12-13	0.520	0.822+j0.138	11	2.762
13-14	0.340	0.822+j0.138	11	2.762
14-15	0.360	0.822+j0.138	11	2.762
15-16	0.420	0.822+j0.138	11	2.762
16-17	0.420	0.822+j0.138	11	2.762
17-18	0.410	0.822+j0.138	11	2.762
18-19	0.320	0.822+j0.138	11	2.762
19-20	0.600	0.822+j0.138	11	2.762
20-21	0.520	0.822+j0.138	11	2.762
21-22	0.360	0.822+j0.138	11	2.762

Table 4. Transmission Line Data



Bus numbers

Fig. 4 Bus Voltages With and Without Capacitor

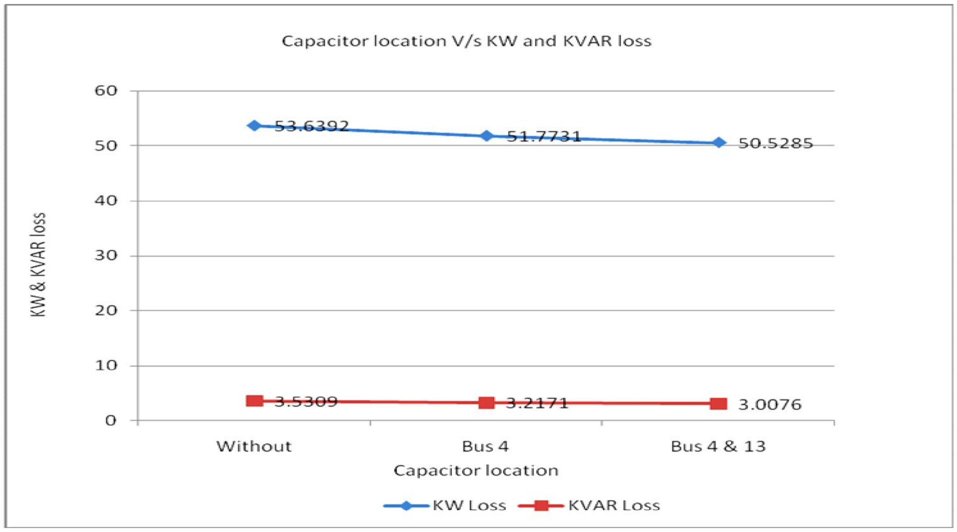


Fig. 5. KW and KVAR losses after placement of capacitor at various optimum locations.

6.1 Results

Fig. 4 shows the bus voltages with and without capacitor placement at optimum locations it was observed there was improvement in voltage profile at respective buses where capacitor was placed. With the improvement in bus voltages the overall system losses were reduced. In Figure 5 it is observed that KW and KVAR losses of the system reduce with MVAR compensation at various locations. It is seen that the optimum location obtained is location 4 and 13 by placing shunt capacitors and at this location the voltages at these buses are improved with decrease in overall losses in system. Before capacitor placement the voltages at buses 4 and 13 were **0.9294 and 0.9273 p.u** and the losses were **53.36 KW and 3.53 KVAR** but after placing the shunt capacitors at these buses the voltages were improved to **0.9299 and 0.9377 p.u** and the losses were reduced to **50.52 KW and 3.00 KVAR.** In Figure 6 it is observed that with increase in compensation at various locations there is decrease in Real and Reactive power loss of the system with improvement in voltage profile at the respective buses.

L-1=Bus 4; L-2= Bus 4, 13

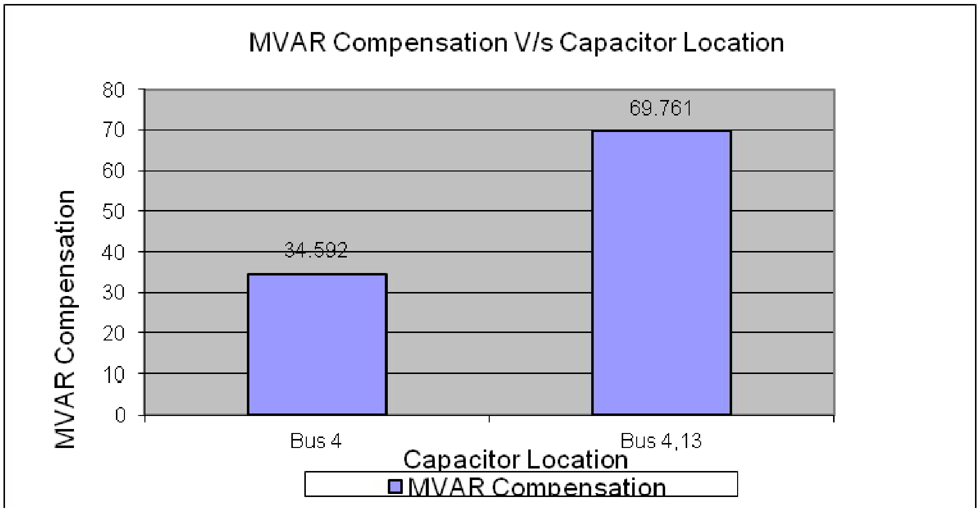


Fig. 6 MVAR Compensation at Various Locations.

Table 5. Summary of Losses before Placement of Shunt Capacitor at Optimum Location

P Loss K (KW)	Q Loss (KVAR)	Bus at which minimum voltage is Obtained	Minimum Voltage (p.u)	Energy Loss for one year in KWhr T=8760hrs ELoss=PLoss*8760	Cost of Energy Loss considering Rs.4.50/KWhr
53.36	3.53	Bus 4, 13	0.9294, 0.9372	4,67,433.60	**21,03,451.00**

The Total cost of energy loss without capacitor is **Rs. 21,03,451.00**

Table 6. Summary of Losses and Energy Saving after Placing Capacitor at Bus-4 & 13

P Loss (KW)	Q Loss (KVAR)	Improved Voltage at Bus-4 and 13 (p.u)	Energy Loss for one year in KWhr T=8760hrs ELoss=PLoss*8760	Cost of Capacitor Installation in Rs.	Cost of Energy Loss at Rs.4.5/KWhr including cost of capacitor

50.52	3.0	0.9299 and 0.9377	4,42,555.20	**58,806.40**	**20,50,304.80**

Total saving in cost after connecting capacitor at Bus-4 & 13 for 1st year is Rs.53,146.20and from the 2nd year onwards the installation cost of capacitor will become Nil and hence the total saving in energy cost will be **Rs.1,11,952.60**

7. Conclusion

The Proposed method of optimal location of shunt capacitor gives the reduced losses, energy saving and total saving in energy cost. This method is implemented on a single feeder real distribution system (Chandur feeder) and the simulated results shown above are obtained by MIPOWER Power System Simulation Software Package.

Acknowledgement

We are grateful to Authorities of Hirasugar Institute of Technology, Nidasoshi for providing all facilities to do the work.

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