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The Sizing & Placement of Capacitor in a Radial Distribution System Using Loss Sensitivity Factor and Simulink

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***Abstract**: The paper determines the optimal location and size of capacitors on radial distribution systems to improve voltage profile and to reduce active power loss. Sizing and placement of capacitor was done by using Loss Sensitivity Factor. Capacitor placement plays an important role in operation and distribution system planning. The concept of loss sensitivity factor can be considered as the new contribution in the area of distribution systems. Loss sensitivity factor offer the important information about the sequence of potential nodes for capacitor placement. These factors are determined using single base case load flow study. The proposed method is tested on 15 and 33 bus distribution systems.*

***Keywords:** Balanced Radial distribution Systems, Capacitor placement, Loss Sensitivity Factors, Power losses, Voltage profile.*

I. Introduction

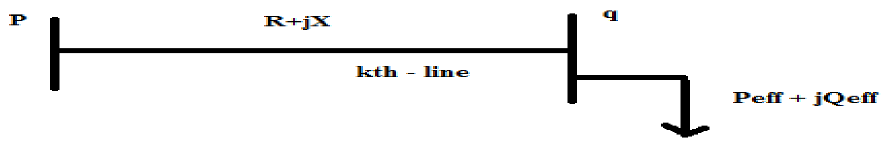
The distribution systems are becoming large and too far which leads to higher system losses and poor voltage regulation. There is a need to reduce the system losses. By minimizing the losses, the system may get the longer life span and has greater reliability. Due to high loads in distribution system, power and energy losses are more. Shunt capacitors are widely used in distribution system. Shunt capacitor results the benefits like improvement of power factor, reduction of power loss, improvement of voltage profile.

An important method of controlling bus voltage is by placement of shunt capacitor banks at the buses at distribution levels, along lines or at substations and loads. Essentially capacitors are a means of supplying VARs at the point of installation [1]The size and location of shunt capacitors for loss reduction in distribution network considering non-uniform distribution of loads[2]. In this paper the capacitor placement and sizing is done by the loss sensitivity factor and PSO .pso is used to estimate the level of shunt capacitor to improve the voltage profile[3].The voltage profile improvement was done by Var compensation using capacitor placement with the help of Voltage Improvement Factor (VIF)[4].The cuckoo search algorithm is used to the optimal capacitor size and for the maximum annual savings[5]. The concept of loss sensitivity factors and alpha-coefficients can be considered as the new contribution in the area of distribution systems[6]. The conventional loss sensitivity factors are introduced to identify the optimal location of capacitors in the distribution system and the amount of injection of reactive power through capacitors[8]. The installation of shunt capacitor at the optimal position there is a significant decrease in power loss, decrease in total annual cost and increase in voltage profile by using firefly algorithm[7][9].Two important methods are feeder reconfiguration and capacitor placement where shunt capacitor are widely used in distribution system to reduce the system losses[11].The optimum location, size of capacitor banks on feeders with uniformly distributed loads and randomly distributed variable loads to evaluate the reduction in costs of active and reactive losses[13].A solution method has been implemented that decomposes the problem into a master problem and a slave problem[10]. The paper presents a method of minimizing the loss associated with the reactive component of branch currents by placing shunt capacitors[12]. In this paper the Voltage profile improvement was increased and the losses were reduced by using capacitor placement .capacitor placement and rating was done by using Loss sensitivity factor and by Voltage improvement factor. The proposed method is tested on 15&33 bus radial distribution system with SIMULINK.

II. Methodology

A method is used to determine the candidate nodes for the placement of capacitor using Loss Sensitivity Factors. The estimation of the candidate nodes basically helps in reduction of the search space for the optimization procedure.

Consider a distribution line connected between ‘p’ and ‘q’ buses.



Active power loss in the K^{th} line is given by $[I_k{}^2] * R[K]$, which can be expressed as,

$$P_{lineloss}[q] = \frac{(P_{eff}{}^2[q]+Q_{eff}{}^2[q])R[k]}{(v[q])^2} \quad (1)$$

Similarly the reactive power loss in the K^{th} line is given by

$$Q_{lineloss}[q] = \frac{(P_{eff}{}^2[q]+Q_{eff}{}^2[q])X[k]}{(v[q])^2} \quad (2)$$

Where, P_{eff}[q]=Total effective active power supplied beyond the node 'q'.

Q_{eff}[q]=Total effective reactive power supplied beyond the node 'q'.

Now, both the Loss Sensitivity Factors can be obtained as shown below:

$$\frac{\partial P_{lineloss}}{\partial Q_{eff}} = \frac{(2*Q_{eff}[q]*R[k])}{(v[q])^2} \quad (3)$$

$$\frac{\partial Q_{lineloss}}{\partial Q_{eff}} = \frac{(2*Q_{eff}[q]*X[k])}{(v[q])^2} \quad (4)$$

III. Proposed Method

3.1 VDLF Method

In any radial distribution system, the electrical equivalent of a branch-1, which is connected between node 1 and 2 having a resistance r(1) and inductive reactance x(1) is shown in figure 1

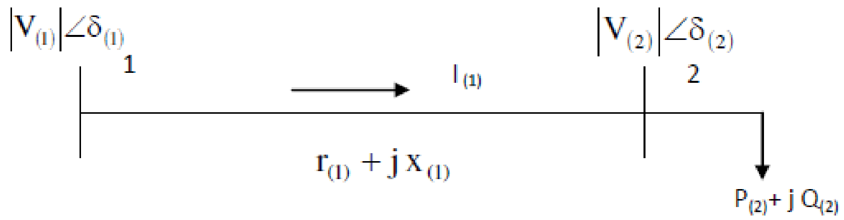


Fig.1 Single line diagram for a system

Current flowing branch-1is given by

$$I_{(1)} = |V_{(1)}|\angle\delta_{(1)} - |V_{(2)}|\angle\delta_{(2)}/(r_{(1)} + jx_{(1)}) \quad (5)$$

And $I_{(1)}$=$(P_{(2)} - jQ_{(2)})/V_{(2)} * \angle\delta_{(2)}$ **(6)**

Where $|V_{(1)}|\angle\delta_{(1)}$, $|V_{(2)}|\angle\delta_{(2)}$ are the voltage magnitudes and corresponding phase angles at sending end node1 and receiving end node 2 respectively. In general

$$|V_{(i+1)}| = \left\{\left(\left(r_{(j)}P_{(i+1)} + x_{(j)}Q_{(i+1)} - 0.5|V_{(i)}|^2\right)^2 - \left(r_{(j)}{}^2 + x_{(j)}{}^2\right)\left(P_{(i+1)}{}^2 + Q_{(i+1)}{}^2\right)\right\}^{1/2} - \left(r_{(j)}P_{(i+1)} + x_{(j)}Q_{(i+1)} - 0.5|V_{(i)}|^2\right)\right\}^{1/2}$$

(7)

Where, node no., i=1,2,…,nd, branch no., j=1,2…,nd-1, nd=total no. of nodes

The active and reactive power losses in branch 'j' are given by,

$$\textbf{Ploss[j]} = \frac{r_{(j)}\{P_{(i+1)}{}^2 + Q_{(i+1)}{}^2\}}{|V_{(i+1)}|^2} \quad \textbf{(8)}$$

$$\textbf{Qloss[j]} = \frac{x_{(j)}\{P_{(i+1)}{}^2 + Q_{(i+1)}{}^2\}}{|V_{(i+1)}|^2} \quad \textbf{(9)}$$

The total active and reactive power losses of the system are

$$\textbf{TPL} = \sum_{j=1}^{nd-1} Ploss[j] \quad \textbf{(10)}$$

$$\textbf{TQL} = \sum_{j=1}^{nd-1} Qloss[j] \quad \textbf{(11)}$$

3.2 SIMULINK Method

The proposed Simulink is a block diagram environment for multi domain simulation and Model-Based Design. It supports simulation, automatic code generation, and continuous test and verification of embedded systems.Simulink provides a graphical editor, customizable block libraries, and solvers for modelling and simulating dynamic systems. It is integrated with MATLAB, enabling to incorporate MATLAB algorithms into models and export simulation results to MATLAB for further analysis.

Application of proposed algorithm has been illustrated using IEEE 15 & 33 bus network. For that buses network has simulated to carry out load flow, results of which is used in determining current utility factors. Simulation model has been developed in MATLAB and its tool SIMULINK and SIM POWER SYSTEM block set. The performance characteristics are obtained from the simulation have been presented in this section.

IV. Test Results Of 15 & 33 Buses

4.1 15 Bus Results

4.1.1 TEST 1:

The VDLF method is tested on 15-node radial distribution system whose single line diagram is shown in fig 2. The test results are given in Table1. The voltage profile of 15 node is given in Table 2. The voltage profile graph before and after compensation are shown in Fig 3. From the results, to observe that active power losses reduce from 60.34821 kW to 29.77601kW i.e., 50.6596 % loss reduction and minimum voltage improved from 0.942389 p.u to 0.967561 p.u. thus voltage regulation improved from 5.7611% to 3.2439%, i.e., 43.6930 % improved.

Table.1 Test results of 15-node system of VDLF before and after compensation for load level of 1 p.u

Node No	Total Kvar Compensated	Before Compensation		After Compensation	
		Total Losses(kw)	Min Voltage (p.u)	Total losses (kw)	Min Voltage (p.u)
4,8,9,11,15	1200	60.34821	0.942389	29.77601	0.967561

Table.2 Voltage profile of 15 node VDLF system of before and after compensation

Node No	Voltage Profile (p.u)	
	Before Compensation	After Compensation
1	1.0000	1.0000
2	0.9713	0.9852
3	0.9547	0.9763
4	0.9489	0.9728
5	0.9479	0.9718
6	0.9618	0.9802
7	0.9611	0.9796
8	0.9593	0.9799
9	0.9652	0.9826
10	0.9635	0.9809
11	0.9478	0.9729
12	0.9437	0.9688
13	0.9424	0.9676
14	0.9466	0.9705
15	0.9465	0.9704

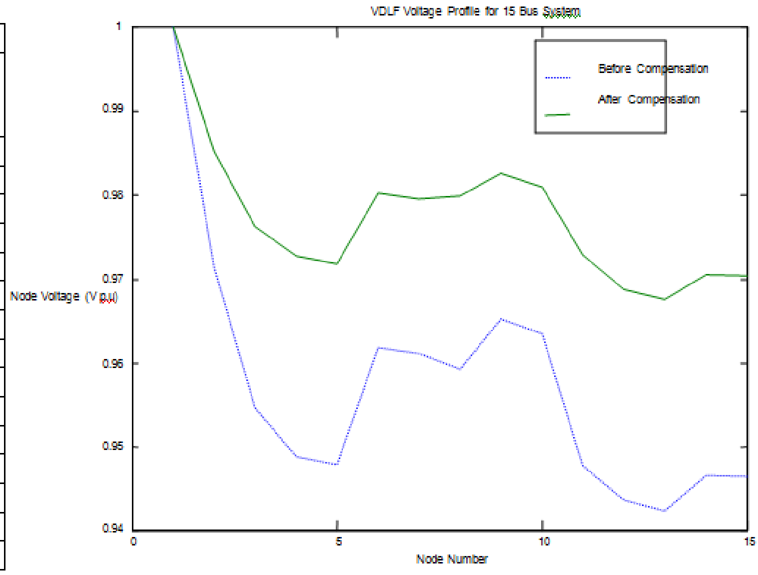


Fig.3 Voltage Profile graph for 15-node VDLF system Before and after compensation

4.1.2 TEST 2:

The proposed method is tested on 15-node radial distribution system by using simulink. The test results are given in Table 4. The voltage profile of 15 node is given in Table 4. The voltage profile before and after compensation are shown in Fig 4. From the results, to observe that active power losses reduce from 48.8808 kW to 26.9496 kW i.e., 44.8666 % loss reduction and minimum voltage improved from 0.9477 p.u to 0.9693 p.u. thus voltage regulation improved from 5.51386% to 3.16694%, i.e., 42.5640 % improved.

Table.3 Test results of 15-node system of SIMULINK before and after compensation for load level of 1 p.u

Node No	Total Kvar Compensated	Before Compensation		After Compensation	
		Total Losses(kw)	Min Voltage(p.u)	Total losses (kw)	Min Voltage(p.u)
4,8,9,11,15	1200	48.8808	0.9477	26.9496	0.9693

Table. 4 Voltage profile of 15 node SIMULINK system of before and after compensation

Node No	Voltage Profile (p.u)	
	Before Compensation	After Compensation
1	1.0000	1.0000
2	0.9738	0.9859
3	0.9588	0.9775
4	0.9536	0.9742
5	0.9527	0.9733
6	0.9650	0.9812
7	0.9644	0.9805
8	0.9627	0.9808
9	0.9681	0.9834
10	0.9665	0.9818
11	0.9526	0.9743
12	0.9489	0.9705
13	0.9477	0.9693
14	0.9515	0.9721
15	0.9514	0.9719

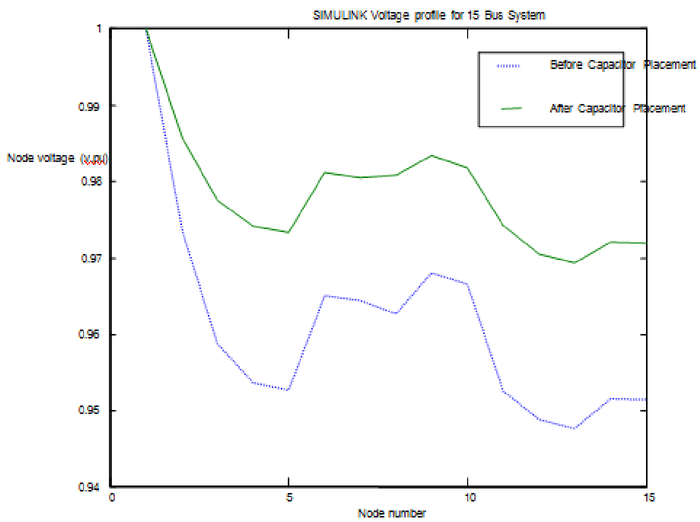


Fig.4 Voltage Profile graph for 15-node Simulink system before and after compensation

4.2 33 Bus Results

4.2.1 TEST 3:

The VDLF method is tested on 33-node radial distribution system whose single line diagram is shown in fig 5.The test results of 33-node radial distribution system are given in Table 6.The voltage profile before and after compensation are shown in fig 3. From the results, to observe that active power losses reduce from 202.7069 kW to 143.7255 kW i.e., 29.096866% loss reduction and minimum voltage improved from 0.913041 p.u to 0.925082 p.u. thus voltage regulation improved from 8.6959% to 7.4918% i.e., 13.8468 % improved.

Table.5 Test results of 33-node system of VDLF before and after compensation for load level of 1 p.u

Node No	Total Kvar Compensated	Before Compensation		After Compensation	
		Total Losses(kw)	Min Voltage(p.u)	Total losses (kw)	Min Voltage(p.u)
30	1200	202.7069	0.913041	143.7255	0.925082

Table.6 Voltage profile of 33 node VDLF system of before and after compensation

Node No	Voltage Profile (p.u) Before Compensation	Voltage Profile (p.u) After Compensation	Node No	Voltage Profile (p.u) Before Compensation	Voltage Profile (p.u) After Compensation
			17	0.9136	0.9257
1	1.0000	1.0000	18	0.9130	0.9251
2	0.9970	0.9974	19	0.9965	0.9969
3	0.9829	0.9855	20	0.9929	0.9933
4	0.9754	0.9795	21	0.9922	0.9926
5	0.9860	0.9738	22	0.9916	0.9920
6	0.9496	0.9612	23	0.9793	0.9819
7	0.9462	0.9578	24	0.9727	0.9752
8	0.9413	0.9530	25	0.9693	0.9719
9	0.9350	0.9468	26	0.9477	0.9601
10	0.9292	0.9411	27	0.9452	0.9588
11	0.9284	0.9402	28	0.9337	0.9550
12	0.9269	0.9387	29	0.9255	0.9525
13	0.9207	0.9327	30	0.9219	0.9511
14	0.9185	0.9304	31	0.9178	0.9470
15	0.9170	0.9290	32	0.9169	0.9462
16	0.9157	0.9277	33	0.9166	0.9459

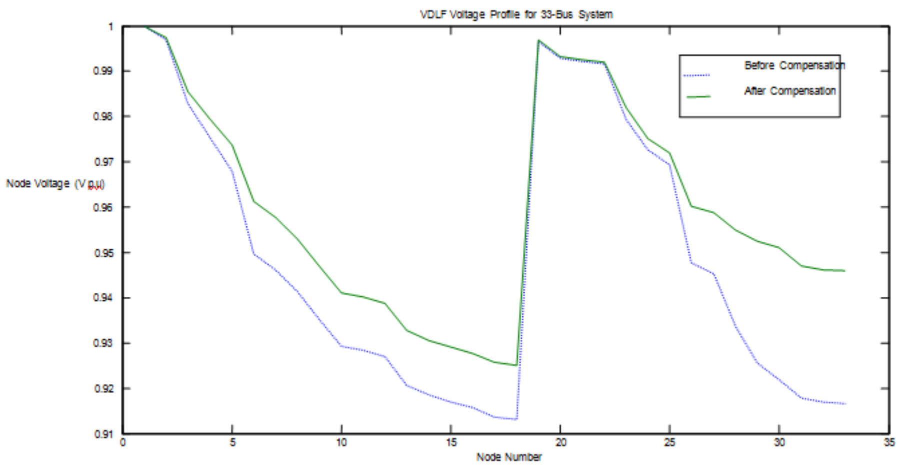


Fig.6 Voltage Profile graph for 33-node VDLF system before and after compensation

4.2.2 TEST 4:

The proposed method is tested on 33-node radial distribution system whose single line diagram is shown in fig 5. The test results of 33-node radial distribution system are given in Table2.The voltage profile before and after compensation are shown in fig 3. From the results, to observe that active power losses reduce from 140.0575 kW to 121.7789 kW i.e., 13.0507% loss reduction and minimum voltage improved from 0.9284 p.u to 0.9312 p.u. thus voltage regulation improved from 7.71662% to 7.3789% i.e., 4.3765% improved.

Table.7 Test results of 33-node system of SIMULINK before and after compensation for load level of 1 p.u

Node No	Total Kvar Compensated	Before Compensation		After Compensation	
		Total Losses(kw)	Min Voltage(p.u)	Total losses (kw)	Min Voltage(p.u)
30	1200	140.0575	0.9284	121.7789	0.9312

Table.8 Voltage Profile for 33-node SIMULINK system before and after compensation

Node No	Voltage Profile (p.u)		Node No	Voltage Profile (p.u)	
	Before Compensation	After Compensation		Before Compensation	After Compensation
			17	0.9289	0.9318
1	1.0000	1.0000	18	0.9284	0.9313
2	0.9973	0.9974	19	0.9865	0.9871
3	0.9870	0.9876	20	0.9830	0.9836
4	0.9806	0.9816	21	0.9823	0.9829
5	0.9742	0.9757	22	0.9817	0.9823
6	0.9586	0.9616	23	0.9939	0.9940
7	0.9557	0.9587	24	0.9875	0.9876
8	0.9517	0.9547	25	0.9843	0.9844
9	0.9467	0.9497	26	0.9569	0.9602
10	0.9421	0.9451	27	0.9547	0.9583
11	0.9414	0.9444	28	0.9448	0.9505
12	0.9401	0.9431	29	0.9378	0.9451
13	0.9349	0.9379	30	0.9347	0.9349
14	0.9330	0.9359	31	0.9312	0.9390
15	0.9318	0.9347	32	0.9304	0.9382
16	0.9306	0.9336	33	0.9302	0.9380

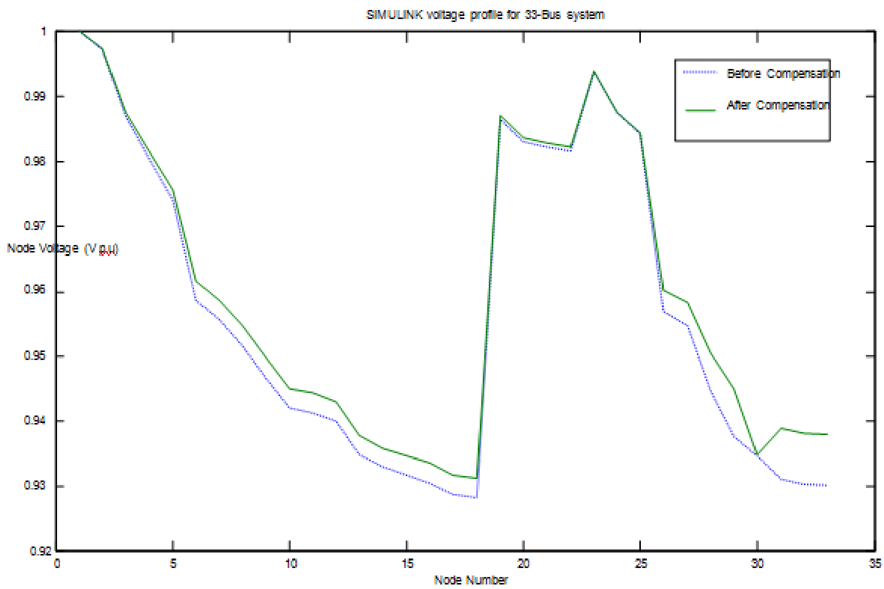


Fig.7 Voltage Profile graph for 33-node VDLF system before and after compensation

Comparison of voltage profiles between VDLF & SIMULINK of 15 and 33 buses Before and After Compensation

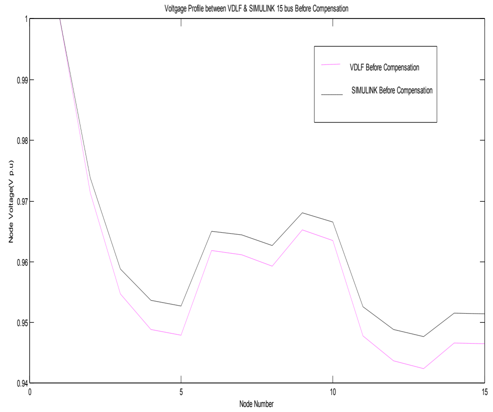


Fig.8 Voltage profile graph comparison between VDLF & between SIMULINK 15 bus before compensation

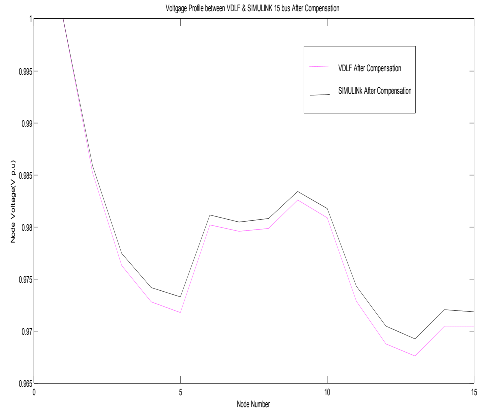


Fig.9 Voltage profile graph comparison VDLF & SIMULINK 15 bus after compensation

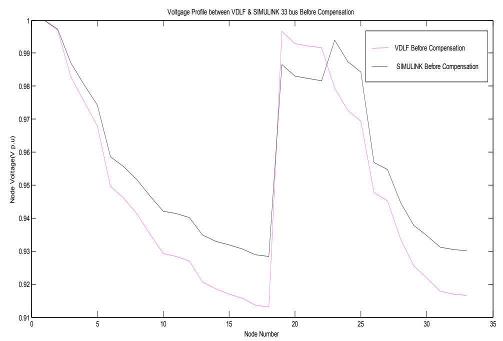


Fig.10 Voltage profile graph comparison between VDLF & between SIMULINK 33 bus before compensation

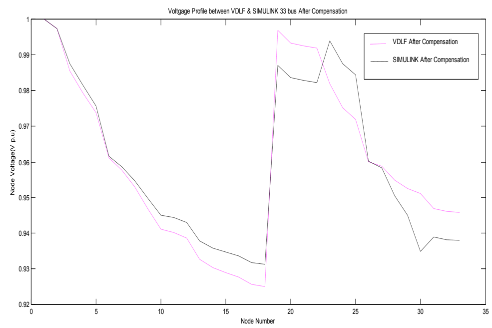


Fig.11 Voltage profile graph comparison VDLF & SIMULINK 33 bus after compensation

It is observed that the voltage profile has been increased in a radial distribution system of IEEE 15 and 33 bus systems by placing the capacitor.From the above figures 8,9,10,11 the SIMULINK will contain the better voltage improvement than the VDLF.

Table.9 Summary of Test Results of 15 & 33 Bus systems Before and After Compensation for load level of '1' p.u

Description	15-Node System		33-Node System	
	Before Compensation	After Compensation	Before Compensation	After Compensation
Total reactive power load (Kvar)	1251.18	51.18	2300	1100
Reactive power loss	48.3791	26.1718	94.9952	82.2121
Released reactive power demand (Kvar)	....	1222.2073	....	1212.7831
Real power losses (Kw)	48.8808	26.9496	140.0575	121.7789
Loss reduction (%)	....	44.8666	....	13.0507
Real power demand (Kw)	1275.2808	1253.3496	3855.0575	3836.7789
Released demand (Kw)	....	21.9312	....	18.2786
Feeder capacity (Kva)	1820.7676	1255.7342	4538.4436	4014.7848
Released feeder capacity (Kva)	....	565.0334	....	523.6588
Min.voltage	0.9477	0.9693	0.9284	0.9312

(p.u)				
Voltage regulation (%)	**5.5138**	**3.1669**	**7.71662**	**7.3789**
Improvement of voltage regulation (%)	**........**	**42.5640**	**.......**	**4.3765**
Power cost (Rs)	**1401901.344**	**772914.528**	**4016849.1**	**3492618.852**
Net savings (Rs)	**...........**	**628986.816**	**............**	**524230.248**

V. Conclusion

This paper presents the rating and placement of capacitor in a balanced radial distribution system using loss sensitivity factor and simulink. The proposed method is tested on IEEE 15 and 33 bus system and the simulation results are reported.

The sizing and location of capacitor in radial distribution system of IEEE 15 and 33 bus systems was done by loss sensitivity factor.The comparison was considered between the VDLF and Simulink.Hence the results that are reported under the Simulink method show the better performance than VDLF.From the results several important observations can be concluded as,The power losses of DS can be efficiently reduced by proper placement of capacitor.However the voltage profile can also be improved.It is observed that due to decreased power losses the net saving were decreased. So the combination of both Loss sensitivity factor and SIMULINK yields good results.

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