International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 2, Issue 4, pp: (84-95), Month: October - December 2014, Available at: www.researchpublish.com

Voltage Profile Improvement and Loss Minimization with Voltage Regulators Using Particle Swarm Optimization

Namrata Sahu

ME Control System, Department of Electrical Engineering, Jabalpur Engineering College, Jabalpur, INDIA

Abstract: **This paper presents selection of optimal location and tap setting for voltage regulators in Unbalanced Radial Distribution Systems (URDS). Power loss index (PLI) is used for the selection of optimal location of voltage regulators and Particle swarm optimization (PSO) is used for selecting the tap position of voltage regulator in an unbalanced radial distribution system. This algorithm makes the initial selection and tap position setting of the voltage regulators to minimize power losses and provide a good voltage profile along the distribution network. The effectiveness of the proposed method is illustrated on a test system of IEEE 33 bus unbalanced radial distribution systems.**

Keywords: **Unbalanced Radial Distribution Systems (URDS), Particle swarm optimization(PSO), Voltage Regulator placement, Loss minimization.**

I. INTRODUCTION

Distribution systems are the networks that transport the electrical energy from bulk substation to many services or loads. Losses in a distribution system are significantly high compared to that in a transmission system. The need of improving the overall efficiency of power delivery has forced the power utilities to reduce the losses at distribution level. By minimizing the losses, the system may acquire longer life span and has greater reliability. Therefore after proper installation of voltage regulator losses in the distribution system reduces and hence voltage profile also improved.

Voltage Regulator (VR) or Automatic Voltage Booster (AVB) is essentially an auto transformer consisting of a primary or existing winding connected in parallel with the circuit and a secondary winding with taps connected in series with the circuit. Taps of series winding are connected to an automatic tap changing mechanism.

A voltage regulator is a device that keeps a predetermined voltage in a distribution network despite of the load variations within its rated power [1].In distribution systems operation, shunt capacitor banks and feeder regulators are necessary for providing acceptable voltage profiles to all end-use customers and reducing power losses on large distribution systems [2]. A voltage regulator is equipped with controls and accessories for its tap to be adjusted automatically under load conditions. Moreover, it can be controlled by the installation of devices such as fixed and controlled capacitors banks, transformers with On Load Tap Changers (OLTCs), and Automatic Voltage Regulators (AVRs) [3].

International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 2, Issue 4, pp: (84-95), Month: October - December 2014, Available at: www.researchpublish.com

1.1 Load Flow Solution

In any radial distribution system, the electrical equivalent of a branch 1, which is connected between nodes 1 and 2 having impedance Z1 is shown in Figure. 1[C.L.Wadhwa, 'Electrical power systems']

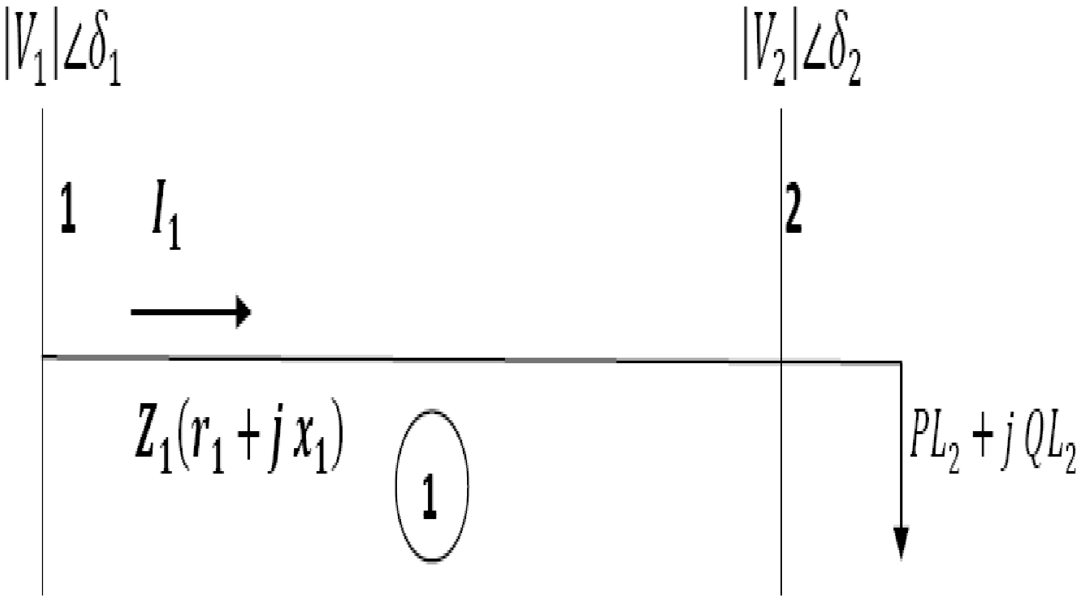


Figure.1 Electrical equivalent of a typical branch '1'

The voltage at source node is taken as 1.0 p.u. The voltage at node 2 is given by [6]

$$V_2 = V_1 - I_1 Z_1$$

In general $$V_{n2} = V_{n1} - I_j Z_j \qquad \text{-- (1)}$$

where 'n1' and 'n2' are sending and receiving ends of branch 'j' respectively.

By using Eqn. (1), the voltage at any node (except node 1) can be calculated.

The load current at node 'i' is calculated by

$$IL_i = \frac{PL_i + j\,QL_i}{V_i}, \text{ for } i = 2,3, \text{----},nn \qquad \text{-- (2)}$$

Where,

PL_i = Real or Active power load at node i

QL_i = Reactive power load at node i

nn= Number of nodes

The real and reactive power losses of branch 'j' can be calculated as

$$LP_j = I_j^2\, r_j \qquad \text{-- (3)}$$

$LQ_j = I_j^2 x_j$ for j=1, 2, ----, nb. -- (4)

where nb= Number of branches

The current in each branch is calculated by applying KCL at node '2' shown in Figure 1 the branch current equation obtained is as follows

$I_1= I_2 +I_5 +I_7+IL_2$ -- (5)

From the above, the current can be calculated in any branch. Initially, a flat voltage profile is assumed at all nodes i.e., 1.0 p.u. Load currents are computed iteratively with the updated voltages at each node.

II. PROBLEM FORMULATION

In a distribution system with an ever increasing load demand there is reduction in voltage and hence power losses increases. Therefore in order to maintain the constant voltage profile and to reduce the power losses, voltage regulators are installed in the distribution system.

2.1 Optimal location of Automatic Voltage Regulators (AVR)

Voltage Regulator (VR) or Automatic Voltage Booster (AVB) is essentially an auto transformer consisting of a primary or existing winding connected in parallel with the circuit and a second winding with taps connected in series with the circuit. In order to maintain the voltage profile and to reduce the power losses these are installed in the distribution systems [5].

• VR provides 10% boost of voltage

• It boosts voltage in four steps of 2.5% each and it also boosts voltage in 32 steps of 0.625% each.

• It has line drop compensation to maintain constant voltage at its location.

The optimal location of voltage regulator (AVR) is defined as function of two objectives, one representing power loss reduction and the other one representing the voltage deviations but both are essential to secure the power supply.

The objective function to be minimized is given below

$$\text{Minimize } f = \sum_{j=1}^{nb} P'_{lossj}{}^{abc} \qquad \text{--(6)}$$

Where, $P'_{loss\,j}{}^{abc}$ is the active power loss in the *jth* branch after voltage regulator placement.

'nb' is the number of branches in the system.

2.2 Tap Position Selection

By finding the optimal number and location of Voltage regulators then tap positions of VR is to be determined as follows.

In general, VR position at node 'i' can be calculated as [4]

$$V^1_i = V_i \pm tap \times V_{rated} \qquad \text{--(7)}$$

Tap position (tap) can be calculated by comparing voltage obtained before VR installation with the lower and upper limits of voltage

'+' for boosting of voltage

'-' for bucking of voltage

The node voltages are computed by load flow analysis, described in section 1.1

2.3 Candidate Node Identification using PLI

Power Loss Index (PLI) is power loss based approach to determine the suitable location for placement of voltage regulators. After running the load flows, the total active power loss is given by 281.5877 kW. Therefore Power Loss Index (PLI) are calculated as

$$PLI[j] = \frac{(\text{Loss. reduction}[j] - \text{Min reduction})}{(\text{Max. reduction} - \text{Min. reduction})} \qquad \text{--(8)}$$

III. IMPLEMENTATION OF PSO

After calculating the total power losses by using load flow analysis and candidate node identification by power loss Index, the voltage regulator tap setting at candidate node of the unbalanced radial distribution system is selected using PSO.

3.1 Initialization of PSO Parameters

The control parameters such as lower and upper bounds of node voltage and tap setting of voltage regulators are selected as initialize parameters. Randomly generate an initial swarm (array) of particles with random positions and velocities.

3.2 Evaluation of Fitness Function

The fitness function should be capable of reflecting the objective and directing the search towards optimal solution For each particle or swarm, the voltage regulators are placed at the nodes and run the load flow to calculate the losses and these losses becomes the fitness function of the PSO.

3.3 Optimal Solution

PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two "best" values. The first one is the best solution (fitness) it has achieved so far. (The fitness value is also stored.) This value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called gbest**.**

The modification can be represented by the concept of velocity (modified value for the current positions). Velocity of each particle can be modified by the following equation.

$$V_i^{k+1} = WV_i^k + C_1\, rand_1 \times (Pbest_i - X_i^k) + C_2\, rand_2 \times (Gbest - X_i^k) \qquad \text{--(9)}$$

The $rand_1$, $rand_2$ are the two random numbers with uniform distribution with range of { 0.0 to 1.0 }

W is the inertia weight which shows the effect of previous velocity vector on the new vector

A larger inertia weight 'W' facilitates global exploration, while smaller inertia weight 'W' tends to facilitates local exploration to fine tune.

Where,

V_i^k: Velocity of particle i at iteration k,

V_i^{k+1}: Modified velocity of particle i at iteration k+1,

W: Inertia weight,

C_1, C_2: Acceleration Constants,

$rand_1$, $rand_2$: Two random numbers

X_i^k: Current position of particle i at iteration k,

$Pbest_i$: $Pbest_i$ of particle i,

Gbest : Gbest of the group.

In the equation (11),

The term $rand_1 \times (Pbest_i - X_i^k)$ is called particle memory influence

The term $rand_2 \times (Gbest - X_i^k)$ is called swarm influence.

$$W = W_{max} - \frac{W_{max} - W_{min}}{iter_{max}} \times iter \qquad \text{--(10)}$$

Where,

W_{max}: Initial value of the Inertia weight,

W_{min}: Final value of the Inertia weight,

$iter_{max}$: Maximum iteration number,

iter : current iteration number.

Accordingly, the optimal types and sizes of voltage regulators to be placed at each compensation node can be determined.

3.4 Algorithm for Optimal Location using PLI and Tap setting of VR using PSO

The detailed algorithm is to determine optimal location along with tap setting of voltage regulator is given below.

Step 1: Read system data such as line data and load data of distribution system.

Step 2: Initialize the PSO parameters such as Number of Agents (M), Number of Particles (N), Number of Iterations (Kmax), Initial value of Inertia weight (Wmax), Final value of Inertia weight (Wmin), Acceleration Constants (C1 & C2).

Step 3: Initialize the parameters as explained in section 5.

Step 4: Obtain the optimal location of VR by using PLI (Power Loss Index) as input.

Step 5: Initialize the swarm by assigning a random position and velocity in the problem hyperspace to each particle, where each particle is a solution of tap setting of VR.

Step 6: Run the load flow and compute the fitness value of each particle using equation (9).

Step 7: Compare the present fitness value of ith particle with its historical best fitness value. If the present value is better than Pbest updating the Pbest, else retain Pbest as same.

Step 8: Find the Gbest value from the obtained Pbest values.

Step 9: Update the particle positions & velocity using eqns. (9) & (10).

Step 10: Apply boundary conditions to the particles

Step 11: Execute steps 6-10 in a loop for maximum number of iterations (Kmax).

Step 12: Stop the execution and display the Gbest values as the final result for optimal tap setting of voltage regulator.

IV. RESULTS AND DISCUSSION

The PSO Parameter values for voltage regulator placement:

Number of Particles (N) =10,

Number of Iterations (Kmax) =30,

Initial value of the inertia weight (Wmax) =0.9 ,

Final value of the inertia weight (Wmin) =0.4, Acceleration constants, (C1 & C2)=4.

The performance of the proposed algorithm is evaluated for test system of 11kV,100MVA,33 bus URDS for voltage regulator placement. Proper allocation of VR gives minimum losses and improves voltage profile of the system. The proposed method is illustrated with test system consisting of 33 bus URDS.

4.1 Case Study

Power loss indices for 33 bus URDS is shown in the Figure.2. The proposed algorithm is tested on IEEE 33 bus URDS ans the single line diagram of IEEE 33 bus URDS is shown in Figure.3

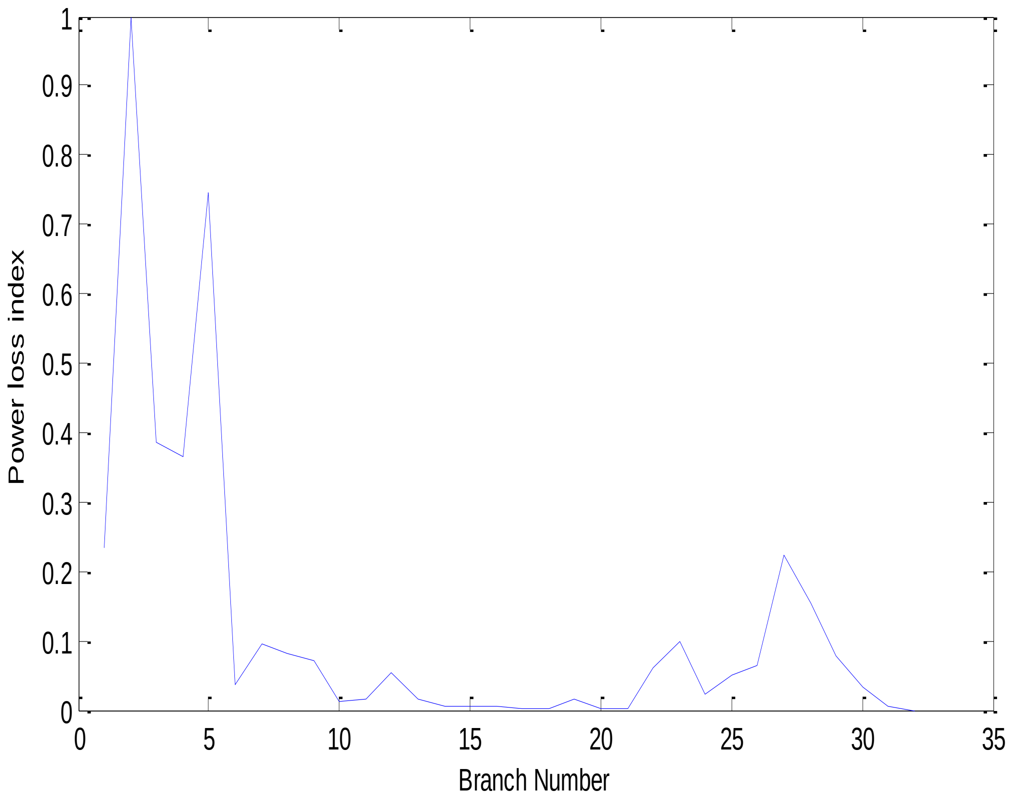


Figure. 2 Power loss indices for IEEE 33 bus URDS

Line and load data, active and reactive power flows are given in tables 1.

Summary of test results of bus IEEE 33 bus URDS for voltage regulator placement are given in table 2.

From table 2 it is observed that the Active Power loss is reduced from 281.5877 kW to 171.8373 kW i.e, 38.97 % .The minimum voltage at bus 18 is 0.8819 and after VR placement it is improved by 1.1133 after VRs placement. Hence, there is an improvement in the minimum voltage and reduction in active and reactive power losses when compared with before and after voltage regulator placement.

International Journal of Electrical and Electronics Research ISSN 2348-6988 (online)
Vol. 2, Issue 4, pp: (84-95), Month: October - December 2014, Available at: www.researchpublish.com

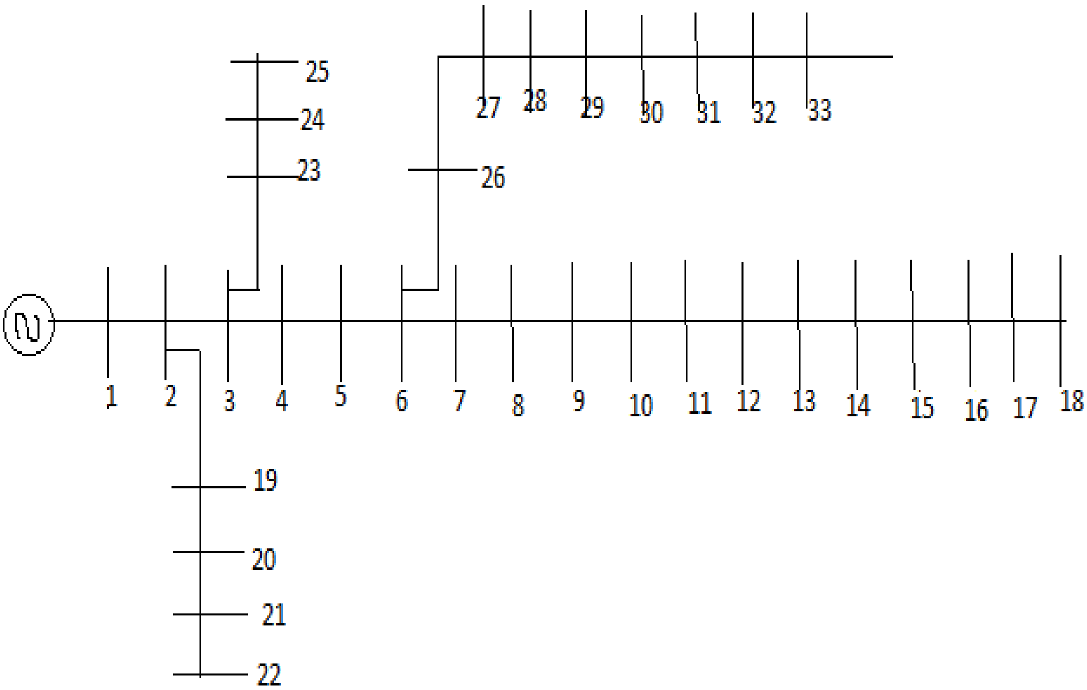


Table.1: Line data and Load data of IEEE 33 bus Radial Distribution System

Branch Number	Sending end bus	Receiving end bus	Resistance R (Ω)	Reactance X (Ω)	Bus Number	Active Power PL (kW)	Reactive Power QL (kVAr)
1	1	2	0.0922	0.0470	1	0	0
2	2	3	0.4930	0.2511	2	100	60
3	3	4	0.3660	0.1864	3	90	40
4	4	5	0.3811	0.1941	4	120	80
5	5	6	0.8190	0.7070	5	60	30
6	6	7	0.1872	0.6188	6	60	20
7	7	8	0.7114	0.2351	7	200	100

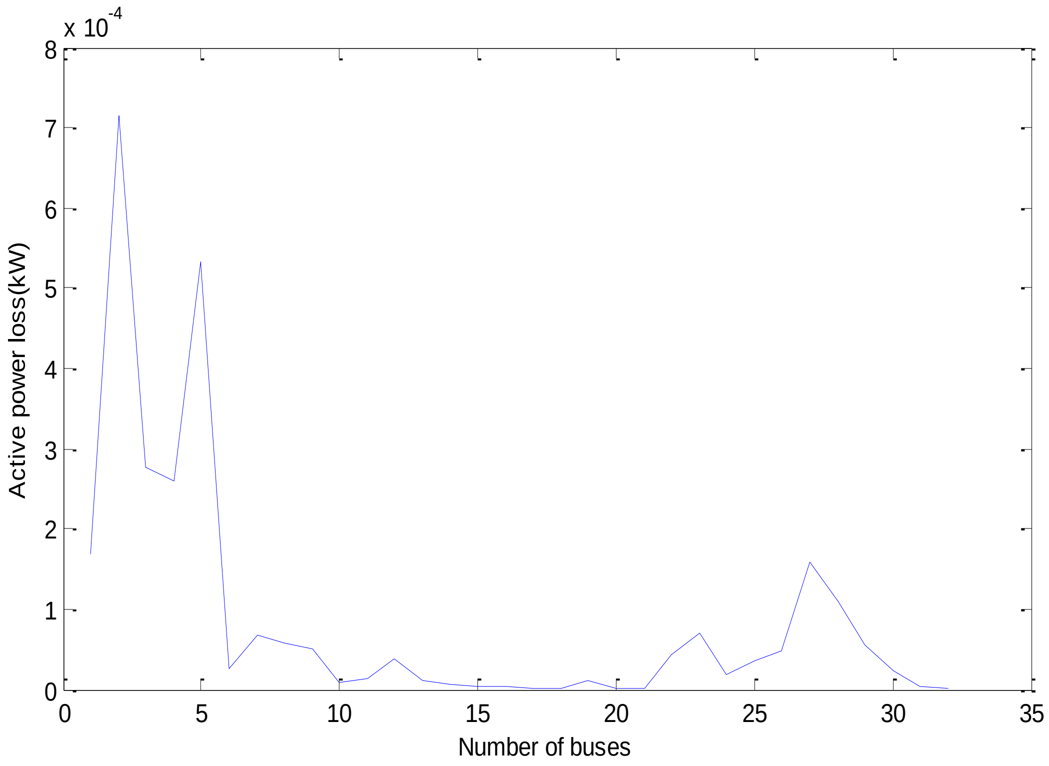
8	8	9	1.0300	0.7400	8	200	100
9	9	10	1.0440	0.7400	9	60	20
10	10	11	0.1966	0.0650	10	60	20
11	11	12	0.3744	0.1238	11	45	30
12	12	13	1.4680	1.1550	12	60	35
13	13	14	0.5416	0.7129	13	60	35
14	14	15	0.5910	0.5260	14	120	80
15	15	16	0.7463	0.5450	15	60	10
16	16	17	1.2890	1.7210	16	60	20
17	17	18	0.7320	0.5740	17	60	20
18	2	19	0.1640	0.1565	18	90	40
19	19	20	1.5042	1.3554	19	90	40
20	20	21	0.4095	0.4784	20	90	40
21	21	22	0.7089	0.9373	21	90	40
22	3	23	0.4512	0.3083	22	90	40
23	23	24	0.8980	0.7091	23	90	50
24	24	25	0.8960	0.7011	24	420	200
25	6	26	0.2030	0.1034	25	420	200
26	26	27	0.2842	0.1447	26	60	25
27	27	28	1.0590	0.9337	27	60	25
28	28	29	0.8042	0.7006	28	60	20
29	29	30	0.5075	0.2585	29	120	70

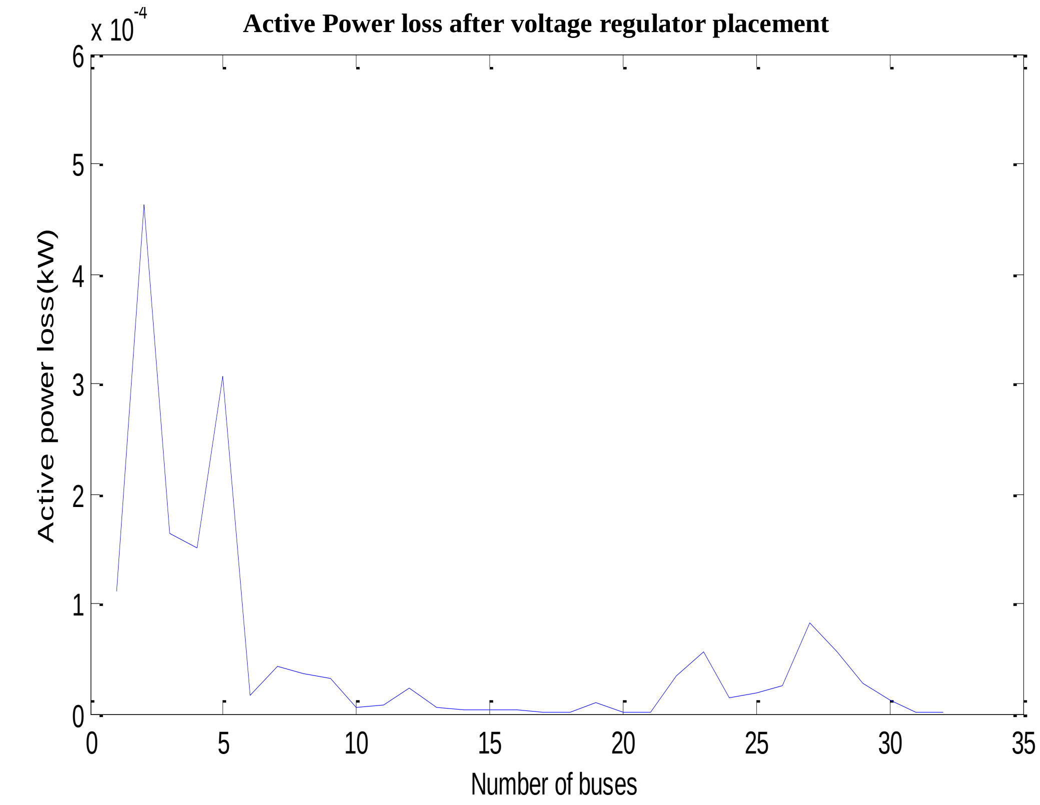
30	30	31	0.9744	0.9630	30	200	600
31	31	32	0.3105	0.3619	31	150	70
32	32	33	0.3410	0.5302	32	210	100
					33	60	40

Table.2: Test results of 33-node system before and after VRs placement

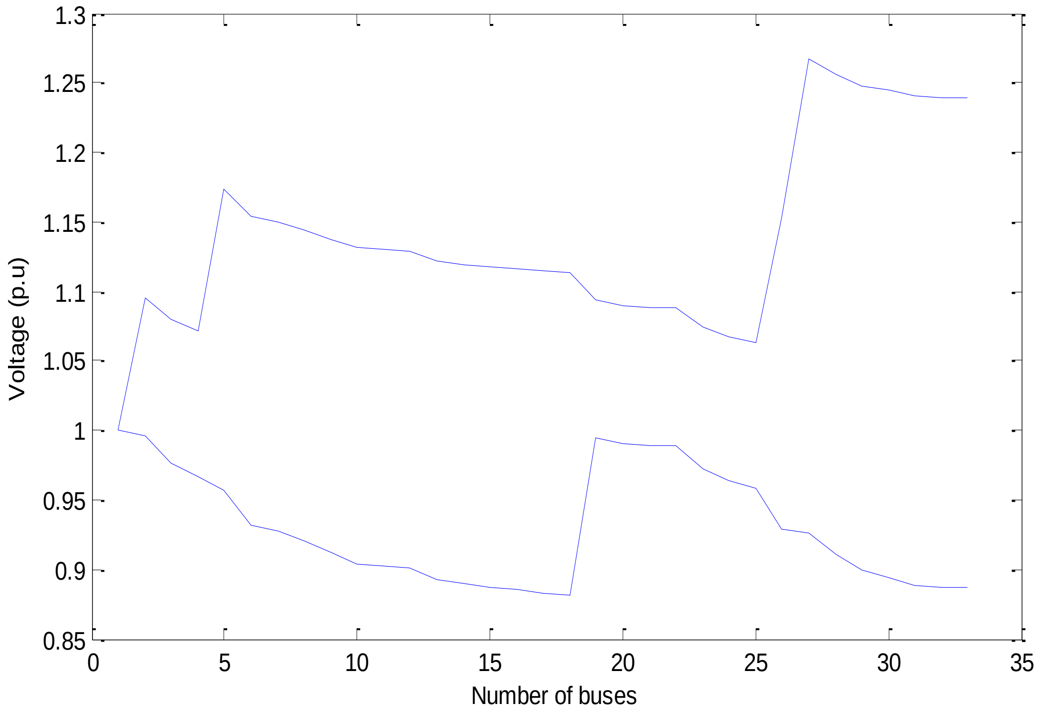
Parameters	Before VRs placement	After VRs placement (VR at buses 2,5,27)	Reduction in %age
Total Active Power PL (kW)	281.5877	171.8373	38.97 %
Minimum Voltage (p.u)	0.8819	1.1133	-

Active Power loss before voltage regulator placement





Voltage comparison before and after voltage regulator placement



V. CONCLUSIONS

The proposed algorithm is tested with IEEE 33 bus URDS. From the results, several important observations can be concluded as follows.

• The power losses of distribution system can be effectively reduced by proper placement of voltage regulator.

• In addition of power loss reduction, the voltage profile can be improved as well by the proposed method.

The obtained solution has succeeded in reducing total active power loss 38.97 % in IEEE 33 bus URDS. From the test results, it is concluded that the proposed model is valid and reliable

REFERENCES

[1] D. Rajicic, R. Ackovski, and R. Taleski, "Voltage correction power flow", IEEE Transactions on Power Delivery, vol. 9, pp. 1056–1062, Apr. 1994.

[2] M. M. A Salama, N. Manojlovic, V. H. Quintana, and A. Y. Chikhani, "Real-Time Optimal Reactive Power Control for Distribution Networks", International Journal of Electrical Power & Energy Systems, vol. 18, no. 3, pp. 185–193, 1996.

[3] M. A. S. Masoum, A. Jafarian, M. Ladjevardi, E. F. Fuchs, and W. N Grady, "Fuzzy approach for optimal Placement and sizing of capacitor banks in the presence of harmonic", IEEE Transactions Power Delivery, vol. 16, no. 2, pp. 822–829, Apr. 2004.

[4] Safigianni and G. Salis, "Optimal voltage regulator placement in radial distribution network," IEEE Trans. on Power Systems, vol. 15, no. 2, pp. 879–886, May 2000.

[5] H.A Attia, "Optimal voltage profile control and losses minimization of radial distribution feeder" Power System Conference, (MEPCON 2008), pp 453-458,March 2008.

[6] CF99800Srikanth Apparaju, Sri Chandan K "impact of Distribution Generation on voltage Levels in Radial Distribution Systems" International Journal of Engineering Research and Applications Vol. 1, Issue 2, pp.277-281, 2010.