OPTIMAL VOLTAGE REGULATOR PLACEMENT IN RADIAL DISTRIBUTION SYSTEMS USING FUZZY LOGIC

S. VIJAYA BHASHKAR REDDY[1] GUNDALA SRINIVASA RAO[2] D. NAGARAJU[3]

ABSTRACT

A computer algorithm for optimal voltage control with voltage regulators, suitable for large radial distribution networks is given in this paper. An objective function concerning the total cost of the voltage regulators (investment and maintenance cost) as well as the cost of losses of the examined networks is developed and constitutes the base of the algorithm. This algorithm makes the initial selection, installation and tap setting of the voltage regulators, which provide a smooth voltage profile along the network, utilizing former algorithms suitably modified and optimized. Then it attempts to minimize the number of the initially selected voltage regulators as much as possible, by moving them in such a way as to control the network voltage at the minimum possible cost (maximization of the objective function). The algorithm is fast, efficient and reliable as its application to practical distribution networks shows.

Index Terms—Radial primary distribution networks, Voltage control, Voltage regulators, Cost minimization.

1. INTRODUCTION

1.1 General description of Distribution System

Distribution system is that part of the electric power system which connects the high voltage transmission network to the low voltage consumer service point. In any distribution system the power is distributed to various uses through feeders, distributors and service mains. Feeders are conductors of large current carrying capacity which carry the current in bulk to the feeding points. Distributors are conductors from which the current is tapped of for the supply to the consumer premises.

1.1.1 Basic Distribution Systems

There are two basic structures for distribution system namely (i) Radial distribution system and (ii) Ring main distribution system

(i) Radial Distribution System:

If the distributor is connected to the supply system on one end only then is system is said to be a radial distribution system. A radial Distribution System is shown in fig 1.2. In such a case the end of the distributor nearest to the generating station would be heavily loaded and the consumers at the distance end of the distributor would be subjected to large voltage variations as the load varies. The consumer is dependent upon a single feeder so that a fault on any feeder or distributor cuts off the supply to the consumers who are on the side of fault away from the station

(ii) Ring Main Distribution System:

Ring main employs a feeder which covers the whole area of supply finally returns to the generating station. The feeder is closed on itself. This arrangement is similar to two feeders in parallel on different buses.

The distribution system in India has low load density in rural areas. Losses in rural distribution system are higher and power factor is also poor as compared to urban distribution system. The length of distribution network is generally 20 to 25 times the transmission network and involves considerable operation and maintenance. Though radial arrangement of distribution system has disadvantages, most of the rural distribution system in India is of this type and in India the length of the rural distribution is more than urban distribution network. So, it is important to study the radial distribution system.

1.2 Distribution System Losses

It has been established that 70% of the total losses occur in the primary and secondary distribution system, while transmission and sub transmission lines account for only 30% of the total losses. Distribution losses are 15.5% of the generation capacity and target level is 7.5%. Therefore the primary and secondary distribution must be properly planned to ensure losses within the acceptability limits.

1.2.1 Factors Effecting Distribution System Losses

Factors contributing to the increase in the line losses in primary and secondary distribution system are:

1. **Inadequate size of conductor**: Rural load is usually scattered and generally fed by radial feeders. The conductor size of the feeders must be adequate. The size of the conductor should be selected on the basis of length, KVA capacity of the stranded conductors.
2. **Feeder Length**: In practice, 11KV and 415V lines in rural areas are extended radially over long distances to feed loads scattered over large areas. This results in high line resistance, low voltage and high current that leads to high $I^2 R$ losses in the line.
3. **Location of Distribution Transformers**: Often the distribution transformers are not located centrally with respect to the customer. Consequently, the farthest customers obtain an extremely low voltage even though a reasonably good voltage level is maintained at the transformer secondary which again leads to higher line losses.
4. **Low Voltage**: Whenever the voltage applied to an induction motor deviates from rated voltage, its performance is adversely affected. A reduced voltage in case of induction motor results in higher currents drawn from the same output leads to higher losses. This can be overcome by installing the tap changing transformers.

5. **Use of over rated Distribution transformers:** Studies on 11KV feeders have revealed that often the rating of distribution transformers is much higher than the maximum KVA demand on the LT feeder. Over rated transformer produces unnecessarily high iron losses.
6. **Poor workmanship in fittings:** Bad workmanship contributes significantly towards increasing distribution losses, as joints are sources of power losses. So, the number of joints should be kept to a minimum and at the same time care must be taken to avoid sparking and heating of contacts.
7. **Low Power Factor:** In most of the LT distribution systems, it is found that the power factor varies from 0.65 to 0.75. For a given load, the low power factor contributes high current which results high distribution losses.

1.3 Reduction of line losses:

The losses in Indian power system are on the higher side. So, the government of India has decided to reduce the line losses and set a target for reduction of T&D losses by 1% per annum in order to realize an overall reduction of 5% in the national average.

Methods for the reduction of line losses:

The following methods are adopted for reduction of distribution losses.

(1) HV distribution system
(2) Feeder reconfiguration
(3) Reinforcement of the feeder
(4) Grading of conductor
(5) Construction of new substation
(6) Reactive power compensation
(7) Installing Voltage regulators.

(1) **HV distribution system:**

The low voltage distribution system contributes about 1/3 of the total losses. The main contributing factors for the losses in this system are the wrong distribution system practice chosen by our country coupled with the non-adherence of prescribed norm for voltage drops. The LT distribution system based on European practice where loads are concentrated in small areas with high load densities and that too with high power factor and load factor is most ill suited to cater the scattered highly inductive load with very low load densities, low power factor and low load factor prevalent in our country. The situation prevailing is that LV lines are extended irrespective of voltage drops up to full capacity of the distribution transformer, some times over and above the transformer capacity. Hence, no purpose will be served by prescribing low KVA-Km loading limits for LV lines when the existing norms are not adhered to at all. The only practice and feasible solution is to eliminate or minimize LV lines by switching over to single phase high voltage distribution. By, adopting HV distribution, the losses in the LV distribution can be reduced by 85%.

Advantages of HV distribution systems:

- It will eliminate losses on lengthy LT lines
- It will have better voltage regulation.
- It will improve the power factor as starting and running capacitors are inherently provided to single phase motors.
- It will improve the supply reliability.
- It virtually eliminates pilferage by direct tapping of energy from LT over head lines.
- Line losses will be reduced by 85% of the LT line losses

(2) **Feeder Reconfiguration**:

Feeder reconfiguration is defined as the process of altering the topological structure of distribution feeders by changing the open/closed status of the sectionalizing and tie switches. Feeder reconfiguration allows the transfer of loads from heavily loaded feeders to less heavily loaded feeders. Such transfers are effective not only in terms of altering the levels of loads on the feeders being switched, but also in improving the voltage profile along the feeders and effecting reduction in the overall system power losses.

(3) **Reinforcement of the feeder conductor:**

Studies on several distribution feeders have indicated that first few main sections of the feeder contribute to 60% to 80% of the feeder total losses. This is mainly due to the fact that the conductor size used at the time of erection of feeders is no more optimal with reference to the increased total load. The total cost is the increased sum of fixed cost of investment of the line and variable cost of energy losses in the conductor due to the power flow.

Addition of a new load on existing feeder is limited by its current carrying capacity. So if the existing feeder gets overloaded, the alternative for catering the extra load is only reinforcement of the feeder. This method is considered to be good for short term planning measures.

Reinforcement of the conductor is considered necessary as the smaller sized conductor's results in high losses due to non standard planning. However at the time of reinforcement much supply interruptions will take place, which leads in loss of revenue.

(4) **Grading of conductors:**

In normal practice, the conductor used for radial distribution feeder is of uniform cross section. However the load magnitude at the substation is high and it reduce as we proceed on to the tail end of the feeder. This indicates that the use of a higher size conductor, which is capable of supplying load from the source point, is not necessary at the tail end point. Similarly use of different conductor cross section for intermediate sections will lead to a minimum both in respect of capital investment cost and line loss point of view.

The use of larger number of conductors of different cross section will result in increased cost of inventory. A judicious choice can however be made in the selection of number and size of cross section for considering the optimal design.

If tie lines exist already it is the most economical method to reduce losses but in practice in rural India tie lines are uncommon. Constructing new tie lines for small excess loads leads to unnecessary increase in capital investment.

(5) **Construction of new substation:**

If a substation is to be constructed and connected to an existing network, several possible solutions are to be studied. These solutions may include various connection schemes of the substation and several feasible solutions, while the principle connection scheme is defined by a limited number of possibilities. The number of possibilities of newly constructed HT line and thus its location determines the cost of their construction and operation. Due to the large number of possible sites, an economical comparison may over look the optimum technical solution. The final decision is easily influenced by additional factors such as topography, land owner ship, environment considerations etc. The optimum size for a substation is defined as that location which will result in minimum cost for construction and minimum losses. These include both the investments for the 11Kv and 33Kv voltage systems and the cost of operating the system.

So, by constructing a new substation at load centers, the line losses will be reduced due to improvement in voltage profile and reduction in length of the lines. But for an excess small quantum of load, the decision for construction of new substation cannot be made as the capital investment is high and the substation will run under load condition for a long time resulting in poor return on the capital. So, in such situations alternate arrangements can be attempted.

(6)**Reactive power compensation:**

It is universally acknowledged that the voltage reactive power control function has pivotal role to play in the distribution automation. The problem of reactive power compensation can be attempted by providing static capacitors.

The present practice to compensate reactive power component is to increase reactive power by increasing the terminal voltage of the generator or by increasing the field current of the synchronous machine in condenser mode at generating stations. This procedure is not effective because the power system losses will be further increased due to increase of reactive power in the transmission system. An alternate method for compensating the reactive power is the use of capacitors in distribution systems at customer points.

There are two methods in capacitor compensation. They are

1. Series compensation. (Capacitors are placed in series with line)
2. Shunt compensation. (Capacitors are placed in parallel with load)

The fundamental function of capacitors whether they are in series or in shunt in a power system is to generate reactive power to improve power factor and voltage, thereby enhancing the system capacity and reducing losses. In series capacitors the reactive power is proportional to the square of the load current where as in shunt capacitors it is proportional to the square of the voltage.

(7) **Installing Voltage Regulators:**

Voltage regulator or Automatic voltage booster 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. Taps of series winding are connected to an automatic tap changing mechanism. AVB is also considered a tool for loss reduction and voltage control is a statutory obligation.

- ❖ AVB 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.
- ❖ KVA rating = rated voltage × %boost of booster × rated current/100
- ❖ It causes sudden voltage rise in discrete steps at its location leading to better voltage profile and reduction in losses.

Benefits of AVB

When a booster is installed at a bus, it causes a sudden voltage rise at its point of location and improves the voltage at the buses beyond the location of AVB. The % of voltage improvement is equal to the setting of % boost of AVB. The increase in voltage in turn causes the reduction in losses in the lines beyond the location of AVB. Multiple units can be installed in series to the feeder to maintain the voltage within the limits and to reduce the line losses. It can be removed and relocated, whenever and wherever required easily.

2. VOLTAGE REGULATORS

The problem of determination of optimal number and location of voltage regulator can be formulated as an optimization problem. This algorithm is to obtain the optimal location for placing Voltage regulators that maintain the voltages within the limits of the RDS so as to maximize an objective function, which consists of capital investment and capitalized energy loss costs.

The objective function is formulated as maximizing the cost function,

Max. $F = K_e \times P_{lr} \times 8760 \times LLf - K_{VR} \times N\ (\alpha+\beta)$ (2)

where

P_{lr} = Reduction in power losses due to installation of VR

= (Power loss before installation of VR - Power loss after installation of VR)

K_e = Cost of energy in Rs./kWh

LLf = Loss load factor = $0.8 \times (Lf)^2 + 0.2 \times Lf$

Lf = load factor

N = Number of voltage regulators

K_{VR} = Cost of each VR

α = the rate of annual depreciation charges for VR

β = Cost of installation of VR. (Generally it is taken as percentage of cost of VR)

The VR problem consists of two sub problems, that of optimal placement and optimal choice of tap setting. The first sub problem determines the location and number of VRs to be placed and the second sub problem decides the tap positions of VR. The first step involves the selection of VRs at the buses where the voltage is violating the upper and lower limits. The optimal number and placement of voltage regulators required is obtained by applying the proposed back tracking algorithm.

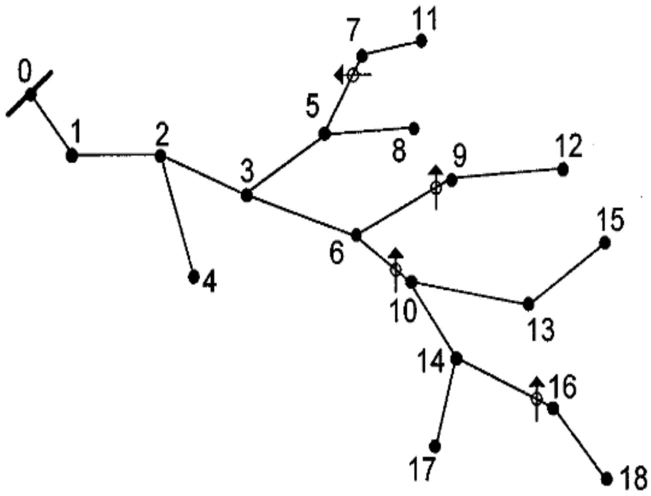

Fig. 2a The 19 bus RDS before installation of Voltage regulators

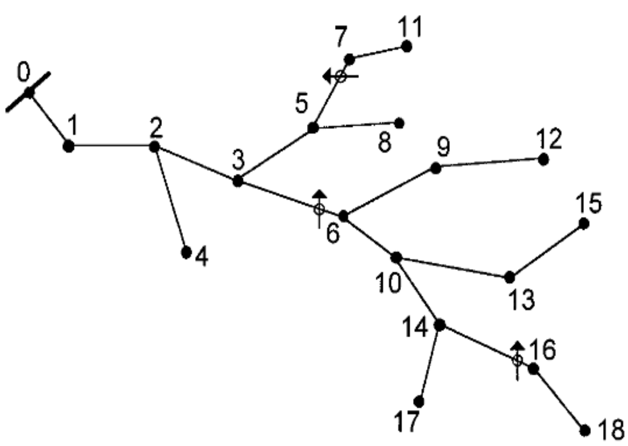

Fig. 2b The 19 bus RDS after installation of Voltage regulators

Let the initial voltage regulators are located at buses 8, 11, 13 and 18 as shown in Fig. 2a.

It is proposed to reduce the number of VRs in a practical system by shifting the VR's to the junction of laterals (such as from buses 11 and 13 to bus 10) and observe the voltage profile and the objective function by computing voltages at each bus. If it satisfies the above two constraints, then this will be taken as optimal position for the single VR at bus 10 instead of two VRs at buses 11 and 13 (shown in Fig 3b). This procedure is repeated starting from the tail end buses towards the source bus and find the optimal number and location of VRs.

2.1 Selection of tap positions of VR's

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

In general, VR position at bus 'j ' can be calculated as

$$V_j^1 = V_j \pm tap \times V_{rated} \quad (3)$$

where

tap = tap position of VR

V_j^1 = the voltage at bus 'j' after VR installation at this bus in p.u

V_j = the voltage at bus 'j' before a VR installation at this bus in p.u.

V_{rated} = Rated voltage in p.u.

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 Bus voltages are computed by load flow analysis [7] for every change in tap setting of VR's, till all bus voltages are within the specified limits. Then obtain the net savings, with above tap settings for VR's. The algorithm for finding optimal place for location of voltage regulators using back tracking algorithm is given below.

2.2 Algorithm for optimum voltage regulator placement in RDS using proposed back tracking algorithm:

Step 1. Read line and load data.

Step 2. Run load flows for the system and compute the voltages at each bus, real and reactive power losses of the system.

Step 3. Identify the buses, which have violation of voltage limits.

Step4. Obtain optimal number of VRs and location of VRs by using back tracking algorithm.

Step 5. Obtain the optimal tap position of VR using Eqn. (3), so that the voltage is within the specified limits.

Step 6. Again run the load flows with VR, then compute voltages at all buses, real and reactive power losses. If voltages are not within the limits, go to step 3.

Step 7. Determine the reduction in power loss and net saving by using objective function (Eqn (2)).

Step 8. Print results.

Step 9. Stop.

3. FUZZY IMPLEMENTATION

The entire frame work to solve the optimal voltage regulator placement problem includes the use of numerical procedures which are coupled to the fuzzy. First a vector based load flow calculates the power losses in each line and voltages at every bus. The voltage regulators are placed at every bus and total real power losses is obtained for each case. The per unit voltages at every bus and the power losses obtained are the inputs to the FES which determines the bus most suitable for placing voltage regulator without violating the limits. The FES(Fuzzy Expert System) contains a set of rules which are developed from qualitative descriptions. In a FES, rules may be fired with some degree using fuzzy interfacing for determining the suitability of voltage regulator placement at a particular bus, a set of multiple antecedent fuzzy rules have been established.

Table 3.1 Rules for Fuzzy Expert System

AND	VOLTAGE				
	Low	**Low-**	**Norma**	**High-**	**High**

			normal	**l**	**normal**	
POWER LOSS INDEX	**Low**	Low-medium	Low-medium	Low	Low	Low
	Low-medium	Medium	Low-Medium	Low-Medium	Low	Low
	Medium	High-Medium	Medium	Low-Medium	Low	Low
	High-medium	High-medium	High-medium	Medium	Low-medium	Low
	High	High	High-medium	Medium	Low-medium	Low-medium

inputs to the rules are the voltages and power loss indices and the output consequent is the suitability of The voltage regulator placement. The rules are summarized in the fuzzy decision matrix in table given above. Fuzzy variables of PLI (power loss index) are low, low-medium, medium, high-medium, high.

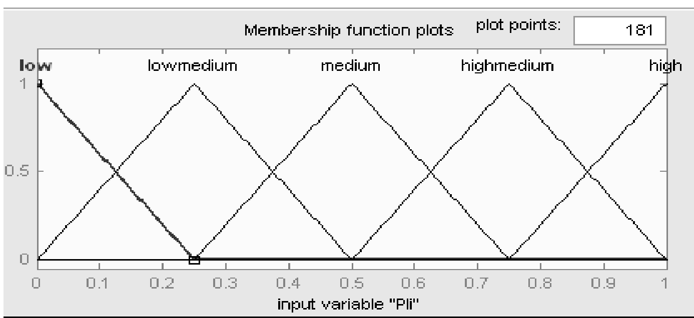

Fig 3.1 Member ship functions for power loss index

Fuzzy variables for Voltage are low, low-normal, normal, high-normal, high.

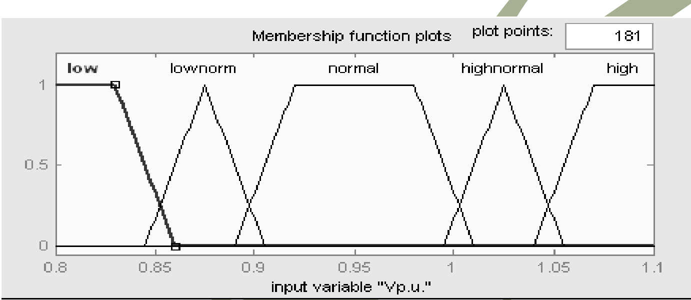

Fig 3.2 Membership Functions for voltage

Fuzzy variables for Voltage regulator suitability index are low, low-medium, medium, high-medium, high.

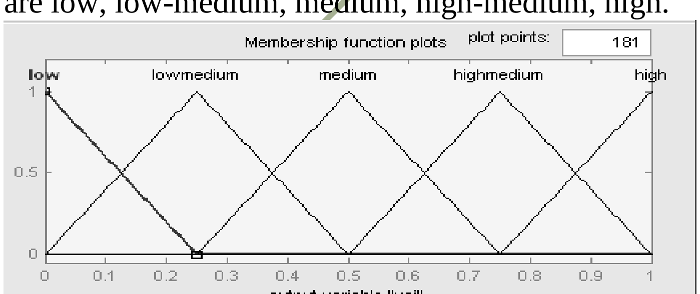

Fig 3.3 Membership functions for Voltage regulator suitability index

These fuzzy variables described by linguistic terms are represented by membership functions.

3.1 Fuzzy inference and defuzzification techniques:

After the FES receives inputs from the load flow program, several rules may fire with some degree of membership the fuzzy inferencing methods used by fuzzy clips are based on the max-min or max-prod methods.

The MAX-MIN METHOD involves truncating the consequent membership function of each fired rule at the minimum membership value of all the antecedents. A final aggregated membership function is achieved by taking the union of all the truncated consequent membership functions of the fired rules. For the voltage regulator problem, resulting voltage regulator placement suitability membership function μ_s of bus i for k fired rules is

$$\mu_s(i) = \min_k[\min[\mu_p(i),\mu_v(i)]]$$

where μ_p and μ_v are the membership functions of the power loss index and voltage level respectively.

Once the suitability membership function of a node is calculated, It must be defuzzified in order to determine the buses suitability ranking. The centroid method of defuzzification is used, this finds the center of area of the membership function. Thus, the voltage regulator suitability index is determined by:

$$S = \int\mu_s(z).zdz/(\int\mu_s(z)dz)$$

3.2 Algorithm for optimum voltage regulator placement in RDS using FES:

Step 1. Read line and load data.
Step 2. Run load flows for the system and compute the voltages at each bus, real and reactive power losses of the system.
Step 3. Install the voltage regulator at every bus and compute the total real power loss of the system at each case and convert into normalized values.
Step4. Obtain optimal number of VRs and location of VRs by giving voltages nd power loss indices as inputs to FES.
Step 5. Obtain the optimal tap position of VR using Eqn. (3), so that the voltage is within the specified limits.
Step 6. Again run the load flows with VR, then compute voltages at all buses, real and reactive power losses. If voltages are not within the limits, go to step 3.
Step 7. Determine the reduction in power loss and net saving by using objective function (Eqn (2)).
Step 8. Print results.
Step 9. Stop.

4. RESULTS AND ANALYSIS

4.1 Results of back tracking algorithm:

The proposed method is illustrated with two radial distribution systems of 47 buses and 69 buses.

4.1.1 Example

Consider 47 bus Radial Distribution System. The Line and Load data is given in Appendix and the single line diagram is shown in Fig.3. For the positioning of voltage regulators, the upper and lower bounds of voltage are taken as ±5% of base value. The voltage regulators are of 11kV, 200MVA with 32 steps of 0.00625 p.u. each

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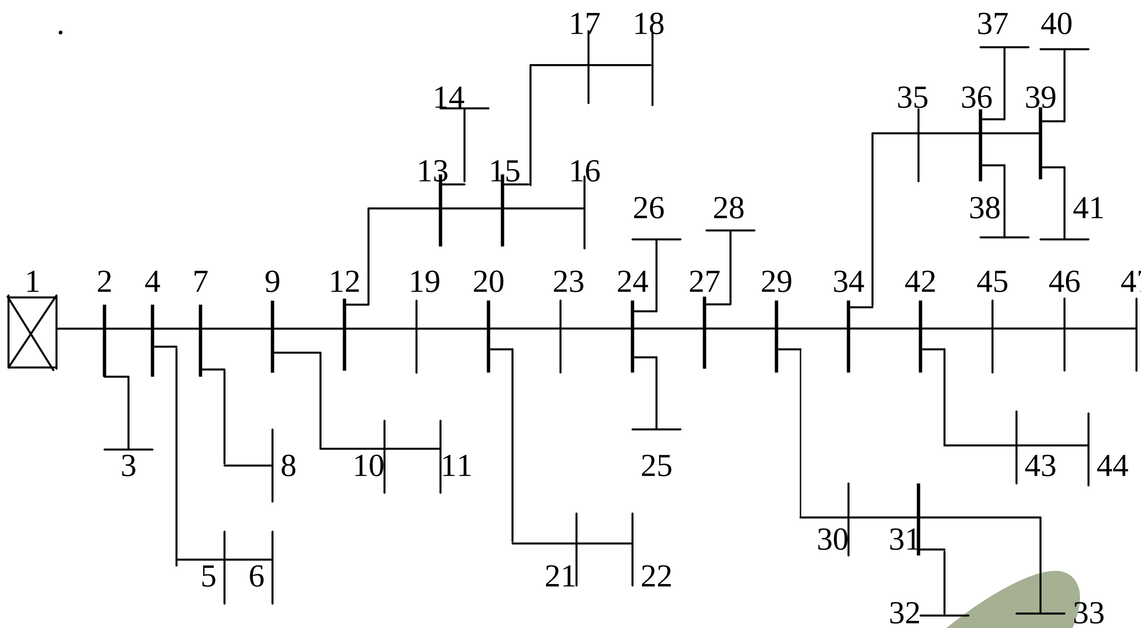

Fig. 4.1 Single line diagram of 47 bus RDS

Load flow solution for 47 bus practical RDS without and with voltage regulators is given in Table 6.1. Observing the voltage levels in first column of Table 6.1, it is found that all bus voltages except bus 1 violate the lower limit of 0.95 p.u. Ideally, voltage regulators are to be installed at all buses except at bus 1. However, in practice, it is not economical to have more number of voltage regulators at all buses to get the voltages within specified limits and hence by applying proposed back tracking algorithm the required optimal number of voltage regulators that will maintain the voltage profile within above limits is determined. By applying the above algorithm for the above systems it is found that voltage regulators at buses 2, 36 and 42 are sufficient to maintain the voltage profile at all buses.

Table 4.1Load Flow Results Without and With Voltage Regulators

Bus No.	Bus Voltages before VR placement	Bus Voltages with Voltage regulators at 2, 36, 42 buses
1	1.0000	1.0000
2	0.9378	1.0378
3	0.9376	1.0377
4	0.9132	1.0160
5	0.9128	1.0156
6	0.9126	1.0155
7	0.9090	1.0122
8	0.9087	1.0120
9	0.9004	1.0046
10	0.9001	1.0043
11	0.8997	1.0040
12	0.8911	0.9963
13	0.8863	0.9921
14	0.8861	0.9919
15	0.8852	0.9911
16	0.8848	0.9908
17	0.8846	0.9905
18	0.8842	0.9902
19	0.8839	0.9900
20	0.8760	0.9830
21	0.8754	0.9825
22	0.8751	0.9822
23	0.8555	0.9645
24	0.8536	0.9632
25	0.8533	0.9630
26	0.8531	0.9628
27	0.8508	0.9607
28	0.8507	0.9607
29	0.8480	0.9583
30	0.8469	0.9573
31	0.8455	0.9561
32	0.8452	0.9558
33	0.8452	0.9559
34	0.8438	0.9546
35	0.8420	0.9530
36	0.8375	1.0490
37	0.8373	1.0488
38	0.8372	1.0487
39	0.8362	1.0480
40	0.8359	1.0477
41	0.8357	1.0476
42	0.8381	1.0495
43	0.8373	1.0489
44	0.8370	1.0486
45	0.8344	1.0466
46	0.8333	1.0457
47	0.8330	1.0454

The reduction in real power loss, net saving and %voltage regulation for the system is shown in Table 4.2.

Table 4.2 Summary of Results of 47 bus RDS

Parameter	Before	With VRs	
		VRs at all buses (except at bus 1)	**After (VR at buses 2, 36, 42)**
P_{loss} (%)	16.6835	13.1796	13.0954
Net saving(in Rs.)	-----	(-) 1,14,850	2,79,380
Voltage regulation (%)	16.7039	6.7039	4.6964

It is observed that from Table 6.2, without voltage regulators in the system the percentage power loss is 16.6835 and percentage voltage regulation is 16.7039. With voltage regulators at all buses (except at bus1), the percentage power loss is 13.1796 and percentage voltage regulation is 6.7039 but the net saving is (-) Rs.1, 14,850 (cost of voltage regulators itself is more than cost of total energy losses), with voltage regulators at optimal locations (obtained with proposed method) of buses 2,36,and 42 the percentage power loss is reduced to 13.0954 and percentage voltage regulation is reduced to 4.6964. The optimal net saving is increased to Rs.2, 79,380.

4.2 Results of FES:

The proposed method is illustrated with two radial distribution systems of 47 bus.

4.2.1 Results of 47 bus RDS:

By applying the above FES algorithm for the 47 bus system, it is found that two voltage regulators at bus 2 are sufficient to maintain the voltage profile at all buses. One voltage regulator with 10% tapping and another voltage regulator with 0.625% tapping. The bus voltages without and with voltage regulators is shown in the Table 4.4.

Table 4.3 Load Flow Results Without and With Voltage Regulators

Bus No.	Bus Voltages before VR placement	Bus Voltages with **two** Voltage regulators at bus 2
1	1.0000	1.0000
2	0.9378	1.0440
3	0.9376	1.0439
4	0.9132	1.0224
5	0.9128	1.0220
6	0.9126	1.0218
7	0.9090	1.0184
8	0.9087	1.0187
9	0.9004	1.0110
10	0.9001	1.0108
11	0.8997	1.0105
12	0.8911	1.0028
13	0.8863	0.9986
14	0.8861	0.9984
15	0.8852	0.9977
16	0.8848	0.9973
17	0.8846	0.9971
18	0.8842	0.9967
19	0.8839	0.9965
20	0.8760	0.9896
21	0.8754	0.9891
22	0.8751	0.9888
23	0.8555	0.9716
24	0.8536	0.9699
25	0.8533	0.9697
26	0.8531	0.9696
27	0.8508	0.9675
28	0.8507	0.9674
29	0.8480	0.9651
30	0.8469	0.9641
31	0.8455	0.9629
32	0.8452	0.9626
33	0.8452	0.9625
34	0.8438	0.9614
35	0.8420	0.9598
36	0.8375	0.9558
37	0.8373	0.9557
38	0.8372	0.9556
39	0.8362	0.9547
40	0.8359	0.9545
41	0.8357	0.9543
42	0.8381	0.9564
43	0.8373	0.9557
44	0.8370	0.9554
45	0.8344	0.9532
46	0.8333	0.9522
47	0.8330	0.9519

Table 4.4 Summary of results:

Parameter	**Before**	**With VRs**	
		VRs at all buses (except at bus 1)	**After (two VRs at bus 2)**
P_{loss} (%)	16.6835	13.1796	12.9647
Net saving	-----	-Rs.1,14,850	Rs.3,26,169
Voltage regulation (%)	16.7039	6.7039	4.8106

It is observed that from Table6.5 , without voltage regulators in the system the percentage power loss is 16.6835 and percentage voltage regulation is 16.7039. With voltage regulators at all buses (except at bus1), the percentage power loss is 13.1796 and percentage voltage regulation is 6.7039 but the net saving is (-) Rs.1, 14,850 (cost of voltage regulators itself is more than cost of total energy losses), with two voltage regulators at optimal location (obtained with proposed method) of bus 2 the percentage power loss is reduced to 12.9647 and percentage voltage regulation is reduced to 4.8106. The optimal net saving is increased to Rs.3, 26,169.

4.3 Comparison of results:

Consider a practical **47 bus** RDS, **without voltage regulators** the total real power loss percentage is **16.6835** and percentage voltage regulation is **16.7039**, by applying **back tracking algorithm** the optimal number and location of voltage regulators is **three** voltage regulators at **2**, **36** and **42** buses. With voltage regulators at these buses the total real power loss percentage is reduced to **13.0954** and percentage voltage regulation is improved to **4.6964** and the net saving is Rs. **2**, **79,380.** By applying the proposed **FES** (Fuzzy Expert System) the optimal number and location of Voltage regulators is **two** regulators at bus **2** only. With Voltage regulators at bus 2 the total real power loss percentage is still reduced to **12.9647** and percentage voltage regulation is **4.8106** and the net saving has still increased to Rs. **3**, **26**,**169**. The results of 69 bus RDS, without and with voltage regulators using back tracking algorithm and FES are compared in Table 4.5.

Table 4.5: Summary of result for 47 bus system with and without fuzzy

Parameter	**Before**	**With voltage regulators**	
		Using back tracking algorithm with voltage regulators at buses 2,36,42	**Using Fuzzy Expert System Two voltage regulators at bus 2 only**
P_{loss} (%)	16.6835	13.0954	12.9647
Net saving (in Rs.)	--------	2,79,380	3,26,169
Voltage regulation (%)	16.7039	4.6964	4.8106

5. CONCLUSIONS

In radial distribution systems it is necessary to maintain voltage levels at various buses by using capacitors or conductor grading or placing VR at suitable locations. The proposed Back tracking algorithm determines the optimal number, location and tap positions of voltage regulators to maintain voltage profile within the desired limits and reduces the losses in the system which in turn maximizes the net savings in the operation of the system. In addition to the back tracking algorithm a method using Fuzzy is also proposed and the results of FES are compared with the results of back tracking algorithm. It is concluded that the FES also gives the optimal location and number along with the tap setting of the voltage regulators. The proposed FES provides good voltage regulation, and reduces the power loss which in turn increases the net savings when compared to the back tracking algorithm. The algorithms are tested with Radial distribution system consisting of 47 buses and the results are provided.

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***S. VIJAYABASKHAR REDDY*[1]** *is a PG student in the Department of Electrical & Electronics Engineering, Sri Venkateswara Engineering College, Suryapet, Andhra Pradesh, India.*

GUNDALA SRINIVASA RAO*[2]** *is presently working as Assistant Professor in the department of Electrical & Electronics Engineering at Sri Venkateswara Engineering College, Suryapet. He obtained master of technology in Power Electronics from Jawaharlal Nehru Technological University, Hyderabad, Andhra Pradesh, India.* ***mail:gundala247@gmail.com

***D.NAGARAJU*[3]** *was born in 1979. He received B.E degree from Osmania University, Hyderabad, India in the year 2000 and M.Tech from J.N.T.University, Hyderabad in the year 2009. He is presently Sr.Assistant Professor in the Electrical and Electronics Engineering Department, Sri Venkateswara Engineering College, Suryapet,A.P., India.*