Imperial Journal of Interdisciplinary Research (IJIR)
Vol-3, Issue-3, 2017
ISSN: 2454-1362, http://www.onlinejournal.in

Placement Of Voltage Regulator By Using BT technique and FES In The Radial Distribution System

Y.Nagendra Babu (M.Tech)[1] & K. Vaisakh[2]
[1,2]Dept. of Electrical Engineering.
Andhra University College of Engg.(A)
Visakhapatnam, India

Abstract— *Voltage stability issues on radial distribution systems is an area of concern. Radial distribution system having high R/X ratio, is highly complicated to analyze. By Placing of voltage regulator in the system the voltage at each bus should be maintain within limits and also reduce power loss in the lines using Fuzzy Expert System technique. This decreases the complexity in load flow analysis. 69-Bus system is taken as a test system and load flow analysis is done before and after placement of Voltage Regulator is done.*

Keywords—*fuzzy, membership functionback, tracting algorithm,defuzzication,RDS, voltage reguiators.*

I. INTRODUCTION

Radial distribution system having high R/X ratio, is highly complicated to analyze with regular methods like the Newton Raphson(NR) and the Decouple methods. In radial distribution systems having high R/X ratio, the slope of parameters, i.e., voltage and load angle with real and reactive powers will be high. Newton Rapshson method is better incooperated for low slope systems, where the input and output relation is tightly coupled. But in radial distribution load system due to high R/X ratio where input and output relation is loosely coupled., NR may be used but it converges for large number of iterations.fig.1 provides clear picture of NR method used in power system DLF.

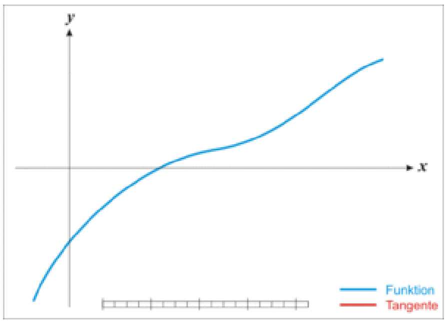


Fig.1 NR method used in power system DLF

II. INTRODUCTION TO RADIAL DISTRIBUTION SYSTEM

The numbers of PV buses are more in the transmission system as compared to distribution load flow system. In the radial distribution system the number of PV buses is usually one.

Figure 2 shows, the general RDS comprising power source, one PV bus at the substation and all other buses are PQ buses. The power is transferred from the power source to the load buses.

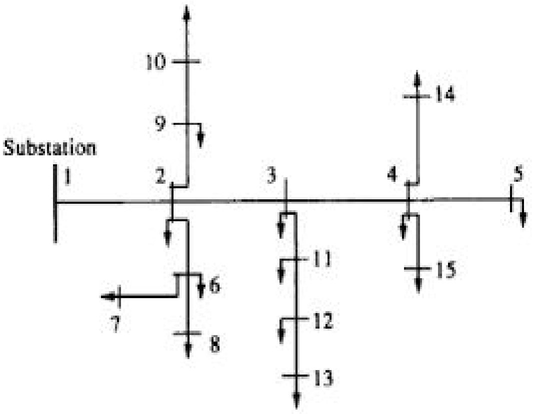


Fig.2 general Radial Distribution System

Here the Load flow is the steady state analysis of the given radial distribution system. This is a computational technique, used in planing and opearation of the power system. Load flow analysis is used to maintain the power system characterstic parameters within the limits so as to avoid the power system instabilities.

Mathematical modelling :

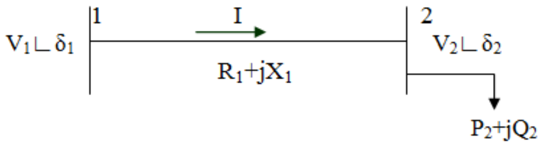


Fig. 3 Mathematical modeling of simple source-end and load-end bus

In fig.3, 1 and 2 are source and load end buses respectively. V1, V2 are voltages and δ1, δ_2 are load angles. Voltages, load angles, real and reactive powers are the characteristic parameters of the power system. The voltage and load angle of the power system are in relation with the real and reactive powers of the system based on which the load flow analysis is run,.

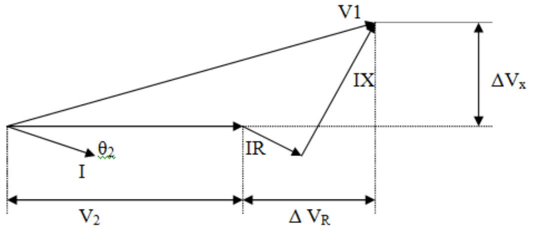


Fig.4Phasor representation of fig.3

From the phasor diagram,

$$|V_1|^2=(|V_2|+\Delta V_R)^2+(\Delta V_X)^2 \text{ ………… (1)}$$

$$|V_1|^2=(|V_2|+(I R_1\cos\theta_2+I X_1\sin\theta_2))^2+(I X_1\cos\theta_2-I R_1\sin\theta_2)^2 \text{ …………….. (2)}$$

To eliminate 'I' in equation (2)

$$I\cos\theta_2=P_2/|V_2|$$

$$I\sin\theta_2=Q_2/|V_2|$$

where ,
P_2 = Total active power load including local load and active power losses beyond bus 2.

Q_2 = Total reactive power load including local load and reactive power losses beyond bus 2.
The equation (2) becomes

$$|V_1|^2=[|V_2|+(P_2R_1+Q_2X_1)/|V_2|]^2+[(P_2X_1-Q_2R_1)/|V_2|]^2$$

$$|V_1|^2=|V_2|^2+2|V_2|*(P_2R_1+Q_2X_1)/|V_2|+(P_2R_1+Q_2X_1)^2/|V_2|^2+(P_2X_1-Q_2R_1)^2/|V_2|^2$$

$$|V_1|^2|V_2|^2=|V_2|^4+(P_2R_1+Q_2X_1)^2+2|V_2|^2(P_2R_1+Q_2X_1)+(P_2X_1-Q_2R_1)^2$$

$$|V_2|^4+2|V_2|^2(P_2R_1+Q_2X_1)+(P_2^2+Q_2^2)(R_1^2+X_1^2)-|V_1|^2|V_2|^2=0$$

$$|V_2|^4+2|V_2|^2(P_2R_1+Q_2X_1-|V_1|^2/2)+(P_2^2+Q_2^2)(R_1^2+X_1^2)=0 \text{ ……………. (3)}$$

From equation (3), straight forward solution is obtained which does not depend on the phase angle. In the distribution system voltage angle is not much required as the voltage angle (load angle) 'δ', has less variation with the source voltage angle 'δ_1', this varaition is neglegible. From equation 3,the 4th power equation we take positive root, which is a realistic value since negative root doesnot exist as the receiving end voltage can be less or equal or greater than the source end voltage based on the loading condition.
If ever the root is negative, the voltage magnitude becomes complex which is never possible.
From the equation(3) , the real and positive root is,

$$|V_2|=\{|V_1|^2-(R_1^2+X_1^2)(P_2^2+Q_2^2)/|V_2|^2-2(P_2R_1+Q_2X_1)\}^{1/2} \text{ ……….. (4)}$$

For general case,

Voltage at (i+1) bus is

$$|V_{i+1}|=\{|V_i|^2-(R_i^2+X_i^2)(P_{i+1}^2+Q_{i+1}^2)/|V_{i+1}|^2-2(P_{i+1}Ri+Q_{i+1}X_i)\}^{1/2} \text{ …….. (5)}$$

The real and reactive power loss of branch 'j' are given by

$$P_{loss}[j]=R_j*(P^2_{i+1}+Q^2_{i+1})/|V_{i+1}|^2 \text{ .... (6)}$$

$$Q_{loss}[j]=X_j*(P^2_{i+1}+Q^2_{i+1})/|V_{i+1}|^2 \text{ ....(7)}$$

Where,
$P_{loss}[j]$= Active power loss at 'jth' bus,

$Q_{loss}[j]$ =Reactive power loss at 'jth' bus,

Total power loss

$$TPL=\sum_{j=1}^{nbus-1} P_{loss}[j] \text{ ……….. (8)}$$

$$TPL=\sum_{j=1}^{nbus-1} Q_{loss}[j] \text{ ……….. (9)}$$

Node Identification

Node identification is done by sparsity technique in radial distribution systems. In the load flow analysis,the number of nodes beyond a particular node is to be found for finding effective loads of the distribution network form the MF , MT, adjoint branch and ad joint node tables.

By forming the MF,MT adjoint node and ad joint branch table the load flow analysis is ready to be processed.

Load Flow Calculation

Once the node identification is done the magnitude of the voltages are calculated from the mentioned equations, by the proposed algorithm

Algorithm for Load flow calculation

Step 1 : Read line and load data of radial distribution system. Initialize TPL,TQL to zero. Assume bus voltages 1 p.u., set convergence criterion $\Delta P_{loss} \leq \varepsilon$
Step 2 : Start iteration iter =1.
Step 3 : Read MF, MT, adn and adb vectors.
Step 4 : Calculate effective load at each bus starting from the last bus.
Step 5 : Initialize real power loss and reactive power loss vectors to zero.
Step 6 : Find effective losses at each bus.
Step 7 : Calculate load at each bus including losses.
Step 8 : Calculate bus voltages, real and reactive power loss of each branch using equations respectively.
Step 9 : Calculate the value of reduction in power loss i.e., .$\Delta P_{loss} \leq \varepsilon$ in Successive iterations. If $\Delta P_{loss} \leq \varepsilon$ go to step 11 otherwise go to step 10.
Step10: Increment iteration number and go to step 6.
Step 11: Calculate TPL and TQL using equations
Step 12: Print voltages at each bus, TPL, TQL and number of iterations.
Step 13: Stop.

Voltage Regulators

Voltage regulators are the devices which maintain the voltages at the buses within the permissible limits. Optimal number of voltage regulators and their optimal placement is done by fuzzy logic technique. In order to maintain the voltages within the permissible limits in the RDS we will maximize the objective function, which consists of capital investment and capitalized energy loss costs.

The objective function is formulated as maximizing the cost function,

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

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)

Selection Of Tap Positions Of VR's

Once the optimal number and optimal location of Voltage Regulators (VR's) are found, we then determine the tap positions of VR as follows.

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

$$V_j^1 = V_j \pm \text{tap} \times V_{rated}$$

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 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.

Back Tracking Method

After the load flow analysis is performed, if any bus still exceeds the voltage limit , we then find the optimal position of VR's and run the load flow analysis with VR's. The power loss and voltages at the buses are reduced and maintained within the limits. The net savings and the energy savings in the system are determined.

Fuzzy Logic

Several Conventional methods are used in power system planning and operation . but for large-scale power systems AI techniques are adopted as these kind of systems have non trivial solutions. Fuzzy logic is considered to be better over the AI techniques for the formulation of power system network .

The fuzzy logic system comprises of four stages i.e,

1. Fuzzification
2. Defuzzification
3. Knowledge/ fuzzy rule base
4. Process/interface

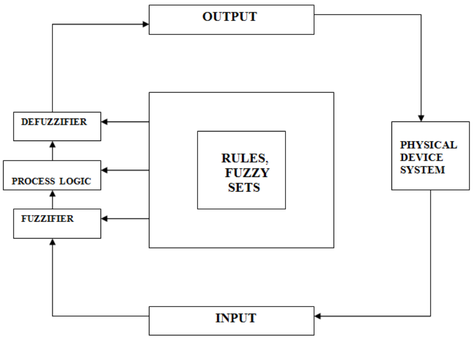


Fig. general procedure in the fuzzy logic system

The process of fuzzification involves in conversion of the given data into the fuzzy system. All RDS variables are converted to fuzzy variables , which are the values that are expressed in English language. The function is a curve that defines how the values of a fuzzy variable in a certain 2region are mapped to a membership value μ between 0 and 1. The numerical interval that is relevant for the description of a fuzzy variable is defined as the universe of discourse.

A membership function can have different shapes. The simplest and most commonly used MF is the triangular-type, which can be symmetrical or asymmetrical in shape.

Membership functions maps the crisp value into fuzzy variable.
The fuzzy set 'A' in 'U' is defined as

$$A = \{(x, \mu_A(x))/x \in U\}$$

Where,

$\mu_A(x)$ is a membership function.

Rule base:

Table: rules for expert fuzzy system

AND		VOLTAGE				
		Low	**Low-normal**	**Normal**	**High-normal**	**High**
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

The fuzzy rule base is designed from the fuzzy variable system based on the limits of the fuzzy variables using if-then rules.The fuzzy rule base system is given in table 1.

Defuzzification:

Defuzzification is the process which converts these fuzzified values back to the crisp values

the fuzzy variable system can be defuzzified by using centre of mass method, or the centroid method.

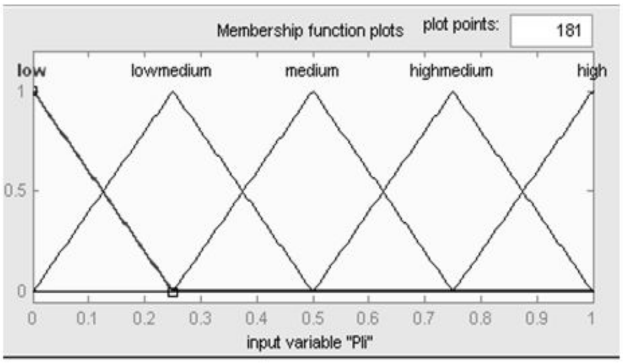


Fig. member ship function for power loss index

Results:

Load Flow Results Without and With Voltage Regulators:

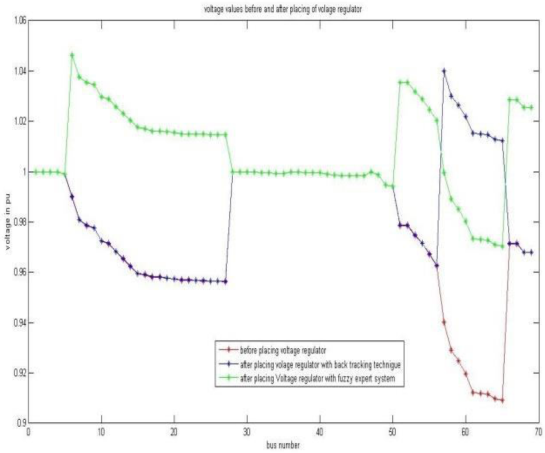
Net Results, variation of parameters for 69 bus system:

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} (%)	5.9323	5.3371	5.2372
Net saving (in Rs.)	--------	1,12,980	1,37,488
Voltage regulation (%)	9.0811	4.3502	2.9494

The voltage variations of 69 bus system without voltage regulator with voltage regulator by using BT technique and FES fuzzy expert system as follows:

Bus number	Voltages before placing VR	Voltages with BT technique	Voltages after placing VR With FES
1	1.0000	1.0000	1.0000
2	1.0000	1.0000	1.0000
3	0.9999	0.9999	0.9999
4	0.9998	0.9998	0.9998
5	0.9990	0.9990	0.9990
6	0.9901	0.9902	1.0463
7	0.9808	0.9809	1.0376
8	0.9786	0.9787	1.0355
9	0.9774	0.9776	1.0345
10	0.9724	0.9726	1.0297
11	0.9713	0.9715	1.0287
12	0.9682	0.9683	1.0257
13	0.9653	0.9654	1.0230
14	0.9624	0.9625	1.0202
15	0.9595	0.9597	1.0175
16	0.9590	0.9591	1.0170
17	0.9581	0.9582	1.0162
18	0.9581	0.9582	1.0162
19	0.9576	0.9578	1.0158
20	0.9573	0.9575	1.0155
21	0.9568	0.9570	1.0150
22	0.9568	0.9570	1.0150
23	0.9568	0.9569	1.0150
24	0.9566	0.9568	1.0148
25	0.9564	0.9566	1.0146
26	0.9564	0.9565	1.0146
27	0.9563	0.9565	1.0146
28	0.9999	0.9999	0.9999
29	0.9999	0.9999	0.9999
30	0.9998	0.9998	0.9998
31	0.9997	0.9997	0.9997
32	0.9997	0.9997	0.9997
33	0.9995	0.9995	0.9995
34	0.9992	0.9992	0.9992
35	0.9992	0.9992	0.9992
36	0.9999	0.9999	0.9999
37	0.9997	0.9997	0.9997
38	0.9996	0.9996	0.9996
39	0.9995	0.9995	0.9995
40	0.9995	0.9995	0.9995
41	0.9988	0.9988	0.9988
42	0.9986	0.9986	0.9986
43	0.9985	0.9985	0.9985
44	0.9985	0.9985	0.9985
45	0.9984	0.9984	0.9984
46	0.9984	0.9984	0.9984
47	0.9998	0.9998	0.9998
48	0.9985	0.9985	0.9985
49	0.9947	0.9947	0.9947
50	0.9942	0.9942	0.9942
51	0.9785	0.9787	1.0355

52	0.9785	0.9787	1.0355
53	0.9747	0.9748	1.0318
54	0.9714	0.9716	1.0288
55	0.9669	0.9672	1.0246
56	0.9626	0.9629	1.0205
57	0.9401	1.0401	0.9995
58	0.9290	1.0302	0.9891
59	0.9248	1.0263	0.9851
60	0.9197	1.0218	0.9804
61	0.9123	1.0152	0.9735
62	0.9121	1.0149	0.9732
63	0.9117	1.0145	0.9728
64	0.9098	1.0128	0.9710
65	0.9092	1.0123	0.9705
66	0.9713	0.9714	1.0287
67	0.9713	0.9714	1.0287
68	0.9679	0.9680	1.0254
69	0.9679	0.9680	1.0254



Apendix:

Data for 69 RDS:

Branch no	From bus	To bus	Resistance (Ω)	Reactance (Ω)
1	1	2	0.0005	0.0012
2	2	3	0.0005	0.0012
3	3	4	0.0015	0.0036
4	4	5	0.0251	0.0294
5	5	6	0.3660	0.1864
6	6	7	0.3811	0.1941
7	7	8	0.0922	0.0470
8	8	9	0.0493	0.0251
9	9	10	0.8190	0.2707
10	10	11	0.1872	0.0619
11	11	12	0.7114	0.2351
12	12	13	1.0300	0.3400
13	13	14	1.0440	0.3450
14	14	15	1.0580	0.3496
15	15	16	0.1966	0.0650
16	16	17	0.3744	0.1238

Bus no.	P(kW)	Q(kVAr)
1	0	0
2	0	0
3	0	0
4	0	0
5	0	0
6	0.0026	0.0022
7	0.0404	0.0300
8	0.0750	0.0540
9	0.0300	0.0220
10	0.0280	0.0190
11	0.1450	0.1040
12	0.1450	0.1040
13	0.0080	0.0050
14	0.0080	0.0055
15	0	0
16	0.0455	0.0300

17	17	18	0.0047	0.0016
18	18	19	0.3276	0.1083
19	19	20	0.2106	0.0690
20	20	21	0.3416	0.1129
21	21	22	0.0140	0.0046
22	22	23	0.1591	0.0526
23	23	24	0.3463	0.1145
24	24	25	0.7488	0.2475
25	25	26	0.3089	0.1021
26	26	27	0.1732	0.0572
27	3	28	0.0044	0.0108
28	28	29	0.0640	0.1565
29	29	30	0.3978	0.1315
30	30	31	0.0702	0.0232
31	31	32	0.3510	0.1160
32	32	33	0.8390	0.2816
33	33	34	1.7080	0.5646
34	34	35	1.4740	0.4873
35	3	36	0.0044	0.0108
36	36	37	0.0640	0.1565
37	37	38	0.1053	0.1230
38	38	39	0.0304	0.0355
39	39	40	0.0018	0.0021
40	40	41	0.7283	0.8509
41	41	42	0.3100	0.3623
42	42	43	0.0410	0.0478
43	43	44	0.0092	0.0116
44	44	45	0.1089	0.1373
45	45	46	0.0009	0.0012
46	4	47	0.0034	0.0084
47	47	48	0.0851	0.2083
48	48	49	0.2898	0.7091
49	49	50	0.0822	0.2011
50	8	51	0.0928	0.0473
51	51	52	0.3319	0.1114
52	9	53	0.1740	0.0886
53	53	54	0.2030	0.1034
54	54	55	0.2842	0.1447
55	55	56	0.2813	0.1433
56	56	57	1.5900	0.5337
57	57	58	0.7837	0.2630
58	58	59	0.3042	0.1006
59	59	60	0.3861	0.1172
60	60	61	0.5075	0.2585
61	61	62	0.0974	0.0496
62	62	63	0.1450	0.0738
63	63	64	0.7105	0.3619
64	64	65	1.0410	0.5302
65	11	66	0.2012	0.0611
66	66	67	0.0047	0.0014
67	12	68	0.7394	0.2444
68	68	69	0.0047	0.0016

17	0.0600	0.0350
18	0.0600	0.0350
19	0	0
20	0.0010	0.0006
21	0.1140	0.0810
22	0.0050	0.0035
23	0	0
24	0.0280	0.0200
25	0	0
26	0.0140	0.0100
27	0.0140	0.0100
28	0.0260	0.0186
29	0.0260	0.0186
30	0	0
31	0	0
32	0	0
33	0.0140	0.0100
34	0.0095	0.0140
35	0.0060	0.0040
36	0.0260	0.0186
37	0.0260	0.0186
38	0	0
39	0.0240	0.0170
40	0.0240	0.0170
41	0.0012	0.0010
42	0	0
43	0.0060	0.0043
44	0	0
45	0.0392	0.0263
46	0.0392	0.0263
47	0	0
48	0.0790	0.0564
49	0.3847	0.2745
50	0.3847	0.2745
51	0.0405	0.0283
52	0.0036	0.0027
53	0.0043	0.0035
54	0.0264	0.0190
55	0.0240	0.0172
56	0	0
57	0	0
58	0	0
59	0.1000	0.0720
60	0	0
61	1.2440	0.8880
62	0.0320	0.0230
63	0	0
64	0.2270	0.1620
65	0.0590	0.0420
66	0.0180	0.0130
67	0.0180	0.0130
68	0.0280	0.0200
69	0.0280	0.0200

References

1. Anastasia S. Safigianni, *Member, IEEE,* and George J. Salis, ”Optimum Voltage Regulator Placement in a Radial Power Distribution Network.” IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 15, NO. 2, MAY 2000

2. **A.S Pabla**, Electrical power distribution,5th edition
3 J.J.Grainger and S. Civanlar,"Volt/Var Control on Distribution System with Lateral Branches Using Shunt Capacitors and Voltage Regulators Part II: The Solution Method." IEEE Trans. on PAS, Vol.104, No.11, pp. 3284-3290, November 1985.
4 J.J.Grainger and S. Civanlar," Volt/Var Control on Distribution System with Lateral Branches Using Shunt Capacitors and Voltage Regulators Part III: The Numerical Results." IEEE Trans. on PAS, Vol.104, No.11, pp 3291-3297 November 1985.
5 M. Chakravorthy and D. Das, "Voltage stability analysis of radial distribution systems", Electrical Power and Energy Systems, Vol. 23, pp.129-135, 2001.
6 "Neural Networks for combined control of capacitor banks and voltage regulators in Distribution systems", Z.Gu, D.T.Dizy, IEEE transactions on power delivery, Vol. II, No.4, pp. 1921-1928 Oct. 1996.
7 Anastasia S.Safigianni, "Optimum Voltage Regulator Placement in a Radial Power Distribution Network", IEEE Trans. on Power Systems, Vol. 15,No.2, pp.879-886 May 2000.
8 D.Das,H.S.Nagi,D.P.Kothari "Novel method for solving Radial Distribution System", IEE proc. Gener.Trans.Distrib., Vol.141, No.4, pp. 291-298, July-1994.
9 S.Ghosh,D.Das "Method for load flow solution of RadialDistribution Networks", IEE proc. Gener.Trans. Distrib., Vol.146, No.6, pp. 641-648 , Nov.-1999