

Load Flow Analysis of Radial Distribution Networks

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Overview

- Introduction
- Per unit conversion
- Data preparation
- Backward/ forward sweep load flow
- Simulation studies

Operation and Planning of Power Distribution Systems
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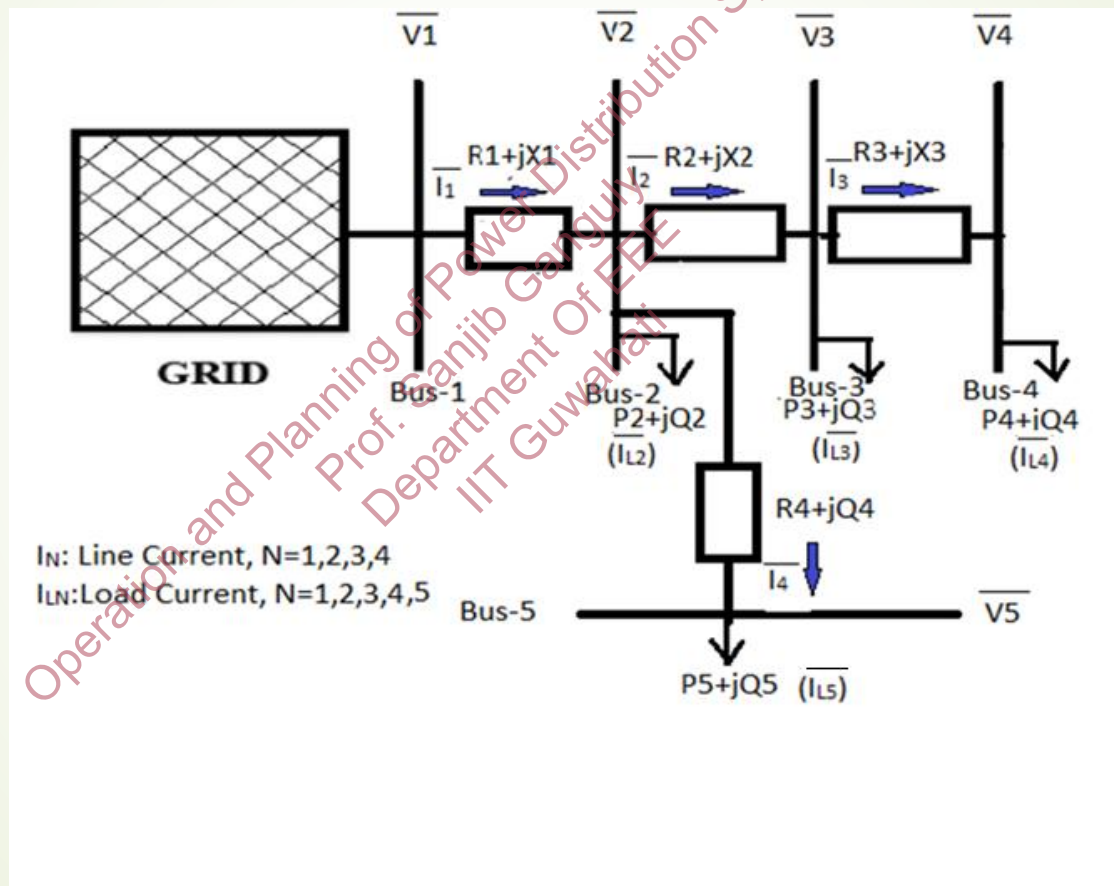
Introduction

- ❖ Load flow studies are performed to know the steady state operating condition of a power system.
- ❖ In power systems, powers are known quantities rather than currents. Thus, the equations used in load flow studies are in terms of power.
- ❖ These power flow equations are nonlinear and solved by iterative techniques.
- ❖ Load flow studies are used for planning, operation, economic scheduling and exchange of power between utilities.
- ❖ Transient, contingency and stability studies are required load flow analysis.

Why backward forward sweep load flow algorithm is used for distribution networks?

- ❖ Due to the following special features Newton Raphson and other transmission network algorithms are failed with distribution network:
 - ✓ Radial and weakly meshed networks
 - ✓ High R/X ratio
 - ✓ Distributed generation

Typical radial distribution network topology: Single line diagram



In load flow approach, all quantities are converted to per unit values.

Need of per unit conversion

- ❖ An interconnected power system has different voltage levels. So, transformation of all the impedances to a single voltage level is required.
- ❖ It gives a clear idea of relative magnitudes of various quantities such as voltage, current, power and impedance.
- ❖ The per unit values vary within narrow range and this makes the computational analysis easier for complex power systems.
- ❖ The per unit values of voltage, current and impedance are same for both primary and secondary side of transformer.

Per unit calculations

- ❖ The per unit value of any quantity is the ratio of actual value to its base value. It is a unit less quantity.
- ❖ In power systems computation, usually three phase base MVA and line to line base voltage in kV are selected to specify the base.
- ❖ The base current (I_B) is calculated as,

$$I_B = \frac{S_B}{\sqrt{3}V_B}$$

- ❖ The base impedance (Z_B) is calculated as,

$$Z_B = \frac{V_B/\sqrt{3}}{I_B} = \frac{V_B^2}{S_B} = \frac{(kV_B)^2}{MVA_B}$$

where, S_B is base volt-ampere (VA) and V_B is base voltage (V)

Changing of base of per unit quantities

- ❖ In power system, the per unit impedance of generators and transformers are based on their own ratings and the per unit impedance of lines are based on their own ohmic values.
- ❖ For power system analysis, all the per unit impedance values must be calculated at same base.
- ❖ Let, S_B^{old} , V_B^{old} and Z (Ω) are old base Volt-ampere, old base voltage and actual impedance, respectively.
- ❖ The per unit value with old and new base values are:

$$Z_{pu}^{old} = \frac{Z}{Z_B^{old}} = Z \frac{S_B^{old}}{(V_B^{old})^2} , \quad Z_{pu}^{new} = \frac{Z}{Z_B^{new}} = Z \frac{S_B^{new}}{(V_B^{new})^2}$$

- ❖ The new per unit value in terms of old is:

$$Z_{pu}^{new} = Z_{pu}^{old} \frac{S_B^{new}}{S_B^{old}} \left(\frac{V_B^{old}}{V_B^{new}} \right)^2$$

Data preparation

- ❖ To perform load flow analysis the following data must be known:
 - ✓ Base MVA of the network
 - ✓ Base kVA of the network
 - ✓ Voltage mismatch accuracy
 - ✓ Maximum number of iterations
 - ✓ Resistance and reactance of each branch of network
 - ✓ Real and reactive power demand at each and every nodes of the network

Bus/Node data file preparation

- ❖ Starting from substation bus assign a number to each buses sequentially
- ❖ For a bus, all the data must be in single row
- ❖ Column 1: enter the buses number sequentially
- ❖ Column 2: enter the buses code (0: load bus, 1: slack bus and 2: voltage controlled bus)
- ❖ Column 3 and 4: enter the initial voltage magnitude and angle to each buses as '1' per unit and '0' (zero) degree respectively
- ❖ Column 5 and 6: enter the load demand of each buses in MW and MVAR respectively

Line data file preparation

- ❖ Connectivity of buses must be known
- ❖ For a branch of network, all the data must be in single row
- ❖ Column 1 and 2: enter the branch buses numbers in sequence
- ❖ Column 3 : enter the branch resistance
- ❖ Column 4: enter the branch reactance

Equations involved in load flow analysis

- ❖ Load current ($\bar{I}_i$) at bus 'i' is calculated,

$$\bar{I}_i = \frac{P_i - jQ_i}{\bar{V}_i^*}$$

- ❖ Branch current ($\overline{I_{im}^b}$) for branch 'im' is calculated by using,

$$\overline{I_{im}^b} = \bar{I}_m + \sum_{i \in \Gamma} \bar{I}_i$$

- ❖ The voltage at receiving end ($\bar{V}_m$) is calculated as,

$$\bar{V}_m = \bar{V}_i - \overline{I_{im}^b} (R_{im} + jX_{im})$$

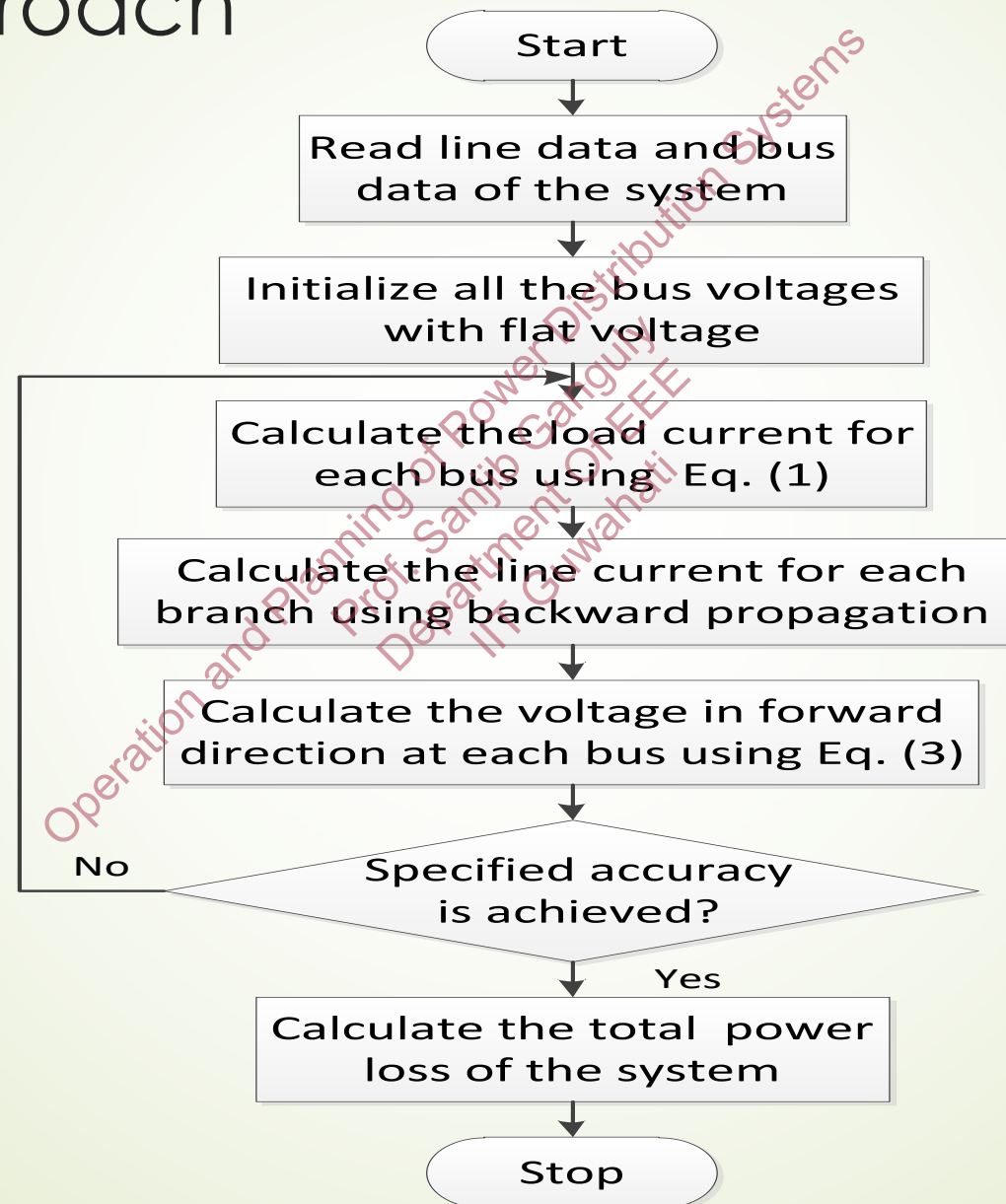
where, $i \in [1, \dots, N]$, $im \in [1, \dots, N - 1]$

N is total number of bus, $\bar{V}_i$ is sending end voltage

Γ is a set of all the nodes which are located beyond node 'm'

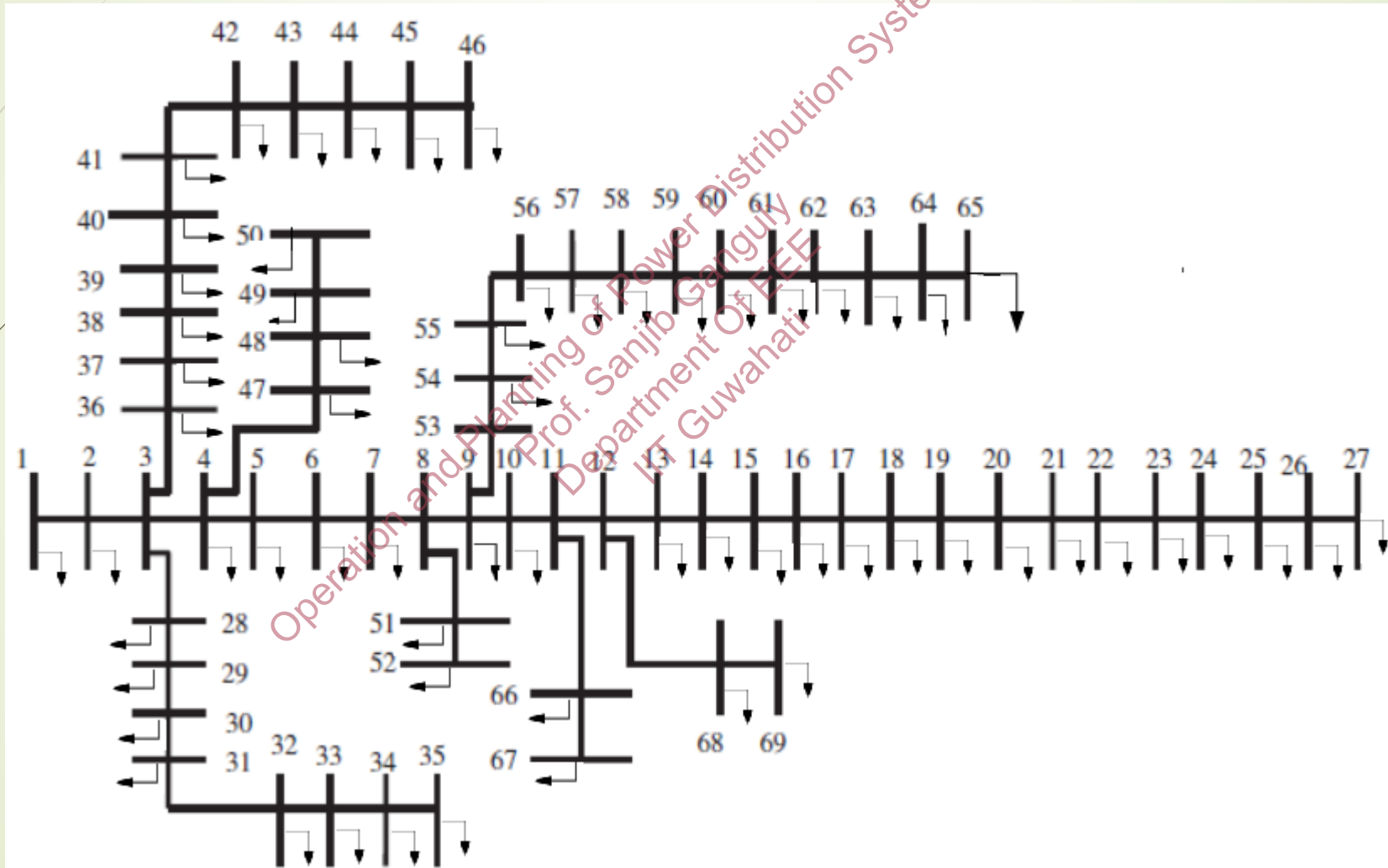
R_{im} and X_{im} are the resistance and reactance of branch 'im'

Flowchart of backward forward sweep approach



69-node radial distribution network

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Node data of 69-node radial distribution network

```
basemva=10; accuracy=0.0001; maxiter=100;
basekv=12.66;
%Distribution System data (69 bus system)
```

%	Bus	Bus	Voltage	Angle	Load	Load
%	no.	code	mag. (pu)	(degree)	(kW)	(kVAR)
busdata=[	1	1	1	0	0	0
	2	0	1	0	0	0
	3	0	1	0	0	0
	4	0	1	0	0	0
	5	0	1	0	0	0
	6	0	1	0	2.6	2.2
	7	0	1	0	40.4	30
	8	0	1	0	75	54
	9	0	1	0	30	22
	10	0	1	0	28	19
	11	0	1	0	145	104
	12	0	1	0	145	104
	13	0	1	0	8	5.5
	14	0	1	0	8	5.5
	15	0	1	0	0	0
	16	0	1	0	45.5	30
	17	0	1	0	60	35
	18	0	1	0	60	35
	19	0	1	0	0	0
	20	0	1	0	1	0.6
	21	0	1	0	114	81
	22	0	1	0	5.3	3.5
	23	0	1	0	0	0
	24	0	1	0	28	20
	25	0	1	0	0	0
	26	0	1	0	14	10
	27	0	1	0	14	10
	28	0	1	0	26	18.6
	29	0	1	0	26	18.6
	30	0	1	0	0	0

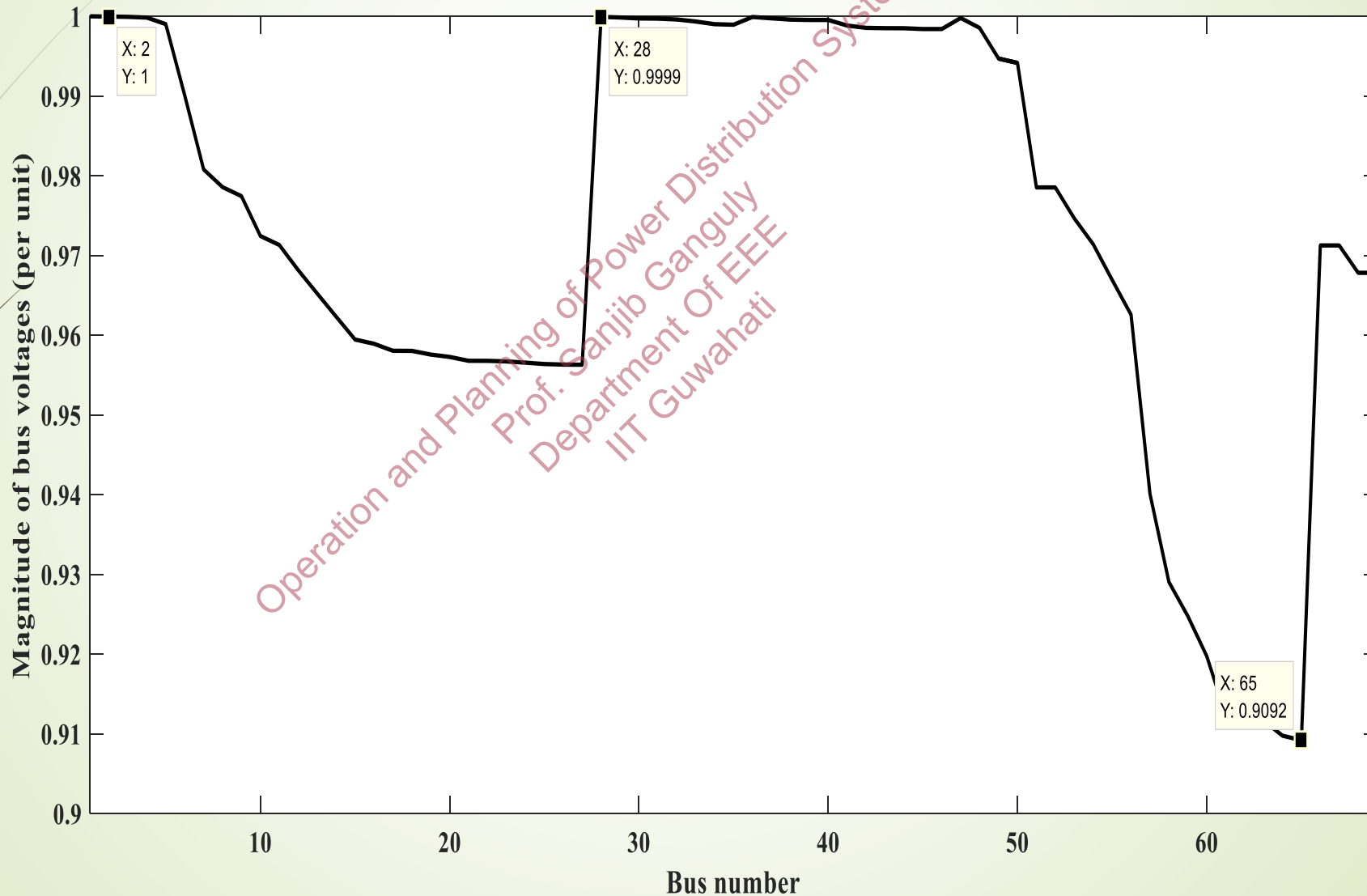
31	0	1	0	0	0
32	0	1	0	0	0
33	0	1	0	14	10
34	0	1	0	19.5	14
35	0	1	0	6	4
36	0	1	0	26	18.55
37	0	1	0	26	18.55
38	0	1	0	0	0
39	0	1	0	24	17
40	0	1	0	24	17
41	0	1	0	1.2	1
42	0	1	0	0	0
43	0	1	0	6	4.3
44	0	1	0	0	0
45	0	1	0	39.22	26.3
46	0	1	0	39.22	26.3
47	0	1	0	0	0
48	0	1	0	79	56.4
49	0	1	0	384.7	274.5
50	0	1	0	384.7	274.5
51	0	1	0	40.5	28.3
52	0	1	0	3.6	2.7
53	0	1	0	4.35	3.5
54	0	1	0	26.4	19
55	0	1	0	24	17.2
56	0	1	0	0	0
57	0	1	0	0	0
58	0	1	0	0	0
59	0	1	0	100	72
60	0	1	0	0	0
61	0	1	0	1244	888
62	0	1	0	32	23
63	0	1	0	0	0
64	0	1	0	227	162
65	0	1	0	59	42
66	0	1	0	18	13
67	0	1	0	18	13
68	0	1	0	28	20
69	0	1	0	28	20];

Line data of 69-node radial distribution network

% linedata =	ns	nr	R	X
	1	2	0.0005	0.0012
	2	3	0.0005	0.0012
	3	4	0.0015	0.0036
	4	5	0.0251	0.0294
	5	6	0.366	0.1864
	6	7	0.3811	0.1941
	7	8	0.0922	0.047
	8	9	0.0493	0.0251
	9	10	0.819	0.2707
	10	11	0.1872	0.0691
	11	12	0.7114	0.2351
	12	13	1.03	0.34
	13	14	1.044	0.345
	14	15	1.058	0.3496
	15	16	0.1966	0.065
	16	17	0.3744	0.1238
	17	18	0.0047	0.0016
	18	19	0.3276	0.1083
	19	20	0.2106	0.0696
	20	21	0.3416	0.1129
	21	22	0.014	0.0046
	22	23	0.1591	0.0526
	23	24	0.3463	0.1145
	24	25	0.7488	0.2745
	25	26	0.3089	0.1021
	26	27	0.1732	0.0572
	3	28	0.0044	0.0108
	28	29	0.064	0.1565
	29	30	0.3978	0.1315
	30	31	0.0702	0.0232

31	32	0.351	0.116
32	33	0.839	0.2816
33	34	1.708	0.5646
34	35	1.474	0.4873
3	36	0.0044	0.0108
36	37	0.064	0.1565
37	38	0.1053	0.123
38	39	0.0304	0.0355
39	40	0.0018	0.0021
40	41	0.7283	0.8509
41	42	0.31	0.3623
42	43	0.041	0.0478
43	44	0.0092	0.0116
44	45	0.1089	0.1373
45	46	0.0009	0.0012
4	47	0.0034	0.0084
47	48	0.0851	0.2083
48	49	0.2898	0.7091
49	50	0.0822	0.2011
8	51	0.0928	0.0473
51	52	0.3319	0.1114
9	53	0.174	0.0886
53	54	0.203	0.1034
54	55	0.2842	0.1447
55	56	0.2813	0.1433
56	57	1.59	0.5337
57	58	0.7837	0.263
58	59	0.3042	0.1006
59	60	0.3861	0.1172
60	61	0.5075	0.2585
61	62	0.0974	0.0496
62	63	0.145	0.0738
63	64	0.7105	0.3619
64	65	1.041	0.5302
11	66	0.2012	0.0611
66	67	0.0047	0.0014
12	68	0.7394	0.2444
68	69	0.0047	0.0016];

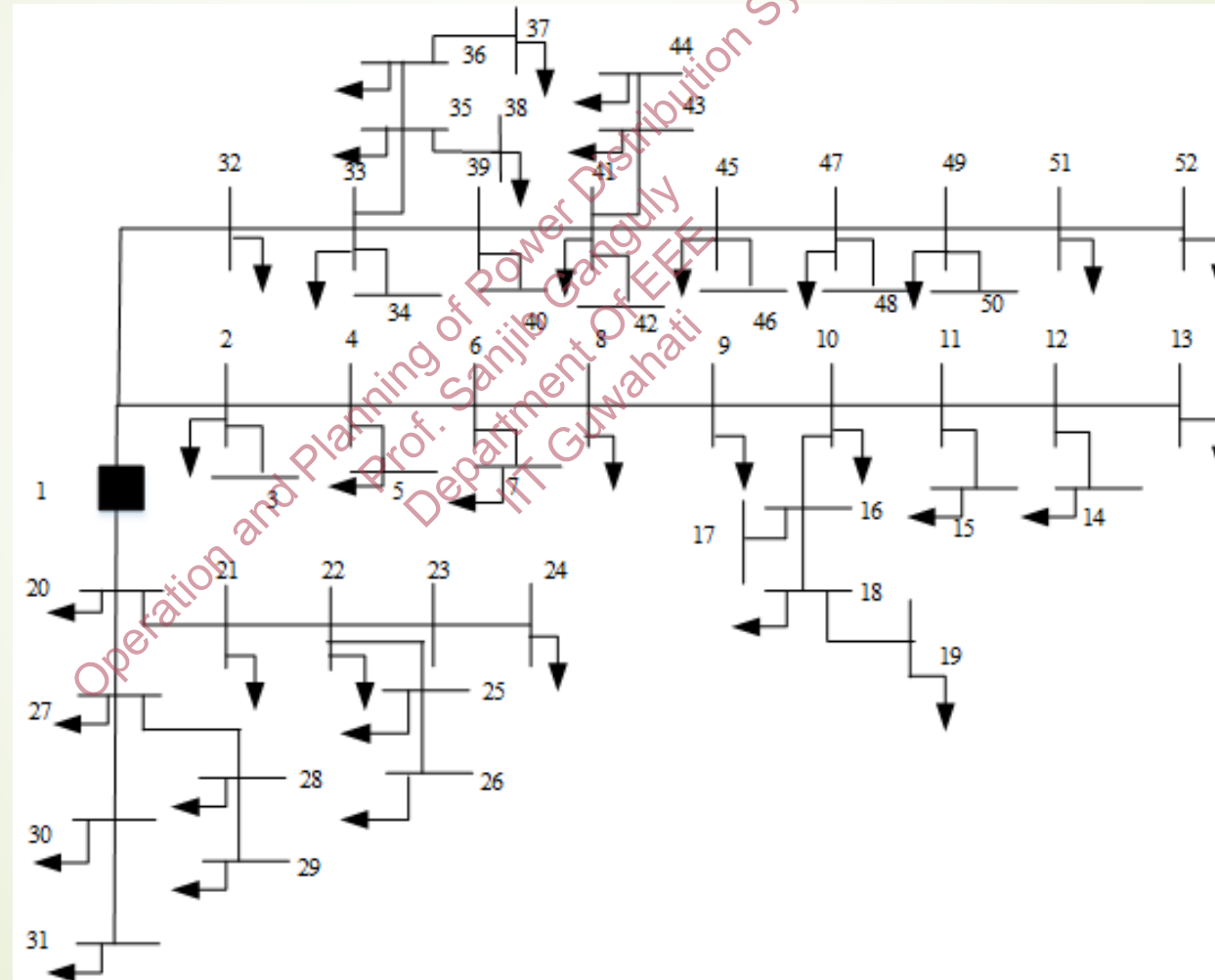
Voltage magnitude plot of 69-node radial distribution network



Bus voltages of 69-node radial distribution network

v=[	1.0000 + 0.0000i	0.9989 + 0.0002i
	1.0000 - 0.0000i	0.9999 - 0.0001i
	0.9999 - 0.0000i	0.9997 - 0.0002i
	0.9998 - 0.0001i	0.9996 - 0.0002i
	0.9990 - 0.0003i	0.9995 - 0.0002i
	0.9901 + 0.0009i	0.9995 - 0.0002i
	0.9808 + 0.0021i	0.9988 - 0.0004i
	0.9786 + 0.0024i	0.9986 - 0.0005i
	0.9774 + 0.0025i	0.9985 - 0.0005i
	0.9724 + 0.0039i	0.9985 - 0.0005i
	0.9713 + 0.0042i	0.9984 - 0.0005i
	0.9681 + 0.0051i	0.9984 - 0.0005i
	0.9652 + 0.0059i	0.9998 - 0.0001i
	0.9623 + 0.0066i	0.9985 - 0.0009i
	0.9594 + 0.0074i	0.9947 - 0.0033i
	0.9589 + 0.0075i	0.9941 - 0.0037i
	0.9580 + 0.0077i	0.9785 + 0.0024i
	0.9580 + 0.0077i	0.9785 + 0.0024i
	0.9575 + 0.0079i	0.9747 + 0.0029i
	0.9572 + 0.0080i	0.9714 + 0.0033i
	0.9568 + 0.0081i	0.9669 + 0.0039i
	0.9567 + 0.0081i	0.9626 + 0.0045i
	0.9567 + 0.0081i	0.9400 + 0.0109i
	0.9565 + 0.0082i	0.9289 + 0.0140i
	0.9563 + 0.0082i	0.9246 + 0.0153i
	0.9563 + 0.0083i	0.9196 + 0.0169i
	0.9563 + 0.0083i	0.9122 + 0.0178i
	0.9999 - 0.0000i	0.9119 + 0.0179i
	0.9999 - 0.0001i	0.9115 + 0.0179i
	0.9997 - 0.0001i	0.9096 + 0.0181i
	0.9997 - 0.0000i	0.9090 + 0.0182i
	0.9996 - 0.0000i	0.9713 + 0.0042i
	0.9993 + 0.0001i	0.9713 + 0.0042i
	0.9990 + 0.0002i	0.9678 + 0.0052i
		0.9678 + 0.0052i];

52-node radial distribution network



Node data of 52-node radial distribution network

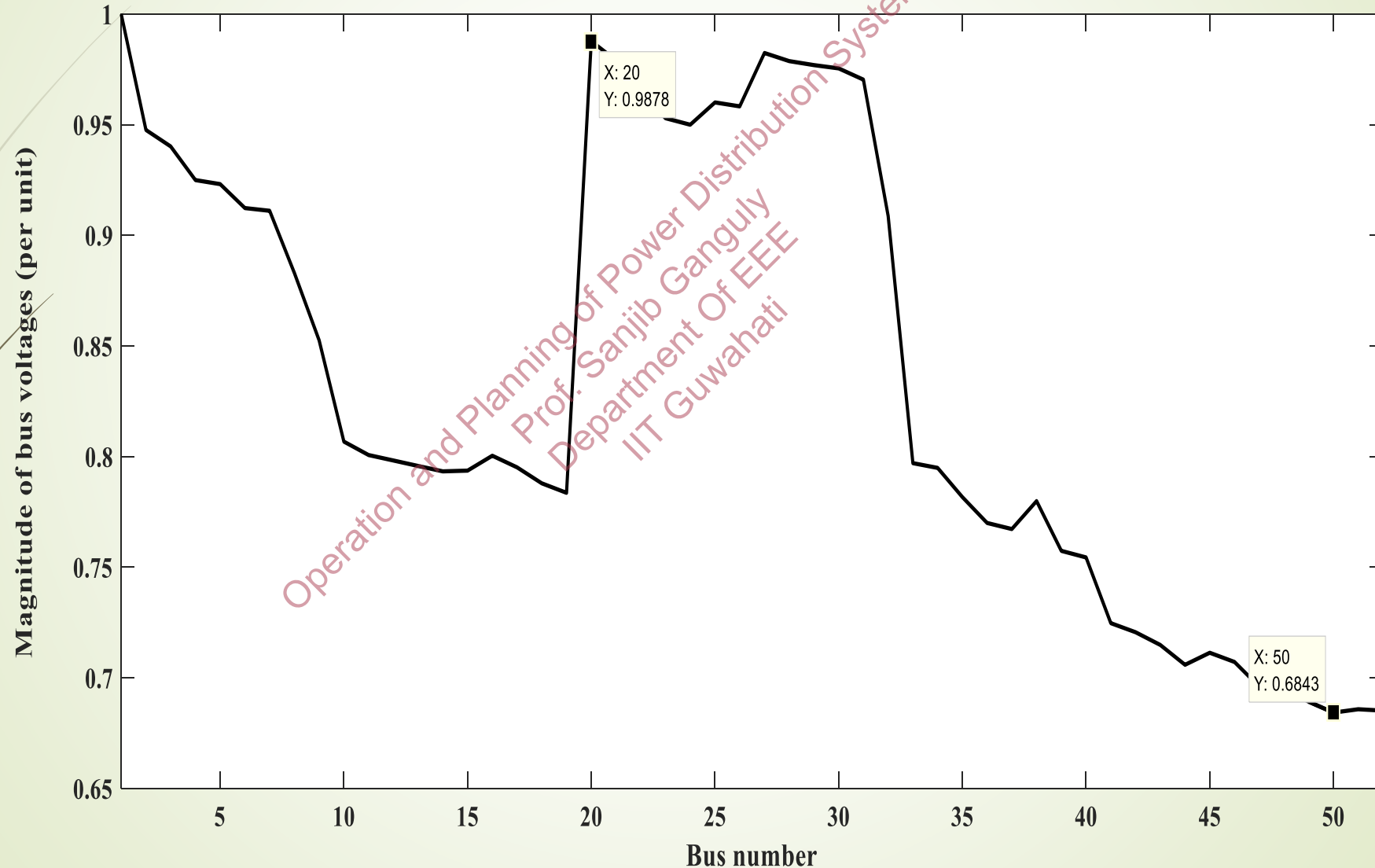
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nbus=52;						
basemva =1 ; accuracy = 0.0001; maxiter=100;						
basekv=11;						
% Distribution System data (52 bus system)						
%	Bus	Bus	Voltage	Angle	Load	Load
%	No.	code	mag. (pu)	(Degree)	(kW)	(kVAR)
busdat						
a=[	1	1	1	0	0	0
	2	0	1	0	81	39
	3	0	1	0	135	65
	4	0	1	0	108	52
	5	0	1	0	108	52
	6	0	1	0	27	13
	7	0	1	0	54	26
	8	0	1	0	135	65
	9	0	1	0	81	39
	10	0	1	0	67	32
	11	0	1	0	27	13
	12	0	1	0	27	13
	13	0	1	0	108	52
	14	0	1	0	54	26
	15	0	1	0	94	45
	16	0	1	0	67	33
	17	0	1	0	67	33
	18	0	1	0	108	52
	19	0	1	0	81	39
	20	0	1	0	108	52
	21	0	1	0	94	46
	22	0	1	0	81	39
	23	0	1	0	108	52
	24	0	1	0	108	52
	25	0	1	0	102	50
	26	0	1	0	41	20
	27	0	1	0	108	52
	28	0	1	0	162	79
	29	0	1	0	68	33
	30	0	1	0	68	33
	31	0	1	0	95	46
	32	0	1	0	41	20
	33	0	1	0	121	59
	34	0	1	0	41	20
	35	0	1	0	41	20
	36	0	1	0	135	66
	37	0	1	0	81	40
	38	0	1	0	68	33
	39	0	1	0	95	46
	40	0	1	0	108	52
	41	0	1	0	41	20
	42	0	1	0	95	46
	43	0	1	0	27	13
	44	0	1	0	122	59
	45	0	1	0	108	52
	46	0	1	0	81	39
	47	0	1	0	68	33
	48	0	1	0	41	20
	49	0	1	0	68	33
	50	0	1	0	81	39
	51	0	1	0	108	52
	52	0	1	0	41	20];

Line data of 52-node radial distribution network

%	ns	nr	R (pu)	X (pu)				
linedata=	[1	2	0.0258	0.0111	20	27	0.0086	0.0037
	2	3	0.043	0.0185	27	28	0.0129	0.0056
	2	4	0.0129	0.0056	28	29	0.0215	0.0093
	4	5	0.0129	0.0056	27	30	0.0344	0.0148
	4	6	0.0086	0.0037	30	31	0.043	0.0185
	6	7	0.0172	0.0074	1	32	0.0344	0.0148
	6	8	0.0215	0.0093	32	33	0.043	0.0185
	8	9	0.0258	0.0111	33	34	0.0344	0.0148
	9	10	0.043	0.0185	33	35	0.0301	0.013
	10	11	0.0129	0.0056	35	36	0.0344	0.0148
	11	12	0.0086	0.0037	36	37	0.0215	0.0093
	11	15	0.043	0.0185	35	38	0.0172	0.0074
	12	13	0.0301	0.013	33	39	0.0215	0.0093
	12	14	0.0344	0.0148	39	40	0.0172	0.0074
	10	16	0.0129	0.0056	39	41	0.0215	0.0093
	16	17	0.0516	0.0222	41	42	0.0258	0.0111
	16	18	0.043	0.0185	41	43	0.0387	0.0167
	18	19	0.0344	0.0148	43	44	0.043	0.0185
	1	20	0.0086	0.0037	41	45	0.0129	0.0056
	20	21	0.0129	0.0056	45	46	0.0301	0.013
	21	22	0.0258	0.0111	45	47	0.0215	0.0093
	22	23	0.043	0.0185	47	48	0.0129	0.0056
	23	24	0.0215	0.0093	47	49	0.0129	0.0056
	22	25	0.0258	0.0111	49	50	0.0344	0.0148
	25	26	0.0344	0.0148	49	51	0.0129	0.0056
					51	52	0.0086	0.0037];

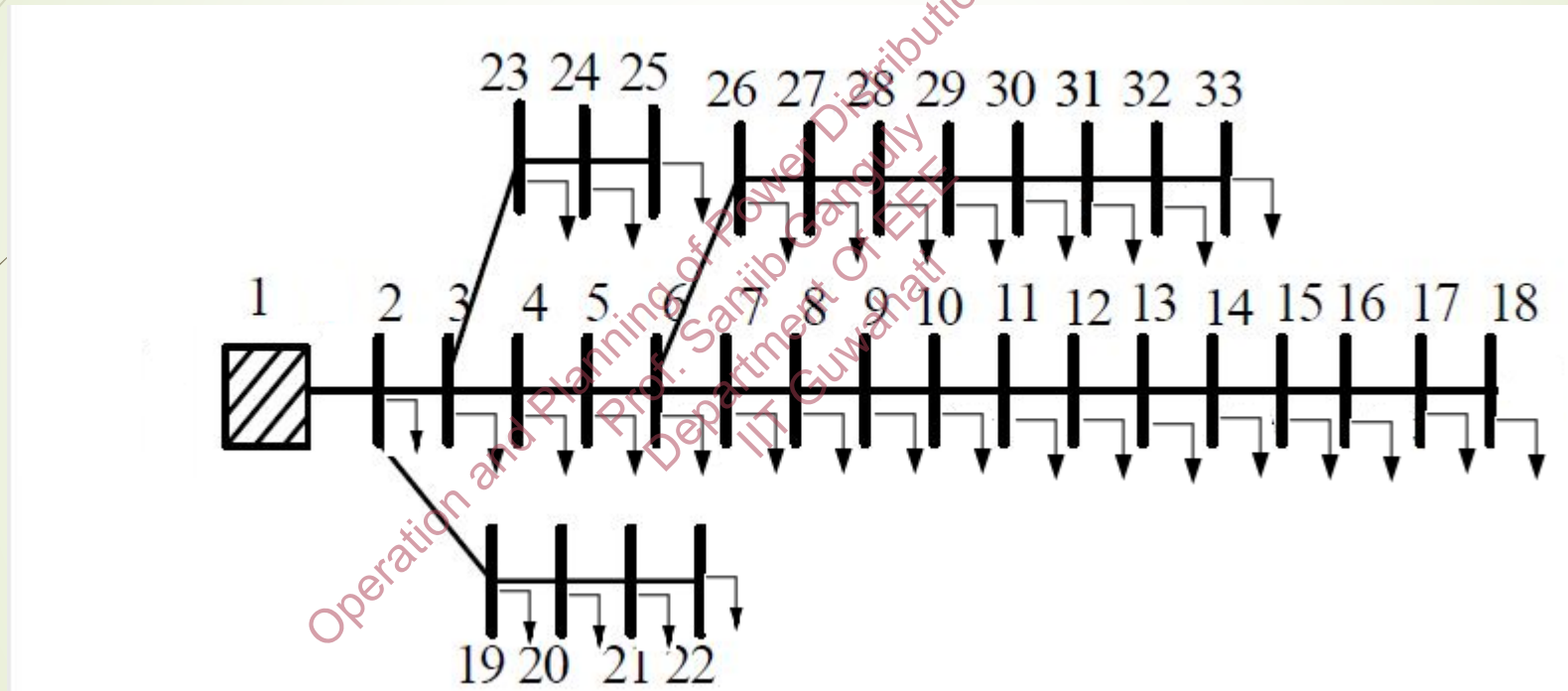
Voltage magnitude plot of 52-node radial distribution network



Node voltages of 52-node radial distribution network

v=[	1.0000 + 0.0000i	0.9824 + 0.0008i
	0.9476 + 0.0019i	0.9788 + 0.0009i
	0.9402 + 0.0022i	0.9769 + 0.0010i
	0.9250 + 0.0027i	0.9755 + 0.0011i
	0.9231 + 0.0027i	0.9704 + 0.0013i
	0.9123 + 0.0031i	0.9087 + 0.0031i
	0.9111 + 0.0032i	0.7970 + 0.0068i
	0.8830 + 0.0041i	0.7949 + 0.0069i
	0.8525 + 0.0051i	0.7817 + 0.0073i
	0.8068 + 0.0067i	0.7700 + 0.0078i
	0.8007 + 0.0069i	0.7672 + 0.0079i
	0.7982 + 0.0070i	0.7799 + 0.0074i
	0.7957 + 0.0071i	0.7574 + 0.0079i
	0.7933 + 0.0074i	0.7544 + 0.0080i
	0.7936 + 0.0071i	0.7247 + 0.0089i
	0.8004 + 0.0069i	0.7206 + 0.0090i
	0.7951 + 0.0072i	0.7148 + 0.0091i
	0.7879 + 0.0074i	0.7058 + 0.0094i
	0.7836 + 0.0075i	0.7113 + 0.0092i
	0.9878 + 0.0005i	0.7071 + 0.0093i
	0.9791 + 0.0009i	0.6959 + 0.0096i
	0.9647 + 0.0015i	0.6950 + 0.0097i
	0.9529 + 0.0020i	0.6891 + 0.0098i
	0.9500 + 0.0021i	0.6842 + 0.0100i
	0.9601 + 0.0017i	0.6857 + 0.0099i
	0.9583 + 0.0018i	0.6851 + 0.0099i];

33-node radial distribution network



Node data and line data of 33-node radial distribution network

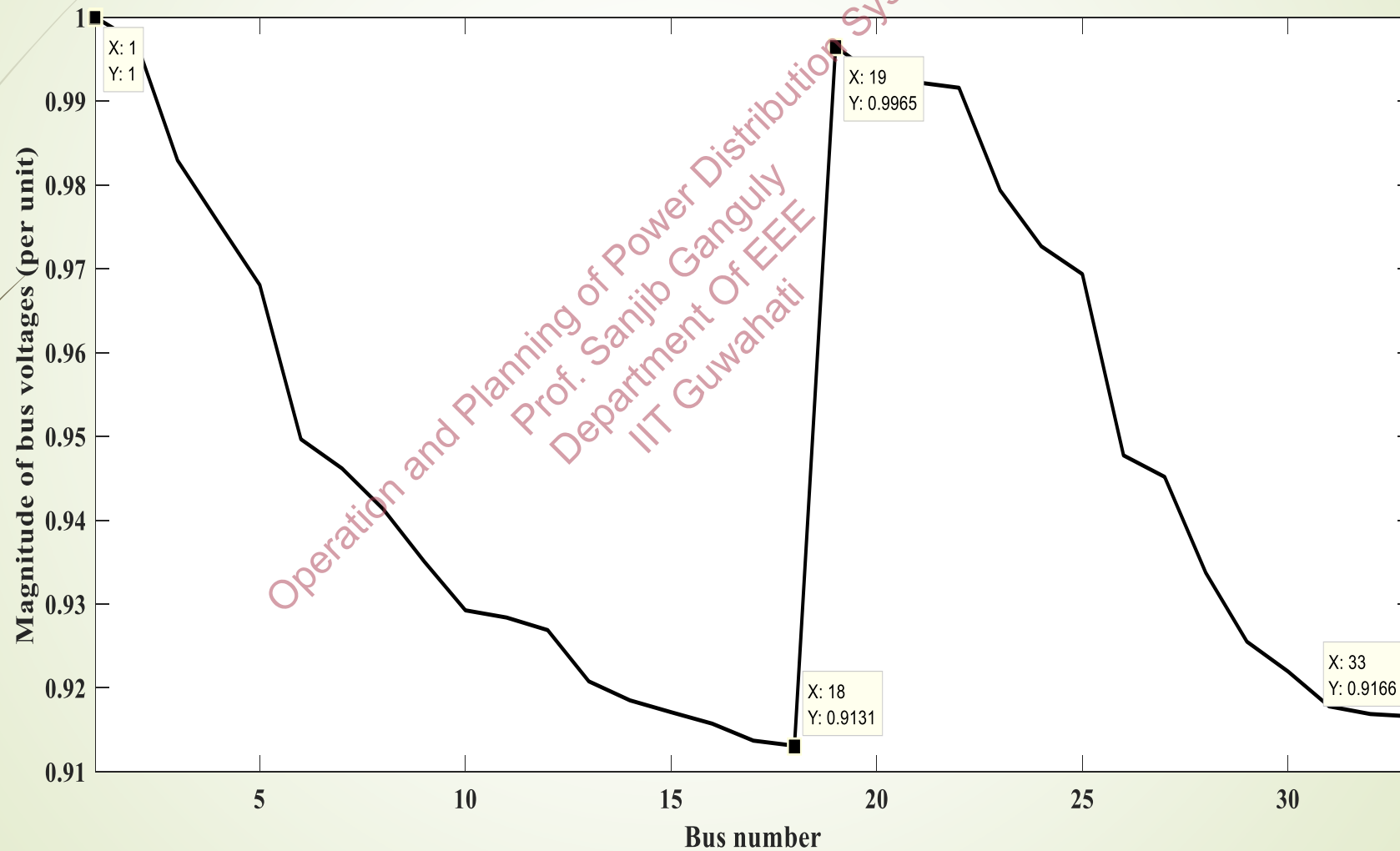
```
basemva=100; accuracy = 0.0001; maxiter=100;
basekv=12.66;
%Distribution System data (33 bus system)
```

%	Bus	Bus	Voltage	Angle	Load	Load
%	no.	code	mag. (pu)	(degree)	(kW)	(kVAR)
busdata	1	1	1	0	0	0
=	2	0	1	0	100	60
	3	0	1	0	90	40
	4	0	1	0	120	80
	5	0	1	0	60	30
	6	0	1	0	60	20
	7	0	1	0	200	100
	8	0	1	0	200	100
	9	0	1	0	60	20
	10	0	1	0	60	20
	11	0	1	0	45	30
	12	0	1	0	60	35
	13	0	1	0	60	35
	14	0	1	0	120	80
	15	0	1	0	60	10
	16	0	1	0	60	20
	17	0	1	0	60	20
	18	0	1	0	90	40
	19	0	1	0	90	40
	20	0	1	0	90	40
	21	0	1	0	90	40
	22	0	1	0	90	40
	23	0	1	0	90	50
	24	0	1	0	420	200
	25	0	1	0	420	200
	26	0	1	0	60	25
	27	0	1	0	60	25
	28	0	1	0	60	20
	29	0	1	0	120	70
	30	0	1	0	200	600
	31	0	1	0	150	70
	32	0	1	0	210	100
	33	0	1	0	60	40];

```
%
```

%	ns	nr	R	X
linedata=	[1	2	0.0922	0.047
	2	3	0.493	0.2511
	3	4	0.366	0.1864
	4	5	0.3811	0.1941
	5	6	0.819	0.707
	6	7	0.1872	0.6188
	7	8	0.7114	0.2351
	8	9	1.03	0.74
	9	10	1.044	0.74
	10	11	0.1966	0.065
	11	12	0.3744	0.1238
	12	13	1.468	1.155
	13	14	0.5416	0.7129
	14	15	0.591	0.526
	15	16	0.7463	0.545
	16	17	1.289	1.721
	17	18	0.732	0.574
	2	19	0.164	0.1565
	19	20	1.5042	1.3554
	20	21	0.4095	0.4784
	21	22	0.7089	0.9373
	3	23	0.4512	0.3083
	23	24	0.898	0.7091
	24	25	0.896	0.7011
	6	26	0.203	0.1034
	26	27	0.2842	0.1447
	27	28	1.059	0.9337
	28	29	0.8042	0.7006
	29	30	0.5075	0.2585
	30	31	0.9744	0.963
	31	32	0.3105	0.3619
	32	33	0.341	0.5302];

Voltage magnitude plot of 33-node radial distribution network



Node voltages of 33-node radial distribution network

v=	[	1.0000 + 0.0000i
		0.9970 + 0.0003i
		0.9829 + 0.0016i
		0.9755 + 0.0028i
		0.9681 + 0.0039i
		0.9497 + 0.0022i
		0.9462 - 0.0016i
		0.9413 - 0.0010i
		0.9351 - 0.0022i
		0.9292 - 0.0032i
		0.9284 - 0.0031i
		0.9269 - 0.0029i
		0.9208 - 0.0043i
		0.9185 - 0.0056i
		0.9171 - 0.0062i
		0.9157 - 0.0065i
		0.9137 - 0.0077i
		0.9131 - 0.0079i
		0.9965 + 0.0001i
		0.9929 - 0.0011i
		0.9922 - 0.0014i
		0.9916 - 0.0018i
		0.9794 + 0.0011i
		0.9727 - 0.0004i
		0.9694 - 0.0011i
		0.9477 + 0.0029i
		0.9452 + 0.0038i
		0.9337 + 0.0051i
		0.9255 + 0.0063i
		0.9219 + 0.0080i
		0.9178 + 0.0066i
		0.9169 + 0.0062i
		0.9166 + 0.0061i];

Summary of the results

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Parameters	69-node system	52-node system	33-node system
Minimum voltage of system	0.9092	0.6843	0.9131
Minimum voltage node number	65	50	18
Maximum voltage node number	2	20	2
Power loss of the network (kW)	225.0021	887.3782	202.6762

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Thank You...

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