Analysis of 440V Radial Agricultural Distribution Networks

K. V. S. Ramachandra Murthy, and K. Manikanta

Abstract : This paper attempts to determine active power losses in the distribution lines which are on the secondary side of 11kV/440V transformers. As distribution systems are growing larger and being stretched too far the system losses are also increasing and resulting in poor voltage regulation. In the distribution studies conducted so far on all standard bus systems, the losses are determined only up to the primary side of 11KV/440V transformer. i.e., active and reactive powers are assumed to be lumped at the 11kV Bus.

No study till now has been carried out to determine losses between distribution transformer of 11kV/440V and load premises. The load considered in this study is restricted to agricultural pumps, as there is a large potential for saving energy in agricultural sector. In this paper, three networks are developed under different capacities of distribution transformers. Losses are obtained by running load flow and minimum voltage profile is observed taking several pessimistic conditions of 0.8 power factor and loading beyond 95% on the distribution transformer.

I. INTRODUCTION

In India, all the 11KV rural distribution feeders are radial and too long. The voltages at the far end of many such feeders are very low with very high voltage regulation. No study has been carried out to determine losses on 440V distribution lines. In most of the cases, they are found unbalanced. In this paper, 3-phase pump motor load is considered. So, unbalance on distribution lines is avoided. Only balanced pump load is considered with constant active and reactive power load model. Power factor considered is 0.8. Loading on the distribution transformer is taken up to its full capacity so that maximum drop in the line voltages can be obtained. Maximum active power loss that would result is also obtained with full load. In this paper, topology based load flow technique proposed by Jen Hao Teng is used to obtain losses and voltage profile on the buses.

K. V. S. Ramachandra Murthy is working as Associate Professor in the Department of E.E.E. at G.V.P. College of Engineering, Visakhapatnam, India.

K. Manikanta is persuing M.Tech in Power System Control and Automation in the Department of E.E.E., G.V.P. College of Engineering, Visakhapatnam, India.

The number of pumps of different capacities are chosen in such a way that the average pump capacity is nearer to 6.5 kW which is the national average capacity of a pump motor in agricultural sector. This study will help in determining the total number of pumps working in Agricultural sector and also for determining the active power loss accurately in agricultural distribution systems. This helps in planning studies of distribution system expansion which includes additional transformers, lines

II. STUDIES CONDUCTED

11kV/440V transformers are taken as sources with different capacities of 100 kVA, 200 kVA, 400kVA. Three networks are formed by choosing appropriate line data, load data. Network data is prepared based on the field observations. AAC conductor is used for 100 kVA transformer and 200 kVA transformer. Resistance and reactance of AAC conductor per kilometer is 0.621+ j0.3556 ohms. The 3HP, 5HP, 7HP and 10HP, 12.5 HP and 15HP pump motors are chosen as loads. The loads are considered in such a way it does not overload the corresponding transformer. Radial networks are considered for analysis.

Network 1:

The total load put on the 100 KVA transformer is 79.822+j 59.858 kVA, which is obtained from connected load of 107 HP consisting of 18 pump motors. The average HP of one pump motor is 5.944 HP under 100 kVA transformer. Network with 100 kVA transformer as source is modeled as 23 bus system. The loss obtained is 2.93 kW and total active power load connected is 79.822 kW. Percentage of loss obtained is found to be 3.67 %. Minimum voltage obtained is 242 V(0.9554pu), where as sending end voltage is 254V.

Network 2:

The total load put on the 200 KVA transformer is 158.525+j 118.876 which is obtained from connected load of 212.5 HP consisting of 37 pumps. The average Horse Power of one pump motor is 5.743 HP under 200 kVA transformer.

Network with 200 kVA transformer as source is modeled as 44 bus system. The loss obtained is 15.7kW and total active power load connected is 158.525 kW. Percentage of loss obtained is found to be 9.903%. Minimum voltage obtained is 224V (0.8821 pu), where as sending end voltage is 254V

Network 3:

The total load put on the 400 KVA transformer is 319.661+j 239.746 which is obtained from connected load of 428.5 HP consisting of 70 pumps. The average Horse Power of one pump motor is 6.121 HP under 400 kVA transformer. Network with 400 kVA transformer as source is modeled as 79 bus system. The loss obtained is 25.52 kW and total active power load connected is 319.66 kW. Percentage of loss obtained is found to be 7.98%. Minimum voltage obtained is 230.6 V (0.9081 pu), where as sending end voltage is 254V

III FORMULATION FOR MODEL

Equivalent current injection: For distribution systems, the models which are based on the equivalent current injection as reported by Shirmohammadi et al., (1988), Chen et al. (1991.) and Teng and Lin (1994) are more convenient to use. At each bus ‘k the complex power S_k is specified by,

$$S_i = P_i + jQ_i \quad \text{---} \quad (1)$$

Corresponding equivalent current injection at the k-th iteration of the solution is given by,

$$I_i^k = I_i^r(V_i^k) + j\,I_i^i(V_i^k) = \left[\frac{P_i + j\,Q_i}{V_i^k}\right]^* \quad \text{---} \quad (2)$$

V_i^k is the node voltage at the kth iteration.

I_i^k is the equivalent current injection at the k-th iteration.

I_i^r and I_i^i are the real and imaginary parts of the equivalent current injection at the k-th iteration respectively.

Bus-Injection to Branch-Current matrix : (BIBC)

The power injections can be converted into equivalent current injections using the equation(1). The set of equations can be written by applying Kirchoff’s current law (KCL) to the distribution network. Then the branch currents can be formulated as a function of the equivalent current injections.

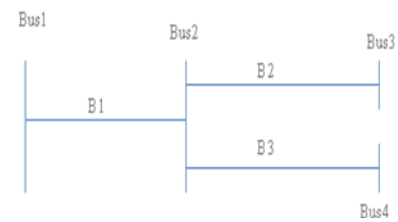

Fig. 1 Sample distribution system.

$$B_1 = I_3 + I_4$$

$$B_2 = I_3$$

$$B_4 = I_4$$

Where, I_2, I_3 and I_4 are load currents respectively at buses 2, 3 and 4

$$[B] = [BIBC]\,[I] \quad \text{----} \quad (3)$$

The constant BIBC matrix has non-zero entries of +1 only. For a distribution system with m-branch sections and n-buses, the dimension of the BIBC is m X (n-1).

Branch-Current to Bus-Voltage Matrix **:**

The relation between the branch currents and bus voltages can be obtained by following equations.

$$V_2 = V_1 - B_1 Z_{12}$$

$$V_3 = V_2 - B_2 Z_{23}$$

where V_2, V_3 are the voltages at node 2 and node 3. Z_{23} is the impedance between 2 and 3 nodes. The above equations can also be written as ,

$$V_1 - V_2 = Z_{12} B_1$$

$$V_1 - V_3 = Z_{12}B_1 + B_2 Z_{23}.$$

In general, $[V_1] - [V_k] = [Z]\,[B]$ where Z matrix will have elements in the transposed matrix of BIBC matrix. V_1 matrix contains all elements equal to 1.0pu.

$$[\Delta V] = [BCBV][I]$$

$$[\Delta V] = [BCBV][BIBC][I]$$

Algorithm for the Load Flow Solution :

1. Read the system data,
2. Build BIBC matrix.
3. Transpose BIBC and multiply with impedances and obtain BCBV matrix
4. Initialize iteration count =1. Calculate equivalent current injections. Considering uniform voltage profile of 1 pu at all buses.
5. Obtain ΔV matrix using.
6. Obtain voltages at all nodes.
7. Calculate current injections using new set of voltages.
8. If the difference in currents between current iteration currents and previous iteration currents is greater than 0.001, then print the result, otherwise, increment of the count and repeat the procedure from step(4).

TABLE –I LOADS CONNECTED UNDER EACH TRANSFORMER

Pump Motor rating	100kVA	200kVA	400kVA
3HP	6	15	24
5HP	6	10	19
7HP	2	5	12
10HP	2	3	7
12.5HP	2	3	5
15HP		1	3
TOTAL	18	37	70

The number of various motors connected on different transformers is given in the Table – I loads connected under each transformer. Table II presents the network and load data on 23 bus system with 100 kVA transformer as source. Table III presents data of 44 bus system with 200 kVA transformer as source., Table IV presents data of 79 bus system with 400 kVA transformer as source.

Fig. 1 gives the single line diagram of the three bus systems designed. Fig 2 Single Line Diagram of 23 Bus system under 100 kVA transformer , Fig 3 Single Line Diagram of 44 Bus system under 200 kVA transformer, Fig 4 Single Line Diagram of 79 Bus system under 400 kVA transformer,

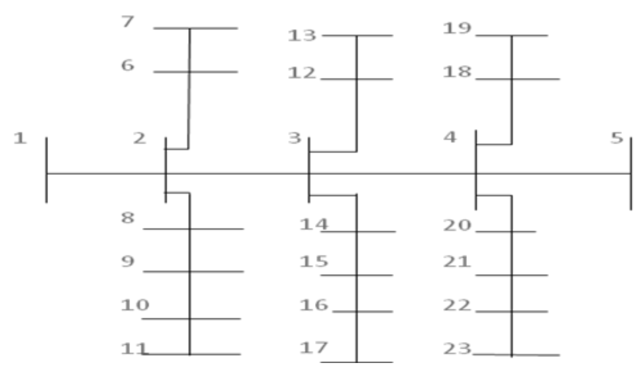

Fig. 2. Single Line Diagram of 23 Bus system under 100 kVA transformer

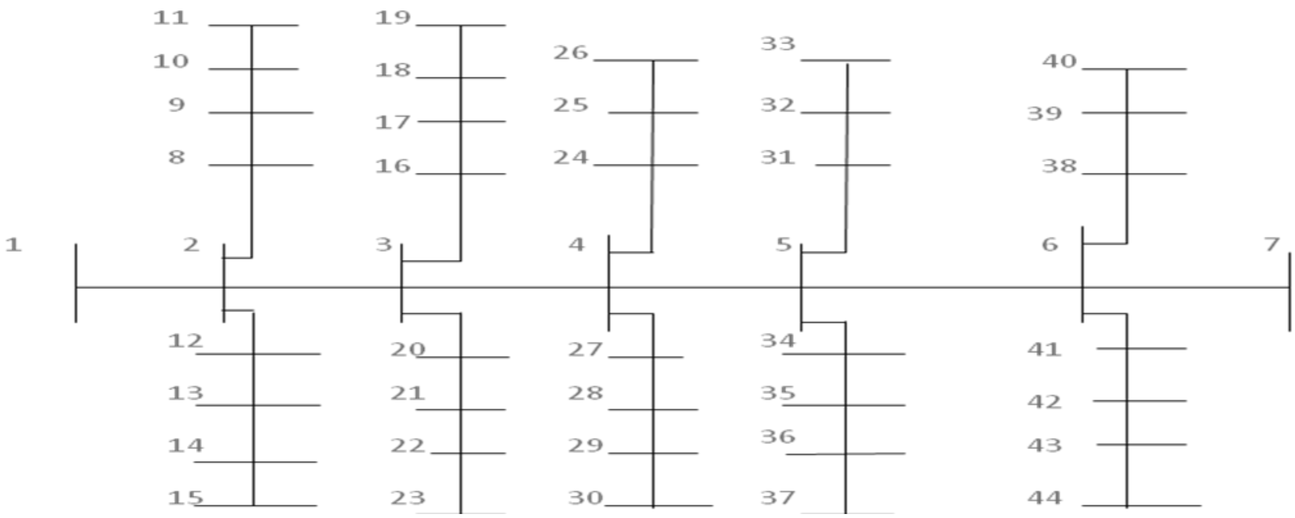

Fig. 3. Single Line Diagram of 44 Bus system under 200 kVA transformer

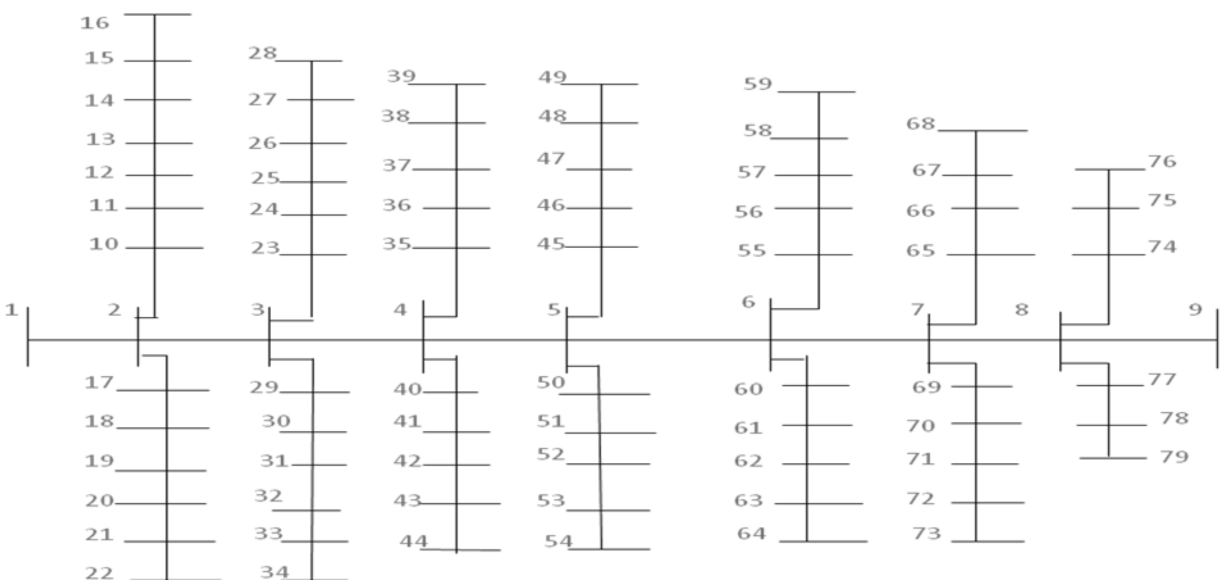

Fig. 4. Single Line Diagram of 79 Bus system under 400 kVA transformer

TABLE II. DATA OF 440 V NETWORK WITH 100 KVA TRANSFORMER AS SOURCE.

Line No.	From	To	Distance	R	x	HP	P load	Q load
							Kw	KVAr
1	1	2	40	0.02484	0.014224	0	0	0
2	2	3	40	0.02484	0.014224	0	0	0
3	3	4	40	0.02484	0.014224	0	0	0
4	4	5	35	0.021735	0.012446	0	0	0
5	2	6	35	0.021735	0.012446	3	2.238	1.678

6	6	7	45	0.027945	0.016002	5	3.73	2.797
7	2	8	35	0.021735	0.012446	5	3.73	2.797
8	8	9	45	0.027945	0.016002	3	2.238	1.678
9	9	10	40	0.02484	0.014224	10	7.46	5.595
10	10	11	45	0.027945	0.016002	7	5.222	3.916
11	3	12	35	0.021735	0.012446	3	2.238	1.678
12	12	13	45	0.027945	0.016002	3	2.238	1.678
13	3	14	35	0.021735	0.012446	3	2.238	1.678
14	14	15	40	0.02484	0.014224	5	3.73	2.797
15	15	16	35	0.021735	0.012446	7	5.222	3.916
16	16	17	40	0.02484	0.014224	12.5	9.325	6.993
17	4	18	35	0.021735	0.012446	3	2.238	1.678
18	18	19	40	0.02484	0.014224	5	3.73	2.797
19	4	20	40	0.02484	0.014224	5	3.73	2.797
20	20	21	45	0.027945	0.016002	5	3.73	2.797
21	21	22	45	0.027945	0.016002	12.5	9.325	6.993
22	22	23	30	0.01863	0.010668	10	7.46	5.595
						107	79.822	59.858

TABLE III. DATA OF 440 V NETWORK WITH 200 KVA TRANSFORMER AS SOURCE.

From	To	Distance	R	x	HP	P load	Q load
						Kw	KVAr
1	2	45	0.027945	0.016002	0	0	0
2	3	35	0.021735	0.012446	0	0	0
3	4	40	0.02484	0.014224	0	0	0
4	5	40	0.02484	0.014224	0	0	0
5	6	35	0.021735	0.012446	0	0	0
6	7	45	0.027945	0.016002	0	0	0
2	8	45	0.027945	0.016002	3	2.238	1.678
8	9	40	0.02484	0.014224	5	3.73	2.797
9	10	35	0.021735	0.012446	3	2.238	1.678
10	11	40	0.02484	0.014224	10	7.46	5.595
2	12	35	0.021735	0.012446	3	2.238	1.678
12	13	40	0.02484	0.014224	3	2.238	1.678
13	14	45	0.027945	0.016002	5	3.73	2.797
14	15	40	0.02484	0.014224	7	5.222	3.916
3	16	35	0.021735	0.012446	3	2.238	1.678
16	17	40	0.02484	0.014224	5	3.73	2.797
17	18	45	0.027945	0.016002	3	2.238	1.678
18	19	30	0.01863	0.010668	12.5	9.325	6.993
3	20	45	0.027945	0.016002	3	2.238	1.678
20	21	40	0.02484	0.014224	5	3.73	2.797

21	22	35	0.021735	0.012446	3	2.238	1.678
22	23	45	0.027945	0.016002	7	5.222	3.916
4	24	40	0.02484	0.014224	5	3.73	2.797
24	25	40	0.02484	0.014224	7	5.222	3.916
25	26	35	0.021735	0.012446	10	7.46	5.595
4	27	45	0.027945	0.016002	3	2.238	1.678
27	28	40	0.02484	0.014224	5	3.73	2.797
28	29	45	0.027945	0.016002	3	2.238	1.678
29	30	40	0.02484	0.014224	7	5.222	3.916
5	31	40	0.02484	0.014224	5	3.73	2.797
31	32	45	0.027945	0.016002	3	2.238	1.678
32	33	35	0.021735	0.012446	12.5	9.325	6.993
5	34	40	0.02484	0.014224	3	2.238	1.678
34	35	40	0.02484	0.014224	5	3.73	2.797
35	36	45	0.027945	0.016002	3	2.238	1.678
36	37	40	0.02484	0.014224	10	7.46	5.595
6	38	35	0.021735	0.012446	5	3.73	2.797
38	39	45	0.027945	0.016002	3	2.238	1.678
39	40	40	0.02484	0.014224	7	5.222	3.916
6	41	40	0.02484	0.014224	3	2.238	1.678
41	42	45	0.027945	0.016002	5	3.73	2.797
42	43	35	0.021735	0.012446	12.5	9.325	6.993
43	44	45	0.027945	0.016002	15	11.19	8.3925
			TOTAL		212.5	158.525	118.8765

TABLE IV. DATA OF 440 V NETWORK WITH 400 KVA TRANSFORMER AS SOURCE.

Line No.	From Bus	To Bus	Length	Resistance	Reactance	HP	P-load	Q-load
1	1	2	40	0.02484	0.014224	0	0	0
2	2	3	45	0.027945	0.016002	0	0	0
3	3	4	35	0.021735	0.012446	0	0	0
4	4	5	40	0.02484	0.014224	0	0	0
5	5	6	45	0.027945	0.016002	0	0	0
6	6	7	35	0.021735	0.012446	0	0	0
7	7	8	40	0.02484	0.014224	0	0	0
8	8	9	35	0.021735	0.012446	0	0	0
9	2	10	45	0.027945	0.016002	3	2.238	1.6785
10	10	11	40	0.02484	0.014224	5	3.73	2.7975
11	11	12	**35**	0.021735	0.012446	3	2.238	1.6785
12	12	13	45	0.027945	0.016002	7	5.222	3.9165
13	13	14	45	0.027945	0.016002	3	2.238	1.6785
14	14	15	40	0.02484	0.014224	5	3.73	2.7975
15	15	16	35	0.021735	0.012446	15	11.19	8.3925
16	2	17	40	0.02484	0.014224	3	2.238	1.6785

17	17	18	45	0.027945	0.016002	3	2.238	1.6785
18	18	19	35	0.021735	0.012446	7	5.222	3.9165
19	19	20	40	0.02484	0.014224	3	2.238	1.6785
20	20	21	35	0.021735	0.012446	3	2.238	1.6785
21	21	22	45	0.027945	0.016002	12.5	9.325	6.99375
22	3	23	35	0.021735	0.012446	5	3.73	2.7975
23	23	24	40	0.02484	0.014224	7	5.222	3.9165
24	24	25	35	0.021735	0.012446	5	3.73	2.7975
25	25	26	40	0.02484	0.014224	3	2.238	1.6785
26	26	27	45	0.027945	0.016002	3	2.238	1.6785
27	27	28	35	0.021735	0.012446	5	3.73	2.7975
28	3	29	40	0.02484	0.014224	3	2.238	1.6785
29	29	30	35	0.021735	0.012446	3	2.238	1.6785
30	30	31	45	0.027945	0.016002	7	5.222	3.9165
31	31	32	45	0.027945	0.016002	3	2.238	1.6785
32	32	33	40	0.02484	0.014224	10	7.46	5.595
33	33	34	40	0.02484	0.014224	12.5	9.325	6.99375
34	4	35	35	0.021735	0.012446	10	7.46	5.595
35	35	36	45	0.027945	0.016002	5	3.73	2.7975
36	36	37	40	0.02484	0.014224	3	2.238	1.6785
37	37	38	45	0.027945	0.016002	7	5.222	3.9165
38	38	39	35	0.021735	0.012446	5	3.73	2.7975
39	4	40	40	0.02484	0.014224	3	2.238	1.6785
40	40	41	45	0.027945	0.016002	7	5.222	3.9165
41	41	42	40	0.02484	0.014224	3	2.238	1.6785
42	42	43	35	0.021735	0.012446	10	7.46	5.595
43	43	44	45	0.027945	0.016002	5	3.73	2.7975
44	5	45	35	0.021735	0.012446	7	5.222	3.9165
45	45	46	40	0.02484	0.014224	5	3.73	2.7975
46	46	47	45	0.027945	0.016002	7	5.222	3.9165
47	47	48	35	0.021735	0.012446	5	3.73	2.7975
48	48	49	**35**	0.021735	0.012446	12.5	9.325	6.99375
49	5	50	40	0.02484	0.014224	5	3.73	2.7975
50	50	51	35	0.021735	0.012446	7	5.222	3.9165
51	51	52	45	0.027945	0.016002	3	2.238	1.6785
52	52	53	40	0.02484	0.014224	5	3.73	2.7975
53	53	54	40	0.02484	0.014224	5	3.73	2.7975
54	6	55	35	0.021735	0.012446	7	5.222	3.9165
55	55	56	45	0.027945	0.016002	5	3.73	2.7975
56	56	57	35	0.021735	0.012446	7	5.222	3.9165
57	57	58	40	0.02484	0.014224	5	3.73	2.7975
58	58	59	35	0.021735	0.012446	12.5	9.325	6.99375
59	6	60	45	0.027945	0.016002	5	3.73	2.7975
60	60	61	40	0.02484	0.014224	7	5.222	3.9165
61	61	62	40	0.02484	0.014224	3	2.238	1.6785
62	62	63	35	0.021735	0.012446	10	7.46	5.595
63	63	64	45	0.027945	0.016002	5	3.73	2.7975
64	7	65	40	0.02484	0.014224	3	2.238	1.6785
65	65	66	35	0.021735	0.012446	3	2.238	1.6785

66	66	67	45	0.027945	0.016002	5	3.73	2.7975
67	67	68	40	0.02484	0.014224	12.5	9.325	6.99375
68	7	69	40	0.02484	0.014224	15	11.19	8.3925
69	69	70	35	0.021735	0.012446	3	2.238	1.6785
70	70	71	45	0.027945	0.016002	3	2.238	1.6785
71	71	72	35	0.021735	0.012446	5	3.73	2.7975
72	72	73	45	0.027945	0.016002	15	11.19	8.3925
73	8	74	35	0.021735	0.012446	10	7.46	5.595
74	74	75	40	0.02484	0.014224	3	2.238	1.6785
75	75	76	40	0.02484	0.014224	10	7.46	5.595
76	8	77	45	0.027945	0.016002	3	2.238	1.6785
77	77	78	40	0.02484	0.014224	10	7.46	5.595
78	78	79	40	0.02484	0.014224	3	2.238	1.6785
			TOTAL			**428.5**	**319.661**	**239.7458**

TABLE V. VOLTAGE PROFILE ON ALL THE THREE BUS SYTESMS

Bus No	23 Bus System	44 Bus system	79 Bus System	Bus No.	44 Bus system	79 Bus System
1	1	1	1	41	0.8942	0.9396
2	0.9847	0.964	0.9774	42	0.8885	0.9386
3	0.9741	0.941	0.9561	43	0.8847	0.9379
4	0.9683	0.9207	0.9425	44	0.8821	0.9376
5	0.9683	0.9065	0.9301	45		0.9283
6	0.9838	0.8997	0.9197	46		0.9268
7	0.983	0.8997	0.9148	47		0.9253
8	0.9817	0.9606	0.9127	48		0.9245
9	0.9785	0.958	0.9127	49		0.9239
10	0.9761	0.9564	0.975	50		0.9287
11	0.975	0.9549	0.9731	51		0.9278
12	0.9734	0.9618	0.9716	52		0.927
13	0.9729	0.9596	0.9699	53		0.9265
14	0.9707	0.9577	0.9686	54		0.9262
15	0.9672	0.9567	0.9676	55		0.918
16	0.9648	0.9379	0.9669	56		0.9162
17	0.963	0.9349	0.9758	57		0.9151
18	0.9673	0.9323	0.9742	58		0.9141
19	0.9666	0.9309	0.973	59		0.9135
20	0.9636	0.938	0.9721	60		0.9179
21	0.9592	0.9358	0.9714	61		0.9166
22	0.9555	0.9345	0.9707	62		0.9156
23	0.9544	0.9333	0.9548	63		0.9149
24		0.9174	0.9536	64		0.9146
25		0.9149	0.9529	65		0.9136
26		0.9135	0.9523	66		0.9126

27		0.9177	0.9518	67		0.9115
28		0.9154	0.9516	68		0.9108
29		0.9137	0.9541	69		0.9126
30		0.9127	0.9524	70		0.9114
31		0.9034	0.9505	71		0.91
32		0.9007	0.9491	72		0.909
33		0.8991	0.9479	73		0.9081
34		0.9033	0.9472	74		0.9116
35		0.9006	0.9411	75		0.9109
36		0.8983	0.9399	76		0.9104
37		0.8968	0.9392	77		0.9117
38		0.8977	0.9384	78		0.911
39		0.8959	0.9382	79		0.9109
40		0.8949	0.941			

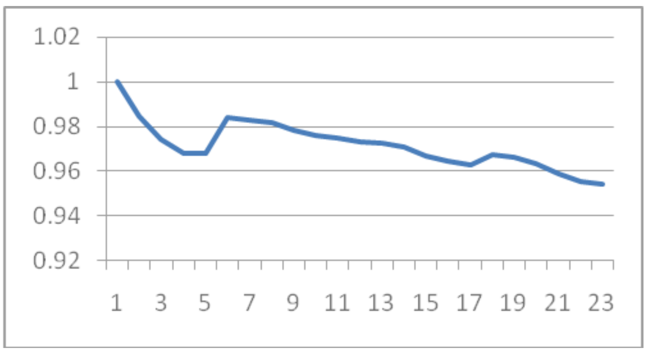

Fig. 4. Voltage Profile on 23 Bus System

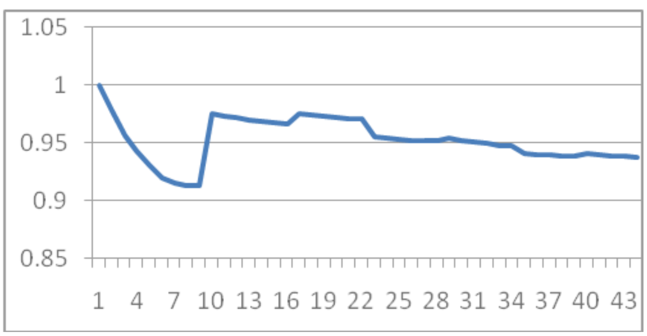

Fig. 5. Voltage Profile on 44 Bus System

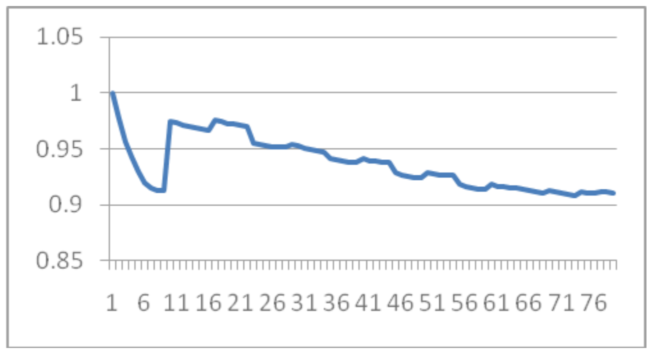

Fig. 6. Voltage Profile on 79 Bus System

IV CONCLUSIONS

Three bus systems with 23, 44, 79 bus systems were proposed for conducting the studies on low voltage agricultural distribution systems at 440V level. The losses are observed to increase with size of the system. The active power losses and voltage profiles were observed on all the systems. More studies are needed to determine the total number of pumps, total energy consumed in agricultural sector, average pump rating of an agricultural pump. These studies are necessary to improve the efficiency of the system and to decrease the active power losses on distribution systems in India.

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K. V. S .Ramachandra Murthy did his graduation in Electrical Engineering and M. Tech in Power Systems from R.I.T., Jamshedpur in 1994 and 2002 respectively. He is pursuing his Ph.D. from J.N.T.U.K, Kakinada, India.

K. Manikanta born in Ongole and did his graduation in Electrical Engineering from C.R.R.college of engineering ELURU W.G,A.P and pursuing M.Tech in Power System control and Automation from G.V.P.College of Engineering, Visakhapatnam, A.P.in 2006-2012 respectively