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Demand Re-Allocation in Conjunction with Feeder Input Power using Iterative Power Flows Method

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***Abstract:** The aim of this paper is to introduce the demand re-allocation process (demand estimation) in conjunction with feeder input complex power for Unbalanced Radial Distribution System (URDS) with mutual impedances using Iterative Power Flows (IPFS) method. The proposed method in this paper is to compute the individual loads on each phase in conjunction with the feeder telemetered complex power input and with the help of backward forward sweep power flow method calculate iteratively nodal voltages and total losses per phase on the feeder. The practical 8 bus and 55 bus unbalanced radial distribution systems with mutual impedances are used to describe the novelty of the proposed algorithm. The simulation results in terms of new individual demands, bus voltages and total per phase losses are summarized. The bus voltages with iterative power flows method are compared with direct approach power flow method results.*

***Key Words:** backward forward sweep, iterative power flows method, demand estimation*

I. INTRODUCTION

The loads connected to the feeders in distribution system are generally multi phase, unbalanced and distributed loads with non uniform load curves. A part from this, it has feeders with "high R/X ratios, huge number of branches and radial in structure". This makes the distribution system into complex and the direct methods using for power-flow solution of transmission system [1] are unable to meet that of distribution system (DS) without some assumptions. These methods are falling short to accomplish distribution system in both performance and robustness aspects. A Generalized Distribution Analysis Systems program has been developed in [2]. But most part of these methods is derived from the conventional load flow methods. For finding out the power flow solution of the radial distribution network, several researchers focused on some techniques and those are available in the literature [3]-[18]. For real time analysis of primary distribution system, a three-phase power flow method has been described in [7]. In [8] direct approach method for unbalanced three-phase distribution load flow solutions is developed. However to the best of our knowledge, most of the researchers prefer Backward Forward Sweep (BFS) algorithm to find the power flow solution for (multi phase) unbalanced distribution system as this method is fast and gives accurate results. Detailed literature on this algorithm is given in [19]-[22].

Demand estimation is a process in distribution system where the individual loads on the distribution system feeder are computed based on the known telemetered feeder input because of the metering available in the substation. In most of the cases, the telemetered data will be complex kW and kVAr values. It is desirable to force the computed input complex power of the feeder to match the feeder telemetered input.

The demand/load allocation to the new substation is computed in such a way that minimum loss, minimum investment cost, high reliability, satisfactory voltage regulation, etc., can be met and is explained in [23]. The pseudo measurements obtained by initial Load/Generation allocation are re-adjusted in [24]. In [25] the power system has been sectionalized as a main branch and some sub-branch for demand allocation. The [26] describes the different methods by which distribution transformer loads can be allocated for power-flow studies. A least-squares estimator is formulated to split the total load measured at the head of a distribution feeder into a set of individual loads served by those transformers connected to the feeder [27]. A survey on different load /demand estimation methods is in [28]. However to the best of our knowledge, paper(s) relevant to demand estimation in conjunction with feeder telemetered complex input power of unbalanced radial distribution system with mutual impedances is not available in the literature.

The main objective of this paper is to compute the individual loads on each phase in conjunction with the feeder telemetered complex power input and with the help of backward forward sweep power flow method calculate iteratively nodal voltages and total losses per phase on the feeder of unbalanced radial distribution system with mutual impedances.

II. BACKWARD FORWARD SWEEP POWER FLOWS METHOD

Practically most of the loads of feeders in DS are unbalanced loads. Figure 1 shows an unbalanced three phase distribution system model with mutual impedances.

In above equation, terminating end voltages (Va, Vb & Vc) are expressed in terms of sending end voltages (V_A, V_B &V_C) and branch currents flows (Ia, Ib, & Ic) in three phase matrix form.

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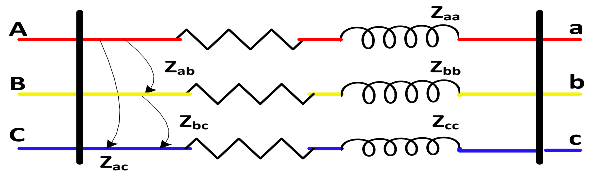

Fig. 1.Unbalanced 3 phase distribution system model

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \begin{bmatrix} VA \\ VB \\ VC \end{bmatrix} - \begin{bmatrix} Zaa-n & Zan-n & Zac-n \\ Zbb-n & Zbc-n & Zba-n \\ Zca-n & Zcb-n & Zcc-n \end{bmatrix} * \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad (1)$$

Branch Currents to Bus Voltages (BCBV) and Bus Injections to Branch Currents (BIBC) matrices together are used to get power-flow solution of DS in case of balanced network. Unlike balanced loads, the calculations of electrical properties of unbalanced three phase circuits become more complicated. For unbalanced distribution system mostly using method is backward forward sweep algorithm. The main focus of backward sweep is to "calculate branch currents" and forward sweep is to "calculate the voltages at each node using the currents of backward sweep".

III. BACKWARD FORWARD SWEEP METHOD WITH SIMPLE 3 NODES LATERAL

As said in section 2, the main focus of backward sweep is to "calculate branch currents" and forward sweep is to "calculate the voltages at each node using the calculated currents of backward sweep" [18].

BFS is an iterative process so the convergence criteria can be checked at the end of each and every iteration. This iterative process terminates whenever it meets the convergence criteria. "The BFS iterative process stops when the total voltage mismatch is less than the specified tolerance by comparing the calculated voltages in previous and present iterations". Otherwise the procedure is repeated until the solution is converged.

Consider a single phase lateral as in Fig.2 [18]. The branch 1-2 impedance is 0.1705+j0.3409 Ω and that of branch 2-3 is 0.2273+j0.4545Ω. The complex loads are S_2=1500+j750 and S_3=900+j500. All the loads real power is in kW and reactive power is in kVar. The Node 1 voltage is 7200 at an angle of 0 deg.

A bus is said to be 'terminal bus' if only one bus is connected to it. A terminal bus is the point where bus route ends. Generally terminal bus is placed at last in the network (far away from source). On the other hand, a bus is said to be junction bus if minimum two buses are connected to it. In Fis.2, bus 2 is junction bus and bus 3 is terminal bus.

The backward sweep begins by assuming Node 3 voltage (terminal bus voltage) is equal to Node 1 voltage (feeder voltage at substation): V_3=7200+0.00j

The load current at Node "n" is given in equation (2).

In=(Sn/Vn)* (2)

From equation (2), the load current at Node 3 is

$I_3 = (S_3/V_3)^* = (900 - j500) * (1000/7200)$

The current flowing in section 2-3 is

$I_{2-3} = I_3 = 125 - 69.44\,j = 143\angle -29$ A

The voltage at Node 2 = $V_2 = V_3 + Z_{2-3} * I_3$

V_2= 7259.9+41.08j

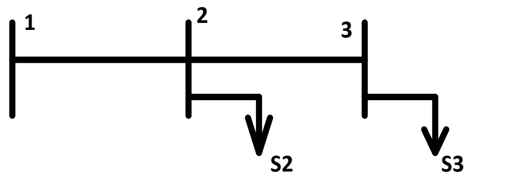

Fig. 2. A single phase lateral with three nodes

The load current at Node 2 is I_2.

$I_2 = (S_2/V_2)^* = (1500 - j750) * (1000/(7259.9 + 41.08j\ )$

I_2= 205.96-104.4j=230.9$\angle -26.8$ A

The current flowing in section 1-2= $I_{1-2} = I_{2-3} + I_2$

$I_{1-2} =\ \ 373.8\angle -27.6$ A

The voltage at source node = $V_1 = V_2 + Z_{1-2} * I_{1-2}$

Voltage at source node (V1) = 7376.2 V

Error=$(Vn)_i$-$(Vn)_{(i-1)}$ (3)

Where "i" is the iteration number.

Here error= $(V_1)_{\mathbf{1st\ iteration}}$ - $(V_1)_{\mathbf{zero\ iteration}}$

Error = 7376.2 -7200=176.2V

Here the error is more than 0.0001 (assumed value).

So the forward sweep begins with the assumption

$V_1 = 7200\angle 0.0$ V.

Now

$V_2 = V_1 - Z_{1-2} * I_{1-2} = 7085.4\angle -0.68$; $V_3 = V_2 - Z_{2-3} * I_{2-3} = 7026.0\angle -1.02$ V

This completes one iteration. Now backward sweep begins with computed voltage (at node 3) in forward sweep rather than the initially assumed value. This process repeats until the solution is converged

IV. DEMAND ESTIMATION (DE) WITH ITERATIVE POWER FLOWS METHOD

The SCADA measurements (in kW and kVAr) of individual 3-phase feeder for each substation are sent to the DMS control centre for every 5 seconds. The 3-phase individual loads (in kW and kVAr) on each feeder are assumed to be calculated through historical data. With the SCADA kW and kVAr measurements, and the individual loads in kW and kVAr available through historical data, the new kW and kVAr of the individual loads are computed. This computation methodology is explained below.

Assume

B= previous iteration computed individual complex demand (load) per phase

Note: ***For the first iteration, B value is taken from the available historical data***.

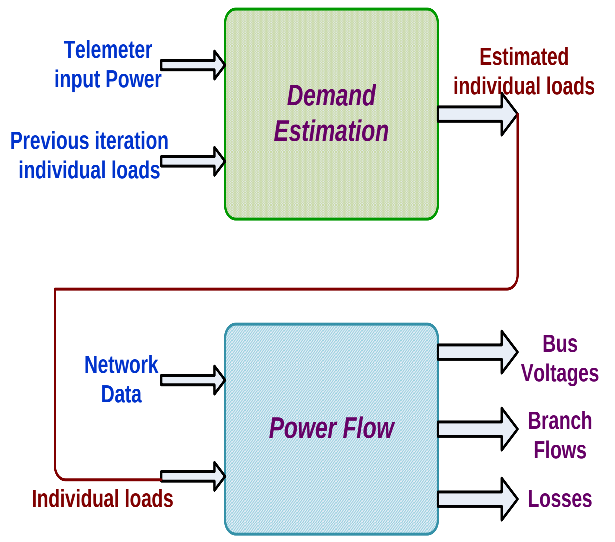

Fig. 3. Block diagram of connecting Demand Estimation and Power Flow

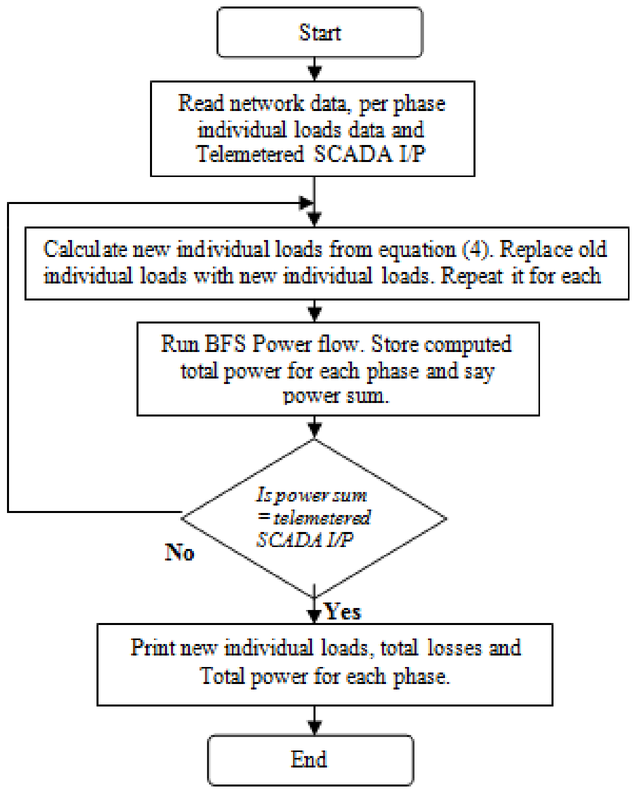

Fig. 4. Flow chart of demand estimation with iterative power flows method

C=Telemetered input total complex power per phase

D=previous iteration computed total complex demand per phase

Then new computed individual complex demand per phase for the current iteration is given below:

$$A=B+[C-D]*(B/D) \quad (4)$$

With the help of equation 4, new value of the demand is estimated. The above procedure is explained with a simple example and is given below.

Consider two loads in phase A of 3-phase unbalanced feeder as L_1=0.5+0.7i and L_2=0.8+0.9i PU/phase. Assume the telemetered SCADA value at the input of the feeder is 1.5+ 2i PU/phase. Now new L_1 and L_2 are calculated as below:

A=new value of L_1
B=0.5+0.7i (old value of L_1)
C=1.5+2i (telemetered SCADA value)
D= (0.5+0.7i) + (0.8+0.9i) =1.3+1.6i
New value of L_1=A= B+[C-D]*B/D
B/D= (0.5+0.7i)/ (1.3+1.6i)
C-D= (1.5+2i) - (1.3+1.6i)
A=B+[C-D]*B/D=0.572+0.870i PU.

Similarly all individual new demands are estimated. With these updated loads, each bus voltage, branch flows and total per phase losses are calculated using MDA power flow method. Now B and D are replaced with the current iteration computed values. It completes one iteration. This process is repeated until the computed total demand per phase is equal to the telemetered SCADA input power per phase. Once this is achieved, total power losses per phase are calculated. The sum of total calculated power loss per phase and total demand per phase is equal to telemetered SCADA input power per phase. The advantage of proposed method is the demand estimation and power flows are computed together where as in practice, demand estimation is computed first and followed by the calculation of power flows. The block diagram for above methodology is shown in figure 3 and the flow chart is shown in figure 4.

V. SIMULATION RESULTS

The 8 bus and 55 bus 3-ø Unbalanced Radial Distribution Systems (URDS) with mutual impedances are considered in matlab simulation environment for demand estimation with iterative power flow method. The 8 bus URDS data is taken from [17] and 55 bus URDS data is given in appendix A. By using backward forward sweep power flow method, total power per phase is computed and it is compared with telemetered SCADA input power. This process repeats until total computed power is equal to the telemetered SCADA input power. Hence it is called Iterative Power Flow (IPF) method. The voltage and angles of 8 bus and 55 bus URDS with IPF method are tabulated in table 1 and 4 respectively. Telemetered and computed total power variation in each iteration per phase in DE with iterative power flow method is given in table 2 and 5 for 8 bus and 55 bus URDS respectively. Telemetered power, computed total demand and total loss per phase in DE with iterative power flow method for 8 bus and 55 bus URDS are listed in tables 3 and 6 respectively. In figure 5, old demands and estimated demands of 55 bus 3-phase unbalanced radial distribution system with mutual impedances with iterative power flow method are compared.

From the results, it is clear that, voltage profile with iterative power flows method is same as in [17]. The computed total power is settled in 3 iterations to match the feeder telemetered complex power input. Figure 5 indicates that per phase individual demand new values are estimated successfully.

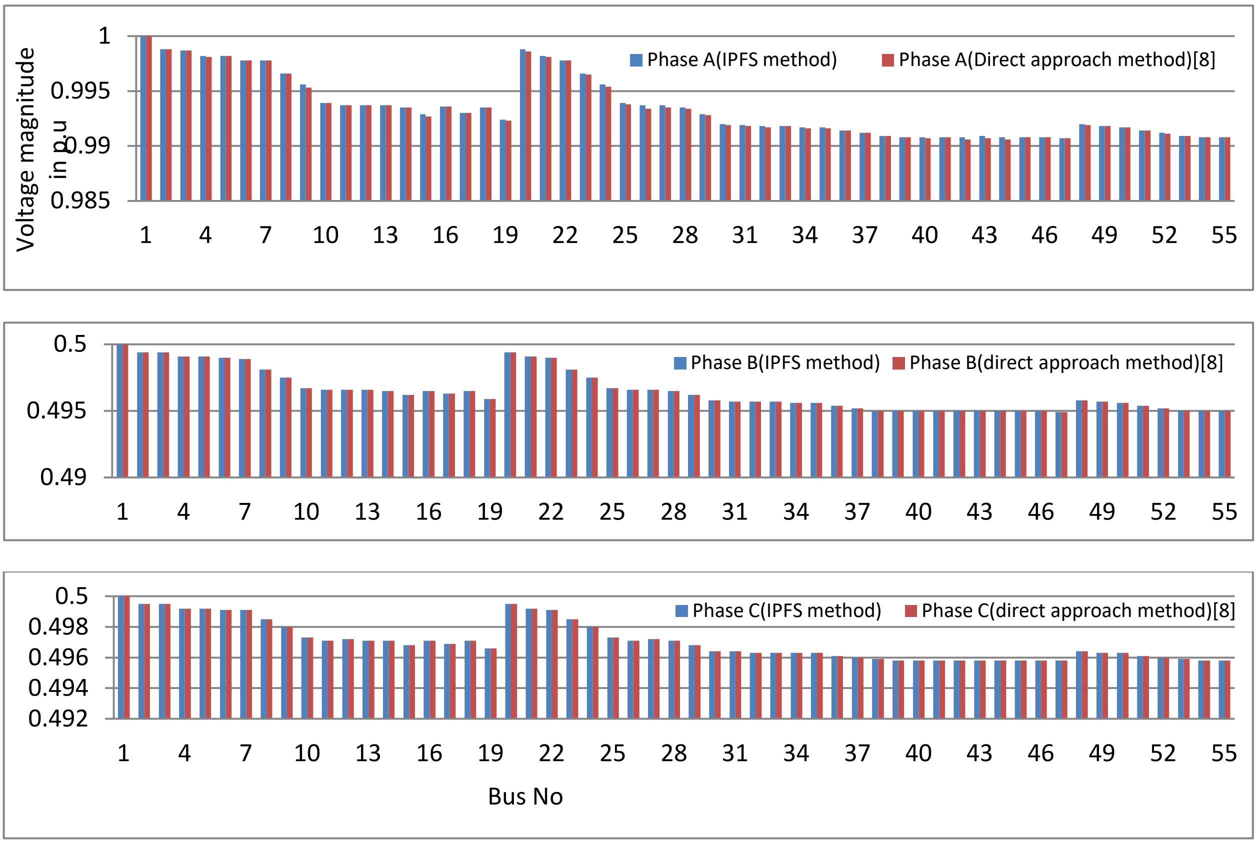

Fig. 5.Comparison of phase voltages with iterative power flows method and direct power flows method [8]

Table- I: Voltage and angles of 8 bus URDS with IPF method

Bus No	Voltages (PU)		
	Va	Vb	Vc
1	1.0000+0.0000i	-0.5000-0.8660i	-0.5000+0.8660i
2	0.9834 + 0.0054i	-0.4877 - 0.8561i	-0.4972 + 0.8495i
3	0.9826 + 0.0056i	-0.4873 - 0.8560i	-0.4971 + 0.8488i
4	0.9756 + 0.0080i	-0.4817 - 0.8512i	-0.4958 + 0.8416i
5	0.9755 + 0.0081i	-0.4816 - 0.8511i	-0.4958 + 0.8415i
6	0.9705 + 0.0097i	-0.4779 - 0.8480i	-0.4949 + 0.8365i
7	0.9702 + 0.0097i	-0.4777 - 0.8479i	-0.4949 + 0.8363i
8	0.9558 + 0.0101i	-0.4685 - 0.8404i	-0.4901 + 0.8234i

Table- II: Total telemetered powers and computed total power variation in each iteration of each phase in DE with IPF method for 8 bus URDS

Telemetered SCADA value	Iteration-1	Iteration -2	Iteration -3	Iteration Count
Phase A : 0.4500 + 0.2000i	0.4000 + 0.1500i	0.4200 + 0.1800i	0.4500 + 0.2000i	3
Phase B: 0.4000 + 0.1800i	0.3000 + 0.1200i	0.3500 + 0.1500i	0.4000 + 0.1800i	3
Phase C: 0.4200 + 0.1900i	0.3500 + 0.1300i	0.3900 + 0.1700i	0.4200 + 0.1900i	3

Table- III: Telemetered power, computed total demand and total loss per phase in DE with iterative power flows method for 8 bus URDS

Telemetered SCADA value (S_{in}) In PU	Computed Total Demand (T.D) in PU	Computed Total power loss(T.L) in PU	Error= (S_{in}) – (T.P+T.L)
Phase A: 0.4500 + 0.2000i	0.3981 + 0.1920 i	0.0519 + 0.0080 i	0.0+0.0 i
Phase B: 0.4000 + 0.1800i	0.3579 + 0.1779 i	0.0421 + 0. 0021i	0.0+0.0 i
Phase C: 0.4200 + 0.1900i	0.3729 + 0.1866 i	0.0471 + 0.0034 i	0.0+0.0 i

Table- IV: Bus voltages of 55 bus URDS with IPF method

Bus No	Voltages (PU)		
	Va	Vb	Vc
1	1.0000+0.0000i	-0.5000-0.8660i	-0.5000+0.8660i
2	0.9834 + 0.0054i	-0.4877 - 0.8561i	-0.4972 + 0.8495i
3	0.9826 + 0.0056i	-0.4873 - 0.8560i	-0.4971 + 0.8488i
4	0.9756 + 0.0080i	-0.4817 - 0.8512i	-0.4958 + 0.8416i
5	0.9755 + 0.0081i	-0.4816 - 0.8511i	-0.4958 + 0.8415i
6	0.9705 + 0.0097i	-0.4779 - 0.8480i	-0.4949 + 0.8365i
7	0.9702 + 0.0097i	-0.4777 - 0.8479i	-0.4949 + 0.8363i
8	0.9558 + 0.0101i	-0.4685 - 0.8404i	-0.4901 + 0.8234i
9	0.9415 + 0.0149i	-0.4575 - 0.8314i	-0.4875 + 0.8088i
10	0.9183 + 0.0226i	-0.4400 - 0.8171i	-0.4832 + 0.7853i
11	0.9150 + 0.0237i	-0.4374 - 0.8151i	-0.4825 + 0.7818i
12	0.9149 + 0.0237i	-0.4373 - 0.8149i	-0.4826 + 0.7818i
13	0.9147 + 0.0238i	-0.4371 - 0.8149i	-0.4824 + 0.7813i
14	0.9129 + 0.0244i	-0.4359 - 0.8138i	-0.4822 + 0.7797i
15	0.9045 + 0.0271i	-0.4295 - 0.8085i	-0.4807 + 0.7714i
16	0.9142 + 0.0241i	-0.4367 - 0.8142i	-0.4825 + 0.7811i
17	0.9060 + 0.0266i	-0.4308 - 0.8098i	-0.4810 + 0.7730i
18	0.9126 + 0.0245i	-0.4356 - 0.8136i	-0.4821 + 0.7794i
19	0.8964 + 0.0297i	-0.4235 - 0.8035i	-0.4793 + 0.7635i
20	0.8907 + 0.0315i	-0.4194 - 0.8001i	-0.4783 + 0.7578i
21	0.8898 + 0.0317i	-0.4190 - 0.7999i	-0.4782 + 0.7571i
22	0.8884 + 0.0324i	-0.4175 - 0.7984i	-0.4778 + 0.7555i
23	0.8882 + 0.0324i	-0.4174 - 0.7984i	-0.4778 + 0.7554i
24	0.8870 + 0.0328i	-0.4164 - 0.7975i	-0.4776 + 0.7540i
25	0.8866 + 0.0329i	-0.4162 - 0.7973i	-0.4775 + 0.7538i
26	0.8834 + 0.0329i	-0.4139 - 0.7953i	-0.4763 + 0.7508i
27	0.8801 + 0.0341i	-0.4111 - 0.7929i	-0.4756 + 0.7472i
28	0.8757 + 0.0358i	-0.4073 - 0.7897i	-0.4745 + 0.7422i
29	0.8751 + 0.0360i	-0.4068 - 0.7894i	-0.4743 + 0.7415i
30	0.8750 + 0.0360i	-0.4068 - 0.7892i	-0.4744 + 0.7416i
31	0.8748 + 0.0361i	-0.4065 - 0.7891i	-0.4742 + 0.7410i
32	0.8748 + 0.0360i	-0.4067 - 0.7892i	-0.4743 + 0.7413i
33	0.8740 + 0.0364i	-0.4059 - 0.7884i	-0.4742 + 0.7405i
34	0.8743 + 0.0363i	-0.4061 - 0.7885i	-0.4743 + 0.7408i
35	0.8745 + 0.0361i	-0.4065 - 0.7891i	-0.4743 + 0.7410i
36	0.8745 + 0.0361i	-0.4064 - 0.7890i	-0.4742 + 0.7409i
37	0.8735 + 0.0366i	-0.4055 - 0.7879i	-0.4741 + 0.7400i
38	0.9004 + 0.0284i	-0.4267 - 0.8064i	-0.4800 + 0.7674i
39	0.8995 + 0.0285i	-0.4263 - 0.8063i	-0.4799 + 0.7667i
40	0.8981 + 0.0292i	-0.4249 - 0.8048i	-0.4796 + 0.7651i
41	0.8979 + 0.0292i	-0.4248 - 0.8047i	-0.4796 + 0.7650i
42	0.8967 + 0.0297i	-0.4237 - 0.8039i	-0.4794 + 0.7637i
43	0.8964 + 0.0297i	-0.4236 - 0.8037i	-0.4793 + 0.7634i
44	0.8931 + 0.0298i	-0.4213 - 0.8017i	-0.4782 + 0.7604i
45	0.8899 + 0.0310i	-0.4185 - 0.7994i	-0.4774 + 0.7569i
46	0.8855 + 0.0326i	-0.4148 - 0.7962i	-0.4764 + 0.7520i
47	0.8849 + 0.0328i	-0.4143 - 0.7959i	-0.4762 + 0.7512i
48	0.8849 + 0.0329i	-0.4142 - 0.7957i	-0.4763 + 0.7513i
49	0.8846 + 0.0330i	-0.4139 - 0.7956i	-0.4761 + 0.7508i
50	0.8847 + 0.0329i	-0.4141 - 0.7958i	-0.4762 + 0.7510i
51	0.8839 + 0.0333i	-0.4133 - 0.7949i	-0.4760 + 0.7502i
52	0.8842 + 0.0332i	-0.4135 - 0.7950i	-0.4761 + 0.7506i
53	0.8844 + 0.0330i	-0.4139 - 0.7956i	-0.4762 + 0.7508i
54	0.8844 + 0.0330i	-0.4138 - 0.7955i	-0.4761 + 0.7507i
55	0.8834 + 0.0335i	-0.4129 - 0.7945i	-0.4760 + 0.7498i

VI. CONCLUSIONS

In most of the cases, the telemetered data will be complex kW and kVAr values. It is desirable to force the computed input complex power of the feeder to match the feeder telemetered input.In this paper, the demand estimation process for unbalanced radial distribution system with mutual impedances using iterative power flow method was introduced. The proposed method was applied on 8 bus and 55 bus three phase unbalanced radial distribution systems with mutual impedances in matlab simulation environment. The individual loads on each phase in conjunction with the feeder telemetered complex power input were computed and with the help of backward forward sweep power flow method iteratively nodal voltages and total losses per phase on the feeder were calculated successfully.

Table- V: Total telemetered powers and computed total power variation in each iteration of each phase in DE with IPF method for 55 bus URDS

Telemetered SCADA value	Iteration-1	Iteration -2	Iteration -3	Iterations Count
Phase A : 0.4500 + 0.2000i	0.4100 + 0.1500i	0.4300 + 0.1700i	0.4500 + 0.2000i	3
Phase B: 0.4000 + 0.1800i	0.3200 + 0.1400i	0.3800 + 0.1700i	0.4000 + 0.1800i	3
Phase C: 0.4200 + 0.1900i	0.3800 + 0.15200i	0.4150 + 0.1860i	0.4200 + 0.1900i	3

Table- VI: Telemetered power, computed total demand and total loss per phase in DE with iterative power flow method for 55 bus URDS

Telemetered SCADA value (S_{in}) In PU	Computed TotalDemand (C.T.D) in PU	Computed Total power loss(T.L) in PU	Error=(S_{in}) –(C.T.P+T.L)
Phase A 0.4500 + 0.2000i	0.3729 + 0.1866 i	0.0471 + 0.0034 i	0.0+0.0 i
Phase B 0.4000 + 0.1800i	0.3981 + 0.1920 i	0.0519 + 0.0080 i	0.0+0.0 i
Phase C 0.4200 + 0.1900i	0.3579 + 0.1779 i	0.0421 +0. 0021i	0.0+0.0 i

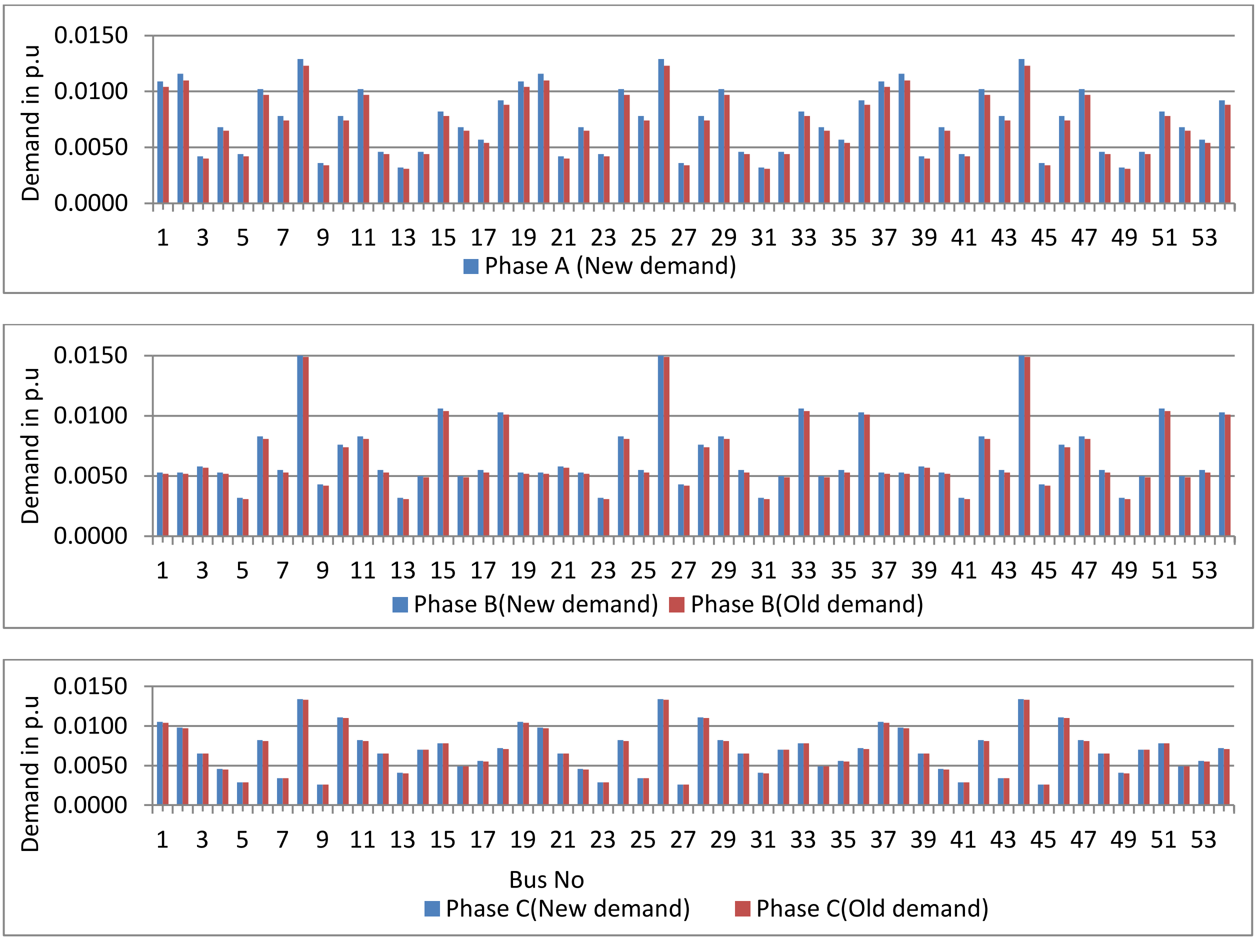

Fig. 6.Comparing new & old demands of 55 bus URDS

APPENDIX

Table- VII: Bus data of 55 bus 3-phase unbalanced radial network

Bus No	SA	SB	SC
1	0.00000+0.00000i	0.00000+0.00000i	0.00000+0.00000i
2	0.01038+0.00501i	0.00519+0.00252i	0.01038+0.00501i
3	0.01101+0.00534i	0.00519+0.00252i	0.00972+0.00471i
4	0.00405+0.00195i	0.00567+0.00276i	0.00648+0.00315i
5	0.00648+0.00315i	0.00519+0.00252i	0.00453+0.00219i
6	0.00420+0.00204i	0.00309+0.00150i	0.00291+0.00141i
7	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i
8	0.00744+0.00360i	0.00534+0.00258i	0.00339+0.00165i
9	0.01230+0.00597i	0.01491+0.00723i	0.01329+0.00642i
10	0.00339+0.00165i	0.00420+0.00204i	0.00258+0.00126i
11	0.00744+0.00360i	0.00744+0.00360i	0.01101+0.00534i
12	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i

13	0.00438+0.00213i	0.00534+0.00258i	0.00648+0.00315i
14	0.00309+0.00150i	0.00309+0.00234i	0.00405+0.00195i
15	0.00438+0.00213i	0.00486+0.00234i	0.00696+0.00336i
16	0.00777+0.00378i	0.01038+0.00501i	0.00777+0.00378i
17	0.00648+0.00315i	0.00486+0.00234i	0.00486+0.00234i
18	0.00543+0.00258i	0.00534+0.00258i	0.00552+0.00267i
19	0.00876+0.00423i	0.01005+0.00486i	0.00714+0.00345i
20	0.01038+0.00501i	0.00519+0.00252i	0.01038+0.00501i
21	0.01101+0.00534i	0.00519+0.00252i	0.00972+0.00471i
22	0.00405+0.00195i	0.00567+0.00276i	0.00648+0.00315i
23	0.00648+0.00315i	0.00519+0.00252i	0.00453+0.00219i
24	0.00420+0.00204i	0.00309+0.00150i	0.00291+0.00141i
25	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i
26	0.00744+0.00360i	0.00534+0.00258i	0.00339+0.00165i
27	0.01230+0.00597i	0.01491+0.00723i	0.01329+0.00642i
28	0.00339+0.00165i	0.00420+0.00204i	0.00258+0.00126i
29	0.00744+0.00360i	0.00744+0.00360i	0.01101+0.00534i
30	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i
31	0.00438+0.00213i	0.00534+0.00258i	0.00648+0.00315i
32	0.00309+0.00150i	0.00309+0.00234i	0.00405+0.00195i
33	0.00438+0.00213i	0.00486+0.00234i	0.00696+0.00336i
34	0.00777+0.00378i	0.01038+0.00501i	0.00777+0.00378i
35	0.00648+0.00315i	0.00486+0.00234i	0.00486+0.00234i
36	0.00543+0.00258i	0.00534+0.00258i	0.00552+0.00267i
37	0.00876+0.00423i	0.01005+0.00486i	0.00714+0.00345i
38	0.01038+0.00501i	0.00519+0.00252i	0.01038+0.00501i
39	0.01101+0.00534i	0.00519+0.00252i	0.00972+0.00471i
40	0.00405+0.00195i	0.00567+0.00276i	0.00648+0.00315i
41	0.00648+0.00315i	0.00519+0.00252i	0.00453+0.00219i
42	0.00420+0.00204i	0.00309+0.00150i	0.00291+0.00141i
43	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i
44	0.00744+0.00360i	0.00534+0.00258i	0.00339+0.00165i
45	0.01230+0.00597i	0.01491+0.00723i	0.01329+0.00642i
46	0.00339+0.00165i	0.00420+0.00204i	0.00258+0.00126i
47	0.00744+0.00360i	0.00744+0.00360i	0.01101+0.00534i

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48	0.00972+0.00471i	0.00810+0.00393i	0.00810+0.00393i
49	0.00438+0.00213i	0.00534+0.00258i	0.00648+0.00315i
50	0.00309+0.00150i	0.00309+0.00234i	0.00405+0.00195i
51	0.00438+0.00213i	0.00486+0.00234i	0.00696+0.00336i
52	0.00777+0.00378i	0.01038+0.00501i	0.00777+0.00378i
53	0.00648+0.00315i	0.00486+0.00234i	0.00486+0.00234i
54	0.00543+0.00258i	0.00534+0.00258i	0.00552+0.00267i
55	0.00876+0.00423i	0.01005+0.00486i	0.00714+0.00345i

Table- VIII: Table 8Line data of 55 bus 3-phase unbalanced radial network with mutual impedances

From	To	Zaa	Zab	Zac	Zbb	Zbc	Zcc
1	2	38.7+16.65i	12.9+5.55i	12.9+5.55i	38.7+16.65i	12.9+5.55i	38.7+16.65i
2	3	64.5+27.75i	21.5+9.25i	21.5+9.25i	64.5+27.75i	21.5+9.25i	64.5+27.75i
2	4	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.775i	19.35+8.325i
4	5	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.775i	19.35+8.325i
4	6	12.90+5.55i	4.3+1.85i	4.3+1.85i	12.90+5.55i	4.3+1.85i	12.90+5.55i
6	7	25.80+11.1i	0.09+0.93i	5.38+4.747i	25.80+11.1i	8.6+3.7i	25.80+11.1
6	8	32.25+13.87i	0.071+0.74i	4.3+3.797i	32.25+13.87i	10.75+4.62i	32.25+13.875
8	9	38.70+16.65i	12.9+5.55i	12.9+5.55i	38.70+16.65i	12.9+5.55i	38.70+16.65
9	10	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
10	11	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
10	12	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
11	13	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
11	14	12.90+5.55i	4.3+1.85i	4.3+1.85i	12.90+5.55i	4.3+1.85i	12.90+5.55i
12	15	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
12	16	77.40+33.3i	25.8+11.1i	25.8+11.1i	77.40+33.3i	25.8+11.1i	77.40+33.3i
14	17	45.15+19.42i	15.05+6.475i	15.05+6.47i	45.15+19.42i	15.05+6.47i	45.15+19.425i
14	18	51.60+22.2i	17.2+7.4i	17.2+7.4i	51.60+22.2i	17.2+7.4i	51.60+22.2i
15	19	51.60+22.2i	17.2+7.4i	17.2+7.4i	51.60+22.2i	17.2+7.4i	51.60+22.2i
19	20	38.7+16.65i	12.9+5.55i	12.9+5.55i	38.7+16.65i	12.9+5.55i	38.7+16.65i
20	21	64.5+27.75i	21.5+9.25i	21.5+9.25i	64.5+27.75i	21.5+9.25i	64.5+27.75i
20	22	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.32i	6.45+2.77i	19.35+8.325i
22	23	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.32i	6.45+2.77i	19.35+8.325i
22	24	12.90+5.55i	4.3+1.85i	4.3+1.85i	12.90+5.55i	4.3+1.85i	12.90+5.55i
24	25	25.80+11.1i	0.099+0.93i	5.38+4.747i	25.80+11.1i	8.6+3.7i	25.80+11.1i
24	26	32.25+13.87i	0.071+0.74i	4.30+3.797i	32.25+13.87i	10.7+4.62i	32.25+13.875i
26	27	38.70+16.65i	12.9+5.55i	12.9+5.55i	38.70+16.65i	12.9+5.55i	38.70+16.65i
27	28	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
28	29	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
28	30	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
29	31	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
29	32	12.90+5.55i	4.3+1.85i	4.3+1.85i	12.90+5.55i	4.3+1.85i	12.90+5.55i
30	33	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i

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30	34	77.40+33.3i	25.8+11.1i	25.8+11.1i	77.40+33.3i	25.8+11.1i	77.40+33.3i
32	35	45.15+19.42i	15.05+6.47i	15.05+6.47i	45.15+19.42i	15.05+6.47i	45.15+19.42i
32	36	51.60+22.2i	17.2+7.4i	17.2+7.4i	51.60+22.2i	17.2+7.4i	51.60+22.2i
33	37	51.60+22.2i	17.2+7.4i	17.2+7.4i	51.60+22.2i	17.2+7.4i	51.60+22.2i
17	38	38.7+16.65i	12.9+5.55i	12.9+5.55i	38.7+16.65i	12.9+5.55i	38.7+16.65i
38	39	64.5+27.75i	21.5+9.25i	21.5+9.25i	64.5+27.75i	21.5+9.25i	64.5+27.75i
38	40	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
40	41	19.35+8.325i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
40	42	12.90+5.55i	4.3+1.85i	4.3+1.85i	12.90+5.55i	4.3+1.85i	12.90+5.55i
42	43	25.80+11.1i	0.091+0.93i	5.38+4.74i	25.80+11.1i	8.6+3.7i	25.80+11.1i
42	44	32.25+13.87i	0.073+0.74i	4.30+3.79i	32.25+13.87i	10.7+4.62i	32.25+13.875i
44	45	38.70+16.65i	12.9+5.55i	12.9+5.55i	38.70+16.65i	12.9+5.55i	38.70+16.65i
45	46	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
46	47	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
46	48	19.35+8.32i	6.45+2.775i	6.45+2.775i	19.35+8.325i	6.45+2.77i	19.35+8.325i
47	49	64.50+27.75i	21.5+9.25i	21.50+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
47	50	12.90+5.55i	4.3+1.85i	4.300+1.85i	12.90+5.55i	4.300+1.85i	12.90+5.55i
48	51	64.50+27.75i	21.5+9.25i	21.5+9.25i	64.50+27.75i	21.5+9.25i	64.50+27.75i
48	52	77.40+33.3i	25.8+11.1i	25.8+11.1i	77.40+33.3i	25.8+11.1i	77.40+33.30i
50	53	45.15+19.42i	15.05+6.47i	15.05+6.47i	45.15+19.42i	15.05+6.4i	45.15+19.42i
50	54	51.60+22.2i	17.2+7.40i	17.2+7.4i	51.60+22.2i	17.2+7.40i	51.60+22.20i
51	55	51.60+22.2i	17.2+7.40i	17.2+7.4i	51.60+22.2i	17.2+7.40i	51.60+22.20i

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