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A three phase unbalanced power flow method for secondary distribution system

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ABSTRACT

An economical load flow study is needed for automatic distribution network for designing, operation, economic dispatch, stability analysis & contingency analysis. This paper introduces an easy three phase unbalanced load flow technique which will handle unbalanced radial secondary distribution networks. The proposed technique uses the modified Forward-Backward technique that addresses the constant-power, constant -impedance and constant-current load models, regulators, transformers and switches. It solves an easy algebraic algorithmic expression of voltage magnitude. The suggested technique having better convergence rate and execution time is also less for any type of load model, size of the network, and resistance to reactance ratio of feeders.19-bus and 25 bus URDNs results are in agreement with the literature and show that the suggested technique is efficient and reliable.

1. INTRODUCTION

Load flow technique is a vital tool for analysis of power systems and can be used in designing stages. Some applications like secondary distribution automation and optimisation need frequent load flow solutions. Because of the complexity of secondary distribution networks, there's a better demand for economical and reliable system operation. In several cases, the RDNs having untransposed lines which leads unbalance in the line. Thus, load flow analysis of balanced RDNs are going to be inefficient to resolve the unbalanced cases and consequently the distribution systems have to be analyzed on a 3-phse basis rather than 1-phase basis.

Today we've several ways to review the load flow analysis like Newton Raphson technique, Gauss- siedel technique, fast decoupled technique, however those strategies are great match for transmission system. In contrast to transmission system, distribution system has completely different characteristics. They are

(1) High Resistance(R) to Reactance(X) ratio.
(2) Unbalanced distributed load.
(3) The load is continuously changing.
(4) Having Large number of buses and branches.

A fast decoupled load flow technique has been proposed in [1]. The size of problem is also reduced to number of laterals. Because this technique orders the laterals rather than buses into layers. Exploitation of lateral variables makes this technique further economical for the given system topology. However it should add difficulties if the configuration is modified frequently and it is common in distribution systems due to switching operations. In [2], a method for solving URDNs based on the N-R method has been proposed. Thukaram et al. [3] have planned a way for determination three-phase URDNs. This methodology uses the F & B propagation to calculate line currents and bus voltages.

In recent years the 3-phase current injection methodology has been proposed [4]. TCIM relies on the current equations written in complex form and may be a full Newton technique [5-6]. For the past twenty five years, there are several load flow strategies proposed for passive RDNs. These strategies can be classified into four classes, Bus Impedance methods [7], Newton-type strategies [8-10], Forward-Backward, modified Forward-Backward [11-12], and Sequential Power Flow strategies [13-15]. Among of these strategies, SPF methodology will promptly accommodate for Voltage controlled buses as long as the distributed generator models in the sequence component frame can be formulate. But, SPF strategies cannot handle the lateral network with single or two-phase lines, and high R/X ratios.

The paper [16] draw special attention to the injection currents are often convey by a family of fixed-point quadratic maps. This paper [17] presents a simple 3- phase load flow method for solving of three-phase URDNs having voltage dependent loads. It solves an easy algebraic expression of voltage magnitude recursively and all the bus voltages, bus currents and line power flows are stored in vectors. Keresting & Mendive [18] and Keresting [19] developed a load flow technique for solution of RDNs. This technique update the currents and voltages based on ladder iterative technique which in turn uses the forward- backward sweep.

This paper introduces an easy three phase unbalanced load flow technique which will handle unbalanced radial secondary distribution networks. The proposed technique uses the modified Forward-Backward technique that addresses the constant-power, constant -impedance and constant-current load models, regulators, transformers and switches. The suggested technique having better convergence rate and execution time.

2. MATHEMATICAL MODEL OF URDN

A distribution feeder provides service to unbalanced 3-ϕ,2-ϕ and 1-ϕ loads. Because of this the 3-ϕ line currents and voltages being unbalanced. For analysing these conditions exactly, it'll be essential to model all 3-ϕ lines of the feeder as precisely as possible.

2.1 Load model

Loads on a distribution line can be modeled as Y-connected or Δ-connected. The loads can be 3-ϕ, 2-ϕ or 1-ϕ with any degree of unbalanced. Following are the various kinds of load models

(1) Constant impedance (Z)
(2) Constant current (I)
(3) Constant power (P)

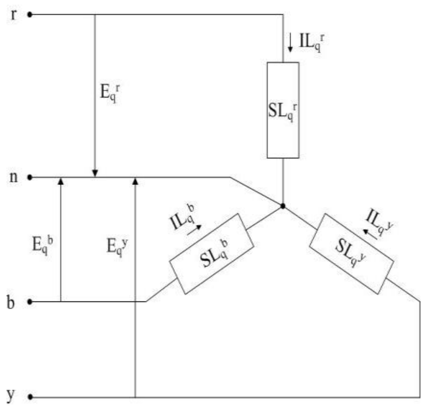

Figure 1. Y-Connected load model

For Y-Connected 3-ϕ loads or 1-ϕ loads connected between line and neutral, the line current at the qth bus will be given by:

$$\begin{bmatrix} SL_q^r \\ SL_q^y \\ SL_q^b \end{bmatrix} = \begin{bmatrix} (SL_{q0}^r)\left[\frac{|E_q^r|}{|E_0^r|}\right]^\alpha \\ (SL_{q0}^y)\left[\frac{|E_q^y|}{|E_0^y|}\right]^\alpha \\ (SL_{q0}^b)\left[\frac{|E_q^b|}{|E_0^b|}\right]^\alpha \end{bmatrix} = \begin{bmatrix} (PL_{q0}^r + jQL_{q0}^r)\left[\frac{|E_q^r|}{|E_0^r|}\right]^\alpha \\ (PL_{q0}^y + jQL_{q0}^y)\left[\frac{|E_q^y|}{|E_0^y|}\right]^\alpha \\ (PL_{q0}^b + jQL_{q0}^b)\left[\frac{|E_q^b|}{|E_0^b|}\right]^\alpha \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} IL_q^r \\ IL_q^y \\ IL_q^b \end{bmatrix} = \begin{bmatrix} \left(\frac{SL_q^r}{E_q^r}\right)^* \\ \left(\frac{SL_q^y}{E_q^y}\right)^* \\ \left(\frac{SL_q^b}{E_q^b}\right)^* \end{bmatrix} \quad (2)$$

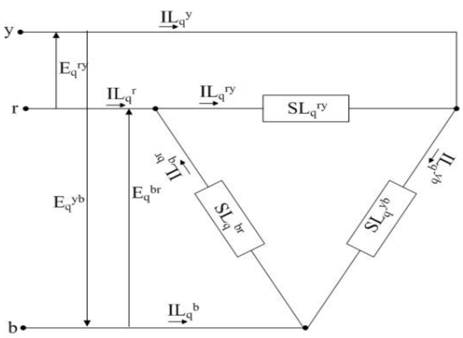

Figure 2. Δ-Connected load model

$$\begin{bmatrix} SL_q^{ry} \\ SL_q^{yb} \\ SL_q^{br} \end{bmatrix} = \begin{bmatrix} (SL_{q0}^{ry})\left[\frac{|E_q^{ry}|}{|E_0^{ry}|}\right]^\alpha \\ (SL_{q0}^{yb})\left[\frac{|E_q^{yb}|}{|E_0^{yb}|}\right]^\alpha \\ (SL_{q0}^{br})\left[\frac{|E_q^{br}|}{|E_0^{br}|}\right]^\alpha \end{bmatrix} = \begin{bmatrix} (PL_{q0}^{ry} + jQL_{q0}^{ry})\left[\frac{|E_q^{ry}|}{|E_0^{ry}|}\right]^\alpha \\ (PL_{q0}^{yb} + jQL_{q0}^{yb})\left[\frac{|E_q^{yb}|}{|E_0^{yb}|}\right]^\alpha \\ (PL_{q0}^{br} + jQL_{q0}^{br})\left[\frac{|E_q^{br}|}{|E_0^{br}|}\right]^\alpha \end{bmatrix} \quad (3)$$

$$\begin{bmatrix} IL_q^r \\ IL_q^y \\ IL_q^b \end{bmatrix} = \begin{bmatrix} \left(\frac{SL_q^{ry}}{E_q^{ry}}\right)^* - \left(\frac{SL_q^{br}}{E_q^{br}}\right)^* \\ \left(\frac{SL_q^{yb}}{E_q^{yb}}\right)^* - \left(\frac{SL_q^{ry}}{E_q^{ry}}\right)^* \\ \left(\frac{SL_q^{br}}{E_q^{br}}\right)^* - \left(\frac{SL_q^{yb}}{E_q^{yb}}\right)^* \end{bmatrix} \quad (4)$$

Eqns. (2) & (4) represent a generalized model for Y and Δ load models respectively. Where α is defined as follows:
α=0, constant power (P)
α=1, constant current (I)
α=2, constant impedance (Z)

2.2 Line model

The modelling of distribution OH and UG lines may be a crucial step in the analysis of a distribution feeder. it's vital in the line modelling to incorporate the particular phasing of the line and maintain correct spacing between conductors. The model of 3-ϕ,2-ϕ and 1-ϕ OH Line is shown in fig 3.

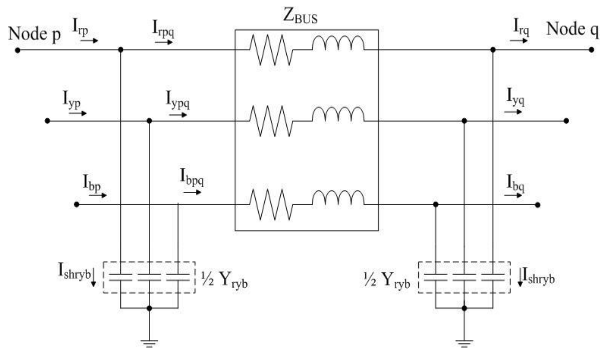

Figure 3. Distribution system line model

The input (node p) voltages and currents to the output (node q) voltages and currents are derived by using KCL and KVL.Apply KCL and KVL to the model shown in fig.1

$$E_p^{ryb} = E_q^{ryb} + Z_{pq}^{ryb} I_{pq}^{ryb} \quad (5)$$

where I_{pq}^{ryb} is the current flowing from bus p to bus q and it can be found by adding all the load currents and the line charging currents ahead of the line segment between p and q. The voltage at bus q can be calculate, once we compute the voltage at bus p, by rewriting eqn. (1), we will get

$$E_q^{ryb} = E_p^{ryb} - Z_{pq}^{ryb} I_{pq}^{ryb} \quad (6)$$

2.3 Power loss calculation

We can calculate the currents through the three phases of the branch between buses p & q by using Eq. 2 & 4 and voltages at buses p & q by using Eqn. 5 & 6. The power losses in the line between bus p & q is the difference between the active and reactive power at bus p & bus q and it can be expressed as:

$$\begin{bmatrix} LS_{pq}^{r} \\ LS_{pq}^{y} \\ LS_{pq}^{b} \end{bmatrix} = \begin{bmatrix} (LP_{pq}^{r} + jLQ_{pq}^{r}) \\ (LP_{pq}^{y} + jLQ_{pq}^{y}) \\ (LP_{pq}^{b} + jLQ_{pq}^{b}) \end{bmatrix} = \begin{bmatrix} E_p^r (I_{pq}^r)^* - E_q^r (I_{qp}^r)^* \\ E_p^y (I_{pq}^y)^* - E_q^y (I_{qp}^y)^* \\ E_p^b (I_{pq}^b)^* - E_q^b (I_{qp}^b)^* \end{bmatrix} \quad (7)$$

2.4 Flowchart

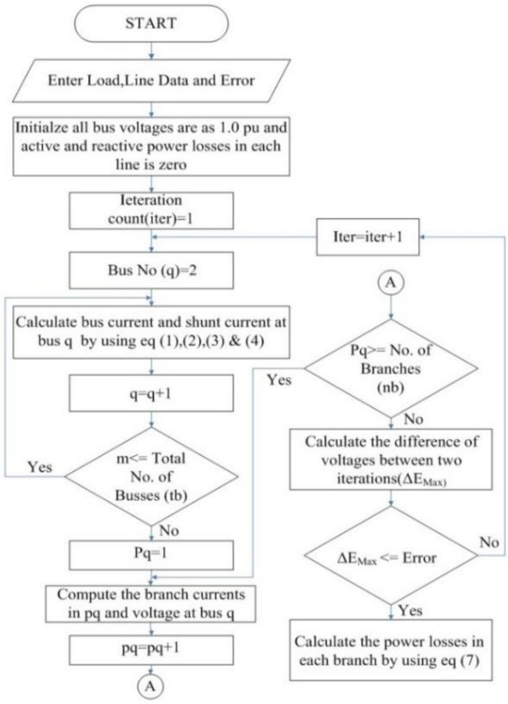

Figure 4. Flow Chart for Unbalanced Load flow of URDNs

Fig 4. represents the complete algorithm in the form of flow chart. The solution is converged when the maximum difference in voltage magnitude between two successive iterations is less than 0.0001 p.u.

3. RESULTS AND ANALYSIS

The use of the suggested technique has been explained with two URDNs.

3.1 Case 1: 19-bus URDN

Bus Voltage and it's angles for 19-bus URDN with the suggested technique are listed in Table 1. From this table, it can be concluded that the minimum voltage occurred in phase r, y & b is 0.9536, 0.9519 and 0.9425 p.u respectively at bus 19. Fig.5 shows the voltage deviation in phases r, y & b is for 19-bus URDN. Table 2 shows power losses for the 19-bus URDN. The total real power loss in phases r,phase y & phase b are 4.11 , 4.09 and 4.21 kW and the total reactive power loss in phases r, phase y and phase b are 1.80, 1.74 and 1.80 kVAr respectively. Fig. 6 shows real power losses and Fig.7 illustrates reactive power losses of the 19-bus URDN.

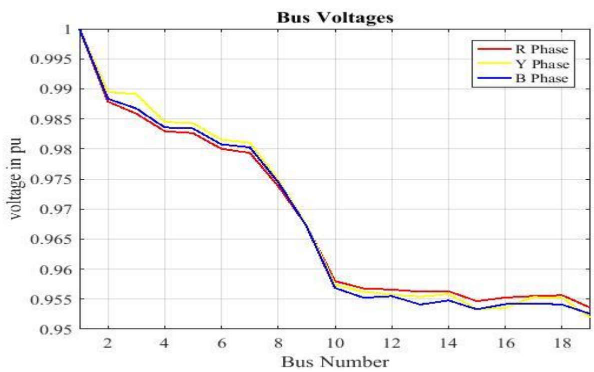

Figure 5. Voltage variation at each bus

Table 1. Bus voltages and angles of the 19-bus urdn

Bus No	|E| (p.u)	∠Er (deg)	|E| (p.u)	∠Ey (deg)	|E| (p.u)	∠Eb (deg)
1	1	0.00	1	-120.00	1	120.00
2	0.9879	0.01	0.9895	-119.98	0.9884	120.05
3	0.9859	0.00	0.9891	-119.98	0.9867	120.08
4	0.983	0.03	0.9845	-119.97	0.9836	120.06
5	0.9826	0.03	0.9843	-119.97	0.9834	120.07
6	0.98	0.04	0.9815	-119.96	0.9807	120.07
7	0.9794	0.04	0.981	-119.96	0.9803	120.07
8	0.9738	0.06	0.9749	-119.94	0.9745	120.08
9	0.9672	0.08	0.9674	-119.91	0.9671	120.09
10	0.958	0.11	0.9574	-119.87	0.9569	120.11
11	0.9568	0.10	0.9562	-119.86	0.9552	120.11
12	0.9566	0.11	0.9557	-119.87	0.9555	120.11
13	0.9562	0.10	0.9554	-119.85	0.9541	120.11
14	0.9563	0.10	0.9558	-119.86	0.9548	120.11
15	0.9547	0.12	0.9533	-119.86	0.9533	120.10
16	0.9553	0.13	0.9536	-119.86	0.9542	120.10
17	0.9555	0.11	0.9554	-119.86	0.9543	120.12
18	0.9557	0.10	0.9552	-119.86	0.9541	120.11
19	0.9536	0.14	0.9519	-119.86	0.9525	120.10

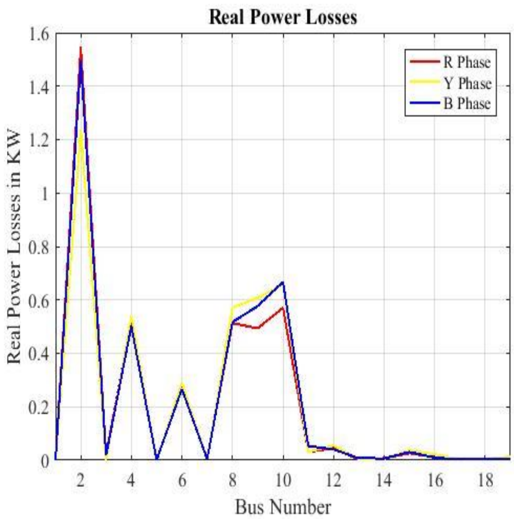

Figure 6. Real power losses at each bus

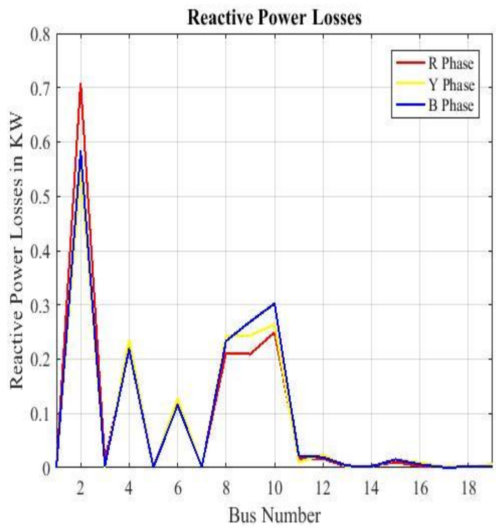

Figure 7. Reactive power losses at each bus

Table 2. Power losses of the 19-bus urdn

From Bus	To Bus	R Phase		Y Phase		B Phase	
		Real Power Losses(kW)	Reactive Power Losses (kVAr)	Real Power Losses (kW)	Reactive Power Losses (kVAr)	Real Power Losses (kW)	Reactive Power Losses (kVAr)
1	2	1.547	0.710	1.241	0.549	1.495	0.584
2	3	0.021	0.013	0.002	0.001	0.018	0.003
2	4	0.530	0.221	0.540	0.237	0.502	0.219
4	5	0.002	0.001	0.001	0.001	0.001	0.000
4	6	0.287	0.119	0.289	0.128	0.266	0.116
6	7	0.007	0.003	0.004	0.002	0.004	0.001
6	8	0.513	0.212	0.572	0.244	0.517	0.234
8	9	0.494	0.209	0.608	0.244	0.577	0.269
9	10	0.571	0.250	0.657	0.264	0.668	0.302
10	11	0.031	0.017	0.032	0.010	0.053	0.022
10	12	0.045	0.017	0.056	0.024	0.041	0.020
11	13	0.002	0.001	0.005	0.001	0.007	0.004
11	14	0.007	0.003	0.005	0.002	0.007	0.003
12	15	0.026	0.011	0.037	0.015	0.031	0.015
12	16	0.011	0.003	0.023	0.010	0.010	0.006
14	17	0.005	0.002	0.002	0.001	0.003	0.001
14	18	0.004	0.002	0.004	0.002	0.004	0.002
15	19	0.011	0.003	0.014	0.007	0.005	0.003

3.2 Case 2: 25-bus URDN

Bus Voltage and it's angles for 25-bus URDN with the suggested technique are listed in Table 3. From this table, it can be concluded that the minimum voltage occurred in phases r, y & b is 0.9664 at bus 12, 0.9716 at bus 15 and 0.9816 at bus 22 p.u respectively. Fig.8 shows the voltage variation in phases r, y and b is for 25-bus URDN. Table 4 shows power losses for the 25-bus URDN. The total real power loss in phases r,phase y and phase b are 6.58, 10.29 and 5.05 kW and the total reactive power loss in phases r, phase y and phase b are 16.54, 9.80 and 14.68 kVAr respectively. Fig. 9 shows real power losses and Fig.10 illustrates reactive power losses of the 25-bus URDN.

Table 3. Bus voltages and angles of the 25-bus urdn

Bus No	|E| (p.u)	∠Er (deg)	|E| (p.u)	∠Ey (deg)	|E| (p.u)	∠Eb (deg)
1	1.0000	0.00	1.0000	-120.00	1.0000	120.00
2	0.9865	-0.27	0.9882	-120.16	0.9891	119.71
3	0.9841	-0.31	0.9853	-120.20	0.9867	119.63
4	0.9828	-0.33	0.9837	-120.23	0.9860	119.61
5	0.9823	-0.38	0.9827	-120.23	0.9866	119.66
6	0.9815	-0.62	0.9821	-120.14	0.9936	120.13
7	0.9770	-0.92	0.9770	-120.12	0.9976	120.50
8	0.9805	-0.72	0.9801	-120.13	0.9947	120.23
9	0.9726	-0.93	0.9754	-120.13	0.9998	120.72
10	0.9699	-0.93	0.9736	-120.15	1.0014	120.85

11	0.9675	-1.00	0.9731	-120.15	0.0000	0.00
12	0.9664	-1.00	0.0000	0.00	0.0000	0.00
13	0.0000	0.00	0.9724	-120.15	0.0000	0.00
14	0.9769	-1.22	0.9736	-120.08	0.9993	120.65
15	0.9760	-1.32	0.9716	-120.07	1.0005	120.75
16	0.9770	-0.92	0.9770	-120.12	0.9976	120.50
17	0.0000	0.00	0.0000	0.00	0.9982	120.66
18	0.9840	-0.48	0.9826	-120.18	0.9878	119.73
19	0.9824	-0.52	0.9811	-120.19	0.0000	0.00
20	0.0000	0.00	0.9788	-120.19	0.0000	0.00
21	0.0000	0.00	0.0000	0.00	0.9839	119.73
22	0.0000	0.00	0.0000	0.00	0.9816	119.73
23	0.9819	-0.37	0.9821	-120.23	0.9868	119.67
24	0.0000	0.00	0.9796	-120.30	0.9861	119.66
25	0.0000	0.00	0.9765	-120.30	0.0000	0.00

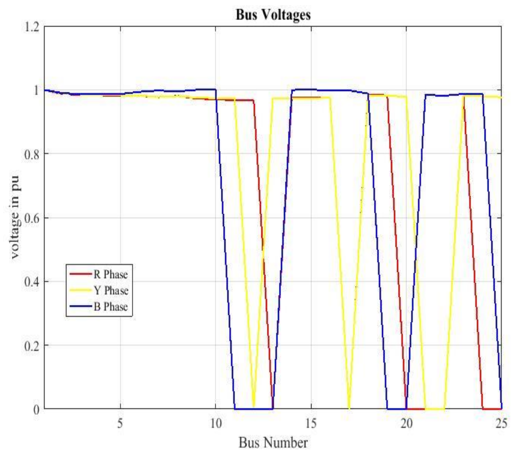

Figure 8. Voltage variation at each bus

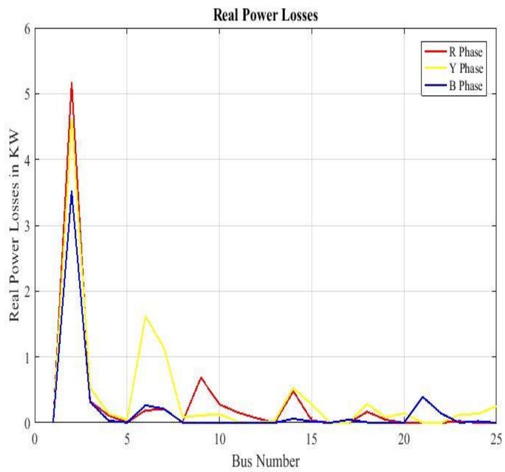

Figure 9. Real power losses at each bus

Table 4. Power losses of the 25-bus urdn

From bus	To bus	R Phase		Y Phase		B Phase	
		Real Power Losses (kW)	Reactive Power Losses (kVAr)	Real Power Losses (kW)	Reactive Power Losses (kVAr)	Real Power Losses (kW)	Reactive Power Losses (kVAr)
1	2	5.177	7.596	4.614	5.520	3.520	6.534
2	3	0.327	0.435	0.536	0.623	0.316	0.664
3	4	0.111	0.139	0.138	0.200	0.033	0.076
4	5	-0.005	0.049	0.042	0.027	0.003	0.051
2	6	0.189	3.244	1.618	1.042	0.267	2.927
6	7	0.204	2.497	1.140	0.732	0.212	2.199
6	8	-0.010	0.098	0.084	0.055	0.006	0.103
7	9	0.687	0.540	0.111	0.119	0.000	0.000
9	10	0.279	0.203	0.130	0.128	0.000	0.000
10	11	0.157	0.283	0.017	0.018	0.000	0.000
11	12	0.071	0.052	0.000	0.000	0.000	0.000
11	13	0.000	0.000	0.032	0.023	0.000	0.000
7	14	-0.480	0.685	0.528	0.259	0.063	0.924
14	15	-0.034	0.325	0.278	0.182	0.018	0.343
7	16	0.000	0.000	0.000	0.000	0.000	0.000
14	17	0.000	0.000	0.000	0.000	0.048	0.035
3	18	-0.167	0.243	0.288	0.161	0.008	0.340
18	19	0.046	0.072	0.083	0.077	0.000	0.000
19	20	0.000	0.000	0.142	0.105	0.000	0.000
18	21	0.000	0.000	0.000	0.000	0.396	0.291
21	22	0.000	0.000	0.000	0.000	0.142	0.105
4	23	0.025	0.075	0.126	0.098	0.000	0.065
23	24	0.000	0.000	0.135	0.241	0.025	0.025
24	25	0.000	0.000	0.253	0.186	0.000	0.000

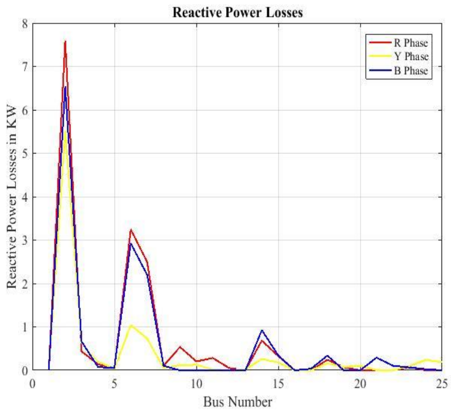

Figure 10. Reactive power losses at each bus

4. CONCLUSIONS

In this paper, an innovative and effective power flow algorithm has been presented to solve URDNs. The distribution system components have been modelled by using network theory concepts. The suggested technique has good convergence property for any realistic distribution networks with practical Resistance to Reactance ratio. The advantage of the suggested technique is the data is stored in vector format, so it will save the computer memory when tested for large realistic systems. This technique can be used efficiently with SCADA and DAC.

REFERENCES

[1] Zimmerman RD, Chiang HD. (1995). Fast decoupled power flow for unbalanced radial distribution systems. IEEE-PES Winter Meeting, paper (95). New York.

[2] Goswami SK, Basu SK. (1991). Direct solution of distribution systems. IEE Proc. C 188(1): 78-88.

[3] Thukaram D, Wijekoon Banda HM, Jerome J. (1999). A Robust three phase power flow algorithm for radial distribution systems. Electric Power System Research 50(3): 227-236.

[4] Garcia PAN, Pereira JLR, Carnerio S, Da Costa VM, Martins N. (2000). Three-Phase power flow calculations using the current injection method. IEEE Trans. on Power Systems 15(2): 508-514.

[5] Garcia PAN, Pereira JLR, Carneiro S, Jr. (2001). Voltage control devices models for distribution power flow analysis. IEEE Trans. Power Syst 16(4): 586–594.

[6] Garcia PAN, Pereira JLR, Carneiro SJr. (2004). Improvements in the representation of PV buses on three-phase distribution power flow. IEEE Trans. Power Del 19(2): 894–896.

[7] Chen TH. (1991). Distribution system power flow analysis-a rigid approach. Power Delivery. IEEE Transactions on 6(3): 1146-1152.

[8] Baran M, Wu FF. (1989). Optimal sizing of capacitors placed on a radial distribution system. Power Delivery, IEEE Transactions on 4(1): 735-743.

[9] Garcia PAN, JLRP, Carneiro S, Da Costa VM, Martins N. (2000). Three-phase power flow calculations using the current injection method. IEEE Transactions on Power Systems 15(2).

[10] Da Costa VM, NM, Pereira JLR. (1999). Developments in Newton Raphson power flow formulation based on current injections. IEEE Transactions on Power System. 14(4).

[11] Chen TH, Yang NC. (2009). Three-phase power-flow by direct ZBR method for unbalanced radial distribution systems. Generation, Transmission & Distribution, IET 3(10): 903-910.

[12] Kersting WH. (2002). Distribution System Modeling and Analysis. CRC Press.

[13] Abdel-Akher M, Nor KM, Rashid AHA. (2005). Improved three-phase power-flow methods using sequence components. power systems. IEEE Transactions on 20(3): 1389-1397.

[14] Kamh MZ, Iravani R. (2010). Unbalanced model and power-flow analysis of microgrids and active distribution systems. Power Delivery, IEEE Transactions on 25(4): 2851- 2858.

[15] Kamh MZAI, R. (2011). A unified three phase power flow analysis model for electronically coupled distributed energy resources. IEEE Trans. Power Deliv. 26(2): 899-909.

[16] Yu S, Nguyen HD, Turitsyn KS. (2015). Simple certificate of solvability of power flow equations for distribution systems in Proc. IEEE PES General Meeting 1–5.

[17] Subrahmanyam JBV, Radhakrishna C. (2010). A simple approach of three phase distribution system modeling for power flow calculations. World Academy of Science, Engineering and Technology 39.

[18] Kersting WH, Mendive DL. (1976). An application of ladder theory to the solution of three-phase radial load-flow problem. IEEE Transactions on Power Apparatus and Systems PAS-98(7): 1060–1067.

[19] Kersting WH. (1984). A method to teach the design and operation of a distribution system. IEEE Transactions on Power Apparatus and Systems PAS-103(7): 1945-1952.

[20] Kersting WH. (2002). Distribution System Modeling and Analysis. CRC Press. www.mathworks.com/products/matlab.

NOMENCLATURE

E_p^{Phase}	Voltage between phase (r,y & b) and neutral at bus p.
E_p^{ry}	Voltage between r phase and y phase at bus p.
E_0^{Phase}	Nominal Voltage between phase (r,y & b) and neutral.
Z_{pq}^{ryb}	Phase Impedance matrix.
I_{pq}^{ryb}	Current at phase (r,y & b) flowing from bus p to bus q.
IL_p^{ryb}	Load Current at phase (r,y & b) at p^{th} bus
PL_{q0}^r, QL_{q0}^r & SL_{q0}^r	Nominal Real, Reactive and Apparent power loads at phase r at q^{th} bus.
PL_q^r, QL_q^r & SL_q^r	Real, Reactive and Apparent power loads at phase r at q^{th} bus.
LP_{pq}^r, LQ_{pq}^r & LS_{pq}^r	Real, Reactive and Apparent power loss in the branch pq.
URDN	Unbalanced Radial Distribution Network.