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MODIFIED DIRECT-ZBR METHOD PSO POWER FLOW DEVELOPMENT FOR WEAKLY MESHED ACTIVE UNBALANCED DISTRIBUTION SYSTEMS

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ABSTRACT

Electrical distribution system is a part of electrical system that is directly connected to the customers. Reliability and power quality of electrical distribution system must be maintained so that they can use electricity continuously. Many methods can be done to improve them of electrical distribution system, such as penetration of Distributed Generations (DG's) and weakly meshed distribution network reconfiguration. These methods will change a passive distribution network to an active one with weakly meshed configuration. Due to the special characteristics of distribution systems, this paper introduces a three phase power flow method that can handle passive/active and radial/weakly meshed distribution networks. The Modified direct-Z_{BR} method is developed in this proposed method and combined with Particle Swarm Optimization (PSO). The proposed method is applied to 20 kV distribution network in Surabaya city, East Jawa, Indonesia. Three simulation cases are studied for the test system. The computational speed of three simulation cases shows the number of iterations for these cases are increased but the apparent losses decrease. It means that the proposed method is robust and suitable for weakly meshed reconfiguration. The results show that the proposed power flow method can handle the active unbalanced distribution system with weakly meshed configuration.

Keywords: modified Direct-Z_{BR} method, particle swarm optimization (PSO), unbalanced load flow, weakly meshed active distribution networks.

INTRODUCTION

Due to the special characteristics of electrical distribution systems, this paper introduces a three phase power flow method that can handle passive/active and radial/weakly meshed distribution networks. The Modified direct-Z_{BR} method is developed in this proposed method and combined with Particle Swarm Optimization (PSO) and the PSO variation's in existing distribution networks. The interconnection of distributed generations (DG's) to existing distribution networks has gained its importance and altered a distribution network from a passive system to an active one.

Distribution systems nowadays are becoming an important part of a power system. Not only because of these systems are directly connected to the consumers, but also these systems have unique characteristics in comparison with transmission systems such as unbalanced loads, high resistance-to-reactance (R/X) ratios, single- or two-phase lines, radial topology, etc. Therefore, three-phase load flow methods have been developed for the past twenty years and can be broadly classified into four categories, which are Bus Impedance methods [4], Newton-type methods [5-7], Forward-Backward (FB) and its variations [2, 8-9], and Sequential Power Flow (SPF) methods [10-13].

A three phase load flow method using K-matrix that can handle both passive and active unbalanced radial distribution networks has been developed in [1]. The method combines direct-ZBR method and Modified Lambda iteration in handling DG's which are operated as voltage controlled (PV) buses.

Many methods can be done to improve reliability and power quality of a distribution system, such as penetration of Distributed Generations (DG's) and weakly meshed distribution network reconfiguration [16-19], [20-21].

The K-matrix, introduced in [2, 14] and also used in [1], is modified in this paper and combined with PSO for solving three phase power flow method that can handle both passive and active unbalanced radial distribution networks with weakly meshed configuration.

METHODOLOGY

Methodology in this paper is based on simulation of experimental results. The methodology steps consist of the first is K-matrix construction, the second is the modified K-matrix construction. And finally in the proposed method, the K-matrix [1, 2, 14] is modified and combined with PSO and the PSO variation's to handle passive/active and radial/weakly meshed distribution networks. The flow chart of the proposed method is shown in Figure-1.

Reference [1] describes the construction of K-matrix in the Direct Z_{BR} power flow method for three phase, radial, passive distribution systems with one and/or two phase lines. For active distribution systems, Modified Lambda iteration is used to estimate reactive power of PV-buses.

The following steps describe the modification of K-matrix for weakly meshed distribution systems.

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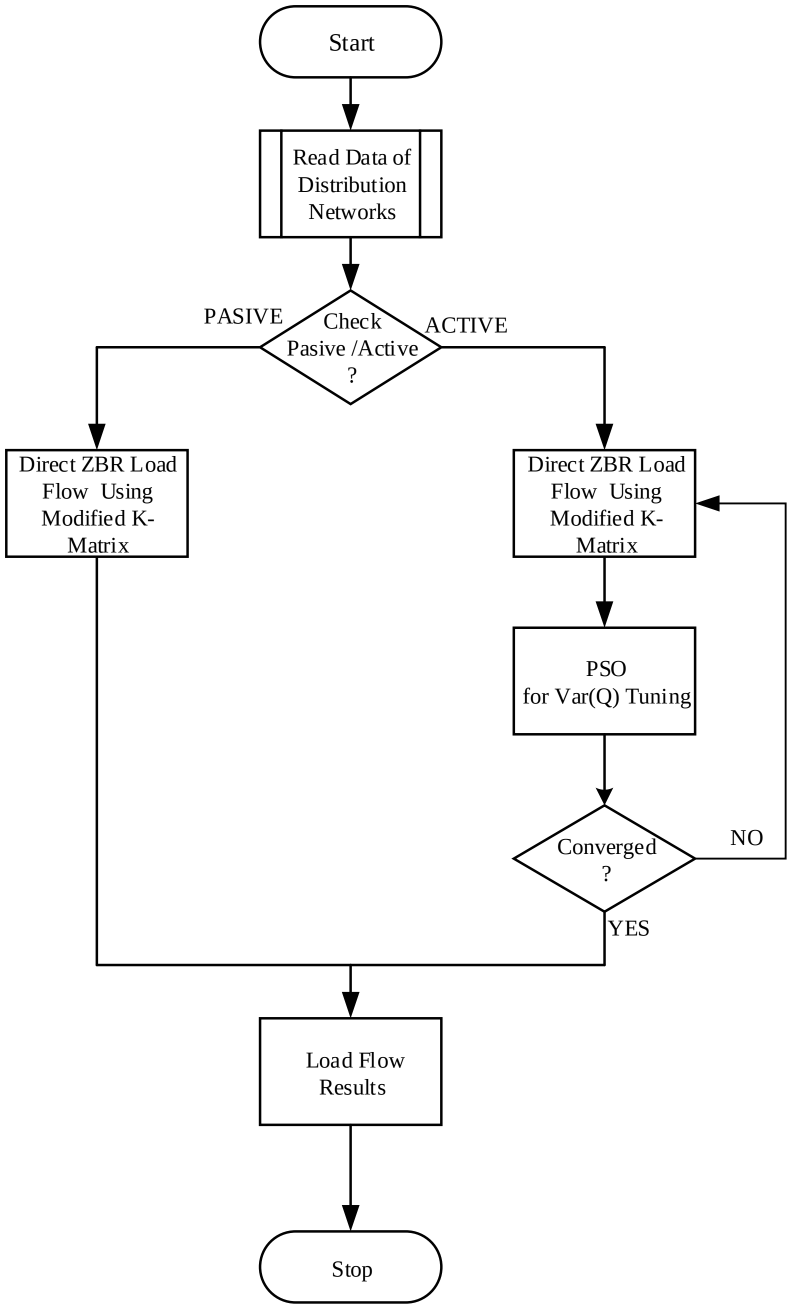

Figure-1. Flow diagram of the proposed power flow method.

For ease of illustration, a six bus system (shown in Figure-2) is used to describe the modification of K-matrix. The reference bus is bus number 1 and the load (PQ) buses are bus number 2 until 6. B_1,…, B6 are the branches/branch currents and B_6 is the branch/branch current which makes the system weakly meshed.

In the radial distribution systems with weakly meshed configuration, the “loops” do not affect the branch currents calculation. These “loops” make the number of branches increases, and will add the number of branches in the primitive impedance matrix [1].

Step 1: K- matrix construction

As described in reference [1,2], the K-matrix of the network shown in Figure-2 without branch B_6 (radial) for branch current calculation is given in Eqn. (1) and Eqn. (2).

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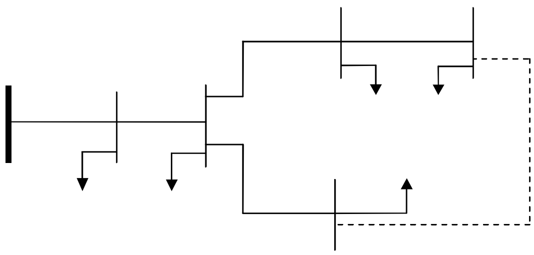

Figure-2. Simple distribution system with one loop [20].

$$[B] = [K][I] \tag{1}$$

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{2}$$

Step 2: Modified K-Matrix construction

Branch B_6 changes the radial distribution system to a weakly meshed configuration as shown in Figure-2. Current injections in bus 5 and 6 can be calculated as:

$$I_5' = I_5 + B_6$$

$$I_6' = I_6 - B_6 \tag{3}$$

Therefore, the K-matrix [1] for the six bus system with one loop is:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 + B_6 \\ I_6 - B_6 \end{bmatrix} \tag{4}$$

Equation 4 can be written as:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} + \begin{bmatrix} 1 & 1 \\ 1 & 1 \\ 1 & 0 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} B_6 \\ B_{-6} \end{bmatrix} \tag{5}$$

Eqn. (5) can be expressed as:

$$[B] = [K][I] + [LILC][B'] \tag{6}$$

where, current in branch B_6 can be calculated as Eqn.(7).

$$B_6 = (V_5 - V_6)/Z_{66} \tag{7}$$

For three phase distribution system, Eqn. (5) can be expressed as shown in Eqn. (8).

The modified K-matrix is represented by the addition of [LILC] [B'] in Eqn. (6) and these matrixes ([LILC] and [B']) represent the "loop" appearance in a weakly meshed configuration. The flowchart of three phase power flow using direct Z_{BR} method [1, 2] with modified K-matrix is shown in Figure-3.

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix}
\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} \\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} \\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} \\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} \\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}
\end{bmatrix} \begin{bmatrix} \begin{bmatrix} I_{2a} \\ I_{2b} \\ I_{2c} \end{bmatrix} \\ \begin{bmatrix} I_{3a} \\ I_{3b} \\ I_{3c} \end{bmatrix} \\ \begin{bmatrix} I_{4a} \\ I_{4b} \\ I_{4c} \end{bmatrix} \\ \begin{bmatrix} I_{5a} \\ I_{5b} \\ I_{5c} \end{bmatrix} \\ \begin{bmatrix} I_{6a} \\ I_{6b} \\ I_{6c} \end{bmatrix} \end{bmatrix} + \begin{bmatrix}
\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} \\
\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} \\
\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} \\
\begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} \\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}1&0&0\\0&1&0\\0&0&1\end{bmatrix}
\end{bmatrix} \begin{bmatrix} \begin{bmatrix} B_{6a} \\ B_{6b} \\ B_{6c} \end{bmatrix} \\ \begin{bmatrix} -B_{6a} \\ -B_{6b} \\ -B_{6c} \end{bmatrix} \end{bmatrix} \tag{8}$$

MODIFIED K-MATRIK + PSO POWER FLOW FOR ACTIVE DISTRIBUTION SYSTEMS

This paper introduces an application of three-phase load flow approach using the direct Z_{BR} method with modified K-matrix which is combined with the Particle Swarm Optimization (PSO). PSO is chosen because it is a robust and simple optimization algorithm [22].

PSO is a heuristic algorithm that inspired by swarm of birds looking for food source [22]. In this paper, PSO is used for tuning the value of reactive power on the buses with specified injected active powers and constant voltage magnitudes (PV buses).

PSO variation's performed several types of inertia weight used in this research. In the first experiment, four fixed inertia weights ranging from 0.4 and 0.9 were tested and n in experiment 2 with two types of decreasing inertia weight and a stochastic inertia weight were tested. This experiment is well known as Inertia Weighting Approach PSO (IWA PSO).

Figure-4 describes the steps of Modified K-matrix-PSO power flow algorithm as follows:

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Step 1. Input load, line and generation data
Step 2. Input PSO parameter
Step 3. Random initialization of Var(Q) for each PV bus.
Step 4. Run modified K-matrix Power Flow
Step 5. Evaluate the fitness
Step 6. Getting the best particle (Pbest) and best global particle (Pgbest)
Step 7. Update velocity and Position by equation:

$$V_i^{k+1} = \omega V_i^k + c_1 r_1 x(Pbest_i^k - Xk_i^k) + \ldots\ldots + c_2 r_2 x(Gbest_i^k - X_i^k) \quad (9)$$

$$X_i^{k+1} = V_i^k + V_i^{k+1} \quad (10)$$

where V_i^k is velocity particle *i* at *k*-iteration, ω is weight parameter, c_1, c_2 *is acceleration coefficient*, r_1, r_2 *is* random value between 0 until 1, $r_1 X_i^k$ is *particle position* at *k iteration*, $Pbest_i^k$ is *Pbest* particle *i* at iteration-*k* and $Gbest_i^k$ *is Gbest* particle at an *i* iteration-*k.*

Step 8. Check constrains Qmin and Qmax.
Step 9. Check stopping criteria, there are two stopping criteria; maximum iteration and tolerance.

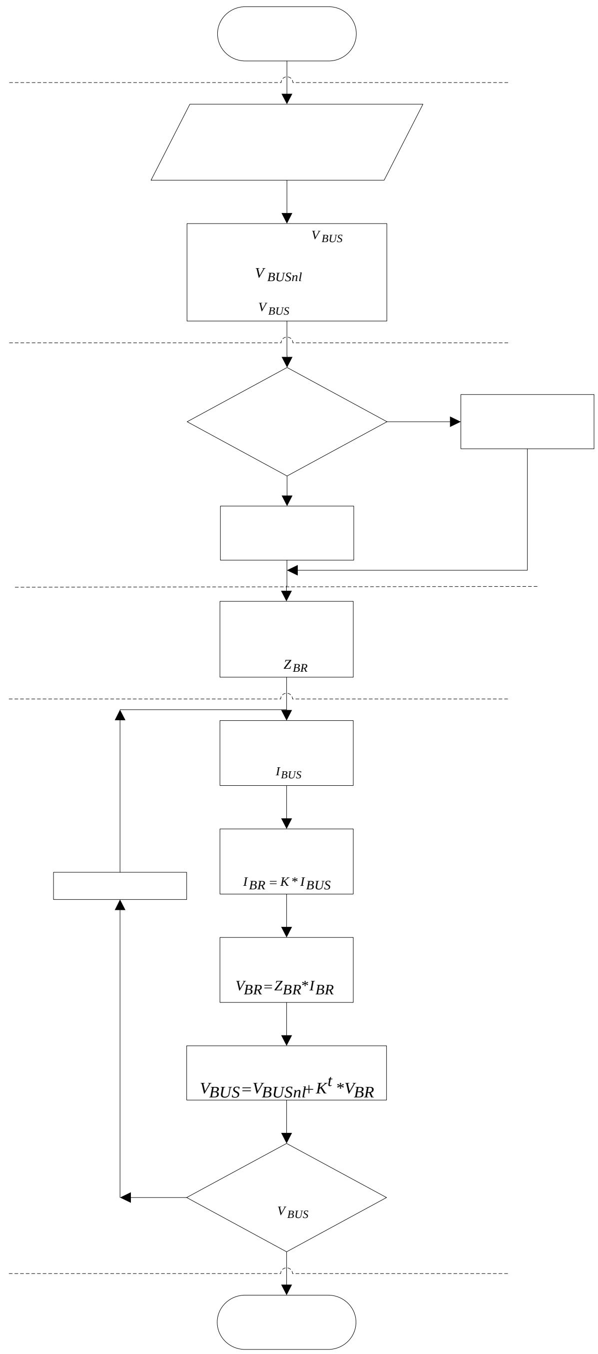

Figure-3. Flowchart of direct Z_{BR} power flow with modified K-matrix.

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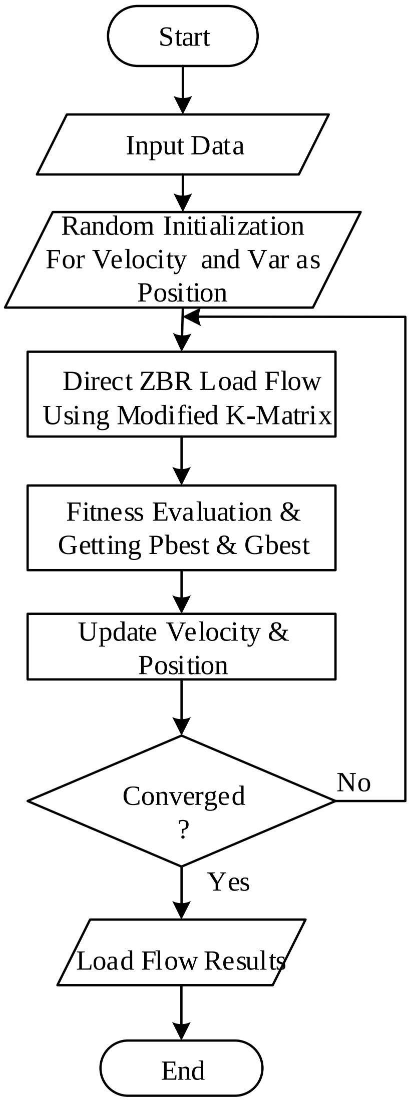

Figure-4. Flow Chart of K-matrix-PSO power flow.

TEST RESULTS

The proposed method is applied to one feeder of the 20 kV passive distribution network in Surabaya city, East Jawa, Indonesia. The test system is Basuki Rahmat feeder with tie switches are open and DG's are not connected as shown in Figure-5. The tie switches and DG's are provided for simulation purposes.

Three simulation cases are studied for the test system:

Case-1: passive radial distribution system.
Case-2: passive distribution system with weakly meshed configuration
Case-3: active distribution system with weakly meshed configuration

a. Case 1

In case 1, the test system is a passive radial system (all tie switches are open and DG's are not connected). Therefore, the Direct Z_{BR} with K-matrix power flow [1,2] is applied here. To verify the method, the results are compared with the commercial ETAP software. The voltage magnitudes and phase angles of phase "a", "b", and "c" are in very close agreement with those obtained by ETAP software.

b. Case 2

The Direct Z_{BR} with Modified K-matrix power flow (Figure-3) is applied in Case 2 for passive distribution system with weakly meshed configuration. The network configuration and data are the same as that in case 1 except that all the tie switches are closed and DG's are not connected. As in Case 1, the results are compared with the commercial ETAP software. The voltage magnitudes of phase "a" for all buses are shown in Figure-6. Similar results as in Case 1 are obtained and for phases "b" and "c" as well, demonstrating that the proposed method can accurately solve for a passive distribution network with weakly meshed configuration.

c. Case 3

For Case 3, active distribution system with weakly meshed configuration is obtained by closing all tie switches and connecting DG's to bus 6, 16 and 23 as shown in Figure-5. The Direct Z_{BR} with Modified K-matrix + PSO power flow (Figure-4) is applied here. As in Case 1 and 2, to verify the proposed method, the results are compared with the commercial ETAP software. The voltage magnitudes and phase angles of phase "b" for all buses are shown in Figure-7(a) and (b). It can be seen that the values are very close with those obtained by ETAP Software as in Case 1 and 2, similar results are obtained for the other phases as well which demonstrate that the proposed method can also accurately solve for an active distribution network with weakly meshed configuration.

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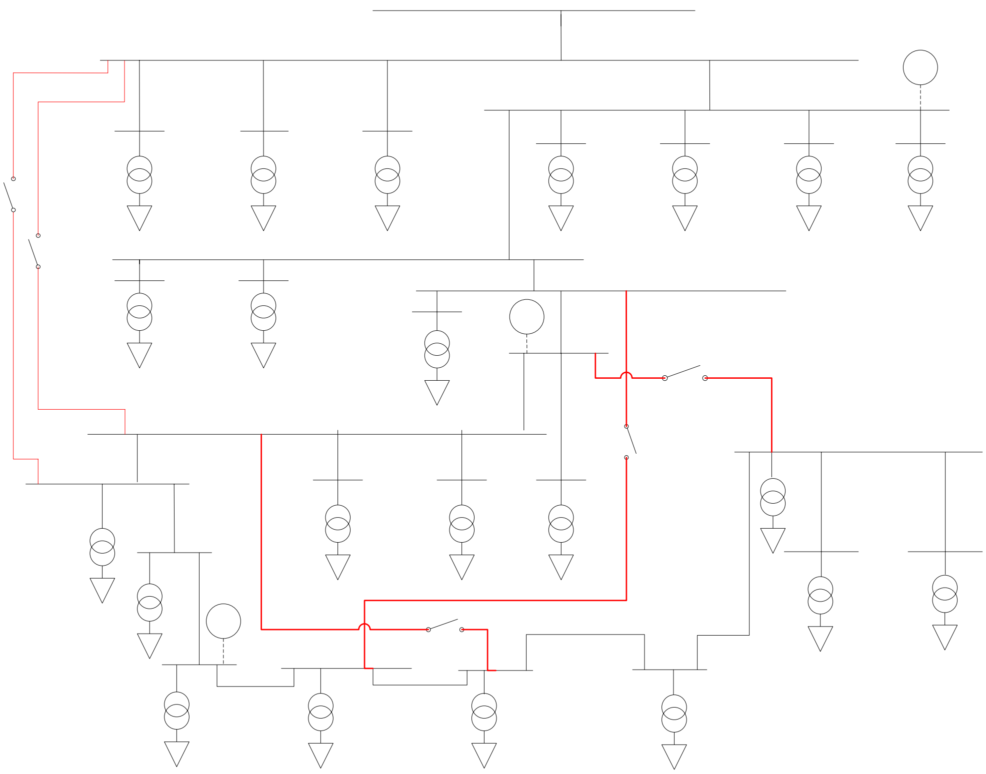
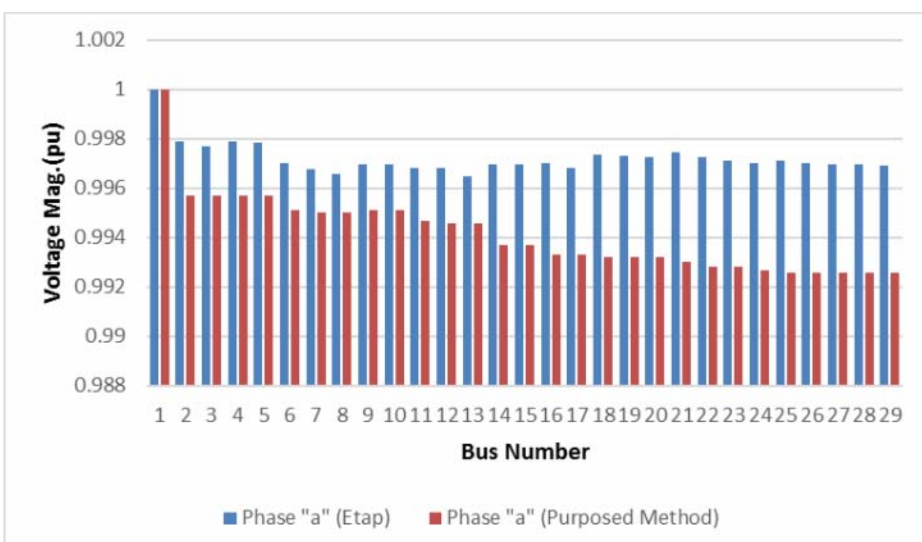


Bus 2

Figure-5. Basuki Rahmat distribution network.



Bus

Figure-6. Voltage Magnitudes of phase “a” for passive distribution system with weakly meshed configuration.

Bus 12 Bus 13

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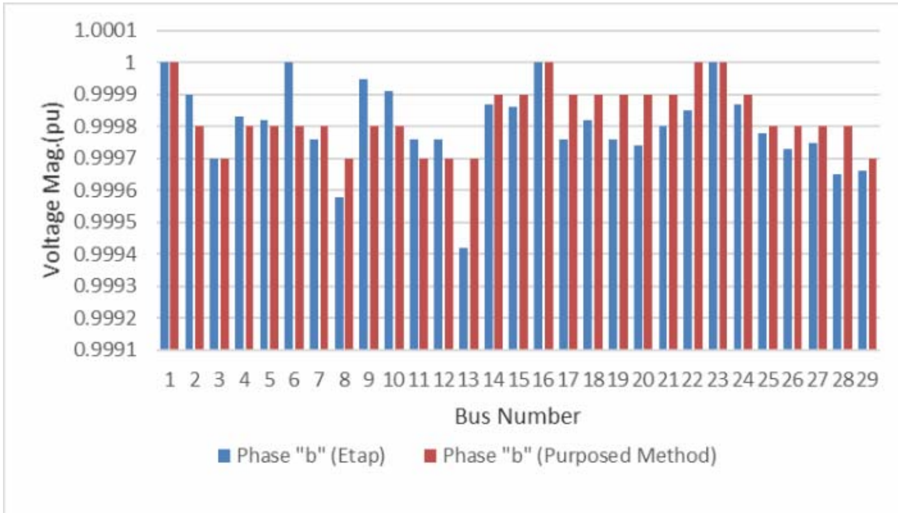
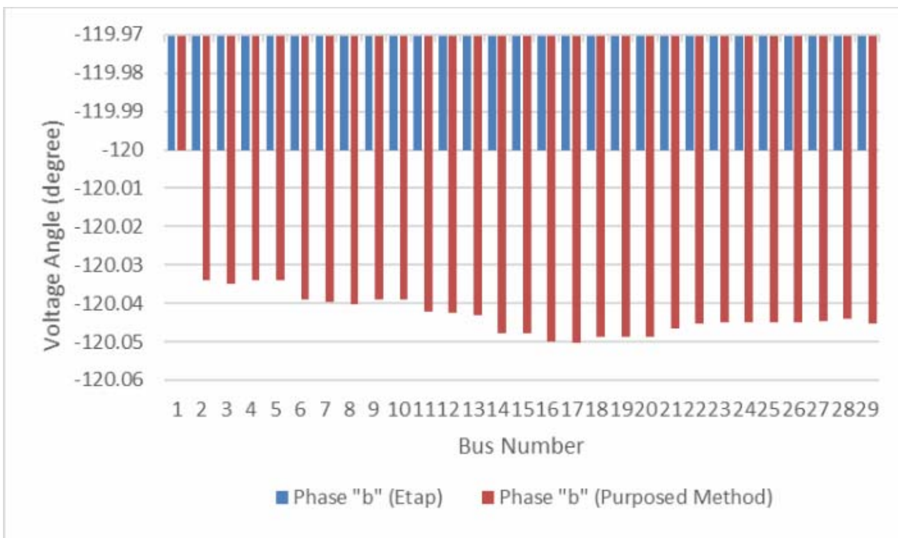


(a) Voltage Magnitude in phase “b”.



(b) Voltage Angle in phase “b”

Figure-7. Voltage Magnitudes and angles of phase “b” for active distribution system with weakly meshed configuration.

CONVERGENCE TEST OF THE PROPOSED METHOD

In order to examine the convergence ability of the proposed method, a convergence test was done on the Basuki Rahmad distribution network. Based on three simulation cases above, it has been gained some results by using the proposed power flow method. Firstly, case 1 in passive radial distribution system is convergent in the 10^{th} iteration and the apparent loss’s 0.5 MW. Secondly, case 2 in passive distribution system with weakly meshed configuration is convergent in the 15^{th} iteration and the apparent loss’s 0.45 MW. Finally, case 3 in active distribution system with weakly meshed configuration is convergent in the 18^{th} iteration and the apparent loss’s 0.3 MW. The computational speed of three simulation cases shows the number of iterations for these cases is increased but the apparent losses decrease. It means that the proposed method is robust and suitable for weakly meshed reconfiguration.

In order to prove that the proposed method can be utilized in severe conditions, IEEE 33-bus test feeder is used. It likes based on three simulation cases above, it so has been gained same result in the computational speed.

CONCLUSIONS

The test results show that the proposed power flow method can handle passive/active unbalanced distribution system with weakly meshed/radial configuration.

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