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Power-Flow Development Based on the Modified Backward-Forward for Voltage Profile Improvement of Distribution System

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ABSTRACT

Unbalanced three-phase radial distribution system has a complex problem in power system. It has many branches and it is sometimes voltage profile's not stable at every end branches. For improvement of voltage profile, it can be performed by penetrating of a distributed generation models. Information of voltage profile can be gained by study of power flow. The Modified Backward-Forward is one of the most widely used methods of development of power flow and has been extensively used for voltage profile analysis. In this paper, a study of power flow based on the Modified Backward-Forward method was used to capture the complexities of unbalanced three phase radial distribution system in the 20 kV distribution network in North Surabaya city, East Java, Indonesia within considering distributed generation models. In summary, for the informants in this study, the Modified Backward-Forward method has had quickly convergence and it's just needed 3 to 5 iteration of power flow simulation which's compared to other power flow development methods. Distributed Generation models in the modified the modified 34 BUS IEEE system and 20 kV distribution network has gained voltage profile value on limited range. One of the more significant findings to emerge from this development is that the Modified Backward-Forward method has average of error voltage about 0.0017 % to 0.1749%.

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1. INTRODUCTION

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 power flow methods have been developed for the past twenty years and can be broadly classified into four categories, which are Bus Impedance methods [1], Newton-type methods [2]-[3], Forward-Backward (FB) and its variations [4]-[7], and Sequential Power Flow (SPF) methods [8]-[11].

Research into study of power flow has a long history. The study by Chang et al. [12] offers probably the most comprehensive empirical analysis of an improved backward/ forward sweep algorithm for three-phase load-flow analysis of radial distribution systems. Based on results show that the algorithm is accurate and computationally efficient. The improved backward/ forward sweep method is one of the more practical ways of finding values of voltage profile. In [13], Chen et al. had introduced a novel three-phase power flow approach for unbalanced radial distribution systems. Their proposed approach is called the 'direct ZBR method' which had applied basic graph theory and injection current technique.

One study by Teng [14] examined the trend in modeling distributed generations in three-phase distribution load flow. In power-flow development, to analyse and simulate the penetrations of DG's have been integrated into three-phase distribution system. A great deal of previous research into study of power flow has focused on development of three-phase unbalanced power flow using PV and PQ models for DG's and study of the impact of DG models. Khushalani et al. [15] investigated the differential impact of DG models on study of power flow using varying DG penetration related to the increase in loading. System losses and voltage deviations are compared. Similarly, Suyanto et al. [16] found a three phase power flow method that can handle passive/active and radial/weakly meshed distribution networks. The Modified direct-ZBR method is developed and combined with Particle Swarm Optimization (PSO). In Shirmohammadi et al. [17], their paper describe a new power flow method for solving weakly meshed distribution and transmission networks, using a multi-port compensation technique and basic formulations of Kirchhoff's laws. Thus far, previous studies have begun to examine the use of power flow in FACTS devices such as thyristor controlled series compensators controls the power flow in the network, by Tadikonda et al. [18].

This paper details the development of power flow based on A Modified Backward-Forward method. The Modified Backward-Forward is one of the most widely used methods of development of power flow and has been extensively used for voltage profile analysis. These method was used to capture the complexities of unbalanced three phase radial distribution system in the 20 kV distribution network in Surabaya city, East Java, Indonesia within considering injection of distributed generation models where the modified the modified 34 BUS IEEE system is as test the effectiveness of the proposed algorithm. Actually the complexities of them are firstly the load change causes the voltage value change, secondly voltage source of main feeder is only disupported by main grid (PLN grid) dan finally in network operation, it is not applied for DG injected to main grid yet. In general, therefore, it seems that development of power flow based on a Modified Backward-Forward method will contribute to voltage profile improvement. This is an important issue for future research in operational and management of a distribution network.

2. DEVELOPMENT OF POWER FLOW IN UNBALANCED THREE PHASE RADIAL DISTRIBUTION SYSTEM

In a study which set out to determine power flow , Shirmohammadi et al. [17] found that development of power flow solution algorithm had the following general characteristics. They are capable of solving radial and weakly meshed distribution networks with up to several thousand line sections (branches) & nodes (buses), robust and efficient. To better understand the mechanisms of development of power flow and its effects, Chang et. al [12] analysed the back-ward/forward (BW/BF) sweep method is commonly used due to the computational efficiency and solution accuracy.

2.1. The Back-Ward/Forward (BW/BF) Method

Up to now, a number of studies have shown that the authors propose the back-ward/forward (BW/BF) method for unbalanced three-phase radial distribution system power-flow analysis. These method includes two stages: the backward stage and the decomposed forward stage. In the backward stage, Kirchoff's Current Law(KCL) and Kirchoff's Voltage Law (KVL) are applied to find the calculated voltage for each upstream bus of a line. In the decomposed forward stage, the linear proportional principles is employed to update the voltage at each downstream bus.

2.2. The Modified Back-Ward/Forward (BW/BF) Method

This development of power flow sheds new light on the modified back-ward/forward (BW/BF) method. The modified back-ward/forward (BW/BF) method is a development of the back-ward/forward (BW/BF) method which can perform the computational efficiency and solution accuracy of power flow analysis. The backward-forward modified method is able to accommodate the unbalanced three-phase of radial distribution system by using of mathematical calculations and modeling systems. The modified backward-forward method is a relationship between nodes adjusted and network topology. Network topology [6] defines all phases, whether the three-phase, two-phase or single-phase. Suppose in a bus which is only two phases or one phase. It is required for definition which bus's is missing phase. In the modified backward-forward method it is necessary formed a line of impedance matrix obtained through searching current line to load. In the modified backward-forward method it is necessary formed a line impedance matrix obtained through searching current line to load. This method will be arranged by two matrixs that will be used for calculation of power flow. There are Bus Injection to Branch Current (BIBC) matrix and Bus Current to

Branch Voltage (BCBV) matrix. BIBC matrix and BCBV matrix are an important aspect of representation model the unbalanced three-phase of radial distribution system.

2.2.1. BIBC Matrix Formation

The simple distribution system as shown in Figure 1 which pure radial circuit model is supplied from a single source at the first bus as main power source. By tracing of current flow direction it will be gained some equations of power flow as follows:

B5 = I6
B4 = I5
B3 = I4 + I5
B2 = I3 + I4 + I5 + I6
B1 = I2 + I3 + I4 + I5 + I6 (1)

Based on Equation (1), BIBC matrix formation is showed as follows:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \\ I_4 \\ I_5 \end{bmatrix} \quad (2)$$

[B] = [BIBC] [I] (3)

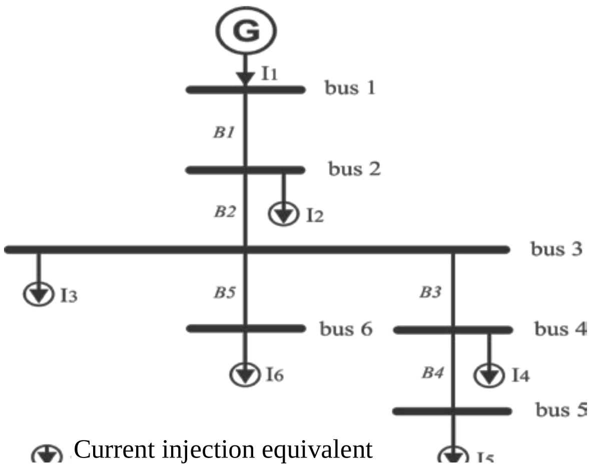

Figure 1. Single line diagram of the simple distribution system within balanced three phase

The other representation of the simple distribution system within unbalanced three phase is shown in Figure 2. Every bus has three lines of distribution path such as R, S and T. Some rules can be adapted in a modified Backward-Forward method for BIBC matrix formation proposed. They are :

First : kij = 1, if a branch-i lies on line between bus-j dan bus-refernce within same direction.
Second : kij = -1, if a branch-i lies on line between bus-j dan bus-refernce within contrast direction.
Third : kij = 0, if a branch-i doesn’t lie on line between bus-j dan bus-reference.

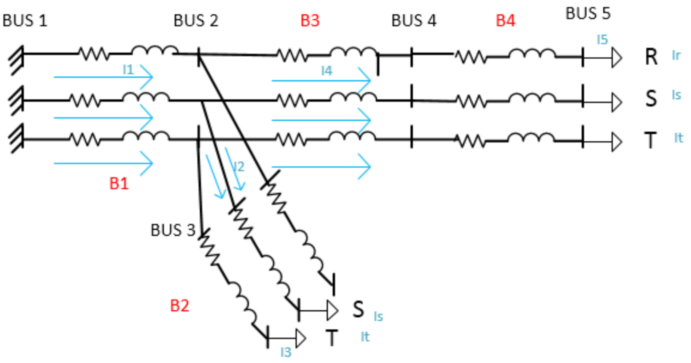

Figure 2. Single line diagram of an unbalanced three phase distribution system

Based on Figure 2, BIBC matrix formation which is derived from Equation (1) to Equation (3) is showed as follows:

$$\mathrm{BIBC}=\begin{bmatrix}
\begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix}\\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix} & \begin{bmatrix}-1&-1&-1\\-1&-1&-1\\-1&-1&-1\end{bmatrix}\\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}-1&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix}\\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&-1&-1\\0&-1&-1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&-1&-1\\0&-1&-1\end{bmatrix} & \begin{bmatrix}0&0&0\\0&-1&-1\\0&-1&-1\end{bmatrix}\\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&-1&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix}\\
\begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&0\end{bmatrix} & \begin{bmatrix}0&0&0\\0&0&0\\0&0&-1\end{bmatrix}
\end{bmatrix} \quad (4)$$

2.2.2. BCBV Matrix Formation

The BCBV matrix can be found by voltage-drop equation from current injection equation adopted. According to Equation (3), BCBV matrix formation is shown as follows:

$$\begin{aligned}
V_1 - V_2 &= B_1.Z_{12}\\
V_1 - V_3 &= B_1.Z_{12} - B_2.Z_{23}\\
V_1 - V_4 &= B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34}\\
V_1 - V_5 &= B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} - B_4.Z_{45}\\
V_1 - V_6 &= B_1.Z_{12} - B_2.Z_{23} - B_3.Z_{34} - B_4.Z_{45} - B_5.Z_{26}
\end{aligned} \quad (5)$$

$$\begin{bmatrix}V_1-V_2\\V_1-V_3\\V_1-V_4\\V_1-V_5\\V_1-V_6\end{bmatrix} = \begin{bmatrix}Z_{12}&0&0&0&0\\Z_{12}&Z_{23}&0&0&0\\Z_{12}&Z_{23}&Z_{34}&0&0\\Z_{12}&Z_{23}&Z_{34}&Z_{45}&0\\Z_{12}&Z_{23}&0&0&Z_{36}\end{bmatrix}\begin{bmatrix}B_1\\B_2\\B_3\\B_4\\B_5\end{bmatrix} \quad (6)$$

$$[\Delta V] = [BCBV] \quad [B] \quad (7)$$

BCBV matrix can be derived from Equation (7) and it is joined together with BIBC matrix. Therefore, it is gained a voltage drop as shown Equation (8).

$$[\Delta V] = [BCBV][BIBC] \quad [I] \quad (8)$$

Based on three phase analysis, configuration of Backward-Forward Modified method can be found by every component of phase, shown as Equation (9).

$$\begin{array}{c} \\ phase\ R \\ phase\ S \\ phase\ T \end{array}\begin{array}{c} \begin{array}{ccc} phase\ R & phase\ S & phase\ T \end{array} \\ \begin{bmatrix} Z_{11} & Z_{21} & Z_{31} \\ Z_{12} & Z_{22} & Z_{32} \\ Z_{13} & Z_{23} & Z_{33} \end{bmatrix} \end{array} \quad (9)$$

Component of Zij matrix is mutual impedance between phase-i and phase-j. According to Figure-2, it can be derived BCBV matrix as shown Equation (10).

$$BCBV = \begin{bmatrix} \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} & 0 & 0 & 0 & 0 & 0 \\ \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} & \begin{bmatrix} Z_a & 0 & 0 \\ 0 & Z_b & 0 \\ 0 & 0 & Z_c \end{bmatrix} & 0 & 0 & 0 & 0 \\ [Z_a] & [Z_a] & [Z_a] & 0 & 0 & 0 \\ \begin{bmatrix} Z_b & 0 \\ 0 & Z_c \end{bmatrix} & \begin{bmatrix} Z_b & 0 \\ 0 & Z_c \end{bmatrix} & 0 & \begin{bmatrix} Z_b & 0 \\ 0 & Z_c \end{bmatrix} & 0 & 0 \\ [Z_b] & [Z_b] & 0 & [Z_b] & [Z_b] & 0 \\ [Z_c] & [Z_c] & 0 & [Z_c] & 0 & [Z_c] \end{bmatrix} \quad (10)$$

Finally a voltage drop at every of feeder can be formulated as shown Equation (11). It should be remembered that transpose of BIBC matrix has correlation to BCBV matrix.

$$[\Delta V] = [BIBC]' \times [Z] \times [BIBC] \times [I] \quad (11)$$

2.3. Distributed Generation Models

The distributed generation (DG) models are of key importance for voltage profile improvement in the unbalance three-phase in radial distribution system, as they can provide continuity in supply after an outage in the main feeder or in the primary substation. This paper details study of power-flow based on a modified backward-forward method for voltage profile improvement of unbalanced three-phase in radial distribution system considering DG models which with DG nodes modeled as PQ and PV nodes.

2.3.1. DG Model as Negative PQ Load

For unbalanced three-phase in radial distribution system, feeder was used to flow power and current from bus to load. In other site, generator provided power and current through bus. It had caused power flow path that opposite power flow path from generator. These phenomenon shown DG as negative load and it has given two impacts : DG decreasing and total load increasing. Bus which is connected DG is addressed as load bus and marked as negative sign. When DG is modeled as negative PQ load, DG does not have ability to regulate reactive power output and so it does not have ability to maintain a voltage at a specific value.

2.3.2. DG Model as PV Model

DG as PV model has ability to regulate reactive power in limited range and it can control voltage on connected bus. Within DG considering as negative PQ load it caused some characteristics of DG are neglected. Therefore, study of power flow algorithm for unbalanced three-phase in radial distribution system has been modified within DG which is as PV model. When DG is represented as a PV model, reactive power is needed to maintain in order specific values required of a large voltage and can be calculated.

3. RESULTS AND ANALYSIS

This method could be easily applied because it depends mainly on the construction of the element incidence matrics of BCBV and BIBC. The results have been compared with the modified 34-BUS IEEE system feeder result to test the effectiveness of the proposed algorithm. Both DG Model as PQ model (Negative PQ Load) and PV model are incorporated in the algorithm to show their effect on the voltage profile improvement.

As shown in Figure 3 and Figure 4, it had been compared the results obtained from the preliminary analysis of power-flow development between voltage and angle values of distribution system before DG injected (passive distribution system) and after DG injected (active distribution system) on the modified 34-BUS IEEE system feeder where DG injected as negative PQ load (PQ model).

Most case developments in power-flow based on a modified backward-forward method have only been carried out in a small number of areas specially in the 20 kV distribution network in North Surabaya city, East Java, Indonesia.

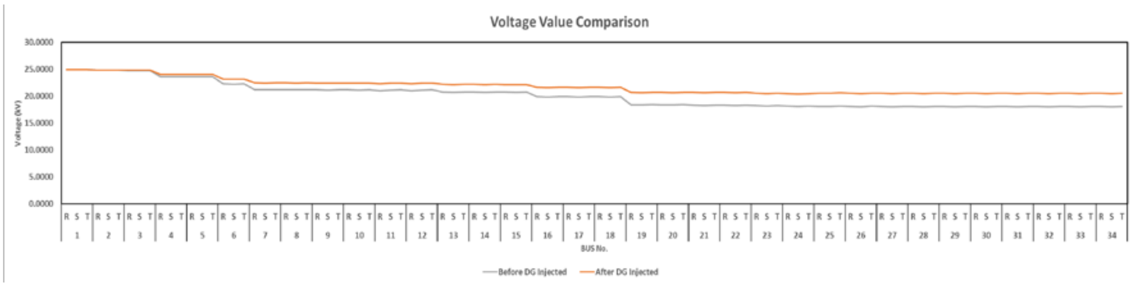

Figure 3. Comparison DG as negative PQ load of power-flow study between voltage value distribution system before DG injected and after DG injected on the modifed 34-BUS IEEE system feeder

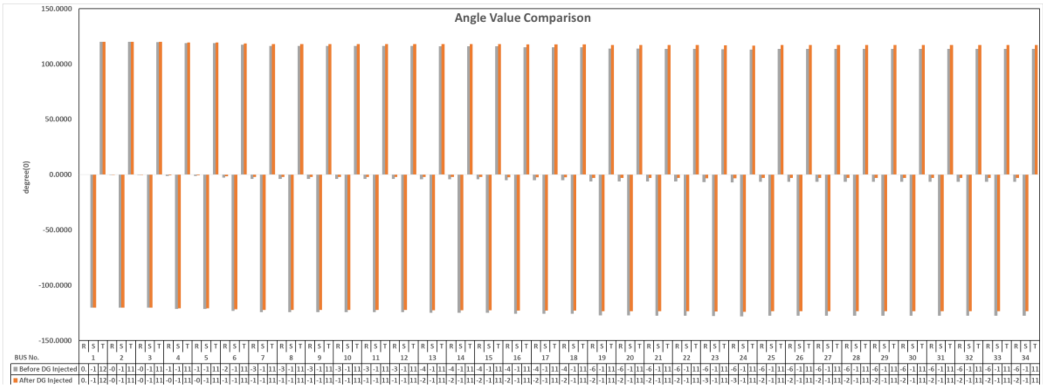

Figure 4. Comparison DG as negative PQ load of power-flow study between angle value distribution system before DG injected and after DG injected on the modified 34-BUS IEEE system feeder

One of case studies in the 20 kV distribution networks is Kaliasin feeder as shown in Figure 5 which has 10 buses of distribution substation which fully radial three phase and different load every phase. And so it has been injected by DG and placed on Bus-7. Line data and load data of Kaliasin Feeder are shown as in Table 1 and Table 2.

Furthermore, DG model as PV model can regulate reactive power and DG model which is injected to distribution system can maintain voltage value on required bus. For this case study, DG injected is 188 kW on Bus-7.

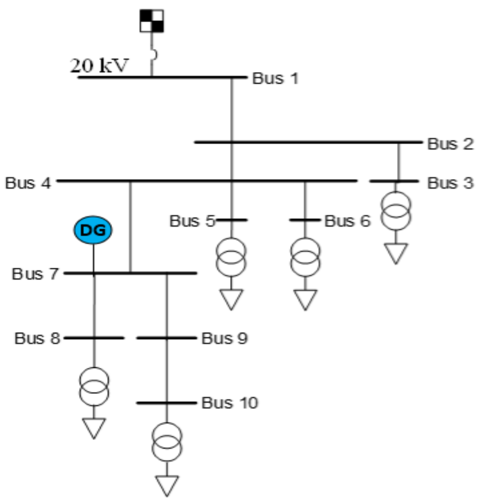

Figure 5. Single line diagram of Kaliasin feeder

Table 1. Line data of Kaliasin Feeder

Line		Impedance		Lenght
Bus	Bus	R (Ω)	X (Ω)	(m)
1	2	0.265	0.13	1000
2	3	0.0053	0.0026	20
2	4	0.06625	0.0325	250
4	5	0.010335	0.00507	39
4	6	0.010547	0.005174	39.8
4	7	0.0137694	0.006755	51.96
7	8	0.06095	0.0299	230
7	9	0.014045	0.00689	53
9	10	0.053	0.026	200

Table 2. Load data of Kaliasin Feeder

Bus	P (kW)			Q (kVAR)		
	R-N	S-N	T-N	R-N	S-N	T-N
2	0	0	0	0	0	0
3	19.992	29.1	24.576	4.06	7.293	7.168
4	0	0	0	0	0	0
5	11.737	22.896	22.988	2.942	7.195	7.877
6	22.889	23.496	47.991	5.324	6.943	14.727
7	0	0	0	0	0	0
8	22.373	24.269	16.93	4.883	8.148	4.016
9	0	0	0	0	0	0
10	109	98	106	27.228	19.9	26.498

Figure 6 compares the results obtained from the preliminary analysis of power-flow development between voltage distribution system before DG injected and after DG injected on Kaliasin feeder. It could be seen that voltage value every bus had increased more significant. It means that DG injected in distribution system can improve voltage profile. However DG model as PV model can regulate reactive power through voltage value can not be maintained on justed value.

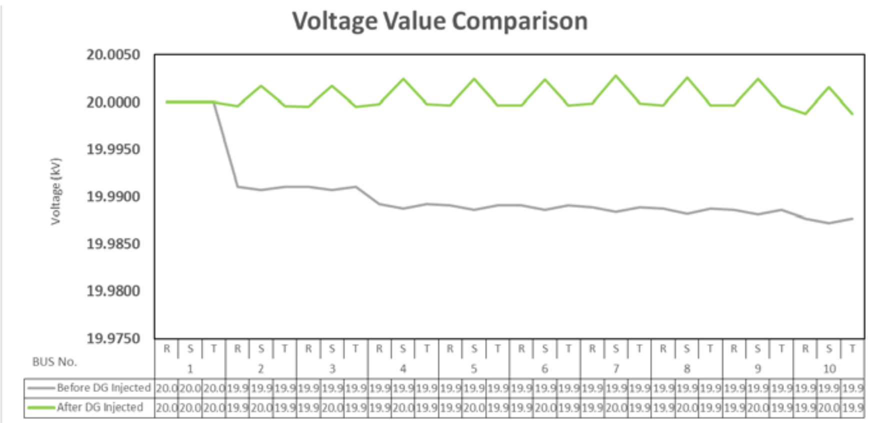

Figure 6. Comparison DG as PV model of power-flow study between voltage value distribution system before DG injected and after DG injected on Kaliasin feeder.

Figure 7 presents comparison of the results obtained from the preliminary analysis of power-flow study between voltage distribution system before DG injected and after DG injected on Kaliasin feeder. It could be seen that angle value every bus had kept more significant. It means that DG injected in distribution system can improve voltage profile. However DG model as PV model can maintain voltage value on 20 kV.

Beside Kaliasin feeder, there are also Tunjungan feeder, Ometraco feeder, Tegal Sari feeder and Basuki Rahmat feeder which affect the overall voltage profile in the 20 kV distribution network in North Surabaya city, East Java, Indonesia. How is voltage profile happen and their impact between one feeder to another feeder?

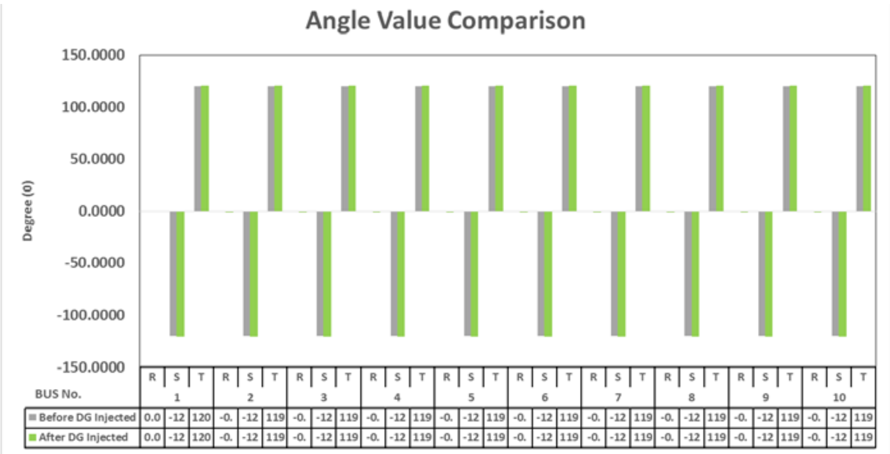

Figure 7. Comparison DG as PV model of power-flow study between angle value distribution system before DG injected and after DG injected on Kaliasin feeder.

Figure 8 and Figure 9 present comparison of error voltage and delta angle on some feeders when DG is adjusted as negative PQ load (PQ model) and PV model in the 20 kV distribution network in North Surabaya city. The Basuki Rahmat feeder has more higher error maximum voltage and angle among other feeders. It’s voltage of error maximum is 0.1749 % and angle of error maximum is 0.1045. A study of power flow based on the Modified Backward-Forward method can capture profile voltage of unbalanced three phase radial distribution system in the 20 kV distribution network in North Surabaya city, East Java, Indonesia within considering DG models.

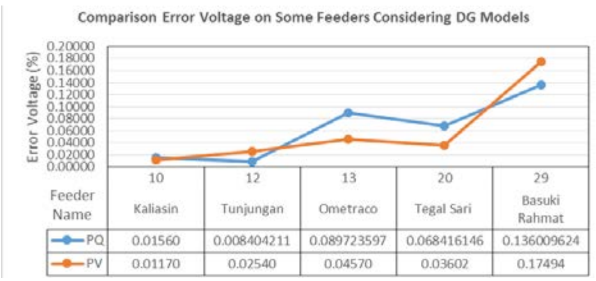

Figure 8. Comparison error voltage on some feeders considering DG model

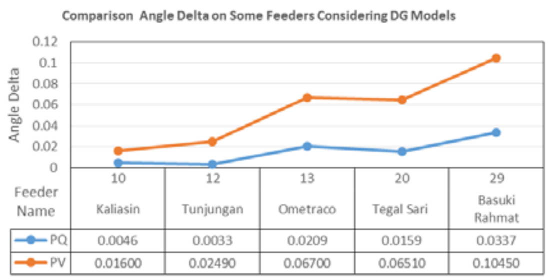

Figure 9. Comparison angle delta on some feeders considering DG model

The results of simulation in this development indicate quickly iteration total and it’s just needed 3 to 5 iterations study of power flow simulation where DG considering as PV model (as shown on Table 3). Overall iteration results of power flow development on several feeders where DG injected as PV model had impacted more significant than to both no DG injected and DG injected as PV model.

Table 3. Iteration Results of Power Flow Development on Several Feeders

Feeder Name	BUS TOTAL	No Injected DG	Injected DG	
		Pasif	PQ Model	PV Model
33 BUS IEEE System	34	7	6	5
Kaliasin	10	3	3	3
Tunjungan	12	3	3	3
Ometraco	13	4	4	3
Tegal Sari	20	3	3	3
Basuki Rahmat	29	4	4	4

The iteration time accuracy in this development shows more significant than other development methods which's based on Bus Impedance methods [1], Newton-type methods [2]-[3], Forward-Backward (FB) and its variations [4]-[7], and Sequential Power Flow (SPF) methods [8]-[11] (as seen on Table 4).

Table 4. Iteration Range of Power Flow Development Methods

Power Flow Development Methods	Bus Impedance (Analysis-a Rigid Approach) [1]	Newton-type (Current Injection) [2],[3]	Forward-Backward (Direct ZBR, A Network-Topology, A Loop Based) [4]-[7]	Sequential Power Flow (Sequence Component Frame) [8]-[11]	Proposed (Modified Backward-Forward)
Iteration Range (time)	4-42	Less (depend on network)	3-6	3-7	3-5

4. CONCLUSION

The Modified Backward-Forward method has had quickly convergence and it's just needed 3 to 5 iteration study of power flow simulation which's compared to other power flow methods. The injected DG as negative PQ load (PQ model) and PV model in the modified the modified 34 BUS IEEE system (as test the effectiveness of the proposed algorithm) and 20 kV distribution network in North Surabaya city, East Java, Indonesia (as test the application of the proposed algorithm) has gained voltage profile value on limited range. One of the more significant findings to emerge from this study is that a Modified Backward-Forward method has average of voltage error about 0.0017 % to 0.1749% which is applied on several feeders.

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REFERENCES

[1] T. H. Chen, *et al.*, "Distribution system power flow analysis-a rigid approach. Power Delivery," *IEEE Transactions on*, vol/issue: 6(3), pp. 1146-1152, 1991.
[2] P. A. N. Garcia, *et al.*, "Three-phase power flow calculations using the current injection method," *IEEE Transactions on Power Systems*, vol/issue: 15(2), 2000.
[3] V. M. da Costa, *et al.*, "Developments in Newton Raphson power flow formulation based on current injections," *IEEE Transactions on Power System*, vol/issue: 14(4), 1999.
[4] T. H. Chen and N. C. Yang, "Three-phase power-flow by direct ZBR method for unbalanced radial distribution systems," *Generation, Transmission & Distribution, IET*, vol/issue: 3(10), pp. 903-910, 2009.
[5] W. H. Kersting, "Distribution System Modeling and Analysis," CRC Press, 2002.
[6] J. H. Teng, "A Network-Topology Based Three: Phase Load Flow for Distribution Systems," *Proceedings of National Science Council ROC (A)*, vol/issue: 24(4), pp. 259-264, 2000.
[7] S. Sivanagaraju, *et al.*, "A loop based load flow method for weakly meshed distribution network," *APRN Journal of Engineering and Applied Sciences,* vol/issue: 3(4), pp. 55-59, 2008.
[8] K. L. Lo and C. Zhang, "Decomposed three-phase power flow solution using the sequence component frame," *Generation, Transmission and Distribution, IEE Proceedings C*, vol/issue: 140(3), pp. 181-188, 1993.
[9] M. A. Akher, *et al.*, "Improved Three-Phase Power-Flow Methods Using Sequence Components," *Power Systems, IEEE Transactions on*, vol/issue: 20(3), pp. 1389-1397, 2005.
[10] M. Z. Kamh and R. Iravani, "Unbalanced Model and Power-Flow Analysis of Microgrids and Active Distribution Systems," *Power Delivery, IEEE Transactions on*, vol/issue: 25(4), pp. 2851-2858, 2010.
[11] M. Z. Kamh, "A unified three phase power flow analysis model for electronically coupled distributed energy resources," *IEEE Trans. Power Deliv.*, vol/issue: 26(2), pp. 899-909, 2011.
[12] G. W. Chang, *et al.*, "An improved backward/forward sweep load flow algorithm for radial distribution systems," *Power Systems, IEEE Transactions on*, vol/issue: 22(2), pp. 882-884, 2007.
[13] T. H. Chen and N. C. Yang, "Three-phase power-flow by direct Z BR method for unbalanced radial distribution systems," *Generation, Transmission & Distribution, IET*, vol/issue: 3(10), pp. 903-910, 2009.
[14] J. H. Teng, "Modelling distributed generations in three-phase distribution load flow," *Generation, Transmission & Distribution, IET*, vol/issue: 2(3), pp. 330-340, 2008.
[15] S. Khushalani, *et al.*, "Development of three-phase unbalanced power flow using PV and PQ models for distributed generation and study of the impact of DG models," *Power Systems, IEEE Transactions on*, vol/issue: 22(3), pp. 1019-1025, 2007.
[16] Suyanto, *et al.*, "Modified Direct-ZBR Method + PSO Power Flow Development for Weakly Meshed Active Unbalanced Distribution Systems," *APRN Journal of Engineering and Applied Sciences*, vol/issue: 9(9), pp. 1476-1483, 2014.

[17] D. Shirmohammadi, *et al.*, "A compensation-based power flow method for weakly meshed distribution and transmission networks," *Power Systems, IEEE Transactions on*, vol/issue: 3(2), pp. 753-762, 1988.
[18] Tadikonda, *et al.*, "ATC Enhancement with FACTS Devices Considering Reactive Power Flows Using PTDF," *International Journal of Electrical and Computer Engineering*, vol/issue: 3(6), pp. 741, 2013.

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