International Journal on Emerging Technologies 11(1): 219-226(2020)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

# Performance Analysis of Phase Reconfiguration on Distribution Systems with Distributed Generation

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*(Received 18 October 2019, Revised 12 December 2019, Accepted 21 December 2019)*
*(Published by Research Trend, Website: www.researchtrend.net)*

**ABSTRACT: Implementation of new trends in modern distribution system planning and operation increases the research opportunities towards development of new methodologies and procedures. The difficulty of increasing performance of distribution system with conventional methods is difficult and decreases the efficacy. Further, the analysis of unbalanced radial distribution system with different loads increases the complexity of problem. By segregating all these aspects, a new phase decoupled methodology is presented in this paper to solve unbalanced distribution load flow problem. Later, the effect of placing unbalanced distributed generation in a given system to enhance performance is analyzed. Total power losses and voltage deviation objectives are considered in optimization problem and are optimized using gravitational search algorithm while satisfying system equality and inequality constraints. The presented methodology is proven its effectiveness in solving complex computational procedures. This methodology is tested on URDS-19 node system with supporting analytical results.**

**Keywords:** Network phase reconfiguration; Optimal location of DG; Total power losses; Voltage deviation; GSA method.

## I. INTRODUCTION

The operation of distribution system planning and operation requires help of modern tools to improve system performance. There are numerous methods to perform this task. Some of these methods are installation of capacitors, automatic voltage regulators, tap changing transformers, etc. This consequently increases the cost of operation and complexity too. Hence, optimization methods can be used to optimize system parameters and as well as system configuration.
Fuzzy based multi objective heuristic algorithm with reconfiguration of network to minimize active power loss, voltage deviations, current carrying capacity of branches and feeder loading capacity to improve the performance of the distribution system [1]. In this method, the reconfiguration is performed in two stages to improve performance of the system. Ant colony search algorithm is simple and reliable methodology for network reconfiguration and reduces system losses [4]. A novel harmonic load flow algorithm was proposed. This is a fast method for network reconfiguration compare to other methods [6].
For minimization active power losses, a simple load flow method proposed by using voltage stability index with network reconfiguration [7]. A new adaptive particle swam optimization algorithm is discussed for network reconfiguration to minimize the active power loss without using any additional components [9]. A simple feeder reconfiguration method was proposed in based on bus voltages and system losses, the number of switching’s required in this method is less and the computational time is also reduced it also works effectively for balanced and unbalanced systems [10]. Mehfuz and Rashid (2014) describe the effect of feeder reconfiguration on minimization of power losses with distributed generations [2]. A hybrid big bang –big crunch algorithm is proposed for obtaining solution for multi objective optimization problem with accuracy, fast convergence and easy for implementation [5]. Sedighizadeh *et al.*, (2013) proposed a new hybrid algorithm based on discrete particle swam optimization, ant colony algorithm and fuzzy for reduction of power losses and to reduce voltage deviations [8]. The effect of both network reconfiguration and capacitor placement of reductions of active power losses is analyzed [3].
Sultana & Roy (2016) Krill herd algorithm was proposed for obtaining optimum network configuration with capacitor placement for minimization of true power in the distribution system [11]. A non-iterative harmonic load flow algorithm based on backward/forward sweep method is presented to decrease the computational time for capacitor compensated distribution networks [12]. A multi objective optimization problem such as power loss, operational cost is solved to reconfigure network using hybrid improved particle swam algorithm [13]. The minimum power loss of network is obtained by novel methodologies based on the concept of receding horizon control and most probable scenario which inherently considering switching loss [14].
The interval multi-objective evolutionary algorithm was proposed to obtain the optimal configuration of distribution feeder by considering uncertainties [15].

Duan *et al.*, (2015) reconfiguration of network is studied with distributed generations as two types of buses P and PQV. The optimization problem was solved with genetic algorithm [16]. The modified genetic algorithm optimization method is proposed to reduce the real power loss and reliability of the reconfigured distribution network [17]. Esmaeilian and Fadaeinedjad (2015) proposed a novel solving approach, Multi-objective Hybrid Big Bang-Big Crunch (MOHBB-BC) for network reconfiguration and at the same time allocates generations to distributed generations [18].

Kaur and Ghosh (2016) used Binary Gravitational search algorithm (BGSA) and fuzzy approach for distribution system network reconfiguration and optimal capacitor allocation not only to minimize energy losses but also to improve the system reliability subjected to operational and power quality constraints [19]. Kaveh *et al.*, (2018) hybrid fuzzy firefly optimization algorithm for the reconfiguration of unbalanced distributed network in order to reduce the total power loss, deviation in bus voltages and also to balance the loads in the feeders [20]. A hybrid bacterial foraging with spiral dynamic (BF-SD) algorithm is presented to rephrase, reconfigure and to obtain the maximum benefits from optimally sized DG [21]. Enhanced Gravitational Search Algorithm (EGSA) was proposed to improve the transient stability issue as the DG penetration is more in the more present distribution system [22]. Rosseti *et al.*, (2013) the authors proposed a new swam intelligence based Fireworks Algorithm (FWA) for the distribution network reconfiguration and optimal placement of distributed generators for the loss minimization and enhancement of voltage stability [23]. Taher and Karimi (2014) develops a heuristic algorithm depending on sensitivity indices for the optimal reconfiguration and distributed generation allocation to reduce the losses [24].

From literature, it is motivated that, the system performance can be enhanced by implementing several methods. Some of the methods such as installation of capacitor bank, automatic voltage regulators, inductor banks, tap changing transformers, distributed generations, etc. Apart from these methods, system configuration can be enhanced by changing configuration of the existing system. Most of the literature highlighted the reconfiguration procedure using tie switches. These tie switches are used to reconfigure the given distribution network not to violate the radiality condition. Somehow this minimizes the total power losses to some extent. But, this generalized procedure is not valid for the unbalanced distribution systems with diversified loads. Hence, there is a need to develop a new methodology to solve unbalanced distribution load flow problem. There are numerous methods to solve unbalanced distribution system with balanced loads. But, in real time, the nature of loads is unbalanced.

By considering all these points into consideration, in this paper a new phase decoupled load flow methodology is developed to solve unbalanced load flow problem with different loads in three phases. As this methodology works independent of the number of nodes and nature of loads, and this can be applied to solve unbalanced distribution system with diverse loads. Further, the performance of given distribution system is enhanced with distributed generations such as Type-1, 3. The effectiveness of DGs is increased if they are placed in optimal locations. The proposed methodology is tested on standard unbalanced radial distribution system (URDS)-19 node system with supporting numerical and graphical results.

## II. PROBLEM STATEMENT

The power transfer capability of distribution lines can be increased by connecting different auxiliary compensating devices. Identifying an optimal device in an optimal location is one of the challenging tasks in modern distribution system planning and operation. Further, the advanced techniques like reconfiguration, optimization, etc empowers research towards development of new methodologies and procedures. By considering all these points into consideration, it is necessary to develop a methodology to solve distribution load flow problem when phases are reconfigured between nodes. It is necessary to identify an optimal placement procedure to install DGs in a given distribution system to enhance the system performance.

## III. MATHEMATICAL MODELING OF PHASE RECONFIGURATION

For an unbalanced radial distribution system (URDS) 'N' number of nodes and 'b' number of branches, 'p' number of unbalanced sections, the load flow solution can be obtained through the following mathematical interpretation.

At first, the nodes connected to main feeder are indentified and numbered sequentially starting from node-1 to end node of the feeder. After this, the node number is continued for the nodes in laterals connected to the main feeder. To understand this, let us consider the unbalanced radial distribution system shown in Fig. 1.

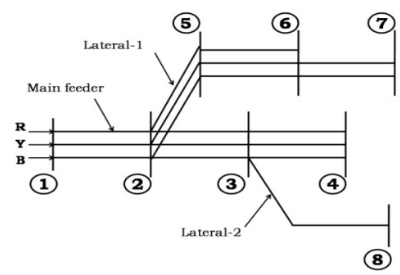



**Fig.1.** Sample URDS without phase reconfiguration and with node numbers.

After this, the unbalanced sections are identified in a given URDS by considering the connectivity between the nodes using line impedances. For example, the line between nodes 6 and 7 has no impedance in R-phase can be treated as one unbalanced section. Similarly the remaining sections are also identified.

In this type of systems, the reconfiguration of phases can enhance the system performance. This reconfiguration can be performed based on the voltage magnitude at the system nodes.

The node at which per phase voltage is decreased drastically is considered to be the optimum node at which phases can be reconfigured. For example, the reconfigured network for the considered URDS is shown in Fig. 2. For this, the phases Y and B are reconfigured at node-2.

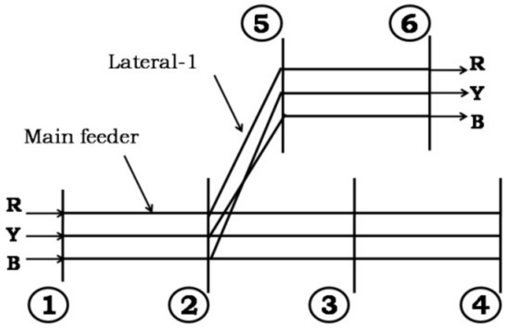
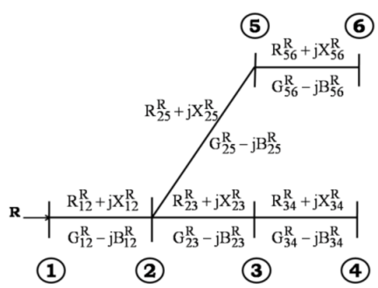


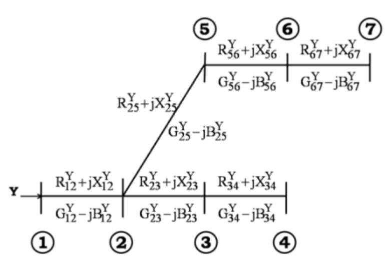

**Fig. 2.** Sample URDS with phase reconfiguration and with node numbers.

## IV. PHASE DECOUPLED DISTRIBUTION LOAD FLOW METHOD

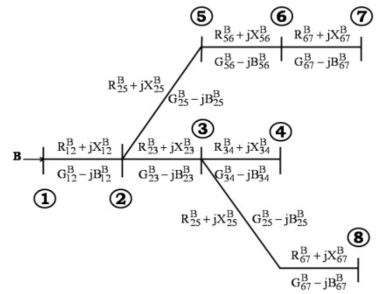
As the unbalanced distribution [25] lines consists self and as well as mutual impedances and shunt admittances, the conventional balanced radial load flow methods are unsuitable for solving unbalanced this type of systems. Hence, a novel methodology is proposed using the number of unbalanced sections. In this, the phase decoupled self impedance networks are drawn for each of the phases using self impedances and their shunt admittances. Further, the phase decoupled mutual impedance networks are drawn between the phases using mutual impedances and their shunt admittances. To exemplify this, for the system shown in Fig. 1, the phase decoupled self and mutual impedance networks are shown in Fig. 3 and 4.



(a) for R-Phase

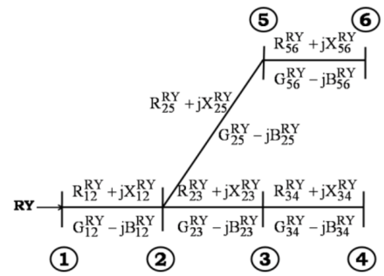


(b) for Y-Phase

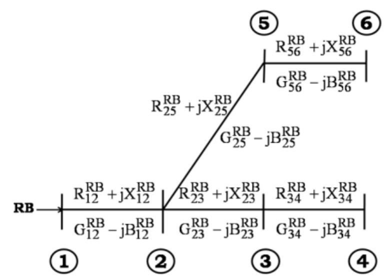


(c) for B-Phase

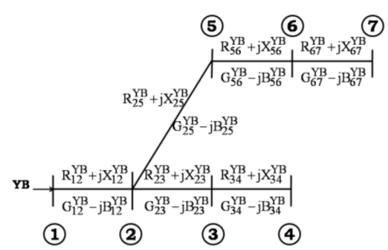
**Fig. 3.** Phase decoupled self impedance networks.



(a) for RY-Phase



(b) for RB-Phase



(c) for YB-Phase

**Fig. 4.** Phase decoupled mutual impedance networks.

Due to this decoupled procedure, the URDS becomes balanced radial distribution system with reduced matrix dimensions. For example, conventionally in unbalanced three phase system, impedance matrix is of the order of 3 × 3 and totally nine elements to be handled for further calculations.

$$Z_{12}^{RYB} = \begin{bmatrix} Z_{12}^{RR} & Z_{12}^{RY} & Z_{12}^{RB} \\ Z_{12}^{YR} & Z_{12}^{YY} & Z_{12}^{YB} \\ Z_{12}^{BR} & Z_{12}^{BY} & Z_{12}^{BB} \end{bmatrix}$$

whereas, in phase decoupled algorithm, the impedance matrix is of the order of 1 × 1 and totally six elements are sufficient for further calculations.

$$\left[Z_{12}^{RR}\right] \; ; \left[Z_{12}^{YY}\right] \; ; \left[Z_{12}^{BB}\right] \; ; \left[Z_{12}^{RY}\right] \; ; \left[Z_{12}^{RB}\right] \; ; \left[Z_{12}^{YB}\right]$$

To following steps are used to solve load flow problem.

**Step 1: Calculation of load currents**

For phase decoupled self impedance networks, current supplied to load connected at each node is calculated by applying Kirchhoff's Current Law (KCL) at each node using

$$I_p^{Load} = \left(\frac{S_p^{Load}}{\overline{V_p}}\right)^* = \frac{P_p^{Load} - jQ_p^{Load}}{V_p \angle -\delta_p} \quad ; \quad \forall \quad p = 2,3,.....N$$

where, $P_p^{Load}$, $Q_p^{Load}$ are the active and reactive loads connected at node-p and Vp and δp are the voltage magnitude and voltage angle at node-p.

**Note:** There is no need to calculate load current at nodes in phase decoupled mutual impedance networks, as there is no concept of mutual load.

**Step 2: Calculation of admittance currents**

Here, the current injected/absorbed by the shunt admittance of distribution lines in phase decoupled self impedance networks can be calculated as

$$I_{k,i}^{Self} = j \times B_{k,i}^{Self} \times \overline{V}_{k,i}^{Self} \quad ; \quad k = R, Y, B \quad ; \quad i = 1,2,....nl$$

where, nl is the total number of lines, $\overline{V}_{k,i}^{Self}$ is the reference voltage of the respective phases.

In phase decoupled mutual impedance networks, the current injected can be calculated as

$$I_{k,i}^{Mutual} = j \times B_{k,i}^{Mutual} \times \overline{V}_{k,i}^{Mutual} \quad ; \quad k = R\text{-}Y, Y\text{-}B, R\text{-}B \quad ; \quad i = 1,2,....nl$$

where, $\overline{V}_{k,i}^{Mutual}$ is the reference voltage of the respective lines.

**Step 3: Calculation of node currents**

Here, the node current is the total current flow through the distribution line due to load and shunt admittances. These currents are calculated starting from end node to substation node using backward sweeping algorithm. This current in phase decoupled self impedance networks can be calculated as

at end nodes of the feeder/laterals is

$$I_q^{Self} = I_q^{Load} \quad ; \quad q = \text{end nodes}$$

at consequent nodes starting from end node is

$$I_p^{Self} = I_q^{Self} + I_p^{Load} + I_{k,i}^{Self} \quad ; \quad k = R, Y, B \quad ; \quad q = p+1,....\text{end node} \quad ; \quad p = 1,2,3,...N$$

Similarly, this current in phase decoupled mutual impedance networks at consequent nodes starting from end node can be calculated as

$$I_p^{Mutual} = I_{k,i}^{Mutual} + I_{k,q}^{Mutual} \quad ; \quad k = R\text{-}Y, Y\text{-}B, R\text{-}B \quad ; \quad i = 1,2,....nl \quad ; \quad q = p+1,....\text{endnode} \quad ; \quad p = 1,2,3,...N$$

**Step 4: Calculation of voltage drops in branches**

Using the node currents and branch impedances, the voltage drops in the branches of phase decoupled self impedance networks can be calculated as

$$VD_p^{Self} = I_p^{Self} \times Z_p^{Self} \quad ; \quad p = 1,2,3,...N$$

where, $Z_p^{Self} = R_p^{Self} + jX_p^{Self}$ is the self impedance of the line connected to node-p towards end node. Similarly, the voltage drop in the branches of phase decoupled mutual impedance networks can be calculated as

$$VD_p^{Mutual} = I_p^{Mutual} \times Z_p^{Mutual} \quad ; \quad p = 1,2,3,...N$$

where, $Z_p^{Mutual} = R_p^{Mutual} + jX_p^{Mutual}$ is the mutual impedance of the line connected to node-p towards end node.

**Step 5: Calculation of node voltages**

In this, the voltage drop of a line is subtracted from the send end voltage to get receiving end voltage. These voltages are calculated starting from substation node to end node using forward sweeping algorithm. The receiving end voltage of a branch of phase decoupled self impedance networks can be calculated as

$$V_r^{Self} = I_p^{Self} \times Z_p^{Self} \quad ; \quad p = 1,2,3,...N$$

*A. Mathematical modeling of PDLF method*

Using the proposed methodology, the voltage in R-phase connected between nodes i and j can be calculated as

$$V_j^R = V_i^R - \left(I_{ij}^R \times Z_{ij}^R\right) + V_i^{RY} - \left(I_{ij}^Y \times Z_{ij}^{RY}\right) + V_i^{RB} - \left(I_{ij}^B \times Z_{ij}^{RB}\right)$$

Upon solving this equation using phasor interpretations, the simplified voltage in R-phase at jth node can be evaluated as

$$V_j^R = V_i^R - \left(I_{ij}^R \times Z_{ij}^R\right) - \left(I_{ij}^Y \times Z_{ij}^{RY}\right) - \left(I_{ij}^B \times Z_{ij}^{RB}\right)$$

Where, $V_j^R$, $V_i^R$ are voltage magnitudes at i*th* and j*th* nodes. $I_{ij}^R$, $I_{ij}^Y$, $I_{ij}^B$ are the current flowing through three phases. '$Z_{ij}^R$' is the self impedance and '$Z_{ij}^{RY}$ and $Z_{ij}^{RB}$' are the mutual impedances of line-ij. The phasor diagram for this simplification is shown in Fig. 5.

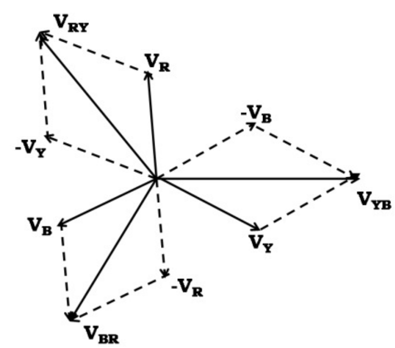



**Fig. 5.** Phasor simplification to calculate phase voltage.

## V. MODELING OF DISTRIBUTED GENERATION

From literature, it has been identified that, based on the type of power injection/absorption, there are four types of DGs in distribution systems which are listed in Table.1.

**Table 1: Types of DGs available in distribution systems.**

| Type of DG | Active power | Reactive power |
|---|---|---|
| Type-1 | Generation | – |
| Type-2 | – | Generation |
| Type-3 | Generation | Generation |
| Type-4 | Generation | Absorption |

This paper aims to identify the effect of optimal DG on system performance in terms of loss minimization and loss allocation aspects. For loss minimization aspect, the reactive power must be generated instead of absorption. Hence, Type-4 DG is not considered for the analysis. Similarly, for loss allocation aspect, active power losses are allocated to active power generation. With this reason, Type-2 DG is also not considered for the analysis. This consideration can also be observed from the analysis presented in section XI.

For Type-1 and 3 DGs, the current injection can be mathematically expressed as

**For Type-1 DG:**

$$\bar{I}_n = \frac{P^n_{load} - P^n_{DG} - jQ^n_{load}}{\left(\bar{V}_n\right)^*} \quad ; \quad n = \text{DG connected node}$$

**For Type-3 DG:**

$$\bar{I}_n = \frac{P^n_{load} - P^n_{DG} - jQ^n_{load} - jQ^n_{DG}}{\left(\bar{V}_n\right)^*} \quad ; \quad n = \text{DG connected node}$$

Where, 'Pn, Qn' are the active and reactive power loads at nth node. 'PDG, QDG' are the active and reactive powers generated by DG at nth node. 'Vn' is the voltage magnitude at nth node.

In order to identify an optimal location of DG in a given system, at first, base case load flow problem is solved. Using this result, the node at which voltage magnitudes are interchanged is considered to be the optimal location to install DG. Since, this node is very sensitive and farer from the substation node. This is demonstrated in section-9 with supporting numerical and graphical results.

## VI. OPTIMAL PHASE RECONFIGURATION

The following step by step procedure is followed to identify an optimal set of phase reconfiguration sets.

**Step 1:** The phase configurations at each node are generated randomly.

$$\begin{bmatrix} Node-1 \\ Node-2 \\ Node-3 \\ ....... \\ Node-n \end{bmatrix} = \begin{bmatrix} 1 & 3 & 2 \\ 3 & 2 & 1 \\ 2 & 1 & 3 \\ .. & .. & .. \\ 1 & 2 & 3 \end{bmatrix}$$ 1->R-phase; 2->Y-Phase; 3-B-Phase

**Step 2:** Using this, phase decoupled self impedance networks are formulated and load flow problem is solved using proposed phase decoupled load flow algorithm.

**Step 3:** Similarly, the phase decoupled mutual impedance networks are formulated and load flow problem is solved.

**Step 4:** By applying mathematical modeling presented in section.4.1, the node voltages are calculated.

**Step 5:** Using this, active and reactive power flows through distribution lines and total active and reactive power losses in a given distribution system is evaluated.

**Step 6:** This process is repeated with DG in an optimal location. The effect of DG on system performance is analyzed.

*A. Gravitational search algorithm*

Gravitational search algorithm is considered to solve optimization problem. As this algorithm has proven its effectiveness in solving complex optimization problem while satisfying system constraints. This algorithm works based on the law of gravity principle.

In this, the gravitational constant G(t) can be calculated as

$$G(t) = G_0 * e^{\left(\frac{-\alpha t_i}{T}\right)}$$

where, $G_0$ is initial value, α is a constant, ti is the current iteration number, T is the total number of iterations. After this, the gravitational (mi) and inertia masses (Mi) can be calculated as

$$M_{ai} = M_{pi} = M_{ii} = M_i$$

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{N} m_i(t)}$$

Here

$$best(t) = \min_{j=1,2......N} fit_j(t) \quad \text{and} \quad worst(t) = \max_{j=1,2......N} fit_j(t),$$

Fitness of an objective function (fit) is calculated by taking inverse of its objective value of respective set of population. Using this, the force acting on each mass, velocity and acceleration of ith particle in (t+1)th iteration are calculated as

$$v_i^d(t+1) = rand_i \times v_i^d(t) + a_i^d(t)$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1)$$

## VII. OBJECTIVEFUNCTION FORMULATION

The optimization problem is solved either by minimizing or maximizing the objective(s) subjected to satisfying system equality and inequality constraints. This can be expressed as

Minimize (TPL)

Subjected to g(x,u)=0; hmin≤h(x,u)≤hmax

Where, 'g' and 'h' are equality and inequality constraints. 'x' and 'u' are state and control vectors of dependent and independent control variables.

In this work, total active power loss (TPL) in a given system is considered as an objective function. The system security can be enhanced by minimizing system severity which is proportional to the total power losses in a system. The power losses in a given system can be calculated as

$$TPL = \sum_{i=1}^{nl} P^i_{loss}$$

where, $P_{loss}^{i}$ is the active power loss in *i*th distribution line.

After minimizing total power loss objective, the effect of DG is analyzed in terms of voltage deviation. The system voltage deviation can be calculated as

$$\mathrm{Vdev} = \sum_{j=1}^{NB} \left(1 - V_j\right)$$

where, 'NB' is the total number of nodes. Vj is the voltage magnitude at jth node.

## VIII. RESULTS AND ANALYSIS

To demonstrate the effectiveness of phase reconfiguration on system performance, URDS-19 node test system is considered. At first basic load flow problem is solved using the proposed phase decoupled load flow algorithm. The obtained results are tabulated in Table 2.

From this table, it is observed that, the value of node voltage magnitude is decreased as moving from substation node. It is also identified that, phase voltage is parallel in all three phases from substation node to node-10. This is because of node-10 is connected with two sub laterals. For example, from substation node to node-10, the R-phase voltage is less when compared to Y and B-phase voltages. Whereas, from node-10-19, the R-phase voltage is high when compared to Y and B-phase voltages. Hence, node-10 is considered to the optimal location to install DG. Further analysis is performed by placing DG at node-10. It is also identified that, the power flow in phases is varied as per the load connected at the respective phases.

The variation of voltage magnitude at system nodes and power flow in lines is shown in Figs. 6 and 7.

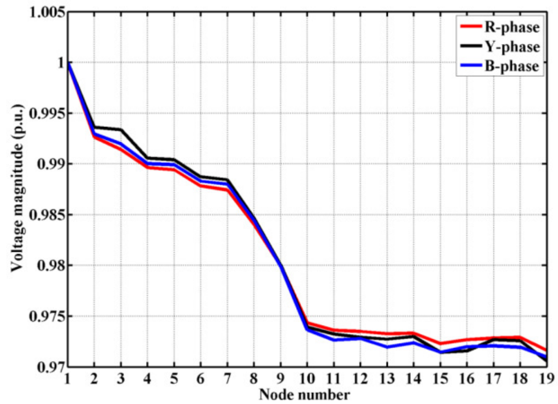



**Fig. 6.** Variation of voltage magnitude for URDS-19 node system.

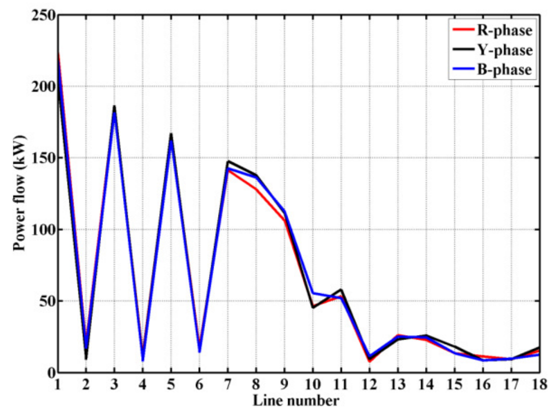



**Fig. 7.** Variation of power flows for URDS-19 node system.

**Table 2: Phase decoupled load flow results for URDS-19 node system.**

| Node No. | Voltage magnitude, p.u. | | | Line No. | From Bus | To Bus | Power flow, kW | | |
|---|---|---|---|---|---|---|---|---|---|
| | R-phase | Y-phase | B-phase | | | | R-phase | Y-phase | B-phase |
| 1 | 1 | 1 | 1 | 1 | 1 | 2 | 223.3 | 205.9 | 218.1 |
| 2 | 0.993 | 0.994 | 0.993 | 2 | 2 | 3 | 19.09 | 8.991 | 16.85 |
| 3 | 0.991 | 0.993 | 0.992 | 3 | 2 | 4 | 184.5 | 186.6 | 181.6 |
| 4 | 0.99 | 0.991 | 0.99 | 4 | 4 | 5 | 11.23 | 8.991 | 7.847 |
| 5 | 0.989 | 0.99 | 0.99 | 5 | 4 | 6 | 165.7 | 167.2 | 162 |
| 6 | 0.988 | 0.989 | 0.988 | 6 | 6 | 7 | 16.84 | 14.03 | 14.03 |
| 7 | 0.987 | 0.988 | 0.988 | 7 | 6 | 8 | 141.3 | 147.5 | 142.7 |
| 8 | 0.984 | 0.985 | 0.984 | 8 | 8 | 9 | 127.8 | 137.7 | 136.2 |
| 9 | 0.98 | 0.98 | 0.98 | 9 | 9 | 10 | 106 | 111.2 | 112.6 |
| 10 | 0.974 | 0.974 | 0.974 | 10 | 10 | 11 | 46.35 | 45.21 | 55.37 |
| 11 | 0.974 | 0.973 | 0.973 | 11 | 10 | 12 | 53.15 | 57.98 | 52 |
| 12 | 0.973 | 0.973 | 0.973 | 12 | 11 | 13 | 7.589 | 9.254 | 11.23 |
| 13 | 0.973 | 0.973 | 0.972 | 13 | 11 | 14 | 25.84 | 23.03 | 25.01 |
| 14 | 0.973 | 0.973 | 0.972 | 14 | 12 | 15 | 22.8 | 25.88 | 24.46 |
| 15 | 0.972 | 0.971 | 0.971 | 15 | 12 | 16 | 13.47 | 18 | 13.47 |
| 16 | 0.973 | 0.972 | 0.972 | 16 | 14 | 17 | 11.23 | 8.42 | 8.421 |
| 17 | 0.973 | 0.973 | 0.972 | 17 | 14 | 18 | 9.253 | 9.253 | 9.565 |
| 18 | 0.973 | 0.973 | 0.972 | 18 | 15 | 19 | 15.18 | 17.42 | 12.37 |
| 19 | 0.972 | 0.971 | 0.971 | | | | | | |

After this, optimization problem is solved with two types of DGs (i.e. Type-1, 3). The obtained results are tabulated in Table 3. From this table, it is identified that, total power losses are minimized with phase reconfiguration when compared to without reconfiguration. Further, the losses are minimized with DG when compared to without DG. It is observed that, with reconfiguration, the loss reduction is 1.16% with Type-1 DG and 0.65% with Type-3 DG.

It is also observed that, loss reduction with Type-3 DG is 222.53% when compared to Type-1 DG.

It is also observed that, with reconfiguration, the voltage deviation is reduced by 0.25% with Type-1 DG and 1.19% with Type-3 DG. It is also observed that, voltage reduction with Type-3 DG is 18.06% when compared to Type-1 DG.

The reconfiguration of phases in distribution feeders in three cases i.e. without DG, with Type-1 DG and with Type-3 DG are shown in Figs. 8-10. From these figures, it is identified that, voltage profile is enhanced with Type-3 DG when compared to remaining cases.

**Table 3: Optimized results of TPL minimization for URDS-19 node system.**

| | | Without phase reconfiguration | | | With phase reconfiguration | | |
|---|---|---|---|---|---|---|---|
| | | **R-phase** | **Y-phase** | **B-phase** | **R-phase** | **Y-phase** | **B-phase** |
| Without DG | TPL, kW | 4.4533 | 4.4403 | 4.5549 | 4.3961 | 4.5481 | 4.4886 |
| | | 13.4484 | | | 13.4327 | | |
| | Vdev, p.u. | 0.3674 | 0.3657 | 0.3728 | 0.3644 | 0.3717 | 0.3697 |
| | | 1.1058 | | | 1.1058 | | |
| With Type-1 DG | PDG | 85.0839 | 86.2407 | 86.8609 | 86.5081 | 86.7257 | 82.5551 |
| | TPL, kW | 1.2329 | 1.1147 | 1.1981 | 1.2754 | 1.1411 | 1.1175 |
| | | 3.5457 | | | 3.5341 | | |
| | Vdev, p.u. | 0.0948 | 0.0847 | 0.0899 | 0.1014 | 0.0892 | 0.0864 |
| | | 0.2695 | | | 0.2670 | | |
| With Type-3 DG | PDG | 85.7049 | 86.4327 | 86.0641 | 86.6036 | 82.6546 | 92.3628 |
| | QDG | 40.3858 | 41.3649 | 42.2961 | 42.5598 | 39.8519 | 42.5181 |
| | TPL, kW | 0.5049 | 0.3731 | 0.4373 | 0.4203 | 0.4142 | 0.4743 |
| | | 1.3153 | | | 1.3088 | | |
| | Vdev, p.u. | 0.0349 | 0.03 | 0.0334 | 0.0192 | 0.0296 | 0.0376 |
| | | 0.0983 | | | 0.0864 | | |

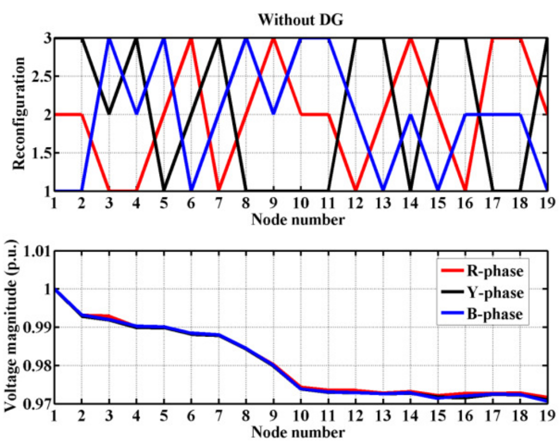



**Fig. 8.** Variation of node voltage and phase reconfigurations for without DG for URDS-19 node system.

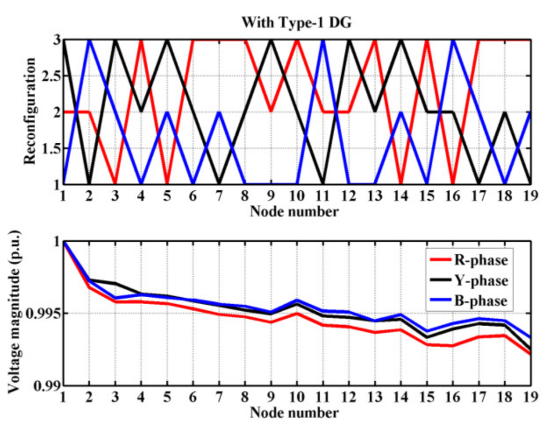



**Fig. 9.** Variation of node voltage and phase reconfigurations with Type-1 DG for URDS-19 node system.

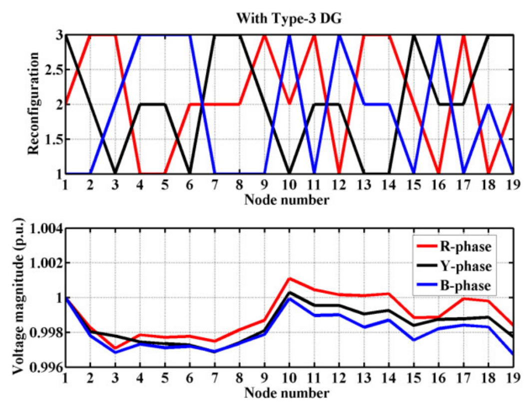



**Fig. 10.** Variation of node voltage and phase reconfigurations with Type-3 DG for URDS-19 node system.

## IX. CONCLUSIONS

In this paper, a methodology to minimize power losses in a given distribution system has been presented. Here, phase reconfiguration procedure has been presented with complete mathematical modeling to identify the effect of same on performance of a given system. Further the performance of given system in terms of total power losses and voltage deviations has been enhanced in the presence of distributed generation. For this, modeling of Type-1, 3 DGs along with its optimal placement procedures has been discussed. From the analytical results, it has been identified that, the system performance is enhanced in terms of voltage profile which consequently minimizes power losses and voltage deviations.

It has been also identified that, the proposed phase reconfiguration procedure has proven its effectiveness in maximizing system performance. This methodology has been tested with supporting numerical and graphical results.

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**How to cite this article:** Sreenivasa, Raju, B. and Sivanagaraju, S. (2020). Performance Analysis of Phase Reconfiguration on Distribution Systems with Distributed Generatio. *International Journal on Emerging Technologies*, *11*(1): 219–226.