

## A New Method for Loss Reduction in Distribution Networks via Network Reconfiguration

This paper proposes a new method for loss reduction in distribution networks through network reconfiguration taking into consideration the bus voltage limits and the thermal limits of the network branches. The method presents the load flow equations in a simplified form which is suitable for radial feeders. The load flow equations are formulated in a modified form that can be adequate for network reconfiguration through opening and closing sectionalized and tie switches while keeping its radial structure and ensuring the supply of all connected loads. The Distributed Generation (DG) that is recently applied in distribution systems has been considered in this paper. The validity of the proposed method has been verified using IEEE 16-bus and 33-bus distribution systems. Furthermore, the comparative results confirm the applicability and suitability of the proposed method.

**Keywords:** Distribution systems, loss reduction, new formulation of load flow equation, optimum feeder reconfiguration.

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### 1. Introduction

Distribution systems are usually designed as an open ring that operates in radial manner such that it consists of groups of interconnected radial circuits. If all tie switches are closed, the network loss will be at the minimal level. However, due to the complexity of the protection system and the high rate of short-circuits, the previously mentioned approach has not been maintained. In recent years, with the development of data processing and transfer technologies, distribution utilities are becoming moving to the automation of distribution systems. One of the most effective applications of automation is the reconfiguration of distribution systems. In distribution systems, reconfiguration means turning switches off and on in order to change the network topology and thus change the power flow. The main purpose of network reconfiguration is to reduce the encountered active power loss in distribution systems, preventing network overloads, improving voltage profile and increasing the system reliability, while the radial structure of distribution system is retained.

In literature, several researchers have addressed loss minimization in distribution systems through network reconfiguration. For example, distribution system reconfiguration for loss reduction was first proposed in [1]. An heuristic algorithm, based on the algorithm given in [1], was presented in [2]. Another approach for network reconfiguration, while maintaining optimal power flow, was presented in [3]. A multi-integer linear programming model to minimize loss is utilized in [4]. A reconfiguration methodology based on a fuzzy multi-objective approach with Distributed Generation (DG) was presented in [5-6].

\* Corresponding author: Heba A. Hassan, Electrical Power and Machines Department, Faculty of Engineering, Cairo University, Giza, Egypt, E-mail: hebahassan@ieece.org

<sup>1</sup> Electrical Power and Machines Department, Faculty of Engineering, Cairo University, Giza, Egypt

Heuristic rules and fuzzy multi-objective approach with an improved fast decoupled load flow algorithm were illustrated in [7] to solve the problem. A self-learning evolutionary multi-agent system for distribution network reconfiguration was proposed in [8]. An efficient algorithm for multi-objective distribution feeder reconfiguration with DG based on Modified Honey Bee Mating Optimization (MHBMO) approach was presented in [9]. A Tabu search-based optimization technique was used in [10-11]. An efficient algorithm for distribution feeder reconfiguration in distribution with DGs was also suggested in [12]. A feeder reconfiguration problem in the presence of DG by using Artificial Bee Colony (ABC) algorithm was given in [13-14]. Furthermore, a method to achieve the optimum reconfiguration of distribution systems using Pareto–Genetic Algorithm was presented in [15]. A new approach using 0-1 integer programming method for reconfiguration of unbalanced radial distribution systems with the presence of DG was deduced in [16]. A technique was suggested in [17] to address the problem of feeder reconfiguration in the context of feeder loss reduction. A work has been carried out to obtain the locations and ratings of optimal tie switches and the optimal sizes of capacitors in [18].

The objective of this paper is to develop a direct mathematical model for feeder reconfiguration of distribution networks to reduce the active power loss encountered by the system to an optimum value. The model takes into account the typical operating constraints such as bus voltage limits and branch thermal limits. The model can also handle the presence of embedded generation and shunt capacitors.

The paper is structured as follows: Section 2 presents the proposed simplified form of the load flow equations of distribution systems, Section 3 illustrates the reconfiguration process using the newly modified load flow equations while the mathematical model formulation is deduced in Section 4. The developed mathematical model is verified using IEEE 16 bus and 33 bus systems in Section 5 and finally, Section 6 presents the main conclusions of this research work.

## 2. Simplified Form of Load Flow Analysis for Distribution Systems

The conventional load flow form that relates the bus injected currents to bus voltages through the bus admittance matrix has proved to be inefficient for distribution systems, especially for the radial ones. Therefore, a simplified form of load flow equations has been introduced as follows:

An equation that relates bus voltages of each branch to the power flow of the branch: Referring to Fig. 1, for a branch  $k$  that connects buses  $i$  and  $j$ , these relations take the following form:

$$V_j^2 = V_i^2 + \frac{S_k^2 z_k^2}{V_i^2} - 2 r_k P_k - 2 x_k Q_k \tag{1}$$

$$V_i^2 = V_j^2 + \frac{S_k^2 z_k^2}{V_j^2} - 2 r_k P_k - 2 x_k Q_k \tag{2}$$

Where,  $k = 1, 2, 3, \dots, M$ ;

$M$  is the total number of branches.

Power flow relation for each branch  $k$ :

This relation relates the active power loss of branch  $k$  to the reactive power loss of the same branch as follows [19]:

$$\mathbf{x}_k (\mathbf{p}_k + \mathbf{p}_k^-) = \mathbf{r}_k (\mathbf{q}_k + \mathbf{q}_k^-) \quad (3)$$

where,  $K = 1, 2, 3, \dots, M$

Power balance relation for each node  $i$ :

Summation of active power at node  $i = 0$

$$\mathbf{p}_k^- + \mathbf{p}_l + \mathbf{p}_m + \mathbf{p}_n + \mathbf{P}_{Di} = \mathbf{0} \quad (4)$$

Summation of reactive power at node  $i = 0$

$$\mathbf{q}_k^- + \mathbf{q}_l + \mathbf{q}_m + \mathbf{q}_n + \mathbf{Q}_{Di} = \mathbf{0} \quad (5)$$

$i = 2, 3, \dots, N$ ; where  $N$  is the total number of nodes while excluding the main substation.

Equations (4) and (5) relate the load power, DG power injection, if any, capacitive power injection, if any, at node  $i$  to the power flow of all branches connected to node  $i$ .

For radial feeders, the number of branches is equal to the number of nodes, excluding the main substation which means that  $M$  is equal to  $N$ . Consequently, the above  $5N$  non-linear equations relate the branch powers and bus voltage magnitudes for any radial system. The solution of these simplified forms of load flow equations will give both bus voltage magnitudes as well as branch powers.

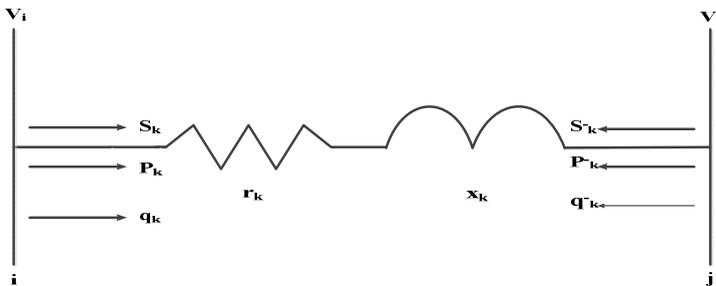


Figure 1: Branch  $k$  connecting buses  $i$  and  $j$ .

### 3. Reconfiguration Technique Using the Newly Modified Load Flow Method

In this reconfiguration technique, some branches will be opened, while a tie line will be closed for the purpose of reducing the loss in active power. Reconfiguration will be carried out while satisfying the following conditions which ensure proper feeding to all loads maintain the radial configuration and preserve the magnitudes of bus voltages, branches and tie lines within their permissible limits. In order to achieve the following conditions, an

integer variable for each branch and tie line is proposed in this paper. Equations (1) and (2) are then modified to guarantee that, if a branch is opened, no direct relations are present between each two end buses. This is represented mathematically as follows:

$$V_j^2 - V_i^2 - \frac{(p_k^2 + q_k^2) Z_k^2}{V_i^2} + 2 r_k p_k + 2 x_k q_k \leq w (1 - Y_k) \tag{6}$$

$$V_j^2 - V_i^2 - \frac{(p_k^2 + q_k^2) Z_k^2}{V_i^2} + 2 r_k p_k + 2 x_k q_k \geq w (Y_k - 1) \tag{7}$$

$$V_i^2 - V_j^2 - \frac{(p_k^{-2} + q_k^{-2}) Z_k^2}{V_j^2} + 2 r_k p_k^- + 2 x_k q_k^- \leq w (1 - Y_k) \tag{8}$$

$$V_i^2 - V_j^2 - \frac{(p_k^{-2} + q_k^{-2}) Z_k^2}{V_j^2} + 2 r_k p_k^- + 2 x_k q_k^- \geq w (Y_k - 1) \tag{9}$$

where,  $Y_k$  is a zero-one integer variable associated with section  $k$  and  $w$  is a positive large number. Hence, if a branch  $k$  is opened, the following equations are satisfied:

$$\left. \begin{aligned} p_k = p_k^- = q_k = q_k^- = 0, \\ Y_k = 0, \\ V_j^2 - V_i^2 \leq w, \\ V_j^2 - V_i^2 \geq -w, \\ V_i^2 - V_j^2 \leq w, \quad \text{and} \quad V_i^2 - V_j^2 \geq -w \end{aligned} \right\} \tag{10}$$

As  $w$  is a large positive value, then the difference  $(V_j^2 - V_i^2)$  or  $(V_i^2 - V_j^2)$  could take any value between  $-w$  and  $w$ . This difference will not exceed 0.2 p.u. or -0.2 p.u. and equations (6) to (9) will be ineffective if a line  $k$  is being opened. On the other hand, if a line  $k$  is kept close, then  $Y_k$  will be equal to one and equations (6) to (9) lend themselves into round load flow equations.

#### 4. Mathematical Model Formulation

##### 4.1 Objective Function

As the main goal of the reconfiguration process is to reduce the active power loss, the objective equation is assumed to take the following form:

$$\text{Min } F = \sum_{k=1}^M (p_k + p_k^-) \quad (11)$$

which can take also the following form:

$$F = \sum_{i=1}^{Ns} p_i \quad (12)$$

where, the minimization of input active power from different substations guarantees the minimization of the overall active power loss.

#### 4.2 Constraints

Equations relating the powers of section k to end bus voltages of the same section take the following form:

$$V_j^2 - V_i^2 - \frac{(p_k^2 + q_k^2) Z_k^2}{V_i^2} + 2 r_k p_k + 2 x_k q_k \leq w (1 - Y_k) \quad (13)$$

$$V_j^2 - V_i^2 - \frac{(p_k^2 + q_k^2) Z_k^2}{V_i^2} + 2 r_k p_k + 2 x_k q_k \geq w (Y_k - 1) \quad (14)$$

$$V_i^2 - V_j^2 - \frac{(p_k^{-2} + q_k^{-2}) Z_k^2}{V_j^2} + 2 r_k p_k^- + 2 x_k q_k^- \leq w (1 - Y_k) \quad (15)$$

$$V_i^2 - V_j^2 - \frac{(p_k^{-2} + q_k^{-2}) Z_k^2}{V_j^2} + 2 r_k p_k^- + 2 x_k q_k^- \geq w (Y_k - 1) \quad (16)$$

where  $K = 1, 2, 3, \dots, M$

a) Loss relation for a branch or tie line k:

$$x_k (p_k + p_k^-) = r_k (q_k + q_k^-) \quad (17)$$

b) Power balance equations at node i:

$$\text{Summation of real power} = 0 \quad (18)$$

$$\text{Summation of reactive power} = 0 \quad (19)$$

c) Limits of bus voltages:

$$V_i \leq V_{\max} \quad (20)$$

$$V_i \geq V_{\min} \quad (21)$$

where  $i = 1, 2, 3, \dots, N$

d) Limits of branch powers:

$$p_k^2 + q_k^2 \leq S_k^2 Y_k \quad (22)$$

$$p_k^{-2} + q_k^{-2} \leq S_k^2 Y_k \quad (23)$$

where  $K = 1, 2, 3, \dots, M$

e) Radiality constraint:

$$\sum_{k=1}^M Y_k = N \quad (24)$$

The optimum reconfiguration problem including capacitors and embedded generation is an integer nonlinear programming problem and the proposed method has been solved using LINGO 14.0 program (LINDO Systems Inc.) which runs on an Intel® Core™2 Duo 2.0 GHz, 3.0 GB personal computer.

## **5. Simulations Results and Verification of the Developed Reconfiguration Method**

### **5.1 The IEEE 16-Bus System**

#### **5.1.1 Description of the IEEE 16-Bus and the Simplified 14-Bus Systems**

Figure 2 illustrates the IEEE 16-bus system which is frequently adopted in literature for this type of study. It consists of 16 buses, 13 load points, 13 normally closed switches and 3 normally open switches. For the sake of simplicity, all feeding substations are considered as a single slack-bus whose phasor voltage is  $V_s \angle 0^\circ$  as shown in Figure 3, [10, 17, 20]. This system represents the 14-bus simplified system for that shown in Figure 2. In addition to the three assumed DG units, the simplified system, contains three fundamental loops and consists of one feeding substation, three radial feeders, 13 sections, 3 tie lines, 13 load buses and 7 capacitors (located at buses 3, 4, 7, 9, 10, 12, and 14), [17]. The voltages of the three DG units (located at buses 2, 6, and 11 which can only feed firm active power to the system) are 0.0255, 0.0453 and 0.0153 p.u., respectively.

The data of the above system including the load demand, branch data and DG output active power and output reactive power of shunt capacitors are given in [17]. The active load power of the system is given by 0.287 p.u. and the reactive load power is 0.167 p.u. The bus voltage limits considered are  $V_{\max} = 1.05$  p.u. and  $V_{\min} = 0.95$  p.u. Furthermore, it is assumed that all sections and tie lines have sectionalizing and tie switches.

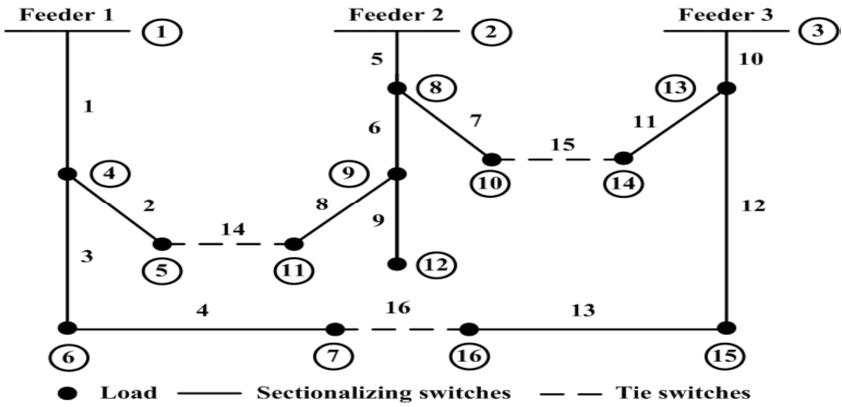


FIGURE 2: Single-line diagram of IEEE 16-bus system.

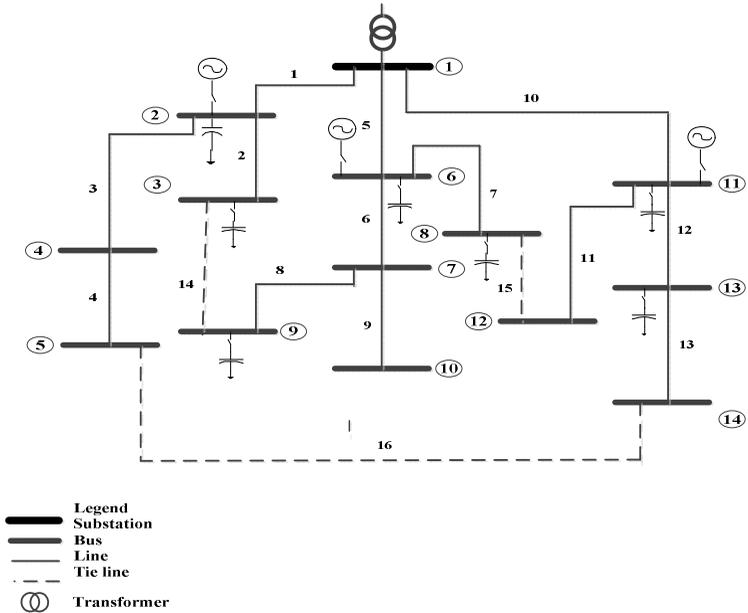


FIGURE 3: A 14-bus simplified system for the IEEE 16-bus system shown in FIGURE 2.

### 5.1.2 Study Cases for the 14-Bus System

In the following cases, it is assumed that all the sectionalizing switches of all the sections are closed, while all tie lines switches are kept open. The minimum bus voltages obtained as well as active power loss  $p_{loss}$  of the six cases are summarized in Table 1.

TABLE 1: Study cases (1-6) of the 14-bus system.

Case No.	Substation Bus Voltage (p.u.)	Minimum Bus Voltage (p.u.)	$P_{loss}$ (kW)	$\Delta P_{loss}$ (%)	Average Voltage (p.u.)
1 (Base-case)	1.0	0.9722	569.21	—	0.9855
2 (Base-case)	1.05	1.0048	493.51	—	1.0321
3 (with capacitor)	1.0	0.9731	368.67	35.2	0.9870
4 (with capacitor)	1.05	1.0214	310.47	37.09	1.0362
5 (with capacitor and DG)	1.0	0.9735	314.09	44.8	0.9897
6 (with capacitor and DG)	1.05	1.0319	296.87	39.85	1.04088

The analysis of the six study cases for a specified load shows that there is no voltage problem, capacitors and DG units improve the voltage profile, raising the substation bus voltage reduces the active power loss (whether capacitors and DG units are in operation or not) and that the shunt capacitors used significantly reduce the active power loss. Hence, the operation of both capacitors and DG units can reduce the active  $p_{loss}$  to the minimum value as they act to reduce both the active and reactive power flow in the feeder sections.

### 5.1.3 Applying the Optimum Reconfiguration Method to the 14-Bus System

In this section, it is assumed that any number of tie switches can be switched on and an equal number of sectionalizing switches should be switched off to maintain system radiality.

TABLE 2: Study cases (7-12) of the 14-bus system.

Case No.	Substation Bus Voltage (p.u.)	Shunt Capacitor	DG Unit	Tie lines Switched On	Sections Switched Off	$V_{min}$ (p.u.)	$\Delta P_{loss}$ (%)	$P_{loss}$ (kW)
7	1.0	Off	Off	14,15,16	4,8,11	0.9632	28.7	405.6
8	1.05	Off	Off	14,15	7,8	1.0087	25.03	370
9	1.0	On	Off	14,16	3,8	0.9697	46.7	303.49
10	1.05	On	Off	14	8	1.0270	38.38	304.06
11	1.0	On	On	15	7	0.9770	65.6	195.76
12	1.05	On	On	16	4	1.0270	60.92	192.87

In addition, the six studied cases carried out in the previous section are recalculated and the results obtained are summarized in the following. The power loss as well as the lines which are switched on or off are all listed in Table 2. The effects of substation voltages on active power loss  $p_{\text{loss}}$  are given in Tables 3 and 4. The percentages of loss reduction for various cases are shown in Figures 4 and 5.

TABLE 3: The effect of feeder reconfiguration ( $V_s = 1.0$  p.u.).

Case No.	Shunt Capacitor	DG Unit	Reconfiguration Method	Tie Lines Switched On	Sections Switched Off	$V_{\text{min}}$ (p.u.)	$P_{\text{loss}}$ (kW)	$\Delta p_{\text{loss}}$ (%)
1	Off	Off	No	—	—	0.9722	569.2	—
3	On	Off	No	—	—	0.9731	368.7	35.2
5	On	On	No	—	—	0.9735	314.1	44.8
7	Off	Off	Yes	14,15,16	4,8,11	0.9632	405.6	28.7
9	On	Off	Yes	14,16	3,8	0.9697	303.5	46.7
11	On	On	Yes	15	7	0.9770	195.8	65.6

TABLE 4: The effect of feeder reconfiguration ( $V_s = 1.05$  p.u.).

Case No.	Shunt Capacitor	DG Unit	Reconfiguration Method	Tie Lines Switched On	Sections Switched Off	$V_{\text{min}}$ (p.u.)	$P_{\text{loss}}$ (kW)	$\Delta p_{\text{loss}}$ (%)
2	Off	Off	No	—	—	1.0048	493.51	—
4	On	Off	No	—	—	1.0214	310.47	37.09
6	On	On	No	—	—	1.0319	296.87	39.85
8	Off	Off	Yes	14,15	7,8	1.0087	370	25.03
10	On	Off	Yes	14	8	1.0270	304.06	38.38
12	On	On	Yes	16	4	1.0270	192.87	60.92

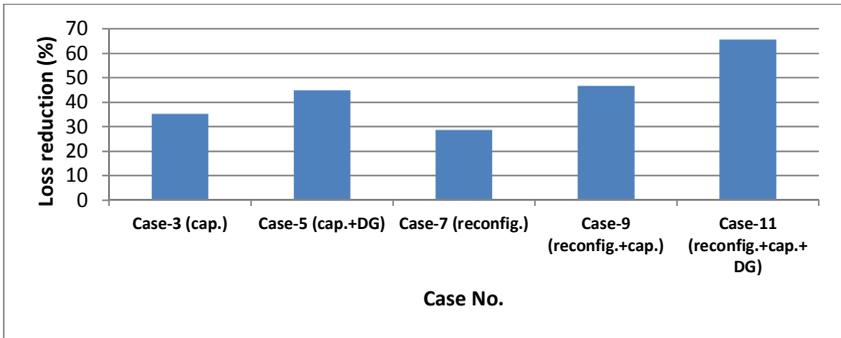


FIGURE 4: Loss reduction for the 4-bus system ( $V_s=1.0$  p.u.).

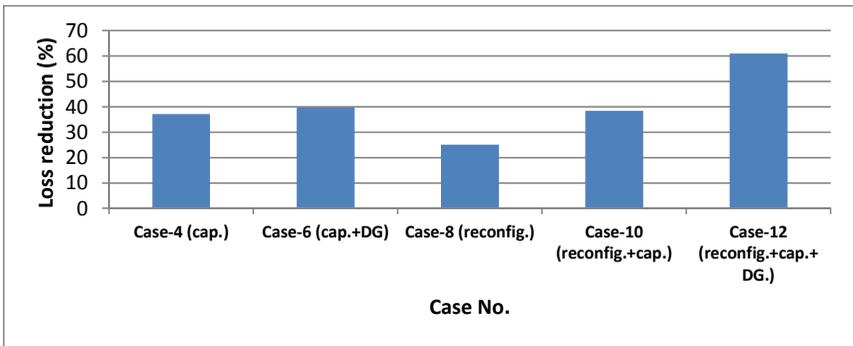


FIGURE 5: Loss reduction for the 14-bus system ( $V_s=1.05$  p.u.).

Analysis of the previously mentioned results leads to the following conclusions:

- Active  $p_{loss}$  in all of the studied cases shows a decrement, when the substation bus voltage is high, i.e. near the highest limit, as long as the reconfiguration is not changed.
- The minimum value of active  $p_{loss}$  has been obtained when reconfiguration method is made with capacitors and DG units in operation.

As shown in Tables 2, 3 and 4, it is clear that the number of tie sections to be closed is reduced due to using capacitors or DGs. No more improvement of system loss using feeder reconfiguration can be achieved, however, the configuration has to be carried out for other operational reasons such as maintaining or improving reliability.

The operation of the system does not suffer problems in terms of its bus voltage and it is observed that the active power loss of the system is also reduced.

## 5.2 The IEEE 33-Bus System

### 5.2.1 Description of the IEEE 33-Bus System

Figure 6 illustrates the IEEE 33-bus system whose data is available in [21]. It consists of 32 buses, excluding the main substation bus, and 5 tie lines (33, 34, 35, 36 and 37). The total load of the system is 3715 kW and 2300 kVAR. The minimum permissible bus voltage is 0.95 p.u. The current carrying capacity of the branch connecting bus 1-9 is 400 A and the remaining branches including tie lines are rated at 200 A. It is assumed that all sections and tie lines have sectionalizing switches and tie switches, respectively.

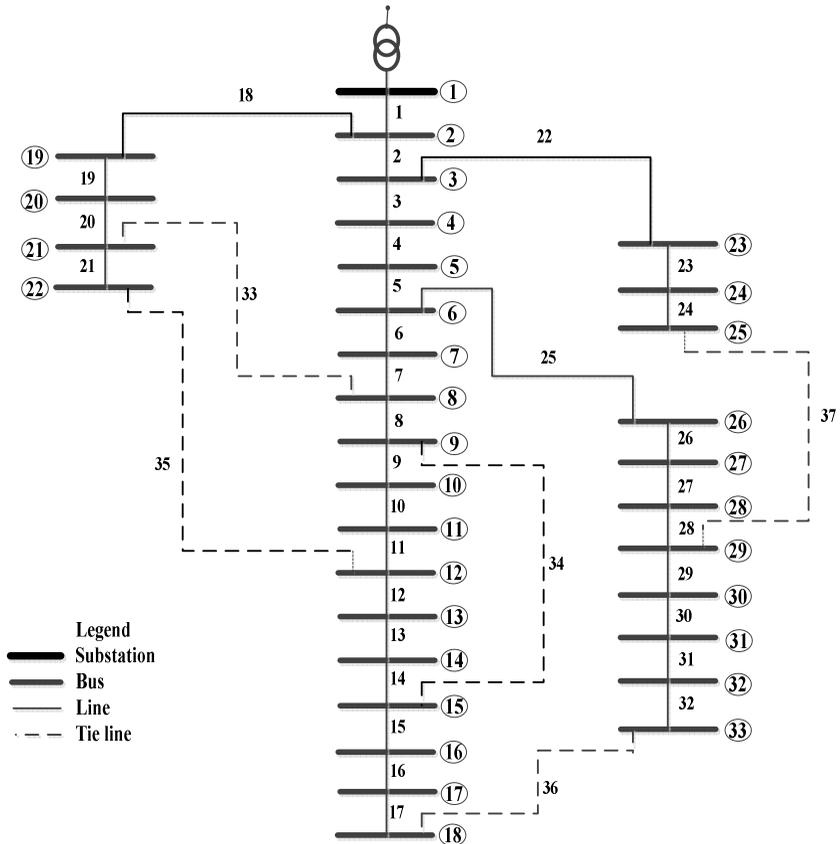


FIGURE 6: IEEE 33-bus system (base case), [21].

### **5.2.2 Base Case Study of the IEEE 33-Bus System**

A load flow study has been made assuming that all tie lines are switched off. Two runs have been made as follows:

Case 1: In this case, the substation bus voltage  $V_s$  is assumed to take 1.0 p.u. The results reveal the following conclusions:

- Some bus voltages cross the limit where the minimum voltage of 0.9128 p.u. is observed at bus 18.
- Active power loss is 204.45 kW.

These results are very similar to those calculated using the ETAP program version 6 which verifies the validity of the developed model.

Case 2: In this case, the substation bus voltage  $V_s$  is raised to 1.05 p.u. The results obtained reveal the following conclusions:

- No bus voltages crossed the limit.
- Active power loss is only 183.2 kW.

A comparison of the above two cases illustrates that, without system reconfiguration, the substation bus voltage must be raised to 1.05 p.u. in order to avoid bus voltage problems. Additionally, raising substation bus voltage will reduce the active power loss with a considerable value of 10.4%.

### **5.2.3 Applying the Optimum Reconfiguration Method to the IEEE 33-Bus System**

In this case, the developed model has been applied for active power loss minimization using reconfiguration method as shown in Figure 7. Results have been obtained assuming that any number of tie lines can be switched on and an equal number of feeder sections should be switched off to maintain radial topology. The substation bus voltage has been considered as follows:

Case 3: Using  $V_s = 1.0$  p.u., no feasible solution has been obtained with the assumed bus voltage limits ( $1 \pm 0.05$ ) p.u. This means that the switching on of any number of tie lines will not bring the voltages of all buses into permissible limits.

Case 4: Using  $V_s = 1.0$  p.u., i.e.: if the minimum permissible voltage limit is relaxed to 0.9 p.u., then in this case, a solution has been obtained. The results of this case study show that:

- Tie lines switched on are lines number 33, 34 and 35.
- Feeder sections switched off are sections number 7, 10 and 14.
- Minimum bus voltage is 0.9328 p.u.

- Numbers of buses where voltages decrease below 0.95 p.u. are the following 5 buses whose numbers are 29, 30, 31, 32 and 33.

- Active power loss is 140.5 kW.

Case 5: Using  $V_s = 1.05$  p.u., a feasible solution has been obtained. The outcomes of this case show the followings:

- Active power loss is 129.8 kW.

- Minimum bus voltage is 0.9864 p.u.

- Tie lines switched on are the same as those in case 4; i.e.: tie lines numbers 33, 34 and 35.

- Feeder sections switched off are the same as those in Case 4; i.e.: sections number 7, 10 and 14.

- The minimum voltage in the system after reconfiguration is improved by 5.43%.

The analysis of the above results reveals the following facts:

The feeders under consideration suffer from voltage problems. However, when raising the reference voltage to 1.05 p.u., this voltage problem does not exist anymore. With the reconfiguration method, voltage problems still exist with a reference voltage of 1 p.u. When the reference voltage is 1.05 p.u., the voltage profile is improved and active power loss is also reduced, as shown in Figure 8.

With reference voltage of 1 p.u. or 1.05 p.u., the reconfiguration method shows an improved voltage profile and reduced active power loss.

The power flow in each branch is reduced after reconfiguration, as shown in Figure 9. This shows that feeders are relieved from being overloaded which makes it possible to load these feeders further.

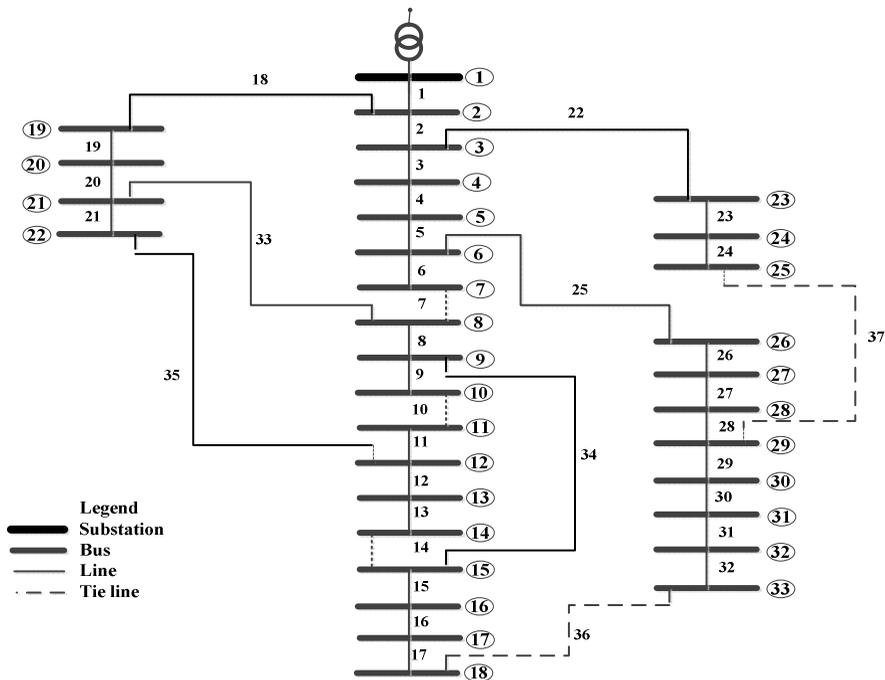
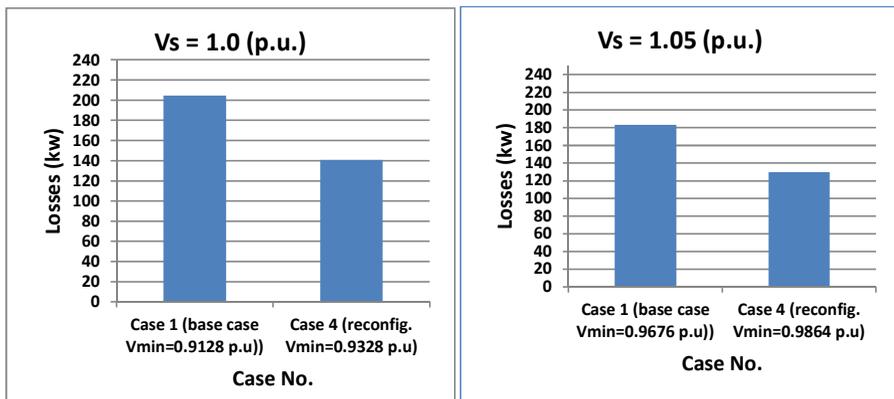


FIGURE 7: Optimum reconfiguration of the IEEE 33-bus system.



a) Power loss ( $V_s = 1.0$  p.u.) b) Power loss ( $V_s = 1.05$  p.u.)

FIGURE 8: Power loss for the IEEE 33-bus system.

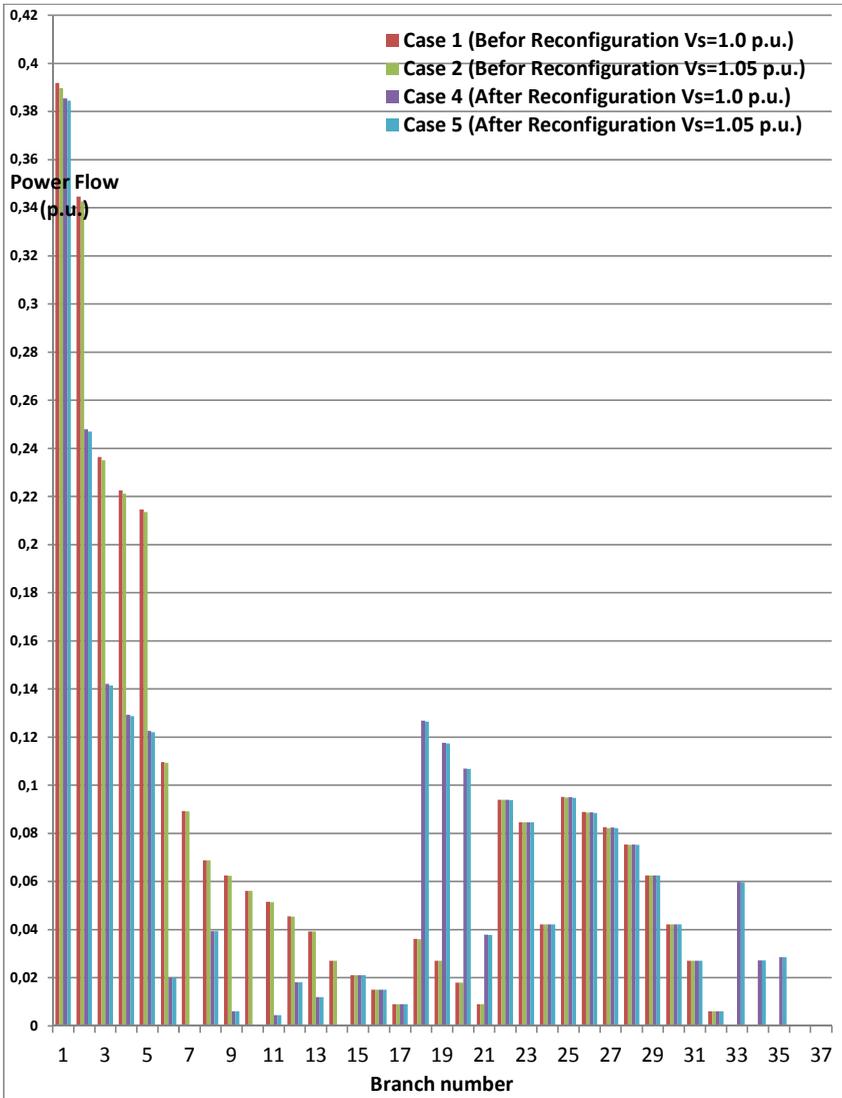


FIGURE 9: Power flow for the IEEE 33-bus system before and after optimum reconfiguration

#### **5.2.4 Comparing Results with Published Work**

In literature, there are numerous research methods [22-25] which were developed for optimum feeder reconfiguration. The comparison is carried out with one of these research methods that is entitled Harmony Search Algorithm (HSA) which is available in reference [20]. That method was also applied to the same case study of IEEE 33-bus system where the least value of the power loss was deduced. The results of comparing the method presented in this paper with that method, given in [20], are as follows:

a) Base case study:

The results given in [20] have been calculated under the assumption of 1 p.u. bus voltage at the main substation. The total losses and minimum bus voltage given in [20] are in the range of 203 kW and 0.91 p.u., respectively. The corresponding values deduced by the model developed in this paper are 204. kW and 0.9128 p.u, respectively. These results are similar to the results obtained using the load flow program of ETAP software package. The slight difference in results may be attributed to the load flow method used, accuracy of calculations and the specifications of computers.

b) Optimum reconfiguration process:

The results obtained by the presented method are:

- Sections 7, 10 and 14 are switched off, while tie lines 33, 34 and 35 are switched on. Tie lines 36 and 37 remain open.
- New power losses are calculated as about 140 kW which means that the reduction in power loss with respect to the base case is about 31 %.
- The minimum bus voltage is 0.9328 p.u.

The results deduced using Harmony Search Algorithm (HSA) given in [20] are the same as those given above using the model developed in this paper. However, the values of losses are given as best, worst and average values, namely, 138.06, 195.10 and 152.33, respectively for 200 solution runs. The minimum bus voltage is given as 0.9342 p.u. as shown in Table 5.

The solution using HSA, similar to other heuristics techniques requires previous determination of the parameters used in the solution that affect the quality of the solution and the convergence behavior, [20]. However, the best solution obtained in this paper using integer nonlinear programming can start immediately without the need for preliminary studies to obtain the optimum solution. Table 6 summarizes results of other heuristics methods. Using ETAP software to calculate load flow for the configuration given by Firefly Algorithm (FA) and consequently system power losses, a slight increase in the power loss

value than given in [25] has been deduced. This may be, as stated upper, due to the accuracy of the load flow used method and the specifications of utilized computers.

TABLE 5: Comparing results with published work, [20]

Method	Base Case		Reconfiguration Method			
	$V_{min}$ (p.u.)	$P_{loss}$ (kW)	$V_{min}$ (p.u.)	$P_{loss}$ (kW)	Tie Lines Switched On	Sections Switched Off
HSA [20]	0.91	203	0.9342	138, 152 and 195 (Best, Average and Worst)	33, 34 and 35	7, 10 and 14
Developed Model	0.9128	204.45	0.9328	140.5	33, 34 and 35	7, 10 and 14

TABLE 6: Comparative results with other heuristics methods

Base Case	Switched off	Losses (KW)
	33,34,35,36,3 (all tie line switches)	203
GA (Genetic Algorithm), [25]	7, 9,14,28,23	139.97
GA (Genetic Algorithm), [26]	7,9,14,23,37	139.54
TS (Tabu Search), [25]	6, 9,14,26,31	163.38
ACS (Ant Colony Search), [25]	7, 9,14,28,32	139.97
FA (Firefly Algorithm), [25]	7, 9,14,32,37	139.55
Developed Model	7,10,14,36,37	139.90

## 6. Conclusion

In this paper, a mathematical model based on a new formulation of load flow equations for distribution systems has been presented. The object of the model is to minimize the distribution system losses through the reconfiguration of the system while maintaining the bus voltages and feeder currents within the permissible limits. The developed model utilizes integer non-linear programming to find the most appropriate topology of distribution systems. As it is a numerical optimization method, it guarantees to achieve global optimal solution; however, heuristic methods need adjusting its parameters before applying it and may lead to suboptimal solution. The model has been applied to two standard test systems of different bus numbers. The results are compared with the work published in literature. Furthermore, the paper has incorporated the DG which is recently used in distribution systems. The obtained results illustrate that the optimal reconfiguration process can yield a significant reduction in the active power losses of the system, which means a considerable amount of financial savings per year as well as improving the bus voltage profile and reducing branch loadings.

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