



## Optimal Reconfiguration of Power Distribution Network for Loss Reduction Using Hybrid Cuckoo Search Algorithm and Particle Swarm Optimization

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### ABSTRACT

The problems of electrical power distribution networks in developing countries like Nigeria include large voltage drops, low voltage stability and huge power losses. These problems can be minimized by network reconfiguration. There is a need to find the most efficient configuration, the one that minimizes loss and improves the voltage profile of the distribution system. This research focuses on performing the network reconfiguration on a standard and practical distribution system using the Cuckoo Search Algorithm (CSA) as an optimization technique to reduce losses, voltage improvement as well as find the best placement of switches. In this work, the distribution load flow will be carried out using the forward/backward sweep power flow. The system mathematical model in terms of active power loss and voltage profile index, which serves as the objective function for the network reconfiguration problems are developed alongside the equality and inequality constraints. CSA will be used to get the optimal switching scheme for the network reconfiguration considering the objective function. The simulation will be carried out using MATLAB. The efficacy of the developed algorithm will be tested using standard IEEE 16, and 33 distribution networks. The scheme is expected to improve the voltage profile and reduce the active power losses of the network.

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### INTRODUCTION

Most distribution systems are weakly meshed and usually radial in nature for simplicity of operation. The Radial Distribution Network (RDN) is fed from a sub-station which receives electrical power from the centralized generating station. This implies that the flow of power in the RDN is unidirectional from the upper stream to the lower stream. The end-users of electricity receive electrical power from the substation through RDN which is a passive network (Moradi, Abedini, 2012). The high ratio of the resistance to reactance of the distribution lines results in large voltage drop, low voltage stability and power losses. Due to low voltage stability index at most nodes in a radial network under critical loading in certain areas, it may experience sudden voltage collapse (Moradi, Abedini, 2012). The existing distribution networks are actually growing in complexity, due to the gradual increase of power

demand and the existence of customers with more sensitive loads. The problem of minimizing distribution systems losses has received a global attention due to high cost of electrical energy, need for better quality of service, efficient utilization of available energy and high power loss in power networks (Charlangsut *et al*, 2012). In an ideal situation, any distribution network must supply electrical power to its entire customer connected to it, while simultaneously avoiding overloading, feeder thermal overload and abnormal voltage across the line, as well as minimizing active power loss and maintaining radial topology (Carcamo-Gallardo *et al*, 2008). There are different techniques for reducing losses within the distribution level which include reconfiguration, capacitor placement, introduction of distributed generator, load balancing and introduction of higher voltage level (Aguero, 2012). These methods of reducing losses are



quite numerous but the major concern is about their technical implications on the network. Introduction of new equipment at distribution level offers tremendous financial burden on the utilities that cannot be justified by the potential saving (Sarfi et al, 1994). A radial distribution network consist of a combination of sectionalizing (Normally Closed) and tie (Normally Opened) switches which play critical role in determining the configuration of the system. By performing switching action, you can alter the topology of the network and obtain the best possible configuration. The switching action depends on the number of switches, the greater the number of switches, the more the possibilities of reconfiguration. Network reconfiguration is therefore defined as the altering the topological structures of the distribution feeders by changing the open/closed states of the sectionalizing and tie switches. Due to the candidate switching combinations in the distribution system, reconfiguration is a complicated combinatorial, non-differentiable constrained optimization problem (Higgins et al, 2010). The reconfiguration problem is one of the multi criteria and multi objective optimization types, where the solution is chosen after the evaluation of some indices such as active power loss, reliability indices, branch load limit and voltage drop limit which represent multiple functions (Tomoiaga et al, 2013). These criteria can be grouped into objective functions that can be minimized and the constraints that must be included with some bounds while some criteria are often modeled along with their objective functions (Tomoigo et al, 2013). The earlier reconfiguration problems were mostly represented by a single objective function (Abdelaziz et al, 2012). The growing demand and increasing connection of smart devices in to the existing network offers a great advantage but increases the burden and complexity of distribution network. The first and main purpose of reconfiguration is reducing losses in distribution systems and preventing overload. It is used for power loss reduction and voltage profile improvement while the radial structure of the system is retained (Sarfi et al, 1994). The distribution network reconfiguration problem then is to find a radial operating

structure that minimizes the system power loss while satisfying critical operating constraints. Many candidate-switching combinations are possible in system, making the operating network reconfiguration become a complicated combinatorial, non-differentiable constrained optimization problem. Many techniques such as branch and bound, analytic approach, heuristic, expert system, and linear programming were presented by different researchers aimed at addressing the problem of reconfiguration of radial distribution network considering active power loss (Zhu, 2009). This research work focuses on using a weighted multi-objective cuckoo search algorithm approach in addressing the problem of reconfiguration of distribution system in Nigeria in order to minimize active power loss and reduce total voltage deviation. Reconfiguration of distribution network based on the followings:

1. Implementation of Backward-Forward Algorithm to ascertain the state of base case of the network parameters.
2. Application of hybrid Cuckoo's Search Algorithm and Particle Swarm Optimization Algorithm for optimal Network Reconfiguration base on objective function.
3. Implementation of objective (2) standard IEEE 16, 33, and 69 bus radial distribution system and practical distribution system using total power loss and voltage profile before and after reconfiguration.

#### **Implementation of Backward-Forward Algorithm to ascertain the state of base case of the network parameters.**

The past, many approaches for distribution system load-flow analyses have been developed [1]–[3]. Among these approaches, the ladder network theory and the backward/forward (BW/FW) sweep methods are commonly used due to their computational efficiencies and solution accuracies. In this letter, the authors propose an improved BW/FW sweep approach for radial distribution system load-flow analysis. The proposed method includes two steps: the backward sweep and the decomposed forward sweep. In the backward sweep, Kirchhoff's Current Law (KCL) and Kirchhoff's Voltage Law

(KVL) are used to find the calculated voltage for each upstream bus of a line or a transformer branch. In the decomposed forward sweep, the linear proportional principle is employed to update the voltage at each downstream bus. After performing each backward sweep, the mismatch of the calculated and specified voltages at the substation is checked. The solution algorithm repeats until the convergence tolerance of the substation voltage is satisfied. The equation 1 to 5 shows the mathematical representation of B/F sweep technique Calculate the nodal current injection at network node 'i'

$$I_i^{(k)} = \left( \frac{N_i}{V_i^{(k-1)}} \right) - Y_i V_i^{(k-1)} \quad i=1, 2, \dots, n \quad (1)$$

Backward sweep: Calculate current in the branch L, JL as

$$JL_{(k)} = IL_{(k)} + \sum(c \text{ node } L2) \quad (2)$$

$$L=b, b-1, \dots, 1$$

Forward sweep: Calculate the voltage at node L2 as

$$VL2 = VL1^{(k)} - ZLJL^{(k)} \quad L=1,2,\dots,b \quad (3)$$

Calculate the power injection at node 'i' as

$$S_i^{(k)} = V_i^{(k)} (I_i^{(k)}) - Y_i |V_i^{(k)}|^2 \quad (4)$$

$$\Delta P_i^{(k)} > \Delta P_{max}, \text{ then}$$

$$\text{se } \Delta P_i^{(k)} = \Delta P_{max}, \quad (5)$$

### Application of hybrid Cuckoo's Search Algorithm and Particle Swarm Optimization Algorithm for optimal Network Reconfiguration base on objective function.

The hybrid of Cuckoo's search Algorithm with the particle swarm optimization was applied followings the steps:

1. Initialize the algorithm parameters of CSA-PSO with population size (100) and 1600 iteration.
2. Generate population base on the size and output the power according to each search agent subject to equation (3.1) on determination of the initial location of closed/open sectionalizing and tie switches

$$P(V_i, \theta_i) = P_i - V_i \sum_{j=1}^{N_{node}} V_j Y_j \cos(\theta_i - \theta_j - \theta_{ij}) \quad (6)$$

For  $i = 1, 2, \dots, N_{node}$

Objective Function

$$P_{loss \text{ min}} = \sum_{i=1}^{N_{br}} R_i \times \frac{(P_i^2 + Q_i^2)}{V_i^2} K \quad (7)$$

Voltage deviation index

$$\Delta V_D = \text{Max} \left( \frac{V_i - V_i^0}{V_i} \right) \quad V_i = 1, 2, 3, \dots, N_{bus} \quad (8)$$

Constraints

$$V_{min} \leq V_i \leq V_{max}; \quad i=1, 2, 3, \dots, N_{bus} \quad (9)$$

$$0 \leq I_i \leq I_{max}; \quad i=1, 2, 3, \dots, N_{br} \quad (10)$$

where,

$K_j$  is the switch state of  $j$ -th branch, with 0 indicating switch open and 1 indicating switch closed.

$Nbr$  is the number of the buses

$R_j$  is the resistance of the  $j$ -th branch

$P_j$  is the active power flowing through the terminal of  $j$ -th branch

$Q_j$  is the reactive power flowing through the terminal of  $j$ -th branch

$V_j$  is the terminal node voltage of the  $j$ -th branch

Evaluate fitness (objective functions) of equation (7) and Sense real power and voltage of the network system base on the fitness of generated molecules position closed/open sectionalizing and tie switches. Improve new position for (closed/open sectionalizing and tie switches on hybrid of CSA-PSO of levy flight to minimize power losses subject to equation (1), (2), and (3):

$$x^{(t+1)} = x_i^{(t)} + \alpha \text{Levy}(S, \tau) \quad (11)$$

Provide the step length

$$\text{Len}(S, \tau) \sim S^{-\tau}, \quad (1 < \tau < 3) \quad (12)$$

$$P_{loss} = \sum_{i=1}^{N_{branch}} 3I_i^2 R_i \quad (13)$$

Update the CSA-PSO and determine the optimal solution If the fitness function of the randomly selection is better than the fitness of the trailing mode, then determined the new random position of the agent and the worst random position of the solution and perform the trailing mode again, otherwise repeat step repeat steps (1-5).

The CSA-PSO flowchart below shows the algorithm sequential reconfiguration considering Real power loss and Voltage profile

improvement used in this research is illustrated in Figure 1

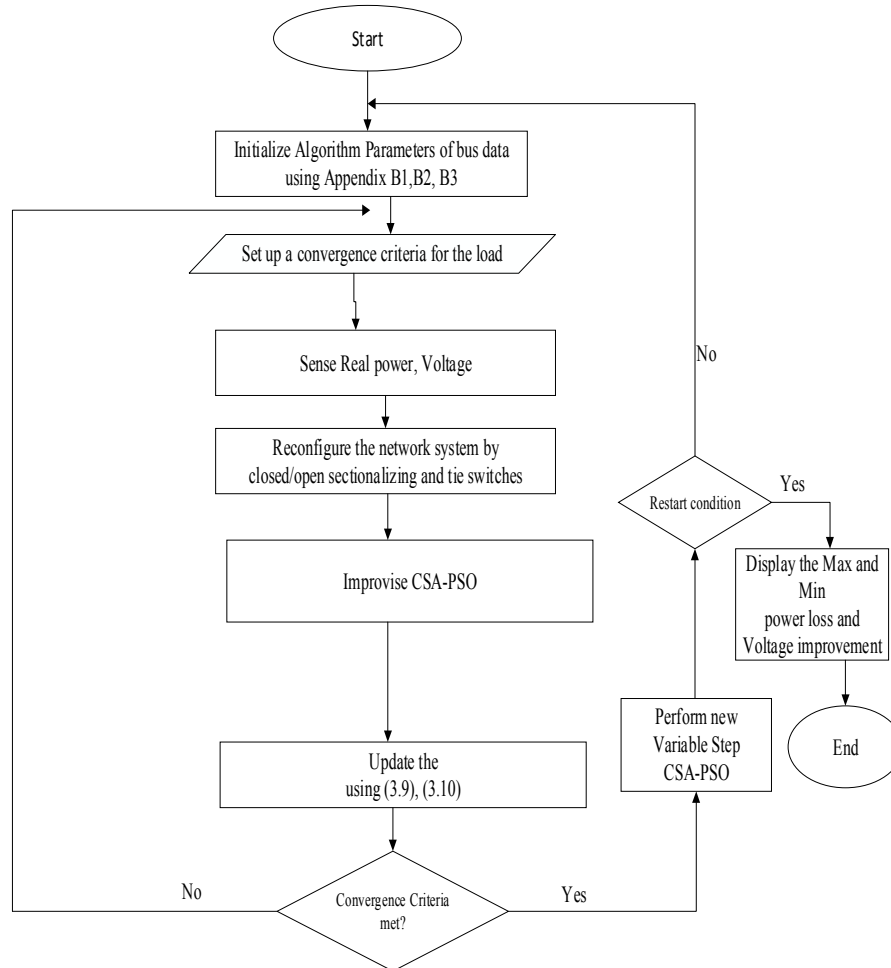
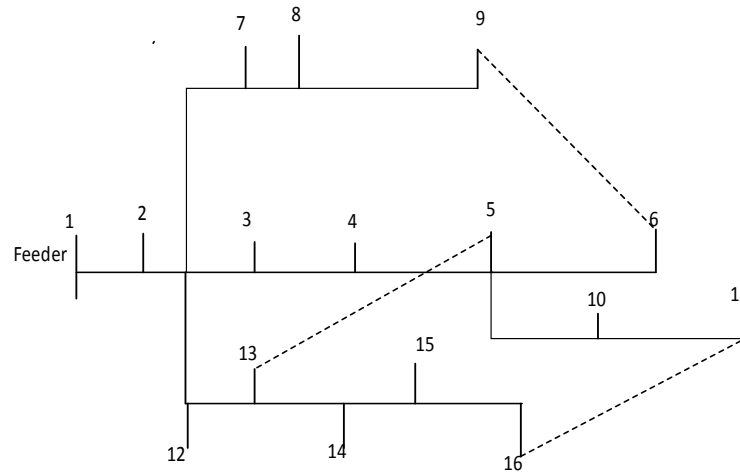


Figure 1: CSA-PSO Flowchart of developed reconfiguration

**Implementation of Objective (2) Standard IEEE 16, 33, and 69 Bus Radial Distribution System and Practical Distribution System using Total Power Loss and Voltage Profile Before and After Reconfiguration.**

The 16-bus, reconfiguration was been carried out in order to locate the optimal positions of the tie and sectionalizing switches for system active power loss and improve in voltage profile.

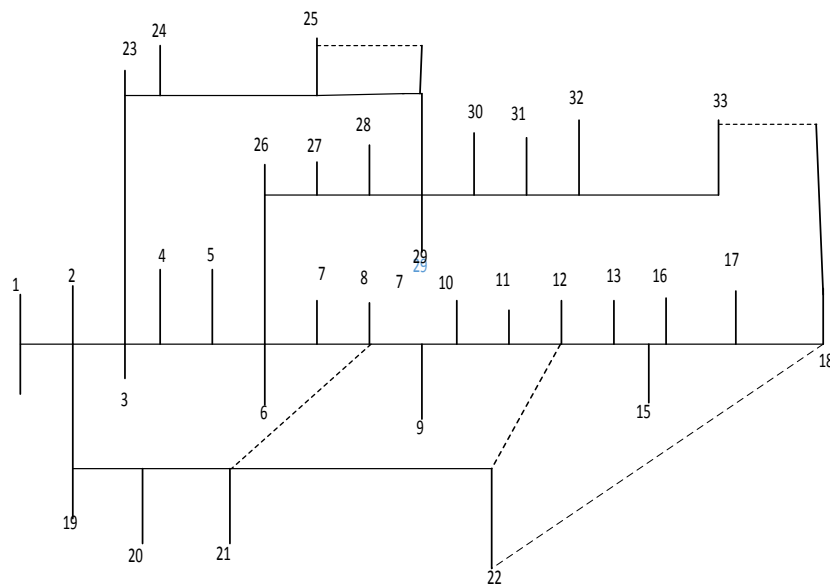
The lines between each bus has a sectional switch for the buses connected to the same feeder and a tie switch for the buses connected to two different feeders as depicted in Figure 1. There are 3 tie, 1 feeders, 14 nodes, 15 lines and 12 such sectionalizing switches are used in this system (Nguyen *et al.*, 2016). This is represented by the single line diagram as shown in Figure 2.



**Figure 2:** IEEE 16- bus network reconfigure system

The reconfiguration of 33kV was carried out in order to locate the optimal positions of the tie and sectionalizing switches for system active power loss and improve in voltage profile. The lines between each bus has a sectional switch for the buses connected to the same feeder and a tie switch for the buses connected

to two different feeders as depicted in Figure 3. There are 5 tie switches, 33 nodes, 39 lines branch and 32 sectionalizing switches are used in this system which has total load of 3.72MW and 2.3MVA<sub>r</sub> (Nguyen *et al.*, 2016). This is represented by the single line diagram as shown in Figure 3.



**Figure 3:** IEEE 33- bus network reconfigured system

### SIMULATION AND RESULTS ANALYSIS

The initial network configuration is made up of 13 normally closed sectionalizing switches (1-13) and three normally opened tie switches (14-16). Figure 1 shows the active power flow result, it is observed that the total base case power loss of 510.99kW was obtained. From Figure 2, it is noticed that the

lowest (minimum) voltage of 0.9463p.u occurred at bus 12, (which violates the  $\pm 5\%$  IEEE tolerance margin of the nominal voltage criterion). This is as a result of the large distance of the bus from the source (Feeder). The base case result (power loss and magnitude of the voltage) at each bus for IEEE 16-Bus network is shown in Figure 4 to 5.

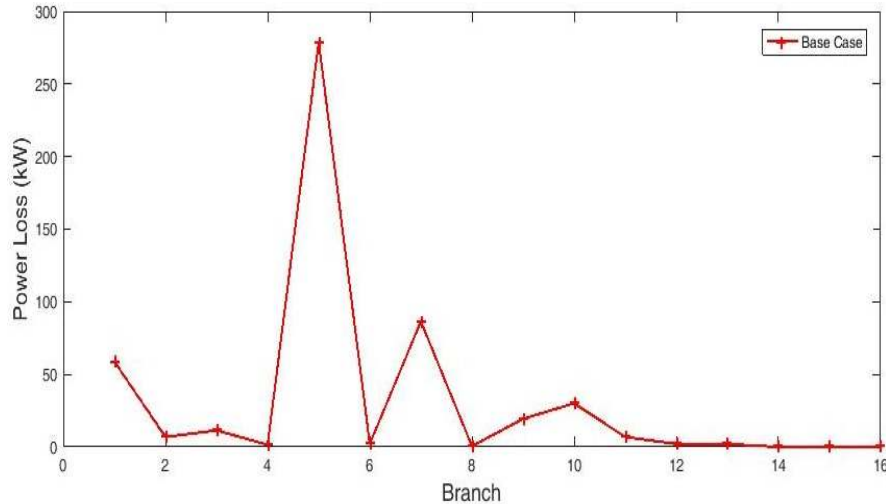


Figure 4: Base Case Power Loss Profile of IEEE 16-Bus System

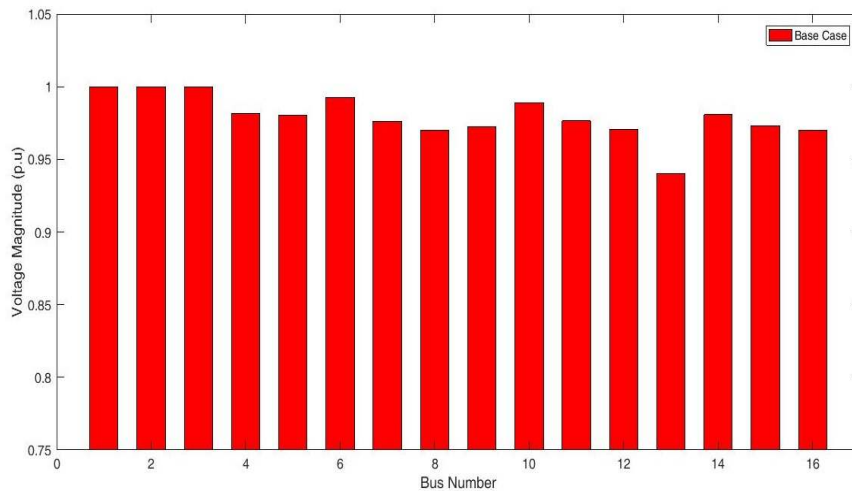


Figure 5: Base Case Voltage Profile of IEEE 16-Bus System

The result of the active power loss obtained before and after reconfiguration is represented by Figure 6, it is observed that the

active power loss obtained before reconfiguration was 510.99kW and after reconfiguration using CSA-PSO it reduces to 426.46kW, which

represents 16.54% power loss reduction. Figure 7 is the voltage profile prior and after reconfiguration, it reveals that the voltage magnitude prior to network reconfiguration was 0.9403p.u which occurred at Bus 12 as a result of the large distance of the bus from the source

(Feeder) and after reconfiguration it improves to 0.9516p.u. The switches that were opened before reconfiguration were 14, 15 and 16 while after the network reconfiguration using CSA-PSO, switches 7, 10, and 14 respectively were found to be optimally opened.

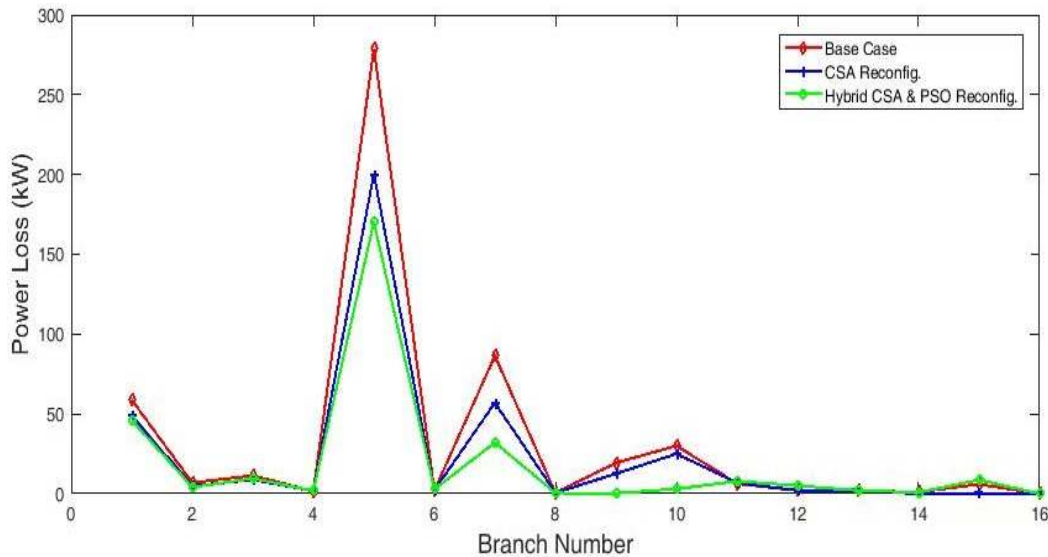


Figure 6: Power Loss Profile after Reconfigure IEEE 16-Bus System with CSA-PSO

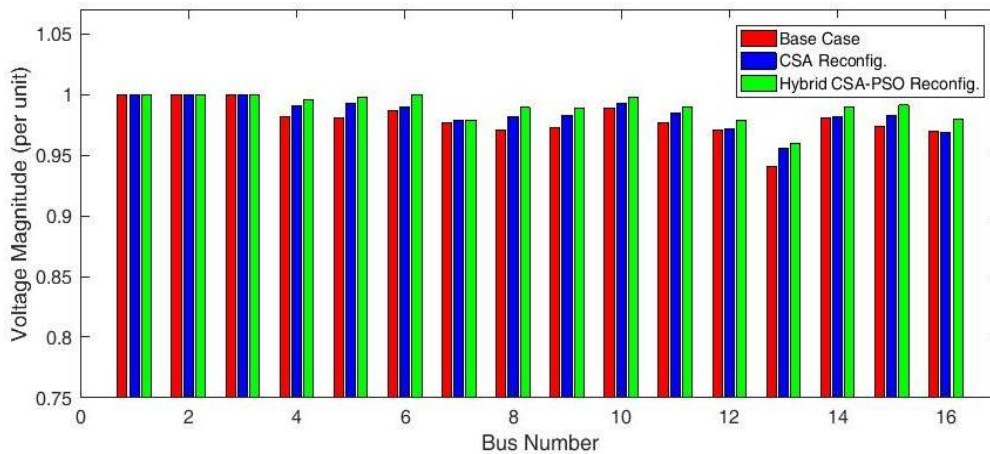


Figure 7: Voltage Profile after Reconfiguration IEEE 16-Bus System with CSA-PSO

The result of the active power loss obtained before and after reconfiguration is using Figure 8. It was also observed that the active power loss obtained before reconfiguration was 207.99kW and after reconfiguration using CSA-

PSO it reduces to 138.89kW, which represents 33.25% power loss reduction. Figure 9 is the voltage profile prior and after reconfiguration, it reveals that the voltage magnitude prior to network reconfiguration was 0.9510p.u which



occurred at Bus 18 as a result of the large distance of the bus from the source (Feeder) and after reconfiguration it improves to 0.9510p.u. The switches that were opened before

reconfiguration were 33, 34, 35, 36 and 37 while after the network reconfiguration using CSA-PSO, switches 7, 10, 16, 32 and 28 respectively were found to be optimally opened.

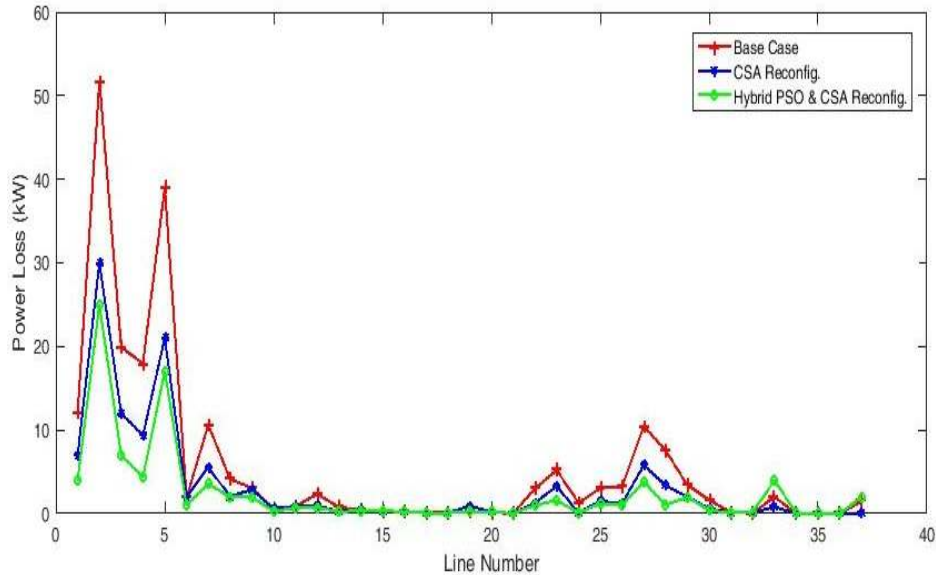


Figure 8: Power Loss Profile after Reconfigure IEEE 33-Bus System with CSA-PSO

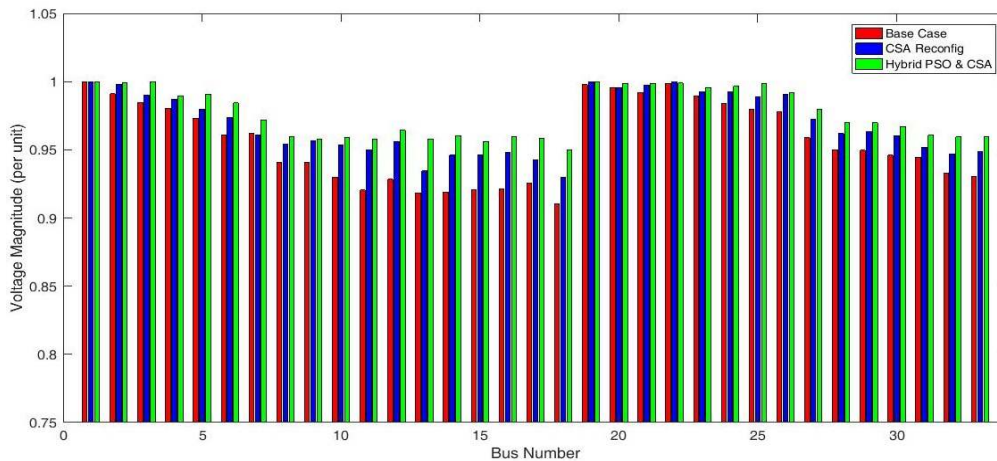


Figure 9: Voltage Profile after Reconfiguration IEEE 33-Bus System with CSA-PSO

## CONCLUSION

A hybrid Cuckoo Search Algorithm and Particle Swarm Optimization technique for the optimal network reconfiguration and sizing on IEEE 16-bus, and IEEE 33-bus has been developed in order to reduce the network power loss and improve voltage profile.

Backward/forward Sweep of power-flow analysis was used to analyze the networks so as to ascertain the state of the network. Active power loss and voltage deviation were formulated as multi-objective function which satisfied the system inequality constrained. The total base case power loss of IEEE 16-bus





network before network reconfiguration is 510.99kW with minimum voltage of 0.9403p.u, but after reconfiguration, the power loss reduces to 426.66kW representing 16.54% power loss reduction and the voltage improved to 0.9516p.u. The total base case power loss of IEEE 33-bus network before network reconfiguration is 207.99kW with minimum voltage of 0.9510p.u, but after reconfiguration, the power loss reduces 138.89kW to representing 33.25% power loss reduction and the voltage improved to 0.9681p.u. reduction with improvement on the voltage magnitude to 0.9510p.u from 0.9681p.u.

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