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Optimal Allocation and Contingency Analysis of Distributed Generation Deployment in Radial Distribution Network using Cuckoo Search Algorithm

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Abstract : Due to the evolution of interconnected power systems, the loss reduction in distribution systems has become a subject of major concern. Integration of distributed generation units which are based on renewable energy, provide potential benefits to conventional distribution systems while considering environmental impact. Practice of insertion of DG units in the distribution network system has increased drastically in the recent years because of multidimensional advantages of DG units. It includes the minimization of power loss in network, sharp improvement of bus voltages profile, improvement of reliability and power quality of system. The main objective of this paper is to demonstrate a simple technique to determine appropriate location and size of distributed generation units in the distribution networks in order to reduce real power losses of system. Cuckoo Search Algorithm (CSA) is used as an optimization technique and is implemented on standard IEEE 69 bus Radial distribution system.

***Index Terms* - Distributed Generation (DG), Contingency Analysis, Distribution Network, Cuckoo Search Algorithm (CSA), Topology Based Load Flow Solution.**

I. INTRODUCTION

Energy crises and widespread power outages are caused by centralized electricity shortage. According to reports, electric power networks with a single huge power source are unable to meet the need for more reliable and enhanced power. Additionally, those conventional power plants, which produce between hundreds and thousands of megawatts (MW), are far from the load centres. A significant proportion of transmission losses take place while the generated electrical power is transferred from the transmission network system to the distribution systems. Due to the length and complexity of these transmission network systems, they cause network congestion in the restructured environment. Conventional power plants, which generally consist of thermal power plants using coal, nuclear power plants, etc., have significant negative effects on the environment. It is a significant factor in the "Green House Effect." Power plants (based on non-conventional sources of energy) are attracting more attention globally as a result of the limited resources and the aforementioned situation. Environmental, commercial, and regulatory factors can be grouped together as the three main driving forces behind the increased penetration of DGs. In order to reduce different contaminants, environmental factors are concentrated. The power market instability, which benefits DGs and small generating plans, is a commercial consideration. This is a very economical strategy that raises the reliability and quality of power. Diversification of energy sources to improve energy security and support is one of the main regulatory drives. DG has recently emerged as a reliable and efficient replacement for those conventional electric energy sources. Adopted technologies increase the viability of DGs from an economic standpoint. The penetration of DGs into electric power plants has expanded as a result of significant technological advancements in power electronic devices, small-range generators, and other energy storage devices for transitory backup.

Distributed Generation (DG) also provides an opportunity to effectively exploit the renewable energy, which is produced from replenishable resources available and abundant in nature. To accommodate this new type of generation, the existing distribution network should be utilized and developed in an optimal manner. Several approaches have been proposed in literature to determine the optimal location of DG in the distribution networks. To date, Artificial Intelligence (AI), evolutionary computation and optimization techniques are among the popular techniques that are normally used to solve these problems. The optimal allocation problem can be solved using Ant Colony Search Algorithm (ACSA). This algorithm is inspired from the natural behavior of the ant colonies on how they find the food source and bring them back to their nest by building the unique trail formation. The property of ACSA or Ant Colony Optimization (ACO) is adapted to solve the optimal location and size of EG. However, the rates of ant colony regulating parameters need to be determined using experimental approach. The complete approach is proposed in [1]. The optimal allocation problem is also solved by using Evolutionary Programming (EP) method. In this, authors use the sensitivity indices as the tools to predict the placement of EG at a particular bus. Sensitive indices are developed from voltage stability index. Buses with highest sensitivity values are selected for the location of the embedded generators [2]. The incorporation of Particle Swarm Optimization (PSO) for distribution generation sizing and allocation is proposed by simultaneously taking losses as objective function along with load flow [3]. The related works on GA for optimal allocation of EG using ET AP software with MA TLAB for solving that problem has been proposed in [4]. However, the implementation of GA is not explained clearly. When Distributed Generation is combined with shunt capacitor placements computation time is more[5].Different evolutionary techniques for optimal operation of distributed generation in terms of cost of Active and Reactive powers are GA, differential evolution, ACO, PSO and tabu search. A comparison of these methods is proposed in [6].

In this paper, a new population-based search algorithm called Cuckoo Search algorithm (CSA), inspired by the interesting brood parasitic breeding behavior of certain species of cuckoos, is presented to evaluate the DG site and size in the distribution network. Using the CSA, the optimization can be solved efficiently, partly because there are fewer parameters to be fine-tuned in CS than in other optimization algorithms. Simulation work is carried out on a IEEE 69 bus radial distribution feeder to validate the effectiveness of the proposed method.

II. Load Flow Solution

Load flow analysis of distribution systems has not received much attention unlike load flow analysis of transmission systems. However, some work has been carried out on load flow analysis of a distribution network but the choice of a solution method for a practical system is often difficult. Generally distribution networks are radial and the R/X ratio is very high. Because of this, distribution networks are ill conditioned and conventional methods like Newton-Raphson (NR) and Fast Decoupled Load Flow (FDLF) are inefficient at solving such networks. In many developing Countries like India, all the 11 KV rural distribution feeders are radial and too long. The voltages at the far end are very low with very high regulation. The proposed method involves only evaluation of a simple algebraic expression of voltage magnitude and no trigonometric terms. Topology based approach is used for evaluating equivalent load at every node. This eliminates the complex process of identifying nodes connected beyond a particular node. The two developed matrices; 'bus injection to node power matrix [10]' and 'line loss to node power matrix [10] are very easy to form. The features of this method are robustness and computer economy. Convergence is always guaranteed. The assumption is that shunt capacitance is negligible at the distribution voltage level. The three-phase radial distribution networks are assumed to be balanced and can be represented by their equivalent single. This assumption is quite valid for 11 kV rural distribution feeders in India and elsewhere. The procedure how we solve the load flow problem is given below.

First read the system data by assuming V1= 1.0 pu. Line losses are assumed to be zero in the first iteration. Obtain effective values of active power and reactive power by using, [N] = [BINP][S] Where, S is the column matrix which represents the complex power of all loads. Receiving end voltages are calculated using simple formulae V2=...j (BUl-Au]) and power losses of all branches using SLOSS =PLOSS + JQLoss. Multiply the power loss column matrix SLOSS with LLNP matrix to get N' matrix. N' represents that part of line losses in the effective load at various nodes. Now Effective load at each node becomes N + N'. Same procedure is repeated until the difference between voltages of present and previous iteration is of low value. The formulas which are used for measuring voltages and losses are taken from [9]. Suppose EG with generating capacity Sg =P g +jQg is connected to Bus 3 where load is $S_L = P_L + j\,Q_L$. Effective load on Bus 3 = $(P_L - P_G) + j\,(Q_L - Q_G)$.

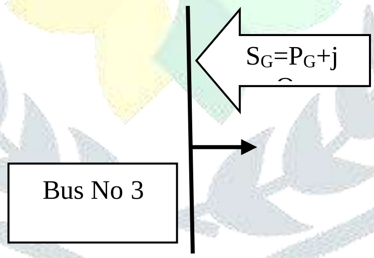

Figure 1

Algorithm for the proposed Method

1. Read the system data, V_1= 1.0 pu. Line losses are assumed to be zero in the first iteration,
   Voltages of remaining all buses treated as zero.
2. Build BINP matrix and LLNP matrix.
3. Obtain $P_{effective} + j^*Q_{effective}$, at each node. N represents the part of load powers in the effective load at various nodes.
   [N] = [BINP] [S], where S is the column matrix of all loads.
4. Initialize iteration count =1.
5. Obtain receiving end voltages using simple formulae $V_2=\sqrt{}\,(B[j]-A[j])$
6. Calculate power loss on all lines using the formulae,
   $P_{LOSS}[j] = R[j]^*(P_2^2+Q_2^2)/V_2^2$
   $Q_{LOSS}[j] = X[j]^*(P_2^2+Q_2^2)/V_2^2$
   $S_{loss} = P_{loss} + jQ_{loss}$
7. Multiply the power loss column matrix, S_L with LLNP matrix to get N' matrix. N' represents the part of line losses in the effective load at various nodes.
   $[N'] = [LLNP]\,[S_{loss}]$
8. Calculate the total effective load at various nodes by adding the N and N' matrix. Effective load at each node = N + N'
9. Increment the iteration count Repeat the steps from step (5) using new effective loads at every node.
10. If the difference in the voltages between present iteration and previous iteration is greater than 0.001 pu, then increment the iteration count and repeat from step (5), otherwise, print the result.

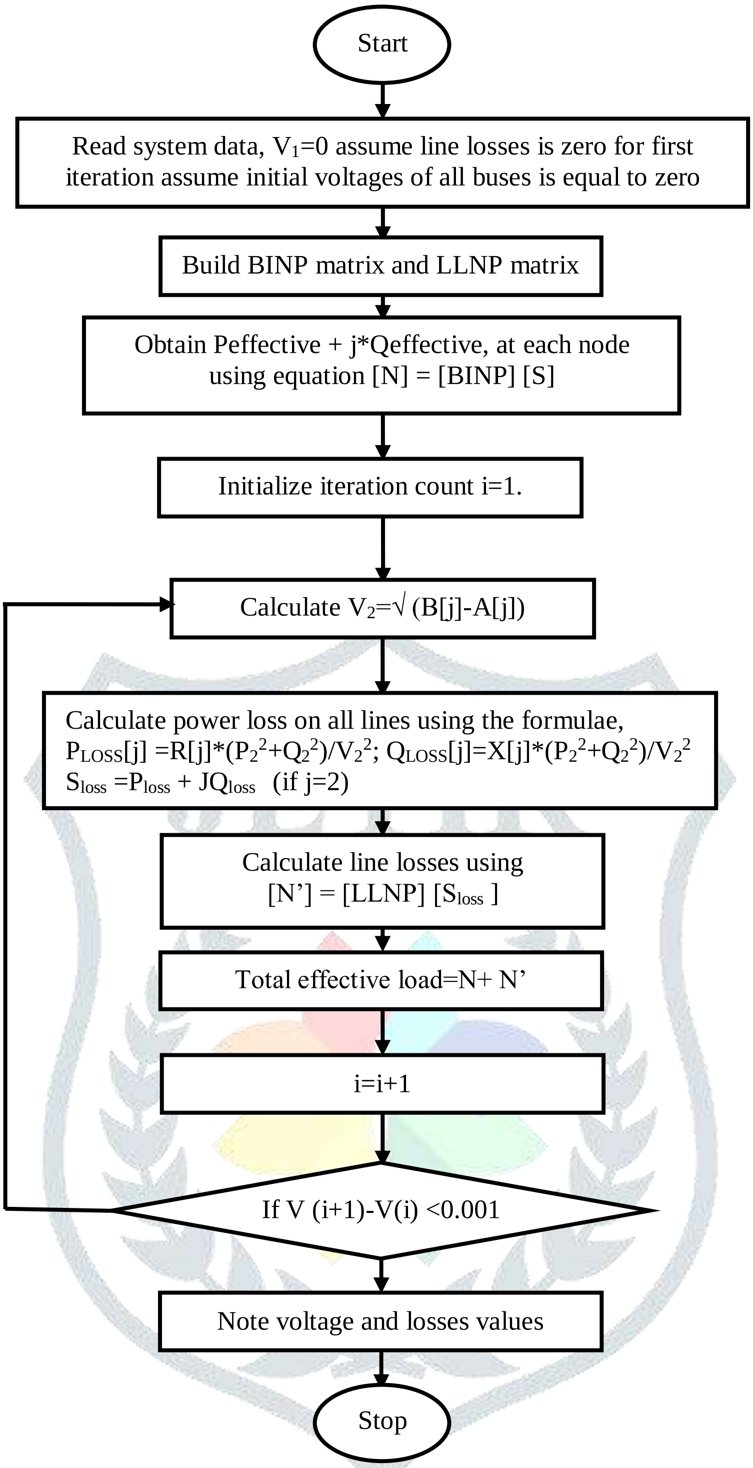

Fig. 2 Flow chart for Load flows

1. Cuckoo Search Algorithm

In 2009, Yang and Deb had proposed Cuckoo Search Algorithm (CSA) . It is an evolutionary algorithm (population based).Its implementation procedure is simple and it has very less control parameters. To determine the optimal size and location of DG unit, power flow is used to compute the power loss. In Cuckoo Search Algorithm (CSA), mainly the principles that are followed during the optimization process

- At a time, each cuckoo lays only one egg (designed solution). It will dump its egg in a randomly chosen nest among fixed number of nests (host nests) which are available at that time.
- The best nests which contain the high quality of eggs will be considered in next solution. Those nests are termed as better solution.
- Total number of host nest (available) is considered to be fixed .It is assumed that a host bird can find an alien egg with probability of Pa lies in between 0 and 1.

In order to build a completely new nest at a new location, it can may throw the egg away from the nest or abandon the nest.
After initialization phase, CSA comes to a phase (an iterative phase) which consists of following two random walks:
1. Levy Flights Random Walk and
2. Biased or Selective Random Walk.

After the random walks, a better solution is selected based on the fitness value of new generated solutions and current solutions by using a greedy strategy.
Step 1: Read Data: Line and Load Data Network Topology Algorithm parameters.
Step 2: Set all the parameters of Cuckoo Search Algorithm:
Number of host nests (n = 30), maximum number of iterations (NTotal = 500), Probability Index (pa = 0.25) for the worst nest. By using the best solution (Best nest i.e. DG location and corresponding size) calculate the Active power loss, Minimum bus voltage, Line flow and Branch power losses.
Step 3: Initialize the solutions (termed as nest) randomly.
nest (i,:)=Lb+(Ub-Lb).*rand(size(Lb)),where Lb and Ub are lower and upper limit of DG location and size respectively Run load flow analysis to find out initial losses without DG placement. The losses value will be the standard fitness value (std_P_Loss) of the algorithm. Get the current best for objective function.
Step 4: Start iterations.
Step 5: By using Lévy Flights Random Walk, initialize new solutions that follow.
Again perform the load flow analysis to find out the power loss with DG placement. These losses value will be the second fitness value of the algorithm.
Step 6: Compare both the values and find out the best solution so far.
Step 7: Discovery for the new nest and the process of randomization are:

g = size (nest, 1)
K = rand (size (nest))>pa;
Step size = rand*(nest(rand perm (g),:)-nest(rand perm (g),:));
new_nest = nest + step size.*K;

Step 8: Find the best objective function (active power loss) so far.
Step 9: Increment the iteration count and if the iteration count does not reach the maximum limit then go to Step 5 again.
Step 10: Repeat the procedure till the end of iterations and find out the value of the objective function that is found to be best so far.

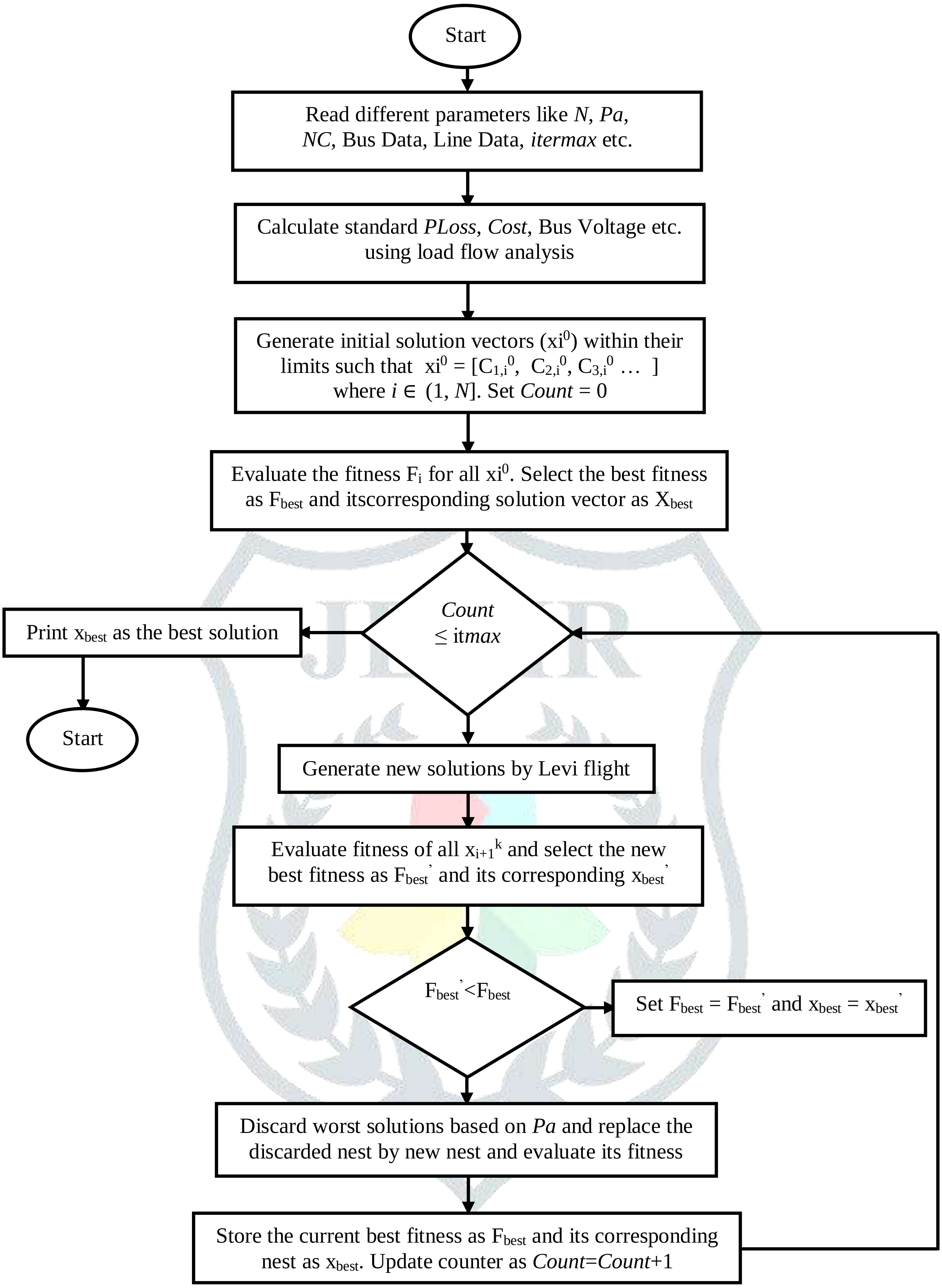

Fig. 3 Flow chart for CSA

III. OPTIMAL ALLOCATION STUDY & DISCUSSION

The method proposed has been tested on IEEE-69 bus radial distribution system. The algorithm has been programmed in MATLAB. This test system is shown in Fig.5 with a total real and reactive power demand of 3802.19 kW and 2694.60 kVAR respectively. The CSA properties are set as follow:

Population 60

Discovery rate of alien eggs/solutions

• Number of EG unit = 1or 2

• DG size = 0.0076 MW < PEG < 1.9243 MW

• Maximum iteration = 100

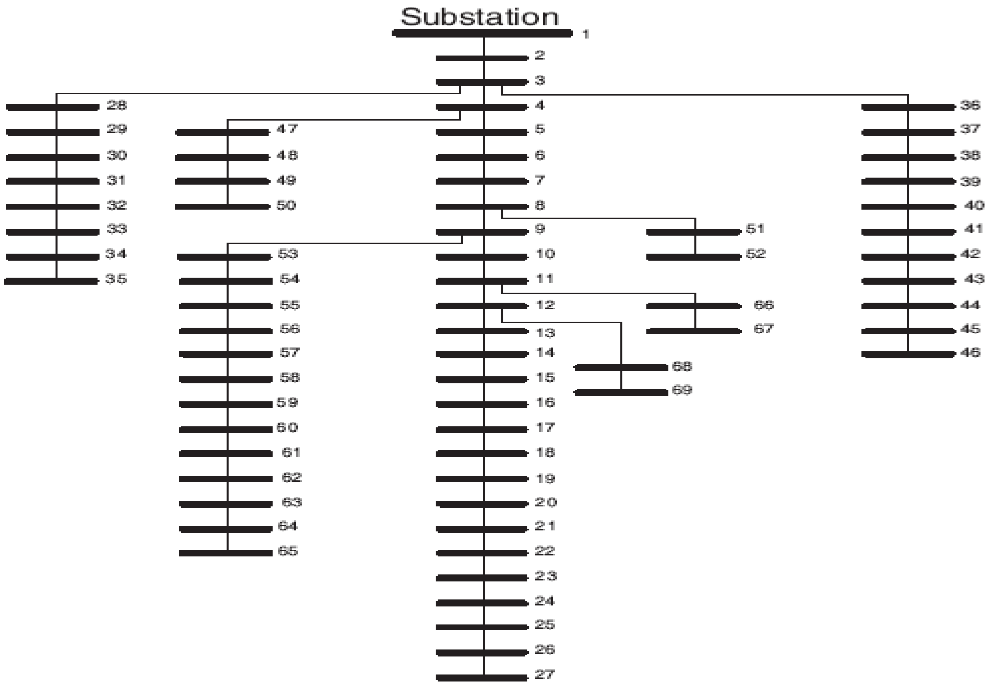

Fig. 4 IEEE-69 bus system

A.Contingency Analysis Study and Discussion

Whenever a line or transformer is removed from service, we say that an outage has occurred. Outages may be planned for purpose of maintenance or they may be forced by weather conditions, faults or other contingencies. A line or transformer is de-energized and isolated from the network by tripping the appropriate circuit breakers. The ensuing current and voltage transients in the network quickly die away and new steady state operating conditions are established. It is important for both the system operator and the system planner to be able to evaluate how the line flows and bus voltages will be altered in the new steady state. Overloads due to excessive line currents must be avoided and voltages that are too high or too low are not acceptable because they render the system more vulnerable to follow on (cascading) outages. Great precision is not required in contingency analysis since the primary interest is in knowing whether or not an insecure or vulnerable condition exists in the steady state following any of the outages. Accordingly, to test for the effects of line and transformer outages on bus voltages and line flows in the network, approximate ac power – flow techniques are generally employed since they can provide a fast solution of the many test cases which need to be run. Figure 6 shows the IEEE 69 bus radial distribution system after reconfiguration.

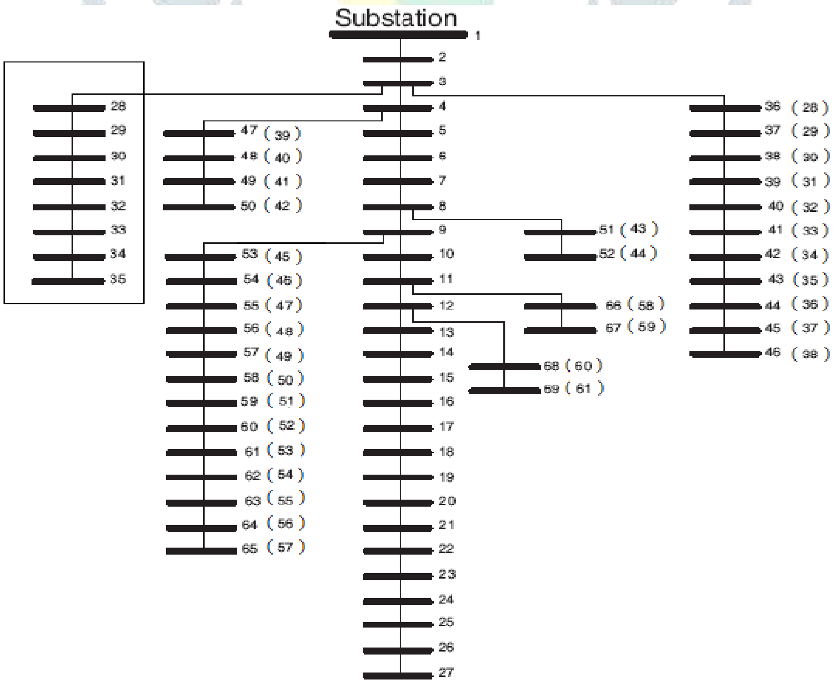

Fig.5 IEEE-69 bus system after reconfiguration

IV. RESULTS AND DISCUSSION

To observe the changes in voltage and losses due to the contingency and impact of DG, the study is divided into the following scenarios:
Case 1: The base case, viz. without DG and without contingency,
Case 2: With two units of DG and without contingency,
Case 3: With two units of DG and with contingency.
All the above cases are implemented on IEEE 69 Bus radial distribution system.

Case 1: The base case viz. without DG and without the contingency:
IEEE 69 radial bus system

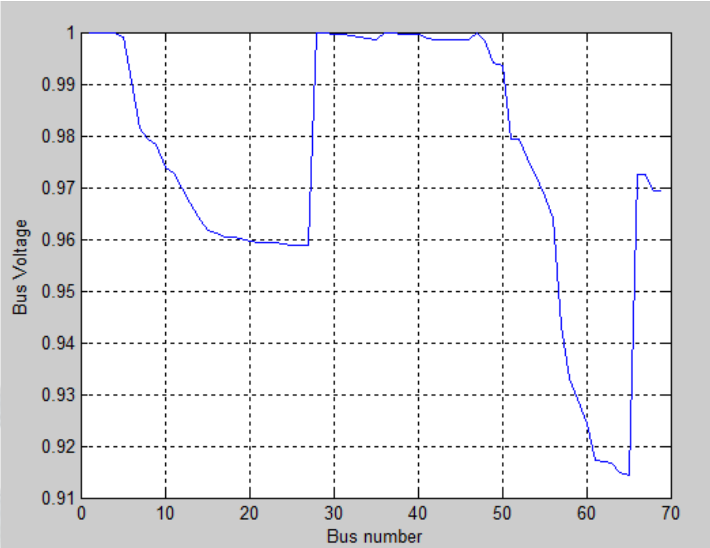

Fig.6 without DG and without Contingency

Fig. 6 shows the voltage profile at each bus where the contingency and distributed generations are not considered. Based on the observations, in this case minimum bus voltage is 0.9143pu at bus number 66 and total real power losses are 0.1454pu.
Case 2: With two units of DG and without contingency:

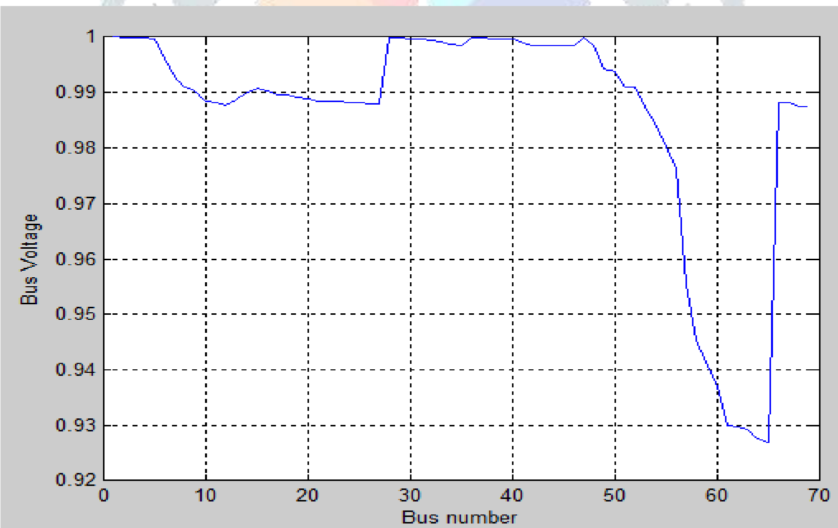

Fig. 7: With 2 DGs and without contingency

Fig. 7 shows the voltage profile at each bus for IEEE 69 bus distribution network with respect to iterations for a system with two DG units and without contingency. Based on observations, in this case the minimum bus voltage is 0.9285 pu at bus number 66.

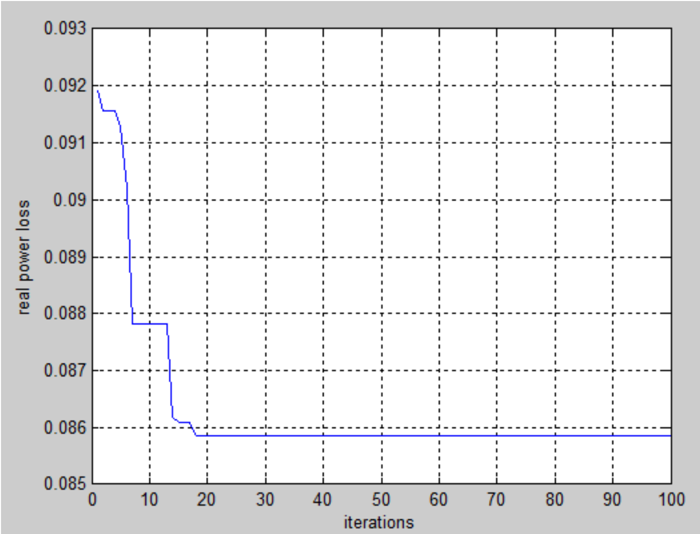

Fig. 8: With 2 DGs and without contingency

Fig.8 shows the variation of total real power losses with respect to iterations for a system with two DG units. Based on observations, minimum active power losses of the given distribution network are 0.0849MW while connecting two DG units where first DG unit is installed at bus 14 with generating active power capacity of 1.3486MW, second DG unit is installed at bus 6 with generating active power capacity of 1.9703MW.With the installation of DG units losses are reduced by 36% when compared to a system without DG.

Case 3: With two units of DG and with contingency

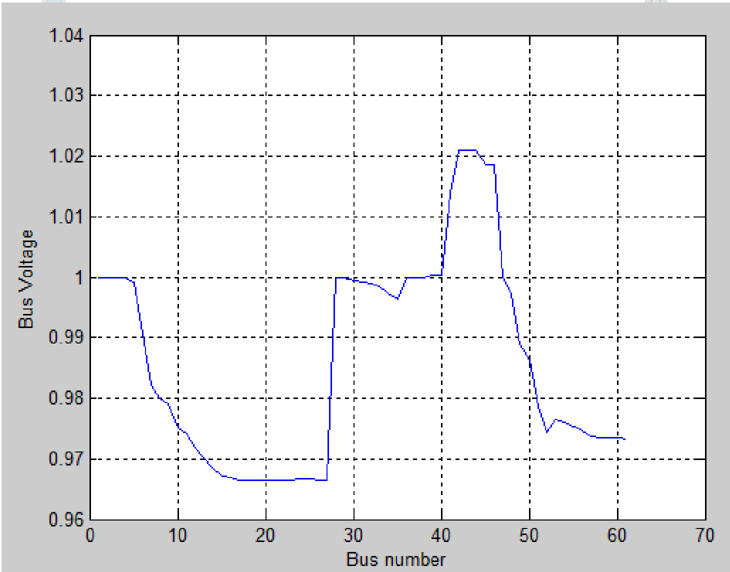

Fig. 9: With 2 DGs and with contingency

Fig. 9 shows the voltage profile at each bus for IEEE 69 bus distribution network with respect to iterations for a system with two DG units and with contingency. Based on observations, in this case the minimum bus voltage is 0.9785 pu at bus number 27.

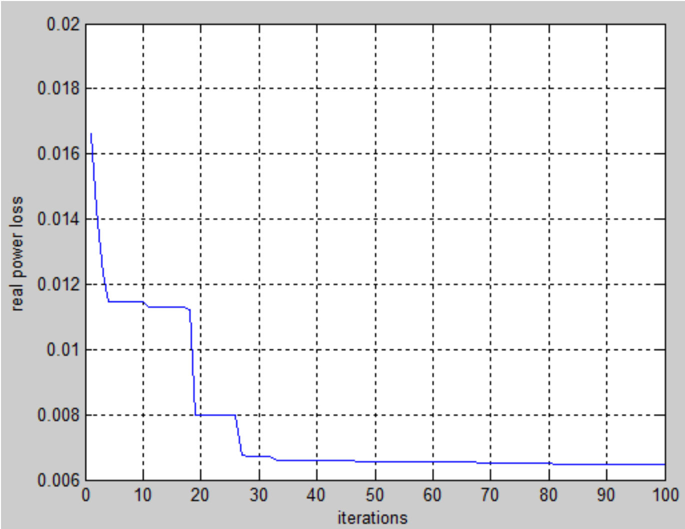

Fig. 10: With 2 DGs and with contingency

Fig. 10 shows the variation of total real power losses with respect to iterations for a system with two DG units and with contingency. Based on the observations, minimum active power losses of the given distribution network are 0.00649 MW while connecting two DG units where first DG unit is installed at bus 19 with generating active power capacity of 0.3902 MW, second DG unit is installed at bus 53 with generating active power capacity of 1.4874 MW. With the installation of DG units losses are reduced by 36% when compared to a system without DG.

CONCLUSIONS

This paper has presented two main issues of Distributed Generation (DG) deployment in the distribution network. The first issue is the introduction of Cuckoo Search Algorithm (CSA) to find the optimal location and size of DG in the system. The second issue is to see the impact of DG deployment when the contingency is created in the system. From the study, the installation of DG giving better results in-terms of reduced system losses before and after contingency. Different cases are considered and have been demonstrated and tested on IEEE 69-bus radial distribution system.

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