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DISTRIBUTION NETWORK RECONFIGURATION VIA SERVICE RESTORATION BY USING IABC ALGORITHM CONSIDERING DISTRIBUTED GENERATION

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ABSTRACT

Distribution network consists of several feeders with many switches. The feeder lines are often cut accidentally by heavy equipment, natural disaster or intentional attacks, which causes blackouts along affected feeders. Therefore, by applying service restoration via network reconfiguration, it will able to revive as many loads as possible by transferring loads in inoperative areas to another distribution feeder via changing the switches status and will help to protect the load and overcome blackout to the consumers. Hence, distribution system must be properly equipped and planned so that consumers will get an uninterrupted supply of power without interruption due to out of service area. The main idea of this technique is to alter the network topology by changing the switches state on the feeders. Therefore, an optimization method which is known from the foraging behaviour of honey bee swarm called as Improve Artificial Bee Colony (IABC) has been introduced. The main objectives of this study are to restore blackout area distribution network by changing the appropriate switches state on the distribution feeders with the proper size of DG while reducing power losses by employing improved ABC algorithm in distribution network reconfiguration. The study has been tested with IEEE-33 bus system by using the simulation in MATLAB environment. Based on the results achieved, can be concluded that network configuration without service restoration produce more power losses and out of service area. However, when service restoration is applied, it shows a reduction of power losses compared to the other cases and it able to restore as many loads as possible by the changes of the switching. Furthermore, by considering DG with DNR simultaneously has surely contributed to the tremendous power loss reduction in the network distribution system.

Keywords: distribution network reconfiguration (DNR), distributed generation (DG), improved artificial bee colony (IABC), service restoration (SR), power losses reduction, size of DG.

INTRODUCTION

As the demand for energy is increasing rapidly and the rise in the environmental concerns, the power system company has to struggle to find the best solutions to overcome the problem related to the increasing power losses in the distribution feeder. Moreover, the protection system is very crucial in the electrical system, thus, service restoration is absolutely needed to protect load side when there is fault occurs and to minimize blackout area. Normally, utility demand needs to consider the demands for power and those demands is from domestic and industrial factories which will give bigger impact to them in terms of economic factors. The reason is that, in heavy load, when the load current is drawn from sources increased, system losses will also increase, where it also knows as distribution losses [1]. Distribution losses will lead to an inefficient performance of the distribution system. However, the distribution network reconfiguration technique has its limitations. If power losses improvement is too great, it will make the solution unreliable. Therefore, we need the distributed generation installed in the distribution network as to improve the distribution system. Besides that, distribution network consists of several feeders with many switches. The feeder lines are often cut accidentally by heavy equipment, natural disaster or intentional attacks which cause blackouts along affected feeders [2]. So, the need to restore as many loads as possible by transferring loads in the blackout area to the other distribution feeder is the real concern. The main objective of this project is to restore the blackout area via service restoration for distribution network reconfiguration by changing the appropriate switches state on the distribution feeders. Besides that, to determine the suitable size of DG and to reduce power losses by employing IABC algorithms in distribution network reconfiguration with considering the DG. Energy distribution utilities are facing a problem where there is a demand for more efficient network and that is why network management is needed. One task to involve in this development is by configuring the network on distribution feeders [3]. By reviewing the previous related work, there are so many optimization methods in solving distribution network reconfiguration in minimizing power losses, service restoration, and DG sizing, but mostly all of the work does not imply power loss, service restoration, and DG altogether such as in [4], [5], [6], [7]. Besides, on [8] it is said that Optimal Distributed Generation (DG) output and reconfiguration are among the well-accepted approach to reduce power loss in a distribution network. So the paper proposed a simultaneous DG output and reconfiguration analysis is proposed to maximize power loss reduction. The impact of the separated analysis and simultaneous analysis are investigated. The research used ABC algorithm optimization techniques for all the analysis of DNR and DG. The main contribution of this paper is on the employment of simultaneous analysis for reconfiguration and DG output in order to find a minimum power loss. The applied Artificial Bee Colony (ABC) algorithm in this work proves its capability to solve the simultaneous analysis. Next, on [9] the paper proposed to minimize power losses in the distribution network by satisfying all distribution network constraint by using the ABC algorithm. The proposed methodology is this study has been tested with 33 bus systems. The results were compared with Refined Generic Algorithm (RGA) and Tabu Search Algorithm (TSA) and it shows that among the other algorithm, ABC algorithm is the best algorithm for minimizing power losses and has been found satisfying the distribution network constraint. Based on the research that has been done, they are none study produced the same title as this study. Therefore, this study is the one and only that, consider distribution network reconfiguration via service restoration by using an improved ABC algorithm considering distributed generation. The formula formulation and constraints will be discussed in II while the test system will be discussed in Section III. In Section IV, result and analysis will be discussed. Next, for Section V and VI will be discussed about conclusion and recommendation.

METHODOLOGY

As stated before, the main objective of this project is to find the ideal size of distributed generation while minimizing the power losses in the distribution system. The voltage constraints also took into consideration as to validate that the minimum and maximum voltage will not be exceeded.

The connection and also the reconfiguration of DG in distribution network will be taken into consideration as it will affect the overall direction of power flow in the network. Both techniques are combined with each other to get minimum active power losses in the distribution system.

Therefore, minimum power losses can be calculated based on the formulation as follows:

Mathematical formulation

The objective of the feeder reconfiguration is to minimize the total power loss. Therefore, the loss reduction in network reconfiguration problem is formulated as below;

$$p_{loss} = \sum_{t=1}^{Nline} \left| I_t \right|^2 k_t R_t \quad (1)$$

Where;

t = line number
I_t = current of line t
R_t = Resistance of line t
Nline = total line
k_t = variable represents the topology status of line t (1=close, 0 = open).

The general power system constraints that applied in the analysis are:

A. Generator operator constraint

$$p_k^{\min} \leq p_{dg,k} \leq p_k^{\max} \quad (2)$$

The value of active power generation ($P_{dg,\ k}$) at DG k (k = 1, 2..total DG) should be within P_k^{min} and P_k^{max} which represents the lower and upper bound of DG output, and for analysis involving DG units, the DG sizing is within this limit and must not be exceeded.

B. Power injection constraint

$$\sum_{k=1}^{Ndg} p_{dg,k} \langle p_{load} + p_{losses} \quad (3)$$

Where, Ndg= total number of DG

In the effort of avoiding power injection from DG unit for its main grid (substation), the DG output cannot be more than the total load and the total power losses.

C. Power balance constraint

$$p_k^{\min} \leq p_{dg,k} \leq p_k^{\max} \quad (4)$$

The sum amount of power by DG unit ($P_{dg,k}$) and substation ($P_{substation}$) must be equal to the total sum of power load (P_{load}) and power losses (P_{losses}).

D. Voltage bus constraint

$$V_{\min} \leq V_{bus} \leq V_{\max} \quad (5)$$

The amount of voltage for each bus should be operated as in (5) within the range of 1.05 and 0.95 ($\pm$ 5).

A. Radial configuration constraints

The network configuration must be in radial form to avoid excessive current flow in the system. Several constraints need to take into account to ensure the radial network is maintained. Few rules have been adopted for the selection of switches. Closed switches that do not belong to the loop, connected to the sources and contributed to a meshed network.

Implementation of Improved Artificial Bee Colony (IABC) algorithm for network reconfiguration

Generally, in finding the best solution of the object function the algorithm that is best to use is ABC algorithm. However, the basic design of the ABC algorithm of the onlooker's bee movement only considers the relation between the employed bees, which is based on roulette wheel selection. Hence, it is not strong enough to maximize the exploitation capacity. [10]

Therefore, influenced by the improved strategies of PSO [11] which will add some non-linear weight factors changing to obtain a better result and this technique has been implied in this study. As to improve the diversity of nectar sources, an inertial weight which known as w where it has been inspired by the PSO evolution equation and its improving strategy is added. The equations are as follows:

$$v_{ij\_new} = \left[x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right) \right] \tag{6}$$

$$w = w_{\max} - \frac{w_{\max -} w_{\min}}{iter_{\max}} \times iter \tag{7}$$

Where;

W_{max} = maximum weight equal to 0.9
W_{min} = minimum weight equal to 0.4
$iter_{max}$ = maximum iteration number
iter = current iteration number.

The local searching process will shift to the global searching phase and will balance the two sides so that it can be converged to the optimal solution effective. In a vigorous searching process, exploration and exploitation processes must be carried out at the same time. Other than that, in order to get a better and diverse food sources in ABC algorithm, the exploitation process executed by an onlooker and employed bees, also the exploration process in scout bees phase need to be controlled and balanced.

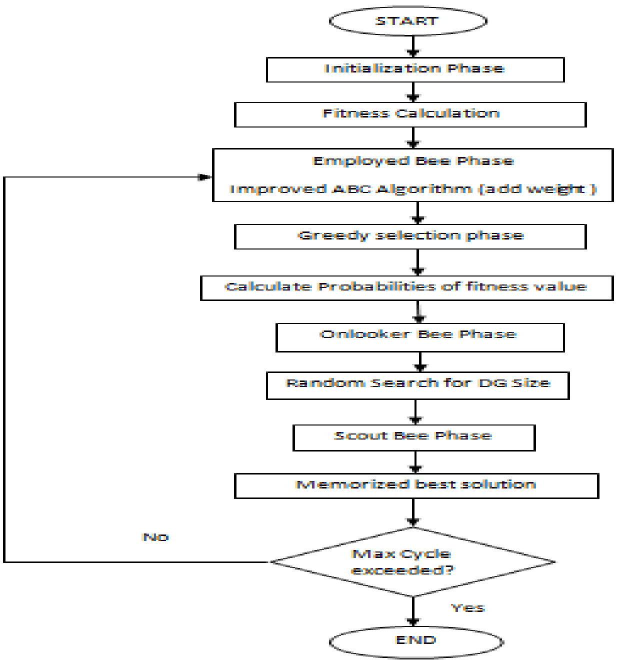

Figure-1. Flowchart of IABC algorithm.

Step 1: Initialize population

In order to run IABC, the data required in initialization procedure are line data, network data, bus data, base apparent power, the maximum number of iterations, the total population size, PSO parameters and accuracy of each iteration. The process starts by choosing a random combination of tie switches from the set of original tie switches depend on the population size bus. In this project, the random populations of tie switches which represent the position of food source which will result in a possible solution to the optimization problem. The whole position of the food source is equal to the half of colony size, which is the sum of employed bees and onlooker bees. The set of tie switches is written as shown in equation (8).

$$suis = \left[s_1, s_2, s_3, \ldots\ldots\ldots\ldots\ldots s_k \right] \tag{8}$$

Where:

S = selected tie switches
k = Number of tie switches

Note that the number of an employed bee is the same as the number of food source position which will be taken advantage of by time.

Note that only populations that satisfy all the constraints in (2), (3), (4) and (5) will take into account as the initial population. To assure network maintained in the radial configuration, certain constraints need to be considered in the system. There are rules that need to be applied for the switching selection. All switches that do not belong to any loop need to be closed. All switches connected to the sources are to be closed state. All switches that will lead to a meshed network need to be closed.

Step 2: Fitness Calculation

In this project, the power loss of the system was taken as the fitness function. The quality of the solution reflects the fitness value and needs to be optimized and solved. The nectar amount of food source is directly proportional to the quality of the solution. The power loss for each of the population is obtained using the Newton - Rhapson method of load flow program. The fitness value is formulated as follows:

$$fitness_i = \begin{cases} \dfrac{1}{1 + ploss(i)} & if\ p_{loss(i) \geq 0} \\ 1 + abs(p_{loss(i)}) & if\ p_{loss(i) \leq 0} \end{cases} \tag{9}$$

$P_{loss(i)}$=Real power losses at bus *i*.

By calculating fitness value for each population, food source position which shows higher values of fitness will be memorized. To reflect in terms of reconfiguration method, the best combination switching who provides best fitness level that achieved so far will be memorized.

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Hence, in terms of reconfiguration, the combination of the switch at minimum power loss will be memorized.

Step 3: Employed Bee Phase (Improved ABC)

In this phase, we will generate a new population. For every iteration of IABC algorithm, a new neighboring food source location of the selected food source position is searched randomly by the employed bees. The following equation has been applied in order to determine new population in the neighborhood.

$$v_{ij} = w\left[x_{ij} + \phi_{ij}\left(x_{ij} - x_{kj}\right)\right] \quad (10)$$

Where: $k \neq i$

$\varnothing_{ij}$ is random number between [-1 , 1] and j $\in \{1, 2, .., D\}$.

In order to get a better and diverse food sources in ABC algorithm, the exploitation process executed by an onlooker and employed bees, also the exploration process in scout bees phase need to be controlled and balanced. Thus, to achieve this, the idea of PSO parameter by adding w into the equation (16).

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \quad (11)$$

Where;

W_{max} = maximum weight equal to 0.9
W_{min} = minimum weight equal to 0.4
$Iter_{max}$ = maximum iteration number
Iter = current iteration number

If the newly generated solution value is out of boundaries, the generated solution is shifted onto the boundaries. To explain in a simple way, the newly generated solution will be set to its limit value if the value exceeds its predetermined limit. Then, the positions of food sources will be evaluated back to determine the fitness value according to the newly generated population.

Step 4: Greedy Selection Phase

The greedy selection method is used in order to compare the performance between the fitness of new food source position and the original current fitness in the memory. If the new fitness produced a better solution than the old one in the memory, the employed bee will be shifting to this new position of food source and forget the old ones. However, if the old one is better than the new food source, the old fitness is kept in the memory and abandoning the new one.

Step 5: Onlooker Bee Phase

At this phase, onlooker bee will evaluate the nectar amount and position of food source gained by the employed bee. By choosing based on probability, which is proportional to the fitness of food source, the onlooker bee will select the best food source among all. The greater the probability of food source, the higher the possibility of the food source will be taken since it produces more quality and valuable food source.

The probability of food source is calculated as below:

$$p_i = \frac{fitness_i}{\sum_{n-1}^{N} fitness_n} \quad (12)$$

Where:

***fitness$_i$*:** fitness value represents by food source *i*
N: total number of food source position

Step 6: Random Search for DG Size

In this program, the DG size will be searched randomly. There will be four DG units with each DG must follow their upper and lower boundaries which have been set within its limit. The limitation range for each DG is less than 5MW. Then, the DG size will be selected randomly from its upper and lower limit. The location of the distributed generation has been set at bus 6, 18, 22, 29 [12]

Step 7: Scout Bee Phase

When the food source is depleted, the position is abandoned by the bee. This shows that when the food source cannot be improved and exceeds their limit value, the food source will be eliminated from the population. In the end, an employed bee with the food source will become scout bee. The scout bees need to search for new food source position randomly and replace the abandoned food source with the new one.

Step 7: Service Restoration

In this project, service restoration for the network reconfiguration will take into account. There are scenarios to help analyze and solve the problem that has been stated in this project. [13] There are:

Scenario 1: System is operated with service restoration via DNR

Scenario 2: System is operated with service restoration via DNR and DG simultaneously.

TEST SYSTEM

The case study of this test system consists of the 33-bus radial distribution system as shown in Figure 2. The radial distribution system consists with one feeder, five normally open tie line which located at the branch (33, 34, 35, 36, 37) and 32 normally closed tie line. The case study of this test system consists of the 33-bus radial distribution system as shown in Figure-2.

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The case study of this test system consists of the 33-bus radial distribution system as shown in Figure-2. The radial distribution system consists with one feeder, five normally open tie line which located at the branch (33, 34, 35, 36, 37) and 32 normally closed tie line. The system load is assumed to be constant with Sbase = 100MVA. The line and load data details can be referred in [1]. The minimum and maximum voltages are set at 0.95 and 1.05p.u. The total load on the system is 3715kW and 2300kVar respectively. All calculations for this method are in per unit system and the convergence value is taken as 0.0001. Four DG units are located in the most optimal locations which are at buses 6, 18,22, and 29.

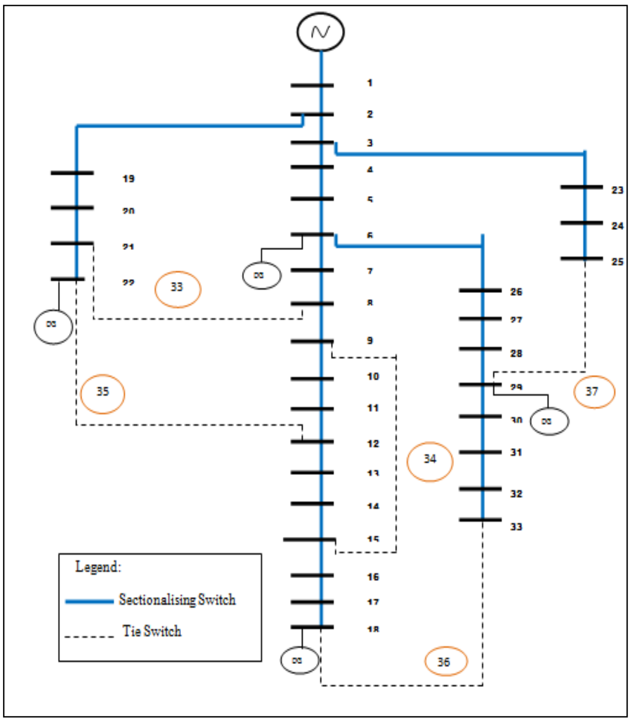

Figure-2. Initial configuration of 33 bus radial distribution system.

As mention earlier, the main contribution of this study is the implementation of using an IABC algorithm with considering DG in network reconfiguration in order to reduce power losses and to restore blackout areas via service restoration. Therefore, in order to validate the results, 4 cases have been introduced. Those cases have been described as follows:

A. In this first case

The system follows the original ABC 33 bus distribution network with network reconfiguration.

A. In this second case

The reconfiguration has been applied in the system by using an IABC algorithm via service restoration.

B. In this third case

The reconfiguration has been applied in the system by using an IABC algorithm with considering DG without service restoration.

C. In this fourth case

The reconfiguration has been applied in the system by using an IABC algorithm with considering DG with service restoration.

RESULT AND ANALYSIS

In the reconfiguration, the analysis contains the distribution network and distributed generation with service restoration and without service restoration. Each size of DG has been set in the limitation range less than 5MW in the program. To observe the changes of DG sizing, the location of DG has been fixed as the controlled measure. Tie switch and sectionalizing switch are considered as the main control variables. The explanation about the system operated by service restoration via DNR with DG is referred to the fault occurs between bus no 7 and 8. Therefore, the most minimum power loss that able to restore the outage area will be selected. The results consist of five opened switches, total power loss, and four optimal DG sizing. There will be three important parts to be analyzed. The part A will be focusing on power loss reduction, part B on the system operated with Service Restoration via DNR and DG simultaneously and part C is on the DG sizing obtained after reconfiguration.

Part A: Power losses reduction

Table-I shows the result of power losses reduction. All three cases have been compared with the initial configuration. Switches, power losses and the size of DG are the main parameters to be observed. All of these parameters are important for the contribution of the optimal value. In Case 2, the configuration is for the Improved ABC algorithm via service restoration, which fault happen between line 7 and 8. The power loss is 132.6kW, which it has been reduced from the original network to 1.66kW where it is about 1.24% reduction compared to the Case 1 which is the original network.

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Table-1.

Parameters	**Case 1: original network**	**Case 2: IABC and DNR via SR without DG**	**Case 3: IABC and DNR with DG only**	**Case 4: IABC and DNR with DG via SR**
Open Switches	4, 10, 19, 25, 35	6, 9, 15, 34, 37	7, 8, 9, 12, 13	7, 9, 15, 21, 37
Total Power Loss(kW)	134.26	132.6	107.519	98.5772
Loss Reduction(kW)	-	1.66	26.741	35.68
Percentage of Loss Reduction (%)	-	1.24	19.92	26.58

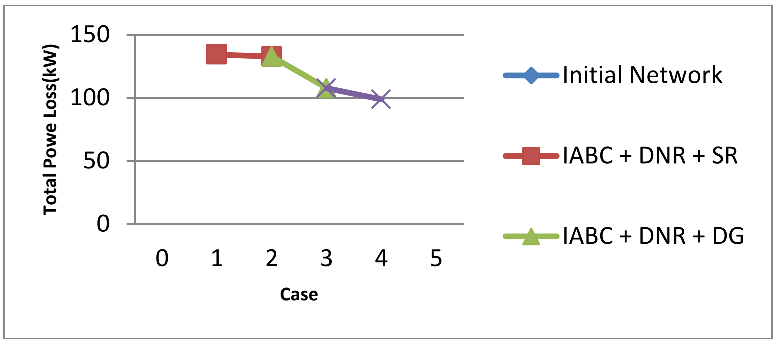

Figure-3. Total power Loss for the original network, DNR with IABC algorithm with and without DG and SR.

Part B: The system operated with service restoration via DNR and DG simultaneously

The objective of service restoration is to restore out of service in distribution system when a fault occurs. The result is then compared with previous related works that have been done. The study has been compared with the study of the modified genetic algorithm for service restoration based on simultaneous DNR and DG sizing [13].

Firstly, the network is set to before the service restoration takes place. The explanation about this situation, the fault is referred to the fault occurs between bus no 7 and 8 as in Figure-4. It shows that the bus from 8 to 18 is considered out of service area. Therefore, to restore this area, switch 33, 35, or 36 needs to be closed. A path that undergoes the shortest distance and the fastest to restore the out of service area will be selected. Besides, to prove that the method is efficient, the outage needs to restore quickly as to avoid other losses.

Refer to Case 2, the reconfiguration with IABC algorithm via service restoration shows that, the open switches have been changed to 6, 9, 15, 34, 37 as in Figure-5. This shows that feeder 8 and 9 get the power supply through switch 33 and power supply for feeder 11 and 18 through switch 35 and 36. The power losses have been reduced from 134.26kW to 132.6kW which is 1.24% of losses. As for Case 4, the reconfiguration is operated via service restoration with the implementation of DG simultaneously as in Figure 6. It is the same as before, but DG has been installed at bus no 6, 18, 22, 29. The program runs in MATLAB for 30 times. The results show that the switch has been changed to 7, 9, 15, 21, 37 which provide the lowest power loss which is 98.5772kW. The percentage of loss is approximately 26.58% with size DG 1.7052MW, 1.1629MW, 0.7575MW and 2.4455MW.

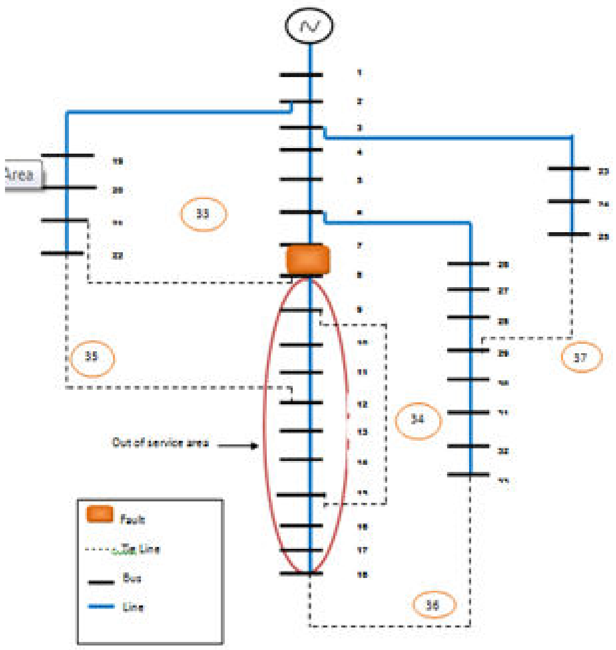

Figure-4. Network after service restoration.

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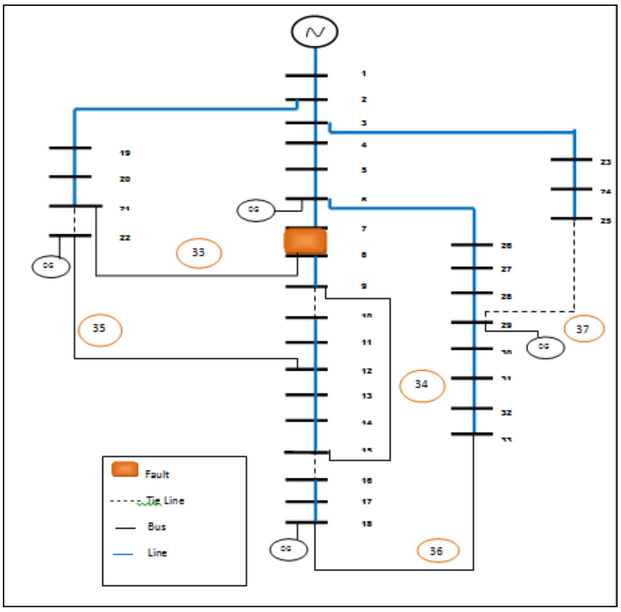

Figure-5. Network after service restoration with DNR and DG simultaneously.

Part C: Distribution generation DG sizing

Table II shows the result of DG Sizing for each case after reconfiguration with IABC algorithm. As stated in section 4.2, the location of DG is set at bus 6, 18, 22, 29. It has been tested with Case 3 and Case 4.

Table-2. The DG sizing for DNR with IABC algorithm with and without SR.

Parameters	Case 1	Case 2	Case 3	Case 4
Chart Area Size of DG (MW)	—	—	DG1: 1.7131	DG1: 1.7052
			DG2: 1.2840	DG2:1.1629
			DG3: 0.6038	DG3:0.7575
			DG4: 3.2329	DG4:2.4455

There is no much difference in the DG's sizing for cases in 3 and 4. Although there is still a bit of difference, it is not much, around >0.01MW for each DG unit and has been configured by IABC algorithm. Figure-7 shows the DG capacity for each DG unit with and without service restoration.

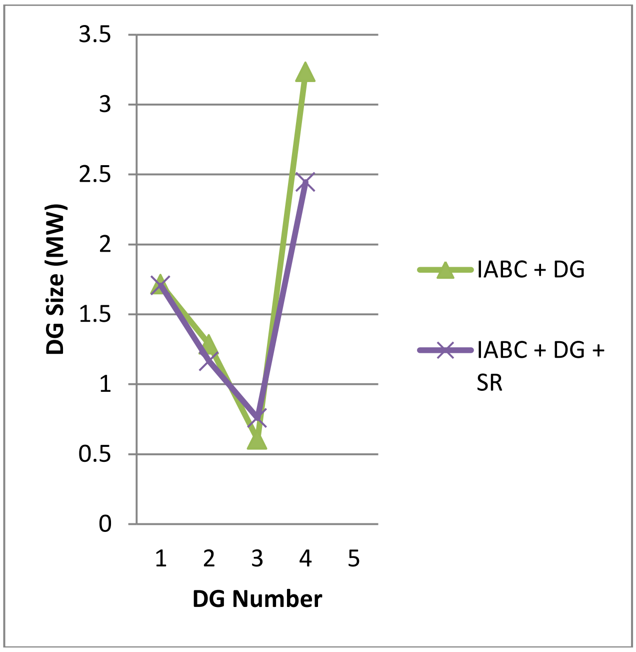

Figure-6. DG capacity for each DG unit with and without service restoration.

Based on the results, it shows that to get the most minimize power losses, the DG sizing for each DG unit must be within the limit. For DG1, the size of the capacity limit is within 1 MW to 1.8 MW. Next, for DG2, it is from 0.9MW to 1.7 MW. Hence, for DG3, the DG limitation capacity is from 0.5MW to 0.9MW and lastly, for DG4, the size capacity limit is within 1.55MW to 3.3MW. Therefore, the limitation for DG in the program is still within the limitation range which is less than 5MW. In a nutshell, it is clearly shown that the size of DG and sectionalizing switches play an important role in the contribution of power loss reduction.

Based on the results and analysis shown, all of the techniques have been successfully implemented to IEEE 33 bus radial distribution system. It shows that the system which operates via service restoration with DNR and DG really gives big impacts in the power loss reduction. It also able to restore as many loads as possible by the changes of switches from out of service areas to other distribution feeders by DNR.

CONCLUSIONS

As the conclusion of this study, the primary objective of this study is to reduce power losses by using IABC algorithm and to restore blackout areas via service restoration for distribution network reconfiguration by changing the appropriate switches state on the distribution feeders with the proper size of DG. Besides that, is to determine the suitable size of DG in a network reconfiguration system. Based on the results achieved, can be concluded that network configuration without service restoration produce more power losses and out of service area. However, when service restoration is applied, it shows a reduction of power losses compared to the other cases and it able to restore as many loads as possible by

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the changes of the switching. Furthermore, by considering DG with DNR simultaneously has surely contributed to the tremendous power loss reduction in the network distribution system.

RECOMMENDATION

As for the recommendation for future research, the IABC algorithm is not only for the 33kV bus system, but it also can be tested with a bigger system such as 69kV. Hence, the comparison between 33kV, 69kV, and 132kV also can be done to get more convincing results while improving the power loss reduction. Lastly, the location of DG also can be tested in the system to get more optimal results and for better understanding.

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