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The Effect of Non Reconnecting Distributed Generation on Islanding and the Cost of Energy Not Supplied in Active Distribution Networks

P.Prasanna Lakshmi[1], G.Naveen[2]

[1,2] *EEE, Narasaraopeta Engineering College, AP (India)*

ABSTRACT

Using distributed generation resources (DGR) in distribution networks is increasing due to their many advantages. One of these advantages is that their capacity can be used as back up for supplying a portion of the load when the main source of the network is lost. In such cases, the distribution network can be divided into several islands. In each of these islands, the load outage duration and the energy not supplied (ENS) of the network can be decreased, considering its distributed generation capacity. This process of the network affects restoration and increases the system's reliability. The every important feature of distributed generation for participation in load restoration is its capability of being islanded. One of the features which is required for islanded operation of DG, is the self-starting capability of DG. This process gives that the generation unit is able to start without the need to an external voltage source. In this paper, a new approach based on the Imperialist Competitive Algorithm (ICA), which is very well-known and most powerful optimization algorithm, is presented for determining the optimal intentional islands in distribution networks. Then, the effect of not reconnecting distributed generation units on the cost of the power not supplied and the boundaries of the intentional islands after occurrence of a permanent fault in the network is studied as a sensitivity analysis. The proposed approach is applied on the IEEE 33-bus test system with four number DGs, and the results are presented.

Index Terms—Energy not supplied, Load restoration, Distributed generation, Intentional islanding, Imperialist competitive algorithm.

I. INTRODUCTION

Nowadays, due to the growth of industrial societies, the need for reliable and continuous electrical energy has increased. Therefore, supplying the energy demand of users with an acceptable level of safety, minimum cost, and proper quality is the major goal of power system management. To achieve this goal, realizing objectives such as meeting the customers' demand, making sure of safe operation of power system components, minimizing generation and transmission costs, minimizing the environmental impacts, and optimal usage of fuel resources are of great importance. Of the aforementioned objectives, supplying the customers' demand is more important, and if it is interrupted, consumers might experience severe damages. Therefore, when an interruption occurs in supplying the network loads, utilizers in control centers are responsible for supplying the customer's load with acceptable quality, lowest cost, and in shortest time possible [1, 2]. In conventional distributed networks, energy is radially transferred from source to consumers. If a fault occurs in distribution

IJARSE
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network, the faulted part should be isolated from the distribution network as fast as possible. Due to this isolation, the flow of energy towards some loads might be interrupted. In other words, some loads might be de-energized. With distributed generation units becoming common in distribution networks, great attention has been paid to islanded operation of these units as a proper and promising way for improving the reliability of the system. When a fault occurs in a distribution network, all downstream consumers are de- energized because of becoming isolated from the main network, and they will remain de-energized until the faulted part is repaired. This process will take a long time. Longer outage duration is not desirable for important consumers such as hospitals, and governmental and industrial centers. Distributed generation units have a great effect on restoration of important loads. By creating intentional islands, these units accelerate restoring operation. Intentional islands are a proper choice for increasing the reliability of the end loads of the network which do not have access to other parts of the network as back up. Otherwise, due to the creation of a permanent fault, these loads have to experience a long outage [3]. The capacity of DGs is usually lower compared to the total load of de-energized part, therefore, these units cannot restore all de-energized loads. Thus, distributed generation is only able to supply loads in islanded mode. The highest improvement in reliability of islanded mode of operation is obtained when the amount of load restored in the intentional island is maximized.

Distributed generation can affect restoring operation in two ways. First, DG itself can create an additional fault (creating unintentional island). Second, it can accelerate restoring operation by creating an intentional island during restoration. After a fault occurs in distribution network, in order to avoid the negative effect of DG on the fault current and the performance of protection system, the DG units must be disconnected. Therefore, all the loads in an islanded area must experience a temporary power failure.

There are some factors which limit the intentional islanding operation. These are [4]:

- The safety of staff,
- The problems of keeping voltage and frequency in the permitted range,
- The possibility of non-coordination between islands when being synchronized to the main network after the fault is removed.

These problems must be sorted out properly, and attention must be paid to the required considerations before starting any islanding operations. Many papers have so far been published in the field of intentional islanding in presence of distributed generation units with the aim of restoring the maximum load [4-8]. In some papers, the intentional islanding problem has been modeled as a knapsack problem, and the topology constraint, which is also used as a determining factor for connecting all the selected buses, has been solved by means of branch and bound algorithm [1, 4]. In some other papers, the rooted tree method in graphs theory has been used for creating islands and determining their boundaries [9]. A heuristic algorithm based on graphs theory has been presented in [10] for isolating islands. In most of the aforementioned researches, the goal is to simply minimize the load interruption during the islanding process [11, 12]. None of these papers has taken into account the impact of the effective factors on intentional islanding (DG as the most effective factor) in the sensitivity analysis and has not dealt with it. Furthermore, in all the previous cases, the number of islands is predetermined whereas in this paper, it is not the case and the algorithm is responsible for determining the number of islands.

In this paper, after presenting a new approach for determining the optimum intentional islands in the distribution network, the effect of not reconnecting the DG units on the cost of the energy not supplied and the boundaries of intentional islands after the occurrence of a permanent fault in the network is studied as a sensitivity analysis. In

IJARSE
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order to obtain an optimum islanding scheme, the ICA algorithm is used. The proposed approach is applied on the modified IEEE 33-bus test system with four DGs and the results are presented.

This paper is organized as follows: in section II, the algorithm proposed for optimum intentional islanding is presented. In section III, the objective function and constraints of the problem are introduced. The results of simulation as a sensitivity analysis, which in fact are the effects of presence and absence of DG units on the amount of load restored, the cost of energy not supplied and the boundaries of intentional islands after the occurrence of a permanent fault in the distribution network, are presented in section IV. And finally, the conclusion is presented in section V.

II.THE PROPOSED ISLANDING APPROACH

In this paper, a new approach based on the graphs theory and network tree is proposed for determining the optimum intentional islands in distribution network. Then, the effect of not reconnecting distributed generation units on the cost of the energy not supplied and the boundaries of intentional islands is discussed. To obtain an optimum islanding scheme, The ICA algorithm is used. This algorithm is a well-known and powerful optimization algorithm and has so far been used in many applications and various research fields [13-16]. Assimilation, imperialist competition, and revolution are the main bases of this algorithm. By imitating the process of social, economic, and political evolution of countries, and by mathematical modeling of some parts of this process, this algorithm presents some operators in a regular structure as an algorithm which can be helpful in solving complicated optimization problems. This algorithm considers the responses of the optimization problem as countries and tries to improve these responses and to finally take them to the optimum response of the problem through an iterative process [16]. Fig. 1 shows the flowchart of the proposed intentional islanding approach.

In general, the implementation process of the proposed algorithm by means of the imperialist competitive is as follows:

1- In this stage, the matrix of switches is formed based on the node-branch incidence matrix of the network. In this structure, if the number of buses in the network is equal to n, the length of each country will be equal to the number of switches i.e. n-1.
2- In this step, an initial population is randomly generated from the responses of the problem of interest. This is done by randomly assigning a number, which is equal to 1 or 0, to each member of the population (countries), so that 1 represents a closed switch and 0 represents an open switch in this structure.
3- In this stage, based on the structure obtained and the node- branch incidence matrix of the network, islands that include distributed generation are identified and isolated.
4- If the maximum generated power and the total load demanded by the islands which include distributed generation are not balanced according to (4), the load interruption is carried out in this stage.
5- In this step, in order to remove the operational obstacles of the system, the load flow is run.
6- According to (1), the objective function is calculated for each country.
7- In this step, empires are formed. This is done by selecting members with higher fitness as emperors from the members of the initial population that are sorted based on their fitness function. The rest of the countries are colonies which are to join the empires.
8- In this stage, the two operators of assimilation and revolution of the imperialist competitive algorithm are

IJARSE
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applied on the colonies to update their positions.

9- Stages 3-6 are repeated.

10- In each empire, the fitness functions of the countries are checked. If the fitness function of a colony is better than that of its emperor, that country itself will become the emperor. This stage is referred to as the internal competition.

11- In this stage, imperialist competition is carried out between the empires to attract each other's colonies. This stage is called the intergroup competition.

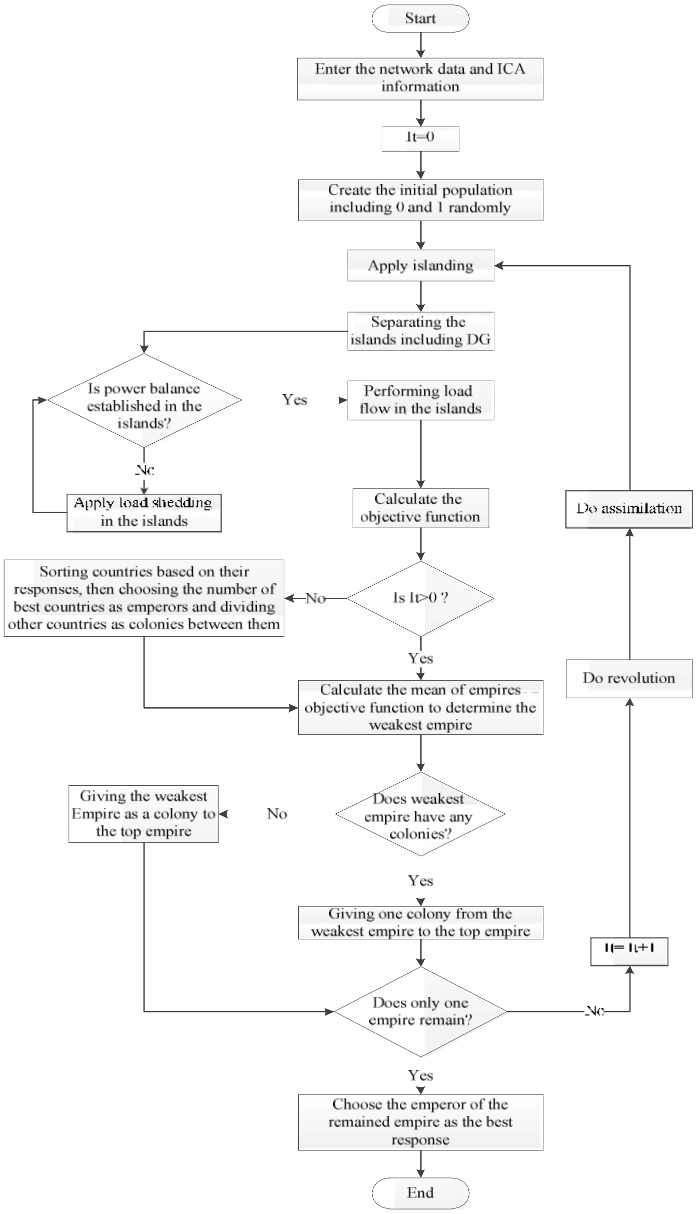

Fig. 1. The proposed algorithm's flowchart

12. This stage includes going back to stage 8 and repeating the abovementioned processes.

This algorithm is repeated until a better response cannot be found, or in other words, only one empire remains. Finally, the emperor of the remaining empire is selected as the response of the problem.

IJARSE
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ISSN (P) 2319 - 8346

III. THE OBJECTIVE FUNCTION AND CONSTRAINTS

In this paper, after presenting a new approach for determining the optimum intentional islands in the distribution network, the effect of not reconnecting the DG units on the cost of the energy not supplied and the boundaries of intentional islands after occurrence of a permanent fault in the network is studied as a sensitivity analysis. Therefore, ENS is selected as the objective function. ENS represents the amount of energy which is not sold to each customer in KWh. If the price of each KWh of energy is multiplied by the value of ENS and the result is changed into the currency of interest, the loss due to power outage will be obtained. The objective function is considered as equation (1).

$$\mathbf{OF = T_{rep}.(\textstyle\sum_{i=1}^{nd} Costj\,.\,Pri.\,Pshi)+(T_{DG}+T_{IS})\,.(\sum_{j=1}^{Kd} Costj\,.\,PdjIS.).(PF+1)} \quad (1)$$

where, $Trep$ is the time required for completely removing the fault of the system, TIS is the time required to form the islands, T_{DG} is the time required by the DG units to enter the grid, Pri represents the load priority at i^{th} bus, $Pshi$ is the amount of outage at i^{th} bus, Pd is the amount of existing load in the islands formed, nd is the total number of load buses in the network, kd is the total number load buses in the islands, *Cost* represents the cost of the electric energy outage due to the interruption created according to the customers type, and *PF* is the penalty factor.

In order to achieve the optimum value for the objective function of interest, the bus voltages limit and the balance between the generated and consumed powers of the islands are considered as the constraints of the problem. The bus voltages of the islands must be within the permitted range represented by the following equation:

$$V_{\mathbf{min}} \le V_i \le V_{\mathbf{max}} \quad \mathbf{(2)}$$

where, V_{min} and V_{max} are equal to 0.95 and 1.05 respectively and represent the lower and upper limits of the bus voltages of the network in per unit.

Violating the permitted voltage range is applied to the objective function as a penalty factor so that the responses in which the bus voltages of islands that are not within the permitted range after the load flow is run, are selected as undesirable responses of the problem. The equation representing the penalty factor is as follows:

$$\mathbf{PF = \alpha.\,(max(\frac{Vi}{Vmax}-1,0)+max(1-\frac{Vi}{Vmin}\,,0))} \quad \mathbf{(3)}$$

where a is a weight factor which is set in a way that the amount of penalty is large enough to make it possible to select the optimum response.

In order to avoid a long outage after the occurrence of a permanent fault in the power system, and to maximally restore important loads, the network can be intentionally divided into several islands for better management. In the intentional island created, the maximum active power generated by the distributed generation resources must be in balance with the amount of the load demanded by the islands. Otherwise, some loads are interrupted so that the stability of the islands is guaranteed. Equation (4) shows the constraint of the balance between the active power generated by the distributed generation resources and the amount of load demanded by the islands. The loads in islands are interrupted so that this equation is satisfied.

$$\sum_{i=1}^{Nl} Pdi < \sum_{j=1}^{Ng} Pg_j^{max} \quad \mathbf{(4)}$$

IJARSE
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where, N_i is the number of loads in the island, i represents the i^{th} load in the island, Pg^{max} is the maximum power generated by the j^{th} DG in the island, and N_g is the number of DG units in the island. In this paper, interruption is applied based on the priority and the level of importance of the loads, and those with lower priorities are interrupted earlier. Determining the priorities in the proposed approach is optional and users can determine and apply it as they wish. In this paper, loads are categorized as residential, commercial, and industrial loads, and if it is necessary to apply an interruption[19], residential loads are interrupted first, then commercial ones, and finally industrial loads are interrupted.

IV.SIMULATION RESULTS

The proposed islanding approach is applied on the modified IEEE 33-bus test system with four DGs and 32 lines, a total loading of 1570 KW, and a total generation of 1100 KW. The network details are available in [17]. DGs with real power outputs of 400, 200, 300, and 200 KW are located at buses 14, 21, 25, and 30, respectively. First, under the assumption that all DG resources are present in the network after the occurrence of a permanent fault, the proposed approach is carried out in order to determine the optimum intentional islands. Then, by removing DG units as different scenarios, the effect of not reconnecting these units on the cost of the energy not supplied and the boundaries of the intentional islands is investigated. In each scenario, by removing each generation unit, the proposed approach is applied on the network again, so that the new boundaries of the optimum intentional islands and the cost of energy not supplied are obtained. First, the DG connected to bus 14, and then DGs connected to buses 21, 25, and 30 are removed from the network, respectively. In this paper, the cost of electrical energy outage due to the interruption created in residential, commercial, and industrial loads are considered to be 0.48, 5.1, and 8.4 \$/KWh, respectively [18]. Also, T_{rep}, T_{IS}, and T_{DG} are selected as 2, 0.016, and 0.333 hours, respectively. The results obtained are presented in Tables I and II. Furthermore, the boundaries of intentional islands obtained from each scenario are shown in Fig. 2.

According to Table I, in different scenarios, the network is divided into 4, 2, 2, and 1 stable islands, respectively. Also, the amount of load restored in these scenarios are 1086, 694.6, 496.8, and 198.2 KW, respectively, which has a descending trend due to the removal of units from the network. According to Table II, the amount of interrupted load, ENS of the network and its cost have ascending trends due to the removal of DG units in different scenarios.

The amount of saving in the costs of the interruption created in the network is \$13573.7 compared to the case that islanding is not carried out. The obtained results show the importance of distributed generation and its reconnection in load restoration after occurrence of a permanent fault in a power network.

TABLE I. THE RESULTS OF EACH SCENARIO AFTER THE IMPLEMENTATION OF THE PROPOSED ALGORITHM

Scenario No.	Bus number of eliminated unit	Islands No.	Islands buses	DG capacity in island	Restored load (KW)			
					Residential	*Commercial*	*Industrial*	*Total*
1	none	4	11-16	400	5	261	820	1086
			21, 22	200				
			23-25	300				
			29-33	200				

IJARSE
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2	14	2	3-12, 23-31	500	none	none	694.6	694.6
			21, 22	200				
3	14, 21	2	2-7, 19, 23-25	300	none	114.5	382.3	496.8
			29-32	200				
4	14, 21, 25	1	29-32	200	none	115.2	83	198.2
5	14, 21, 25, 30	none	none	none	none	none	none	none

TABLE II. ENERGY NOT SUPPLIED AND IT'S COST IN EACH SCENARIO

Scenario No.	Loads (KW)		ENS (KWh)	Cost of ENS ($)
	Interrupted	*Restored*		
1	484	1086	1347.01	8615.26
2	875.4	694.6	1993.2	12555.96
3	1073.2	496.8	2319.7	15922.55
4	1371.8	198.2	2814.77	20084.68
5	1570	none	3410	22188.96

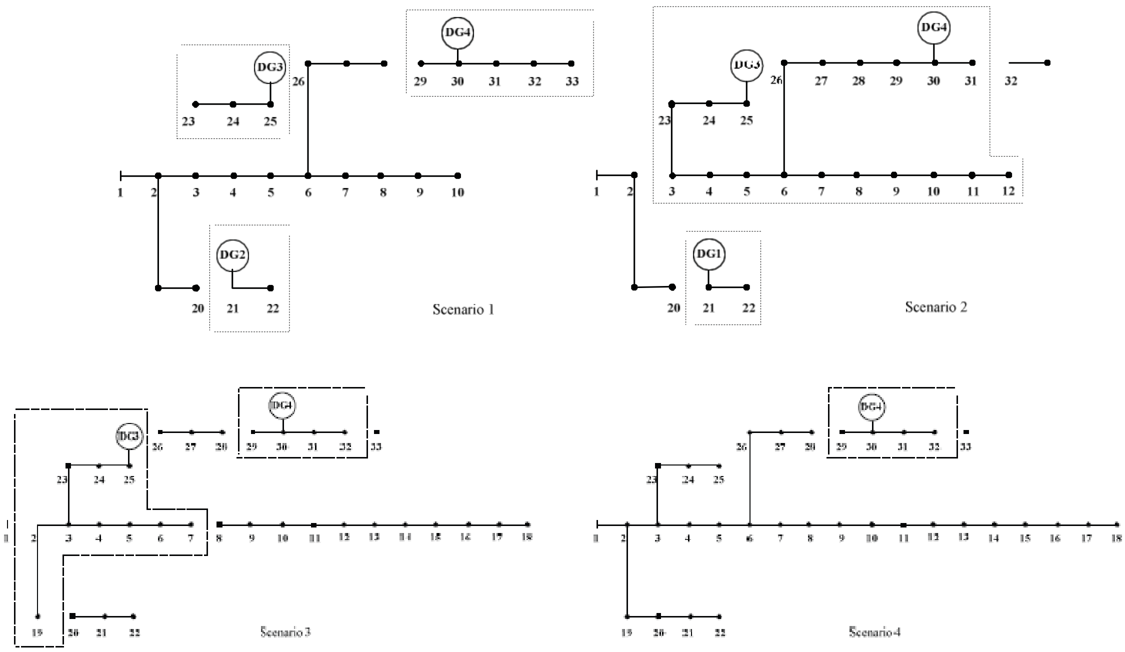

Fig. 2. Islands formed in different scenarios

V.CONCLUSION

When a fault occurs in a distribution network, all downstream consumers are de-energized because of becoming isolated from the main network, and they will remain de-energized until the faulted part is repaired. In this case, the distributed generation units can accelerate restoring operation by creating intentional islands. One of the features essential for islanded operation of DG is the self-starting capability of DG. This means that the generation unit is able to start without an external voltage source. In this paper, after presenting a new approach for determining the optimum intentional islands in the distribution network, the effect of not reconnecting the DG units on the cost of the energy not supplied and the boundaries of intentional islands is studied as a sensitivity analysis. To achieve an optimum islanding scheme, the ICA algorithm which is a well-known and

IJARSE
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powerful optimization algorithm is used. The proposed approach is applied on the modified IEEE 33-bus system with 4 distributed generation units and the results are presented. The simulation results show the high accuracy of the proposed approach in solving the intentional islanding problem and the importance of distributed generation and its reconnection in load restoration, reduction of Energy Not Supplied and its cost after the occurrence of a permanent fault in a power system.

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