On the Improvement of the Reliability of the Electrical Distribution Networks by Using Smart Electric-supply Restoration Algorithm

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Abstract – One of the greatest goals of smart networks is to make consumers happy by ensuring the continuity of electricity delivery under normal and abnormal conditions. On occurrence of a permanent fault, the electric supply to all download feeder sections is interrupted with power outage of all loads until the maintenance crew move to fix the faulty section. This reflects itself on a negative impact on the network reliability indices including network average interruption duration and frequency indices. With the increasing demand for electricity, power distribution utilities must provide an efficient and appropriate Service Restoration strategy to restore customers as soon as possible after power outages. A self-healing is defined as recovering the all out-of-service loads in the shortest time possible without violating the network operating-constraints. This paper is aimed at proposing a smart technique based on a genetic algorithm and load-curve as well as the feeder-curve to recover the out-of-service loads following a permanent fault in the power distribution network. The proposed algorithm is tested on IEEE 16-bus system in various scenarios. It was found that using this proposed method would lead to optimal, accurate, and applicable solutions for service restoration in distribution networks. The proposed technique showed better improvements when compared with that achieved by other methods reported in the literature.

Keywords: self-healing; smart distribution networks; electric-supply restoration; smart technique

I. Introduction

The fault in the distribution networks causes an interruption in the faulty location and all downstream customers [1-2]. The ability of the network to feed the end-users under abnormal conditions is called a self-healing network. The classical network to be smart, it should be supported with intelligent algorithms, equipment, and communication technologies [2]. A guarantee of continuity of the electric supply to all customers in distribution network is an objective of the network to be smart whatever the conditions is normal or abnormal [1]. Two factors help in measuring the reliability of the network. The average interruption duration index (SAIDI) and the network average interruption frequency index (SAIFI). The self-healing algorithms provide improvements to SAIDI and SAIFI indices [3].

The authors in [4] proposed a modified algorithm based on load transferring and load curtailment for in-service consumers in six steps. The proposed algorithm has lower efficiency when tested under multi simultaneous faults than a single fault.

In [5], the authors design a restoration decision making algorithm depending on gap decision theory. The proposed technique could restore a lot of out-of-service loads in small time under single fault.

The authors in [6] built an algorithm to grantee the continuity of supply of the out-of-service loads after occurring fault. The proposed algorithm based on generating all possible spanning trees for the isolated area after reduce the network to two parts; the healthy part and the faulty part. The proposed algorithm chooses a tree to apply some rules to grantee the continuity of supply.

In [7], the research paper based on two-dimensional depth-coded technique which is a combination between on particle swarm optimization and depth-first search algorithms to solve the self-healing issues after a fault in a distribution network with distributed generators.

This paper is aimed at proposing a smart technique to recover the out-of-service loads following a permanent fault in the power distribution network without violating the operating constraints. This paper is aimed at proposing a smart technique based on a genetic algorithm and load-curve as well as the feeder-curve to recover the out-of-service loads following a permanent fault in the power distribution network. The proposed algorithm is tested on IEEE 16-bus system in various scenarios. It was found that using this proposed method would lead to optimal, accurate, and applicable solutions for service restoration in distribution networks. The proposed technique showed better improvements when compared with that achieved by other methods reported in the literature.

II. The Challenge

The proposed technique is modelled as a multi-objective function problem as follows:

Main function (f_1): Minimizing the percentage of the outage load following the occurrence of single fault or multi- simultaneously faults. In other words, the main objective function aims at restoring the electric supply for all outage loads without violating the constrains and expressed as follows:

$$f_1 = minimize\left(\frac{L_{OOS}}{L_{tot}} x100\right) \quad (1)$$

where:

L_{OOS}: Number of out-of-service loads with application of the proposed technique

L_{tot}: The total number of out-of-service loads following fault occurrence.

The previous constraint functions to be taken in consideration as follows.

Function 2 (f_2): Rated capacity including the overload factor for all electrical equipment including feeders, transformers, cables…. etc must not be exceeded as expressed as follows:

$$f_2 = I_k \leq I_{k(rated)} \quad (2)$$

where:

I_K: Current passes through branch K.

$I_{K(rated)}$: Rated capacity current of branch K.

Function 3 (f_3): The voltage must be within limits to avoid voltage sag or swell for every electrical equipment as expressed as follows:

$$f_3 = V_{k(min)} \leq V_k \leq V_{k(max)} \quad (3)$$

where:

V_K: voltage at branch K

$V_{K(min)}$: Minimum acceptable voltage at branch K; equals to 0.9 pu.

$V_{K(max)}$: Maximum acceptable voltage at branch K; equals to 1.1 pu.

Function 4: Minimizing the total losses during restoration. If the proposed technique produced more than one maneuverer, the maneuverer that achieved the shortest path should be chosen.

Function 5: During restoration, high priority should be assigned to critical (important) load sectors.

Function 6: Self-healing should avoid shedding of in-service loads.

Function 7: Decisions through the proposed technique must guarantee radiality of the network.

Three indices evaluate the reliability of the distribution network [5-7]. Firstly, the SAIFI which represents the network average interruption frequency index, which provides information about the average number of interruptions after restoration, equation (4). Secondly, SAIDI which represents the network average interruption duration index, which describes the total time that loads became out of service due to interruptions after restoration, equation (5). Thirdly, ENS which represents the total energy not supplied index, equation (6).

$$\text{SAIF}=\frac{N_{(interruption)}}{n_{(customers)}} \quad (4)$$

Where: $N_{(interruption)}$: the total number of all interruptions after restoration and $n_{(customers)}$: the total number of connected customers

$$\text{SAIDI}=\frac{T_{(interruption)}}{n_{(customers)}} \quad (5)$$

Where: $T_{(interruption)}$: the total duration of all interruptions after restoration.

$$\text{ENS}=\frac{U_{(not\ supplied)}}{n_{(customers)}} \quad (6)$$

Where: $U_{(not\ supplied)}$: the total energy not supplied after restoration.

III. Proposed Method

This paper is aimed at proposing a smart technique based on a genetic algorithm and load-curve as well as the feeder-curve to recover the out-of-service loads following a permanent fault in the power distribution network, Fig, 1.

Step 1: Input the basic information. The basic information is classified into two categories: the information about the distribution network and the information used in the genetic algorithm. The data about distribution networks include: all number of the branches, sending and receiving end node number of each branch, branch number, the type of switch installed on each branch, resistance and reactance of each branch, ampacity of each branch, feeder number that each branch belongs to all number of the power sources, all number of the nodes in distribution networks, power feeder number, active load power and reactive load power of each point, type of consumers for each node, load curves for each type of consumers, maximum and minimum acceptable node voltage. The basic information used in the genetic algorithm includes: cross-over rate, size/volume of the population, generation gap, maximum evolution generation, and mutation probability.

Step 2: The active/reactive load power of every node for each hour is calculated and the system configuration is determined in normal conditions. Based on the data about active/reactive load power of each node and the different types of load curves inputted in step 1, calculate the hourly active/reactive load power of each node based on the fundamental of keeping the power-factor unchanged. Then according to the location of each installed tie-switch in distribution networks, determine the system configuration in normal condition.

Step 3: Classical genetic algorithm (GA) is adopted to identify the set of candidate network configurations for each time interval over the fault restoration period with minimum loss of load. In the network configuration obtained in step 3 after fault isolation, use the loads, which are obtained according to the load curves, of each time interval over the fault restoration period to solve the corresponding optimization mathematical model for the service restoration of distribution systems. Identifying network configurations for each time interval over the fault restoration period with minimum loss of load by adopting the conventional genetic algorithm can be divided into sub-steps which are described as following:

Step 3.1: Generates the initialized population. Based on the size of the population inputted in step 1, the binary coding system {0, 1} is used to randomly encode the strings to form the initialized population. The number of the strings is the size of the population. The length of each string in initialized population is the total number of the branches, and every bit of the string represents the status of the switch installed at the head of the corresponding branch. If the bit of the string is the binary digit 0, the status of the switch installed on the corresponding branch is open; if the bit of the string is the binary digit 1, the status of the switch installed on the corresponding branch is closed.

Step 3.2: Calculates the value of objective function of each string in population. In order to evaluate the fitness of each string obtained in step 4.1, in initialized population, the value of objective function of each string is calculated. The smaller value of objective function is, the better fitness the string has. The details about how to calculate the value of objective function of each string are described as below:

Step 3.2.1: Revises the string. The bits representing the statuses of switches installed on the source-side of the healthy branches are set to binary digit 1; and bits representing the statuses of switches, which are installed on the boundary branches of faulty zone, are revised as binary digit 0 to realize the fault isolation.

Step 3.2.2: Decodes the string. Based on the revised string and the inputted data for the branches, identify the data about the corresponding branches with binary digit 1.

Step 3.2.3: Forms radial distribution systems connected with different power sources. In order to form the radial network configuration connected to each power source, the depth-first search algorithm is adopted using branch data after decoding.

Step 3.2.4: Load-flow calculation is used for different radial network configurations connected with different feeders.

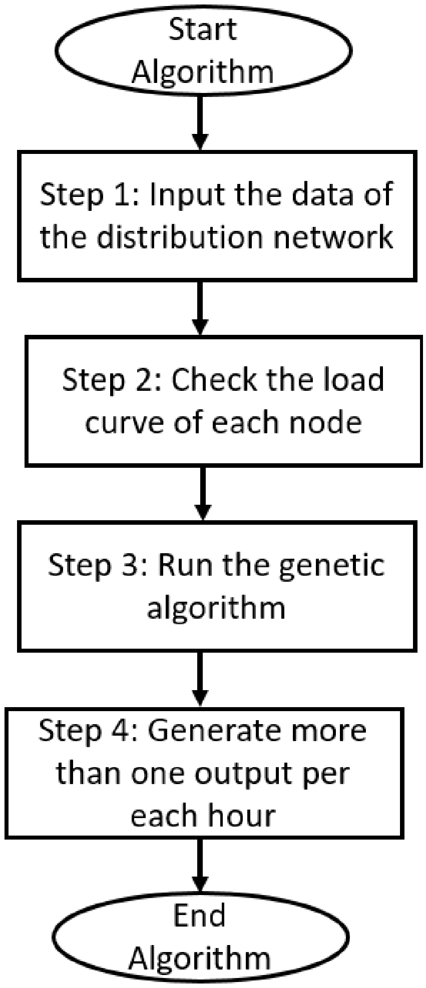

Fig. 1: Flowchart of the proposed algorithm

Step 3.2.5: By adopting conventional genetic algorithm conduct evolutionary computation of the population. First, define the current population as the father/parent population, and calculate the fitness of every string. Load flow calculations are used for different radial system configurations connected with not similar feeders. First, according to the set of the branches of the radial network configurations obtained, based on the inputted basic data about the distribution networks and the calculated active/reactive load power of every node over the permanent fault restoration duration, identify the resistance/reactance of every branch and the active/reactive load power of every node of the radial system configurations connected with different feeder at this time interval.

Secondly, conventional backward/forward sweep algorithm is used to calculate the node voltages and branch currents of each network configuration connected with different power sources. If load flow is not converged for the network configuration connected by any power source during the calculation, stop the entire load flow process.

Step 4: Calculate the value of the objective function of the array. If load flow does not converge for any system configuration connected with different feeders in step 4.2.4, assign a large value as the value of objective function of the array. When the load flow converges for all of system configurations connected with different feeders, calculate the all value of violation of the array.

If the load transferring to a feeder breaks a constrain of feeder ampacity/capacity, the observation of the load-curve of each feeder and load over the duration of fixing the fault may be a way to the proposed algorithm to solve this constrain. During the fault fixing period, if the available ampacity of the feeder exceeds the out-of-service load capacity, the automatic switch closes to recover the out-of-service load, otherwise the automatic switch does not operate.

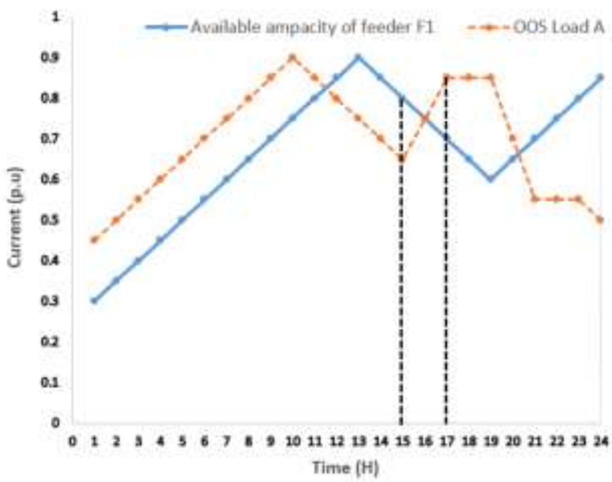

Fig. 2: The load-curve and available ampacity of a feeder

Assume the fixing of a fault requires two hours from 15th to 17th time intervals and transferring the out-of-service load (A) to a feeder (F_1) is the only way to recover the load (A). According to Fig. 2, the available ampacity of the feeder (F_1) is more than the load capacity of load (A) from 15th to 16th time interval, so the proposed algorithm gives an order to the responsible automatic switch to close during this time . On the other hand, the load capacity of load (A) exceeds the available ampacity of feeder (F_1) from 16th to 17th time interval, so the proposed algorithm does not give an order to the responsible automatic switch to close during this time interval to recover the load (A) without an overloading on feeder (F_1) and the outage duration of the consumers of load (A) is reduced from two hours to an hour to enhance the reliability of the distribution network. So, the proposed algorithm may generate outcome such as close an automatic switch at 15th time interval and then open the same automatic switch at 16th time interval.

IV. Results and Discussion

An 11-kV distribution system shown in Fig. 3 is studied. This distribution system contains 3 feeders, 13 load and 16 branches. Data for genetic algorithm is: size of the population is 100; maximum evolution generation is 300; generation gap is 0.95; rate of cross-over is 0.9 and mutation probability is 0.01.

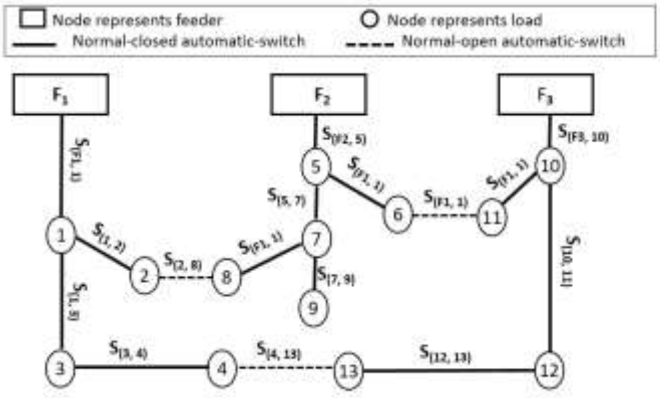

Fig. 3: Single diagram of IEEE 16 buses

IV.1 Maneuverer 1: Single failure at load (1)

The occurrence of the fault on feeder 1 during the 18th~21th time intervals will cause outages for load points 1~4. All these loads are unaffected outage load points, this is why it can be restored by feeder 2 and feeder 3 over the fault restoration period.

During the 18th~21th time intervals, all statuses of switches are the same in each time interval except for the sectionalizing switches on the switches S_{1-2}, S_{1-3}, S_{3-4}, S_{2-8} and S_{4-13} changing their statuses with the time. Different from the normal operational situation, the sectionalizing switches on branches S_{2-8} and S_{4-13} are changed to be closed and the tie switches installed on branches S_{1-2}, S_{1-3} and S_{3-4} are changed to be open. As shown in Fig. 3, open the sectionalizing switches on branch S_{F1-1} to isolate the fault. Feeders 2 and 3 have the ability to restore the service to these load points depends on the influence of load variation on the statuses of switches installed.

Table 1: Status of switches during time

Plan implementation time	18th time interval	19th time interval	20th time interval	21st time interval
S(1-2)	1	1	0	1
S(1-3)	0	0	0	0
S(3-4)	0	0	1	1
S(2-8)	1	1	1	1
S(4-13)	0	1	1	1
Supplied load points in outage area	1, 2	1, 2, 4	2, 3, 4	1, 2, 3, 4

Table 2: The outage duration of the out-of-service healthy loads

Node number	Proposed method	Method in [10]	Method in [11]
1	1 h	4 h	4 h
2	0 h	4 h	4 h
3	2 h	4 h	4 h
4	1 h	4 h	4 h

Table 3: Restored electrical quantities over the fault restoration period

Method	Restored Energy
Proposed method	1809.9 Kw. h
Method in [10]	503.1 Kw. h
Method in [11]	1050.3 Kw. h

V. Conclusion

The paper proposes a new methodology for dynamic servicerRestoration to be utilized in distribution systems. The method is enhanced by considering the system operational constraints. The algorithm uses system load curves to stablish a fully optimized restoration plan with alarming customers about possible outages if required. taking the load variation into consideration, the proposed method can identify the optimal service restoration network configurations based for each hour during the fault restoration period. The proposed optimal service restoration plan takes full advantage of the load curves. This will change the configuration of the network in a timely fashion to reduce the number outages as well as their durations. Comparing the results of the service restoration plan to existing methodologies, our methodology enhances the distribution system reliability indices by decreasing the duration of outages as well as their frequency of occurrence. Furthermore, the unnecessary cost of sudden blackouts will have avoided utilizing the technology.

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Mohamed Goda was born in Egypt in 1991, he joined the faculty of Electrical Engineering at Ahram Canadian university, Egypt, as a teaching assistant, and in August 2018, he became an assistant lecturer. In 2021, he joined the faculty of Electrical Engineering at 6 October university, Egypt. Goda’s research areas are renewable energy and smart grids.

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