Optimal Load Restoration in Distribution Network Using Intentional Islanding

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Abstract: *In this paper, service restoration problem in distribution systems with distributed generation is studied as a multi-objective and multi-constraint problem. The main goal of the restoration problem is determining a new configuration with the minimum active power loss to restore the maximum loads and an optimal switching sequence to improve costumers' reliability. The objective function which includes minimum active power loss, energy not supplied during restoration process and power not supplied is minimized using Genetic algorithm (GA). In the proposed method, some disconnected loads of the isolated areas are restored by the distributed generations when the others are connected through the tie lines to the main power supply. Simulation results on a 118- bus distribution network are presented to demonstrate the effectiveness of the proposed method.*

Key words: *Load Restoration, Reliability, Distributed Generation, Islanding, Reconfiguration*

1. Nomenclature.

ENS	Energy not supplied
$x(c)$	Corresponding matrix with switching sequence in the configuration c
t_i	Time interval for i+1th switching operation
p_i	Power not supplied after ith switching operation
P_{ns}	Power not supplied in the final configuration
c	The new configuration of the network
α_1	Coefficient of ENS
α_2	Coefficient of power not supplied in the final configuration
α_3	Coefficient of active power loss
m	The number of DGs
n	The number of switching operations
NCSS	The number of sectionalizing switches
NOTS	The number of tie lines

2. Introduction

Distribution systems are usually operated in radial configurations. When a fault occurs in one of their sections, protection devices isolate this section as soon as possible, so the downstream costumers of the affected area left de-energized and service should be restored in the out of service area via network reconfiguration. This procedure which is a combinatorial optimization problem called service restoration.

Distribution systems generally contain some tie-switches (normally open switches) which cause to have a kind of meshed structure and several possible operating configurations. In a service restoration, closing tie-switches are replaced by opening sectionalizing switches to have a new operating configuration.

Reliability of distribution systems depends on the restoration time therefore the main objective of restoration problem is to provide customers reliability by minimizing the number of de-energized loads as quickly as possible.

Various approaches have been applied for restoration problem through the network reconfiguration such as Genetic algorithm (GA) [1, 2], Tabu search (TA) [3], and Simulated annealing [4]. A multi objective restoration plan [6, 7] and a combination of genetic algorithm and fuzzy method [8] are used to solve the restoration problem.

The preoccupation in finding an optimal restoration strategy for reducing the network losses has the same importance as finding an optimal switching sequence which plays a key role in the network reliability indices. In [9-11], evolutionary algorithms are presented to determine the optimal switching sequence during restoration process.

The integration of distributed generation into the distribution system has great effects on the service restoration procedure. DG's capability of islanding operation prevents large area from being blackout and leads to network reliability improvement. In [12], the influence of DG's location and capacity during service restoration and load priorities is determined by means of PSO algorithm. In [13] an adapted Branch-and-Bound algorithm is used to solve the restoration problem in a distribution system with distributed generation

This paper studies service restoration in a distribution system with DG along with tie lines by using an intentional islanding scheme. In the proposed method, restoration problem is formulated as a multi objective and multi constraint optimization problem. Then, the optimal new configuration with the minimum active power loss and optimal switching sequence is determined that shows network reliability rise. Energy not supplied index (ENS) is used as reliability improvement index and to assess the reliability of distribution networks. Different constraints such as voltages, acceptable line currents and radial topology are maintained during restoration process.

The simulation associated with Genetic Algorithm is tested on a 118- bus distribution network for three scenarios (using tie lines only, using distributed generations only and using both tie line and distributed generations together) and the results are presented and compared to illustrate the methodology.

3. Problem Statement

After fault occurrence, the downstream loads of the affected area are disconnected by opening the section's sectionalizing switch, as shown in Fig 1. Service restoration process, involves all of the emergency operations, restores many loads as soon as possible by transferring de-energized loads to other feeders through the network reconfiguration.

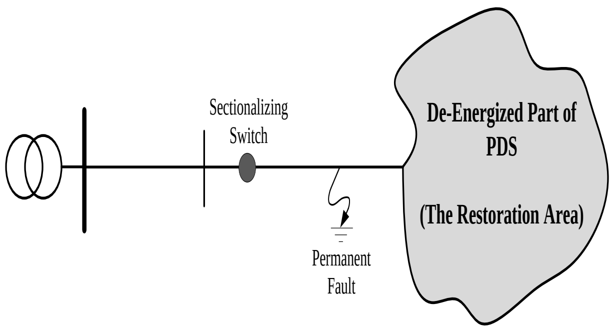

Fig. 1. Restoration area of a typical distribution network

There are different solutions to the maximum load restoration in a distribution system with a lot of sectionalizing switches and tie lines. Tie lines involve in network configuration by transferring de-energized loads from out-of-service areas to other feeders without changing their loading constraints. In some cases, using tie lines may lead to line current growth out of allowable limits during restoration process (Fig. 2), which cause to conductor ageing in long time.

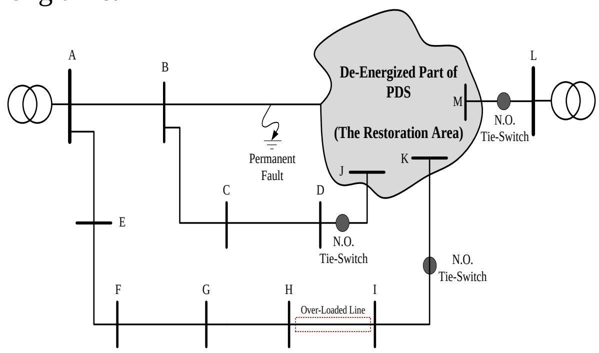

Fig. 2. Normally Open Switches (Tie-Switches) in a distribution network

Participating distributed generations in load restoration by means of its islanding property is another possible solution. In a distribution system with DG, isolated areas can be energized by dividing the network into intentional islands. But in some cases, DG can’t able to provide the power for consuming total loads in each island because of inappropriate location of sectionalizing switches.

The best condition is utilizing tie lines along with intentional islanding strategies which are discussed in this paper. Genetic algorithm is used to determine the optimal switching sequence by minimizing energy not supplied (ENS) during restoration process, power not supplied in the final configuration and active power loss without violating network constraints.

4. Solution Presentation and Formulation

To restore an out of service area after occurring permanent fault in the upstream section, the isolated part can be supplied by neighboring branches of the network or by DGs in that area.

The switching sequence in addition to the final configuration is of great importance because restoration time and energy not supplied (ENS) depends on the order of the switching sequence.

4.1 Restoration objective function

Minimum active power loss, minimum amount of power not supplied in the final configuration and minimum ENS are the main objectives of the proposed algorithm.

There is a specific amount of power loss in each radial configuration where a specific number of switching operations is needed to obtain it, and each switching sequence has a specific amount of ENS as shown in Eq.1. The total objective function and the switching sequence are shown in Eq.2 and Eq.3 respectively.

$$ENS(x) = \sum_{i=0}^{n-1} p_i \times t_i \quad (1)$$

$$OF = \alpha_1 ENS(x) + \alpha_2 P_{ns} + \alpha_3 loss(c) \quad (2)$$

$$x = [\overbrace{S_1 \quad S_2 \quad \dots \quad S_{NCSS}}^{N.C\ Sectionalizing\ Switches}\ \overbrace{T_1 \quad T_2 \quad \dots \quad T_{NOTS}}^{N.O\ Tie\text{-}Switches} \dots$$
$$\dots\ \overbrace{DG_1 \quad DG_2 \quad \dots \quad DG_m}^{Circuit\ Breakers\ in\ front\ of\ DGs}] \quad (3)$$

Where, x is switch state vector, Si is the state of ith sectionalizing switch, Ti is the state of ith tie switch and DGi is the state of ith circuit breaker in front of DGs.

4.2 Restoration objective function

Feasible configuration or switching sequence mustn't violate the following constraints:

-Radial configuration constraint: after each switching operation, the network configuration should remain in redial configuration.

-Distributed generation capacity bound: the total power consumption in each island should not exceed the DG power capacity as follows:

$$P_{L_k} \le P_{DG_k}$$

P_{L_K} : The active power capacity of the DG of the kth island.

P_{DG_K} : The total power consumption of kth island

- Node Voltage and line current constraints: after each switching operation, the node voltages and line currents must be within the described range as follows:

$$V_i^{\min} \le V_i \le V_i^{\max}$$

$$I_j \le I_j^{\max}$$

$V_i^{\max}$: The maximum acceptable voltage of ith node

$V_i^{\min}$: The minimum acceptable voltage of ith node

$I_j^{\max}$: The maximum acceptable current of jth branch.

The Flow chart of the restoration method is shown in Fig. 3.

5. Numerical results

The 11 kV radial distribution system having 118 buses, 20 sectionalizing switches and 9 tie lines is employed to validate the proposed method shown in Fig. 4. The total load is 22.91MW and 17.04Mvar. Four DGs are installed at buses 27, 43, 77, and 113. The detailed specifications of these DGs are given in Table I.

Table I. DGs specifications

DG	Bus number	Nominal active power (MW)	Power factor	Xd (Ω)	Xq (Ω)
DG_1	27	1/3	0/9	2/54	2/31
DG_2	43	2/1	0/9	2/54	2/31
DG_3	77	2	0/87	2/33	2/05
DG_4	113	1/2	0/85	1/86	1/77

In the following cases by opening a special switch in the distribution network, the downstream area is isolated and DGs are disconnected from that part via their islanding detection relays. After isolation of the area, the presented restoration routine has to be implemented to restore as many loads as possible. One of the approaches is using tie-switches and sectionalizing switches to restore the loads of the black-out area.

In the following scenarios, load restoration is implemented to achieve minimum loss and power not supplied of the final configuration and minimum ENS by means of optimal switching sequences of sectionalizing switches and tie switches.

S5 is assessed to be closed because of a fault occurrence. Table II shows optimal switching sequence of each scenario. Switching operation time interval is assumed 2 minutes. Weighting coefficient of objective function is considered as bellow:

$$\alpha_1 = \frac{1}{3}, \alpha_2 = \frac{1}{2}, \alpha_3 = \frac{1}{6}$$

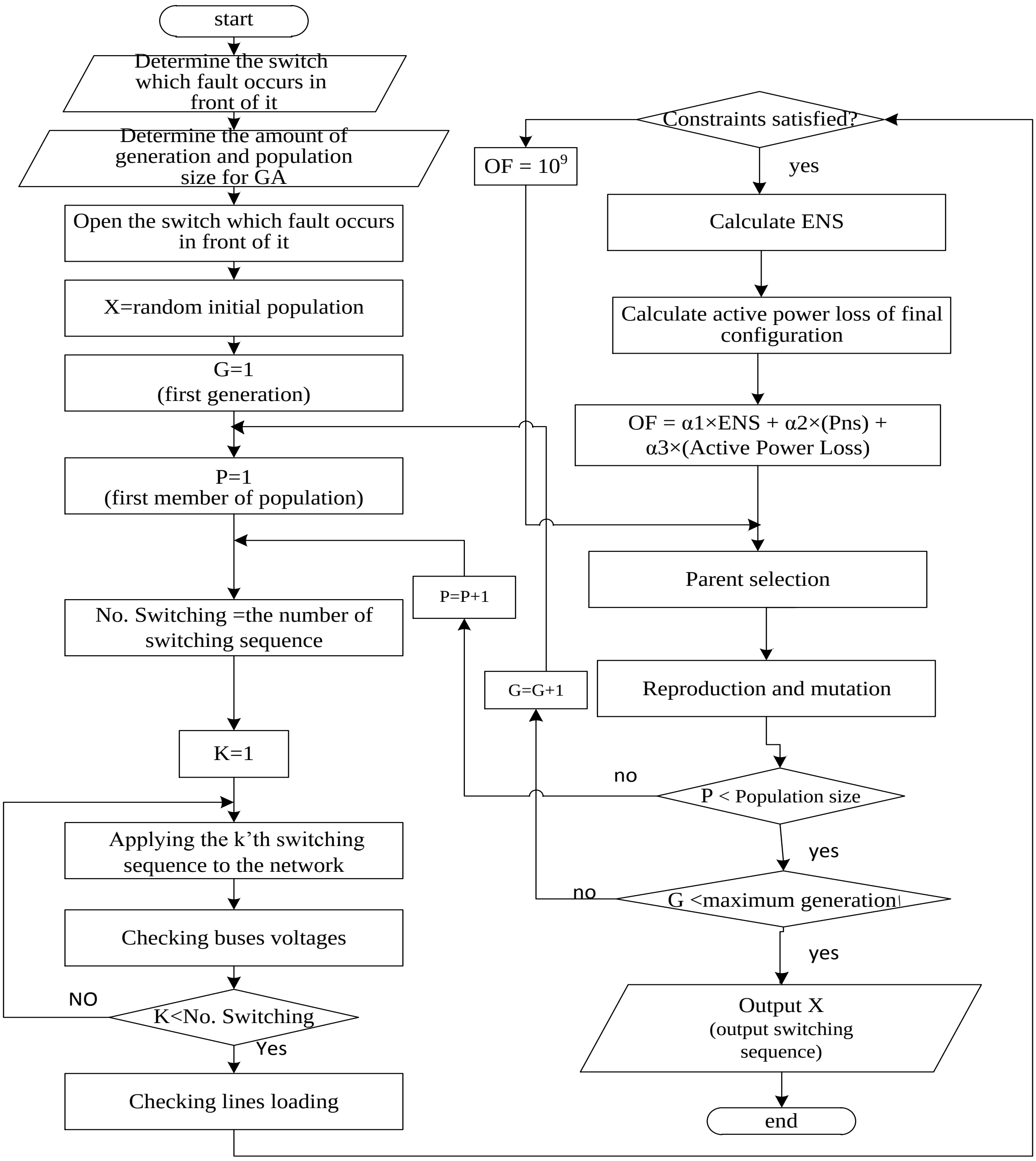

Fig. 3. Flow chart of restoration procedure

Three different scenarios are considered to compare different restoration strategies in distribution system:

1. Restoration using tie lines without distributed generations
2. Restoration using distributed generations without tie lines
3. Restoration using both tie lines and distributed generations

Simulation results show that third scenario leads to the best condition in the restoration process and final configuration. Maximum active power of the distributed generation installed at bus 43 is 2/1MW, so in the second scenario, it can't supply all the de-energized loads and 5/66MW are left disconnected, but in two other scenarios all the disconnected loads are restored.

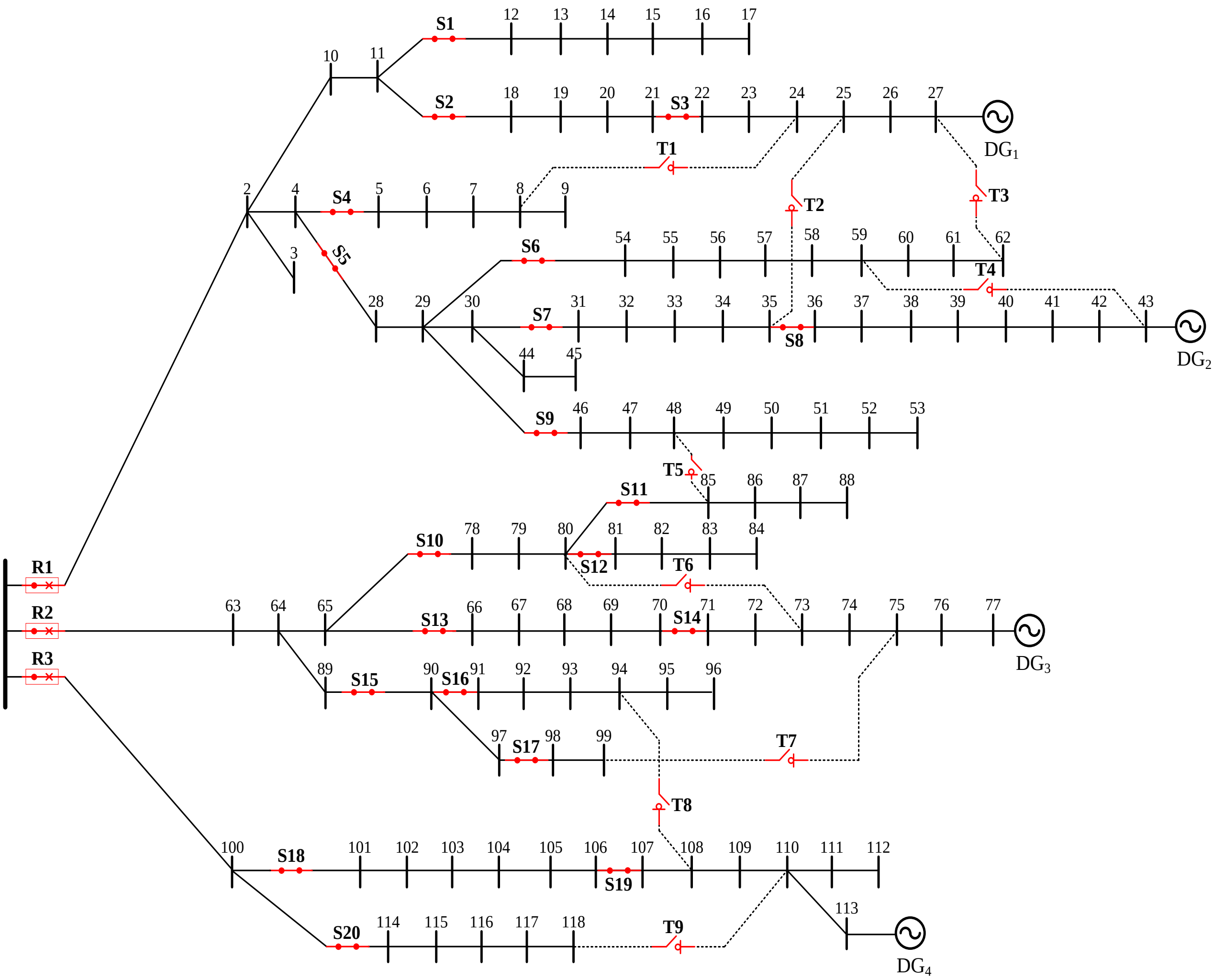

Fig. 4. 118 Buses Test System

Table II-objective function in three scenarios

scenario	Switching sequence	ENS(KWh)	loss (KW)	Power not supplied(KW)	Objective function
1	S5-S7-T2-S6-T3-T5	1137	4840	·	1185.6
2	S5-S8-SDG2	1072	880	5660	3334
3	S5-S8-SDG2 -S7-T2-T5	1056.3	2860	·	828.6

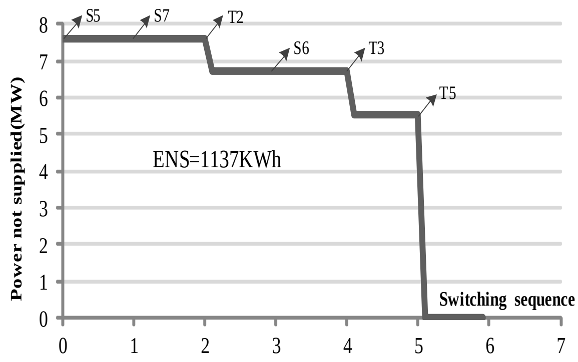

Fig. 4 - Power not supplied in the first scenario

Power not supplied of the final configuration in three scenarios is showed in Fig. 4,5,6

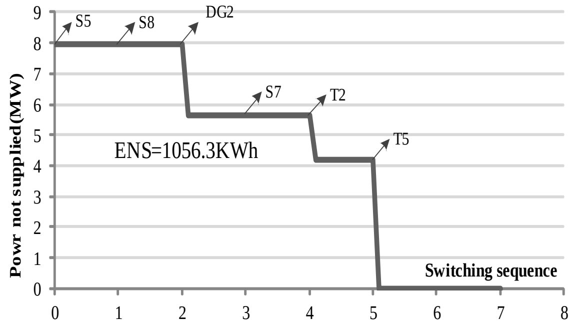

Fig. 5- Power not supplied in the second scenario

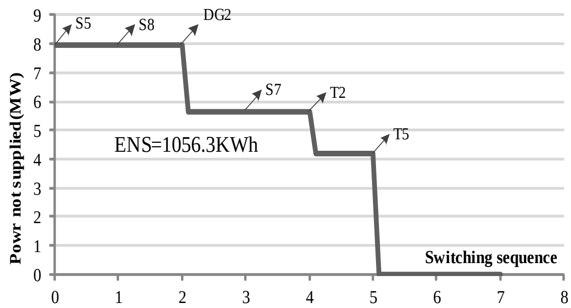

Fig. 4- Power not supplied in the third scenario

As shown in figures, ENS in the third scenario is less than two other scenarios; the total objective function of third scenario is the least too. So, utilizing both tie lines and distributed generations lead to the best results.

6. Conclusion

This paper presents a method for service restoration problem in distribution systems with distributed generation in order to enhance system reliability and minimize active power loss considering network constraints. Normally open branches (tie lines) of the network and distributed generation's property of islanding are used in service restoration process. A genetic algorithm is used to determine the network new configuration and the optimal switching sequence. The results of applying the proposed method on 118-buses test system, illustrate the best answer is found by using tie lines and distributed generations simultaneously.

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