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Service restoration for unbalanced distribution networks using a combination two heuristic methods

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ABSTRACT

In this paper, two heuristic methods are proposed to find the effective and fast solution for solving service restoration problem in unbalanced three phase distribution networks. Switch selection indices based on analytically approach and practicable heuristic graph-based method are proposed for solving the service restoration problem in unbalanced distribution networks. The problem formulation proposed, consists of three different objective functions: First, minimizing the de-energized customers' load, second, minimizing the number of switching operation, and finally, customer's priority. A suitable assignment of switch indices to all tie switches (ts) in networks are used to find best solution and decrease number of switching operation. New graph-based approach for finding best sectionalizes switch (ss) and minimizing voltage drop's amount is utilized. The validity of these approaches has been tested on the two unbalanced three phase distribution networks. Results have been presented for modified IEEE 13-node and IEEE 37-node test case. The fastness and effectiveness convergence of these approaches helps finding best solution for service restoration problem.

Introduction

With significant extension of the modern power distribution networks in the world, the likelihood of occurrence of fault and then blackout for one or more area will increase. Therefore, customer's satisfaction and service reliability are the important topic where most of the paper localizes in this issue. Revenue earned by the Power Distribution Companies and customer's satisfaction is closely depending on reliability in distribution networks. In order to satisfy users demand and maintain profit of power Supply Company, it is necessary to restoring power service as soon as possible [1]. Due to a high number of switches, feeders and branches in typical distribution systems, it is not easy to restore an out-of-service area solely depending on the past experiences of human operators [2]. Therefore, with the advent of quick computers and changing technology, to reduce the out of service area as efficiently as possible, a computer aided decision supports assist the operators. How to arriving a fast and effective service restoration in power distribution networks (PDNs), considering unbalanced distribution network is of major concern in this paper. Protection devices in network detect the fault location, when a fault is occurred in the PDN. After isolating the fault by operation line switches, the PDN is divided to three sections: First, the upstream section that is supplied from same feeder, second, the downstream un-faulted section that are transferred to neighboring feeders according to presented approaches in this paper, and finally, damage buses and lines that are isolated from network. In service restoration problem, several issues must also be considered that are described as follow:

- Service restoration plan must be restored maximum safe out-of-service loads.
- Service restoration plan is implemented by changing switches state in PDNs, therefore, the time taken by the service restoration depends on the number of switching operation. Therefore, the number of switching operation should be kept to minimum as possible.
- Hospital, police station, firehouse, etc, are the highest priority in PDNs. This issue must be considered in service restoration plan that the supply must be restored to highest priority customers.
- In each PDN, most important constraint is radial structure due to various reasons, such as ease of fault location detection, fault isolation and protective devices coordination. When the structure of the network is changed during the service restoration, this constraint must be kept on.

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- Buses voltage, lines current and elements loading also changes during the service restoration plan. Therefore, it is important that these constraints do not cross their respective operational limits.
- Customer's satisfaction and reliability of distribution networks are closely dependent on interruption frequency and duration. Therefore, the restoration plan runtime must be minimized for finding a quick solution.

In past years, many methods have been proposed to find solution for restoration problem from different perspective. Considering complexity PDNs, analytic method for solving the restoration problem can hardly be applied. Therefore, heuristic search method [3–8] or expert system approach [9] have been adopted. In [10] G-net inference mechanism with operation rules is applied. In [11] Petri Net combined with a rule-based expert systems have been applied to implement the service restoration. In [12] fuzzy cause-effect networks are used to model the heuristic knowledge inference involved in the restoration plan. In [13] a fuzzy decision-making approach has been applied to determine the most desirable restoration plan with consideration different practical factors, but fuzzy method does not guarantee the optimal solution. In [14] non-dominated sorting genetic algorithm-II (NSGA-II) for solving the service restoration problem is presented and to reduce the software runtime, a faster version of NSGA-II has been implemented. In [15] mathematical programming is presented to reconfigure the network to restore un-faulted section of the system. In [16,17] combination methods are applied. In [16] objective functions are modeled with fuzzy sets, and then optimization problem is solved by the Genetic Algorithm (GA) [17] consist of two stages: First, the fuzzy multi criteria evaluation, and afterward, the Grey relational analysis. In [18], service restoration with Load curtailment of in-service customers via direct load control has been implemented. In [19], reliability assessment of complex radial distribution systems is presented, however this paper simplifies the restoration plan. In [20,21], restoration problem in distribution network with dispersed generation is implemented. In this paper, a fast and effective methods based on two new heuristic algorithms for service restoration in unbalanced PDNs is presented. Unbalanced distribution network, customer's priority, buses voltage, lines current, equipments loading and minimum software runtime consideration, are the main features of the proposed method.

This paper is organized as follows: Section 'Problem formulation' describes the problem formulation of a typical restoration problem. In Section 'Switch ranking', indices for ranking the networks' switch are described. In Section Graph-based method, graph-based method is described. Section 'Service restoration algorithm' reviews two new heuristic algorithms for service restoration. Section 'Fast load flow technique' briefly describes three-phase load flow program for fast response to the network change inducted by system reconfiguration. Section 'Numerical example' shows a numerical example to demonstrate the fastness and effectiveness of the proposed methods and the conclusion are drawn in Section 'Conclusions' finally.

Problem formulation

Service restoration in unbalanced distribution networks considering customer's priority as a multi-constraint and multi-objective optimization problem is formulated. In this paper, three different objective functions are presented. Maximizing total load to be restored, minimizing the number of the switching operations and maximizing priority load restored are these objective functions. Besides, important constraints consists of network radial structure, buses voltage, lines current, equipments loading have also been considered in this paper.

Objective function briefly:

$$\max \sum_{k \in N_t} L_k \tag{1}$$

$$\max \sum_{k \in N_{HP}} L_k \tag{2}$$

$$\min N_{op} \tag{3}$$

where
L_k energized load in network;
N_t total bus those are restorable;
N_{HP} bus with high priority those are restorable;
N_{op} number of switch operation;

Constraints:

(1) Radial network structure should be maintained.
(2) Satisfy network operation equation.
(3) Bus voltage limits (for all buses):

$$V_k^{\min} < |V_k^p| < V_k^{\max} \tag{4}$$

where
$V_k^{\min}$ minimum acceptable bus voltage;
V_k^p voltage at bus k, phase p;
$V_k^{\max}$ maximum acceptable bus voltage.
(4) Line current limits (for all lines):

$$I_j^{\min} < |I_j^p| < I_j^{\max} \tag{5}$$

where
$I_j^{\min}$ minimum acceptable line current;
I_j^p current in line j, phase p;
$I_j^{\max}$ maximum acceptable line current.
(5) Equipment loading limits (for transformers):

$$|tr_i| < tr_i^{\max} \tag{6}$$

where
tr_i loading for i transformer;
$tr_i^{\max}$ rated loading for i transformer.

Operational constraint can be obtained by a three phase load flow calculations. In actual practice, the minimum limit of the line current should not be taken and, in fact, this limit has been taken as zero [14]. In this study, we use two heuristic approaches based on switch indices and graph-based to find best solution for restoring the maximum total customers in de-energized area. In most restoration plan, there are several plans available for a restoration problem, however, how to select best plan, two methods must describe. These methods are presented in next sections.

Switch ranking

In this paper, two switch indices for best selection have been used. The base of the proposed algorithm for these indices is voltage drop. A first and most important index is VD that is proportionate with voltage drop between substation bus and primary side of each tie switch (ts). For each ts, VD is defined as follow:

$$VD = \frac{P_i^p R_i + Q_i^p X_i}{V} \quad p = a, b, c \tag{7}$$