Electrical Power and Energy Systems 93 (2017) 374–383

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Dynamic phase balancing in the smart distribution networks

S.H. Soltani [a], M. Rashidinejad [b], A. Abdollahi [b,*]

[a] Electrical Engineering Department, Graduate University of Advanced Technology, Kerman, Iran
[b] Department of Electrical Engineering, Shahid Bahonar University, Kerman, Iran

ARTICLE INFO

Article history:
Received 7 May 2016
Received in revised form 13 April 2017
Accepted 9 June 2017

Keywords:
Dynamic phase balancing
Smart distribution networks
Re-phasing strategy
Sensitivity analysis
Modified shuffled frog leaping algorithm

ABSTRACT

A distribution system might be unbalanced due to various reasons which can cause some major problems. Re-phasing strategy is the most effective method for phase balancing performed manually in distribution networks. Dynamic phase balancing is the main objective of this paper that means re-phasing performance at any time of day when unbalance is more than permissible limit. It is possible only in smart distribution networks by installing the automatic re-phasing switches at busbars. Automatic re-phasing eliminates the customer service interruption cost and labour cost available in the manual re-phasing operation. There are two basic operations in the optimal dynamic phase balancing: detecting the best time for re-phasing and considering the load variations in real distribution networks. This paper consists of two scenarios. First scenario is switches installation at all nodes of feeder and second scenario is switches installation at the limited strategic nodes. First scenario focuses on search space reduction by employing a sensitivity analysis method which improves the convergence along with time saving. In order to solve the proposed optimization problem, the modified shuffled frog leaping algorithm (MSFLA) is implemented. Simulation studies greatly demonstrate the benefits achieved from this operation by reducing power loss cost and improving network phase balancing.

1. Introduction

1.1. Motivation and technique

Unbalancing creates several problems in distribution systems including: over-current relay action, over-loads in distribution network equipment, loss increment and inappropriate performance of a group of loads such as induction motors. Various factors contribute to the distribution system unbalance while the single-phase loads are the most important factor in the network. With the advancement of technology, new factors such as the effect of high-speed railway demands, electric vehicles parking and demand response, are joined to the mentioned factors. These factors show the phase balancing importance in distribution networks. The phase balancing in distribution networks is mainly carried out by reconfiguration or re-phasing method. Also other methods exist for system phase balancing such as usage of energy storage [1] or electric vehicles [2] in smart grids. Ability of re-phasing strategy in phase balancing is much more than other phase balancing methods. It is conventional in distribution networks to perform the re-phasing of distribution laterals and transformers for improving the phase balancing with trial-and-error methods, which are very costly and time-consuming. So in this paper, dynamic phase balancing using automatic re-phasing is performed.

1.2. Literature review and contributions

Re-phasing technique was introduced for the first time in 1997 as a linear objective function with mixed-integer programming [3]. However, re-phasing method may not be expressed as a linear function problem very well. Then simulated annealing method (SA) was implemented for phase balancing as a large-scale nonlinear integer programming problem [4]. Since then re-phasing was considered as a nonlinear problem. Because of the high performance time of SA method, intelligent methods were exploited. Chen et al. effectively solved the re-phasing problem by genetic algorithm [5]; the number of re-phasing operations is not limited causing cost increment. In Ref. [6], the heuristic algorithm is proposed to adjust the phasing arrangement of laterals. In Ref. [7,8], the methods using expert system and immune algorithm respectively, are designed to derive the re-phasing strategy of laterals and distribution transformers for three-phase balancing of distribution systems. In these two literatures, cost is reduced as much as possible by implementation of the customer interruption cost in the objective function. Self-adaptive hybrid differential evolution [9] and none dominated genetic algorithm-II (NSGA-II) [10]

* Corresponding author.
E-mail addresses: sh.soltani@student.kgut.ac.ir (S.H. Soltani), mrashidi@uk.ac.ir (M. Rashidinejad), a.abdollahi@uk.ac.ir (A. Abdollahi).

http://dx.doi.org/10.1016/j.ijepes.2017.06.016
0142-0615/

are also utilized for the phase balancing problem. Ref [11] solved the re-phasing problem in a meshed network using bacterial foraging-particle swarm optimization (BF-PSO) algorithm. In Ref. [12], two phase balancing algorithms (reconfiguration and re-phasing) are combined for a better phase balancing. The voltage dependency of loads in the phase balancing problem is considered in Ref. [13].Automatic re-phasing was only represented in Ref. [14] which introduces a data collection method based on the automated mapping/facilities management/geographic information system (AM/FM/GIS), however the re-phasing is performed in one or two phase loads, and the main factors of automatic re-phasing are not considered. All of these methods are static or in other words, until now re-phasing operation is performed at the peak load conditions and one time in the year. Due to the various problems related to unbalanced conditions, this method of re-phasing is not efficient. The search space reduction of the phase balancing problem is not paid to attention in none of these articles and the search space includes all nodes of network.

In recent years, importance of power quality and reliability in power systems causes research progress in the field of smart grids and automation. Flexibility and high speed performance are the main highlights of smart grids [15]. Distribution automation through remote controlled switches is mainly introduced in reconfiguration [16–18], capacitor placement problems [19] and in this paper, re-phasing problem.

1.3. Paper novelty and organization

This paper deals with the issue of dynamic phase balancing in the smart distribution network. It means, when the network unbalance exceeds the certain level, the re-phasing operation must be implemented in real time (not only one time in the year, but also even several times a day). It could be only possible by the installation of special switches which change automatically the phases, at busbars. Automatic re-phasing eliminates the labour cost and interruption cost related to manual re-phasing performance. In dynamic phase balancing, the load variations in real distribution networks should be considered. In this article, two scenarios are existed. In the first scenario, re-phasing switches are placed at all nodes of feeder that it does not seem economic. So in the second scenario, they are installed at the limited strategic nodes selected according to network topology. In the first scenario, the re-phasing sensitivity analysis is also introduced for re-phasing search space reduction. The candidate buses for re-phasing operation are specified by sensitivity analysis. In this method, VUF (voltage unbalance factor) is used and the search space reduction improves the algorithm convergence speed. This search space reduction method is also practical in the conventional re-phasing operation. The proposed optimization strategy is carried out using modified shuffled frog leaping algorithm (MSFLA) which is a memetic algorithm. This class of algorithms is gaining acceptance in solving well-known large combinatorial optimization problems, while other meta-heuristics have failed. The comparison between MSFLA, shuffled frog leaping algorithm (SFLA) and genetic algorithm (GA), shows the efficiency of this algorithm. The proposed method minimizes the power loss and improves unbalance of the network. The ability of the proposed method for finding a global minimum is tested on the Kheibar feeder in Behbahan, Iran and 37 bus IEEE test feeder.

2. Dynamic re-phasing formulation

In this section, at first, the benefits and the requirements of automatic re-phasing are explained. Next, the dynamic re-phasing problem and its objective function are stated. Finally, re-phasing sensitivity analysis is introduced.

2.1. Automatic re-phasing benefits and requirements

Nowadays, due to the cost of re-phasing operation, this operation is limited and is usually done once a year. The cost incurred by the re-phasing operation includes the interruption cost and labour cost. The re-phasing strategy is now manually performed by workers in the network making this operation a timeframe to take. At this time, the power of the customers after the re-phased busbar is interrupted which imposes the interruption cost to the network. If the re-phasing is automatically performed, this cost will be eliminated. Installation of the remote re-phasing switches is the most important requirements of the dynamic re-phasing in smart distribution networks. Remote re-phasing switches are the switches with a three state contact in each phase. These contacts operate simultaneously according to received re-phasing strategy command (Positive or negative phase sequence) from SCADA. The structure of a remote control re-phasing switch is illustrated in Fig. 1. The switches installation cost which is imposed by the automatic re-phasing for the first time, will be compensated by the great benefits of re-phasing operation.

Necessary data such as lines' currents and loads' demand are measured by smart meters and are sent to the supervisory control and data acquisition (SCADA) [15–16]. Details of an application program, based on the automated mapping/facilities management/geographic information system (AM/FM/GIS) for data collection are developed in [14].The SCADA system is an interface between re-phasing program and network equipment. Re-phasing program transmits the proposed re-phasing strategies to the SCADA system using communication lines. Then SCADA sends the required command to the installed re-phasing switches and re-phasing operation is carried out. This operation diagram is shown in Fig. 2.

2.2. The phasing arrangement

Three-phase motors are sensitive to the phase sequence and if the appropriate phase sequence is not implemented in re-phasing operation, they might be damaged. Accordingly, among the six existing re-phasing strategies, only two strategies are selected including: positive phase sequence and negative phase sequence. In other words, if the phasing arrangement is denoted (x, y, z) for the three-phases of the network, only two general strategies for re-phasing can be existed including:1-Positive phase sequence (z, x, y). 2-Negative phase sequence (y, z, x). In this paper, the numbers one to three are considered for the re-phasing arrangement (RA) of the nodes. Number one is related to when re-phasing is not performed in the node, number two shows

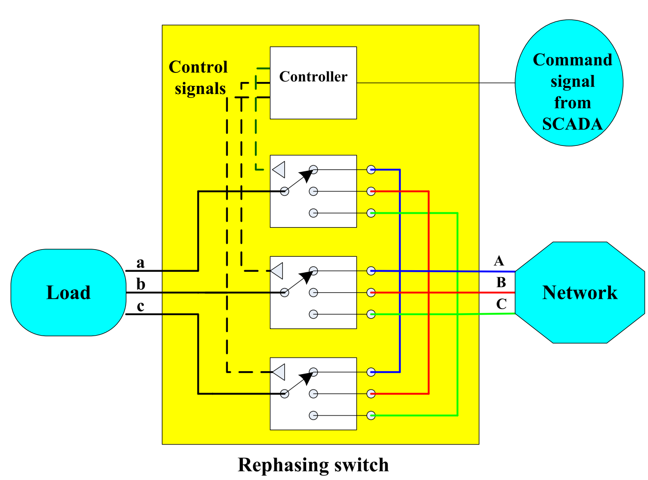

Fig. 1. Re-phasing switch structure.