Electrical Power and Energy Systems 85 (2017) 1–11

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Multi objective optimal allocation of fault current limiters in power system

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ARTICLE INFO

Article history:
Received 16 November 2015
Received in revised form 2 June 2016
Accepted 28 June 2016
Available online xxxx

Keywords:
Fault
Fault current limiter
Multiobjective optimization
Reliability
Short circuit current

ABSTRACT

Transmission systems, connection of distributed generation to the grid are increased due to increase in power demands. This fact causes the increase in short circuit level of power networks. The occurrence of fault in such networks leads to large short circuit currents throughout the system, which may exceed the rating of existing circuit breakers and can damage system equipment. There are some approaches to reduce this fault current such as power network reinforcement and utilization of fault current limiter (FCLs) in power systems. Power system reinforcement is too difficult if not impractical. Therefore, the utilization of FCLs can provide an effective way to suppress fault currents. The effectiveness of FCL depends on the number of FCLs and their installation location. In this paper, a novel approach is presented to determine the optimal number and location of FCLs to improve the power network reliability and fault current reduction based on different conflicting objective functions. IEEE 39 BUS system and IEEE 57 BUS system are considered to evaluate the effectiveness and feasibility of the proposed method. The objective functions considered for the optimal allocation are reliability of power system, economic impact and short circuit current reduction. Unlike what has been previously done in literature, in this paper Pareto based optimization algorithms, namely non-dominated sorting algorithm, multiobjective particle swarm optimization and multiobjective evolutionary algorithm based on decomposition, are utilized to deal with this problem. The use of these methods made it possible to obtain the Pareto optimal front in which these objective functions are optimized simultaneously.

1. Introduction

Nowadays, with the increasing demand for electric energy, power systems have become greater and more complex, as a result fault current increases. By increasing the fault current, in some cases allowable level of equipment on the network particularly circuit breakers (CBs) may exceed the allowable level and even can damage equipments. Therefore, it is necessary to use CBs with higher breaking current. This, in turn imposes heavy costs on the system. If after identifying the fault, its current can clearly be limited by a method, a technically and economically significant saving is achieved. This is possible by fault current limiters (FCLs). FCLs are elements that are placed in series with the network equipment to reduce the level of short circuit current during a fault. This equipment normally reveals little resistance against the flow of the current; however, if short-circuit happens and in the initial moments after fault, their resistance suddenly increases which prevents more short circuit current [1,2]. Limiters do not cause voltage sag and power loss in the steady state conditions of the system [3]. In [4], authors examined transient stability due to use of FCLs in network with studying the rotor oscillation of generator after the occurrence of fault with large amplitude, e.g. short circuit. In [5], an application of a superconducting fault current limiter (SFCL) to enhance the power system transient stability is presented. In Ref. [6], power system security and stability enhancement is examined and particle swarm optimization (PSO) algorithm is used to optimize the system. In [7], two characteristics of FCL utilization, fault current limiting and voltage sag suppression in distribution network are examined. The effect of FCLs in distribution network in the presence of wind turbine generators is also investigated [8].The main focus of this paper is on fault current limitation effect of FCLs. In addition to the short circuit current limitation, studies have shown that the use of FCLs in power network allows the incensement in the transient stability of generators and consequently the global stability of the network [9,10]. Previous studies on FCL optimal allocation mainly focus on one objective function either fault reduction as in [11–13] or stability as in [9,13]. Hierarchical genetic algorithm (GA) combined with a

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http://dx.doi.org/10.1016/j.ijepes.2016.06.013

micro GA was used to find the optimum locations of FCLs [14,15]. In [12], authors used a search space reduction technique and GA to find the optimum number and locations of FCLs. In Ref. [16], a two-stage placement approach is proposed, where Stage I benefits from the hierarchical fuzzy logic decision method and a variant of generic algorithm so-called Hashing-integrated. In order to sort feasible solutions, the hierarchical fuzzy logic decision method is used. The Hashing-integrated genetic algorithm determines an optimal FCL placement in the reduced search space. PSO is then employed in Stage II for optimizing the FCL parameters. The main focus of [17] is on the total operating time, which is the sum of the operating times of primary relays for each fault and minimax regret criterion is proposed for power system protection considering the uncertainty of the (distributed generation) DGs to determine SFCL placement. However, multiobjective approach and adaptive penalty factor are not considered in this research. In Ref. [18], an iterative mixed integer nonlinear optimization method is proposed to optimally locate and size FCLs in a power system. Another approach has examined the influence of fault type on the optimal allocation of SFCL in electrical power grid [10]. Eigenvalue analysis is also used to optimize resistive SFCL for multi-machine power system [19]. Multiobjective optimization algorithm is applied to solve different problems of power system such as reactive power and voltage control [20], power flow [21], and optimal power flow with FACTS devices [22]. In Ref. [23], sensitivity calculation of capacity constraints method is used to find out the optimal placement and value of the determined number of SFCLs. In Ref. [24], the effect of the presence of FCLs for maintaining over current relay coordination in power network with distributed generation is discussed.

In this paper, in order to optimally allocate the FCLs in a power system, three objectives functions are considered. The objective functions considered in FCL placement problem are: (a) improving reliability; (b) economical usage of FCLs and (c) minimizing the short circuit current. The benchmark problems considered are IEEE 39 Bus and IEEE 57 Bus. Unlike what can be seen in literature which combine different objective functions in a single objective function, in this study, the three objective functions are solved using Pareto based algorithms. The uses of such algorithms make it possible to simultaneously determine the number, location and the impedance values of FCLs. Moreover, existing methods in literature do not optimize the location and the value of FCLs; but rather choose some locations for the FCLs and then optimize their values. However, the proposed approach optimizes the location and the values of FCLs, simultaneously. The Pareto based optimization algorithms are multiobjective evolutionary algorithm based on decomposition (MOEA/D), multiobjective particle swarm optimization algorithm (MOPSO) and non dominated sorting genetic algorithm-II (NSGA-II). Since Swarm intelligence and evolutionary methods are two main classes of optimization methods used in multiobjective optimization approaches, MOPSO which is based on swarm intelligence and NSGA-II and MOEA/D which are evolutionary based methods are selected. Moreover, another contribution of the proposed approach in this study is the use of an adaptive penalty factor. The penalty factor used is relative to the violation of maximum short circuit allowed in the system. Furthermore, since the power system can tolerate some levels of short circuit current, another constraint is defined for the lower bound of the short circuit current which causes less FCLs to be used and reduces the costs considerably. In addition, another penalty term is considered for the violation of allowable interval of impedances. It is shown that the three multiobjective optimization algorithms are capable of obtaining an appropriate Pareto optimal front.

The rest of the paper is organized as follows: in Section 2, fault current calculation and the effect of adding a FCL on impedance matrix is described. In Section 3, the networks studied in this paper are introduced. In Section 4, the main problem considered in this paper, is formulated. In Section 5, multiobjectives optimization algorithms which are used in this paper are presented. Section 6 covers the simulation results. The concluding remarks are given in Section 7.

2. Fault current calculation and the effect of adding a FCL on Z_{BUS} impedance

Three phases symmetrical faults are used to specify the rating of CBs because it is the worst type of faults. For a balanced three-phase fault at bus i, the short-circuit current can be calculated as follows:

$$I_i^{sc} = \frac{E_i}{Z_{ii}} * I_b \tag{1}$$

where I_i^{sc} is the three-phase short circuit current at bus i and E_i is the voltage before the fault at bus i. Commonly, E_i can be set as 1.0 p.u. The parameter Z_{ii} is the diagonal impedance of the impedance matrix (Z_{bus}) and I_b is the base current [12]. When adding a line with impedance Z_b between buses j and k, each element of Z_{bus} can be modified as follows [12]:

$$Z_{xy}^{new} = Z_{xy}^{old} - \frac{(Z_{xj} - Z_{xk})(Z_{jy} - Z_{ky})}{Z_{jj} + Z_{kk} - 2Z_{jk} + Z_b} \tag{2}$$

where Z_{xy}^{new} and Z_{xy}^{old} are the modified and old elements of Z_{bus}, respectively. In addition, the effect of inserting the impedance Z_b series with the transmission line can be considered as a parallel impedance Z_p with the network which can be obtained as follows:

$$Z_p = (-Z_b)//(Z_b + Z_{FCL}) = -\frac{Z_b(Z_b + Z_{FCL})}{Z_{FCL}} \tag{3}$$

Fig. 1 represents the Thevenin equivalent by looking into the system from two existing buses when impedance Z_b is added between them. The modification to the diagonal entries of Z_{bus} after the FCL fired up at a branch between buses j and k is as follows:

$$\Delta Z_{ii} = -\frac{(Z_{jj} - Z_{ik})^2}{Z_{jj} + Z_{kk} - 2Z_{jk} + Z_p} \tag{4}$$

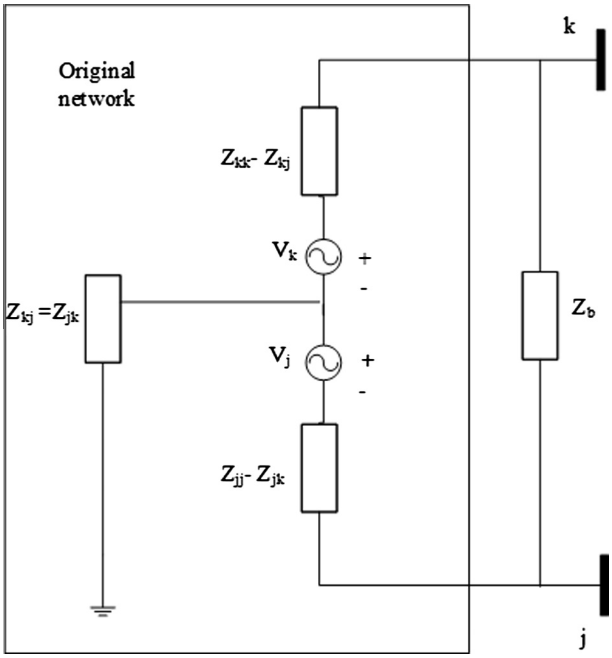

Fig. 1. Thevenin equivalent when line is added between k and j buses.