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Optimal power flow considering fault current level constraints and fault current limiters

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ABSTRACT

The aim of this paper is to present a novel method to dispatch the active generation power properly in the power system while incorporating fault current levels as constraints for the optimization problem. Due to the limited capacity of protective devices such as circuit breakers, allocating active power without considering fault current levels can probably lead to fault currents exceeding the rating of these devices. Hence restricting the fault current levels to an allowable amount while minimizing a specified objective function seems to be necessary. In a number of cases even the appropriate allocation of active power is not able to reduce the fault current levels to the permitted amount therefore using fault current limiters (FCL) is unavoidable. In this paper also a planning scheme is presented for the location and sizing of fault current limiters and the effect of fault current limiters on the objective functions is investigated.

1. Introduction

The optimal power flow problem is affective on secure and economical operation of power systems. This problem denotes optimal settings of control variables such as active power of generators, tap ratios of transformers and generator bus voltages to minimize a certain object while satisfying equality and inequality constraints. Transformer tap settings is a discrete value while bus voltage magnitudes and active power generation outputs of generators are continuous variables so the OPF problem can be modeled using mixed integer nonlinear programming.

The optimal power flow problem has been investigated in many works. In [1–4] the problem is solved using mathematical approaches. Also in [5–9] the problem has been solved using different heuristic approaches assuming different objective functions such as total fuel cost, active power line loss, voltage stability and voltage deviations. Although in [10,11] the optimal power flow problem is solved with regarding fault current limits, no work is presented that solves the OPF problem regarding the fault current levels and effect of fault current limiters. Also it should be noticed that solving the OPF problem considering fault current levels can lead to an unfeasible problem. In other words there is no solution for the OPF problem which can suppress the fault currents to under the permitted value which is determined by the rating of circuit breakers. In this state using fault current limiters in the system is unavoidable.

In the last decade considering the increasing demand for power, electric systems have expanded rapidly. Consequently, the level of fault currents has increased and can exceed the fault currents of circuit breakers installed in the system. Hence the fault current level can create a critical situation in the power system especially when the highest capacities of circuit breakers are used in the system [11].

In the recent years fault current limiters (FCL) have been used as effective devices to overcome high fault current levels. FCLs are capable of limiting the fault current at the first peak and also limiting short circuit current at steady state without disturbing the normal operation. Different types of FCLs are used in power systems including FCLs using power devices and superconductivity [12]. Fault current limiters have a very low impedance during their normal operation. However when a fault occurs these devices increase their impedance [13]. In [14] a hybrid fault current limiter is presented for distribution systems. The introduced device is implemented to a 11 kV distribution systems with distributed generation. In [15] the FCL is utilized by an impedance combined with bus sectionalizing circuit breakers. The economical observations show the profit of the combination. [16] Proposes solid state fault current limiters as cost efficient approach to minimize distributed generation expansion in the distribution network. Genetic algorithm is used in this paper for determining the optimal number, location and size of fault current limiters with the object of

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minimizing protection costs. In [17] in addition to the limitation of fault currents the FCL is used for preventing voltage sags. In the presence of distributed generation the settings of over current relays have to be readjusted. However in [18] fault current limiters are used for restoring the coordination of over current relays.

Utilizing fault current limiters can facilitate the connection of independent power producers (IPP) to the system. It can also increase the capacity of lines and totally increase the security and reliability of the system. However, the impedance and installation location of fault current limiters have an important effect on the improvement of the system, therefore developing a method that can determine the sufficient number of FCLs, there location and impedance seems to be necessary. In radial systems the appropriate place for installing fault currant limiters can be specified simply. But in loop systems this problem is complicated and requires a suitable method to determine the location, number and impedance of FCLs considering the system specifications [19,20].

In [20] a micro genetic algorithm approach has been used for solving the optimization problem considering superconducting fault current limiters. Also [21] utilizes a genetic algorithm and sensitivity factor calculation method. In [22] a rectifier type superconducting fault current limiter is placed in a large scale power system. In this work a method is implemented for determining the optimal placement and location of fault current limiters.

In this paper initially the OPF problem is solved regarding the fault current levels. It is indicated that for a number of specified cases the proper allocation of power is capable of suppressing the fault current levels to under the rated amount of protection devices such as circuit breakers. But in other cases even the appropriate settings of control devices are not adequate and using fault current limiters are inevitable. In the next stage an optimal FCL programming is represented for specifying the optimal location and amount of fault current limiters. Also the impacts of using FCLs in the system for suppressing the fault current levels to under the permitted amount is investigated on total generation cost, power loss of the system and voltage deviations. The proposed method is implemented to the New England 39-bus system and the results exhibit the effectiveness of the proposed method.

2. Fault current calculation and fault current limiters

The majority of faults in power systems are unsymmetrical however the three phase fault is the most intensive type of faults and is used for specifying the rating of circuit breakers. In the following the calculation of fault current at each bus and the effect of three phase faults on the currents flowing in the lines are described:

2.1. Fault current at bus

For a symmetrical fault at bus i the fault current can be obtained by (1):

$$I_i^{SC} = (E_i/Z_{ii}) \cdot I_b \tag{1}$$

where I_i^{SC} is the fault current at bus i and E_i is the voltage before the fault at bus i which is usually assumed to be 1 p.u. Z_{ii} is the diagonal members of the impedance matrix. Finally I_b is the base current [21].

By adding the impedance Z_b between buses j and k each element of the impedance bus is modified as [21]:

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

where Z_{xy}^{new} is the modified element of the impedance matrix. Therefore the effect of inserting the impedance Z_b series with the transmission line is equivalent to inserting the impedance Z_p parallel with the transmission line which can be obtained by the following relation:

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

Fig. 1 shows the Thevenin equivalent from the bus under study when impedance Z_b is added between two buses. Finally Z_p is used to modify the elements of the impedance matrix by the below relation:

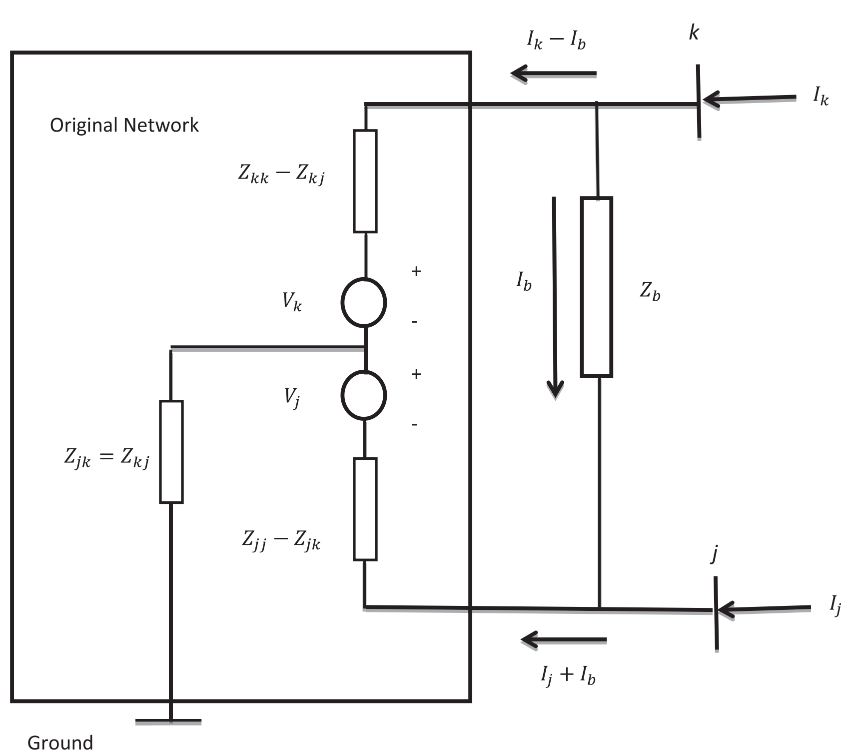

Fig. 1. Thevenin equivalent when line is added between *k* and *j*.