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Power system security enhancement with unified power flow controller under multi-event contingency conditions

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Abstract Power system security analysis plays key role in enhancing the system security and to avoid the system collapse condition. In this paper, a novel severity function is formulated using transmission line loadings and bus voltage magnitude deviations. The proposed severity function and generation fuel cost objectives are analyzed under transmission line(s) and/or generator(s) contingency conditions. The system security under contingency conditions is analyzed using optimal power flow problem. An improved teaching learning based optimization (ITLBO) algorithm has been presented. To enhance the system security under contingency conditions in the presence of unified power flow controller (UPFC), it is necessary to identify an optimal location to install this device. Voltage source based power injection model of UPFC, incorporation procedure and optimal location identification strategy based on line overload sensitivity indexes are proposed. The entire proposed methodology is tested on standard IEEE-30 bus test system with supporting numerical and graphical results.

1. Introduction

Nowadays, power system operation, and control and management become one of the challenging tasks to maintain the continuity and reliability of the supply. The system security should be analyzed to avoid uncontrolled conditions such as line overloadings, bus voltage violations, and system collapse conditions. Dynamic security analysis is necessary due to the continuous change in the system operating conditions [1]. Risk based security constrained optimal power flow (SCOPF)

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problem was implemented to investigate the stability of the system using QV-curves [2]. From this, the system security level has been enhanced because of SCOPF including risk modeling. Robust power system security (RPSS) method was presented to analyze the $(n-1)$ contingency conditions for PV penetration problem [3]. From this literature, it is identified that, power system security should be analyzed in terms of line loadings and bus voltage variations. In general, optimal power flow (OPF) problem with security constraints can solve this problem.

In [4], they proposed bacterial foraging algorithm for optimal power flow under the consideration of security constraints and non-smooth cost function. The proposed method is used to alleviate the congestion and voltage stability, improves the loadability and reduces the line losses and production cost by controlling the power flow in the network. In [5], they proposed Security-Constrained OPF (SCOPF) in electricity networks in which the transmission lines are potentially instrumented with Flexible AC Transmission Systems (FACTS). The single objective OPF problem was solved using some of the advanced optimization techniques reported in [6–11] while satisfying system constraints. Nowadays, hybrid algorithms reported in [12–14] are used to solve OPF problem. Because of this implementation, the convergence has been improved rapidly and global optimal solution is obtained in less time. In the same way, multi objective optimal power flow problem was solved in the presence of flexible AC transmission system (FACTS) controllers, using some of the latest optimization methodologies reported in [15–19]. Incorporation of FACTS controllers enhances the system parameters such as voltage magnitudes, power flow in transmission lines, and total system losses. Out of the various FACTS devices, unified power flow controller (UPFC) can control voltage magnitude at a bus and active and reactive power flow in line, in which, it is connected.

FACTS devices can play an important role for demand side management and thereby controlling transmission line congestion [20]; in this, they proposed two-step market clearing procedure for transmission lines congestion management in a restructured market environment using a combination of demand response (DR) and FACTS controllers. UPFC in overhead lines under line outage condition is used to increase the availability of the transmission network during peak loads effectively [21]. In [22], they proposed a dynamic model of UPFC for enhancing the active power flow in transmission line, improving the bus voltages and power losses reduction. In [22], they developed a steady state model of UPFC under the load variation condition. It has been used to improve the capability of power flow in power transmission lines and to enhance the transmission power flow in line, thereby reducing the active power losses as well as enhancing the bus voltages. A novel severity function was formulated in [15], to identify an optimal location to install one of the advanced multiline FACTS controllers, namely, generalized unified power flow controller. In this location, system security can be enhanced by minimizing the severity of the system.

From the careful review of the literature, it is identified that, the system can be operated under contingency conditions to analyze the system security. For this, critical transmission line(s) are identified using line collapse proximity indexes (LCPI) and sensitive generator(s) are identified using generator shift factors (GSF). The effect of optimal power flow (OPF) on system severity with generation fuel cost and system severity functions is solved while satisfying system equality and in equality constraints. In this paper, a new improved teaching learning based optimization (ITLBO) algorithm is presented. To enhance the system security, under transmission line(s) and/or generator(s) contingency conditions, voltage source based power injection model of unified power flow controller (UPFC) is presented. The optimal location of UPFC is identified through line overload sensitivity index (LOSI) analysis. The various scenarios to analyze the system security under contingency conditions, using OPF and to enhance the system security using UPFC are tested on standard IEEE-30 bus test system with supporting numerical and graphical results.

2. Power system security

In general, the main aim of power system operation and control is to meet the demand continuously without any failures. While, in this operation, sometime, outage of generator due to failure of the auxiliary equipment or removal of a transmission line for maintenance purpose or due to storm and other effects may happen. Due to which, the system frequency may drop and lead to load shedding or uncontrolled operation and sometime lead to system collapse condition. This happens mainly due to the overloading of the transmission lines, voltage deviation and lack of reactive power support at the load buses.

From this discussion, while operating power system, it is necessary to consider a factor which relates to the system security and involves the design of the system to maintain the system security under various contingencies. In common practice, outage of a transmission line or a generator increases the loading on some of the transmission lines and voltage magnitudes at load buses may violate their minimum or maximum limits. It is necessary to minimize the system severity and analyze the system condition to enhance the system security. For this purpose, in this paper, two different parameters are defined to identify the most critical line(s) and generator(s) in a given system.

2.1. Line collapse proximity index

From the literature, it is identified that, there are variety of indices to identify the most severe lines in a given system. Due to the difficulties reported in the literature for the available indices, a new index based on the effect of power flow in transmission lines, line charging reactance and the direction of reactive power flow with respect to the direction of active power flow known as ''Line collapse proximity index'' (LCPI) is proposed. The modeling of this index is based on the exact pi-model of the transmission lines using ABCD-parameters [23].

Conventionally, the relation between system parameters for a transmission line connected between buses 's' and 'r' can be expressed as follows:

$$\begin{bmatrix} \overline{V}_s \\ \overline{I}_s \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} \overline{V}_s \\ \overline{I}_s \end{bmatrix} \tag{1}$$

where A, B, C and D are the transmission line parameters related to two-port network and can be expressed as