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Contingency management of power system with Interline Power Flow Controller using Real Power Performance Index and Line Stability Index

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Abstract As a result of privatization of the electrical industry the power transmission lines have to transfer power at their maximum transmission limits because of the competitive scenario of the electrical market. Hence, secured operation of power system has become one of the most important issues of modern era. In this paper, a probability of severity based placement strategy for Interline Power Flow Controller (IPFC) has been proposed based on Composite Severity Index (CSI). The composite severity index provides an exact measure of stress in the line in terms of mega watt overloading and voltage instability. IPFC is placed on the line which has the highest probability of severity during the occurrence of different outages. The IPFC has been tuned for a multi-objective function using Differential Evolution (DE) and the results have been compared with genetic Algorithm (GA). To verify the proposed method, it has been tested and implemented on IEEE 14 and 57 bus systems.

1. Introduction

Electric power is the backbone of every industrialized country and its economy. The increased reliance on electricity of the modern world in terms of electronics, industrial production and other daily life activities makes continuous uninterrupted supply extremely important. A complete interruption of electricity (blackout) of even a few hours can totally disrupt the basic infrastructures of the region such as communication, transport, hospital, water supply and even emergency services such as fire, ambulance, and police. On the other hand due to increased stress on the transmission lines the probabilities of its failure are ever increasing. Blackouts have become quite a frequent occurrence worldwide in recent times. Hence, development of an effective system for management of contingency is the biggest issue of today's world.

Contingency severity calculation is one of the most important aspects of power system reliability. Although, dynamic security assessment is also being performed [1], but ensuring the security of the power system in static condition still remains the primary objective of power system engineers. Several methods have been used for static contingency analysis in the literature, namely, combinatory linear sensitivity and

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eigenvalue analysis [2], artificial neural network based method [3], and analytical hierarchy process based method [4]. The traditional method for contingency analysis, although lengthy, is still the most accurate method of severity assessment. During system disturbances, system stability becomes vulnerable and there is a high risk of moving toward global instability or total collapse or blackout if preventive actions are not taken quickly. Facts devices provide good solution to various power system issues including congestion and contingency provided the devices have been optimally placed and tuned in the system. Many computational intelligence methods viz., Cat Swarm optimization [5], artificial bee colony and gravitational search algorithm [6], Differential Evolution [7], and Improved Teaching Learning based technique [8] have been applied for optimal placement and tuning of UPFC. Moazzami et al. [9] have presented a strategy for blackout prevention in a power system using parallel FACTS devices and a combination of corrective actions. Roselyn et al. [10] have used multi-objective rescheduling with FACTS devices using Genetic Algorithm for improvement of voltage stability. Some researchers have also used index based methods such as voltage stability Index [11] and composite index [12] for optimal location of FACTS devices such as TCSC.

Traditionally PV and QV curves have been used in the industries for the voltage stability analysis. But these curves require selection of precise buses for analysis. Unless problems already exist, the choice of buses could omit the problematic buses. Also, PV curves show the behavior of system bus voltages only when the system is under stressed condition. Hence, it is not a good tool for power system planning issues. Index based method for optimal placement of FACTS devices is found to be very accurate and at the same time uses very less computational time. It is equally suited for both static and dynamic analysis of the system. When the load on the transmission systems increases the problem of line overload and voltage collapse both are an issue of major concern. Therefore, it is necessary to consider the combination of a voltage stability index and a line overload index for assessing the actual system stress under contingency condition. Line stability index has major advantages that it is easy to compute, computational cost is less, and identification of weak buses by this method is very easy. Metaheuristic methods have shown good success in tuning FACTS devices. Differential evolution developed by Storn is a very simple and accurate method and has very less computation time [13]. Out of all FACTS devices IPFC is considered to be most flexible, powerful and versatile as it employs multiple VSCs with a common DC link. IPFC has the capability of compensating multitransmission line. It can regulate both real and reactive power flow along with real power transfer in between lines [14]. Optimal placement and sizing of IPFC for contingency management are expected to provide good solution to the post-contingency issues.

In this paper, an off-line long term investment strategy for placement of IPFC is being proposed for protection of power system against contingency. The line which has the highest probability of severity is proposed to be the optimal location for IPFC placement. Two separate indices have been combined to form a Composite Severity Index (CSI) to evaluate line overloads and bus voltage violations. Real Power Performance Index (PI) is employed for the measurement of line overloads in terms of real power flow. Line Stability Index (L_{mn}) has been used for voltage stability assessment. The IPFC is placed on the line which is repeated most frequently on the severity list for the various outages. Thereafter, the IPFC is tuned for a multi objective function using Differential Evolution. The results obtained have been compared with a state of art method, Genetic Algorithm. The multi-objective function chosen is the reduction of real power loss, voltage deviation, security margin and capacity of installed IPFC. The load on the system is increased by 10% and 25% respectively in order to observe the performance of IPFC in stressed conditions. The proposed method is implemented and tested on an IEEE 14 and 57 bus system.

2. Proposed Composite Severity Index

2.1. Real Power Performance Index

Severity of loading on the system for normal and contingency condition can be determined from Real Power Performance Index [15]. It is given by Eq. (1):

$$\mathrm{PI}_{ij} = \sum_{m=1}^{N_L} \frac{w_m}{2n} \left(\frac{P_{lm}}{P_{lm}^{\max}} \right)^{2n} \tag{1}$$

where
P_{lm} is the real power flow,
${P_{lm}}^{\max}$ is the rated real power capacity of line m,
n is the exponent,
w_m is a real non-negative weighting factor which may be used to show a relative importance of the lines, and
N_L is the total number of lines in the network.

PI will have a small value when all the line loads are within limits and takes a high value during overloads. Thus, PI is a good measure of line overloading. 'n' is used for normalization. Since, a composite index is being used, so, in order to keep the values of both indices in the same range, the value of n is chosen to be 1. Equal importance has been given to all lines. Hence, the value of weighting factor, w_m is designated as 1. The overall PI of the system is the sum of PI's of all lines and is given by Eq. (2):

$$\text{Overall PI} = \sum_{\forall L} \mathrm{PI} \tag{2}$$

where L is the no. of lines in the system.

2.2. Line Stability Index

Line Stability Index (L_{mn}) is a voltage collapse proximity indicator [11,16]. Let us consider a single line of an interconnected system. The power flow at the sending end and receiving end is given in Eqs. (3) and (4):

$$S_r = \frac{|V_s||V_r|}{Z} \angle(\theta - \delta_1 + \delta_2) - \frac{|V_r|^2}{Z} \angle\theta \tag{3}$$

$$S_s = \frac{|V_s|^2}{Z} \angle\theta - \frac{|V_s||V_r|}{Z} \angle(\theta + \delta_1 - \delta_2) \tag{4}$$

From the above equations, the active and reactive power is given in Eqs. (5) and (6):