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Multi-Objective Genetic Algorithm for voltage stability enhancement using rescheduling and FACTS devices

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Abstract This paper presents the application of Multi-Objective Genetic Algorithm to solve the Voltage Stability Constrained Optimal Power Flow (VSCOPF) problem. Two different control strategies are proposed to improve voltage stability of the system under different operating conditions. The first approach is based on the corrective control in contingency state with minimization of voltage stability index and real power control variable adjustments as objectives. The second approach involves optimal placement and sizing of multi-type FACTS devices, Static VAR Compensator and Thyristor Controlled Series Capacitor along with generator rescheduling for minimization of voltage stability index and investment cost of FACTS devices. A fuzzy based approach is employed to get the best compromise solution from the trade off curve to aid the decision maker. The effectiveness of the proposed VSCOPF problem is demonstrated on two typical systems, IEEE 30-bus and IEEE 57 bus test systems.

1. Introduction

Due to economic and environmental constraints, power systems are being operated very near to loadability limit. The rapid increase in load and nonoptimal use of transmission lines adversely affect the stability of the power systems. Under this scenario, maintaining a stable and secure operation of power system is a very challenging issue. Therefore, voltage stability [1] is being regarded as one of the main concerns to maintain system security. Voltage stability is the ability of the power system to maintain acceptable voltage profile under normal conditions and even after being subjected to disturbances. Voltage collapse [2] is the process by which the system voltage falls to a low, unacceptable value as a result of an avalanche of events accompanying voltage instability. The approaches for voltage stability assessment can be classified into static and dynamic approaches. Static voltage stability assessment is suitable for operational scheduling problems. In this work, L-index [3] one of the static voltage stability index is used for assessing voltage stability of the system.

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Voltage security enhancement can be achieved through preventive or corrective control. Preventive control is applied so as to ensure that operating point is away from point of collapse in anticipation of incredible contingencies. The corrective control action on the other hand is activated only when the contingency has occurred endangering voltage stability. Corrective control is considered as economic one in the market environment, nevertheless preventive control is also needed to reduce system interruption. In this paper, Optimal Power Flow (OPF) is used for corrective strategies by determining the optimal settings of control variables to minimize generation cost in the transmission system. OPF [4–8] is a large scale, nonconvex, nonlinear static optimization problem with both discrete and continuous variables. To achieve voltage security enhancement, the contingency state voltage stability index is included **as** additional constraint in the formulation of OPF problem [9–11] along with the contingency state constraints. Generation rescheduling [12,13] is necessary to change the real power settings of the generators in contingency state to improve the voltage stability of the system. The generator ramp rates can significantly restrict the speed with which the active power is rerouted in the network. Monticelli et al. [14] describe mathematical programming techniques that allow the iterative solution of economic dispatch and separate contingency analysis with generation rescheduling to eliminate constraint violations. In [15], generation rescheduling was taken to change the system operating conditions to ensure voltage security margins of contingencies above certain minimal value with a multi-contingency sensitivity based approach. Abido [16] proposed an effective scheme involving generation rescheduling by minimizing the real power control variable adjustments for VAR dispatch problem. Mohapatra et al. [17] proposed coordinated preventive and corrective rescheduling actions attempt to make the system correctively secure with respect to line and generator outages. In contingency state, by including voltage stability index in the objective function, voltage stability is achieved at the expense of operating costs. This increase in operating costs can be reduced by generation rescheduling in contingency states. Hence, one of the objectives in the security enhancement problem is to minimize the deviation of control variables in the contingency state from the base case value. To ensure voltage security of the system, Flexible AC Transmission Systems (FACTS) [18] devices based on power electronics technology are a good choice due to their fast and flexible control. A proper co-ordination between FACTS devices and conventional power system control devices is essential to make system voltage secure in addition to economical aspects. However, to obtain good performance from these controllers, proper placement and sizing [19,20] of these devices is crucial. In practical system, suitable allocation of FACTS devices depends on system stability and other factors such as installation cost and conditions also need to be considered [21,22]. In [21], both technical and economic benefits arising from the installation of FACTS devices with the emphasis on generator cost reduction is carried out by solving GA based OPF procedure. Saravanan et al. [23] proposed the application of PSO technique for optimal placement and sizing of FACTS devices with minimum cost of installation and to improve system loadability. Phadke et al. [24] proposed fuzzy performance index based on fuzzy logic and real coded GA to determine the optimal placement and sizing of FACTS devices. This paper investigates modal analysis method [25] to find the optimal location of multi-type FACTS devices namely: SVC and TCSC to enhance voltage stability and reduce system losses considering investment cost of these devices. The issue of optimal settings of the FACTS devices is formulated as an optimization problem taking into account the installation cost along with voltage security enhancement. In this paper, traditional OPF problem is extended to include multi-type FACTS devices for improvement in system stability. This objective along with FACTS investment cost has not been reported in many literatures. Hence in this paper, rescheduling of generators by minimizing the deviation of real power control variables is considered as the other objective in addition to the FACTS installation cost.

In this paper, a new solution method for VSC-OPF problem including FACTS devices taking into account the issues mentioned above is formulated as multi-objective optimization problem and is addressed through two approaches. Firstly, the problem is formulated in corrective control considering minimization of real power control variable adjustment and voltage stability index, L-index in the postcontingency state. Secondly, the problem is investigated in suitable control actions with minimization of investment cost of FACTS devices and voltage stability index along with generation rescheduling.

The OPF problem based on mathematical programming techniques such as linear programming [4], nonlinear programming [5], quadratic programming [6], Newton method [7] and Interior point method [8] in solving large scale problems are not guaranteed to converge to global optimum. Also, the discrete variables related to the tap changing transformer and shunt capacitors cannot be incorporated directly into the general Optimal Power Flow problem. Recently, evolutionary computation techniques such as Genetic Algorithm [26] and Evolutionary Programming [27] have been successfully applied to solve the OPF problems. Evolutionary computation techniques do not require any space limitations such as smoothness, convexity or unimodality of the function to be optimized. They are not largely affected by the size and nonlinearity of the problem, and they can perform well in highly constrained and integer (or mixed integer) optimization problems. This feature makes it suitable for many real world applications including the OPF problem.

This paper proposes Multi-Objective Genetic Algorithm (MOGA) [28] which produces multiple solutions in one single simulation run for solving this complex multi-objective optimization problem. Generally, binary strings are used to represent the decision variables of the optimization problem in the genetic population irrespective of the nature of decision variables. This binary coded GA has hamming cliff problems [29,30] which sometimes causes difficulties in the case of coding continuous variables. Also, for discrete variables with total number of permissible choices not equal to 2^k (k is an integer) it becomes difficult to use fixed length binary coding to represent all permissible values. To overcome the above difficulties, the control variables namely generator active power settings (P_{gi}), generator voltage settings (V_{gi}) are represented as floating point numbers and variable settings of SVC and TCSC (SVC_i and $TCSC_i$) and transformer tap settings (Tap_i) are represented as integers in the genetic population.