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Genetic algorithm based reactive power dispatch for voltage stability improvement

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ABSTRACT

Voltage stability assessment and control form the core function in a modern energy control centre. This paper presents an improved Genetic algorithm (GA) approach for voltage stability enhancement. The proposed technique is based on the minimization of the maximum of *L*-indices of load buses. Generator voltages, switchable VAR sources and transformer tap changers are used as optimization variables of this problem. The proposed approach permits the optimization variables to be represented in their natural form in the genetic population. For effective genetic processing, the crossover and mutation operators which can directly deal with the floating point numbers and integers are used. The proposed algorithm has been tested on IEEE 30-bus and IEEE 57-bus test systems and successful results have been obtained.

1. Introduction

Due to the continuous growth in the demand for electricity with unmatched generation and transmission capacity expansion, voltage instability is emerging as a new challenge to power system planning and operation. Contingencies such as unexpected line outages in stressed system may often result in voltage instability which may lead to voltage collapse. After a voltage collapse, the system becomes dismantled owing to the wide spread operation of protective devices. Unavailability of sufficient reactive power sources to maintain normal voltage profiles at heavily loaded buses are the prime reasons for the voltage collapse. Research efforts have been made in understanding the phenomenon associated with the voltage instability [1–5] and suggesting the remedial measures to protect the power system networks against such failures [6–11]. There are two different approaches to take control action against voltage instability: preventive and corrective control. The preventive control involves taking preventive actions so as to ensure that the operating point is sufficiently away from the point of collapse under a selected set of contingencies. The corrective control, on the other hand is activated when a contingency has occurred endangering voltage stability. The main objective of this work is to study the voltage instability problem in the framework of the short-term operation planning, where the optimal corrective action has to be found to improve the voltage stability by considering just the existing facilities and equipment operational limits.

Several approaches have been proposed in the literature to identify the most effective action to improve the voltage stability. Tiranuchit and Thomas [6] have proposed minimum singular value of the load flow Jacobian as voltage stability index. The sensitivity of the minimum singular value to power adjustments at each bus was used to identify the VAR support needed to maintain the voltage profile when an increase in power flow is required. Bansilal et al. [7] have proposed a non-linear least squares optimization algorithm for voltage stability enhancement. They have used the *L*-index proposed in [1] for voltage stability assessment. A linear programming-based reactive power dispatch algorithm was proposed in [8] for voltage stability improvement. In Ref. [9] two control methods for improving voltage stability based on the concept of Voltage Instability Proximity Index (VIPI) have been proposed. The first method maximizes the value of VIPI by using a Successive Quadratic Programming method to find optimal controls in various system conditions. The second approach determines the controls needed to maintain the specified threshold value, based on the sensitivities of VIPI with respect to control variables. Tare and Bijwe [10] have reported a voltage stability monitoring and enhancement algorithm based on the angle between P and Q gradient vectors at the load bus. In this approach a simple quadratic objective function is formed using sensitivities of the proposed voltage stability index and the minimization of this objective function leads to improvement in voltage stability limit. Sequential primal dual LP algorithm was used in [11] for the improvement of the static voltage stability. Choube et al. [12] presented a corrective scheduling method based on the linear relationship between static voltage stability index and reactive power control variables. The validity of the sensitive approaches is restricted to small incre-

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ments in reactive power variables only. Although linear programming methods are fast and reliable they have some disadvantages with the piecewise linear cost approximation. Quadratic programming based techniques have some disadvantages with the piecewise quadratic cost approximation.

Recently, evolutionary computation techniques [13] like genetic algorithm and evolutionary programming have been applied to solve the reactive power optimization problems. In [14], a differentially evolutionary algorithm has been proposed for optimal dispatch for reactive power and voltage control in power system operation studies. The inequality operational constraints were handled by penalty parameterless approach. He et al. [15] proposed a multi objective optimization approach to minimize both losses and payment for the reactive power service while maintaining voltage security margin of the system. In this paper, the problem of voltage stability enhancement is formulated as a non-linear optimization problem and a genetic algorithm-based approach is proposed to obtain the optimal settings of reactive power control variables. The algorithm is based on the minimization of an objective function which is the maximum of the L-indices at load buses.

Generally, binary strings are used to represent the decision variables of the optimization problem in the genetic population irrespective of the nature of the decision variables. The conventional binary-coded GA has Hamming cliff problems [16] which sometimes may cause difficulties in the case of coding continuous variables. Also, for discrete variables with total number of permissible choices not equal to 2^k (where k is an integer) it becomes difficult to use a fixed length binary coding to represent all permissible values. To overcome the above difficulties this paper proposes a flexible algorithm to solve the optimization problem. The proposed GA-based approach is applied to obtain the optimal control variables so as to improve the voltage stability level of the system under base case and against the critical single line outages in the system. The effectiveness of this algorithm is demonstrated through voltage stability improvement in IEEE 30-bus system and IEEE 57-bus test system.

2. Voltage stability index

Voltage stability analysis involves both static and dynamic factors. As dynamic computations are time consuming, the static approach is generally preferred for stability assessment and control. Static voltage stability analysis involves determination of an index called voltage stability index. This index is an approximate measure of closeness of the system to voltage collapse. There are various methods of determining the voltage stability index. One such method is L-index proposed in [1]. It is based on load flow analysis. Its value ranges from 0 (no load condition) to 1 (voltage collapse). The bus with the highest L-index value will be the most vulnerable bus in the system. The L-index calculation for a power system is briefly discussed below:

Consider a N-bus system in which there are N_g generators. The relationship between voltage and current can be expressed by the following expression:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{1}$$

where I_G, I_L and V_G, V_L represent currents and voltages at the generator buses and load buses.

Rearranging the above equation we get,

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{2}$$

Here

$$F_{LG} = -[Y_{LL}]^{-1}[Y_{LG}] \tag{3}$$

The L-index of the jth node is given by the expression,

$$L_j = \left| 1 - \sum_{i=1}^{N_g} F_{ji} \frac{V_i}{V_j} \quad \angle \quad (\theta_{ij} + \delta_i - \delta_j) \right| \tag{4}$$

where V_i, V_j are the voltage magnitude of ith and jth generator, θ_{ij} is phase angle of the term F_{ji}, δ_i, δ_j are the voltage phase angle of ith and jth generator unit.

The values of F_{ji} are obtained from the matrix F_{LG}. The L-indices for a given load condition are computed for all the load buses and the maximum of the L-indices ($L^{\max}$) gives the proximity of the system to voltage collapse. The indicator $L^{\max}$ is a quantitative measure for the estimation of the distance of the actual state of the system to the stability limit.

3. Problem formulation

We introduce the following notation:

G_{ij}, B_{ij}	conductance and susceptance of transmission line connected between ith and jth bus
P_i,Q_i	real and reactive power injection of ith bus
P_s	real power generation of slack bus
Q_{ci}	Reactive power generation of ith capacitor bank
V_{gi}	generator voltage magnitude at bus i
t_k	tap setting of transformer at branch k
N_l	number of transmission lines
N_C	number of capacitor banks
N_T	number of tap-setting transformer branches
N_{PV}	number of voltage buses
N_B	total number of buses
N_{PQ}	number of load buses
N_{B-1}	total number of buses excluding slack bus

Maintaining the specified voltage stability level under normal and contingency state is a major concern in the operation of power system. The basic idea behind the proposed voltage stability improvement scheme is to minimize the $L^{\max}$ value of the system through rescheduling of reactive power control variables while satisfying the unit and system constraints. This is mathematically stated as,

$$\text{Minimize } (L^{\max}) \tag{5}$$

Subject to

(i) Real power balance equation:

$$P_i - V_i \sum_{j=1}^{N_B} V_j [G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}] = 0; \qquad i = 1, 2, \ldots N_{B-1} \tag{6}$$

(ii) Reactive power balance equation:

$$Q_i - V_i \sum_{j=1}^{N_B} V_j [G_{ij} \cos \delta_{ij} - B_{ij} \sin \delta_{ij}] = 0; \qquad i = 1, 2, \ldots N_{PQ} \tag{7}$$

(iii) Slack bus real power generation limit:

$$P_s^{\min} \leqslant P_s \leqslant P_s^{\max} \tag{8}$$

(iv) Generator reactive power generation limit:

$$Q_{gi}^{\min} \leqslant Q_{gi} \leqslant Q_{gi}^{\max} \qquad i \in N_{PV} \tag{9}$$