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Voltage stability enhancement using VSC-OPF including wind farms based on Genetic algorithm

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ABSTRACT

This paper describes the impact of wind generation to enhance the voltage stability of power system in optimal power flow problem. In this work, the Voltage Stability Constrained Optimal Power Flow (VSCOPF) algorithm is used, which combines the economical aspects and the voltage stability control of power system networks. A voltage stability index called *L*-index has been utilized to identify the most sensitive node prone to voltage collapse. Here Improved Genetic Algorithm (IGA) with mixed form of representation has been used for multi-objective formulation. Real power setting and voltage magnitudes are represented as floating point numbers and transformer tap settings and capacitors as integers. For effecting genetic processing, crossover and mutation operator, which can be directly deal with floating point number and integers, are used. The IGA has been implemented on IEEE 30 bus system to study the impact of wind farm on voltage stability. The obtained simulation shows the effectiveness of Improved Genetic algorithm on voltage stability of the power systems.

Introduction

The Optimal Power Flow (OPF) problem is one of the important aspects of the modern power system. The aim of OPF is to minimize the total cost of generation by adjusting the power system control variables while satisfying the system design and operational requirements. There are several mathematical programming techniques proposed to solve the optimization problem. But due to non linear and non convex nature of power system, these methods do not guarantee for global optimization. Recently Evolutionary computation techniques like Genetic Algorithm (GA) [1] have been successfully applied to solve the OPF problems.

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.

In just a few decades, wind power has developed from alternative energy source to a new fast growing industrial branch. Today wind power plants produce electric power at competitive costs and contribute a large share of power in many countries.

This paper it shows the impact of wind turbine on contingency state voltage stability which is incorporated in the contingency constrained OPF formulation through the *L*-index value proposed by Kessel and Glavitsch [5].

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 [6,7] 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 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.

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Voltage stability index

Voltage stability analysis involves both static and dynamic factors. 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 [7]. 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 Ng generators.

For multi node system

$$I_{Bus} = Y_{Bus} * V_{Bus} \tag{1}$$

By separating the load buses from generator buses from equation

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

where I_G, I_L and V_G, V_L represents the current and voltage at generator and load buses.

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \tag{3}$$

Here

$$F_{LG} = -[Y_{LL}]^{-1} * [Y_{LG}] \tag{4}$$

The *L*-index of the *j*th node is given by the expression

$$L_f = \left| 1 - \sum_{i=1}^{N_g} F_{ji} \frac{V_i}{V_j} \angle(\theta_{ij} + \delta_i - \delta_j) \right| \tag{5}$$

where V_i, V_j are the voltage magnitude of *i*th and *j*th generator, θ_{ij} is phase angle of the term F_{ji}, δ_i, δ_j are the voltage phase angle of *i*th and *j*th generator unit. The values of F_{ji} are obtained from the matrix. 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.

Model of fixed speed WTGU (FSWTGU)

The power flow model for a FSWTGU system is developed [8], [11] in order to calculate the injected wind power of the FSWGTU system. FSWTGU system always draws reactive power from the grid. This type of WTGU has a squirrel cage induction generator which is driven by a wind turbine either having a fixed turbine blade angle (stall regulated fixed speed WTGU) or having a pitch controller to regulate the blade angle (pitch regulated fixed speed WTGU). In both these types of WTGU, the induction generator is directly connected to the grid. In the operating range the rotor speed varies within a very small range (around 5% of the nominal value) and hence, these are reckoned as fixed speed WTGU and is shown in Fig. 1. Normally in these WTGU a fixed shunt capacitor, can be used to provide reactive power compensation.

The method used in this work is stall regulated fixed speed wind turbine. The power output of this class of WTGU depends on the turbine and generator characteristics, wind speed, rotor speed and the terminal voltage.

In order to take this interdependency of rotor speed and voltage into account, the power output is calculated iteratively. For a given wind speed, the power output is computed for an assumed terminal voltage. The calculation is repeated if the computed power output results in a change in the terminal voltage. The power output calculation requires finding the rotor speed common to both the turbine and the generator. This rotor speed corresponds to the intersection of the turbine and the generator characteristics. Since the two characteristics are non-linear an iterative method has been developed for computing the rotor speed.

The passive stall regulated wind turbines [10] have their rotor blades bolted onto the hub at a fixed pitch angle (v). The wind turbine mechanical power output is a function of rotor speed as well as the wind speed and is expressed as,

$$P_m(u_w, \omega_r) = \frac{1}{2}\rho A v^3 C_p(\lambda, v) \tag{6}$$

where A is area swept by the rotor, ρ is density of air, u_w is wind speed, $C_p(\lambda, v)$ is the power coefficient, λ is the tip speed ratio which is equal to $\frac{\omega_r \eta R}{u_w}$, v is pitch angle ω_r is generator rotor angular speed, R is the rotor radius at turbine blades

The induction generator output in terms of ω_r and V the terminal voltage, is obtained by using the equivalent circuit of the induction machine shown in Fig. 2. From the equivalent circuit the expression for air gap power is obtained as:

$$C_P(u_w, w_r, v) = \frac{c_1\left(c_2\left(\frac{1}{(\lambda+0.08v)} - \frac{0.035}{(1+v^3)}\right) - c_3 v - c_3 v^x - c_5\right)}{\exp}\left(c_6 \Big/ \left(\frac{1}{(\lambda+0.08v)} - \frac{0.035}{(1+v^3)}\right)\right) \tag{7}$$

$$P_g = |I_2|^2 R_2 \frac{1-S}{S} \tag{8}$$

where I_2 is the rotor current.

For a given wind speed and terminal voltage, the rotor speed is determined by [8] equating the mechanical power input and the developed electrical power. Once the rotor speed is determined, the electrical power output can be computed.

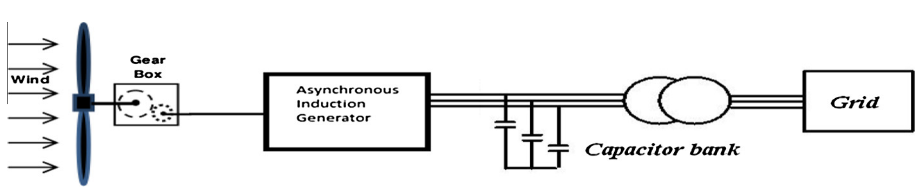

Fig. 1. Fixed speed wind turbine.