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Cat Swarm Optimization for optimal placement of multiple UPFC's in voltage stability enhancement under contingency

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ABSTRACT

Voltage stability categorized under various classifications of power system stability is considered one of the important subjects in power systems stability studies. A power system, experiencing disturbances, is at risks of voltage instability. Main reason for the cause of voltage instability is the sag in reactive power at various locations due to circuit contingencies classified under large disturbance voltage stability. The aim of this paper is to identify the optimal location of Unified Power Flow Controller in an interconnected power system under N-1 contingency. As the size and the cost of the FACTS devices are high, an optimal location and size has to be identified before they are actually installed. We are trying to improve the voltage profile and Maximum Loading Parameter using Unified Power Flow Controller while determining their optimal location based upon Cat Swarm Optimization.

1. Introduction

Due to continuous expansion of power system in accordance with the growing demand, stability studies have become a fascinated area for research in the modern day. Power system stability [13,14] is a very complex subject that has been challenging the power system engineers from the past three decades. Due to the continuous expansion of power systems to cater the needs of growing population, power system stability problems also are a continuous and fascinating area of study. When we operate a bulk power transmission network close to the voltage stability limit, it becomes difficult to control the reactive power demand for that system. Voltage stability is of major concern in power systems stability [10,11]. Main reason for the cause of voltage instability is due to the sag in reactive power at various locations in an interconnected power system network. Voltage stability is a problem in power systems which are heavily loaded, have a shortage of reactive power or faulted [19]. Although it usually has an involvement in one critical area, the problem of voltage stability concerns the whole power system. Voltage stability is concerned with the ability of a power system to maintain steady voltages at all buses in the system under normal operating conditions, and after being subjected to a disturbance. Instability may occur in the form of a progressive fall or rise of voltages at some buses. The possible outcome of voltage instability is a loss of integrity of the power system network or loss of load in the area where voltages reach unacceptably low values [17]. A power system at a given operating state is small disturbance voltage stable if, following any small disturbance such as unbalanced loads and load variations, voltages near loads are identical or close to the pre-disturbance values. Large disturbance voltage stability [10,11] refers to the system's ability to maintain steady voltages following large disturbances such as system faults, circuit contingencies or loss of generation. The voltages at various points after such a disturbance may reach the pre-disturbance values or not, leading to voltage sag at certain points. Though in India, power transmission and distribution systems have been centralized and cause of power system instability is very minimal, the line outages caused due to weather conditions is still being considered a serious problem. Reactive power deficiency and voltage degradation is serious during such situations. There is a necessity to throw light in this area to assess the voltage stability of an interconnected power system affected by such a contingency.

Using FACTS controllers [12] one can control the variables such as voltage magnitude and phase angle at chosen bus and line impedance where a voltage collapse is observed. Introducing FACTS devices is the most effective way for utilities to improve the voltage profile and voltage stability margin of the system. With the ongoing expansion and growth of the electric utility industry, including deregulation in many countries, numerous changes are continuously being introduced to a once predictable business. Although electricity is a highly engineered product, it is

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increasingly being considered and handled as a commodity. Flexible AC Transmission Systems (FACTS), provide proven technical solutions to address these new operating challenges being presented today. FACTS technologies allow for improved transmission system operation with minimal infrastructure investment, environmental impact, and implementation time compared to the construction of new transmission lines. Traditional solutions to upgrading the electrical transmission system infrastructure have been primarily in the form of new transmission lines, substations, and associated equipment. However, as experiences have proven over the past decade or more, the process to permit, site, and construct new transmission lines has become extremely difficult, expensive, time-consuming, and controversial. FACTS technologies [12] provide advanced solutions as cost-effective alternatives to new transmission line construction. The potential benefits of FACTS equipment are now widely recognized by the power systems engineering and T&D communities.

The aim of this paper is to identify the optimal location and size of Unified Power Flow Controller in an interconnected power system under N-1 contingency for voltage stability analysis. As the size and the cost of the FACTS devices are high, an optimal location and size has to be identified before they are actually installed. We are trying to improve the voltage profile and Maximum Loading Parameter using the FACTS controllers. Optimization techniques find a variety of use in many fields. As artificial intelligence techniques are improving day by day, the use of these techniques in power systems is playing an important role for the optimal location of FACTS devices. We are using Cat Swarm Optimization [5,6] to identify the optimal location and size of FACTS controllers. This is the first paper to introduce Cat Swarm Optimization technique for voltage stability analysis under contingency for the optimal placement of Unified Power Flow Controller.

2. Problem statement

A contingency is a failure or loss of an element (e.g., generator, transformer, transmission line, etc.), or a change of state of a device (e.g., the unplanned opening of a circuit breaker in a transformer substation) in the power system. Contingency analysis is essentially a "preview" analysis. It simulates and quantifies the results of problems that could occur in the power system in the immediate future. CA is used for the off-line analysis of contingency events, and show operators what would be the effects of future outages. This allows operators to be better prepared to react to outages by using pre-planned recovery scenarios. An "outage" is the removal of equipment from service. Line contingency refers to the removal of transmission line from the system. Where as in the case of generator contingency we assume that the particular generator is no longer a part of the system and usually the voltage variation is high. Both line contingency and generator contingency come under large disturbances. In this paper we are doing (N-1) line outage contingency analysis and we are trying to improve the voltage profile and Maximum Loading Parameter through the use of FACTS devices. (N-1) contingency refers to removal of transmission lines individually for (N-1) cases. At any instant only one particular line can be removed.

3. Objective function

The objective function is defined as follows

$$F = \{F_1, F_2, F_3\} \tag{1}$$

The functions F_1, F_2 and F_3 are defined and used in optimization process.

$$F = \Phi_1 F_1 + \Phi_2 F_2 + \Phi_3 F_3 \tag{2}$$

In our study, the fitness function is defined as a sum of three terms with individual criteria. The first part of the objective function concerns the voltages level. It is favorable that buses voltages be as close as possible to 1 p.u. Eq. (3) shows the voltage deviation in all buses.

$$F_1 = F_\mathrm{v} = \left[\sum_{\mathrm{i}=1}^{n_\mathrm{b}} (V_\mathrm{i} - 1)^2\right]^{1/2} \tag{3}$$

where n_b is the number of buses and V_i is the voltage of bus i.

F2-this function represents the optimal location and size of UPFC which has its dependence on F_1. This is related to having the minimum possible UPFC sizes regarding to the control of UPFC and is given by (4):

$$F_2 = F_\mathrm{S} = \alpha \sum_{\mathrm{j}=1}^{m} Q_\mathrm{j} \tag{4}$$

where 'm' is the number of UPFCs and 'Q_j' is the value of UPFC's kvar and 'α' is a weight in order that the terms in the fitness function are comparable in magnitude. Value of UPFC's kvar considering the control strategy and UPFC's model is achieved.

The maximum loadability of power system is extremely important and hence it is considered as the third part of the objective function. The third issue in our problem is determining inverse of maximum loadability, given as follows:

$$F_3 = F_\mathrm{SM} = 1/\lambda_\mathrm{Critical} \tag{5}$$

Therefore, the objective function is given by the following equation.

$$F = \Phi_1 F_\mathrm{V} + \Phi_2 F_\mathrm{S} + \Phi_3 F_\mathrm{SM} \tag{6}$$

The parameter that is used to examine system proximity to voltage collapse is called Maximum Loading Parameter, λ. In the bifurcation theory, it is assumed that system equations depend on a set of parameters together with state variables as shown in the equation below:

$$\Psi(\rho, \lambda) = 0 \tag{7}$$

Here, "ρ" is power system state variable and "λ" represents loading parameter. Stability or instability properties are assessed varying "slowly" these parameters.

The reason behind improving the Maximum Loading Parameter is to understand the maximum loadability limits of the interconnected power network and to determine the stability limits for run-up under secure conditions.

4. Test systems & software used

We are testing our algorithm here on two test systems: the 3-bus system and IEEE 14-bus system. The specifications of 3 bus system can be given as: Total number of buses used here are 3, total number of Lines used is 3, total Number of Generators is 1 and the total number of Loads is 2. The specifications of IEEE 14 bus system can be given as: the number of buses being 14, the number of Lines being 16, the generator count is 5 (including slack bus) and the number of loads being 11. Base MVA of 100 is assumed for the two test cases. All the analysis and testing here is performed in MATLAB [1]. Fig. 1 shows the 3 bus network and Fig. 2 displays the IEEE 14 bus network.

5. Cat Swarm Optimization and FACTS

5.1. Introduction to Cat Swarm Optimization

Optimization techniques find a variety of use in many fields. The use of these techniques in power systems is playing an