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Hybrid Mutation Particle Swarm Optimisation method for Available Transfer Capability enhancement

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ABSTRACT

A Hybrid Mutation Particle Swarm Optimisation (HMPSO) technique for improved estimation of Available Transfer Capability (ATC) as a decision criterion is proposed in this paper. First, this is achieved by comparing a typical application of the Particle Swarm Optimisation (PSO) technique with conventional Genetic Algorithm (GA) methods. Next, a multi-objective optimisation problem concerning optimal installation and capacity allocation of Flexible AC Transmission Systems (FACTSs) devices is presented and demonstrated.

Modern heuristic techniques such as PSO have been demonstrated to be suitable approaches in solving non-linear power system problems. The outcome of this research further demonstrates that with better utilisation of FACTS devices, it is possible to improve transmission capabilities.

The motivation of this research is a direct consequence of the deregulation of electricity industries and power markets worldwide. The current deregulated environment provides transmission systems operators (TSOs) with more options when procuring transmission services.

The effectiveness of the proposed algorithm is demonstrated across a range of case studies, and the results are validated through analyses conducted on IEEE 30-bus and 57-bus test systems.

1. Introduction

The liberalisation of electricity markets has created the need for researchers and practitioners to put forward better power systems optimisation techniques [1]. The open access to transmission networks enables international involvement in the global electrical power supply markets. The market forces and resultant squeeze on profit margins demand better utilisation of the existing transmission facilities [2,3]. Improvements to Available Transfer Capability (ATC) in power transmission systems are constrained by relatively low voltages and heavily loaded circuits and buses. FACTS devices offer a versatile alternative to conventional reinforcement methods through increased flexibility, lower cost and reduced environmental impacts. They provide new control facilities, both in steady state power flow control and dynamic stability control. Static VAr Compensator (SVC) and Thyristor Controlled Series Compensator (TCSC) are the most popular FACTS devices for effective parallel and series compensation in order to enhance ATC.

The capacity of transmission equipment can be improved without resorting to costly installation of new transmission networks. This can be achieved by prudent deployment of FACTS devices in the transmission system [4,35]. The deployment of series and parallel reactive compensators would improve ATC. Typically an optimisation method determines the capacity and the location of these compensators [5,36]. The multi objective optimisation problem that deals with deployment of FACTS devices in power networks is capable of handling conflicting objectives in different operational modes. The parameters for optimisation in this paper include ATC enhancement, voltage profile improvement and active power losses reduction. Moreover, the objectives are constrained by power flow limits, network reliability and system security [3,6].

The Particle Swarm Optimisation (PSO) method [7,37] is used in this paper to solve the problem of installation and capacity allocation of FACTS devices in power transmission networks. Over the last decade, PSO algorithms have been successfully deployed in power system optimisations studies [8–12,38]. One of the advantages of PSO is the capability of particles to share information amongst each other. For example, during a search process the particles can benefit from the discoveries and previous experiences of all other particles with solution information in the system, which in turn leads to higher overall solution speed. However, due to

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the multimodality of the objective function, the former advantage could seriously harm the search for a global optimal solution. The multi objective function may also degrade the diversity criteria of the algorithm, and reduce the global searching capability of the PSO algorithm [13].

In order to overcome this weakness and improve the overall solution process, a novel Hybrid Mutation PSO (HMPSO) method consisting of a standard PSO method and a new mutation operator is proposed in this paper. The proposed hybrid method combines fuzzy logic and the Analytical Hierarchy Process (AHP) to model the qualification of each problem objective [28], and prioritise of the objectives. The fitness evaluation applies the velocity of each particle to the global optimum point. A mutation operator that initiates artificial diversification in the particle population is embedded in the PSO to prevent premature convergence to a local optimum.

In the following section, the definition of the problem and the resultant mathematical formulation is discussed. In Section 3, the PSO and the novel HMPSO method are explained. In Section 4, the model is validated across a range of case studies followed by analysis of results. Section 5, outlines the concluding remarks.

2. Problem definition and mathematical modelling

This research focuses on a multi-objective optimisation problem. The problem is formulated in order to find the best location and capacity of FACTS devices. The objective function includes the enhancement of Available Transfer Capability (ATC), the maintenance of the voltage profile and minimisation of active power losses.

2.1. Problem definition and modelling

The most important goal is to enhance ATC with respect to the economical constraints of a typical interconnected network. In order to achieve this goal, a formal definition of ATC as well as its role in power system operation and control is presented in the first step.

2.1.1. Available Transfer Capability

According to the North American Electric Reliability Council (NERC), ATC is the difference between Total Transfer Capability (TTC) and the summation of the Existing Transmission Commitment (ETC), the Transmission Reliability Margin (TRM) and the Capacity Benefit Margin (CBM) [15]:

$$\mathrm{ATC} = \mathrm{TTC} - (\mathrm{ETC} + \mathrm{TRM} + \mathrm{CBM}) \tag{1}$$

The TTC is the largest transfer increase between the selected source and sink with no violation of any security constraints or contingency [14].

In order to calculate the TTC, the thermal and voltage limits are also considered. The three most practical and popular methods for calculating TTC are:

i. Repeated Power Flow (RPF) method [15].
ii. Continuation Power Flow (CPF) method [16].
iii. Security Constrained Optimal Power Flow (SCOPF) method [17].

The method adopted in this research to calculate TTC is based on a simple implementation of the RPF method, which is a suitable method for large-scale power systems in comparison with other methods [4]. The RPF method needs to trace the *PV* curve up to the nearest distance to the 'nose' point (at the nose point the RPF method will diverge). This offers the possibility of considering voltage stability in TTC calculation. According to the RPF method, the system load and power generation will be increased by a specified rate. The power increase continues until at least one of the system constraints related to TTC is breached. Variations in the real power generation and demand for each bus are shown in

$$P_{Gi} = P^{\circ}_{Gi}(1 + \lambda k_{Gi}) \tag{2}$$

$$P_{D} = P^{\circ}_{D}(1 + \lambda k_{Di}) \tag{3}$$

where P_{Gi} is the increased real power generation at bus i; P°_{Gi} the original real power generation at bus i; P_{Di} the increased real load demand at bus i; P°_{Di} the original real load demand at bus i; λ the scalar parameter; k_{Gi} the constant rate of changes in generation as λ varies; k_{Di} is the constant rate of changes in load as λ varies.

The reactive power demand (Q_D) is also increased to fix the power factor for all loads.

Therefore, TTC can then be calculated using the Eq. (4). The equation shows the maximum loadability of an electric power system before reaching the voltage collapse point along with the maximum exchange flows on interfaces, which have not violated the capacity limitation. Thereby, voltage limits and thermal limits are considered in TTC calculation. The TTC calculation is based on static consideration and does not account for the dynamic stability limitations.

$$\mathrm{TTC} = \min\left[\left(\sum_{i\in k} P_{Di}(\lambda_{\max}) - \sum_{i\in k} P^{\circ}_{Di}\right), \sum_{ij\in \text{Tie Lines}} P_{\text{Max}ij}\right] \tag{4}$$

where $\sum_{i\in k} P_{Di}(\lambda_{\max})$ is the sum of the load in sink area at $\lambda = \lambda_{\max}$, $\sum_{i\in k} P^{\circ}_{Di}$ is the sum of the load in sink area when $\lambda = 0$, and $\sum_{ij\in \text{Tie Lines}} P_{\text{Max}ij}$ is the sum of tie-lines capacity between the send and the sink area.

The Existing Transmission Commitment (ETC) is calculated using the power flow calculation. The Transmission Reliability Margin (TRM) is treated as a constant percentage (i.e. 10%) of the TTC. The Capacity Benefit Margin (CBM) can be based on the market value between energy contractors. For the sake of simplicity, CBM is assumed to be zero. Based on the above assumptions, ATC can be estimated by

$$\mathrm{ATC} = \mathrm{TTC} - \mathrm{ETC} - \mathrm{TRM} = (1 - k)\mathrm{TTC} - \mathrm{ETC} \tag{5}$$

where k is a predefined percentage of the calculated TTC. Voltage profile and active power losses are calculated using the power flow solution.

2.1.2. Static VAr Compensator (SVC) model

In the steady state case, an SVC can be modelled as a reactive power injection/absorption illustrated in Eq. (6) [18]:

$$Q_{SVC} = V_t(V_t - V_{ref})X_{SL} \tag{6}$$

where X_{SL} is the voltage control, V_t is the terminal voltage and V_{ref} is the reference voltage. Eq. (7) can be used as the alternative representation of Eq. (6):

$$Q_{SVC} = B_{SVC} \times V^2_{ref} \tag{7}$$

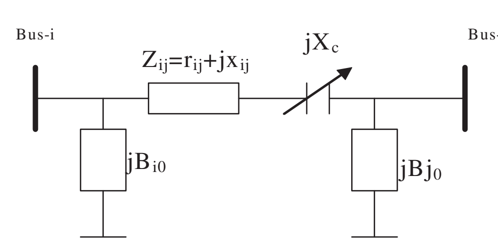

Fig. 1. Equivalent circuit of line with TCSC.