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ATC enhancement using TCSC via artificial intelligent techniques

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Abstract

Procurement of optimum available transfer capability (ATC) in the restructured electricity industry is a crucial challenge with regards to open access to transmission network. This paper presents an approach to determine the optimum location and optimum capacity of TCSC in order to improve ATC as well as voltage profile. Real genetic algorithm (RGA) associated with analytical hierarchy process (AHP) and fuzzy sets are implemented as a hybrid heuristic technique in this paper to optimize such a complicated problem. The effectiveness of the proposed methodology is examined through different case studies.

Keywords: Available transfer capability (ATC); Analytical hierarchy process (AHP); Real genetic algorithm (RGA); Flexible AC transmission systems (FACTS); Electricity markets

1. Introduction

Artificial intelligent techniques cover a broad spectrum of optimization methods in which the well-known field of expert systems or knowledge-based decision making is addressed [1]. Numerous applications of these techniques in power systems that have been reported in literature are artificial neural networks, fuzzy logic and evolutionary search algorithms. Fuzzy-based approaches are generally deal with uncertainties in power system planning as well as operating, while uncertainties can be handled via fuzzification of ambiguous variables by assigning membership functions [2]. Genetic algorithm (GA) as a powerful random search technique has broadly been applied in power systems optimization. Ordinary (binary) GA can be modified using real codes; the so-called real-GA (RGA), in which decoding is not needed while speed and accuracy of search might be increased [3]. To solve a multi-objective power system optimization problem; fuzzy optimization is a suitable candidate that is addressed in ref. [4]. Due to the complexity and highly non-linearity of large scale power systems, a hybridization of RGA and fuzzy-AHP is proposed in this paper. On the other hand, electricity industry around the world is undergoing restructuring in order to encourage competition in power markets. Under these conditions, the right of non-discriminatory open access to transmission facilities should be provided to all market participants. Transmission system operators (TSOs) are dealing with a major duty, the so-called available transfer capability (ATC) improvement, where lack of transfer capacity may have a direct effect on generation as well as transmission costs.

For the first time, ATC has been defined by the North American Electric Reliability Council (NERC) as: “a measure of the transfer capability remaining in the physical transmission network for further commercial activities over and above already committed uses” [5]. The main part of ATC is total transfer capability (TTC), which is the largest flow increase between the selected source/sink that transfers without violation of thermal limits, voltage limits as well as dynamic stability limits [6]. ATC enhancement is led to focus on the possible ways by which such constraints can be alleviated. In addition, power utilities must take into account the increased environmental sensitivity to potential reinforcement solutions.

Flexible AC transmission systems (FACTS) devices offer a versatile alternative to conventional reinforcement methods with potential advantages of increased flexibility, lower operation and maintenance costs with less environmental externalities [7]. They will provide new control facilities, both in steady

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state power flow control and dynamic stability control [1,8]. The possibility of controlling power flow in electric power systems without generation rescheduling or topological changes can considerably improve the system performance [9].

Thyristor controlled series capacitor (TCSC) as a FACTS device is an effective series compensation device, which can be used for the purpose of ATC improvement. In this paper, the impacts of using TCSC on enhancing TTC under steady state conditions are investigated. The location and the desired amount of compensation are determined via a hybrid heuristic optimization technique. The proposed method is based on the sensitivity analysis with respect to control parameters for ATC improvement. Reducing the capital costs of FACTS devices, improving voltage profile and ATC enhancement are considered as the three objectives, while the optimization process is handled through a combination of RGA, AHP and fuzzy as a hybrid heuristic approach. The modified IEEE 9_bus and 30_bus systems are used to examine the applicability of the proposed methodology. This paper is organized as follows: in Section 2, the optimization problem is defined and formulated. RGA algorithm is described in Section 3. Section 4 illustrates the proposed hybrid heuristic technique and RGA fitness value is defined. Section 5 presents and discusses the application of the proposed reliability model and the results are presented. The conclusion drawn from the analysis is provided in Section 6.

2. Problem definition and formulation

A multi-objective optimization algorithm is developed in this paper to determine the optimum location and capacity of TCSCs. The objective function includes three terms: optimum value of ATC, best voltage profile and minimum investment costs of TCSCs. The optimization model also includes the above-mentioned objectives associated with power flow equations as well as security/reliability constraints.

2.1. Optimization modeling

Location and capacity of TCSCs are defined as control variables in the optimization problem. The general formulation can be expressed by Eq. (1):

$$Z = \mathrm{Optim}(O_{\mathrm{ATC}} + O_{\mathrm{Voltage}} + O_{\mathrm{Capital\ Cost}})$$

$$\text{s.t.}\begin{cases} P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j|(G_{ij-\mathrm{FACTS}}\cos\delta_{ij} + B_{ij-\mathrm{FACTS}}\sin\delta_{ij}) = 0 \\ Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |V_i||V_j|(G_{ij-\mathrm{FACTS}}\sin\delta_{ij} - B_{ij-\mathrm{FACTS}}\cos\delta_{ij}) = 0 \\ |V_i|_{\min} \le |V_i| \le |V_i|_{\max} \\ S_{ij} \le S_{ij}^{\max} \\ P_{G_{\min}} \le P_{G_i} \le P_{G_{\max}} \quad i = 1, \ldots, N_G \\ Q_{G_{\min}} \le Q_{G_i} \le Q_{G_{\max}} \quad i = 1, \ldots, N_G \\ X_{\min}^{\mathrm{TCSC}} \le X^{\mathrm{TCSC}} \le X_{\max}^{\mathrm{TCSC}} \end{cases} \tag{1}$$

where O_{ATC} is the value of ATC, O_{voltage} the voltage profile vector, P_{Gi} and Q_{Gi} the real and reactive power generation at bus i, P_{Di} and Q_{Di} the real and reactive load demand at bus i, n the total number of buses, $|V_i|$ the voltage magnitude at bus i, $G_{ij-\mathrm{FACTS}}$, the real part of the ijth element of Y_{bus} matrix including FACTS devices, $B_{ij-\mathrm{FACTS}}$ the imaginary part of the ijth element of Y_{bus} matrix including FACTS devices, S_{ij} the apparent power flow in line ij, $S_{ij\,\max}$ the thermal limit of line ij, N_G the number of generators, $P_{G_{\max}}/P_{G_{\min}}$ the maximum and minimum real power generation at bus i, respectively, $Q_{G_{\max}}/Q_{G_{\min}}$ the maximum and minimum reactive power generation at bus i, respectively, and X^{TCSC} is the TCSC reactance.

Here, TCSC is modeled as a variable capacitor with the capacity limited up to 60% of the corresponding line reactance indicating that $X_{\min}^{\mathrm{TCSC}} = 0$, $X_{\max}^{\mathrm{TCSC}} = 60\%$ of the line reactance. The objective function including three terms is required to be mathematically modeled.

2.1.1. Total transfer capability calculation

NERC established a framework for determining ATC of an interconnected network for a commercially viable wholesale electricity market [5]. ATC is consisted of the following terms and definitions: TTC is the maximum power transfer that causes no limit violations, while the sum of existing transmission commitment between two areas is defined as ETC. Transmission reliability margin (TRM) is the amount of transmission capability necessary to ensure that the interconnected system under a reasonable range of uncertainty is secure. Capacity benefit margin (CBM) is the amount of transfer capability reserved by load serving entities to guarantee access to generation from interconnected systems to meet generation reliability requirements [5]. Thus, ATC can be formulated as:

$$\mathrm{ATC} = \mathrm{TTC} - \mathrm{TRM} - \mathrm{ETC} - \mathrm{CBM} \tag{2}$$

TTC is the key component in ATC calculation and is defined as the maximum value of power transfer that causes no limit violations, with or without any contingency. Although various mathematical methods have been developed to calculate TTC, the popularly applied methods can be categorized as follows [10]:

- repeated power flow (RPF) method [10,11];
- continuation power flow (CPF) method [11,12];
- security constrained optimal power flow (SCOPF) method [10,13].

RPF method repeatedly solves power flow equations and is used in this paper, for TTC calculation. The implementation of RPF provides some part of PV/QV curves, which offer the possibility of taking voltage stability criterion into account [10].

2.1.2. TCSC modeling

Transmission lines are represented by lumped π equivalent circuits. A series compensator TCSC is simply a static capacitor/reactor with impedance "jX_c" as shown in Fig. 1 [14].