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Optimal location of STATCOM using chemical reaction optimization for reactive power dispatch problem

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Abstract Optimal reactive power dispatch (ORPD) problem has a significant influence on optimal operation of power systems. However, getting optimal solution of ORPD problem is a strenuous task for the researchers. The inclusion of flexible AC transmission system (FACTS) devices in the power system network for solving ORPD problem adds to its complexity. This paper presents the application of chemical reaction optimization (CRO) for optimal allocation of a static synchronous compensator (STATCOM) to minimize the transmission loss, improve the voltage profile and voltage stability in a power system. The proposed approach is carried out on IEEE 30-bus and IEEE 57-bus test systems and the simulation results are presented to validate the effectiveness of the proposed method. The results show that the proposed approach can converge to the optimum solution and obtains better solutions as compared to other methods reported in the literature.

1. Introduction

The electric power grid is the largest man-made machine in the world. It consists of synchronous generators, transformers, transmission lines, switches and relays, active/reactive components, and loads. Power system networks are complex systems that are nonlinear, non-stationary, and prone to disturbances and faults. Reinforcement of a power system can be accomplished by improving the voltage profile, increasing the transmission capacity and others. Nevertheless, some of these solutions may require considerable investment that could be difficult to recover. FACTS devices are an alternate solution to address some of those problems [1,2].

Optimal reactive power dispatch (ORPD) is an important tool for power system operators for both planning and reliable operation in the present day power systems. The important aspect of ORPD is to determine the optimal settings of control variables for minimizing transmission loss, improve the

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voltage profile and voltage stability, while satisfying various equality and inequality constraints. The ORPD problem is in general non-convex and non-linear and exists many local minima.

Over the last two decades, many researchers performed a lot of researches on ORPD. Various optimization techniques are evolved to solve ORPD problem. These algorithms are generally divided into two categories, namely, classical mathematical optimization algorithms and intelligent optimization algorithms. The classical algorithms are starting from an initial point, continuously improve the current solution through a certain orbit, and ultimately converging to the optimal solution. These algorithms include linear programming (LP) [3] quadratic programming (QP) [4], non-linear programming (NLP) [5] and mixed integer linear programming (MILP) [6], and benders decomposition [7]. Though, some of these techniques, have a good convergence but most of them suffer from local optimality. Since ORPD is multimodal and non-linear optimization problem and severely depends on the initial guess, the classical techniques are unable to produce global optimal solution. To overcome this deficiency, various intelligent optimization algorithms known as heuristic techniques are applied to solve ORPD problem. Some of the well popular optimization techniques are evolutionary programming (EP) [8], genetic algorithm (GA) [9,10], simulated annealing (SA) [11,12], tabu search (TS) [13,14], differential evolution (DE) [15,16], particle swarm optimization (PSO) [17,18] and artificial bee colony (ABC) [19], etc. Recently, a harmony search algorithm (HSA) was developed by Sirjani et al. [20] for simultaneous minimization of total cost, the voltage stability index, voltage profile and power loss of IEEE 57-bus test system using shunt capacitors, SVC and static synchronous compensators (STATCOM). Saravanan et al. presented PSO [21] to find optimal settings and location TCSC, SVC and UPFC devices for improving system load ability with minimum cost of installation.

The literature survey shows that most of the population based techniques successfully solved optimal located FACTS based ORPD problem. However, the slow convergence toward the optimal solution is the main concern for most of these heuristics algorithms. Furthermore, these techniques often produce the local optimal solution rather than global optimal solution.

In this article, a recently developed heuristic algorithm named chemical reaction optimization (CRO) algorithm based on the different chemical reactions on the molecular structure of molecules, introduced by Lam et al. in 2010 is used to find the optimal location of STATCOM device for solving ORPD problem. The effectiveness of the proposed CRO algorithm is demonstrated by implementing it in two standard systems namely IEEE 30-bus and IEEE 57-bus systems and its performance is compared with PSO, DE and other optimization techniques recently published in the literature.

The remaining sections of this paper are organized as follows: Section 2 describes the problem formulation of ORPD problem. Section 3 briefly describes the CRO technique and the different steps of the proposed CRO approach. Section 4 discusses the computational procedure and analyzes the DE, PSO and CRO results when applied to case studies of FACTS based ORPD problem. Lastly, Section 5 outlines the conclusions.

2. Mathematical problem formulation

2.1. Static model and mathematical analysis of static synchronous compensator

Although, there are several FACTS devices for controlling power flow [22] and voltage profile in power system, for this study, only STATCOM device is considered to minimize the transmission loss, improve the voltage profile and voltage stability of power system network. Static model of this FACTS device is as described below.

Static synchronous compensator (STATCOM) is connected in parallel with the specific bus of a power system. The primary goal of STATCOM is to enhance the reactive power compensation which adjusts the reactive power and voltage magnitude of power system network. It consists of three basic components, namely, transformer, voltage source converter (VSC) and capacitor. The STATCOM is modeled as a controllable voltage source (E_p) in series with an impedance [23]. The real part of this impedance represents the cupper losses of the coupling transformer and converter, while the imaginary part of this impedance represents the leakage reactance of the coupling transformer. STATCOM absorbs requisite amount of reactive power from the grid to keep the bus voltage within reasonable range for all power system loading. Fig. 1 shows the circuit model of a STATCOM connected to the ith bus of a power system. The injected active and reactive power flow equation of the ith bus are given below:

$$P_i = G_p|V_i|^2 - |V_i||E_p||Y_p|\cos(\delta_i - \delta_p - \theta_p) + \sum_{j=1}^{N}|V_i||V_j||Y_{ij}|\cos(\delta_i - \delta_j - \theta_{ij}) \quad (1)$$

$$Q_i = -B_p|V_i|^2 - |V_i||E_p||Y_p|\sin(\delta_i - \delta_p - \theta_p) + \sum_{j=1}^{N}|V_i||V_j||Y_{ij}|\sin(\delta_i - \delta_j - \theta_{ij}) \quad (2)$$

The implementation of STATCOM in transmission system introduces two state variables ($|E_p|$ and δ_p); however, $|V_i|$ is known for STATCOM connected bus. It may be assumed that

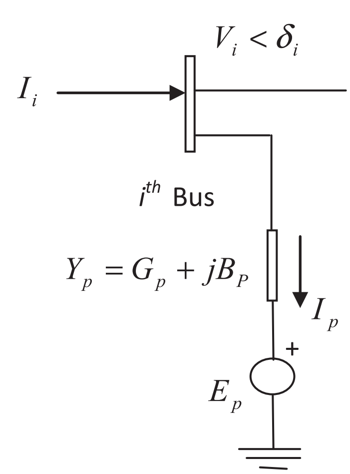

Figure 1 Schematic static model of STATCOM.