Electrical Power and Energy Systems 43 (2012) 562–572

Contents lists available at SciVerse ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal allocation of shunt Var compensators in power systems using a novel global harmony search algorithm

Reza Sirjani *, Azah Mohamed, Hussain Shareef

Department of Electrical, Electronic and Systems Engineering, Universiti Kebangsaan Malaysia (UKM), 43600 Bangi, Selangor, Malaysia

ARTICLE INFO

Article history:
Received 13 March 2012
Received in revised form 25 May 2012
Accepted 29 May 2012
Available online 7 July 2012

Keywords:
Shunt Var compensators
Power loss
Modal analysis
Voltage profile
Harmony search algorithm

ABSTRACT

In this paper, a novel global harmony search algorithm (NGHS) is used to determine the optimal location and size of shunt reactive power compensators such as shunt capacitors, static Var compensators (SVCs), and static synchronous compensators (STATCOMs) in a transmission network. The problem is decomposed into two subproblems. The first deals with the optimal placement of shunt Var compensation devices using the modal analysis method. The second subproblem is the optimization of the load flow using the NGHS algorithm. A multi-criterion objective function is defined to enhance the voltage stability, improve the voltage profile, and minimize power loss while minimizing the total cost. The results from a 57-bus test system show that the NGHS algorithm causes lower power loss and has better voltage profile and greater voltage stability than the improved harmony search algorithm (IHS) and particle swarm optimization (PSO) techniques in solving the placement and sizing problem of shunt Var compensators. Finally, a comparison of the convergence characteristics of three optimization methods demonstrates the greater accuracy and higher speed of the proposed NGHS algorithm in finding better solutions compared with PSO and IHS.

1. Introduction

Shunt compensation is used to influence the natural electrical characteristics of transmission lines to increase the steady-state transmittable power and control the voltage profile along the line [1]. Providing adequate reactive power support at the appropriate location not only leads to a reduction in the power loss and improvement in the voltage profile, but also solves voltage instability problems. Many reactive compensation devices are used by modern electric power utilities for this purpose, and each device has its own characteristics and limitations. At present, utilities aim to achieve this purpose using the most beneficial compensation device [2].

Traditionally, shunt capacitors are installed in power networks to compensate for reactive power. They are used for many purposes, such as power loss reduction, voltage profile improvement, and increasing the maximum transmitted power in cables and transformers [3]. Among the reactive compensation devices, shunt flexible AC transmission system (FACTS) devices play an important role in controlling the flow of reactive power to the power network, thereby affecting the system voltage fluctuations and stability [4]. The static Var compensator (SVC) is the most widely used shunt FACTS device in power networks because of its low cost and good performance in system enhancement. It is a shunt-connected static Var generator or absorber with an adjustable output, which allows the exchange of the capacitive or inductive current so as to provide voltage support. When installed at a proper location, the SVC can also reduce power losses [5]. The static synchronous compensator (STATCOM) is also a shunt compensator and one of the important members of the FACTS family that are increasingly being used in long transmission lines in modern power systems. STATCOMs can have various applications in the operation and control of a power system, such as in power flow scheduling, reducing the number of unsymmetrical components that damp the power oscillations, and enhancing the transient stability [3]. The shunt capacitor, SVC, and STATCOM increase the static voltage stability margin and power transfer capability. However, SVC and STACOM perform better in terms of reducing the loss and improving the voltage profile [2]. The increase in losses when a shunt capacitor is used under lightly loaded conditions is due to poor voltage profile. Overall, SVC and STACOM behave better than a simple shunt capacitor; however, these controllers are more expensive [2]. The benefits of reactive power compensation greatly depend on the placement and size of the added compensators. The installation of shunt controllers in all buses is impossible and unnecessary because of economical considerations. Identifying the best location for Var compensators involves the calculation of steady-state conditions for the network. However, the problem becomes highly complex because of the nonlinearity of the load flow

* Corresponding author. Tel.: +60 166191510.
E-mail address: sirjani@eng.ukm.my (R. Sirjani).

0142-0615/$ - see front matter
http://dx.doi.org/10.1016/j.ijepes.2012.05.068

equations, and an extensive investigation has to be undertaken in order to solve it. Several studies on the use of these controllers for voltage and angle stability applications have been conducted and reported in literature. A variety of techniques are used to optimize the allocation of these devices in power systems. At present, the shunt Var compensator placement problem is generally solved using evolutionary programming methods.

Numerous techniques for solving the optimal capacitor placement problem in power systems have been reported. These techniques may be classified into the following categories: analytical, numerical programming, heuristic, and artificial intelligence-based techniques [6]. Of these, the heuristic-based techniques have been widely applied in solving the optimal capacitor placement problem [7]. Several methods and approaches to determining the optimal location of SVC in the power system have been reported in literature, and different techniques, such as the genetic algorithm (GA), simulated annealing (SA), artificial immune system (AIS), and particle swarm optimization (PSO), have been used [8]. A solution algorithm based on SA is used to determine the location, types, and sizes of Var sources, as well as their settings at different loading conditions [9]. The purchase, installation, and total costs of energy loss over the life of Var sources are minimized by considering the operational constraints [9]. In [10], GA is used to determine the best location of only one SVC within a power system, in which the objective function is to reduce the power loss, voltage deviation, and cost. An AIS technique is used to minimize the total loss and improve the voltage in a power system [11] by determining the correct SVC placement. The well-known PSO is explored in [12] to obtain the optimal locations of SVCs in the IEEE 30 bus system. In [13], a new method is proposed to optimally locate the STATCOMs in distribution networks. The suggested approach uses sensitivity analysis and a genetic algorithm (GA). A step-by-step sensitivity analysis approach is utilized to determine the optimal placement of compensators. The objective function takes into account the voltage stability, the reduction of active losses, and the reduction of the reactive power of the network. The use of PSO for the sizing and location of a STATCOM in a power system while considering voltage deviation constraints is demonstrated in [14]. Results from their illustrative example show that the PSO algorithm can find the best size and location, with statistical significance and a high degree of convergence, when evaluating the minimum, maximum, average, and standard deviation values of the voltage deviation metric. The performance of the enhanced PSO algorithm is compared with classical optimization approaches in [15] using a case study of the optimal allocation of STATCOM devices while considering steady-state and economic criteria. The application of PSO and the continuation power flow (CPF) for the optimal allocation of multiple STATCOMs is also introduced in [4]. The goal of the optimization is to improve the voltage profile, minimize the total power system loss, and maximize the system loadability while considering the size of the STATCOMs.

This paper uses a new optimization technique, referred to as the novel global harmony search (NGHS) algorithm, to find the optimum placement and sizing of shunt Var compensators in power systems. The harmony search (HS) algorithm is a metaheuristic optimization method that is inspired by musicians adjusting the pitches of their instruments to find better harmony [16]. It has several advantages over other methods, one of which is that it does not require initial value settings for the decision variables, and that it can handle both discrete and continuous variables.

The HS algorithm is successfully applied to a wide range of optimization problems, especially in electrical engineering. In [17], a harmony search approach is presented for annual reconfiguration in electric distribution networks considering annual load level and switching costs. A multi-objective harmony search (MOHS) algorithm for optimal power flow (OPF) problem is proposed in [18]. The HS algorithm is implemented to the optimal reactive power dispatch problem for determination of the global or near global optimum solution [19]. In [20], the concept of opposition-based learning is employed to accelerate the HS algorithm. The potential of the proposed algorithm is assessed by means of an extensive comparative study of the solution obtained for four standard combined economic and emission dispatch problems of power systems [20]. The application of a hybrid harmony search algorithm to the Spread-Spectrum Radar Polyphase (SSRP) codes design is presented in [21]. The results have demonstrated that the proposed hybrid harmony search algorithm is a robust algorithm capable to outperform previous heuristic approaches tailored for this specific optimization problem. A harmony search approach has been presented for centralized and distributed spectrum channel assignment in cognitive wireless networks [22]. In the proposed algorithm, a novel single-parametric logarithmic progression of the parameters has been employed which allowed balancing the trade-off between the explorative and exploitative behavior of the heuristic allocation procedure [22].

Recently, the novel global harmony search (NGHS) algorithm is proposed to solve complex problems [23,24]. The NGHS is a modified version of the HS algorithm, and is inspired by the swarm intelligence of the PSO algorithm. The NGHS is a simple but practical optimization algorithm. In previous works, the authors of the present paper have successfully applied the improved harmony search (IHS) algorithm for determining the optimal location and size of shunt capacitors in a radial distribution network [7]. Furthermore, a multi-objective Improved Harmony Search (IHS) algorithm has been employed to optimal placement and sizing of only SVCs in a transmission system [5]. In this paper, a novel global harmony search (NGHS) algorithm is used to optimal placement and sizing of multi-Var compensators in power systems.

In the present paper, the suitable buses are first identified using modal analysis. The NGHS algorithm is then used to determine the amount of shunt compensation required to minimize loss and improve the voltage and voltage stability with respect to the total cost. The results obtained using the proposed algorithms in a 57-bus test system are compared with that of other optimization methods for validation.

2. Shunt capacitor, SVC, and STATCOM

Shunt compensation can be used to provide reactive power compensation. Traditional shunt capacitors or newly introduced FACTS controllers can be used for this purpose. FACTS controllers are very expensive; Table 1 gives an idea of the cost of various shunt controllers [25,26]. Descriptions of each of these controllers are given in the next subsections [2].

2.1. Shunt capacitor

Shunt capacitors are relatively inexpensive to install and maintain, and installing them in the load area or at the point where they are needed increases the voltage stability. However, They have poor voltage regulation and, beyond a certain level of compensation, a stable operating point is unattainable. Furthermore, the reactive power delivered by the shunt capacitor is proportional

Table 1
Cost comparison of shunt controllers (US $/kVar).

Shunt controller	Cost (US $/kVar)
Shunt capacitor	8
SVC	40 (controlled portion)
STATCOM	50 (controlled portion)