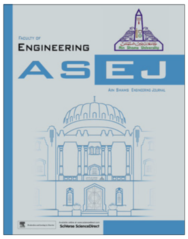
Ain Shams Engineering Journal (2015) **xxx**, xxx–xxx

Ain Shams University

Ain Shams Engineering Journal

www.elsevier.com/locate/asej
www.sciencedirect.com



A review of meta-heuristic algorithms for reactive power planning problem

Abdullah M. Shaheen [a,*], **Shimaa R. Spea** [b], **Sobhy M. Farrag** [c], **Mohammed A. Abido** [d]

[a] *South Delta Electricity Distribution Company (SDEDCo), Ministry of Electricity, Tanta, Egypt*
[b] *Electrical Engineering Department, Faculty of Engineering, Menoufiya University, Egypt*
[c] *Electrical Power Systems, Electrical Engineering Department, Faculty of Engineering, Menoufiya University, Egypt*
[d] *Electrical Engineering Department, King Fahd University of Petroleum and Minerals, Saudi Arabia*

Received 14 June 2015; revised 9 October 2015; accepted 4 December 2015

KEYWORDS

Reactive power planning;
Multi-objective optimization;
Arithmetic programming methods;
Meta-heuristic optimization techniques;
Hybrid techniques

Abstract Reactive power planning (RPP) is generally defined as an optimal allocation of additional reactive power sources that should be installed in the network for a predefined horizon of planning at minimum cost while satisfying equality and inequality constraints. The optimal placements of new VAR sources can be selected according to certain indices related to the objectives to be studied. In this paper, various solution methods for solving the RPP problem are extensively reviewed which are generally categorized into analytical approaches, arithmetic programming approaches, and meta-heuristic optimization techniques. The research focuses on the disparate applications of meta-heuristic algorithms for solving the RPP problem. They are subcategorized into evolution based, and swarm intelligence. Also, a study is performed via the multi-objective formulations of reactive power planning and operations to clarify their merits and demerits.

1. Introduction

Nowadays, reactive power planning (RPP) problem has become one of the most challenging problems in power systems. It has been an important stage of transmission expansion planning (TEP) problem in recent years [1–3]. In addition, reactive power control/dispatch is an important function in the planning process for the future of power systems. It aims to utilize all the reactive power sources efficiently, which are suitably located and sized in the planning process [4–10].

Generally, the various RPP solutions are divided into three groups which are analytical approaches [11–13], arithmetic programming approaches [3,4,11,12–15,16(Ch. 2),17(Ch. 3),18–23], and meta-heuristic optimization techniques. Various Meta-heuristic Optimization Algorithms (MOA) have been applied to the RPP problem such as Genetic Algorithms (GA) [5,24–33], Differential Evolution (DE) [6,17,24,34–42],

---

[*] Corresponding author. Tel.: +20 1141520206.
E-mail addresses: engabdoushaheen@yahoo.com (A.M. Shaheen), shi_spea@yahoo.com (S.R. Spea), sobhy_f@hotmail.com (S.M. Farrag), mabido@kfupm.edu.sa (M.A. Abido).

Peer review under responsibility of Ain Shams University.

ELSEVIER **Production and hosting by Elsevier**

http://dx.doi.org/10.1016/j.asej.2015.12.003
2090-4479 © 2015 Faculty of Engineering, Ain Shams University. Production and hosting by Elsevier B.V.

Please cite this article in press as: Shaheen AM et al., A review of meta-heuristic algorithms for reactive power planning problem, Ain Shams Eng J (2015), http://dx.doi.org/10.1016/j.asej.2015.12.003

Harmony Search (HS) [43–45], Seeker Optimization Algorithm (SOA) [46–48], Evolutionary Programming (EP) [49–54], Ant Colony Optimization (ACO) [7,55], Immune Algorithm (IA) [8], Particle Swarm Optimization (PSO) [2,9,16,56–58], Artificial Bee Colony (ABC) [59], Gravitational Search Algorithm (GSA) [60,61], Firefly Algorithm (FA) [62], Teaching Learning Algorithm (TLA) [63], Chemical Reaction Optimization (CRO) [64], Water Cycle Algorithm (WCA) [65], and Differential Search Algorithm (DSA) [66]. Hybrid techniques have been suggested in some researches that make use of advantages of different algorithms simultaneously to improve the quality of solution [5,10,16(Ch. 5),53,55,67–75].

Also, multi-objective formulation of optimization problems for reactive power planning and operation has been treated using the mathematical sum approach [1,11,24,25,28,35–38,50,51,53,56,68], weighting functions [27,29,40,43,44,47,69], ε-constraint approach [6,18,20,43,76,77], fuzzy goal programming techniques [28,58], and Pareto concept [4,8,16(Ch. 4),17,26,31–34,57].

Various conventional methods have been presented to solve the RPP problem and assured their incompetence in handling multi-objective nonlinear problems and they may converge to a local optimum. MOAs that mimic the nature opened a new era in computation. For the past decades, numerous research applications of MOAs have been concentrated for solving the RPP problem. In this particular area, the research is still young which broadens the scope and viability of MOAs exploring new modifications and developments in solving the RPP problem. This paper presents a broad overview of solution methods for solving the RPP problem which are analytical approaches, arithmetic programming approaches, and meta-heuristic optimization techniques. Also, the different applications of meta-heuristic algorithms for solving the RPP problem are extensively reviewed and thoroughly discussed. Furthermore, the multi-objective formulations of reactive power planning and operations are studied to clarify their merits and demerits. This paper is organized as follows. The formulation of the RPP problem is presented in Section 2. Section 3 discusses the different methods applied to solve the RPP problem. The multi-objective formulations of the RPP problem are discussed in Section 4. The concluding remarks are highlighted in Section 5.

2. General formulation of the RPP problem

The purpose of the RPP problem is to determine "where" and "how many" new VAR compensators must be added to a network for a predefined horizon of planning at minimum cost while satisfying an adequate voltage profile during normal conditions and contingencies. Fig. 1 illustrates the flowchart of the RPP problem.

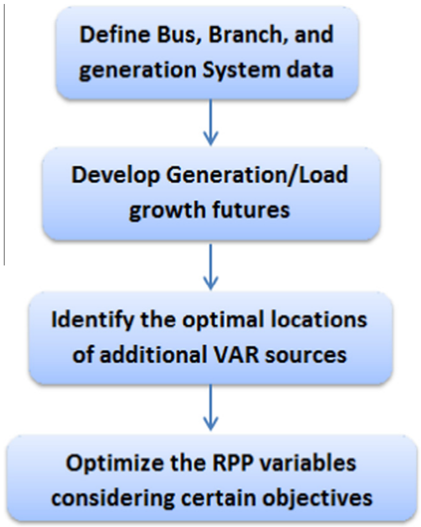


Figure 1 Flowchart of the RPP problem.

After defining the system data, the generation/load patterns are developed for a predefined horizon of planning. Then, the optimal locations of new reactive power sources are identified. They may be selected according to certain indices or all load buses may be considered as candidate buses [14,15].

After that, the control variables (RPP variables) are optimized to achieve certain objective functions subject to set of equality and inequality constraints. Control variables include generator bus terminal voltages, reactive power generation of existing and new VAR sources and transformer tap ratio. The generator bus voltages are continuous in nature, while both reactive power generation of existing and new VAR sources and transformer tap ratio are discrete. The dependent variables include load bus voltage magnitude, active power generation at slack bus, the power flows through the transmission lines, and reactive power outputs of the generators.

There are various objective functions that have been utilized in the RPP problem such as minimization of VAR investment cost and system operational cost of real power losses, improvement of voltage profile, and enhancement of voltage stability. However, the modeling of each objective has different shapes. Conventionally, the classical objective of the RPP problem is to achieve the minimum investment cost of additional reactive power supplies and minimize the system operational cost of power losses [1,11,24,25,28,35–38,50,51,53,56,68] as follows:

$$\text{Min } F = \text{Min}(I_C + O_C) \tag{1}$$

where I_C is the investment cost of new reactive power supplies and O_C is the operational cost of power losses. The investment costs of VAR sources can be generally modeled with two components, a fixed installation cost at bus i (e_i) and a variable purchase cost of capacitive or inductive source at bus i ($C_{ci}|Q_{ci}|$), [16,24–26,28,31,34,35,37,38,50,51,53,56,68] as follows:

$$I_C = \sum_{i=1}^{N_c} (e_i + C_{c_i}|Q_{c_i}|) \tag{2}$$

where N_c is the reactive compensator buses. This model requires considering the reactive power devices to be already installed before the optimization for its size. On the other hand, another general model of I_C has been used as [1–3,27,43]:

$$I_C = \sum_{i=1}^{N_b} (e_i + C_{c_i}|Q_{c_i}|)\beta_C \tag{3}$$

where N_b is the total number of busses, and β_C is the binary decision variables for installing capacitive source. Although the complexity of using binary variables to indicate whether the VAR source will be installed, this model will give a chance

Please cite this article in press as: Shaheen AM et al., A review of meta-heuristic algorithms for reactive power planning problem, Ain Shams Eng J (2015), http://dx.doi.org/10.1016/j.asej.2015.12.003