Annals of Electrical and Electronic Engineering, 2(7) 2019, Pages: 16-21

Published by IASE

Annals of Electrical and Electronic Engineering

Journal homepage: www.aeeej.org

Genetic algorithm based optimization method for reactive power management

F. Oliynyk, A. Kolisnyk, S. Ponomarenko *

Institute of Power Engineering and Control Systems, Lviv Polytechnic National University, Lviv, Ukraine

ARTICLE INFO

Article history:
Received 18 February 2019
Received in revised form
15 June 2019
Accepted 15 June 2019

Keywords:
GA
Voltage
Reactive
Generators

ABSTRACT

Reactive power management is a complicated and nonlinear problem. With the development of computer-based methods, some new methods have been proposed for this problem. The nature-based optimization algorithms are an efficient way of solving the nonlinear and not differentiable functions. One of the interesting of these algorithms is a genetic algorithm or GA. In this study, we proposed the application of a genetic algorithm for solving reactive power optimization. The proposed method must find the best parameters of power network including the generator node voltage, the transformers tap situation, and the parallel compensators value. In existing electrical power networks, these variables don't consider and all capacity of the system didn't use. In the traditional power network, the voltage profile is weak and the active power loss in transmission lines is high. With optimizing the reactive power control parameters, the voltage profile improved and the active power loss will be reduced significantly. In order to test the proposed system, the IEEE standard 25-node network is chosen. The simulation results show that the proposed method has a good effect on system performance.

1. Introduction

In modern electrical power network many problem merged such as weak voltage profile, active power loss in transmission lines, low power factor. These problems can be removed or modified by reactive power compensation. There are many different methods and techniques for reactive power compensation. The first one is capacitor placement in different nodes of electrical power network. In last year's many intelligent approaches have been proposed for optimal capacitor placement in power network. These methods are based on nature based optimization algorithm (Lee et al., 2015; Vuletić and Todorovski, 2014; Shuaib et al., 2015; Mukherjee and Goswami, 2014; Elsheikh et al., 2014; Sultana and Roy, 2014). The second method is FACTS devices that introduced in 1980s. There are several FACTS devices such as SVC, STATCOM and UPFC. In last year's many techniques based on FACTS devices are introduced for system quality improvement. Also many control system have been proposed to control these devices (Sreejith et al., 2015; Balamurugan et al., 2015; Dash et al., 2015; Gasperic and Mihalic, 2015; Castoldi et al., 2014; Kumar and Mittapalli, 2014).

The mentioned methods to reactive power control have some financial investment. These problems restrict the usage of these methods. The one efficient method to reactive power control is setting of reactive power control variables. The setting of reactive power control variables involve of tuning of synchronous generators voltage magnitude, the position of power transformers tap, the value of parallel capacitors, the value of inductors. In this problem the voltage of synchronous generators is continuous variable and the position of power transformers tap, the value of parallel capacitors, the value of inductors are discrete. The management of reactive power is very complicated optimization problem. This problem has many limitation and variables that must be considered. All the variables have its special search space. Also the characters of each variable are special and are independent with other variables. For solving this nonlinear and complicated optimization problem, the powerful algorithm is needed.

With development in computer capability in computing and solving nonlinear problem, the solution of this problem is come easier. In last decades the nature based optimization algorithms are emerged such as genetic algorithm (GA), particle swarm optimization (PSO) algorithm, bee's algorithm (BA), imperialist competitive algorithm (ICA) and cuckoo optimization algorithm (COA) (Zhang et al., 2015; Yu et al., 2015; Gopalakrishnan and Kosanovic, 2015; Chen et al., 2015; Cheng and Jin, 2015; Li et al., 2015; Liu et al., 2015). One of the most efficient and powerful of these algorithms is genetic algorithm. This optimization algorithm has many applications in many areas of industrials and sciences (Quiroz-Castellanos et al., 2015; Anglada and Garmendia, 2015; Lu et al., 2015; Király and Abonyi, 2015; Duan et al., 2015; Wang et al., 2015; Changdar et al., 2015; Herath et al., 2015). In this paper an intelligent technique is proposed for reactive power variable setting. In each optimization algorithm to features are essential: exploration and extraction. The exploration feature is the capability of finding the global solution's vicinity. The extraction feature is capability of optimization algorithm to find the global solution from this vicinity. The genetic algorithm has good exploration and extraction capability. Therefore in this study exploration and extraction is selected as optimization algorithm.

Wu et al. (1998) suggested application of optimal reactive power dispatch by modified GA version for reactive power management. Varadarajan and Swarup (2008) introduced DE algorithm for best reactive power management. Zhang et al. (2010) have introduced multi-group self-adaptive DE algorithm for reactive power forecasting and management. Nedwick et al. (1995) have proposed an intelligent technique for reactive power optimization in power network. The proposed system uses fix

* *Corresponding Author.*
Email Address: *s.ponomarenko9@lpnu.ua (S. Ponomarenko)*
https://doi.org/10.21833/AEEE.2019.07.004

capacitors in several nodes. Dong et al. (2005) have been introduced a smart approach to reactive power management by Bender's decomposition approach. Yang et al. (2007) constrained programming accounting uncertain factors is used to reactive power optimization. In this paper the power that generated by synchronous generators and the load consumed by final load modeled as distribution variables. In Wu et al. (2008); an intelligent technique based on OPF is proposed for reactive power management in heavy load power network condition. He et al. (2008) proposed the optimization method to reactive power prediction with considering the voltage profile. In Zhang et al. (2009) researchers proposed a computational system in order to reactive power market clearing. The simulation results show good performance.

In this paper an intelligent technique based on GA is proposed for reactive power prediction for next load condition. More details about the proposed method are described in next sections. The proposed method enhances the voltage profile significantly and reduces the active power loss. In the proposed method, reactive power is reserved to be used in emergency situations. In the proposed method, the voltage based reactive power applied to compute the reactive power demand. The description about GA is come in section two. Section 3 presents the formulation of power system. Section 4 presents proposed method and some simulation results. The section 5 concludes the study.

2. Genetic algorithm

In soft computing science, genetic algorithm is an optimization algorithm that models the process of natural selection in animals and human. The genetic algorithm is used for many optimization problems that are very complicated and nonlinear. Also genetic algorithm can be used for discrete optimization problem. The genetic algorithm is one of the evolutionary algorithms (EA) that generate random solutions to optimization problems that this procedure is based on natural events in human or animal's life. The genetic algorithm has several main operators: elitism, crossover, mutation and roulette wheel. The flowchart of genetic algorithm is depicted in Fig. 1.

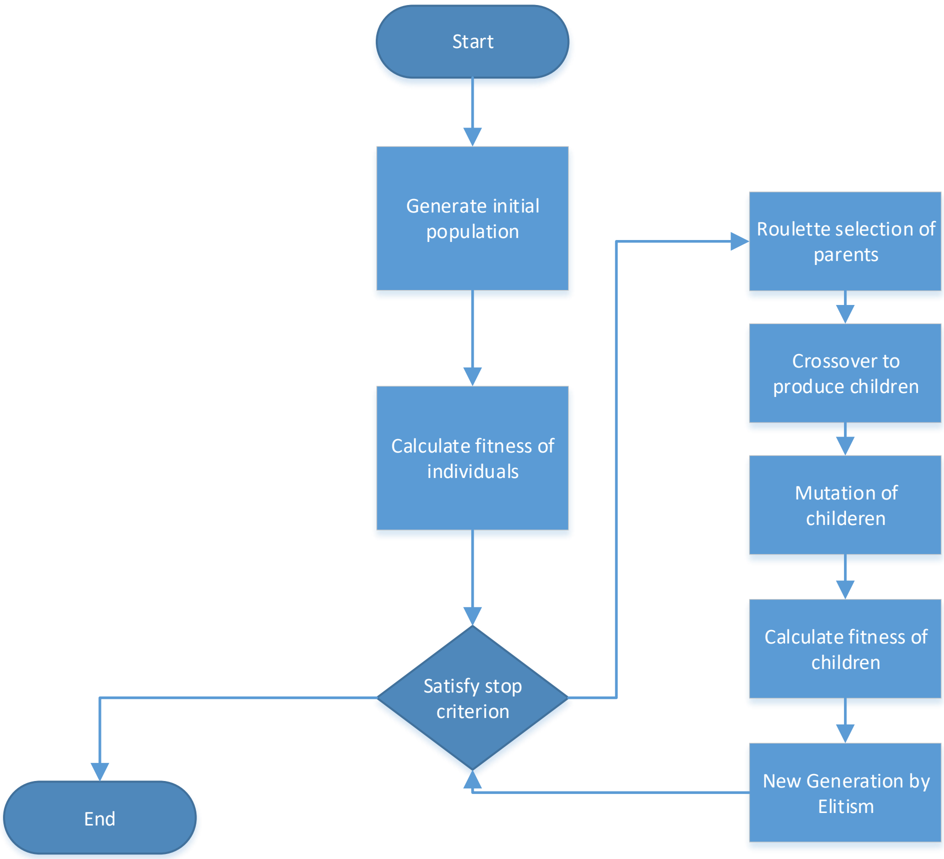

Fig. 1: GA flowchart

In the genetic algorithm like other nature based optimization algorithms, initial random population is generated. The each candidate in initial random population is called chromosome. These chromosomes are like particle in particle swarm optimization algorithm, bee in bee's algorithm or countries in imperialist competitive algorithm. The chromosomes must be generated in predetermined search space. The low boundary and maximum boundary of each problem is unique. The optimization process starts with initial random population, and in each iteration or generation, the fitness function is calculated. Based on the evaluated fitness function for each chromosome, the elitism and crossover is performed. The chromosomes with high level of fitness are randomly chosen from the existing population, and each chromosome is modified by crossover operator. The new generated population is used in following iteration. The same procedure is performed iteratively. In any iteration the stopping criteria must be checked. If the stopping criteria are satisfied, the algorithm will stop the searching procedure. Fig. 2 shows the crossover operation. Also Fig. 3 shows the mutation operation. Fig. 4 shows the pseudo code of GA.

3. Problem formulation

In this paper reactive power reserve is investigated and new smart approach is proposed for this complicated and nonlinear problem. For this purpose GA is used. The GA is used to find the optimal parameters of reactive power control variables. The objective function of this optimization problem is as follow (Arya et al., 2010):

$$J = \sum_k p_{gk}(\overline{Q}_{gk} - Q_{qk}) \tag{1}$$

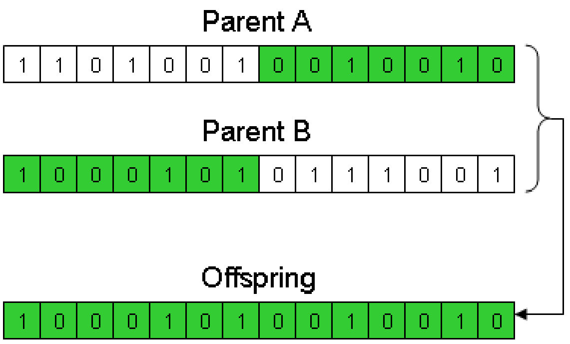

Fig. 2. Crossover operation.

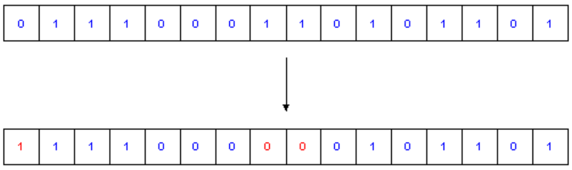

Fig. 3. Mutation operation.

```
0. GENERATE POPULATION P[0]
1. DO{
    1.1 EVALUATE FITNESS OF INDIVIDUALS IN P[k]
    1.2 DO{
            SELECTION (ROULETTE WHEEL)
            APPLY GENETIC OPERATORS:
                PMX CROSSOVER (PROBABILITY p_c)
                MUTATION (PROBABILITY p_m)
        }
        WHILE NEW GENERATION NOT COMPLETED
    1.3 EXECUTE CREATE-ELITE
    }
    WHILE {TERMINATION CRITERIA = NO}
2. PRINT BEST ASSIGNMENT SOLUTION u_i

FUNCTION CREATE-ELITE:
{
    SELECTION OF BEST INDIVIDUALS
    MUTATION (PROBABILITY p_m)
    ELITE = MUTATED ELITE + NOT-MUTATED ELITE
    INSERT ELITE INTO POPULATION:
        P[k+1]=INSERT(ELITE,P[k])
}
```

Fig. 4. The pseudo code of GA algorithm.

In the fitness function, some limitations and constraints are considered. These limitations and constraints are described below:

(a) Power flow limitations and constraints. The mathematical formulation of this limitation is defined as follow:

$$\underline{P} = f(\underline{V}, \delta)$$
$$\underline{Q} = g(\underline{V}, \delta) \qquad (2)$$

(b) Limitation and relation of node voltages and next predicted load situation and the level of reactive power demand. Eq. 3 defines these conditions:

$$\underline{V}_i \le V_i^o \le \overline{V}_i$$
$$\underline{V}_i \le V_i^p \le \overline{V}_i \qquad (3)$$
$$i \in NL$$

(c) Limitation on Jacobin matrix and its related determinant.

$$\lambda_{\min,p} \ge \lambda_{\min,th} \qquad (4)$$

(d) The boundaries of generated reactive power in power network. Eq. 5 shows this limitation.

$$\underline{Q}_{gk} \le Q_{gkp} \le \overline{Q}_{gk} k = 1,2,\ldots,NG \qquad (5)$$

(e) Limitation on control parameters:

$$\underline{X}_i \le X_i \le \overline{X}_i i \in NC \qquad (6)$$

In the proposed method, p_{gk} is generation association factor. This factor is calculated for next forecasting load condition. For this purpose first obtain minimum eigenvalues and their related vectors. For simplicity the reduced Jacobin matrix is applied. The procedure is as follow:

$$\begin{bmatrix} J_1 J_2 \\ J_3 J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \begin{bmatrix} 0 \\ \Delta Q \end{bmatrix} \qquad (7)$$

$$J_1\Delta\delta + J_2\Delta V = 0$$
$$\Delta\delta = -J_1^{-1}J_2\Delta V \qquad (8)$$
$$\left[J_4 - J_3J_1^{-1}J_2\right][\Delta V] = [\Delta Q]$$
$$J_R = J_4 - J_3J_1^{-1}J_2 \qquad (9)$$
$$\Delta Q = [\xi_i]$$
$$\Delta V = \frac{\xi_i}{\lambda_i}$$
$$\Delta\delta = -J_1^{-1}J_2\Delta V = -\frac{(J_1^{-1}J_2\xi_i)}{\lambda_i} \qquad (10)$$
$$V = V + \Delta V$$
$$\delta = \delta + \Delta\delta$$

In next step, the demanded reactive power that must be injected is computed as follow:

$$p_{gk} = \frac{\Delta Q_{gk}}{\max_p \Delta Q_{gp}} \qquad (11)$$

The steps of proposed method are as follow:

1. The parameters of power network, including the reactive power parameters, transmission lines impedance, transformers power.
2. Compute the load flow for network. Compute all nodes voltage value and their angles.
3. Compute the following condition demanded power.
4. Compute the load flow calculation for next load condition.
5. Generate the initial population for optimization algorithm.
6. Evaluate the fitness function for generated random chromosomes.
7. Do elitism operation.
8. Apply crossover.
9. Apply mutation.
10. Check the stop criteria. If it is satisfied, go to next step, else go to step 6.
11. Finish.

4. Simulation results

In this section the performance of proposed method is evaluated. For this purpose IEEE standard system is selected. The selected is power network system has 25 terminals. The chosen system has twelve parameters that can affect the generation of reactive power. In this system there are five generation terminal and the other remaining terminals are load nodes. The control parameters are voltages of generator terminals, parallel compensations and on line tap changeable transformers. The parallel compensations are placed at 22, 23, 24 and 25th terminal. The on line tap changeable transformers are located in 6, 13 and 35th transmission lines. The nominal values of voltages and impedance of system are listed in Table 1. Also Table 2 shows the system constants. Table 3 shows the voltage boundaries.

Table 1
Parameters and constants of power network.

Parameter	Value
$E_{\max1}$	$2.66pu$
$E_{\max2}$	$2.17pu$
$E_{\max3}$	$2.11pu$
$E_{\max4}$	$2.32pu$
$E_{\max5}$	$2.14pu$
X_{d1}	$1.00pu$
X_{d2}	$1.16pu$
X_{d3}	$1.08pu$
X_{d4}	$1.21pu$
X_{d5}	$1.13pu$

Table 2
System parameters.

Maximum value for reactive power	$\overline{Q}_{gk}$
Value of reactive power reserved	$Q_{gk(res)}$
The value of generator voltage	V_g
The generator voltage (internal voltage)	$\overline{E}$
Impedance of generator	X_d
armature current for generators	$\tilde{I}_{gk}$
The voltage in terminals	V
Phase	δ
The number of optimization parameters	NC
The number of consuming terminals	NL
The number of nodes that generate active power	NG
Fitness function	J
Random number	$rand_j$
Factor	α
Chancily number	j_{rand}
The boundaries	$\underline{x}_i, \overline{x}_i$
Location of individual	X_i^k
Crossover rate	C
The maximum iteration	$NIT, NIT_{\max}$
Best individual	$P_{best(i)}^k$
position of the best individual of the whole swarm	P_{best}^k

Table 3
Voltage boundaries.

Node	Boundaries
PV-bus	0.95– 1.15 pu
Parallel capacitor	0.00–0.055 pu
On line tap changeable transformers	0.90–1.10 pu
First generator	-0.0500 pu to 3.0000 pu
Second generator	-0.0500 pu to 1.0000 pu
Third generator	-0.0500 pu to 1.0000 pu
Forth generator	-0.0500 pu to 1.0000 pu
Fifth generator	-0.0500 pu to 1.0000 pu

The other power system constants and parameters are as follow. The total active power is 15.731 pu and reactive power is 4.828 pu. The proximity indicator is 0.363 and the fitness function is 2.33. Table 4 shows the voltage of power network before optimization.

The obtained results after optimization are listed in Table 5. The parameters of GA have high effect on its performance. For this purpose several collection of these parameters are tested. Also in Fig. 5 the increasing of fitness function during the optimization is plotted. It is clear that the optimization has good effect on fitness function. Also Table 6 shows the optimized control variables.

Table 4
Voltage before optimization.

Terminal voltages	Values (PU)	Control parameter	Values (PU)
V_{n6}	1.0061	V_{G1}	1.014
V_{n7}	1.0056	V_{G2}	1.093
V_{n8}	0.8521	V_{G3}	1.076
V_{n9}	0.8651	V_{G4}	1.054
V_{n10}	0.8654	V_{G5}	1.049
V_{n11}	0.9016	$B_{C,SH22}$	0.0241
V_{n12}	0.9351	$B_{C,SH23}$	0.0237
V_{n13}	0.8962	$B_{C,SH24}$	0.0231
V_{n14}	1.0667	$B_{C,SH25}$	0.0229
V_{n15}	0.8521	TAP_{T6}	0.9156
V_{n16}	0.8619	TAP_{T13}	0.9154
V_{n17}	0.8654	TAP_{T35}	0.9187
V_{n18}	0.9013		
V_{n19}	0.9336		
V_{n20}	0.8962		
V_{n21}	1.0667		
V_{n22}	0.8450		
V_{n23}	0.8642		
V_{n24}	0.9062		
V_{n25}	0.8641		

Table 5
Obtained results after optimization.

Case	Crossover rate	Mutation rate	Fitness function
1	0.7	0.1	14.431
2	0.7	0.15	13.87
3	0.7	0.2	14.04
4	0.7	0.25	14.16
5	0.7	0.3	14.12
6	0.75	0.1	13.97
7	0.75	0.15	13.76
8	0.75	0.2	14.53
9	0.75	0.25	14.41
10	0.75	0.3	13.98
11	0.8	0.1	14.17
12	0.8	0.15	14.21
13	0.8	0.2	14.21
14	0.8	0.25	13.95
15	0.8	0.3	13.76
16	0.85	0.1	14.53
17	0.85	0.15	14.431
18	0.85	0.2	13.83
19	0.85	0.25	14.04
20	0.85	0.3	14.01
21	0.9	0.1	14.18
22	0.9	0.15	14.22
23	0.9	0.2	13.76
24	0.9	0.25	14.53
25	0.9	0.3	14.12
26	0.95	0.1	13.97
27	0.95	0.15	13.76
28	0.95	0.2	14.53
29	0.95	0.25	13.88
30	0.95	0.3	14.31

5. Conclusion

The power system is very complicated and nonlinear. There is no linear relation among different sections of this network. In this study an intelligent system proposed for reactive power optimal management. The proposed is based on GA. The computer simulation results show that the optimization has very high impact on power quality. After optimization, the voltage profile is enhanced significantly.

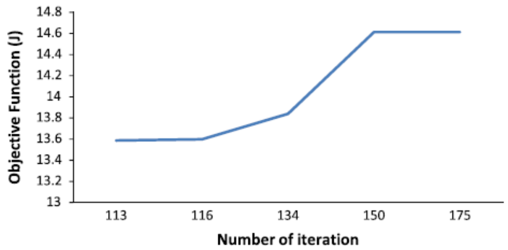

Fig. 5. Increasing of fitness function during optimization procedure.

Table 6
Control parameters after optimization.

Terminal voltages	Values (PU)	Control parameter	Values (PU)
V_{n6}	1.0065	V_{G1}	1.094
V_{n7}	1.0051	V_{G2}	1.01
V_{n8}	1.0032	V_{G3}	1.02
V_{n9}	0.9976	V_{G4}	1.021
V_{n10}	1.0043	V_{G5}	1.026
V_{n11}	0.9965	$B_{C,SH22}$	0.0232
V_{n12}	0.9954	$B_{C,SH23}$	0.0269
V_{n13}	1.0021	$B_{C,SH24}$	0.0481
V_{n14}	1.0001	$B_{C,SH25}$	0.0375
V_{n15}	0.9934	TAP_{T6}	0.9201
V_{n16}	1.0043	TAP_{T13}	0.9219
V_{n17}	0.9962	TAP_{T35}	1.043
V_{n18}	0.9951		
V_{n19}	1.0087		
V_{n20}	1.0076		
V_{n21}	0.9995		
V_{n22}	1.0056		
V_{n23}	1.0003		
V_{n24}	1.0021		
V_{n25}	0.9959		

References

Anglada E and Garmendia I (2015). Correlation of thermal mathematical models for thermal control of space vehicles by means of genetic algorithms. Acta Astronautica, 108: 1-17. https://doi.org/10.1016/j.actaastro.2014.11.042

Arya LD, Titare LS, and Kothari DP (2010). Improved particle swarm optimization applied to reactive power reserve maximization. International Journal of Electrical Power and Energy Systems, 32(5): 368-374. https://doi.org/10.1016/j.ijepes.2009.11.007

Balamurugan K, Muralisachithanandam R, and Dharmalingam V (2015). Performance comparison of evolutionary programming and differential evolution approaches for social welfare maximization by placement of multi type FACTS devices in pool electricity market. International Journal of Electrical Power and Energy Systems, 67: 517-528. https://doi.org/10.1016/j.ijepes.2014.12.007

Castoldi MF, Sanches DS, Mansour MR, Bretas NG, and Ramos RA (2014). A hybrid algorithm to tune power oscillation dampers for FACTS devices in power systems. Control Engineering Practice, 24: 25-32. https://doi.org/10.1016/j.conengprac.2013.11.001

Changdar C, Mahapatra GS, and Pal RK (2015). An improved genetic algorithm based approach to solve constrained knapsack problem in fuzzy environment. Expert Systems with Applications, 42(4): 2276-2286. https://doi.org/10.1016/j.eswa.2014.09.006

Chen CH, Liu TK, Chou JH, Tasi CH, and Wang H (2015). Optimization of teacher volunteer transferring problems using greedy genetic algorithms. Expert Systems with Applications, 42(1): 668-678. https://doi.org/10.1016/j.eswa.2014.08.020

Cheng R and Jin Y (2015). A social learning particle swarm optimization algorithm for scalable optimization. Information Sciences, 291: 43-60. https://doi.org/10.1016/j.ins.2014.08.039

Dash P, Saikia LC, and Sinha N (2015). Comparison of performances of several FACTS devices using Cuckoo search algorithm optimized 2DOF controllers in multi-area AGC. International Journal of Electrical Power and Energy Systems, 65: 316-324. https://doi.org/10.1016/j.ijepes.2014.10.015

Dong F, Chowdhury BH, Crow ML, and Acar L (2005). Improving voltage stability by reactive power reserve management. IEEE Transactions on Power Systems, 20(1): 338-345. https://doi.org/10.1109/TPWRS.2004.841241

Duan DL, Ling XD, Wu XY, and Zhong B (2015). Reconfiguration of distribution network for loss reduction and reliability improvement based on an enhanced genetic algorithm. International Journal of Electrical Power and Energy Systems, 64: 88-95. https://doi.org/10.1016/j.ijepes.2014.07.036

Elsheikh A, Helmy Y, Abouelseoud Y, and Elsherif A (2014). Optimal capacitor placement and sizing in radial electric power systems. Alexandria Engineering Journal, 53(4): 809-816. https://doi.org/10.1016/j.aej.2014.09.012

Gasperic S and Mihalic R (2015). The impact of serial controllable FACTS devices on voltage stability. International Journal of Electrical Power and Energy Systems, 64: 1040-1048. https://doi.org/10.1016/j.ijepes.2014.08.010

Gopalakrishnan H and Kosanovic D (2015). Operational planning of combined heat and power plants through genetic algorithms for mixed 0–1 nonlinear programming. Computers and Operations Research, 56: 51-67. https://doi.org/10.1016/j.cor.2014.11.001

He R, Taylor GA, and Song YH (2008). Multi-objective optimal reactive power flow including voltage security and demand profile classification. International Journal of Electrical Power and Energy Systems, 30(5): 327-336. https://doi.org/10.1016/j.ijepes.2007.12.001

Herath MT, Natarajan S, Prusty BG, and John NS (2015). Isogeometric analysis and genetic algorithm for shape-adaptive composite marine propellers. Computer Methods in Applied Mechanics and Engineering, 284: 835-860. https://doi.org/10.1016/j.cma.2014.10.028

Király A and Abonyi J (2015). Redesign of the supply of mobile mechanics based on a novel genetic optimization algorithm using Google maps API. Engineering Applications of Artificial Intelligence, 38: 122-130. https://doi.org/10.1016/j.engappai.2014.10.015

Kumar A and Mittapalli RK (2014). Congestion management with generic load model in hybrid electricity markets with FACTS devices. International Journal of Electrical Power and Energy Systems, 57: 49-63. https://doi.org/10.1016/j.ijepes.2013.11.035

Lee CS, Ayala HVH, and dos Santos Coelho L (2015). Capacitor placement of distribution systems using particle swarm optimization approaches. International Journal of Electrical Power and Energy Systems, 64: 839-851. https://doi.org/10.1016/j.ijepes.2014.07.069

Li Y, Jiao L, Shang R, and Stolkin R (2015). Dynamic-context cooperative quantum-behaved particle swarm optimization based on multilevel thresholding applied to medical image segmentation. Information Sciences, 294: 408-422. https://doi.org/10.1016/j.ins.2014.10.005

Liu Y, Niu B, and Luo Y (2015). Hybrid learning particle swarm optimizer with genetic disturbance. Neurocomputing, 151: 1237-1247. https://doi.org/10.1016/j.neucom.2014.03.081

Lu HL, Wen XS, Lan L, An YZ, and Li XP (2015). A self-adaptive genetic algorithm to estimate JA model parameters considering minor loops. Journal of Magnetism and Magnetic Materials, 374: 502-507. https://doi.org/10.1016/j.jmmm.2014.08.084

Mukherjee M and Goswami SK (2014). Solving capacitor placement problem considering uncertainty in load variation. International Journal of Electrical Power and Energy Systems, 62: 90-94. https://doi.org/10.1016/j.ijepes.2014.04.004

Nedwick P, Mistr AF, and Croasdale EB (1995). Reactive management a key to survival in the 1990s. IEEE Transactions on Power Systems, 10(2): 1036-1043. https://doi.org/10.1109/59.387949

Quiroz-Castellanos M, Cruz-Reyes L, Torres-Jimenez J, Gómez C, Huacuja HJF, and Alvim AC (2015). A grouping genetic algorithm with controlled gene transmission for the bin packing problem. Computers and Operations Research, 55: 52-64. https://doi.org/10.1016/j.cor.2014.10.010

Shuaib YM, Kalavathi MS, and Rajan CCA (2015). Optimal capacitor placement in radial distribution system using gravitational search algorithm. International Journal of Electrical Power and Energy Systems, 64: 384-397. https://doi.org/10.1016/j.ijepes.2014.07.041

Sreejith S, Simon SP, and Selvan MP (2015). Analysis of FACTS devices on security constrained unit commitment problem. International Journal of Electrical Power and Energy Systems, 66: 280-293. https://doi.org/10.1016/j.ijepes.2014.10.049

Sultana S and Roy PK (2014). Optimal capacitor placement in radial distribution systems using teaching learning based optimization. International Journal of Electrical Power and Energy Systems, 54: 387-398. https://doi.org/10.1016/j.ijepes.2013.07.011

Varadarajan M and Swarup KS (2008). Differential evolutionary algorithm for optimal reactive power dispatch. International Journal of Electrical Power and Energy Systems, 30(8): 435-441. https://doi.org/10.1016/j.ijepes.2008.03.003

Vuletić J and Todorovski M (2014). Optimal capacitor placement in radial distribution systems using clustering based optimization. International Journal of Electrical Power and Energy Systems, 62: 229-236. https://doi.org/10.1016/j.ijepes.2014.05.001

Wang J, Huang W, Ma G, and Chen S (2015). An improved partheno genetic algorithm for multi-objective economic dispatch in cascaded hydropower systems. International Journal of Electrical Power and Energy Systems, 67: 591-597. https://doi.org/10.1016/j.ijepes.2014.12.037

Wu H, Yu CW, Xu N, and Lin XJ (2008). An OPF based approach for assessing the minimal reactive power support for generators in deregulated power systems. International Journal of Electrical Power and Energy Systems, 30(1): 23-30. https://doi.org/10.1016/j.ijepes.2007.06.002

Wu QH, Cao YJ, and Wen JY (1998). Optimal reactive power dispatch using an adaptive genetic algorithm. International Journal of Electrical Power and Energy Systems, 20(8): 563-569. https://doi.org/10.1016/S0142-0615(98)00016-7

Yang N, Yu CW, Wen F, and Chung CY (2007). An investigation of reactive power planning based on chance constrained programming. International Journal of Electrical Power and Energy Systems, 29(9): 650-656. https://doi.org/10.1016/j.ijepes.2006.09.008

Yu W, Li B, Jia H, Zhang M, and Wang D (2015). Application of multi-objective genetic algorithm to optimize energy efficiency and thermal comfort in building design. Energy and Buildings, 88: 135-143. https://doi.org/10.1016/j.enbuild.2014.11.063

Zhang C, Zheng J, and Zhou Y (2015). Two modified artificial bee colony algorithms inspired by grenade explosion method. Neurocomputing, 151(part3): 1198-1207. https://doi.org/10.1016/j.neucom.2014.04.082

Zhang T, Elkasrawy A, and Venkatesh B (2009). A new computational method for reactive power market clearing. International Journal of Electrical Power and Energy Systems, 31(6): 285-293. https://doi.org/10.1016/j.ijepes.2009.03.015

Zhang X, Chen W, Dai C, and Cai W (2010). Dynamic multi-group self-adaptive differential evolution algorithm for reactive power optimization. International Journal of Electrical Power and Energy Systems, 32(5): 351-357. https://doi.org/10.1016/j.ijepes.2009.11.009