Solving Reactive Power Dispatch Problem Using Evolutionary Computational Algorithm

Vivek Kumar Jain, Upendra Prasad and Abhishek Kumar Gupta

Abstract This paper presents an evolutionary computational technique for optimizing reactive power problems. In a power system our main objective is to minimize the losses of power, improve the voltage deviation, and to reduce the cost of fuel for getting the desired response in the power system and for these purposes we use the evolutionary computational algorithm. There are various variable devices including the voltage control bus, tap-changing transformer, and switchable shunt capacitor banks by which we can control the flow of reactive power. For the verification of our proposed algorithm, the simulation results are done on a standard IEEE-30 bus system. The test results indicate that the results of this proposed algorithm are better compared to other methods.

Keywords Reactive power dispatch · Evolutionary computational algorithm · Voltage deviation · Minimization losses of power

1 Introduction

An electrical power system comprises various operational methods among which symmetrically steady-state operation is considered the most prominent mode of operation. As the control of frequency is the essential parameter for controlling power, it is somewhat difficult to control the active and reactive power.

Separately active and reactive power can be controlled by load frequency control (LFC) using closed- loop real power frequency and by an automatic voltage regulator (AVR) for regulation of magnitudes and bus voltages, respectively [1]. In order to control active power it is required to control the supply voltage; this is very

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important for the interconnection of the power plant and the reactive power can be controlled by controlling the reactive component frequency power and its behavior.

Frequency controlling mainly classifies the controlling and gives information about the control of the transmission and distribution lines' parameter characteristics [2]. Here consideration is made regarding the factors employed in controlling the power system:

- Power system stability
- Voltage (Vs and Vr)
- Environment condition or weather condition
- Nonlinear characteristics
- EHV electrostatic field
- Conductor surface and reductions of switch conductor

It should be essential to notice the effective role of the balanced conductor, as the increment in conductor size is proportionate to the increase in cost of transmission lines. As per the consideration of losses, the efficiency is increased because of the decrement in corona losses inversely proportional to the size of the conductors [3]. Controlling the voltage is also a necessary issue and is done at the generating station using various methods also introduced in power systems that are currently being used in industries. The real and reactive power required for different kinds of loads having different levels of frequencies and bus voltages is kept in defined permittivity for optimum economy. Estimation of the dependent factors at the initial stages (i.e., at the planning stages) to obtain the desired structure of plant with economic operation and quality power supply [4]. A number of works have been done in the area of reactive power in earlier times of electricity history. Optimal reactive power dispatch comprises many desired issues including reliability with a reduction in fuel cost. Supply levels have also been improved by providing suitable protection using instruments of the uploading system. From the view of optimization issues, reactive power dispatch shows nonlinearity. To overcome the problems of power dispatching, solutions to this problem are made by using mathematical approaches after making a tremendous effort during the last several years [6]. The factors that decide the complexity of a system are listed below.

- Configurations of network having complex and large size
- Nonlinearity of injection of reactive power with respect to voltage levels
- Isolation in rated power of compensator
- Constant factors of components in cost of compensator
- Requirement of variables as concerned with the change in demands of loads

The complexity of these problems can be solved by conventional and evolutionary computational techniques. The conventional techniques refer to linear, nonlinear, quadratic programming, and gradient methods [4, 5], which need more time to solve the reactive power problems. On the other hand, because of fast convergence much research has been focused towards evolutionary computational techniques such as the ant bee colony (ABC) algorithm, particle swarm optimization

(PSO) [5, 11], evolutionary strategy and differential evolution (DE) algorithm [9, 11], genetic algorithm (GA), and evolutionary programming (EP) [7, 8].

An evolutionary computational algorithm is used for optimal solutions, such as the differential evolution (DE) algorithm considered to solve the reactive power dispatch (RPD) problem. The evolutionary computational algorithm is a dominant optimization technique analogous to the natural selection process in genetics [15].

This paper presents the reactive power dispatch problem using a differential evolution algorithm because of less computational time, number of iterations, and ease of implementation. Here the main purpose is the minimization of transmission losses, reduction in cost of fuel, and voltage drops across the transmission line so that the voltage regulation will be improved and the voltage profile will be maintained and working on the standard IEEE 30-bus system. Simulation results show that the better solutions are much faster than the previous approaches. Finally, a case study is presented and optimal settings for the entire network are shown.
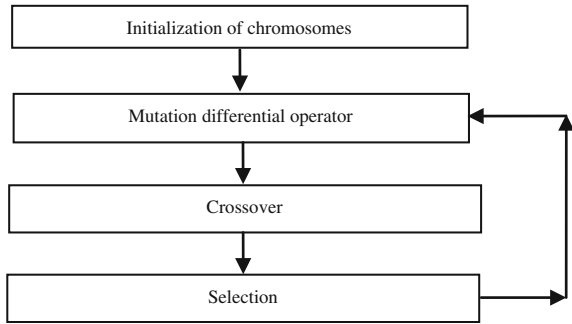
2 Algorithm

As already mentioned above the evolutionary computational algorithm for global optimization is also known as a differential evolution technique which is applied for the optimal setting of transformer tap positions and VARs generated by the generators, and so on. The results obtained by each of these heuristic techniques and evolutionary computation techniques are compared with the results obtained by using each of the evolutionary computational (GA, PSO, DE, etc.) techniques [13]. This algorithm produces advanced generations through candidates that are successively better suited to their background.

Differential evolution is a stochastic population-based comprehensive optimization algorithm proposed by Storn and Price [11]. Differential evolution has the capacity of handling nonlinear, nondifferentiable, and multimodel objective functions. In DE the population generally consists of the real values vector whose number is equal to that of control variables [14].

This algorithm starts with an initial population of individuals generated at random. Similarly to the GA and PSO algorithms, an individual is represented by the vector where the ith element of X represents the ith fundamentals of control variables subsequently. Using various measures of the main function, the population of the next generation is created through differential evolution operators such as initialization, mutation, crossover, and selection which are explained as follows [10].

- Easy to construct, simplicity of use and robustness, compactness.
- Using floating point format for their operation by high precision.
- For discrete, integral, and mixed parameter optimization it is highly efficient.
- Managing nondifferentiable, noisy, and/or time-dependent objective functions.
- Effective used for nonlinear constraint optimization problems with penalty functions, and the like.

Fig. 1 DE procure cycle

Initialization of chromosomes

$\downarrow$

Mutation differential operator

$\downarrow$

Crossover

$\downarrow$

Selection

Similar to the supplementary evolutionary computational algorithm relations, differential evolution also depends on initial random population generation and their improvement is done by using selection, mutation, and crossover repeated all the way through generations until the convergence criterion is met (Fig. 1).

2.1 *Initialization*

At the initialization of this process run and independent variables are initialized in their reasonable numerical selection. Therefore, if the jth element of the given problem has its subordinate and superior vault at the same time as X_i^L and x_i^U, respectively, then the jth and ith components are:

$$X_{i,j}(0) = X_j^L + \text{rand}(0, 1) \cdot \left(X_j^U - X_j^L \right) \tag{1}$$

where $\text{rand}(0, 1)$ = regularly circulated random quantity between 0 and 1.

2.2 *Mutation*

The parameter of each generation to modify each individual population element $\overrightarrow{X_l(t)}$ a donor vector $\overrightarrow{v_i(t)}$ is created. It is the technique of creating this patron vector that demarcates between the various proposed schemes. This mutation approach is known as differential evolution/rand/1.

$$v_{i,j}(t+1) = X_{r1,j}(t) + F \cdot (X_{r2,j}(t) - X_{r3,j}(t)) \tag{2}$$

2.3 Crossover

The two types of crossover schemes used are exponential crossover and binomial crossover. Even though the exponential crossover was proposed in the original work of Storn and Price [11], the binomial variant was widely used in recent applications [12]. The performance of the binomial crossover scheme on all DE variables can be expressed as

$$u_{i,j}(t) = \begin{cases} v_{i,j}(t) & \text{if rand}(0,1) < \text{CR} \\ x_{i,j}(t) & \text{else} \end{cases} \tag{3}$$

where $u_{i,j}(t)$ = represents the child that will compete with the parent $x_{i,j}(t)$.

2.3.1 Selection

For the population range to remain continuous over the following generations, the selection procedure is carried out to decide which one of the child and the parent will continue to exist after that generation, that is, at time $t = t + 1$. DE actually involves the survival of the fittest principle in its selection process.

$$\overrightarrow{X_1}(t+1) = \begin{cases} \overrightarrow{U_1}(t) \, \text{if} f\left(\overrightarrow{U_1}(t)\right) \le f(\overrightarrow{X_i}(t)) \\ \overrightarrow{X_1}(t) \, \text{if} f\left(\overrightarrow{X_1}(t)\right) < f(\vec{U}(t)) \end{cases} \tag{4}$$

2.4 DE Algorithm Main Steps

1. An initial population is arbitrarily chosen inside the control variable limits.
2. For each entity in the population, run the power flow algorithm to find the operating end.
3. Compute the fitness of the persons.
4. Perform mutation and crossover to create offspring from parents.
5. Execute collection between parent and issue:

   a. Any feasible resolution is favored to any infeasible solution.
   b. In the middle of two feasible solutions, the one having the better objective function value is preferred.
   c. In the middle of two infeasible solutions, the one having the smaller constraints violation is preferred.

6. Accumulate the current generation.

7. Repeat Steps 2–5 till the termination criteria meet.
8. The control variable setting is parallel to the overall finest individuals.
9. Determine VSM for the selected control variable setting and check whether if a greater than specified value VSM_{spec}.
10. If the solution is acceptable, output the best individual and its objective value; otherwise take the setting corresponding to the next best individual and repeat Step 8.

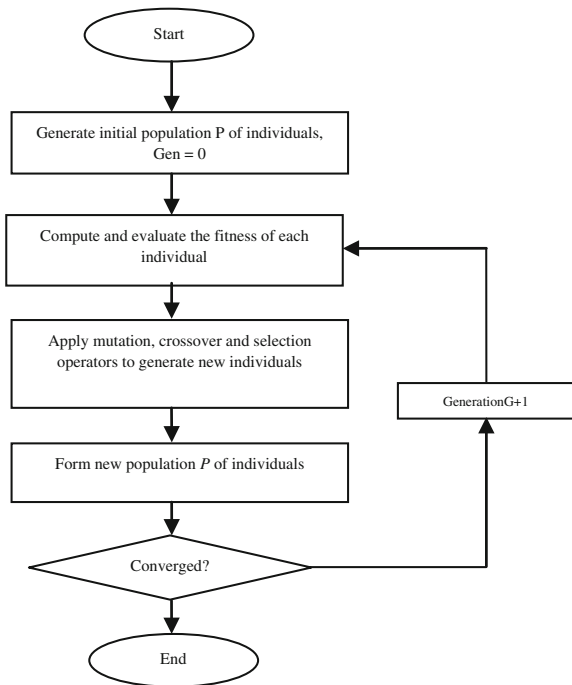### 2.4.1 Flow Chart of DE Algorithm

See Fig. 2.

3 Problem Formulation

The reactive power dispatch problem is treated as a single objective optimization problem by linear combination of two objective functions, P_{Loss} and VD, which can be written:

$$F = F_1 + F_2 = P_{Loss} + VD \tag{5}$$

Fig. 2 Flowchart of DE process

3.1 Minimization of System Losses of Power (P_{loss})

This objective is accomplished through appropriate modification of reactive power variables such as generator voltage magnitudes (v_{gi}), reactive power generation of capacitor banks (Q_{ci}), and transformer tap settings (t_k) terminal [15].

This is mathematically stated as

$$F_1 = P_{\text{Loss}} = \sum_{k=1}^{nl} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos \theta_{ij}] \tag{6}$$

where n_l is the number of transmission lines, g_k is the conductance of the kth line, V_i and V_j are the voltage magnitude at the end buses i and j of the kth line, respectively, and θ_{ij} is the voltage phase angle at the end buses i and j.

3.2 Voltage Deviation (VD)

The voltage profile can be improved by the minimizing the load bus voltage deviations. It can deviate from 1.0 per unit [16].

This function can be expressed as

$$F_2 = \text{VD} = \sum_{i \in \text{NL}} |V_i - V_i^{\text{ref}}| \tag{7}$$

where NL = number of load bus and V_i^{ref} is the prescribed reference value of the voltage magnitude of the ith load bus. V_i^{ref} is usually taken as 1.0 p.u.

3.3 Minimization Cost of Fuel

$$F_3 = \min. \sum_{i=1}^{\text{NG}} (a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \$/h \tag{8}$$

where a_i, b_i, c_i = cost coefficient of the ith generator.

The reactive power dispatch problem is subjected to the following equality and inequality constraints.

3.4 Equality Constraints

$$P_{Gi} - P_{Di} - V_{\mathrm{i}} \sum_{j=1}^{N_B} V_j \big(G_{ij}\mathrm{Cos}\theta_{ij} + B_{ij}\mathrm{Sin}\theta_{ij}\big) = 0, \quad i = 1, 2 \ldots N_B - 1 \quad (9)$$

$$Q_{Gi} - Q_{Di} - V_i \sum_{j=1}^{N_B} V_j \big(G_{ij}\mathrm{Sin}\theta_{ij} + B_{ij}\mathrm{Cos}\theta_{ij}\big) = 0, \quad i = 1, 2 \ldots N_B \quad (10)$$

where N_B = buses number, P_G = active power generator, Q_G = reactive power generated, Q_D = the load of reactive power, PD = load active power, and G_{ij} and B_{ij} = transfer conductance.

3.5 Inequality Constraints

Voltage constraints

$$V_{Gi}^{\min} \leq V_{Gi} \leq V_{Gi}^{\max}; \quad i = 1, \ldots N_G \quad (11)$$

Reactive power generator capability limit

$$Q_{Gi}^{\min} \leq Q_{Gi} \leq Q_{Gi}^{\max}; \quad \mathrm{i} = 1, \ldots N_G \quad (12)$$

Generation limit of capacitor terminal

$$Q_{ci}^{\min} \leq Q_{ci} \leq Q_{ci}^{\max}; \quad i = 1, \ldots N_c \quad (13)$$

Transformer tap setting limit

$$t_k^{\min} \leq t_k \leq t_k^{\max}; \quad i = 1, \ldots N_T \quad (14)$$

Security constraints

$$V_{Li}^{\min} \leq V_{Li} \leq V_{Li}^{\max}; \quad i = 1, \ldots N_L \quad (15)$$

$$S_{li} \leq S_{li}^{\max}; \quad i = 1, \ldots nl \quad (16)$$

4 Simulation Results

In order to investigate the usefulness of the reactive power dispatch problem, this section presents an approach to test the standard IEEE 30-bus 6-generator (at buses 2, 5, 8, 11, and 13) system.

The differential evolution-based reactive power dispatch algorithm is implemented using MATLAB® 7.14.0.739 (R2012a) on Core i3 Dual core processor and 4 GB RAM. The IEEE 30-bus test system consists of 6 generator bus, 24 load bus, and 41 transmission lines with four-tap setting transformers with nine-switchable VAR as shown in Fig. 3 and Table 1. The minimum and maximum limits for the control variables along with the initial settings are given in Table 2. Regulation of bus voltage plays a very important role to get a significant secure system and to
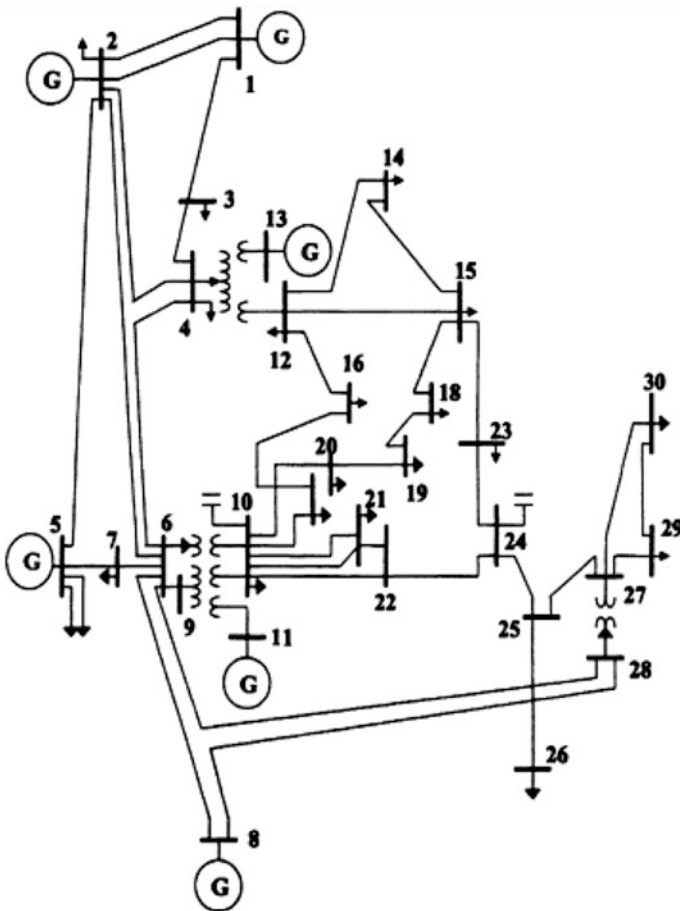

Fig. 3 Single line diagram of 30-bus system

Table 1 Calculation parameters

Parameter	Value
Size of generation	200
Size of population	06
Crossover	0.80
Mutation	0.80

Table 2 Result of 30-bus systems with initial settings and optimal setting for proposed algorithm

Variable	Min.	Max.	Initial (base case)	Proposed algorithm
V1	1.00	1.10	1.05	1.07209
V2	1.00	1.10	1.04	1.06184
V5	1.00	1.10	1.01	1.03990
V8	1.00	1.10	1.01	1.04153
V11	1.00	1.10	1.05	1.10000
V13	1.00	1.10	1.05	1.06095
T11	1.00	1.10	1.078	1.01101
T12	1.00	1.10	1.069	1.00000
T15	1.00	1.10	1.032	1.04270
T36	1.00	1.10	1.068	1.00000
Qc10	0.00	5.00	0.00	1.74085
Qc12	0.00	5.00	0.00	2.14649
Qc15	0.00	5.00	0.00	1.70740
Qc17	0.00	5.00	0.00	4.73443
Qc20	0.00	5.00	0.00	0.12395
Qc21	0.00	5.00	0.00	1.56385
Qc23	0.00	5.00	0.00	1.79046
Qc24	0.00	5.00	0.00	0.32048
Qc29	0.00	5.00	0.00	3.46295
Losses of power (MW)			5.8603	**4.8937**
Voltage deviation			1.1701	**0.7516**

have excellent performance indices. Improving the voltage profile can be obtained by minimizing the load bus voltage deviations from 1.0 per unit (Figs. 4 and 5).

In the proposed algorithm for optimal control variable settings, the results of different objective functions are compared with base case and other methods (shown in Tables 2, 3, 4 and 5). The losses of power, cost of fuel, and voltage deviation are 4.8937 MW, 613.9648 $/h, and 0.7516 p.u.

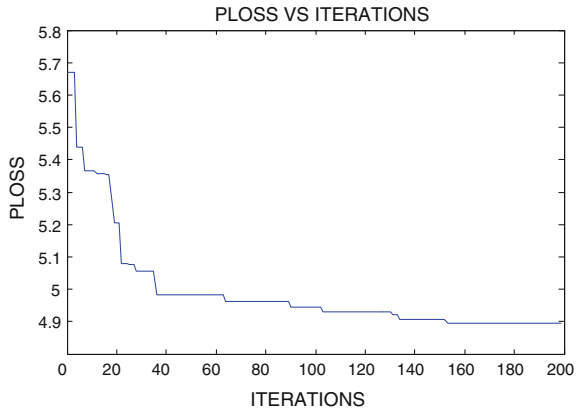**Fig. 4** Optimal graph between losses of power versus iterations

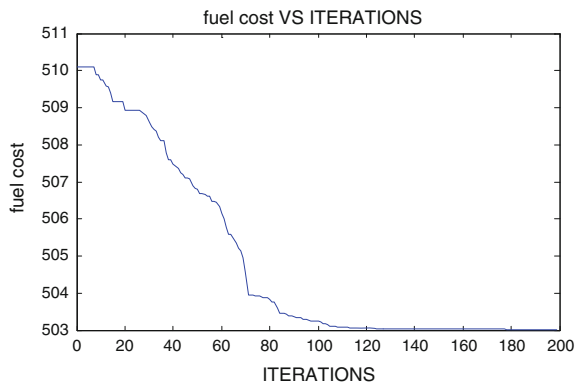**Fig. 5** Optimal graph between cost of fuel versus iterations

Table 3 Losses of power for other methods

Method	P Loss (MW)
Particle swarm optimization	5.833
Proposed algorithm	**4.8937**

Table 4 Comparison of voltage deviation for other methods

Method	Voltage deviation
PSO	0.7733
Proposed algorithm	**0.7516**

Table 5 Comparison cost of fuel for other methods

Method	Fuel cost
PSO	628.6874
Proposed algorithm	**613.9648**

5   Conclusion

This paper is based on an evolutionary computational algorithm which is proposed, developed, and then successfully applied for solving reactive power dispatch problems. The algorithm takes into consideration the equality and inequality constraints. The various objective functions have been used to improve the voltage profile by lowering the cost of fuel and minimizing the losses of power. It can be observed that the results obtained by the proposed algorithm can be utilized in real-life power systems for operation and analysis. Based on simulation investigations it is observed that the losses of power in the system are minimized to 4.8937 MW from the base case of 5.8603 MW and reduce the cost of fuel to 613.9648 \$/h and voltage deviation to 0.7516 p.u. The above calculations have been tested and examined on the standard IEEE 30-bus system. It can be concluded that the proposed method for an optimal solution is suitable for implementing in a modern power system operation. The simulation results obtained by the proposed approach show its robustness and effectiveness to solve the reactive power dispatch problem.

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