International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 5, Sept-Oct-2024, ISSN (Online): 2395-566X

Active and Reactive Power Dispatch using Differential Evolution

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Abstract- The paper presents an approach for the optimal dispatch of active and reactive power with an aim to generate the optimal generation schedule satisfying the equality and inequality constraints and minimizing the cost of operation of generating units by using Genetic Algorithm and Differential Evolution. The approaches have been applied to IEEE 30 Bus system and the obtained results are compared.

Index Terms- Active Power, Reactive Power, Optimal Dispatch, Differential Evolution, Genetic Algorithm

I. INTRODUCTION

Reactive power maintenance in today's power system gains more importance in view of overloading of lines, insufficient system voltage and voltage instability/ collapse. Hence, power engineers and researchers have been motivated to use the devices in an optimal manner in order to maintain the reactive power and such reactive power needs to be priced. The different reactive power sources have different cost models for reactive power production. The power industries are in transition from monopolies to competitive market and thereby provide opportunity for innovation in reactive power service. Active power does the useful work. Reactive power is required for efficient supply of active power, maintenance of voltage stability and maintaining security and power factor of the system. Without the maintenance of the voltage, active power cannot be transferred to the load. Reactive power is helpful to supply necessary voltage in the system. In general, voltage reduces, when the reactive power supply decreases. Similarly, voltage rises, when the reactive power increases. Insufficient reactive power in the system leads to voltage collapse which is identified as the major reason for system blackouts.

If the voltage drops in the system, few generators will be disconnected automatically. Lower generation or transmission facilities and increased demand cause further reduction in voltage and it leads to voltage collapse. This progressive decline in voltage makes the system unable to meet the demands. Voltage is maintained in the system by the production or absorption of reactive power.

Three main reasons which makes necessary to manage reactive power and voltage are given below.

- The power system equipment such as induction motors, light bulbs, air conditioner etc is designed to operate with the ±5% variation of operating voltage. Above or below this operating voltage leads to equipment damage and reduces the life time of the equipment.
- Minimization of reactive power leads to maximize the real power (i.e.) Production of reactive power from the generator leads to reduction of real power capability.
- Reactive power flow in the line leads to real power losses.

Reactive Power Dispatch (RPD) is the injection of reactive power into the power system under heavily loaded condition. Addition of load in the system bus makes the system to be under stressed condition and there will be voltage reduction which sometimes leads to cascading blackout, if proper action is not taken. By performing RPD, the voltage stability condition is improved. Number of conventional optimization techniques is available to solve the RPD problem. Mota-palomino proposed Linear Programming (LP) method for solving the RPD [1]. Mamundur and Chenoweth introduced Dual LP technique for finding the solution of RPD problem [2]. Shoults and Sun decomposed the Optimal Power Flow (OPF) problem into real power model and reactive power model [3]. Liu et al. suggested the Newton OPF method and proposed penalty function based algorithm for solving optimization problem [4]. Santos has used Newtons method to solve optimization problem which uses Lagrangian function [5][6]. Burchett et al. proposed Quadratic programming solution to find the optimal solution of OPF [12]. Granville suggested Interior point method to solve the ORPD problem [7].

However, these classical optimization techniques have several limitations such as difficulty in handling inequality constraint, discontinuous function and difficult to handle discrete variables. These techniques easily converge to local minima. To overcome these difficulties, artificial intelligence technique

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and evolutionary techniques have been used. The artificial intelligence technique such as fuzzy logic and artificial neural network and the evolutionary algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Differential Evolution (DE) and Simulated Annealing (SA) have shown success for obtaining solution for ORPD problem. Dai et al. have proposed Seeker Optimization Algorithm (SOA) to solve the RP problem [8]. SOA acts similar to human search where the gradient decides the direction of search and the step distance is uncertainty. Tomsovic proposed a fuzzy linear programming approach to RPD problem [9]. The insufficient information sometimes leads to uncertain region of decision making. So, the fuzzy set theory plays a vital role and provides the results of ORPD problem, if sufficient information is provided.

Hasanpour et al. [10] have introduced the multiobjective OPF in which objective function is the maximization of social welfare and maximization of distance to voltage collapse. Here, to assign the value for weighing factor of the objective function, the index called Herfindahl– Hirschman Index (HHI) is used. They preserve the social welfare and system secure by adjusting the weighing factor and monitoring the HHI with referenced reactive power market. Lamont has discussed the various cost of reactive power sources such as generation source and transmission sources [11].

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In this paper, optimal dispatch of active and reactive power has been solved using Differential Evolution (DE), the problem is investigated and simulation results are presented.

II. PROBLEM FORMULATION

The aim of optimal dispatch problem is to minimize the generation cost of reactive power and minimizing the cost transmission losses. The problem is formulated in two steps: i.) Obtain the optimal schedule for the dispatch of reactive power minimizing the reactive power cost and determine the marginal cost for each generator, ii.) Minimize the combined cost of reactive power generation and transmission losses.

1. Optimal Dispatch of Reactive Power

For the determination of the reactive power cost, the reactive power cost coefficients has to be calculated on the basis of operating point of the generator obtained from the capability curve of generator as shown in Fig. 1.

When the generator produces the maximum value of active power then no reactive power is generated. Therefore, the complex power equals the maximum value of active power by the following relation between active and reactive power:

$$S^2 = P^2 + Q^2 \quad (1)$$

where, S is complex power, P is active power, Q is reactive power.

Reactive power production will decrease the production of active power as:

$$P_i = \sqrt{(P^2 \quad - Q^2)}$$

$$mx \qquad i$$

and

$$\nabla P = P_{mx} - P_i \quad (2)$$

Where, ∇P represents the change in active power for the generation of reactive power.

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International Journal of Scientific Research & Engineering Trends
Volume 10, Issue 5, Sept-Oct-2024, ISSN (Online): 2395-566X

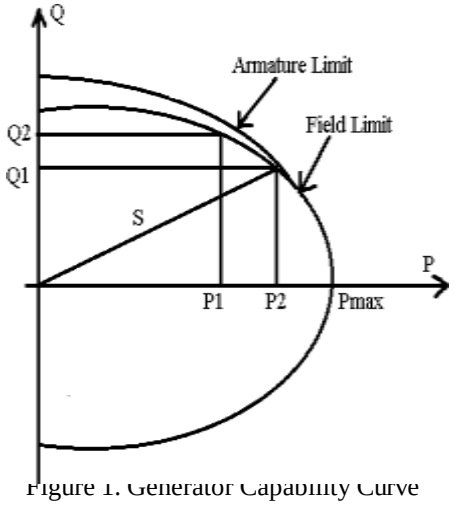

Figure 1. Generator Capability Curve

The generation of reactive power will decrease the active power generation capability of the generator. The cost of reactive power is to be expressed in terms of reactive power generated.

The cost curve is a quadratic function of generator's active and reactive power output. Cost function F(1) is obtained by considering the cost coefficients ai, bi, ci, di, ei, fi and active, reactive power generations, *Pgi* and *Qgi*, as:

$$F(1) = \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{gi} c_i) + \sum_{i=1}^{NGz} (d_i Q_{gi}^2 + e_i Q_{gi} + f_i) \$/h \quad (3)$$

where, NG is the number of generators.

The cost coefficients di, ei, fi are obtained by using the curve fitting method for each generator [12].

For step-1, the objective function is formulated as:

$$\text{Minimize } F(1) = \sum_{I=1}^{NG} (di\ Qgi^2 + ei\ Qgi + fi) \quad (4)$$

Subject to the following Constraints [13]:

Inequality Constraints

The active and reactive power limits in the generators:

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad ; i=1, 2\ldots NG \quad (5)$$

Where, P_{gi}^{min} and P_{gi}^{max} are the active power generation maximum and minimum limits for each generator, i.

$$Q_{gi}^{min} \le Q_{gi} \le Q_{gi}^{max} \quad ; i=1, 2\ldots NG \quad (6)$$

Where, Q_{gi}^{min} and Q_{gi}^{max} are the reactive power generation maximum and minimum limits for each generator, i.

Equality Constraints

The real and reactive power balance is achieved by subtracting the sum of demand and losses from the total power generation.

$$\sum_{i=1}^{NB} P_{gi} - (\sum_{i=1}^{NG} P_{di} + P_L) = 0; \quad i=1, 2\ldots NG \quad (7)$$

Where, $\boldsymbol{P_{gi}}$ is the active power generation for each generator, i; $\boldsymbol{P_{di}}$ is the active power demand for each bus, i; P_L is the active power losses.

$$\sum_{i=1}^{NB} Q_g - (\sum_{i=1}^{NG} Q_{di} + Q_L) = 0; \quad i=1, 2\ldots NG \quad (8)$$

Where, $\boldsymbol{Q_{gi}}$ is the reactive power generation for each generator, i; $\boldsymbol{Q_{di}}$ is the reactive power demand for each bus, i; $\boldsymbol{Q_L}$ is the reactive power losses.

The solution methodology searches the generation schedule with in maximum, $\boldsymbol{P_{gi}^{max}}$ $\boldsymbol{Q_{gi}^{max}}$ and minimum, $\boldsymbol{P_{gi}^{min}}$, $\boldsymbol{Q_{gi}^{min}}$ limits of active and reactive power generation.

The real and reactive power balance equations are used to calculate the error to satisfy the power balance constraints given by:

$$Er(1) = \sum_{i=1}^{NB} P_{gi} - \sum_{i=1}^{NG} P_{di} - P_L; \quad (9)$$

Where, $\boldsymbol{P_{gi}}$ is the active power generation for each generator, i; $\boldsymbol{P_{di}}$ is the active power demand for each bus, i; P_L is the active power losses.

$$Er(2) = \sum_{i=1}^{NB} Q_{gi} - \sum_{i=1}^{NG} Q_{di} - Q_L; \quad (10)$$

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Where, Q_{gi} is the reactive power generation for each generator, i; Q_{di} is the reactive power demand for each bus, i; Q_L is the reactive power losses.

The errors calculated [15] from eq. (9) and (10) are used in calculation of fitness value of objective function as:

$$F(P_{gi}) = F(P_{gi}) + v \times (E_{r1})^2 \quad (i=1, 2,\ldots NG) \qquad (11)$$

$$F(Q_{gi}) = F(Q_{gi}) + v \times (E_{r2})^2 \quad (i=1, 2,\ldots NG) \qquad (12)$$

Where, v is the penalty for constraint violation kept at high value.

III. DIFFERENTIAL EVOLUTION

Differential Evolution is a meta-heuristic approach that optimizes by searching a large space of solutions. DE uses the multi-dimensional real value function. So it can be used for the optimization problems that are not a continuous function or change with time.

This method optimizes a function by creating the new solutions from the existing solution combinations and stores the best solution according to the best fitness value from the solution set based on the problem [12-15].

The basic DE algorithm starts by creating a population of random candidates in solution. The candidates then search around the search space to combine with existing solution candidates. If this combination presents an improved solution then this will be accepted and become a part of candidate solutions in population else the combination can be denied. On repetition of the combination process, it is thought that an optimal and satisfactory solution would be achieved.

Differential Evolution generates new candidates in solution by adding the weighted difference between two population candidates to a third candidate vector, known as mutation. The mutated candidate vectors are then mixed with the candidates of other predetermined candidate vector, the target vector, to get the trial vector.

This combination is known as “crossover". If the value of trial vector results a lower function value than the target vector, the trial vector is then replaced by the target vector in the upcoming generation, this is called selection. This process of mutation, crossover and selection continues for a given number of generations or till the given termination.

The differential evolution algorithm will repeat the illustrated steps until it finds the optimal solution.

IV. ALGORITHM FOR DIFFERENTIAL EVOLUTION BASED OPTIMIZATION

Stepwise algorithm is described below to achieve the solution by DE

- Read the database for the generator data and bus data. Main function handle and required data is given as input.
- Suitable population size and maximum number of iterations is assumed.
- Run DE. It will use main function, which does the following:
- Determines the active and reactive power generation schedule.
- Calculates the active power cost
- Calculates the reactive power cost.
- Modifies the power generation to satisfy the equality constraint
- Calculates the errors and fitness
- DE is run for the given number of iterations to give the final best solution until otherwise terminated by some stopping criteria**.**

V. GENETIC ALGORITHM

Genetic algorithms are powerful stochastic search algorithms based on the mechanism of natural selection and natural genetics. GAs works with a population of binary string, searching many peaks in parallel. By employing genetic operators, they exchange information between the peaks, hence reducing the possibility of ending at a local optimum. GAs are more flexible than most search methods because they require only information concerning the quality of the solution produced by each parameter set (objective function values) and not like other optimization methods which require derivative information, or worse yet, complete knowledge of the problem structure and parameters[24].
There are some difference between GA’s and traditional searching algorithms [16-18]. They are summarized as follows:

- The algorithms work with a population of string, searching many peaks in parallel, a supposed to a single point.
- GAs work directly with strings of characters representing the parameters set not the parameters themselves.
- GAs use probabilistic transition rules instead of deterministic rules.
- GAs use objective function information instead of derivatives or others auxiliary knowledge.
- GAs has the potential to find solutions in many different areas of the search space simultaneously [19-23].

Genetic programming is a domain-independent problem-solving approach in which computer programs are evolved to

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solve, or approximately solve, problems. Genetic programming is based on the Darwinian principle of reproduction and survival of the fittest and analogs of naturally occurring genetic operations such as crossover and Mutation.

The genetic algorithm attempts to find a good (or best) solution to the problem by genetically breeding a population of individuals over a series of generations. In the genetic algorithm, each individual in the population represents a candidate solution to the given problem.

The genetic algorithm (GA) transforms a population (set) of individuals, each with an associated fitness value, into a new generation of the population using reproduction, crossover, and mutation.

VI. ALGORITHM FOR GENETIC ALGORITHM BASED OPTIMIZATION

Stepwise algorithm is described below to achieve the solution by GA.

- Read the database for the generator data and bus data. Main function handle and required data is given as input.
- Suitable population size and maximum number of iterations is assumed.
- Run DE. It will use main function, which does the following:
- Determines the active and reactive power generation schedule.
- Calculates the active power cost
- Calculates the reactive power cost.
- Modifies the power generation to satisfy the equality constraint
- Calculates the errors and fitness
- DE is run for the given number of iterations to give the final best solution until otherwise terminated by some stopping criteria**.**

VII. TEST SYSTEM

The Genetic Algorithm and Differential Evolution Optimization is applied to the IEEE 30 bus, 6 Generators, 41 lines, as shown in Fig. 2 with a total load demand of 238.40 MW and 177.50MVAR [10].

Different combinations of active and reactive power generations are searched using DE and GA using MATLAB Software. The generation coefficients are given in Tables 1. The lower and upper limits of generators and are shown in Table 2 respectively.

Table 1. Active Power Generator Cost coefficients

Unit	ai ($/MWh²)	bi ($/MWh)	ci
1	0.00375	2.00	0
2	0.01750	1.75	0
3	0.06250	1.00	0
4	0.00834	3.25	0
5	0.02500	3.00	0
6	0.02500	3.00	0

Table 2. Active and Reactive Power Generation Limits

UNIT	Pi min (MW)	Pi max (MW)	Qi min (MVAR)	Qi max (MVAR)
1	50	200	-50	200
2	20	80	-20	100
3	15	50	-15	80
4	10	35	-15	60
5	10	30	-10	50
6	12	40	-15	60

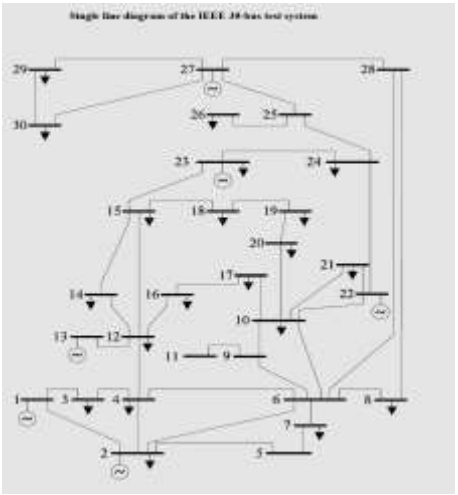

Figure 2. IEEE 30 Bus Test System

VIII. RESULTS AND DISCUSSION

The reactive power cost coefficient values for the generators given in table 3 were determined using the curve fitting method.

Table 3**.** Reactive power cost coefficients for IEEE- 30 Bus system

Unit	di ($/Mvarh²)	ei ($/Mvarh)	fi
1	-0.00375	0.3825	27.746
2	-0.0175	0.735	20.283
3	-0.0625	1.375	31.5
4	-0.0083	0.1418	1.9516
5	-0.025	0.3	4.725
6	-0.025	0.45	7.975

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Table 4 shows the results after 50 generations run for Genetic algorithm. The combined cost of active and reactive power is reduced to 1.1656e+03 $/h.

With the increase in generations the Generator active power loss is reduced from 1.33 per unit to 0.91 per unit. After the optimized schedule of active and reactive power is obtained, load flow is run with Newton Raphson method.

Table 4. Objective function values corresponding to best solution schedule with GA for IEEE-30 Bus system.

No. of Generations	10	20	30	40	50
Active Power Cost ($/h)	389.4	1014.5	1149.5	1154.2	1153.2
Reactive Power Cost ($/h)	88.0	1.3431e +06	48.9	13.4	12.4
Active Power Loss, P_{GL} (p.u)	1.33	0.59	0.97	0.94	0.91
Error function, Er(1)	267.8	0	0	0	0
Error Function, Er(2)	379.2	115.9	0	0	0
Time (Seconds)	0.816 4	1.3592	1.4328	2.2786	2.269 6

The power convergence i.e. the equality constraint on the active and reactive in terms of errors, Er1 and Er2 is also shown in Table 4. The time taken for the optimization is shown, as the number of generations rise, time of execution also increases. Time taken for the optimization process i.e. at 50 generations is 2.2696 sec.

Table 5. Objective function values corresponding to best solution schedule with DE for IEEE-30 Bus system.

No. of Generations	10	20	30	40
Active Power Cost ($/h)	5.2667e +06	1.0662e +03	941.740 0	860.840 9
Reactive Power Cost ($/h)	4.6786e +05	1.0643e +06	299.785 4	134.612 5
Active Power Loss, P_{GL} (p.u)	1.14	0.77	0.66	0.13
Error function, Er(1)	229.483 2	0	0	0
Error Function, Er(2)	68.3999	103.165 7	0	0
Time (Seconds)	0.1770	1.2404	1.8659	1.6759

Table 5 shows the results after 40 generations run for Differential Evolution. The combined cost of active and reactive power is reduced to 995.4534 $/h. With the increase in generations the Generator active power loss is reduced from 1.14 per unit to 0.13 per unit. After the optimized schedule of active and reactive power is obtained, load flow is run with Newton Raphson method.

The power convergence i.e. the equality constraint on the active and reactive in terms of errors, Er1 and Er2 is also shown in Table 5. The time taken for the optimization is shown, as the number of generations increase, the time also increases. Time taken for the optimization process i.e. at 40 generations is 1.6759 sec.

IX. CONCLUSION

In the present paper, a problem of an optimal dispatch of active and reactive power problem has been solved using GA and DE method. The active and reactive power optimization problem for the IEEE-30 Bus System was solved, and the findings show that although 50 iterations were needed to reach the solution, DE achieved the best results after 40. By using DE instead of GA optimization, the aggregate cost was lowered to 995.4534 $/h, which is less than 1.1656e+03 $/h. DE also shows the better results in terms of losses as the losses are reduced to 0.13 per unit. DE takes very less time taken for generating the best optimized results in 40 iterations as compared to 0.91 per unit GA algorithms. The minimum time is taken for the optimized results with DE as compared to GA method used. Time taken by GA for the optimization process i.e. at 50 generations is 2.2696 sec whereas it is reduced to 1.6759 sec with DE. Overall the DE has been shown to be very helpful in studying optimization problems in power systems.

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