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Combined Active and Reactive Power Dispatch Using Particle Swarm Optimization

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Abstract

Major objective for the Thermal power generation is to minimize fuel consumption by allocating optimal power generation from each unit subject to equality and inequality constraints. In most of cases fuel cost consist of active power cost only however reactive power is very essential for secure and reliable operation of power systems, so the reactive power cost has to be included in the cost calculation function. However, reactive power production by a generator will reduce its capability to produce active power. Hence, provision of reactive power by generator will result in reduction of its active power production, so the reactive power pricing is equally important with real power pricing, therefore a fair price calculation method seems to be essential. The objectives considered in this paper are minimization of active power cost and reactive power cost subject to equality and inequality constraints. In this paper Particle Swarm Optimization (PSO) technique has been applied to minimize both active and reactive power cost. The equality constraints have been handled by exterior penalty method. In order to show the effectiveness, the proposed approach has been tested on IEEE 9-bus standard network. Numerical results obtained from the proposed approach are compared with another technique confirms its validity and effectiveness.

Keywords: Active power dispatch, Reactive power dispatch, Reactive power pricing, Particle Swarm Optimization

Introduction

The objective of economic load dispatch (ELD) of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost. The remote location of power plant from the load centre has been identified as one of the reasons which caused high cost. The increase in fuel cost these days has also contributed to this phenomenon. Under ELD problem the generator's output has to be varied within minimum-maximum limits so as to meet a particular load demand and losses with overall minimum fuel cost (Miller & Malinnowski, 1994). As each generator load has reactive power demand so for secure and reliable operation reactive power is also necessary with real power but reactive power has dominant effect on real power. However, reactive power production by a generator will reduce its capability to produce active power. Hence, provision of reactive power by generator will result in reduction of its active power production, so the reactive power pricing is equally important with real power pricing. In most of cases the cost of reactive power is not considered whereas the cost of only active power is considered in the cost calculation of ELD which gives inaccurate cost function. On the other hand, while reactive power production cost is highly dependent on real power output. An appropriate pricing of reactive power has been a challenging problem during the past decade so a fair cost function has to be developed for reactive power pricing which gives a accurate cost function for secure and reliable operation. This cost function of reactive power generation by committed generating unit has to be included in the cost calculation function of ELD to get an accurate cost of generating units (Hasanpour et al., 2009).

A modern heuristic optimization techniques such as simulated annealing, evolutionary algorithms, neural networks, and ant colony have been given much attention by many researchers due to their ability to find an almost global optimal solution in Economic dispatch problems(Coelho & Mariani,2006; Song & Chou,1999; Yalcinoz & Altun,2001).In previous research different techniques have been suggested to calculate the reactive power pricing (Baughman & Siddiqi, 1993; Deksnys & Staniulis, 2007; Hogan, 1993; Kahn & Baldick, 1994; Muchayi & El-Hawary, 1999; Niknam et al.,2004)**.** Some of these methods utilize various search techniques such as genetic and ant colony algorithms for pricing (Niknam et al., 2004). A coupled market framework for energy and reactive power is proposed in Chung et al. (2004)**.** An integrated method to calculate both real and reactive power spot price and to decompose them into the prices of selected ancillary services has been developed in Bialak and Kattuman(2004).

In this paper, PSO algorithm has been applied to solve the combined active and reactive dispatch problem. Particle Swarm Optimization (PSO) constraint-handling algorithm has been applied to search the active and reactive generation from each generating unit within generator limits so that total cost(Active and reactive) corresponding to that generation becomes minimum subject to equality and inequality constraints.

Problem Formulation

Problem Objectives

Minimization of fuel cost with real power output

The fuel cost function of each fossil fuel fired generator is expressed as a quadratic function. The total fuel cost in terms of real power output can be expressed as:

$$F(P_{gi}) = \sum_{i=1}^{NG} \left(a_i P_{gi}^2 + b_i P_{gi} + c_i \right) \tag{1}$$

where, a_i, b_i and c_i are the fuel cost coefficients of ith unit. NG is the number of generators.

Minimization of fuel cost with reactive power output

Reactive power production cost is highly dependent on real power output. If a generator produces its maximum active power *(P*max*)* then no reactive power is produced and therefore, Apparent power (S) equals *P*max. However, reactive power production by a generator will reduce its capability to produce active power. Hence the production of reactive power by generator will result in reduction of its active power production. So to generate reactive power Q_{gi} by generator *i,* which has been operating at its nominal power *(P*max*)*, it is required to reduce its active power to *Pgi* (Hasanpour, et.al., 2009). So at the different values of Q_{gi} with respect to P_{gi} the Quadratic cost expression for reactive power is calculated by fitting a curve into a quadratic polynomial.

The fuel cost in terms of reactive power output can be expressed as:

$$F(Q_{gi}) = \sum_{i=1}^{NG} \left(a_{qi} Q_{gi}^2 + b_{qi} Q_{gi} + c_{qi} \right) \tag{2}$$

Where a_{qi}, b_{qi}, c_{qi} are reactive power cost coefficients are calculated using a curve fitting and NG is the number of generators.
This equation is very simple and as it is extracted from the power cost function of the generator, it is more realistic and can provide accurate results in reactive power pricing **(**Hasanpour, et.al.,2009)**.**

Constraints

Real and reactive power balance constraint

The total real power generation must balance the predicted real power demand plus the real power losses.

$$\sum_{i=1}^{NG} P_{gi} - \sum_{i=1}^{NB} P_{Di} - P_L = 0 \tag{3}$$

where, P_{Di} is the active power demand in the ith bus, NB is the number of buses and P_L is real power losses.

The total reactive power generation must balance the predicted reactive power demand plus the reactive power losses.

$$\sum_{i=1}^{NG} Q_{gi} - \sum_{i=1}^{NB} Q_{Di} - Q_L = 0 \tag{4}$$

where, Q_{Di} is the Reactive power demand, NB is the number of buses, NG is the number of generators and Q_L is the reactive power losses.

Active and reactive power operating limit

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i=1,2,......, NG) \tag{5}$$

where, $P_{gi}^{\min}$ and $P_{gi}^{\max}$ are the minimum and maximum limits for active power generation by ith unit.

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (i=1,2,......, NG) \tag{6}$$

where, $Q_{gi}^{\min}$ and $Q_{gi}^{\max}$ are the minimum and maximum limits for reactive power generation by i^{th} unit.

Combined active and reactive power cost

In order to obtain an accurate cost function the reactive power cost is to be included in the active power cost function .The Total cost is given by combining the active and reactive power cost. The objective function become as given below:

$$\text{Minimize } F_{Total} = \sum_{i=1}^{NG} F(P_{gi}) + F(Q_{gi}) \tag{7}$$

Subject to

$$\sum_{i=1}^{NG} P_{gi} - \sum_{i=1}^{NB} P_{Di} - P_L = 0 \tag{8}$$

$$\sum_{i=1}^{NG} Q_{gi} - \sum_{i=1}^{NB} Q_{Di} - Q_L = 0 \tag{9}$$

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \qquad (i=1,2,......, NG) \tag{10}$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \qquad (i=1,2,......, NG) \tag{11}$$

Particle Swarm Optimization

A modern heuristic optimization techniques such as simulated annealing, evolutionary algorithms, neural networks, and ant colony have been given much attention by many researchers due to their ability to find an almost global optimal solution in EDPs (Balakrishnan, et al., 2003; Coelho & Mariani, 2006; Song & Chou, 1999; Yalcinoz & Altun, 2001). One of these modern heuristic optimization paradigms is the particle swarm optimization (PSO) (Eberhart, & Kennedy, 1995; Kothari & Dhillon, 2011; Singh et al., 2013).

PSO is a kind of evolutionary algorithm based on a population of individuals and motivated by the simulation of social behavior instead of the survival of the fittest individual. Similar to the other population-based evolutionary algorithms, PSO is initialized with a population of random solutions. Unlike the most of the evolutionary algorithm solution (individual) in PSO is associated with a randomized velocity, and the potential solutions, called particles, are then “flown” through the problem space.

Representation of PSO

Let X and v denotes a particle’s coordinate (position) and its corresponding velocity in a search space, respectively. Therefore, the i^{th} particle is represented as $X_i = [X_{i1}, X_{i2}, X_{i3},........., X_{iNG}]$ in the NP-dimensional space. The best previous position of each particle is recorded and represented as $Xb_i = [Xb_{i1}, Xb_{i2}, Xb_{i3}... Xb_{iNG}]$. The index of best particle among all the particles in the group is represented by the $[G_1, G_2, G_3,......., G_{NG}]$. The rate of velocity of the particle is represented as $v_i =[v_{i1}, v_{i2}, v_{i3},.........., v_{iNP}]$. The modified velocity and position of each particle can be calculated using the current velocity and the distance from Xb_{ij} to G_j as shown in following formulas(Kothari & Dhillon, 2011).

$$v_{ij}^{r+1} = W \times v_{ij}^{r} + C_1 \times R_1 \times (Xb_{ij}^{r} - X_{ij}^{r}) + C_2 \times R_2 \times (G_j^{r} - X_{ij}^{r}) \quad (i = 1,2,....NP; j = 1,2....,NG) \tag{12}$$

$$X_{ij}^{r+1} = X_{ij}^{r} + v_{ij}^{r+1} \qquad (i = 1,2,.....NP; j = 1,2.....,NG) \tag{13}$$

where, NP is the number of particles in a group, NG is the number of members in a particle, r is the pointer of iteration (generation), W is the inertia weight factor, C_1 and C_2 are the acceleration constants, R_1 and R_2 are uniform random values in range[0,1], v_{ij}^{r} is the velocity of j^{th} member of i^{th} particle at r^{th} iteration, $v_j^{min} \le v_{ij}^{r} \le v_j^{max}$, P_{ij}^{r} is the current position of j^{th} member of i^{th} particle at the r^{th} iteration.

In the above procedure, the parameter $v_j^{\min}$ determined the resolution, or fitness, with which regions are to be searched between the present position and the target position. If $v_j^{\max}$ is too high, particles might fly past good solutions. If $v_j^{\max}$ is too small, particle may not explore sufficiently beyond local solutions. In many experiences with PSO, $v_j^{\max}$ was often set at 10-20% of the dynamic range of the variable on the variable of each dimension.

The constant C_1 and C_2 represents the weighting of the stochastic acceleration terms that pull each particle toward the Xb_{ij}^{r}, G_j^{r} positions. Low values allow particles to roam far from the target region before being tugged back. On the other hand, high values result in abrupt movement toward, or past, target regions. Hence, the acceleration constants C_1 and C_2 were often set to be 2.0 according to past experiences (Kothari & Dhillon, 2011).

The generalized Eq.(12) can be updated in order to find new value of velocity by considering the global best and particle best position as given below:

$$v_{ij}^{new} = W \times v_{ij} + C_1 \times R_1 \times (X_{ij}^{best} - X_{ij}) + \left(C_2 \times R_2 \times (G_j^{best} - X_{ij})\right) \tag{14}$$

Now the new positions are updated using Eq.(14) as given below:

$$X_{ij}^{new} = X_{ij} + v_{ij}^{new} \qquad (i = 1, 2 ...NP; j = 1,2....NG) \tag{15}$$

In the strategy of PSO, the particle's best position, x_{ij}^{best} and the global best position G_j^{best} are the key factors. The best position out of all x_{ij}^{best} is taken as G_j^{best} Suitable selection of inertia weight in Eq.(16) provides balance between global and local explorations, thus requiring less iteration on average to find a sufficiently optimal solution. As originally developed, W often decrease linearly about 0.9 to 0.4 during a run. In general inertia weight W is set according to the following equation (Kothari & Dhillon, 2011).

$$W = W^{\max} - \frac{W^{\max} - W^{\min}}{IT^{\max}} \times IT \tag{16}$$

where, $IT^{\max}$ is the maximum number of iterations (generation) and IT is the current number of iterations.

Solution Approach

Errors from the best solution are calculated using power balance equation to satisfy the power balance constraints.

Evaluation of Objective Function

In order to satisfy the power balance constraint, Errors are calculated using the power balance equation, which is given as:

$$E_1 = \sum_{i=1}^{NG} P_{gi} - \sum_{i=1}^{NB} P_{Di} - P_L \tag{17}$$

where, P_{Di} is the demand, P_L are active power losses

similarly

$$E_2 = \sum_{i=1}^{NG} Q_{gi} - \sum_{i=1}^{NB} Q_{Di} - Q_L \tag{18}$$

where, Q_{Di} is the demand, Q_L are the reactive power losses

The errors as calculated in Eq.(17) and Eq.(18) is then introduced in Eq.(1) and Eq.(2) to penalize its fitness value. When so introduced the, Eq.(1) and Eq.(2) are changed to the following generalized forms:

$$F_1(P_{gi}) = F(P_{gi}) + r \times (E_1)^2 \;\; (i=1,2,...NG) \tag{19}$$

$$F_2(P_{gi}) = F(Q_{gi}) + r \times (E_2)^2 (i=1,2,...NG) \tag{20}$$

where, r is set at higher value.

The combined total cost is given by Eq.(21), Now minimize the total cost as given below:

$$F_{Total} = \sum_{i=1}^{NG} F_1(P_{gi}) + F_2(Q_{gi}) \;\; (i=1,2,...NG) \tag{21}$$

Algorithm for Solution Technique

According to the discussion in above sections, the following procedure can be used for implementing the PSO algorithm.

- For each particle in the swarm X_i
  - Initialize the particle's position with a uniformly distributed random vector in the lower and upper boundaries of search-space.
  - Evaluate the performance (fitness) of each particle using Equation (21)
  - Find the minimum fitness out of each particle performance
  - Assign the particle's best known position(local) to its initial position
  - Assign the Global best position to the swarm's best known position(local) according to the minimum fitness value
  - Initialize the particle's velocity within minimum and maximum boundaries of search-space
- Until a termination criterion is met (e.g. number of iterations performed, or adequate fitness reached), repeat
  - For each particle
    - Create a uniformly distributed random vectors R_1 and R_2

- Update the particle's velocity: using Eq.(14)
- Update the particle's position by adding the velocity: using Eq.(15)
- Evaluate the performance(fitness)using Eq.(21) according to new positions:
- IF the new fitness is less than the previous fitness THEN
- Update the new particle positions as the particle's best(local) known position
- Assign new fitness as the local fitness and find the minimum out of each.
- Update the swarm's best (global best) known position according to minimum fitness.

Now best new positions hold the best found solution.

Results and Discussion

In this paper, the results have been obtained by using proposed Technique, which as discussed in previous section. The proposed technique has been tested on IEEE 9 Bus system shown in Figure 1.

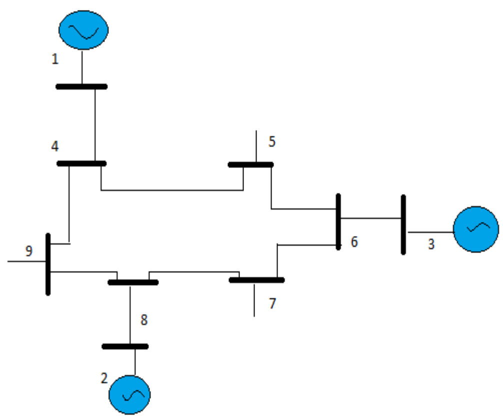

Figure 1: IEEE 9 Bus System

Table 1.- Generator Characteristics							
No. Of Buses	a_P	b_P	Cp	P_{max}	P_{min}	Q_{max}	Q_{min}
1	0.11	5	150	250	10	300	-300
2	0.08	1.2	600	600	10	300	-300
3	0.12	1	335	335	10	300	-300

Table 1 and Table 2 show the generator and load characteristics respectively in which values of active power cost coefficients, maximum and minimum limits of active and reactive power and total demand of active and reactive power are given. Using data as given in Table 1 and Table 2 respectively, the problem is solved using the proposed algorithm and the results obtained are shown in Table 3, which shows the scheduling of active and reactive power with their individual and total operating cost.

The Coding has been carried out on system having 2.40 GHz intel (R) Core(TM) i5 processor with 3 GB of RAM in Fortran power station 4.0.

Table 2.- Load Characteristics

No. Of Buses	Active Power(MW)	Reactive power(MVAR)
5	90	30
7	100	35
9	125	50

Table 3.- Active power Generation (P_G),Reactive power Generation,(Q_G),Active and Reactive power cost per hour bases, Total cost in $.

No. Of Buses	P_G(MW)	Q_G(Mvar)
1	112.824700	21.288760
2	128.743800	82.631210
3	73.431460	11.080020
Cost($)	5250.3430	210.17720
Total Cost($)	5460.5205	

Comparison of Results

To show the effectiveness of the proposed approach, results are compared with related work carried out by researchers Hasanpour et al., (2009). Table 4 shows the comparison of results obtained from proposed PSO and work carried out by Hasanpour et al.,(2009), it is found that total operating fuel cost ($5460.5205) obtained from proposed approach is comes out to be less as compared to fuel cost ($5690.612) calculated from approach discussed by Hasanpour et al., (2009).

Table 4.- Comparison of proposed approach with Hasanpour et.al., (2009)**.**

Bus No.	Proposed Approach		(Hasanpour, et.al., 2009)	
	P_G(MW)	Q_G(Mvar)	P_G(MW)	Q_G(Mvar)
1	64887.88	1283.401	64843.00	1286.00
2	113421.6	4114.019	113480.00	4124.90
3	125730.3	195254.80	125790.00	211190.00
Total Cost($)	5460.5205		5690.612	

Conclusion

The ELD Problem including Reactive power pricing has been solved using an algorithm based on particle swarm optimization (PSO). The problem has been solved for IEEE 9 bus system. Results obtained with proposed approach are compared with approach as discussed by Hasanpour et al., (2009). The developed algorithm is capable to handle both the objectives. The results drawn by proposed approach are found to be better as compared with approach discussed by Hasanpour et al., (2009).

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Dr. D.P. Kothari is presently working as Director Research, Wainganga College of Engineering & Management, He received his BE (Electrical) in 1967, ME(Power Systems) in 1969 and Ph.D in 1975 from the Birla Institute of Technology & Science(BITS) Pilani, Rajasthan. Prior to assuming charge as Director Research, Wainganga College of Engineering & Management, Hyderabad, he served as Director Research, MVSR Engineering College, Hyderabad , DG JBI ,Hyderabad, DG RGI, DG VGI, Indore, Vice Chancellor, VIT, Vellore, Director in-charge and Deputy Director (Administration) IIT Delhi as well as Head in the Centre of Energy Studies at Indian Institute of Technology, Delhi and as Principal, Visvesvaraya Regional Engineering College, Nagpur. He was Visiting Professor at the Royal Melbourne Institute of Technology, Melbourne, Australia, during 1982-83 and 1989 for two years. He was also NSF Fellow at Purdue University, USA in 1992. He is fellow of Indian National Academy of Engineering (INAE), Indian National Science Academy (FNASc), Institution of Engineers, India (IEI) and Institute of Electrical and Electronics Engineers (FIEEE). He has authored /co-authored/more than 771 papers in International/National Journals/Conferences & 32 books including Power System Engineering, 2e Electric Machines, 4e Electric Machines (Sigma Series), 2e and Basic Electrical Engineering, 3e. His fields of specialization are Optimal Hydrothermal Scheduling, Unit Commitment, Maintenance Scheduling, Energy Conservation (loss minimization and voltage control), Power Quality and Energy System Planning and Modelling.