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Considering Environmental Pollution in Optimal Power Flow.

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ABSTRACT

This paper provides a new optimal power flow (OPF) considering environmental pollution. The proposed optimal power flow is mathematically formulated as a constrained optimization programming, which aims at minimizing generation and pollution costs at the same time. The problem is solved by using particle swarm optimization (PSO) method. Simulation results demonstrate the effectiveness of the method.
Keywords: Environmental Pollution; Optimal Power Flow; Constrained Optimization Programming; Particle Swarm Optimization

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INTRODUCTION

The optimal power flow (OPF) is a well-known and most studied problem in electric power systems. The main purpose of OPF is to minimize the total thermal unit fuel cost, total emission, and total real power loss while satisfying physical and technical constraints on the network. Many studies have been carried out about OPF so far [1-6]. Some of these studies are reviewed in the following. Paper [7] discusses that harmful ecological effects caused by the emission of gaseous pollutants like sulfur dioxide (SO2) and nitrogen oxides (NOx), can be reduced by load adequate distribution between power plants. However, this leads to a noticeable increase in their operating cost. In order to eliminate this conflict, and to study the trade-off relation between fuel cost and emissions, an approach to solve this multiobjective environmental/economic load dispatch problem, based on an efficient successive linear programming technique is proposed. Simulation results on the Algerian 59-bus power system prove the efficiency of this method thus confirming its capacity to solve the environmental/economic power dispatch problem. Paper [8] addresses optimal power flow with environmental constraints using paired bacterial optimizer. This paper explanis that pollution of the power plant has caused harmful environmental effects due to the emission of greenhouse gas. The pollution can be reduced by adjusting the real power outputs of different power plants. However, the relocation of real power outputs results an additional outlay in the system. In order to eliminate the conflict between the cost and emission, an optimal power flow is introduced in this paper, which aims to study the trade-off relationship between the economic dispatch and the power plant emission. Simulation results on the IEEE 30-bus power system demonstrates the perspective of solving the environmental-economic power dispatch problem by a novel optimization algorithm. Paper [9] presents the use of a meta-heuristic nature-inspired algorithm, called firefly algorithm for the solution of the optimal power flow problem. The objective is to minimize the total fuel cost of generation and environmental pollution caused by fossil based thermal generating units and also maintain an acceptable system performance in terms of limits on generator real and reactive power outputs, bus voltages, shunt capacitors/reactors and power flow of transmission lines. In this work the standard IEEE 30-bus test system with six generating units has been used to test the effectiveness of the proposed method. Satisfactory results obtained from the proposed method were compared to those obtained by genetic algorithm (GA) and particle Swarm methods (PSO). Paper [10] provides optimal power flow of receiving power network considering distributed generation and environment pollution. This paper discusses that by the fact that more and more distributed generations located in receiving power network, proper power arrangement of distributed generations is presented to optimize active power flow of receiving power network. Considering different effect on environment of various distributed generation, environment value index of contamination is used to evaluate the effect on environment of contamination. Based on it a model of environment cost included charge of emission and cost of environment guard against pollution is established. And then a model of OPF included environment cost is established by penalty function method. And primal dual interior point method is used to solve it. At last, simulation test is carried out on data of a receiving power network. The result indicates that cost and loss can be debased at one time, environment pollution can be reduced, on condition that considering environment cost, production cost and loss. Paper [11] presents the use of a novel evolutionary algorithm called Biogeography-based optimization (BBO) for the solution of the optimal power flow problem. The objective is to minimize the total fuel cost of generation and environmental pollution caused by fossil based thermal generating units and also maintain an acceptable system performance in terms of limits on generator real and reactive power outputs, bus voltages, shunt capacitors/reactors and power flow of transmission lines. BBO searches for the global optimum mainly through two steps: Migration and Mutation. In the present work, BBO has been applied to solve the optimal power flow problems on IEEE 30-bus test system with six generating units to test the effectiveness of the proposed method. Satisfactory results obtained from the proposed method were compared to conventional and evolutionary optimization methods.

This paper provides a new optimal power flow (OPF) considering environmental pollution. The proposed optimal power flow is mathematically formulated as a constrained optimization programming, which aims at minimizing generation cost and pollution cost at the same time. The problem is solved by using particle swarm optimization (PSO) method. Simulation results demonstrate the effectiveness of the method.

Problem formulation

OPF is a constrained and nonlinear optimization programming which calculates the optimal values of generation for generation units. The optimal values are mainly calculated to achieve a certain purpose such as generation cost minimization or line transmission power loss minimization subject to equality and inequality constraints. The standard OPF problem can be mathematically formulated as follows [11]:

Min (F(x))
Subject to
g(x)=0
h(x)>0

where,
F(x) shows the objective function;
g(x) indicates the equality constraints;
h(x) shows the inequality constraints;
x is the vector of control variables such as generated active power, generation bus magnitudes, and transformers tap … etc.
$x=[P_g, V_g, T_p, \ldots]$;
Based on the proposed formulation, the problem can be formulated in details as follows:

$$\mathrm{Min}\left[\alpha\sum_{i=1}^{ng}\left(A_i+B_iP_{gi}+C_iP_{gi}^2\right)+\beta\sum_{i=1}^{ng}\left(a_i+b_iP_{gi}+c_iP_{gi}^2+d_i\exp\left(e_iP_{gi}\right)\right)\right] \quad (1)$$

Subject to

$$\sum_{i=1}^{ng}P_{gi}-P_D-P_L=0 \quad (2)$$

$$P_{gi}^{min}\le P_{gi}\le P_{gi}^{max} \quad (3)$$

$$Q_{gi}^{min}\le Q_{gi}\le Q_{gi}^{max} \quad (4)$$

$$V_i^{min}\le V_i\le V_i^{max} \quad (5)$$

$$\theta_i^{min} \le \theta_i \le \theta_i^{max} \quad (6)$$

$$T^{min} \le T \le T^{max} \quad (7)$$

Objective function (1) comprises two terms, the first term shows the generation cost and second one shows the pollution cost. Where, α and β show the weighting factors, A, B and C show the constant factors of generation cost and P_{gi} shows the generation power of unit i_{th}. Number of generation units is shown by ng. a, b, c and show the constant factors of pollution cost. Constraint (2) shows the equality constraint of the problem, which reflects the physics of the power system. In this equation, P_D is the total power demand of the plant and P_L is the total power losses of the plant. Constraint (3) shows the upper and lower bounds on the active generations at generator buses. Constraint (4) shows the upper and lower bounds on the reactive power generations at generator buses and reactive power injection at buses with VAR compensation. Constraint (5) shows the upper and lower bounds on the voltage magnitude at the all buses. Constraint (6) shows the upper and lower bounds on the buses voltage phase angles. Constraint (7) shows the upper and lower transformer tap setting.

Particle swarm optimization

Particle swarm optimization (PSO) is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best known position but, is also guided toward the best known positions in the search-space, which are updated as better positions are found by other particles. This is expected to move the swarm toward the best solutions. PSO is a meta-heuristic as it makes few or no assumptions about the problem being optimized and can search very large spaces of candidate solutions. However, meta-heuristics such as PSO do not guarantee an optimal solution is ever found. More specifically, PSO does not use the gradient of the problem being optimized, which means PSO does not require that the optimization problem be differentiable as is required by classic optimization methods such as gradient descent and quasi-Newton methods. PSO can therefore also be used on optimization problems that are partially irregular, noisy, change over time.

Algorithm

A basic variant of the PSO algorithm works by having a population (called a swarm) of candidate solutions (called particles). These particles are moved around in the search-space according to a few simple formulae. The movements of the particles are guided by their own best known position in the search-space as well as the entire swarm's best known position. When improved positions are being discovered these will then come to guide the movements of the swarm. The process is repeated and by doing so it is hoped, but not guaranteed, that a satisfactory solution will eventually be discovered.

Parameter selection

Performance landscape showing how a simple PSO variant performs in aggregate on several benchmark problems when varying two PSO parameters. The choice of PSO parameters can have a large impact on optimization performance. Selecting PSO parameters that yield good performance has therefore been the subject of much research. The PSO parameters can also be tuned by using another overlaying optimizer, a concept known as meta-optimization. Parameters have also been tuned for various optimization scenarios

Convergence

In relation to PSO the word convergence typically means one of two things, although it is often not clarified which definition is meant and sometimes they are mistakenly thought to be identical. Convergence may refer to the swarm's best known position g approaching (converging to) the optimum of the problem, regardless of how the swarm behaves. Convergence may refer to a swarm collapse in which all particles have converged to a point in the search-space, which may or may not be the optimum. Several attempts at mathematically analyzing PSO convergence exist in the literature. These analyses have resulted in guidelines for selecting PSO parameters that are believed to cause convergence, divergence, or oscillation of the swarm's particles, and the analyses have also given rise to several PSO variants. However, the analyses were criticized for being oversimplified as they assume the swarm has only one particle, that it does not use stochastic variables and that the points of attraction, that is, the particle's best known position p and the swarm's best known position g, remain constant throughout the optimization process. Furthermore, some analyses allow for an infinite number of optimization iterations which is not possible in reality. This means that determining convergence capabilities of different PSO algorithms and parameters therefore still depends on empirical results.

Biases

As the basic PSO works dimension by dimension, the solution point is easier found when it lies on an axis of the search space, on a diagonal, and even easier if it is right on the centre. A first approach to avoid this bias, and for fair comparisons, is precisely to use non-biased benchmark problems, that are shifted or rotated. Another approach is to modify the algorithm itself so that it is not any more sensitive to the system of coordinates.

Illustrative Test System

A six-bus test system is considered as case study and this system is depicted in Figure 1. The proposed system has six buses and five loads on buses 1 to 5. Bus 1 is swing bus, buses 3 and 6 are PV and buses 2, 4 and 5 are PQ type. The system data for power flow studies are provided at Tables 1 to 4.

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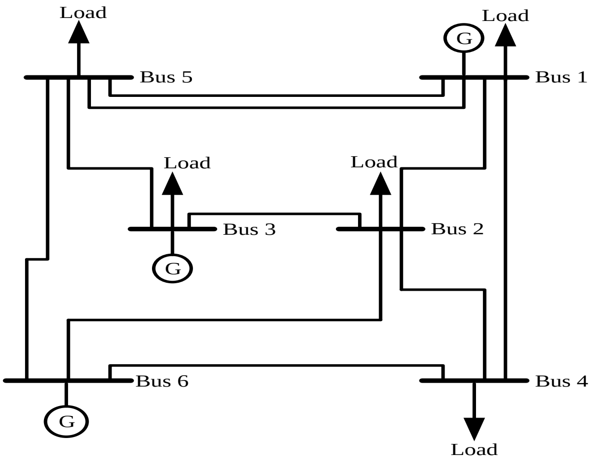

Figure 1: Six bus test system

Table 1: The generators data of six-bus test system

Bus	Type	P_D [MW]	Q_D[MVar]	P_G^{max} [MW]	P_G^{min} [MW]	Q_G^{max} [MW]	Q_G^{min} [MW]
1	VΘ	80	16	200	0	50	-10
2	PQ	240	48	-	-	-	-
3	PV	40	8	400	0	100	-10
4	PQ	160	32	-	-	-	-
5	PQ	240	48	-	-	-	-
6	PV	0	0	600	0	180	-10

Table 2: The branches data of six-bus test system

Bus From	Bus To	r_{ij}[p.u.]	x_{ij}[p.u.]	b_{ij}^{sh} [p.u.]	s_{ij}^{max} [MVA]
1	2	0.040	0.400	0.00	120
1	3	0.038	0.380	0.00	120
1	4	0.060	0.600	0.00	100
1	5	0.020	0.200	0.00	120
1	6	0.068	0.680	0.00	90
2	3	0.020	0.200	0.00	120
2	4	0.040	0.400	0.00	120
2	5	0.031	0.310	0.00	120
2	6	0.030	0.300	0.00	120
3	4	0.059	0.590	0.00	120
3	5	0.020	0.200	0.00	120
3	6	0.048	0.480	0.00	120
4	5	0.063	0.630	0.00	95
4	6	0.030	0.300	0.00	120
5	6	0.061	0.610	0.00	98

Table 3: The generation costs

bus	MW	
1	200	A=0; B=9; C=0;
3	400	A=0; B=20; C=0;
6	600	A=0; B=15; C=0;

Table 4: The pollution costs

bus	MW	
1	200	$a=4.09\times10^{-2}$ $b=-5.55\times10^{-5}$ $c=6.49\times10^{-6}$ $d=2.00\times10^{-4}$ $e=2.85\times10^{-2}$
3	400	$a=2.54\times10^{-2}$ $b=-6.04\times10^{-5}$ $c=5.63\times10^{-6}$ $d=5.00\times10^{-4}$ $e=3.33\times10^{-2}$
6	600	$a=4.25\times10^{-2}$ $b=-5.09\times10^{-5}$ $c=4.58\times10^{-6}$ $d=0.01\times10^{-4}$ $e=8.00\times10^{-2}$

Simulation results

Tables 5 and 6 show the simulation results for the proposed problem. Table 5 shows that the active powers of all generators are between minimum and maximum limits. Table 6 also shows that the reactive powers are lie between allowable limits. Figure 2 shows the voltages at all buses and it is clear that all voltage are between minimum (0.95 pu) and maximum (1.05 pu) limits.

Table 5: The active powers of generators

Bus No.	P_g^{min} (MW)	P_g (MW)	P_g^{max} (MW)
Bus 1	1	200	200
Bus 3	1	187.66	400
Bus 6	1	386.95	600

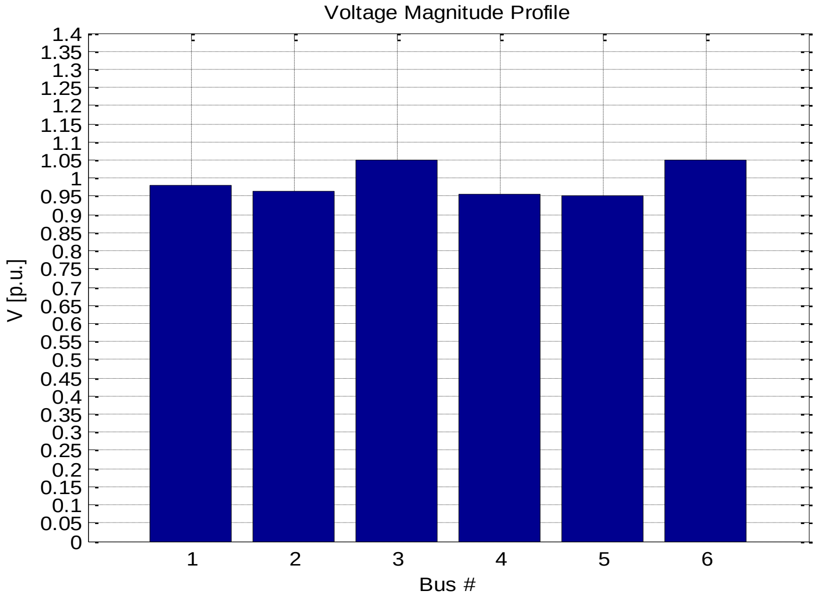

Figure 2: the bus voltages and the limits

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Table 6: The reactive powers of generators

Bus No.	Q_g^{min} (MVar)	Q_g (MVar)	Q_g^{max} (MVar)
Bus 1	-10	48	48
Bus 3	-10	99.97	101
Bus 6	-10	150.26	183

CONCLUSIONS

Optimal power flow considering environmental pollution was addressed by this paper. The problem was formulated as a constrained optimization programming and solved by using particle swarm optimization. Simulation results demonstrated the effectiveness of the method.

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