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Research Article

The Effect of Wind Power Plants on the Total Cost of Production in Economic Dispatch Problems

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Abstract: This Study presents a new approach for Economic Dispatch (ED) problems incorporating wind power plants using Particle Swarm Optimization (PSO) method. As the wind power plant is renewable and clean, widely distributed, produces no greenhouse gas emissions during operation and uses little land, its effect to conventional units that should be analyzed. Also the total cost is dependent on wind speed in specific period of time. Therefore, the mathematical techniques are not appropriate to find the global optimum ED. In this study, PSO is proposed to deal with wind power plants in ED. The system employed to apply the PSO in ED is three generators power system. Finally, to show the good performance of wind power plants to decreasing the total cost of production, two different scenarios with and without wind power plants are simulated and the results are compared to each other.

Keywords: Cost, nonsmooth cost function, particle swarm optimization, penalty, reserve cost, weibull probability density function, wind energy

INTRODUCTION

With increasing fuel prices and environmental concerns, the governments all over the world has commissioned research and application on renewable energy applications under the consideration of diversifying energy source (Yue *et al*., 2001). The total energy generation cost and the emission of greenhouse will be reduced with application of sustainable energy. The wind power is the one of the renewable energy resources that has found the appropriate position among other resource in recently years and has the suitable development in power systems. Therefore with increasing of this resource, it's necessary to will be studied the effect of it at power system operation such as optimal selection of on-line units (unit commitment) (Gibescu *et al*., 2006) and optimal output levels of committed units (economic dispatch procedures) (Holttinen and Pedersen, 2003; Chen *et al*., 2006). Therefore it is necessary to develop the better wind-thermal coordination ED to determine the optimal dispatch scheme that can integrate wind power reliably and efficiently (Ren and Jiang, 2009; Ummels *et al*., 2007; Holttinen and Pedersen, 2003). But the main problem is the limited predictability and variability (Fabbri *et al*., 2005) .This problem can be solved by several investigations have looked at the prediction of wind speed for use in determining the available wind power (Justus *et al*., 1978). For considering of wind power plant in economic dispatch several studies has been done. In the several cases the output of wind power plant is assumed to be specified and the probabilistic feature of wind speed is not included. Yong and Tao (2007) subtract the output of wind power plant from total load and with new load system solved the ED problems among the conventional units. Due to the intermittency and unpredictability nature of wind power generation, which can influence the schedule of generation and operational system conditions, the more scientific and reasonable model should be researched to help wind power be used in power grid in a large scale. So how to make reasonable short-term schedules and manage the uncertainty of wind power in the power generation including wind turbine generators is the main thesis of this study In this study, Weibull Probability Distribution Function (PDF) that its parameters are estimated by the maximum likelihood method (Seguro and Lambert, 2000), is used as the basis numerical solution of the ED model. Because of the uncertainty of the wind energy available at any given time, factors for overestimation and underestimation of available wind energy must be included in the cost function of wind power plant (Hetzer *et al*., 2008). The ownership of wind power plant is another factor that is considered in the cost function. In this study, Particle Swarm Optimization (PSO) method is applied to ED problem with nonsmooth cost functions including valve-point effects.

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To show the efficiency of wind power plant in total cost, PSO method is applied to 3 units system incorporating a wind power plant with different scenarios, with and without wind power plant and with different ownership of them.

MATERIALS AND METHODS

In this study, we deal with ED problem with nonsmooth cost function with equality and inequality constraints. To better understand the issue, it is necessary to know the ED problem with smooth cost function and then we should extend this to nonsmooth cost function.

ED problem with smooth cost function: The ED problem is to detect the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. The most simplified cost function of each generator can be indicated as a quadratic function as given in (1) and total cost of generation given in (2):

$$F_j(P_j) = a_j + b_j P_j + c_j P_j^2 \quad (1)$$

$$C = \sum_{j\epsilon J} F_j(P_j) \quad (2)$$

where,

C : Total generation cost
F_j : Cost function of generator j
a_j, b_j, c_j : Cost coefficients of generator j
P_j : Electrical output of generator j
J : Set for all generators

While minimizing the total generation cost in power systems, the total generation should be equal to the total system demand plus the transmission network loss. But, the network loss is not considered in this study for simplicity. This gives the equality constraint:

$$D = \sum_{j\epsilon J} P_j \quad (3)$$

where, D is the total system demand:

The generation output of each unit should be between its minimum and maximum limits. So, the following inequality constraint for each generator should be satisfied:

$$P_{j\,min} \leq P_j \leq P_{j\,max} \quad (4)$$

where, the P_{jmin}, P_{jmax} is the minimum and maximum output of generator j.

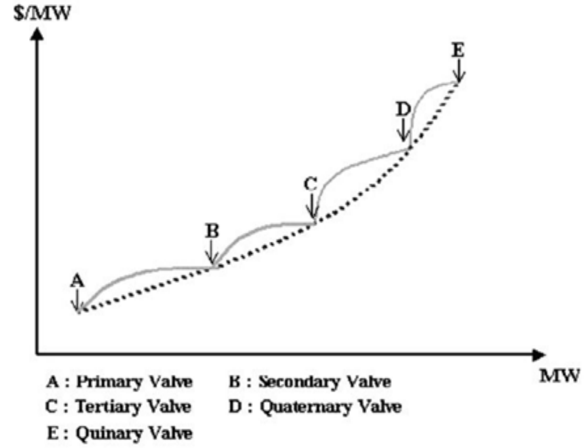

Fig. 1: Valve point effect

ED problem with nonsmooth cost functions with valve-point effects: In fact, the practical function of an ED problem has no differentiable points according to valve-point effects and change of fuels (Victoire and Jeyakumar, 2005); therefore, the practical function should be composed of a set of nonsmooth cost functions. In this study, nonsmooth cost function according to valve-point effects is considered. The generator with multi-valve turbines has very different input-output curve compared with the smooth cost function. Typically, the valve point results as each steam valve begins to open, the ripples like in Fig. 1. To calculate and consider the valve-point effects, sinusoidal functions are added to the quadratic cost functions as follows:

$$F_j(P_j) = a_j + b_j P_j + c_j P_j^2 + \left|e_j \times \sin\left(f_j \times (P_{j\,min} - P_j)\right)\right| \quad (5)$$

where, e_j and f_j are the coefficient of generator j causing valve-point effects.

In this case, the problems have multiple minima (Sinha *et al*., 2003); therefore, the task of finding the global solution still remains to be tackled (Park *et al*., 2005).

ED problem incorporating wind power plant: Due to lack of using fuel to generate energy, the cost function of the wind power plant must be described in another model. Also, because of the uncertain nature of wind and output of the wind power plant, the factors must be considered for underestimation and overestimation of the available wind energy in this model. In another hand, it is necessary to consider the ownership of the wind power plant. Thereby, the cost function of wind power plant can be calculated as fallows (6):

$$C = \sum_{i=1}^{N} C_{w,i}(w_i) + \sum_{i=1}^{N} C_{p,wi}\left(W_{i,av} - w_i\right) + \sum_{i=1}^{N} C_{r,wi}\left(w_i - W_{i,av}\right) \quad (6)$$

where,

- N : Number of wind-powered generators
- w_i : Scheduled wind power from the i_{th} wind-powered generator
- $W_{i,av}$: Available wind power from the i_{th} wind-powered generator. This is a random variable, with a value range of $0 \leq W_{i,av} \leq w_r$ and probabilities varying with the given PDF. We considered Weibull PDF for wind variation
- $w_{r,i}$: Rated wind power from the i_{th} wind-powered generator
- $C_{w,i}$: Cost function for the i_{th} wind-powered generator. This factor will typically take the form of a payment to the wind farm operator for the wind-generated power actually used
- $C_{p,w,i}$: Penalty cost function for not using all available power from the i_{th} wind-powered generator
- $C_{r,w,i}$: Required reserve cost function, relating to uncertainty of wind power. This is effectively a penalty associated with the overestimation of the available wind power

In Eq. (6), the first term is the cost that system operator must pay to producer of wind power. A linear cost function will be assumed for the wind-generated power actually used as (7):

$$C_{w,i}(w_i) = d_i w_i \quad (7)$$

where, d_i is the direct cost coefficient for the i_{th} wind generator.

The second term is the penalty cost for not using all the available wind power that will be assumed that it will be linearly related to the difference between the available wind power and the actual wind power used. The penalty cost function will then take the following form:

$$C_{p,wi}\left(W_{i,av} - w_i\right) = k_{p,i}\left(W_{i,av} - w_i\right) = k_{p,i}\int_{w_i}^{w_{r,i}} (w - w_i) f_W(w)\,dw \quad (8)$$

where,

- $k_{p,i}$: Penalty cost (underestimation) coefficient for the i_{th} wind generator
- $f_W(w)$: Wind Energy Conversion System (WECS) wind power PDF

The third part is the reserve requirement cost that will be similar to penalty cost, except that, in this case, it is a cost due to the available wind power being less than the scheduled wind power. It is indicated in (9):

$$C_{r,wi}\left(w_i - W_{i,av}\right) = k_{r,i}\left(w_i - W_{i,av}\right) = k_{r,i}\int_{0}^{w_i} (w_i - w) f_W(w)\,dw \quad (9)$$

where, $k_{r,i}$ is the reserve cost (overestimation) coefficient for the ith wind-powered generator.

If the wind power plant is not owned by the system operator, the direct cost coefficient and penalty cost may be zero.

The wind speed is a random variable. A comprehensive review for probability distributions of wind speed can be found in Carta *et al*. (2009), where the authors cited more than two hundred publications and described more than ten well-known distributions. They indicated that the two-parameter Weibull distribution had become the most widely accepted model. The PDF of Weibull distribution is as follows:

$$f_V(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-(vc)^k}, \quad 0 < v < \infty \quad (10)$$

where,

- V : Wind speed random variable
- v : Wind speed
- c : Scale factor at a given location (units of wind speed)
- k : Shape factor at a given location (dimensionless)

Methods of estimating the Weibull shape and scale factors using the available wind speed data are given in.

Given the forecast wind speed distribution and speed-to power conversion function, the wind power output distribution can be obtained. In this study, a linear speed-to-power conversion function is used:

$$w = 0 \quad \text{for } v < v_i \text{ and } v > v_o$$

$$w = w_r \frac{v - v_i}{v_r - v_i} \quad \text{for } v_i < v < v_r$$

$$w = w_r \quad \text{for } v_r < v < v_o \quad (11)$$

where

- w : WECS output power (typical units of kilowatt or megawatt)
- w_r : WECS rated power
- v_i : Cut-in wind speed (typical units of miles/hour or miles/second)
- v_r : Rated wind speed
- v_o : Cut-out wind speed

According to the probability theory for function of random variables (Garcia, 2008), in the interval $v_i < V < v_r$, the PDF of W is:

$$f_W(w) = \frac{klv_i}{c}\left(\frac{(1+\rho l)v_i}{c}\right)^{(k-1)} \times \exp\left(-\left(\frac{(1+\rho l)v_i}{c}\right)^{k}\right) \quad (12)$$

where,

$\rho = \frac{w}{w_i}$ is the ratio of wind power output to rated wind power

$l = \frac{(v_r - v_i)}{v_i}$ is the ratio of linear range of wind speed to cut-in wind speed

Implementation of particle swarm optimization: Kennedy and Eberhart (1995) developed a PSO algorithm based on the behavior of individuals (i.e., particles or agents) of a swarm. It has been perceived that members within a group seem to share information among them, a fact that causes to increased efficiency of the group. An individual in a swarm approaches to the optimum by its present velocity, previous experience and the experience of its neighbors.

In a physical n-dimensional search space, parameters of PSO technique are defined as follows:

$X_i = (x_{i1}, \dots, x_{in})$: Position individual i
$V_i = (v_{i1}, \dots, v_{in})$: Velocity individual i
$Pbest_i = (X_{i1}^{Pbest}, \dots, X_{in}^{Pbest})$: Best position of individual i
$Gbest_i = (X_{i1}^{Gbest}, \dots, X_{in}^{Gbest})$: Best position neighbors of individual i

Using the information, the updated velocity of individual i is modified by the following equation in the PSO algorithm:

$$V_i^{k+1} = wV_i^k + c_1 rand_1 \times (Pbest_i^k - X_i^k) + c_2 rand_2 \times (Gbest_i^k - X_i^k) \quad (13)$$

where,

V_{ik}	: Velocity of individual i at iteration k
ω	: Weight parameter
c_1, c_2	: Weight factors
$rand_1$, $rand_2$	: Random numbers between 0 and 1
X_{ik}	: Position of individual i at iteration k
P_{besti}^{k}	: Best position of individual i until iteration k
Gbestik	: Best position of the group until iteration k

The individual moves from the current position to the next position by Eq. (14):

$$X_i^{k+1} = X_i^k + V_i^{k+1} \quad (14)$$

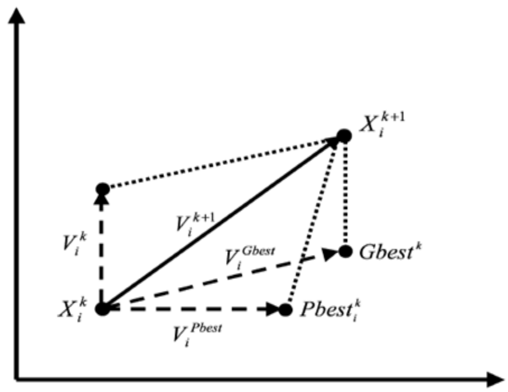

Fig. 2: Mechanism of PSO

The search mechanism of the PSO using the modified velocity and position of individual i based on Eq. (13) and (14) is illustrated in Fig. 2.

RESULTS AND DISCUSSION

To assess the efficiency of the wind power plant, it has been applied to ED problems where objective function can be nonsmooth. The simulated system is 3 units conventional and the demand of systems is divided into 24 h (intervals) for a whole day that are listed as Table 1. For this system three scenarios are considered:

- Without wind power plant
- With wind power plant owned by private sector
- When system operator is owner of wind power plant that in this case the direct cost coefficient and penalty cost will be zero

The wind speed data to use in cost function of wind power plant is obtained from Renewable Energy Organization of Iran (2012) site and is shown in Fig. 3.

The PSO is applied to ED problem with 3 units (i.e., generators) where valve-point effects are considered for this problem. The input data of 3-generator system is given in ref. 6. The parameters of wind power plant are given in Table 2.

Having simulations using PSO in the above system, we obtained results that are shown in Table 3:

One can see that using wind power plants have realistic and powerful performance in total cost production. As can be seen in Table 3 when that the wind power plant is not in system the total cost in the best state is 181105.4 unit while when it is placed in power system the total cost in best state reduced to 174753.1 unit and 166419.5 unit for private sector and system operator scenarios respectively.

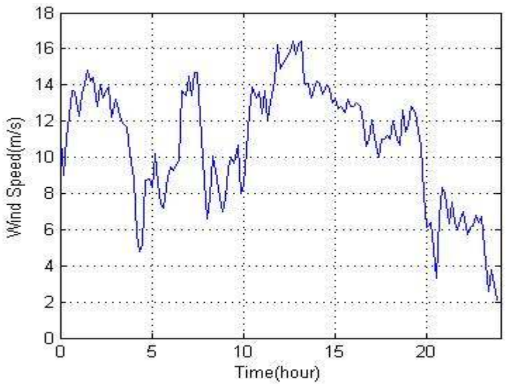

Fig. 3: Wind speed variation diagram

Table 1: Load demand for 24 h

Hour	Load (MW)	Hour	Load (MW)	Hour	Load (MW)
1	700	9	885	17	750
2	770	10	890	18	680
3	810	11	900	19	630
4	834	12	1000	20	615
5	850	13	950	21	600
6	868	14	880	22	580
7	875	15	850	23	500
8	880	16	800	24	420

Table 2: Parameters of wind power plant

P_{min} (M/W)	P_{max} (MW)	Vi (m/s)	Vr (m/s)	Vo (m/s)	Kd	Kp	Kr
0	35	5	15	45	1.12	1	1

Table 3: Cost results of 4 units system

4 unit (100 iteration)		With wind power owned by	
Compared item	Without wind power	Private sector	System operator
Best	181105.4	174753.1	166419.5
Worst	182106.4	175383.2	174826.9
Average	181395.9	175036.0	170694.1

By comparing results, also one can find out that if wind power plant owned by system operator, total cost can be decreased more than when private sector is owner of wind power plant. This is due to the cost that pays to private company for power production while in system operator scenarios the power plant is owned by system operator and no cost is paid for production.

CONCLUSION

This study develops a model to include wind power plants in the Economic Dispatch (ED) problems. The uncertain nature of the wind speed is represented by the Weibull PDF. We have successfully employed Particle Swarm Optimization (PSO) method to solve ED problem incorporating wind power plants. In this study, the PSO has applied to 3-generator system with and without one wind power plant. The comparative simulations with and without wind power plants, illustrate that wind power plants have powerful performance in total cost production and can reduce total cost in power systems. Also, if wind power plant owned by system operator, total cost can be decreased more than when private sector is owner of wind power plant.

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