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Genetic Algorithm for the coordination of wind thermal dispatch

***Abstract**. In this paper Genetic Algorithm (GA) is utilized to coordinate the wind and thermal generation dispatch and to minimize the total production cost in the economic dispatch considering wind power generation and valve effect of thermal units. To demonstrate the effectiveness of the proposed approach, the numerical simulation have been performed for two different test systems with and without wind power production. Simulation result shows the effect of wind power generation in reducing total fuel cost.*

Streszczenie.** W artykule przedstawiono wykorzystanie algorytmu genetycznego do koordynacji rozsyłu energii pochodzącej od elektrowni wiatrowych i cieplnych. Przeprowadzono symulację numeryczną dla dwóch różnych systemów w skład których wchodziły lub nie jednostki wiatrowe. **(Algorytm genetyczny wykorzystanych do koordynacji rozsyłu energii z elektrowni wiatrowych i cieplnych)

Keywords: Genetic Algorithm, Wind power generation, Thermal generation Dispatch, Economic Dispatch.
Słowa kluczowe:. Algorytm genetyczny, elektrownie wiatrowe, ekonomiczny rozdział energii

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Introduction

Most of the present world thrives on the electricity obtained from thermal power station by burning fossil fuels like coal, oil and natural gas. Combustion of such fuels results in emission of pollutant like oxides of nitrogen, carbon and Sulfur [1].The drastic changes in environment and climate can be avoided by replacing fossil energy sources with clean and fuel free energy generation [2].The main advantages of electricity generation from renewable sources are the absence of harmful emissions. One way of generating electricity from renewable sources is to use wind turbines that convert the energy contained in flowing air into electricity [3].

The growing concern for environment has asked for rapid developments in wind power generation technology. On the other hand because of variability and uncertainty of this energy, using it has made some challenges to power system operators. In order to adjust the unforeseeable nature of the wind power, planned productions and uses in electricity market must be improved during the real operation of the power system [4]. Wind energy is a clean renewable resource, its exploitation and utilization has recently been paid more attention in the world. It has become apparent that wind energy is a good alternative to thermal energy power generation. Additionally, wind power generation would yield profit, as there is essentially no fuel cost involved in the production of power from wind energy conversion system except specific investment costs. Therefore, it becomes apparent that there is a need for alternatives to a concern [5]. Due to the uncertain nature of wind power, it is widely believed that large wind penetrations would put an increased burden on system operations [6]. One of these issues is the provision of emergency reserve for the system security. In general, the largest proportion of the emergency reserve is carried to cover the loss of the largest generation unit in the system. However, with wind power penetrations increasing in isolated power systems, scheduling of additional emergency reserves will be needed to maintain an adequate level of supply reliability. In addition, maintaining sufficient emergency reserve across several units in the system is much more capable of responding to frequency deviations and system load pickup following a contingency for an isolated system [7]. Apart from the up spinning reserve requirements, there are strong demands for enough down spinning reserve requirements to satisfy the sudden rise of wind power generation at low system load times to avoid the forced shut down of thermal units. The load variations, which are combined with wind power fluctuations, have to be absorbed by the system ramping capacity. The importance of wind–thermal coordination problem is, thus, likely to increase, and more advanced algorithms for solving the wind–thermal generation scheduling problem are worth developing to operate an isolated hybrid power system reliably and efficiently [8]. In recent years several optimization algorithms based on classical calculus-based techniques or stochastic searching techniques, including priority list [9], dynamic programming [9], branch-and-bound [10], Lagrangian relaxation approach [11], genetic algorithm [12], evolutionary programming [13], and hybrid optimization technique [14] could be used to solve the dispatch problem. However, the previous approaches [9–14] on solving the dispatch problem have ignored the wind-power generation. Both the intermittency and unpredictability of wind generator output require different strategies to be developed. Hence in this paper Genetic Algorithm is employed to optimize the cost of generation for the three test systems. The simulation results with and without considering wind power are obtained and compared with those existing in previous literatures to validate the effectiveness of the proposed algorithm.

Problem Formulation

The economic dispatch of generation in a power system incorporating wind power plant involves the allocation of generation among the wind and thermal plants so as to minimize the total production cost while satisfying various constraints [9].

The generation cost of wind power generation is ignored in the optimization process since renewable energy law regulate that all of them must be adopted and there is not fossil fuel cost. After evaluate the interrelation between wind power and conventional plant, the cost of wind power plant will add up to the total cost.

The objective of economic dispatch is to minimize the total generation cost of the power system within a defined interval (i.e. one hour) while satisfying various constraints.

The economic dispatch problem can be formulated as a constrained optimization problem [9] of the form

$$(1) \qquad F_T = \sum_{t=1}^{T}\sum_{i=1}^{NT} F_i(P_i(t))$$

where: n - total number of generation units; F_T - total generation cost; $P_i(t)$ - pPower generation cost function of ith unit

Generally, the fuel cost of a thermal generation unit is considered as a second order polynomial function

$$F_i(P_i) = a_i + b_iP_i + c_i\,P_i^2 \tag{2}$$

However, when the generation units change its output, there is a nonlinear cost variation due to valve effect [9]. The fuel cost of a thermal generation unit considering nonlinear effect of valve will be nonlinear function as (3)

$$F_i(P_i) = a_i + b_iP_i + c_i\,P_i^2 + \left[P_i^{min} - P_ie_i * \sin\{f_i(P_i^{min} - P_i)\}\right] \tag{3}$$

where, a_i, b_i, c_i, e_i and f_i are the cost coefficients of the i[th] generating unit

Constraints

Power balance constraint

$$\sum_{i=1}^{NT} U_i(t) * P_i(t) + P_{WT}(t) = P_L(t) \tag{4}$$

Where: $U_i(t)$ - scheduled state of thermal unit i for hour t; $P_i(t)$ - generation of thermal unit I at hour t; $P_{WT}(t)$ - total actual wind generation at hour t; $P_L(t)$ - system load demand at hour t

System up/down spinning reserve requirements

$$\sum_{i=1}^{NT} U_i(t) *\ US_i(t) \geq USR_B + ASR_1(P_{WT}(t)) \tag{5}$$

$$\sum_{i=1}^{NT} U_i(t) *\ DS_i(t) \geq ASR_2(P_{WT}(t)) \tag{6}$$

Minimum/maximum thermal plant output constraints

$$P_L(t) -\ P_{WT}(t) \geq ASR_2(P_{WT}(t)) + \sum_{i=1}^{NT} U_i(t)\ * P_i^{min}(t) \tag{7}$$

$$\sum_{i=1}^{NT} U_i(t) * P_i^{max}(t) + P_{WT}(t) \geq P_L(t) + USR_B + ASR_1(P_{WT}(t)) \tag{8}$$

where: ASR_1- Additional up reserve requirement considering wind power generation; ASR_2 - Additional down reserve requirement considering wind power generation; $US_i(t)$ - Up reserve contribution of thermal unit *i* at hour *t; $DS_i(t)$* - Down reserve contribution of thermal unit i at hour t; $P_i^{max}(t)$ - Maximum generation of thermal unit i at hour t; $P_i^{max}(t)$ - Minimum generation of thermal unit i at hour t; $P_{WT}(t)$ - Total actual wind generation at hour t.
Power loss is not taken into consideration.

Unit capacity constraint

$$P_i^{min}(t) * U_i(t) \leq P_i(t) \leq P_i^{max}(t) * U_i(t) \tag{9}$$

Where,
$P_i(t)$ - Present output power
$P_i^{min}(t)$, $P_i^{max}(t)$ - Minimum and maximum power outputs of the ith generating unit
In this paper, the ramp-rate limits and prohibited operating zone constraints as well as valve point effect are considered

Ramp rate limit constraints

In ED research, a number of studies have focused upon the economical aspects of the problem under the assumption that unit generation output can be adjusted instantaneously. Even though this assumption simplifies the problem, it does not reflect the actual operating processes of the generating unit. The actual operating range of all on-line units is restricted by their corresponding ramp-rate limits [9]. The inequality constraints due to ramp-rate limits can be written as:

$$DR_i(t) = \min\{DR_i^{max}, P_i(t) - P_{i,r}^{min}\} \tag{10}$$

$$UR_i(t) = \min\{UR_i^{max}, P_{i,r}^{max} - P_i(t)\} \tag{11}$$

If generation increases

$$P_i(t) -\ P_i(t-1) \leq UR_i \tag{12}$$

If generation decreases

$$P_i(t-1) - P_i(t) \leq DR_i \tag{13}$$

where,
$P_i(t)$ - Present output power
$P_i(t-1)$ - Previous output power
UR_i - the up ramp limit of the i[th] generator (in units of megawatts per time period)
DR_i - is the down ramp limit of the i[th] generator (in units of megawatts per time period)

Genetic algorithm

The genetic algorithm is essentially a search algorithm based on the mechanics of natural selection and natural genetics. It combines solution evaluation with randomized, structured exchanges of information between solutions to obtain optimality. By simulating "the survival of the fittest" criterion of Darwinian evaluation among chromosome structures, the optimal solution is searched by randomized information exchange. The three prime operators associated with the GA are reproduction, crossover and mutation.

GA based Algorithm

The series of operations carried out when implementing a genetic algorithm is:

1. Construct an initial population(P) of chromosomes by random process.
2. Evaluate fitness of each chromosome.
3. Generate mating pool based on fitness function values.
4. Select mating pair of chromosomes called parent chromosomes from mating pool.
5. Create two child chromosomes from the parent chromosomes by applying genetic operators.
6. Repeat steps(4-5), till the child population of size P is generated.
7. Store the chromosome having the maximum fitness and also the corresponding objective function.
8. Repeat steps (2-7) until the specified numbers of genetic iterations are completed.
9. Return the chromosome with highest fitness funtion as the solution.

Solution methodology

Economic dispatch of power generation is a complex and highly nonlinear optimization problem with heavy equality and inequality constraints [10- 14]. Recently, as an alternative to the conventional mathematical approaches a series of optimization techniques are considered as realistic and powerful solution schemes to obtain the global and quasi-global optimums in ED. In this paper canonical GA is utilized for economic dispatch of power system incorporating wind power generation. The population size is 500 and the maximum generation is 1000. The GA adopts elitism selection and single point crossover with probability of 0.85. The mutation probability is set to 0.019.

Initialization

The control variables are the generation power outputs. Therefore, an individual is a vector of 24 hour output of n generation units and it can be described as the following matrix structure:

$$P = \begin{bmatrix} P_{11} \dots & P_{1j} \dots & P_{1n} \\ P_{i1} \dots & P_{y} \;\; \dots & P_{in} \\ P_{241} \dots & P_{24j} \dots & P_{24n} \end{bmatrix} \quad (14)$$

Each P_{ij} is randomly initializes satisfying the ramp rate constraints.

Fitness Evaluation

Since not all the individuals are applicable, we must first define the fitness function to evaluate the fitness of each individual in the population. Thus, the fitness function is defined as the reciprocal of the sum of the generation cost function and the penalized demand and prohibited zone constraints as follows:

$$F_x = \frac{1}{C_k + PD_k + PZ_k} \qquad k = 1, \dots n \quad (15)$$

Where F_x and C_k are the fitness function and the production cost for the k^{th} individual of the population, respectively.

PD_k and PZ_k are the penalized demand and the violation against ramp rate limits respectively, defined as follows:

$$PD_k = K_D \left(\sum_{j=1}^{n} P_{k,j} - D \right)^2 \quad (16)$$

$$PZ_k = K_Z \left(\sum_{j=1}^{n} V_{k,j} \right) \quad (17)$$

Where K_D and K_Z are the penalty factors associated with power balance and ramp rate constraints, respectively. These factor are turned by trial and they are set to K_D = 1 and K_Z = 2.5 in this paper.

Population Evolution

The evolution of the population takes place following the general GA principles through selection, crossover and mutation.

- *Selection*

After the evaluation of the initial randomly generated population, the GA begins the creation of the new generation. Individual from the parent population are selected in pairs with a probability proportional to their fitness to replicate and form offspring individual. The selection scheme is known as Roulette wheel selection.

- *Crossover*

. In this paper the crossover probability is set to 0.85.

- *Mutation*

Every parameter of the offspring undergoes a uniform mutation with a probability of 0.019. It is an occasional (with small probability) random alteration of the position. This provides background variation and occasionally introduces beneficial materials into the population.

- *Elitism*

The previous procedure described for the two individual is repeated until all of the individuals of the parent generation are replaced by the newly formed ones. The best individual of the parent generation and the best individual found in all of the previous generations are moved directly to the next generation to improve the overall performance.

Numerical Simulation

In order to demonstrated the performance of the proposed method two test systems with 6 and 13 thermal units are considered. The proposed algorithm is applied to the test systems with and without considering wind power. Software programs were developed using MATLAB 7.3 software package and the two economic dispatch scenarios with and without wind generation are calculated for 100 trials.

Six unit test system

This test system consists of 6 thermal generating units[15] with valve point effect and one wind farm of overall 165MW capacity. The parameters of all thermal units are presented in table1. The total demand on the system is 1263MW. The results for the overall cost of operation with and without wind power by GA are given in table 2 and the convergence characteristics are shown in Fig. 1.

Table I Generating units capacity and coefficients (6- units)

Unit	$P_i^{min}(MW)$	$P_i^{max}(MW)$	a	b	c	e	f
1	100	500	0.0070	7.0	240	300	0.035
2	50	200	0.0095	10.0	200	200	0.042
3	80	300	0.0090	8.5	220	200	0.042
4	50	150	0.0090	11.0	200	150	0.063
5	50	200	0.0080	10.5	220	150	0.063
6	50	120	0.0075	12.0	190	150	0.063

Table.2 Simulation results for six unit systems with and without wind power using GA

Unit output	without wind power	with wind power
P1 (MW)	474.8078	400.3752
P2 (MW)	178.7618	167.7021
P3 (MW)	262.2079	215.2312
P4 (MW)	133.4365	114.0125
P5 (MW)	141.9154	197.4521
P6 (MW)	71.8766	70.2615
Wind power produced(MW)	---	97.9654
Total power output(MW)	1263.0060	1263.0000
Total generation cost ($/h)	**15464.3852**	**15320.3086**

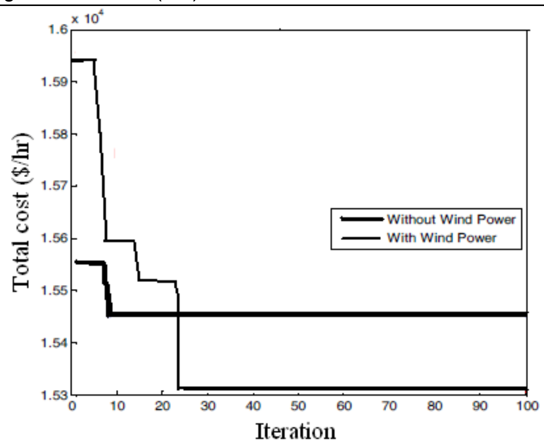

Fig.1.Convergence characteristics of six unit system by GA

Thirteen unit test system

This test system consists of 13 thermal generating units[13] with valve point effect and one wind farm of overall 420MW capacity. The total demand on the system is 2520MW. The results for the overall cost of operation with and without wind power by GA are given in table 3 and the convergence characteristics are shown in Fig. 2.

Table.3 Simulation results for thirteen unit systems with and without wind power using GA

Unit output	without wind power	with wind power
P1 (MW)	622.321	530.230
P2 (MW)	300.120	274.510
P3 (MW)	300.310	269.100
P4 (MW)	158.126	160.320
P5 (MW)	156.480	155.231
P6 (MW)	159.230	162.350
P7 (MW)	158.463	149.650
P8 (MW)	160.125	144.685
P9 (MW)	160.230	138.750
P10 (MW)	100.550	121.305
P11 (MW)	98.025	100.235
P12 (MW)	85.135	75.230
P13 (MW)	60.886	63.054
Wind power produced(MW)	---	175.350
Total power output(MW)	2520.000	2520.000
Totalgeneration cost ($/h)	**24438.365**	**24232.015**

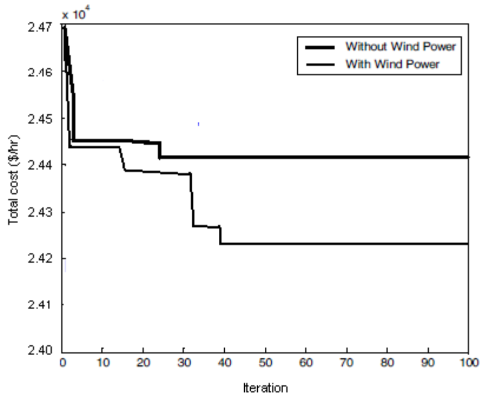

Fig.2.Convergence characteristics of thirteen unit system by GA

Conclusion

This paper shows a new approach for solving the economic dispatch problem of a power system incorporating thermal power plant and wind power generation using GA. The results present the overall cost of operation of wind-thermal system for given values of cost coefficients associated with wind power. It is evident from the results that the optimal total generation cost obtained by Genetic Algorithm is better than other optimization algorithms. The GA algorithm has been demonstrated to have competence in handling highly nonlinear optimization problem. Many nonlinear characteristics of the generator such as ramp rate limits, valve point zone and non smooth cost functions are considered for practical generator operation in the proposed method. The simulations with and without wind power production show that total system operating costs and consumption of fossil fuel can be reduced notably by utilizing wind power generation.

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