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Optimization of Wind Thermal Coordination Dispatch using Flower Pollination Algorithm

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ABSTRACT

Non conventional energy sources have turned the attention of power system experts due to the environmental and economic issues. Among the different renewable energy sources wind energy is considered to be remarkable because it can be obtained at free of cost. Normally power generation is carried out using thermal generators. In this paper the integration of thermal generators with wind units are considered and the solution of wind thermal dispatch problem using Flower Pollination Algorithm (FPA) is implemented. This algorithm is implemented to find the minimum production cost with valve effects of thermal units included. The effectiveness of the proposed approach is validated using two IEEE test systems consisting of six and thirteen units with a wind farm of 100MW capacity. The analysis is carried out neglecting the transmission losses. Simulation results predict the inclusion of wind power reduces the overall production cost.

Indexing terms/Keywords

Fuel cost, Flower Pollination Algorithm, Economic Dispatch, wind power

1. INTRODUCTION

One of the rapid increasing renewable energy sources is wind energy. Wind energy is famous for its cleanliness and cheapness. It is available at free of cost. Wind system provides challenges to the operators due to its uncertainty and unpredictability [1]. The economic dispatch problem is classic mathematical optimization problem in power system operation. The goal is to find the allocation of active power output from various available generators to minimize the total operating cost, while fulfilling all the necessary equality and inequality constraints of the power system [2]. Wind-thermal dispatch model takes into account both thermal power plants and wind power generators and involves the dispatching of generation among wind and thermal plants in order to minimize the total generation costs while satisfying the constraints [3].

For solving small problems conventional methods which gives exact solution such as Lambda Iteration method, Linear Programming method, Quadratic Programming method, Lagrangian Relaxation method and dynamic Programming method are adopted. However when the number of units increase, its computational memory requirement and computational time increases exponentially with multiple local minimum. Very often the only suboptimal solution can be found. Both the intermittency and unpredictability of wind generator output require different strategies to be developed. These complex conditions make it very difficult to solve the wind- thermal coordination dispatch problems using mathematical approaches [4].

To overcome this difficulty random optimization methods in the field of Artificial Intelligence such as the Simulated Annealing [5] & [6], Genetic Algorithm [7] & [8], Differential Evolution [9], Particle Swarm Optimization [10] Evolutionary Programming [11] have been proposed as alternatives where the problem size precludes traditional techniques. These methods are effective optimization techniques with the capability to find the global optimal solution. These techniques are completely distinct from classical programming and trial-and-error heuristic methods. In this paper Flower pollination algorithm (FPA), a recent optimization technique [12] is employed to solve coordinated economic dispatch problem due to its simplicity and robustness in solving constrained problems.

The remaining paper is organized as follows: Section 2 formulates the wind thermal coordination dispatch problem. Section 3 explains the algorithm for solving coordination dispatch problem using Flower pollination algorithm. In Section 4 the numerical simulation is performed in IEEE test system consisting of six and thirteen units using FPA are discussed and the performance of FPA is shown. The conclusions of the proposed FPA algorithm are discussed in section 5.

2. 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 within defined interval (i.e. one hour) while satisfying various constraints [13].

2.1 The Mathematical Model for the Generation Cost of all Thermal Units

The total generation cost of thermal units can be formulated as

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

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

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

However, when the generation units change their output, there is a nonlinear cost variation due to valve effect. The valve-point effects cause ripples in the cost curves of thermal units and create discontinuous, non convex objective function which has multiple minima. For an accurate modeling of valve-point loading effects, a rectified sinusoidal function is added in the fuel input-power output cost function of the ith unit. The fuel cost of a thermal generation unit considering nonlinear effect of valve will be a nonlinear function as in Equation (3)

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + [P_i^{\min} - P_i e_i * \sin\{f_i(P_i^{\min} - P_i)\}] \quad (3)$$

2.2 The Mathematical Model of Power System with Wind Farm

The total output power of all the wind turbines in the wind farm can be expressed as:

$$P_{WT}^*(t) = \sum_{t=1}^{T} \sum_{j=1}^{NW} P_{Wj}(t) \quad (4)$$

Under the electricity market environment, after considering the randomness of wind power which leads to an increase in operating cost with no energy consumption during the operation, the cost for the total life cycle of wind power system is as follows

$$F_w = C_{WT}(P_{WT}^*(t)) \quad (5)$$

If the generators are owned by the system operators even if accounting only for the incremental fuel cost, which is zero for the wind, this term CWT may not even exist. However, if the system operator is paying for the wind power from the owner of the wind farm, the operating cost coefficient will be involved. The analysis in literature shows that the cost coefficient can be chosen accordingly in optimal dispatch formulation [14].

2.3 Objective Function

Based on the above mathematical model of power system consisting of thermal units and wind farms the objective function of the wind thermal coordination system is

$$MinF_{Ti} = \min(F_T + F_W) \quad (6)$$

$$MinF_{Ti} = \sum_{t=1}^{T} \sum_{i=1}^{NT} F_i(P_i(t)) + C_{WT} \sum_{t=1}^{T} \sum_{j=1}^{NW} P_{Wj}(t) \quad (7)$$

The generation cost of wind power generation is ignored in the optimization process since there is no fossil fuel cost. After evaluating the inter relation between wind power and conventional plant, the cost of wind power plant will add up to the total cost.

2.4 Constraints of Wind Thermal Dispatch Problem

There are typical constraints for solving wind thermal dispatch problems. The following are some of the constraints presented in the literature [15].

In order to make the solution feasible certain constraints should be fulfilled. Some of the basic constraints which should be set up are power balance, spinning reserve, thermal plant output, unit capacity, ramp rate limit and so on.

2.4.1 Power balance constraint

The real power produced must be sufficient to satisfy the load demand and the constraint to be satisfied can be given as

$$\sum_{t=1}^{NT} U_i(t) * P_i(t) + \sum_{j=1}^{NW} P_{WT}(t) = P_L(t) \quad (8)$$

2.4.2 Unit capacity constraint

Each unit is designed to work between minimum and maximum power capacity. A range of unit power outputs is specified by either machine output limits or economical output limits. However, the minimum and maximum limits that bound the generation output of each generating unit in particular hour can be varied within the range of unit power outputs due to unit ramp rate constraints. The following constraint ensures that the unit is within its respective rated minimum and maximum capacity.

$$P_i^{\min}(t) \le P_i(t) \le P_i^{\max}(t) \tag{9}$$

2.4.3 Output of wind power

In recent studies, the Weibull Probability Distribution function is considered to be the best fitting model for the empirical wind speed distribution [16].

Owing to the randomness of wind speed, wind turbine output power is random variable value related to the wind speed. When the wind speed is lower than a critical value (cut-in speed) or higher than a certain value (cut-out speed), the wind turbine will stop running, and the output power is 0. If the nonlinear factors which affect the wind turbine output power are ignored the wind turbine output can be expressed as follows

$$\begin{cases} P_{Wj}(t) = 0 \ \ (V_{in} \ge V) or \ (V_{out} \le V) \\ P_{Wj}(t) = P_{WR} \times \frac{V - V_{in}}{V_r - V_{in}} \ (V_{in} \le V \le V_r) \\ P_{Wj}(t) = P_{WR} \ (V_r \le V \le V_{out} \end{cases} \tag{10}$$

As the focus of this paper is on the wind-thermal dispatch and not on wind power forecasting, fuzzy logic or similar theories to develop the wind speed profile will not be used, but a known probability distribution function for the wind speed will be assumed, and then, transformed to the corresponding wind power output for use in the economic dispatch model.

2.4.4 Total actual wind power generation limit

The total actual wind power generation limit is given by

$$0 \le P_{WT}(t) \le P_{WT}^{*}(t) \tag{11}$$

Researchers have focused much attention on wind-thermal coordination dispatch of power system in order to improve the economic posture of the power system. Thus the main objective is to develop a methodology for the exploration of the impacts of wind power on the economic dispatch of conventional generation units. Currently, conventional generation plays a pivotal role in maintaining the power balance between generation and demand. Wind power challenges power system balancing in two ways. Firstly, the presence of wind power reduces the amount of conventional generation capacity scheduled and available for balancing purposes. Secondly, wind power reduces the output level and/or operating hours of the conventional generation units, thereby reducing the total generation cost, including the fuel cost, operation and maintenance cost of generating units in power systems.

3. PROPOSED FLOWER POLLINATION ALGORITHM (FPA) FOR WIND-THERMAL COORDINATION DISPATCH PROBLEM

Flower pollination algorithm is a recent optimization technique developed by Yang in 2012. It is developed based on the phenomenon of pollination of flowers. The steps for solving economic dispatch involving wind thermal system using Flower pollination algorithm are as follows:

Step 1. Initialize the system data and parameters. Set the values for Population of Flowers, population size, number of generating units, maximum iteration, maximum and minimum limit for generation, Probability switch and load demand.

Step 2. Initialize the population of flowers with random solution 'rand'.

Step 3. Check whether a specified number of evaluations have not been reached.

Step 4. Determine the optimal generation scheme by selecting each generator and each flower corresponds to occupy the candidate node location.

Step 5. if rand < P (generation), assign a step vector which obeys Levy distribution. Then perform global pollination and evaluate latest solution.

Step 6. else do local pollination and evaluate latest solution, and end.

Step 7. Update the new solution if it is better than the previous solution.

Step 8. end

Step 9. Give the results statistics of the solved objective function for wind thermal Coordination dispatch.

The details steps are explained through the flow chart shown in Fig.1

4. DESCRIPTION OF TEST SYSTEMS

To verify the feasibility of the proposed algorithm, two different thermal test systems: six units system and thirteen units systems with 100MW wind farm are considered. The proposed algorithm is applied to the test systems with and without considering wind power.

4.1 Test System I: Six Unit System

The test system consists of six thermal units, 26 buses and 46 transmission lines. The system consists of six thermal generating units with valve point loading effects [17]. The total load demand on the system is 1263 MW. The operation data for the six unit system is presented in Table 1.

4.2 Test System II: Thirteen Unit System

This test system consists of 13 generating units with valve point loading effects (Nidul Sinha et al 2004). The load demand considered is 2520MW. The operation data for the thirteen unit system is presented in Table 2.

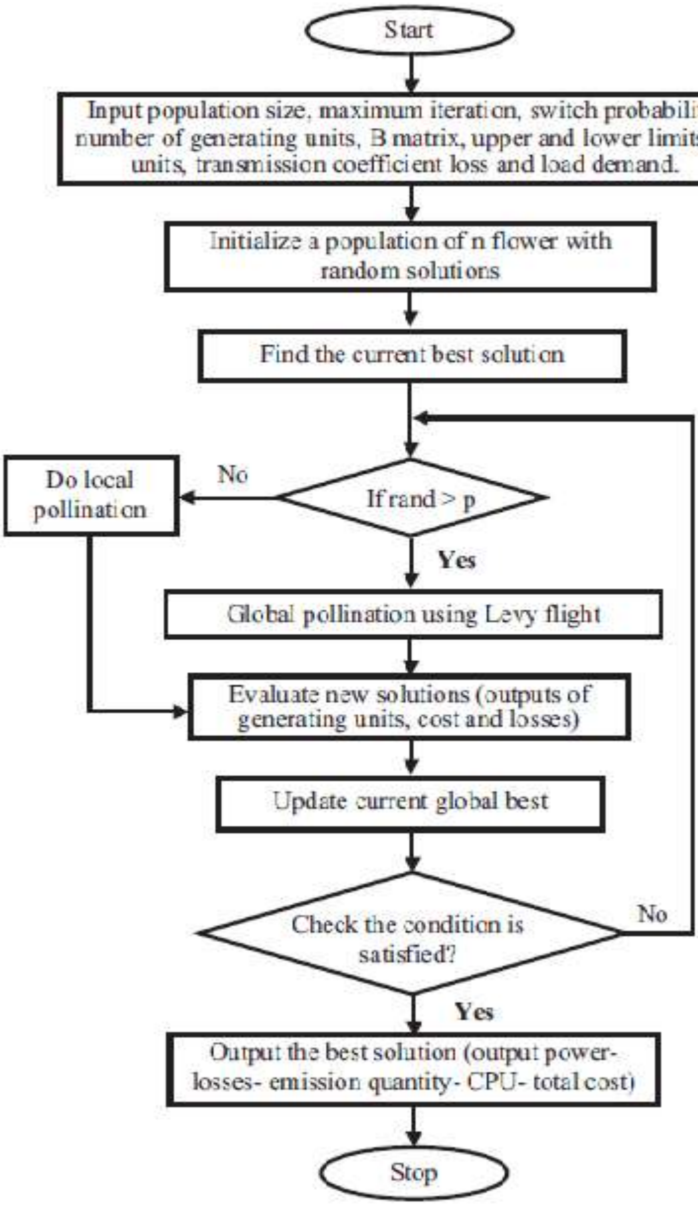


Fig. 1: Flow chart for Flower Pollination Algorithm for wind thermal dispatch problem

Table 1. Operation data of six unit test system

Unit	P_i^{min}	P_i^{max}	a_i	b_i	c_i	e_i	f_i
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. Operation data of thirteen unit test system

Unit	P_i^{min}	P_i^{max}	a_i	b_i	c_i	e_i	f_i
1	0	680	0.00028	8.10	550	300	0.035
2	0	360	0.00056	8.10	309	200	0.042
3	0	360	0.00056	8.10	307	200	0.042
4	60	180	0.00324	7.74	240	150	0.063

5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.60	126	100	0.084
11	40	120	0.00284	8.60	126	100	0.084
12	55	120	0.00284	8.60	126	100	0.084
13	55	120	0.00284	8.60	126	100	0.084

5. IMPLEMENTATION OF FLOWER POLLINATION ALGORITHM (FPA) ON IEEE TEST SYSTEMS

The proposed algorithm for wind thermal coordination problem has been implemented in the working platform of MATLAB (version 7.8) and was tested on 6 and 13 units IEEE test system.

The overall cost of operation with and without wind power generation by the proposed algorithm for the test system consisting of 6 thermal generating units with valve point effect and wind farm of overall 100MW capacity with a total demand of 1263MW is given in Table 3.

Table 3. Optimal generation cost of six unit system with and without wind power using Flower Pollination Algorithm

Unit	P_i^{min} (MW)	P_i^{max} (MW)	Without Wind Power (MW)	With Wind Power (MW)
1	100	500	477.56	350.23
2	50	200	185.34	137.25
3	80	300	266.25	278.72
4	50	150	127.19	123.73
5	50	200	191.56	181.84
6	50	120	100.23	91.63
Wind power output (MW)			-----	100.00
Total power output (MW)			1263	1263
Fuel cost for thermal units($/h)			15327.12	14550.70
Cost of wind power($/h)			-----	750.00
Total generation cost ($/hr)			**15327.12**	**15300.70**

The performance of the algorithm is evaluated and it is found that the total generation cost of thermal units excluding wind power is 15327.12$/h, that for wind and thermal system with wind farm is 15300.70$/h. The simulations with and without wind power production show that the total system operating costs and consumption of fossil fuel can be reduced notably by utilizing wind power generation. The convergence characteristics for six units system with and without wind power system is given in Fig. 2.

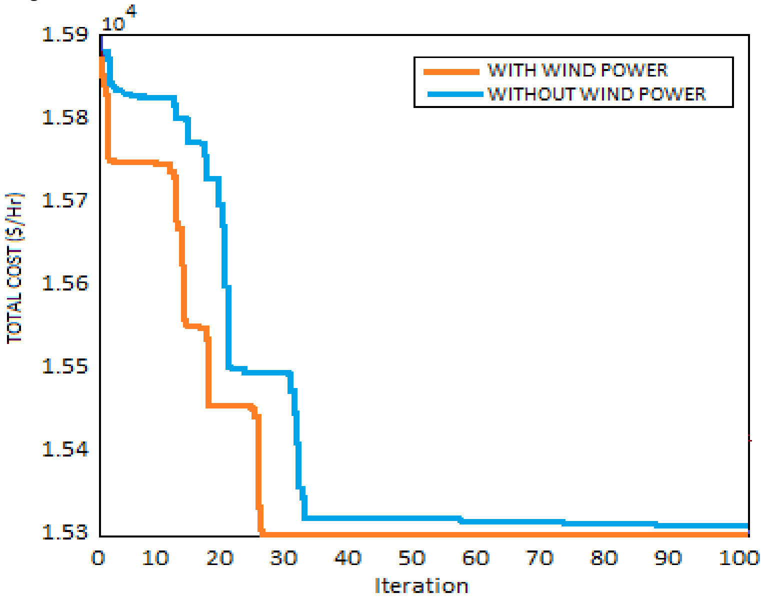


Fig 2: Convergence characteristics of six unit system with and without wind power system using Flower Pollination Algorithm

It is found that for a given demand of 1263 MW, the system including wind power converges faster than the system excluding wind power.

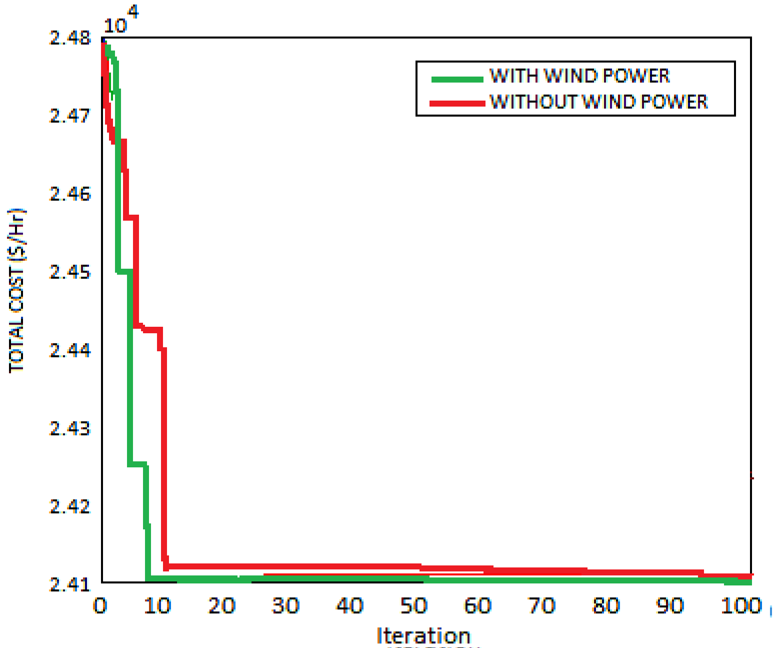
The results for the overall cost of operation with and without wind power by the proposed algorithm are given in Table. 4 for the test system consisting of 13 thermal generating units with valve point effect and wind farm of overall 100MW capacity with a total demand of 2520MW.

The performance of the proposed algorithm is evaluated and is found that the total generation cost of thermal units excluding wind power is 24104.32$/h, that for wind and thermal system with wind farm is 24101.25$/h.

Table 4. Optimal generation cost of thirteen unit system with and without wind power using Flower Pollination Algorithm

Unit	P_i^{min} (MW)	P_i^{max} (MW)	Without Wind Power (MW)	With Wind Power (MW)
1	0	680	609.35	518.91
2	0	360	310.32	252.56
3	0	360	290.34	350.25
4	60	180	178.00	140.56
5	60	180	170.32	165.51
6	60	180	140.50	146.34
7	60	180	150.25	140.12
8	60	180	157.35	157.26
9	60	180	150.30	160.25
10	40	120	114.28	113.40
11	40	120	94.15	116.11
12	55	120	76.23	86.65
13	55	120	82.41	76.90
Wind power output (MW)			-----	99.25
Total power output (MW)			2520.000	2520.000
Fuel cost for thermal units($/h)			24104.32	23356.87
Cost of wind power($/h)			----	744.38
Total generation cost ($/hr)			**24104.32**	**24101.25**

The simulations with and without wind power production shows that the total system operating costs and consumption of fossil fuel can be reduced notably by utilizing wind power generation. The outputs of the generators are all within the generator's permissible output limit. The convergence characteristics for thirteen units system with and without wind power system is given in Fig. 3.



Nomenclature

V	-	Actual wind speed
$P_{Wj}(t)$	-	Available output power of j^{th} wind turbine in time t
e_i and f_i	-	Cost coefficients for i^{th} generator reflecting valve point effects
a_i, b_i and c_i	-	Fuel cost coefficients of i^{th} thermal generating unit
$P_{i,r}^{min}$	-	Lower generation limit of thermal unit *i*
P_i^{max}	-	Maximum power outputs of the ith generating unit
$V_{\min}$	-	Maximum velocity
P_i^{min}	-	Minimum power output for the i^{th} generating unit
P_i^{min}	-	Minimum power outputs of the ith generating unit
$V_{\max}$	-	Minimum velocity
NW	-	Number of wind turbines operation at a time T
C_{WT}	-	Operating cost coefficient of wind turbine
$U_i(t)$	-	Scheduled state of thermal unit *i* for *t* hour
$P_L(t)$	-	System load demand at hour *t.*
$P_{WT}(t)$	-	Total actual wind generation at hour t
$P_{WT}^{*}(t)$	-	Total available output power of all the wind turbines in the wind farm
F_T	-	Total cost for the thermal power of the system
F_W	-	Total cost for wind power of the system
F_{Ti}	-	Total cost of the wind-thermal system
NT	-	Total number of conventional generation units over time interval T
N_p	-	Total number of particles in the swarm
$P_{i,r}^{max}$	-	Upper generation limit of thermal unit *i*
V_{in}	-	Wind turbine cut-in speed
V_{out}	-	Wind turbine cut-out speed.
P_{WR}	-	Wind turbine rated power
V_r	-	Wind turbine rated wind speed

Fig 3:Convergence characteristics of thirteen unit system with and without wind power system using hybrid PSO-EP-GA technique

It is found that for a given demand of 2520 MW, the system including wind power converges faster than the syste excluding wind power.

6. CONCLUSION

In this paper, flower pollination algorithm has been considered and which exhibits good performance in solving the wind- thermal coordination dispatch problem. The main aim of wind-thermal dispatch problem is to ensure minimum generation cost satisfying the system constraints which is tested on IEEE 6 and 13 unit test system. From the analysis of results it is inferred that the proposed algorithm generates a more efficient solution for the wind-thermal coordination dispatch problem.

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Author' biography with Photo

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