WIND AND SOLAR PENETRATION IN DYNAMIC ECONOMIC EMISSION DISPATCH USING FLOWER POLLINATION ALGORITHM

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Abstract—*Economic operation of power plant is an important task for planning and operation. Economic Load Dispatch is the best method to solve this need but for the welfare of the society emission has to be reduced as much as possible. Hence Combined Economic Emission Dispatch (CEED) is formulated which is having bi-objective of minimization of both generation cost as well as emission of the generating plant. Renewable energy sources such as wind power generation and solar power generation may inject into the power system and further generation cost and emission is reduced. In this research work, predicted wind and solar power generation is penetrated into the power system. Dynamic CEED for 24 hours is formulated with penetrated renewable energy generation. Flower Pollination Algorithm (FPA) which is an intelligent algorithm is implemented to find global optimal solution for the considered dynamic CEED problem. IEEE Standard test case power system for 24 hours dynamic loading with predicted renewable energy penetration impact is analyzed in this paper.*

Keywords—*CEED; economic operation; FPA; renewable energy penetration, solar; wind;*

1. Introduction

Electrical power system operation is a complex problem which has a combination of continuous, discrete control and dependent variables. It has a nature of iteration based convergence for the planning and operation problem. Unit commitment and economic load dispatch is the most widely used power system problems in operation and planning. After unit commitment the committed generating plants are scheduled optimally using economic load dispatch. In the economic load dispatch, power flows and its constraints have not given importance hence in the recent days, optimal power flow (OPF) is used which is the combination of economic load dispatch and load flow problem. Though the practical implementation load flow along with economic operation of the power plant is considered in the OPF, the welfare of the society is not focused in this approach [1]. Later Combined Economic Emission Dispatch (CEED) is attracted more intention since it has considered the bi-objective of generation cost and emission minimization [2]. This complex CEED has many local optimal solutions and to find the best global solution, evolutionary algorithms are better than conventional approach [3]. Economic load dispatch is solved using Differential Evolution (DE) and proved its performance for finding global optimal solution [4]. For practical application, the power system with valve point loading is considered [5] and DE was used to find the best solution. The hybrid of Genetic Algorithm (GA) and DE is used to solve OPF and proves its ability to find the global solution [6]. For static CEED problem DE is used to find best solution [7-8]. Artificial Bee Colony Algorithm is also used to solve static CEED problem [9]. Dynamic CEED is the Combined Economic Emission Dispatch for the 24 hours of a day [10]. It gives more realistic information for a day schedule of the generating plant and to optimize both generating cost and emission. Real Coded Genetic Algorithm (RCGA) is used to solve this dynamic CEED gives global solution [11]. For real load application electric vehicle charging is considered in CEED [12]. Renewable energy resources penetration into the power system is required along with dynamic CEED problem. Hence, this paper solves dynamic CEED problem with the penetration of renewable energy.

In CEED, minimum generating cost along with minimum emission is calculated and subjected to real and reactive power balance equation, upper and lower bound of real and reactive power, voltage and complex power in Mega Volt Ampere (MVA), power transfer in the transmission lines. CEED in the earlier literatures is used to find minimum generating cost and emission but reactive power is not taken into account and line flow limits are not checked. In this paper CEED is solved to find its bi-objective, real and reactive power losses are calculated using Newton Raphson (NR) method and subjected to power balance equality constraints and inequality constraints of real, reactive, voltage and line flow limits. The objectives are minimization of generating cost and emission of sulphur oxides SO_X, carbon oxide CO_X and nitrogen oxides NO_X. This bi-objective is converted into single objective function and subjected to equality and inequality constraints as same as OPF. The objective functions are quadratic function of real power generation.

Wind energy generation is depends on the flow of wind which is based on the climatic condition. In this research work different wind flow for the 24 hours is considered and this power is directly injected into the power system as new generation. Solar power generation is based on irradiation of the sun and it is available during the day [10]. Based on forecasted irradiation, solar power generation is calculated and directly injected into the power system during the solar energy available.

Flower Pollination Algorithm (FPA) is the latest intelligent algorithm having simple process to find the global optimal solutions in the solution space [13]. It mimics the process of flowering plants reproduction of its generation. The flowering plants is pollinated either by the same flower of the plant or by another flower from the best grown flower of some other plant of same species [14-15]. These two types of pollination are engineered as local pollination and global pollination. In global pollination levy flight movement is incorporated to mimic insect's aid of pollination in flowers [16]. This FPA is used to solve OPF and results are compared with Particle Swarm Optimization (PSO) [17]. FPA also gives good global solution to find best setting point for maximum power point tracking in solar panel [18]. Demand side management control is also considered in the latest CEED problems [19]. Since DE is one of the good intelligent algorithm and to improve its performance, memory base is included and used to solve dynamic CEED [20]. From the literature survey it is clear FPA has good capability to solve dynamic CEED and implemented in this work.

2. CEED Problem Formulation

CEED is a bi-objective problem and the objectives are minimization of generating cost and emission of sulphur oxides SO_X, carbon oxide CO_X and nitrogen oxides NO_X. This bi-objective is converted into single objective function using price penalty factor and subjected to equality and inequality constraints as same as OPF. The objective functions are quadratic function of real power generation. For generating cost, quadratic cost function is considered.

Objective function:

$$\text{Minimize } F = F_1 + h{*}F_2 \quad \$/\text{hour} \tag{1}$$

$$F_1 = \sum_{i=1}^{NG} \alpha_i + \beta_i P_{Gi} + \gamma_i P_{Gi}^2 + \left|\zeta_i \sin\left[\lambda_i \left(P_{Gi}{}^{\min} - P_{Gi}\right)\right]\right| \tag{2}$$

$$F_2 = \sum_{i=1}^{NG} 10^{-2} (a_i + b_i P_{Gi} + c_i P_{Gi}^2) + d_i \exp(e_i P_{Gi}) \tag{3}$$

Where,

NG is number of generators

F_1 is total generating cost in United States Dollar ($)/hr

F_2 is total emission in tons/hr

h is price penalty factor in $/tons

Price penalty factor is used to combine these two objectives and to convert bi-objective function into single objective function. Emission is computed in tons/hr which is converted into $/hr by multiplying with price penalty factor. This final single objective function is calculated in terms of $/hr. The price penalty factor of i^{th} generator is the ratio between the maximum fuel cost and maximum emission of the i^{th} generator. The following steps are used to find the price penalty factor for a particular load demand.

1. Find the ratio between maximum fuel cost and maximum emission of each generator.
2. Arrange the values of price penalty factor in ascending order.
3. Arrange the maximum real power generation capacity for the corresponding penalty factor.
4. Add maximum real power generation capacity of each unit one by one, starting from smallest price penalty factor till the summation is greater than total load demand P_D.
5. The value of price penalty factor for the particular load demand P_D is calculated by interpolating the values of corresponding load demand values.

This CEED problem is subjected to equality and inequality constraints. Power balance equation forms equality constraints and limits on control and dependent variables forms inequality constraints.

Subject to:

Equality constraints

Power balance condition of power system

$$\sum_{i=1}^{NG} P_{gi} = P_D + P_L \tag{4}$$

$$\sum_{i=1}^{NG} Q_{gi} = Q_D + Q_L \tag{5}$$

Inequality constraints

Limits on control and dependant variables

$$P_{gi}{}^{\min} \le P_{gi} \le P_{gi}{}^{\max} \qquad \text{for i=1to NG} \tag{6}$$

$$Q_{gi}{}^{\min} \le Q_{gi} \le Q_{gi}{}^{\max} \qquad \text{for i=1to NG} \tag{7}$$

$$V_i{}^{\min} \le V_i \le V_i{}^{\max} \qquad \text{for i=1to NB} \tag{8}$$

$$T_i{}^{\min} \le T_i \le T_i{}^{\max} \qquad \text{for i=1to NT} \tag{9}$$

$$MVA_i \le MVA_i{}^{\max} \qquad \text{for i=1to Nbr} \tag{10}$$

Where,

P_{gi}, Q_{gi} – i^{th} generator real and reactive power generation
P_D, Q_D – total real and reactive power demand
P_L, Q_L – total real and reactive power loss
V_i – i^{th} bus voltage magnitude
T_i – i^{th} transformer tap position
MVA_i – i^{th} transmission line MVA flow
NG – number of generators
NB – number of bus
NT – number of transformer
Nbr – number of branch / transmission line

In the objective functions, constants α, β, γ are fuel cost coefficients and ζ, λ are valve point effect coefficients of the generator. Units of the coefficients α, β, γ, ζ and λ are $/hr, $/Mwhr, $\$/Mw^2hr$, $/hr and $/Mwhr respectively. Constants a, b, c, d and e are emission coefficients of the generator and units of these constants are ton/hr, ton/Mwhr, ton/Mw^2hr, ton/hr and ton/Mwhr respectively.

3. Flower Pollination Algorithm

Flower Pollination Algorithm (FPA) is developed by mimic flowering plants life cycle. Most of the plants or trees in this universe use flowering technique to generate its next generation. This technique in the universe is started well earlier than any other species created and still it is working in an efficient manner. This inspires to develop the algorithm in the recent years. Reproduction or producing next generation of its species is carried out by the flower pollination process. Pollination is the process of transferring pollen grain from anther into stigma. This transfer may takes place within the same flower as shown in Figure 1, is called abiotic or self pollination. In this figure it is shown that pollen grain from plant-A is transfer into its stigma and this process is called self pollination.

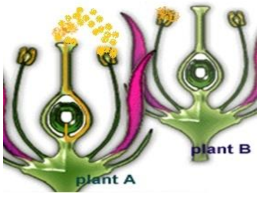

Figure 1: **Self Pollination**

This local or self pollination is implemented by using the following equation (11). F is the flowers which contain the set of control variables of the problem under consideration.

$$F_i^{t+1} = F_i^t + \varepsilon(F_j^t - F_k^t) \qquad (11)$$

Where,

F_i^{t+1} is the ith flower in the population of (t+1)th generation.

F_i^t is the ith flower in the population of tth generation.

F_j^t is the jth flower in the population of tth generation.

F_k^t is the kth flower in the population of tth generation.

ε is the random number between 0 to 1.

Nature optimizes this process to get best off-spring or child by overcome some deficiencies in the parent plants by biotic pollination. This is also called cross pollination. In this process insects or bees or birds or animals are involved to transfer pollen grains from anther of one flower from one plant to another plant as given in Figure 2.

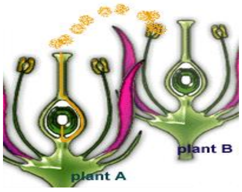

Figure 2: **Cross Pollination**

In the Figure 2 pollen grain of the flower from plant-B is transferred into stigma of flower in the plant-A. This transfer requires some insects and this might be highest fitness off spring by taking goodness of the both plant-A and plant-B. The insect is flying from one plant to other in a random flying motion and in an optimized path. This optimized path is obtained by Levy flight movement and used for cross pollination. This cross pollination or global pollination process is given by the equation (12).

$$F_i^{t+1} = F_i^t + \gamma L(\lambda)(F_i^t - F_g^t) \qquad (12)$$

Where,

F_i^{t+1} is the ith flower in the population of (t+1)th generation.

F_i^t is the ith flower in the population of tth generation.

F_g^t is the *global* flower in the population of tth generation.

γ is the scaling factor

$L(\lambda)$ is the Levy flight mimics the movement of insect.

The nature inspired population based flower pollination algorithm steps are given below.

Algorithm

Step 1: Set the objective function of the problem as fitness function of the flower.

Step 2: Identify the set of control variables which gives the character of the flower.

Step 3: Create the character of flower from the solution space bounded by the limits of the control variables.

Step 4: Using the character of the flower find the fitness of the flower.

Step 5: Find the fitness of all the flowers in the population and choose the global flower which has highest fitness.

Step 6: Generate a random number for each flower in the population, if the random number is greater than the switching probability then it has to follow local pollination using the equation (11)

Step 7: If the random number is less than the switching probability then it has to follow cross or global pollination using the equation (12)

Step 8: Increase the generation count if the entire flowers in the population are pollinated.

Step 9: Check the generation count, if it reaches the maximum number of generation then stop the process and print the results.

Step 10: If the generation count is less than the maximum number of generation, then repeat the steps 4 to step 9.

4. Implementation of developed algorithm

To evaluate the performance of developed algorithms, bench mark test case IEEE 30 bus system is considered. Numerical result for IEEE 30 bus is presented and discussed in this section. The system has 6 generators including slack bus, hence 5-real power generation, 6 generator bus voltage magnitude and 4 transformer tap position are considered as control variables and hence these 15 control variables are considered in a flower. 80 flowers are considered as the population size. This system has 41 transmission lines whose MVA limit provides line flow limit constraint. Base MVA of the system is 100MVA. Forecasted wind power and solar power is injected as real power into power system and these powers are subtracted from the total real power demand. The net real power demand after the subtraction of renewable power is allotted to the committed generators for the optimization. The optimization is bi-objective of minimization of fuel cost and emission of the power system. Flower Pollination Algorithm does the optimization of allotting best generating pattern. The load demand for the 24 hours is considered to implement the developed algorithm. 24 hour wind power and solar irradiation is also implemented in this research work. Generation cost coefficients of the test case is given in the Table 1.

Table 1: **Generator Limits and Cost Coefficients for CEED**

Gen. No	P Limit (MW)		Q Limit (Mvar)		Cost Coefficients				
	Min	*Max*	*Min*	*Max*	α ($/hr)	β ($/Mwhr)	γ ($/$Mw^2$hr)	ζ ($/hr)	λ ($/Mwhr)
1	5	50	-40	50	10	200	100	15	6.283
2	5	60	-40	50	10	150	120	10	8.976
3	5	100	-40	40	20	180	40	10	14.784
4	5	120	-10	40	10	100	60	5	20.944
5	5	100	-6	24	20	180	40	5	25.133
6	5	60	-6	24	10	150	100	5	18.480

The emission coefficients of the test case is given in the Table 2. Generation cost coefficients are used to find the fuel cost for the generating plants and emission coefficients are used for the calculation of emission of the generating plants in tons/hr.

Table 2: **Generator Emission Coefficients for CEED**

Gen. No	Emission Coefficients				
	a (ton/hr)	b (ton/ Mwhr)	c (ton/ Mw^2hr)	d (ton/ hr)	e (ton/ Mwhr)
1	4.091	-5.554	6.490	2e-4	2.857
2	2.543	-6.047	5.638	5e-4	3.333
3	4.258	-5.094	4.586	1e-6	8.000
4	5.426	-3.550	3.380	2e-3	2.000
5	4.258	-5.094	4.586	1e-6	8.000
6	6.131	-5.555	5.151	1e-5	6.667

5. Results & Discussions

MATLAB version 7 software is used for the simulation. The FPA is developed using programming codes of MATLAB. IEEE 30 bus data is given as input to the developed FPA and numerical results are obtained. This section provides numerical result of CEED using FPA.

Simulation is a MATLAB program. This program is run for with and without valve point loading data of the test case. The program output or results are given in Table 3. It shows developed FPA gives minimum generating cost and emission as compared to other algorithms in the literatures. Results of FPA for CEED are compared to other algorithms. Other limits of real and reactive power generation, voltages in all buses and transformer tap positions are within the limits. Using FPA for with valve point loading fuel cost and emission is improved by 3.5% and 0.15% as compared to the latest PSO algorithm.

Table 3: Comparison of FPA CEED Solution

Gen. (MW)	Without valve point loading				With Valve point loading	
	SPEA [3]	DE [4]	PSO [5]	FPA	PSO [5]	FPA
P_{G1}	29.96	25.2758	17.613	21.8777	14.089	5.7696
P_{G2}	44.74	40.6968	28.188	35.5781	34.415	40.5630
P_{G3}	73.27	56.1153	54.079	58.0203	67.558	47.9630
P_{G4}	72.84	66.9946	76.963	74.0125	83.971	79.9877
P_{G5}	11.97	53.6240	65.019	54.4699	49.043	55.1418
P_{G6}	53.64	43.6732	44.569	41.5252	39.797	56.7346
Fuel Cost $/hr	629.394	617.996	612.35	**611.325**	639.650	**617.862**
Emission ton/hr	0.21043	0.1999	0.20742	**0.20459**	0.21205	**0.21173**

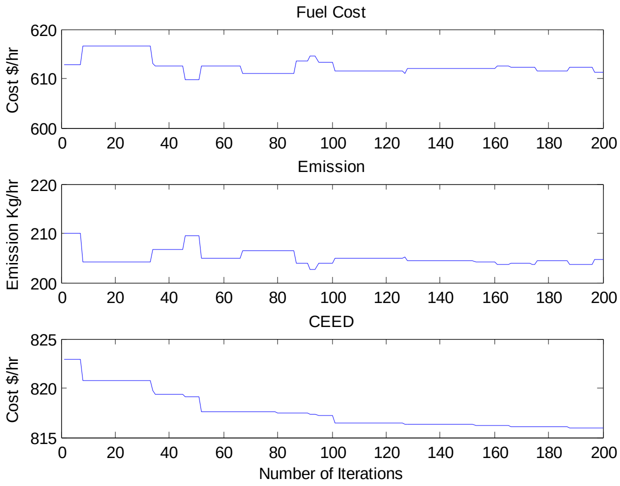

Figure3:**Convergence Curve without Valve Point Loading**

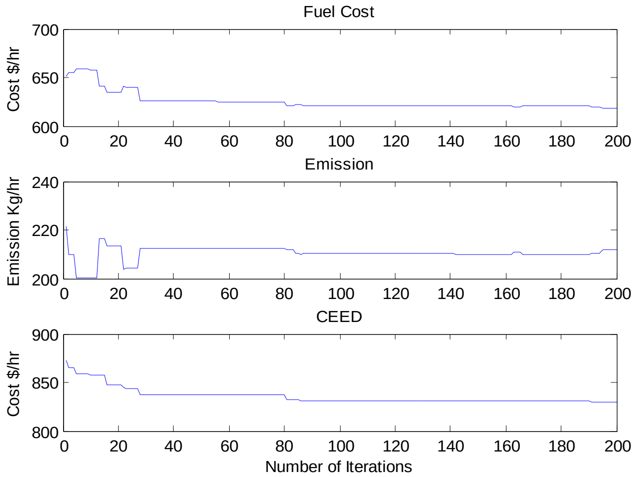

Figure 4: **Convergence Curve with Valve Point Loading**

The convergence curve for this condition is shown in Figure 3. First graph shows fuel cost in $/hr for 200 iterations, second graph shows emission in kg/hr for 200 iterations and final graph shows the combination generating cost and emission after multiplied by price penalty factor in $/hr for 200 iterations. Convergence curve for the same system with same constraints but valve point loading is considered is shown in Figure 4. In this approach the line flow limits are not forced only the generating cost, emission and CEED are minimized. Table 4 gives nature variation of wind power generation and solar irradiation for the 24 hours.

Table 4: Wind Power and Solar Irradiation

Hours	Wind power (MWhr)	Solar irradiation(W/m^2)
1	50	0
2	15	0
3	36	0
4	35	0
5	22	0
6	17	0
7	30	0
8	17	25
9	8	125
10	21	150
11	5	175
12	5.5	200
13	7.5	175
14	13	170
15	14	150
16	6	30
17	12	0
18	23	0
19	75	0
20	43	0
21	36	0
22	62	0
23	71	0
24	65	0

Table 5: Power Generation of 6 Generators for 24 Hour

Hrs	PG1	PG2	PG3	PG4	PG5	PG6
1	29.24	20	15	10	10	12
2	81.17	20	15	10	10	12
3	49.89	20	15	10	10	12
4	35.69	20	15	10	10	12
5	56.28	23.27	15.50	10.74	10.36	12
6	72.13	20	17.23	10	10.47	12.69
7	55.36	20	15	10	10	12
8	77.29	23.25	17.02	14.91	11.34	12
9	93.67	20.49	15.94	10	10.52	12.12
10	77.41	21.75	17.26	11.61	10.67	14.02
11	111.52	33.75	21.98	18.20	15.80	20.61
12	129.90	24.56	19.04	12.77	11.37	15.97
13	128.44	27.44	19.01	10.39	12.08	12
14	123.54	22.58	15	10	10	12
15	113.97	33.50	21.87	15.31	11.43	12.94
16	167.93	30.83	25.08	17.02	12.64	14.21
17	165.00	26.91	21.66	14.53	12.61	15.09
18	152.20	36.04	24.35	16.68	15.34	19.48
19	93.39	21.04	15	10	10	12
20	123.24	32.52	22.30	15.21	14.17	17.84
21	137.97	30.59	15	10.79	10	12
22	52.50	26.12	15	10	10	12
23	18.89	20	15	10	10	12
24	32.18	20	15	10	10	12

Separate program is developed for this wind and solar power penetration. After the penetration of wind and solar power into the power system the generating pattern is changed. Table 5 gives 24 hours generating pattern of the 6 committed generators in the IEEE 30 bus system. The first generator is considered as the slack bus. The net load is shared to these 6 generators optimally by the Flower Pollination Algorithm. From Table 5, it is observed that depending on load demand and availability of renewable power the generating is optimized to get minimum generating cost and emission.

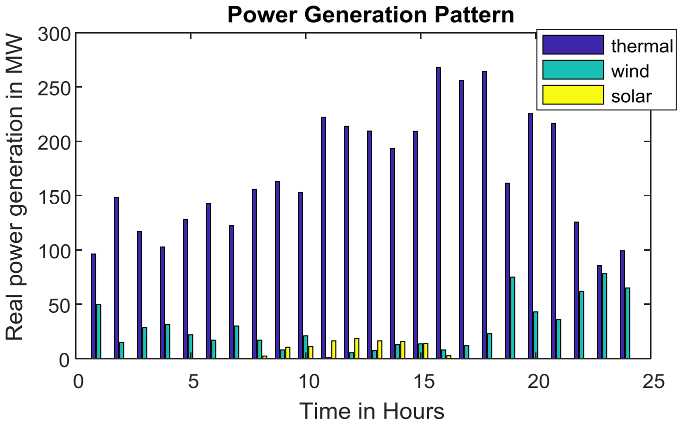

Figure 5: Power Generation of Thermal, Wind, Solar Generators

Figure 5 shows the generating pattern for 24 hours of the day. The solar power is available during noon hours as shown in yellow colour. Wind power generation is depends on the natural wind as shown in cyan color. The net demand after supplied by the renewable energy is allotted to committed 6 generators and their optimal generation is shown in blue colour. Thermal power generation is optimized based on demand and availability of renewable resources is depicted in the Figure 5.

6. Conclusion

CEED is the bi objective problem. The generating cost minimization is one objective and minimization of emission is another objective but these two objectives are opposite to one another. The intelligent algorithms FPA is used to solve CEED problem. IEEE 30 bus system is used to evaluate the performance of the FPA algorithm; the results are compared with other SPEA, DE and PSO algorithms in the literatures. In addition to CEED problem valve point loading is considered and their results are presented in this paper. This developed algorithm provides better optimal solution as compared to other algorithm. Renewable energies wind power and solar power is considered. During the availability of wind and solar power the demand is supplied by these resources remaining net demand is supplied by the committed thermal generators. This intern reduces the generating cost as well as emission of the power system.

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