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Integrated Renewable Energy Sources for the minimization of Emission and Economic Operation of Power System

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Abstract: Carbon foot print is latest hot discussion and all the countries are started the initiation to minimize it. One of the main carbon emission industries is thermal electrical power generating company. For the social welfare the emission has to minimize to maximum extend. The electrical power generation company as well needs to minimize the generation cost for the better operation. Minimizing carbon foot print and minimal power generation cost are opposite to each other. When the optimization focused to minimize the generation cost it lead to increase the carbon foot print and vice versa. This chapter addresses the constraint the optimization problem which needs the objective of reducing both emission and generation cost. Electrical power generating cost of thermal power plant is nonlinear and non-convex in nature. Likewise the emission produced by the thermal power plant is complex mathematical problem. Intelligent algorithms are best suitable to solve these types of practical problems. In this paper differential evolution technique is adopted to find the constrained emission minimization and cost minimization. Differential evolution technique has better mutation process and hence it is good in exploration of solution. Renewable energy sources PV solar and wind energy from the wind mills are green energy and helps the power systems to reduce the pollution. Solar PV system converts the light energy of the Sun into the electrical energy without any intermediate energy conversion. Solar energy is renewable and green energy suitable for low, medium and high voltage and power generation. The running cost is least as compared to the thermal power plant and suitable for both minimization of emission as well the operating cost. Wind is formed by indirect solar action and free in cost. Wind has enormous kinetic energy; wind mills are suitable device which converts the kinetic energy into mechanical energy. Wind mill is the system which houses wind turbine, generator and other ancillary devices to convert the winds' kinetic energy into electrical energy. The running cost for the wind is also least as like solar PV system and suitable to minimize the emission and operating cost of the power system. For the case study and implement the proposed algorithm IEEE 30 bus system is considered. The test power system has 6 thermal power generators and need to supply the demanded load. The solar PV and wind mill are installed in the sensitive buses and part of the demanded load is supplied by the renewable sources. The remaining power is supplied by the thermal power stations. As the renewable energy

sources are dependents on nature, thermal power plants are must run generators during day and night. During the availability of renewable energy sources thermal power station stress is relived and improves the performance of the power system.

This paper addresses the issues of the thermal power plants in the power system and suggests the integration of renewable energy sources. The renewable energy sources are located at the most effective location based on sensitive analysis. During the availability of the renewable energy, it is injected into the power system and reduces the generation of thermal plant. The emission is reduced due to this integration and intelligent algorithm Differential Evolution (DE) is devised to find combined emission and economic optimal solution.

Keywords: Renewable Energy System, Economic dispatch, Emission dispatch, intelligent algorithm, Differential Evolution, constraint optimization.

1. INTRODUCTION

Emission from the power generating plants has to be minimized for the society welfare. The economic operation of the power plant is important to minimize the electricity unit price [1]. These two objectives are important for the power generating plants. Multi objective optimization problem are complex to solve. The simple method to solve the multi objective optimization is converting into single objective problem [2]. The simple optimization problems may solved by the conventional mathematical methods such as linear programming (LP), NLP, QP, Newton method and interior method. The conventional method uses the gradient decent approach and may stick to the local minima points [3]. Intelligent algorithms are superior in solving the optimization problem [4]. They have the ability to overcome the local minima and find the global minima [5]. As the intelligent algorithms using multiple agents for the initial point and parallel search of the multiple agents makes the efficient search for the global minima solution [6]. The most versatile intelligent algorithms are Genetic Algorithm (GA) and Differential Evolution (DE) algorithm [7]. In this paper these two algorithms are used to find the minimization of cost and emission of the generating plant. GA is mimic of the Darwin’s theory and introduced in the year 1960 [8]. It uses initialization, cross over, mutation and selection process. The number of decision variables is considered as the number of genes. The group of genes are called chromosome. The chromosomes are cross over and mutated to get off springs of the chromosomes [9]. This intelligent algorithm is the basic and applied in all engineering field for the optimization process. Mathematical vector operation with improved mutation process is the power of the differential evolution algorithm introduced by Storn and Kenneth [10]. It has initialization, mutation and selection from mutated and trail vector. The inherent property of DE is minimization and well suited for the problem under consideration [11]. IEEE 30 bus was used for the optimal power flow by Alsac first and then it becomes standard bench mark for the most of the optimal power flow [12,13]. For the minimization of emission, the gaseous emission of the thermal power plant such as nitrogen oxides and sulfur oxides are considered [14, 15]]. The quadratic cost function and quadratic emission function is considered for the minimization of the considered problem [16, 17]. The bi-objective problem is converted into single objective using conversion factor and solved as single objective problem [18,19]. Solar PV is the device, which converts solar light energy into electrical energy. This electrical power is DC power has only real power and not able to give the reactive power. For the reactive power additional reactive power support devices are required for the PV system. Wind in the free energy may used to generate electrical power. Wind turbine is used to convert the wind energy into mechanical power. Induction generator is commonly used in the wind mill to convert the mechanical power into electrical power. This wind power is also real power and not able to supply reactive power [20,21. The thermal power plant is the only source to generate and supply the reactive power to the power system. These wind power generator and PV may add into power system and when the renewable energy is available they may be used for the minimization of real power from the thermal power plants. This reduction of the real power generation may lead to reduce the emission of the power plant and minimization generating cost of the electrical unit supplied to the consumer.

Problem formulation

The valve point loading of the thermal power plant is considered for the generating cost. It is the quadratic cost function for the first three terms and next two terms is for the valve point loading. Emission function is the quadratic function of real power generation. The combined single objective function is given in the equation (1).

1.1 Objective function:

Min. $F = F_1 + CC*F_2$ $/hour (1)

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

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

Where,

F_1 is fuel cost, $/hr
F_2 is emission, tons/hr
CC is conversion constant, $/tons

Conversion constant used to convert the bi-objective into single objective. The unit difference between fuel cost and emission is adjusted by the conversion constant. The unit of emission is matched with the fuel cost unit for the single objective problem. Equation (1), (2) and (3) are fuel cost, emission and combined single objective function respectively.

1.2 Subject to:

Equality constraints

The equality constraint equation uses the equal symbol and it balances the left and right side of the equation. In the equation (4) real power demand and losses should be supplied by the generated real power. Equation (5) is the balanced equation of reactive demand, losses and reactive power generation .

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

(4)

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

(5)

Inequality constraints

Boundary conditions of the decision variable and dependant variables are listed in the equation (6) to (10).

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

(6)

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

$$V_{i}^{min} \leq V_{i} \leq V_{i}^{max} \quad \text{for i=1to NB} \tag{8}$$

$$T_{i}^{min} \leq T_{i} \leq T_{i}^{max} \quad \text{for i=1to NT} \tag{9}$$

$$MVA_{i} \leq MVA_{i}^{max} \quad \text{for i=1to Nbr} \tag{10}$$

Where,

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

Hybrid RGA-DE Algorithm to Solve CEED

For the considered 30 bus test case system 15 control variables are considered as the genes. Hence a chromosome has 15 genes. 80 chromosomes are considered for the population. The size of this population is common for both GA and DE. The GA has very good cross over operation and DE has very good mutation process. The hybrid is the combination of these two algorithms. The initialisation, cross over process is derived from the GA and mutation, selection process is derived from the DE for the hybrid algorithm. In the initialisation process 15 control variables are randomly selected within its boundary condition and form the 80 chromosome. The fitness of this chromosome is calculated and based on its fitness the high fitness chromosomes are selected for the cross over. In the mating pool the cross over is taken place and for the two parents two off springs are created. The best fitness chromosome is preserved. This population of 80 chromosomes is given to mutation process derived from the DE. Here the mutated, trail vectors are created and the best vector is selected by the selection process. After the selection process same 80 chromosomes are available for the next generation. For the cross over process and for the mutation scaling factor 0.7 is considered. The stopping condition is maximum of 200 iteration is considered.

1.3 Algorithm

The step by step procedure for solving the problem is given below
Step 1: decision variables of the system is randomly selected within its boundary limits
Step 2: chromosomes are created from the decision variables
Step 3: for all chromosome fitness value is calculated
Step 4: based on the fitness value eligible chromosome is selected for the mating pool
Step 5: single point cross over is performed on the chromosome in the mating pool
Step 6: mutation and trail vectors are generated from the chromosome of the population
Step 7: best vectors are selected among the mutated and trail vector to form the new population
Step 8: step 4 to step 7 repeated till the convergence criterion is satisfied

Step 9: after the convergence the results are printed

Case Study

The bench mark 30 bus system is considered for the test case system. This system has 24 load bus and 6 generator bus. The first bus is considered as the slack bus. The real power generation and voltage magnitude of the generator bus are considered as the control variables and hence 15 control variables are considered for the simulation. These control variables are considered as genes and the group of genes is called chromosome. 80 chromosomes are considered for the simulation. 100 MVA base MVA is considered for the system. The system has 41 transmission lines among the 30 buses. Table 1 gives the cost coefficient and Table 2 gives the emission coefficient of the system.

Table 1 Cost coefficients

Gen. No	Q Limit (Mvar)		P Limit (MW)		Cost Coefficients				
	Min	Max	Min	Max	γ (\$/Mw^{2}hr)	β (\$/Mwhr)	α (\$/hr)	λ (\$/Mwhr)	ζ (\$/hr)
G1	-40	50	5	50	100	200	10	6.283	15
G2	-40	50	5	60	120	150	10	8.976	10
G3	-40	40	5	100	40	180	20	14.784	10
G4	-10	40	5	120	60	100	10	20.944	5
G5	-6	24	5	100	40	180	20	25.133	5
G6	-6	24	5	60	100	150	10	18.480	5

Table 2 Emission coefficients

Generator	a (ton/hr)	b (ton/Mwhr)	c (ton/Mw^{2}hr)	d (ton/hr)	E (ton/Mwhr)	c (ton/Mw^{2}hr)
G1	4.091	-5.554	6.490	2e-4	2.857	6.490
G2	2.543	-6.047	5.638	5e-4	3.333	5.638
G3	4.258	-5.094	4.586	1e-6	8.000	4.586
G4	5.426	-3.550	3.380	2e-3	2.000	3.380
G5	4.258	-5.094	4.586	1e-6	8.000	4.586
G6	6.131	-5.555	5.151	1e-5	6.667	5.151

2. NUMERICAL RESULTS

The result for the simulation is given in the table 3. The result of hybrid algorithm is compared with the literatures published earlier. The comparison shows that the hybrid algorithm gives the better result as compared to other algorithms for the considered problem. The results are given for both with and without valve point loading effect for the generators.

Table 3 Results comparison

Generator	With Valve point loading		Without valve point loading			
	PSO	RGA-DE	SPEA	DE	PSO	RGA-DE
1	14.089	5.7696	29.96	25.2758	17.613	21.8777
2	34.415	40.5630	44.74	40.6968	28.188	35.5781
3	67.558	47.9630	73.27	56.1153	54.079	58.0203

4	83.971	79.9877	72.84	66.9946	76.963	74.0125
5	49.043	55.1418	11.97	53.6240	65.019	54.4699
6	39.797	56.7346	53.64	43.6732	44.569	41.5252
Fuel Cost $/hr	639.6507	**617.862**	629.394	617.9962	612.35	**611.325**
Emission ton/hr	0.21205	**0.21173**	0.21043	0.1999	0.20742	**0.20459**

Figure 1 shows the convergence curve for the simulation result given in the table 1. There are 3 convergence curves. First one is the minimization of generation cost, second one is the minimization of emission and third one is the combined generation cost and emission as a single objective function. For the result given in the table 3, the transmission line limits are not considered. For the practical operation of the transmission lines the limits must be within the limits. The line flow in the 41 transmission line are estimated and given in the table 4. From the table transmission line number 11 connecting the buses 10 and 6, is overloaded and not viable for the practical operation. This shows the optimization has to reschedule for practical application. The line capacity is 32 MVA but the actual flow is 40.4 MVA the excess power flow has to be avoided and hence the generation are rescheduled. After the reschedule the power flow in the same line is reduced to 27.3 MVA. The rescheduled power generation is given in the table 5. After reschedule the generation cost is increased and emission is reduced. This increases the stability of the power system and welfare of the society. The cost is slightly increased for the better operation.

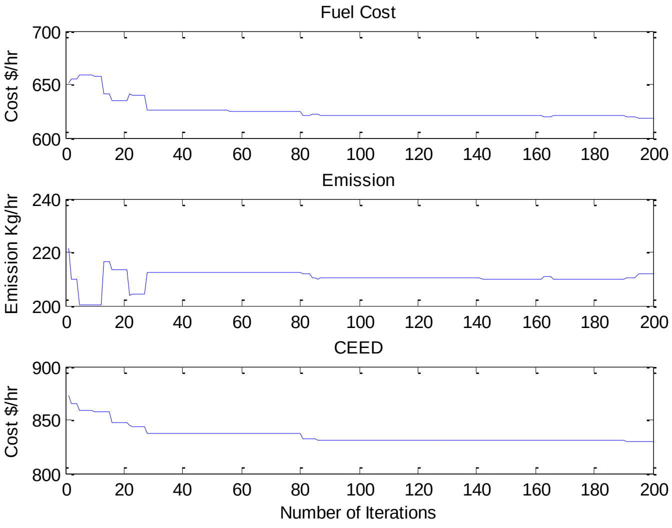

Fig.1. Convergence curve

Table 4 MVA flow violation with valve point loading

S. No	MVA	Line between buses	MVA flow before reschedule	MVA flow after reschedule
1	130	1-2	17.3	5.31
2	130	1-3	5.21	4.29
3	65	2-4	1.96	3.7
4	130	2-5	29.5	20
5	65	2-6	2.84	2.85

S. No	MVA	Line between buses	MVA flow before reschedule	MVA flow after reschedule
6	130	3-4	2.61	1.54
7	90	4-6	10.1	20.6
8	65	4-12	11.2	19.6
9	70	5-7	23.9	12.1
10	130	6-7	42.3	30
11	32	6-8	40.4	27.3
12	65	6-9	25.4	24.7
13	32	6-10	3.26	4.96
14	32	6-28	3.4	13
15	32	8-28	9.83	8.46
16	65	9-11	57.1	62.1
17	65	9-10	41	45.5
18	32	10-20	9.95	12.3
19	32	10-17	9.2	13.5
20	32	10-21	18.4	16.7
21	32	10-22	8.93	8.18
22	65	12-13	59.4	46.9
23	32	12-14	8.38	7.04
24	32	12-15	21	17
25	32	12-16	9.26	6.39
26	16	14-15	2.28	2.08
27	16	15-18	6.7	4.7
28	16	15-23	8.39	8.74
29	16	16-17	6.23	5.66
30	16	18-19	3.6	2.4
31	32	19-20	7.51	9.76
32	32	21-22	6.02	9.75
33	16	22-24	9.84	12.8
34	16	23-24	6.62	9.39
35	16	24-25	6.4	6.27
36	16	25-26	4.27	4.26
37	16	25-27	2.28	9.77
38	16	27-29	6.43	6.4
39	16	27-30	7.3	7.27
40	65	28-27	12.7	22.5
41	16	29-30	3.76	3.75

Table 5 Reschedule of the generators

Generator	After rescheduling	Before rescheduling
1	9.0023	5.7696
2	40.4567	40.5630
3	67.8302	47.9630
4	65.4647	79.9877
5	60.8947	55.1418

6	42.1097	56.7346
Fuel Cost $/hr	629.839	617.862
Emission ton/hr	0.20699	0.21173

3. CONCLUSION

The hybrid algorithm developed form the GA and DE algorithm gives the better result. Standard test case is considered for the implementation of the developed algorithm. The practical aspects of valve point loading are considered for the generators. For the transmission line the practical issue of overloading is addressed in this paper. When one can minimize the generation cost and not considering the transmission line loading then it may not be implementable. In this paper the line limits are considered and generation pattern is rescheduled to maintain the transmission power limit. Hence this approach is practical implementable.

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