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Short-Term Wind-Thermal Scheduling of Electric Power System and Enviornment Protection Goal Achievement Using Hybrid PSO-GSA Algorithm

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***Abstract* - Wind Power and Solar energy are the two most vital energy resources in the electric power industry's transition to an environmental-friendly operation. The use of Wind Power and renewable energy in electric power sector has grown significantly in recent years. The proportion of wind energy in the pattern of world energy has been increasing since the beginning of the twenty-first century. Since wind power plays a positive role in energy saving and reducing emissions of pollutants, power companies should transport and distribute wind power electricity as much as possible. This research papers aims to present the Short-Term Wind-Thermal Scheduling of Electric Power System Using hybrid PSO-GSA Algorithm. The Effectiveness of Proposed Algorithm is Tested with IEEE Test System Consisting of Three, Six and Fifteen Unit Test System. To achieve the goal of environmental protection, Wind-Power is combined with Thermal power to satisfy time-varying load demand and incorporate transmission losses. Also, environment protection goal is achieved in the proposed research.**

***Keywords* - Environmental Protection Goal(EPG), Particle Swarm Optimization-Gravitational Search Algorithm(PSO-GSA), Wind-Thermal Scheduling (WTS)**

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1. INTRODUCTION

In Modern power system, the proportion of wind energy in the pattern of world energy has been increasing since the beginning of the twenty-first century. Since wind power plays a positive role in energy saving and reducing emissions of pollutants, power companies should transport and distribute wind power electricity as much as possible. Also, the integration of wind-power, natural gas and electricity sectors has sharply increased in the last decade as a consequence of combined cycle thermal power plants. However, when large-scale wind power accesses the power system, the generation scheduling and reserve need to be re-arranged and adjusted due to intermittent and variable characteristic of wind power output. The modern power system around the world has grown in complexity of interconnection and power demand. The focus has shifted towards enhanced performance, increased customer focus, low cost, reliable and clean power. In this changed perspective, scarcity of energy resources, increasing power generation cost, environmental concern necessitates optimal scheduling of power plants. In reality, power stations neither are at equal distances from load nor have similar fuel cost functions. Hence for providing cheaper power, load has to be distributed among various power stations in a way which results in lowest cost for generation. To achieve lowest cost of generation optimal scheduling of generating units is required, which can be achieved by Economic Dispatch and Unit Commitment [10].

2. LITERATURE REVIEW

In Recent Years, Various numerical optimization and mathematical programming based optimization techniques had been applied to solve scheduling problem of electric Power System. Researchers in India and abroad have done a lot of work. In the study of optimal scheduling model, in literature [1], a dynamic economic scheduling model is built considering the random variation of the wind speed; and in dynamic optimization model, the unit ramp rate must be a constraint [2]. In the research of unit commitment for power systems with wind farms, the credible data of wind speed and wind power output are needed, in [3], the wind speed is predicted by time series method based on neural network. The optimization of unit scheduling is a large-scale nonlinear mixed integer model, and a variety of algorithms are used to solve the problem. Traditional methods like priority list [4-5], LaGrange Relaxation and dynamic programming have been applied to solve the model. With the development of artificial intelligence algorithms, a variety of intelligent algorithms, such as genetic algorithms [6], ant colony algorithm [7], particle swarm optimization [8-9] have also been used to deal with optimization scheduling. Some important work related to scheduling problem of electric power system is reported below:

Valenzuela J. and Smith A. E. [11] demonstrated that a memetic algorithm (MA) combined with Lagrangian relaxation (LR) can be very efficiently used for solving large unit commitment problems.Mafteiu L. O. and Mafteiu-Scai E. J. [12] developed a memetic algorithm (MA) for the solution of linear system of equations by converting into an optimization problem. Mafteiu-Scai L. O. [13] proposed a technique using memetic algorithm (MA) for the improvement of convergence of iterative methods to solve linear or nonlinear systems of equations. Sanusi H. A.et al. [14] investigated the performance of GA and MA for a constrained optimization and found that MA converges quicker than GA and produces more optimal results but the time taken by iteration in GA is less than that in MA. Yare Y. et al.[15] proposed the differential evolution (DE) approach for generator maintenance scheduling (GMS) and economic dispatch (ED) of the Indonesian power system to optimize the cost of operation of 19 units. Chakraborty S.et al. [16] presented a fuzzy modified differential evolution approach for solving thermal UC problem integrated with wind power system. Sharma R.et al. [17] developed a new method to solve the economic dispatch (ED) problem known as Self-Realized Differential Evolution which was tested for 40- unit system and 10- unit system. Hardiansyahet al. [18] investigated the features of artificial bee colony algorithm (ABC), differential evolution (DE) algorithm and particle swarm optimization (PSO) for 3 and 6-unit systems and found that differential evolution algorithm converges faster than artificial bee colony algorithm and particle swarm optimization. Ravi C.N. and Rajan C. C. A. [19] used differential evolution (DE) optimization algorithm to solve optimal power flow (OPF) problem considering IEEE 30 bus standard power system. Lee K. S. and Geem Z. W. [20] developed a new Harmony search (HS) algorithm for global ooptimization. Coelho L.S. and Mariani V.C. [21] improved the established harmony search (HS) algorithm using exponential distribution for a 13- unit system. Coelho L.S.et al. [22] proposed a customized harmony search algorithm with differential evolution (DE) and chaotic sequences, CHSDE algorithm, for solving the ELD problemfor a 10- unit system. Tuo S. and Yong L. [23] presented an enhanced harmony search with chaos (HSCH). The test results show that the HSCH algorithm is a convincing algorithm and it is much better than the classical HS technique and harmony search algorithm with differential evolution (HSDE). Shukla S. and Anand A. [24] applied harmony search technique for the multi-objective optimization of a styrene reactor. Arul R.et al. [25] applied harmony search algorithm to solve ELD problem with transmission losses under the changing patterns of consumer load for standard 6-bus system, standard IEEE-14 bus system, and the standard IEEE-30 bus system. Xue-hui L.et al. [26] adopted a meta-heuristic algorithm, the shuffled frog-leaping algorithm (SFLA) and applied to solve travelling salesman problem. Reddy A. S. and Vaisakh K. [27] customized the shuffled frog-leaping algorithm into a modified shuffled frog- leaping algorithm (MSFLA) for solving the economic emission load dispatch problem for IEEE- 30 bus system. Pourmahmood M.et al. [28] also proposed a modified shuffled frog- leaping (MSFL) algorithm. Jebaraj L.et al. [29] applied SFLA to optimize the location and the size of the two FACTS devices, TCSC and SVC, for IEEE 30- bus system under certain considered conditions.Anita J. M. and Raglend I. J. [30] presented the application of SFLA optimization algorithm to find the solution of UCP to a 10- unit thermal system.

Fang H., et al. [31] presented a new snake algorithm which is demonstrated to overcome the drawbacks of traditional snake/ contour algorithms for contour tracking of multiple objects more effectively and efficiently. The experimental results of the tests carried out have proved that the proposed method is robust, effective and accurate in terms of finding the boundary solutions of multiple objects. Simon D. [32] developed biogeography-based optimization (BBO) algorithm and tested for 14 benchmark functions using BBO and compared the results with GA, PSO, DE, ES, stud genetic algorithm (SGA), PBIL and ACO. Kamboj V.K. and Bath S.K.[33] applied biogeography-based optimization (BBO) for the solution of economic load dispatch problem of electric power system and specified the scope of BBO for Multi-Objective Scheduling problem.

A survey of existing literature on the problem reveals that various numerical optimization and mathematical programming based optimization techniques have been applied to solve Economic Load Dispatch and Hydro-Thermal Scheduling problem and some of them are applied to wind-thermal scheduling problem. Most of these are calculus-based optimization algorithms that are based on successive linearization and use the first and second order differentiations of objective function and its constraints equations as the search direction. They usually require heat input, power output characteristics of generators to be of monotonically increasing nature or of piecewise linearity thus resulting in an inaccurate dispatch and scheduling. Also, very few work is done to solve the combined wind-thermal generation scheduling problem, which is a mixture of conventional and Non-Conventional Generating Units. Therefore to overcome the above mentioned limitations, research proposal here is to explore and present Short-Term Wind-Thermal Scheduling of Electric power System using hybrid PSO-GSA Algorithm. Also, Environment protection is most important for safe and economic operations of electric power system. To achieve such eco-friendly environment goal, research proposal for wind-thermal scheduling problem of electric power system using hybrid PSO-GSA has been undertaken.

3. MATHEMATICAL FORMULATION OF WIND-THERMAL SCHDEULING PROBLEM

The classical formulation of the standard Wind-Thermal Scheduling problem is an optimization problem of determining the schedule of the fuel costs of real power outputs of generating units subject to the real power balanced with the total load demand, subtracting the Wind-Power from the total Generation of Thermal Generating Units, as well as the limits on generators outputs. In mathematical terms the Wind-Thermal Scheduling problem objective function can be defined as following:

$$\min[FC(P_n)] = \sum_{n=1}^{U} (C_{0n} P_n^{\,2} + C_{1n} P_n + C_{2n}) \qquad \text{Rs./Hour} \tag{1}$$

subject to below mentioned constraints:

(i) The energy balance constraints:

$$\sum_{n=1}^{U} P_n = P_{Demand} + P_{Loss} - P_{Wind} \tag{2}$$

(ii) The inequality constraints:

$$P_n^{\min} \le P_n \le P_n^{\max} \qquad (\mathrm{n} = 1, 2, 3, \ldots\ldots\ldots\ldots, \mathrm{U}).$$

(3)

The most simple and approximate method of expressing power transmission loss, P_{Loss} as a function of generator powers using B-coefficients and mathematically can be expressed as:

$$P_{Loss} = \sum_{n=1}^{U}\sum_{m=1}^{U} P_{g_n} B_{nm} P_{g_m} \quad \text{MW.} \tag{4}$$

The constrained Wind-Thermal Scheduling Problem can be converted to unconstrained Wind-Thermal Scheduling Problem using Penalty of definite value, which can be mathematically expressed as:

$$\min[FC(P_n)] = \sum_{n=1}^{U} F_n(P_n) + 1000 * abs(\sum_{n=1}^{U} P_n - P_{Demand} + P_{wind} - \sum_{n=1}^{U}\sum_{m=1}^{U} B_{nm} P_n P_m) \tag{5}$$

4. Hybrid PSO-GSA ALGORITHM FOR WIND THERMAL SCHEDULING

Talbi in [11] has presented several hybridization methods for heuristic algorithms. According to [11], two algorithms can be hybridized in high-level or low-level with relay or coevolutionary method as homogeneous or heterogeneous. In this paper, we hybridize PSO with GSA using low-level coevolutionary heterogeneous hybrid. The hybrid is low-level because we combine the functionality of both algorithms. It is co-evolutionary because we do not use both algorithm one after another. In other words, they run in parallel. It is heterogeneous because there are two different algorithms that are involved to produce final results. The basic idea of PSOGSA is to combine the ability of social thinking (gbest) in PSO with the local search capability of GSA. In order to combine these algorithms, (6) is proposed as follow:

$$V_i(t+1) = w \times V_i(t) + c_1' \times rand \times ac_i(t) + c_2' \times rand \times (gbest - X_i(t)) \tag{6}$$

Where, $V_i(t)$ is the velocity of agent i at iteration t, $c_j'(t)$ is a weighting factor, w is a weighting function, rand is a random number between 0 and 1, $ac_i(t)$ is the acceleration of agent i at iteration t, and gbest is the best solution so far. In each iteration, the positions of particles are updated as follow:

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{7}$$

In PSOGSA, at first, all agents are randomly initialized. Each agent is considered as a candidate solution. After initialization, Gravitational force, gravitational constant, and resultant forces among agents are calculated using (8), (9), and (10) respectively.

$$F_{ij}^{d}(t) = G(t)\frac{M_{pi}(t) \times M_{aj}(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right), \tag{8}$$

$$G(t) = G_0 \times \exp(-\alpha \times iter/maxiter) \tag{9}$$

$$F_i^d(t) = \sum_{j=1, j \neq i}^{N} rand_j F_{ij}^d(t), \tag{10}$$

After that, the accelerations of particles are defined as per equation shown below:

$$ac_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)}, \tag{11}$$

In each iteration, the best solution so far should be updated. After calculating the accelerations and with updating the best solution so far, the velocities of all agents can be calculated using equation (6). Finally, the positions of agents are defined as (7). The process of updating velocities and positions will be stopped by meeting an end criterion. The steps of PSOGSA are represented in fig.1.

ALGORITHM AND FLOW CHART FOR PROPOSED HYBRID PSO-GSA

The proposed GSA approach for short-term wind thermal problem can be summarized as follows:

Step 1. Identify Search space.

Step 2. Generate initial population between minimum and maximum values.

Step 3. Evaluate Fitness function considering wind power agents.

Step 4. Update *G(t)*, *best(t)*, *worst(t)* and $M_i(t)$ *for* $i = 1,2,...,m$.

Step 5. Calculation of the total force in different directions.

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Step 6. Calculation of acceleration and velocity using equation (11) and (6) respectively.
Step 7. Updating agents' position using equation(6).
Step 8. Repeat step 3 to step 7 until the stop criteria is reached.
Step 9. Stop.

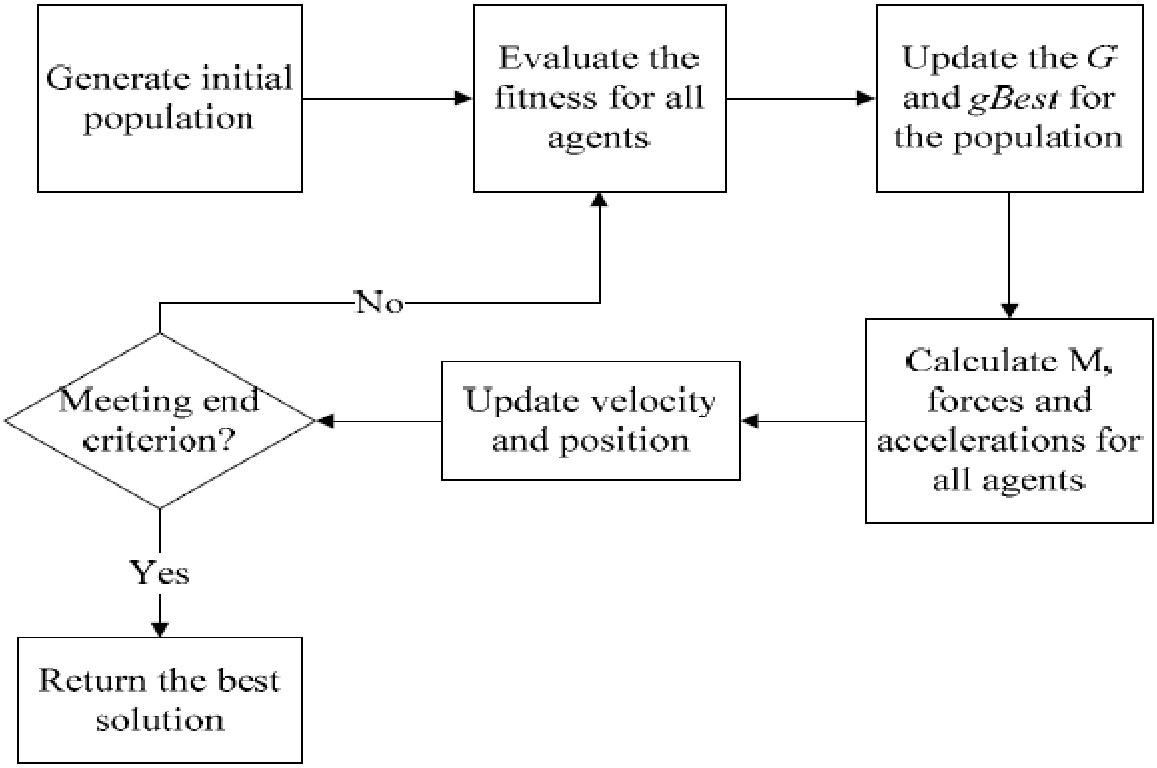


Fig.2: Flow Chart of Hybrid PSO-GSA Algorithm for Wind-Thermal Scheduling

5. TEST SYSTEMS AND SIMULATION DATA

In order to verify the feasibility and efficiency of the proposed algorithm for wind-thermal scheduling problem, the algorithm was tested three test cases considering loss coefficients for calculation of Transmission losses. The test System Consist of 3, 6 and 15 Generating Units. The valve point effect is ignored for thermal generating units, while considering wind power for generation scheduling problem. The proposed algorithm is executed with following parameters: m=40 (masses), G is set using Eq.(9). where G_0 is set to 100 and α is set to 10, and T is the total number of iterations. Maximum iteration numbers are 250 for these case studies.

6. RESULTS AND DISCUSSION

In this paper, the test system contains 3, 6 and 15 thermal generating units and three wind farms and the test systems are generalized from a certain region power system in North Korea and South China. The scheduling period for 3 and 6 units system is divided into 8 hours and for 15 units test system, it is divided into 12 hours. The operating parameters of thermal units are listed in **Table-I, II, III, IV, V** and **VI** and the load demand and the wind power output predicted are shown in **Table-VII, Table-VIII** and **Table-IX** for 3, 6 and 15-units test system respectively. The MATLAB simulation software is used to obtain the corresponding results. It has been found that optimal fuel cost for three generating unit test system is **Rs. 32607.4217** and power Loss **is 214.7802 MW.** The optimal fuel cost for six generating unit test system is **Rs. 158955.7171** and power Loss **is 171.6144939 MW.** The Scheduling pattern of 15 units generating system is shown in **Fig.6.1.** The convergence of Gravitational Search Algorithm for 3 and 6 units test system are shown in **Fig.6.2.** and For 15-units test system, convergence curve is shown in **Fig.6.3.**

HYBRID PSO-GSA ALGORITHM FOR WIND THERMAL SCHEDULING
Test data for Three Generating Unit System

Table-I: Thermal Unit Chatacteristics

C0	C1	C2	P_{min}	P_{max}
0.00482	7.97	78	50	200
0.00194	7.85	310	100	400
0.001562	7.92	562	100	600

Table-II: Loss Coefficient Matrices

B	0.000676	0.0000953	-0.0000507
	0.0000953	0.000521	0.0000901
	-0.0000507	0.0000901	0.000294
B0	-0.00766	-0.00342	0.0189
B0	0.40357		

Test data for Six-Generating Unit System

Table-III: Thermal Unit Chatacteristics

C0	C1	C2	P_{min}	P_{max}
0.007	7	240	100	500
0.0095	10	200	50	200
0.009	8.5	220	80	300
0.009	11	200	50	150
0.008	10.5	220	50	200
0.0075	12	190	50	120

Table-IV: Loss Coefficient Matrices

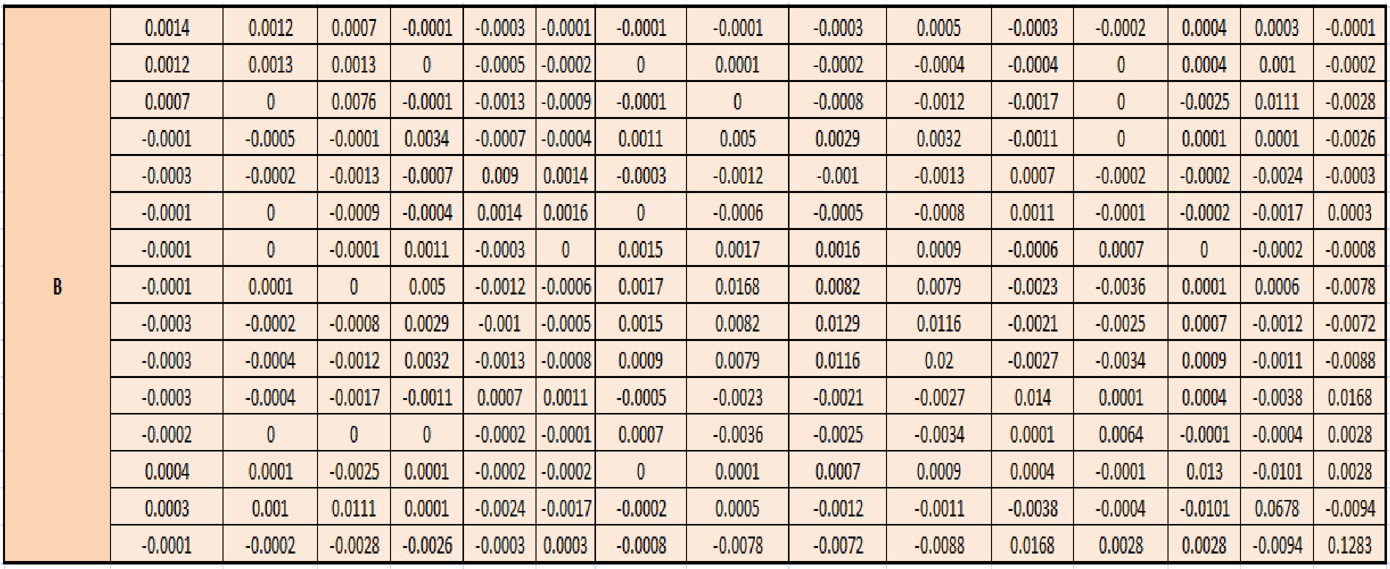
B	0.000017	0.000012	0.00007	-0.00001	-0.000005	0.000002
	0.000012	0.000014	0.000009	0.000001	-0.000006	0.000001
	0.000007	0.000009	0.000031	0	-0.00001	0.000006
	-0.000001	0.000001	0.0000	0.00024	-0.000006	0.000008
	-0.000005	-0.000006	-0.00001	-0.000006	0.000129	0.000002
	-0.000002	-0.000001	-0.000006	-0.00008	-0.000002	0.00015
B0	-0.3908	-1.29	7.047	0.591	2.161	-6.63
B00	0.0056					

Test data for 15-Generating Unit System

Table-V: Thermal Unit Chatacteristics

C0	C1	C2	Pmin	Pmax
0.000299	10.1	671	150	455
0.000183	10.2	574	150	455
0.001126	8.8	374	20	130
0.001126	8.8	374	20	130
0.000205	10.4	461	150	470
0.000301	10.1	630	135	460
0.000364	9.8	548	135	465
0.000338	11.2	227	60	300
0.000807	11.2	173	25	162
0.001203	10.7	175	25	160
0.003586	10.2	186	20	80
0.005513	9.9	230	20	80
0.000371	13.1	225	25	85

0.001929	12.1	309	15	55
0.004447	12.4	323	15	55



B	0.0014	0.0012	0.0007	-0.0001	-0.0003	-0.0001	-0.0001	-0.0001	-0.0003	0.0005	-0.0003	-0.0002	0.0004	0.0003	-0.0001
	0.0012	0.0013	0.0013	0	-0.0005	-0.0002	0	0.0001	-0.0002	-0.0004	-0.0004	0	0.0004	0.001	-0.0002
	0.0007	0	0.0076	-0.0001	-0.0013	-0.0009	-0.0001	0	-0.0008	-0.0012	-0.0017	0	-0.0025	0.0111	-0.0028
	-0.0001	-0.0005	-0.0001	0.0034	-0.0007	-0.0004	0.0011	0.005	0.0029	0.0032	-0.0011	0	0.0001	0.0001	-0.0026
	-0.0003	-0.0002	-0.0013	-0.0007	0.009	0.0014	-0.0003	-0.0012	-0.001	-0.0013	0.0007	-0.0002	-0.0002	-0.0024	-0.0003
	-0.0001	0	-0.0009	-0.0004	0.0014	0.0016	0	-0.0006	-0.0005	-0.0008	0.0011	-0.0001	-0.0002	-0.0017	0.0003
	-0.0001	0	-0.0001	0.0011	-0.0003	0	0.0015	0.0017	0.0016	0.0009	-0.0006	0.0007	0	-0.0002	-0.0008
	-0.0001	0.0001	0	0.005	-0.0012	-0.0006	0.0017	0.0168	0.0082	0.0079	-0.0023	-0.0036	0.0001	0.0006	-0.0078
	-0.0003	-0.0002	-0.0008	0.0029	-0.001	-0.0005	0.0015	0.0082	0.0129	0.0116	-0.0021	-0.0025	0.0007	-0.0012	-0.0072
	-0.0003	-0.0004	-0.0012	0.0032	-0.0013	-0.0008	0.0009	0.0079	0.0116	0.02	-0.0027	-0.0034	0.0009	-0.0011	-0.0088
	-0.0003	-0.0004	-0.0017	-0.0011	0.0007	0.0011	-0.0005	-0.0023	-0.0021	-0.0027	0.014	0.0001	0.0004	-0.0038	0.0168
	-0.0002	0	0	0	-0.0002	-0.0001	0.0007	-0.0036	-0.0025	-0.0034	0.0001	0.0064	-0.0001	-0.0004	0.0028
	0.0004	0.0001	-0.0025	0.0001	-0.0002	-0.0002	0	0.0001	0.0007	0.0009	0.0004	-0.0001	0.013	-0.0101	0.0028
	0.0003	0.001	0.0111	0.0001	-0.0024	-0.0017	-0.0002	0.0005	-0.0012	-0.0011	-0.0038	-0.0004	-0.0101	0.0678	-0.0094
	-0.0001	-0.0002	-0.0028	-0.0026	-0.0003	0.0003	-0.0008	-0.0078	-0.0072	-0.0088	0.0168	0.0028	0.0028	-0.0094	0.1283

Table-VI: Wind-Thermal Scheduling for 3-Generating Unit System

Hour	Demand	Pwind	Scheduling of Thermal Units			Power Supplied By Wind Sources	Ploss	Fuel Cost
			P1	P2	P3			
1	350	30	64.12362811	105.3841563	171.0882477	30	20.59603	3729.411
2	380	40	79.04386459	101.5766977	182.1359815	40	22.75654	3921.409
3	400	23	85.32503995	108.0353761	211.8907424	23	28.25116	4284.157
4	420	34.3	87.40089322	110.5690556	217.4064216	34.3	29.67637	4370.777
5	360	33	70.71893301	100	177.3963755	33	21.11531	3796.27
6	375	21.58	189.2791491	100	100	21.58	35.85915	4051.921
7	385	20.5	82.00286404	104.5232968	204.2604241	20.5	26.28658	4160.59
8	390	24	82.28972656	105.0044433	205.2286319	24	26.5228	4175.364
Total Power Loss							**211.063949**	
Total Generation Cost							**32489.8996**	

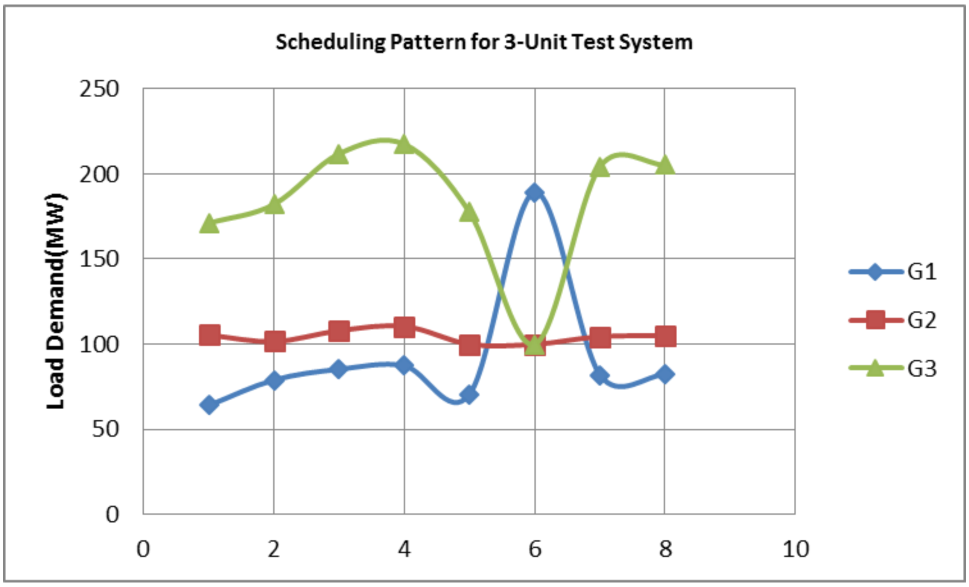


Fig.6.3(a) : Scheduling Pattern for 3- Units System

To see how PSOGSA is efficient some remarks are noted as follow. In PSOGSA, the quality of solutions (fitness) is considered in the updating procedure. The agents near good solutions try to attract the other agents which are exploring the search space. When all agents are near a good solution, they move very slowly. In this case, the gBest help them to exploit the global best. PSOGSA use a memory (gBest) to save the best solution has found so far, so it is accessible anytime. Each agent can observe the best solution so far and tend toward it. With adjusting c1 and c2 , the abilities of global search and local search can be balanced.

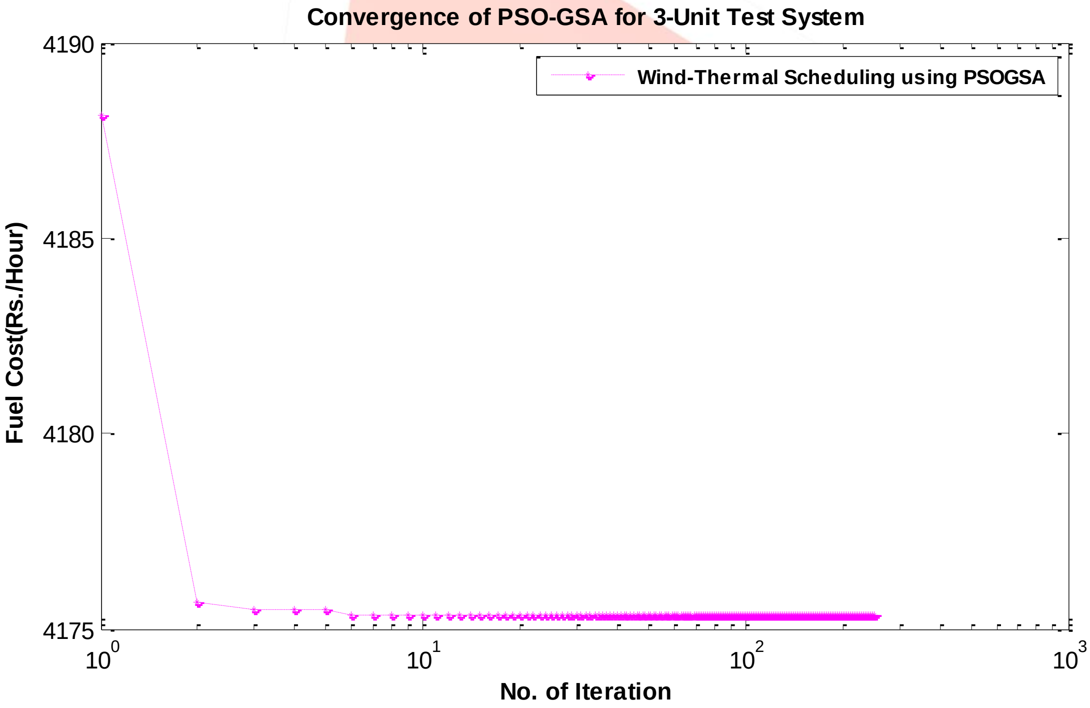


Fig.6.3 (b): Convergence of PSO-GSA for 3- Units System

Table-VII: Wind-Thermal Scheduling for 6-Generating Unit System

Hour	Demand	Pwind	Scheduling of Thermal Units						Power Supplied By Wind Sources	Ploss	Fuel Cost
			P1	P2	P3	P4	P5	P6			
1	1200	200	500.00	69.05	173.13	61.63	138.66	75.82	200	15.15182016	12232.334
2	1180	130	500.00	76.41	138.44	81.35	146.55	120.00	130	15.32806723	12932.241

3	1175	122	500.00	50.81	245.26	55.94	144.54	74.74	122	18.49135158	12948.571
4	1160	130	296.26	200.00	80.00	150.00	200.00	120.00	130	15.02821195	14131.770
5	1155	136	500.00	81.58	229.80	110.04	54.99	60.64	136	18.26950892	12506.456
6	1120	82	500.00	199.72	80.20	122.86	98.74	50.37	82	13.93483799	12861.965
7	1100	94	500.00	101.88	161.52	96.55	88.64	72.69	94	15.02753228	12294.543
8	1050	72.5	267.83	156.85	144.34	104.41	200.00	120.00	72.5	13.62165417	13329.020
9	1200	85.5	500.00	149.75	201.02	113.04	50.26	119.97	85.5	19.27054036	13753.913
10	1188	88.35	500.00	139.04	192.65	79.57	86.68	119.03	88.35	17.76044071	13507.965
11	950	130	184.65	189.73	80.00	150.00	172.81	54.63	130	11.09550363	11083.370
12	870	85.5	172.90	179.82	80.00	149.70	161.93	51.25	85.5	10.42200911	10599.351
									Total Power Loss	**183.4014781**	
									Total Generation Cost	**152181.500**	

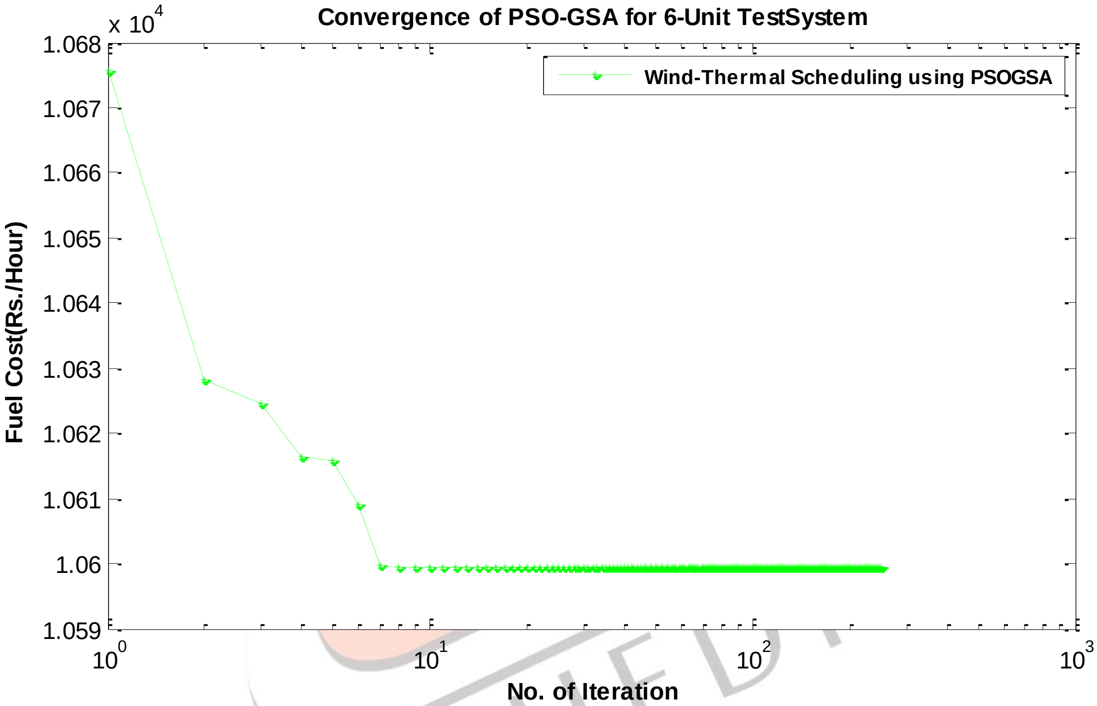


Fig.6.4 Convergence of PSO-GSA for 6-generating unit system

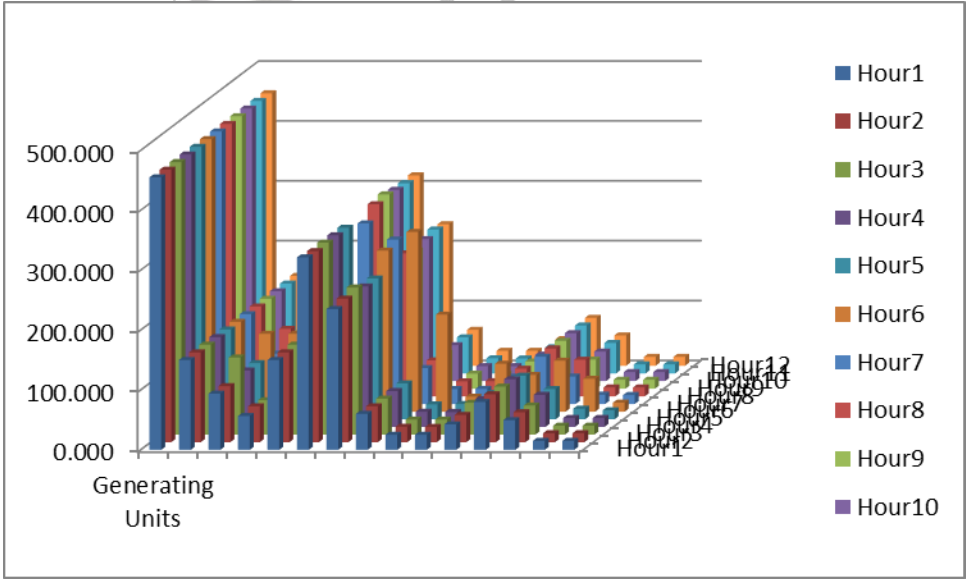


Fig.6.5: Distribution of Load Among various Units for 15-Unit Test system

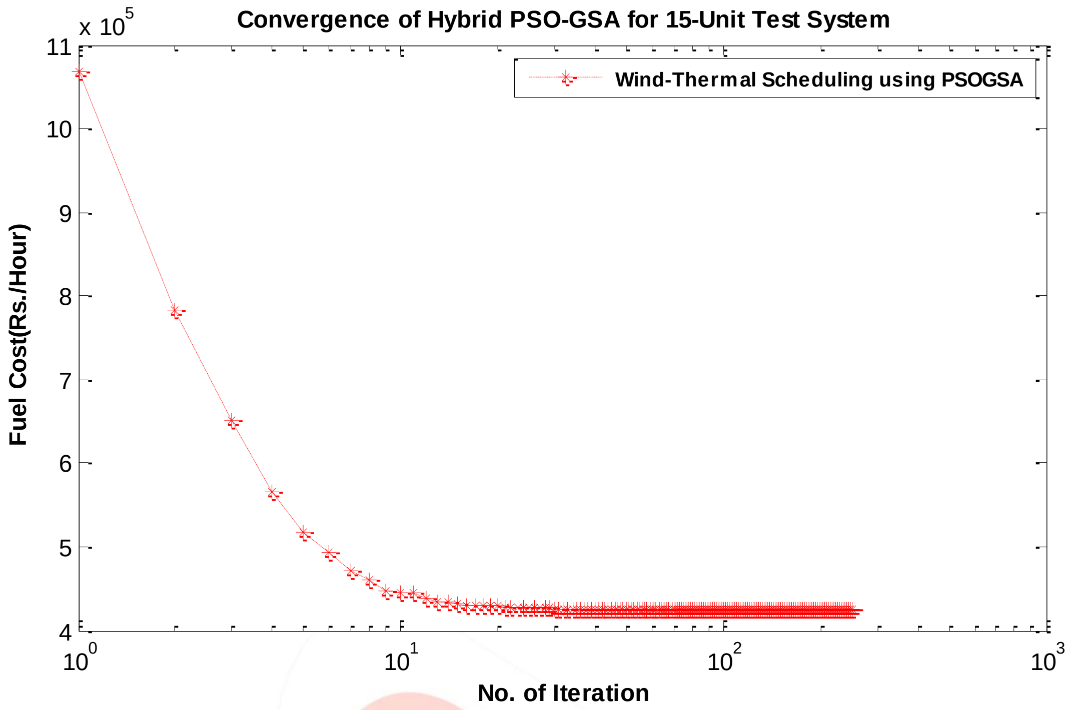


Fig.6.6 Convergence of PSO-GSA for 15-generating unit system

6.3 Achievement of Environment Protection Goal

In order to verify the feasibility and efficiency of the proposed algorithm for wind-thermal scheduling problem for environmental protection goal, the algorithm was tested for two different test cases considering loss coefficients for calculation of Transmission losses. The test System Consist of standard IEEE 14-Bus and IEEE-30 Bus system consisting of 5 and 6-generating unit. The valve point effect is ignored for thermal generating units, while considering wind power for generation scheduling problem. The proposed algorithm is executed with following parameters: m=40 (masses), G is set using Eq.(5.4). where G_0 is set to 100 and α is set to 10, and T is the total number of iterations. Maximum iteration numbers are 250 for these case studies.

Test System-I: This test case study considered IEEE 14-Bus system of five thermal units of generation without effects of valve-point as given Table VIII. The Loss coefficients matrices given in Table-IX are used to calculate the transmission losses. In this case, the load demand is considered for short duration of 8 hours. Wind farm and this system is generalized from a certain region power system in North Korea. The IEEE 14-bus system is shown in **Fig.6.7.** The results of 14-Bus system for GSA algorithm are shown in Fig.6.8(a) and Fig.6.8(b) and results of 14-Bus system for Hybrid PSO-GSA algorithm are shown in Fig.6.10(a) and Fig.6.10(b) and results

Table-VIII: Cost and Emission Coefficient data for 14-Bus test system

Cost and Emission Coefficient data for 14-Bus System							
Fuel Cost Coefficients			Emission Coefficients			P_{min}	P_{max}
a	B	c	α	β	γ		
0.00375	2	0	22.983	-0.90	0.0126	50	250
0.0175	1.75	0	25.313	-0.10	0.02	20	160
0.0625	1	0	25.505	-0.01	0.027	15	100
0.00834	3.25	0	24.900	-0.005	0.0291	10	70
0.025	3	0	24.700	-0.004	0.029	10	60

Table-IX: Loss Coefficient data for 14-Bus test system

Loss Coefficient data for 14-Bus System					
10^-4 x	2.1	8.5	6	2	2
	8	1.8	-6	5.1	2
	6	6	4.8	-1.3	-1.6
	2	5	-1.3	2.18	-2.51
	2	2	-1.6	-2.51	1.4

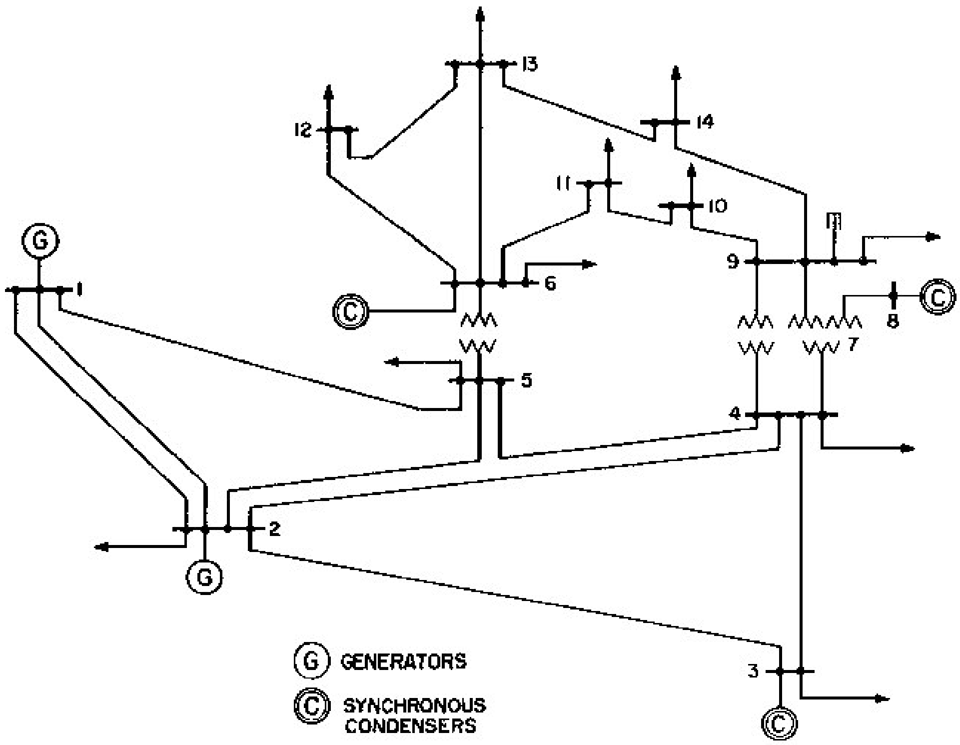


Fig.6.7: IEEE 14-Bus System

Results of 14-Bus System Using GSA

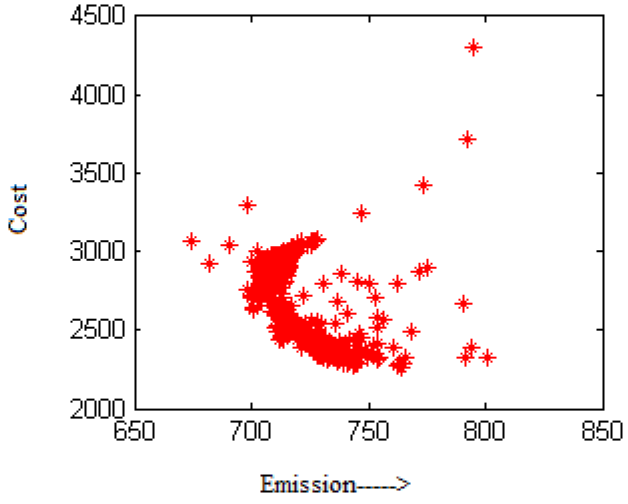


Fig.6.8(a) Emission V/s Cost

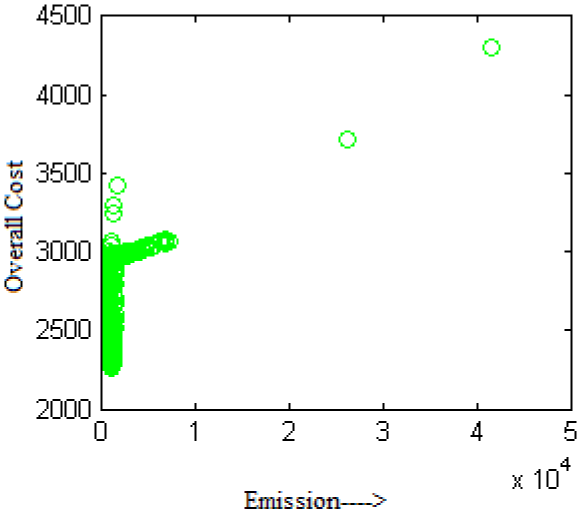


Fig.6.8(b): Emission V/s Overall Cost

Results of 30-Bus System Using GSA

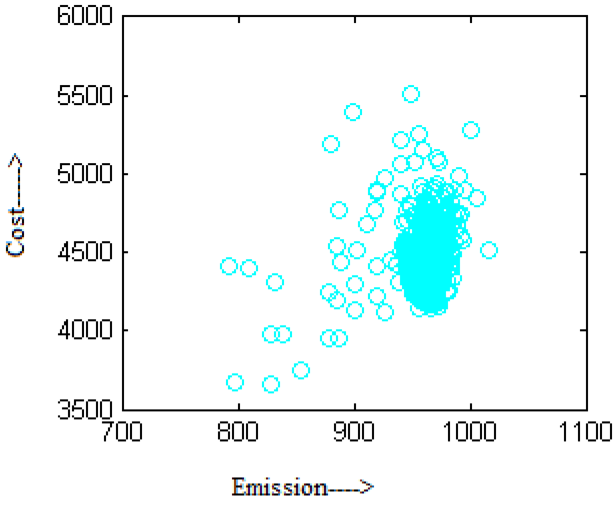


Fig.6.9(a) Emission V/s Cost

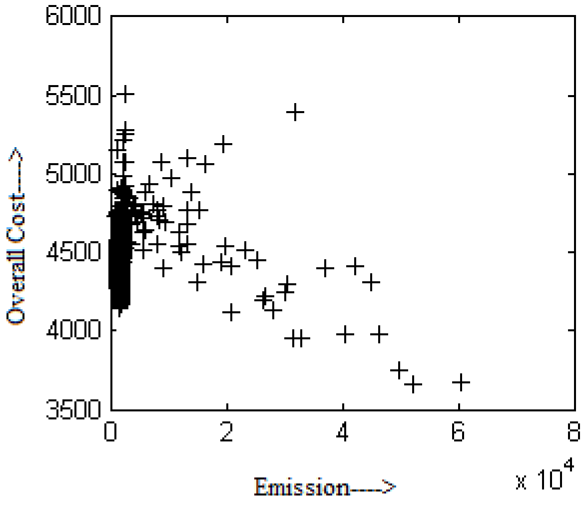


Fig.6.9(b): Emission V/s Overall Cost

Test System-II: This test case study considered IEEE 30-Bus system of five thermal units of generation without effects of valve-point as given Table VIII. The Loss coefficients matrices given in Table-IX are used to calculate the transmission losses. In this case, the load demand is considered for short duration of 8 hours. Wind farm and this system is generalized from a certain region power system in North Korea. The IEEE 14-bus system is shown in **Fig.6.7.** The results of 30-Bus system for GSA algorithm are shown in Fig.6.9(a) and Fig.6.9(b) and results of 30-Bus system for Hybrid PSO-GSA algorithm are shown in Fig.6.11(a) and Fig.6.11(b) and results. The results for Wind-Thermal Scheduling for Load dispatch and Emission dispatch (for 700 MW) for GSA and PSO-GSA algorithm are shown in Table-XXI and Table-XXII.

Table-XIX: Cost and Emission Coefficient data for 30-Bus test system

Cost and Emission Coefficient data for 30-Bus System							
Fuel Cost Coefficients			**Emission Coefficients**			**P_{min}**	**P_{max}**
a	**b**	**C**	**α**	**β**	**γ**		
0.00375	2	0	22.983	-0.90	0.0126	50	200
0.0175	1.75	0	25.313	-0.10	0.02	20	80
0.0625	1	0	25.505	-0.01	0.027	15	50
0.00834	3.25	0	24.900	-0.005	0.0291	10	35
0.025	3	0	24.700	-0.004	0.029	10	30
0.025	3	0	25.3	-0.0055	0.0271	12	40

Table-XX: Loss Coefficient data for 30-Bus test system

Loss Coefficient data for 30-Bus System						
10^-4 x	2	1	3	-1.1	1.2	1.3
	1.09	1	1	-1.9	5	8
	3	1	3.14	-1.55	-5	-2
	-0.1	-1	-1.5	2.98	5.5	1.1
	1.2	5	-5	5.5	1.3	5
	1.3	8	-2	1.14	5	1.2

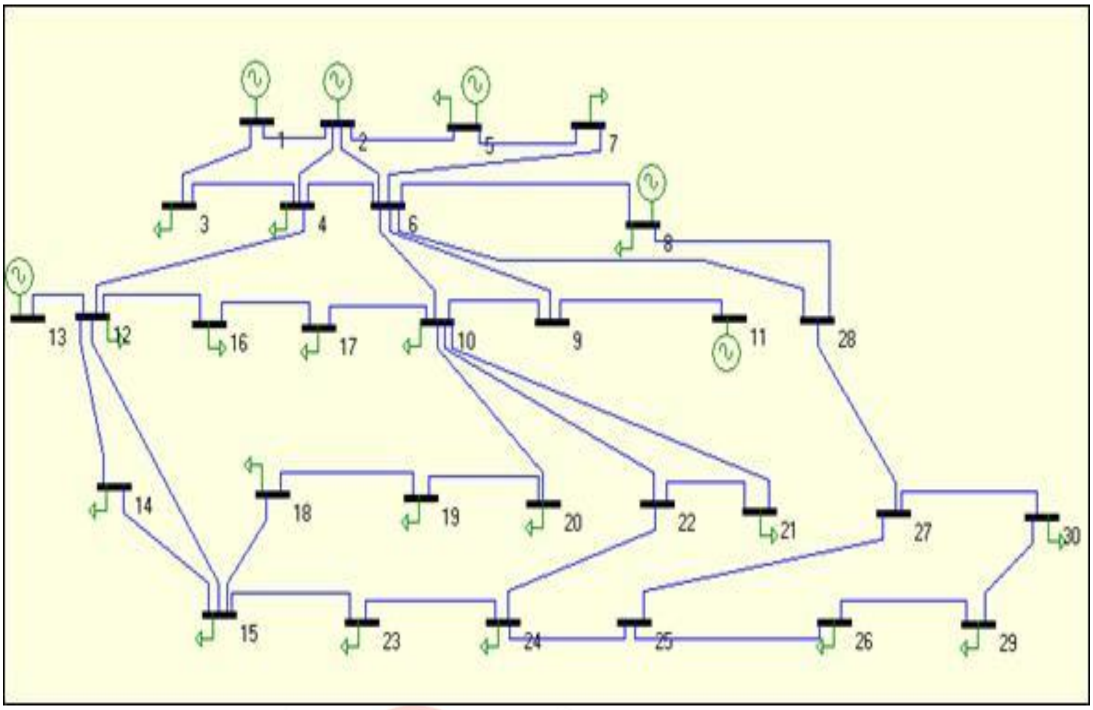
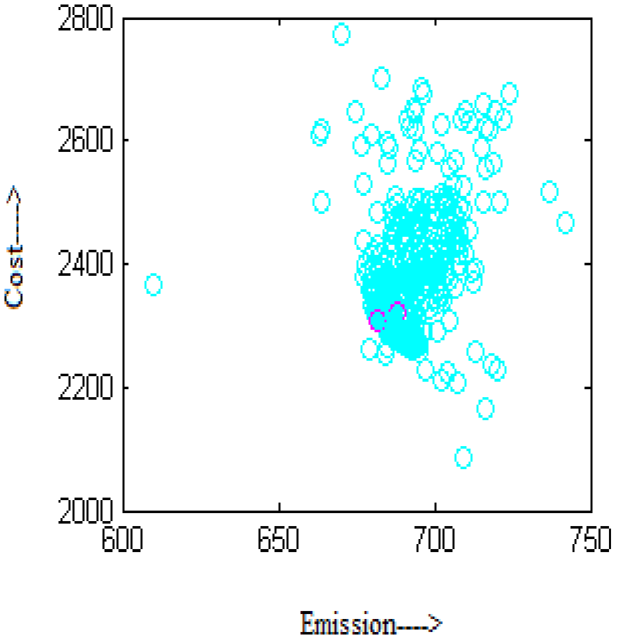


Fig.6.8© : IEEE 30-Bus System

Results of 14-Bus System Using Hybrid PSO-GSA



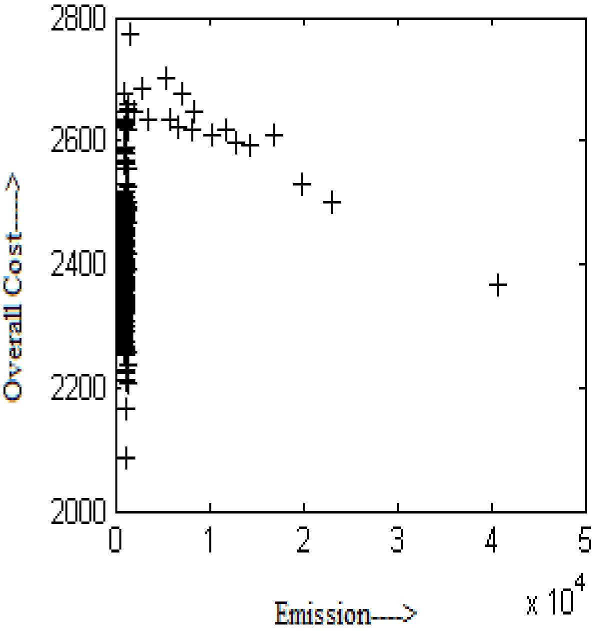


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Fig.6.10(a) Emission V/s Cost **Fig.6.10(b): Emission V/s Overall Cost**

Results of 30-Bus System Using Hybrid PSO-GSA

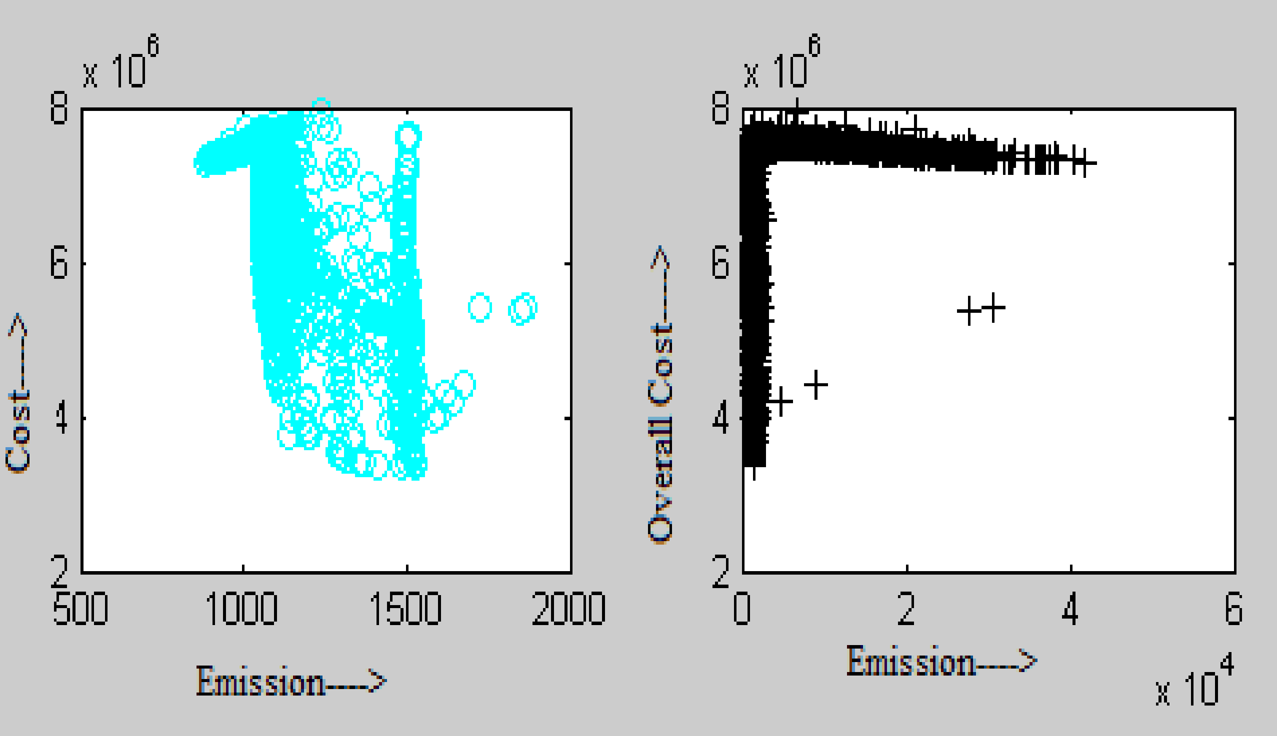

Fig.6.11(a) Emission V/s Cost **Fig.6.11(b): Emission V/s Overall Cost**

COMPARISON OF RESULTS for GSA and PSO-GSA algorithm

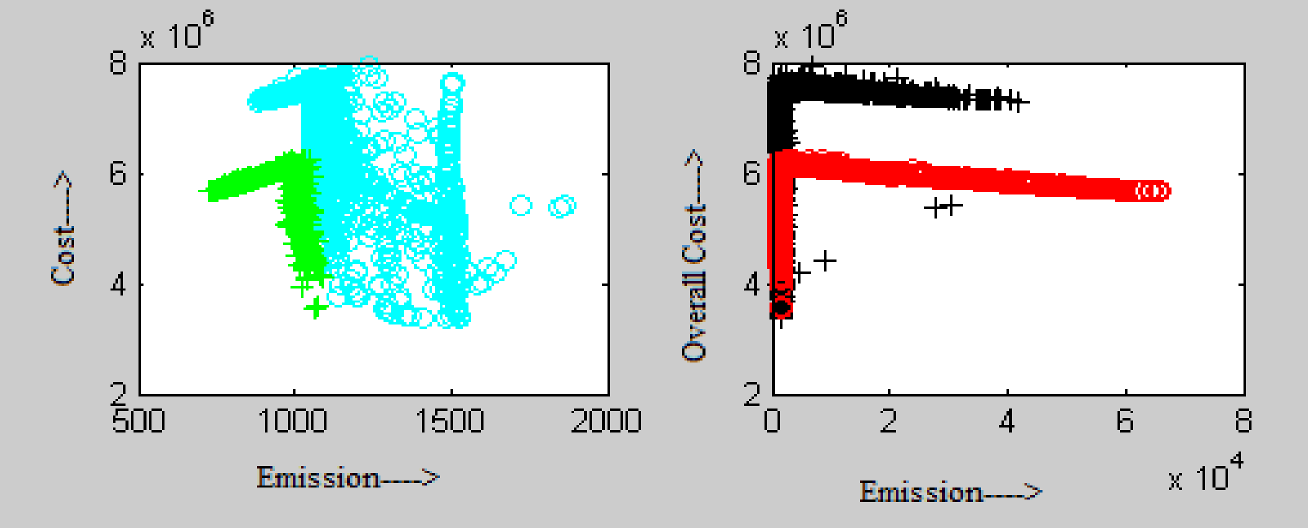

Fig.6.12: Comparison of Results for 30-Bus System for GSA and PSO-GSA

Table-XXI: Wind-Thermal Scheduling (Economic load dispatch) results (Load Demand=700 MW)

Methods	Fuel Cost(Rs./h)	Emission(Kg/h)	Losses(MW)	Execution Time(Sec.)
Classical Method	37.288.70	495.348	26.57	0.25
Real Coded Genetic Algorithm(RGA)	37137.96	489.559	23.124	14.61
Hybrid Genetic Algorith(HGA)	37137.96	489.559	23.124	1.21
PSO	36921.5274	494.9329	19.164	1.16
Proposed GSA	36912.326	498.683	19.405	0.54
Proposed PSO-GSA	36912.277	492.783	18.998	0.38

Table-XXII: Wind-Thermal Scheduling (Emission dispatch) results (Load Demand=700 MW)

Emission Dispatch Results for Wind Thermal Scheuling[Load Demand=700 MW]				
Methods	**Fuel Cost(Rs./h)**	**Emission(Kg/h)**	**Losses(MW)**	**Execution Time(Sec.)**
Classical Method	38364.5	437.966	20.24	0.26
Real Coded Genetic Algorithm(RGA)	38186.4	435.075	17.366	14.61
Hybrid Genetic Algorith(HGA)	38186.4	435.075	17.366	1.21
PSO	38099.352	434.138	16.5517	1.32
Proposed GSA	38081.946	433.178	16.552	0.54
Proposed PSO-GSA	38081.943	433.172	16.55	0.39

CONCLUSION

In this paper, the test system contains 3, 6 and 15 thermal generating units and three wind farms and the test systems are generalized from a certain region power system in North Korea and South China. The scheduling period for 3 and 6 units system is divided into 8 hours and for 15 units test system, it is divided into 12 hours. The operating parameters of thermal units are listed in **Table-I, II, III, IV, V** and **VI** and the load demand and the wind power output predicted are shown in **Table-VII, Table-VIII** and **Table-IX** for 3, 6 and 15-units test system respectively. The MATLAB simulation software is used to obtain the corresponding results. It has been found that optimal fuel cost for three generating unit test system is **Rs. 32607.4217** and power Loss **is 214.7802 MW.** The optimal fuel cost for six generating unit test system is **Rs. 158955.7171** and power Loss **is 171.6144939 MW.** The Scheduling pattern of 15 units generating system is shown in Fig.3. The convergence of Gravitational Search Algorithm for 3 and 6 units test system are shown in Fig.4. and For 15-units test system, convergence curve is shown in Fig.5.

Table-XXI and Table-XXII depicts the results of Emission dispatch for 700 MW demand using GSA and PSO-GSA algorithm. From Table-XXII, it is clear that Emission Dispatch using GSA algorithm is 433.178 Kg/h and Using Hybrid PSO-GSA algorithm, it is 433.172 Kg/h.

Hence to achieve the environmental protection goal, the Hybrid PSO-GSA algorithm yields much better results as compared to other algorithms. Also, the simulation time for PSO-GSA is much better than PSO, GSA and other well known algorithms.

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