International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 4 Issue 4, April-2015, pp: (317-330), Impact Factor: 1.252, Available online at: www.erpublications.com

Short-Term Wind-Thermal Scheduling of Electric Power System using Gravitational Search 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 Gravitational Search 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.

Keywords: Environmental Protection, Gravitational Search Algorithm, Wind-Thermal Scheduling (WTS).

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1. INTRODUCTION

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. 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. 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 Gravitational Search 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 Gravitational Search Algorithm 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:

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

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:

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

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:

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

4. GRAVITATIONAL SEARCH ALGORITHM FOR WIND THERMAL SCHEDULING

Rashedi et. al. proposed one of the newest heuristic algorithms, namely Gravitational Search Algorithm (GSA) in 2009. GSA is based on the physical law of gravity and the law of motion [35,36]. The gravitational force between two particles is directly proportional to the product of their masses and inversely proportional to the square of the distance between them [34]. GSA a set of agents called masses has been proposed to find the optimum solution by simulation of Newtonian laws of gravity and motion [35]. In the GSA, consider a system with m masses in which position of i^{th} mass is defined as follows:

$$X_i = \left(x_i^1, \ldots, x_i^d, \ldots, x_i^n\right), \quad i = 1, 2, \ldots, m \tag{6}$$

where x_i^d is position of the i^{th} mass in the d^{th} dimension and n is dimension of the search space. At the specific time 't' a gravitational force from mass 'j' acts on mass 'i', and is defined as follows [34, 36]:

$$F_{ij}^d(t) = G(t)\frac{M_{pi}(t) x M_{aj}(t)}{R_{ij}(t) + \varepsilon}\left(x_j^d(t) - x_i^d(t)\right) \tag{7}$$

where M_i is the mass of the object i, M_j is the mass of the object j, G(t) is the gravitational constant at time t, $R_{ij}(t)$ is the Euclidian distance between the two objects i and j, and ε is a small constant.

The total force acting on agent i in the dimension d is calculated as follows:

$$F_i^d(t) = \sum_{j=i\ \ j\neq i}^{m} rand_j F_{ij}^d(t) \tag{8}$$

Where, $rand_j$ is a random number in the interval [0,1]. According to the law of motion, the acceleration of the agent i, at time t, in the d^{th} dimension, $a_i^d(t)$ is given as follows:

$$a_i^d(t) = \frac{F_i^d(t)}{M_{ii}(t)} \tag{9}$$

Furthermore, the next velocity of an agent is a function of its current velocity added to its current acceleration. Therefore, the next position and the next velocity of an agent can be calculated as follows [36]:

$$v_i^d(t+1) = rand_i\, x\, v_i^d(t) + a_i^d(t) \tag{10}$$

$$x_i^d(t+1) = x_i^d(t) + v_i^d(t+1) \tag{11}$$

Where, $rand_i$ is a uniform random variable in the interval [0, 1]. The gravitational constant, G, is initialized at the beginning and will be decreased with time to control the search accuracy. In other words, G is a function of the initial value (G0) and time (t):

$$G(t) = G(G_0, t) \tag{12}$$

$$G(t) = G_0 e^{-\alpha \frac{t}{T}} \tag{13}$$

The masses of the agents are calculated using fitness evaluation. A heavier mass means a more efficient agent. This means that better agents have higher attractions and moves more slowly. Supposing the equality of the gravitational and inertia mass, the values of masses is calculated using the map of fitness. The gravitational and inertial masses are updating by the following equations [34,36]:

$$m_i(t) = \frac{fit_i(t) - worst(t)}{best(t) - worst(t)} \tag{14}$$

$$M_i(t) = \frac{m_i(t)}{\sum_{j=1}^{m} m_j(t)} \tag{15}$$

where $fit_i(t)$ represents the fitness value of the agent i at time t, and the best(t) and worst(t) in the population respectively indicate the strongest and the weakest agent according to their fitness route. For a minimization problem:

$$best(t) = \min_{j \in \{1,\ldots,m\}} fit_j(t) \tag{16}$$

$$worst(t) = \max_{j \in \{1,\ldots,m\}} fit_j(t) \tag{17}$$

5. ALGORITHM AND FLOW CHART FOR 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* $i = 1,2,\ldots,m$.

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

Step 6. Calculation of acceleration and velocity.

Step 7. Updating agents' position.

Step 8. Repeat step 3 to step 7 until the stop criteria is reached.

Step 9. Stop.

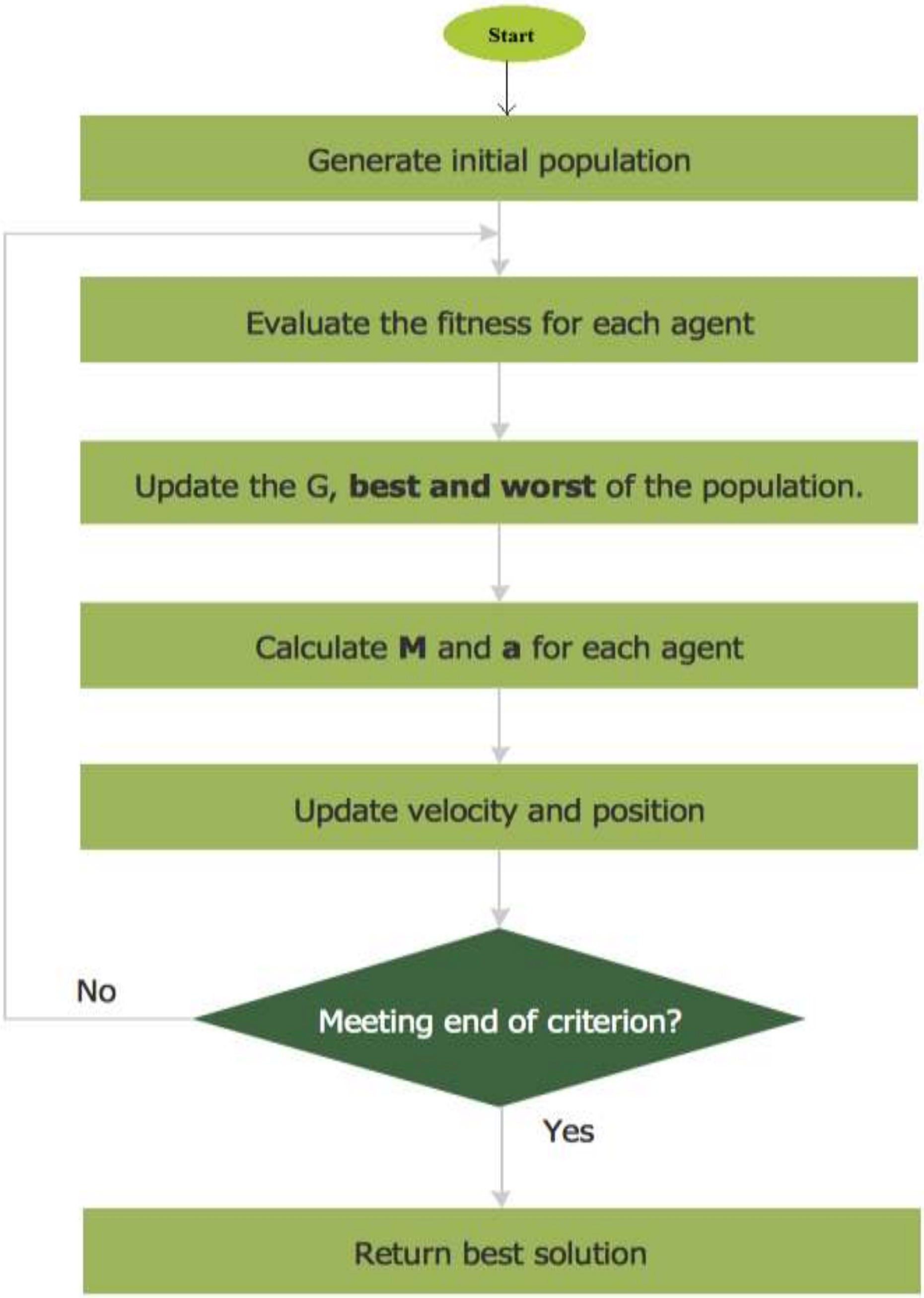

Fig.2: Flow Chart of Gravitational Search Algorithm for Wind-Thermal Scheduling

6. 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.(12) and (13). 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 of three thermal units of generation without effects of valve-point as given Table I. The Loss coefficients matrices given in Table-II 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.

Table-I: Test data for Three Generating Unit System

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 System-II: This test case study considered of six thermal units of generation without effects of valve-point as given Table III. The Loss coefficients matrices given in Table-IV 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 South China.

Table-III: Test data for Six-Generating Unit System

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 for 6-unit test system

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 System-III: This test case study considered of fifteen thermal units of generation without effects of valve-point as given Table V. The Loss coefficients matrices given in Table-VI are used to calculate the transmission losses. In this case, the load demand is considered for short duration of 12 hours. Wind farm and this system is generalized from a certain region power system in North Korea.

Table-V: Test data for 15-Generating Unit System

C0	C1	C2	P_{min}	P_{max}
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

International Journal of Enhanced Research in Science Technology & Engineering, ISSN: 2319-7463
Vol. 4 Issue 4, April-2015, pp: (317-330), Impact Factor: 1.252, Available online at: www.erpublications.com

Table-VI: Loss Coefficient Matrices for 15-Unit Test system

	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
B	-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

7. 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.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-VII: Wind-Thermal Scheduling for 3-Generating Unit System

Hour	Demand	P_{wind}	Scheduling of Thermal Units			Power Supplied By Wind Sources	P_{loss}	Fuel Cost
			P1	P2	P3			
1	350	30	59.28498	189.7524	100	30	29.0374	3806.456
2	380	40	88.02416	121.409	154.5448	40	23.978	3931.773
3	400	23	85.44908	129.0023	191.8779	23	29.3293	4288.347
4	420	34.3	87.53005	110.4553	217.3835	34.3	29.6689	4370.777
5	360	33	73.408	106.3483	168.6003	33	21.3566	3797.525
6	375	21.58	79.13333	101.4446	197.4547	21.58	24.6126	4051.921
7	385	20.5	80.57659	112.51	198.055	20.5	26.6416	4161.117
8	390	24	82.40665	156.0358	157.7133	24	30.1558	4199.506
						Total Power Loss	214.7802 MW	
						Total Generation Cost	32607.4217	

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

Hour	Demand	P_{wind}	Scheduling of Thermal Units						Power Supplied By Wind Sources	P_{loss}	Fuel Cost
			P1	P2	P3	P4	P5	P6			
1	1200	200	500.00	71.20	154.99	135.14	93.66	60.86	200	15.850	12276.385
2	1180	130	328.13	200.00	127.81	150.00	160.55	101.08	130	15.234	15299.421
3	1175	122	435.99	170.82	80.00	135.11	160.78	86.52	122	14.404	14833.077
4	1160	130	363.61	178.97	80.00	150.00	176.65	96.81	130	14.571	14242.672
5	1155	136	500.00	150.44	161.44	95.35	69.54	60.72	136	15.502	12502.184
6	1120	82	366.78	176.48	110.49	137.88	155.02	108.08	82	14.464	15035.872
7	1100	94	500.00	94.19	124.35	127.28	69.95	105.04	94	14.808	12405.028
8	1050	72.5	319.59	175.68	80.00	150.00	171.01	96.00	72.5	13.491	13414.772
9	1200	85.5	500.00	156.41	129.53	116.98	137.18	90.83	85.5	16.427	13721.186
10	1188	88.35	500.00	126.19	195.10	100.13	119.63	76.38	88.35	17.783	13456.732
11	950	130	198.49	167.90	80.00	122.65	161.14	100.43	130	9.747	11145.544
12	870	85.5	168.48	191.76	80.00	142.06	130.55	81.67	85.5	9.332	10622.842
Total Power Loss										171.6144939	
Total Generation Cost										158955.7171	

Table- IX: Wind-Thermal Scheduling for 15-Generating Unit System

Scheduling of 15-Geneating Units Test System for 1-6 Hours						
Hour	1	2	3	4	5	6
P1	455.000	455.000	455.000	455.000	455.000	455.000
P2	333.276	309.431	287.395	318.492	307.329	327.785
P3	68.875	80.233	76.724	72.748	55.495	80.350
P4	77.051	76.283	63.314	64.813	88.654	64.265
P5	197.595	223.652	281.382	264.983	180.500	247.649
P6	304.834	329.495	316.547	253.479	326.600	273.291
P7	303.199	303.558	308.628	297.207	173.092	334.026
P8	77.570	63.153	104.533	97.237	100.184	64.887
P9	59.793	75.371	74.753	53.650	28.580	61.517
P10	54.349	63.162	56.073	79.734	85.834	71.552
P11	38.115	53.832	49.296	52.038	71.434	50.536
P12	64.019	49.770	52.640	47.727	68.060	57.716
P13	50.504	53.214	45.822	51.759	39.988	61.912
P14	34.968	32.530	33.829	34.584	24.002	39.962
P15	24.619	29.005	34.610	35.980	32.330	35.143
Power Supplied By Wind Sources	173.000	160.000	152.000	160.000	180.000	230.000
Load Demand	1800.000	1825.000	1845.000	1890.000	1920.000	2000.000

Scheduling of 15-Geneating Units Test System for7-12 Hours						
Hour	**7**	**8**	**9**	**10**	**11**	**12**
P1	455.000	455.000	455.000	455.000	455.000	455.000
P2	285.315	303.628	321.996	297.225	284.427	173.277
P3	67.392	69.200	81.670	83.240	67.707	42.234
P4	88.871	72.671	76.149	83.367	67.544	90.783
P5	221.167	255.825	260.598	236.531	258.763	188.278
P6	346.983	299.500	272.641	277.422	300.696	384.184
P7	207.511	251.532	303.464	329.839	297.692	235.030
P8	80.239	60.000	81.499	67.480	60.000	78.528
P9	85.952	88.829	79.644	75.092	72.903	78.939
P10	45.846	67.144	82.728	76.056	58.718	49.146
P11	60.303	45.572	52.724	51.237	47.511	75.286
P12	37.602	54.436	51.245	59.354	47.168	39.767
P13	49.452	58.382	51.806	49.399	50.335	52.537
P14	28.842	35.682	32.046	37.134	34.866	40.178
P15	34.558	28.345	38.399	34.714	27.260	16.291
Power Supplied By Wind Sources	250.000	300.000	270.000	180.000	240.000	280.000
Load Demand	2050.000	2500.000	1800.000	1900.000	1730.000	1600.000

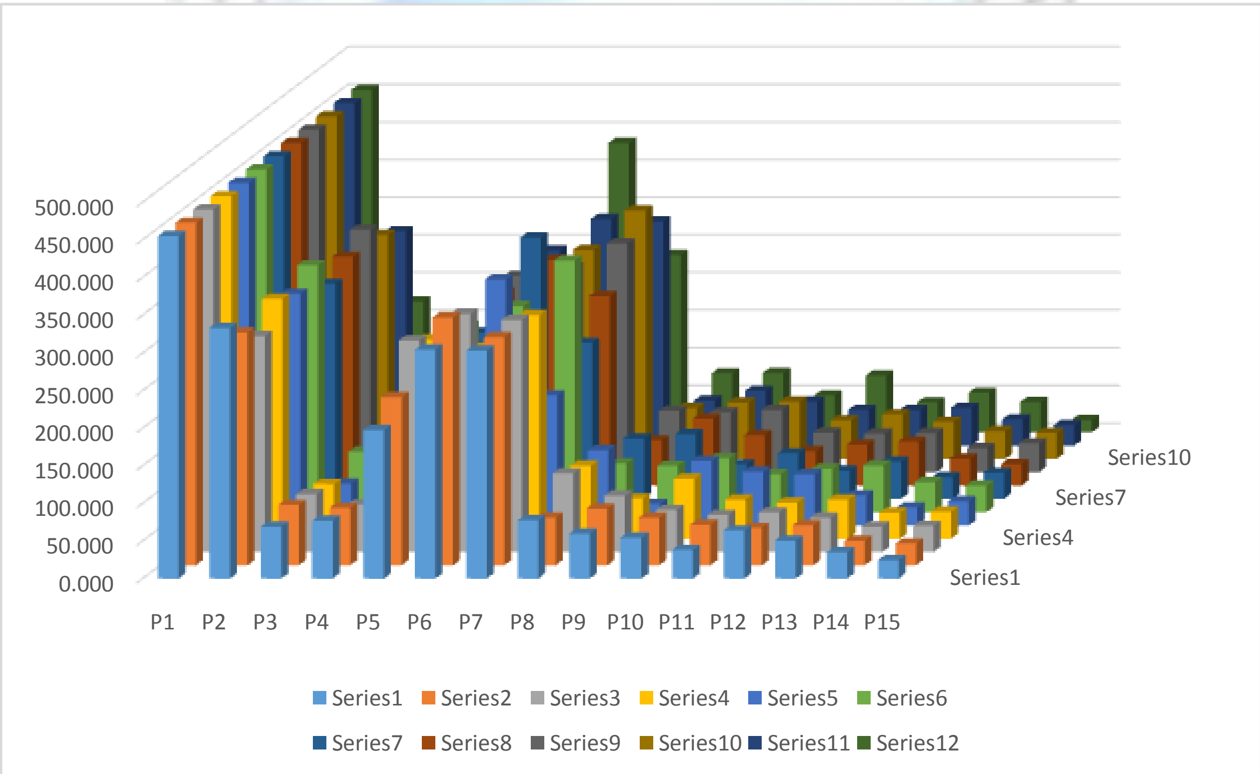

Fig.3: Wind-Thermal Scheduling Pattern for 15-Units Test System

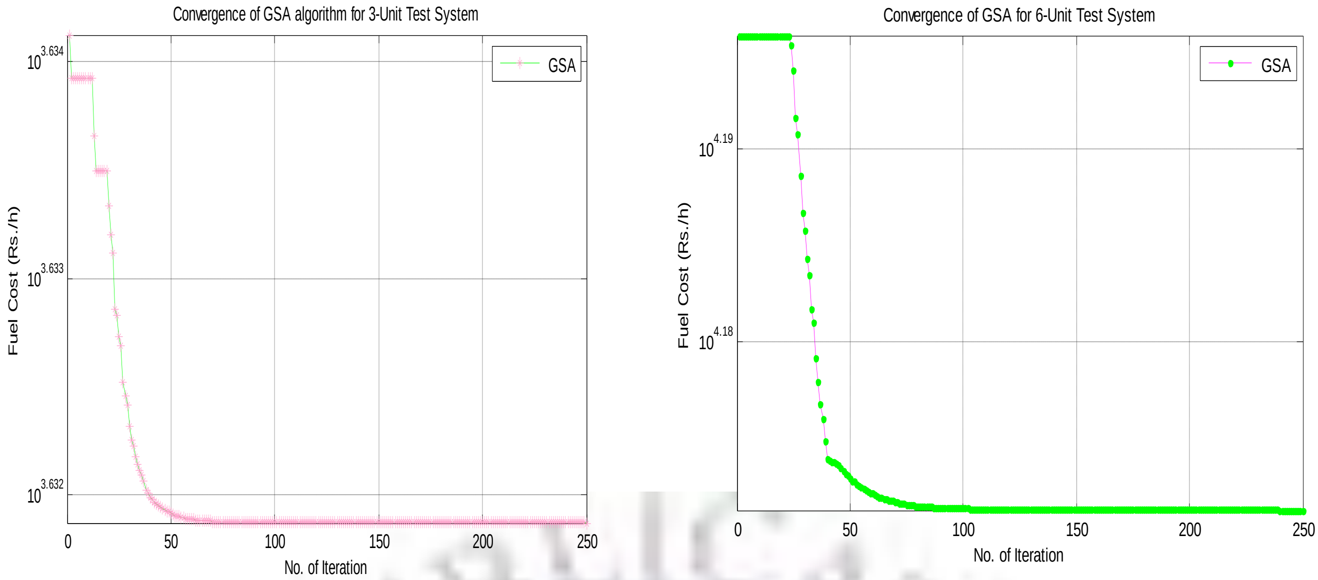

Fig.4: Convergence of GSA algorithm for 3 and 6-Generating Unit Systems

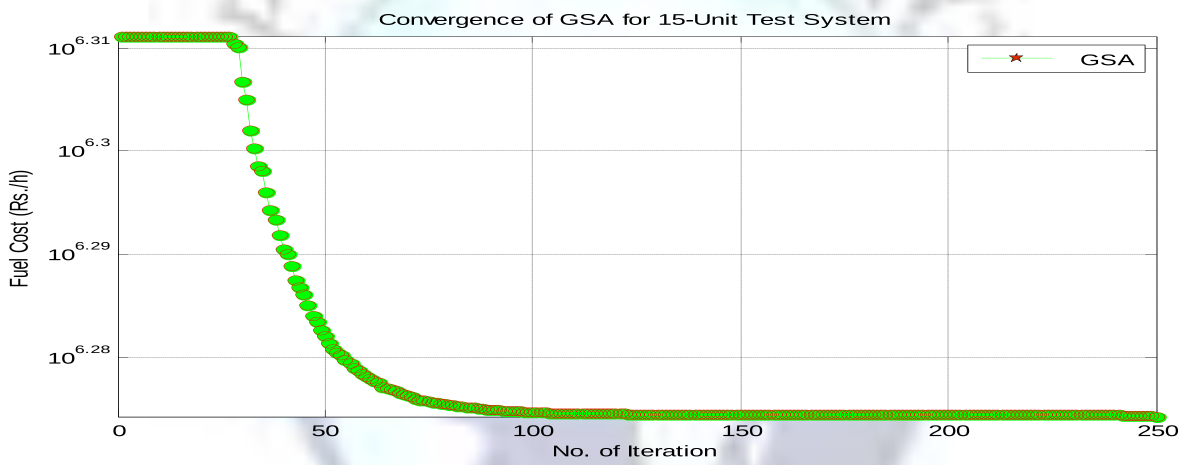

Fig.5: Convergence of GSA algorithm for 15-Generating Unit System

ACRONYM USED

C_{0n}, C_{1n} and C_{2n} are cost coefficients.

P_{Demand} is Load Demand.

P_{Loss} is power transmission Loss.

P_{Wind} is the available Wind Power

U is the number of electric generating units.

P_n is real power generation and will act as decision variable.

P_{g_n} and P_{g_m} are the real power generations at the nth and mth buses respectively.

B_{nm} is the loss coefficients which are constant under certain assumed conditions and U is the number of electric generating units.

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