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GENERATION SCHEDULING OF THERMAL AND PV GENERATING UNITS USING HPSO

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ABSTRACT

In this paper economic dispatch with PV generation is obtained using a hybrid version of continuous and binary particle swarm optimization. Society is demanding cheap electricity and eco-friendly resources. Therefore, it's a challenge to achieve reliable and cheap electricity with depletion of fossil fuel reserves and rapidly increasing fuel price. These increased concerns about renewable energy sources in the energy market as an option. The main objective is to minimize the operating cost of thermal generating units with scheduling for sharing of different photo-voltaic generating units to fulfill the load demand. This is a mixed integer problem in which PV generating units are either ON/OFF with the generation schedule of thermal power plants. The hybrid particle swarm optimization (HPSO) technique is used in a way to minimize the total generating cost and satisfy equality and inequality constraints. In this paper, the test is conducted for 13 PV plants and six thermal units. HPSO is mainly for providing optimal solutions of the problem and simulation results have been computed in FORTRAN 90.

Keywords: *Economic load dispatch (ELD), Renewable Energy Sources, Photo-voltaic generating plants, Particle swarm optimization (PSO).*

I. INTRODUCTION

With the rapid development of alternative energy technologies, the electric power network can be made of several renewable energy resources. In terms of operational costs and dependability, energy resources vary considerably. In this study, the problem is the Economic Dispatching (ED) of hybrid power systems including solar thermal energies. Renewable energy resources depend on the data of the climate such as the solar radiation and the temperature for solar thermal energy. The resolution considers fuel costs as well as the reduction of polluting gas emissions. The rise of the energy crisis, as well as the excessive increase in consumption, has compelled manufacturing companies to invest in renewable energy sources. However, this production presents potential technical challenges for their integration into the electric system.

The economic dispatch [1] is a significant function in the modern energy system. It consists of programming correctly the production of power in order to reduce the operational cost.

Recently, different heuristic approaches listed in literature have been shown to be efficient with significant performance, such as evolutionary programming (EP), simulated annealing (SA), Tabu search (TS), pattern search (PS), Genetic algorithm (GA), Differential evolution (DE), Ant colony optimization, neural network and particle swarm optimization (PSO)[2-6].

This paper researches power system economic dispatch including solar generating units. The model of economic dispatch including solar power is established with the lowest generating cost of the total power system as the objective function.

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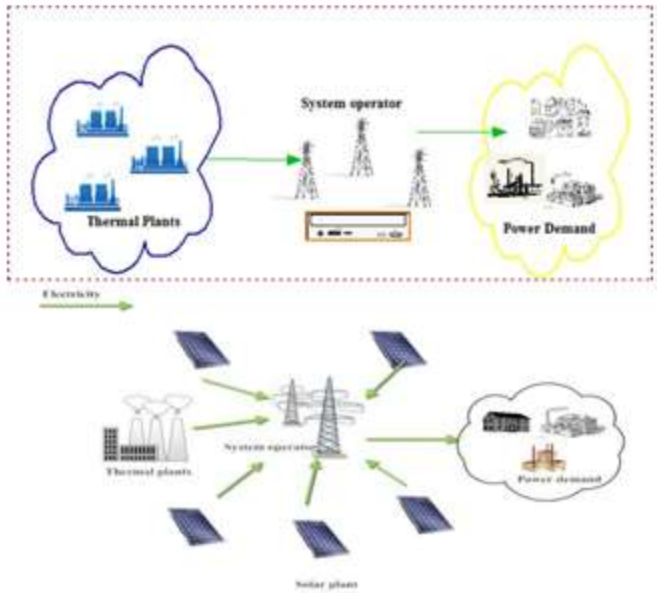

Fig.1. conventional system and modern power system with generating units

The cost of generation of electric energy depends mostly on the purchasing cost, installation cost, cost of erection of equipment and auxiliary, fuel cost and miscellaneous cost like repairing cost, labor cost etc. The fixed cost is determined by the investment cost of the plant's financial rates, regardless of the quality of energy generated, whereas the variable cost covers fuel expenses, labor charges, supervision, and so on. Generation cost includes both fixed and operating cost.

Recently, different heuristic approaches listed in literature have been shown to be efficient with significant performance, such as evolutionary programming (EP), simulated annealing (SA), Tabu search (TS), pattern search (PS), Genetic algorithm (GA), Differential evolution (DE), Ant colony optimization, neural network and particle swarm optimization (PSO)[2-6].

Particle swarm optimization, an optimum global search technique provides effective and easier computational implementation with reduced memory requirement. PSO has wider global searching capability at the commencement of the run and effective local searching abilities near the end of the run.[5]. Hocaoglu et. al. [2] presented the wind–photovoltaic hybrid system (WPHS). Yang et. al. [3] presents a novel hybrid unit commitment framework, which considers a wide range of scenarios in renewable generations and demand side management. Perera et. al. [4] considers distributed generation using grid-tied electrical hubs, which consist of Internal Combustion Generator (ICG), non-dispatchable energy sources and energy storage for providing the electricity demand in Sri Lanka for this study. Perera et. al. [5] has proposed hybrid energy systems considering multi objective optimization with a multi-criterion decision making (MCDM) technique. Sheble [6] presents a real time economic dispatch algorithm suitable for on-line generation control and for study programs. Lo et. al. [7] has used battery energy storage systems that promised savings for both the utility and the customer. Yorino et al. [8] proposed an alternative dynamic ELD method that satisfies the general requirements for real-time use in a future power system. Using a layered approach and restricted resources, Bustos et al. [9] created an optimization model with cost and reliability goal functions for the design and operation of micro-networks. Nikmehr et. al. [10] proposed a probabilistic analysis of optimal power dispatch considering economic aspects in Microgrids (MGs) environment with technical constraints. Khan et al. [11] proposed a combined emission economic dispatch model for a solar photovoltaic integrated power system with various solar and thermal producing units.

In this paper, optimal scheduling of thermal and PV generating units is obtained i.e. ON/OFF status of PV and generation schedule of thermal units. The constraints for the scheduling are satisfied with the help of a swarm based technique, hybrid PSO. The test system is applied on six thermal and thirteen PV generating units. The problem solutions and simulation results were calculated in FORTRAN 90.

This paper is organized as follows: Section II describes the mathematical formulation of optimization models. Section III presents a brief overview of Hybrid Particle Swarm Optimization. Section IV involves the modelling of a single test system. Section V contains the conclusion, which demonstrates the problem's possible solution and future work.

II. MATHEMATICAL FORMULATION OF OPTIMIZATION MODEL

This problem is coordination of different generating units having thermal and solar PV generations. Economic Dispatch problem is to determine the generated power of all on-line generating units which minimize the total operating cost of the system, while satisfying equality and inequality constraints.
The ED problem can be formulated as:

$$Min\, F_{st} = \sum_{i=1}^{n} \left(F_i (P_i) \right) \tag{1}$$

The minimum fuel cost of i^{th} unit is formulated as:

$$F_C(P_i) = \begin{pmatrix} a_i P_i^2 + b_i P_i + C_i + e_i \times \sin \\ \left(f_i \times \left(P_{gi_{min}} - P_{gi} \right) \right) \end{pmatrix} \$/h \tag{2}$$

Subject to:

a) Equality constraints

$$\left(\left(\sum_{i=1}^{n} P_{gi} \right) - P_D \right) = 0 \tag{3}$$

b) Inequality constraints:

$$P_{gi_{min}} \le P_{gi} \le P_{gi_{max}} \tag{4}$$

$$Min\, F_C = \sum_{i=0}^{n} \begin{pmatrix} a_i P_i^2 + b_i P_i^2 + c_i + e_i \times \\ Sin\left(f_i \times \left(P_{gi_{min}} - P_{gi} \right) \right) \end{pmatrix} \$/h \tag{5}$$

The power generated by solar plant is calculated as:

$$P_{gs} = P_r \left\{ 1 + \left(T_{ref} - T_{amb} \right) \times \alpha \right\} \times \frac{S_i}{1000} \tag{6}$$

The solar share is calculated for m generating units taking part in the dispatch:

$$E_{SS} = \sum_{j=1}^{m} P_{gsj} \times U_{gsj} \quad (7)$$

The objective function of solar share and total available solar power to harness the maximum benefit of solar availability, taking into account the cost minimization, formulation of the objective function is as below:

$$Min\ F_T = F_C(P_i) + F_{SS}(P_i) \quad (8)$$

Subject to:

$$P_D - \sum_{i=1}^{n} P_{gi} - \sum_{j=1}^{m} P_{gsj} \times U_{gsj} = 0 \quad (9)$$

$$P_{gi_{\min}} \le P_{gi} \le P_{gi_{\max}}$$
(10)

III. PARTICLE SWARM OPTIMIZATION

PSO is a metaheuristic technique aiming at obtaining satisfactory results in practical scheduling problems. The velocities of particles in PSO are updated using the global best value and personal best experience of the particle i.e. local best value and is given below:

$$V_{s,i}^{k+1} = \begin{bmatrix} w \times V_{s,i}^{k} + C_1 \times ran() \times (\mu_{s,i}^{best} - \mu_{s,i}^{k}) \\ + C_2 \times ran() \times (\mu_i^{Gbest} - \mu_{s,i}^{k}) \end{bmatrix} \quad (11)$$

Where, w represents the inertia weight. The inertia weight was introduced by Shi and Eberhart controls the convergent behavior and momentum of particles by weighing contribution to the previous velocity. It is expressed as:

$$w = w^{\max} - (w^{\max} - w^{\min}) \times IT / IT_{\max} \quad (12)$$

Thus, positional coordinates of each of the particle in swarm is expressed as:

$$\mu_{s,i}^{k+1} = V_{s,i}^{k+1} + \mu_{s,i}^{k} \quad (13)$$

A set of coefficients contained in the model of the PSO algorithm, to control the system's convergence tendencies. Constriction coefficients can prevent explosion due to high values of C1, C2, and w.

BPSO

Binary version of PSO is used for binary decision variables. The sigmoid function is used Eq. 4 to scale velocities between 0 and 1, which is given as:

$$sig(v_i^{k+1}) = \frac{1}{1 + e^{v_i^{k+1}}} \quad (14)$$

Updating the position as follows:

$$\mu_i^{k+1} = \begin{cases} 1, & \text{if } ran() < sig(v_i^{k+1}) \\ 0, & \text{otherwise} \end{cases} \qquad (15)$$

///……….................HPSO method......................////

Initialize the parameter of PSO.

For it = 1: IT_{max}

$$v_{S,i}^{k+1} = w \times v_{S,i}^{k} + C1 \times ran() \times (\mu_{S,i}^{best} - \mu_{S,i}^{k}) + C2 \times ran() \times (\mu^{Gbest} - \mu_{S,i}^{k})$$

$$\mu_{s,i}^{k+1} = v_{s,i}^{k+1} + \mu_{s,i}^{k}$$

F^{it} //evaluate and comparison of objective function for all particles

Update the personal and global best location corresponding to minimum objective function

If (Ran < 0.5)
Then
Gbest remains same
ELSE
Gbest is updated with new random value
End if
End for

FIG. 2 Pseudo code of hpso method

Overview of Hybrid PSO

In PSO when the search process reaches the local search area then convergence is slow for exploitation and does not find the best solution. So hybrid PSO (HPSO) comes into account to overcome the limitation of PSO to find optimum solution. To increase the search ability of technique by applying probability i.e. random number greater than 0.5 then compare random global best with updated. According to the above discussion, PSO explores more areas at the time of starting. Then the global best is updated in HPSO as shown in fig2.

F_T	Objective function to be is minimized.
Fc (Pi)	Fuel cost of ith generating unit.
F_{ss} (Pi)	Cost of i^{th} solar generating unit.
P_{gsj}	Power is available from j^{th} solar plant in the operating zone.
P_r	is its rated power
T_{ref}, T_{amb}	Reference temperature, is the ambient temperature,
α, Si	Temperature coefficient and incident solar radiation.
P_{gi}	Generated power by i^{th} unit,
U_{gi}	Unit status of solar generating i^{th} unit,

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P_D	Power demand and n is total number of generating units.
$Pgi_{min.}$, Pgi_{max}	Minimum and maximum generating power limits of i^{th} generating units.
W	Inertia weight.
w^{max}, w^{min}	Maximum and minimum inertia weight.
C_1, C_2	Acceleration coefficient.
$\mu_{s,i}^{k}$	Position of s^{th} particle of i^{th} dimension at k^{th} iteration.
$V_{s,i}^{k}$	Velocity of s^{th} particle of i^{th} dimension at k^{th} iteration.
μ_i^{Gbest}	Global best position of i^{th} dimension.
$\mu_{s,i}^{best}$	Local best position of s^{th} particle of i^{th} dimension.
N	Number of particles.
IT	Iteration number.
IT_{max}	Maximum number of iterations

IV. RESULT AND DISCUSSION

The HPSO has been applied for the reduction of the cost from the thermal and PV generating units. In-spite of this reduction of cost and analysis of generation scheduling during cloudy conditions is the main purpose of this paper. The HPSO is applied on a standard six thermal and 13 PV generating units test system. The above sections have been discussed to provide the complete knowledge of ELD with scheduling of PV generation problems and its formulation using HPSO. In this section, we will study one case to show the results of the applied method in terms of its effect on PV generating units including different weather conditions. In this research work, an algorithm based on HPSO is carried out to solve ELD with scheduling of PV generation. To find the global best solution, the program is run for different values of C1, C2, 4, W^{max}, W^{min}, ITmax, which are given in table 1. Six generating units are connected to meet the demand along with 13 PV units. Results are obtained for economic load dispatch with scheduling of PV generation from PSO and tabulated. The obtained results show that all the constraints are fully satisfied and within their ranges.

Table 1 parameter setting of HPSO

PR	ITmax	w^{max}	w^{min}	C1	C2
60	2000	.9	.4	2	2

Full radiation: Solar radiation from the time interval 01 to 04 and at evening from 20 to 24 is zero. So there is no power generation from PV generating units at this time interval. Solar radiation is maximum at time interval 14 so the total power generated from PV generating units is maximum, 377 MW as shown in table 2. Now power generation of each PV generating unit at each time interval is shown in table 2 AND power generation from thermal units is shown in Table3.

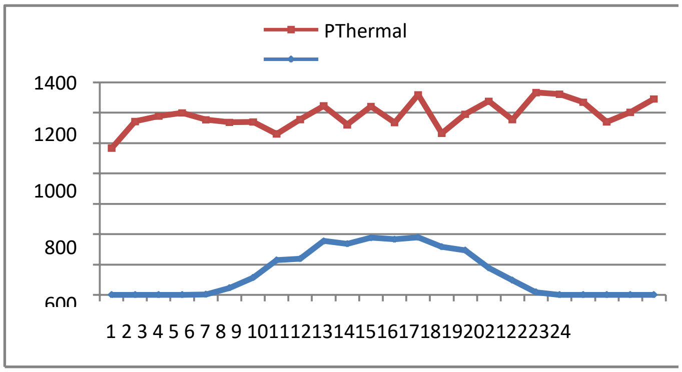

Fig. 3 Power generated from pv and thermal units for full radiation

In Table 2 it is seen that power from PV generating units at time interval 12 and 14 power is greater than 300 MW and corresponding to this time interval cost of thermal generating units at interval 12 is 47369.11 ($/hour) and at interval 14 is 78410.09 ($/hour) to meet the demand of 1240 MW and 1318 MW respectively.

Table 3 Hourly status of power from thermal units for full radiation

Hrs	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	COST
1	33.9398	14.4257	150.843	150.295	300.496	315	48639.65
2	36.1263	150	161.615	157.779	325	311.48	59328.22
3	65.9624	109.272	218.971	210	257.795	315	60476.18
4	54.91	43.09	250	210	325	315	60613.55
5	48.937	32.8061	218.854	210	325	315	58103.95
6	46.3829	62.6683	233.248	153.96	302.056	292.741	55281.47
7	27.8285	116.947	129.809	185.47	296.858	268.079	52826.08
8	23.7673	92.7232	161.18	134.637	199.248	220.459	43202.07
9	30.3395	97.4028	168.223	151.199	224.124	246.504	47352.93
10	33.4586	10	139.046	149.73	281.795	276.685	84768.11
11	10	66.969	102.689	114.812	267.653	223.457	146712.2
12	84.0346	55.9713	130.709	142.714	260.418	191.153	47369.11
13	43.806	55.8702	153.546	60.2214	275.179	181.377	130077.8
14	32.9711	10	146.24	145.211	290.751	315	78410.09
15	28.6377	10	115.375	117.412	263.139	214.115	39339.76
16	30.5841	10	132.072	133.197	325	266.08	45417.4
17	37.4963	49.6396	221.496	197.518	278.612	315	55650.42
18	40.5799	74.0665	162.652	168.885	325	287.193	53661.86
19	65.7476	150	250	210	325	315	68357.83
20	72	150	250	210	325	315	68723.1
21	83.9163	85.0837	250	210	325	315	64854.52
22	64.0051	48.7725	176.222	210	325	315	57584.01
23	34.5518	150	250	147.601	304.847	315	62530.23
24	41	150	250	210	325	315	67002.93

As seen from above results of solar PV panels, power generated from solar units is maximum during 10 to 15 hours due to which power demand from thermal units gets reduced. Now the combined total power generation of solar and thermal is calculated and compared with the actual demand

Table 2 Hourly status of power

Power Generation from PV Generating Units													
Hrs	P S1	P S2	P S3	PS4	P S5	P S6	P S7	PS8	P S9	PS 10	PS 11	PS 12	PS 13
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.108	0.135	0.135	0.162	0.162	0.189	0.216	0.216	0.216	0.216	0.216	0.216	0.216
6	2.02	2.525	2.525	3.03	3.03	3.535	4.04	4.04	4.04	4.04	4.04	4.04	4.04
7	5.0790 74	6.348843	6.348843	7.61861 1	7.6186 11	8.88837 9	10.1581 5	10.158 15	10.158 15	10.158 15	10.158 15	10.158 15	10.158 15
8	10.856 47	0	13.57059	16.2847 1	16.284 71	18.9988 3	21.7129 4	21.712 94	21.712 94	21.712 94	21.712 94	21.712 94	21.712 94
9	10.661	13.3263	13.3263	15.9915	15.991	18.6568	21.3220	21.322	21.322	21.322	21.322	21.322	21.322

	04			6	56	2	8	08	08	08	08	08	08
10	15.878	19.8475	19.8475	23.817	23.817	27.7865	31.756	31.756	31.756	31.756	31.756	31.756	31.756
11	20	25	25	0	30	35	40	40	40	0	40	40	0
12	20	25	25	0	30	35	40	40	40	40	40	40	0
13	20	25	25	30	30	35	40	40	40	0	40	40	0
14	16.98096	21.22621	21.22621	25.47145	25.47145	29.71669	33.96193	33.96193	33.96193	33.96193	33.96193	33.96193	33.96193
15	4.6212	18.2765	18.2765	21.93181	21.93181	25.58711	29.24241	29.24241	29.24241	29.24241	29.24241	29.24241	29.24241
16	13.17156	16.46445	16.46445	19.75734	19.75734	23.05023	26.34312	26.34312	26.34312	26.34312	26.34312	26.34312	26.34312
17	7.920864	9.90108	9.90108	11.8813	11.8813	13.86151	15.84173	15.84173	15.84173	15.84173	15.84173	15.84173	15.84173
18	4.297698	5.372123	5.372123	6.446547	6.446547	7.520972	8.595396	8.595396	8.595396	8.595396	8.595396	8.595396	8.595396
19	0.77539	0.9692375	0.9692375	1.163085	1.163085	1.356933	1.55078	1.55078	1.55078	1.55078	1.55078	1.55078	1.55078
20	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0

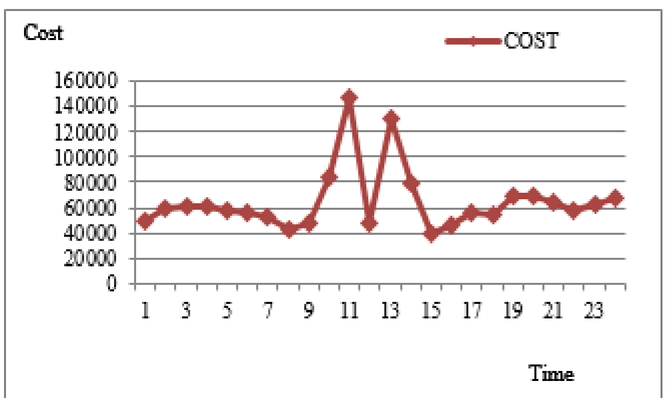

Fig. 4 Thermal cost for full radiation

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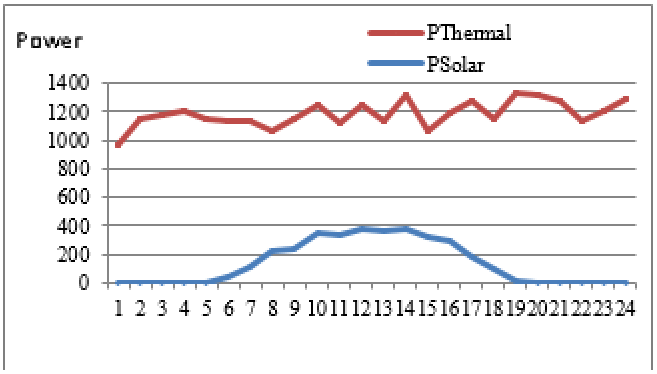

Fig.5. Power generated by pv and thermal generating units for 10% reduced radiation

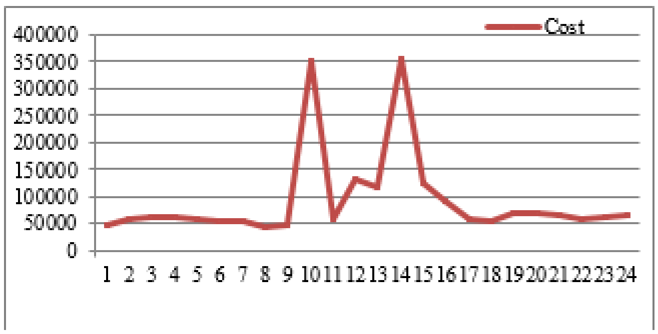

Fig.6. Thermal cost for 10% reduced radiation

Table 4 Hourly status of power from pv units for reduction of 10% solar radiation

Power Generation from PV Generating Units													
Hrs	PS1	PS2	PS3	PS4	PS5	PS6	PS7	PS8	PS9	PS10	PS11	PS12	PS 13
1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0.108	0.135	0.135	0.162	0.162	0.189	0.216	0.216	0.216	0.216	0.216	0.216	0.216
6	2.02	2.525	2.525	3.03	3.03	3.535	4.04	4.04	4.04	4.04	4.04	4.04	4.04
7	5.079074	6.348843	6.348843	7.618611	7.618611	8.888379	10.15815	10.15815	10.15815	10.15815	10.15815	10.15815	10.15815
8	10.85647	0	13.57059	16.28471	16.28471	18.99883	21.71294	21.71294	21.71294	21.71294	21.71294	21.71294	21.71294
9	7.46273	9.32841	9.32841	11.1941	11.1941	13.0598	14.9255	14.9255	14.9255	14.9255	14.9255	14.9255	14.9255
10	11.1146	13.8933	13.8933	16.6719	16.6719	19.4506	22.2292	22.2292	22.2292	22.2292	22.2292	22.2292	22.2292
11	14.112	17.64	17.64	21.168	21.168	24.696	28.224	28.224	28.224	28.224	28.224	28.224	28.224
12	14.3584	17.948	17.948	21.5376	21.5376	25.1272	28.7168	28.7168	28.7168	28.7168	28.7168	28.7168	28.7168

13	14.049	17.5613	17.5613	21.0735	21.0735	24.5858	28.098	28.098	28.098	28.098	28.098	28.098	28.098
14	11.8867	14.8583	14.8583	17.83	17.83	20.8017	23.7734	23.7734	23.7734	23.7734	23.7734	23.7734	23.7734
15	10.2348	12.7936	12.7936	15.3523	15.3523	17.911	20.4697	20.4697	20.4697	20.4697	20.4697	20.4697	20.4697
16	9.22009	11.5251	11.5251	13.8301	13.8301	16.1352	18.4402	18.4402	18.4402	18.4402	18.4402	18.4402	18.4402
17	5.54461	6.93076	6.93076	8.31691	8.31691	9.70306	11.0892	11.0892	11.0892	11.0892	11.0892	11.0892	11.0892
18	3.00839	3.76049	3.76049	4.51258	4.51258	5.26468	6.01678	6.01678	6.01678	6.01678	6.01678	6.01678	6.01678
19	0.77539	0.9692375	0.9692375	1.163085	1.163085	1.356933	1.55078	1.55078	1.55078	1.55078	1.55078	1.55078	1.55078
20	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0

V. CONCLUSION

A binary particle swarm optimization algorithm is implemented to solve economic dispatch with PV generation. The technique provides a well defined balance between exploration and exploitation property during the search. The performance of PSO was tested on generating units with 13 PV generations. The results of economic load dispatch with PV generation using HPSO. This paper suggests that Hybrid Particle swarm optimization technique is the answer to address ED with PV scheduling problems. Considering the environmental and economical conditions simultaneously using maximum PV generating units at different hours with scheduling for obtaining maximum power generation for the data given in Table 2, 4, computation of above method has been done. Results presented above have shown that results enhanced in lesser total cost for ED problems with minimal computational time and more accurate global best solution.

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