Multi-objective unit commitment with spinning reserve cost using hybrid method

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ABSTRACT

Under the generation of electrical power, fuel consumption, and emission are emphasized in the thermal power industry. Based on this, emission and cost were considered objectives with inequality and equality constraints. The spinning reserve was replenished as one of the constraints. In this paper, the spinning reserve cost (SRC) was incorporated with the total cost objective function. The hybrid technique is steered to achieve minimal value which is the combination of the cuckoo search method and flower pollination algorithm. To predict the potential of the proposed technique, two systems are considered namely a four-unit system and an IEEE thirty-nine bus system. The obtained simulation outcome shows a better improvement with the proposed technique in optimal value.

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1. INTRODUCTION

In power systems, thermal power plants are a pivotal source in the entire world. In the modern span, the unmatched power demand is enhancing day to day of life. In meeting the desired load demand, thermal units are addressed with a major portion of the power demand in the power network. Based on the realization of environmental protection and draining of fossil fuels requirements are targeted to enhance performance and clean environment. In enhancing the requirements of operational strategies, the economy concerned with fuel consumption and the clean air act related to the environment are added to the account at the instant of time. To address the objectives mathematical concepts are applied that focus on the optimization problem. The computational procedure of predicting the best solution of the objective, among all feasible solutions is termed optimization. Optimization problems are categorized into two types mono-objective [1] and multi-objective optimization problems [2], [3]. Over several decades research is carried out on unit commitment extensively based on optimization. Unit commitment (UC) is used to predict optimal value by the line-up of thermal units to increase the performance with the minimization of objectives to avoid the wastage of fuel [4]. The major task in handling complex systems requires computational efforts in achieving the solution to a problem of optimization. The results of the UC problem gives information, on which unit should work and which unit turned off, and how much power to generate from each thermal unit concerned to power over a period of short interval [5]. A committed unit is termed as the unit which is decided to be connected to the network for contributing to load demand.

Scheduling the on/off status of power units with a reduction in fuel cost for twenty-four hours while maintaining all the systems constraints [6] is termed as UC. The size of the problem increases by enhancing the objectives and constraints. There are two types of constraints namely inequality constraints and equality constraints [7]. The more the number of constraints as consequence the more complexity of the problem increases and becomes tedious in evaluating the optimal solution of a UC optimization problem. The criteria of UC are to reduce the total production cost for one week or one day with many constraints like spinning reserve, power balance, minimum downtime, minimum uptime and ramp rate limits [8]. In a mono objective problem, the total cost is the amalgamation of fuel cost, startup cost, and shutdown cost. More than one objective of UC is termed a multi-objective unit commitment (MOUC) optimization problem [9]. Many strategies were applied for achieving the optimal values of UC over several decades. Still, there are further many more paths for predicting the best optimal values.

In the literature, there are different techniques applied for solving the UC problem. Some of them are techniques are branch bound method [10], Lagrangian relaxation method (LR) [11], dynamic programming method (DP) [12], genetic algorithm (GA) [4], particle swarm optimization (PSO) [13], harmony search algorithm (HAS) [14], grey wolf algorithm (GOW) [15], non-dominant sorting genetic algorithm (NSGA-II) [16], artificial bee colony algorithm [17], Tabu search method [18], simulated annealing [19]. Since there is a need to increase the performance to achieve a best optimal solution. The new concept of hybrid method is proposed which is the amalgamation of two or more algorithms. Some of the literature methods of hybrid models are Lagrangian relaxation with genetic algorithm (LR&GA) [20], genetic algorithm based artificial neural network (GAANN) [21], simulated annealing genetic algorithm (SAGA) [22], non-dominant sorting genetic algorithm-ii with population variant differential evolution algorithm (NSGA-II &PVDE) [23], [24], particle swarm optimization with grey wolf optimization (PSOGWO) [25], imperialist competitive algorithm with particle swarm optimization (ICA&PSO) [26], hybrid many objective cuckoo search algorithm (HMOCS) [27], Lagrangian relaxation with evolutionary programming (LREP) [28], a modified hybrid method [29].

In this paper, a new hybrid technique is introduced which is the amalgamation of the cuckoo search method with the flower pollination algorithm. The contribution of this paper, in general, the spinning reserve is considered a constraint by many of the researchers. In this paper along with constraints, the cost of spinning reserve is also considered and amalgamated with the total cost and applied to two test systems. The remaining paper is as follows, the section 2 presents the formulation of two objectives minimization, the section 3 deals with the proposed hybrid technique is a union of two algorithms, and the section 4 discusses the simulation results which are applied to the mono and multi-objective problem and the finally, section 5 presents the conclusion.

2. PROBLEM FORMULATION

The mathematical expression for minimization of total cost is given as:

$$min \sum_{v=1}^{T} \sum_{u=1}^{M} \left[F_u\left(Pg_u(v)\right) + SUC_u\left(1 - U_u(v-1)\right)\right] U_u(v) + SRC(v) \quad (1)$$

$$SRC(v) = SR(v) * P_v \quad (2)$$

$Pg_u(v)$ is the active power of u[th] power unit at 'v' hour, SUC is the start-up cost, M indicates the total no of units, T for 24 hours, U_u prescribes the status of the u[th] thermal unit. SRC is spinning reserve cost, P_v is the unit cost of spinning reserve at an hour 'v'. F_u represent the cost function which is represented in (3). .

$$\mathrm{F_u}\left(Pg_u(v)\right) = a_u + b_u Pg_u(v) + c_u Pg_u^2(v) \quad (3)$$

Where a_u, b_u, c_u is the cost coefficient of thermal unit 'u'.

$$E = \sum_{v=1}^{T} \sum_{u=1}^{M} EF_u(Pg_u(v)) * U_u(v) \quad (4)$$

EF represents the emission function which is represented in quadratic form as follows:

$$EF_u\left(Pg_u(v)\right) = \alpha_u + \beta_u Pg_u(v) + \gamma_u Pg_u^2 \quad (5)$$

$\alpha_u, \beta_u, \gamma_u$ represent emission coefficients. The startup cost is expressed in terms of hot startup cost or cold startup cost is presented in (6).

$$SUC(u) = \begin{cases} HC(u), & if MD(u,v) \leq TC(u) \leq MD_{vo} \\ CSC(u), & if TC(u) > MD_{vo} \end{cases} \quad MD_{vo} = MD(u,v) + CST(u) \tag{6}$$

$CSC(u), HSC(u)$ are termed as cold and hot start-up cost of uth thermal unit. TC(u) represents the online status of unit u. $MD(u,v)$ represents the minimum downtime of thermal unit u at hour v.The constraits are as follows.

2.1. Balanced power constraints:

This constraint in which the sum of generated power must meet the demand at hour$v$. The mathematical expression is presented as (7).

$$\sum_{u=1}^{M} Pg_u(v).U_u(v) = d_o(v) \tag{7}$$

$d_o(v)$ represents the demand at hour v.

2.2. Spinning reserve (SR)

Spinning reserve is considered and maintained at each time interval of one hour and is mathematically expressed as (8).

$$\sum_{u=1}^{M} Pg_u^{max}(v).U_u(v) \geq d_o(v) + SR(v) \tag{8}$$

$SR(v)$ presents the spinning reserve at hour 'v'.

2.3. Real power range

The real power generation from the thermal units lie in the range of minimum and maximum power which indicate the inequality constraints.

$$Pg_{u,min} \leq Pg \leq Pg_{u,max} \tag{9}$$

$Pg_{u,min}, Pg_{u,max}$ are the low and high-power generation limits of thermal unit 'u'.

2.4. Minimum uptime and downtime

Based on the de-commitment and commitment of the thermal unit there will be associated minimum times with each unit for commitment and de-commitment.

$$TC_{u,on} \geq MUT_u \tag{10}$$

$$TC_{u,off} \geq MDT_u \tag{11}$$

MUT, MDT is the minimum up-time and downtime.

3. METHODOLOGY

The combination of cuckoo search and flower pollination technique is implemented for solving optimization problem of UC.

3.1. Cuckoo search algorithm (CSA)

CSA is a meta-heuristic algorithm and it is a nature-inspired one, found on the cuckoo species behavior. This species lay its egg in the nest of host bird's. There is a probability of 0.1 percent of identifying the other species egg by the host bird. There are two chances to be done by the host bird after predicting the cuckoo's egg. The host bird may throw off the cuckoo's egg or it may abandoned the nest by replacing the new one. In CSA the egg is the solution and the host nest is the concern to the population whose size is fixed. The CS is endured with three major basic rules [30].

i) Individual cuckoo bird lay only egg and places it in the host bird's nest stochastically.
ii) Host bird nest with superior quality eggs is taken for the next production.
iii) The chances of detecting egg of the cuckoo by host bird is considered as $P_b \in (0, 1)$.

CS commences with an initial population that represents cuckoos. These cuckoo's lay eggs in the host bird's nests. The egg is analogous to host bird's egg there will be more probability to grow as the young chick otherwise the egg is thrown. The area where more cuckoo's eggs survive the area is more profitable. After the cuckoo chicks hatch from the eggs and grow as adults, groups and communities are formed. Each group has its own identity of habitat. Among all the groups the best habitat will be considered as the next location and migrate towards it.

The current location of habitat is prescribed as {y_1^g,y_2^g,y_3^g,y_4^g,…y_n^g} where n represents the no of host bird nests and ‘g’ is the no of generations. By using the Levy flight, the random walk of the cuckoo’s bird for the new solution is given by:

$$y_i^{(g+1)} = y_i^g + \alpha \oplus Levy(\curlywedge) \tag{12}$$

$\oplus$ is the entry-wise multiplication, $Levy(\curlywedge)$ is the stochastic number taken from $Levy$ distribution. α is the step size and is evaluated using (13).

$$\alpha = \alpha_{oo} * (y_i^g - y_{best}^g) \tag{13}$$

The scaling factor is represented as α_{oo} and present the best solution prescribed as u_{best}^g. The $Levy(\curlywedge)$ value is predicted by a procedure [31].

$$l = \frac{x}{z^{\frac{1}{\rho}}} \tag{14}$$

l presents the value of $Levy(\curlywedge)$ after simulation. The x and zare the numbers selected randomly from the normal distribution with a mean zero. ρ is the parameter of Levy distribution.

$$\sigma_x = \left\{\frac{\Gamma(1+\rho)\sin(\frac{\pi\rho}{2})}{\Gamma[\frac{1+\rho}{2}]2^{(\rho-1)/2}\rho}\right\}^{1/\rho}, \sigma_z = 1 \tag{15}$$

The random walk based on the local is given by (16).

$$y_i^{(g+1)} = \begin{cases} y_i^g + ra(y_m^g - y_n^g) & if\ ra' > P \\ y_i^g & otherwise \end{cases} \tag{16}$$

y_m^g, y_n^g are selected randomly from the given population and ra', ra are the arbitrarily number between (0,1). The best value is sort-out for each iteration process. CSA is mainly focused on the minimization of an optimization problem.

3.2. Flower pollination algorithm

Flowers have played a pivotal role in the development of flowering plants over the past years that is impossible to imagine without them. Through pollination, there will be subsequent reproduction with the purpose of the flower. Pollen is usually transferred when flowers are pollinated and this transfer is frequently attributed to pollinators like birds, insects, bats, and other animals. Two categories of pollination exist namely biotic and abiotic [32]. Figure 1 shows the hybrid technique flowchart.

The majority of flowering plants are related to pollination of biotic which is approximately about 90%. Cross-pollination occurs from the pollen of a flower with a various plant. Abiotic pollination which doesn’t requires any pollinators it’s about approximately 10%. Self-pollination is when pollen of the same or different flowers of the similar plant is considered for fertilization. Pollen carriers are also termed pollinators, which are wide in variety. Almost 2 lakhs of different pollinators exist in nature. The following rules are applied for pollinator behaviour and flower consistency.

- Global pollination process in which cross-pollination takes place where pollinators with pollen perform levy fights.
- Local pollination process where self-pollination takes place.
- When two flowers are involved, flower constancy can be thought of as the reproduction chance being proportional to the resemblance of two flowers.
- Switching probability controls the global and local pollination.

$$L \sim \frac{\lambda\Gamma(\lambda)\sin(\frac{\pi\lambda}{2})}{\pi}\frac{1}{q^{1+\lambda}} \tag{17}$$

L is the Levy distribution which represents the pollination strength. $\Gamma(\lambda)$ is the function of gamma which is applicable for large step sizes q>0. There is the existence of global and local pollination. Both global scale and local scale is taken place in the flower pollination and are controlled by switching probability.

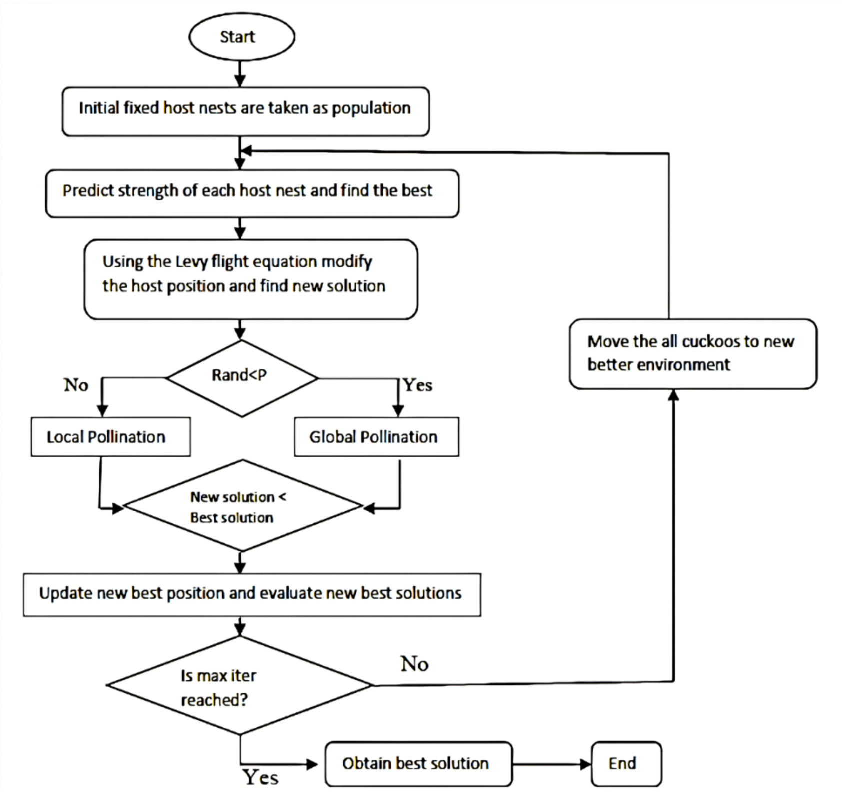

Figure 1. Hybrid technique flowchart

4. SIMULATION RESULTS DISCUSSION

The mono objective and multi-objective problem related to UC is solved using a hybrid method which is the amalgamation of two meta-heuristic methods. The cuckoo search method and flower pollination method are amalgamated to form a hybrid method. Two test systems are considered to predict the potential of the proposed technique i.e. four unit system and IEEE 39 bus system.

- Case (i)

In this case, a four-unit system is implemented. The initial parameters of are cuckoo search algorithm is initialized. The population was considered as 40, the number of iterations is 20, the cost coefficients, minimum and maximum power limits, start-up cost, minimum uptime and downtime, and a number of decision variables are initialized [33].

The on/off status of the thermal units is shown in Table 1. The scheduling of thermal units and their startup cost, fuel cost, and total cost value is shown in Table 2. The comparison of total cost value without spinning reserve cost is shown in Table 3 and with spinning, the reserve is shown in Table 4.

Table 1. Four thermal units for eight-hour status

TU1	TU2	TU3	TU4
1	1	0	0
1	1	0	0
1	1	1	0
1	1	1	0
1	0	1	1
1	0	1	0
1	0	0	0
1	1	0	0

Table 2. Scheduling of thermal unit

$TU1_{(MW)}$	$TU2_{(MW)}$	$TU3_{(MW)}$	$TU4_{(MW)}$	SUC ($)	Cost ($)	Total cost($)
300	150	0	0	0	9145.360	9145.36
300	230	0	0	0	10629.04	10629.04
300	250	50	0	150	12262.86	12412.86
300	215	25	0	0	11079.38	11079.38
300	0	80	20	0.02	8531.82	8531.84
255	0	25	0	0	5845.56	5845.56
290	0	0	0	0	5742.05	5742.05
300	200	0	0	0	10066.36	10066.36
				150.02	73,302.43	73,452.45

- Case (ii)

In this case, the multiobjective problem is considered in which cost and emission are considered as two clash objectives. The test case IEEE 39 bus with 10 units is considered to find the effectiveness of the proposed technique. The optimization problem is subjected to constraints.

The respective data of the IEEE thirty-nine bus with 10 units is considered [34]–[38]. The initial parameters are assigned the same as in a single objective problem. The spinning reserve was considered as 10 percent. The commitment status of the ten thermal units is illustrated in Table 5 and the corresponding sharing of load demand for twenty-four hours among ten units is shown in Table 6. Figure 2 shows the load curve for twenty-four hours.

Table 3. Comparison of total cost value with the proposed method

Method	Total Cost($)	Method	Total Cost($)
ILR [35]	75,231	BDE [37]	74,676
B. SMP [36]	74,812	Proposed Method	73,452
LRPSO [35]	74,808		

Table 4. Scheduling of thermal units with spinning reserve cost of four unit system

$TU1_{(MW)}$	$TU2_{(MW)}$	$TU3_{(MW)}$	$TU4_{(MW)}$	SUC ($)	S.R Cost($)	Cost ($)	Total cost($)
300	150	0	0	0	33.30	9145.360	9178.66
300	230	0	0	0	39.22	10629.04	10668.26
300	250	50	0	150	44.40	12262.86	12307.26
300	215	25	0	0	39.96	11079.38	11119.34
300	0	80	20	0.02	29.60	8531.82	8561.42
255	0	25	0	0	20.72	5845.56	5866.28
290	0	0	0	0	27.55	5742.05	5769.6
300	200	0	0	0	47.50	10066.36	10113.86
				150.02	282.25	73,302.43	73,584.68

Table 5. Scheduling of ten-unit system of IEEE 39 bus system

TU 1	TU 2	TU 3	TU 4	TU 5	TU 6	TU 7	TU 8	TU 9	TU 10
1	1	0	0	0	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0
1	1	0	0	1	0	0	0	0	0
1	1	0	0	1	0	0	0	0	0
1	1	1	0	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	1	1	0
1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	0	0	0	0	0
1	1	1	1	1	1	1	1	0	0
1	1	1	1	1	1	1	0	0	0
1	1	0	0	1	1	1	0	0	0
1	1	0	0	1	0	0	0	0	0
1	1	0	0	0	0	0	0	0	0

Table 6. Dispatching of load demand among thermal units of IEEE 39 bus system

$TU1_{(MW)}$	$TU2_{(MW)}$	$TU3_{(MW)}$	$TU4_{(MW)}$	$TU5_{(MW)}$	$TU6_{(MW)}$	$TU7_{(MW)}$	$TU8_{(MW)}$	$TU9_{(MW)}$	$TU10_{(MW)}$
455	245	0	0	0	0	0	0	0	0
455	295	0	0	0	0	0	0	0	0
455	370	0	0	25	0	0	0	0	0
455	455	0	0	40	0	0	0	0	0
455	390	130	0	25	0	0	0	0	0
455	360	130	130	2	0	0	0	0	0
455	410	130	130	25	0	0	0	0	0
455	455	130	130	30	0	0	0	0	0
455	455	130	130	85	20	25	0	0	0
455	455	130	130	162	33	25	10	0	0
455	455	130	130	162	73	25	10	10	0
455	455	130	130	162	80	25	43	10	10
455	455	130	130	162	33	25	10	0	0
455	455	130	130	85	20	25	0	0	0
455	455	130	130	30	0	0	0	0	0
455	310	130	130	25	0	0	0	0	0
455	260	130	130	25	0	0	0	0	0
455	360	130	130	25	0	0	0	0	0
455	455	130	130	30	0	0	0	0	0
455	455	130	130	162	33	25	10	0	0
455	455	130	130	85	20	25	0	0	0
455	455	0	0	145	20	25	0	0	0
455	420	0	0	25	0	0	0	0	0
455	345	0	0	0	0	0	0	0	0

The respective startup cost, total cost, fuel cost and emission are illustrated in Table 7. The total cost is the addition of operating cost and startup cost. From Table 7 it can be illustrated that the total cost was 5,64,018 ($) and the emission value is 20,267.69 (lb). With the observation of Table 8 the optimal values are better that other existing methods.

The total cost with the incorporation of the spinning reserve cost can be illustrated in Table 9 (see in Appendix). The total spinning reserve cost for different load demands of twenty-four hours is 24,033 ($). The total cost is the sum of the startup cost, spinning reserve cost, and operating cost. With the incorporation of SRC the total cost is enhanced but there is a miniature reduction in the value of emission.

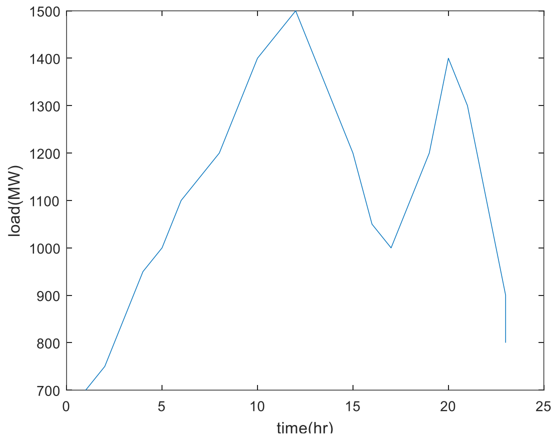

Figure 2. Load curve with respect to time

Table 7. Total cost and emission of IEEE 39 bus system without SRC

S.No	Load (MW)	SUC ($)	COST ($)	Total Cost ($)	Emission (lb)
1	700	0	13683.12	13683.12	613.97
2	750	0	14554.49	14554.49	714.84
3	850	900	16809.44	17709.44	651.42
4	950	0	18597.66	18597.66	857.23
5	1000	550	20051.16	20601.16	753.24
6	1100	1120	22387.04	23507.04	758.87
7	1150	0	23261.97	23261.97	856.31
8	1200	0	24150.34	24150.34	961.56
9	1300	860	27251.05	28111.05	883.20
10	1400	60	30057.55	30117.55	1001.07
11	1450	60	31916.06	31976.06	1017.83
12	1500	60	33890.16	33950.16	1035.64
13	1400	0	30057.55	30057.55	1001.07
14	1300	0	27251.05	27251.05	883.20
15	1200	0	24150.34	24150.34	961.56
16	1050	0	21513.65	21513.65	669.22
17	1000	0	20641.82	20641.82	587.38
18	1100	0	22387.04	22387.04	758.87
19	1200	0	24150.34	24150.34	961.56
20	1400	490	30057.55	30547.55	1001.07
21	1300	0	27251.05	27251.05	883.20
22	1100	0	22735.52	22735.52	881.31
23	900	0	17684.69	17684.69	750.43
24	800	0	15427.41	15427.41	823.52
		4100	5,59,918.1	5,64,018.12	20,267.69

Table 8. Comparison of emission and total cost values with the hybrid technique

Method	Total cost($)	Emission(lb)
IBPSO	599,782.0	----
Particle swarm optimization	581,450	----
Hybrid PSO-SQP	568,032	----
Proposed method	5,64,018.12	20,267.69

5. CONCLUSION

The single and multi-objective optimization problem related to UC is solved using the hybrid method. The amalgamation of cuckoo’s search and flower pollination techniques is applied as a hybrid method. Two conflicting objectives cost and emission is considered. In addition to the cost, the spinning reserve cost is also amalgamated. The two systems are implemented to predict the potential of the proposed technique. The outcome of the two systems shows better optimal values in comparison with the other existing methods. Total cost and emission get modified with the effect of spinning reserve cost.

APPENDIX

Table 9. Total cost and emission of IEEE 39 bus system with SRC

S.No	Load (MW)	SUC ($)	S.R COST($)	COST ($)	Total cost ($)	Emission (lb)
1	700	0	518	13683.12	14201.12	613.97
2	750	0	555	14554.49	15109.49	714.84
3	850	560	629	16892.15	18081.15	716.54
4	950	900	703	19145.70	20748.7	658.92
5	1000	0	740	20020.01	20760.01	753.24
6	1100	1100	814	22387.04	24301.04	758.87
7	1150	0	1092.50	23261.97	24354.47	856.31
8	1200	0	1140	24150.34	25290.34	961.56
9	1300	860	1235	27251.05	29346.05	883.20
10	1400	60	1330	30057.55	31447.55	1001.07
11	1450	60	1377.50	31916.06	33353.56	1017.83
12	1500	60	1425	33890.16	35375.16	1035.64
13	1400	0	1330	30057.55	31387.55	1001.07
14	1300	0	1235	27251.05	28486.05	883.20
15	1200	0	1140	24150.34	25290.34	961.56
16	1050	0	997.50	21513.65	22511.15	669.22
17	1000	0	950	20641.82	21591.82	587.38
18	1100	0	1045	22387.04	23432.04	758.87
19	1200	0	1140	24150.34	25290.34	961.56
20	1400	490	1330	30057.55	31877.55	1001.07
21	1300	0	1235	27251.05	28486.05	883.20
22	1100	0	814	22735.52	23549.52	881.31
23	900	0	666	17684.69	18350.69	750.43
24	800	0	592	15427.41	16019.41	823.52
		4090	24,033.5	5,60,517.7	5,88,641.2	20,134.38

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