A PSO Based Solution Methodology for Short Term Hybrid Generation Scheduling Problem

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Abstract: A multiple stage solution methodology involving Priority List method and Particle Swarm Optimization Technique with Time Varying Acceleration Coefficients has been proposed for solving short term generation scheduling problem having ten thermal generating units and one solar generating unit. The per day revenue saving in operational cost after inclusion of 300 MW solar plant is quantified. The proposed method is found reliable after executing the simulations several times.

Keywords: Unit Commitment Problem (UCP), Priority List Method (PLM), Particle Swarm Optimization with Time Varying Acceleration Coefficients (PSO_TVAC), Solar Energy Resources (SER), Economic Load Dispatch (ELD)

I. INTRODUCTION

Unit Commitment Problem (UCP) is an onerous non-linear optimization problem where load for a scheduled time frame is satisfied by generation with minimum cost under various constraints \cite{1}. The rising demand of energy warrants inclusion of Renewable Energy Resources (RES) as fossil fuel resources are becoming scarce. Today energy saving associated with environmental protection has become prudent. The inclusion of RES into mainstream power system is inexorable because it can not only reduce the overall operating cost but can also prove to be sustainable and eco-friendly in nature \cite{2-3}. In wake of this, efforts have been done to include solar generation with conventional thermal generation \cite{4-6}.

Particle Swarm Optimization (PSO) technique is found to be one of the most effective techniques in obtaining solution for rigorous optimization problems like UCP and Economic Load Dispatch (ELD) \cite{7-9}. The advantages of PSO are that it is robust, its parameter tuning is easy and it can be hybridized with other techniques available in literature \cite{10-12}. The adaptability of PSO allows hybridizing Priority List Method (PLM) which is an effective classical solution technique for providing better feasible solutions to the problem \cite{13-15}.

II. PROBLEM FORMULATION

There are two sub sections where the modeling of thermal generation \cite{14, 16} and solar generation \cite{5} have been carried out.

(a) Thermal Generation:

The cost function \(\text{Cost}_N\) is given by Equation (1).

\[
\text{Cost}_N = \sum_{i=1}^{N} [\text{FC}_i(p_{ih}) + \text{STC}_i(1 - U_{i(h-1)})]U_{ih}
\]

\(\text{FC}_i(p_{ih})\) is the fuel cost of \(i\)\textsuperscript{th} unit with power output \(p_{ih}\) at the \(h\)\textsuperscript{th} hour. FC is fuel cost function which is quadratic polynomial with coefficients \(a_i, b_i\) and \(c_i\). It is represented by Equation (2).

\[
\text{FC}_i(p_{ih}) = a_i + b_i p_{ih} + c_i p_{ih}^2
\]

If the downtime of \(i\)\textsuperscript{th} unit is less than or equal to the summation of minimum down time (MD) and the Cold start up time (Cs), then the start-up cost of that unit (STC\(_i\)) is taken as Hot start-up cost (Hsc\(_i\)). Else it is taken as Cold start-up cost (Csc\(_i\)) represented by Equation (3).

\[
\text{STC}_i = Hsc_i
\]

When, \(X_{i}^{off} \leq MD_i + Cs\) (3)

\(X_{i}^{off}\) is the duration in which the \(i_{th}\) unit is continuously off. If the downtime of related unit is greater than the summation of minimum down time hours (MD) and cold start-up hours (Cs) then the cold start-up cost (Csc\(_i\)) is considered.
This can be represented by Equation (4).

\[ STC_i^j = C_{si} \]

When, \( X_i^{off} > MD_i + Cs \)  

Thus, the total cost \( \text{Cost}_{NH} \) for the complete schedule of the given time frame is given by Equation (5).

\[
\text{Cost}_{NH} = \frac{H}{N} \sum_{i=1}^{N} \left( FC_i(P_{ih}) + STC_i(1 - U_i(h-1)) \right) U_{ih}
\]

\( U_{ih} \) is the ON/OFF status of the \( i^{th} \) unit at \( h^{th} \) hour. Digit ‘1’ represents ON, while ‘0’ represents the OFF status.

The constraints of UCP (only thermal) considered here are as follows.

1) Power Balance Constraint

\[
\sum_{i=1}^{N} P_{ih} U_{ih} = LD_h
\]

\( P_{ih} \) is the generation in MW of \( i^{th} \) unit in \( h^{th} \) hour, \( U_{ih} \) is the ON/OFF status of \( i^{th} \) unit and \( LD_h \) is the load demand at \( h^{th} \) hour.

2) Spinning Reserve Constraint

\[
\sum_{i=1}^{N} P_{i(max)} U_{ih} \geq LD_h + SR_h
\]

\( P_{i(max)} \) is the maximum generation in MW of \( i^{th} \) unit and \( SR_h \) is the spinning reserve at \( h^{th} \) hour. In this paper for ten thermal generating units the spinning reserve is taken as 5% of total load.

3) Generation Limit Constraint

\[
P_{i(min)} \leq P_{ih} \leq P_{i(max)}
\]

4) Minimum up time constraints

\[
X_{i \to on}(t) \geq MU_i
\]

5) Minimum down time constraint

\[
X_{i \to off}(t) \geq MD_i
\]

6) Initial Status

It is the initial down time status that is required to be considered in the first hour of scheduling. The data regarding thermal generating units and load profile is given in Appendix I and II respectively.

(b) Solar Generation System

The power balance constraint under the lights of solar generation is given as

\[
\sum_{i=1}^{N} [P_i(t) + P_{solar}(t)] U_{ih} = LD_h
\]

Where, \( P_{solar}(t) \) is the hourly solar power output. The total availability of hourly solar power is calculated by using following equations [17].

\[
P_{solar}(s(t)) = P_{sn} \left( \frac{s(t)}{S_{stand}} \right)^2 ; 0 \leq s(t) \leq R_s
\]

\[
P_{solar}(s(t)) = P_{sn} \left( \frac{s(t)}{S_{stand}} \right)^2 ; s(t) \geq R_s
\]

Where, \( s(t) \) is forecasted solar radiation at hour \( t \), \( S_{stand} \) is solar radiation in standard environment taken as 1000 W/m² and \( R_s \) is the cut-in radiation point set as 150W/m² [17]. \( P_{sn} \) is maximum generation capability of solar system taken as 300 MW. The data regarding radiation is provided in Appendix III.
III. SOLUTION METHODOLOGY

A two stage solution methodology involving Priority Listing Method (PLM) and Particle Swarm Optimization with Time Varying Acceleration Coefficients (PSO_TVAC) is proposed for the solution of problem. The ON/OFF schedule in the first stage is determined by PLM and economic allocation of load among thermal generating units is done by PSO_TVAC.

(a) Stage One-

The priority vector is obtained by using equation (26) [14, 16].

$$\text{priority vector} = \frac{P_{\text{max vec}}}{\text{max}} + \frac{MD_{\text{vec}}}{\text{max}}$$

This priority vector is updated with the help of a pseudo code [14, 16] given below.

Fig.1. Pseudo code for obtaining ON/OFF Schedule

(b) Stage Two-

The ON/OFF status obtained from stage one serves as an input to stage two where the load is distributed among thermal generating units economically. PSO_TVAC [17, 18] is proposed to solve non-linear UCP. The equations are as follows

$$v_{id}^{(k+1)} = W \cdot v_{id}^k + c_1 \cdot Rand_1 \cdot (P_{\text{best id}} - x_{id}^k) + c_2 \cdot Rand_2 \cdot (G_{\text{best gd}} - x_{id}^k)$$  \hspace{1cm} (15)

$$x_{id}^{(k+1)} = x_{id}^k + v_{id}^{k+1}$$  \hspace{1cm} (16)

Where, ‘W’ is the inertia weight parameter which controls the global and local exploration capabilities of the particle. The linearly varying ‘W’ is given as

$$w = w_{\text{max}} - \frac{w_{\text{min}} - w_{\text{min}}}{\text{iter}_{\text{max}}} \cdot \text{iter}$$  \hspace{1cm} (17)
'c₁' and 'c₂' are acceleration coefficients, to deal with the high non-linear nature of UCP some modifications are done in classical PSO algorithm, in this paper PSO with Time Varying Acceleration Coefficients (TVAC) is used, the values of ‘c₁’ and ‘c₂’ can be given as

\[ c_1 = \left( c_{1f} - c_{1i} \right) \frac{\text{iter.}}{\text{iter}_{\text{max}}} \times c_{1i} \]  \hspace{1cm} (18)

\[ c_2 = \left( c_{2f} - c_{2i} \right) \frac{\text{iter.}}{\text{iter}_{\text{max}}} \times c_{2i} \]  \hspace{1cm} (19)

Where, \( c_{1i}, c_{1f}, c_{2i}, c_{2f} \) are initial and final values of cognitive and social acceleration factors respectively.

The values considered for acceleration coefficients are-

\( c_{1i}=0.5, c_{1f}=2.5, c_{2i}=2.5, c_{2f}=0.5 \).

The bounds for velocity are set to make sure that the solution does not fly away. These bounds are set as explained below.

If, \( V_{d}^{(k+1)}>V_{d}^{\text{max}} \), then \( V_{d}^{(k+1)}=V_{d}^{\text{max}} \)

If, \( V_{d}^{(k+1)}<V_{d}^{\text{min}} \), then \( V_{d}^{(k+1)}=V_{d}^{\text{min}} \)

Where, \( V_{d}^{\text{min}} = -0.5 \ P_{g}^{\text{min}}, V_{d}^{\text{max}} = +0.5 \ P_{g}^{\text{max}} \) \hspace{1cm} (20)

IV. SIMULATION AND RESULTS

Case (a) Thermal Generation

The ON/OFF schedule obtained by Stage One is given in Table 1.

| Hrs. | Unit No |
|------|--------|
| 1    | 2      |
| H1   | 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H2   | 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H3   | 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H4   | 1 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H5   | 1 1 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 |
| H6   | 1 1 0 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H7   | 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H8   | 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H9   | 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 0 |
| H10  | 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 0 0 0 |
| H11  | 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0 |
| H12  | 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 |
| H13  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H14  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H15  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H16  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H17  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H18  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H19  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H20  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H21  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H22  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H23  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |
| H24  | 1 1 1 1 1 1 1 1 1 1 1 1 0 0 0 0 0 0 0 |

The economic allocation of load obtained by Stage Two is given in Table 2.
Table 2-Economic Load Dispatch Case (a)

| Hrs | Unit No. | Gen. (MWh) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | Tot. Gen. (MW) |
|-----|----------|------------|---|---|---|---|---|---|---|---|---|---|----------------|
| H1  |          |            | 455| 245| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 700            |
| H2  |          |            | 455| 295| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 750            |
| H3  |          |            | 455| 395| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 850            |
| H4  |          |            | 455| 455| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 950            |
| H5  |          |            | 455| 455| 0 | 90| 0 | 0 | 0 | 0 | 0 | 0 | 1000           |
| H6  |          |            | 455| 455| 130| 60| 0 | 0 | 0 | 0 | 0 | 0 | 1100           |
| H7  |          |            | 455| 410| 130| 25| 0 | 0 | 0 | 0 | 0 | 0 | 1150           |
| H8  |          |            | 455| 455| 130| 30| 0 | 0 | 0 | 0 | 0 | 0 | 1200           |
| H9  |          |            | 455| 455| 130| 110| 20| 0 | 0 | 0 | 0 | 0 | 1300           |
| H10 |          |            | 455| 455| 130| 162| 43| 25| 0 | 0 | 0 | 0 | 1400           |
| H11 |          |            | 455| 455| 130| 162| 80| 25| 13| 0 | 0 | 0 | 1450           |
| H12 |          |            | 455| 455| 130| 162| 80| 25| 53| 10| 0 | 0 | 1500           |
| H13 |          |            | 455| 455| 130| 162| 43| 25| 0 | 0 | 0 | 0 | 1400           |
| H14 |          |            | 455| 455| 130| 110| 20| 0 | 0 | 0 | 0 | 0 | 1300           |
| H15 |          |            | 455| 455| 130| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 1200           |
| H16 |          |            | 455| 310| 130| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 1050           |
| H17 |          |            | 455| 260| 130| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 1000           |
| H18 |          |            | 455| 360| 130| 25 | 0 | 0 | 0 | 0 | 0 | 0 | 1100           |
| H19 |          |            | 455| 455| 130| 30 | 0 | 0 | 0 | 0 | 0 | 0 | 1200           |
| H20 |          |            | 455| 455| 130| 162| 43| 25 | 0 | 0 | 0 | 0 | 1400           |
| H21 |          |            | 455| 455| 0 | 130| 162| 73| 25 | 0 | 0 | 0 | 0 | 1300           |
| H22 |          |            | 455| 455| 0 | 0 | 145| 20| 25 | 0 | 0 | 0 | 0 | 1100           |
| H23 |          |            | 455| 425| 0 | 0 | 0 | 20 | 0 | 0 | 0 | 0 | 900            |
| H24 |          |            | 455| 345| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800            |

The generation in MWh and operating costs details (fuel cost and start-up costs) are given in Table 3.

Table 3-Operating Cost for Individual Generators for 24 hours for Case (a)

| Unit No. | Gen. (MWh) | Fuel Cost ($) | Start-up Cost ($) |
|----------|------------|---------------|-------------------|
| 1        | 10920      | 203180        | 0                 |
| 2        | 9870       | 194928.7      | 0                 |
| 3        | 1820       | 40485.2       | 1100              |
| 4        | 2080       | 45770.54      | 1120              |
| 5        | 1717       | 43255.23      | 900               |
| 6        | 442        | 13718.89      | 510               |
| 7        | 175        | 8249.063      | 1040              |
| 8        | 66         | 3043.019      | 60                |
| 9        | 10         | 937.922       | 60                |
| 10       | 0          | 0             | 0                 |
| **Total**| **27100**  | **553569**    | **4790**          |

The convergence of the proposed method is shown in Fig.2.
The total operating cost for Case (a) is $5583598$.

**Case (b) Solar Integrated Thermal Generation**

The hourly generation from solar plant is shown in Fig.3.

After calculating the generation from a 300 MW Solar power plant the demand is further updated by subtracting the hourly solar power from the demand. This updated load demand is fed to Stage One to obtain the ON/OFF schedule.

The ON/OFF schedule, Economic allocation of load, operational cost for generation and convergence of the proposed method for Case (b) is given in Table 4, Table 5, Table 6 and Fig.4 respectively.
Table 4-ON/OFF Schedule for Case (b)

| Hrs. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|------|----|----|----|----|----|----|----|----|----|----|
| 1    | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 2    | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 3    | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 4    | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |
| 5    | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 6    | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 7    | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 8    | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 9    | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 10   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 11   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 12   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 13   | 1  | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  |
| 14   | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 0  |
| 15   | 1  | 1  | 0  | 0  | 1  | 1  | 0  | 0  | 0  | 0  |
| 16   | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |
| 17   | 1  | 1  | 0  | 0  | 1  | 0  | 0  | 0  | 0  | 0  |
| 18   | 1  | 1  | 0  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 19   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 20   | 1  | 1  | 1  | 1  | 1  | 0  | 1  | 1  | 0  |
| 21   | 1  | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  |
| 22   | 1  | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  |
| 23   | 1  | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 24   | 1  | 1  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |

Table 5-Economic Load Dispatch Case (b)

| Hrs. | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | P_{Solar} | Tot. Gen. (MW) |
|------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----------|----------------|
| 1    | 455 | 245 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 700       |                |
| 2    | 455 | 295 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 750       |                |
| 3    | 455 | 395 | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 0   | 850       |                |
| 4    | 455 | 455 | 0   | 40  | 0   | 0   | 0   | 0   | 0   | 0   | 950       |                |
| 5    | 455 | 390 | 0   | 130 | 25  | 0   | 0   | 0   | 0   | 0   | 1000      |                |
| 6    | 455 | 455 | 0   | 130 | 60  | 0   | 0   | 0   | 0   | 0   | 1100      |                |
| 7    | 455 | 455 | 0   | 130 | 86  | 0   | 0   | 0   | 0   | 0   | 1150      |                |
| 8    | 455 | 455 | 0   | 130 | 67  | 0   | 0   | 0   | 0   | 0   | 93        | 1200           |
| 9    | 455 | 448 | 130 | 130 | 25  | 0   | 0   | 0   | 0   | 0   | 112       | 1300           |
| 10   | 455 | 455 | 130 | 130 | 80  | 0   | 0   | 0   | 0   | 0   | 150       | 1400           |
| 11   | 455 | 455 | 130 | 130 | 95  | 0   | 0   | 0   | 0   | 0   | 185       | 1450           |
| 12   | 455 | 455 | 130 | 130 | 105 | 0   | 0   | 0   | 0   | 0   | 205       | 1500           |
| 13   | 455 | 455 | 130 | 130 | 20  | 0   | 0   | 0   | 0   | 0   | 210       | 1400           |
| 14   | 455 | 455 | 0   | 0   | 150 | 0   | 0   | 0   | 0   | 0   | 220       | 1300           |
| 15   | 455 | 455 | 0   | 0   | 95  | 20  | 0   | 0   | 0   | 0   | 175       | 1200           |
| 16   | 455 | 443 | 0   | 0   | 25  | 0   | 0   | 0   | 0   | 0   | 127       | 1050           |
| 17   | 455 | 433 | 0   | 0   | 25  | 0   | 0   | 0   | 0   | 0   | 87        | 1000           |
| 18   | 455 | 455 | 0   | 0   | 46  | 0   | 0   | 0   | 0   | 0   | 14        | 1100           |
Table 6: Operating Cost for Individual Generators for 24 hours for Case (b)

| Unit No. | Gen. (MWh) | Fuel Cost ($) | Start-up Cost ($) |
|----------|------------|---------------|-------------------|
| 1        | 10920      | 203180        | 0                 |
| 2        | 10049      | 198056        | 0                 |
| 3        | 1300       | 28918         | 1650              |
| 4        | 1690       | 37188.6       | 1120              |
| 5        | 1351       | 35254.2       | 900               |
| 6        | 168        | 6363.17       | 510               |
| 7        | 0          | 0             | 0                 |
| 8        | 10         | 919.613       | 60                |
| 9        | 10         | 937.922       | 60                |
| 10       | 0          | 0             | 0                 |
| **Total**| **25498**  | **510818**    | **4300**          |

The total operating cost for Case (a) is **515118 $**.

V. CONCLUSION

It can be concluded from this work that after properly scheduling renewable energy resources with conventional thermal generation the fuel cost of thermal generation can be significantly reduced. In this case after inclusion of a 300 MW Solar generation plant the total saving in fuel cost is **43241$ per day**. The hybridization of Priority List Method (PLM) with Particle Swarm Optimization Technique with Time Varying Acceleration Coefficients (PSO_TVAC) gives satisfactory results for a non-linear, complex and constraints based problem like UCP. The convergence of the proposed method remains unaltered even after inclusion of renewable generation.
## APPENDICES

### Appendix I (Thermal Units Detail)[5, 14]

| Unit No. | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 |
|----------|----|----|----|----|----|----|----|----|----|----|
| P_{fan}  | 455| 455| 130| 130| 80 | 85 | 55 | 55 | 55 | 55 |
| P_{sh}   | 150| 150| 20 | 20 | 20 | 25 | 10 | 10 | 10 | 10 |
| α($/h)   | 1000| 970 | 700 | 680 | 370 | 480 | 660 | 665 | 670 |
| h($/MWh) | 18.19| 17.26| 16.60| 16.50| 22.26| 27.74| 25.92| 27.27| 27.79 |
| c($/MW h) | 0.00048| 0.00031| 0.002| 0.00211| 0.0072| 0.00079| 0.00413| 0.0022| 0.00173 |
| MD(h)    | 8 | 8 | 5 | 5 | 3 | 3 | 1 | 1 | 1 |
| MU(h)    | 8 | 8 | 5 | 5 | 3 | 3 | 1 | 1 | 1 |
| H_{5c}($/h) | 4500 | 5000 | 550 | 560 | 170 | 160 | 30 | 30 | 30 |
| C_{5c}($/h) | 9000 | 10000 | 1100 | 1120 | 340 | 320 | 60 | 60 | 60 |
| C(h)     | 5 | 5 | 4 | 4 | 2 | 2 | 0 | 0 | 0 |
| Initial Status | 8 | 8 | -5 | -5 | -3 | -3 | -1 | -1 | -1 |

### Appendix II (Load Profile for 24 Hours)[5, 14]

| Hour | H1 | H2 | H3 | H4 | H5 | H6 |
|------|----|----|----|----|----|----|
| Load (MW) | 700 | 750 | 850 | 950 | 1000 | 1100 |
| Hour | H7 | H8 | H9 | H10 | H11 | H12 |
| Load (MW) | 1150 | 1200 | 1300 | 1400 | 1450 | 1500 |
| Hour | H13 | H14 | H15 | H16 | H17 | H18 |
| Load (MW) | 1400 | 1300 | 1200 | 1050 | 1000 | 1100 |
| Hour | H19 | H20 | H21 | H22 | H23 | H24 |
| Load (MW) | 1200 | 1400 | 1300 | 1100 | 900 | 800 |
Appendix III (Solar Radiation Data for 24 Hours)[5]

| Hour | SR/Wm² | SR/Wm² | SR/Wm² | SR/Wm² | SR/Wm² | SR/Wm² |
|------|--------|--------|--------|--------|--------|--------|
| 1    | 0      | 0      | 0      | 0      | 0      | 0      |
| 2    | 7      | 8      | 9      | 10     | 11     | 12     |
| 3    | 111    | 311    | 375    | 503    | 617    | 686    |
| 4    | 13     | 14     | 15     | 16     | 17     | 18     |
| 5    | 705    | 736    | 380    | 425    | 291    | 80     |
| 6    | 19     | 20     | 21     | 22     | 23     | 24     |
| 7    | 0      | 0      | 0      | 0      | 0      | 0      |

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