# Solution of Profit Based Unit Commitment Including Wind Energy Using Improved Shuffled Frog Leaping Algorithm

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**Abstract—**This paper presents the use of Improved Shuffled frog leaping Algorithm for the solution of unit commitment of the profit based GENCO environment with thermal and wind units. Wind energy is a promising resource of renewable energy and also free from emission. The wind energy is intermittent in nature and it depends on various factors like humidity and temperature. The available energy from wind units is calculated based on the wind speed. The thermal units are scheduled with enough reserve is maintained to overcome the intermittent nature of wind energy along with maximum profit. The proposed Improved Shuffled Frog Leaping algorithm is a memetic algorithm is based on the food searching behavior of frogs. Leaping of the frog is improved by the using a cognitive component. It will ensure the faster convergence and global optimal solution. Implementation of the integer coded UC is done which avoids any extra penalty function for satisfying the lowest up/down constraint. Two cases have been considered such as Profit Based Unit Commitment (PBUC) case with no wind units included, and PBUC with wind units included. The results are discussed related to these cases to explain the effect of wind in GENCOs profit. Also the inclusion of emission constraints has been compared for the above two cases. Standard 10 bus system is taken along with two wind farms each having 10 units to validate the results.

**Key Words** Profit Based Unit Commitment, GENCO, Wind, Ramp up/down, Cognitive component, Frogs, Local Search, Shuffling.

## 1. Introduction

The revolution in green energy concepts has made a necessity for another renewable energy source. Wind power has become a promising source of alternative energy. Also the installation and operation cost of wind energy has been reduced considerably. According to the statistics of WETC (Wind Energy), China has the maximum installed wind energy of 221 GW USA has 96.4 GW and Germany has 59.3 GW and whereas Spain, UK and India also has a reasonable amount of installed wind energy. The penetration of wind energy needs changes in economic and technical aspects of Power System Operation in deregulated energy markets. The operating constraints may also vary with utilities, since the utilities may vary with type of mixture of available generating units. Also the wind energy is intermittent in nature. This may lead to congestion in transmission lines and voltage rise in bus bars. To maintain the required Power system stability, the system schedule should also include the required reserve margin along with the demand.

In independent distribution, generation and transmission network, which are controlled by an independent authority ISO (Independent System Operator). In this deregulated energy market, the system demand is taken as a softer constraint that it may or may not be satisfied and only the reserve and profit are to be maximized. GENCOs compete with each other for supplying the demand of the consumers. Several methods are available in literature to solve Unit commitment (UC) and Profit Based Unit Commitment (PBUC).

Several mathematical techniques are used in the past to solve the UC problem. Dynamic Programming, Priority Listing, Mixed Integer Programming, Lagrangian Relaxation are the conventional mathematical techniques used for solving non-linear complex problems like UC problem. Heuristic algorithms are quiet promising when the complexity of the nonlinear problem increases. Genetic Algorithm, Evolutionary Programming, Particle Swarm Optimization, Bacterial Foraging and Shuffled Frog Leaping Algorithm (SFLA) are available in literature for solving UC problem [1-8].

Forecasting the wind energy by building an arithmetic model is very essential as the wind energy is intermittent in nature. Artificial Neural Network has been used for the estimation of wind power considering the uncertainty in forecasting the wind energy. Several advanced forecasting models are available for wind forecasting. Thang et.al [9] have used Clustered adaptive teaching learning-based optimization algorithm for solving Large scale wind thermal problem. [10] Suresh Domodran used the load forecast by using probability distribution functions for Hydro thermal and wind generation scheduling. [11] Marhi Sedehi has applied Modified Adaptive Selection based on Cuckoo Search Algorithm for solving the optimal scheduling of Wind Thermal Hydro Systems. [12] Shine Derlu has proposed Modified Particle Swarm Optimization for Hydro Thermal Wind Generation Scheduling System.

Eusuff and Lansey introduced a heuristic memetic algorithm that can solve complex nonlinear multimodal optimization problems. The main idea behind this memetic algorithm is based on how a group of frogs move towards the place at which maximum food is available. While searching for food the frog will move in groups and the ideas of each frog is interchanged with the individuals of the same group and also the best idea of a particular group is also interchanged with other groups. This process of interchanging of ideas will be repeated until the optimal location of food is reached. This algorithm is has become a good choice for solving the Unit commitment problem as this algorithm promises a faster convergence speed. An addition of cognitive component which is the addition of self-ideas of the frog which is even far away from the food can even help the best frog which is closer to the food. This additional component improves the efficiency of the search procedure.

The complete system data is used to create the set of initial frog population. The frogs are modified at each stage and the final optimal frog will give the optimal profit schedule of the GENCO considering all system and unit constraints. The Improved SFLA based PBUC gives the optimal max profit GENCO schedule based on the system data and satisfying the unit and system constraints.

The integer coding technique is used for determining the ON/OFF time of the units. This type of coding avoids the requirement for penalty function for min up/down time constraint. The wind speed data is modelled using ARMA modelling using the data taken from the location. The WTG is modelled as the two stage space model to convert the wind speed into equivalent generation. The wind generation is added only when the speed range of the wind is suitable for the generation of electricity. But whenever the wind generation is available, the thermal generation can be reduced but with required spinning reserve availability.

The objective function, system and unit constraints of the PBUC and the Modelling of the Wind Energy Conversion System (WECS) is discussed in section ii. Formation of frogs, grouping frogs into memplexes, memetic evolution and shuffling process of Improved SFLA is discussed in Section 3. Implementation of Improved SFLA to PBUC including wind energy is discussed in section 4. The results and discussions are given in section 5.

## 2. Problem Formulation

### *2.1. Modelling of wind Energy Conversion System*

The wind generation depends on the wind speed which further depends on the location, temperature and climatic conditions. The wind speed data is collected for some sample years and is used for designing the hourly available wind power for the Wind Turbine Generators. The auto correlative nature of the wind is incorporated when the time sequence model is developed. The wind rate is simulated based on the sample measured data obtained from the location using time sequence model. The simulated wind speed $Ws_t$ is obtained from the mean wind speed $\mu_t$ and its standard deviation $\sigma_t$ at time as follows:

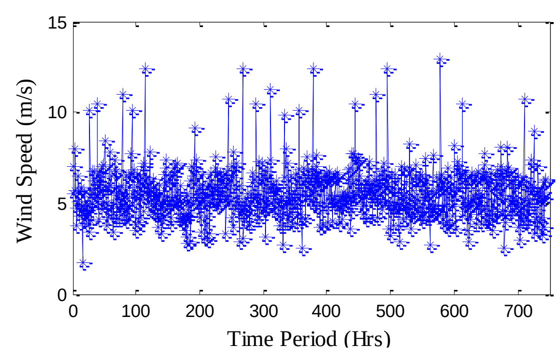


**Fig. 1.** Simulated Wind Speed for a sample month

$$WS_t = \mu_t + \sigma_t y_t \quad (1)$$

To create a wind speed time series referred to as an ARMA (n, m) series model (Auto-Regressive and Moving Average Model), the original data series set can be used

$$y_t = \sum_{i=1}^{n} \emptyset_i y_{t-i} + \alpha_t + \sum_{j=1}^{m} \theta_j \alpha_{t-j} \quad (2)$$

Where $\emptyset_i$ and $\theta_j$ are the auto regressive and moving average parameters of the model. $\alpha_t$ is a Normally Independent Distributed noise with zero mean and variance of $\sigma^2$.

$$\boldsymbol{\alpha_t} \in \boldsymbol{NID}(\boldsymbol{0}, \boldsymbol{\sigma^2}) \tag{3}$$

he values of $y_t$ are calculated using random noise values $\alpha_t$ and values of $y_t$at previous time intervals. The generated wind speed is given in fig.1.

### 2.2. *Calculation of available Wind Energy*

Usually a WTG representation can be done either by a two-state model or multi-state model. The electric energy output of a WTG in the state depends strongly on the wind profile and performance characteristics of the generator.

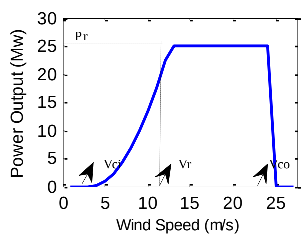


**Fig. 2.** Wind Turbine Generator Power- curve

There are three critical states of the wind speed, cut in wind speed*($V_{ci}$)* and cut out wind speed *($V_{co}$)* beyond and below which the WTG cannot generate and its rated wind speed*($V_r$)* at which the WTG generates its rated power. The hourly output of a WTG can be obtained from the modeled hourly wind speed as given in Fig.1 by applying equation

$$P_{GW}(SW_t) = \begin{cases} 0 \;\; ; \;\; 0 \leq SW_t < V_{ci} \\ (A + B * (SW_t) + C * SW_t^2 \;\; ); V_{ci} \leq SW_t < V_r \\ P_r; V_r \leq SW_t < V_{co} \\ 0 \,; SW_t > V_{co} \end{cases} \tag{4}$$

Where $P_r$ is the rated power output. The values of A, B, C depends on the three critical states of wind speed. The power curve for the WTG is as given in fig.2

### 2.3. *Formulation of Wind – Thermal Scheduling*

In the competitve GENCO environment the objective function of wind- thermal production scheduling is the difference between the total revenue from the power sold and the cost involved in generation of the power. The objective function is given as

$$Max\ (Profit) = Revenue - OC \tag{5}$$

The above objective function is maximised while satisfying the following constraints.

*(i) Power Balance Constraint*

$$\sum_{i=1}^{NGT} P_{GT}(i,t) * U(i,t) + \sum_{j=1}^{NGW} P_{GW}(j,t) * V(j,t) \leq P_D(t) \; ; \; 1 \leq t \leq T \tag{6}$$

where, $P_{GWT}(t)$ is the total available wind generation at the given instant 't'. Where, $P_D(t)$ gives the real power demand at the $t^{th}$ hour and $P_{Gi}^t$ is the real power generation of $i^{th}$ unit at $t^{th}$ hour. The power balance constraint is taken as a softer constraint. It is different from the traditional unit commitment problem. In PBUC the system demand need not to be satisfied at all instance.

*(ii) System spinning reserve requirements*

The reliability of power supply is assured only when there is an additional generation to meet the unexpected sudden increase in load or sudden failure of any generating units or sudden drop in wind generation. Two cases need to be considered for this constraint.

1. When only thermal units are committed.

We have taken a fixed value of $P_R$ as a reserve generation throughout the scheduling period.

$$\sum_{i=1}^{N} X_i(t)P_{Gi}(t) \leq P_D(t) + P_R(t), \quad t = 1,2 \ldots \ldots T \tag{7}$$

2. When wind generation is also included.

An additional spinning reserve is also needed to incorporate the intermittent nature of the wind.

$$\sum_{i=1}^{N} X_i(t)P_{Gi}(t) \leq P_D(t) + P_R(t) + ASR_{PGWT}\,(t) \quad t = 1,2 \ldots \ldots T \tag{8}$$

Whenever the wind speed falls down there is an abrupt drop in wind generation, the thermal units need to suddenly increase generation to meet up the power balance. At the same time the thermal units are needed to ramp down to leave space for wind generation whenever there is a rise in wind speed and wind generation. The additional spinning reserve

$$ASR_{PWG}(t) = \beta\,\% * P_{GWT}(t) \tag{9}$$

*(iii) Total Available Wind Generation*

The wind generation $P_{GWT}\;(t) = \sum_{j=1}^{N_G} P_{GWj}\;(t)$ (10)

*(iv) Maximum/Minimum power limits of wind units*

$$P_{WGi}^{min} \leq P_{WGi}^{t} \leq P_{WGi}^{\max} \tag{11}$$

*(v) Maximum/Minimum power limits of thermal units*

Every unit has its own maximum or minimum power level of generation, beyond and below which it cannot generate

$$P_{Gi}^{min} \leq P_{Gi}^{t} \leq P_{Gi}^{max} \tag{12}$$

*(vi) Min up/down time*

Each unit should satisfy its lowest up/down time before it is turned OFF/ON respectively.

$$\begin{cases} T_i^c \geq MUT_i if T_i^c > 0 \\ -T_i^c \geq MDT_i if T_i^c < 0 \end{cases} \tag{13}$$

$MUT_i$ and $MDT_i$ gives the lowest up/down time of $i^{th}$ unit.

*(vii) Ramp rate constraints*

This constraint has its significance in wind thermal scheduling since wind energy is intermittent in nature. The thermal generating units should be capable enough to ramp up/ down depending on the availability of the wind.

$$P_{imax}(t) = min(P_{imax}, P_i^{(t-1)} + \tau RD_i)$$
$$P_{imin}(t) = max(P_{imin}, P_i^{(t-1)} + \tau RD_i) \quad (14)$$

Where τ=60 min. $RD_i$ gives the permissible change in real power of $i^{th}$ unit.

## 3. Improved Shuffled Frog Leaping Algorithm

The SFLA algorithm involves a set of frogs in which each frog is a possible solution. The initial population of frogs are randomly generated. The size of the population is chosen optimally between convergence and computation. The health of each frog is calculated by the objective function and the frogs are arranged based on their fitness values. Now the frogs are grouped into memeplexes. The grouping of memeplex is done such that the frogs are evenly distributed based on their fitness values. This has created parallel groups with same goal. Now the frog in each memeplex will undergo leaping towards the best frog. The idea of best frog will improve the fitness of the frog towards the best frog.

The leaping of the frogs helps in improving the fitness of the frog. This process of sharing ideas within a memeplex is known as memetic evolution step or local search process The quality of all the memeplexes is improved after a prescribed no of times. Now to reach the common goal, each memeplex needs to improve its fitness. The memeplexes are now reshuffled are rearranged and then again regrouped into memeplexes which is known as shuffling process. This process enhances the cultural evolution towards the common goal. These two search processes are repeated till a required convergence is reached.

The above described frog shuffling algorithm suffers with a local convergence because the best frog of each memeplex influence other frogs. This is because of the lack of thinking capability of each frog. Each frog leaps forward in a path behind the best frog. Now, the addition of the cognitive component will help each frog to take a decision before leaping based on their own idea as well as the idea got from the best frog. This nature will definitely expedite the search process towards the best solution and also helps to overcome the local convergence. The idea of each member of the population is utilizing the search space. The cognitive component is added to the frog as an error component in the leaping process when a frog is moving towards the target.

The random population covers a multivariate space and each individual frogs will move in that space. During every leaping process the frog will compare its position with the frog least error. The error has two components and they are the distance between the frog's current position and the best frog's position. And the other is the cognitive component which is nothing but the distance between frog's current and previous position. To speed up the convergence process a random weightage between [0 1] is chosen. This frog leaping is explained in the fig.3

$$D_i = rand(1) * (P_w - X_w) + rand(1) * (X_g - X_w)$$
$$X_w = X_w + D_i D_{imin} < |D_i| < D_{imax} \quad (15)$$

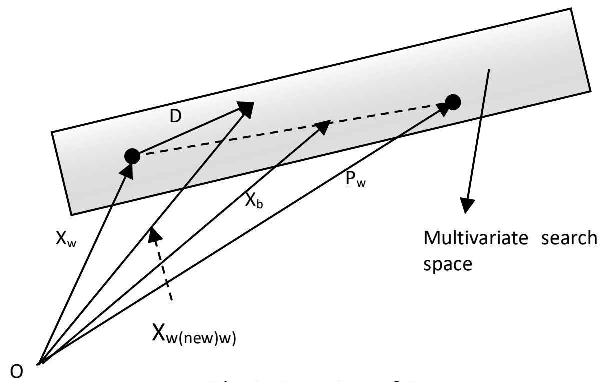


**Fig.3**. Leaping of Frog

## 4. Implementation of improved SFLA to PBUC including wind penetration

The minimum up and down time is the major constraint of the unit commitment problem.

**Table 1**. Sample frog for 5 unit 5 cycle system

| Unit | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| 1 | $T_1^1$ | $T_1^2$ | $T_1^3$ | $T_1^4$ | $T_1^5$ |
| | 24 | 0 | 0 | 0 | 0 |
| 2 | $T_2^1$ | $T_2^2$ | $T_2^3$ | $T_2^4$ | $T_2^5$ |
| | 24 | 0 | 0 | 0 | 0 |
| 3 | $T_3^1$ | $T_3^2$ | $T_3^3$ | $T_3^4$ | $T_3^5$ |
| | -4 | 19 | -1 | 0 | 0 |
| 4 | $T_4^1$ | $T_4^2$ | $T_4^3$ | $T_4^4$ | $T_4^5$ |
| | -5 | 17 | -2 | 0 | 0 |
| 5 | $T_5^1$ | $T_5^2$ | $T_5^3$ | $T_5^4$ | $T_5^5$ |
| | 15 | -9 | 0 | 0 | 0 |

This is directly satisfied in the coding of the frog itself thereby avoiding a penalty function for this constraints. This integer coded frog will give the ON/OFF duration of all the generating units for a period of 24 hours is coded as a sequence of alternatively signed integers which will always satisfies the up/down constraints. This kind of coding also reduces the size of the frog than using the hourly status of the units. Considering a two peak load profile, the peak load units will be operated during the peak load periods while the base load units operate throughout the scheduling period. The intermediate units operate only when the load level exceeds the capacity of the base load units. The peak units will have the maximum switching of the 5 times which is decided by the no of load peaks of the load profile considered.

The unit constraint minimum up/down time and the system constraint no of load peaks in the scheduling period will be the deciding factors of frog size. The No.of cycles (C) is the no of switching a peak unit will have and depends on the no of loads peak on the load curve. The size of the frog for a 5 units 5 cycle system for a 24 hr period load schedule will be a 5X5 matrix. The steps involved are explained below.

***Step 1.*** *Creating Initial Population*

Each row of the frog represents ON/OFF duration of each unit. For any unit the unsigned addition of its cycle duration should be equal to the total scheduling period. $\sum_{c=1}^{C}|T_i^c| = T$. The values of $T_i^c$ are generated randomly at the initial stage by only considering the lowest up/down time of the units. The sample frog is given in Table.1**.** Random frogs are generated and their fitness are calculated and are grouped into memeplexes.

***Step 2.*** *Leaping of worst solution*

Once the frogs are grouped into memeplexes the leaping of the frogs are carried out by the local search process. The worst and best fitted frogs in each memeplex, and the global best frog are identified. The worst frog of each memeplex will leap towards the best frog by a random vector which includes the distance between the best frogs and the frog tries to leap. This random vector is given by $D_i = rand(1) * (X_b - X_w)$ or by $D_i = rand(1) * (X_g - X_w)$. Some modifications are required in the new leaped frog as it may violate some constraints. Required modifications are as follows

(i)Sum of all $T_i^c$ of unit 'i' will not be equal to 'T'. To adjust the following correction is done.

$$(T_i^1, T_i^2, \ldots\ldots T_i^C) = \frac{T.*\left(T_i^1, T_i^2, \ldots\ldots T_i^C\right), i=1,2,\ldots.N}{\sum_{k=1}^{C}|T_i^k|} \qquad (16)$$

(ii) A random vector is added to the frog which may lead to a non-integer frog and then it is rounded off using is done by $X_w^1 = \text{Round}\,(X_w)$

(iii) The above modification may lead to a vector which the total time period is not equal to the total scheduling time.

$$T_i^l = T - \sum_{k=1}^{l-1}\left|T_i^k\right|, i = 1,2, \ldots.N \qquad (17)$$

iv) The components of the frog are adjusted to satisfy the minimum up/down constraints.

***Step 3.*** *Computation of fitness function*

There are two terms in the objective function. The first term is the total operation cost which involves the total fuel cost based on their real power generation and the start-up and shut down cost.

$$TC = \sum_{t=1}^{T}\sum_{i=1}^{N} FC_i\,(P_i^t) * X_i(t) + SU_T + SD_T \qquad (18)$$

The penalty function has two terms. The first term for spinning reserve violation and is given by

$$\prod_{res} = \omega\sum_{t=1}^{T}\frac{1}{D^t}R((P_D^t + R^t) - \sum_{i=1}^{N} X_i(t)P_{imax}^t \qquad (19)$$

The second term for excessive capacity is given by

$$\prod_{cap} = \omega\sum_{t=1}^{T}\frac{1}{D^t}R(\sum_{i=1}^{N} X_i(t)P_{imin}^t - P_D^t) \qquad (20)$$

where 'ω' depends on maximum operating cost of the system over a scheduling period 'T'

$$\omega = \alpha T\sum_{i=1}^{N} FC_i(P_{imax}), \text{ where } \alpha \text{ is a constant.} \qquad (21)$$

At this time the objective is to minimize the fitness function

$$\text{Fitness} = A/(TC + \Pi_{res} + \Pi_{cap}) \qquad (22)$$

$A = 10^8$. A constant in the order of operating cost is added to the fitness to avoid too low values of the fitness of the frogs.

***Step 4.*** The memeplexes are shuffled to ensure distribution of fitness values and again sorted in to sub groups. Again the local search process is performed.

***Step 5.*** The repetition of the local search and shuffling process are done until the required convergence is reached.

## 5. Results and Discussions

Standard 10-unit system is taken as the test system. Two wind farms W1 and W2 each having 30 turbines rated 2 MW.

**Table 2.** Simulated Wind Speed data for an average wind speed of 5.43 m/s for a sample day

| **Hour** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Wind speed(m/s) | 5.700 | 4.280 | 4.348 | 2.385 | 1.192 | 2.218 | 2.265 | 6.976 | 6.166 | 6.817 | 5.887 | 10.30 |
| **Hour** | **13** | **14** | **15** | **16** | **17** | **18** | **19** | **20** | **21** | **22** | **23** | **24** |
| Wind speed(m/s) | 10.30 | 9.625 | 9.923 | 7.547 | 6.740 | 8.640 | 2.505 | 1.667 | 1.839 | 0.060 | 1.164 | 2.3562 |

**Table 3.** Generation Scheduling and Cost details of PBUC without including wind penetration

| | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Cost and | Hourly Emission (Kg/hr) | 661.0 | 747.0 | 933.8 | 1090.1 | 1090.1 | 1146.8 | 1184.9 | 1911.1 | 1240.4 | 1299.8 | 1300.4 | 1298.3 | 1270.4 | 1238.8 | 1051.1 | 1072.4 | 983.0 | 1133.3 | 1153.2 | 1153.2 | 1153.2 | 1153.2 | 915.2 | 842.4 | | 26303 |

| Unit / Hour | Power Generation of Units (MW) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | W1 | w2 | Hourly revenue ($) | Hourly Fuel cost (Thermal)($) | Hourly Cost (wind)($) | Hourly Profit($) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 455 | 227.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 9.68 | 8.10 | 15505 | 13374 | 234.6 | 1896 |
| 2 | 455 | 290.1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.70 | 2.23 | 16500 | 14469 | 65.2 | 1966 |
| 3 | 455 | 389.6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 2.93 | 2.44 | 19635 | 16208 | 71.1 | 3356 |
| 4 | 455 | 455 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20612 | 17353 | 0 | 3258 |
| 5 | 455 | 455 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 21157 | 17353 | 0 | 3804 |
| 6 | 455 | 455 | 78 | 0 | 97.2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24905 | 21763 | 0 | 3143 |
| 7 | 455 | 455 | 130 | 0 | 110 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 25875 | 22910 | 0 | 2965 |
| 8 | 455 | 455 | 130 | 0 | 124.5 | 0 | 0 | 0 | 0 | 0 | 19.4 | 16.2 | 26580 | 23208 | 470.4 | 2901 |
| 9 | 455 | 455 | 130 | 78 | 158.5 | 0 | 0 | 0 | 0 | 0 | 12.9 | 10.7 | 29640 | 25896 | 311.6 | 3432 |
| 10 | 455 | 455 | 130 | 130 | 162 | 35 | 0 | 0 | 0 | 0 | 18.0 | 15.0 | 41090 | 28009 | 436.8 | 12644 |
| 11 | 455 | 455 | 130 | 130 | 162 | 80.0 | 0 | 0 | 0 | 0 | 10.9 | 9.08 | 43174 | 29048 | 264.3 | 13862 |
| 12 | 455 | 455 | 130 | 130 | 162 | 58 | 0 | 0 | 0 | 0 | 60.0 | 50.0 | 47475 | 28537 | 1455.6 | 17483 |
| 13 | 455 | 455 | 130 | 130 | 100 | 20.0 | 0 | 0 | 0 | 0 | 60.0 | 50.0 | 34440 | 26384 | 1455.6 | 6601 |
| 14 | 455 | 455 | 130 | 130 | 38.4 | 0 | 0 | 0 | 0 | 0 | 49.9 | 41.6 | 31850 | 24318 | 1212.1 | 6320 |
| 15 | 455 | 385.5 | 130 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 54.3 | 45.2 | 27000 | 21888 | 1316.8 | 3795 |
| 16 | 455 | 419.6 | 78 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 24.7 | 20.7 | 23415 | 20212 | 601.4 | 3233 |
| 17 | 455 | 383.2 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 17.3 | 4.45 | 22250 | 18956 | 0 | 2873 |
| 18 | 455 | 447.2 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 37.0 | 30.8 | 24255 | 20078 | 0 | 3281 |
| 19 | 455 | 455 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23088 | 20214 | 0 | 2874 |
| 20 | 455 | 455 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23556 | 20214 | 0 | 3342 |
| 21 | 455 | 455 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 24024 | 20214 | 0 | 3810 |
| 22 | 455 | 455 | 0 | 130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 23868 | 20214 | 0 | 3654 |
| 23 | 455 | 367 | 0 | 78 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 20475 | 17764 | 0 | 2711 |
| 24 | 455 | 345 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 18040 | 15427 | 0 | 2613 |
| | Start up cost of Thermal units & Fixed cost of Wind units | | | | | | | | | | | | | 4360 | | |
| | Total | | | | | | | | | | | | 628410 | 504010 | 9213.0 | 110827 |

Simulated Wind Speed data (2) for an average wind speed of 5.43m/s is given in Table.2.The reserve price is taken as 10% of the energy price. The spinning reserve requirement is taken as 10 % of the load at that hour. Since, Wind power is intermittent in nature, to assure stability at every instant an additional spinning reserve is added. It is taken as 10% of the available wind power generation. Also the ramping capacity of thermal units is very essential to take up the sudden rise/drop in wind generation. It is taken as 60% of the rated capacity of each unit. The average operating and maintenance cost is taken as 1.25% of the capital cost.

Before executing the simulated work, it is essential to determine certain parameters of improved shuffled frog leaping algorithm. The population size is taken as 200. No of memeplexes is taken as 20 and each memeplex has 20 frogs each.

Local search process takes 10 iterations. To discuss the effect of wind generation on profit of GENCOs we have taken two cases.

Case 1: Considering thermal units only for supplying the demand.

Case: 2: Including wind units along with thermal units for supplying the demand

Case:1 Only the thermal units are committed. The units are committed only when the GENCO gets the profit. It is not essential for the GENCO to meet the demand at all instants. The generation schedule of this case is given in Table .6. At 8th hour the GENCOs are supplying a total power of 1170 MW only but the demand at that instant is 1200 MW. The profit at this instant is 2810$. The GENCOs are not meeting the demand at instants 11,12,16,18-22 hours. But the GENCOS are making maximum profit at these instants by supplying the maximum power that it can generate to maximize its profit. The total profit obtained in 24 hrs by the GENCO is $ 105180. The amount of emission in 24 hrs duration is 26.71 tons. The reserve is also maintained within the limit.

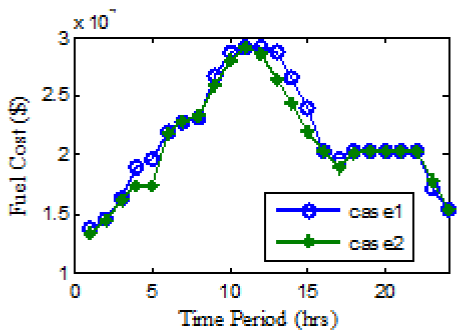


**Fig. 5.** Comparison of Fuel Cost between two cases

Case:2 The wind units are also included along with the thermal units. The fore casted wind speed is given in Table.2. The wind speed is calculated using ARMA modelling (1) -(4) from the calculated value taken from the location. The average wind speed is taken as 5.43. m/s. The forecasted wind power is calculated using the wind speed using state space model (4). The wind speed is greater than the cut in speed during the period 1-3 and 7-18 hours. So the wind generation can be included only during these hours. Also the additional spinning reserve of 10% of the available wind energy is to be added along with the thermal units reserve requirement. The generation schedule is given in Table. 2. The total profit of GENCO for a period of 24

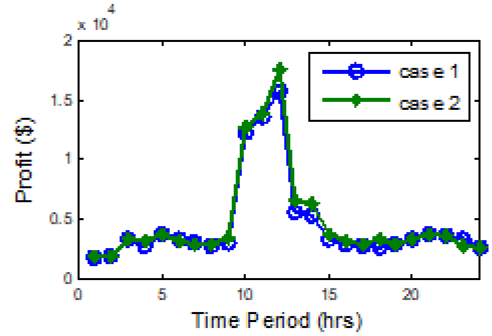


**Fig. 6.** Comparison of Profit between two cases

## 6. Conclusion

In this paper , a new evolutionary algorithm improved SFLA based PBUC including wind penetration is presented. The effect of wind on operating cost and emission is clearly observed using two cases. The wind speed is modelled using ARMA modelling by taking an average wind speed from the location. The profit of GENCOs is also maximised by allowing wind penetration. The thermal units are scheduled using the Improved SFLA. The GENCOs profit when only thermal units are committed is $105180 whereas the profit is increased to $110827 improved when wind generation is included and it is 7% higher than the former case for a scheduling period of 24 hrs. There is an effective reduction of 0.4 tons of emission per day. The Improved SFLA also guarantees faster convergence It has been observed that the convergence of SFLA is faster and the optimal result is obtained in 6 to 12 shuffling iterations for all the test systems and cases.

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