Hydro-Thermal-Wind Integrated Optimal Generation Scheduling of GENCOs in a Competitive joint Energy and Reserve Market

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Abstract:-

This paper solves the generation scheduling problem in a joint energy and reserve competitive electricity market considering renewable energy sources of hydro and wind generating units. A computational intelligent approach of an Improved Ant line optimizer (IALO) is proposed to solve the problem. The prime objective of problem is to maximize the profit of GENCOs and satisfying the standard system, thermal, hydro and wind plants constraints. Here, schedule the generators with and without reserve power generation in a joint energy and reserve market for improve the profit of GENCOs. The projected ALO algorithm is based on the best and worst solutions obtained during the optimization process and the random interactions between the candidate solutions. It require only the common control parameters like population size and number of iterations and do not require any algorithm-specific control parameters. In the proposed algorithm, the search space is explored by the ant lion optimization first, and then the domain is searched by the particle swarm optimization (PSO) in each iteration cycle. Numerical examples with four hydro, three thermal and two wind units are considered for determining the profit at the time period of 24 hours also evaluate the performance of proposed IALO. The simulation results are obtained from the proposed method in terms of water discharge ware storage volume, hydro power, thermal power, wind power; reserve power, revenue, total operating cost and Profit GENCOs are tabulated. Finally, the simulation results are compared with existing approaches and prove the performance of this proposed algorithm.

Keywords *— Optimal Generation Scheduling, Valve point loading effect, Hydro, thermal and wind generation, Fuel cost minimization, profit maximization, Improved Ant line optimizer.*

1. INTRODUCTION

The restructuring of electric power systems has resulted in market-based competition by creating an open market environment. A restructured system allows the power supply to function competitively, as well as allowing consumers to choose suppliers of electric energy. According to this change, traditional methods for power generation operation and control need modification [1]. Generation scheduling is one of those methods that need changes. On the other hand, generation scheduling under deregulated environment is more complex and more competitive than traditional one. Generation companies (GENCOs) run optimal scheduling not for minimizing total production cost as before but for maximizing their own profit. Moreover in the past, utilities had an obligation to serve their customers. That means all demand and spinning reserve must be met. However, it is not necessary in the restructured system. The GENCO can now consider a schedule that produces less than the predicted load demand and reserve but creates a maximum profit [2]

Under deregulated environment, many researchers have proposed various multi-objective procedures to solve the short-term hydrothermal self-scheduling problem. Mixed Integer Programming (MIP) based hydro-thermal self-scheduling problem has been described in a day-ahead joint energy and reserve market [3]. The problem has modeled in the form of multi-objective framework to simultaneously maximize GENCOs profit and minimize emissions of thermal units. In the proposed model the valve loading effects which is a nonlinear function by itself is linearized. Smajo Bisanovic *et.al* [4] addresses the self-scheduling problem of determining the UC status for power generation companies before submitting the hourly bids in a day-ahead market. The hydrothermal model is formulated as a deterministic optimization problem where expected profit is maximized using the 0/1 mixed-integer linear programming technique.

A stochastic midterm risk-constrained hydrothermal scheduling problem has been solved using combined approach of mixed integer programming with Monte Carlo simulation [5]. The objective of a GENCO is to maximize payoffs and minimize financial risks when scheduling its midterm generation of thermal, cascaded hydro, and pumped-storage units. The proposed GENCO solution may be used to schedule midterm fuel and natural water inflow resources for a few months to a year. The multi-objective function of maximizing the profit and minimizing the emission of a Hydro -Thermal System (HTS) using Lagrangian Relaxation-Evolutionary Programming (LR-EP) technique has been presented in the article [6]. The various constraints of the hydro and thermal units were considered such as power balance, reservoir storage, turbine flow rate and loading limits of both thermal and hydro plants. In [7-9], emissions of thermal units are considered as a constraint of objective function and the valve loading effects and dynamic ramp rat

Wind power generation is continuously increasing around the world, but due to uncertainty in wind power generation, the unit commitment problem has become complex. A scenario generation and reduction techniques have been used to consider wind power uncertainty on system operation by Shukla and Singh [10]. This paper wind-hydro-thermal coordination problem along with the pumped storage plant was established. Combination of weighted-improved crazy particle swarm optimization along with a pseudo code based algorithm and scenario analysis method has been utilized to solve the problem. The effectiveness and feasibility of this method was tested on systems with and without pumped storage plant integration.

Siahkali and Vakilian [11] has been proposed a type-2 fuzzy membership function (MF) has been implemented to model the linguistic uncertainty of type-1 MF of available wind power generation which stems from opinions of different experts. This approach was applied to two test systems (six and twenty-six conventional generating units both with two wind farms) and the results of generation scheduling using both fuzzy modelling type-1, and type-2 are presented. Lakshmi and Vasantharathna [12] has been proposed an Artificial Immune System approach for solving generation scheduling problem of a GENCO comprised of thermal and wind energy systems. In this work, the impact of wind energy on short term generation scheduling problem is analyzed through the adaptive search which is inspired from the Artificial Immune System.

Xu *et al.* [13] has been proposed carbon emission reduction and reliable electricity generation, an equilibrium strategy based on a hydro-wind-thermal complementary system under an uncertain environment that fully considers the cooperation of hydro power plants, wind power plants, and coal combusted thermal power plants. The authors considering the randomness of seasonal wind speeds, the water flow uncertainty and the fuzziness of coal thermal plant carbon emissions, the complementary model is more scientific and practical than current models.

Security constrained generation scheduling (SCGS) problem for a grid incorporating thermal, wind and photovoltaic (PV) units has been formulated by ElDesouky [14]. The formulation takes into account the stochastic nature of both wind and PV power output and imbalance charges due to mismatch between the actual and scheduled wind and PV power outputs. A genetic algorithm (GA) with artificial neural network (ANN) and a priority list (PL) was used to minimize the total operating costs while satisfying all operational constraints considering both conventional and renewable energy generators. Numerical results are reported and discussed based on the simulation performed on the IEEE 24-bus reliability test system.

Angarita *et al* [15] has been proposed a technique that maximizes the joint proft of hydro and wind generators in a pool-based electricity market, taking into account the uncertainty of wind power prediction. This imbalance produces overcast in the system, which must be paid by those who produce it, e.g., wind generators among others. As a result, wind farm revenue decreases, but it could increase by allowing wind farms to submit their bids to the markets together with a hydro generating unit, which may easily modify its production according to the expected imbalance. Dawn and Tiwar [16] developed a approach to optimally allocate the Thyristor Controlled Series Compensator (TCSC) and Unified Power Flow Controller (UPFC) with wind generator under deregulated power system..The double auction bidding model has been incorporated in this paper. The impacts on the locational marginal pricing and system voltage have been also investigated in this work. The effectiveness of the proposed approach for optimal placement of TCSC and UPFC has been tested and analyzed on muddied IEEE 14-bus and muddied IEEE 118-bus systems.

In this paper, addresses the problem of establishing a conceptual frame work using a new intelligent tool of improved ALO algorithm for wind, thermal and hydro integrated generation scheduling problem to maximize the profit of GENCOs in the day-ahead energy and reserve markets. Numerical example with 4 hydro, 3 thermal and 2 wind units with 24 hour test are conceded to illustrate the performance of proposed IALO algorithm.

2. SOLUTION METHODOLOGY

2.1 Overview of Ant Line Optimizer (ALO) algorithm

The ant line optimizer is a meta-heuristic population based search optimization algorithm. This algorithm recently developed by Seyedali Mirjalili [17] in 2014 and used to solve the several Engineering constrained and Non-constrained optimizations problems. The ALO is a trouble-free control parameters algorithm and has colony size, maximum cycle number and less parameter to tune and getting the global optimal solution. It is inspired by life cycle of Antlions (doodlebugs), which belong to the Myrmeleontidae family and Neuroptera order (net-winged insects). The mathematical function and characteristics of ALO is taken from reference [18].

2.2 Improved ALO

In the ALO algorithm, the ants' position updates depend on the random walks around the antlion selected by Roulette wheel and the elite, and the best particle is preserved by setting the elite in the searching process. These make ALO have the advantages of fast calculating speed, high efficiency, and good convergence. But, there are phenomenon of the premature convergence and local optimum for complex optimization problems. Some improvements are added to enhance optimization ability and accuracy in this section [19-20].

2.2.1. Combination with Particle Swarm Optimization

PSO is a stochastic algorithm that is based on group collaboration by simulating the behaviour of birds foraging. As described above, the antlion group is one of crucial parts in the ALO algorithm. So, in this paper, after searching space by ALO, PSO is introduced to optimize and update the current positions of antlions group in each iteration. Through this mechanism, the proposed algorithm has characteristics of both ALO and PSO. The antlions with the ability of communication and memory can move toward the optimal solution faster. In the search strategy of the newly algorithm, the search characteristics of ALO is kept and the communication characteristics of PSO is embedded. This can enhance the search capabilities and improve the searching efficiency in the search period. The searching strategies of PSO are expressed as [1]

$$v_i^{kg+1} = \omega v_i^{kg} + c_1 r_1\left(p_i^{kg} - x_i^{kg}\right) + c_2 r_2\left(BestS_i^{kg} - x_i^{kg}\right) \tag{1}$$

$$x_i^{kg+1} = x_i^{kg} = v_i^{kg+1} \tag{2}$$

Where v_i is the speed of the *i*th particle, x_i is the position of the *i*th particle, p_i is the best previous position of the *i*th particle, Best S is the best previous position among all the particles, k_g is the current iteration, ω is the inertia weight, r_1 and r_2 are two random variables in the range [0,1], c_1 and c_2 are positive constants.

2.2.2. Chaotic Mutation Operator

The mutation operator plays an important role in improving the performance of global searching. It can accelerate the convergence to the optimal solution and maintain the various solutions. In this section, a chaotic mutation operator, namely Logistic map, is incorporated into the improved algorithm and the elite's position is chosen to be modified by the chaotic mutation. The mathematical function can be written as:

$$X_{N+1} = \lambda \times X_N \times (1 - X_N) \qquad 0 < \lambda \le 4 \tag{3}$$

where N is the current iteration number, λ is a constant.

For different λ, the system of equation (3) takes on different characteristics. It is not chaotic when $0 < \lambda < 3$. It starts to cycle when $\lambda > 3$, and it becomes chaotic status when $\lambda = 4$. In this paper, λ is set as 4.

2.2.3. A Serial-Parallel Combined Method to Obtain Mutant Particles

In general, N new particles can be obtained after N mutations of each element in the elite. This commonly used method to get new particles in this case is named parallel method. In this paper, a serial-parallel combined method is proposed. The serial approach is to get the new particles by replacing the corresponding element in the elite with the new mutates element. This new approach ensures stochastic character and increases the diversity of the mutant particles with the same mutation iterations. The procedure is as follows:

(1)Set the elite $x_0 = (x_0(1),.....,x_0(d),....,x_0(dim))$, dim is the dimension of the elite, N_m is the iteration number of chaotic mutation.

(2) Loop A: $k = 1: N_m$

Loop B: $d = 1: dim$

Convert the position of the elite into a chaos vector y_0 in the domain [0,1];

$$y_0(d) = \frac{x_0(d) - lb(d)}{ub(d) - lb(d)} \tag{4}$$

Where $ub(d)$ and $lb(d)$ are, respectively, upper limit and lower limit in the dth dimension.

Get a new element by Logistic map as follows:

$$y_k(d) = 4 \times y_{k-1}(d) \times (1 - y_{k-1}(d)) \tag{5}$$

Where k is the kth iteration, λ is set as 4.

Convert $y_k(d)$ into the actual position as follows:

$$x_k(d) = lb(d) + y_k(d) \times (ub(d) - lb(d)) \tag{6}$$

Replace $x_0(d)$ with $x_k(d)$. Obtain the new particle $x_{new}=(x_0(1),.....,x_0(d),....,x_0(dim))$ and calculate its fitness. If x_{new} is better, replace x_0 with x_{new}.
End Loop B.

Obtain the new particle $x_k=(x_k(1),.....,x_k(d),....,x_0(dim))$ and calculate the fitness. If is better, replace x_0 with x_k Through chaotic mutation and the series-parallel combined method to obtain mutant particles, there is greater possibility to make the elite to overstep the local optimum and get a better solution for the new algorithm.

According to the above improvements to the ant lion optimization (ALO), IALO is summarized below. Figure 2 shows the flowchart of the newly IALO algorithm. In the following sections, IALO will be applied to identify the parameters of HTGS and the identification experiments will be used to demonstrate the validity and feasibility of IALO.

3. PROBLEM FORMULATION

3.1 Objective Function

The main objectives of wind integrates hydrothermal scheduling problem under competitive energy and reserve market is to maximize the total profit of GENCOs. In this model, in order to meet the market need, power generation performed with the combination of wind power units and thermal power units. The profit function is the difference between total revenue and total operating cost of Hydrothermal-wind units. The objective functions are mathematically defined as

$$\mathrm{Pr}\,ofit(i,j,k,t)=\mathrm{Re}\,venue(i,j,k,t)-Total\cos t(i,j,k,t) \quad (7)$$

$$Maximize\ PF=RV-TC \quad (8)$$

The revenue is obtained by sale of wind, hydro and thermal power in the joint energy and reserve market.

$$\begin{aligned}TR=&\sum_{t=1}^{T}\sum_{i=1}^{N_{TG}}\{P_{TG}(i,t).SP(t)\}U(i,t)+\sum_{t=1}^{T}\sum_{i=1}^{N_{TG}}\{P_{TGR}(i,t).RP(t)\}U(i,t)\\&+\sum_{t=1}^{T}\sum_{j=1}^{N_{HG}}\{P_{HG}(j,t).SP(t)\}X(j,t)+\sum_{t=1}^{T}\sum_{k=1}^{N_{WG}}\{P_{WG}(k,t).SP(t)\}V(k,t)\end{aligned} \quad (9)$$

The total operating cost includes power and reserve generation of thermal units, start-up and shut-down cost of thermal units, operating cost and fixed cost of wind generating units.

$$\begin{aligned}TC=&\sum_{t=1}^{T}\sum_{i=1}^{N_{TG}}\{F(P_{TG}(i,t)+P_{TG}R(i,t))+SU_{TG}(i,t)+SD_{TG}(i,t)\}U(i,t)\\&+\sum_{t=1}^{T}\sum_{k=1}^{N_{WG}}\{(P_{WG}(k,t).OCWG(k))+FCWG(k)\}V(k,t)\end{aligned} \quad (10)$$

Mathematical model of Thermal plant

The total operation expense of a system is the fuel cost of thermal plants. The valve-point effects, which make the fuel cost function a non-convex curve, are taken into consideration. The objective function to minimize the fuel cost of thermal plants during the scheduling horizon can be defined by

$$F\left(P_{TG}(i,t)\right)=a(i)P_{TG}^{2}(i,t)+b(i)P_{TG}(i,t)+c(i)+d(i)\sin\left\{e(i)\left[P_{TG}^{\min}(i,t)-P_{TG}(i,t)\right]\right\} \quad (11)$$

Mathematical model of hydro plant

The hydropower generation is a function of water discharge rate and reservoir storage volume, which can be expressed as follows

$$P_{HG}=C_1(j)V_{HG}^{2}(j)+C_2(j)Q_{HG}^{2}(j)+C_3(j)V_{HG}(j)Q_{HG}(j)+C_4(j)V_{HG}(j)+C_5Q_{HG}(j)+C_6(j) \quad (12)$$

3.2 System Constraints

a. Power balance constraints

The sum of power generation committed thermal units and sum of power generation of wind turbine generators are envisages to be lesser than or equal to the system load demand. Hence, the eqn. (6.6) becomes

$$\sum_{i=1}^{N_{TG}}P_{TG}(i,t).U(i,t)+\sum_{j=1}^{N_{HG}}P_{HG}(j,t).X(j,t)+\sum_{k=1}^{N_{WG}}P_{WG}(k,t).V(k,t)\leq P_D(t) \quad (13)$$

b. Spinning reserve constraints

The sum of the reserve power of committed thermal units during the planning period augurs to be less than or equal to total spinning reserve of the power plants and is mathematically defined as in equation (6)

$$\sum_{i=1}^{N_{TG}}P_{TG}(i,t).U(i,t)\leq SR(t) \quad (14)$$

$$0\leq R_{TG}(i,t)\leq\left[P_{TG}^{\max}(i,t)-P_{TG}^{\min}(i,t)\right] \quad (15)$$

$$R_{TG}(i,t)+P_{TG}(i,t)\leq P_{TG}^{\max}(i,t) \quad (16)$$

3.3 Thermal Generator Constraints

c. Thermal unit generation limits

Each thermal generator generate the power of $P_{TG}^{\min}$ to $P_{TG}^{\max}$ and given in eqn. (26)

$$P_{TG}^{\min}(i,t).U(i,t)\leq P_{TG}(i,t)\leq P_{TG}^{\max}(i,t).U(i,t) \quad (17)$$

d. Thermal unit up/down spinning reserve contribution constraints

The thermal unit up/down spinning reserve contribution constraints are shown in eqn. (27) to (30).

$$US(i,t) \le \min\{US_{\max}(i), P_{\max}(i,r) - P_{TG}(i,t)\} \tag{18}$$

$$DS(i,t) \le \min\{DS_{\max}(i), P_{TG}(i,t) - P_{\min}(i,r)\} \tag{19}$$

Where

$$US_{\max}(i) \le d\% \times P_{\max}(i,r) \tag{20}$$

$$DS_{\max}(i) \le d\% \times P_{\min}(i,r) \tag{21}$$

e. Thermal unit minimum up/down time constraints

The thermal unit minimum up/down time constraints is mathematically described by eqn. (31) and eqn. (32).

$$[t_{ON}(i,(t-1)) - MU(i)] \times [U(i,(t-1)) - U(i,t)] \ge 0 \tag{22}$$

$$[t_{OFF}(i,(t-1)) - MU(i)] \times [U(i,t) - U(i,(t-1))] \ge 0 \tag{23}$$

f. Thermal unit ramp up/down capacity constraints

The thermal unit ramp up/down capacity constraints are written using eqn. (33) and eqn. (34).

$$UR(i,t) = \min\{UR_{\max}(i), P_{\max}(i,r) - P_{TG}(i,t)\} \tag{24}$$

$$DR(i,t) = \min\{DR_{\max}(i), P_{TG}(i,r) - P_{\min}(i,t)\} \tag{25}$$

3.4 Hydro Generator Constraints

g. Water discharge constraints

The water discharge rate of turbine must be within the maximum and minimum operating limits given by $Q_{HG}^{\min}(j)$ and $Q_{HG}^{\max}(j)$ espectively

$$Q_{HG}^{\min}(j) \le Q_{HG}(j,t) \le Q_{HG}^{\max}(j) \tag{26}$$

h. Storage volume constraints

The operating volume of the reservoir storage must lie in between the maximum and minimum capacity limits given by $V_{HG}^{\min}(j)$ and $V_{HG}^{\max}(j)$ respectively.

$$V_{HG}^{\min}(j) \le V_{HG}(j,t) \le V_{HG}^{\max}(j) \tag{27}$$

3.5 Wind Generator Constraints

i. Wind power curve constraints.

The wind power generation of K^{th} units as follows

$$P_{WG}{}^{*}(k,t)=\begin{cases}0, & v(t)\le v(I,k) or v(t)>v(O,k)\\ \varphi(k,v(t)), & v(I,k)\le v(t)\le v(R,k)\\ P_{WG}^{\max}(k), & v(R,k)\le v(t)\le v(O,k)\end{cases} \quad (28)$$

Where

$$\varphi(j,v(t))=P_{WG}^{\max}(j)\left[A+Bv(t)+Cv(t)^{2}\right]$$ and A, B, C are the constants (29)

j. Total available wind power generation

The total available power is equal to sum of power generation of wind units and it represented in eqn. (39).

$$P_{WGT}^{*}(t)=\sum_{j=1}^{N_{WG}}P_{WG}^{*}(j,t) \quad (30)$$

k. Total actual wind power generation limit

Wind power generated between zero to actual wind power is written in using eqn. (40).

$$0\le P_{WGT}(t)\le P_{WGT}^{*}(t) \quad (31)$$

l. Wind power generation fluctuation constraints

The fluctuation of wind power is mathematically represented by eqn. (41) and eqn.(42).

$$P_{WGT}(t)-P_{WGT}(t-1)\le SDR(t), if P_{WGT}(t-1)\le P_{WGT}(t) \quad (32)$$

$$P_{WGT}(t-1)-P_{WGT}(t)\le SUR(t), if P_{WGT}(t-1)\ge P_{WGT}(t) \quad (33)$$

4. EXECUTION OF IMPROVED ALO ALGORITHM FOR OPTIMAL GENERATION SCHEDULING OF GENCOs

The technical steps of the proposed algorithm are as follows

4.1 Evaluation and selection of hydro, thermal and wind Variables

Step 1: Read the system data (Forecasted load and reserve demand, market price) and generator data of hydro, thermal and wind test system..

Step 2: Initialize the proposed IALO algorithmic parameters such as population size NP, maximum number of generation G, probability of the crossover rate CR and mutation rate MR.

Step 3: Randomly initialize the population of all dependent variables like water discharge rate, thermal plant generation outputs and velocity of the wind units.

$$Q_{HG}(j,t)=rand\left(Qj^{\min}-Qj^{\max}\right) \quad (34)$$

$$P_{TG}(i,t) = rand\left(Pi^{\min} - Pi^{\max}\right) \tag{35}$$

$$V_{WG}(k,t) = rand\left(Vk^{\min} - Vk^{\max}\right) \tag{36}$$

Step 4: Determine water discharge rate for the last interval of time while satisfying the initial and final reservoir constraints using the following equation.

$$Q_{HG}(j,t) = V_{HG}^{begin}(j) - V_{HG}^{end}(j) - \sum_{j=1}^{T-1} Q_{HG}(j,t) + \sum_{j=1}^{T} I_{HG}(j,t) + \sum_{k=1}^{Ru_i}\sum_{j=1}^{T}\left(Q_{HG}(k,j) - Td(k,i)\right) \tag{37}$$

Step 5: Check the water discharge for its minimum and maximum limits. If it is less than the minimum limits it is made equal to its minimum value and if it is greater than maximum limit it is made equal to maximum limit.

Step 6: Compute the reservoir water storage volume of j^{th} hydro plant for t^{th} time interval using equation.

$$V_{HG}(j,0) - V_{HG}(j,T) = \sum_{t=1}^{T}\sum_{I=1}^{Rui} Q_{HG} I(t - t1j) - \sum_{j=1}^{T} I_{HG}(j,t) \tag{38}$$

Step 7: Check for the operating limits of water storage volume.

$$V_{HG}(j,t) = V_{HG}^{\min}(j) \quad \text{if} \; V_{HG}(j,t) \le V_{HG}^{\min}(j) \tag{39}$$

$$V_{HG}(j,t) = V_{HG}^{\max}(j) \quad \text{if} \; V_{HG}(j,t) \ge V_{HG}^{\max}(j) \tag{40}$$

Step 8: Estimate the hydro power generation of j^{th} hydro plant for t^{th} time interval using equation (21).

Step 9: Check it for its minimum and maximum limits.

$$P_{HG}(j,t) = P_{HG}^{\min}(j) \quad \text{if} \; P_{HG}(j,t) \le P_{HG}^{\min}(j) \tag{41}$$

$$P_{HG}(j,t) = P_{HG}^{\max}(j) \quad \text{if} \; P_{HG}(j,t) \ge P_{HG}^{\max}(j) \tag{42}$$

Step 10: Compute the hydro wind power generation of k^{th} hydro plant for t^{th} time interval using equation (51)

$$P_{WG}{}^{*}(k,t) = \begin{cases} 0, & v(t) \le v(I,k) or v(t) > v(O,k) \\ \varphi(k, v(t)), & v(I,k) \le v(t) \le v(R,k) \\ P_{WG}^{\max}(k), & v(R,k) \le v(t) \le v(O,k) \end{cases} \tag{43}$$

Step 11: The thermal and wind generation of plants can be estimated using equation (2i) and (51) by subtracting hydro generation from the power demand by neglecting transmission losses.

$$\sum_{i=1}^{N_{TG}} P_{TG}(i,t) + \sum_{j=1}^{N_{HG}} P_{HG}(j,t) + \sum_{k=1}^{N_{WG}} P_{WG}(k,t) - P_D(t) \le 0 \tag{44}$$

Step 12: Check the inequality constraints of thermal power, if it is less than minimum limits it is made equal to its minimum value and if it is greater than maximum limit it is made equal to maximum limit.

4.2 Implementation of IALO algorithm

Step 13: Initialization. Randomly initialize the positions of ants and antlions.

$$\begin{bmatrix} P_{TG1}, P_{TG2}, \ldots\ldots, P_{TGi}, \ldots\ldots, P_{TGN_{TG}}, Q_{HG1}, Q_{HG2}, \ldots\ldots, Q_{HGj}, \ldots\ldots, Q_{HGN_{HG}}, \\ V_{WG1}, V_{WG2}, \ldots\ldots, V_{WGk}, \ldots\ldots, V_{WGN_{WG}} \end{bmatrix}^T \tag{45}$$

Where

$$P_{TGi1} = \left[P_{TGi1}, P_{TGi2}, \ldots, P_{TGit} \ldots, P_{TGiT}\right] \tag{46}$$

$$Q_{HGj1} = \left[Q_{HGj1}, Q_{HGj2}, \ldots, Q_{HGjt} \ldots, Q_{HGjT}\right] \tag{47}$$

$$V_{WGk1} = \left[V_{WGk1}, V_{WGk2}, \ldots, V_{WGkt} \ldots, V_{WGkT}\right]$$

Step 14: Calculate the fitness of the antlions and choose the antlion whose fitness is best as the elite.

Step 15: Select an antlion using Roulette wheel and calculate the random walks around the chosen antlion and the elite. Update the ants' position..

Step 16: Repeat Step 3 until the positions of all the ants are updated.

Step 17: Update the antlions' positions with Equation (1). Compare fitnesses of the new antlions with the fitness of the elite. If the antlion has better fitness than the elite, then the elite will be replaced by the position of the antlion.

Step 18: PSO is adopted to search better antlions with Equations (1) and (2). Update the elite.

Step 19: Chaotic mutation is conducted for the elite and gets the mutant particles using a serial-parallel combined method with Equations (4)–(6).

Step 20: Repeat Step 14 to Step 18 until the stop criteria are met.

5. RESULTS AND DISCUSSION

In order to prove the performance and efficiency of the proposed IALO algorithm, it has been applied on a test system to solve generation scheduling problem for maximizing the GENCOs profit under deregulated environment. The proposed test system consists of hydro, wind and thermal units with valve point loading effect. The proposed algorithm is programmed in MATLAB 14.0 and numerical simulations are carried out in a computer with i3 processor, Intel (R), core (i3), is 2.40 GHz, 4GB RAM.

In this assignment, a test system has been considered, to illustrate the proposed ITLBO based wind integrated hydrothermal scheduling problem. The data for valve point loading effect of thermal units are adopted from the reference [21]. The proposed test system consists of a multi-chain cascade of four hydro plants, two wind and three thermal units

In order to maximize the profit of GENCOs, the wind, hydro and thermal system need proper scheduling that must satisfy constraints such as Power balance, Generator limits of wind, hydro and thermal units, water storage and discharge limits of hydro units and wind power curve constraints. So it is recommended that the improved ALO can directly solve to solve the optimal scheduling problem considering the valve-point loading effect of thermal units.

The characteristic of the hydro power plant is described by considering the reservoir storage limits, plant discharge limits, generation limits and the initial and final station of reservoir. The corresponding data is taken from same reference [21] and it is provide power generation coefficients of hydro generation units and thermal plants. Hour-by-hour forecasted load demand, Reserve demand and market price of power system is taken from reference [12].

This problem is analyzed in two different cases to maximize the [profit of GENCOs such as

- Case - 1:Wind integrated Hydrothermal generation scheduling without reserve power generation
- Case - 2: Spinning reserve constrained Wind integrated Hydrothermal generation scheduling.

Case- 1

In the first case, load demand and fore casted market price only used to determine profit of GENCOs by the optimal schedule of the thermal, hydro and wind turbine units. The maximum power demand of 1150 MW is predicted for the test system at 12th hour in the scheduled time period. Here, the wind, Hydro and thermal units dispatch power is lesser than or equal to the forecasted load demand.

The powerful searching operators of the IALO effectively optimize the system variables of water discharge, water storage volume, wind speed and real power of thermal units with help of PSO algorithm. A chaotic mutation operation is applied for the elite to break out of the local optimum and obtain the global optimal solutions. The optimized parameters of best water discharge and storage volume for 24 hour time period is presented in

Table 1. The hydro power generation is obtained by the optimized value of water discharge and storage volume of four hydro plants. The optimal generation scheduling of four hydro power generations, two wind power units and three thermal power generations is shown in Table 2. In this paper, unit commitment process is done for thermal units. From table 6, the thermal unit 1 should be de-committed for entire planning period because of its high start-up cost.

Table 1 Water discharge and water storage volume of proposed test system

Hour (h)	Water Discharge ($* 10^4 m^3$)				Volume ($* 10^4 m^3$)			
	Plant1	Plant2	Plant3	Plant4	Plant1	Plant2	Plant3	Plant4
1	15.5000	15.3760	30.4970	22.6540	95.0000	73.1240	148.1030	100.6460
2	15.8790	15.4950	30.4980	24.0530	89.5000	65.7480	125.7060	80.7920
3	15.5000	15.4500	30.4990	25.5000	83.0210	60.0000	113.0080	70.0000
4	15.4580	15.4710	30.4960	25.4970	80.0000	60.0000	102.4090	70.0000
5	12.3750	15.8390	30.9000	13.9290	80.0000	60.0000	104.7680	70.0000
6	13.1310	15.2780	21.8380	13.3290	80.0000	60.0000	107.8630	86.5680
7	15.8970	15.9000	20.1290	13.3040	80.0000	60.0000	120.9330	103.7370
8	15.4880	15.4650	22.5270	14.6130	80.0000	60.0000	131.6500	120.3320
9	8.1780	15.4990	19.4620	15.9770	80.0000	60.0000	140.0930	136.2150
10	14.9380	15.4750	19.2320	17.1570	81.8220	60.0000	152.8060	151.1380
11	15.8020	15.6130	20.8740	19.1690	80.0000	60.0000	165.9620	155.8190
12	15.4730	15.5000	21.9000	19.7380	80.0000	60.0000	169.7310	156.7790
13	12.6040	15.2310	20.8750	19.3900	80.0000	60.0000	180.2680	159.5680
14	15.0000	15.4060	20.2710	19.9650	80.0000	60.0000	194.6700	159.6400
15	15.3170	15.6870	24.0970	19.7760	80.0000	60.0000	208.4850	158.9070
16	15.3940	15.4560	19.9860	22.9850	80.0000	60.0000	215.4920	160.0000
17	15.4990	15.2540	20.6010	19.9940	80.0000	60.0000	227.7370	158.9150
18	14.6080	15.0750	19.7230	20.2760	80.0000	60.0000	239.8590	159.7960
19	14.2530	15.2850	18.3660	23.7090	80.0000	60.0000	240.0000	159.7910
20	15.1730	13.8460	16.9250	21.2320	80.0000	60.0000	240.0000	160.0000
21	14.8630	15.3000	16.1610	18.9020	80.0000	60.0000	240.0000	158.7540
22	15.3000	15.2920	30.3000	24.1530	80.0000	60.0000	240.0000	160.0000
23	15.8910	12.3040	15.7160	24.4450	80.0000	60.0000	240.0000	155.5700
24	5.9000	6.9000	16.2010	25.9000	80.0000	60.0000	240.0000	149.4910

Table 2 Hydro, wind and thermal power generation of proposed test system without reserve power generation

Hour (h)	Hydro power (MW)				Wind power (MW)		Thermal power (MW)		
	Ph1	Ph2	Ph3	Ph1	Pw2	PW3	Ps1	Ps2	Ps3
1	95.8650	83.9838	0.0000	244.1652	41.5693	37.7039	0.0000	0.0000	246.7128
2	92.6263	78.1170	0.0000	216.6198	44.729	37.7039	0.0000	0.0000	310.2102
3	88.4702	73.0693	0.0000	199.7175	46.2842	37.7039	0.0000	0.0000	254.7550
4	86.4403	73.0928	0.0000	199.7173	47.8286	36.0062	0.0000	0.0000	206.9148
5	84.2509	73.4634	0.0000	157.2865	49.3511	29.5781	0.0000	0.0000	276.0699
6	85.5267	72.8660	10.7263	174.8609	47.8286	29.5781	0.0000	0.0000	378.6135
7	86.1027	73.5170	26.3496	200.7673	41.5693	29.5781	0.0000	251.2702	240.8457
8	86.4224	73.0861	17.8550	225.7005	41.5693	37.7039	0.0000	272.5976	255.0651
9	68.4377	73.1239	37.2305	253.7923	44.7229	46.4599	0.0000	295.7415	270.4913
10	87.8488	73.0973	42.6416	278.0692	49.3511	55.1571	0.0000	252. 242	241.5400
11	86.1895	73.2455	39.7996	296.6432	56.4639	55.1571	0.0000	251.4905	241.0108
12	86.4314	73.1250	35.8648	301.1339	56.4639	69.6196	0.0000	272.4274	254.9340
13	84.6881	72.8074	43.9191	301.8394	62.2912	69.6196	0.0000	240.9046	233.9307
14	86.6200	73.0189	49.8969	305.4252	62.2912	69.6196	0.0000	0.0000	383.1282
15	86.5144	73.3202	33.7891	303.5465	62.2912	69.6196	0.0000	0.0000	380.9189
16	86.4760	73.0760	54.6082	320.9090	62.2912	69.6196	0.0000	0.0000	393.0200
17	86.4156	72.8362	53.9404	304.8544	56.4639	55.1571	0.0000	208. 253	212.1270
18	86.6339	72.6033	57.8785	307.4006	56.4639	46.4599	0.0000	251.5351	241.0249
19	86.5350	72.8746	61.3698	323.4585	49.3551	46.4599	0.0000	213.9681	215.98300
20	86.5728	70.4849	63.8588	312.8229	49.3551	37.7039	0.0000	213.5304	215.6752
21	86.6395	72.8930	64.6731	297.8875	41.5693	37.7039	0.0000	0.0000	308.6337
22	86.522	72.8832	0.0000	325.2391	41.5693	36.0062	0.0000	0.0000	297.7799
23	86.1084	66.5451	64.9860	321.0803	41.5693	34.3393	0.0000	0.0000	235.3716
24	53.6598	41.4770	64.6391	317.4123	41.5693	36.0062	0.0000	0.0000	245.2362

Table 3 Simulation results of proposed test systems without reserve power generation

Hour (h)	Load Demand (MW)	Revenue ($)	Thermal cost ($)	Wind cost ($)	Profit ($)
1	750	16612.50	759.3980	641.6790	15211.40
2	780	17160.00	945.7070	665.3300	15548.90
3	700	16170.00	782.3360	677.0400	14710.60
4	650	14722.50	648.7420	673.7690	13400.00
5	670	15577.50	844.0690	628.9410	14104.50
6	800	18360.00	1160.1100	617.5220	16582.40
7	950	21375.00	1508.8700	570.5780	19295.60
8	1010	22371.50	1609.9600	641.6790	20119.90
9	1090	24852.00	1721.3600	741.9450	22388.70
10	1080	31698.00	1513.7200	852.7580	29331.50
11	1100	33165.00	1509.9600	906.1040	30748.90
12	1150	36397.50	1609.1000	1032.6500	33755.80
13	1110	27306.00	1460.2700	1076.3600	24769.40

14	1030	25235.00	1174.7500	1076.3600	22983.90
15	1010	22725.00	1167.5800	1076.3600	20481.10
16	1060	23638.00	1207.0400	1076.3600	21354.16
17	1050	23362.50	1309.3500	906.1040	21147.00
18	1120	24696.00	1510.1200	830.0030	22355.90
19	1070	23754.00	1335.7300	776.6570	21641.60
20	1050	23782.50	1333.6800	700.0420	21748.80
21	910	21021.00	941.0130	641.6790	19438.30
22	860	19737.00	908.3470	626.8250	18201.80
23	850	19337.50	727.3800	612.2390	17997.90
24	800	18040.00	755.2070	625.8250	16658.00
Total profit ($)					**493980.00**

Table 3 explains the simulation results of 3 thermal, 4 hydro and 2 wind test system. It includes power demand, thermal cost, wind cost, total operating cost, revenue and profits of hydro, thermal and wind generating units for 24 hours time period. The obtained total profit is $ 493980.00 and computational time is 102 sec.

Case - 2

In the second case, spinning reserve has been included in the objective function. The revenue obtained from sale of generated power and reserve allocation and the profit of GENCOs are calculated in both energy and reserve market. The additional spinning reserve requirement is assumed to be 10% of forecasted load demand and reserve prices are taken as 10% of actual energy prices. The average operation and maintenance cost of a wind turbine generator is 1.25%of the capital cost. Power generation and reserve allocation of wind integrated hydrothermal system are presented in Table 4.

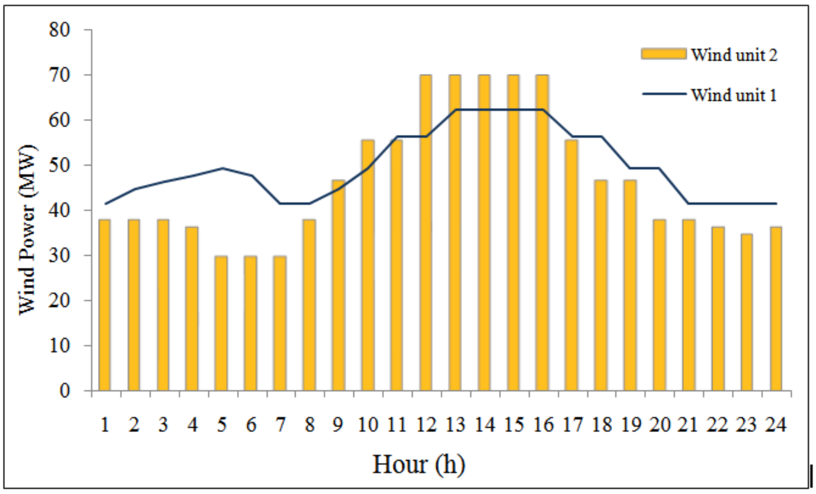

Fig.1. Power generation of two wind farm

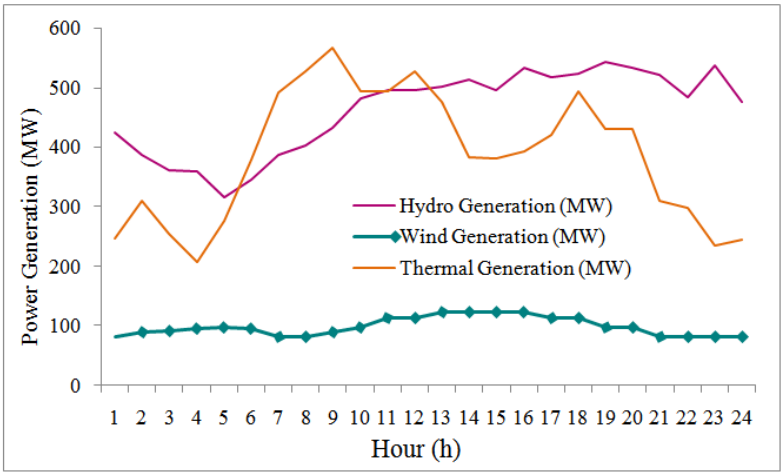

Fig.2. Power generation of thermal, hydro and wind farm

The IALO operators optimize the hydro, thermal and wind variables also considering the reserve demand and reserve price of the proposed test system and determine fitness value of objective function. Also satisfy the standard system and unit constraints of wind, hydro and thermal units. The graphical representation of power generation of two wind farm is displayed in fig. 1. The total thermal, hydro and wind power generation for 24 hour time period are obtained by proposed method and shown in fig. 2.

Table 4 Hydro, wind and thermal power generation of proposed test system considering reserve power generation

Hour (h)	Hydro power (MW)				Wind power (MW)		Thermal power (MW)			Reserve power (MW)		
	Ph1	**Ph2**	**Ph3**	**Ph1**	**Pw1**	**Pw1**	**Ps1**	**Ps2**	**Ps3**	**Rs1**	**Rs2**	**Rs3**
1	95.8650	83.9838	0.0000	244.1652	41.5693	37.7039	0.0000	0.0000	321.7128	0.0000	0.0000	75.0000
2	92.4322	78.5447	0.0000	217.0776	44.7229	37.7039	0.0000	0.0000	387.5189	0.0000	0.0000	77.3087
3	88.2025	73.0693	0.0000	199.7175	46.2842	37.7039	0.0000	0.0000	325.0227	0.0000	0.0000	70.2677
4	86.4403	73.0928	0.0000	199.7173	47.8286	36.0062	0.0000	0.0000	271.9148	0.0000	0.0000	65.0000
5	83.8331	73.2721	0.0000	155.8233	49.3511	29.5781	0.0000	0.0000	345.1422	0.0000	0.0000	69.0723
6	85.5267	72.8660	11.0320	175.1169	47.8286	29.5781	0.0000	0.0000	458.0518	0.0000	0.0000	79.4383
7	86.5236	72.8930	29.4335	196.4524	41.5693	29.5781	0.0000	300.0000	288.5501	0.0000	48.7298	47.7044
8	86,5276	72.8499	19.5174	225.3746	41.5693	37.7039	0.0000	300.0000	327.4574	0.0000	27.4024	72.3923
9	67.3148	72.8918	38.4314	253.6878	44.7229	46.4599	0.0000	300.0000	375.4914	0.0000	4.2585	105.0001
10	87.8787	73.4953	41.2346	282.4012	49.3511	55.1571	0.0000	300.0000	298.4820	0.0000	58.4600	56.9420
11	86.5625	72.5181	42.3299	293.7416	56.4639	55.1571	0.0000	300.0000	303.2269	0.0000	48.5095	62.2161
12	86.1253	73.5170	33.5834	304.5226	56.4639	69.6196	0.0000	300.0000	341.1683	0.0000	27.5726	86.2343
13	85.3459	73.2640	41.9074	304.7107	62.2912	69.6196	0.0000	300.0000	283.8613	0.0000	59.0954	49.9306
14	86.6432	72.7757	50.4204	304.0231	62.2912	69.6196	0.0000	0.0000	487.2269	0.0000	0.0000	104.0987
15	86.5909	73.1106	34.728	302.7338	62.2912	69.6196	0.0000	0.0000	481.9321	0.0000	0.0000	101.0132
16	86.3530	73.2893	53.8726	321.7105	62.2912	69.6196	0.0000	0.0000	498.8638	0.0000	0.0000	105.8438
17	86.5227	72.5747	54.6414	303.8672	56.4639	55.1571	0.0000	271.4656	254.3074	0.0000	59.3386	42.1804
18	86.5602	73.3083	55.9580	310.9480	56.4639	46.4599	0.0000	300.0000	302.3017	0.0000	48.4649	61.2768
19	86.6388	73.3182	60.4579	324.1789	49.3511	46.4599	0.0000	277.9647	258.6304	0.0000	63.9966	42.6474
20	86.5728	70.4849	63.8588	311.7486	49.3511	37.7039	0.0000	277.1608	258.1191	0.0000	63.6304	42.4439
21	86.4374	73.5170	64.0631	600.8857	41.5693	37.7039	0.0000	0.0000	396.8236	0.0000	0.0000	88.1899
22	86.4150	73.1162	0.0000	324.5675	41.5693	36.0062	0.0000	0.0000	384.3257	0.0000	0.0000	86.5458
23	86.1084	66.5451	64.9860	320.1872	41.5693	34.3393	0.0000	0.0000	321.2647	0.0000	0.0000	85.8931
24	50.6150	38.9250	64.9354	316.1227	41.5693	36.0062	0.0000	0.0000	331.8263	0.0000	0.0000	86.5901

Table 5 Simulation results of proposed test system considering reserve power generation

Hour (h)	Load and Reserve Demand (MW)	Revenue ($)	Thermal cost ($)	Wind cost ($)	Profit ($)
1	825	18273.80	980.8460	641.6790	16651.20
2	858	18876.00	1189.0500	665.3300	17021.60
3	770	17787.00	991.0070	677.0400	16119.10
4	715	16194.80	831.9280	673.7690	14689.10
5	737	17135.30	1053.4800	628.9410	15452.80
6	880	20196.00	1426.6300	617.5220	18151.90
7	1045	23512.50	1786.8500	570.5780	21155.10
8	1111	24608.60	1904.5000	641.6790	22062.50
9	1199	27337.20	2056.0200	741.9450	24539.20
10	1188	34867.80	1816.4500	852.7580	32198.60
11	1210	36481.50	1830.7000	906.1040	33744.70
12	1265	40037.30	1947.0500	1032.650	3705.60
13	1221	30036.60	1772.9700	1076.360	27187.30
14	1133	27758.50	1529.2600	1076.360	25152.90
15	1111	24997.50	1510.4500	1076.360	22410.70
16	1166	26001.80	1570.9100	1076.360	23354.50
17	1155	25698.80	1604.5500	906.1040	23188.10
18	1232	27165.60	1827.9100	830.0030	24507.70
19	1177	26129.40	1635.600	776.6570	23717.10
20	1155	26160.80	1631.8200	700.0420	23828.90
21	1001	23123.10	1219.5300	641.6790	21261.90
22	946	21710.70	1178.6400	626.8250	19905.20
23	935	21271.30	979.4720	612.2390	19679.50
24	880	19844.00	1012.0000	626.8250	18205.20
	Total profit ($)				**541240.00**

Table 6 Comparison of fuel cost of proposed with existing methods

Method	Best total fuel cost, $
IALO	**63963.0000**
MPSO [21]	66,083.6629
PSO [21]	68,646.8010
GA [21]	71016.9724
His [21]	71300.9716
JAYA [21]	85394.0271

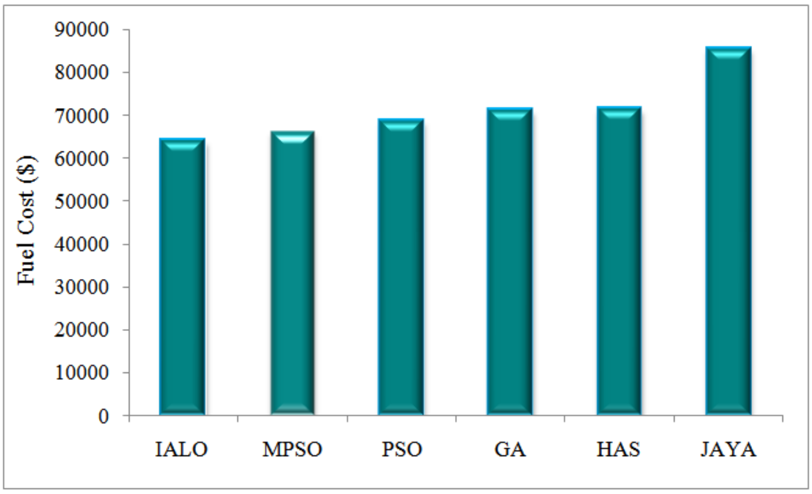

Fig.3. Comparison of fuel cost of proposed with existing methods

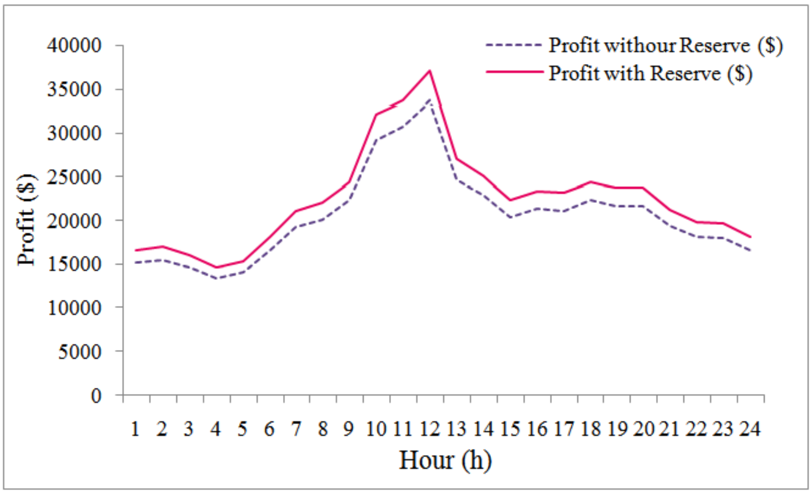

Fig.4. Comparison of profit of with and without reserve power generation

The simulation results of spinning reserve constrained proposed system is reported in Table 5. This table lists out the revenue, thermal cost, wind cost and profits of GENCOs under energy and reserve market. The total profit of proposed system is $ 541240.00 and computational time is 120 sec. The comparative studies are made to prove effectiveness of proposed method. The total operating cost of proposed with existing methods such as MPSO, PSO, GA, HSA and JAYA are compared and displayed in Table 6 and graphically represented in fig. 3. The comparison of profit of with and without reserve power generation of the test systems are shown in fig. 4. From the results, we come to know that the suggested algorithm provides maximized profit, minimum fuel cost and less computational burden when compared with existing literature.

6. CONCLUSION

This article contributes the solution of price based generation scheduling problem to maximize the profit of GENCOs under competitive environment. This paper has been integrating the renewable energy source of wind and hydro generating units with thermal power plants. The problem has been solved considering reserve power generation and valve point loading effect. The suggested improved ALO is proposed to solve this problem. The problem is modelled as stochastic optimization problem that is maximize the profit of GENCOs subjected to standard prevailing wind, hydro and thermal constraints. By integrating hydro, wind and thermal system, the profit is more when compared with using thermal generators alone for power generation. Case study with 3 thermal, 4 hydro and 2 wind units with 24 hour time period is considered to validate the performance of applied Imposed ALO. The simulation results are compared with other evolutionary programming techniques From the comparisons, this approach is one of the best and reliable approach for solving of engineering optimization problems.

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