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Antlion Optimization Algorithm for Optimal Self-Scheduling Unit Commitment in Power System Under Uncertainties

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Abstract- *optimal and economic operation is one of the main topics in power systems. In this paper, a stochastic single objective framework for GenCo's optimal self-scheduling unit commitment under the uncertain condition and in the presence of SH units is proposed. In order to solve this problem, a new meta-heuristic optimization technique named antlion optimizer (ALO) has been used. Some of the capabilities of the ALO algorithm for solving the optimization problems included : (1) the exploration and utilization, (2) abiding convergence, (3) capable of maintaining population variety, (4) lack of regulation parameters, (5) solving problems with acceptable quality. To approximate the simulation conditions to the actual operating conditions, the uncertainties of the energy price, spinning and non-spinning reserve (operating services) prices, as well as the renewable energy resources uncertainty, are considered in the proposed model. The objective function of the problem is profit maximization and modeled as a mixed-integer programming (MIP) problem. The proposed model is implemented on an IEEE 118-bus test system and is solved in the form of six case studies. Finally, the simulation results substantiate the strength and accuracy of the proposed model.*

Keyword: Antlion optimization algorithm, Hydro-thermal self-scheduling, Price uncertainty, WP and PV power uncertainty, SH power plant.

NOMENCLATURE

Indices

t	Time interval index(hour)
s	Scenario index
v	photovoltaic unit index
q	small hydro unit index
w	Wind unit index
i	Thermal unit index
h	Hydro unit index

Parameters

SDC^{i}	Shut-down cost of unit i ($)
SUC^{h}	Start-up cost of unit h ($)
n^{AL}	Number of antlion
Ic	Fixed ratio
γ	Repetition in progress
λ	Maximum number of repetitions
α^{r}	Fixed value based on running iteration
$\pi^{b,t}$	Bilateral contract price ($/MWh)
$N^{bp,l}$	Number of blocks in piecewise linearization of start-up fuel function
N^{p}	Number of price levels
$RDL^{n,i}$, $RUL^{n,i}$	Ramp down and Ramp up limits for block n (MW)
SUE^{i} , SDE^{i}	Start-up and shut-down emissions generated by unit i (lbs)
t	The walk step random (t^{th} repeat in time)
M^{ANT}	The position of each ant
A^{ij}	Indicator j^{th} variable ant i^{th}
n_{A}	Number of ant
M^{OA}	Storages the value of each ant's fitness function
$M^{Antlion}$	The position function matrix of each ant
M^{OAL}	The objective function matrix of each ant
$SUR^{i}_{i,i}$,$SDR^{i}_{i,i}$	Start-up and shut-down ramp rate limits of unit i (MW/h)
RDLPi,t,s ,RULPi,t,s	Ramping down and ramping up limits of unit i (MW)
$p^{b,t}$	Power capacity of bilateral contract (MW)
p^{s}	Probability of scenario s
$p^{nr,s}$	Normalized probability of scenario s
$p^{max,i}$, $p^{min,i}$	Maximum and Minimum power output of unit i (MW)
$p^{min,h,n}$	Minimum power output of unit h for performance curve n (MW)
$p^{c,h}$	Capacity of unit h (MW)
AL^{ij}	Dimension j^{th} antlion i^{th}
$Antlion^{\gamma,j}$	The position of the j^{th} antlion in duplicate γ^{th}
$Ant^{\gamma,j}$	Ant i^{th} in repetition γ^{th}
$R^{\gamma,A}$	Random movement around antlions by roulette wheel in t^{th} repeat
$R^{\gamma,E}$	Random movement around elite mode in t^{th} repeat
$Ant^{\gamma,i}$	Indicates the ant i^{th} position in the t^{th} repeat
$p^{d,n,i}$	Lower limit of the n^{th} prohibited operating zone of unit i (MW)

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$p^{u,n-1,i}$	Upper limit of the (n – 1)th prohibited operating zone of unit i (MW)
$Q_{max}^{out,h}$	Maximum water discharge of unit h (m^3/s)
$Q_{min}^{out,h}$	Minimum water discharge of unit h (m^3/s)
$b^{n,i}$	Slope of block n in the fuel cost curve of unit i ($/MWh)
$b^{n,h}$	Slope of the volume block n of the reservoir associated with unit h ($m^3/s/Hm^3$)
$b^{n\,h\,k}$	Slope of block n in the performance curve k of unit h ($MW/m^3/s$)
e^i, f^i	Valve loading cost coefficients
A^W	Represents the whole covered area of wind units
η	Efficiency of generator and wind turbine inverter
N^{WG}	Denotes the number of important generators corresponding to wind turbines
$F_{Pu,n-1,i}$	Cost of generation of n-1th upper limit in fuel cost curve of unit i ($/h)
$Rain^{h,t,s}$	Forecasted natural water inflow of the reservoir associated with unit h (Hm^3/h)
L	Number of performance curves
Np^i	Number of prohibited operating zones
$vol^{max,h,x}$	Maximum volume of the reservoir h associated to the nth performance curve (Hm^3)
$vol^{min,h,x}$	Minimum volume of the reservoir associated to unit h (Hm^3)
V	Wind speed (m/s)
p^r	Rated out power (KW)
v^{in}	Cut-in speed (m/s)
v^{out}	Cut-out speed (m/s)
v^r	Rated output speed (m/s)
p	Wind power generation (KW)
p^w	Solar irradiance in standard environment (1000 W/m^2)
$R^{cr,t}$	Certain irradiance point (150 W/m^2)
$p^{e,rpo}$	Rated output power of the solar PV unit
β_t	Solar irradiation forecast in W/m^2
η^{SH}	Efficiency of turbine generator (0.85)
ρ^{SH}	Water density (1000 kg/m^3)
g^{SH}	Acceleration due to gravity (9.81 m/s^2)
H^{SW}	Effective pressure head (25m)
Q^{SHW}	Water flow rate

Sets

I	Thermal units
T	Periods of market time horizon
W	Wind units
H	Hydro units
S	Scenario

Binary variables

$\delta^{n,i,t,s}$	1 If Block n in fuel cost curve of unit i is selected
$\delta^{n,i,h,s}$	1 If The volume of reservoir water is greater than v_n (h)
$Z^{i,t,s}$	1 If Thermal unit i is started-up
$I^{h,t,s}$	1 If Hydro unit h is started-up
$Y^{i,t,s}$	1 If Unit i is shut-down
$\chi^{n,i,t,s}$	1 If The power output of unit i exceeds block n of the valve loading effects curve
$I^{i,t,s}$	1 If Unit i is online
$I^{h,t,s}$	1 If Unit h is online
$I^{d,i,t,s}$	1 If Unit *i* provides non-spinning reserve when the unit is off

List of abbreviations

ST-HTS	Short-term hydro-thermal scheduling
SHTSS	Stochastic hydro-thermal self-scheduling
LMCS	Lattice monte carlo simulation
RWM	Roulette wheel mechanism
MIP	Mixed integer programming
PDF	Probability distribution function
SHPPs	Small-hydro power plants
RERs	Renewable energy resources
PV	Photovoltaic
SH	Small hydro
HTSS	Hydro-thermal self-scheduling
HT	Hydro-thermal
WP	Wind Power
VLC	Valve loading cost
SS	Self-scheduling
HTWSS	Hydro-thermal-wind self-scheduling
PFM	profit maximum

1. INTRODUCTION

The regular unit Commitment is the problem of determining the schedule of generating units. Besides achieving the minimum operating cost, generation schedule needs to satisfy several operating constraints. These constraints reduce freedom in the choice of starting up and shutting down generating units. The constraints to be satisfied are usually the status restriction of individual generating units, minimum up-time, minimum down-time, capacity limits, generation limit for the first and last hour, limited ramp rate, group constraint, power balance constraint, spinning reserve constraint, and etc. The high dimensionality and combinatorial nature of the UC problem have led to numerous researches in this field in recent years. In this regard, in Ref. [3], a stochastic optimization framework for short-term self-scheduling of hydro-thermal units with concurrent reserve energy and energy market is presentedHourly-relying diurnal/hebdomadal scheduling of hydro-thermal (HT) power plants is addressed in Ref. [4]. In Ref. [5], A new optimization method with a MILP formulation for the HTSS problem was introduced and joint energy and reserve electricity considered into account. In Ref. [6], studies the use of MIPin the day-ahead market to solve the HTSS. Moreover, in Refs.[7,8], new methods were proposed for solving scheduling problems by MIP modelling. It should be noted that the effects of headwaters hydro-plant with three performance curves have been linearized by piecewise function. In Refs. [9,10], a multi-functionality approach for the HT problem in the day-ahead market has been introduced and the uncertainty of the hydro units is considered. In recent years, the authors have been focused on population development. In Ref. [12], the use of renewable energy resources in the last years is still increasing thanks to their convenient features. In Ref. [13] powerful equipment such as pumped energy storage for energy reserve objectives was introduced In Ref. [14], the lack of regulation is mentioned as a new field for investigating the collaboration and scheduling of HW power plans. A new approach for environmental problems of hydro-thermal-wind (HTW) units in power systems is provided in Refs. [15-17]. A risk-averse optimization model for trading wind energy in a market environment under uncertainty has been proposed in Ref. [18]. In Ref. [19] an optimal hydro scheduling and offering strategies have been introduced and the uncertainties and risk management are considered into account. In Ref. [20], GENCO's risk-based maintenance outage scheduling has been discussed, taking into account the uncertainties of generation prices. Given that GenCo's seek to maximize their profits, a stochastic midterm scheduling algorithm is suggested for HT power plants in Ref. [21], and risk constraints are considered into account. Moreover, solving the hydro-thermal self-scheduling (HTSS) problem of generation units using the deterministic method is proposed in Ref. [22]. In Ref. [23], A stochastic structure of MIP is introduced for scheduling a power system included HW power plans. Besides, the autoregressive integrated moving mediocre model was used as a tool in the HTSS problem in Ref. [24]. In Ref. [25], an IFTSP (interval-fuzzy two-stage stochastic programming) method is developed for planning carbon dioxide (CO2) emission trading under uncertainty. In Ref. [27] provides the modeling of dynamic ramping in unit commitment. Ramping up/down limits could be a constant, stepwise, or piecewise linear function of generation dispatch. The dynamic ramping restriction is modeled as MIP problem, and unit commitment is solved by the CPLEX solver. In Ref. [31] a stochastic optimization model considering the strong regulation capacity of cascade hydropower stations and the uncertainty of wind and photovoltaic (PV) power is presented. This model is solved with a proposed two-stage approach, in which a heuristic algorithm is used to solve the first-stage unit commitment optimization. In Ref. [32] provides a methodology to compute the optimal bidding by a wind power producer in a multi-stage market and the uncertainties of generation and consumption are considered into account. In Ref. [33], an optimal scheduling strategy considering multiple parks shared energy in the absence of grid power supply was proposed. The simulation results substantiate that the optimal strategy proposed in this article can effectively improve the electricity utilization rate and reduce the economic costs and customer dissatisfaction in multiple parks. In Ref. [34] impacts of large-scale wind power generation on energy and reserve markets are studied. This model is implemented on an 18-unit power system and simulation results are analyzed. In Ref. [35] proposes a novel nature-inspired algorithm called Ant Lion Optimizer (ALO). The proposed algorithm is benchmarked in three phases and the simulation results show that the ALO algorithm finds superior optimal designs for the majority of classical engineering problems. In Ref. [36] A new framework for the combined hydro-thermal-wind scheduling problem of multi-reservoir cascaded hydro plants is presented employing the ALO algorithm and The effect of reserve and penalty coefficients and WP uncertainty is also investigated for the multi-objective (MO) problem. In Ref. [37], the optimum system size for the economical operation of a run-of-the-river type hydropower plant is identified. The power system is designed using the best-suited turbine and generator technologies and the Power system model is designed in Matlab/Simulink environment. In Ref. [39] proposed a Multi-objective optimization framework for integrated hydro–photovoltaic power system. The proposed model was applied to the Longyangxia hydro/PV hybrid power system in Qinghai province of China, which is supposed to be the largest hydro/PV hydropower station in the world.The simulation results of this research substantiate that the dimension was reduced by decoupling hydropower and PV power in time scales. The contribution of this study is to propose a structure for the problem of HTSS with a wind power plant, as well as disparate uncertainties of energy price, special as a result, the most axial contribution of this paper is to propose use of antlion optimization algorithm (various uncertainties such as energy price, spinning and non-spinning reserve prices, WP, PV, SH units) for HTSS problem considering a short-term time spacing. In the remaining, a pattern is presented that enjoys a formulation along with MIP to provide the required optimization. However, the main objective of this investigation which will be described later is to attain profit maximization (PFM) simultaneously by taking into account some types of uncertainties and important constraints of HT, WP, PV and SH units. The main contributions of this paper are as follows:

- implementing the ALO algorithm and the fuzzy method for solving the generation scheduling problem and finding the best solution, respectively.
- Taking into account different types of uncertainties (energy price, operating services, RERs output power)
- Modeling the problem formulation in the form of a MILP problem for reducing the computational burden.

- The proposed method is capable to increase the GenCo's profit.
- Implementing PDF, RWM and LMCS methods for error prediction.

The rest of this paper is organized as follows. Section 2 introduced the stochastic method.Section 3 represents the mathematical formulation. Section 4 discusses the antlion optimization algorithm method. Section 5 presents a description of the system. Simulation results are proposed in section 6. Section 7 proposed a comparative analysis and finally some concluding remarks are introduced in section 8.

2. STOCHASTIC MODELING OF UNCERTAINTIES

In Ref. [44], Among various available methods,the LMCS method can be used for the outage of various types of units. Moreover, taking into account the price prediction error, other types of uncertainties (wind/ photovoltaic power) that are partly related to the price can be employed. There is a standard deflection for each interval with a price prediction error(σ) in Refs. [45,46]. Regarding different price prediction levels and the obtained probabilities from PDF, RWM is used to form price scenarios for each hour in Refs. [46,47]. The scenario reduction approach is used, where feeble scenarios or scenarios with low probability have been eliminated [45,46]. Hence, scenarios with high probability are preserved to take part in the SHTSS problem with wind /photovoltaic/ small hydropower plants. Fig.1 illustrates scenario-based modeling of uncertain parameters.

3. MIP FORMULATION OF STOCHASTIC HTSS

3.1. Maximization of expected profit

The prime objective function of the stochastic HTSS with WP, PV and SH power plants is the maximization of expected profit (EP) of GenCo's and is expressed as in Eqs. (1) and (2):

$$f:\max E=\pi p+p\ \text{profit} \qquad (1)$$

$$\text{profit}=\sum_{t\in T}\left\{\begin{array}{l}\pi\, p+\sum_{i\in I}\left\{\begin{array}{l}SR\ \pi+(N+N)\\ \pi\end{array}\right\}\\ +\sum\{SR\ \pi+(N+N)\pi\}\\ -\sum SUC\ Z-\sum\left\{\begin{array}{l}F+SDC\ Y+SUC\\ +VLC\end{array}\right\}\\ +\sum\{SR\ \pi+(N+N)\pi\}-\\ \sum SUC\ Z\end{array}\right\} \qquad (2)$$

Therefore the prime part equalizes the bilateral convention for extracting fixed revenue, and the second part is equal to the sum of the times of each scenario multiplied by the corresponding revenue. The start-up cost of hydro units is obtained from Eq. (2) [48]. The proposed SHTSS with WP, PV and SH units is comprised of constraints. One of the most important constraints is the sum of generated power by HT, WP, PV and SH units, which is equal to the sum of power traded in the spot market plus the bilateral convention. This is given in Equation (3):

$$\sum_{i\in I} pout^{i,t,s}+\sum_{h\in H} pout^{i,t,s}+\sum_{w\in W} pout^{w,t,s}+\sum_{v\in V} pout^{v,t,s}+\sum_{q\in Q} pout^{q,t,s}=p^{b,t}+p^{sp,t,s}\ \ \forall i\in I,\forall h\in H,\forall w\in W,\forall q\in Q,\ \forall v\in V,\forall t\in T,\forall s\in S \qquad (3)$$

Moreover, the total active power generation from all integrated power units must be balanced to the predicted power demand at each time interval over the scheduling horizon (system load balance constraints). This is given in Equation (4)

$$\sum_{i\in I} pout_{i,t,s}+\sum_{h\in H} pout_{i,t,s}+\sum_{w\in W} pout_{w,t,s}+\sum_{v\in V} pout_{v,t,s}++\sum_{q\in Q} pout_{q,t,s}-p_{D,t,s}=0, P_h^{Min}\le P_{t,h}\le P_h^{Max}, P_i^{Min}\le P_{t,i}\le P_{h,i}^{Max}, -P_i^{ramp}\le P_{t+1i}-P_{t,i}\le P_{h,i}^{ramp} \qquad (4)$$

3.2. Model of Thermal Units

It should be noted that as the equations of thermal units have nonlinear structures they must be converted into linear equations. Hence, the equations presented in portions 3.2.1, 3.2.2, 3.2.3, 3.2.4, and 3.2.5 for these units are linearized.

3.2.1. Fuel cost function considering POZs

In thermal power plants, a quadratic function is assigned to calculate the fuel cost. For this, from a mathematical point of view, Equations (5-6):

$$F^{i,t,s}=\sum_{n=1}^{M+1}\left[Fp^{u,n-1,i}\delta^{n,t,s}+b^{n,i}G^{n,i,t,s}\right]\quad \forall i\in I,\forall t\in T,\forall s\in S \qquad (5)$$

$$pout^{i,t,s}=\sum_{n=1}^{M+1}[p^{u,n-1,i}(\delta^{n,i,t,s})+G^{n,i,t,s}]\quad \forall i\in I,\forall t\in T,\forall s\in S \qquad (6)$$

The result is that the output power of the thermal unit is obtained from Eq. (6). In the rest of the discussion, the fuel cost function of units can be transformed from a non-linear to linear form [49]. The necessary constraints are given in Equations (7-9):

$$G^{n,i,t,s}\ge 0;\ n=1,2,...,M+1\quad \forall i\in I,\forall t\in T,\forall s\in S \qquad (7)$$

$$\delta^{n,i,t,s}\,[p^{d,n,i}-p^{u,n-1,i}]\ge G^{n,i,t,s}\quad n=1,2,...,M+1 \qquad (8)$$

$$I=\delta\quad \forall i\in I,\forall t\in T,\forall s\in S \qquad (9)$$

3.2.2. Valve loading cost effects

A general case of VLC function for thermal units in [26,50-51], is presented which is in a completely non-

Table 1. provides a comprehensive comparison between the model proposed in this paper and other recent researches (CM-Cost Minimization ; **EM**-Emission Minimizationl; **PFM** - Profit Maximization; **FC**-Fuel Consumption; **GM**-Generation Maximization; **LM**-Loss Minimization; **PLM**-Power Loss Minimization; **VDM** -Voltage Deviation Minimization; **MILP**-Mixed Integer Mathematical Modelling; **BFA**-Bacteria Foraging Algorithm; **ALO**-Antlion Optimazation Algorithm; **WOA**-Whale Optimization Algorithm; **CSA**-Crow Search Algorithm; **MSSO**-Multi-Stage Stochastic Optimization; **VPP**-Visual Power Plant**)**

Authors	System	Objective function	Methodology
Wang et al. (2017)	Hydro, Wind , PV	GM	Non dominated sorting GA
Biswas et al. (2017)	Thermal, Wind , PV	CM	Adaptive differential Evolution
Mandalet al. (2018)	PV, Wind , Diesel	CM , EM	HOMER software
Movahediyan et al.(2018)	PV and Diesel	CM, EM, LM	CSA
Rakhshani et al. (2019)	Wind, Diesel , Battery	CM, EM, LM	MILP
Behnamfar et al. (2019)	Hydro, Thermal ,Wind	PFM	MIP
Shi et al. (2019)	Large consumer	CM	Robust optimization
Abedinia et al. (2019)	Large consumer	CM	Robust optimization
Faisal Z et al.(2019)	VPP	CM	ALO
Li et al. (2020a,b)	Thermal, PV, Battery	FC, EM	Chao mutation WOA
Hooman Khaloie(2020)	Thermal	PFM	Probabilistic possibilistic
Anastasia Ioannou et al.(2020)	H -WP-PV-COAL-BIO-GAS-GEO	CM	MSO
Feilin Zhu et al.(2020)	H -WP-PV	Peak Shaving	PSO
Tenghui Li et al.(2020)	H -WP-PV	PFM	ε-constraint
Ambarish Panda et al.(2020)	Hydro, Thermal ,Wind ,Solar	CM, EM, PLM, VDM	Modified BFA and Fuzzy
This proposed study	Hydro,Thermal,WP, PV,SH	PFM	ALO

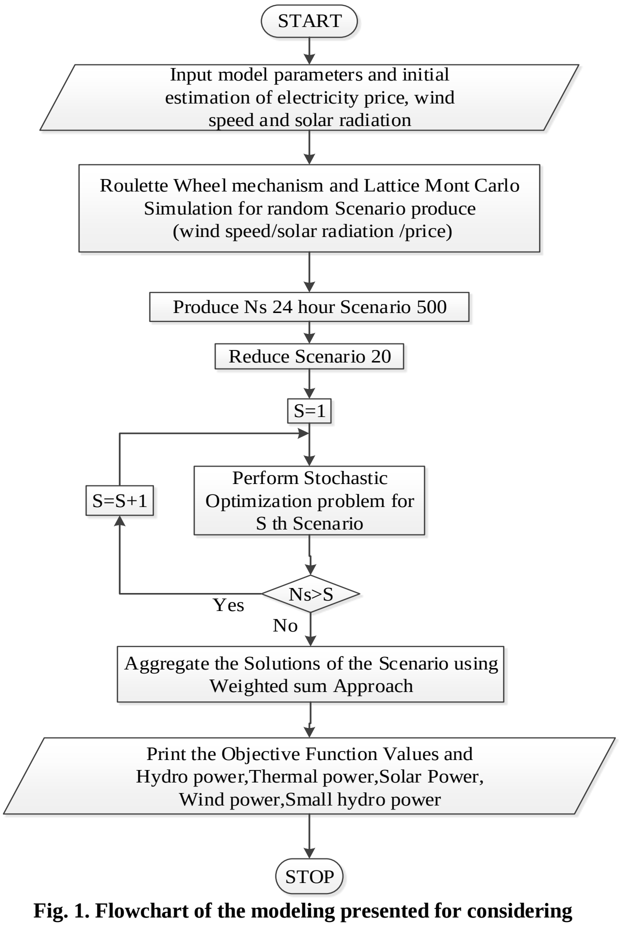

Fig. 1. Flowchart of the modeling presented for considering different uncertainties based on a stochastic scenario

linear or non-convex form Eqs. (10-13) on investigating the effects of VLC.

$$VLC^{i,t,s}=(e^{i}f^{i})\left\{\begin{aligned}&(\sqrt{2})\sum_{n=0}^{k_i}[\psi^{4n+1,i,t,s}-\psi^{4n+4,i,t,s}]\\&+(2-\sqrt{2})\sum_{n=0}^{k_i}\left[\psi^{4n+2,i,t,s}-\psi^{4n+3,i,t,s}\right]\end{aligned}\right\}(\frac{2}{\pi}) \quad (10)$$
$$\forall i\in I,\forall t\in T,\forall s\in S$$

$$pout^{i,t,s}=\sum_{n=0}^{k_i}\left[\psi^{4n+1,i,t,s}+\psi^{4n+2,i,t,s}+\psi^{4n+3,i,t,s}+\psi^{4n+4,i,t,s}\right]$$
$$+\left[p^{min,i}I^{i,t,s}\right] \quad \forall i\in I,\forall t\in T,\forall s\in S \quad (11)$$

$$(\frac{\pi}{4f^{i}})(I^{-})\geq\psi^{-}\geq(\frac{\pi}{4f^{i}})(\chi^{-}) \quad \forall i\in I,\forall t\in T,\forall s\in S \quad (12)$$

$$(\frac{\pi}{4f^{i}})(\chi^{n-1,i,t,s})\geq\psi^{n,i,t,s}\geq(\frac{\pi}{4f^{i}})(\chi^{n,i,t,s}) \quad (13)$$
$$\forall i\in I,\forall t\in T,n=2,3,...,x_{i},\forall s\in S$$
$$\chi^{n,i,t,s}\in\{0,1\}$$
$$k_i=bottom[(p^{max,i}-p^{min,i})(\frac{f^{i}}{\pi})],x_{i}=bottom[(p^{max,i}-p^{min,i})(\frac{4f^{i}}{\pi})]$$

3.2.3. Generation capacity limits of the thermal unit

The mathematical equations related to the ramping down limit (RDL) and ramping-up limit (RUL) of the thermal power plant constraints can be written:

$$(p^{min,i}I^{i,t,s})\leq pout^{i,t,s}\leq(pout^{max,i,t,s}) \quad (14)$$
$$(I^{i,t,s}-Y^{i,t+1,s})p^{max,i}+(SDR^{i}_{i,i})Y^{i,t+1,s}\geq(pout^{max,i,t,s}) \quad (15)$$
$$(SDR^{i}_{i,i}(Y^{i,t,s})+RDL^{p}_{i,t,s})\geq(pout^{i,t-1,s}-pout^{i,t,s}) \quad (16)$$
$$(RUL^{p}_{i,t,s})+(SUR^{i}_{i,i})Z^{i,t+1,s}\geq(pout^{i,t+1,s}-pout^{i,t,s}) \quad (17)$$

3.2.4. Dynamic RDL and RUL

In this section, according to Ref. [27], a function with a dynamic ramp rate (DRR) is adopte. In this regard, Eqs. (18-9) are introduced to specify RDL and RUL:

$$RDL^{p}_{i,t,s}=\sum_{n=1}^{M+1}\left[RDL^{n,i}(\delta^{n,i,t,s})\right] \quad \forall i\in I,\forall t\in T,\forall s\in S \quad (18)$$
$$RUL^{p}_{i,t,s}=\sum_{n=1}^{M+1}\left[RUL^{n,i}(\delta^{n,i,t,s})\right] \quad \forall i\in I,\forall t\in T,\forall s\in S \quad (19)$$

3.2.5. Other constraints of thermal units

We can briefly say that in Ref. [51] reserve services are categorized into three parts: spinning reserves, non-spinning reserves, and other or backup reserves. It should be noted that the reserves are important for active and reactive powers. In the following, other constraints given for thermal units [6,52].

3.3. Model of hydro units

It is worth mentioning that hydro units can have a relationship with upstream-units reservoirs. In the MIP formulation of hydro plants scheduling problem, some parameters including unit dam reservoirs with small storage volumes, water decrement fluctuations and the unit output power are considered.

3.3.1. Linear formulations for volume and multi-performance curves

This part of the hydro unit model includes linear equations along with performance curves of hydro units. These equations are presented in Eqs. (20-23).

$$(vol^{hts})^3(vol^{min,h}) \qquad \forall h \in H \tag{20}$$

$$\left[(\delta^{L-1,h,t,s})(vol^{max,h,L})\right]+ \sum_{n=2}^{L}\left[(\delta^{n-2,h,t,s}-\delta^{n-1,h,t,s})(vol^{max,h,n-1})\right] \geq \left[vol^{hts}\right] \tag{21}$$

$$\left[\delta^{L-1,h,t,s} vol^{max,h,l-1}\right]+ \sum_{n=3}^{L}\left[vol^{max,h,n-2}(\delta^{n-2,h,t,s}-\delta^{n-1,h,t,s})\right] \leq \left[vol^{hts}\right] \tag{22}$$

$$(\delta^{1,h,t,s}) \geq (\delta^{2,h,t,s}) \geq .... \geq (\delta^{L-1,h,t,s}) \tag{23}$$

3.3.2. Linear power discharge performance curves

As mentioned before, this section discusses the linearized equations, water depletion of dam reservoirs, hydropower, and their performance curves. These equations are presented in Eqs. (24) and (25).

$$\left[pout^{h,t,s}-p^{min,h,k}(I^{h,t,s})\right]-\sum_{n\in N}(Qd^{n,h,t,s}\,b^{n,h,k})-(p^{c,k}) \\ [\sum_{n=k}^{L-1}(\delta^{n,h,t,s})+(k-1)-\sum_{n=1}^{k-1}(\delta^{n,h,t,s})] \leq 0 \;,\; 1\leq k\leq L \tag{24}$$

$$\left[pout^{h,t,s}-p^{min,h,k}(I^{h,t,s})\right]-\sum_{n\in N}(Qd^{n,h,t,s}\,b^{n,h,k})+(p^{c,h}) \\ [\sum_{n=k}^{L-1}\delta^{n,h,t,s}+(k-1)-\sum_{n=1}^{k-1}(\delta^{n,h,t,s})] \geq 0 \;,\; 1\leq k\leq L \tag{25}$$

The case studies will be as follows: ((i) overflow of water from dam reservoirs of hydropower plants; (ii) water balance, initial amount of water in the reservoir and operation services).

3.4. Models of the renewable energy system

3.4.1. Model of wind units

Based on Refs. [57,58] some researchers have employed a simple model for determining the relationship between the generated power of wind units and the wind speed. In order to resolve HTSS problems, the main point is wind power uncertainty. The uncertainties of wind power are modelled by the Weibull probability density function (pdf).v, expresses wind speed. Constraints c> 0 and k> 0 are the limits of scale and shape in wind speed, respectively. It should be noted that the wind speed probability distribution function (PDF) can be obtained according to Equation (27) by calculating the cumulative distribution function (CDF). Finally, the wind turbine output power is calculated based on wind speed per hour and according to Equation (28).

$$pdf^{\nu,k,c}=\frac{k_i}{c}(\frac{\nu}{c})^{k_i-1}.e^{(-(\frac{\nu}{c})^{k_i})} \qquad (\nu>0) \tag{26}$$

$$cdf^{\nu,k,c}=1-e^{(-(\frac{\nu}{c})^{k})} \tag{27}$$

$$P=\begin{Bmatrix} 0 & v\leq v^{ci} \\ (a+bv+cv^2) & v^r\geq v\geq v^{ci} \\ P_r & v^{co}\geq v\geq v^r \\ 0 & v\geq v^{co}\end{Bmatrix} \tag{28}$$

$$a=\frac{1}{(v^{ci}-v^r)^2}((v^r+v^{ci})v^{ci}-(\frac{v^{ci}+v^r}{2v^r})^3 4\,v^{ci}\times v^r)$$

$$b=\frac{1}{(v^{ci}-v^r)^2}((\frac{v^{ci}+v^r}{2v^r})^3\times 4(v^{ci}+v^r)v^{ci}-3(v^{ci}+v^r))$$

$$c=\frac{1}{(v^{ci}-v^r)^2}(2-4(\frac{v^{ci}+v^r}{2v^r})^3)$$

The pdf can be obtained from equation (29), when wind speed is equal When the wind speed in the range [vin, vr) and h is equal to (vr/vin) -1, the PDF can be calculated by equation (29). Therefore, Equation (29) is used for probabilistic continuity in Equations (30) and (31). Considering equations (29) - (31), the CDF can be Calculated through Equation (32).

$$pdf^{w,W}=(\frac{v^{in}}{c})(\frac{kh}{w^r})\left[\frac{v^{in}}{c}(1+\frac{hw}{w^r})\right]^{k-1}.\exp\left\{-\left[\frac{(\frac{v^{in}}{c})}{(1+\frac{hw}{w^r})}\right]^k\right\} \tag{29}$$

$$p^{W=0}=p^r(v^{in}>v)+p^r(v>v^{out})=1-e^{(-(\frac{v^{in}}{c})^k)}+e^{(-(\frac{v^{out}}{c})^k)} \tag{30}$$

$$p^{W=w^r}=p^r(v^{out}\geq v\geq v^{in})=1-e^{(-(\frac{v^{in}}{c})^k)}+e^{(-(\frac{v^{out}}{c})^k)} \tag{31}$$

$$cdf^{w,W}=\begin{Bmatrix} 0 & (0>w) \\ (\frac{v^{in}}{c})(\frac{kh}{w^r})\left[\frac{v^{in}}{c}(1+\frac{hw}{w^r})\right]^{k-1}. \\ \exp\left\{-\left[(\frac{v^{in}}{c})(1+\frac{hw}{w^r})\right]^k\right\} & (w^r>w\geq 0) \\ 1 & (w^r\leq w)\end{Bmatrix} \tag{32}$$

If the total generated power by wind energy at the places with a great number of wind units located close to each other (wind farms) is required then the real generated power of such units is found in Eq. (33).

$$p^{WG,t}=p^w.A^w.\eta.N^{WG} \tag{33}$$

3.4.2. Model of small hydro units

Small hydro units generated power is calculated through Equation (34), where this power depends on the rate of water flow and effective pressure head.

$$P^{SH,Q_W} = H^{SHW} . Q^{SHW} . g^{SH} . \rho^{SH} . \eta^{SH} \quad (34)$$

3.4.3. Model of photovoltaic units

The power generated by PV panels is calculated according to Equation (35), which is a function of the solar radiation [17].

$$p^{pv,\beta_t} = \begin{Bmatrix} P^{e,rpo} \dfrac{(\beta_t)^2}{\beta^{s,rs}.R^{c,r}} & R_r^{c,r} > \beta_t > 0 \\ P^{e,rpo} \dfrac{\beta_t}{\beta^{s,rs}} & \beta_t > R_r^c \end{Bmatrix}, \quad t=1,...T \quad (35)$$

4. ANTLION OPTIMIZATION METHOD

To model ant and antlion, first, we consider the ant in the search space as an ant, then the ant is allowed to hunt it [35-36]. Since the ant moves randomly to different areas, then it is necessary to model the ant's movement according to Eq. (36). Then there is another random function called R^t, which is stated as Eq. (37).

$$X^t = \left[0, Cumsum(2r^{t_1}-1, ..., Cumsum(2r^{t_n})\right] \quad (36)$$

$$R^t = \begin{Bmatrix} 0 & \text{if rand} \le 0.5 \\ 1 & \text{if rand} \ge 0.5 \end{Bmatrix} \quad (37)$$

The important point is the position of the ants that should be stored in the matrice (38) and used during the optimization. To evaluate each ant, an objective function is utilized during the optimization. These functions are stored as matrice:

$$M^{ANT} = \begin{bmatrix} A^{1,1} & \cdots & A^{1,d} \\ \vdots & \vdots & \vdots \\ A^{n_A,1} & \cdots & A^{n_A,d} \end{bmatrix} \quad (38)$$

$$M^{OA} = \begin{bmatrix} f(A^{1,1},...,A^{1,d}) \\ \vdots \\ f(A^{n_A,1},...,A^{n_A,d}) \end{bmatrix} \quad (39)$$

Suppose the antlions are hiding in space, so it is necessary to use Eqs. (40-41) matrices to store this position and its objective function.

$$M^{Antlion} = \begin{bmatrix} AL^{1,1} & AL^{1,2} & ... AL^{1,d} \\ & \vdots & \\ AL^{n_{AL}1} & AL^{n_{AL},2} & ... AL^{n_{AL},d} \end{bmatrix} \quad (40)$$

$$M^{OAL} = \begin{bmatrix} f(AL^{1,1}, ..., AL^{1,d}) \\ \vdots \\ f(AL^{n_{AL},1},...,AL^{n_{AL},d}) \end{bmatrix} \quad (41)$$

Eq. (42) must be used in each iteration to make random moves in the search space. According to the aforementioned material, ants walking is affected by antlion traps. So to express its mathematical model, Eqs. (43-44) are used:

$$X^{t,i} = \left[\left(\frac{1}{(d^{t,i}-a^i)}\right)((X^{t,i}-a^i)(b^i-c^{t,i})) \right] + c^i \quad (42)$$

$$c^{t,i} = Antlion^{t,j} + c^t \quad (43)$$

$$d^{t,i} = Antlion^{t,j} + d^t \quad (44)$$

The ALO algorithm requires the roulette wheel mechanism (RWM) function during optimization to determine the infants based on the fitness function. When an ant is trapped, the antlion throws itself towards the edges of the rock cavity, with Equations (45-46) referring to its mathematical model:

$$c^t = \frac{c^t}{I_C} \quad (45)$$

$$d^t = \frac{d^t}{I_C} \quad (46)$$

Where I_c is defined as Equation (47):

$$I_C = 10^{\alpha^r} (\gamma / \lambda) \quad (47)$$

But α^r is defined as Equation (48) :

$$\alpha^r = \begin{Bmatrix} 2 \text{ if } \gamma > 0.1\lambda \\ 3 \text{ if } \gamma > 0.5\lambda \\ 4 \text{ if } \gamma > 0.7\lambda \\ 5 \text{ if } \gamma > 0.9\lambda \\ 6 \text{ if } \gamma > 0.95\lambda \end{Bmatrix} \quad (48)$$

The last stage of predation is when the prey reaches the bottom of the trap and is placed in the mouth of the antlion. After this step, the antlion lures the prey into the sand and eats it. Suppose hunting takes place when the ant is immersed in the sand. Then, in order to increase the chance of new hunting by the antlion, its position should be updated relatively to that of the ant that predates in Equation (49).

$$Antlion^{\gamma,j} = Ant^{\gamma,i} \text{ if } (f^{Ant^{\gamma,j}}) > (f^{Antlion^{\gamma,j}}) \quad (49)$$

4.1. Elitism and ALO algorithm

In this study, the best antlion obtained is stored in each iteration and considered an elite. Since elites are the most appropriate answers, they must be able to influence all ants. It is assumed that each ant will approach an ant by using the roulette wheel mechanism (RWM) structure. Then in Eq. (50) can be used to simulate the elitism.

$$Ant^{\gamma,i} = 0.5(R^{\gamma,A} + R^{\gamma,E}) \quad (50)$$

The ALO algorithm is a three-dimensional function defined for Equation (51) to estimate the overall optimality for optimization problems:

$$ALO^{\rho,\psi,\xi} \quad (51)$$

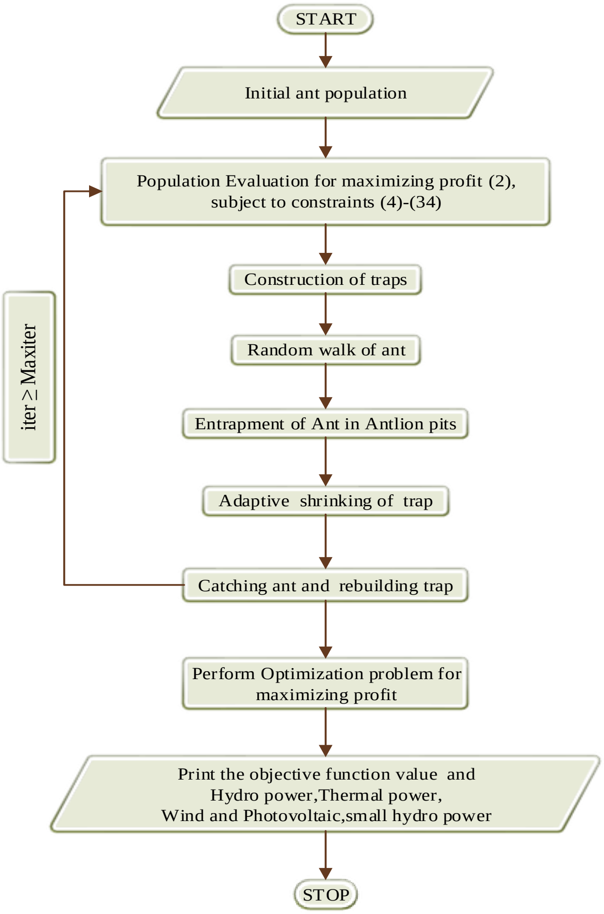

Fig. 2. The proposed modelling flowchart for considering ALO algorithm method

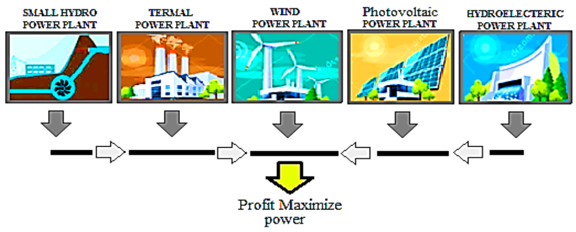

Fig. 3. A schematic of HT and WP-PV-SH power plans in a system

Where the functions ρ, ψ and ξ are defined as:

$$F \xrightarrow{\rho} \left\{M^{Ant}, M^{OA}, M^{Antlion}, M^{OAL}\right\} \quad (52)$$

$$\left\{M^{Ant}, M^{Antlion}\right\} \xrightarrow{\psi} \left\{M^{Ant}, M^{Antlion}\right\} \quad (53)$$

$$\left\{M^{Ant}, M^{Antlion}\right\} \xrightarrow{\xi} \left\{true, false\right\} \quad (54)$$

4.2. Problem-solving optimization using ALO

To solve the optimization problem, using the ALO algorithm it is necessary to consider the following steps:

- **Step 1:** The initial population of ants is generated, which means that a set of completely random solution s to the problem has been created.
- **Step 2:** Check the the ant position.
- **Step 3:** Calculate the ant fitness function where an ant competency function shows how optimized this solution is as one of the most important parts of an algorithm.
- **Step 4:** An antlion should be selected for each ant until the criterion of termination is calculated using each roulette wheel mechanism.
- **Step 5:** Normalize by Eqs. (38) and (43) randomly generated step.
- **Step 6:** The ant position is updated with Eq. (51).
- **Step 7:** Terminates the inner loop (for loop).
- **Step 8:** According to the amount of fitness function from the most graceful to the most inappropriate, the ants should be sorted.
- **Step 9:** If the ant is stronger than an antlion, it should be replaced using the relation Eq. (50).
- **Step 10:** Elitism occurs when an antlion is more compatible than elitism.
- **Step 11:** Terminates the main loop (While loop).
- **Step 12:** Should be defined as the output of elitism.

4. 3. Accomplishment of wind-photovoltaic and small hydropower HTSS problem using ALO

In general, the steps were taken by the ALO algorithm for the short-term planning of HT units in the energy and reserves markets in the presence of uncertainty due to WP, PV, and SH power plants include a linear formulation for the impact of the VLC, fuel costs, POZs, power generation limitation, dynamic limitation increase in power,emission function and fuel limitation, proficiency curve as well as minimum up/downtime units, etc. In addition, Fig. 2, shows how the different steps of this research as performed using this algorithm.

5. SIMULATION RESULTS

5.1. Description of the power system

The test system includes Among these units there are,10 units with cruel oil fuel,11units with gas fuel, and 33 units with charcoal fuel. In addition, the data of 8 hydropower plants are extracted from Ref. [7]. Fig. 3 shows a schematic of a simple scheme for five different power plants in power systems.

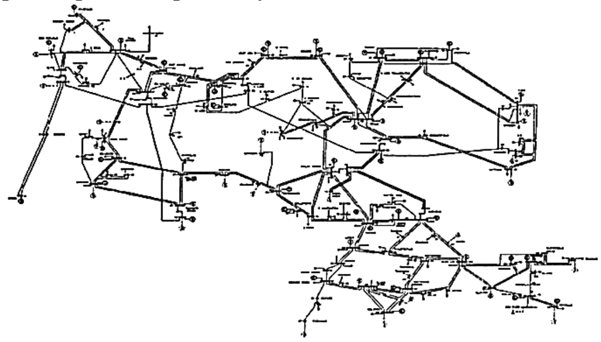

Fig.4. The utilized IEEE 118-bus test system for study and tests

This simple scheme illustrates the locations of HT and WP/PV/SH units. It is worth noting that in this study the assumed time for short-term scheduling is 24 hours (one day). In this study, the antlion optimization algorithm method was used. In the following, It is noted that a large-scale case study (IEEE118-bus) test system is used to study the problem of SHTSS with WP/PV/SH power plant along with testing the proposed case studies and approving their validity. Moreover, the IEEE 118-bus test system is shown in Fig. 4. Necessary assumptions and data for case studies of the research are reported in this portion: (I) It should be said that due to the availability of required data of ramp rate these data are assumed as constant values in this study. (II) During the scheduling and cooperation process among units, some thermal units, such as 33, 41, 46, and 49 are not employed because they impose high costs on the system. (III) In a bilateral contract of electricity pricing, it is necessary to determine the amount and price of energy for each hour. Therefore, these two values are assumed to be 1000MWh and 45$/MWh, respectively. (IV) A part of hydro unit modeling is comprised of the relationship between three parameters which is stated in Section (3.3.3). (V) In ref. [54], it is concluded that the amount of fuel consumption and costs of hydro units will be equal to the used energy at the startup time. (VI) In Refs. [55,58-60], The required data for scheduling wind power /photovoltaic/SH units by other generating units are draw out respectively. (VII) All data of thermal units like POZs and coefficients of VLC are extracted in Ref. [56]. (VIII) In Refs. [7,55], For scheduling and cooperation of H and T units, the required data given are used. This portion of the paper addresses the solution of the SHTSS problem aiming at the profit-maximizing (PFM) of GenCo’s. Hence, the goal is to study the effects of VLC, POZs, the uncertainty of energy price, uncertainties of operating services prices, with considering and neglecting WP/PV power uncertainty and SH units on the profit maximization (PFM). In the following, the six cases utilized for investigations are described.

- **Case 1:** Stochastic HTSS problem considering VLC and POZs.
- **Case 2:** Stochastic HTSS problem neglecting VLC and POZs.
- **Case 3:** Stochastic HTSS problem considering, WP, VLC and POZs.
- **Case 4:** Stochastic HTSS problem considering WP, neglecting VLC and POZs.
- **Case 5:** Stochastic HTSS problem considering WP, PV, SH, VLC and POZs.
- **Case 6.** Stochastic HTSS problem considering WP, PV, SH, neglecting VLC and POZs.

6. SIMULATION RESULT AND ANALYSIS

6.1. Case 1

In order to maximize the profit of GenCo’s, we introduce an optimal model for solving the SHTSS problem using an antlion optimization algorithm. The purpose of this study was to investigate the effects of VLC, POZs, energy price uncertainty, spinning and non-spinning reserve(operating services)uncertainty on based maximizing profit. The results in Table 2, show the maximum value of each of the objectives. According to Table 2, the expected profit(EP) from a stochastic solution of the SHTSS problem in the absence of wind units will be 5419896.15 $. However, it should be noted that thermal units 7, 10, 30, 34, 35, and 45 have limitations on POZs. Overall, the HT power plant,spinning, and non-spinning reserve produce 165840.16MW, 15762.05MW, 4000.03MW, 2410.15 MW, electrical power,respectively. It should be noted that from 9 p.m. to 11 p.m., as electricity prices rise, the turbine generates more power and makes a profit.

Table 2.The ALO algorithm solution of the stochastic HTSS problem (considering, VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	181602.31
Total reserve (MW)	4000.03
Profit($)	5419896.15
Computation time (s)	62

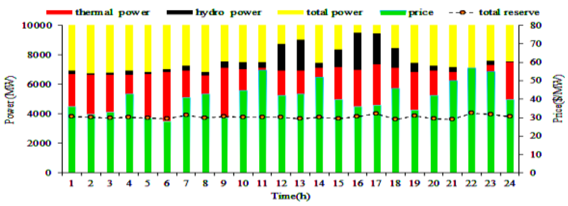

Fig. 5. The results of the planning of HT power GenCo’s and energy price

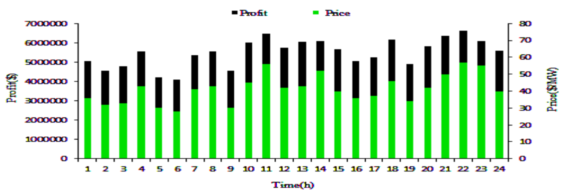

Fig. 6. The energy price and profit curves of GenCo’s

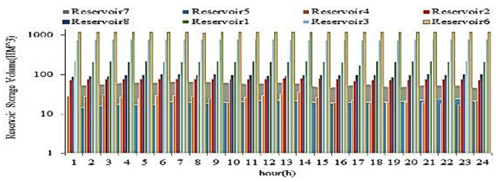

Fig. 7. Hourly reservoir storage volumes for case 1

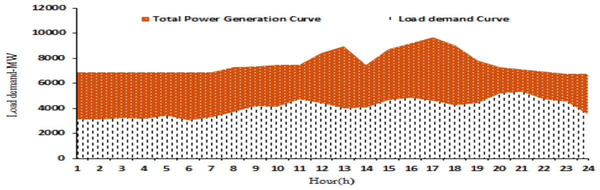

Fig. 8. Hourly power generation and demand curves for case 1

Besides, from Table 2, it can be seen that the total power 181602.31MW, total reserve 4000.03MW, and computation time 62 Sec is the optimum time according to the proposed ALO algorithm. Nevertheless, at the midmost hours due to the increase of the energy price, the generated power of hydropower plans is increased as well. Finally, at the last hours and with the decrease in energy prices, the produced power is also decreased and water is stored in reservoirs to meet the constraint of the final volume of the reservoir water. Also, Fig. 5, Shows the results of the planning of HT power GenCo's and energy price, as well as Fig. 6, the results of the energy price and expected profit, over the 24-hour period using the algorithm are obtained. In addition, Fig. 7 and Fig. 8 depict the hourly reservoir storage volumes and hourly total power generation and load demand curves, respectively.

6. 2. Case 2

In this section,we investigate a optimal solution of the stochastic hydro-thermal self-scheduling (SHTSS) problem using an antlion optimization algorithm to maximize the profit of GenCo's. The purpose of this study was to investigate the effects of energy price uncertainty, spinning and non-spinning reserve uncertainty ,but without considering VLC,POZs, on based maximizing profit.The results in Table 3, show the maximum value of each of the objective. According to Table 3, the expected profit(EP) from a stochastic solution of the HTSS problem in the absence of wind units will be 5665420.53$. Nevertheless,it should be noted that thermal units 7,10,30,34, 35 and 45 have limitations on POZs.

Table 3.The ALO algorithm solution of the stochastic HTSS problem (neglecting ,VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	182115.31
Total reserve (MW)	3500.11
Profit($)	5665420.53
Computation time (s)	51

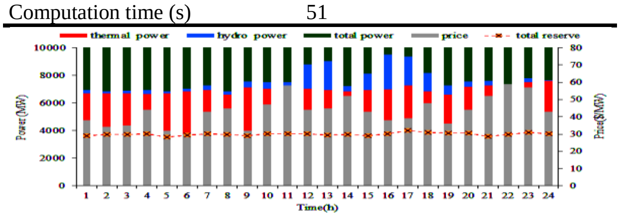

Fig. 9. The results of the planning of HT power GenCo's and energy price

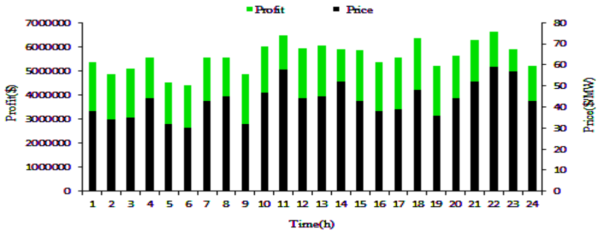

Fig. 10. The energy price and profit curves of GenCo's

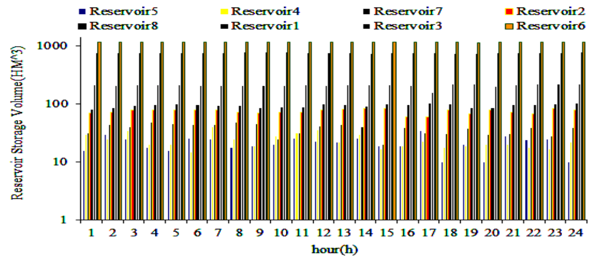

Fig. 11. Hourly reservoir storage volumes for case 2

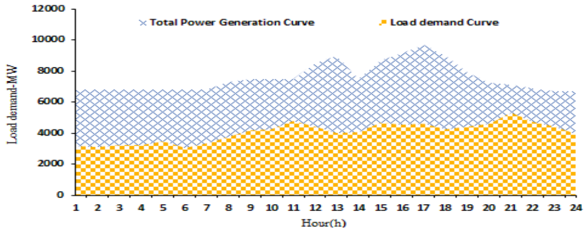

Fig. 12. Hourly power generation and demand curves for case 2

Overall,the thermal,hydro units,SR and NSR produce 166260.7MW, 15854.61MW, 3500.11MW, 2433.72 MW, electrical power, respectively. Besides, from Table 3,it can be seen that the total power 182115.31MW,total reserve 3500.11MW,and computation time 51 Sec is the optimum time according to the proposed ALO algorithm. Also, Fig. 9, Shows the results of the planning of generating companies and energy prices, as well as Fig. 10, the results of the energy price and expected profit, over the 24-hour period using the algorithm are obtained. It should be noted that from 9 p.m. to 10 p.m., as electricity prices rise, the turbine generates more power and makes a profit. Nevertheless, at the midmost hours due to the increase of the energy price, the generated power of hydro power plans is increased as well. Finally, at the last hours and with the decrease of energy prices, the produced power is also decreased and water is stored in reservoirs to meet the constraint of final volume of the reservoir water. Moreover, Fig. 11 and Fig. 12 depict the hourly reservoir storage volumes and hourly total power generation and load demand curves respectively.

6. 3. Case 3

In this section, we investigate an optimal solution for the SHTSS problem using an antlion optimization algorithm to maximize the profit of GenCo's.The purpose of this study was to investigate the effects of VLC, POZs, energy price uncertainty, spinning and non-spinning reserve uncertainty on based maximizing profit. According to Table 4, the expected profit (EP) from a stochastic solution of the HTSS problem in the existence of WP will be 5419915.40 $. However, it should be noted that thermal units7, 10, 30, 34, 35, and 45 have limitations on POZs.Overall, the thermal, hydro, and wind units, spinning, and non-spinning reserve produce165568.26 MW,15718.07 MW, and 325MW, 4008.74MW, 2442.82 MW, electrical power, respectively. It should be noted that, from 9 p.m. to 10 p.m., as electricity prices rise, the turbine generates more power and makes a profit. Nevertheless, during the mid hours due to the increase in the energy price, the generated power of hydropower plans is increased as well. Finally, at the last hours and with the decrease in energy prices, the produced power is also decreased and water is stored in reservoirs to meet the constraint of the final volume of the reservoir water. Besides, from Table 4, it can be seen that the total power 181611.33MW, total reserve 4008.74MW, and computation time 67 Sec is the optimum time according to the proposed ALO algorithm.

Table 4.The ALO algorithm solution of the stochastic HTSS problem (considering WP ,VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	181611.33
Total reserve (MW)	4008.74
Profit($)	5419915.40
Computation time (s)	67

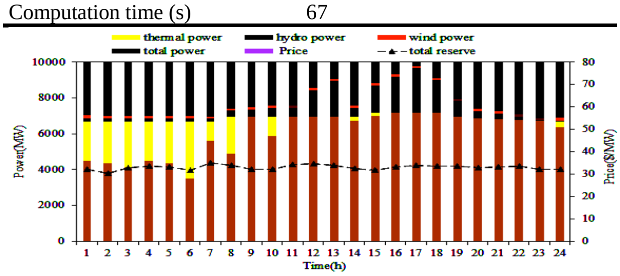

Fig. 10. The results of the planning of HTW power GenCo's and energy price

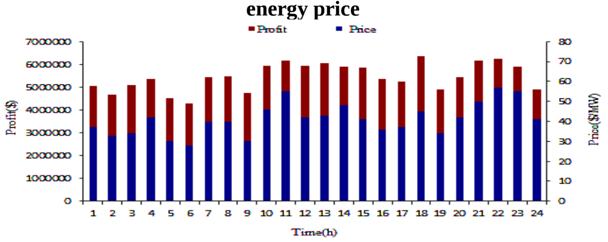

Fig. 11. The energy price and profit curves of GenCo's

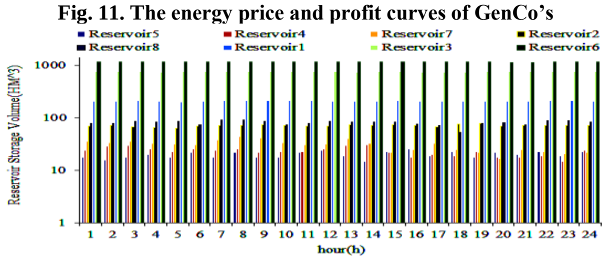

Fig. 12. Hourly reservoir storage volumes for case 3

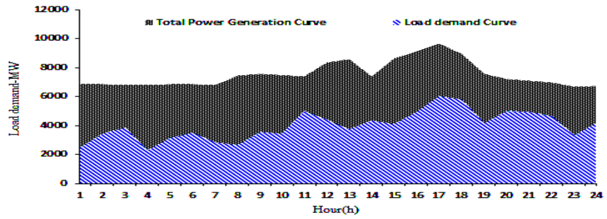

Fig. 16. Hourly power generation and demand curves for case 3

As can be seen from Fig. 13, That there is a connection between the changes of the energy price and the total generated power by the plants, as well as Fig.14, the results of the energy price and expected profit(EP), over the 24hours using the algorithm are obtained. Moreover, Fig. 15 and Fig. 16 depict the hourly reservoir storage volumes and hourly total power generation and load demand curves respectively. As expected, the use of renewable energy sources, in addition to being able to affect the amount of profit and produce power of all power plant units, has also changed the amount of spinning and non-spinning reserve of HT units.

6. 4. Case 4

In this section, we investigate an optimal solution for the stochastic hydro-thermal self-scheduling (SHTSS) problem using an antlion optimization algorithm to maximize the profit of GenCo's. The purpose of this study was to investigate the effects of energy price uncertainty, spinning and non-spinning reserve uncertainty, but without considering VLC, POZs, on based maximizing profit. The results in Table 5, show the maximum value of each of the objectives. According to Table 5, the expected profit(EP) from a stochastic solution of the HTSS problem in the absence of wind units will be 5841301.22 $. However, it should be noted that thermal units 7, 10, 30, 34, 35, and 45 have limitations on POZs. It should be noted that, from 9 p.m. to 11 p.m., as electricity prices rise, the turbine generates more power and makes a profit.

The thermal, hydro, and wind units, spinning, and non-spinning reserves generate 165652.66, 16283.86, 315, 3510.35 and 2450.32 MW active power, respectively. As expected, the use of RERs, in addition to being able to affect the amount of profit and produce power of all power plant units, has also changed the amount of SR and NSR of HT units. It can be seen from Table 5 that the total power and total reserves are 182251.52 and 3510.35 MW, respectively. Moreover, the solving time in this case is 54 seconds, which confirms the speed of the ALO algorithm.Fig. 17 shows that there is a connection between the variations of the price and the total generated power by the plants. Energy prices and expected profits are calculated for 24 hours. In addition, Fig.19 and Fig. 20, depicts the hourly reservoir storage volumes, total power generation and load demand, respectively. However, during the mid hours due to the increase in the energy price, the generated power by hydropower plans is increased. besides, during the last hours with decreasing energy prices, the generated power is decreased and water is stored in reservoirs to meet the constraint of final volume of the reservoir water.

Table 5. The ALO algorithm solution of the stochastic HTSS problem (considering WP, neglecting VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	182251.52
Total reserve (MW)	3510.35
Profit($)	5841301.22
Computation time (s)	54

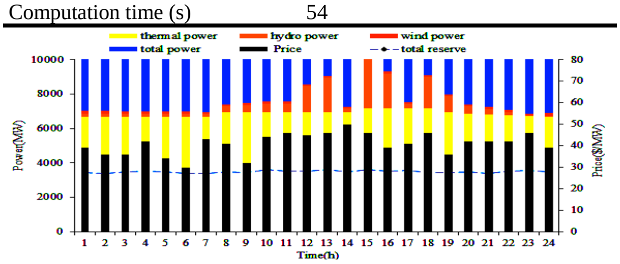

Fig. 17. The results of the planning of HTW power GenCo's and energy price

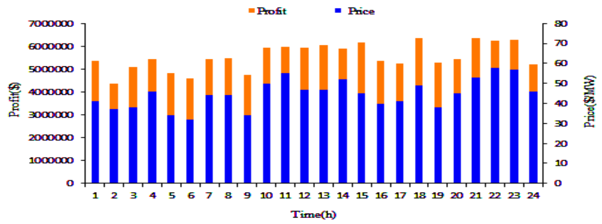

Fig. 18. The energy price and profit curves of GenCo's

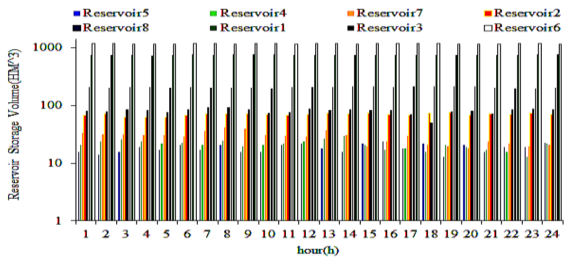

Fig. 19. Hourly reservoir storage volumes for case 4

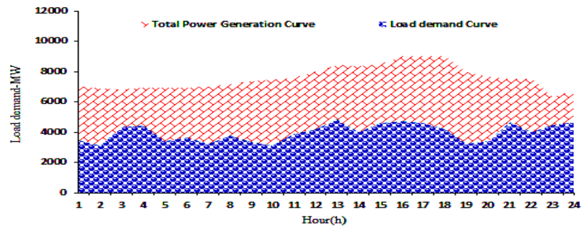

Fig. 20. Hourly power generation and demand curves for case 4

6. 5. Case 5

In this section, an optimal approach for the SHTSS problem was adopted for maximizing the profit of GenCo's using the antlion optimization algorithm. The purpose of this study was to investigate the effects of VLC, POZs, energy price as well as SR, and NSR uncertainties on maximizing profit. It should be noted that from 9 p.m. to 11 p.m., as electricity prices rise, the turbine generates more power and makes a profit. According to Table 6, the obtained profit from a stochastic solution of the HTSS problem in the existence of WP/PV/SH will be 5421812.19$. However, it should be noted that thermal units 7, 10, 30, 34, 35, and 45 have limitations on POZs.Overall, the thermal, hydro, WP, PV and SH units, SR and NSR produce 165900MW, 15800.43MW, 290 MW, 15MW, and 300MW, 4014.09MW, 2468.09MW, electrical power, respectively.

Table 6. The ALO algorithm solution of the stochasticHTSS problem (considering WP/PV/SH, VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	182305.43
Total reserve (MW)	4014.09
Profit($)	5421812.19
Computation time (s)	78

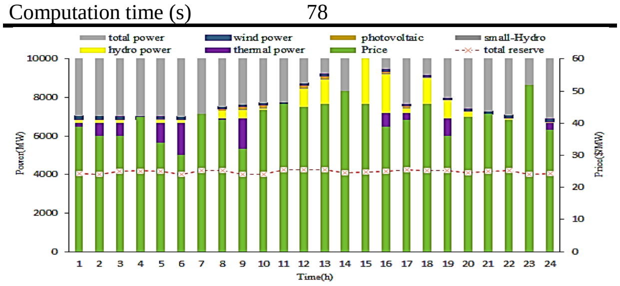

Fig. 21. The results of the planning of HT/WP/PV/SH power GenCo's and energy price

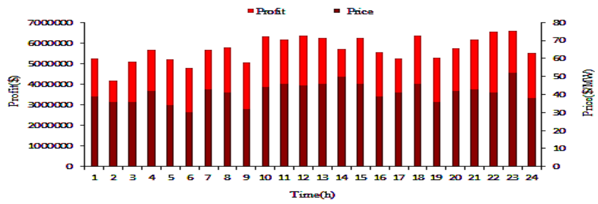

Fig. 22. The energy price and profit curves of GenCo's

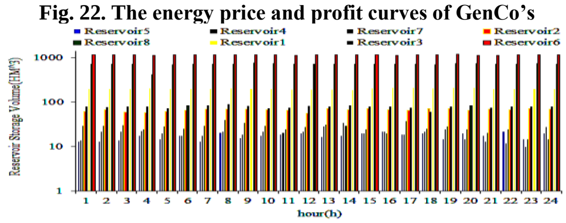

Fig. 23. Hourly reservoir storage volumes for case 5

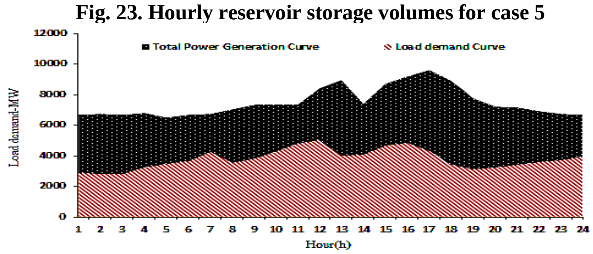

Fig. 24. Hourly power generation and demand curves for case 5

Besides, from Table 6, it can be seen that the total power 182305.43MW, total reserve 4014.09MW, and computation time 78 Sec is the optimum time according to the proposed ALO algorithm. One can observe from Fig. 21, That there is a connection between the changes of the energy price and the overall generated power by the plants, as well as Fig.22, the results of the energy price and expected profit (EP), over the 24-hour period using the algorithm are obtained. Moreover, Fig. 23, depicts the hourly reservoir storage volumes. Moreover, Fig. 23 and Fig. 24 depict the hourly reservoir storage volumes and hourly total power generation and load demand curves respectively. However, at the midmost hours due to the increase in the energy price, the generated power of hydropower plans is increased as well. Finally, at the last hours and with the decrease in energy prices, the produced power is also decreased and water is stored in reservoirs to meet the constraint of the final volume of the reservoir water. As expected, the use of RERs, in addition to being able to affect the amount of profit and produce power of all power plant units, has also changed the amount of SR and NSR of HT units.

6. 6. Case 6

In this section, we investigate an optimal solution of the stochastic hydro-thermal self-scheduling (SHTSS) problem using an antlion optimization algorithm to maximize the profit of GenCo's.The purpose of this study was to investigate the effects of energy price uncertainty, SR and NSR uncertainty, but without considering VLC, POZs, on based profit maximizing. The results in Table 7, show the maximum value of each of the objectives.According to Table 7, the expected profit from a stochastic solution of the HTSS problem in the existence of WP/PV/SH will be 5841383.53 $. It should be noted that, from 9 p.m. to 11 p.m., as electricity prices rise, the turbine generates more power and makes a profit. It should be noted that thermal units 7, 10, 30, 34, 35, and 45 have limitations on POZs.

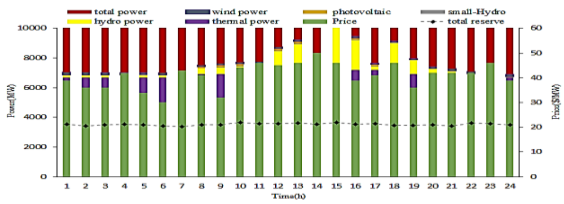

Fig. 25. The results of the planning of HT/WP/PV/SH power GenCo's and energy price

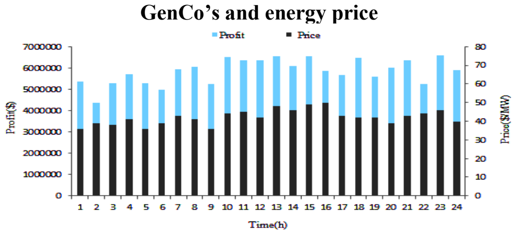

Fig. 26. The energy price and profit curves of GenCo's

Table 7.The ALO algorithm solution of the stochastic HTSS problem (considering WP /PV/SH, neglecting VLC and POZs)

Objective function	Expected profit($)
Total power (MW)	182375.81
Total reserve (MW)	3520.35
Profit($)	5841383.53
Computation time (s)	60

Table 8. Results summary of different case studies Ref. [59]

Objective function	Expected profit($)	
Case study	Case 1	Case 2
Total power (MW)	181599.38	182117.85
Total reserve (MW)	3432.25	3968.32
Profit($)	5419857.42	5841292.48
Computation time (s)	1740	1369

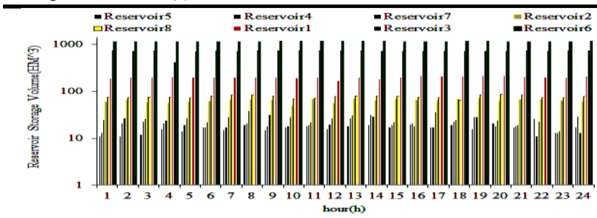

Fig. 27. Hourly reservoir storage volumes for case 6

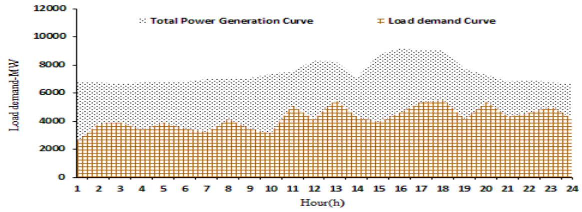

Fig. 28. Hourly power generation and demand curves for case 6

Overall, the thermal, hydro, WP, PV, and SH units, SR and NSR produce 165598.08 MW,16239.73MW, 219MW, 10 MW and 309MW, 3520.35MW, 2491.55 MW,electrical power,respectively.As expected, the use of RERs, in addition to being able to affect the amount of profit and produce power of all power plant units, has also changed the amount of spinning and non-spinning reserve of HT units. Besides, from Table **7**, it can be seen that the total power182375.81MW, total reserve 3520.35MW, and computation time 60Sec is the optimum time according to proposed ALO algorithm. One can observe from Fig. 25 That there is a connection between the changes of the energy price and the overall generated power by the plants, as well as Fig. 26, the results of the energy price and expected profit (EP), over the 24-hour period using the algorithm are obtained. In addition, Fig. 27 and Fig. 28 depict the hourly reservoir storage volumes and hourly total power generation and load demand curves respectively. However, at the midmost hours due to the increase of the energy price (EP), the generated power of hydropower plans is increased as well. Finally, at the last hours and with the decrease in energy prices, the produced power is also decreased and water is stored in reservoirs to meet the constraint of the final volume of the reservoir water.

Table 9. Summary of recent studies of hybrid (HT,WP, PV...etc) energy system

Discription	Ref.[42]	Ref.[67]	Ref.[68]	Ref.[69]	Ref.[72]	Our research
Generation unit type	H-T-WP-PV	T -WP -PV	H- WP- PV	WP-PV-BATTERY	H -WP-PV-COAL-BIO-GAS-GEO	H-T-WP-PV-SH-
Multi-objectiv function	✓	✓	✓	✓	×	×
Single-objectiv function	×	×	×	×	✓	✓
Uncertaite number	2	3	2	3	3	4
Max.profit	×	✓	×	×	×	✓
Min.emission	×	✓	✓	✓	✓	×
Case stady number	2	2	4	2	3	6
Uncertainty modeling	✓	✓	✓	✓	✓	✓
Simulat random method	✓	×	×	✓	✓	✓
Consider the load	✓	×	×	×	✓	✓
Solution method	MOCS	WST	MBFA	CCP,FMP	MSO	ALO
Operation	GenCo’s	GenCo’s	GenCo’s	GenCo’s	GenCo’s	GenCo’s

7. COMPARATIVE ANALYSIS

In this section, a comparative analysis is conducted to investigate the results. Cases 1-6 are based on a single-objective function. Case1 with considering VLC and POZs, has a total power capacity of 181602.31MW, total reserve 4000.03MW, expected profit 5419896.15$, computation time 62S, but for Case 2 with neglecting, VLC and POZs, has a total power capacity of 182115.31MW, total reserve 3500.11MW, expected profit 5665420.53$, computation time 51S, respectively. Case 3 with considering, WP , VLC and POZs, has a total power capacity of 181611.33MW, total reserve 4008.74MW, expected profit 5419915.40$, computation time 67S, respectively. Case 4 with considering WP, neglecting VLC and POZs, has a total power capacity of 182251.52MW, total reserve 3510.35MW, expected profit 5841301.22$, computation time 54S, respectively, but for case 5 with considering WP, PV, SH, VLC and POZs, has a total power capacity of 182305.43MW. Total reserve 4014.09MW, expected profit 5421812.19$, computation time 78S, respectively, while for the case 6 with considering WP, PV, SH, VLC and POZs, has a total power capacity of 182375.81MW, total reserve 3520.35MW, expected profit 5841383.53$, computation time 60S , respectively. In order to compare the numerical results obtained from the proposed algorithm (ALO) in this research with other articles, we can refer to Ref. [59]. The numerical results of the objective function related to the profit studied in this paper for the six case studies,are more acceptable than those obtained in Ref. [59], listed in Table 8. In order to compare the proposed method in this paper with previous studies, Table 9 is presented. It should be noted that one of the important features of the proposed method is the use of renewable energy sources and consideration of uncertainties. In addition, the results prove that the use of ALO algorithm is another strength of the proposed model.

8. CONCLUSION

In this paper, the problem of short-term hydro-thermal-photovoltaic-small hydro-wind power self-scheduling with the aim of maximizing profits is investigated. In order to solve the planning problem, the ALO algorithm is utilized and the uncertainty of energy price and the output power of renewable sources are considered in it. It should be noted that all operating constraints are considered in the proposed model, the final problem is modeled as a MILP problem and is solved in the form of 6 studies. In general, by comparing each of the obtained results with each other, it can be seen that the highest expected profit(EP) belongs to case study 6 (with considering WP, PV, SH, VLC and POZs, expected profit 5841383.53$, computation time 60S, respectively). The results prove that the proposed model has been capable to maximize the profits of GenCo’s. Besides, the study of solution time shows that the ALO algorithm has a high speed and accuracy for solving problems with heavy computational burden.

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