Coordinated Operation of Wind Farms, Cascaded Hydro, Photo-voltaic and Pump-storage Units by WT-ANN-ICA Prediction Method for WFPG

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Abstract
In this paper, it is presented a new algorithm to reduce the uncertainty effect of wind farms power generation (WFPG) and photo-voltaic generation (PVG) in a day-ahead energy and ancillary services market. First, it is tried to predict the uncertainty of the WFPG precisely. So it has been used of the hybrid method (HM) of wavelet transform (WT) in order to reduce the fluctuations in the input historical data, of the improved artificial neural network (ANN) based on the nonlinear structure for better training and learning and of imperialist competitive algorithm (ICA) in order to find the best weights and biases for minimizing the mean square error (MSE) of prediction. Then, considering high-level penetration of wind farms (WF) on the power system cascaded hydro units (CHU) and pump-storage units (PSU) were used as coordinated operation and supplementary units for WF and photo-voltaic (PV) resources. The uncertainty of energy price, spinning and non-spinning reserve in the electricity market, WFPG, and PVG causes that this problem be a scenario-based stochastic optimization one. The aim of this problem is to increase the profit and decrease the financial risk (FR) of all of the units. The proposed method tested on WF, CHU, PV and PSU of IEEE 118-bus standard system. Studying the result of profit and FR in the coordinated operation (CO) and the independent operation (IO) confirms to increase the profit and decrease the FR in the CO and the ability of the HM of WT-ANN-ICA.
Keywords:
Wind farms, Expected profit, Cascaded hydro, Photo-voltaic and Pump-storage units.

Introduction

One of the main goals in countries with restructured in electrical market which is support and subsidiary is omitted from producers for participation in electrical market. This goal is necessary for create the complete competition in electrical market. On the other hand by omitting the support from renewable resources like wind and photo-voltaic resources and expanding these units because of environmental reasons and increasing cost of fossil fuels, it is possible that they don’t have enough profit for these producers (imbalance costs by ISO (independent system operator) results from difference between generation and bided power).

Owner of renewable units predict generation of units to reduce imbalance costs. In [1] Autoregressive Moving Average (ARMA) was used to predict generation capacity of wind farm. In addition, in [2] Adaptive neuro fuzzy inference system (ANFIS) and in [3] ANFIS and particle swarm optimization (PSO) methods were used to predict generation of wind farms. In [4], first, by using WT the historical data of WF is decomposed, and then the wind power is predicted by ANN. This method is tested in two region of china. Then by comparing WT-ANN method with ANN and ARMA method, the results show that the proposed method, the minimum, and in ARMA method, the maximum rate of prediction error are obtained. In [5], the optimal weights and biases of ANN are determined by genetic algorithm (GA), ICA and ICA-GA method, and tested on six specified data-bases, that the obtained results will confirm ICA ability. Also in [6], in order to predict the WFPG, it has been used of ANN, that for determining the optimal weights and biases, it has been used three algorithm including ICA, GA and PSO. The prediction results will have fewer errors by using ICA. The second solution of reducing the uncertainty in renewable units including WF is coordinated the other energy resources which are likely to be expensive, but available and have fewer uncertainty, such as PSU, CHU, gas turbines, combine cycle power plants and energy storage batteries. But the need for energy and using these generation resources for increasing the profit should be less and less [7].

In [8] the coordinated planning of WF, PSU and thermal units is presented by the multi-stage stochastic planning and solved by scenario decreasing algorithm of PSO. In [9], the requirement reserve level has been estimated despite the high-level penetration of WF. In [10], the optimal strategy of wind power units is determined in instance market. The wind speed and market price are predicted by ARMA. Also the expected profit has been limited by FR and the requirement reserve is determined because of the error in WFPG prediction. In [11], the coordinated planning problem of WF and thermal power plants is done by artificial immune optimization method. This optimization method has been implemented on a system including ten thermal power plants and two WF. In [12], with the aim of maximizing the profit in CO of WF and PSU, it is used of mixed integer programing for period planning of operation status/shutdown and generating/pumping mod of PSU. It has been used of scenario-based and chance constrained optimization method in order to consider the WFPG prediction error. Determining the optimal coordinated strategy in stochastic planning for WF and PSU has been discussed in [13]. This

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stochastic planning is based on PBUC, and includes the imbalance cost in WF. It is used of chance-based method in order to solve the optimization problem, and the results have been compared with Monte Carlo method. Studying the risk and the limitation of the FR of GENCOs is discussed in [14]. It is used of a rolling optimization method for WF coordinated with the energy-storage systems in the intraday market in order to increase the profit of these power plants. The CO and IO of a system including a WF, PSU and photovoltaic resources is compared in [15]. Predicting WFPG has been done by ARMA method. The results show increasing the profit and decreasing the FR in the CO. The optimal cascaded hydro unit scheduling and biding strategies considering price uncertainty and risk is discussed in [16]. The optimal scenario-based operation management of MicroGrid including WF, Photovoltaic, Micro-Turbine/Fuel Cell and Energy Storage devices has been studied in [17]. In this paper, the uncertainties are load, WFPG, Photovoltaic power generation and market price. Optimal biding strategy model in an electricity distributed company in order to earn maximum profit in a day-ahead market is considered in [18]. In [19], the reliability of WF in coordination with PSU in power system has been estimated. In this reference, for making coordination between WF and PSU, it is used of Monte Carlo simulation method, and the aim is to compute the adequacy indexes for one year period.

The presented issue, in this paper, can be shortly explained as follows:

1- Prediction of WFPG by the HM of WT-ANN-ICA. According to the done studies in [4-6], prediction of WFPG using proposed method has the less error of prediction than the ARMA, ANN, WT-ANN, WT-ANN-PSO and WT-ANN-GA methods, and this means to generate the scenarios closer to reality and causes the optimal programming.
2- Generating the scenarios of WFPG, market price (energy price, spinning reserve and non-spinning reserve), PVG, and decreasing the scenarios with the Scenario-reduction backward method, and modeling them by scenario tree method.
3- The coordination programming of WF, CHU, PV and PSU, by considering constrains of these units and the uncertainty of WFPG, market price and PVG.
4- Studying the expected profit and FR in the CO and IO of four types of units.

2. The Proposed Method

The proposed algorithm for programming of generation and unit commitment of WF, CHU, PV and PSU including two WF, one PV and three CHU and PSU in both CO and IO states in a day-ahead energy and ancillary services market is presented and shown in Fig. (1).

2.1. Prediction and scenarios generation

The proposed method for prediction of WFPG is shown in Fig. (1). First, it is assumed that the prediction for d-th day will be done, and historical data are available for every hour of 24 hours from 100 days ago.

Stage 1: first, the historical data is recalled and normalized in order to improve the homogenization of data.

Stage 2: Data Processing Using Wavelet Theory: Using the mathematical equations, the components and features of data can be extracted. WT is used in order to extract the components and features of time and frequency domain of signal data. The basic equations of WT are as Eq. (1), (2).

$$WT(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t)\psi(\frac{t-b}{a})dt \quad a = 2^{-j}, b = k2^{-j} \in R, a \neq 0 \tag{1}$$

$$f(t) = \frac{1}{C_{\Psi}^{2}} \iint_{a,b} \Psi_{\psi} \frac{1}{a^{2}} \psi(\frac{t-b}{a}) dadb \tag{2}$$

Where, ψ *(a,b)* is wavelet function and *f(t)* is input signal on which wavelet function is done until resulting the *WT (a,b)* signal. Also *a* and *b* are the parameters related to the WT which depend on the kind of wavelet function. By repeating the process, approximations are again decomposed, and signal is decomposed to the smaller parts [2, 18]. In Fig. (2, a) the output power of wind farm 1(WF1) is shown along with its WT signal for every hour of the past year. Because of the numerous disturbances in historical data and reducing the fluctuation of input data, it has been used of WT. The input data decomposed to three approximate components (D_{h1}, D_{h2}, D_{h3}) with less adaptation and an accurate component (A_h) which plays the most important role in the prediction [20].

Stage 3: Artificial Neural Network (ANN): the first, McCulloch and Pitts tried to simulate the ANN by a logical model, which, today, it is widely used. The ANN used in this paper is three layer perceptron including the output layer with one neuron, the input layer with five neurons, and the hidden layer with three neurons. This ANN will be used to predicting the information of hours d(t+1,……t+24) for the output signals of WT as the initial data.

Stage 4: Imperialist Competitive Algorithm (ICA): ICA is a new optimization strategy based on political and social evolution of human. More precisely, this algorithm is the mathematical model of social-political process of imperialist. As, it is inspired of biological evolutions in GA and PSO, and the chromosomes and particles are used for determining the best solution, the source of inspiration of ICA is the social-political evolution, and it is used of colonies (countries) as the variable for finding the optimal solution [5,6]. The steps to implementation of ICA can be summarized as follow:

1-Creating the initial colonies: To determine the number of every colony's variables, according to the neural network input signals (A_h,D_{h1},D_{h2},D_{h3}), and the five neurons in the input layer (IL), three neurons in hidden layer(HL), and one neuron in output layer(OL), the matrixes of wrights(W) and biases(B) are respectively as IL_W=[5×4], IL_B=[5×1], HL_W=[5×3], HL_B=[3×1] ، OL_W=[3×1], OL_B=[1×1], so every colony has 47 variables. Initial colonies are selected randomly through specific range based on initial training of ANN. Then, by helping the function cost which is based on decreasing the prediction error, the optimization of weights and biases are performed for the neural network for better training. The function cost used in this paper is MSE which is implied as the Eq. (3).

$$\min FunctionCost \qquad MSE = \frac{1}{IN}\sum_{in=1}^{IN}\left|\hat{y}_{in} - y_{in}\right|^{2} \tag{3}$$

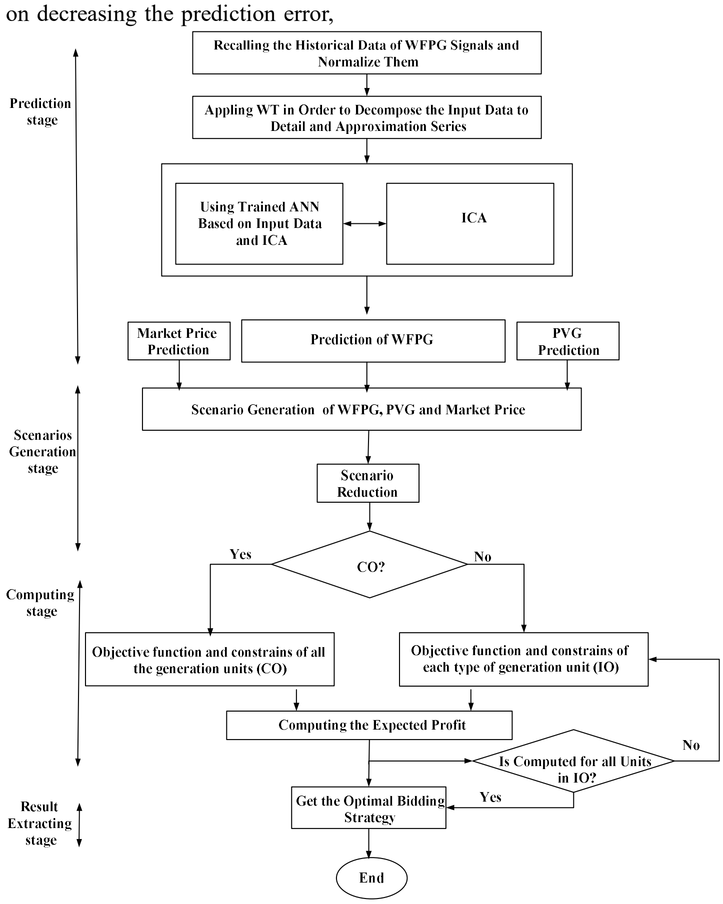

Fig. (1): The Flowchart of the proposed method

2- Selecting the imperialist: In this stage the colonies which have minimum cost are selected as the imperialists.

3- Allocating the other colonies as the colony to the imperialists: in this stage, some colonies are allocated to each of imperialists and empires will be generated. This allocation is done according to imperialists fitness (fewer cost) by stochastic universal sampling (SUS) method [6]. The stages of 1-3 are the initialization stages of ICA.

4-Peforming the act of assimilation or absorption policy: in this stage, each of the colonies is moved towards the imperialist in each empire. This stage is performed in order to improve the exploitation of algorithm.

5-Performing the act of revolution: In this stage, the random changes are applied on each of the colonies. This action causes to improve the exploration of algorithm, and prevent from involving the optimization in the local optimal points.

6-Computing the cost of colonies and imperialists

7-Comparing the cost of colonies with imperialist in each empire: if a colony has a fewer cost than the imperialist, it will be take placed.

8- Evaluating the empires: the cost for each empire is computed according to the Eq. (4).

$$Cost_{empire} = Cost_{imperialist} + \frac{0.1}{N_{COL}}\sum_{n=1}^{N_{COL}}(Cost_n) \tag{4}$$

Where: N_{CLO} is the number of colonies.

9- Decreasing the colonies: in this stage, a colony is omitted

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from the weakest empire and will be transmitted to another empire by roulette wheel method. According this method, the empire which have a fewer cost, have more chance to seize the colony.

10-Ommitting the empire: if the weakest empire has not any colony, the related imperialist will be transmitted to another empire as a colony.

Stage 5: Studying the termination condition: the stop condition is set based on the number of repetitions, which is obtained by trial and error method. If the stop condition of program is stablished, the results will transmitted to scenario generation stage, otherwise, the algorithm will be returned to (4) for generation new colonies. ICA flowchart is shown in Fig. (3). WFPG prediction curves are shown in Fig. (2, b,c).

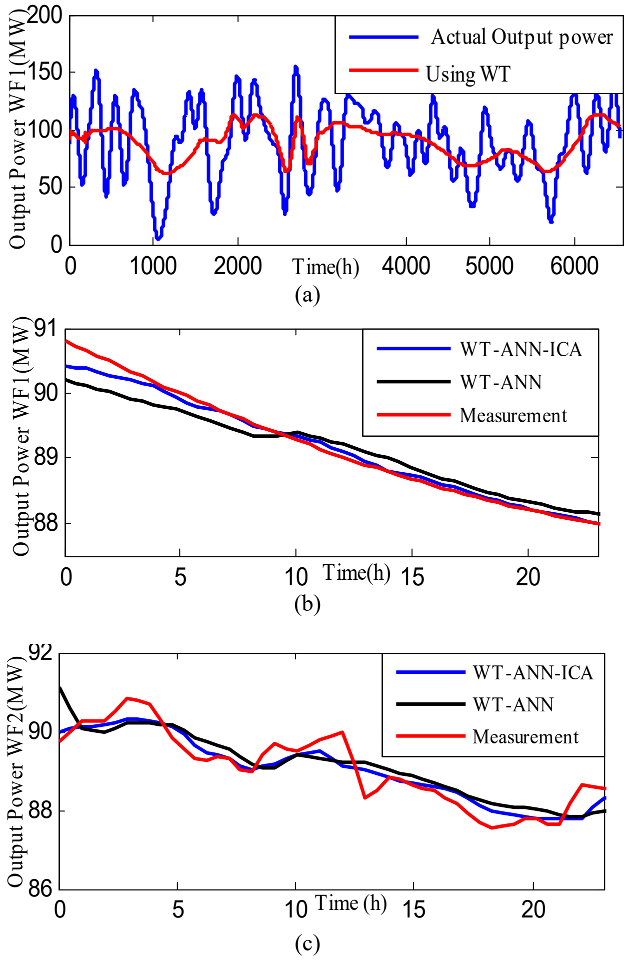

Fig. (2): (a): The real output power which its noise has been removed by WT in a period of one year of WF1. The output power measured and predicted by methods of WT-ANN and WT-ANN-ICA related to (b):WF1 (c):WF2 in d=101.

2.1.2. Generating scenarios for WFPG, PVG and market price

After predicting the uncertainty variables, the predicted error of each one is considered with a known probability distribution function. This distribution function is discretized to N parts with the mean of zero from the center with the width of α, and it is allocated an occurrence probability and specific error percentage for each level as is shown in Fig. (4). The probability of each occurrence is normalized so that their accumulated distribution function is equal to 1. Then a number is randomly selected for the each uncertainty variable and each time interval by roulette wheel method, which generates intended scenario. The rate of each scenario is obtained by the sum of error and the predicted amount of variable [17]. The Eq. (5) shows the amount of scenario for the WF. So, 500 scenarios are generated for each the WFPG, PVG and market price.

$$P_G^W(w,s,t) = P_{Gforcasted}^W + \Delta P_G^W(w,s,t)$$
$$t = 1,....,24, s = 1,......,w = 1,......,W_N \quad (5)$$

2.1.3. Backward method scenario reduction

For modelling all three uncertainty parameters including WFPG, market price and PVG, many scenarios will be generated. By increasing the number of scenarios, solving the stochastic problem will be so difficult and time consuming. In order to solve this problem, the number of scenarios will be reduced to an arbitrary number by backward method. The basis of this method is to integrate the scenarios with close probability and eliminate them to one. This will be continued until decreasing the scenarios to the favorable number [15, 17]. The number of scenarios has been reduced to 5 scenarios for each state.

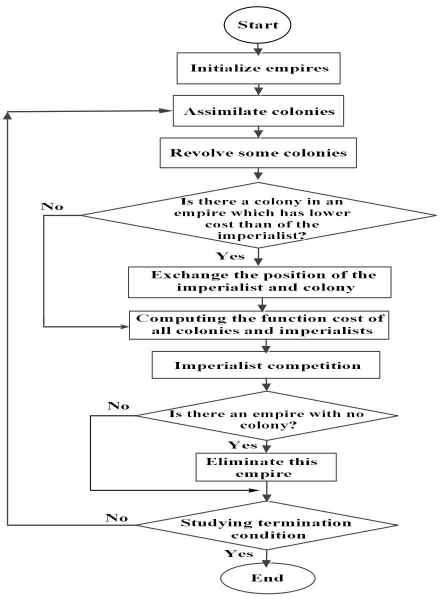

Fig. (3): Flowchart of ICA

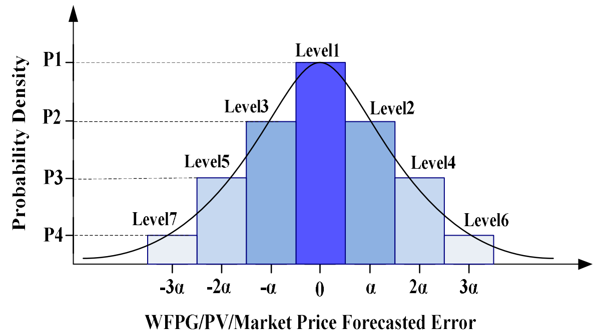

Fig. (4): The probability density of function of the WFPG/PV and market price

2.2. Coordination operation (CO) of WF, PV, CHU and PSU

In the day-ahead market, GENCOs and consumers submit their bids to ISO according to the predicted market price and demand. In this condition, the profit of generation units is determined according to market clearing price, operation cost, imbalance revenue/cost, proposed energy and delivered energy as the Eq. (6). These parameters are computed as the Eq. (7)-Eq. (9) [13, 15]. Where Eq. (7), shows the revenue obtained from sailing the energy to the amount of $P_S(i,t)$ with the price of $E_P(t)$. The Eq. (8), also, shows the operation cost, which is a function of unit generation power $P_G(i,t)$. The Eq. (9) shows the imbalance revenue/cost of unit, which it is the function of difference between sold (proposed) and generation (delivered) energy $(P_S(i,t)-P_G(i,t))$. Eq. (10) shows imbalance revenue/cost function. Where, $\alpha(t)$ andare variously $\beta(t)$ defined in different market. In this paper, the relation between imbalance penalty factor and generation power by a relation which is commensurate with market price is determined as Eq. (11). In Eq. (11), η is a number between zero and one, also three variables ‘ $P_G(t)$ $\widetilde{C}_{imb}(t)$ andare unknown till $E_P(t)$ the energy delivery time. These three variables cause the uncertainty and, therefore, risk in programming.

2.2.1. Modelling of the proposed problem of units coordinated programming

In this section, the problem of determining the optimal bidding strategy is modelled as an optimization problem. The objective function of optimization problem is as Eq. (12). The aim of the optimization problem is to maximize the expected profit (difference between incomes and costs (Eq. (13)) of units considering constrains related to use of units. The revenues are from selling the energy and reserve proposed to the market, and the revenue from generation is more than the amount proposed to the market (positive imbalance revenue) by all of the units (Eq. (14). Also the costs include the cost of operation, startup and shutdown the units, purchased power of PSU in the state of pumping operation and imbalance cost are presented in Eq. (15), Eq. (16).

3.1.1. Constrains of the proposed optimization problem

3.1.2. General constrains:

a) Maximum energy offer limit (Eq. (17)).

b) Output generation power of the CO (Eq. (18)).

3.1.3. Constrains of PSU:

a) Produced / consumed power of PSU in Generation / pumping operation: (Eq. (19).

b) Balance of water constrains: (Eq. (20), Eq. (21)).

c) Upper /lower reservoirs water volume limits: (Eq. (22), Eq. (23)).

d) Initial /terminal reservoirs water volume: (Eq. (24)-Eq. (27)).

e) Charge/discharge of water limits: (Eq. (28), Eq. (29)).

f) Proposed power to the energy and ancillary services market limit: (Eq. (30), Eq. (31)).

g) Non-spinning reserve limit in down state: (Eq. (32)).

h) Operation in pumping /generating operation: (Eq. (33)).

k) Reserve power supply generated in pumping mod: (Eq. (34)).

l) Proposed spinning/non-spinning reserve limit: (Eq. (35), Eq. (36)).

3.1.4. Wind farms constrain:

a) Wind power generation limit: (Eq. (37)).

3.1.5. Cascaded hydro units Constraints: In this section, the programming constrains used in this paper are presented. These constraints consist of the electrical and hydro operation constraints of hydro units. Because of the complicated nature of stream on a reservoir, it is used of matrix model. In the matrix model, to display each variable of charge and discharge water from the dam, turbine and units, a matrix is used. For this purpose, two main variables used in matrix modelling constraints of hydro system will be introduced as Eq. (38).

It should be mentioned that if h-th unit is directly upstream of the unit: (Eq. (39)).

a) The balance Constraint of water for CHU: According to this constraint, the volume of water stored in h-th hydro unit in the time t is obtain according to the reservoir water volume at time (t-1), the reservoir natural inflow at hour (t-1), the reservoir discharge and the reservoir spillage at time (t-1), as Eq. (40):

b) Water discharge rate limit: (Eq. (41)).

c) Reservoir water volume limit: (Eq. (42)).

d) Initial /terminal reservoir water volume: (Eq. (43), Eq. (44)).

e) The generation power of CHU: (Eq. (45)).

f) Ramping up/down limit: (Eq. (46), Eq. (47)).

g) Water spillage limit: (Eq. (48)).

h) Operation status/shutdown state: (Eq. (49), Eq. (50)).

3.1.6. Photo-voltaic unit Constraints:

a) Limits on the battery of the photo-voltaic unit while getting charged and discharged: (Eq. (51), Eq. (52)).

b) Charge/discharge switching constraint: (Eq. (53)).

c) Initial and terminal energy of the photo-voltaic unit: (Eq. (54)).

d) Amount of saved energy in the battery: (Eq. (55)).

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e) The power generation of the photo-voltaic unit and battery: (Eq. (56)).

$$R_T(i,t) = R_S(i,t) - C_T(i,t) - C_{imb}(i,t)$$
(6)

$$R_S(i,t) = P_S(i,t).E_P(t) + P_{SR}(i,t).E_{SR}(t) + P_{NSR}(i,t).E_{NSR}(t)$$
(7)

$$C_T(i,t) = (a_i + b_i.P_G(i,t) + c_i.P_G^2(i,t)).M(i,t) + (U_{COST}(i,t) + D_{COST}(i,t))$$

$$C_{imb}(i,t) = \widetilde{C}_{imb}(i,t).f(P_S(i,t) - P_G(i,t))$$
(9)

$$C_{imb}(i,t) = \left(\alpha(t) + \beta(t).(\frac{P_S(t)}{P_G(t)})^2\right).(P_S(t) - P_G(t)) \quad (10)$$

$$\begin{cases} \beta(t) = (1+\eta).E_P(t), \alpha(t) = 0 & P_S \rangle P_G \\ \alpha(t) = (1-\eta)E_P(t), \beta(t) = 0 & P_S \langle P_G \end{cases}$$
(11)

$$\max \quad ER_T = \sum_{t=1}^{T} \sum_{s_p=1}^{S_{NP}} \sum_{s_w=1}^{S_{NW}} \sum_{s_{pv}=1}^{S_{NPV}} \rho(s_w, s_p, s_{pv}).\left(\sum_{w=1}^{W_N} \sum_{ps=1}^{PS_N} \sum_{pv=1}^{PV_N} \sum_{h=1}^{H_N} R_T(s_w, s_p, s_{pv}, w, ps, pv, h, t) \right) \quad (12)$$

$$R_T(s_w, s_p, s_{pv}, w, ps, pv, h, t) = \left(R_S(s_p, t) - C_T(s_w, s_p, s_{pv}, w, ps, pv, h, t) - C_{imb}(s_w, s_p, s_{pv} w, ps, pv, h, t)\right)$$
(13)

$$R_S(s_p, t) = \left(E_P(s_p, t).P_S(t) + E_{SR}(s_p, t).P_{SR}(t) + E_{NSR}(s_p, t).P_{NSR}(t)\right)$$
(14)

$$C_{imb}(s_w, s_p, s_{pv}, w, ps, pv, h, t) = \widetilde{C}_{imb}(s,t).f\left(P_S(t) - P_G(s_w, s_p, s_{pv}, w, ps, pv, h, t)\right) \quad (15)$$

$$C_T(s_w, s_p, s_{pv}, w, ps, pv, h, t) = \left(\sum_{w=1}^{W_N} A_w \right) + \left(\sum_{ps=1}^{PS_N} (A_{ps} + U_{COST}(ps,t)) \right)$$
$$+ \left(\sum_{h=1}^{H_N} (A_h + B_h.P_G^H + U_{COST}(h,t).N(h,t) + D_{COST}(h,t).N'(h,t)) \right) + \left(\sum_{pv=1}^{PV_N} BATT_{COST}(k = pv, t) \right)$$
(16)

Where: $BATT_{COST}(k,t) = [a^{CH}(k)Z_{BATT}^{CH}(k,t) + b^{CH}(k)P_{BATT}^{CH}(k,t)] + [a^{DCH}(k)Z_{BATT}^{DCH} + b^{DCH}P_{BATT}^{DCH}(k,t)] + CC(k)$

$$P_S(t) \le \sum_{w=1}^{W_N} P_{G\max}^W(w) + \sum_{ps=1}^{PS_N} P_{G\max}^{PS}(ps) + \sum_{h=1}^{H_N} P_{G\max}^H(h) + \sum_{pv=1}^{PV_N} (P_{G\max}^{PV}(pv) + \delta P_{BATT}^{\max DCH}(k = pv)) \quad (17)$$

$$P_G(s_w, s_p, s_{pv}, t) = \sum_{ps=1}^{PS_N} P_G^{PS}(s_w, s_p, s_{pv}, ps, t) + \sum_{w=1}^{W_N} P_G^W(s_w, w, t) + \sum_{pv=1}^{PV_N} P_G^{PV}(s_{pv}, pv, t) + \sum_{h=1}^{H_N} P_G^H(s_w, s_p, s_{pv}, h, t) \quad (18)$$

$$P_G^{PS} = \begin{Bmatrix} P_g^{PS}(s_w,s_p,s_{pv},ps,t) = a_{ps}(qr(s_w,s_p,s_{pv},ps,t))^2 + b_{ps}qr(s_w,s_p,s_{pv},ps,t) + c_{ps} & Generating\,\mathrm{mod} \\ -P_P^{PS}(s_w,s_p,s_{pv},ps,t) = -(a_{ps}(pr(s_w,s_p,s_{pv},ps,t))^2 + b_{ps}pr(s_w,s_p,s_{pv},ps,t) + c_{ps}) & Pumping\,\mathrm{mod} \end{Bmatrix}$$

(19)

$$v^u(ps,t) = v^u(ps,t-1) - gr(s_w,s_p,s_{pv},ps,t-1) + pr(s_w,s_p,s_{pv},ps,t-1)$$

(20)

$$v^L(ps,t) = v^L(ps,t-1) + gr(s_w,s_p,s_{pv},ps,t-1) - pr(s_w,s_p,s_{pv},ps,t-1)$$

(21)

$$v^u_{\min}(ps) \le v(s_w,s_p,s_{pv},ps,t) \le v^u_{\max}(ps)$$

(22)

$$v^L_{\min}(ps) \le v(s_w,s_p,s_{pv},ps,t) \le v^L_{\max}(ps)$$

(23)

$$v^u(ps,t=1) = v^u(ps,ini)$$

(24)

(25) $$v^u(ps,t=T) > v^u(ps,end)$$

$$v^l(ps,t=1) = v^l(ps,ini)$$ (26)

$$v^l(ps,t=T) = v^l(ps,end)$$

(27)

$$gr_{\min}(ps).I^g(ps,t) \le gr(s_w,s_p,s_{pv},ps,t) \le gr_{\max}(ps).I^g(ps,t)$$ (28)

$$pr_{\min}(ps).I^p(ps,t) \le pr(s_w,s_p,s_{pv},ps,t) \le pr_{\max}(ps).I^p(ps,t)$$

(29)

$$\begin{pmatrix} P_G^{PS}(s_w,s_p,s_{pv},ps,t).I^g(ps,t) \\ + SR^g(s_w,s_p,s_{pv},ps,t) + N.SR.on(s_w,s_p,s_{pv},ps,t) \end{pmatrix} \le p^{PS}_{G\max}(ps).I^g(ps,t)$$ (30)

$$\begin{pmatrix} P_P^{PS}(s_w,s_p,s_{pv},ps,t).I^p(ps,t) \\ + SR^p(s_w,s_p,s_{pv},ps,t).I^p(ps,t) \\ + \mathrm{N.SR.down}(s_w,s_p,s_{pv},ps,t).I^p(ps,t) \end{pmatrix} \ge -\mathrm{p}^{\mathrm{p}}_{\max}(ps).I^p(ps,t)$$

(31)

$$\mathrm{N.SR.down}(s_w,s_p,s_{pv},ps,t) \le \left(QSC(ps).(1 - I^g(ps,t) - I^p(ps,t))\right)$$

(32)

$$I^g(ps,t) + I^p(ps,t) \le 1$$

(33)

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$$\begin{pmatrix} SR^{p}(s_w,s_p,s_{pv},ps,t).I^{p}(ps,t) \\ +\,\mathrm{N.SR.down}(ps,t).I^{p}(s_w,s_p,s_{pv},ps,t) \end{pmatrix} \le P_p^{PS}(s_w,s_p,s_{pv},ps,t).I^{p}(ps,t)$$

(34)

$$R_{C,PS}(ps,t) \le SR^{p}(s_w,s_p,s_{pv},ps,t) + SR^{g}(s_w,s_p,s_{pv},ps,t) \tag{35}$$

$$N_{C,PS}(ps,t) \le N.SR.on(s_w,s_p,s_{pv},ps,t) + N.SR.down(s_w,s_p,s_{pv},ps,t) \tag{36}$$

$$P_G^W(w,t) \le P_{G\max}^W(w) \tag{37}$$

$$Q_h(\hat{h},t) = QS_h(\hat{h},t-\tau_{h,\hat{h}}) + QT_h(\hat{h},t-\tau_{h,\hat{h}}) \tag{38}$$

$$Q_h(\hat{h},t+\tau_{h,\hat{h}}) = q(h,t) + S(h,t) = QS_h(\hat{h},t) + QT_h(\hat{h},t) \tag{39}$$

$$v(h,t) = v(h,t-1) + \left(\sum_{\hat{h}=1}^{H_N} (R_{\hat{h},h}.Q_{\hat{h}}(s_w,s_p,s_{pv},h,t-1)) - q(s_w,s_p,s_{pv},h,t-1) + u(h,t-1) - S(s_w,s_p,s_{pv},h,t-1) \right) \tag{40}$$

$$q_{\min}(h).M(h,t) \le q(s_w,s_p,s_{pv},h,t) \le q_{\max}(h).M(h,t) \qquad t \in \{1,\ldots T\}$$

(41)

(42)

$$v_{\min}(h) \le v(h,t) \le v_{\max}(h) \qquad t \in \{1,\ldots T\}$$

(43)

$$v(h,0) = v(h,ini) \qquad t \in \{1,\ldots T\}$$

(44)

$$v(h,T) = v(h,end) \qquad t \in \{1,\ldots T\}$$

$$P_G^H(s_w,s_p,s_{pv},w,ps,pv,h,t) = (k_{1h} \times q^2(s_w,s_p,s_{pv},w,ps,pv,h,t) + k_{2h} \times q(s_w,s_p,s_{pv},w,ps,pv,h,t) + k_{3h}) \qquad t \in \{1,\ldots T\}$$

(45)

$$P_G^H(s_w,s_p,s_{pv},w,ps,pv,h,t+1) - P_G^H(s_w,s_p,s_{pv},w,ps,pv,h,t) \le 60.RU_h$$

(46) $$P_G^H(s_w,s_p,s_{pv},w,ps,pv,h,t) - P_G^H(s_w,s_p,s_{pv},w,ps,pv,h,t+1) \le 60.RD_h \tag{47}$$

$$S_h^{\min} \le S_h(s_w,s_p,s_{pv},w,ps,pv,h,t) \le S_h^{\max}$$

(48) $$M(h,t) - M(h,t-1) = N'(h,t) - N(h,t) \tag{49}$$

$$N'(h,t) - N(h,t) \le 1 \tag{50}$$

$$0 \le P_{BATT}^{CH}(pv,s_{pv},t) \le P_{BATT}^{\max CH}(pv) Z_{CH}(pv,s_{pv},t) \tag{51}$$

$$0 \le P_{BATT}^{DCH}(pv, s_{pv}, t) \le P_{BATT}^{\max DCH}(pv) Z_{DCH}(pv, s_{pv}, t) \quad (52)$$

$$0 \le Z_{CH}(pv, t) + Z_{DCH}(pv, t) \le 1 \quad (53)$$

$$ENR(k, t = 1) = ENR_{ini}(k), ENR(k, pv, t = 24) \ge ENR_{end} \quad (54)$$

$$ENR(k, s_{pv}, t) = ENR(k, s_{pv}, t-1) + P_{BATT}^{CH}(k, s_{pv}, t-1) - P_{BATT}^{DCH}(k, s_{pv}, t-1) \quad (55)$$

$$(56) \quad P_S^{pv}(pv, s_{pv}, t) = P_G^{pv}(pv, s_{pv}, t) - P_{BATT}^{CH}(pv, s_{pv}, t) + \delta P_{BATT}^{DCH}(pv, s_{pv}, t)$$

2.2.2. Coordinated operation (CO) and independent operation (IO)

In order to consider an independent or coordination planning of units, uncertainty parameters are market price, WPG and PVG (s_w, s_p, s_{pv}). First, the objective function of each type of units and related constrains are optimized separately and determined the generation bids, then the expected profit and a FR are calculated.

This process is repeated for the CO, such that the objective function of all WF, CHU, PV and PSU (Eq. (12)) is optimized considering constrains of all four types of units and other constrains forced by CO, then one generation bid is offered to ISO, and WF, CHU, PV and PSU will be participated in a day-ahead energy and ancillary services market considering maximum generation power of each unit. In this case, the expected profit and FR are calculated and compared. This optimization problem is solved by using GAMS / CPLEX software.

3. Numerical Example

The improved IEEE 118-bus standard system includes two WF, one PV and three CHU and PSU. The WF nominal power are $P_{\max}^{MW} = 300$, $P_{\min}^{MW} = 10$ also, it is used of IEEE standard for the historical data of WFPG. The PV nominal power is $P_{\max}^{MW} = 4.68, P_{\min}^{MW} = 0$ and $\delta = 0.75$. The CHU nominal power are $H_1 : P_{\max}^{MW} = 70, P_{\min}^{MW} = 9$, and $H_2 : P_{\max}^{MW} = 70, P_{\min}^{MW} = 4$

re upstream a2 and H 1H , where, $H_3 : P_{\max}^{MW} = 115, P_{\min}^{MW} = 17$ units of H_3 as is shown in Fig. (5). And their additional information are presented in [13].The information related to PSU is presented in [22]. In this paper η is equal to 0.9. The market price data are available in Fig. (6).

After solving the optimization problem related to CO and IO of WF, CHU, PV and PSU, the proposed power is obtained in each operation and hour, which is presented in table (1), using the HM of WT-ANN-ICA in order to predict of WFPG.

Another important point is that ISO has predicted the demand in each hour according to the weather condition and the price of energy and reserve are determined. So, the generation power bids, in the hours in which the market price is high (more demand), will be more in IO in PSU and CHU also, in the CO. while, in the hours in which the energy price is low(less demand), the tendency to purchasing the power and working in pumping mod in PSU in IO is more, and in the CO, WFPG and/or PVG can be spent for PSU pumping operation.

The expected profit of CO and IO of units are shown in table (2). By WT-ANN-ICA method, the expected profit in the CO (WF, CHU, PV and PSU coordinated) is 198318.3 USD, which has been increased in the rated of 15764.84 USD, in comparing with the sum of expected profit in IO as it is expected. Using WT-ANN-ICA method is more accurate in comparing with WT-ANN method, which the mathematical expected profit has been respectively increased to 4292.89 and 7034.47 for IO and CO.

In order to the FR the imbalance revenue/cost, which is one of the main factors of FR in the proposed model, is obtained in a table (3). Imbalance revenue has been increased in CO, in comparing with IO. Using WT-ANN-ICA method, imbalance revenue has been decreases in CO and IO. Because, if the units have been failed in its obligations more than energy prices will be fined and if production would be more than its obligations, less than energy price will be rewarded.

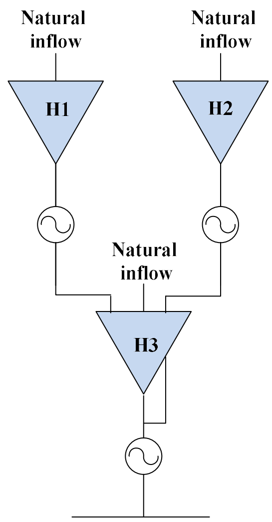

Fig. (5): Hydro system configuration used in this study

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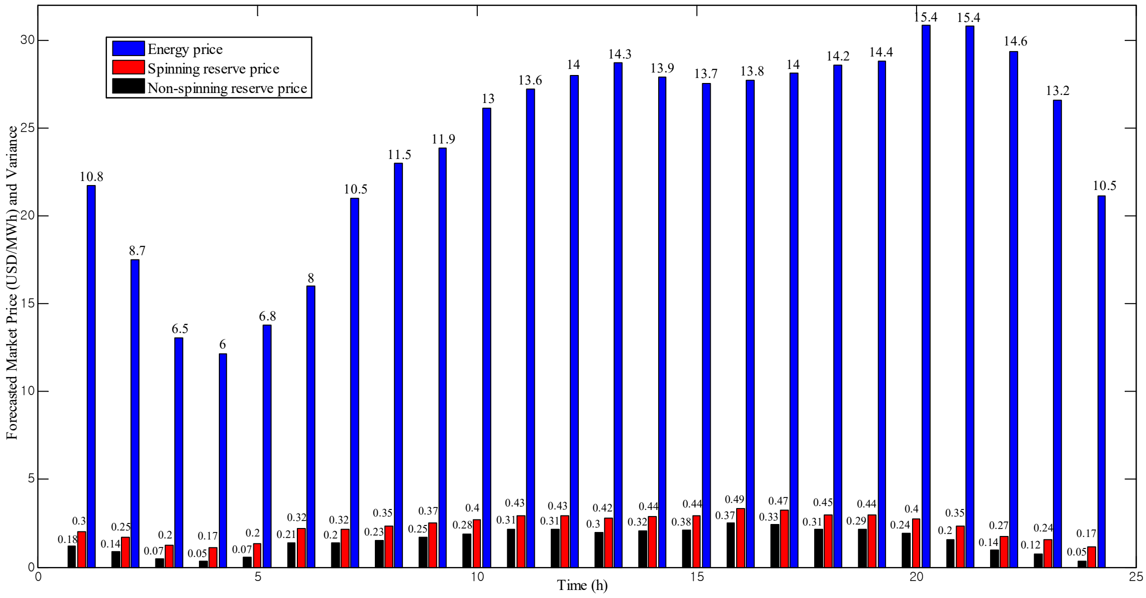

Fig. (6): The forecasted market price (energy price, spinning reserve and non-spinning reserve) and their variance.

Table (1): power generation bids of WF, CHU, PV and PSU in CO and IO with WT-ANN-ICA method

State operation	IO				CO
Time/Unit	WF	PV	CHU	PSU	
t1	171	0	93	-36	244.5
t2	171.5	0	57.6	-98	129.1
t3	171	0	26	-98	85
t4	170	0	27.3	-98	110.7
t5	168.5	0	30.3	-98	115.6
t6	168.5	1.008	40	-98	125
t7	167.3	1.548	57.7	12	259.5
t8	168	1.95	80.1	-89	178
t9	166.5	2.002	101.5	44	310.5
t10	165.5	2.56	111.2	58	349
t11	165	3.2	118.9	58	355.5
t12	165	4.12	121.5	58	361
t13	164.5	4.68	124	58	349.5
t14	165.7	4.61	126.2	58	365
t15	163	4.2	130.7	58	371.4
t16	163.6	3.31	145.87	58	380.6
t17	164	3	147.3	58	378
t18	163	2.145	148.9	58	382.3
t19	159.5	1.45	152.6	-36	291
t20	161.5	0	162.5	98	412
t21	161	0	162.8	58	386.8
t22	159	0	162.8	68	395
t23	158.6	0	140.1	-4	308.8
t24	158.5	0	120.5	58	349

Table (2): Expected profit in CO and IO with WT-ANN-ICA and WT-ANN methods

		Expected Profit (USD)	
		WT+ANN	WT+ANN+ICA
IO	WF	89915.88	94208.77
	PV	1068.28	1068.28
	CHU	74525.01	74525.01
	PSU	12751.42	12751.4
	Total	178260.57	182553.46
CO	(WF+PV+CHU)&PSU	182378.65	188355.37
	(WF + PSU+PV)&CHU	186856.3	192123.42
	WF+PV+CHU+PSU	191283.83	198318.3

Table (3): Imbalance revenue (USD) in CO (WF+PV+CHU+PSU) and IO with WT-ANN-ICA and WT-ANN methods

	WT-ANN		WT-ANN-ICA	
State Operation	IO	CO	IO	CO
Imbalance revenue	24946.63	28904.77	21162.3	25863.65

4. Conclusion

In this paper, two methods were proposed for decreasing the WFPG uncertainty, which is the main factor of decreasing the profit and increasing the FR of these units.

In the first method, by the HM of WT-ANN-ICA, it was tried perdition more accurately and decreased the short-term prediction error of WFPG. By this method, the scenarios closer to reality are generated with a greater probability, and WF optimal programming is done more accurately, and this will cause to increase the expected profit.

In the second method, by making commitment among WF, CHU, PV and PSU, the uncertainty and FR of WF and PV will be decreased by using of two pumping and generating of PSU and CHU in the case that PSU generation mod does not have enough capacity when decreasing WFPG and PVG severely. Also, by making shift capabilities of WFPG and PVG based on the PSU and CHU capabilities to the hours with more demands, the profit of these units will be increased in comparison with IO.

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