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The Presentation of a Two Stages Model for an Optimum Operation of a Hybrid System of Wind-Pumped Storage Power Plant in the Power Market Environment

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Abstract: In this study we present a new method in power market environment. One of the weaknesses in the utilization of wind units is severe dependence of output power level on wind. However, considering the high uncertainty in the prediction of wind speed and wind forecast unit production capacity is also having an error. Also, regarding to the uncontrollable generators of this type, it is better to use combined systems for utilization. This study presents a new model based on the a two stage for an optimum operation of a hybrid system of wind-pumped storage power plant in the power market environment that causes to provide a successful presentation condition in market environments for the producers of wind power. In the suggestive hybrid system of wind-pumped storage power plant of this study the modeling is done in two stages for the optimum presence in power market environment with the a most possible benefit. At first, the suggestive model is optimized regarding to uncertainty in the prediction of power price and producing the wind power, for presenting the suggestion of power to market, in order to gain the most benefit. At the second stage, the suggestive model is optimized regarding to uncertainty in producing wind power, in order to gain the most benefit and paying the least penalty for unbalancing in market for operation of the system. In this study, the Particle Swarm Optimization algorithm (PSO) is used for optimization. At the end of a model example for applying the results of the proposed model will be examined and analyzes the results. Results show that the model is an appropriate method for the operation of this combined system in market environment.

Keywords: Optimum operation, profit maximization, PSO algorithm, the hybrid system of wind-pumped storage, uncertainty

INTRODUCTION

Increasing Green house gases and finishing fossil fuel sources in using fossil fuel resources and improvement of environment performance made the countries appeal to renewable resources energy. Wind energy is one of the renewable resources that are everlasting and concurrent with environment and using it causes decrease of affinity the fossil fuels (Hotline, 2005).

Regarding to this that the daily and seasonal wind manner is unsteady, to use wind power plant in a large scale, it is required to use another system for patronage of this power plant to management tools on that two systems do an optimum beneficiary for shale the consumable load (Matevosyan and Soder, 2006; Hu *et al*., 2008) and make a condition that provides the ability of controlling the wind energy, to adopt the best beneficiary strategy of system and gain from wind power plant system.

Using energy storage strategies can provide the possibility of wind energy producers' participation in market environment. The pumped storage system is one of these energy storage technologies that causes increase of incorporation in wind energy producing system by combining the hybrid with wind power plant (Matevosyan and Soder, 2006).

By using pumped storage, by the storage of wind energy in the term of surplus of wind electricity producing and transferring this term to use peak, the product benefit for producers of wind energy in market environment will be increased. The optimization in a wind-pumped storage hybrid system, regarding to the prospects of wind energy, the load and the electricity cost in markets and with coordination of the performance wind turbine and pumped storage units obtain. In references (Papaefthimiou *et al*.,2009; Caralis and Zervos, 2010; Magnus *et al*., 2003; Castronuovoa and Peps Lopes, 2004a, b;

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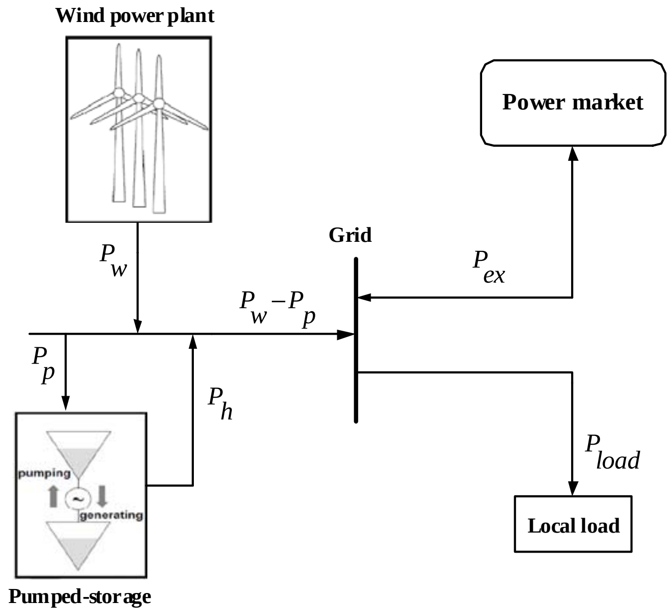

Fig. 1: Structure and direction of energy current

Castronuovoa and Peps Lopes, 2003) the operation of system of wind-pumped storage power plant was predicted regarding to wind power and the price of electricity was done for gaining the most benefit of optimization. In the reference (García-González *et al*., 2008) the operation of system regarding to uncertainty in the prediction of the electricity price and wind power, is done for gaining the most benefit and paying the least penalty of optimization. In this study, the performance of the hybrid system of wind-pumped storage power plant is optimized in two stages regarding to market models. In first stage, the hybrid system is optimization based on uncertainty of prediction of wind unit power and the prediction of the clearing price of electricity markets, for the suggestion of productive power to market sake gaining the most benefit, then the optimization of operation is done based on uncertainty in prediction of wind unit power and regarding to the clearing price of market sake gaining the most benefit and paying the least penalty for unbalance in market. The suggestive model optimization of this study is done by using Particle Swarm Optimization (PSO).

For confirming product result of optimization algorithm, the suggestive model of reference () was optimized which the product result becomes twice almost.

METHODOLOGY

Structure and direction of energycurrent in suggestive model: The suggestive model of the hybrid system of wind-pumped storage power plant is like to Fig. 1 in this study.

As it is observed in Fig. 1, a part of produced power of wind power plant (P_w) for providing the needed power of water pump (P_p) in pumped storage power plant in this system and the remainder of this power (P_w-P_p) is transferred to network. The pumped storage power plant transfers its own product power (P_h) to network, regarding to saved energy in upper reservoir. In this model, the providing local load (P_{load}) and power exchange with market (P_{ex}) is done by the conjunct network to hybrid system. The hybrid system is bound that provide the network local load. If the hybrid system can't provides the needed consumed power of local load, it can provide the amount of shortage power by buying from markets. regarding to specified pattern of energy current in this model, when the produced power hybrid system is more than consumed power of local load, the exchanged power with market is equal to suggested power by hybrid system to market (the amount of positive P_{ex}) and when the produced power by hybrid is less than the amount of consumed power of network local load, the exchanged power with market is equal to bought power from market (the value of negative P_{ex}).

Wind turbine model: Most power systems have more wind turbine generators than wind turbine plants. This study emphasizes the equivalent wind turbine plant to avoid tedious computations.

The power curve of equivalent wind turbine generators was approximated by fourth-order polynomials as Eq. (1) (Magnus *et al*., 2003):

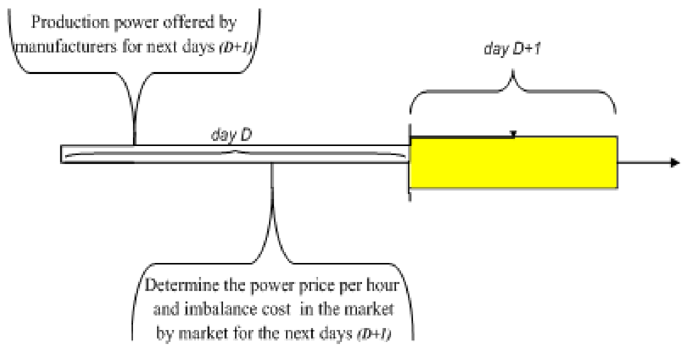

Fig. 2: Power market model

$$Pw,t = \begin{cases} PWG_{R,} & V_t \geq VF \\ a.V_t^4 + b.V_t^3 + c.V_t^2 + d.V_t + e & \\ VD < V_t < VF & \\ 0, & V_t \leq VD \end{cases} \tag{1}$$

$P_{w,\ t}$ is the power output of the w^{th} wind turbine generator, which can be calculated by observing the power curve of the wind turbine generators, V_t is the t^{th} hour wind speed at hub height and PWG_R is the rated power output of the wind turbine generators. VD denotes the cut in wind speed of the wind turbine generators. VF is the cut off wind speed of the wind turbine generators and a, b, c, d and e are constants.

Pumped-storage power plant model: The present study proposes the improvement of the Wind power generation controllability through the addition of a pumped-storage power plant. For this purpose, the following devices are required:

- A pumped-storage power plant with an electric generator
- A water pump station
- Lower and upper water reservoirs
- Penstock and pumping pipes

Equipments (a) and (b) can be replaced by a reversible hydro unit. The water pump station (b) pumps water from a source (i.e., river, lake, other reservoir) to the upper water reservoir, only using the electrical power generated by the Wind power generation.

However, the hydro components and the wind plant can be situated in different places, in the present study it is supposed an electrical proximity between them. An extension of this model, not analysed in the present study, regards the utilisation of a pump station to control a cluster of wind parks.

Power market model: The market model is according to pay to winner based on Market Clearing Price (MCP). As observed in Fig. 2, at first the producers suggest their own produced power to marketing hour, then the electricity price and the cost of unbalanced is indicated in market by market. Uncertainty in forecasting wind energy production and electricity prices in the market

Uncertainty in wind energy production is the characteristic of this natural energy, so when the utilization of networks, including the type of units are considering the issue of uncertainty is essential. If the location of wind units are geographically dispersed set of output changes greatly reduced the units and of course still has the problem of uncertainty considered. Fluctuations in power output of wind turbines in wind speed changes to come there, not completely random and are not completely predictable. For a long period activity of a wind farm, the prediction error is similar to a normal distribution function. In order for risk prediction error at issue reduced the utilization of the combined system, we can predict the errors at different levels, we calculated reliability. Prediction error of wind energy production, known as risk. For example, 95% said the level of probability that the prediction error is greater than the amounts of production risk is less than 5%. This method of production for the proposed wind energy to a specific level of reliability in production planning gains. Wind energy minus the predicted rate of production risk that can issue operating system should be used. Since the operator more willing to overestimate the production of wind generators is therefore a unilateral distribution curve is considered as normal distribution curve. The operator to determine the issue of risk needs to determine the production of a certain confidence level. The following equation estimates the high error level unilateral normal distribution curve with confidence level (α-100) %:

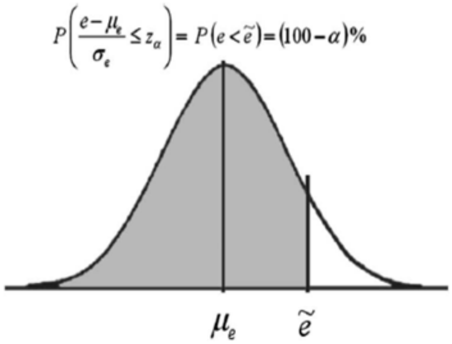

Fig. 3: Level of confidence level on a normal distribution curve

Table 1: Z_α value for different confidence levels

Z_α	$P[e-\mu e \le Z_\alpha\ \sigma_e](\%)$
1.285	90
1.645	95
2.329	99

$$P\left[e - \mu_e \ge Z_\alpha \sigma_e\right] = \frac{\alpha}{100} \tag{2}$$

$$\tilde{e} = \mu_e + Z_\alpha\ \sigma_e \tag{3}$$

$\tilde{e}$ represents the high-risk relationships, μ_e producing an average forecast wind error standard deviation and σ_e are the wind forecasting error. Below a graphic expression of these equations with the confidence is level (α-100) % (Fig. 3).

$\tilde{e}$ is some probability that states that the prediction error is higher than $\tilde{e}$ is less than% α:

$$P(e < \tilde{e}) = \alpha\% \tag{4}$$

Hundred % of the total area under the curve and the area eaten part hachure % (α-100) is. Z_α value for the reliability levels of 90, 95 and 99% in Table 1 is given, respectively.

Mean error Mean error as a historical period is calculated. We have For N observation:

$$\mu_e = \frac{1}{N}\sum_{i=1}^{N} e_i \tag{5}$$

$$\sigma_e = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(e_i - \mu_e\right)^2} \tag{6}$$

The e_i prediction error rate in sample i, μ_e and σ_e mean wind forecast error standard deviation error of prediction are wind. To enter risk production in the utilization plan, planners should first determine what level of confidence they need. The mean error and standard deviation can be recorded from the previous authentication information and relationships (5) and (6) come get. Values using the error mean value, standard deviation and risk production value of $Z_\alpha(\tilde{e})$ relation (3) is calculated. Value obtained for ($\tilde{e}$) of the predicted value is low and this number as the output of wind generators will enter the optimization problem. Considering the above mentioned wind turbine output matching relationship (7) is considered:

$$P_{wt} = (1 - \tilde{e}).P_{wt}^{forcs} \tag{7}$$

The term P^{force}_{wt} represents an equivalent wind turbine production forecast and $\tilde{e}$ is the production risk.

This study also shows uncertainty in electricity price forecasting is considered and the amount of electricity prices used in the optimization problem based on the explanations provided and the relations (2) Organic (6) According to relationship (8) is calculated:

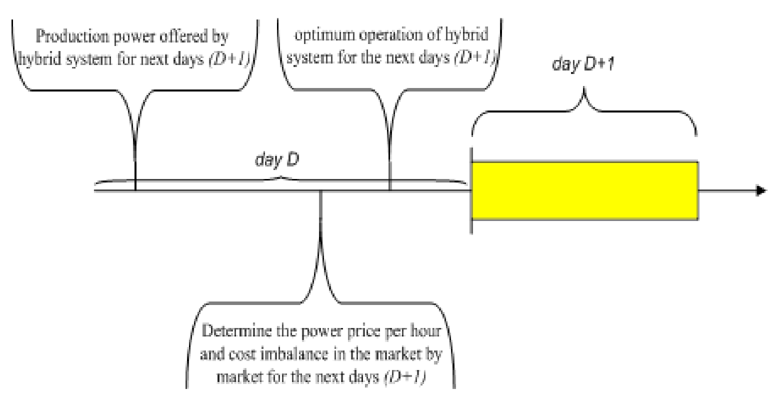

Fig. 4: Modeling for maximization of system profit

$$C_{mt} = (1 - \tilde{e}).C_{mt}^{forcs} \tag{8}$$

The term C^{forcs}_{mt} represents an equivalent power price forecast and $\tilde{e}$ is the prediction risk.

The modeling with the aim of maximization of System profit: In studied wind-pumped storage power plant hybrid system in this study, modeling for optimum presence in market environment with the most possible profit is done in two stages according to Fig. 4.

At first regarding to uncertainty in wind speed prediction, the model of suggesting power to market is optimization for gaining more profit.

In second stage, regarding to uncertainty in wind speed prediction the model of operation of system is optimized for gaining more profit and paying fewer penalties for unbalance in market.

The made errors of wind speed prediction increase the time horizon, also how much the wind speed prediction is looser to operation time, the prediction is more particular and its error is less (García-González *et al*., 2008).

Therefore in second stage of operation of system done with more confidence border and uncertainty in wind power in this stage is spotted less than the first stage.

Also the accuracy of prediction of the amount of local load (P_{load}) is supposed 100% in suggestive model.

Modeling for presenting of suggestion to market: Electricity price and wind speed the amount of local network consumed must be predicted before presenting suggestion of produced power by hybrid system to market. It is supposed that the electricity price prediction and wind speed are not done with the accuracy 100% in this model, also the value of local load is predicted with the accuracy 100%.

The function of system goal in electricity price prediction and wind speed, for suggestion of produced power to market, for gaining the most profit, regarding to uncertainty is defined as below:

$$\max \sum_{w=1}^{Nw} p_w . \sum_{s=1}^{Nw} p^s . \left\{ \sum_{i=1}^{T} \Big(C_l(i).P_{load}(i) \right.$$
$$+ C_m(i,s). \begin{pmatrix} P_w(i,w) - P_p(i,s,w) \\ + P_h(i,s.w) - P_{load}(i) \end{pmatrix} \tag{9}$$
$$\left. - C_p . P_p(i,s,w) \right\}$$

That the aim of each parameter is defined as below in this function: p_s is the price probability according to scenario *s*, N_s is the number of electricity price prediction scenarios, p_w is the wind speed probability according to scenario *w*, N_w is the number of wind speed prediction scenarios, $C_l(i)$ is the electricity price for local load in time i at (€/MWh), $P_{load}(i)$ is the value of suggested power of local load in time i at MW, $C_m(i,s)$ is the predicated electricity price under the scenario of price *s* in time i at (€/MWh), $P_w(i,w)$ is the predicated power of wind power plant produced under the wind speed scenario w in time i at MW, $P_h(i,s.w)$ is the produced power by pumped storage power plant under the s price scenario and w wind speed scenario in time i at MW, $P_p(i, s, w)$ is the produced power of pump under the s price scenario and w wind speed scenario in time i at MW, C_p is the pump cost (€/MWh), T is the number of hours of programming confine.

The bridle of the target function for operation of system is regarding below:

- The saved energy in reservoir under s scenario, w wind speed scenario in any set energy increases with water pump and decreases with water electricity produced:

$$E(i+1,s,w) = E(i,s,w) + \left(\eta_p . P_p(i,s,w) - \frac{P_h(i,s,w)}{\eta_h} \right) \tag{10}$$
$$\forall\, i \in T, \forall\, s \in N_s, \forall\, w \in N_w$$

E(i, s, w) is the level of saved energy in reservoir subject s scenario and w wind speed scenario in time i at MWh, η_h is the productivity of pumped storage power plant during turbine operation, η_p is the productivity of pumped storage during pump operation.

- The amount of saved energy in reservoir is equal to zero in the initial and final hours, it means the reservoir is empty in initial and final hours:

$$E(1) = E(T) \tag{11}$$

E (1) and E(T) are the initial and final reservoirs.

- The limitations of maximum and minimum capacity of wind power plant produced power:

$$P_g \min \le P_w(i,w) \le P_g \max \quad \forall\, i \in T,\ \forall\, w \in N_w \tag{12}$$

P_g min and P_g max is the low and high range of wind power plant produced power.

- The limitations of maximum and minimum produced power by the pumped storage power plant:

$$P_h \min \le P_h(i, s, w) \le \min(P_h \max, \eta_h.E(i, s, w))$$
$$\forall\, i \in T, \forall\, s \in N_s, \forall\, w \in N_w \tag{13}$$

P_h min and P_h maxis the low and high range of pumped storage power plants:

- The limitations of maximum and minimum consumed power by pump:

$$P_p \min \le P_p(i, s, w) \le P_p \max \forall i \in T, \forall s \in N_s, \forall w \in N_w \quad (14)$$

P_p min and P_p maxis the low and high range of consumed power range of pump.

- The limitations of the level of saved energy in reservoirs:

$$E \min \le E(i, s, w) \le E \max \quad \forall i \in T, \forall s \in N_s, \forall w \in N_w \quad (15)$$

E min and E max is the minimum and maximum capacity of reservoir storage:

$$i = 1,\ldots,t \quad , \ \forall \ i \in T$$

- For presenting the suggestion to market, the produced power for selling to market and the needed power of local load for purchasing from market and if it isn't provided by the hybrid system is obtained from the below Eq. (16):

$$P_{ex}(i) = \left(\sum_{w=1}^{Nw} p_w . \sum_{s=1}^{Ns} p_s . \begin{pmatrix} p_s(i,w) + P_h(i,s,w) \\ - P_p(i,s,w) \end{pmatrix} \right) - P_{load}(i) \quad (16)$$

After the optimization, the value of produced power of hybrid system is obtained by probability burden average of price prediction scenarios and wind speed, which the value of suggestive power for selling or buying from the market (P_{ex}) is resulted by reducing the amount local load (P_{load}) of from this value.

If the value of P_{ex} is larger than zero, power is suggested to market by hybrid system for selling to market and if the value of P_{ex} is negative, power is suggested to market for buying, so that it can provide the local load.

Modeling for system optimum operation: In developed model of system target function, it is defined as below, regarding to uncertainty in wind speed prediction for gaining the most profit, paying the least penalty for unbalance in market:

$$\max \sum_{w=1}^{Nw} p_w . \left\{ \sum_{i=1}^{T} \left(C_l(i) . P_{load}(i) \right) + C_m(i) . \begin{pmatrix} P_w(i,w) - P_p(i,w) \\ + P_h(i.w) - P_{load}(i) \end{pmatrix} - \omega . C_m(i) . \begin{vmatrix} P_w(i,w) - P_p(i,w) - P_h(i.w) \\ - P_{load}(i) - P_{ex}(i) \end{vmatrix} - C_p . P_p(i,s,w) \right\} \quad (17)$$

That each parameter is defined as below: p_w is the wind speed probability according to scenario w, N_w is the number of wind speed prediction scenarios, $C_l(i)$ is the electricity price for local load in time i at (€/MWh), P_{load} (i) is the value of suggested power of local load in time i at MW, $C_m(i)$ is the electricity market clearing price in time i at (€/MWh), $P_w(I, w)$ is the predicted power of wind power plant produced under the wind speed scenario w in time I at MW, $P_h(i, w)$ is the produced power by pumped storage power plant subject w wind speed scenario in time i at MW, $P_p(i,w)$is the produced power of pump subject w wind speed scenario in time i at MW, $P_{ex}(i)$ is the exchanged power among hybrid system and market in time i at MW which is used for presenting the produced power to market in the first stage of optimization and its value is obtained by the Eq. (16), C_p is the pump cost (€/MWh), T is the number of hours of programming limitation, ω is the penalty for unbalance in market in percent that it is defined as the Eq. (19):

The amount of exchangeable power among hybrid system and market in optimum operation model (P^{new}_{ex}) which is obtained according to the Eq. (18):

$$P_{ex}^{New}(i) = \left(\sum_{w=1}^{Nw} p_w . \begin{pmatrix} P_w(i,w) \\ + P_h(i,w) - P_p(i,w) \end{pmatrix} \right) - P_{load}(i) \quad (18)$$

If amount of suggestive power for exchanging among the hybrid system and market in system optimum operation model is more than the amount of suggestive power for exchanging among the hybrid system and market in first stage model per hour for presenting the suggestion to market, we should sell the additional power several percent cheaper according to market rules (ω_1) and if this value is less, we should buy this shortage of power by several percent more expensive (ω_2) than the real price of electricity in market:

$$\begin{Bmatrix} \omega = \omega_1 & P_{ex}^{new}(i) > P_{ex}(i) \\ \omega = \omega_2 & P_{ex}^{new}(i) > P_{ex}(i) \\ \omega = 0 & P_{ex}^{new}(i) > P_{ex}(i) \end{Bmatrix} \quad (19)$$

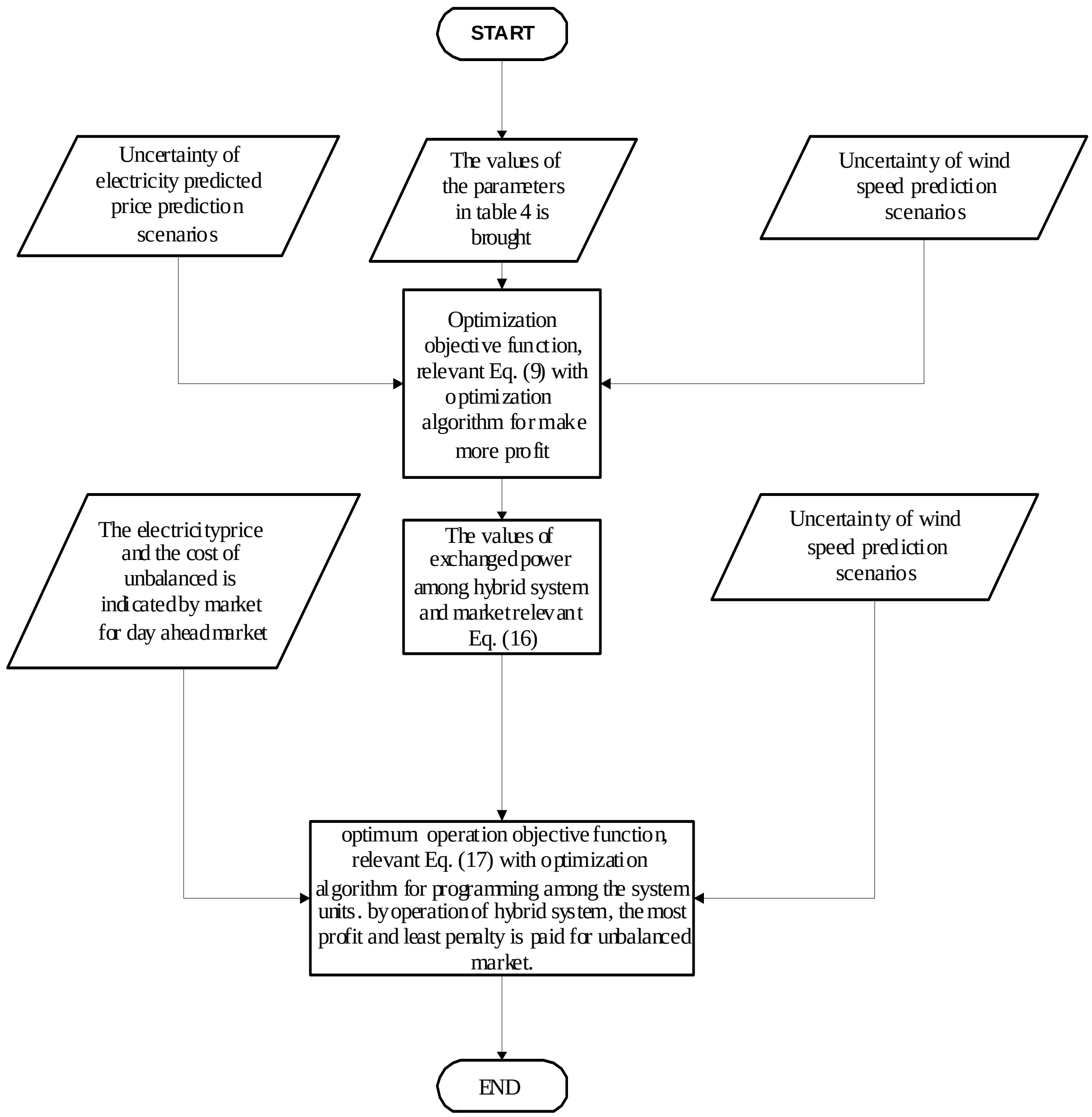

Fig. 5: Flow chart optimization program

Operational constraints for the objective function accordance with the constraints of the system to provide the objective function is proposed to the market but because the price is determined by the market just so relationships are based on variable wind speeds, which are as follows:

$$E(i+1,w) = E(i,w) + \left(\eta_p . P_p(i,w) - \frac{Ph(i,w)}{\eta_h} \right) \quad (20)$$

$$\forall\, i \in T, \forall\, w \in N_w$$

$$E(1) = E(T) \quad (21)$$

$$P_g \min \leq P_w(i, w) \leq P_g \max \; \forall\, i \in T, \forall\, w \in N_w \quad (22)$$

$$P_h \min \leq P_h(i, w) \leq \min(P_h \max , \eta_h.E(i, w)) \; \forall\, i \in T, \forall\, w \in N_w \quad (23)$$

$$P_p \min \leq P_p(i, w) \leq P_p \max \;\; \forall\, i \in T, \forall\, w \in N_w \quad (24)$$

$$E \min \leq E(i,w) \leq E \max \;\; \forall\, i \in T, \forall\, w \in N_w \quad (25)$$

$$i = 1,\ldots, t, \qquad \forall\, i \in T$$

After the optimization of target function, regarding to uncertainty in wind speed prediction, through average regarding to possibility of scenario, the values of $P_w(i,w)$,

$P_h(i, w)$, $P_p(i, w)$ and $E(i, w)$ parameter are obtained for programming among the system units. Then by operation of hybrid system, the most profit and least penalty is pay for unbalanced market.

The software development of suggestive model: Regarding to target function and discussed bridles, for optimization instead of wind speed prediction and the electricity market clearing price it is needed wind power plant features, pumped storage, the amount of consumed power of local load, electricity selling price to local load subscribers.

It is exhibited the flow chart optimization program in Fig. 5.

As it is observed in Fig. 5, in first stage regarding to uncertainty of wind speed scenario of wind speed scenario and electricity predicted price and the other needed parameters, the stated target function as Eq. (9) is optimized by using PSO optimization algorithm with the optimization aim rather than the amount of suggestive power for exchanging among the system and market is determined as Eq. (16). Then regarding to uncertainty scenario in wind speed prediction the electricity market clearing price, the cost of unbalance claimed by using PSO optimization on algorithm for increasing the profit and paying the least penalty for cost of unbalance in market.

Optimization of suggestive model by using of PSO algorithm: In this study, the optimization of suggestive model is accepted by using PSO algorithm.

PSO algorithm is applied for optimization:

The first step:

- The production of initial population of articles, all of the articles accidentally are produced in limit which provides the bridles.
- Set the repetition number equal to 1.

The second step:

- Calculation of the value of objective function.
- Calculation of the amount of sufficiency.

Third step: producing the new articles.

Fourth step:

- Consideration the constraints: if constraints aren't provided by an article, that part of article, which over step from the free bridle is produced accidently than that constraint will be produce finally.
- Edit the repetition number: If the repetition number is smaller than its maximum, it goes to second step, if not, goes to fifth step.

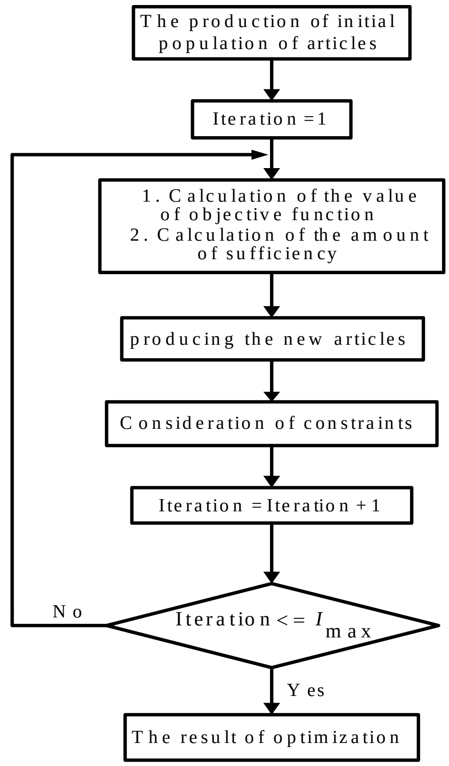

Fig. 6: Flowchart of optimization by using of PSO algorithm

Fifth step: the result of optimization.

Regarding to the explained stages, the flowchart of optimization by using PSO algorithm is as Fig. 6.

CASE STUDY

In this section the optimum operation stages of suggestive model on a sample model is done for different parameters and the result of optimization are studied.

Table 2: The values of parameters wind turbine

Parameter	Value
PWG_R (MW)	2.0000
The number of wind turbine	6.0000
VF (m/s)	15.0100
VD (m/s)	3.0000
a (MW s^4/m^4)	a-0.2156
b (MWs^3/m^3)	4.7784
c (MWs^2/m^2)	-12.8300
d (MW s/m)	-29.8110
e (MW)	101.3500

Table 3: Values for the parameters given the uncertainty in forecasting electricity price and wind energy

Uncertainty in forecasting	Z_α	$P[e-\mu_e \geq Z_\alpha \sigma_e]$	$\tilde{e}$
Wind energy for bid	1.285	90%	0.1642
Electricity price for bid	1.645	95%	0.1822
Wind energy for operation	2.329	99%	0.2164

Table 4: The values of the other parameters

Parameter	Value
P_g min (MW)	0.00
P_g max (MW)	12.00
P_h min (MW)	0.00
P_h max (MW)	3.00
P_p min (MW)	0.00
P_p max (MW)	3.00
E min (MWh)	0.00
E max (MWh)	24.00
C_P (€/MWh)	1.50
$\eta_L = \eta_h * \eta_p$	0.75
ω_1	0.10
ω_2	1.25

Table 5: The parameter values for the PSO algorithm

Parameter	Value
Population size	200
Number of replications	1200
Acceleration coefficient C_1	2
Acceleration coefficient C_2	3
Retention Weight (W)	1

Also a comparison is done among the different states of optimization and finally the function of obtained answers for different parameters of model is considered.

Input data: In Table 2 to 5 and Fig. 7 to 12, the internal data are brought for program performance.

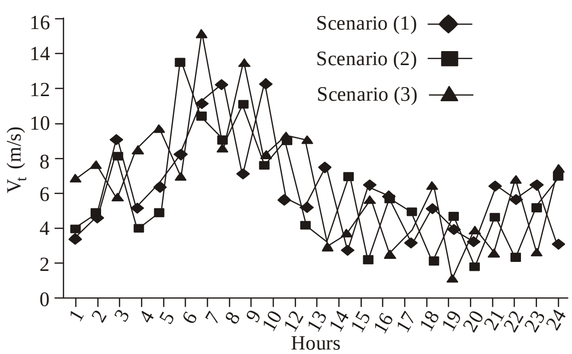

Fig. 7: The scenarios of predicted wind speed in 24 h of market day

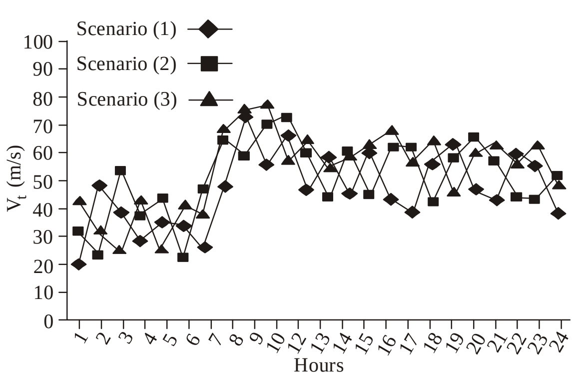

Fig. 8: The predicted electricity price scenario in 24 h of market day

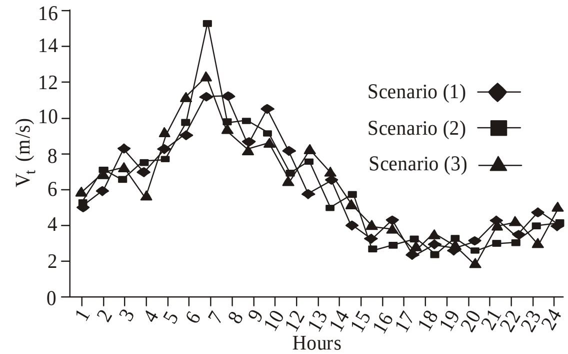

Fig. 9: The scenarios of predicted wind speed in 24 h of market day

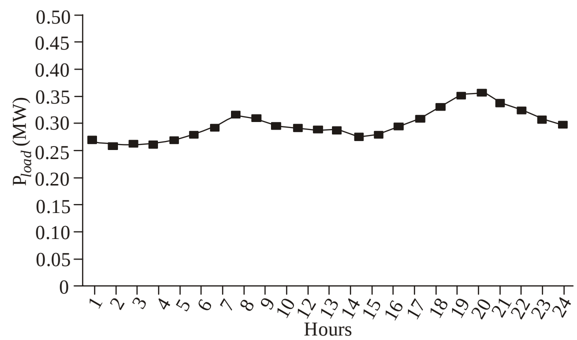

Fig. 10: Amount of consumed load for local load in 24 h

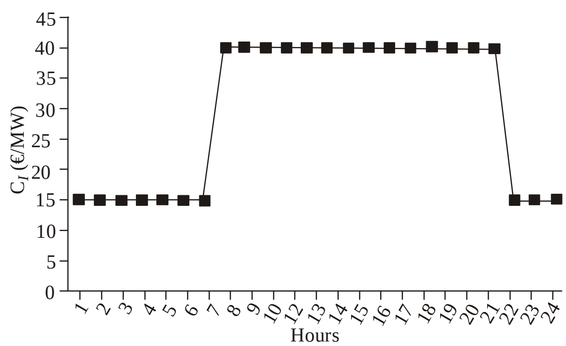

Fig. 11: Amount of electricity price for local load in 24 h

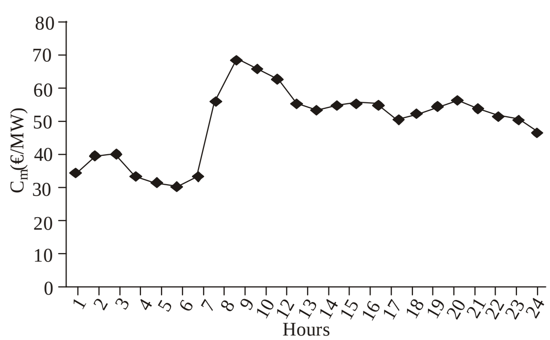

Fig. 12: The electricity market clearing price in 24 h of market day

The used wind turbine in this model has the power 2MW, which it used 6 wind turbine 2MW that have the same features. The values of parameters a, b, c, d, VF, VD of used wind turbine in this study is brought in Table 2.

The scenarios of predicted wind speed in 24 h of day for presenting of suggestion to market is as Fig. 7.

The predicted electricity price scenario in 24 h of market day is as Fig. 8.

Also the predicted wind speed scenarios in 24 h of market day for presenting the operation of hybrid system is as Fig. 9.

The uncertainty in forecasting electricity prices and wind energy production, the average error in predicting the 10% and standard deviation of the predicted 5% to be considered. Referencing Table 1 the amount of Z_α will be obtained, then using relation (3) the amount of production risk ($\tilde{e}$) will be obtained. Values of these parameters in Table 3 is given.

Considering the amount of production risk ($\tilde{e}$) in Table 3 and using relationship (7) and (8) the amount of wind power production capacity in each stage and the price of electricity in the first stage of considering the uncertainty in predicting energy Wind and electricity prices are calculated.

Amount of consumed load and electricity price for local load in 24 h is according to Fig. 10 and 11, respectively.

The electricity market clearing price in 24 h of market day for operation of hybrid system is as Fig. 12.

The values of the other parameters in Table 4 is brought.

Applied to the parameter values for the PSO algorithm are in Table 5.

The program exit and analysis of results: The results of optimization of hybrid system of wind-pumped storage power plant in power market environment, regarding to uncertainty in wind speed prediction and electricity price for presenting power suggestion to market to gain more profit is as Fig. 13.

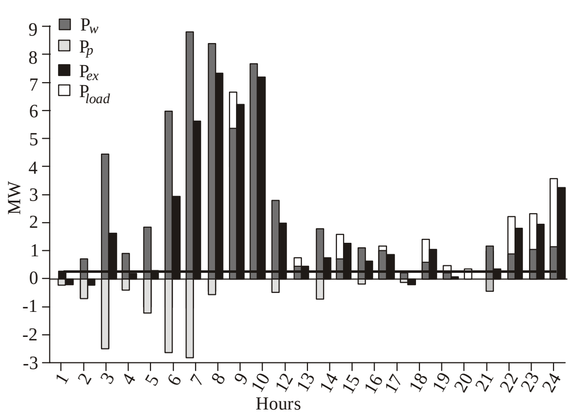

Fig. 13: The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 h

Figure 13 shows the amount of wind power plant produced power (P_w), pumped storage power plant (P_h), pump consumed power (P_p) and amount of exchanged power among hybrid system and power market (P_{ex}) regarding to the values of hybrid system produced power in 24 h.

As it is observed in Fig. 13, regarding to wind power plant produced power and the price scenarios in Fig. 7 and 8, when the electricity price is low in market and the wind power plant produced power is high, the pump unit engaged to wind energy storage and when the electricity price is high in market and when wind power plant can't provide the local load consumed power, the pumped storage power plant produces electricity. For example in initial hour 1 to 8 which the electricity price in market is low and the wind power plant power is high, the pump unit engaged to wind energy storage and in 9, 18, 12, 22 to 24 h which the electricity price is high in market and in 19 to 20 h which wind power plant can't provide the local load consumed power, pumped storage power plant produces electricity. The amount of obtained profit of system optimization is equal to 2857.74 €.

The results of optimization of hybrid system wind-pumped storage in power market environment, regarding

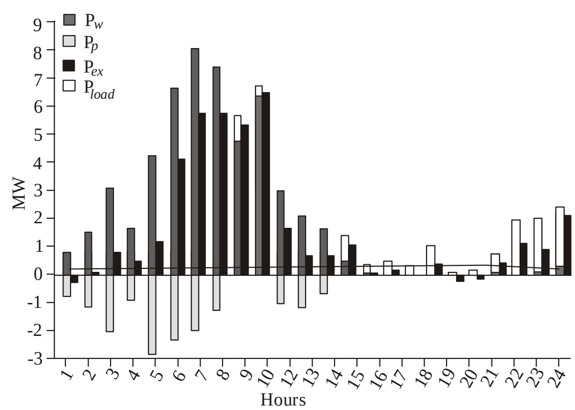

Fig. 14: The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 h

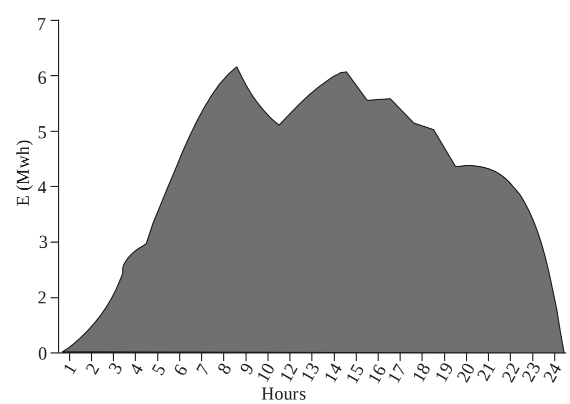

Fig. 15: Saved energy level in upper reservoir of pumped storage (E)

to uncertainty in wind speed predication for optimum operation of system to again the most profit and paying the least penalty to market are brought in Fig. 14 and 15. Figure 14 shows the amount of wind power plant produced power (P_w), pumped storage power plant (P_h), pump consumed power (P_p), amount of exchanged power among hybrid system and power market (P_{ex}) regarding to the values of hybrid system produced power in 24 h.

As it is observed in Fig. 14, regarding to wind power plant produced power and market clearing price in Fig. 12, when the electricity price is high and when the amount of produced power of wind power plant is low or zero, it uses pumped storage power plant power. For example at 9 and 10 o'clock the electricity price is high and at 14 and 24 o'clock when the amount of wind power plant produced power is low or zero, it uses pumped storage power plant power.

Also saved energy level in upper reservoir of pumped storage (E) is as Fig. 15.

The amount of obtained profit of system optimization is equal to 1372.9 € regarding to the amount profit of optimization in presenting the power suggestion to the market, the difference between this two values is for uncertainty in wind speed prediction scenario, power market clearing price and the cost engaging of unbalanced market.

Considering different models: In this section, it is engaged to consider different states of optimization and analysis of results of optimization. In the suggestive model of study it is spotted the uncertainty in wind speed prediction and power market clearing price in the presenting power suggestion stage to market. Now if uncertainty in wind speed prediction, the power market clearing price prediction and scenarios is not spotted in the first stage, the difference profit of optimization in two stages and the effect of uncertainty in wind speed prediction and power market clearing price in differences of profit in two stages are considered.

For this, at first uncertainty in wind speed prediction isn't considered and the difference profit in two stages is calculated. Then uncertainty in prediction of power market clearing price is not spotted and the differences of profit in two stages is calculated.

At first state, for optimization of presenting of power suggestion to market, each of scenarios (1), (2) and (3) in Fig. 7 are spotted as the wind speed prediction and at second state each of scenarios (A), (B) and (C) in Fig. 8 are spotted as the power market clearing price prediction and the results of optimization state are considered.

- **First state:** If the scenarios (1), (2) and (3) are spotted as the wind speed scenarios the amount of exchanged power among hybrid system and power market is brought regarding to values of produced power of hybrid system (P_{ex}), pump power and local load consumed power in Fig. 16, 17 and 18.

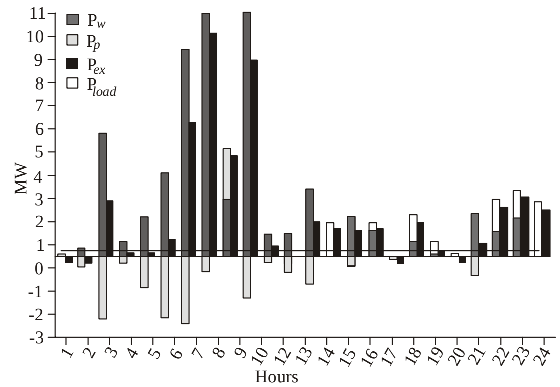

Fig. 16: The values of (P_w), (P_p), (P_h) (P_{ex}) and (P_{load}) in 24 h with scenario (1) is spotted

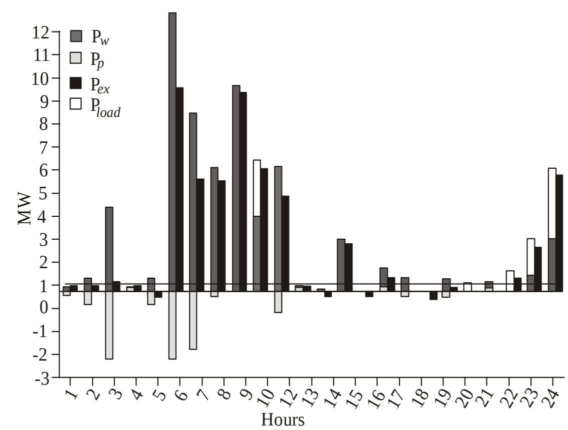

Fig. 17: The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 h with scenario (2) is spotted

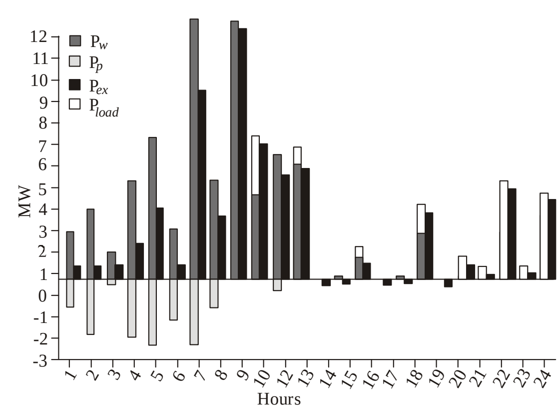

Fig. 18: The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 h with scenario (3) is spotted

The profit of optimization for presenting power suggestion to market and the profit of optimization for

Table 6: The profit of optimization for each of scenarios (1), (2) and (3) the wind speed prediction

States optimized without considering uncertainty in the forecast wind speed	The optimization benefits of offered to the market (€)	The optimizing the profit from operation of the system (€)
The scenario (1) to predict the wind speed	2845.3	930.546
The scenario (2) to predict the wind speed	2673.2	807.180
The scenario (3) to predict the wind speed	3504.07	408.965

Table 7: The profit of optimization for each of scenarios (A), (B) and (C) the market clearing price prediction

States optimized without considering the uncertainty in predicting the market clearing price of electricity	The optimization benefits of offered to the market (€)	The optimizing the profit from operation of the system (€)
The scenario (A) to predict the market price	2087.106	1237.98
The scenario (B) to predict the market price	2689.023	1132.046
The scenario (C) to predict the market price	2193.8	1294.7

Table 8: The result of the optimization of states

States optimized		The optimization benefits of offered to the market (€)	The optimizing the profit from operation of the system (€)
Considering both the uncertainty	2857.74 €	1372.9	
Without considering uncertainty in	scenario (1)	2845.3	930.546
the forecast wind speed	scenario (2)	2673.2	807.180
	scenario (3)	3504.07	408.965
Without considering the uncertainty	scenario (A)	2087.106	1237.98
in predicting the market	scenario (B)	2689.023	1132.046
clearing price of electricity	scenario (C)	2193.8	1294.7

operation of system for each of scenarios (1), (2) and (3) are as Table 6 as the wind speed prediction.

As it was observed in Table 4, the most difference of profit of optimization in two staged, is in scenario (3) which shows that the most errors of wind speed prediction are in scenario (3).

- **Second state:** In this state the profit for optimizing for presenting power suggestion to market and the profit of optimization for operation of system for each of scenarios (A), (B) and (C) as the market clearing price prediction is according to Table 7.

  As it was observed in Table 5, the most difference of optimization in two stages, is in scenario (B) which shows that the most errors of wind speed prediction is at scenario (B).

Table 8 shows the result of the optimization of first, second states and the results of considering of uncertainty of wind speed and market clearing price prediction.

As it is observed in Table 6, the most difference of profit of optimization in two stages is in the state that uncertainty in wind speed prediction is not considered which shows that uncertainty in wind speed prediction is more effective and more important than uncertainty in prediction of power market clearing price in the profit of optimum operation of system.

CONCLUSION

In this study it is presented a two stage model for optimum operation of a hybrid system of wind-pumped storage power plant in power market environment. That by using this model, one can the most profit of presenting of producer power suggestion to market.

The wind speed prediction and power market clearing price prediction are two important factors for optimum operation of this hybrid system in market environment to gain the most profit. In this study with considering the uncertainty in the wind speed prediction and the prediction of power market clearing price in the stage of presenting the suggestion of produced power to market and considering the uncertainty in prediction of wind unit power in operation stage of hybrid system can reach to the most profit and least penalty for cost of unbalance market.

Also in this study for determination of friction of the obtained answers from uncertainty in wind speed prediction and power market clearing price prediction, the friction analysis is done that uncertainty in wind speed prediction than the uncertainty in prediction of power market clearing price in profit of optimum operation of system is more effective and more important factor.

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