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Optimal Utilization of a Combined System of Wind –Pumped Storage Power Plant Using PSO Algorithm

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ABSTRACT

In this paper a new model for optimal utilization of a combined system of wind **-** Pumped Storage power plant is provided for electricity market; which causes successful presence of wind energy producers in the market environment. Combined system of wind **-** pumped storage of this article, optimal model for the presence in the environment of electricity market with the greatest possible benefit, due to uncertainties in wind energy production, is presented. Particle Swarm Optimization Algorithm (PSO) is used for the optimization. At the end of a model example for applying the results of the proposed model will be examined and analyzed the results will be discussed. Results show that the model an appropriate method for the operation of this combined system in market environment.

KEYWORDS: Combined System of Wind- Pumped Storage, Optimal Utilization, Profit Maximization, Uncertainty, Power Market.

I. 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 [1].

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 [2, 3] 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 [4].

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 [5, 6, 7, 8, 9] 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 [10] 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 paper, 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. The suggestive model optimization of this paper is done by using particle swarm optimization (PSO).

In the section 2 of this paper, we'll explain the structure and the direction of energy current in a suggestive model. In section 3 it is presented the uncertainty in forecasting wind energy production and electricity prices in the market. In section 4, we'll explain suggestive model modeling and the extension of model by using the PSO algorithm. we'll explain numeral calculations and result analysis in section5. The case study is presented in section 6.

II. STRUCTURE AND DIRECTION OF ENERGY CURRENT IN SUGGESTIVE MODEL

The suggestive model of the hybrid system of wind-pumped storage power plant is like to fig. 1 in this paper.

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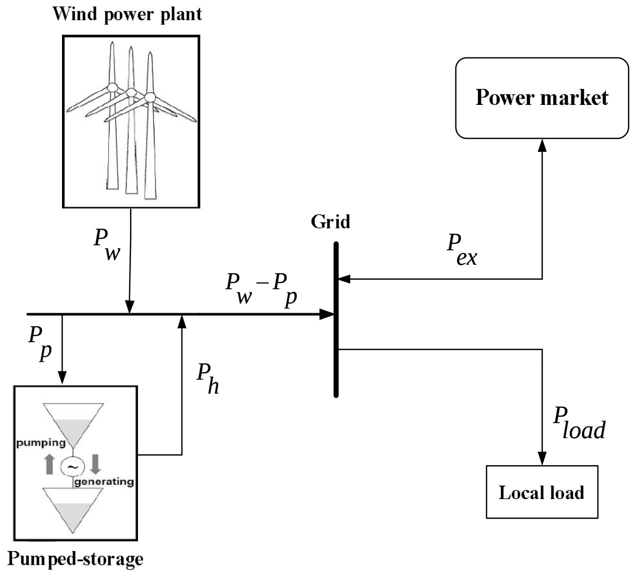

Fig. 1. Structure and direction of energy current

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}).

A. 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) [7].

$$P_{w,t} = \begin{cases} PWG_R\,, & V_t \geq VF \\ a.V_t^4 + b.V_t^3 + c.V_t^2 + d.V_t + e\,, & \\ VD < V_t < VF & \\ 0, & V_t \leq VD \end{cases} \qquad (1)$$

$P_{w,t}$ 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, e are constants.

B. Pumped-storage power plant model

The present paper 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) A pumped-storage power plant with an electric generator;

(b) A water pump station;
(c) Lower and upper water reservoirs;
(d) 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 work it is supposed an electrical proximity between them. An extension of this model, not analysed in the present paper, regards the utilisation of a pump station to control a cluster of wind parks.

C. 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.

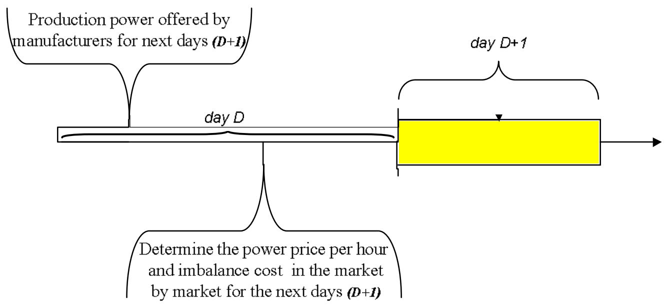

Fig. 2. Power market model

III. 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) %.

$$P[e-\mu_e \geq Z_\alpha \sigma_e] = \frac{\alpha}{100} \qquad (2)$$

$$\tilde{e} = \mu_e + Z_\alpha \sigma_e \qquad (3)$$

$\tilde{e}$ 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) %.

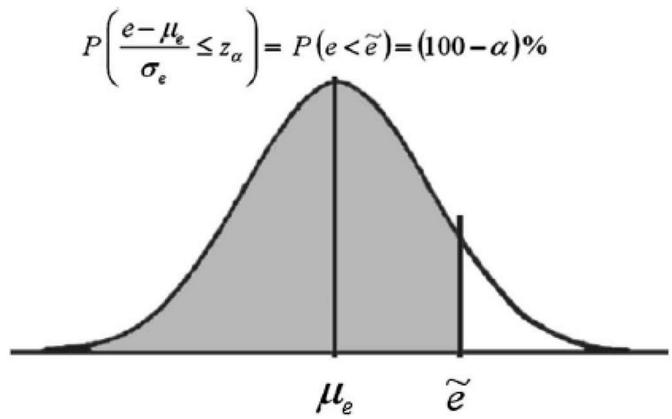

Fig. 3. Level of confidence level on a normal distribution curve

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

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

100% 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 I is given.

TABLE I

Z_αVALUE FOR DIFFERENT CONFIDENCE LEVELS

Z_α	$P[e-\mu_e \ge Z_\alpha \sigma_e]$
1.285	90%
1.645	95%
2.329	99%

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

$$\mu_e = \frac{1}{N}\sum_{i=1}^{N} e_i \qquad (5)$$

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

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_α ($\tilde{e}$) 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.

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

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

This paper 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.

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

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

IV. THE MODELING WITH THE AIM OF MAXIMIZATION OF SYSTEM PROFIT

A. 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:

$$\max\left\{\sum_{i=1}^{T}(C_l(i).P_{load}(i) + C_m(i).\left(P_w(i)-P_p(i)+P_h(i)-P_{load}(i)\right)-C_p\,.\,P_p(i)\right\} \tag{9}$$

That the aim of each parameter is defined as below in this function:

$C_l(i)$ 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 predicated electricity price in time i at (€/MWh), $P_w(i)$ is the predicated power wind power plant produced in time i at MW, $P_h(i)$ is the produced power by pumped storage power plant in time i at MW, $P_p(i)$ is the produced power of pump 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:

1. The saved energy in reservoir in any set energy increases with water pump and decreases with water electricity produced.

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

$E(i)$ is the level of saved energy in reservoir subject 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.

2. 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.

3. The limitations of maximum and minimum capacity of wind power plant produced power.

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

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

4. The limitations of maximum and minimum produced power by the pumped storage power plant.

$$P_h\min \le P_h(i) \le \min\left(P_h\max\ ,\eta_h.E(i)\right) \qquad \forall\, i\in T \tag{13}$$

$P_h\min$ and $P_h\max$ is the low and high range of pumped storage power plants.

5. The limitations of maximum and minimum consumed power by pump.

$$P_p\min \le P_p(i) \le P_p\max \qquad \forall\, i\in T \tag{14}$$

$P_p\min$ and $P_p\max$ is the low and high range of consumed power range of pump.

6. The limitations of the level of saved energy in reservoirs.

$$E\min \le E(i) \le E\max \qquad \forall i \in T$$

(15)

$E\min$ and $E\max$ is the minimum and maximum capacity of reservoir storage.

7.

$$i = 1,\dots,t \qquad , \quad \forall i \in T$$

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 Esq. (16).

$$P_{ex}(i) = \left((P_w(i) + P_h(i) - P_p(i))\right) - P_{load}(i)$$

(16)

After the optimization, the value of produced power of hybrid system, 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.

B. 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. 4.

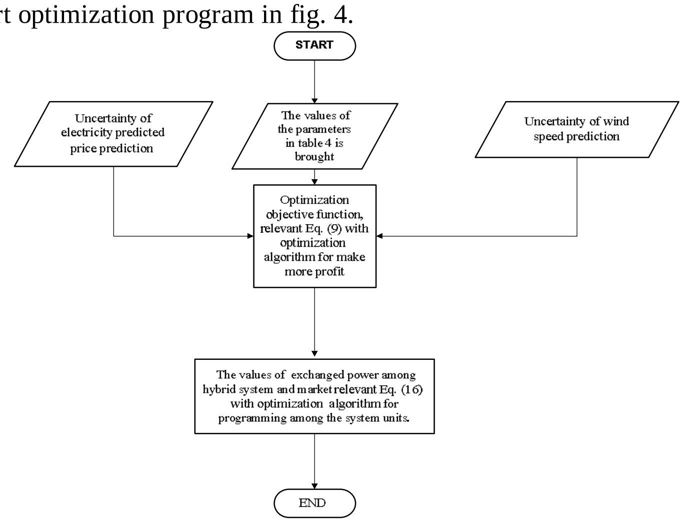

Fig. 4.Flow chart optimization program

As it is observed in this figure, 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 optimization algorithm for programming among the system units.

C. Optimization of suggestive model by using of PSO algorithm

In this paper, the optimization of suggestive model is accepted by using PSO algorithm.

PSO algorithm is applied for optimization:

The first step:

1) The production of initial population of articles, all of the articles accidentally are produced in limit which provides the bridles.

2) Set the repetition number equal to 1.

The second step:

1) Calculation of the value of objective function.

2) Calculation of the amount of sufficiency.

Third step: producing the new articles.

Fourth step:

1) 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.

2) edit the repetition number: If the repetition number is smaller than its maximum, it goes to second step, if not, goes to fifth step.

Fifth step: the result of optimization.

Regarding to the explained stages, the flowchart of optimization by using PSO algorithm is as fig. 5.

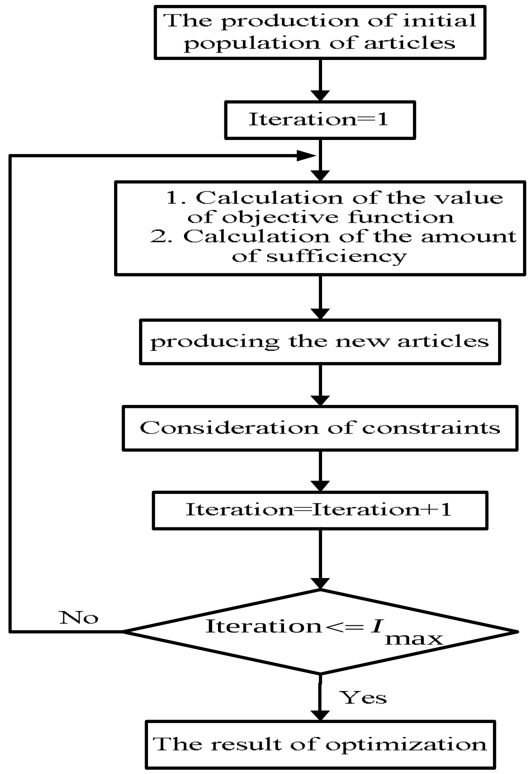

Fig. 5. Flowchart of optimization by using of PSO algorithm

V. 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.

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.

A. Input Data

In table II to V and fig. 6 to 9, the internal data are brought for program performance.

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 paper is brought in table II.

TABLE II. THE VALUES OF PARAMETERS WIND TURBINE

Parameter	Value
PWG_R (MW)	2
The number of wind turbine	6
VF (m/s)	15.01
VD (m/s)	3
a (MW s^4/m^4)	-0.2156
b (MWs^3/m^3)	4.7784
c (MWs^2/m^2)	-12.83
d (MW s/m)	-29.811
e (MW)	101.35

The predicted wind speed in 24 hours of day for presenting of suggestion to market is as fig. 6.

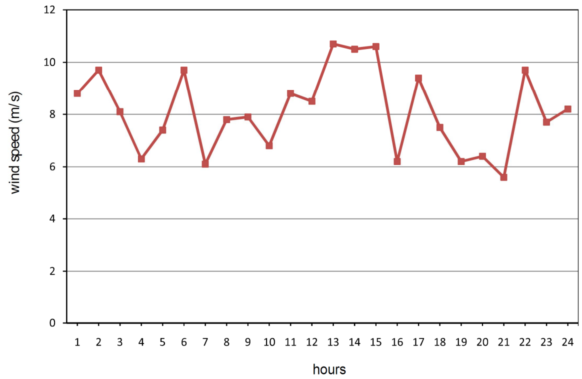

Fig. 6. The predicted wind speed in 24 hours of market day

The predicted electricity price in 24 hours of market day is as fig .7.

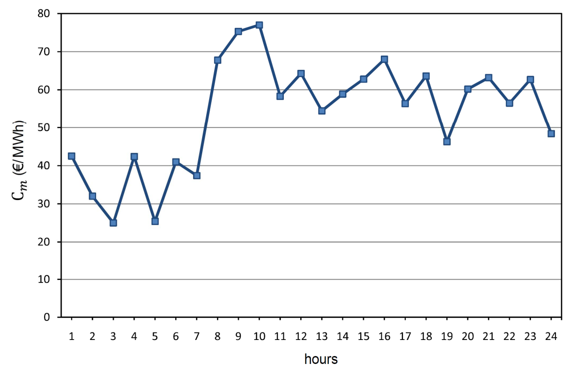

Fig. 7. The predicted electricity price in 24 hours of market day

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 III is given.

TABLE III

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

Considering the amount of production risk ($\tilde{e}$) in Table III, 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 hours is according to fig. 8 and 9 respectively.

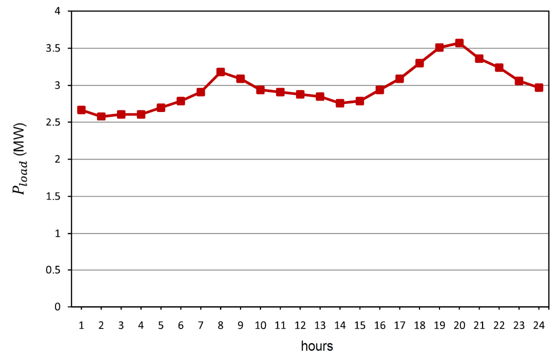

Fig. 8. Amount of consumed load for local load in 24 hours

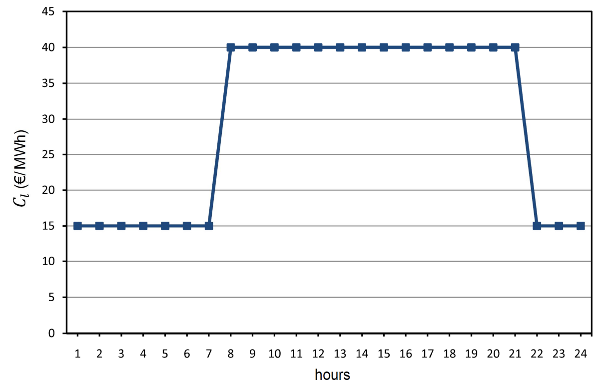

Fig. 9. Amount of electricity price for local load in 24 hours

The values of the other parameters in table IV is brought.

TABLE IV
THE VALUES OF THE OTHER PARAMETERS

Parameter	Value
P_g min (MW)	0
P_g max (MW)	12
P_h min (MW)	0
P_h max (MW)	3
P_p min (MW)	0
P_p max (MW)	3
E min (MWh)	0
E max (MWh)	24
C_P (€/MWh)	1.5
$\eta_L = \eta_h * \eta_p$	0.75

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

TABLE V
THE PARAMETER VALUES FOR THE PSO ALGORITHM

Parameter	Value
Population size	200
Number of replications	1500
Acceleration coefficient C_1	2
Acceleration coefficient C_2	2
Retention Weight (W)	1

B. 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. 10.

Fig. 10 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 hours.

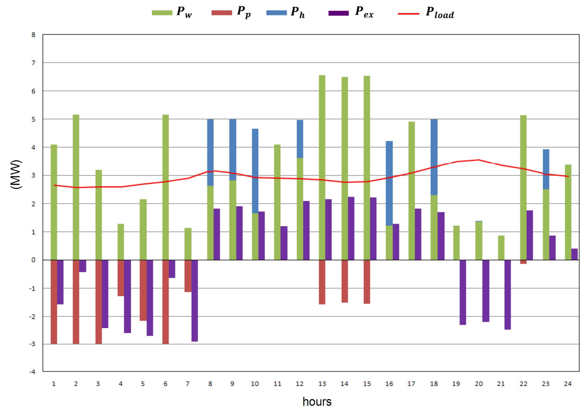

Fig. 10. The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 hours

As it is observed in fig. 10, 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 to8 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 hours 9, 18, 12, 22 to 24 which the electricity price is high in market and in hours 19 t0 20 which wind power plant can't provide the local load consumed power, pumped storage power plant produces electricity.

Also saved energy level in upper reservoir of pumped storage (E) is as fig. 11.

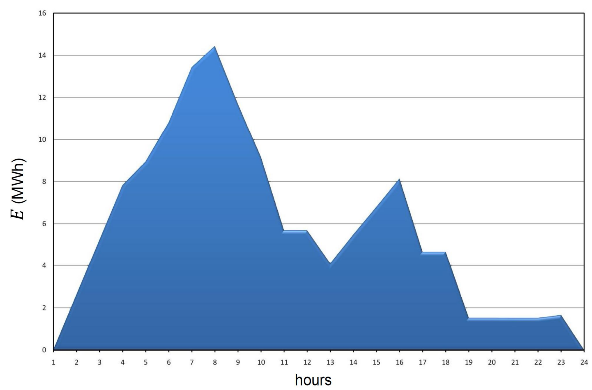

Fig. 11.Saved energy level in upper reservoir of pumped storage (E)

The amount of obtained profit of system optimization is equal to 2728.7€.

VI. CONCLUSIONS

In this paper it is presented a 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 paper with considering the uncertainty in the wind speed prediction and the prediction of power market clearing price in the suggestion of produced power to market. Results show that the model is an appropriate method for the operation of this combined system in market environment.

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