J. Basic. Appl. Sci. Res., 3(2s)671-681, 2013
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ISSN 2090-4304
Journal of Basic and Applied
Scientific Research
www.textroad.com

Planning between producing units a Combined System of Wind –Pumped Storage Power Plant in Power Market Environments

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Received: June 10 2013
Accepted: July 10 2013

ABSTRACT

In this paper a model for Planning between produce units a Combined System of wind –Pumped Storage in Power Market Environments; 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 power market with the greatest possible benefit and minimum penalty for unbalancing in power market environments, is presented. In this paper 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. 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, Planning, Penalty for Unbalancing in Market, Uncertainty, Power Market, PSO Algorithm.

1. INTRODUCTION

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 [5-9] 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.

2. 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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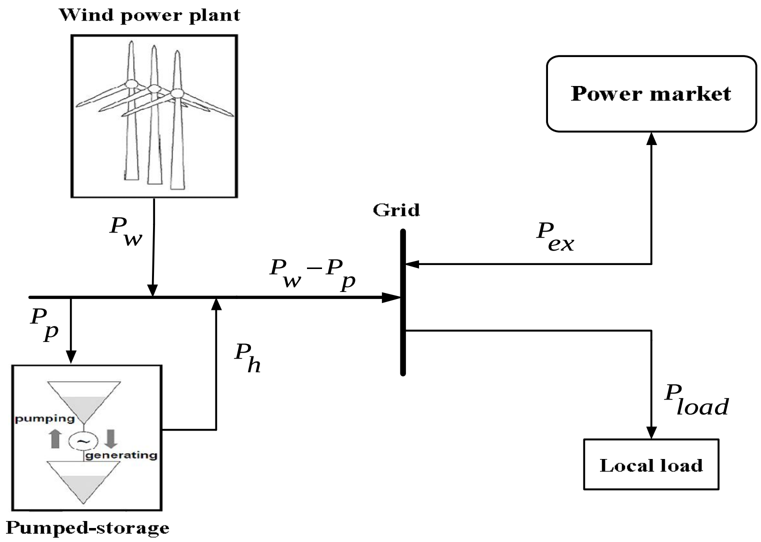

Fig. 1. Structure and direction of energy current

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}).

2.1. Wind turbine model

In order to account and amount of wind turbine output power according to different velocities of wind during 24 hours and Cut-in and Cut-out velocity of wind turbine we can use Eq (1) [5].

$$P_{wt}(t) = \begin{cases} a.V^3(t) - b.P_R & V_{c_i} < V < V_r \\ P_R & V_r < V < V_{co} \\ 0 & V < V_{c_i} \end{cases} \qquad (1)$$

Which for a, b we have:

$$a = P_r / (V_r^3 - V_{ci}^3) \qquad (2)$$

$$b = V_{ci}^3 / (V_r^3 - V_{ci}^3) \qquad (3)$$

At above equation, P_r is indicator of generator rated power, V_{ci} is cut-in velocity, V_{co} is cut-out and V_r is turbine rated velocity.

Curvy of power-velocity of wind turbine is shown at fig.2.

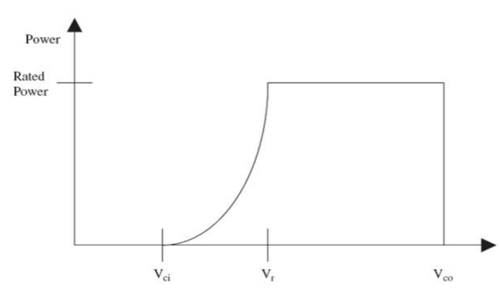

Fig. 2. Curvy of power-velocity of wind turbine

2.2. 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 analyzed in the present paper, regards the utilization of a pump station to control a cluster of wind parks.

2.3. Power market model

The market model is according to pay to winner based on market clearing price (MCP). As observed in fig. 3, 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.

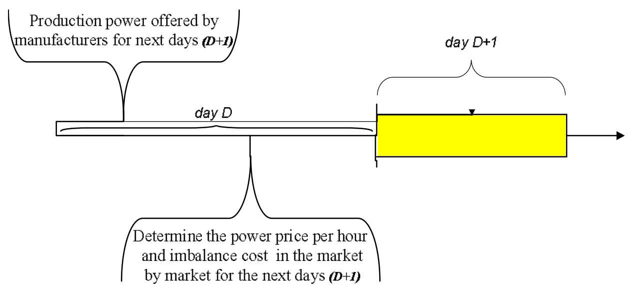

Fig. 3. Power market model

3. Uncertainty in forecasting wind energy production

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) %.

$$P\left[e-\mu_e \geq Z_\alpha \sigma_e\right]=\frac{\alpha}{100} \qquad (4)$$

$$\tilde{e}=\mu_e+Z_\alpha \sigma_e \qquad (5)$$

$\tilde{e}$ 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) %.

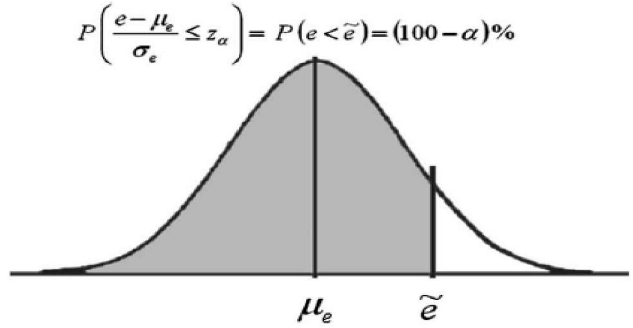

Fig. 4. Level of confidence level on a normal distribution curve

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

$$P(e < \tilde{e}) = \alpha\% \qquad (6)$$

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 1 is given.

Table1. Z_α value 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:

$$\mu_e = \frac{1}{N}\sum_{i=1}^{N} e_i \qquad (7)$$

$$\sigma_e = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(e_i - \mu_e)^2} \qquad (8)$$

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 (7) and (8) come get. Values using the error mean value, standard deviation, and risk production value of Z_α ($\tilde{e}$) relation (5) 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 (9) is considered.

$$P_{wt} = (1-\tilde{e}).P_{wt}^{forcs} \qquad (9)$$

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

4. The modeling with the aim of maximization of system profit

In studied wind-pumped storage power plant hybrid system in this paper, regarding to uncertainty in wind energy prediction the model of operation of system is optimized for gaining more profit and paying fewer penalties for unbalance in market according to fig. 5.

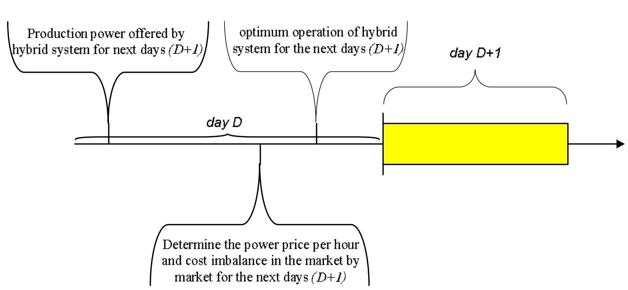

Fig. 5. Modeling for maximization of system profit

The made errors of wind energy prediction increase the time horizon, also how much the wind energy prediction is looser to operation time, the prediction is more particular and its error is less [10].

Therefore in stage of operation of system done with more confidence border and uncertainty in wind energy 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.

4.1 Modeling for system optimum operation

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

$$\max.\left\{\sum_{i=1}^{T}(C_l(i).P_{load}(i)+C_m(i).\left(P_{pw}(i)-P_p(i)+P_h(i)-P_{load}(i)\right) \right.$$
$$\left. -\omega.C_m(i).\left|P_{pw}(i)-P_p(i)+P_h(i)-P_{load}(i)-P_{ex}^{offer}(i)\right|-C_p\,.\,P_p(i)\right\} \qquad (10)$$

That each parameter is defined as below:

$C_l(i)$ 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), $P_{pw}(i)$ is the predicted power of wind unit 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, $P_{ex}^{offer}(i)$ is the suggestive power for exchanging among hybrid system and market in time i at MW, 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. (12):

The amount of exchangeable power among hybrid system and market in optimum operation model (P_{ex}^{new}) which is obtained according to the Eq. (11).

$$P_{ex}^{new}(i)=(P_{pw}(i)+P_h(i)-P_p(i))-P_{load}(i) \qquad (11)$$

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.

$$\left\{\begin{array}{ll}\omega=\omega_1 & P_{ex}^{new}(i)>P_{ex}^{offer}(i)\\ \omega=\omega_2 & P_{ex}^{new}(i)<P_{ex}^{offer}(i)\\ \omega=0 & P_{ex}^{new}(i)=P_{ex}^{offer}(i)\end{array}\right\} \qquad (12)$$

Operational constraints for the objective function is regarding below:

$$E(i+1)=E(i)+\left(\eta_p.P_p(i)-\frac{P_h(i)}{\eta_h}\right) \qquad \forall\, i\in T \qquad (13)$$

$$E(1)=E(T) \qquad (14)$$

$$P_g\min\le P_{pw}(i)\le P_g\max \qquad \forall\, i\in T \qquad (15)$$

$$P_h\min\le P_h(i)\le\min\left(P_h\max\ ,\eta_h.E(i)\right) \qquad \forall\, i\in T \qquad (16)$$

$$P_p\min\le P_p(i)\le P_p\max \qquad \forall\, i\in T \qquad (17)$$

$$E\min\le E(i)\le E\max \qquad \forall\, i\in T \qquad (18)$$

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

After the optimization of target function, regarding to uncertainty in wind energy prediction, the values of $P_{pw}(i)$ ، $P_h(i)$ ، $P_p(i)$ and $E(i)$ 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.

4.2. 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. 6.

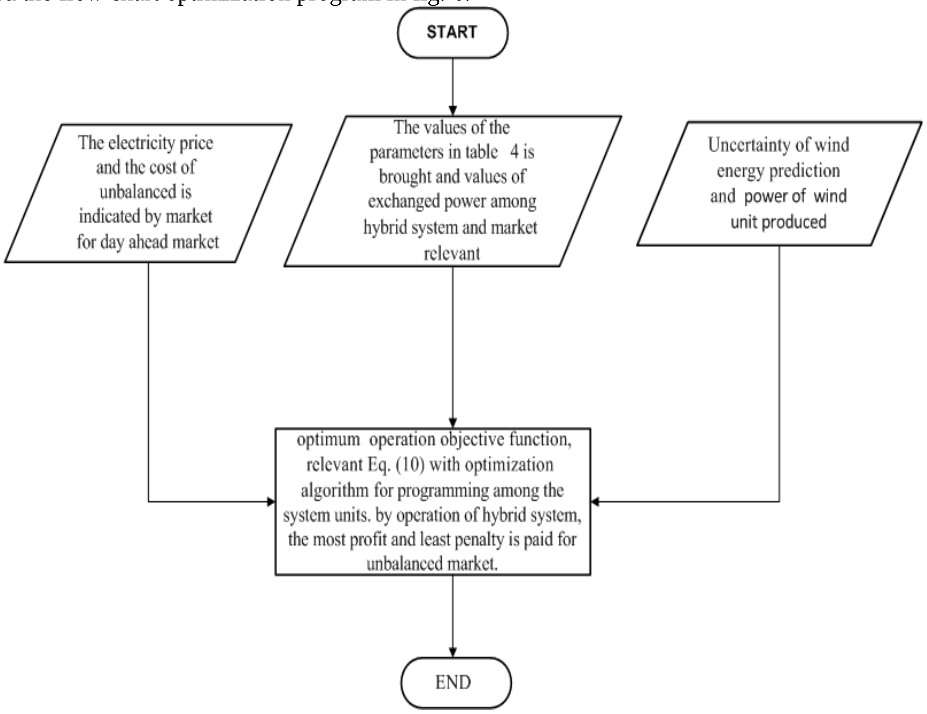

Fig. 6. Flow chart optimization program

As it is observed in this figure, regarding to uncertainty in wind energy 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.

4.3 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. 7.

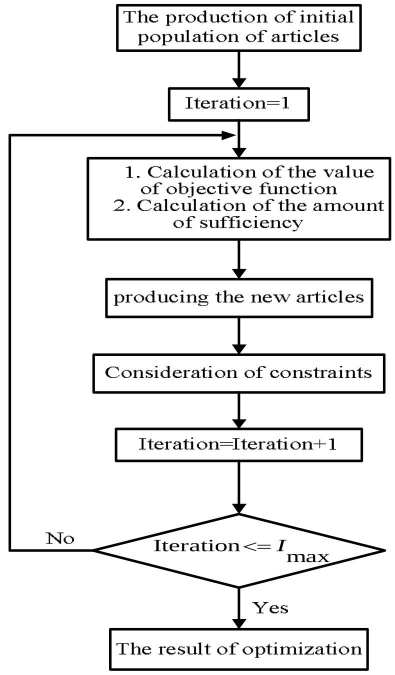

Fig. 7. Flowchart of optimization by using of PSO algorithm

5. 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.

5.1 Input Data

In table 2 to 5 and fig. 8 to 12, the internal data are brought for program performance.

The used wind turbine in this model has the power 3MW, which it used 4 wind turbine 3MW that have the same features. The values of parameters of used wind turbine in this paper are brought in table 2.

Table 2. The values of parameters wind turbine

Parameter	Value
Rated power	3 MW
V_r	15 (m/s)
V_{c_i}	3.5 (m/s)
V_{c_i}	25 (m/s)

The predicted wind speed in 24 hours of day for presenting of suggestion to market is as fig. 8.

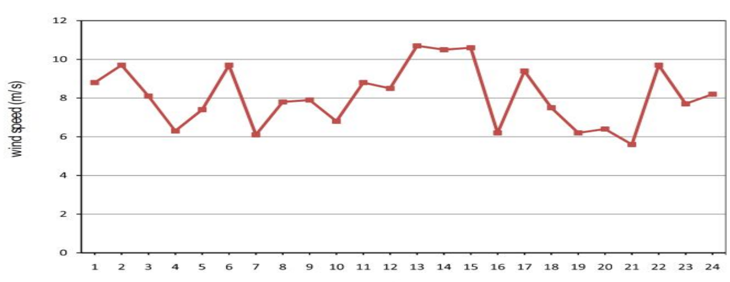

Fig. 8. The predicted wind speed in 24 hours of market day

The uncertainty in forecasting 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 (5) the amount of production risk ($\tilde{e}$) will be obtained. Values of these parameters in Table 3 is given.

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 operation	2.329	99%	0.2164

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

The predicted electricity price in 24 hours of market day is as fig .9.

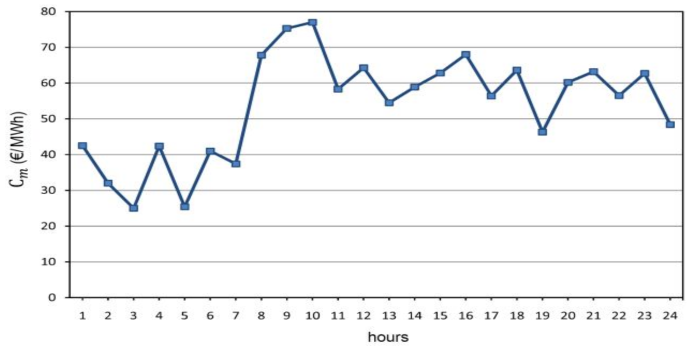

Fig. 9. The predicted electricity price in 24 hours of market day

Amount of consumed load and electricity price for local load in 24 hours is according to fig. 10 and 11 respectively.

Fig. 10. Amount of consumed load for local load in 24 hours

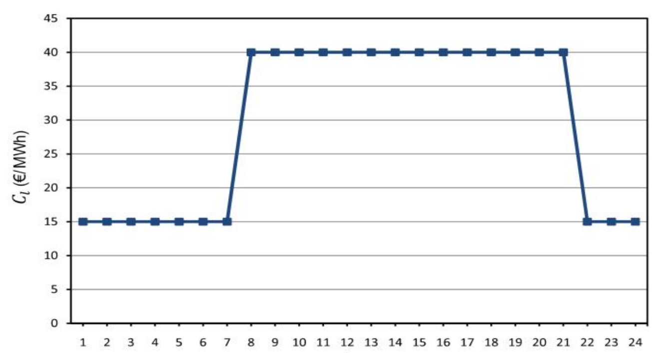

Fig. 11. Amount of electricity price for local load in 24 hours

Also the exchanged power among hybrid system and market ($P_{ex}^{offer}(i)$) which is used for presenting the produced power to market is as fig .12.

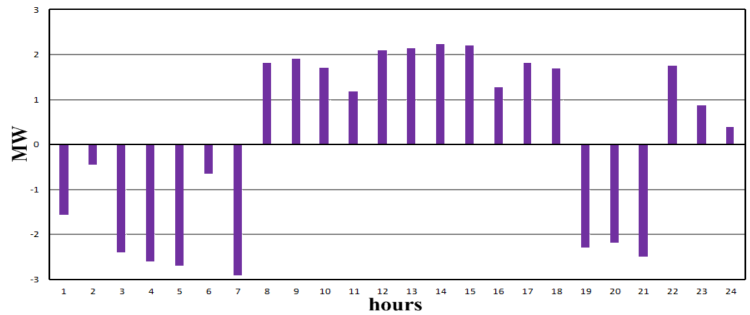

Fig. 12. The values of exchanged power among hybrid system and market (P_{ex}^{offer}) in 24 hours

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

Table 4. 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
CP (€/MWh)	1.5
$\eta L = \eta h^* \eta p$	0.75
$\omega 1$	0.1
$\omega 2$	1.25

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

Table 5. The parameter values for the PSO algorithm

Parameter	Value
Population size	150
Number of replications	3000
Acceleration coefficient C1	2
Acceleration coefficient C2	2
Retention Weight (W)	1

5.2 The program exit and analysis of results

The results of optimization of hybrid system wind-pumped storage in power market environment, regarding to uncertainty in wind energy predication for optimum operation of system to again the most profit and paying the least penalty to market are brought in fig. 13 to 15.

Fig. 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 hours.

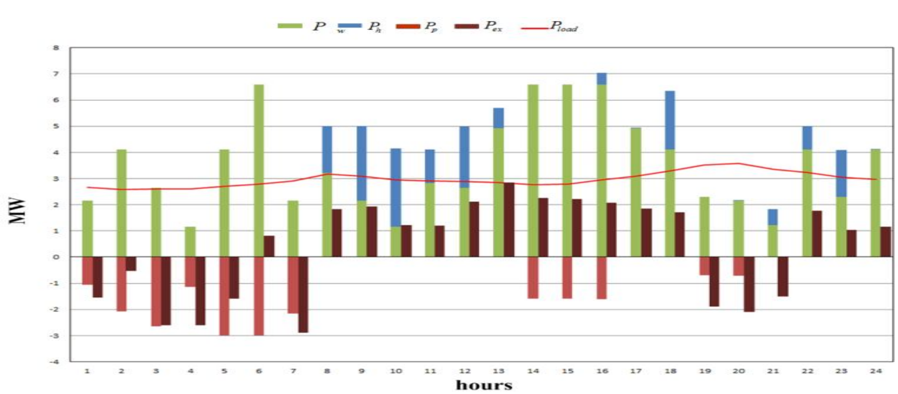

Fig. 13. The values of (P_w), (P_p), (P_h), (P_{ex}) and (P_{load}) in 24 hours

As it is observed in fig. 13, regarding to wind power plant produced power and the market clearing price in fig. 8 and 9, 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 and 14 to16 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 8 to 13, 16, 18, 21 to 23 which the electricity price is high in market and in hours 9 to 12 which wind power plant can't provide the local load consumed power, pumped storage power plant produces electricity.

Figure (14) the amount proposed to be offered to the market by a hybrid system (P_{ex}^{offer}) and the amount of power that the operation of the system is optimized for exchange market (P_{ex}) shows.

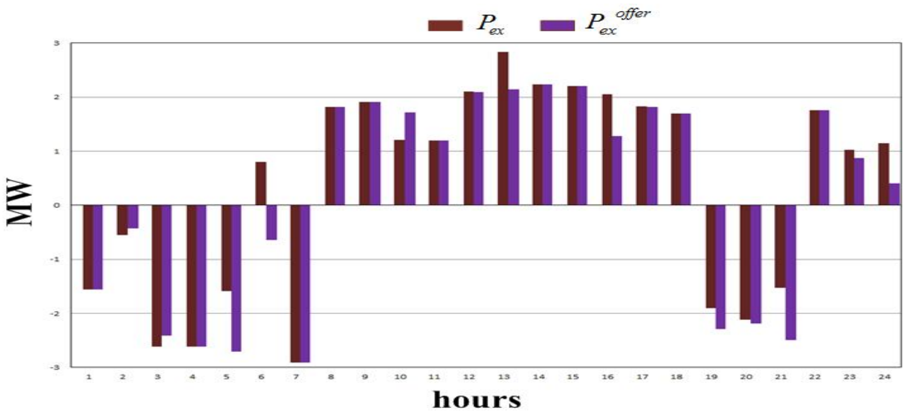

Fig. 14. The values of (P_{ex})and (P_{ex}^{offer}) in 24 hours

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

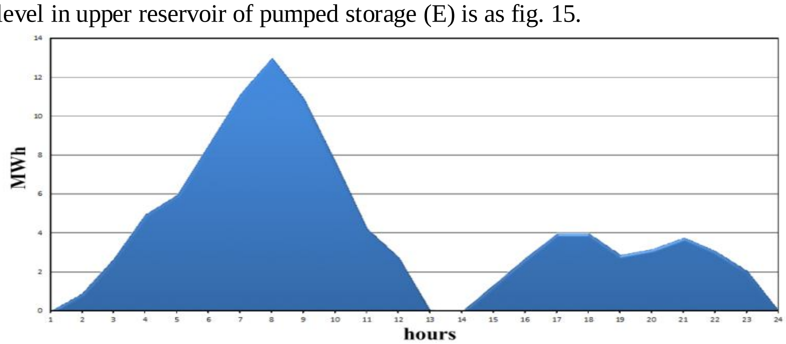

Fig. 15. Saved energy level in upper reservoir of pumped storage (E)

The combined profit optimization of hybrid system of wind-pumped storage power plant is equal to 2983.14 €.

Also, if the proposal can be offered in the exchange market is a hybrid system (P_{ex}^{offer}), the amount of 254.44€ under the optimized operating point (exchange P_{ex}) for penalties for failure to pay the balance on the market, therefore, using this method can be a 10% increase in profits.

6. Conclusions

In this paper a model for Planning between produce units a Combined System of wind –Pumped Storage in Power Market Environments; which causes successful presence of wind energy producers in the market environment. Combined system of Photovoltaic - pumped storage of this article, optimal model for the presence in the environment of power market with the greatest possible benefit and minimum penalty for unbalancing in power market environments, is presented.

The wind speed prediction prediction is 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 in the planning of produced power to market. Results show that the model is an appropriate method for the operation of this combined system in market environment.

REFERENCES

1. H. Hotline (2004) “Optimal electricity market for wind power” Elsevier, Energy Policy, pp 2052–2063
2. J. Matevosyan and L. Soder (2004) “Minimization of Imbalance Cost Trading Wind Power on the Short Term Power Market” IEEE transactions on Power Systems, pp 1–7.
3. M. Hu, J. Kehler (2006) “Integration of Wind Power into Alberta’s Electric System and Market Operation” IEEE transactions on Power Systems, pp 1–6.
4. J. Matevosyan and L. Soder, (2006) “Optimal Daily Planning for Hydro Power System Coordinated with Wind Power in Areas with Limited Export Capability” IEEE transactions on International Conference on Probabilistic Methods Applied to Power Systems, KTH, Stockholm, Sweden, pp1- 8.
5. S.Papaefthimiou,E.Karamanou,S.Papathanassiou, M.Papadopoulos (2009) “Operating Policies for Wind-Pumped Storage Hybrid Power Stations in Island Grids” IET Renewable Power Generation, Vol. 3, No. 3pp. 293-307.
6. G. Caralis and A. Zervos (2010) “Analysis of the combined use of wind and pumped storage systems in autonomous Greek islands” IEEE transactions on Renewable Power Generation,Vol. 1, No. 1, pp 49–60.
7. Magnus Korpaasa, , Arne T. Holena, Ragne Hildrum (2003)” Operation and sizing of energy storage for wind power plants in a market system” Elsevier, Electrical Power and Energy Systems, pp 599–606.
8. Edgardo D. Castronuovoa, Joao A. Pec¸as Lopes (2004) ” Optimal operation and hydro storage sizing of a wind–hydro power plant” Elsevier, Electrical Power and Energy Systems, pp 771–778.
9. Edgardo D. Castronuovoa, Joao A. Pec¸as Lopes (2003) ”wind and small-hydro generation and optimization approach for daily integrated operation” Ines Porto – Institute de Engenharia de Sistemas e Compotators do Porto FEUP – Faculdade de Engenharia da Universidade do Porto Rua Roberto Frias 378, Porto, Portugal, 420-465.
10. J. García-González, Rocío Moraga and Luz Matres (2007) “Stochastic joint optimization of wind generation and pumped-storage units in an electricity market” IEEE transactions on 2008 IEEE Electrical Power & Energy Conference, pp 1–5.
11. E. D. Castronuovo, J. A. Peps Lopes (2004) “Bounding Active Power Generation of a Wind-Hydro Power Plant” IEEE transactions on international Conference on Probabilistic Methods Applied to Power Systems, Iowa State University, Ames, Iowa, September 12-16, pp 705- 710.