Energy Management of Wind Power Generation with Pumped Hydro Energy Storage and Participation in Frequency Control: Study in Electricity Market

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Abstract-*:* The integration of wind power into electric power system has an impact in grid stability (frequency and voltage stability). Recently, the integration of storage element can be compensating the wind power fluctuation and improve their participation in ancillary services. This paper investigated the combination of a wind farm and a PHES facility from the point of view of a generation company in a market environment. A joint operation model between the wind farm and PHES is proposed and the participation of in primary and secondary frequency control is studied. An algorithm of energy management system (EMS) is proposed to identify the daily operational strategy to be followed in order to:1) Minimize the penalty cost resulted from wind-PHES output imbalances; 2) Maximize the daily revenue profit taking into consideration all constraints of joint operation. Simulation results under MATLAB/Similink ®environment are presented and discussed.

Keys words: Wind turbine, PHES, EMS, penalty cost, investment cost, reservoir, participation, frequency control.

1. Introduction

Wind energy is one of the economic renewable sources. It is a valuable supplement to conventional energy sources. According to the estimation of the International Energy Agency, wind power installed capacity experiencing a rapid growth rate, with the 2010 worldwide capacity growing by 23.6% [1]. Also, countries such as Denmark, Portugal, Spain, and Germany have high wind penetration, producing 45%, 29%, 22%, and 20% of their electrical energy from wind turbines, respectively in 2017[2]. However, it will be a big challenge to operate the power system with high wind power penetration securely and reliably due to the inherent variability and uncertainty of wind source. Wind system needs to improve their operation in terms of efficiency and integration to the power grid both from technical. Also, the wind production contribute to minimize the cost production and to limit fossil fuel[3]. With the flexible charging–discharging characteristics, the inclusion of Energy Storage System (ESS) (batteries, flywheels, ultra-capacitors, pumped hydro energy storage….) allows improving wind system's stability and performances [4]. In the case of high wind penetration, the PHES is recognized as one of the most promising storages that faces wind energy's fluctuation in a large scale. The PHES has its unique characteristics in terms of technologies, capacity and efficiency. In addition, the PHES is operated in two modes: generating and pumping mode. At pumping mode, the pump moves the water from the lower reservoir to the upper one taking into account all the reservoir constraints. At generating mode, the hydraulic generator produces electricity during the discharge of the reservoir. A control of wind turbine system based on magnet synchronous generator is studied in [5]. In this work, a methodology is based on defining various cases combining structural and operational parameters of the wind energy system. A topology was proposed based on a synchronous machine and voltage source converter was suggested for obtaining variable speed operations of PHES. Also a dynamic modeling of adjustable-speed PHES is dealt in [6]. A combined operational control methodology for a hydro turbine and DFIG was presented and implemented as an integrated control topology. In this study, the optimization of control was executed via the speed control of the hydro turbine based on the reference power command and the reservoir head. Moreover, the PHES can improve the reliability of the power system and due to their performance the PHES gives to the grid operator to make more financial revenues. Management of electrical energy storage system is an important research topic, in particular in combination with intermittence wind energy. The EMS in an electrical system is studied into several levels according to the time scale considered. The first level is to study the EMS over a time scale ranging from one day to one week. This step involves determining the plant's production plan based on the data from the forecast and the constraints inherent in the technologies used. Medium-term supervision, ranging from one hour to one day (D-1), will make it possible to refine the reference power based an updated forecast. Medium-term supervision, ranging from one hour to one day, will make it possible to refine the reference power based on an updated forecast. Finally, the third level represents a real-time supervision to determine the storage reference power in order to guarantee the commitments made on power supply and system services. There is a wide variety of works handling different methods in terms of modeling and EMS strategy of the joint operation of wind farm-PHES. The authors in [7] dealt the optimization of renewable energy system using EMO. In this paper, they proposed an optimization problem under multi objective optimization which are the introduction cost, the operation cost and the environmental load. The authors in [8] proposed a unified energy management for a grid connected included renewable sources and a hybrid energy storage system and local load. This study shows the importance of EMS in hybrid system. The writers in [9] analyzed the optimal scheduling of the joint operation and uncoordinated operation of a wind farm and PHES in a day ahead (D-1) and studied the ancillary service market. The scheduling problem in D-1 is modeled by a stochastic optimization problem. The results show that the profit is increased with the joint operation in comparison with their uncoordinated operation. The authors in [10] dealt with a joint scheduling optimization strategy for wind and pumped storage systems considering imbalance cost and grid frequency in real time. This paper present used the PHES in order to minimize the fluctuation of wind energy and maximize the profit of the wind-thermal. The proposed strategy is implemented using MATLAB Interior Point Solver (MIPS) to solve the optimal power flow problem. The authors in [11] tries to investigate the effects of PHES usage along with the local network reinforcement as a long-term solution to wind energy curtailment in power systems. In this regard, through a multi-objective optimization algorithm, a planning method is proposed. In addition, the proposed approach aimed to maximize the wind power capacity. It takes into account wind energy curtailment cost, total social cost and energy of PHES units' revenues as objectives functions. Authors in [12] studied the day ahead optimal dispatching model of power system containing wind generator-hydro-thermal-pumped storage units. The particle swarm optimization algorithm (PSO)used in this study aims to define the operational strategy of the system including wind generators, thermal generators, and PHES, and to reduce the production costs and the carbon devastating emissions. The writers in [13] investigate the combined optimization of a wind farm and PHES in a day ahead. Two stages stochastic programming approach has proven to model the decision making process that the wind park operator's faces in a spot-market framework under uncertainty. The authors in [14] proposed the utilization of water storage ability to improve wind farm operational economic gains and to attenuate the active power output variations due to the intermittence of the wind-energy resource. An hourly-discredited optimization algorithm is proposed to identify the optimum daily operational strategy in a day ahead, to be followed by the wind turbines and the hydro generation pumping equipment's. In addition, authors in [15] proposed an optimization of combining wind energy with the pumped storage hydro plant. This study proposed an approach that includes three complementary functions to optimize the power of pumped hydro storage, maximize the revenues and minimize the penalty costs. The authors in [16] presented a dynamic programming method to build the optimal energy management of a wind farm, gas turbines and PHES to reduce the imbalance between wind energy production and the demand load. The writers in [17] studied the optimization of the combination of PHES and wind farm. They aim to utilize the excess energy from the grid during off peak hours or the excess energy produced by the wind farms or solar photovoltaic power plants to pump the water from the lower reservoir to the higher one and then release the water from the higher reservoir to the lower one through the hydraulic turbines to produce energy. The authors in [18] study a cooperative dispatch model for the coordination of the wind and pumped –storage generating companies in the Day-ahead electricity market. The independent system operator (ISO) requires a powerful intelligent calculation tool to optimize operation costs while clearing day-ahead market and determining hourly generation schedule. In addition, authors in [19] used mixed integer linear programming method to obtain the optimal hourly thermal, hydro and pumping power in day a head to enhance the cost lowering process of the entire system. Authors in [20] presented a tool to design the optimal configuration of a wind farm combined with PHES. Moreover, the writers in [21] proposed two methods to minimize the penalties in the wind farm's power output. The first of these methods considered a wind farm bidding alone in the day-ahead market. It attempted to minimize the wind fluctuation based on a statistical analysis of the expected production probability. The second one coupled a PHES containing a water reservoir with the wind farm to minimize the imbalanced costs incurred by the wind farm owner. Furthermore, writers in [22] studied the hydro power storage as secondary control reserve. An economic study is achieved by calculating the profit cost of participating as secondary control. The authors in [23] considered the optimum sizing as well as the design of a pump station unit for a combined operation with the wind farm. Their work aimed to find the optimal net present value for the investment in a one- year simulation by varying the number of pumps used in the station. All the previous papers studied some algorithms of the EMS including wind farm and PHES in a day ahead, in the framework electricity market. They developed EMS strategy to schedule power in a day ahead under economic criteria. While these works have been investigating the effect of PHES on the optimal scheduling of wind energy in power system in a day ahead, it still needed to have representative and simple models for joint operation of wind farm and PHES. In addition, the developing of real time EMS is also crucial to instantly following day ahead planning. Thus, in this paper a comprehensive modeling of joint operation of wind farm-PHES is proposed to explain the behavior of the system. Also, the participation of PHES in primary and secondary frequency control is developed. A real time strategy of EMS is developed in order to minimize the penalty cost and to maximize the revenue profit. This paper is structured as follows: system is described in section 2. In section 3, the modeling of joint operation is presented. In section 4, problem formulation is presented. In section 5, the model of system is described. In section 6, the primary and secondary frequency control is presented. In section 6, the EMS is described. In section 7, simulation results in MATLAB/Simulink are presented. Finally, section 8 contains the conclusion.

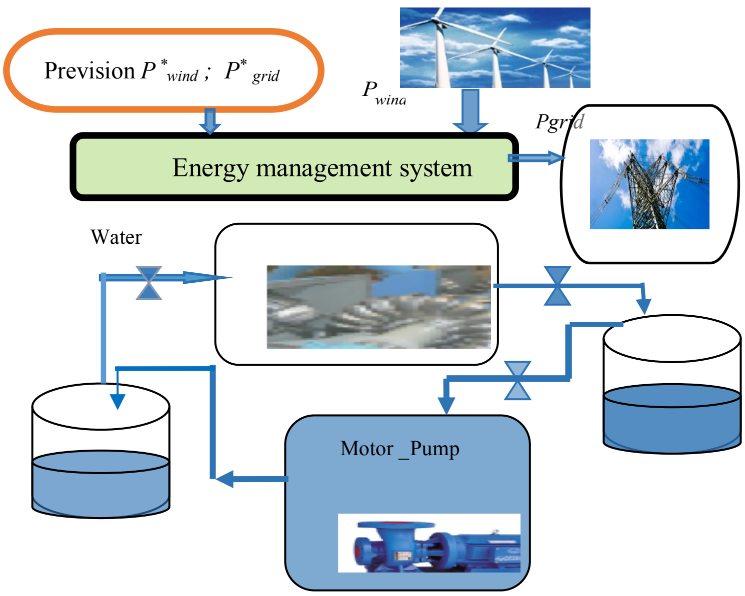


Fig. 1. Configuration of joint operation including wind farm and PHES

2. System description

The study developed in this paper is carried out for Grid-connected Renewable Energy Systems in electricity market context. This system is located in Spain. It's called Elhierro station, which is composed of a wind farm and a PHES.

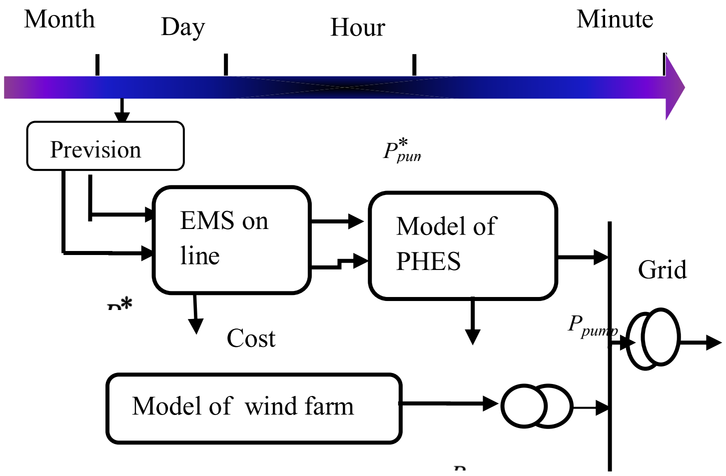


Fig. 2. Description of the system

The wind farm is composed of a set of five aero generators (Enercon E-70) each with a 2.3 MW of power with a total power of 11.5 MW. The pumped station contains two 1500 KW pump sets, and six pumps 500 KW so makes a total power of 6MW. Four Pelton groups of 2.38 MW of power each make the hydraulic turbine capacity, the total power equals to 11.32MW. The maximum flow generation equals to 2 m^3/s with a gross head of 655 meters. The joint operation between elements of station(Wind-PHES) makes it possible to match grid power requirements and generate the required revenues. As shown in the literature, the study of wind integration in electricity market is summarized in three main parts as represented in figure.2. In the first part, the forecasting of wind power as well as the prediction of the grid power requirements is developed. The forecasting power on a time proportion can help to define the planning of energy production. In this study we consider no wind forecasting error. Secondly, a joint configuration model is described. In other part, an EMS is developed to satisfy economic criteria. The wind farm has the priority to generate electricity and inject it to the grid. The PHES ensures the balance between wind power production and required power. The PHES recovers the excess of energy by pumping water from lower to higher reservoir through an induction motor-pump and centrifugal pump. Then, it generates electricity by using hydraulic turbine PELTON, and permanent magnet synchronous generator (PMSG).

3. Problem formulation

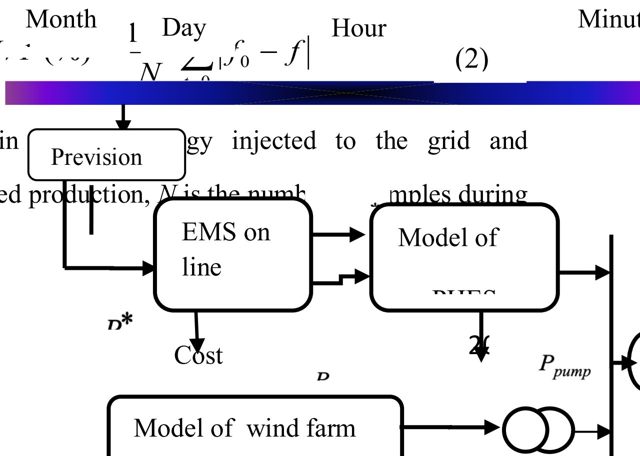
The problem is formulated with a time step of half of an hour (30 minutes) to find a daily operating strategy of both wind farm and PHES. Performances indicators are designed to measure the effectiveness of the management algorithm. Three indicators are proposed.

-Indicator of program production satisfaction: This indicator is based on the MAPE score evaluated each 30 minutes and with the formula expressed as follow:

$$MAPE(\%) = \frac{100}{N} \sum_{t=0}^{N} \frac{\left| E_{inj} - E_{pg} \right|}{E_{pg}} \qquad (1)$$

- Indicator of frequency variation: This indicator is based on calculating the average of frequency change in 15minutes.

$$I_f(\%) = \frac{1}{N} \sum_{t=0} |f_0 - f| \qquad (2)$$



E_{inj}: 30 min ... gy injected to the grid and E_{pg} planned production, N is the numb... mples during

Parameters	Description	Valeur	Unit
P_{wind_min} ; P_{wind_max}	minimal et maximal of wind power	0,12	MW
P_{demd_min}; P_{demand_m}	Minimal et maximal of required power	0,12	MW
$P_{hyd,min}$; $P_{hyd,max}$	Minimal and maximal of hydraulic power	0,12	MW
$P_{pump,min}$; $P_{pumpmax}$	Minimal and maximal of pumped power		MW
$V_{ol,min}$; V_{ol_max}	Min et max de volume de réservoir		m^3
T	Periode of time		h

the period of time, f is the frequency of grid, f_0 is the nominal frequency (50Hz)

-Financial indicator: Financial indicator is based on minimizing of the penalty also maximizing the revenue profit during one day, as expressed in equation as follow:

$$Cp = C_{penalt} * \sum \left| P^*_{grid} - P_{grid} \right| \quad (3)$$

$$Ce = C_{profit} * \sum P_{grid} - C_p \quad (4)$$

In this paper, the available wind power is assumed similar to the wind power forecasting, which implicates that no wind forecasting error ($P_{wind}=P^*_{wind}$), as well as we suppose there is no error prediction for requirement power. Referring to figure.2, according to the direction of the corresponding arrows, the reference power of PHES is calculated as follows

$$P^*_{ref} = P^*_{wind} - P^*_{grid} = P_{wind} - P^*_{grid} \quad (5)$$

The power injected to grid is expressed as follows:

$$P_{grid} = P_{wind} + P_{hyd} - P_{pump} \quad (6)$$

P^*_{ref} is the reference power of PHES (difference between wind production and required power), P_{wind} is the wind power forecasted, P_{grid} the grid power injected, P_{hyd} is the hydraulic power, P_{pump} is the pumped power, In accordance with the pumped power and the hydraulic power, the expression relating flow rate (Q), head reservoir (H) and energy stored in the reservoir is represented as follows:

$$\dot{Q} = \frac{P_{pump}}{H_t.(\eta_{pump}.g.\rho)} + \eta_{hyd} \cdot \frac{P_{hyd}}{H_t.(g.\rho)} \quad (7)$$

$$\Delta Q_{t \to t+1} = Q.\Delta t \quad (8)$$

$$H_{t+1} = H_t + \frac{\Delta Q_{t \to t+1}}{S} \quad (9)$$

$$E_{t+1} = E_t + \Delta t * \left(\eta_{pump} * P_{pump} - \frac{P_{hyd}}{\eta_{hyd}} \right) \quad (10)$$

$$Vol = \frac{E}{\Delta t \rho g H} \quad (11)$$

Where η_{pump} is the efficiency of pumped station, η_{hyd} is the efficiency of hydraulic turbine, Δt is the time period, $\rho (kg/m^3)$ is the density, $g (N/kg)$ is the acceleration, $vol (m^3)$ is the volume of reservoir, $\Delta Q (m^3/s)$ is the variation of flow rate, $S (m^2)$ is the surface of reservoir. The constraints of joint operation are expressed in table.1

Table.1 : constraints of system

4. Model of joint configuration

4.1. Model of wind turbine

The mathematical relationship between the wind power generation and the wind speed to cube is expressed as follows[24]:In which P_{mec} is the extracted power from the wind turbine, ρ is the air density, R is the blade radius, v is the wind speed in m/s, A is the area swept by the wind turbine rotor, λ is the tip speed ratio, β is the pitch an

$$P_{mec} = \frac{\rho A v^3}{2} C_p(\lambda, \beta) \quad (12)$$

$$C_p = 0.5\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 10\right) e^{-\frac{18.4}{\lambda_i}} \quad (13)$$

$$\lambda_i = \frac{1}{\frac{1}{\lambda - 0.02\beta} - \frac{0.003}{\beta^3 + 1}} \quad (14)$$

$$\lambda = \frac{\Omega m R}{v} \quad (15)$$

The C_p is a very important coefficient since it describes how much mechanical power can be extracted from the incoming aerodynamic power. C_p is a function of the tip speed ratio λ, which is the ratio between the tangential speed of the rotor blades and the incoming wind speed, Ω_m is the angular speed of wind turbine rotor

2.1. Model of PHES

a. Model of pump-motor

During the over production of wind farm energy, the PHES operates as a pumping station which is based on an induction motor -pump. Consequently, a model of induction-motor and centrifugal pump is investigated

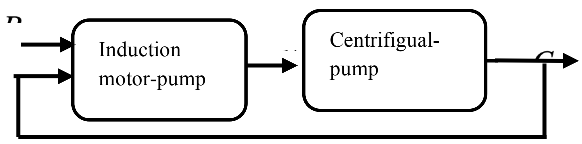


Fig.3: configuration of PHES in pumping mode

The expression of pump torque is expressed as follows:

$$C_p = k_r w_p^2 \quad (16)$$

The expression of speed induction motor pump is e (23) as follows:

$$\frac{dw_p}{dt} = \frac{1}{J}(C_{em} - C_p - fw_p) \quad (17)$$

The equation of nominal power of the pump is formulated as follows:

$$P_{pump\_ref} = k_r * w_p^3 \quad (18)$$

$$w_{p\_ref} = \sqrt[3]{\frac{P_{pump\_ref}}{k_r}} \quad (19)$$

P_{pump} is the pump torque, k_r is constant of centrifugal pump, C_p is the nominal torque of pump, P_{pump_ref} is the nominal power of induction-motor pump ,J_{mot} is the inertia of induction motor w_p is the speed of induction motor,f is the viscosity of induction motor-pump, C_{em} is the electromagnetic torque

b. In generating mode

This is also called discharging mode. In this mode, PHES unit generates power and injects it to grid. The modeling of hydraulic turbine is based on a turbine speed governor [25]and a servomotor in order to define the wicket gate position. As a function of wicket gate, the mechanical power is determined.

The servo motor is modeled by the transfer function which is expressed by: $T_f = \frac{1}{1+sT_p}$ (20)

The mechanical power of hydraulic turbine is simplified as a transfer function, which can be formulated by [23]:

$$\frac{\Delta P_m}{\Delta G} = \frac{1-T_w s}{1+0.5T_w s} \quad (21)$$

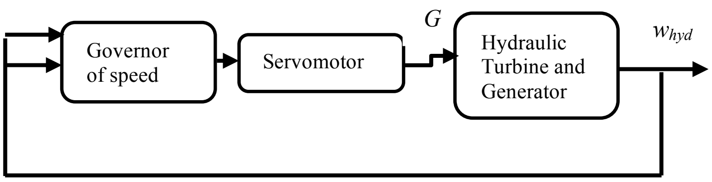


Fig. 4. generating mode

T_w is the constant hydraulic time:

$$T_w = \frac{LU_0}{gH_0} \quad (22)$$

Where $L(m)$is the length of the penstock, $U_0(m^3/s)$ is the initial speed water, g is the acceleration, $H_0(m)$ is the initial head, G is the gate opening.

The reference speed is calculated as a function of nominal power follow.

$$w_{hyd\_ref} = \sqrt[3]{\frac{P_{m\_ref}}{k_{opt}}}$$

Or the power exploited from hydropower at a particular site is proportional to the product of flow rate and head as given in the following [24]:

$$P_m = \eta\rho gHQ \quad (24)$$

by using equation (28) a equation (29), the mechanical hydro power is expressed as follow:

$$P_m = \eta\rho gQ \frac{h0}{3} w_m^3 \rightarrow P_m = K_{opt} w_{hyd}^3 \quad (25)$$

Fig .5: Idealized governor characteristic of a turbo alternator

The re… of hydraulic speed is calculated as:

$$\frac{dw_{hyd}}{dt} = \frac{1}{H_s}(P_m - Pe - D\Delta w_{hyd}) \quad (26)$$

w_{hyd} (rad/s) is the speed of hydraulic generator, G is the gate opening ,$P_m(W)$ is the mechanical power, D is damping coefficient.

5. Frequency control

5.1. Primary and secondary frequency control

Nowadays, the synchronous operation of the conventional power plants and the power balance is maintained by the grid frequency control [26]. Classically, when the frequency deviation exceeds a pre-defined threshold value, controllers will be activated to increase or decrease the power from the prime movers to restore the power balance. The primary frequency control contribution of the generators is based on the droop constant, which gives the additional power that is supplied as a function of the frequency deviation.

$$\Delta P = K(f - f_0) \quad (27)$$

Where f is the measured frequency, f_0 is the normal frequency (50 Hz), K is the constant of power-frequency

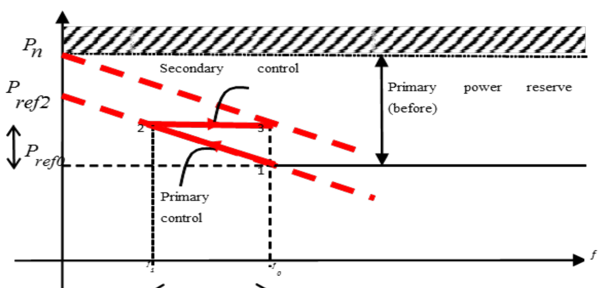


Fig .5: Idealized governor characteristic of a turbo alternator

After restoration of the power balance by the primary control, the system is stable (point 2 in fig. 4) but at another frequency (f_1). The secondary frequency control brings the frequency back to its value in a normal operating (f_0) and the power operating point is changed (point 3 in fig. 4)[27].

5.2. Participation of PHES in frequency control

In our application, the EMS needs the reference power to be able to contribute in the frequency control. It equals to the sum of the real desired power by the secondary and the primary frequency regulation.

$$P_{ref\_freq}=P_{ref\_prim}+P_{ref\_sec} \quad (28)$$

The classical power/frequency control principle has been derived inside the interactive interface in order to create a storage system contribution to the primary frequency control (fig. 5). The power/frequency constant is calculated as follows:

$$K=\frac{1}{\delta}\frac{P\max}{f_0} \quad (29)$$

With the droop is: δ =5% and P_{max} the maximum available power, which can be exported to the distribution network P_{grid_max}. Once the primary control does not correct the frequency error during 15 minutes, the controllers activate the secondary control in 15 minutes. For our application, the EMS sends a wished power reference P_{sto_ref} to the storage system, which is the sum of the reference power for contribution in frequency control and power programmed P_{sto_prog}. The primary frequency control occurs with the response time of $T_{prim}=500ms$, while the response time in secondary control $T_{sec}=100s$.

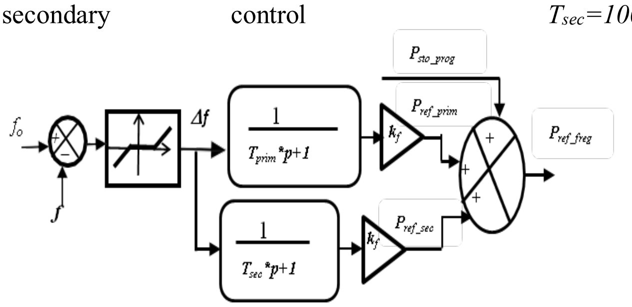


Fig.6: Primary and secondary frequency control

6. Energy management system

The EMS is designed in order to smooth the power injected into the grid.

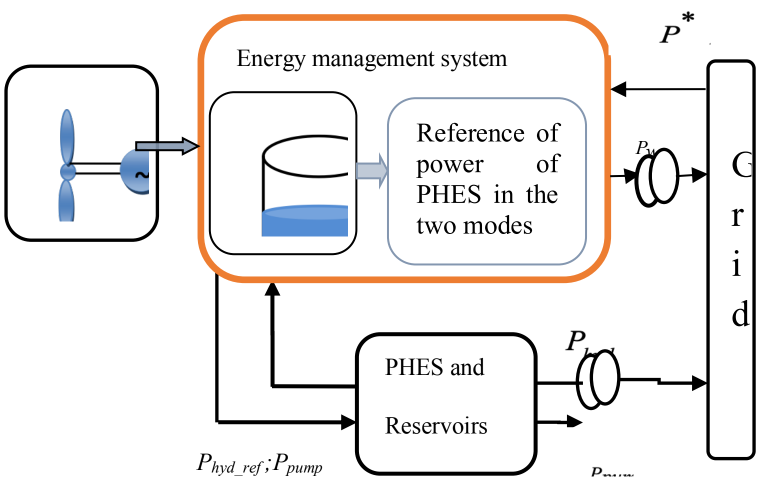


Fig.7: Configuration of energy management system of wind farm and PHES

It's uncertainties of renewable energy, and to balance the energy in the power system concurrently satisfying at any time the grid power requirements. It aims to follow he daily operational strategy in real time of and to maximize the profit revenues. Once the objectives are identified, it is necessary to define the structure of EMS. It is therefore necessary to identify the right inputs in order to establish the right management rules for the output set point. Two representatives input variables are considered as the imbalance power between wind power production and required power and the volume of reservoir. The EMS proposed is based on Boolean rules. The objectives, the constraints and all actions on the power system by the EMS are given in table1.

Table.2: objectives, constraints and actions of EMS

Objectives	Constraints	Action
-Prioritize the wind energy p -Respect energy day ahead s - Increase the benefit -Participate in frequency support (primary and secondary supports).	-Availability of wind energy production - Storage element size -Primary support in less than 500sec for 15minutes.Respons e in less than 15 minutes. for 15 minutes in case of secondary support. (Error of 0.5% with respect to the basic frequency 50 Hz).	-Storage management

As represented in figure.8, the EMS strategy aims to define the reference power storage P_{ref}, minimize the penalty cost, and maximize the revenue. The reference power of PHES can be determined as function to the volume of reservoir Vol and the imbalance power. Thus, the storage system is controlled by the water volume Vol in the reservoir. Specifically, as concluded in the flowchart above, two modes are encountered in practice. When the wind power is lower than the grid requirement power and the volume water of reservoir is between maximal and minimal $Vol_{min}<Vol<Vol_{max}$, the PHES operates as hydraulic generator, and the reference power is equal to P_{sto_ref} and in this case,when -1< $\Delta f'$ <-0.1, the frequency control is achieved.Unless, when the wind power is higher than the grid power requirement and the volume of reservoir $Vol_{min}<Vol<Vol_{max}$, Moreover, if $Vol=Vol_{max}$ and -1<$\Delta f'$ <-0.1or$Vol=Vol_{min}$ and 0.1< $\Delta f'$<1, the PHES is operated in

Parameters	Description	Unit
P_{wind}	Wind power	MW
P_{demd}	Required power	MW
P_{hyd}	Storage power in generating mode	MW
P_{pump}	Storage power at pumping mode	
$V_{vol,}$	Volume of reservoir	m^3
C_{penal}	Penalty cost	€/Kwh
C_{profit}	Profit cost	€/Kwh
T	Periode of time	h

order to participate in primary and secondary frequency and P_{ref}=P_{ref_freq} .

- Δf' is the frequency error
- Vol is the volume reservoir.
- Vol_{min} and Vol_{max} are the minimum and maximum of reservoir volume.
- P_f is the reference power for contribution in primary frequency control
- P_{sto_ref} is the reference of power storage
- P_{freq} is the power storage to primary control of frequency.
- k_f is the power/frequency

7. Results and discussion

The simulation of the EMS described above is performed by MATLAB® using the parameters described in Table 3. It is run with a time step of half hour (30min) over a period of 1 month (1440 data points).

Table.3: parameters of system

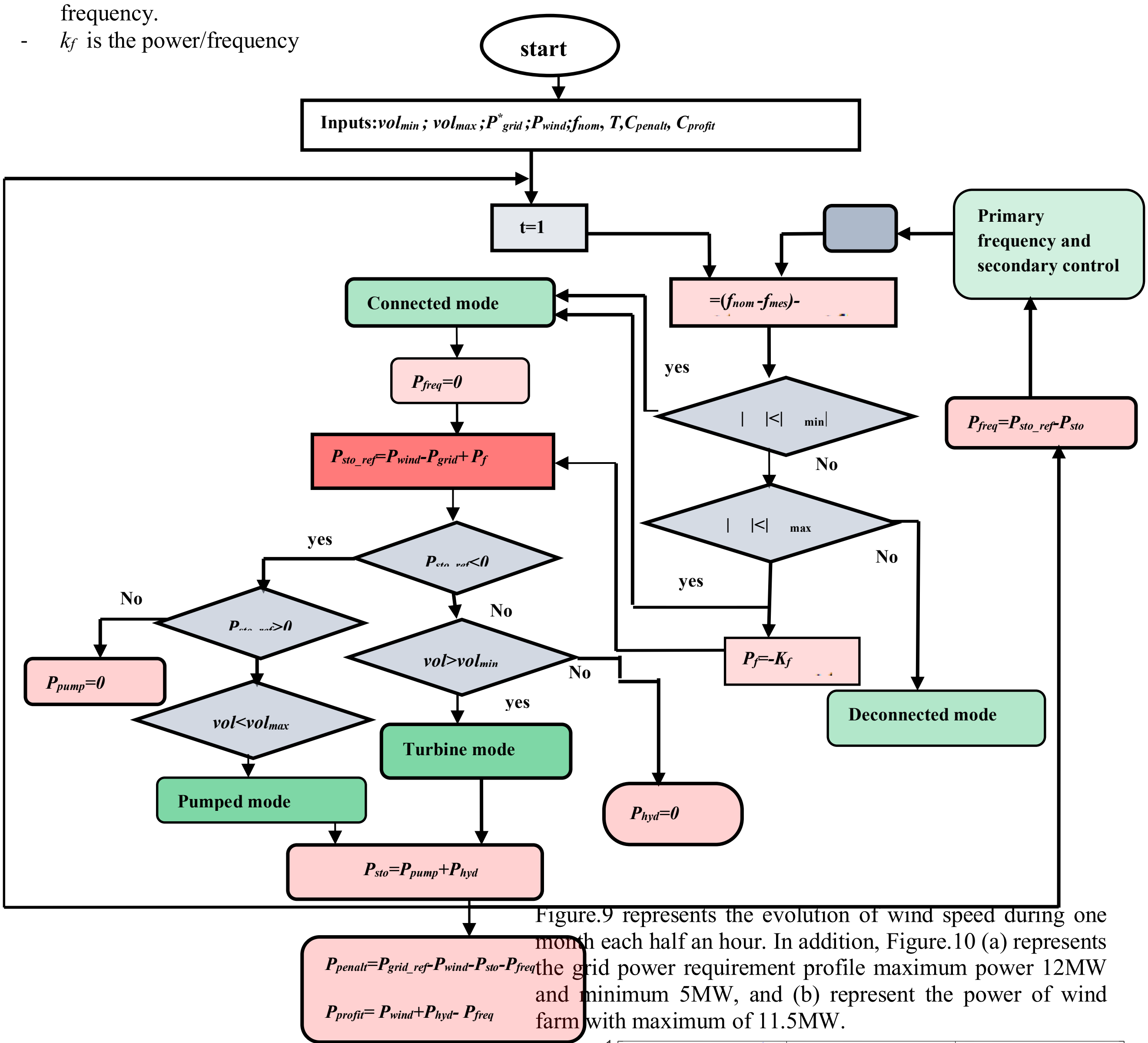
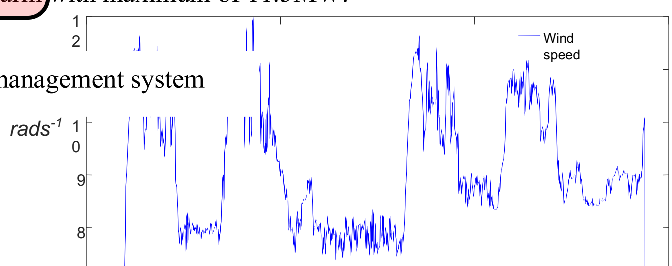


Fig.8: Flowchart of energy management system

Figure.9 represents the evolution of wind speed during one month each half an hour. In addition, Figure.10 (a) represents the grid power requirement profile maximum power 12MW and minimum 5MW, and (b) represent the power of wind farm with maximum of 11.5MW.



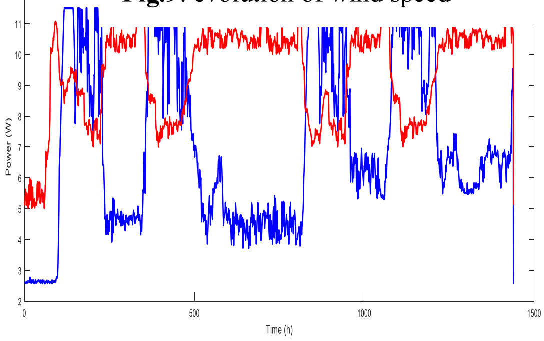
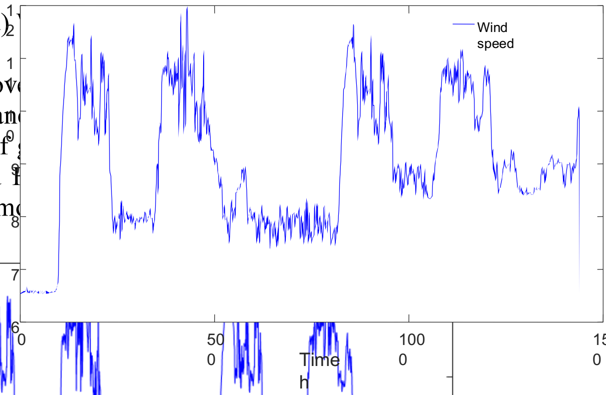


Fig.9: evolution of wind speed

Fig .10: (a)



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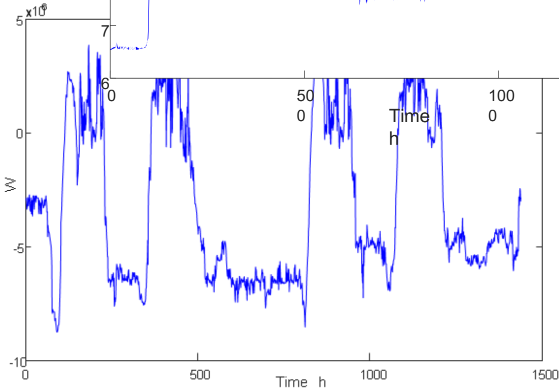

Fig.11: Imbalance power

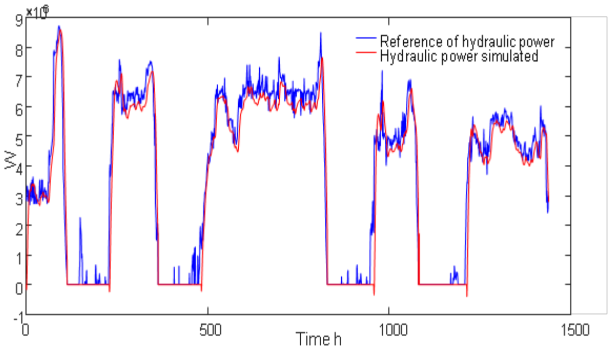

Fig.12: Power of PHES in generating mode

As shown in the simulation results, we have obtained five cycles of pumping and generating during month. Then, the PHES is operated in generating mode at *1h<t<24h, 115h<t<184h, 250h<t<414h ;477h<t<546h, 614h<t<720h* to recover the imbalance energy with maximum 8.8MW. However, during *59h<t<113h, 182h<t<241h, 423h<t<459h ;546h<t<614h,* the PHES operates in pumping mode to pump water from lower reservoir to higher reservoir.

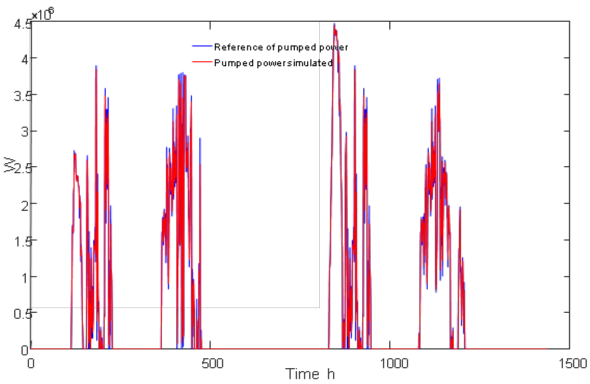

Fig.13: Power of PHES in pumping mode

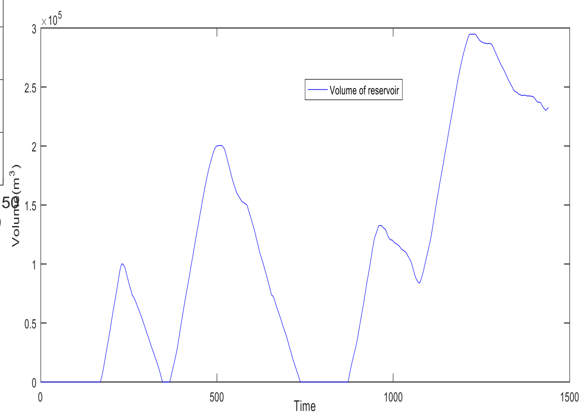

Fig.14: Volume of reservoir

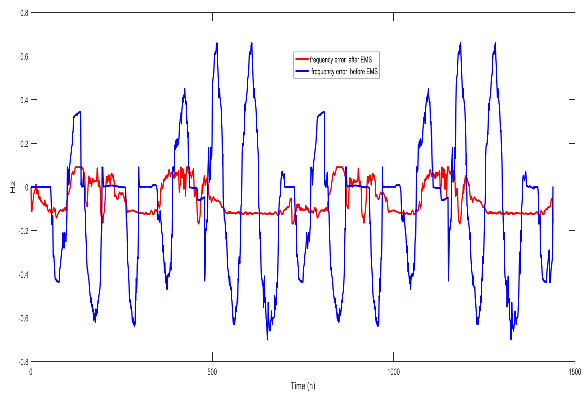

Fig.15: frequency error before and after EMS

In figure.11 and figure.12, the pumped-storage hydro plant operates coordinately with the wind farm. Generally, the wind farm will sign an electricity contract with the pumped-storage hydro plant, saying that the pumped-storage hydro plant should compensate 97% of the deviations from wind power output. Also, the PHES participate in primary and secondary of frequency control. Then, the frequency error is compensated during the month as shown in figure.14. Additionally, the effectiveness of the proposed EMS is also verified by the computing of power planning satisfaction criteria defined in section.3. The evaluation of EMS strategy is summarized in the table below: Brief, the effect of the participation of PHES in balancing energy in power system is obtained whether in pumped storage mode and in generating mode. In addition, the PHES participates in ancillary services market and frequency control as shown in figure.15. In fact, as shown in table .4, the suggested EMS achieves a remarkable reduction in the penalty costs of the system coupled with an improvement in the revenues and minimize the frequency error.

Table.4: Evaluation of EMS

	Penalty cost(€)	Revenue Profit (€)	Profit(€)	MAPE (%)	IVF (%)
1stweek	9299	61205	51906	1.271	0.2
2st week	2782	18357	15575	1.205	0.1
3 stweek	4608	30546	25938	2.109	0.15
4st Week	8593	57204	48611	2.149	0.01
Evaluation During month	25283	167312	142029	2.208	0.11

8. Conclusion

In this paper, the modeling of wind farm/PHES has been investigated. The proposed system is composed of wind turbine, hydraulic turbine, centrifugal pump and two reservoirs. We have modeled all elements of system. Also, we described an approach to achieve two objectives: the minimization of penalty cost and maximization of the revenue profit. We propose an algorithm of EMS based on if-then to reach to the objectives predefined. However, an optimization of EMS in a day ahead will must be developed in the future research. The proposed algorithm can guarantee the requirement power which it is shown by the minimization of (MAPE). In this case, we had gets as a MAPE 2.2%, so that the satisfaction energy is ensured at more than 97.8%. As results, the using PHES is a primordial solution to minimize the wind fluctuation and guarantee the grid stability.

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