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ARTIFICIAL NEURAL NETWORK CONTROL OF HYBRID RENEWABLE ENERGY SYSTEM CONNECTED TO AC GRID

SAMI YOUNSI[1], MONCEF JRAIDI[2], NEJIB HAMROUNI[3], ADNANE CHERIF[4]
[1]Higher Institute of technological studies Charguia, Tunis, Tunisia, Sami_younsi@yahoo.fr
[2]Higher School of technology and informatic Charguia, Tunis, Tunisia, m_jraidi@yahoo.com
[3]National School of engineering Gabes, Tunisia, hamrouni_nejib2003@yahoo.fr
[4]Faculty of Sciences, Manar University Tunis, Tunisia, Adnane.cher@fst.rnu.tn
Corresponding Author: Email- Sami_younsi@yahoo.fr

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Abstract- This paper discusses the development of new control method using artificial neural network model for the optimum operation of hybrid renewable energy system (HRES) connected to AC grid. The hybrid system consists of wind generator (WG), diesel generator (DG), and flywheel energy storage system (FESS). The system is based on permanent magnet synchronous machines (PMSM) which are controlled by sliding mode control, according to type of subsystems.
An artificial neural networking supervisor control is designed to determine the energy transfer type of flywheel energy storage system (charging / discharging / no transfer of energy), and to take decision on diesel generators ON/OFF status, these two parameters are used to simplify the control mode of these subsystems. The supervisor inputs are the difference between the reference power of hybrid renewable energy system and the power generated by wind generator, and the energy stored in flywheel. The objectives of the supervisor are to satisfy the hybrid system reference power (power requested by AC network), to manage the energy transfer between hybrid system and AC grid, to optimize the use of wind energy, and to reduce fuel of diesel generator. The ANN testing and the system simulation give encouraging results such as power requested is satisfied.
Key words -Artificial Neural Network, Control and Supervision; Hybrid Renewable Energy System; Wind Generator; Flywheel Energy Storage System; Diesel Generator; Permanent Magnet Synchronous Machine; Sliding mode control.

Introduction

Currently, following the progressive reduction of energy resources, the wind energy appears clearly to complete the used energy. The wind generators are decentralised sources, their production of electricity varies quickly according to wind speed which is very fluctuating in very short time. The studies of Al Aimani [1] and Cimuca [2] showed that their connection to network pause many problems, such as the unbalances of consumption-production, and absence of frequency-power and voltage adjustment, what causes a bad quality of wind energy and limits their rate of penetration to networks, to guarantee their stability.The combination of wind generator with other energy sources in hybrid system can reduce these problems, and optimize to maximum this generator technically and economically. Many solutions of hybrid systems which collects wind generator with other renewable energy sources such as wind - photovoltaic system [3-4-5], and wind - hydraulic system [6], these systems require geographical places which can provide these types of sources. Other solutions of hybrid systems which does not depend on the geography, and collect wind generator with controllable sources such as wind - diesel system [7-8], which is very significant to improve wind power quality. Association in addition to storage energy system with wind - diesel system, can provide a reserve of energy which is used for various adjustments. An energy storage system allows the increasing of the generated power value by providing energy for the peak periods and by accumulating energy during the period when the energy requested is reduced. Among storage system, the flywheel energy storage system is well adopted because of its raised dynamics, its good efficiency, and its long period of life to store energy for short periods [2]. In particular flywheel energy storage system is most profitable if the period of storage does not exceed 10mn [2].

In this work, we proposed a hybrid renewable energy system which collects wind generator (WG) with diesel generator (DG), and flywheel energy storage system (FESS). The unit is based on permanent magnet synchronous machines (PMSM), this type of machine is very recommended in the wind power conversion systems. The hybrid system is connected to AC network by using power electronic. We developed control methods for each subsystem (wind generator, diesel generator, flywheel energy storage system) and we applied the sliding mode control for the permanent magnet synchronous machine, it is a robust method for very disturbed models and it can be well chosen for wind renewable energy systems of production which are very fluctuating in very short time. The system control requires also the development of a supervisor. This supervisor based on artificial neural network (ANN) model decides the energy transfer type of flywheel energy storage system (charging / discharging / no transfer energy) and take decision on diesel generators ON/OFF status, These two parameters are selected respectively to determine the control mode of the machine of the flywheel energy storage sytem (motor/generator / not controlled) and to control the intervention of diesel generator. The supervisor inputs are the reference power of hybrid system (power requested by AC grid), the power generated by wind generator, and the energy stored in flywheel. The objectives of the control and supervision of hybrid system are to satisfy the reference power of hybrid system, to manage the energy transfer between hybrid system and AC grid, to optimize the use of wind energy, and to reduce fuel of diesel generator. A data base was developed and contains all inputs and outputs which will be trained by ANN model; this base treats all possible cases of the system. The ANN is training using Matlab software by “newff” function, and after various tests we determined his final parameters and architecture.

System description

The Fig. (1) shows the structure of hybrid renewable energy system. This structure is consisted of wind generator (WG), diesel generator (DG), and flywheel energy storage system (FESS), which are based on permanent magnet synchronous machines (PMSM). The AC/DC converters are used to connect the system elements to DC link voltage, and to control machines, and that put with flywheel energy storage system is bidirectional converter. The DC link voltage and AC grid are connected via condenser, DC/AC converter and RL filter.

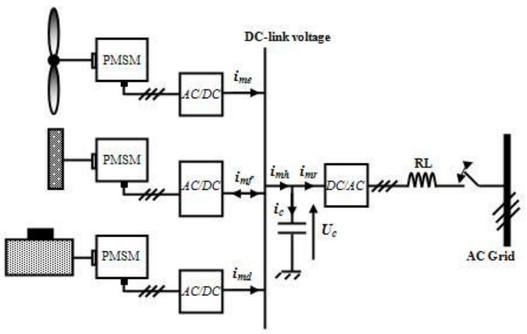

Fig.1 -Hybrid renewable energy system configuration.

Hybrid system modelling

Wind turbine modelling

The aerodynamic power on the rotor of the wind turbine is given by the following equation:

$$P_m = \frac{1}{2}\rho\pi R^2 v^3 C_p \qquad (1)$$

ρ Is the density of the air, *R* is the length of the blade (*m*), v is the wind speed (*m/s*). C_p is the power coefficient. It represents the aerodynamic efficiency of the turbine and depends on the specific speed λ and the orientation angle of the blades β .

The dynamic fundamental equation determines the mechanical speed evolution of the synchronous generator. The simplified model of this equation is given by:

$$J\frac{d\Omega_m}{dt} = T_m - T_{em} - f\cdot\Omega_m \qquad (2)$$

Where *J* is the total inertia (turbine and generator), T_m is the mechanical torque, T_{em} is the electromagnetic torque, Ω_m is the mechanical speed of the rotor and *f* is a coefficient of various.

Flywheel energy storage system modelling

The flywheel energy storage system is based on the kinetic energy of the flywheel such as:

$$E_c = \frac{1}{2}J_f\cdot\Omega_f^2 \qquad (3)$$

Where J_f *and* Ω_f are respectively the inertia moment and the speed of the wheel.

The dynamic fundamental equation is given by:

$$J\cdot\frac{d\Omega_f}{dt} = T_f - T_{em} - f\cdot\Omega_f \qquad (4)$$

Diesel generator modeling

Once the fuel is injected in the cylinders of the engine, there will be a delay before the torque is produced on the rotor [7-9]. This delay depends on the phenomenon of combustion. It depends also on the number of cylinders of the engine, and the rotation speed [7-9-10]. The torque produced by the engine is given by the following equation:

$$T_{di}(s) = \frac{K}{\tau s + 1}Y(s) \qquad (5)$$

Where τ is the time delay of the combustion and *K* is a gain that adapts the torque and the fuel consumption. The engine is speed controlled by an outer loop. It drives a PMSM attached to an AC/DC converter.

The dynamic fundamental equation is given by:

$$J\cdot\frac{d\Omega_{di}}{dt} = T_{di} - T_{em} - f\cdot\Omega_{di} \qquad (6)$$

Permanent magnet synchronous machine modelling

The generally used model of the PMSM is the model of Park. By considering only the fundamental harmonic of the field distribution in the air-gap of the machine and by neglecting the homopolar component, the theory of the vector of space gives the dynamic equations of the stator currents such as:

$$\begin{cases}\dfrac{di_{Sd}}{dt} = \dfrac{1}{L_d}(V_{Sd} - R_S i_{Sd} + p\Omega_m L_q i_{Sq}) \\ \dfrac{di_{Sq}}{dt} = \dfrac{1}{L_q}(V_{Sq} - R_S i_{Sq} + p\Omega_m L_d i_{Sd} - p\Omega_m \phi_m)\end{cases} \qquad (7)$$

The electromagnetic torque produced is expressed by:

$$T_{em} = p(\phi_m i_{sq} + (L_d - L_q) i_{sd} i_{sq}) \quad (8)$$

Where R_S is the phase resistance of the stator, L_d and L_q are respectively cyclic inductances of d and q axis, ϕ_m is the field induced by the permanent magnet, V_{Sd} and V_{Sq} are respectively the d and q axis components voltages of the stator, i_{Sd} and i_{Sq} are respectively the d and q axis components currents of the stator, *p* is the pairs poles number.

Hybrid system Control strategy

Sliding mode control of PMSM

The implementation of this control method requires three stages necessary: the sliding surface, the condition of convergence and the law of order.

The general form of the sliding surface proposed by JJ Slotine [11] is:

$$S(x) = \left(\frac{\partial}{\partial t} + \lambda_x\right)^{r-1} e(x) \quad (9)$$

Where:

$e(x) = x_{ref} - x$: Variation of the variable to be regulated

λ_x : Positive constant which interprets the band-width of desired control.

r : Relative degree, equal to the number of times that it is necessary to derive the output to reveal the order.

$S(x) = 0$: A linear differential equation whose single solution is: $e(x) = 0$.

The general form of the order is $U = U_{eq} + U_{nl}$

Ueq: equivalent order, it is the solution of the equation $\dot{S}(X) = 0$,and it can be interpreted as the overage value of the order *U* which makes it possible to maintain the state of the system on the sliding surface [12-13].

Unl: nonlinear order, it is given to guarantee the attractivity of the variable to be controlled towards the sliding surface and to satisfy the condition of convergence, the simplest function is in the form of relay $U_{nl} = K.signS(X)$, where *K* a positive constant [12-13].

For the permanent magnet synchronous machine PMSM, the vector consisted by the errors of regulation of the stator currents is:

$$\begin{cases} y_1 = I_{sd\_ref} - i_{sd} \\ y_2 = I_{sq\_ref} - i_{sq} \end{cases} \quad (10)$$

From the system of equation (7), the first derivative of the system (10) can lead to the system (11):

$$\begin{cases} \dot{y}_1 = \dot{I}_{sd\_ref} + \frac{1}{L_d}\left[R i_{sd} - p L_q \Omega_m i_{sq}\right] \\ -\frac{1}{L_d} V_{sd} \\ \dot{y}_2 = \dot{I}_{sq\_ref} + \frac{1}{L_q}\left[R i_{sq} - p \frac{L_d}{L_q} \Omega_m i_{sd} + p \phi_m \Omega_m\right] \\ -\frac{1}{L_q} V_{sq} \end{cases} \quad (11)$$

The relative degree of the system $r = 1$ since the variables of order appear in the first derivation of the variables to be controlled. From system of equation (11) we can deduce:

$$\begin{cases} \dot{y}_1 = B_1 + A_1 V_{sd} \\ \dot{y}_1 = B_2 + A_2 V_{sq} \end{cases} \quad (12)$$

Where:

$$\begin{cases} B_1 = \dot{I}_{sd\_ref} + \frac{1}{L_d}\left[R i_{sd} - p L_q \Omega_m i_{sq}\right] \\ A_1 = -\frac{1}{L_d} \\ B_2 = \dot{I}_{sq\_ref} + \frac{1}{L_q}\left[R i_{sq} - p L_d \Omega_m i_{sd} + p \phi_m \Omega_m\right] \\ A_2 = -\frac{1}{L_q} \end{cases} \quad (13)$$

S_1 and S_2 are respectively the two sliding surfaces of the exits variables i_{sd} and i_{sq} :

$$\begin{cases} S_1 = y_1 \\ S_2 = y_2 \end{cases} \quad (14)$$

The solution of equation $\dot{S} = 0$ leads to the equivalent order

$$\begin{cases} \dot{S}_1 = 0 \\ \dot{S}_2 = 0 \end{cases} \Rightarrow \begin{cases} \dot{y}_1 = 0 \\ \dot{y}_2 = 0 \end{cases} \quad (15)$$

What gives:

$$\begin{cases} V_{sd\_eq} = -\frac{B_1}{A_1} \\ V_{sq\_eq} = -\frac{B_2}{A_2} \end{cases} \quad (16)$$

The nonlinear order is given in the following form:

$$\begin{cases} V_{sd\_nl} = K_d \, signS_1 \\ V_{sq\_nl} = K_q \, signS_2 \end{cases} \quad (17)$$

The order $U = \left[V_{sd} V_{sq}\right]^T$ is the sum of equivalent order and nonlinear order:

$$\begin{cases} V_{sd} = L_d \dot{I}_{sd\_ref} + R_s i_{sd} - pL_q \Omega_m i_{sq} \\ + K_d \, signS_d \\ V_{sq} = L_q \dot{I}_{sq\_ref} + R_s i_{sq} - pL_d \Omega_m i_{sd} + p\phi_m \Omega_m \\ + K_q \, signS_q \end{cases} \quad (18)$$

The permanent magnet synchronous machines PMSM are controlled by the choice of references currents values, I_{sd_ref} and I_{sq_ref}. The d-axis reference current is maintained to zero (to minimize the Joule losses), the electromagnetic torque of equation (8) becomes:

$$T_{em} = p.\phi_m.i_{sq} \quad (19)$$

Wind generator control

The permanent magnet synchronous machine of wind generator is controlled by maximum power point tracking (MPPT). Using the mechanical characteristic of the wind turbine for various wind speed shown in Fig. (2), it possible to calculate the reference of electromagnetic torque deduced graphically by maximum power point $(\Omega_{m\_\max}, T_{m,\max})$.

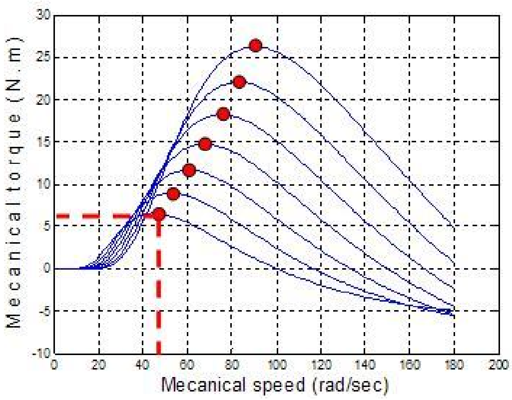

Fig.2 -Mechanical characteristic of wind turbine.

The reference current I_{sq_ref} can be deduced by equation (2) in permanent mode and equation (19):

$$I_{sq\_ref} = \frac{T_{m\_\max} - f.\Omega_{m\_\max}}{p.\phi_m} \quad (20)$$

The Fig. (3), shows the diagram of control

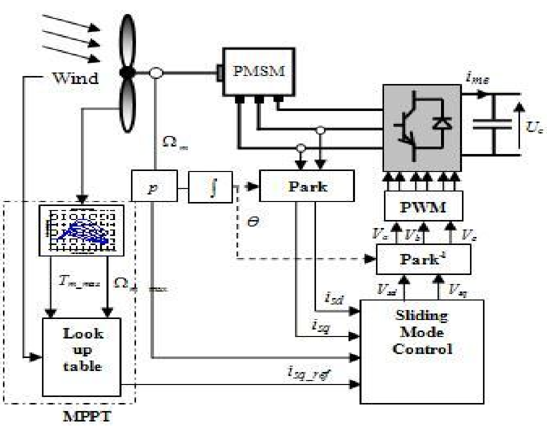

Fig.3 -Diagram of wind generator control.

Flywheel energy storage system control

For the flywheel energy storage system, the q-axis reference current of permanent magnet synchronous machine is determined by:

$$I_{sq\_ref} = k_{sign} \frac{T_{em\_ref}}{p.\phi_m} \quad (21)$$

Where: k_{sign} is the energy transfer sign of flywheel energy storage system, it determine the control mode of machine:

$k_{sign} = -1$: When the FESS is in charging mode, transfer of energy from DC-link voltage to flywheel, machine controlled in motor;

$k_{sign} = 1$: When the FESS is in discharging mode, transfer of energy from flywheel to DC-link voltage, machine controlled in generator;

$k_{sign} = 0$: When the FESS is in no-transfer mode, No transfer of energy between flywheel and DC-link voltage, machine not controlled.

The equation (4) in permanent mode and equation (21) gives:

$$I_{sq\_ref} = k_{sign} \frac{\dfrac{P_{f\_ref}}{\Omega_{f\_ref}} - f.\Omega_{f\_ref}}{p.\phi_m} \quad (22)$$

P_{f_ref} is the reference power of flywheel energy storage system; it can be calculated as follows:

$$P_{f\_ref} = P_{ref} - P_{wind} \quad (23)$$

Where P_{ref} and P_{wind}, are respectively the reference power of hybrid system, and the generated wind power. The reference speed of flywheel energy storage system Ω_{f_ref} can be calculated as follows:

$$\Omega_{f\_ref} = \sqrt{\frac{2}{J_f} \cdot E_{c\_ref}^2} \quad (24)$$

Where E_{c_ref} is the reference value of kinetic energy, it can be calculated us follows:

$$E_{c\_ref} = E_{c0} + \int_{t_1}^{t_2} P_{f\_ref} \, dt \quad (25)$$

The Fig. (4) shows the diagram of control.

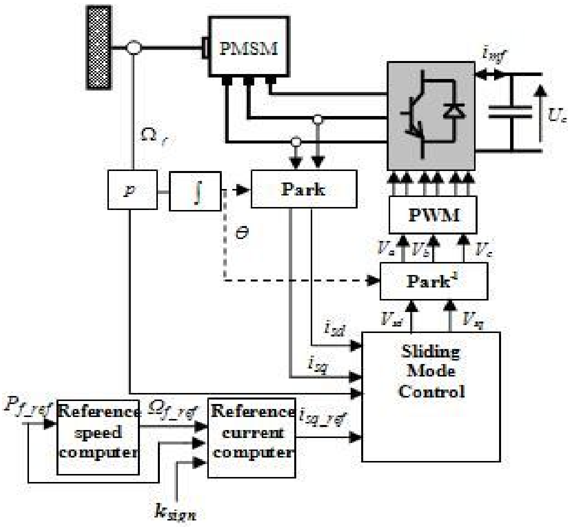

Fig.4 -Diagram of FESS control.

Diesel generator control

The PMSM of diesel generator is also controlled by the same strategy, the q-axis reference current of permanent magnet synchronous machine is determined by:

$$I_{sq\_ref} = k_{stat}\frac{T_{em\_ref}}{p\cdot\phi_m} \tag{26}$$

Equation (6) in permanent mode and equation (26) gives:

$$I_{sq\_ref} = k_{stat}\frac{\dfrac{P_{di\_ref}}{\Omega_{di\_ref}} - f.\Omega_{di\_ref}}{p\,\phi_m} \tag{27}$$

Where k_{status}, is the diesel generator ON/OFF status, it can be 0 (OFF) or 1(ON) and it control the intervention of diesel generator.

P_{di_ref}: is the reference power of diesel generator

$$P_{di\_ref} = P_{ref} - P_{wind} - P_f \tag{28}$$

The diagram of diesel generator control is shown in Fig. (5).

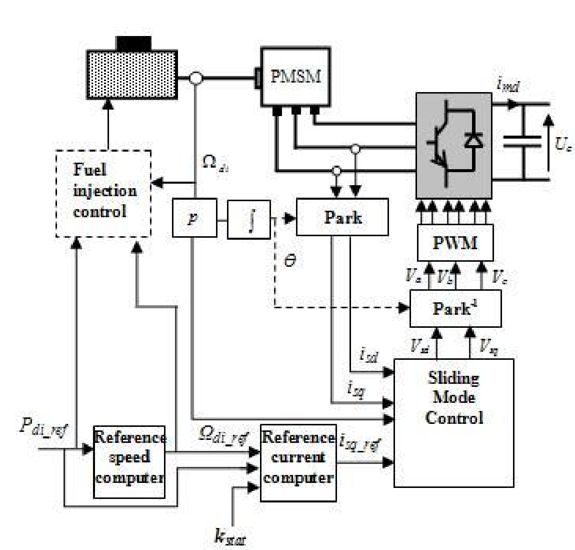

Fig.5 -Diagram of diesel generator control.

ANN supervisor control for hybrid system

In the recent years, the ANN models are largely used in the renewable energy conversion system such as in PV-diesel system [14], in wind systems [15], and in hybrid system [16]. In this study we propose an ANN model for hybrid renewable energy system control.

The flywheel energy storage system control requires the determination of energy transfer sign k_{sign} depending on the state of the global system. The permanent magnet synchronous machine will be controlled in motor (**k_{sign} = -1:** energy transferred from DC-link voltage to flywheel), in generator (**k_{sign} = 1:** Energy transferred from flywheel to DC-link voltage), or it can be not controlled (**k_{sign} = 0:** No energy transferred between DC-link voltage and flywheel). The diesel generator control uses diesel generator ON/OFF status k_{stat} (**k_{stat} = 0:** for **OFF**/ **k_{stat} = 1:** for **ON**). A supervisor based on artificial neural network (Fig. (6)) is developed then to determine k_{sign} and K_{stat}. The supervisor's inputs are the difference between reference power of hybrid renewable energy system and generated wind power ($P_{ref} - P_{wind}$), and the energy stored in the flywheel E_{stock}; this energy is not represented by a value it is represented by X parameter which describes its limits, and can be 0 or 1, it is calculated as follows:

$$X = 0,\ \text{if}\ E_{stock} < E_{stock\_min}\ \text{or}\ E_{stock} > E_{stock\_max}$$

$$X = 1,\ \text{if}\ E_{stock\_min} \le E_{stock} \le E_{stock\_max}$$

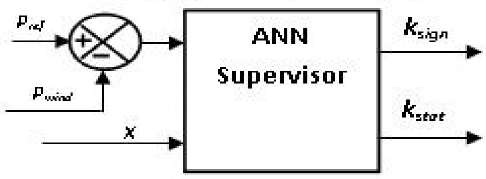

Fig.6 -ANN supervisor configuration.

The Table 1 shows the operating mode of flywheel energy storage system and diesel generator which can be chosen by the ANN supervisor depending on the state of global system.

ANN architecture and operation

The ANN architecture it consist of three principal layers of neuron: the input layer, the hidden layer, and the output layer. ANN model can be found in different topologies. Simpson [17] provides a coherent description of different popular ANN paradigms and presents comparative analyses, applications, and implementations of these paradigms. Of these, the more used is the back propagation paradigm [18]. Each layer (i) is composed of N_i neurons take their inputs on N_{i-1} neurons in the previous layer. With each synapse is associated a synaptic weight, so that the N_{i-1} are multiplied by this weight and then summed by the neuron level i, which is equivalent to multiplying the input vector by a transformation matrix. Put one behind the other layers of a neural network would cascading several transformation matricx and could be reduced to a single matrix, the other product, if there were at each layer, output function which introduces a nonlinearity at each step. This shows the importance of the choice of a good output function: a neural network whose outputs are linear has no interest. In the back propagation architecture each neuron receives inputs from the real-word environment.

ANN training

The ANN training is the most interesting phase. The first stage for this training is the development of data base for desired input and output. The ANN is trained to identify the relationship between inputs and outputs data. The back propagation algorithm uses the supervised training technique. In this technique, the interlayer connection weights and the processing elements thresholds are first initialized to small random values. Before forming the network we developed a data base which treats all possible cases which can be presented for the hybrid system. The ANN model used is composed of two nodes of input and two nodes of output. The nodes of input are P_{ref} – P_{wind}, and X parameter. The nodes of output are k_{sign} and k_{stat}.. An example of data training of some values is shown in the Table 2.

The ANN is training using Matlab software by "newff" function. Several tests one made to determine the network parameters which converged by using four hidden nodes. The Fig. (7) shows the architecture of ANN model.

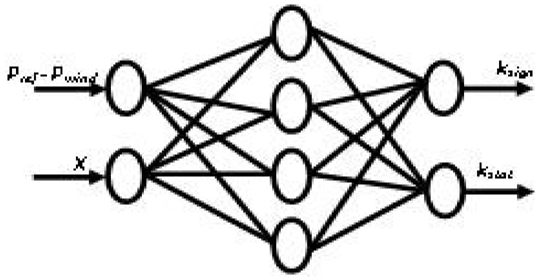

Fig.7 -The architecture of ANN model.

ANN testing and simulation results

The ANN model is tested with Matlab software, after its convergence to desired outputs values we simulate the system with Matlab-Simulink software. We used a wind profile which is applied to the turbine and is shown in Fig. (8), the wind generator produces then a power P_{wind} which is shown in Fig. (9). We still proposed a reference power for hybrid renewable energy system P_{ref} shown in Fig. (10), its total generated power P_{gen} is shown on the same figure. The evolution of the flywheel energy storage system during this operation is shown by the energy transfer sign k_{sign} shown in Fig. (11) (***k*$_{sign}$ = -1:** energy transferred from DC-link voltage to flywheel / ***k*$_{sign}$ = 1:** Energy transferred from flywheel to DC-link voltage), and generated power P_f shown in Fig. (12). The Fig. (13) and Fig. (14) show the diesel generator ON/OFF status k_{stat} and the diesel generator power, the diesel generator is always OFF (k_{stat} = 0) and its generated power P_{di} is null, that because the reference power of hybrid renewable energy system is satisfied by the wind generator and the flywheel energy storage system without the intervention of diesel generator.

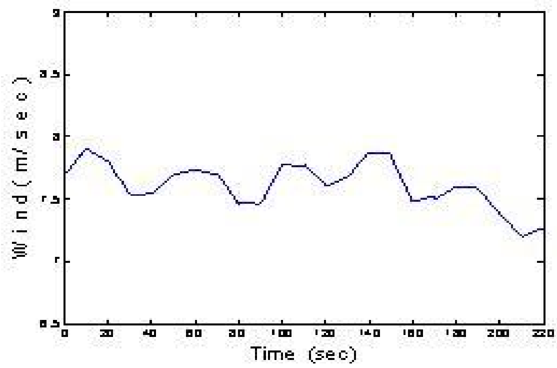

Fig.8 -Wind speed.

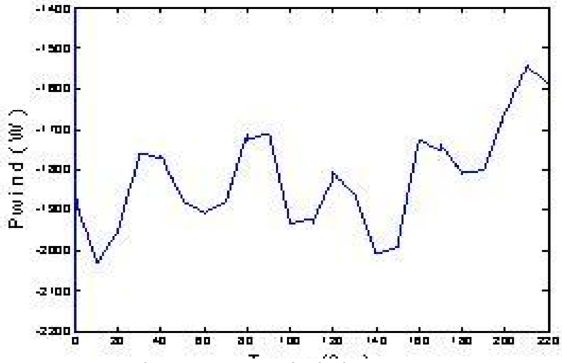

Fig.9 -Generated wind power.

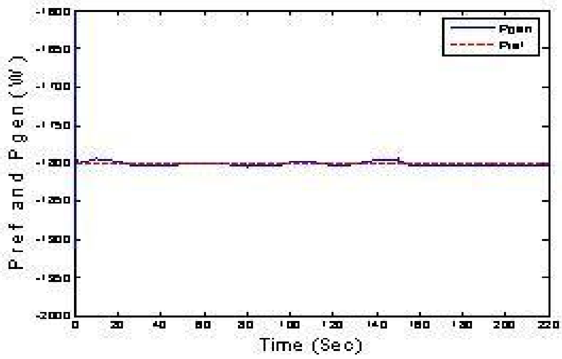

Fig.10 -Reference and generated powers.

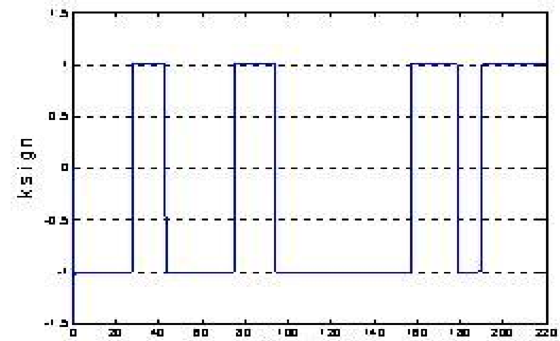

Fig.11 -Energy transfer sign of FESS.

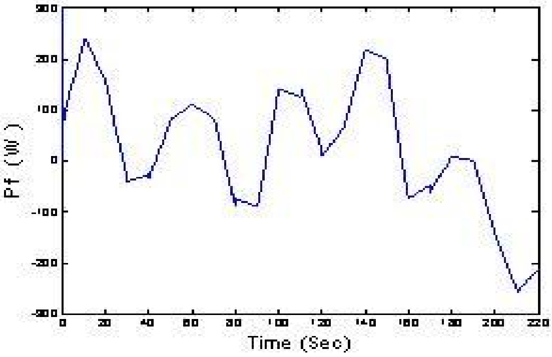

Fig.12 -Power of FESS.

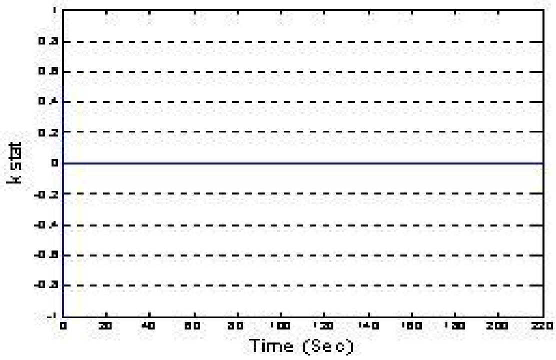

Fig.13 -Diesel generator ON/OFF status.

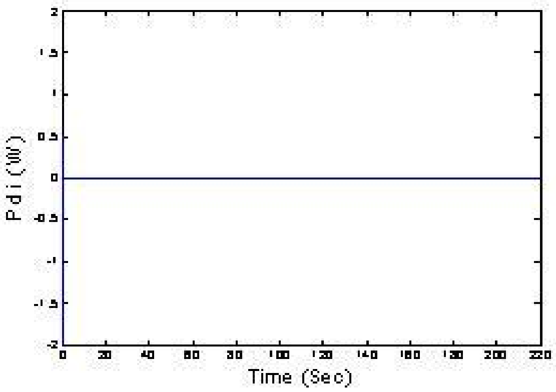

Fig.14 -Diesel generator power.

For the second simulation the reference power is variable (Fig. (15)). The energy transfer sign of flywheel energy storage system k_{sign} (***k_{sign}* = -1:** energy transferred from DC-link voltage to flywheel / ***k_{sign}* = 1:** Energy transferred from flywheel to DC-link voltage / ***k_{sign}* = 0:** No energy transferred between DC-link voltage and flywheel) the diesel generator ON/OFF status k_{stat} (0 for OFF and 1 for ON), and its generated powers are shown respectively in Fig. (16), Fig. (17), Fig. (18), and Fig. (19). Initially diesel generator is deactivate, the reference power of hybrid renewable energy system is satisfied without its intervention, then it is activated to supplement the missed power, at this time wind generator and flywheel energy storage system cannot satisfy the reference power. The starting of the diesel generator is slow what made a delay on the generated power (Fig. (15)).

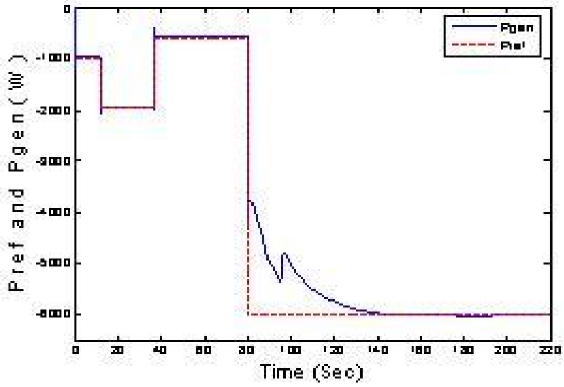

Fig.15 -Reference power and generated power.

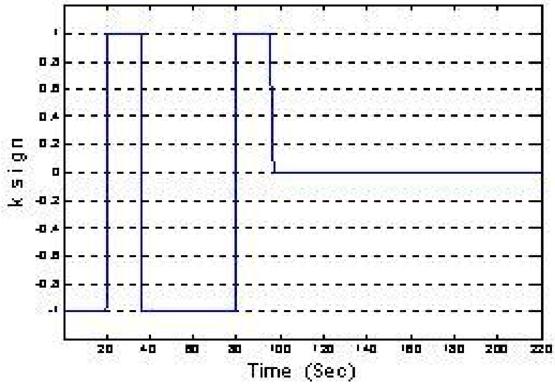

Fig.16 -Energy transfer sign of FESS.

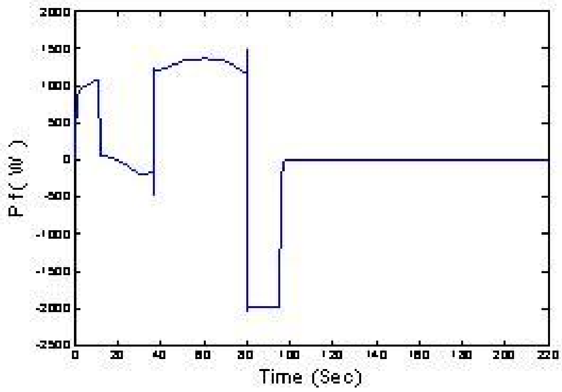

Fig.17 -Power of FESS.

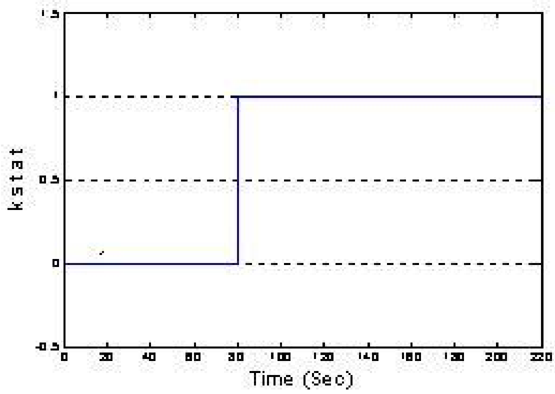

Fig.18 -Diesel generator ON/OFF status.

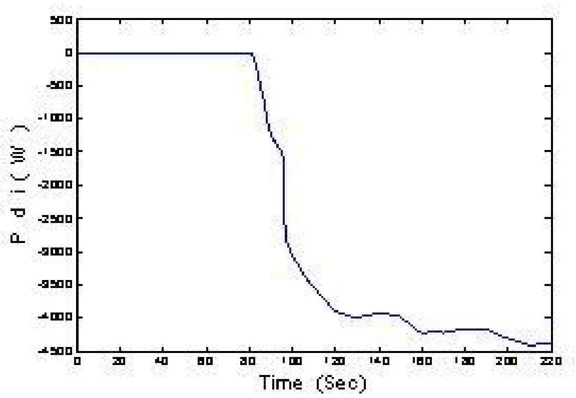

Fig.19 -Diesel generator power.

The negative sign of power represents physically the generated powers.

Conclusion

In this paper, local controls methods are determined for the energy production subsystems which constitute the hybrid renewable energy system proposed and modelled. A supervisor based on artificial neural network model is also developed for system control and to satisfy the power requested by AC grid, to manage the energy transfer between hybrid system and AC grid, to optimize the use of wind energy, and to reduce fuel of diesel generator. Thereafter the laws of control are validated with Matlab simulink software. The simulation Results show the advantages of hybrid renewable energy system and its control as solution for the consumption-production problem allocated to wind generators which are decentralized production sources. This solution improves the wind power quality and increases the penetration of wind generators in the electrical supply networks without causing any risk to disturb their stability.

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Table-1 - Operating modes:

<table>
<tr><th>State of system</th><th>Flywheel Energy Storage System (FESS)</th><th>Diesel Generator (DG)</th></tr>
<tr><td>$P_{ref} < P_{wind}$</td><td>• $X=1$
Energy transfer sign k_{sign} = -1
⇨ Energy storage in flywheel: energy transferred from DC-link voltage to flywheel.
• $X=0$
Energy transfer sign k_{sign} = 0
⇨ No energy transferred between DC-link voltage and flywheel.</td><td>Diesel generator status k_{stat} = 0
⇨ Diesel generator is OFF</td></tr>
<tr><td>$P_{ref} = P_{wind}$</td><td>• $X=1$ or $X=0$
Energy transfer sign k_{sign} = 0
⇨ No energy transferred between DC-link voltage and flywheel.</td><td>Diesel generator status k_{stat} = 0
⇨ Diesel generator is OFF</td></tr>
<tr><td rowspan="2">$P_{ref} > P_{wind}$</td><td>• $X=1$
Energy transfer sign k_{sign} = +1
⇨ Energy transferred from flywheel to DC-link voltage.</td><td>• $P_{ref} < P_{wind}+P_f$
Diesel generator status k_{stat} = 0
⇨ Diesel generator is OFF
• $P_{ref} > P_{wind}+P_f$
Diesel generator status k_{stat} = +1
⇨ Diesel generator is ON</td></tr>
<tr><td>• $X=0$
Energy transfer sign k_{sign} = 0
⇨ No energy transferred between DC-link voltage and flywheel.</td><td>Diesel generator status k_{stat} = +1
⇨ Diesel generator is ON</td></tr>
</table>

Table-2 - Example of training:

INPUTS		**OUTPUTS**	
$P_{ref} - P_{wind}$ (W)	X	k_{sign}	k_{stat}
0	0	0	0
0	1	0	0
-1000	1	-1	0
-1000	0	0	0
1000	1	1	0
1000	0	0	1