# Intelligent management of multi renewable energy sources using fuzzy logic control

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#### Abstract

The renewable resources integration in power system became primordial interest, their integration reduces global warming especially greenhouse gas. The clean energies integration for standalone power systems need a choose of adapted renewable energy according to the weather conditions, each region and also according to the installation cost, generally solar and wind resources are complemented. The intelligent management is necessary for this hybrid system using a modern technical method which is able to manage the power flow to electric load and/or store exceeding of power production in storage dispositive, it need also an adapted architecture in order to get a good power quality and to reduce the global cost of the system, in this context, an intelligent energy management control is necessary, the intelligent supervisory based on fuzzy logic control must manage the system in order to answer several stakes: the energy efficiency of the system for the smooth-running production-consumption and the service continuity and reliability. This work provides a fuzzy logic to control multisource system's according to the weather conditions and to manage the power flow generation. The study was implemented under MATLAB/Simulink and the simulation results with fuzzy logic control are compared with another result with maximum power point tracking based proportional integral derivative controller, the study is applied in Bechar (in the south of Algeria). The results show a very good performance, the power quality produced is better when the system is managed by a fuzzy logic control, this intelligent management control is able to use the energy produced to supply the load and/or to battery charge without a power loss and discontinuity.

Keywords: energy management, fuzzy logic controller, hybrid system, multi-source system, renewable energies, standalone system.

## 1. Introduction

In the future, a renewable energy used to stabilize the climatic change and decrease the global warming, the generation will be emitting any noise and requiring less maintenance when the technology evolutions will reduce the cost of all clean energy generations. The Algerian government try to make sustainable investment by installing many photovoltaic central and wind farm in the south of the country, the aim is to make a lot of isolate village able to produce the electrical energy without need interconnection network. The energy combined providing from wind turbines and solar photovoltaic is intermittent and fluctuated because of the different renewable energy resources nature's, which is reliable with weather changing conditions, the combination between Photovoltaic and Wind energy is very important to provide a power continuity to the load whatever the changing of power demand [1-3]. The necessity of optimizing load and having a power production equivalent to power consumption oblige the national company of electricity (SONALGAZ) to integrate a farm renewable energy in stand-alone system. In the stand-alone system there are an instability of frequency due to the power generation and load at that time a voltage sag caused some faults which makes the management of the system delicate and complicate.

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There are also harmonics created in the renewable energy generation by the use of power electronics devices, in order to create an efficacy intelligent management in the system. Several multisource system architectures are utilized with a relative PMC based on logical states or intelligent algorithm, which is adapted to the standalone applications, at present a different intelligent method like FLC whit good performance. The mathematics model permit to get the modelling of different sources, for the nonlinear system the FLC is simple and adequate to PV with MPPT and frequency regulation generations, the battery output current, and also to control the hybrid system voltage [5]. The MPPT and climatologically variables have a big non-relationship, there are a lot of intelligent control tracking the maximum power in order to have the optimum efficiency, the climatologically variable confuse observation and the performance is limited because it's impossible to using SCC and OCV, in the conventional method the value of proportionality constant depends on the PV panel aging. The model is simulated under MATLAB/Simulink and the architecture is conceived for isolate site in Bechar in the west-south of Algeria, this region has a big solar potential and significant wind sources. This performance confirm that Bechar site is favourable for Wind/PV/battery installations. [2-4].

This present study contains a hybrid system with Wind/Photovoltaic/battery storage managed by an intelligent power management based on FLC. Firstly, there are definition of the global system architecture whereas developing a Multi-source system integrating various sources of renewable energy. Secondly there are a detail of the intelligent power management integrating FLC, according to the weather conditions the multiple operating process are determined, that offer the possibilities of know the power supply of each sources.

#### 1.1. Architecture choice

The architecture system's is configured by a DC bus .The power management control of the hybrid system use FLC to satisfy the load and insure the continuity and the power supply efficiency, this strategy maintain the state of charge battery bank, in this way the life time of battery is extended. "Fig.1" present the global architecture of system [06]. The hybrid system and storage system is created to assure the power supply of a stand-alone site in Bechar. The resources chosen have a complementary characteristics ,wind energy production is very random during the hours of day and photovoltaic production follows variations during the day in the form of a satellite dish and nullifies the night .



Fig.1. Architecture choice of the proposed system





Fig.2. The photovoltaic and wind potential

Bechar have an inexhaustible solar potential, which is characterized by a hot spring, summer and winter total exploitation [5-7]. The ONM give the climatic state, the speed of wind and irradiance all the year round from 1994 to 2010. The average of global annual mediwatt is shown in "Fig.2.a" which is significant all the year. The wind potential is also important referring to the wind speed data unregistered in the weather station of Bechar, the max wind speed is 17 (m/s) but the average speed in the year is 4 (m/s) "Fig.2.b" [5-8].

#### 2. The Modeling of the System

The most important control gives equal power production to power demand in spite under climatic variations.

#### 2.1 Photovoltaic generation of power and current



Fig. 3. Model "a diode" of a photovoltaic cell

The theoretical researches and experimental in the photovoltaic domain are much more considerable, numerous laboratory research focus in: the efficiency materials used in the production. In the photovoltaic power plants the model of equivalent generator to a bus is often recommended "Fig.3" this model is considered as a reliable model for the power flow, photovoltaic generators models represent the nonlinear behaviour which results from the semiconductor junctions. [11-13]

$$I_{pv} = N_{P} \cdot I_{pv_{C}}$$
(1)

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$$V_{pv} = N_{s} V_{pv}$$

$$C$$
(2)

$$Ns = n \cdot n s c$$
(3)

The current and the global voltage of the installation are spelling in "Eq. (1)" and "Eq. (2)"

$$I_{pvc} = I_{PH} - I_{S} \begin{bmatrix} \frac{V_{pvc} + R_{Spv} I_{pvc}}{V_{T}} \\ e \end{bmatrix} - \frac{V_{pvc} + R_{Spv} I_{pvc}}{R_{sh}}$$
(4)

$$I_{PH} = \frac{Ir}{1000} \left[ I_{PH_0} + \frac{\partial I_{pv}}{\partial T_C} (T_c - 25) \right]$$
(5)

diode: 
$$\begin{cases} V_{\rm T} = \frac{T_{\rm c} k_{\rm b}}{\rho} \\ I_{\rm S} = I_{\rm S_0} \left(\frac{273 + T_{\rm C}}{298}\right)^3 e^{-\frac{E_{\rm gap}}{k_{\rm b}} \left(\frac{1}{273 + T_{\rm C}} - \frac{1}{298}\right)} \end{cases}$$
(6)

$$E_{gap} = 1,12 \,(eV)$$
 (7)

$$I_{S_0} = 1,442.10^{-10} \text{ (A)}$$

 $\rm R_{sh}\,$  et  $\,\rm R_{S_{pv}}$  ( constants),  $\rm V_{T}$  and  $\rm I_{S}$  depends on the internal temperature of the cell  $\,\rm T_{C}$ 

$$T_{atm} : T_{C} = T_{atm} + \frac{I_{r}}{800} (N \text{ OCT- } 20)$$
 (9)

NOCT : Approximate datum temperature who does not hold counts of thermal dynamic of cells. It indicates the internal temperature of cell functioning in the following conditions:

$$T_{atm} = 20^{\circ} C \text{ and } I_r = 800 (W/m^2)$$
 (10)

# 2.2 Modeling of wind system

The wind system with variable speed DFAM is entailed by the turbine through a multiplier, its connected to DC bus according to three-phase statics converter based on IGBT, the rotor is provided with systems rings/brooms.[11]

$$\frac{\mathbf{E}_{\mathbf{S}}}{\mathbf{E}_{\mathbf{r}}} = \left(\frac{\mathbf{N}_{\mathbf{S}}}{\mathbf{N}_{\mathbf{r}}}\right) \cdot \frac{\omega_{S} - \Omega_{m} p}{\omega_{S}} = m \cdot \frac{\omega_{S} - \omega_{e}}{\omega_{S}}$$
(11)

$$g = \frac{(\omega_S - \omega_e)}{\omega_S} \tag{12}$$

$$\frac{E_r}{E_S} = g \cdot m \tag{13}$$

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$$\frac{i_r}{i_S} = \frac{1}{m}$$
(14)

$$\frac{\mathbf{S}_{\mathbf{r}}}{\mathbf{S}_{\mathbf{S}}} = \left(\frac{\mathbf{E}_{\mathbf{r}}}{\mathbf{E}_{\mathbf{S}}}\right) \cdot \left(\frac{\mathbf{i}_{\mathbf{r}}}{\mathbf{i}_{\mathbf{S}}}\right) = \mathbf{g}$$
(15)

the model of the wind turbine is: [12-15]

$$\Lambda = \frac{\Omega_{\tau} R}{v_{t}}$$
(16)

$$P_t = C_p(\lambda, \beta). \ \rho \ . \ S\frac{v^3}{2}$$
(17)

Aerodynamic model is detailed in "Eq. (16)" and "Eq. (17)".

$$C_{p}(\lambda,\beta) = (0.35 - 0.00167).(\beta - 2)\sin\left[\frac{\pi(\lambda + 0.1)}{14.34 - 0.3(\beta - 2)}\right] - 0.00184.(\lambda - 3)(\beta - 2)$$
(18)

Cp Depends on the characteristic of the turbine and represents the aerodynamic efficiency in the wind turbine:

$$C_{t} = \frac{P_{t}}{W_{t}} = \frac{C_{p}(l, b) \cdot v^{2} \cdot r \cdot \mathbf{R}^{3} \cdot p}{2l}$$
(19)

The mechanical couple C<sub>t</sub> available on the slow shaft of the turbine is detailed in "Eq. (19)"

$$C_m = \frac{C_t}{G} \tag{20}$$

$$\Omega m = \Omega_t.G$$
(21)

The multiplier adapts the turbine rotation speed on DFAM rotation speed "Eq. (20)" .

$$J_m + J_t / G^2 (d\Omega m / dt) + f_v^* \Omega m = C_m - C_{em}$$
 (22)

The dynamics mechanical system on the DFAM mechanical shaft is spelt in "Eq. (22)". [15]

2.3 Modeling of battery Li-Ion



Fig. 4. Modelling simplified of battery Li-ion Bnch

"Fig. 4" present the battery bench electrical schema. The battery efficiency is surrounding of 85 %, its characterized by the low auto-discharge. The battery bench is directly connected to the DC bus.

$$SoC = SoC_0 - \int_0^t \frac{I_B}{C_{batt}} dt$$
(23)

State of charge SoC<sub>batt</sub>, is not taken into account in the previous equations, it is given for  $t_0$  by the equation "Eq.(23)". The variations caused by states of charge is unimportant in front of the metrological variations and the consumption.

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$$\frac{V_{C_{DL}}}{V_{DC}} = \frac{1}{1 + j\omega_e C_{DL} r_{HF}}$$
(24)

We have one hypothesis saying that battery is not at the end of charge or discharge with a modelling which uses the elements  $V_B$  and  $R_b$  of the previous equivalent "Fig.4". The modeling is obtained by the function of transfer between  $V_{DC}$  and  $V_B$  in "Eq. (24)" [15-16].

## 2.4 Modeling of converter DC/DC Buck-Boost

The modeling include 02 part:

$$0 < t \le uT$$

$$V_{K}$$

$$V_{K}$$

$$V_{L}$$

Fig.5. Plan of a closed Switch and open Switch

Diode is switched off and the transistor is in the state ON. The current of load is assured by the condenser of exit and the inductance L stores the energy "Fig.5.a"

$$L\frac{di}{dt} = E$$
(26)

$$C\frac{dU_C}{dt} = I_L - \frac{U_C}{R}$$
(27)

The resultant equation of state spells in "Eq. (26)" and "Eq. (27)".

$$uT \le t \le T \tag{28}$$

The diode is switched on and the transistor is blocked. The voltage in the borders of the inductance changes polarity and the inductance supply the load "Fig.5.b".[16-17].

$$\begin{cases} L \frac{d_{11}}{dt} = U_{c} \\ c \frac{dU_{c}}{dt} = I_{L} - \frac{U_{C}}{R} \end{cases}$$

$$\begin{cases} \dot{X}_{1} = (1 - u) \frac{1}{L} X_{2} + u \frac{E}{L} \\ \dot{X}_{2} = -(1 - u) \frac{1}{C} X_{1} - \frac{1}{RC} X_{2} \end{cases}$$
(30)

$$X_1 = i_L \quad X_2 = U_c \tag{31}$$

The resultant equation of state spells in "Eq. (29)" and "Eq. (30)" and "Eq. (31)".

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## 3. Management Strategy Using FLC

The management strategy objective is to supply the load necessity at every moment under variable conditions weather and to protecting the system in perfect conditions, the control strategy consists to managed the power flow production or stored energy power exceeding in battery [18-23] Table 1. Table of Roles

E / De	NL	NM	NS	Z	PS	PM	PL
NI	DI	DI	DI	DI	7	7	7
NL	PL	PL	PL	PL	L	Z	L
NM	PL	PL	PL	PM	PS	Z	Z
NS	PL	PM	PS	PS	PS	Z	Z
Z	PL	PM	PS	Z	NS	NM	NL
PS	Z	Z	NM	NS	NS	NM	NL
PM	Z	Z	NS	NM	NL	NL	NL
PL	Z	Z	NM	NL	NL	NL	NL

"Table1." shows the fuzzy controller rules.

Negative Medium (NM), Negative Small (NS), Zero (Z), Positive Small (PS), Positive Medium (PM), Negative Large (NL), Positive Large (PL).

The energy power stored in the battery is spells:  $P_{bat} = P_S + P_W - P_D$  (32)

 $P_{\rm bat} > 0$  : When the battery is charged,  $\,P_{\rm bat} < 0$  : When the battery is discharged.

Static dc-dc converter allows to regularize the battery voltage and to limit the current to a maximal value which is determined in the cycles charge-discharge [21-25]. The difference between the battery voltage and the reference voltage in load phase serve to produce the reference current of battery.



Fig.6 · Current memberschip fonction (e,de,du).

The controller contains 02 input (e and de) and 01 output gate control du, the current memberschip fonction are defined in "Fig.6". The relationship between input and output can be understandable clearly using surface waveform." Fig.6" which shows the surface waveform of proposed FLC.

Table 2 Parameters of subsystem

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Battery bank	Values
Capacity	6.5 (Ah)
Rated voltage	300 (v)
Min acceptable voltage lever (V <sub>min</sub> )	
Max acceptable voltage lever $(V_{max})$	200 (v)
	353 (v)
DC Bus	Values
Voltage	666 (v)
Minimum power	5 (w)
Maximum power	20 (kw)
*	

"Table 2." shows the parameters of each subsystem.

#### 4. Simulation Result and Discussion

The MPPT Algorithm of control is conceived using PID, after that the same system is controlled with FLC than we compare the global power flow of each cases. The wind turbine speed is taken as an interval [5 12 9] (m/s), the solar irradiance is taken as an interval [1000 850] (w/m<sup>2</sup>). The output voltage of wind turbine and PV panel is biphasic, the wind turbine deliver AC/DC voltage using rectifier and the output voltage of PV panels is DC/DC voltage using buck boost. We simulate for a period of 6 (s) under MATLAB/ Simlulink, every measure of the multisource system is shown in the appropriate unit value.



Fig.7 Speed of wind and Wind turbine power.



Fig.8 Wind turbine voltage and Wind turbine current.

The figures "Fig.7.a" and "Fig.7.b" and "Fig.8.a" and "Fig.8.b" show the wind (speed, power, voltage, current) respectively for an interval of time included between t=0 and t=6 (s). Between t=0 and t=0.5 (s) there isn't a significant wind speed so the values of power, voltage and current is appropriate to 0,

between moment t=0.5 and t=3 (s) an increase of wind speed from 5 to 12 (m/s) / 10 to 150 (rd/s) "Fig.7.a" it allow wind turbine to increase the produced power to 6 (kw) "Fig.7.b" with an equivalent current equal to 14 (A) "Fig.8.b" and an equivalent voltage equal to 450 (v) "Fig.8.a" between the moment t=3 and t=6 (s) the amplitude decreased to 9 (m/s) / 110 (rd/s) "Fig.7.a" which decrease the power produced by the wind turbine to 2.5 (kw) "Fig.7.b" with an equivalent current equal to 7 (A) "Fig.8.b" and an equivalent voltage equal to 370 (v) "Fig.8.a".

The figures "Fig.9" and "Fig.10" show the solar (irradiance, power, voltage, current) respectively for an interval of time included between t=0 (s) and t=6 (s). Between t=0 (s) and t=2 (s) the solar irradiance was equal to 1000 (w/m<sup>2</sup>) "Fig.9.a" which allows the photovoltaic generator to produce 9.5 (kw) of power "Fig.9.b" with a current equal to 14.9 (A) "Fig.10.b"



Fig.9. Solar irradiance and solar power.



Fig.10. Solar voltage and solar current.

The reduction in the solar irradiance to a value equal to 850 (w/m<sup>2</sup>) between t=2 and t=6 (s) "Fig.9.a" involved a reduction in the produced power to 8.05 (kw) "Fig.9.b" with a current equal to 12.5 (A) "Fig.10.b" whereas the voltage was constant throughout all the interval of time with a constant amplitude equal to 640 (v) "Fig.10.a".



Fig. 11. State of charge ,Voltage of battery and Battery current.

The figures "Fig.11" show the battery (SOC, voltage, current) respectively for an interval of time included between t=0 (s) and t=6 (s), for the same interval the state of charge passes from 58.6 % to 59.1 % "Fig.11.a" so a charge of 0.083 % for every second what is equivalent to 1204.81 (s) or 20 (min) for a complete charge 100 %. Between t=0 and t=2 (s) the current is variable from 5 to 25 (A) "Fig.11.c" and the battery is charging with a variable voltage included from 328 to 345 (v) "Fig.11.b". Between t=2 and t=5 (s) the current is variable from 7 to 25 (A) "Fig.11.c" and the battery is discharging , the voltage is variable from 335 to 330 (v) "Fig.11.b".Between t=5 and t=6 (s) the current is equal to 5 (A) "Fig.11.c" and the battery is charging and the voltage is equal to 335 (v) "Fig.11.b".



Fig.12. Voltage and current of the hybrid source.

The figures "Fig.12.a" show the voltage and current of the hybrid source respectively for an interval of time included between t=0 (s) and t=6 (s), throughout the interval of time, the hybrid source current is valuated to 6 (A) for "Fig.12.b" with an equivalent voltage equal to 640 (v) "Fig.12.a".



Fig.13. Three-phase current load side and current load side with zoom.

The figures "Fig.13" shows three-phase voltage load side without zoom and with zoom respectively, the zoom is established between t=3.8 and t=4.2 (s) "Fig.13.b" between t=4 and t=5 (s) the current pass from 16 to 22 (A) after an increase of load power demand from 10 to 14 (kW) "Fig.15". Between t=5 and t=6 (s) the current pass from 22 to 16 (A) after a decrease of power demand at the level of load from 14 to 10 (kW) "Fig.15", The three-phase load voltage side is equal to 240 (v).



Fig.14. Power of load, battery, wind turbine and solar using PID.

The figure "Fig.14" shows firstly the power at level of PV, wind turbine, battery and secondly the load power using the technique MPPT controller based PID for an interval of time between t=0 and t=6 (s). Between t=0 and t=4 (s) only PV produce 10 (kw) of power and supply the load without using FLC, the wind turbine does not work whereas the battery is not charging ,the power values at level of wind turbine and battery are equal to 0 (kw). Between t=4 and t=5 (s) the value of wind turbine power increase from 10 to 25 (kw) after an increase of power load demand from 10 to 24 (kW) so there is 1 (kw) exceed production, the PV generation is stoped, the battery isn't charging with the production exceed because of the manual power flow orientation ,the value is equal to 0 (kw). Between t=5 and t=6 (s) the wind turbine power decrease from 25 to 11 (kw) after a decrease in power load demand from to 24 to 10 (kw) so there is 1 (kw) exceed production , the PV generator does not work whereas the battery is not charging by the production exceed because of the manual power flow orientation , the PV generator does not work whereas the battery is not charging by the production exceed because of the manual power flow orientation, the PV generator does not work whereas the battery is not charging by the production exceed because of the manual power flow orientation , the PV generator does not work whereas the battery is not charging by the production exceed because of the manual power flow orientation, the power values at level of PV and battery are equal to 0 (kw).



Fig.15. Power of load, battery, wind turbine and solar using FLC

The figure "Fig.15" shows firstly the power at the level of the PV, wind turbine and the battery and secondly the power load with FLC for an interval of time between t=0 to t=6 (s), the graph defuses that the sum of the powers of the hybrid system (PV, wind turbine and battery) at every subinterval is equal to the power load as follows:  $P_{load}=P_b+P_{wind}+P_{PV}$ . All values are detailed in the "Tab 3." with the adequeted interval . It confirms the continuity criterion of service without deficit nor break even in the interval of time between t=4 and t=5 (s) presenting an increase of the load power .

Time (s) / Hybrid system	PV (Kw)	Wind turbine (Kw)	Battery (Kw)	Load (Kw)	
0-1	10	0	-4.5	5.5	
1-2	10	5.5	-10	5.5	
2-3	08	5.5	-08	5.5	
3-4	08	02	-4.5	5.5	
4-5	08	02	-3.3	6.7	
5-6	08	02	-4.5	5.5	

Table 3. Power values of Load, Battery, Wind turbine and Solar with fuzzy logic for each interval.

The management intelligent using FLC allow to charge battery automatically by hybrid sources and to discharge it when one/all of sources deliver a non significant power or one/all of power sources are not available. The regulation performance using FLC is better than the technique MPPT controller based PID in term of managing power flow, setting time ,speed and reliability.

#### 5. Conclusion

This study provides a fuzzy logic to control a stand-alone hybrid system (PV/Wind/Batteries) according to the weather conditions and to manage the power flow generation, the combination between photovoltaic and wind energy is very important to provide a power continuity to the load whatever the

changing of power demand, the study is applied in Bechar (in the south of Algeria). The simulation results confirm that the power management control of the studied multi-sources system's based on fuzzy logic controller show a very good performance, the power management control allow to manage the power flow and to supply the load continuously at any time with efficiency and reliability without power loss, also the power management control is able to operate the system under a different weather conditions which offer stabilities for the overall system.

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# **Conflict of Interest**

The authors declare no conflict of interest.

## **Author Contributions**

R.H. designed and modeled the system, conducted research, analyzed the data and wrote the paper, provided the data.

B.A. Supervised the research, analyzed the data, and revise the final paper.

All authors had approved the final version.

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# Appendix

### A. Nomenclature

 $V_{pv}$ ,  $I_{pv}$ : The voltage's cell and the current's cell respectively

 $V_{pvc}$ ,  $I_{pvc}$ : Voltage in the borders of the solar cell and the current in the borders of the solar cell.

 $N_p$ ,  $N_s$ ; Number of parallel benches in a photovoltaic generator, number of solar panels rose in series.

 $n_c$ ,  $R_{sh}$ : Numbers of cells rose in series in the solar panel, the resistance shunt respectively.

I<sub>PH</sub>, I<sub>PH0</sub>: The current of diode and the constant close to the value of short circuit Icc of solar panels

T<sub>C</sub>, V<sub>T</sub> ;The internal temperature of cell ,the internal characteristics of the equivalent diode.

Is, k<sub>b</sub>: The internal current of the equivalent diode ,the constant of Boltzmann respectively.

q, m : The elementary electrical charge, the report of transformation rotor/stator respectively.

Nr ,Ns: The turns number of the windings rhetoric, the turns number of the windings statoric.

Es, Er: Static flow and rhetoric flow respectively.

R, p: Beam of the wind generator or the length of a blade, the number of pairs of poles respectively.

P<sub>t</sub>:A mechanical power of the turbine respectively.

S,g :The circular surface swept by the turbine, the DFAM Sliding respectively

Cp, Ct: Power coefficient, the mechanical couple of the turbine respectively.

Cem, Cm: The PWM electromagnetic couple, the mechanical couple on the shaft respectively .

 $J_t$ ,  $\Omega m$ : The inertia moment of the turbine, the rotational speed respectively.

fv ,J<sub>m</sub>: The coefficient due to the viscous frictions ,the inertia moment respectively.

C<sub>batt</sub>, S<sub>0</sub>C: The battery capacity, SOC respectively.

IB, G : Current generated by battery, gain of the multiplier respectively.

V<sub>DC</sub>, C<sub>DL</sub> Voltage of continue bus , capacity of an element of battery respectively.

P<sub>D</sub>, P<sub>W</sub>, P<sub>S</sub> Power demand, power wind, power solar respectively.

# B. Greek letters

 $\omega_{g}, \omega_{e}$ : Statoric and electric pulsations of the PWM.

 $\rho$ ,  $\beta$ : The density of the air equal to 1,225 (kg / m<sup>3</sup>), Angle of alignment of the bled respectively.

v,  $\lambda$ :Wind speed and relative speed respectively.

 $\Omega_{-}$ : The rotation speed of the turbine.

## C. Abbreviations

Power Management Control	(PMC), Artificial Neural Network	(ANN)
Fuzzy Logic Controller	(FLC) ,Maximum Power Point Tracking	(MPPT)
Photovoltaic	(PV) ,National Meteorological Office	(ONM)
Pulse Widith Modulation	(PWM) ,Double-fed Asynchronous Machine	(DFAM)
Center Of Gravity	(COG) ,State Of Charge	(SOC)
Maximum	(Max) ,Minimum	(Min)

Short Circuit Current	(SCC)	,Open Circuit Voltage	(OCV)
Irradiance	(G)	,Proportional Integral Derivative	(PID)
Temperature	(T)	,National company of electricity and gas	(SONALGAZ)
Alternative Current	(AC)	,Insulated-Gate Bipolar Transistor	(IGBT)
Direct current	(DC)	,Membership Functions	(MFs)

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