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Control a Photovoltaic/Wind Turbine/Diesel generator with storage battery

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Abstract. Wind/Photovoltaic energy systems are among the most used configurations in multi-sources energy systems because their reliability, robustness and power sources complementarily. For heavy loads, it is more convenient to add backup systems (diesel generator) for an enhanced power availability. In order to protect power sources and increase their lifespan, several power management strategies are such as fuzzy logic control, artificial neural networks and metaheuristic algorithms are proposed and used in literature. This paper presents a power supervisory control (PMC) based on fuzzy logic control dedicated for photovoltaic/wind turbine/ diesel generator/battery systems. The application of the aforementioned technique makes it possible to predict how the hybrid system various operating processes would change in response to solar irradiation and wind speed variations. The study was implemented under Matlab/Simulink. To obtain more realistic results, measured weather values have been incorporated in the simulation. The application is made in a coastal town which has a good potential values of solar irradiance and wind speeds. The obtained results show that the load have been supplied while the batteries were protected due to the PMC.

Key words. Fuzzy logic control, Photovoltaic panels, Wind turbine, Diesel generator, Batteries, Power management control

1. Introduction

Renewable energy systems are considered an attractive option for electric power generation, especially solar and wind power, due to the various benefits they provide [1-5]. However, the fluctuation of the resources restricts their utilization, and demand changes are typically unrelated to the available energy sources. Using various sources and combining them, like in hybrid wind-photovoltaic systems with storage, is the greatest approach to get over this restriction, especially for remote sites. A PV-wind hybrid system must be upgraded with battery storage and/or a diesel generator for greater performance in stand-alone or off-grid operation. The maximum load power is obtained using Maximum power point tracking (MPPT) algorithms when the wind or solar irradiation changes. A variety of these technologies are used to this. They each behave differently despite working toward the same goal of increasing power. Power supervision control (PMC) is used to control the various powers. These techniques depend on the kind of energy system and its constituent parts. In particular, its power exchange, this regulates the DC-bus voltage [6], [7]. Additionally, it works to coordinate the various sources (PV, wind) which make the power or energy generated controllable.

In this work, a hybrid power system which comprises wind turbine, photovoltaic panels, diesel generator an battery storage, is presented. Compared to traditional approaches based on logical states, this system is simple and enables us to manage the various sources quickly and easily. The proposed PMC's initial goal is to supply the load power requirement, and the second goal is to keep the battery charged in order to avoid blackouts and prolong battery life. The different results are displayed and show that the suggested strategy is feasible.

2. Studied System

Our study focuses on a hybrid energy system that combined wind and solar energy, a diesel backup generator, and batteries (Fig.1).

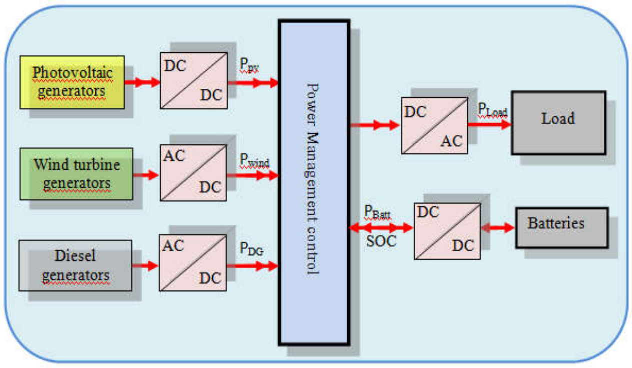


Fig.1. Proposed system

A. Photovoltaic Model

There are a number of mathematical models for PV generator modeling that explain how the solar generator operates. In our work, the following model has been used (Fig.2). The used panels are about 80 Wp and the electrical current of single diode model is [6, 13, 14].

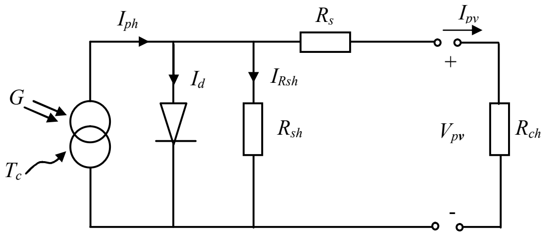


Fig.2. PV one diode model

$$I_{pv} = I_{ph} - I_d - I_{Rsh} \tag{1}$$

$$I_{pv} = I_{ph} - I_0 \times \left[exp\left(\frac{q \times (V_{pv} + R_s \times I_{pv})}{A \times N_s \times K \times T_j} \right) - 1 \right] - \frac{V_{pv} + R_s \times I_{pv}}{R_{sh}} \tag{2}$$

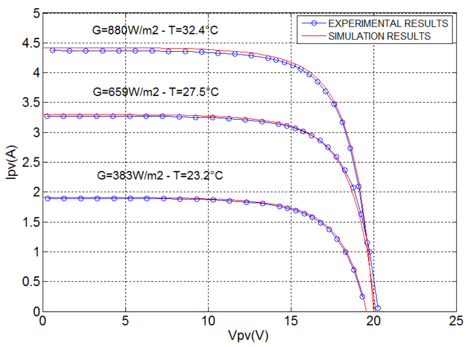
With:I_{ph} the photo-current, I_d the diode-current and I_{Rsh} the shunt resistance R_{sh}.

Using the test bench illustrated in Fig.3, the electrical characteristics of PV have been established (Fig. 4) using PV panel's parameters listed in table1.

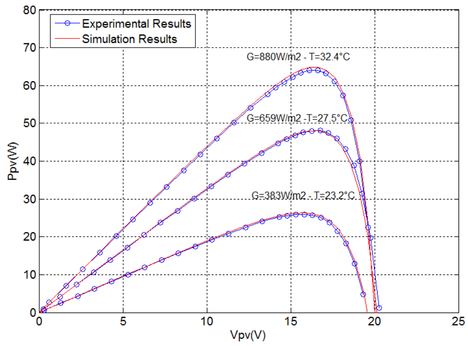
TABLE I. PARAMETERS OF THE PHOTOVOLTAI PANEL 80 WP

Parameters	Values
photovoltaic power P_{pv}	80 W_p
maximum current at PPM I_{mpp}	4.65 A
maximum voltage at PPM V_{mpp}	17.5V
short circuit current I_{sc}	4.95A
open circuit voltage V_{oc}	21.9V
temperature coefficient of short-current α_{sc}	3 mA/°C
voltage temperature coefficient of short-current B_{oc}	-150mV/°C

Fig.3.Test bench to determinate the electrical caracteristics



(a) $I_{pv}(V_{pv})$



(b)$P_{pv}(V_{pv})$

Fig.4. Simulation and experimental curves

B. Wind turbine model:

It consists of a wind turbine and a diode bridge rectifier connected to a permanent magnet synchronous generator. The following equations give the wind turbine output power and torque [15]:

$$P_{wind} = \frac{1}{2} C_p(\lambda).\rho.\pi.R^2.V_{wind}^3 \tag{3}$$

$$T_{wind} = T_{mec} = \frac{1}{2} \frac{C_p(\lambda).\rho.\pi.R^3.V_{wind}^2}{\lambda} \tag{4}$$

The power coefficient C_p is given as:

$$C_p = \frac{2.P_{wind}}{\lambda..\pi.R^2.V_{wind}^3} \tag{5}$$

Where: λ is the tip speed ratio, V_{wind} is the wind speed (m/s), R is the rotor's radius (in meters), and ρ is the air density.

The PMSM equations are given as [16]:

$$\begin{aligned} V_{ds} &= R_{st} I_{ds} + L_{ds} \frac{dI_{ds}}{dt} - p\omega L_{qs} I_{qs} \\ V_{qs} &= R_{st} I_{qs} + L_{qs} \frac{dI_{qs}}{dt} + p\omega L_{ds} I_{ds} + p\omega\phi_f \end{aligned} \tag{6}$$

In this equation, p denotes the pole pairs number R_{st} symbolizes the stator windings resistance, L_{ds}, L_{qs} denote inductances along the direct and quadrate axes, I_{ds}, I_{qs} represent (d-q) stator currents, V_{ds}, V_{qs} represent (d-q) stator voltages, and Φ_f denotes the magnetic flux produced by the permanent magnet and voltage pulse rate (rad/s) is represented by the symbol ω=$p\Omega$.

The electromagnetic torque is written as:

$$T_{em} = \frac{3}{2} P\left[(L_{ds} - L_{qs}) I_{ds}.I_{qs} + \phi_f.I_{qs}\right] \tag{7}$$

C. Battery storage modeling:

This chosen model is shown in Fig.4. [12-14]:

$$V_{Batt} = n_{Batt}.E_{Batt} \pm n_{Batt}.R_{Batt}.I_{Batt} \tag{8}$$

Where: n_{Batt} series cells, V_{Batt} is the battery voltage, E_{Batt} is the open circuit voltage, R_{Batt} the internal battery resistance and. I_{Batt} is the battery current.

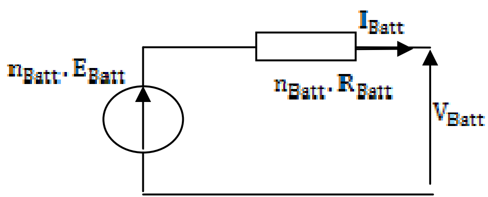


Fig.4. Equivalent battery electrical circuit

3. Proposed Power management based on Fuzzy logic control

The stand-alone hybrid energy system's management approach aims to fulfill load demand in a variety of weather situations and control power flow while assuring the effective operation of the various energy systems. To meet the load requirement, the management approach should primarily use the power produced by the PV and wind systems. The operating approach is based on managing long-term storage. It is used to supply the load for a longer duration. By using this method, the diesel generator's start/stop cycles are reduce, which decreases fuel consumption while improving the energy balance. With this approach, the DG is turned off until the battery storage's state of charge reaches a minimal value. Once it is reached, the GD is restarted and kept running until the battery storage's state of charge reaches its maximum, and the cycle is repeated once again and so on. To supervise this system, we must control the four inputs: the solar radiation E_s, the wind speed $V_{wind,}$ the battery state of charge (SOC) and the diesel generator. The power balance can be written as:

$$P_{load}=P_{Hyb}+P_{wind}+P_{DG}\pm P_{batt} \tag{9}$$

In our work, it is proposed a power management using FLC to control an hybrid wind/PV/DG/batteries system (Fig.6).The fuzzy logic controller's basic operation is to produce the three control signals K_{pv}, K_{wind}, and K_{DG} from three inputs: solar irradiation E_s, wind speed Vwind, and battery state of charge SOC (Fig.5). The fuzzy inference in our application was created using the Mamdani approach, and the fuzzy logic outputs were defuzzified using the center of gravity method [10].

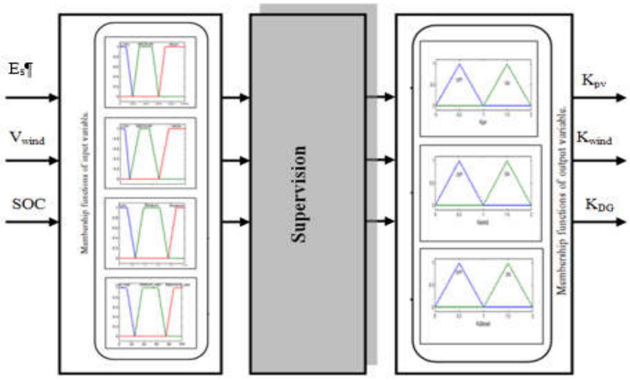


Fig.5. Supervision of hybrid Photovoltaic/Wind/Diesel Energy System.

The solar irradiance (Es), wind speed (Vwind), and battery charge state (SOC) are the fuzzy regulator's three inputs. Table2 provides explanations of the various input and output variables.

Table.2.
Inputs and output variables used in the power supervision

Inputs variables		Output variables	
E_s (W/m²)	Solar irradiation	K_{pv}	control signal of photovoltaic generators
V_{wind} (m/s)	Wind speed	K_{wind}	wind turbine control signal
SOC (%)	State of charge	K_{DG}	diesel generators control signal

Each input of the fuzzy regulator is connected to the linguistic variables that present the fuzzy sets (table3).

Table.3.
Fuzzy inference of fuzzy controller inputs/outputs

SOC	*G*	V_{wind}	K_{pv}	K_{wind}	K_{DG}
LOW	LOW	LOW	OFF	ON	OFF
	LOW	MED	OFF	OFF	OFF
	LOW	MAX	OFF	ON	OFF
	MED	LOW	OFF	ON	OFF
	MED	MED	OFF	OFF	OFF
	MED	MAX	OFF	ON	OFF
	MAX	LOW	OFF	ON	OFF
	MAX	MED	OFF	OFF	OFF
	MAX	MAX	OFF	ON	OFF
	LOW	LOW	LOW	LOW	LOW
MED and SUP	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
	LOW	LOW	LOW	LOW	LOW
MAX	$\forall$ *G*	$\forall V_{wind}$	ON	ON	ON

Where:

Es (W/m²)	0-200	200-600	600-100	
	LOW	MED	MAX	
V_{wind} (m/s)	0-3	3-12	12-20	
	LOW	MED	MAX	
SOC (%)	0-25	25-75	75-99	100
	LOW	MED	SUP	MAX

Eight different modes can be obtained as seen in Table4.

Table4.
The different operating mode

Modes	Sources	P_{Load}	K_{pv}	K_w	K_{DG}
Mode1	PV+WTb +DG	P_{load}=P_{pv}+P_{wind}+P_{DG}-P_{batt}	1	1	1
Mode2	PV+WTb	P_{load} =P_{pv}+P_{wind} -P_{batt}	1	1	0
Mode3	PV	P_{load} = P_{pv}-P_{batt}	1	0	0
Mode4	PV+ WTb	P_{load} =P_{pv}+P_{DG}-P_{batt}	1	0	1
Mode5	WTb	P_{load} = P_{vent} -P_{batt}	0	1	0
Mode6	WTb+DG	P_{load} =P_{wind}+P_{DG}-P_{batt}	0	1	1
Mode7	DG	P_{load} = P_{DG}	0	0	1
Mode8	Batteries	P_{load} = -P_{batt} or P_{load} =0	0	0	0

4. Application under Mathlab/Simulink

MATLAB program was used to simulate the studied system. The hybrid system's various components are sized as follows (Table 4.)

Table4.
Sizing components

Components	Powers	Total
Photovoltaic generator	05 panels in parallel. (80 W_p)	400 Wp
Wind generator: turbine	900 W, R=1.05m	900 W

Diesel Generator:	2 kVA	2 kVA
Battery bank	02 batteries of 192 Ah-12V	384 Ah

The objective of the applied controls is to control the voltages of the renewable energy sources in such a way that they will be equal to the DC bus voltage, whatever the variations of the solar irradiance and the wind speeds, and to extract the maximum power from the renewable sources (Fig.7)

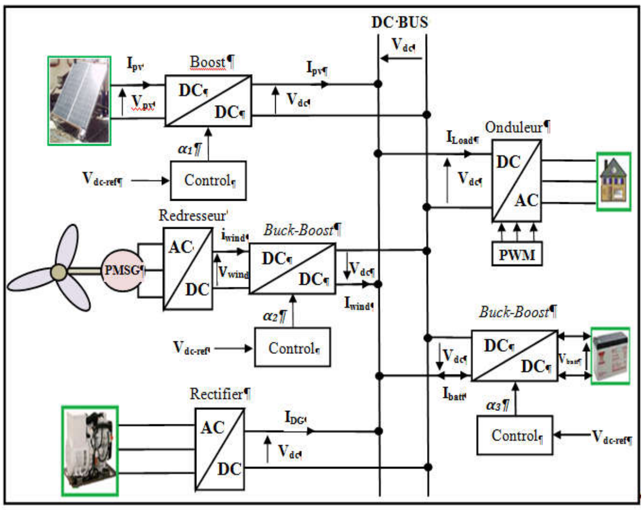


Fig.7 Proposed control scheme

We have introduced the profiles of solar irradiation (Fig.8), temperature (Fig.9), wind speed (Fig.10) and load (Fig.11) of different days. Battery voltage and battery state of charge are shown respectively in Fig.12 and 13 while control signals the three sources K_{PV}, K_{wind} and K_{die} generated by the IEM with FLC are given in Figs.14-16 . The DC voltage is well controlled whatever solar irradiation and wind speed variations (Fig.17). Figures 18-21 show the power waveforms of the different sources. From these results we can observe that the proposed IEM satisfy the load power demand whatever the meteorological conditions and maintain the battery charge state to prevent blackout and extend battery lifetime.

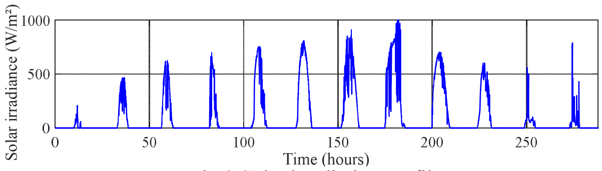


Fig.8.Solar irradiation profile

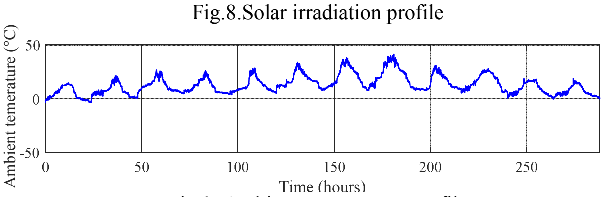


Fig.9. Ambient temperature profile

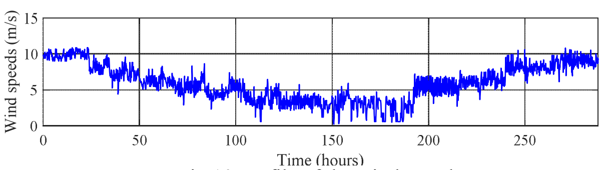


Fig.10.Profile of the wind speed

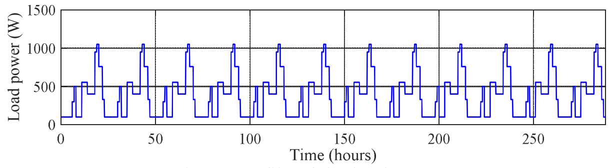


Fig.11.Profile of the load power

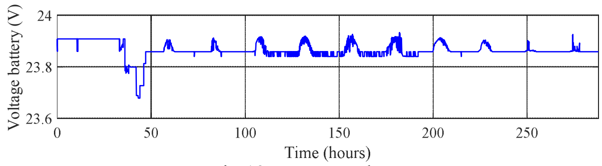


Fig.12. Battery voltage

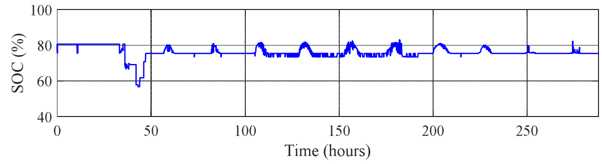


Fig.13. Battery state of charge

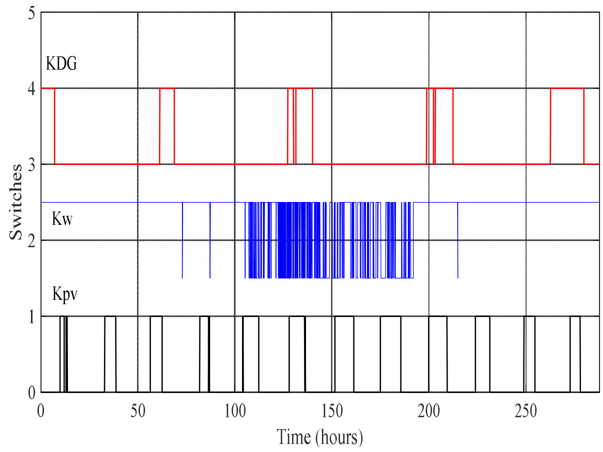


Fig.14.Control signals of PV generators, wind turbine and .diesel generator

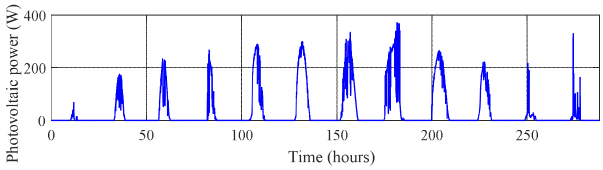


Fig.15. Photovoltaic power.

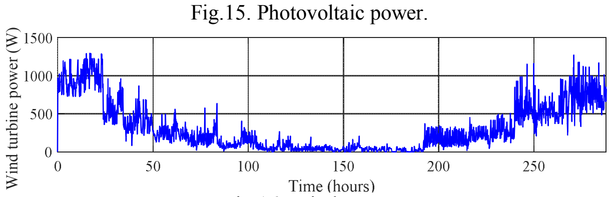


Fig.16. Wind power

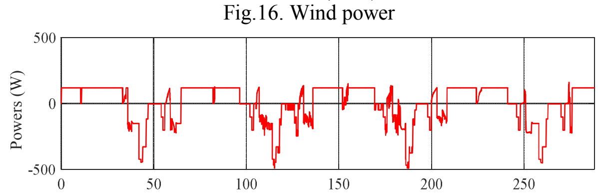


Fig. 17.Battery power.

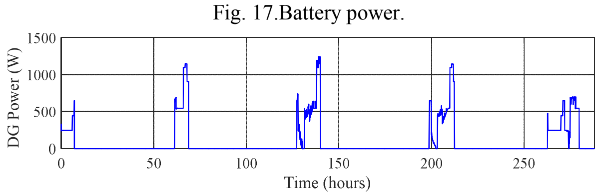


Fig.18. Diesel generator power

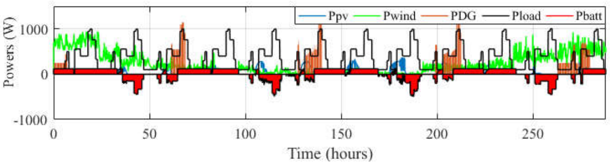


Fig.19.Power waveforms during two diffrent days

From the simulation results obtained in Fig. 19, It can be seen that during these two days, the renewable energy sources were exploited to the maximum, of course, depending on their availability, in order to use at least the diesel generator.

4. Conclusion

In this study, a hybrid energy system involving Wind/Photovoltaic/Diesel generator with batteries is studied. Power flow between the different used energy sources is ensured using a designed fuzzy logic controller. The proposed intelligent power management control strategy succeded to ensure power availability and the load demand was permanently satisfied. Simulation results demonstrate the effectiveness of the developed smart energy management strategy. As a further work, it is intended to study the feasibility and integration the proposed hybrid energy system is several sectors such as water pumping in irrigation systems.

Acknowledgement

In this section financial or other support can be acknowledged. Please, don't number neither this section, nor the following references section.

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