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Performance evaluation of hybrid Photovoltaic-Wind power systems

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Abstract

This paper presents experimental results from the operation of a test bench constituted of a PV-Wind hybrid system. This device includes photovoltaic (PV) and wind subsystems, battery energy storage, load and a hybrid system, controller for battery charging and discharging condition. The system includes a 600W PV array, 1KW wind turbine; in the day the energy produced is stored in a battery bank 24V/1600Ah and used for public lighting at night, with an average daily energy consumption of 2640 Wh. The experimental set up has been realized in the Research Unit in Renewable Energies in Saharan Medium, Adrar (South of Algeria). The photovoltaic panel group constitutes the primary energy supplier of the system; while the wind turbine is the secondary supplier since the contribution of wind turbine is small as compared to the share of the photovoltaic subsystem.

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Keywords: Hybrid energy system; phtovoltqiaue; wind; battery energy storage; electricty generation; load profile.

1. Introduction

Today, Algeria's energy needs are fulfilled exclusively thorough hydrocarbons exploitation, mainly natural gas. The level of natural gas volumes, produced of the domestic market would be 45 billions m^3 in 2020 and 55 billions m^3 in 2030. Other volumes of natural gas are intended for export to finance national economy. Electricity

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consumption is expected to reach 75 to 80 TWh in 2020 and 130 to 150 TWh in 2030 [1,2].

All these considerations justify the strong integration, right today, of renewable energies in the strategy of long-term energy offer. The strategic choice is motivated by the huge potential in solar energy. This energy is the major focus of the programme of which solar power and photovoltaic systems constitute an essential part. It is expected that in 2030, solar should cover more than 37% of national electricity production [1,2].

Despite its relatively low potential, wind energy is not excluded from the program because it constitutes the second axis of development with a share in electricity production expected to reach about 3 % in 2030. Algeria also plans to install some experimental size units to test the various technologies in renewable energies such as biomass, geothermal energy and desalination of brackish water [1,2].

In the literature, the hybrid systems are described in many studies both experimentally and numerically such as PV/Wind/Battery [3-5], PV/Wind only [6-10], PV/Wind/Battery/Diesel [11,12], wind/Diesel/battery [16-18], PV/Wind/Diesel [13-15], PV/diesel [19, 20], PV/Wind/Diesel/Microhydroelectric turbine [22], PV/Wind/micro-turbine/battery [21] and PV/Wind/Fuel cell [23,24]. The selection process for hybrid power sources at a given site is dependent on a combination of many factors, including the load demand, site topography, seasonal availability of energy sources, cost of energy storage and delivery, seasonal energy requirements, etc. [24].

The aim of this paper is to presents and discusses the results of measurements of solar radiation, wind speed, temperature, energy production data from photovoltaic modules and from wind turbine and the load during period testing of a photovoltaic-wind–battery hybrid power system used for public lighting at night, with an average daily energy consumption of 2640 Wh.

2. Potential energy of Adrar

Adrar is a province in southwestern Algeria. It is bordered to the north by the province of Bechar, El-Bayadh and Ghardaïa; to the west by the Wilaya of Tindouf; to the east by the Wilaya of Tamanrasset; to the south by Mauritania and Mali [25-28].

Its geographical coordinates are represented by a latitude of 27°52′ North of the equator and longitude of 0°17′ West of Greenwich, Adrar occupies an area of 427,368 km^2, a population of 422,331 inhabitants with very low population density estimated at 0.98 inhabitants/km^2 [25-28].

3. The hybrid PV-Wind experimental system description

The hybrid system considered in this study is a combination of photovoltaic and wind subsystems, intended for use in residential applications. Here, the amount of the electricity produced depends on the total solar radiation on tilted plan (a slope roughly equal to the latitude of the site $\beta = 28°$) and the wind speed.

The seven main components of the experimental residential power system are a PV array (UDTS50, 600 W monocrystralline silicon), wind turbine (1KW, Whisper 100), hybrid charge controller (Steca " Tarom 245 ", 24V), battery bank (SP 12V-100Ah, lead-acid type), inverter (DC/AC, CP 300), load (AC and DC) and data acquisition.

The proposed system is composed of: 3.33 m^2 photovoltaic (PV) panels and 1 kW wind turbine interconnected to a DC bus through converters. The PV-Wind hybrid system is coupled to battery storage. PV panels transform solar radiation into direct current (DC), and the electricity (AC) generated by the wind turbine transforming it to direct current (DC) by the Whisper controller. The DC voltage obtained at the output of the photovoltaic and wind subsystems are connected to the inputs of the hybrid system controller.

The system can satisfy both DC and AC loads. For the AC 220V loads a CP300 inverter is used between the hybrid charge controller and the AC loads, to convert direct current DC 24V into alternative current AC 220V.

The schematic diagram of the experimental system and all of its components are shown in Fig.1, along with photos 2 and 3 of the actual installation. The experimental set up has been realized in the Research Unit in

Renewable Energies in Saharan Medium, Adrar. The photovoltaic panel group constitutes the primary energy supplier of the system; while the wind turbine is the secondary supplier since the contribution of wind turbine is small as compared to the share of the photovoltaic subsystem (small wind turbine 1Kw and law wind speed in the testing period).

We also setup a data acquisition system and connected to the computer for recorded the meteorological data (solar radiation, temperature…), load profiles and energy production data from photovoltaic module and wind turbine subsystems.

4. Measurements

The following data were regularly recorded with a time interval of 30 second during the experimental period 05 to 14 May 2013.

- Radiation measurements obtained using CM 11 pyranometer (measurements of global tilted radiation).
- Measurement of wind speed at a height of 10 m above sea level.
- Corresponding temperature measurements of the photovoltaic module battery and ambient conditions using J-, T- and K-type thermocouples.
- Energy production data from monocrystralline silicon UDTS50 modules.
- Energy production data from a wind turbine Whisper 100.
- Load profiles during period testing.

A very important parameter to consider when designing a standalone PV system is the battery bank nominal voltage, which can be 12, 24 or 48 V DC. The parameters affecting the determination of the suitable nominal voltage for a system are the nominal voltage of the PV, the system size and the inverter input requirements [29].

The battery bank consists of 16 batteries (SP 12V-100Ah) lead-acid type. The battery bank nominal voltage is decided to be at 24 V and the nominal voltage of each battery cell is 12 V then the configurations of the battery bank used in the system 2 strings of 12 batteries connected in parallel (24V/1600Ah). The battery storage capacity is assumed to be equivalent to about 3 days of maximum average daily demand.

Fig.1. Basic layout of the wind energy system with battery storage and power conditioning equipment, coupled with PV modules as auxiliary power supply.

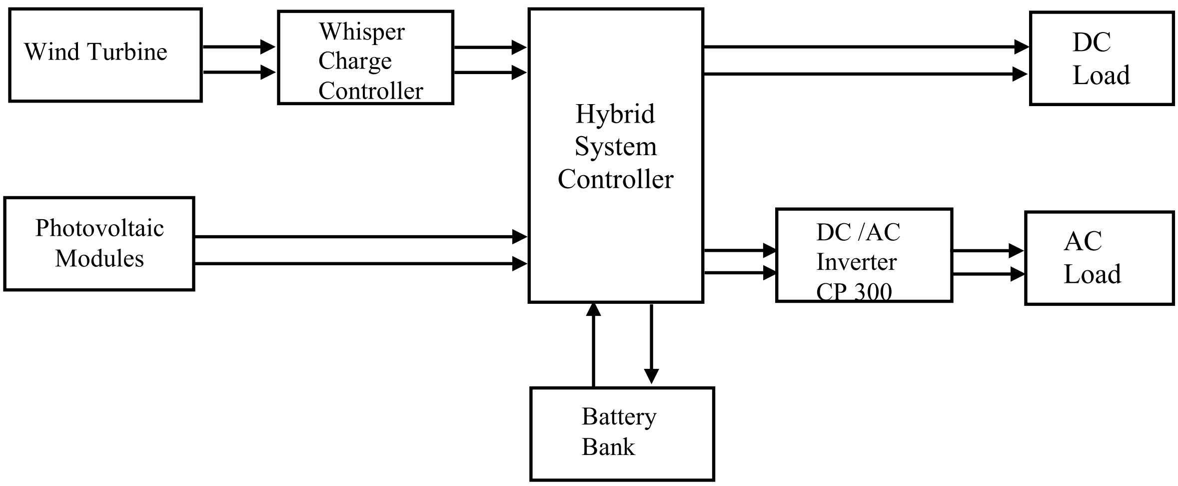

Fig. 1: Schematic diagram of the Standalone hybrid PV-Wind system

Fig. 2: Photo of the PV panels and wind turbine

Fig. 3: Photo of the Whisper charge controller and hybrid system controller

5. Load analysis

The third stochastic data is the electricity consumption of the load charges (AC and DC). The statistical data are collected every 30 second and integrated over each hour and the hourly values are transferred on daily basis [30].

$$E_d = \sum_{i=1}^{n} I_n V_n D_n \quad (1)$$

Where, I_n, V_n, and D_n are the current, voltage and duty cycle of each appliance used in one day, respectively and Ed shows the total energy demand for the house. As shown in Table 1, the average daily energy consumption of the house is calculated as 2640 Wh according to Eq. (1).

Table 1. Calculated energy consumption

Appliance	Power [W]	Number of used hours /day [hours]	Used energy /Day [Wh]
Lighting	220	From 20 H –00 H = 4 H	880
Lighting	220	From 00 H –08 H = 8 H	1760
Total		**12**	**2640**

Fig. 4 illustrates the hourly mean electricity consumption values of the load charges.

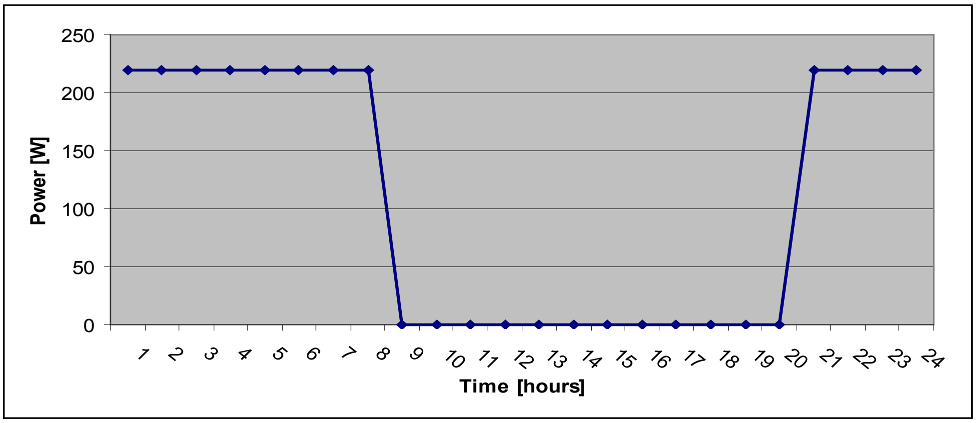

Fig. 4: Hourly average electricity demand

6. Results and discussion

The system performance was evaluated in ten days, from 05 to 14 May 2013. Relevant data are presented in Figures 5 to 14. Figures shows the evolution of the global radiation, wind speed, ambient temperature, photovoltaic temperature, battery temperature, battery bank voltage and power output from wind turbine and photovoltaic as a function of time.

Fig.5 and Fig.9 shows respectively the hourly variation of the wind speed and the wind turbine output power. The hourly variation shows relatively higher winds between 10:00h and 18:00h while lower values during the rest of the day.

Fig.6 and 10 shows plot of the global irradiance and photovoltaic output power on the tilted plan, the hourly variation shows relatively higher winds between 09:00h and 17:00h.

Fig.7 and Fig.8 illustrates the distribution of the ambient temperature and photovoltaic module temperature with the hours of the day. The curve has the shape of bell. Sun starts to be significant at 09:00h and decreases at 16:00h.

The generated power of PV panels is also a function of temperature, when the temperature increases, the efficiency of the panel decreases [30,31].

The surface temperature of the PV module is approximately the same as the ambient temperature at night; however, it can exceed the ambient temperature by 25 °C or more at noon.

Fig.11 and Fig.12 describes respectively the variation of the hourly battery voltage and the hourly-mean battery SOC of the hybrid power generation project. It was observed that the hourly-mean battery SOC is much higher during the hour's 10:00h-19:00h than the rest hours. A distinct increase of battery SOC is observed since 10:00h. With solar radiation getting stronger and stronger the battery will be recharged, and the battery SOC will be recovered. For the first testing day 05 May, the highest battery SOC 66% occurs between 14:00h and 17:00h, while the whole evening is characterized by the decreasing battery SOC until 50% occurs between 05:00h and 07:00h. For the last testing day 14 May 2013, the hourly-mean battery SOC varied between a maximum of 74% occurs between 15:00h and 16:00h and a minimum of 56% occurs between 05:00h and 07:00h. For all days, the peaks of the state-of-charge SOC (%) occur around between 15:00h and 16:00h the power output from PV modules and from wind turbine were highest (a high hourly mean solar radiation, high hourly mean wind speed).

We can note also that the charge state of the battery bank can never exceed the permissible maximum value SOC_{max} (100 % of SOC), and can never be below the permissible minimum value SOC_{min} (20 % of SOC).

From Fig.13 and Fig.14, it can be observed that the power supplied by the PV array is more important than power wind turbine, and the total generated power meets the load at all days.

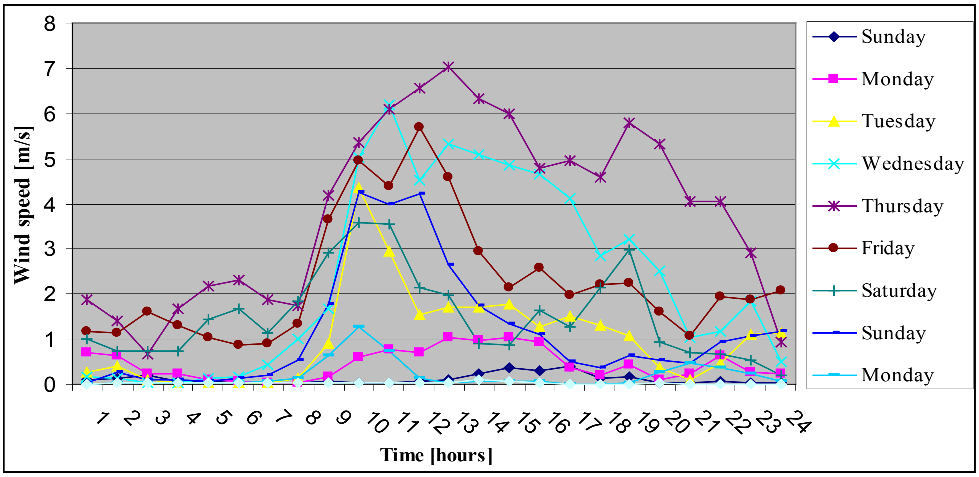

Fig.5: Hourly variation of wind speed (From 05 to 14 May 2013)

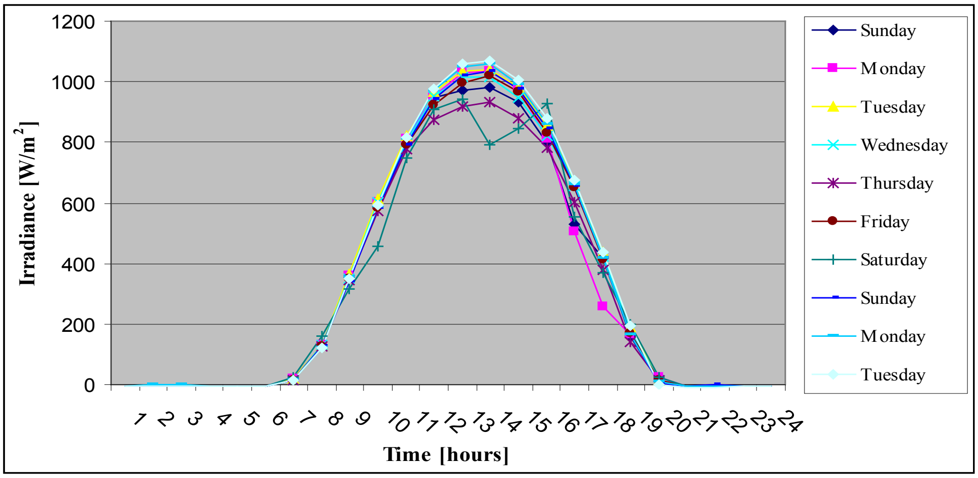

Fig. 6: Hourly variation of solar radiation (From 05 to 14 May 2013)

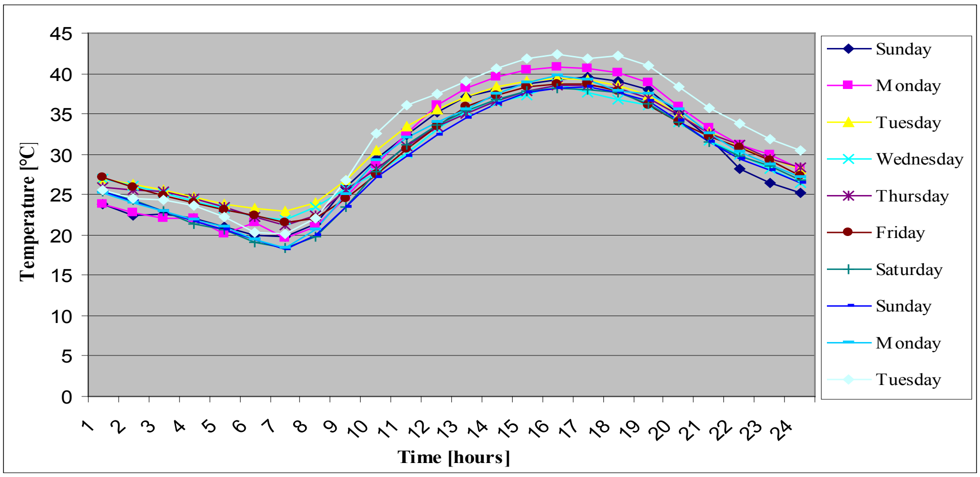

Fig. 7: Hourly variation of ambient temperature (From 05 to 14 May 2013)

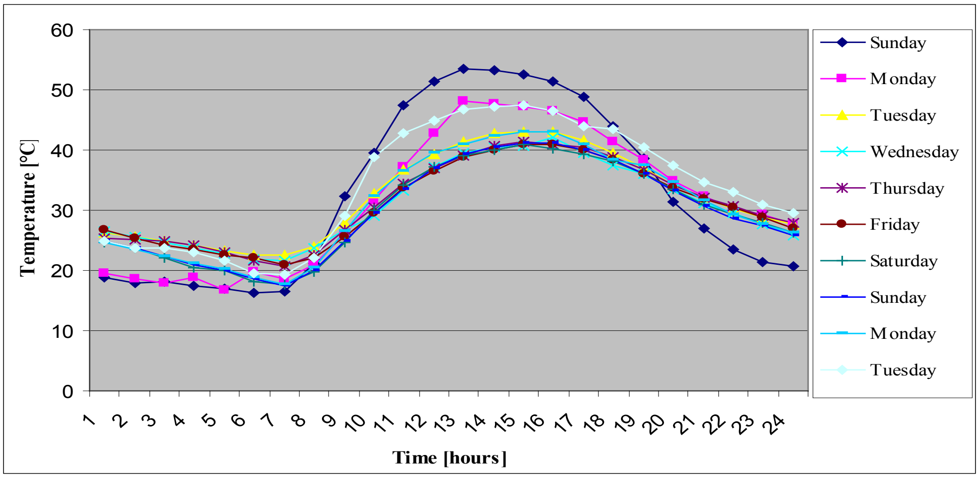

Fig. 8: Hourly variation photovoltaic module temperature (From 05 to 14 May 2013)

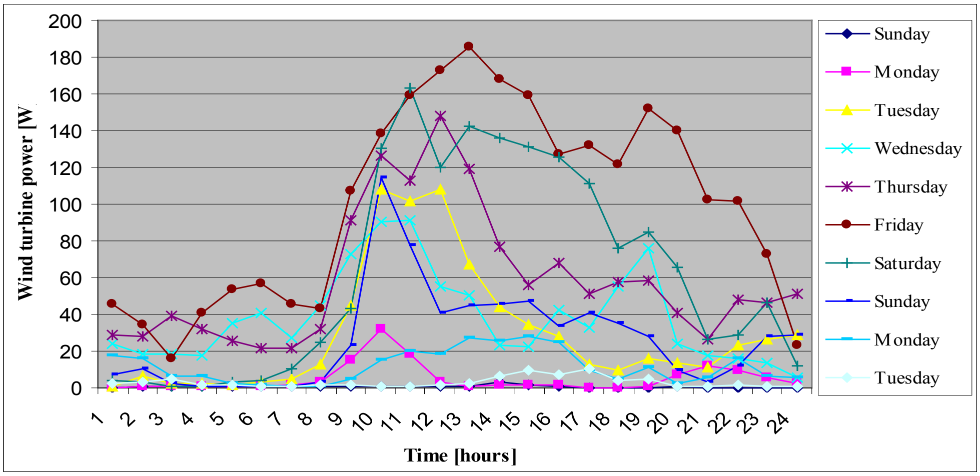

Fig. 9: Hourly variation of wind turbine output power (From 05 to 14 May 2013)

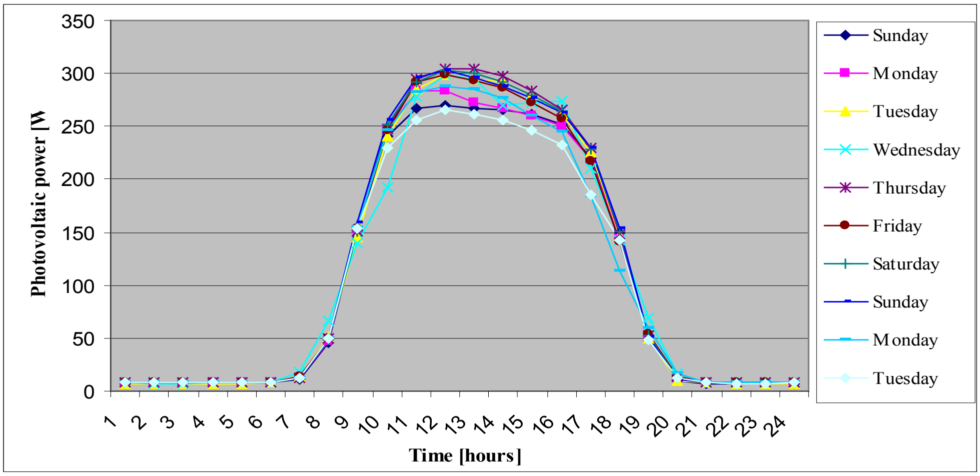

Fig. 10: Hourly variation of photovoltaic output power (From 05 to 14 May 2013)

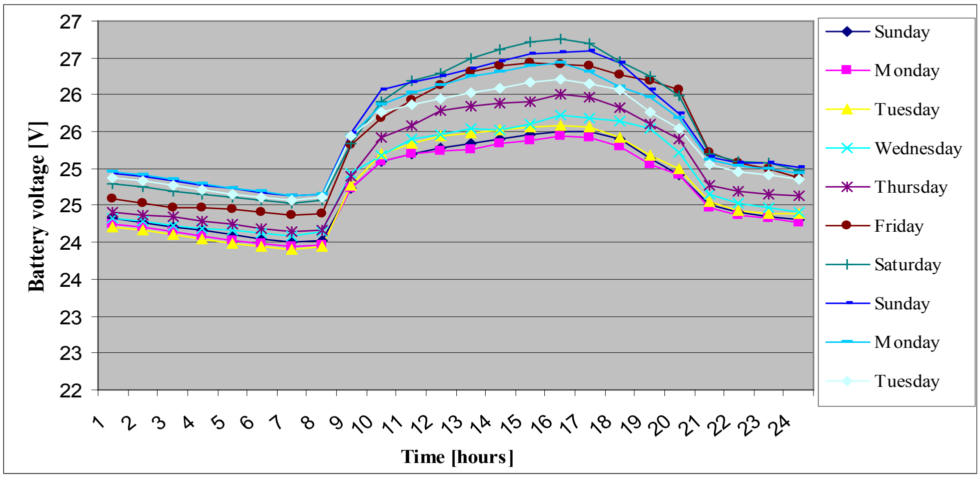

Fig. 11: Hourly voltage of the battery bank (From 05 to 14 May 2013)

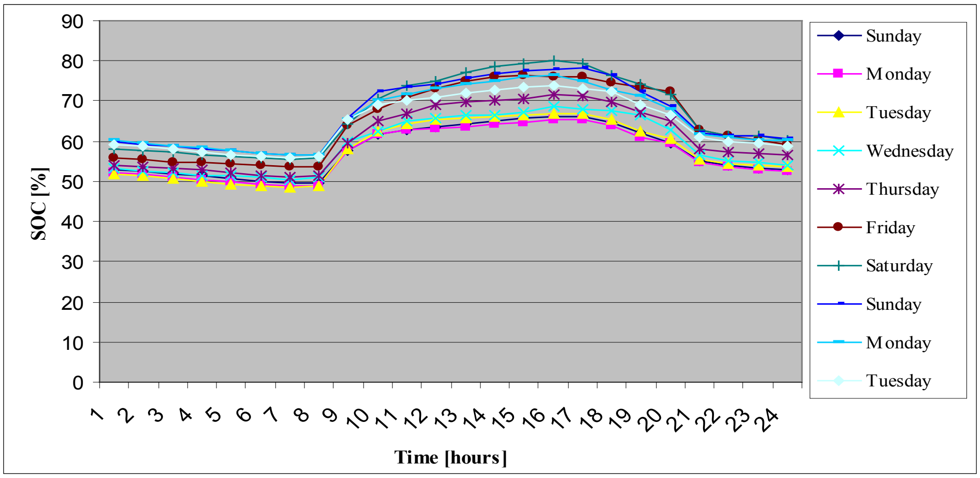

Fig. 12: Hourly state of charge SOC of the battery bank (From 05 to 14 May 2013)

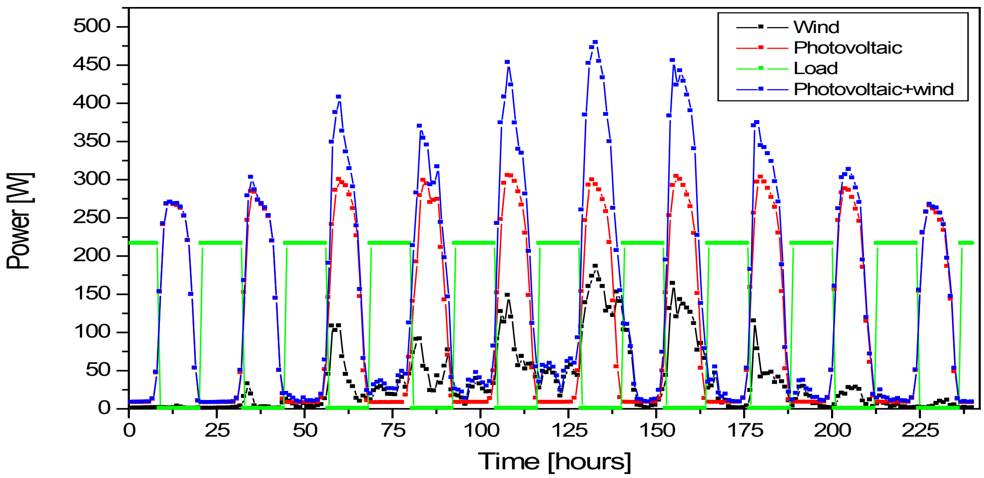

Fig. 13: Daily variation of load and power output from wind turbine, photovoltaic and hybrid systems (From 05 to 14 May 2013)

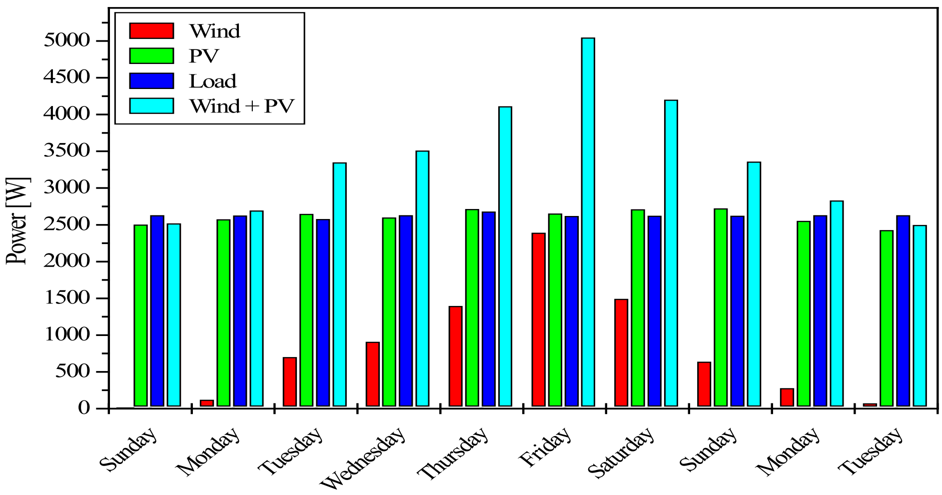

Fig. 14: Daily variation of load and power output from wind turbine, photovoltaic and hybrid systems (From 05 to 14 May 2013).

Table 2. Energy contribution by wind, PV systems of total energy production by the hybrid system.

	Contribution of PV	Contribution of Wind	Hybrid system PV + Wind	PV (%)	Wind (%)	Total (%)
Sunday	2555,52	16,68	2572,20	1	99	100
Monday	2572,07	120,53	2692,60	4	96	100
Tuesday	2688,35	711,33	3399,68	21	79	100
Wednesday	2608,76	910,26	3519,03	26	74	100
Thursday	2726,22	1403,70	4129,92	34	66	100
Friday	2662,33	2399,75	5062,08	47	53	100
Saturday	2718,72	1497,27	4215,99	36	64	100
Sunday	2727,75	638,42	3366,17	19	81	100
Monday	2552,07	277,76	2829,83	10	90	100
Tuesday	2439,51	71,34	2510,85	3	97	100
Daily Moy.	**2616,95**	**634,33**	**3251,28**	**16**	**84**	**100**

The Table 2 summarizes the energy contribution by wind, PV systems of total energy production by the hybrid system. As seen from this table, 84% of the energy is supplied by PV system and the remaining 16% by the wind system.

The daily mean power contribution of PV systems to the hybrid power system remain almost the same with slight variation of minimum 53% in Friday and maximum 99% in Sunday.

However, the wind power contribution varied between minimum of a maximum of 1% in Sunday and 47% in Friday.

7. Conclusion

In this paper, the study first part presents a system components description and than its technical specification. The system is composed of the interconnection of: Photovoltaic and Wind turbine with converter interfaces. Then, experimental results are provided which demonstrate the capability system to supply at the energy demands for public lighting at night, with an average daily energy consumption of 2640 Wh.

From the testing period, we can observe that:

- The power supplied by the PV array (84%) is more important than power wind turbine (16%).
- The battery SOC is dominated by power from the PV array.
- The total generated power meets the load at any time of the day.
- There exists daily complementary relationship between solar energy and wind energy.
- The peak electricity production of the wind-solar system coincides with peak house energy demands.
- The wind speed is higher on average between 10:00h and 18:00h while lower values are recorded during the rest of the day.
- The hourly-mean battery SOC varied between a maximum of 74% and a minimum of 56 %.
- For all days, the peak battery charging occurs between 15:00h and 16:00h (a high hourly mean solar radiation, high hourly mean wind speed).

Dashes

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