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Power Supervision of a Standalone Renewable Energy Production System

Abdelhaq Amar Bensaber, Mustapha Benghanem and Mohamed Bourahla
Faculty of Electrical Engineering, University of Science and Technology of Oran, Mohamed-Boudiaf, USTO-MB, Bir El Djir, Algeria

Key words: PV, MPPT, power flow, management, wind, battery, DC/DC converter

Corresponding Author:
Abdelhaq Amar Bensaber
Faculty of Electrical Engineering, University of Science and Technology of Oran, Mohamed-Boudiaf, USTO-MB, Bir El Djir, Algeria

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Abstract: Stand-alone renewable systems comprise one of the most promising electrification solutions for covering the demand of remote consumers. However, the high dependency on weather state and the nonlinearity of the system cause a variation in voltage, power and frequency. This study presents a nonlinear controller to attain maximum performance for both sources, then a smart strategy to control the power flow between the hybrid power system and the batteries in order to satisfy the load requirements while keeping the state of charge within secure limits is introduced. To accomplish efficient energy management, we combine two powerful renewable energies solar and wind, batteries were also used to store the excess of energy or to supply the system with the required energy. The proposed standalone is tested with variable solar irradiation, temperature and wind speed and the results presented affirm the efficiency of the proposed control.

INTRODUCTION

Environment friendly energies have been found to be promising solution to deal with issues like pollution and global warming[1, 2]. Currently, wind energy and photovoltaic system are the brightest renewable source of electrical power generation for the future it has been proved as one acknowledged potential source of energy. Compared with other clean energies, like it cost efficiency and reliability[1-5]. Thus, those factors became important topics in industry and research[6]. However, climatic conditions affect the power output. Thus, it is difficult to generate the power to fulfil load demand and also the generated power contain frequency/voltage variations[3-5]. The combination of solar and wind energy sources along with a storage unit such as batteries, offers an excellent solution to problems caused by the stochastic nature of these sources, we have chosen solar and wind energy because they complement each other[6, 7]. The subsystems are connected into a DC bus to ensure adaptability of the energy and because this method doesn't require synchronization[8, 9]. However, adding battery banks is necessary to satisfy a peak or temporary period load demands[1, 10, 11]. Battery is widely used in standalone system because of its mature technology, high efficiency, quick response, low cost and improve the power-supply stability, quality and reliability. However, frequent charge and discharge decreases the battery life cycle, thus power management is necessary to prolong the battery life cycle and to suppress the power fluctuation and to supply a quality power to load[4, 11, 12].

Control strategies are necessary to attain maximum performance. Control schemes are established with the vector control with the classical controller but this controller can provide favorable performance restrictive under ideal voltage conditions. Furthermore, disturbances and parameter variations will leave us with imperfect performance. Therefore, papers have offered many control strategies like Sliding Mode Control, smart control or adaptive algorithms, HOSMC. SMC, despite robust, it suffers two main deficiencies. First, chattering phenomenon which produced from the high-frequency switching that damage the performance and excites high frequency oscillations.

In the literature, all of the early management methods have used conventional approaches such as linear PI controller which can't handle various changes in weather circumstances[6, 10, 13]. This made researchers search for other approaches with ability to handle various changes without any major problems by establishing new management criteria depending upon informational data and the environmental changes[2, 14].

In this study, control methods are proposed to track the maximum power from the wind/solar energy source to achieve much higher generating capacity factors, then an implementation of a fuzzy logic controller to manage the flow of energy in a wind-PV-battery standalone for island communities. the aim of our method is to optimize the power between the sources for various operation modes and to preserve the SOC at a reasonable level.

The study is organized as follows. First we will describe the architecture of the PV and the wind turbine, then the proposed management will be presented. Finally, results will be introduced to verify it performance even under various weather circumstances.

Standalone configuration: In this study a PV/wind/battery power system with an AC load is considered as presented in Fig. 1. The common DC bus is used because it's robust, economics and easy to control. The system is connected to load through a DC-AC inverter associated with an LCL filter. To stabilize the system, a controllable load is considered[1]. The battery system has its bidirectional converter and it is charged or discharged depending on the availability of power. The DC link is connected to the sinusoidal PWM IGBT based inverter which is fed to single phase AC load. The harmonics of the inverter is filtered by a LC filter. In this study we propose an intelligent management strategy in order to ensure energy of a standalone. To achieve our objective, our strategy is based on two steps is considered. The first step consists on generating the maximum power from for the PV and the wind turbine in order to generate enough energy to satisfy the load, then an intelligent controller is designed to manage the power flow form the source and play an important role in charging and discharging of the battery.

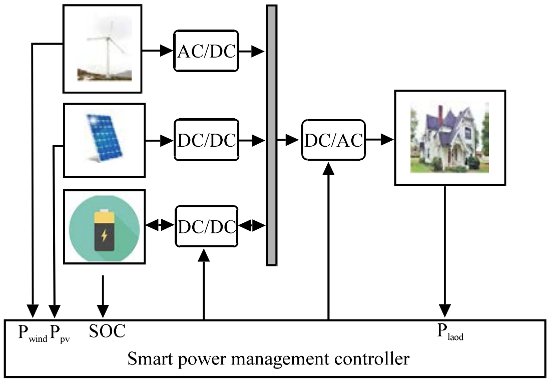

Fig. 1: The proposed hybrid system

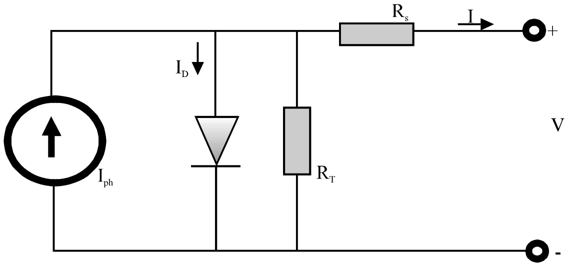

Fig. 2: PV module equivalent circuit

MATERIALS AND METHODS

PV device modelling: PV device will generate electrical power by transforming solar irradiation into direct current[14].

In Fig. 2, the current source presents the incident solar irradiance, we represent the polarization phenomena with a diode, resistance represent the power losses. The mathematical equation is given, respectively by:

$$I = I_{ph} - \underbrace{I_{sat}\left(e^{\frac{V}{N_s A V_T}} - 1\right)}_{I_D} \tag{1}$$

Where:

I:PV = Current (A)
I_{ph} = Photo generated current
V:PV = Voltage (V)
I_{sat} = Diode saturation current

MPPT control: In this study we have chosen to use sliding mode control, the main advantage of this control is its simplicity and robustness in spite of uncertainties in the system and external disturbances and on the other hand it needs relatively less information about the system and also is insensitive to the parametrical changes of the system plus it doesn't need to the mathematical models accurately like classical controllers but needs to know the range of parameter changes for ensuring sustainability and condition satisfactory. The sliding mode control has three stages choice of surface:

$$S(x) = \frac{dP_{pv}}{dV_{pv}} = I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv} \tag{2}$$

Convergence condition:

$$\dot{V}(x) = \dot{S}(x) S(x) < 0$$

Calculation of the control laws:

$$\begin{cases} u = u_{eq} \text{-ksign}(S) = \frac{I_{pv}}{i_L} \text{-ksign}\left(I_{pv} + \frac{dI_{pv}}{dV_{pv}} V_{pv} \right) \\ u_n = \text{-ksign}(S) \end{cases} \tag{3}$$

Turbine model: The power contained in kinetic energy form at a speed Vv, surface A1 is expressed by Samina etc:

$$P_v = \frac{1}{2} \rho A_1 V_v^3 \tag{4}$$

where, ρ the air density but WT can regain just a part of that power:

$$P_v = \frac{1}{2} \rho \pi R^2 V_v^3 C_p \tag{5}$$

where, C_p is power coefficient. The speed ratio λ introduced by:

$$\lambda = \frac{R\Omega_t}{V_v} \tag{6}$$

Where:

R = The blades length

Ω = Rotor angular speed. The theoretical extreme rate of Cp obtained by Betz limit

$$C_{p\_theo\_max} = 0,593 = 59,3\%$$

The torque and power Coefficient Cp is represented in function of tip step ratio (λ) and pitch angle (β) as fellow:

$$C_p = C_1 \left(\frac{C_2}{\lambda_i} \text{-} C_3 \beta \text{-} C_4 \beta^{C_5} \text{-} C_6 \right) \left(e^{C_7/\lambda_i} \right) \tag{7}$$

$$\lambda_i = \frac{1}{\lambda + C_8} \tag{8}$$

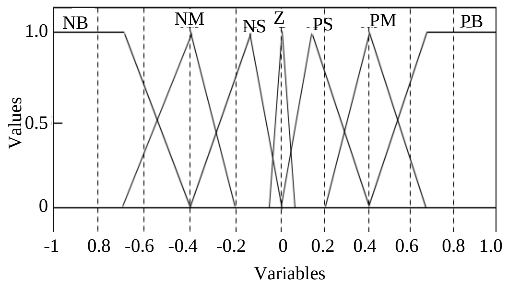

Fig. 3: Input dp

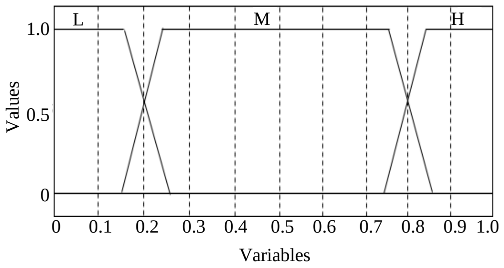

Fig. 4: Input SOC

The slow shaft mechanical torque Ct is expressed by:

$$C_t = \frac{P_t}{\Omega_t} = \frac{\pi}{2\lambda} \rho R^3 v^2 C_p \tag{9}$$

Maximum Power Tracking MPPT: Aiming to extract the supreme power is the fundamental objective of the speed control. Many methods are used to ensure that. Direct Speed Controller (DSC) is presented in Fig. 3 and 4, its concept is founded on generating the optimal turbine speed for various wind speed value and use it as speed reference. Next with the help of a regulator the turbine rotational speed is controlled and the mechanical power aimed to be maximal for each operating point the reference rotational speed is defined by:

$$\Omega_t^* = (\lambda_{opt} v)/R \tag{10}$$

Thus,

$$\Omega_m^* = G\Omega_t^* \tag{11}$$

We obtain the active power reference by:

$$P_{s\_ref} = C_{cem\_ref} \Omega_m \tag{12}$$

Mathematical model of DFIG: We have chosen to use the double-fed induction generator because with the help of the bidirectional converter in the rotor it is possible to work in both sub-synchronous and super-synchronous. The electrical model of the machine obtained using Park transformation is given by the following equations (23, 30, 31). Stator, rotor voltages:

$$V_{qs} = R_s I_{qs} + \frac{d\phi_{qs}}{dt} - \omega_s \phi_{ds} \quad (13)$$

$$V_{ds} = R_s I_{ds} + \frac{d\phi_{ds}}{dt} - \omega_s \phi_{qs} \quad (14)$$

$$V_{dr} = R_r I_{dr} + \frac{d\phi_{dr}}{dt} - \omega \phi_{qr} \quad (15)$$

$$V_{qr} = R_r I_{qr} + \frac{d\phi_{qr}}{dt} - \omega \phi_{dr} \quad (16)$$

Where:

$$\omega = \omega_s - \omega_m \quad (17)$$

Second order sliding mode control: SMC is an interesting nonlinear method approach. Nevertheless, the biggest problem of this control is the chattering phenomenon which causes mischievous effects on the generator because of the discontinuous surveillance and that cause overheating and trigger unmodeled high frequency dynamics (34). SOMC is an attractive solution (35), it generalizes the sliding mode idea by going to a higher order time derivatives which decrease chattering and avoid powerful mechanical efforts while maintaining advantages of the SMC (34, 35) such as robustness under uncertainties. Aiming at achieving satisfactory tracking performance for Ps and Qs, the switching functions given next are adopted:

$$\begin{cases} S_P = e_P + c_P \int e_P dt \\ S_Q = e_Q + c_Q \int e_Q dt \end{cases} \quad (18)$$

The integral terms cp sand cQ are positive constant are added for steady-state errors elimination[6]. The voltage applied represented in the equation below:

$$\begin{cases} V_{dr} = V_{dreq} + V_{drn} \\ V_{qr} = V_{qreq} + V_{qrn} \end{cases} \quad (19)$$

The system in reach the sliding surface with the help of the switching control Vdrn and Vqrn, Vqreq and Vdreq are the equivalent control terms, they make the system move along the sliding manifold and accelerate the response of the system while reducing the steady-state errors (36). The equivalent controls terms are derived by letting, the voltage to be applied to the rotor are expressed as:

$$\begin{cases} V_{qreq} = -\frac{L_s L_r \sigma}{M V_s}\left(\overset{\bullet}{P}_{s\_ref} + c_P \left(P_{s\_ref} - P_s \right) \right) + \\ R_r I_{qr} - g w_s L_r \sigma I_{dr} - g \frac{M V_s}{L_s} \\ V_{dreq} = -\frac{L_s L_r \sigma}{M V_s}\left(\overset{\bullet}{Q}_{s\_ref} + c_P \left(Q_{s\_ref} - Q_s \right) \right) + \\ R_r I_{dr} - g w_s L_r \sigma I_{qr} \end{cases} \quad (20)$$

Thus (24):

$$\begin{cases} V_{drn} = y_1 + B_1 \left| e_P \right|^{\frac{1}{2}} \operatorname{sign}\left(e_Q \right) & \dot{y}_1 = B_2 \operatorname{sign}\left(e_Q \right) \\ V_{qrn} = y_2 - B_3 \left| e_P \right|^{\frac{1}{2}} \operatorname{sign}\left(e_P \right) & \dot{y}_2 = -B_4 \operatorname{sign}\left(e_P \right) \end{cases}$$

where, the constants B1, B2, B3 and B4:

$$\begin{cases} B_1 \succ \frac{\Phi_2}{\sigma L_r} \quad B_2^2 \geq \frac{4\Phi_1 \left(B_1 + \Phi_1 \right)}{\sigma^2 L_r^2 \left(B_1 - \Phi_1 \right)} \\ B_3 \succ p \frac{M}{\sigma L_r L_s} \Phi_1 \quad B_4^2 \geq \frac{4\Phi_2 \left(B_3 + \Phi_2 \right)}{\sigma^2 L_r^2 \left(B_3 - \Phi_2 \right)} \\ \left| \overset{\bullet}{G}_1 \right| \prec \Phi_1 \quad \left| \overset{\bullet}{G}_2 \right| \prec \Phi_2 \end{cases} \quad (21)$$

And

$$\begin{cases} G_1 = \overset{\bullet}{P}_{s\_ref} + V_s \frac{M}{L_s L_r \sigma} \begin{pmatrix} -R_r I_{qr} + \\ g w_s L_r \sigma I_{dr} + g \frac{M V_s}{L_s} \end{pmatrix} \\ G_2 = \overset{\bullet}{Q}_{s\_ref} + V_s \frac{M}{L_s L_r \sigma} \left(-R_r I_{dr} + g w_s L_r \sigma I_{qr} \right) \end{cases}$$

Inverter modelling: Voltage inverter is used to convert DC link voltage to AC. It possessed of 6 IGBT. The ratio between the commutation variable $[S_a, S_b, S_c]^T$ vector and voltage vector $[V_a, V_b, V_c]^T$ is:

$$\begin{bmatrix} V_{an} \\ V_{bn} \\ V_{cn} \end{bmatrix} = \frac{V_{dc}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (22)$$

RESULTS AND DISCUSSION

Battery charging: The intermittent nature of renewable sources is the reason why storage systems are important in the hybrid renewable system. Batteries store the surplus power generated and uses it to supply the load if it is required.

PV, wind energy system and battery bank are integrated to a combined DC bus of constant voltage[1, 10, 12]. Any power transfer whether from generator to battery bank or generator to load or from the battery bank to the load takes place via. this constant voltage DC bus. Bidirectional converter is needed to charge or discharge the battery in case of overflowing or deficit of the power[9].

The proposed controller for battery charge/discharge control is implemented using FLC. The FLC receives the inputs to the controller and generates a degree of membership relative to each fuzzy set in the membership function then evaluates these fuzzy set memberships and decides which rules should be fired, finally it converts these values into an output control signal. Our controller has two inputs "dP, SOC" and one output-battery reference power depending on the input values controller generates a desired value for reference battery power. The battery reference power is then divided by the battery voltage to generate the reference current for the battery. The membership functions which used for inputs data are shown in Fig.. 3-5 and the rules to be evaluated are given in Table 1. The core of the rule set of the fuzzy controller is illustrated as follows.

Simulation study: The proposed standalone PV-wind hybrid system with energy storage is tested under different operating conditions and variable load condition as presented in Fig. 9 and 10. SOC is considered 60%.

The output voltage and load current response are shown in Fig. 8 and 9, we can see clearly that load current increase and decrease when the load power change. Further, DC-link voltage is constant at 640 V with a good precision and stability even with a change in hybrid power, load demand and under various weather circumstances as presented in Fig. 10. The PV and wind system manage to extract the maximum power even with the variation of the irradiance and wind seed as presented in Fig. 6 and 7 when the generated hybrid power (PV/wind) is more than the required load power, the additional power will be transfer to the battery but if the hybrid system power can't meet the load power, the battery bank discharge and fulfil the load with the help of the DC-DC bidirectional converter. We can see that battery power vary (discharge/charge) to maintain the stability of the system as shown in Fig. 11. It is also can be seen that our system executes satisfactorily under various conditions while having a constant voltage and frequency. It is seen that the battery power is positive during this time duration, from time t = 5 sec to t = 6 sec we turned off the load, total power generation is used to charge the battery during this period. Figure 11 shows the variation in battery SOC.

Table 1: Fuzzy logic rules

SOC/dP	PB	PM	PS	Z	NS	NM	NM
L	NB	NM	NS	Z	Z	Z	Z
M	NB	NM	NS	Z	PS	PM	PB
H	Z	Z	Z	Z	PS	PM	PM

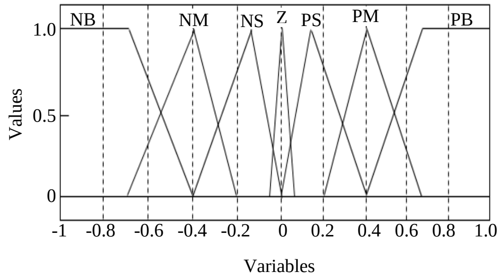

Fig. 5: Output db

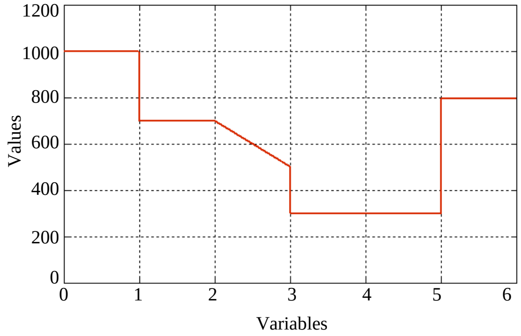

Fig. 6: Irradiation profile

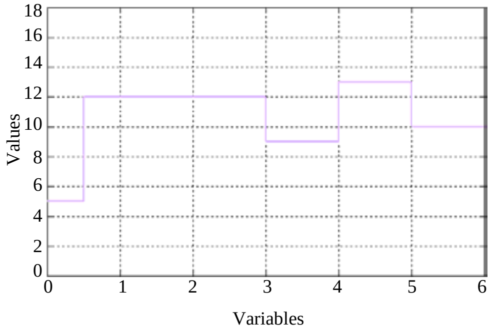

Fig. 7: Wind profile

Figure 12 shows the power distribution curve of all generated power sources, it can be observed that the outputs manage to extract the maximum power even with parameter uncertainties. Load power profile is variable to ensure that the hybrid energy system can serve the load in any case, it is initially 8 kW and it change to 12 kW at time t = 1 sec. From time t = 0 to time t = 1 sec the total power generation from wind and solar is more than the load power requirement and the battery is charged during this period. In t = 2.5 sec total power generation is equal

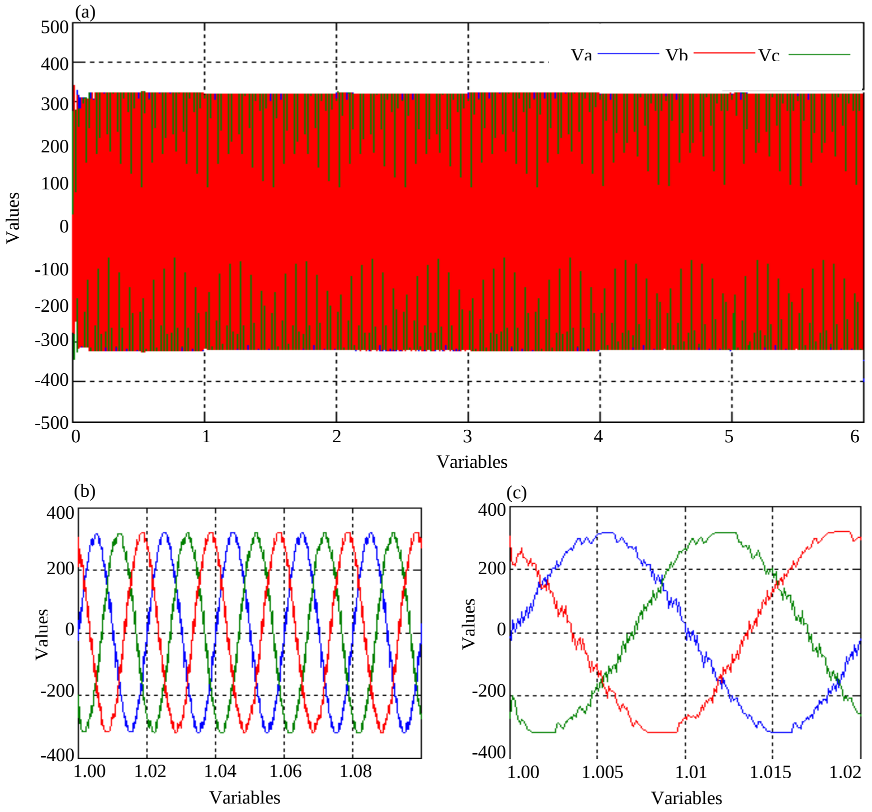

Fig. 8(a-c): Output load voltage

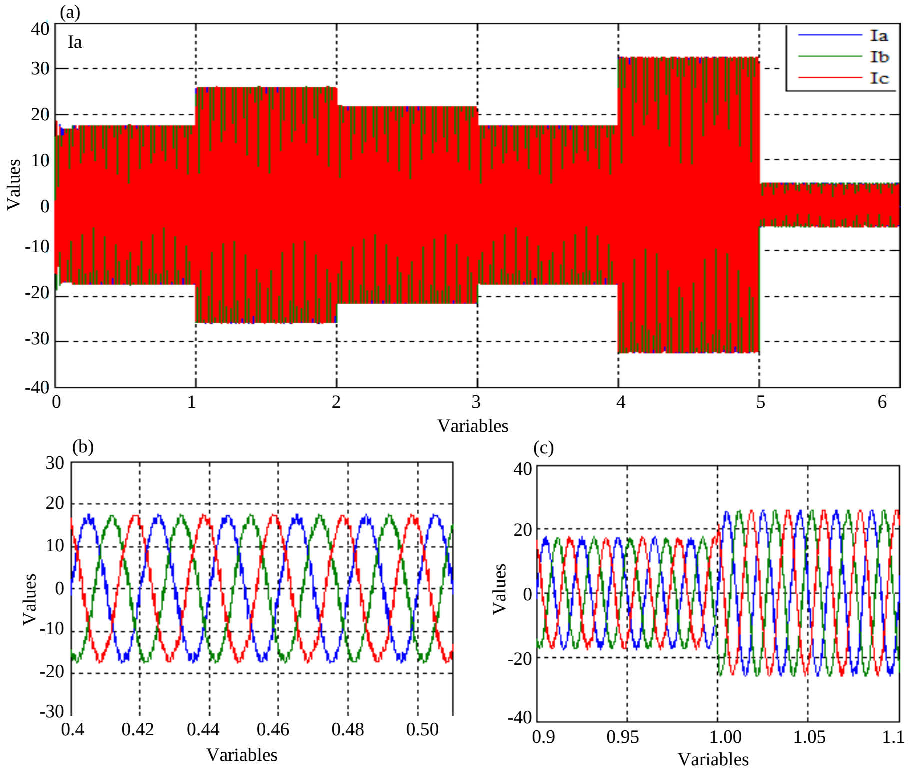

Fig. 9(a-c): Output load current

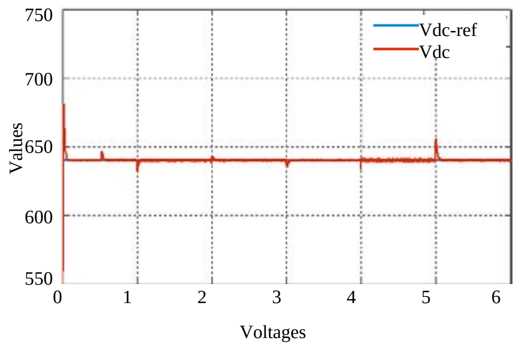

Fig. 10: DC-link voltage

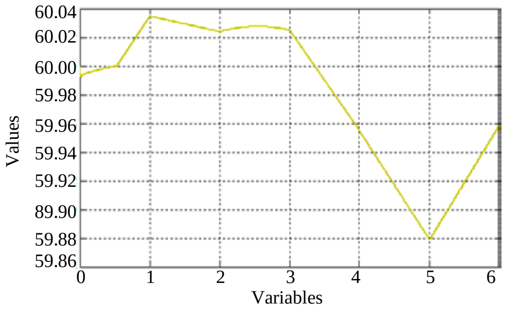

Fig. 11: SOC (%)

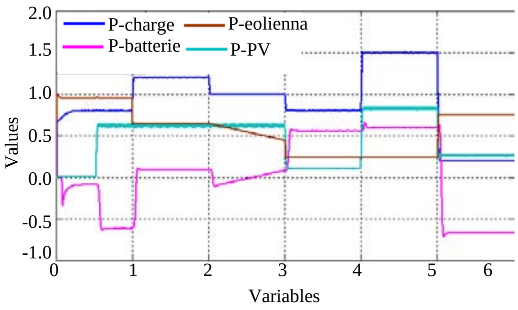

Fig. 12: Wind-PV-battery-load hybrid power

to power demand that is battery power is 0. From time t = 4 sec to t = 5 sec the load increased to and reached 15 kw, total power generation is less than power demand. The battery is discharged during this period to meet the load power.

CONCLUSION

This study presented a standalone hybrid system combining solar and wind sources with batteries in one system to satisfy the electrical load demand for an isolated house. In this study, a fuzzy logic controller is implemented to control the power flow for the systems even under different scenarios of power generation and power consumption by load and at the same time maintaining the battery SOC with in it limits to increases it life. Results showed that the fuzzy controller presented an efficient way to control the flow of energy between input sources and storage units while ensuring a continuous power supply for the load demand even under different operation cases.

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