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Power flow control and management of a Hybrid Power System

***Abstract**. Recently eco-friendly solutions are gaining attraction for energy generation to overcome the environmental problems, but unpredictable nature and high dependency on weather state are the main restriction of renewable sources. To overthrown this drawbacks, various renewable sources need to be integrated such us PV, wind turbines and battery, the biggest challenge of this integration is to control and manage the power flow. In this paper a control method is proposed to deal with the power flow from a standalone PV–wind-battery to meet the load demand. The system is validated in the Matlab/Simulink environment and the simulation results obtained confirm the effectiveness of the proposed control.*

Streszczenie.** Ostatnio ekologiczne rozwiązania zyskują na atrakcyjności dla wytwarzania energii ale nieprzewidywalny charakter i wysoka zależność od stanu pogody są głównymi ograniczeniami źródeł odnawialnych. Aby usunąć te wady, należy zintegrować różne źródła odnawialne, takie jak PV, turbiny wiatrowe i baterie. Największym wyzwaniem związanym z tą integracją jest kontrolowanie przepływu energii i zarządzanie nim. W niniejszej pracy zaproponowano metodę sterowania, aby poradzić sobie z przepływem mocy z autonomicznej baterii wiatrowej PV i aby sprostać wymaganiom obciążenia. System jest walidowany w środowisku Matlab / Simulink, a uzyskane wyniki symulacji potwierdzają skuteczność proponowanej kontroli.* ***Sterowanie i zarządzanie mocą w hybrydowych sysytemach wytwarzania energii

Keywords: PMSG, PV, MPPT, Wind, Battery, DC/DC converter, IC.
Słowa kluczowe: PMSG, PV, MPPT, elektrownia wiatrowa, bateria, konwerter DC / DC, IC

Introduction

Renewable energy application like the solar cell, wind turbine..., has expanded in the last decade especially in isolated areas like Sahara in Algeria where there is a great solar resource and a modest wind potential. The prime renewable sources disadvantages are uncontrollable and unpredictable in nature. Thus it is difficult to generate require quantity of power to fulfill load demand and also the generated power contain frequency/voltage variations. Hybrids renewable energy system utilizes two or more energy sources [1-4], usually solar along with wind sources because its abundance in nature and both can complement each other [5]. The subsystems are connected into a DC bus to ensure adaptability of the energy; this method doesn't require synchronization [6-15]. However, adding battery banks is necessary to satisfy a peak or temporary period load demands. Battery based energy storage system 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 [5, 12, 13, 15]. Both the energy systems are used to charge a battery using bi-directional converter.

In this article, modelling, controls of hybrid system are developed. The main control methods proposed are to track the maximum power from the wind/solar energy source to achieve much higher generating capacity factors then to manage the power flow from these sources. A simple LC filter is applied to eliminate the undesirable high frequency harmonics.

The proposed standalone PV-wind-battery hybrid system model in this paper has been modeled, designed, and simulated using Matlab, results are presented to verify it performance under various weather circumstances.

The general configuration of the system

This configuration is fit for stand-alone hybrid power system. Wind and solar energy are converted into electricity and then sent to loads or stored in battery bank. Our system combines a PMSG WT, PV array and battery as shown in figure 1. The power sources are linked in parallel to a mutual dc bus via their dc-dc converters. A PWM inverter is necessary to convert the dc power into AC.

PV device modeling

PV Device will generate electrical power by converting solar irradiation into direct current[16].

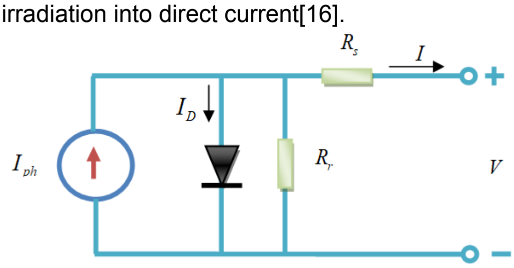


Figure 2: PV module equivalent circuit.

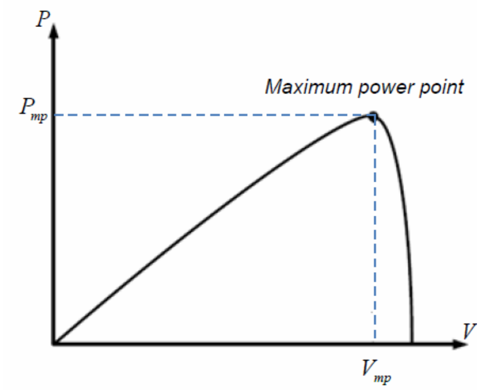


Figure 3: P-V curve for a PV module.

In Fig.2, the current source is used to model the incident solar irradiance, a diode representing the polarization phenomena, resistance represent the power losses. The mathematical equation is given respectively by:

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

where, I: PV current (A); I_{ph}: Photo generated current; V: PV voltage (V); I_{sat} : Diode saturation current; A typical (P-V) characteristic of a PV is shown in Fig 3.

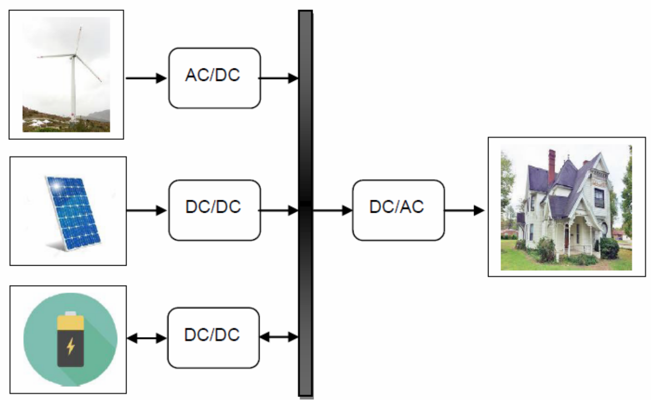


Figure 1: The Proposed Hybrid system.

MPPT control

Due to it precise perform even under the constant change in atmospheric conditions. The incremental conductance maximum power tracking algorithm is the most used method; it is based on that the slope of the PV power curve dP/dV is zero at the MPP, positive on the left, negative on the right

(2) $$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV}$$

The previous equation can be transformed into:

(3) $$\begin{cases} \dfrac{dI}{dV} = -\dfrac{I}{V} & at\ MPP \\ \dfrac{dI}{dV} > -\dfrac{I}{V} & \text{left of } MPP \quad V_{mp} \\ \dfrac{dI}{dV} < -\dfrac{I}{V} & \text{right of } MPP \end{cases}$$

The principle of this algorithm is shown in the Figure 4.

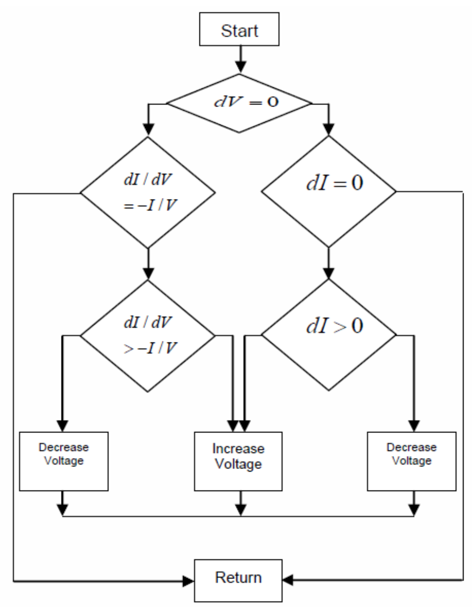


Figure 4: Increment Conductance.

Turbine model

The power contained in kinetic energy form at a speed Vv, surfaceA1, is expressed by[17]:

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

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

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

Where: C_p is power coefficient [18]. The speed ratio λ introduced by:

(6) $$\lambda = \frac{R\Omega_t}{V_v}$$

Where R is the blades length, Ω_t : rotor angular speed. The theoretical extreme rate of Cp is 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:

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

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

The slow shaft mechanical torque Ct is expressed by:

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

Mechanical system

Mechanical model will be represented in Figure 5

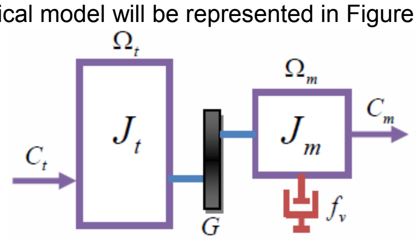


Figure 5: Mechanical model

where: Jt: the turbine inertia, while Jm: generator inertia, G: gearbox rate. The generator speed and the fast shaft torque are given in:

(10) $$\Omega_m = G\Omega_t$$

(11) $$C_m = C_t / G$$

Next,

(12) $$C_m - C_{em} = \left(\frac{J_t}{G^2} + J_m\right)\frac{d\Omega_m}{dt} + f_v\Omega_m$$

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 [19, 20]. Direct speed controller (DSC) is presented in fig 6, 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:

(13) $$\Omega_t^* = \left(\lambda_{opt} v\right) / R$$

Thus,

(14) $$\Omega_m^* = G\Omega_t^*$$

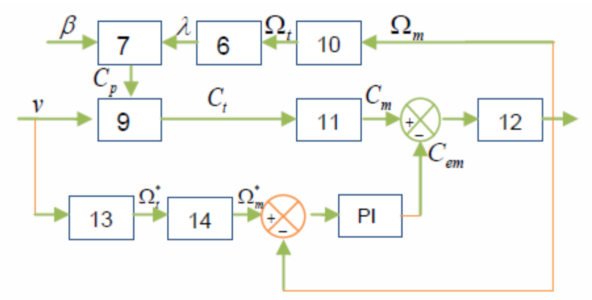


Figure 6: Direct speed control.

We obtain the active power reference by:

(15) $$P_{s\_ref} = C_{cem\_ref}\Omega_m$$

PMSG mathematical model

PMSG mathematical model in the dq reference is:

(16) $$U_d = R_s I_d + L_d \frac{di_d}{dt} - L_q i_q \omega_r$$

(17) $$U_q = R_s I_q + L_q \frac{di_q}{dt} + \left(L_d i_d + \phi_m\right)\omega_r$$

Thus, (16) - (17) can be indicated by:

(18) $$\frac{di_d}{dt} = -\frac{R_s}{L_d} i_d + \frac{L_q}{L_d}\omega_r i_q - \frac{1}{L_d} U_d$$

(19) $$\frac{di_q}{dt} = -\frac{R_s}{L_q} i_q - \frac{L_d}{L_q}\omega_e i_d - \frac{1}{L_q} U_q + \frac{1}{L_q}\phi_m \omega_r$$

The motion equation is:

(20) $$C_{em} - C_r = J\frac{d}{dt}\Omega_r + f_v \Omega_r$$

(21) $$J = \frac{J_{turbine}}{G^2} + J_g$$

Furthermore, consider Lq=Ld=Ls denotes the inductance of the stator.

Inverter modelling

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

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

Battery charging

The intermittent nature of renewable energy sources is the cause that storage systems play a significant role in the hybrid renewable system. Battery is a storage device which stores the excess power generated and uses it to supply the load in addition to the generators when power is required. PV, wind energy systems and battery bank are integrated to a common DC bus of constant voltage[5, 12, 15, 21]. 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. The control of this converter can maintain the DC bus voltage constant at its reference value as shown in 7. In this control technique, V_{dc} is detected and compared with the reference DC bus voltage. The error between these two values is applied to PI regulator. The output signal is the duty cycle D1 and D2 of the switches Q_1 or Q_2 of the converter. In addition, to evade degradation of the battery, the control signal is preserved within a limit of the SOC range.

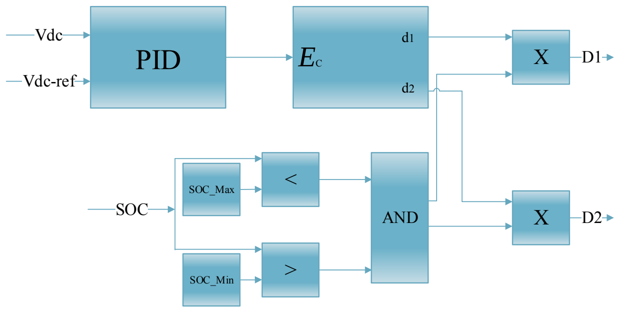


Figure 7: Control of the DC-DC bidirectional converter.

Proposed topology of power management

The flow chart of the power management proposed in this work is shown in Fig. 8.

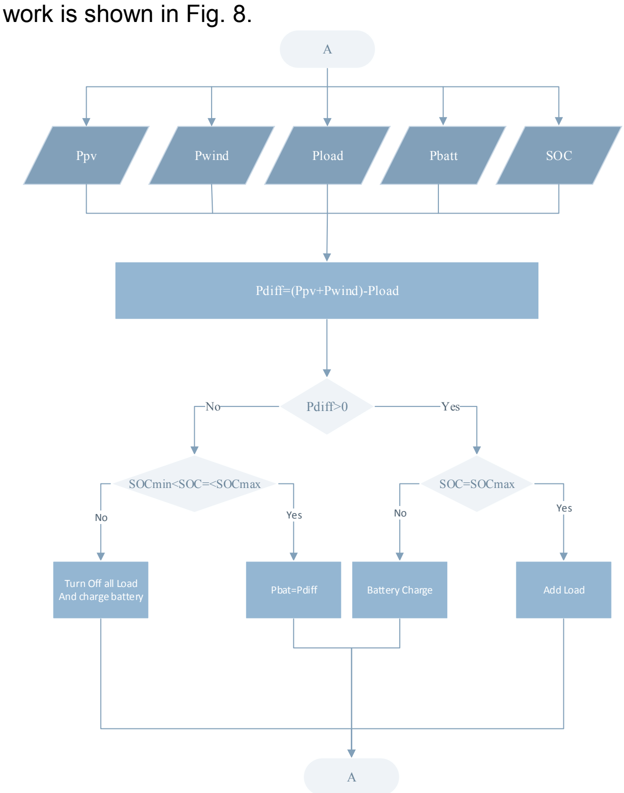


Figure 8: Power management flow chart of hybrid energy system.

where: P_{pv}: is the PV system power, P_{wind}: is the wind system power, P_{load}: is the load demand, SOC: is the state of charge.

Simulation results

The proposed standalone PV-wind hybrid system with energy storage is tested under different operating conditions and variable load condition as shown in Figure 9/10.

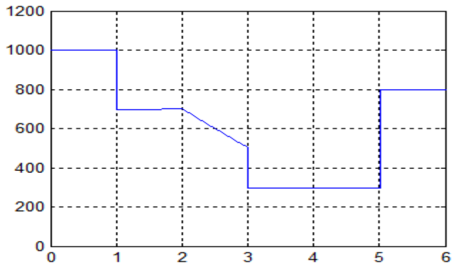


Figure 9: Irradiation Profile

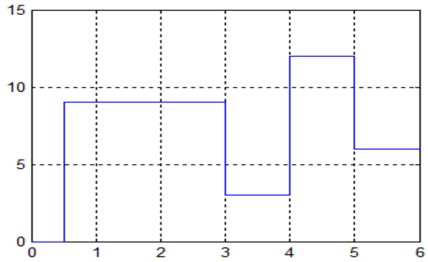


Figure 10: Wind Profile

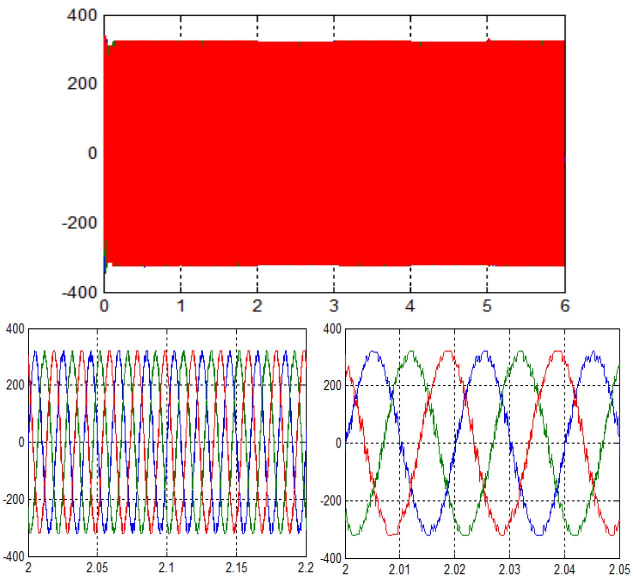
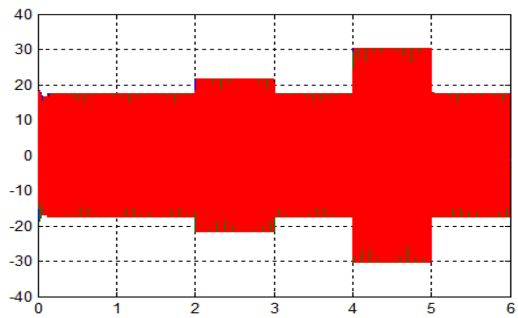


Figure 11: Output load Voltage



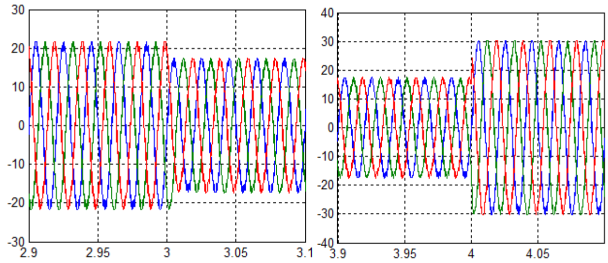


Figure 12: Output load current

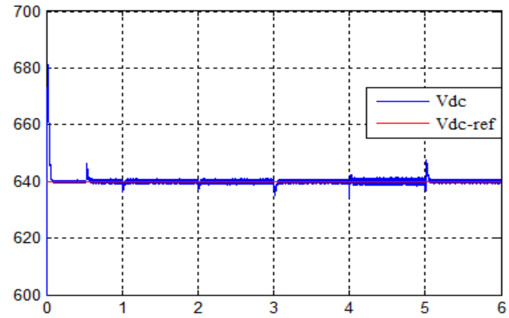


Figure 13: Dc-link voltage.

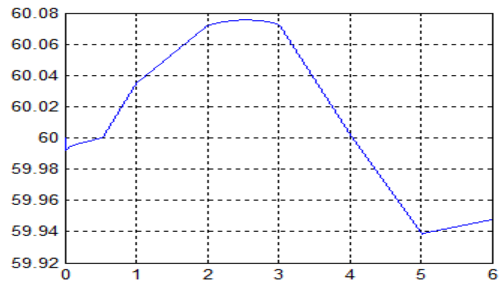


Figure 14: SOC

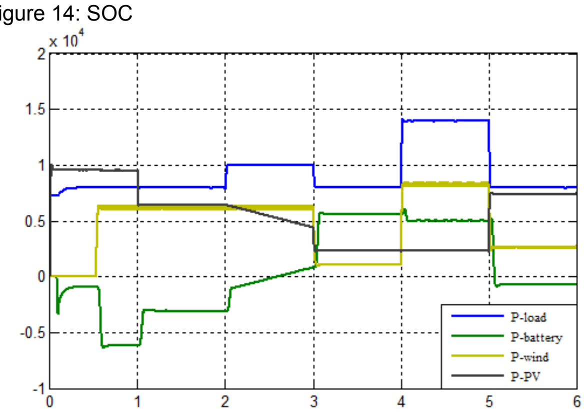


Figure 15: Wind-PV-Battery-Load Hybrid Power

The output voltage and load current response are shown in Figures 11 and 12, we can see clearly that load current increase and decrease whenever the load power change. Further, dc-link voltage is constant at 640V with a good precision and stability even with a change in hybrid power, load demand and under various weather circumstances, as shown in Figure 13.

Figure 15 shows the power distribution curve of all generated power sources. The PV and wind system manage to extract the maximum power even with the variation of the irradiance and wind speed as presented in figure 9 and 10, 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 bank power changes (discharge/charge) to maintain the power stability of the system as shown in figure 14. It is also can be seen that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency

Conclusion

The hybrid system becomes a viable way to produce electrical energy where grid connections are not available especially in rural areas plus it's eco-friendly. The system is also able to meet the variable load demand while maintaining dc-link voltage constant. It has been demonstrated that the proposed hybrid system performs satisfactorily under different dynamic conditions while maintaining constant voltage and frequency. The power balance between wind, PV power system, battery and load has been maintained while extracting maximum power for both sources. The simulation results showed the effectiveness of the integrated control strategy adopted.

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