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Modelling and Simulation of the Hybrid System PV-Wind

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Abstract In this paper, we focused on modeling and simulation of a hybrid solar-wind energy system, consisting of a photovoltaic cell and a wind turbine driven by a Permanent Magnet Synchronous Generator (PMSG). The proposed system gives details of the hybrid solar-wind system. In the PV subsystem, there will be a photovoltaic energy subsystem, MPPT controller, and a DC-DC boost converter. The wind turbine subsystem includes a wind turbine energy subsystem, PMSG, and MPPT controller. The MPPT controllers were designed to extract the maximum power regardless of the weather conditions and temperatures. The P and O algorithm is introduced in the MPPT used in the PV energy subsystem and on the control of the machine side converter (MSC). The proposed wind turbine energy subsystem is based on Direct Torque and Flux Control (DTFC). The simulated results are demonstrated to show that the hybrid solar-wind generating system can realize a maximum power point tracking control of wind and solar power to satisfy the energy demand over an extensive range under unpredictable atmospheric conditions. The system has been demonstrated by MATLAB/Simulink and tested for variable weather conditions and temperatures.

Keywords Wind energy generator, Photovoltaic energy generator, Permanent Magnet Synchronous Generator (PMSG), Maximum Power Point Tracking (MPPT), DC-DC Boost Converter

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1. Introduction

Energy is the most important of all resources. We need energy for light, to cook, and to keep us warm. The energy demand is constantly increasing, partly due to an increase in consumer needs, increasing population, and economic development. In recent years, wind energy and solar energy are considered alternative products in the energy electric system. Robust energy service is essential for economic development, to lift people out of poverty, increase the quality of education, and health services to empower women and children [1]. However, the majority of people living in developing countries (most of them located in rural areas) do not have access to any of the modern services including electricity, clean cooking, water purification, air conditioning, telecommunications, entertainment, and refrigeration [2]. Consequently, renewable energy resources (for example wind and solar) based off-grid become the most convenient solution to electrifying these areas [3][4][5].

In this paper, a hybrid solar-wind system is proposed to ensure a more stable energy-generating system. The proposed system ensures clean, reliable, and cheap energy on an annual basis. The system can adapt to the unpredictability of weather conditions and temperatures with two energy sources that can complement each other [3][6]. In other terms, the complementary nature between solar energy and wind energy. For example, there is high solar irradiation and relatively low wind energy in the daytime, while there is high wind energy but little irradiation at night[7][8]. The research includes using variable weather conditions and temperatures which are simulated in

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the MATLAB/Simulink environment to evaluate the efficiency of the system. The rest of the work is organized as follows. Section 2 provides a detailed analysis of the proposed system and the required electronic components (including interconnections). Section 3 describes the implementation of the PV system and its pilot strategy. Section 4 describes the implementation of the wind turbine system and its pilot strategy. Simulation results of the simulation are discussed in Section 5. Section 6 discussed modeling a Permanent Magnet Synchronous Generator (PMSG). Section 7 presents the results of the simulated proposed hybrid system. Finally, conclusions and references.

2. Proposed system description

The proposed system is made up of a wind turbine energy subsystem with a permanent magnet synchronous generator, a machine side converter, a direct torque, and flux control system, a PV energy subsystem, and a DC-DC boost converter. The hybrid solar-wind system is shown in Figure 1.

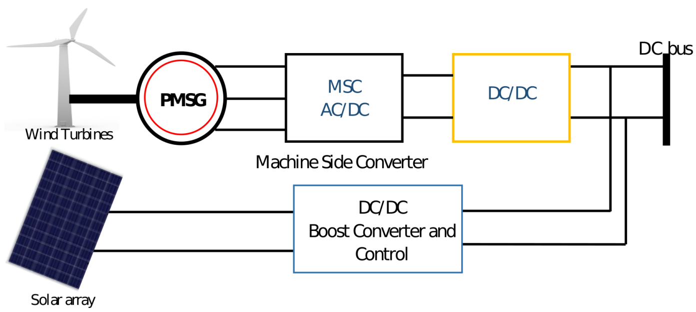

Figure 1. Diagram of the studied system.

3. Modelling of a Photovoltaic Generator

The PV cell (single diode) is modeled as a solar irradiance-dependent current source, photo-current (Iph) in parallel with the diode [7]. The single diode model of PV cells is simple and easy to implement and show in the circuit diagram in Figure 1 below. The circuit model is represented in the following equations. The circuit consists of an ideal diode in parallel with a photo-current, generated by photons [7].

$$Irs = Isc/(exp\frac{q.Vd}{n.K.T}) - 1 \tag{1}$$

$$Io = Irs[\frac{T}{Tn}]exp[\frac{q.Ego(\frac{1}{Tn} - \frac{1}{T})}{n.K}] \tag{2}$$

$$Iph = \frac{G}{Gref}[Isc + (Ki.(T - Tn))] \tag{3}$$

$$Ish = \frac{V + IRs}{Rsh} \tag{4}$$

$$I = Iph - Io.[exp\frac{q(V + I.Rs)}{n.Ns.K.T} - 1] - Ish \tag{5}$$

$$I = Iph - Id - Ish \tag{6}$$

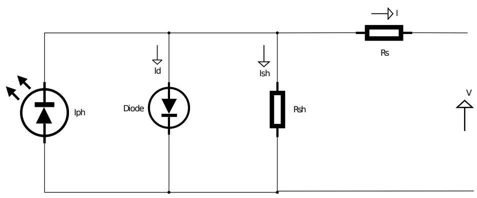

Figure 2. A single diode model of a PV cell circuit.

where Iph is the photo generated current, Id is the diode current, n is the ideality factor, Io output current, K is Boltymann constant, Rs is the series resistance, Ish is the current across (Rsh) shunt resistance, Vd is the diode voltage, Is saturation current of diode at T, and q is the charge on the electron.

3.1. Piloted strategy of the PV generator

Figure 3 shows a P and O pilot algorithm used in the PV energy subsystem. The MPPT calculates its location by oscillating on the power curve. From left to right, $\frac{dP}{dV}$ >0, the power increases while the voltage decreases[12]. From right to left, $\frac{dP}{dV}$ <0, the power decreases while the voltage increases[12]. At, $\frac{dP}{dV}$ =0 the photo-voltaic system reaches its maximum. The process has been simplified and shown in Figure 3.

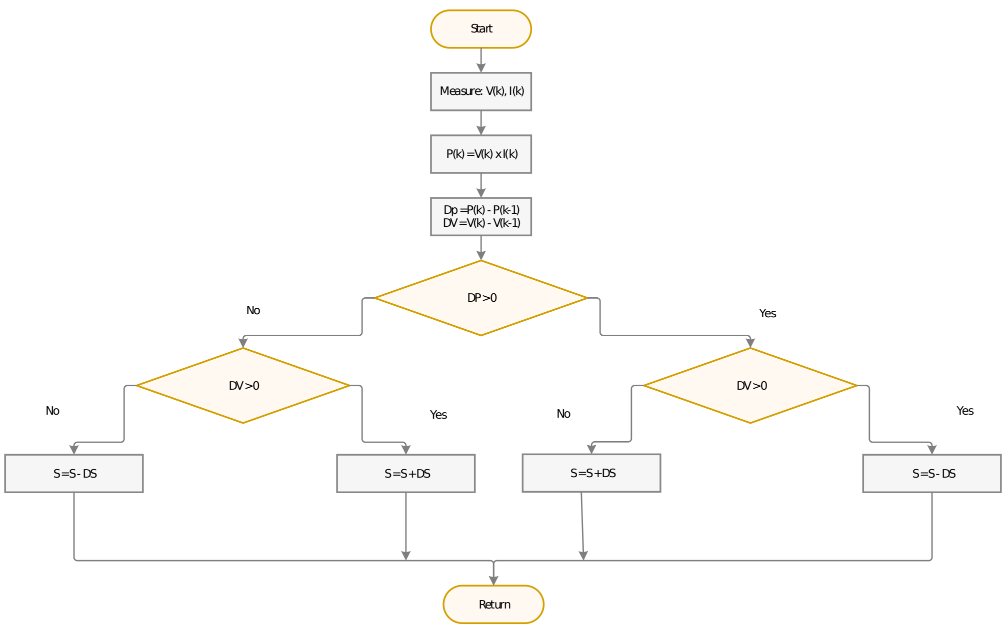

Figure 3. Diagram of pilot MPPT algorithm (P and O)

A change in light intensity on a photovoltaic cell affects the solar cell parameters, which include: short-circuit current Isc, open-circuit voltage Voc, and the efficiency of the cell. A reduction of sunlight resulting primarily in a reduction in current and consequently a reduced power output. At a constant temperature 25°C and variable irradiations, the characteristics of the P(V) and I(V) are shown in Figure 4[5].

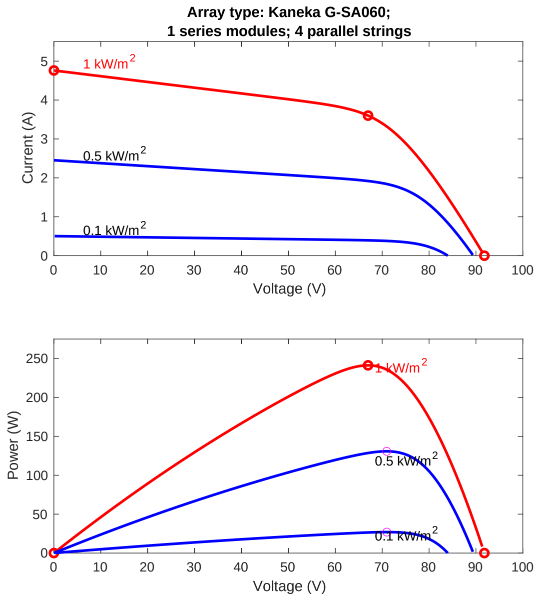

Figure 4. PV characteristics under variable weather conditions and constant temperature at 25°C

The output power and voltage of the DC-DC boost converter with a variation of radiation and temperature are shown in Figure 5[8].

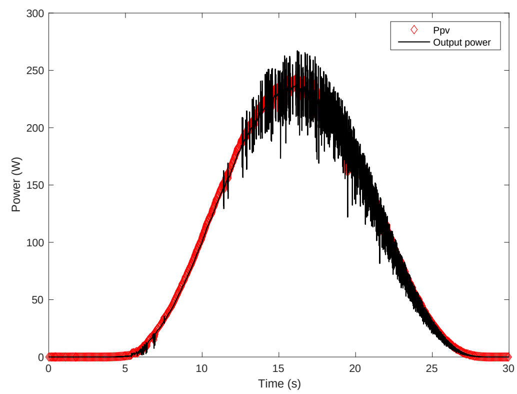

Figure 5. Photovoltaic generator characteristics when connected to DC-DC boost converter under variable irradiations Irrand constant Temperature at 25°C

The variation curve of the DC signal at the DC-DC boost converter output obtained is shown in Figures 5 and 6. The output voltage of the PV cell is 67V, which is increased considerably with a variety of radiations while the current value at the output decreases[8].

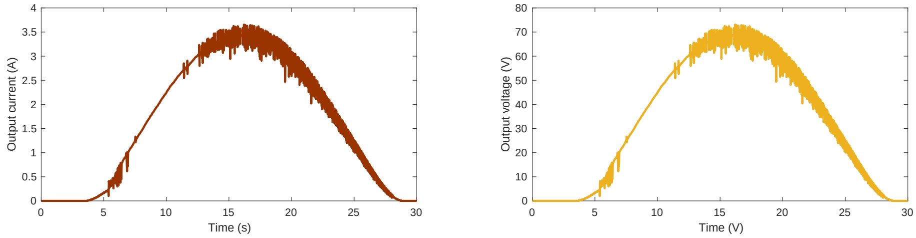

Figure 6. Voltage and current at the output of the boost converter.

Photovoltaic generator characteristics are shown in Table 1

Table 1. Kaneka G-SA060 module (60.3W) characteristics.

Parameters	Values
Ppm(W)	60.3
Vpm(V)	67
Ipm(A)	0.91
Rs(Ω)	0.161351
Isc(A)	1.19
Voc(V)	91.8
Ns	108
Rsh(Ω)	254.8275

The radiation is varied as shown in Figure 7: for the first few seconds, the irradiation is at its lowest, then it increases. Finally, it returned to its initial state when there was less penetration of the sun.

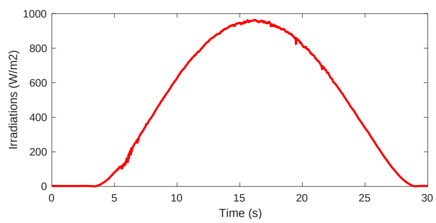

Figure 7. Variation of the radiation at 25°C

From Figure 8 below, we observed that a change in radiation leads to change in the output of the PV generator.

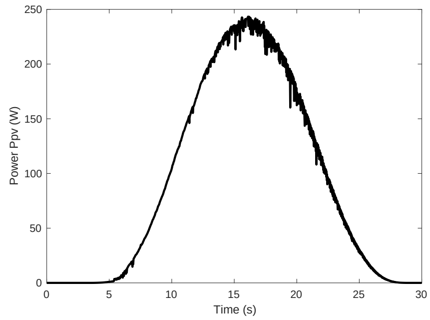

Figure 8. Output power of the photovoltaic generator.

4. Modulization of the wind turbine

The wind generator model comprises a wind turbine, a Machine Side Converter (MSC), a Direct Torque and Flux Control, and a PMSG that produces electricity from the mechanical energy obtained from the wind [8].

4.1. *Modelling of the wind turbine*

The wind turbine is a mechanical device that extracts the energy of moving air and converts it into useful work (Mechanical power that can be characterized by speed of rotation and mechanical torque)[9]. This work can be used for generating electrical power when combined with a generator[10]. The factors that determine the relationship between wind energy and the recovered mechanical energy are wind speed, air density, and the area swept by the rotor.

$$Pt = \frac{1}{2}Cp(\beta, \lambda)\rho\pi R^2 Vm^3 \tag{7}$$

The power coefficient varies depending on a given turbine[8][9]. The expression of the power coefficient has been approximated, for this turbine, the following Cp is given:

$$Cp = C1[((\frac{C2}{\lambda.i}) - C3\beta - C4)exp\frac{-C5}{\lambda.i} + C6.\lambda \tag{8}$$

And the tip speed ratio is demonstrated as:

$$\lambda = \frac{\Omega m.R}{Vm} \tag{9}$$

Where: C1 to C6 represents coefficients of wind turbine characteristics (C1=0.51, C2=116, C3=0.4, C4=5, C5=21, and C6=0.0068), β is the pitch angle, Vw is the wind speed, Ωm is the turbine speed, ρ is the air density, R is the rotor radius, and λ is the tip speed ratio.

4.2. *Piloted strategy of the wind generator*

The Tip speed Ratio method is the technique that is commonly used to extract the maximum power because of its simplicity and independence to wind turbine characteristics. The algorithm consists of determining the speed of the wind which makes it possible to obtain the maximum power generated. This MPPT control strategy is without wind speed measurement. An optimal tip-speed ratio max that corresponds to the maximum power coefficient (Cpmax) is fixed. Given the difficulties of measuring the wind speed, an estimate of its value can be obtained.

Control strategy for the Machine Side Converter (MSC):

The principle of Direct Torque and Flux Control is based on directly selecting the appropriate stator voltage vectors according to the differences between the reference and actual values of the magnitude of the stator flux vector and the electromagnetic torque[11]. In this research, the Direct Torque Control implementation is done with Space Vector Modulation (DTC-SVM). Space Vector Modulation is an algorithm for the control of Pulse Width Modulation (PWM)[11]. It ensures lower harmonics of stator current and allows to reduce the electromagnetic torque ripple. it also presents the possibility of maintaining the constant switching frequency[11].

5. Simulation Results

- Data and parameters of the wind turbine system; Rated power Pwt=586W at 12.5m/s; diameter, R=1.15m.
- Data and parameters of PMSG generator: rated power Pe=10kW; stator resistance, Rs=0.05Ω; stator dq-axis inductances, Ld,Lq=0.645mH; permanent magnet flux ψf=0.192Wb; rated speed, ns=100rad/s; and pole pairs P=4.

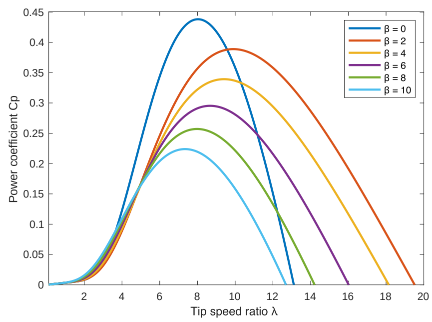

Figure 9. Curves of power coefficient Cp for different values of tip speed ratio λ and blade pitch angle β

Figure 9 shows that for each value of the blade pitch angle, there is a certain optimal value of the tip speed ratio for which the power coefficient reaches its maximum value. It also shows that the power coefficient is at its maximum Cpmax=0.45 at which λ opt=8.02 and so do Figures 10 and 11 respectively.

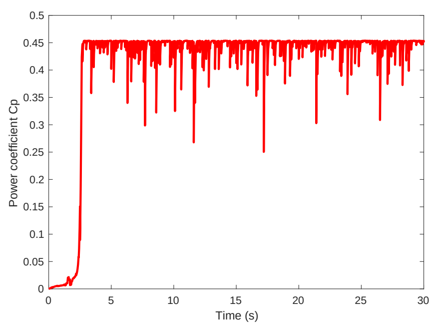

Figure 10. Power Coefficient Cpmax

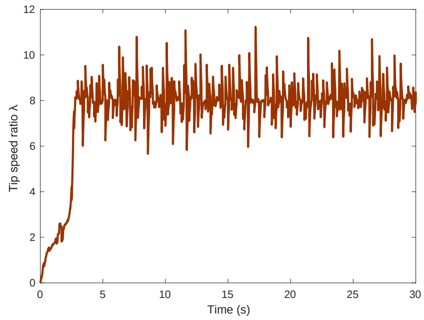

Figure 11. Lambda optimal λopt

6. Modelling of the PMSG

PMSG is suitable for wind turbines as it is stable and secure during operation[11]. The PMSG choice allows direct-drive systems that avoid gearbox use thus low maintenance[10]. The mathematical model of the PMSG is divided into parts; electric, magnetic, and mechanical as defined by the following equations[11]:

Electric equations:

$$Vd = -Rs.Id - \frac{d\omega d}{dt} + \omega e.\omega q \tag{10}$$

$$Vq = -Rs.Id - \frac{d\omega q}{dt} + \omega e.\omega d \tag{11}$$

with

$$\omega d = Ld.Lq + \psi f \tag{12}$$

$$\omega q = Ld.Lq \tag{13}$$

$$\omega e = P.\omega g \tag{14}$$

Electromagnetic torque:

$$Tem = \frac{1}{2}[(Ld - Lq)Id.Iq + Iq\psi f] \tag{15}$$

Mechanical equation:

$$Tm - Tem - f\Omega m = J\frac{d\Omega}{dt} \tag{16}$$

Where: Rs is the stator resistance, (Ω) Ld and Lq are the inductances (H) of the generator on the d and q axes, ψf is the permanent magnetic flux (Wb), ωe is the electrical rotating velocity of the generator (rad/s) of the PMSG rotor, Tem is the electromagnetic torque (N.m), Tm is the mechanical torque applied to the generator, f is the viscous coefficient of friction, J is the total moment of inertia of the machine, P is the number of generator pole pairs, ωe and ωg are respectively the electrical rotating velocity (rad/s) and the mechanical rotating velocity of the generator[13].

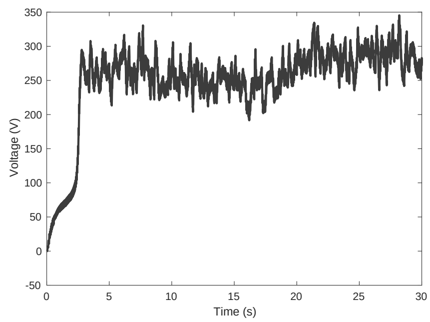

Figure 12. Output voltage Vdc of the wind turbine

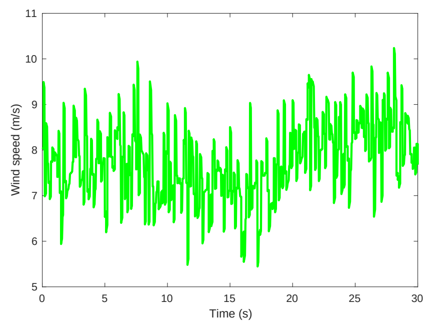

Figure 13. Variation of the wind speed.

In Figures 12 and 13, we observe that the output DC voltage and the output power follow the variation of the wind speed in Figure 14.

7. Hybrid system PV-Wind simulation

The hybrid system PV-Wind is made up of a Kaneka-GSA060; 1 series module; 4 parallel strings, Air X wind turbine driven by permanent magnet synchronous generator (PMSG). The power generated from the wind turbine, photovoltaic cell, and sum of wind/photovoltaic are shown in Figure 15 below. From the figure we observed that P(pvw) is the sum of the power generated from the wind turbine and photovoltaic cell.

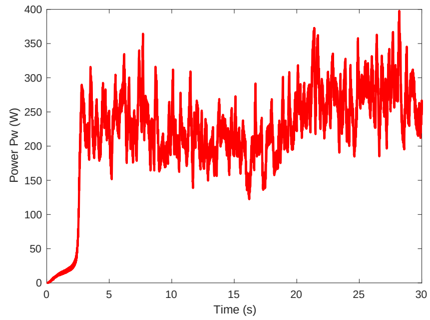

Figure 14. Wind turbine generator power.

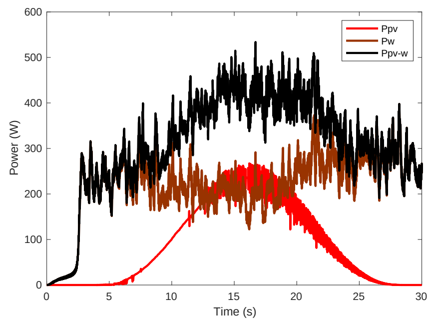

Figure 15. Photovoltaic, Wind, and sum of the wind and photovoltaic generators power

8. Conclusion

In this paper, modulization and simulation of a hybrid renewable energy system have been performed. The proposed system comprises a wind turbine energy subsystem with a permanent magnet synchronous generator and photovoltaic energy subsystem. The objective is accomplished by ensuring a stable desired power flow to the load under different weather conditions and temperatures. The simulation demonstrated the effectiveness of the proposed system. In summary, the proposed system and control strategy achieved their intended objectives.

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