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Simulation Model of Hybrid Renewable Sources Integration Using MATLAB/Simulink

Abdelrahman. M. Elgarhy*, Mohamed Talaat, Mohamed.A. Farahat

Electrical Power and Machines, Faculty of Engineering, Zagazig University, P.O. 44519, Zagazig, Egypt

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ABSTRACT

Renewable energy is an indispensable source at present, where many resorted to the use of renewable energy, but there is a problem as a discontinuous source, according to climatic conditions and the surrounding environment. Thus, researchers worked on a new system to control climate changes affecting the production of renewable energy, which is a Hybrid system where uses more than one source to maintain energy continuity and uses an energy storage system. In this paper, three different sources of renewable energy (solar energy - wave energy - fuel cell energy) are integrated and an energy storage system was used. Buck-boost converter circuits were used in the three sources and connecting them to the DC bus bar. The inverter was used to convert from DC to AC to supply the load. A new integrating system was used to connect three sources and store energy at the same time from the surplus energy. When there is a problem with one of the sources, the battery bank feeds the system directly. The simulation model of the whole hybrid power system is implemented using Matlab / Simulink. It is clear from the results that the controller has high efficiency and accuracy and has the ability to integrate more than two sources.

Nomenclature

$r_{o\,hm}$	Internal resistance (Ω)	FC	Fuel cell
E_{oc}	Open circuit voltage	I_p	Parallel resistance current.
i_{FC}	FC current (A)	ρ	water density (998 kg/m^3)
V_{FC}	FC voltage (V)	I_S	Diode saturation current
I_o	Exchange current (A)	q	Electron charge.
T_d	The response time (at 95% of the final value) (sec)	HHV_{H_2}	Higher heating value of the hydrogen fuel
V	terminal voltage of the cell	$\dot{m}_{H_2}$	Mass flow rate (Kg/s)
T	cell temperature	A	Tafel slope (V)
g	gravity term (9.81 m/s^2)	T	wave time period
H	incoming wave height	b	width of the rotor (1 m)
λ	Wavelength	h	water depth
I_λ	Photocurrent.		

*Corresponding author. Tel.: +2- 01065428343
E-mail address: a.garhy21@eng.zu.edu.eg

1. Introduction

Renewable energy is constantly increasing with the decrease of traditional energy resources, and the concerns increasing from the decline of traditional energy and with the increasing environmental costs due to its production, and at the same time, alternative energy appears that makes us move towards a sustainable future[1]. Renewable energy sources (solar energy - wind energy - wave energy ...... etc.) take a lot of attention as an alternative to conventional energy, not only because of diminishing fuel sources but also due to environmental pollution and global warming problems[2]. One of the best new energy sources is solar energy, as it is considered to be less expensive at present, but there are some problems in controlling the energy output at different times of the sun, and therefore a merging of another renewable energy system with the solar energy source has been made, so the fuel cell energy is combined with the energy The solar system is considered an integrated system as it maintains continuous power generation throughout the day[3, 4] Most of the new and renewable energy sources are not available 24 hours, so energy storage devices such as batteries are used, but this method is very expensive, so researchers have studied a hybrid system which is the link between solar energy, fuel energy, and batteries, as this system needs to design control circuits to link the sources together[5].A hybrid system is designed that combines three sources of renewable energy and diesel and the design of a weather forecast system in order to maintain the continuity of the production of electrical energy to feed the boats where solar energy, fuel cells ,and the diesel engine were used where they are automatically converted to the diesel engine when the rate of renewable energy production decreases and this system is simulated on Simulink[6]. A hybrid system was developed to integrate three sources of renewable energy. Three renewable energy sources have been selected. Each of them has a different nature. These sources are wave, wind and solar energy. This study was based on a buck-boost converter. The three sources were practically tested. A new turbine was tested to generate wave power. This turbine is a savory rotor wave turbine. The results obtained by the researchers showed the effectiveness of this controller and its ability to integrate the three sources[7]. Another study has been conducted to study the feasibility of integrating the wave, wind, and solar energies taking into account the possibility of determining the operating reserve. The different nature of the three sources increases the reliability of the system. It was found that operating reserve is very important in renewable energy systems as a result of the Irregular nature of renewable energy sources. The results of this study showed that operating reserves increased the efficiency and reliability of the power systems[8]. Several renewable energy sources such as wind energy, solar energy, wave energy, and fuel cells were displayed. Hybrid energy was produced from these sources, and the merger system was worked on due to these sources seasonal and daily climate changes. Therefore, energy storage systems were used to improve energy quality. A full study has been made on most of the expected possibilities of sudden changes in this system through simulation programs[9]. DC / DC converters and DC / AC transformers were used to transmit and convert energy to feed the loads and the loss ratio during the conversions was maintained to obtain a high quality[10]. In this paper, the design of the hybrid energy system presented combines three sources of renewable energy (solar energy - wave energy - fuel cell energy) to obtain the best energy amount and to maintain the continuity of supplying the loads. The energy storage system was used due to the changing climatic conditions to obtain the best result. A new system was used to link two sources and more and at the same time activate the storage system to be used automatically when a problem occurs with any of the three sources. The system is simulated on MATLAB / Simulink.

2. Paper contributions

This paper presents a new model for integrating wave energy, fuel cells and solar energy. This paper presents many contributions, which are explained below:

1- This study is one of the first studies focus on the integration of wave energy with other sources such as fuel cells and solar energy.

2- The study of the integration of the three sources under different operating conditions, which contributes to the assurance of the efficiency and effectiveness of the controller.

3- The dynamic performance of the used hybrid system is investigated under different weather conditions.

4- individually control is done in each of the three sources, in addition to controlling the whole system.

3. Methodology and design analysis

To maintain the stability of the system and reduce the problems of renewable energy, more than one source must be integrating together to cover the existing and expected loads, and therefore a new controller is designed to incorporate three different renewable energy sources. The controller unit works to reduce the changes in the output voltage of each source, where these changes result from the irregularity of renewable energy sources. Renewable energy sources cannot be relied upon without controlling them. Therefore, a controller is designed to regulate load feeding and to integrate more than one renewable energy source. The control unit that links more than one source has been developed to supply the loads when the electric power output is low by the determination of the operating reserve required to be stored. In this paper. Three different sources are controlled and combined in a new way through the logic circles as shown in Fig.2. The energy sources are considered, and if the power generated is greater than the required capacity, only two sources are combined and the third source is connected to the battery bank and thus the largest amount is preserved of energy. The energy produced by the solar system, wave energy conversion system, and fuel cell system are all DC energies, so a DC-DC converter is designed for this system and connected to the control unit that is designed and determining the operating reserve for each source of energy. The inverter is used to convert from DC to AC and excess energy is fed to the batteries to be used when needed. The block diagram of the system is shown in Fig.1.

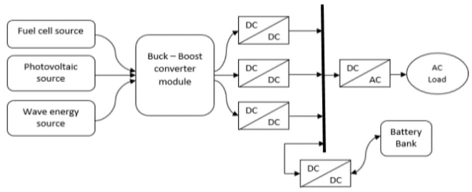

Fig.1.The block diagram of the integration system

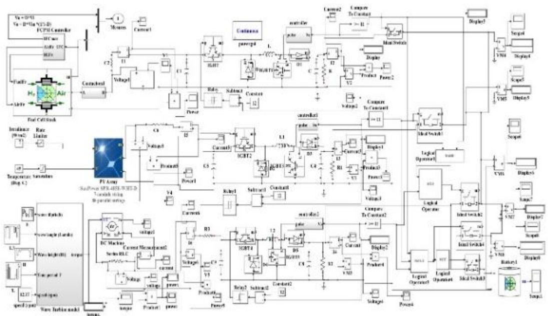

Fig.2. Connection diagram of the proposed hybrid system.

4. Hybrid energy system components description

The proposed integrated system is used to make the most of the energy sources. It can achieve a higher generating capacity compared to the systems that operate on a single power source. The hybrid system improves the reliability and stability of the system. Fluctuations in off-grid renewable energy systems can be avoided regardless of weather conditions. The hybrid energy system used in this paper consists mainly of fuel cells, wave energy and solar energy conversion system, a suitable energy storage system, inverter in addition to the proposed control unit that integrates the three sources together. The proposed system is shown in Fig.2.

4.1. Solar photovoltaic system

Solar energy is the energy obtained through solar radiation. The process of energy generating from the PV energy system depends on converting the power coming from the sun radiation into direct current (DC) electricity using semiconductors. This energy is constantly present on Earth and in large amounts. The problem of solar energy is the difficulty of producing energy in bad weather conditions and at night. But it is more efficient than other sources. The sun is the original source of all other sources used to produce energy. PV solar panels consist of a number of cells. The photovoltaic cell is considered the main part of the photovoltaic array. It is a p-n junction device. The equivalent circuit of the solar cell is shown in Fig.3[11].

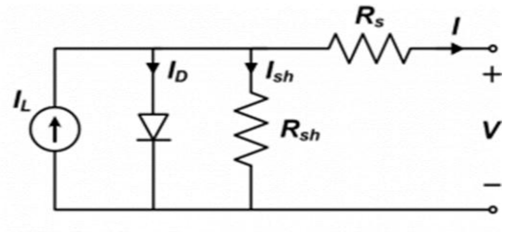

Fig.3.The electrical equivalent circuit of a solar cell.

The net current equation of the solar cell is given below[12, 13].

$$I = I_L - I_S\left[\exp\frac{q(V+IR_S)}{NKT} - 1\right] - \frac{(V+IR_S)}{R_{sh}} \qquad (1)$$

where

I_S Diode saturation current.

q Electron charge.

V Terminal voltage of the cell

N Diode ideality factor.

K Boltzmann constant.

T Cell temperature

The PV module used in this paper is shown in Fig.4. The technical parameters of the PV generator used in the proposed hybrid system are shown in Table 1. It consists of 40 parallel strings. Each of the parallel strings consists of one series connected module of Sun power SPR-415E-WHT-D.

Table. 1. PV module parameter.

Parameters	Values
Maximum Power P_{max}	416
Cells per Module	130
Voltage at P_{max}	73.8
Current at P_{max}	5.69
Open circuit voltage V_{oc}	86.2
Short-circuit Current I_{sc}	7.01
Shunt Resistance R_{sh}	419.7813
Series Resistance R_s	0.5371
Light-generated current I_L	6.0978
Diode ideality factor	0.87223

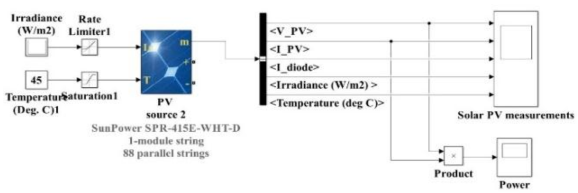

Fig. 4. Solar PV model in Matlab/Simulink.

4.2. Fuel cells (FCs)

The FC is an electrochemical cell used in energy conversion without any mechanical process. It is used to convert chemical energy into electricity. Electricity is produced by reduction and oxidation reactions it depends on three main components a fuel, an oxidant, and an electrolyte. It depends on the reaction of H_2 and O_2 to produce DC electricity with the help of an electrolyte. It uses H_2 as a fuel, O_2 as an oxidant, a proton exchange membrane as an electrolyte, and emits only water as waste. These cells are characterized by the absence of combustion and thus avoid the side effects of combustion such as greenhouse gas emissions. It is a good and efficient choice for use with irregular energy sources such as wind energy and solar cells, as it is characterized by high efficiency and fast response to load and fuel flexibility. It does not need to be recharged as in batteries. It has been proven that it works in coordination with the photovoltaic systems successfully for both on-grid and off-grid systems. The parameters of the FC stack that has been chosen are shown in Table 2. The output voltage of FC is calculated using Eq. 2[14-16]. In the present paper, fuel cells are used to be integrated with Solar and wave energy conversion systems to cover the load to avoid the problem of Irregular electricity production from renewable energy sources[11].

$$V_{FC} = N(E_{oc} - A\ln\left(\frac{i_{FC}}{i_0}\right) . \frac{1}{sT_d\ /\ 3\ +1} - r_{ohm} . i_{FC}) \qquad (2)$$

The FC power is given by

$$P_{FC} = N\ x\ V_{FC}\ x\ I_{FC} \qquad (3)$$

The FC electrical efficiency is given by[17].

$$\eta_{FC} = \frac{P_{FC}}{m_{H_2} HHV_{H_2}} \qquad (4)$$

where

E_{oc} Open circuit voltage (V)

N Number of cells

A Tafel slope (V)

i_0 Exchange current (A)

T_d The response time (at 95% of the final value)

r_{ohm} Internal resistance (Ω)

i_{FC} FC current (A)

V_{FC} FC voltage (V)

$\dot{m}_{H_2}$ Mass flow rate (Kg/s)

HHV_{H_2} Higher heating value of the hydrogen fuel

Table 2: Fuel stack parameters

Open circuit voltage	65
Nominal operating point	I=133.3 A , V= 45V
Maximum operating point	I_{max}=255 A $V_{max} = 37\ V$
Number of cells	65
Nominal stack efficiency (%)	55
Operating temperature	65
Nominal air flow rate (lpm)	300
Nominal supply pressure	H_2:1.5bar, Air: 1bar
Nominal composition (%)	H_2:9.95, O_2:21, H_2O(Air):1

4.3. Wave energy conversion system

The electric energy that is produced from the waves is considered promising energy and the focus of the attention of many countries of the world. The seas and oceans cover a large area of the earth, therefore researchers believe that they must have a significant role in the global energy output. Therefore, researchers recently started seeking to achieve the maximum benefit from them. In this paper, a wave energy conversion system is designed. This model works in the case of irregular waves through the Matlab Simulink environment. The turbine used in the wave energy conversion system is called savonius turbine. It is implemented in the Matlab Simulink environment. It has been used in wind energy conversion systems and recently began to be used in wave energy conversion systems. The energy produced by the wave turbine is affected by the depth of the water, the wavelength of the wave, the height of the wave in addition to the time period. The block diagram of the wave energy conversion system is shown in Fig.5.

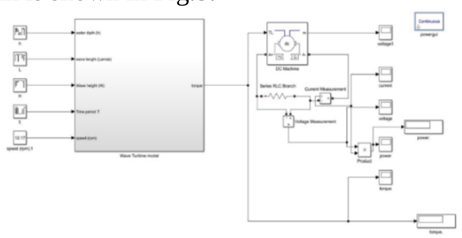

Fig.5.The block diagram of the wave energy.

4.4. Battery storage system

The response of renewable energy sources to feed the loads is somewhat slow so it should be improved by adding energy storage systems. The surplus of electrical energy resulting from the hybrid system is stored in a battery bank to use this surplus in the event of a shortage in electricity production from the three systems used in this paper. Sometimes the energy produced by the three systems is not sufficient to cover the required loads, so the energy that was previously stored in the energy storage system has resorted.– Battery bank sizing mainly depends on a variety of different factors. These factors are temperature correction, rated power capacity, battery lifetime, depth of discharge (DOD), etc. Lead-acid batteries are usually used in renewable energy systems as the initial and maintenance costs for this type are much lower than for other types. A 12-Volt Lead-acid battery is being utilized as a part of the hybrid system. Battery specific specification is shown in (Table 3). The required battery capacity is determined through this equation[18].

$$B_{rc} = \frac{E_c\ x\ D_s}{DOD_{max}\ x\ \eta_t} \quad (5)$$

where

DOD_{max} Maximum depth of discharge

D_s Battery autonomy days

E_c Electrical load in ampere hour (Ah).

η_t Temperature correction factor.

Table 3: Battery Specification

Parameter	**Value**
Type	Lead acid 12ICS150
Nominal voltage	12V
Float voltage	2.25V/cell@25℃
Number of cells	6
Rated capacity	150 AH
Max. charge current	37.5A

4.5. Inverter

The inverter is an electrical device used to convert Direct Current (DC) to Alternating Current (AC) to cover AC loads. When sizing the inverter, it should be noted that the rated power of the inverter must be higher than the maximum load at a value between 20-

25% [19-21]. The block diagram of the inverter used in the Simulink model is shown in Fig.6.

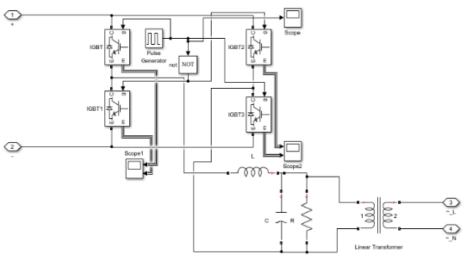

Fig.6. Block diagram of the inverter

4.5.1. Inverter circuit design

A Single-phase voltage source inverter was made with a Simulink model with the help of four IGBTs, one 470μF capacitor, and a 12V dc voltage supply. 10Ω resistor is used as an output load. We have run or simulated this circuit at a 50% duty cycle.

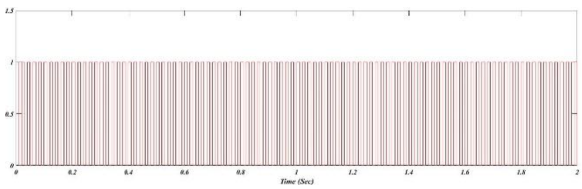

Fig.7.The pulse generator for the inverter

This design converts and step up the voltage from 12V DC to 220V AC with 4 IGBT by controlling through pulse generator on IGBT gates as shown in Fig.7 and the output voltage after the inverter as shown in Fig.8.

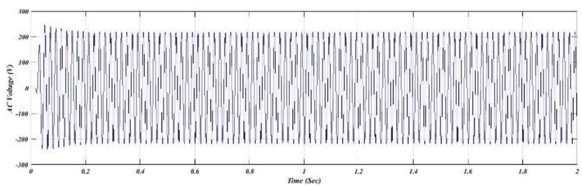

Fig.8. AC output voltage

The design parameters and the values of components of the buck-boost converter are presented in table 4.

Table 4. The design parameters

Parameters	Values
Supply voltage (Vs)	4 to 100 V
Output voltage1 (Vo)	12 VDC
Output voltage2 (Vo)	220VAC
Capacitor C1	1000μF
Capacitor C2	17 μF
Inductor (L)	21.12μH

Logic circuits were used to control the connection between the three sources in terms of loading on the inverter and charging the batteries. When the conditions for merging two or three sources together are fulfilled, logic circuits are activated, According to the following cases,

- When the three sources are effective and the load is small so that it is possible to supply the loads from only two sources, one of the sources is transferred to charge the batteries.
- When one of the sources is not working, the loads are fed directly from the effective sources.
- When one of the sources is not working and the loads are greater than the energy generated, a battery bank is added with the effective sources to supply the loads.

5. Controller

5.1. Buck converter

The DC-DC converter is used to step down the input voltage for a constant output voltage by controlling the switch on-off, as shown in Fig.9. To make auto-tuning for buck converter, must be setting the minimum, maximum input voltage, determine the output voltage and the maximum output current. Determine the inductor, capacitor, and duty cycle for buck converter circuit by equations:

$$L = \frac{V_{out} * (V_{in} - V_{out})}{\Delta I_l * f_s * V_{in}} \quad (6)$$

$$C_{out} = \frac{\Delta I_l}{8 * f_s * \Delta V_{out}} \quad , \; V_o = D\, V_{in} \quad (7)$$

where:

ΔI_l : Estimated inductor ripple current, assume 5% to 10%

f_s Minimum switching frequency of the converter.

ΔV_{out} Desired output voltage ripple, assume 15%

- Power is transmitted through the existing coil where it makes charging and discharging.
- Resistance is used immediately after the source to keep the current running continuously.
- In this circuit, Turn on and off time controlled.
- The required value is set and the circuit controls the duty cycle.

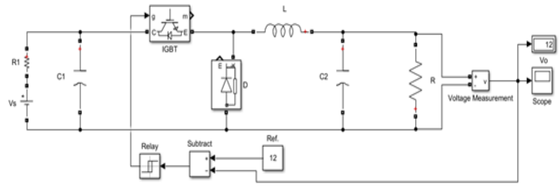

Fig.9. Buck converter circuit.

5.2. Boost converter

The DC-DC converter is used to convert the irregular DC voltage to regular DC voltage, the output voltage is higher than the input voltage, as shown in Fig.11. PID control was used in Boost converter to make automatic voltage adjustment by duty cycle control from equation (8) and shown in Fig.10

- Determine the inductor, capacitor, and duty cycle for buck converter circuit by equations:

$$P + I\frac{T_s}{2}\frac{1}{z-1} + D\frac{N}{1+NT_s\frac{1}{z-1}} \qquad (8)$$

where,

T_s Discrete – time

P Proportional control

I Integral control

N Filter coefficient

$$L = \frac{V_{in}*(V_{out}-V_{in})}{\Delta I_l * f_s * V_{out}} \qquad (9)$$

$$C_{out} = \frac{I_{out}*D}{f_s * \Delta V_{out}} \qquad (10)$$

$$V_o = V_{in} * \frac{1}{1-D} \qquad (11)$$

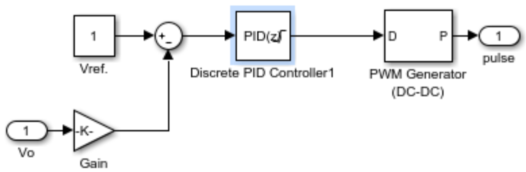

Fig.10. PID control circuit.

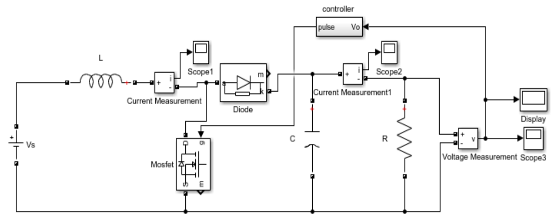

Fig.11. Boost converter circuit.

where:

ΔI_l : Estimated inductor ripple current, assume 5% to 10%

f_s : Minimum switching frequency of the converter.

ΔV_{out} : Desired output voltage ripple

D : Duty cycle

5.3. ***Buck-boost converter***

The output voltage is controlled by changing the duty cycle of the buck converter and the boost converter to obtain a constant output voltage. In the case of the input voltage greater than the output voltage, the duty cycle of the buck converter is controlled and in the case of the input voltage is less than the output voltage. The duty cycle of the boost converter is controlled, as shown in Fig.12.

The voltage was controlled from 4 V to 100 V to get 12 volts by buck-boost converter with closed feedback.

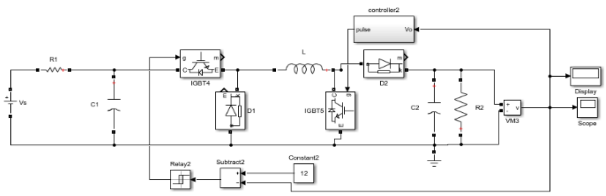

Fig.12. Buck-Boost converter equivalent circuit.

- The proposed control is implemented through experimental correction and theoretical analysis based on the traditional buck-boost control strategies, the Buck mode modulation in the proposed control strategy share hysteresis relay control, and Boost mode modulation in the proposed control strategy share PI control as in the traditional boost-mode control strategy.

- In this design, the integrated buck-boost converter was made to control the input source from 4V to 100V to get a constant voltage of 12V DC.

6. Results and discussion

6.1. Wave energy system results

Fig.13 shows the resulting power of the wave energy conversion system, where the resulting power value was about 88 watts. The controller is set to adjust the voltage at 12 V, as shown in Fig.14, and the value of the output current was about 7.3 A, as shown in Fig.15. The energy produced by the wave energy conversion system depends on five factors. These factors are wave speed, wave height, wavelength, water depth, and periodic time. These factors affect the torque, which in turn is the input to the DC machine.

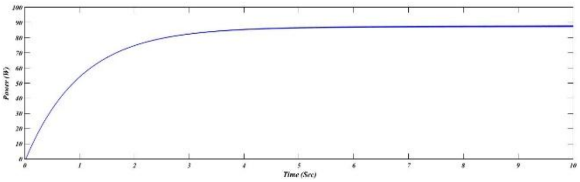

Fig.13.The simulated output power of the wave energy conversion system as a function of time variation

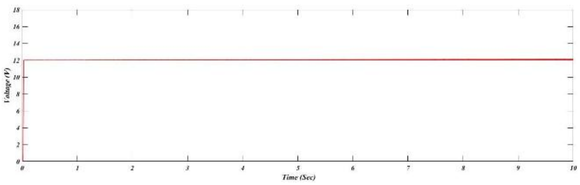

Fig.14.The simulated output voltage of the wave energy conversion system after using the controller as a function of time variation.

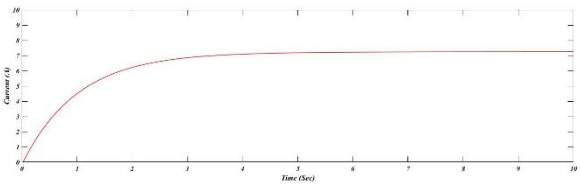

Fig.15.The simulated output current of the wave energy conversion system as a function of time variation

6.2. Fuel cell system results

The output voltage of the fuel cell system is adjusted using the controller, which is designed depending on the buck-boost technology. The output voltage of the fuel cell system before using the controller reaches 68 V as shown in Fig.16. The output voltage of the controller is 12 V as shown in Fig.17. Fig.18 shows the resulting power of the fuel cell system, where the resulting power value was about to 86 while the value of the output current reaches about 7.1A as shown in Fig.19.

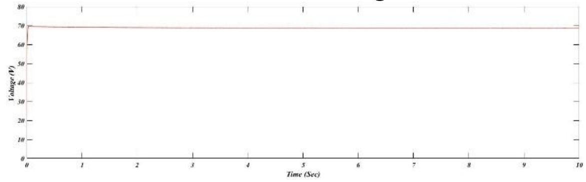

Fig.16.The simulated output voltage of the fuel cell system before using the controller as a function of time variation.

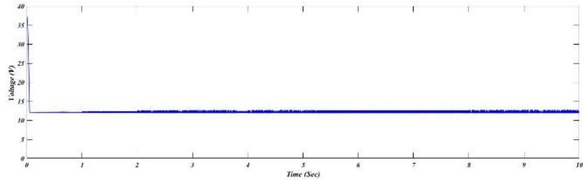

Fig.17.The simulated output voltage of the fuel cell system after using the controller as a function of time variation.

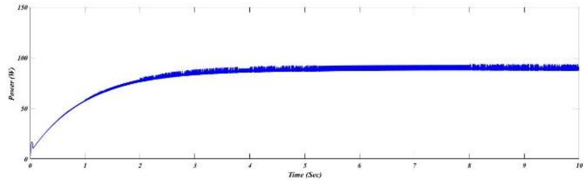

Fig.18.The simulated output power of the fuel cell system as a function of time variation.

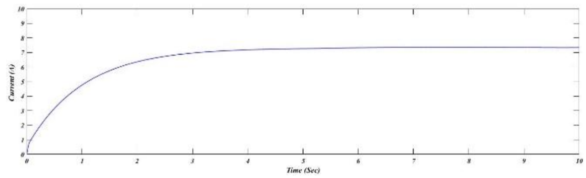

Fig.19.The simulated output current of the fuel cell system as a function of time variation.

*6.3. **Solar system results***

The output power of the solar system depends on the irradiance and temperature. Illustrates the simulated output voltage of the solar system before using the controller, as shown in Fig.20, The value of voltage changed depending on the irradiance as the temperature is constant. After using the controller the voltage reaches the desired value of 12 V as shown in Fig.21. Fig.22 shows the resulting power of the solar system, where the resulting power value was about 87 W while the value of the output current reaches about 7.2 A as shown in Fig.23.

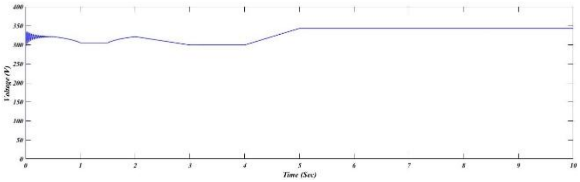

Fig.20.The simulated output voltage of the solar system before using the controller as a function of time variation.

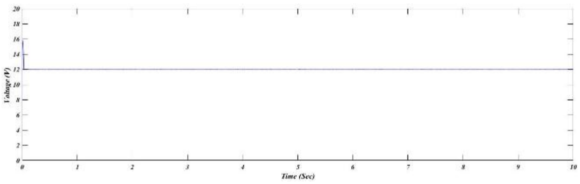

Fig.21.The simulated output voltage of the solar system after using the controller as a function of time variation.

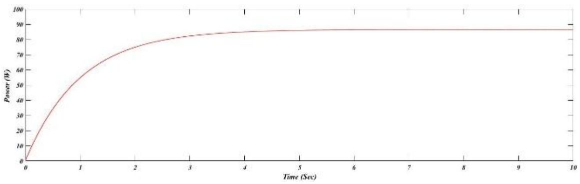

Fig.22.The simulated power of the solar system as a function of time variation.

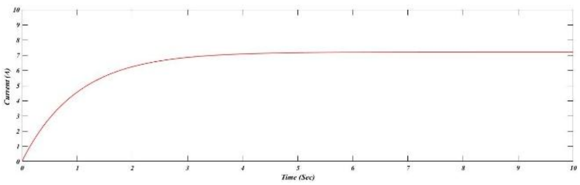

Fig.23.The simulated output current of the solar system as a function of time variation.

7. Conclusions

In this paper, three renewable energy sources (solar energy - fuel cell energy - wave energy) were used and the system was simulated on Matlab / Simulink. The expected changes that could affect the system were studied. The controller depended on the Buck-boost converter technology was used for each source, connecting the three sources to the DC bus bar and then connecting it to the Inverter and the battery bank. A constant load was used to check the performance of the system. The controller proved high efficiency and proved the ability to face all unexpected changes. The buck-boost circuit is designed to operate at a range of voltage from 4V DC to 200V DC and Voltage stabilization at 12V DC. When the load is small and the three sources work efficiently, only two sources for the load are combined and the third source is connected to the battery bank to feed the storage system. On the contrary, when there is no output voltage on one source, the storage system is automatically combined with the other two sources to cover the load without interruption.

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