Simulation Model of Solar, Wind and Fuel Combined System based on Fusion of CUK & SEPIC Converters

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Abstract: **Deregulation of energy has lowered the investment in larger power plants, which means the need for new electrical power sources may be increased in the near future. This paper discuss the most emerging renewable energy sources, wind energy & solar energy which by means of power electronics are changing from being minor energy sources to be acting as important power sources in the electrical network.**

This paper proposes a hybrid energy system consisting of a wind turbine, a photovoltaic source, and a fuel cell unit designed to supply continuous power to the load. A simple and economic control with dc-dc converter is used for maximum power extraction from the wind turbine and photovoltaic array. Due to the intermittent nature of both the wind and photovoltaic energy sources, a fuel cell unit is added to the system for the purpose of ensuring continuous power flow. The fuel cell is thus controlled to provide the deficit power when the combined wind and photovoltaic sources cannot meet the net power demand. The proposed system is attractive owing to its simplicity, ease of control and low cost. Also it can be easily adjusted to accommodate different number of energy sources.

Keywors: solar energy system, wind energy system, fuel cell, cuk – sepic converter, simulation models of all

I. INTRODUCTION

The rate of energy consumption increasing and supply is decreasing or depleting resulting in inflation and energy shortage. This is called energy crisis. Energy is the primary and most universal measure of all kind of work by human beings and nature.

Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable [9].

However, by combining these two intermittent sources the system's power transfer efficiency and reliability can be improved significantly.

In this proposal, operation control of solar, wind and fuel cell based hybrid system is performed by using Cuk-Sepic converter[12].The features of the proposed topology are:

- The inherent nature of these two converters eliminates the need for separate input filters for power factor correction.
- It can support step up/down operations for each renewable source (can support wide ranges of PV and wind input).
- MPPT can be realized for each source.
- Individual and simultaneous operation is supported.

The fusion of the buck and buck-boost converter have a disadvantage that it require passive input filters to remove the high frequency current harmonics injected into wind turbine generators.

World renewable electricity generation by energy source, excluding wind and hydropower, 2007–2035 (billion kWh) is shown in figure1 given as below-

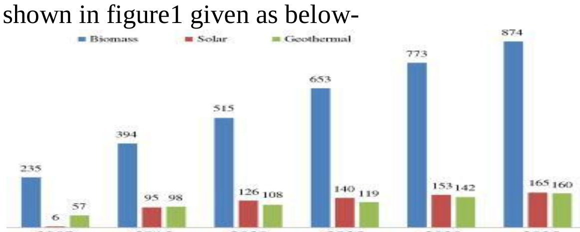

Fig.1 World Renewable Electricity Generation by NCER Energy Source, 2007–2035 (billion kWh)

II. PHOTOVOLTAIC TECHNOLOGY

Solar cells are the building blocks of a PV array. A thin semiconductor wafer is specially treated to form an electric field, positive on a side and negative on the other. Electrons are knocked loose from the atoms of the semiconductor material when light strikes upon them. If an electrical circuit is made attaching a conductor to the both sides of the semiconductor, electrons flow will start causing an electric current. It can be circular or square in construction. The photovoltaic cell output voltage is basically a function of the photocurrent which is mainly determined by load current depending on the solar irradiation level during the operation [4].

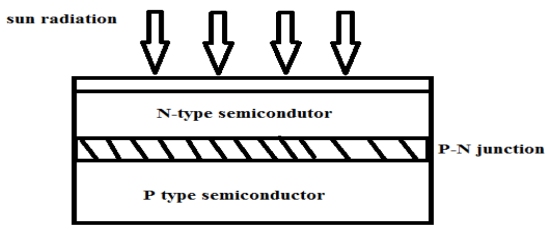

Fig. 2 Block diagram of a solar PV cell

The graph shown below represents the V-I characteristic of PV cell.

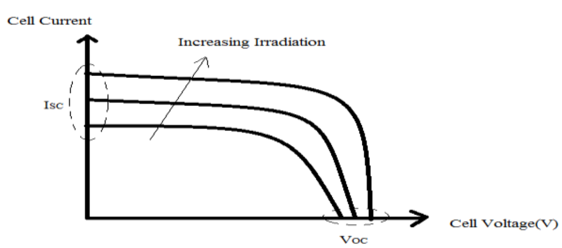

Fig. 3 V-I characteristic of PV cell

The energy payback time of a photovoltaic cell is an indication about the energy required to make a cell compared to how much it could generate in its lifetime. The energy payback time of a modern photovoltaic module is anywhere from 1 to 20 years (usually under five) depending on the type and where it is used. The module energy payback time (EPBT) is computed using this formula [5]:

$$EPBT = \frac{E_S}{E_g}$$

Where

E_S: Specific energy (kWh_e / kW_p) for production of PV module.

E_g: Energy generation rate (kWh / kW_p- year), this corresponds to peak sun hours (PSH) of the location where the PV module is installed multiplied by number of days in a year.

III. WIND ENERGY SYSTEMS

The movement of air (created because pressure difference between two uneven heated places) is called wind. Wind energy is a clean, eco-friendly, safe and renewable source of energy. The 25% of the total solar radiation reaching on the earth surface transformed to the wind energy. Wind energy system convert the kinetic energy of wind to more useful forms of mechanical power and have been used for irrigation and milling since ancient times .wind turbines convert the energy of wind into mechanical power which can converting into electric power by means of generator.[9]

A. *Characteristics of wind*

1) Wind Speed-Power Characteristic

The power outputs from wind turbine vary with wind speed.

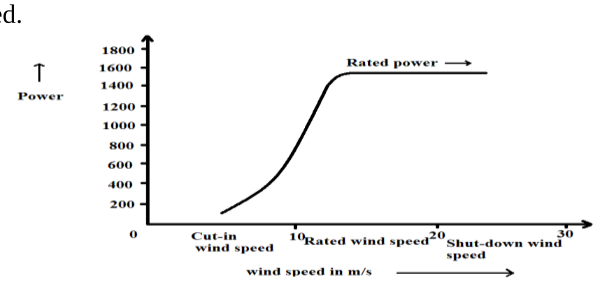

Fig.4 Power-Speed Characteristics of Wind Turbine

B. *Dynamic Characteristics*

This characteristic will match the rotational frequency of the turbine for particular wind speed for optimum efficiency and is shown in figure 5.

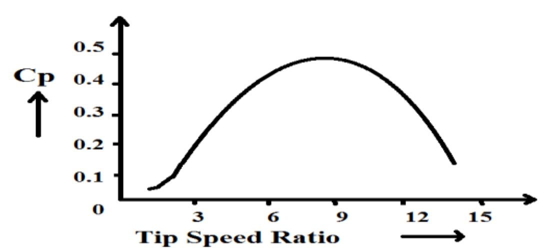

Fig. 5 C_p-TSR characteristics of Wind Turbine

C. *Axial Force Characteristics*

The variation of thrust force coefficient with tip speed is shown in figure 6.

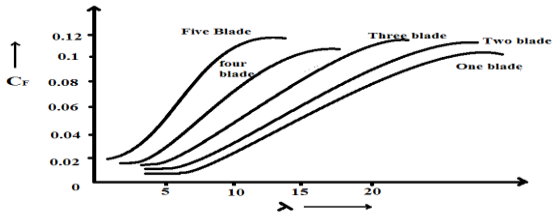

Fig.6 C_f - Tip Speed Characteristics of Wind Turbine

IV. FUEL CELLS

The amount of power that is produced by a fuel cell depends on many factors, like the fuel cell type, the size of the fuel cell, the temperature and pressure at which it operates, the fuel supplied to the fuel cell, etc. [10].

A schematic representation of a fuel cell is shown in Figure 7. The fuel cell consists of an electrolytic layer and two catalyst-coated electrodes (cathode and anode) as shown in Figure 7. The electrodes are composed of porous material and located on either side of the electrolytic layer.

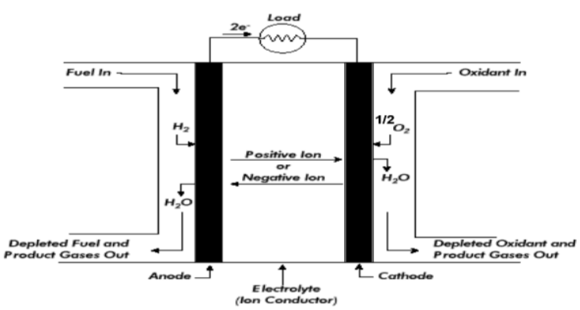

Fig. 7: Schematic of a fuel cell

The instantaneous electric power of each fuel cell are given by equations [10]:

$$P_{FC}=V_{FC}\times i_{FC}$$

Where:

i_{FC}: Cell operating current (A),

V_{FC}: Output voltage of the fuel cell for a given Operating condition (V),

P_{FC}: Output power of each fuel cell (W).

V. HYBRID WIND-SOLAR & FUEL SYSTEM

"Hybrid power systems are combinations of two or more conversion devices (e.g., electricity generators or storage devices), or two or more fuels for the same device, that when integrated, overcome limitations that may be inherent in either."

Alone, wind energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. The common inherent drawback of wind and photovoltaic systems are their intermittent natures that make them unreliable [12].

In this figure 8, an alternative multi-input rectifier structure is proposed for hybrid wind/solar energy systems.

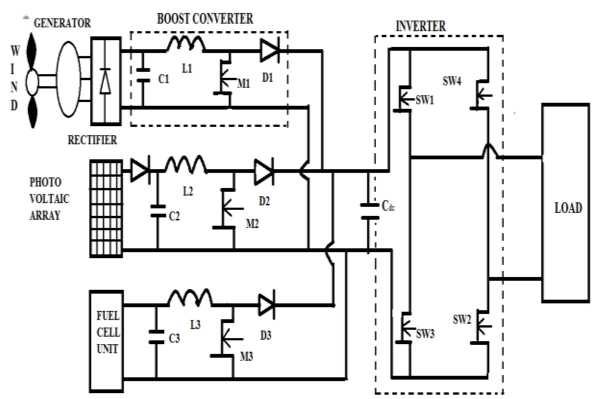

Fig. 8 Hybrid System with Multi-Connected Boost Converter

VI. CUK-SEPIC CONVERTER

Switch Mode Power Supply topologies follow a set of rules. A very large number of converters have been proposed, which however can be seen to be minor variations of a group of basic DC-DC converters – built on a set of rules.

A. *Cuk converter*

Many consider the basic group to consist of the three: BUCK, BOOST and BUCK-BOOST converters. The CUK, essentially a BOOST-BUCK converter, may not be considered as basic converter along with its variations: the SEPIC and the zeta converters.

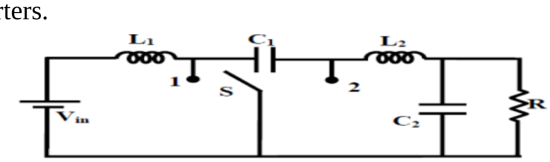

Fig. 9 Schematic Diagram of Cuk Converter

B. *Sepic converter*

The single-ended primary-inductance converter (SEPIC) is a DC/DC-converter topology that provides a positive regulated output voltage from an input voltage that varies from above to below the output voltage. Single-ended primary-inductor converter (SEPIC) is a type of DC-DC converter allowing the electrical potential (voltage) at its output to be greater than, less than, or equal to that at its input, the output of the SEPIC is controlled by the duty cycle of the control transistor.

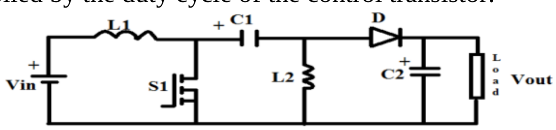

Fig. 10 Circuit Diagram of SEPIC Converter

VII. Proposed Multi-Input Rectifier Stage

A system diagram of the proposed rectifier stage of a hybrid energy system is shown in Figure 11, where one of the inputs is connected to the output of the PV array and the other input connected to the output of a generator.

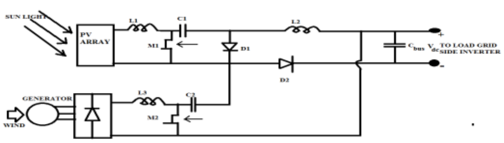

Fig.11 Proposed Rectifier Stage of a Hybrid Energy System

The fusion of the two converters is achieved by reconfiguring the two existing diodes from each converter and the shared utilization of the Cuk output inductor by the SEPIC converter. This configuration allows each converter to operate normally individually in the event that one source is unavailable.

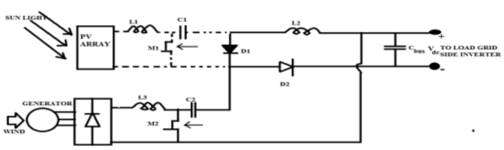

Fig. 12 Only Wind Source is Operational (SEPIC)

On the other hand, if only the PV source is available, then D_2 turns off and D_1 will always be on and the circuit becomes a Cuk converter as shown in Figure 13.

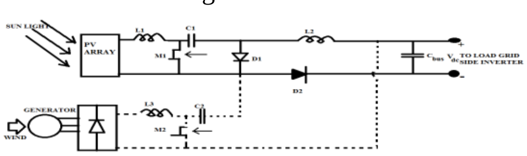

Fig. 13 Only PV Source is Operation (Cuk)

VIII. Simulation Of Hybrid System

PV array, Wind turbine, Cuk converter, SEPIC converter and the proposed hybrid system is modeled using MATLAB/ SIMULINK software.

A. *Simulink model of PV cell*

The PV array has been designed by considering the irradiance, temperature and number of PV cells connected in series and parallel. Figure 14 shows the Simulink model of PV cell.

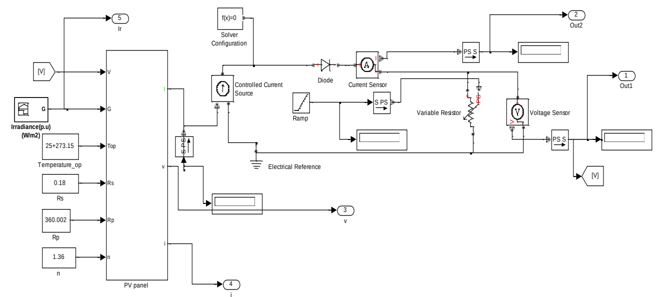

Fig.14 Simulink Model of PV Cell

The figure 14 is equivalent Simulink model of a solar cell.

B. *Simulink Model of Wind Turbine*

The simulation model of wind turbine is shown in Figure 15.

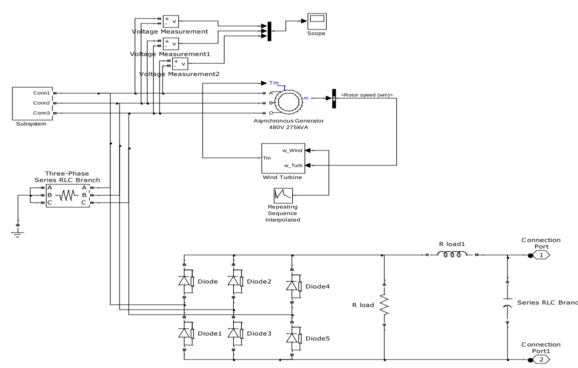

Fig.15 Simulink Model of Wind Power Generation

C. *Simulink Model of Cuk Converter*

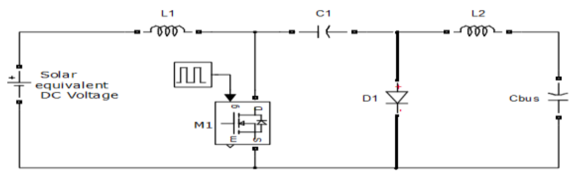

Fig. 16 Simulink model of Cuk converter

D. Simulink Model of SEPIC Converter

Wind turbine is given as the input to the SEPIC converter. Figure 17 shows the Simulink model of the SEPIC converter.

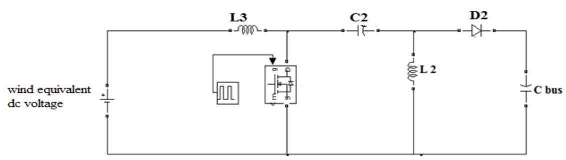

Fig.17 Simulink Model of SEPIC Converter

Simulink model of Cuk and SEPIC converter consist of dc voltage source, MOSFET switch which is controlled by duty cycle fed by pulse generator and a diode. The output is taken across capacitor.

E. Simulink model of fused CUK-SEPIC converter

The below figure 18 shows the fusion of cuk and sepic converter. In this model the solar system is connected to cuk and the wind system is connected to sepic converter.

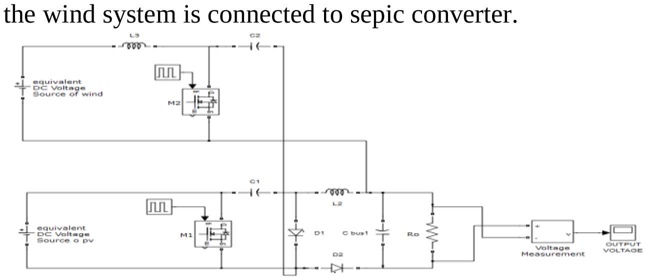

Fig.18 Simulink Model of fusion of CUK and SEPIC Converter

F. Simulink Model of Hybrid System

Hybrid system consists of wind and solar system connected by sepic and cuk converter respectively. Figure 19 shows the Simulink model of the hybrid system. Here Cuk and SEPIC work in boost mode.

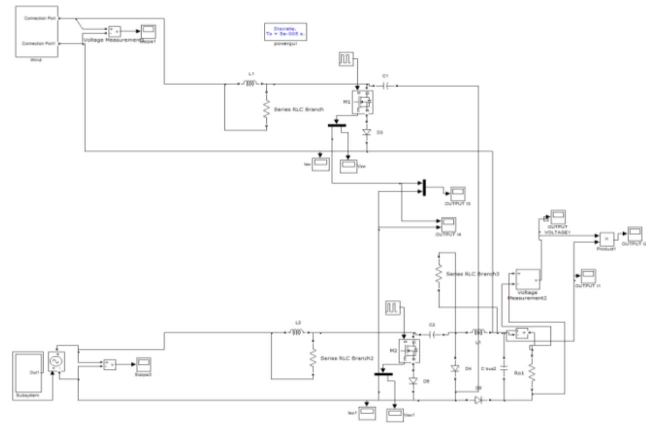

Fig. 19 Simulink Model of Hybrid Wind Solar Generation

Hybrid wind and solar systems provide more consistent year-round performance and reduces the need for back up generation.

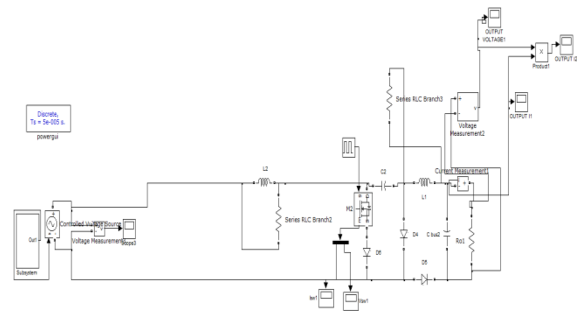

Fig. 20 PV Model Cuk operation

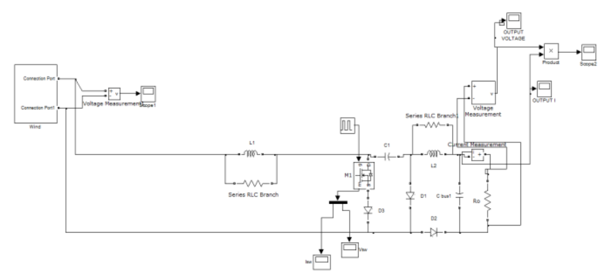

Fig. 21 Wind model SEPIC operation

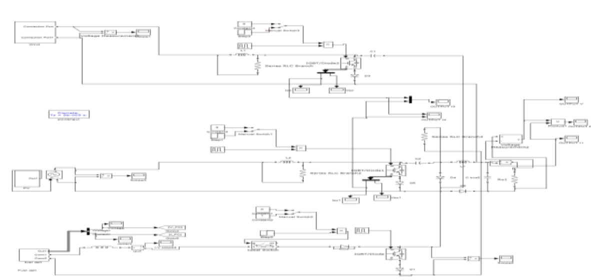

Fig. 22 Simultaneous operation of PV, Wind & fuel cell combined

Figure 20 shows the Simulink model of individual operation with only photovoltaic source In this mode model is working as cuk operation. Figure 21 illustrates the Simulink model where only the wind turbine generates power to the load which is in SEPIC converter mode. Finally Figure 22 illustrates the Simulink model of the simultaneous operation (Cuk-SEPIC fusion mode) of all three sources.

IX. Results And Discussion

In this section, simulation results from MATLAB/SIMULINK are given to verify that the proposed multi-input rectifier stage can support individual as well as simultaneous operation.

A. Simulation Results with only PV source

Figure 23 shows Individual operation with only PV source (Cuk operation).

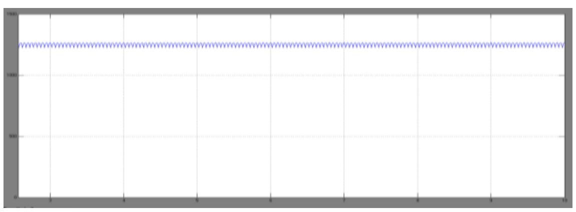

Fig. 23 PV Generated output Power

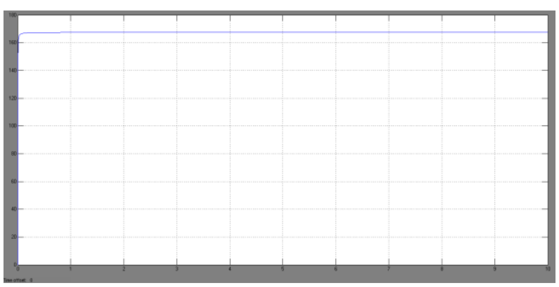

Fig. 24 PV Generated Voltage

B. Simulation Results with only wind source

Figure 25 shows Individual operation with only wind source (SEPIC operation).

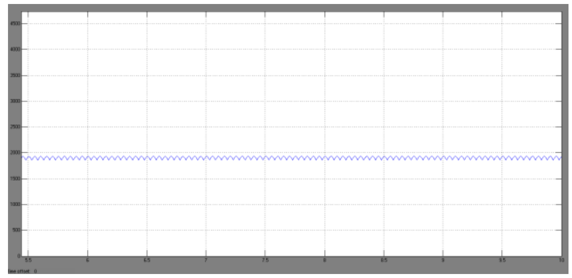

Fig. 25 Wind generated output power

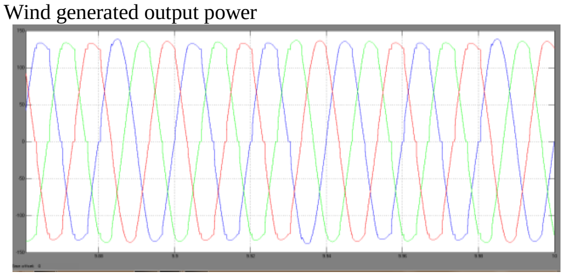

Fig. 26 Three phase generator Voltage

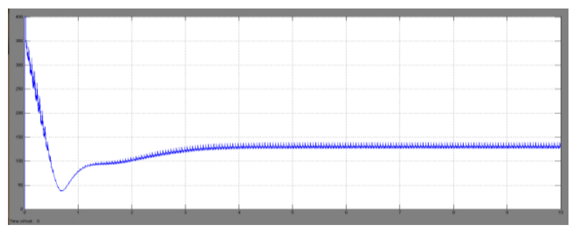

Fig. 27 Wind generated voltage

C. Simulation Results with both PV and Wind source

Figure 28 shows simultaneous operation with both wind and PV source. In this mode Cuk and SEPIC converters are fused.

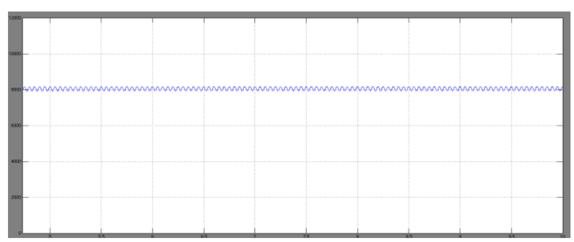

Fig. 28 Output Power (Fusion mode with cuk and SEPIC)

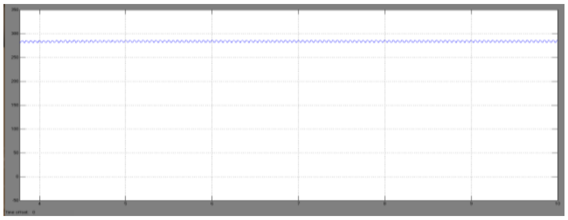

Fig. 29 Output voltage (Fusion mode with cuk and SEPIC)

D. *Variation of solar irradiance*

In fig 30 from instant t=0 sec to t=1 sec the solar irradiance is 1pu or 1000 W/m^2. At instant t=1 sec the solar intensity falls to 0.2 pu or 200 W/m^2, which is remain constant till t=4 sec, and at t=4 sec intensity takes its original value of 1pu or 1000 W/m^2.

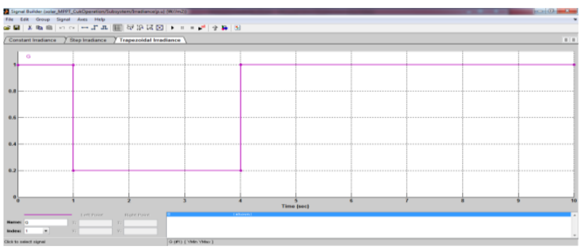

Fig. 30 Step Solar Irradiance

E. *I-V and P-V characteristics of photovoltaic cell*

Figure 31 shows the variation of the PV cell current with respect to PV cell voltage, and figure 32 shows the variation of output power of PV cell with respect to the PV cell voltage.

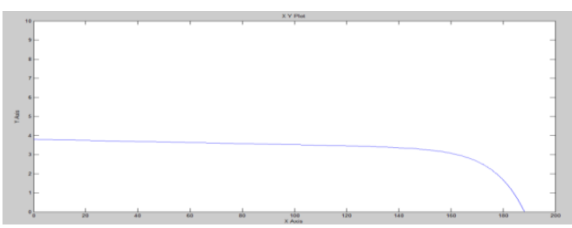

Fig. 31 I-V plot PV cell

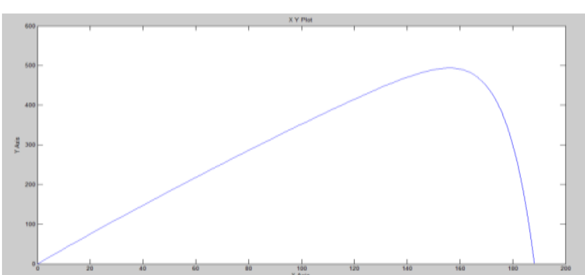

Fig 32 P-V plot of PV cell

F. *Simulation result of combined hybrid system with PV, Wind and Fuel cell*

Figure 33 shows the variation of output power of combined operation of PV, Wind and Fuel cell. At instant t=0 sec only fuel cell is working, at instant t=2 sec PV is connected. Now PV and Fuel cell is working together. At instant t=5.5 sec wind adds up with already conducting PV and Fuel cell. Now all three sources are working simultaneously and gives the power in order to meet the load demand. At instant t=9 sec it is shown that both the sources .

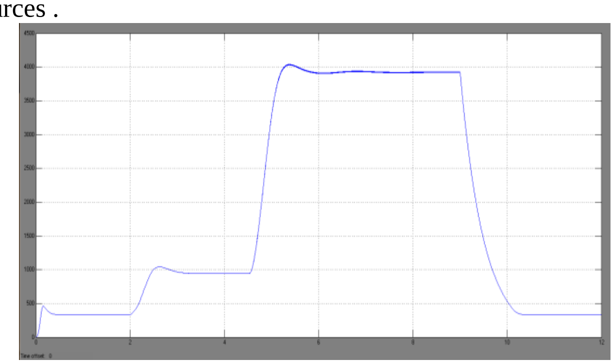

Fig.33 Output power with P-V, Wind and Fuel cell

X. CONCLUSION

Hybrid systems are the right solution for a clean energy production. Hybridizing solar and wind power sources provide a realistic form of power generation. Here, a hybrid wind and solar energy system with a converter topology is made which makes use of Cuk and SEPIC converters in the design. This converter design overcomes the drawbacks of the earlier proposed converters. This topology allows the two sources to supply the load separately or simultaneously depending on the availability of the energy sources. The output voltage obtained from the hybrid system is the sum of the inputs of the Cuk and SEPIC converters. This system has lower operating cost and finds applications in remote area power generation, constant speed and variable speed energy conversion systems and rural electrification.

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