Solar Photovoltaic and Fuel cell based hybrid system with boost converter for renewable energy sources

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Abstract: A new two input dc–dc boost converter is proposed in this paper. The proposed converter interfaces two unidirectional input power ports and a bidirectional port for a storage element in a unified structure. This converter is interesting for hybridizing alternative energy sources such as photovoltaic (PV) source, fuel cell (FC) source. Supplying the output load, charging or discharging the battery can be made by the PV and the FC power sources individually or simultaneously. The proposed structure utilizes only four power switches that are independently controlled with four different duty ratios. Utilizing these duty ratios, tracking the maximum power of the PV source, setting the FC power, controlling the battery power, and regulating the output voltage are provided. Depending on utilization state of the battery, three different power operation modes are defined for the converter. In order to design the converter control system, small-signal model is obtained in each operation mode. Due to interactions of converter control loops, decoupling network is used to design separate closed-loop controllers. The validity of the proposed converter and its control performance are verified by simulation and experimental results for different operation conditions.

I. Introduction

The power generation from the fossil fuel may not be possible very long as they are depleting and also they are disadvantageous because they cause the environment pollution. Recently the researchers are interested in the techniques for power generation with the renewable energy sources such as solar, hydro, wind, tidal biomass etc. The power generation using the renewable energy sources is advantageous because renewable energy sources are omnipresent, free of cost and maintenance and have longer life. The Distributed Generation in fact offers enhanced voltage support, reduced transmission & distribution losses, improved reliability & power quality. The fuel cell based distributed generation can be placed anywhere in the system to upgrade system integrity, reliability and efficiency. The PEM fuel cell technology is the best candidate for residential and commercial applications due to low operating temperature, quick start up and high power density. If the available fuel cell generation is not sufficient to meet the sustainable load demand, there is a need of additional energy storage device such as battery, capacitors and ultra capacitors to meet the peak power demands. Among this energy storage devices, the ultra capacitors can be placed at the dc link without any additional circuits because it has long life and maintenance free. But an energy storage e.g. Battery requires additional control circuit for the bidirectional DC/DC power flow operations during charging and discharging conditions. This increases the cost of the system and reduces life span and reliability.

II. Objectives

It has been well-proven that a photovoltaic power source should be integrated with other power sources, whether used in either a stand-alone or grid-connected system, as it cannot produce power during night hours or under cloudy weather conditions. The system under study in this thesis is a stand-alone hydrogen PVFC power system, which is constituted of a photovoltaic generator, an alkaline water electrolyser, a proton-exchange membrane fuel cell stack, battery as a secondary back-up unit and a tank used for hydrogen storage. This method is a very effective way of producing and using pure hydrogen. For the study of the system the physical properties of the components were studied, and the corresponding mathematical formulas were derived. Then Matlab/Simulink was used for a dynamic simulation of the system. In general the goals of this paer are:

- Proper data collecting and/or data synthesizing that describes the system operation and the load profile
- Visualizing and analyzing the system dynamic behaviour using power flow trace over middle-term duration, such as one week or one day.
- Creating an accurate simulation system model to predict the real performance of the hydrogen PVFC power system
- Making the parameters of the system as configurable as possible in order the models to be used for a larger variety in applications (mostly different sized applications or components with different datasheets)

III. OVERVIEW OF PV-FC BASED HYBRID SYSTEM

The utilization of intermittent natural energy resources such as solar, wind and hydro energy requires some form of energy storage. The concept of utilizing hydrogen as a substance for storage of energy is shown in Figure-1. In this paper, a hybrid system based on hydrogen technology is considered. It needs hydrogen producing unit (electrolyser), a unit for hydrogen storage (tank), and a hydrogen utilizing unit (PEM fuel cell stack). However, the system based on intermittent energy sources and is likely to experience large minutely, hourly and daily fluctuations in energy input. Thus, it should be emphasized that the main purpose of the hydrogen storage system is to store energy over short and long periods of time, i.e., hour to hour and season to season.

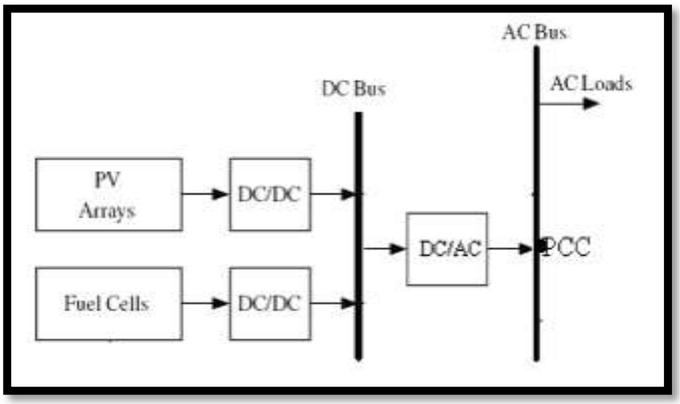

Fig-1-Grid connected PV-FC Hybrid system

IV. SOLAR CELL

There are several types of solar cells. However, more than 90 % of the solar cells currently made worldwide consist of wafer-based silicon cells. They are either cut from a single crystal rod or from a block composed of many crystals and are correspondingly called mono-crystalline or multi-crystalline silicon solar cells. Wafer-based silicon solar cells are approximately 200 µm thick. Another important family of solar cells is based on thin-films, which are approximately 1-2 µm thick and therefore require significantly less active, semiconducting material. Thin-film solar cells can be manufactured at lower cost in large production quantities; hence their market share will likely increase in the future. However, they indicate lower efficiencies than wafer-based silicon solar cells, which mean that more exposure surface and material for the installation is required for a similar performance. A number of solar cells electrically connected to each other and mounted in a single support structure or frame is called a „photovoltaic module". Modules are designed to supply electricity at a certain voltage, such as a common 12 volt system. The current produced is directly dependent on the intensity of light reaching the module. Several modules can be wired together to form an array. Photovoltaic modules and arrays produce direct-current electricity. They can be connected in both series and parallel electrical arrangements to produce any required voltage and current combination.

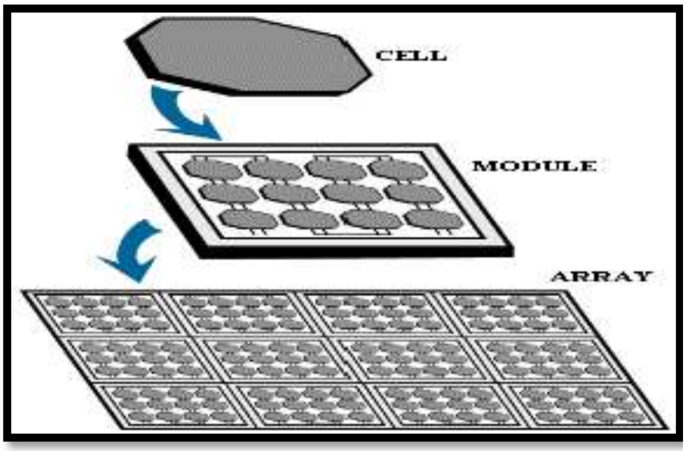

Fig-2 ELECTRICAL CONNECTION OF THE CELLS

The electrical output of a single cell is dependent on the design of the device and the Semi-conductor material(s) chosen, but is usually insufficient for most applications. In order to provide the appropriate quantity of electrical power, a number of cells must be electrically connected. There are two basic connection methods: series connection, in which the top contact of each cell is connected to the back contact of the next cell in the sequence, and parallel connection, in which all the top contacts are connected together, as are all the bottom contacts. In both cases, this results in just two electrical connection points for the group of cells. Series connection: Figure-3 shows the series connection of three individual cells as an example and the resultant group of connected cells is commonly referred to as a series string. The current output of the string is equivalent to the current of a single cell, but the voltage output is increased, being an addition of the voltages from all the cells in the string (i.e. in this case, the voltage output is equal to 3Vcell).

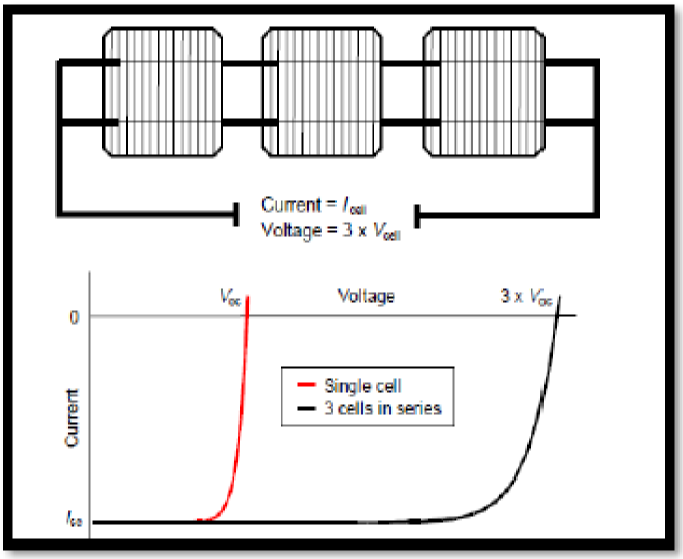

Fig-3 Series connection of cells, with resulting current–voltage characteristic

It is important to have well matched cells in the series string, particularly with respect to current. If one cell produces a significantly lower current than the other cells (under the same illumination conditions), then the string will operate at that lower current level and the remaining cells will not be operating at their maximum power points.

Parallel connection Figure-4 shows the parallel connection of three individual cells as an example.

In this case, the current from the cell group is equivalent to the addition of the current from each cell (in this case, 3 Icell), but the voltage remains equivalent to that of a single cell. As before, it is important to have the cells well matched in order to gain maximum output, but this time the voltage is the important parameter since all cells must be at the same operating voltage. If the voltage at the maximum power point is substantially different for one of the cells, then this will force all the cells to operate off their maximum power point, with the poorer cell being pushed towards its open-circuit voltage value and the better cells to voltages below the maximum power point voltage. In all cases, the power level will be reduced below the optimum.

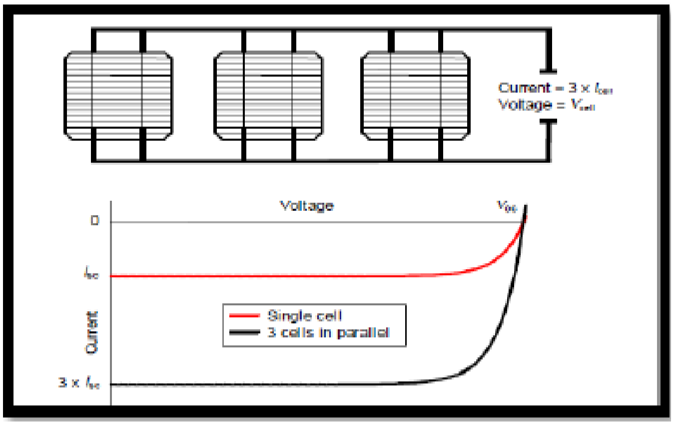

Fig-4 Parallel connection of cells, with resulting current– voltage characteristic

Solar panel is a device that converts solar energy directly into electrical energy. Solar panel is made up off photovoltaic cells which are made by semiconductor. When sun beam is fall on the PV cell they absorb the heat and electron are emitted from the atom. Due to the movement of the electron current is generated. With this process solar panel, convert solar energy directly into the electric energy. Photovoltaic is known as the process between radiation absorbed and the electricity induced. Solar power is converted into the electric power by a common principle called photoelectric effect.

The basic unit of a photovoltaic power system is the PV cell, where cells may be grouped to form panels or modules. The panels then can be grouped to form large photovoltaic array that connected in series or parallel. Panels connected in parallel increase the current and connected in series provide a greater output voltage.

Fig-5 PV Cell, PV Module, PV Array

Fig-6 Solar PV System

The energy generated by the sun radiation is calculated by the formulae:

P = A·x2 + B·x + C (in Watts)

Where,

X = Solar radiation

P= Power Formation

And A,B,C are constant

By the above formula, we can calculate the amount of power generated by the Sun.

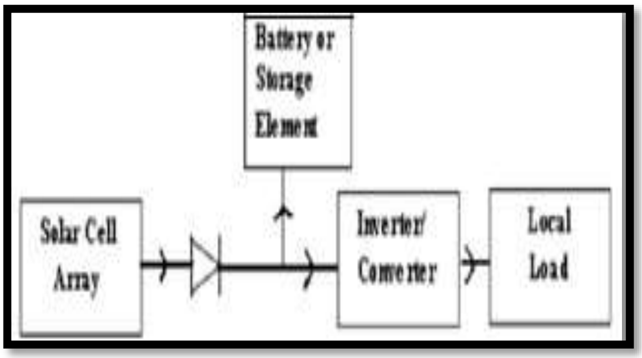

Fig-7 Basic PV System

Storage batteries as shown in Fig. provide the backup power during cloudy weather to store the excess power or some portion of power from the solar arrays. This solar power generating system is used for domestic power consumption, meteorological stations and entertainment places like theatre, hotel, restaurant etc.

V. FUEL CELL

A fuel cell consists of a negatively charged electrode (anode), a positively charged electrode (cathode) and an electrolyte membrane. Hydrogen is oxidized at the anode and oxygen is reduced at the cathode. Protons are transported from the anode to the cathode through the electrolyte membrane, and the electrons are carried to the cathode over the external circuit. In nature, molecules cannot stay in an ionic state; therefore they immediately recombine with other molecules in order to return to the neutral state. Hydrogen protons in fuel cells stay in the ionic state by travelling from molecule to molecule through the use of special materials. The protons travel through a polymer membrane made of persulfonic acid groups with a Teflon backbone. The electrons are attracted to conductive materials and travel to the load when needed. On the cathode, oxygen reacts with protons and electrons, forming water and producing heat. Both the anode and cathode contain a catalyst to speed up the electrochemical processes, as shown in figure 8. A typical PEM fuel cell (proton exchange membrane fuel cell) has the following reactions:

Anode:

$$H_2(g) \rightarrow 2H^+(aq) + 2e^-$$

Cathode:

$$\frac{1}{2}O_2(g) + 2H^+(aq) + 2e^- \rightarrow H_2O(l)$$

Overall:

$$H_2(g) + \frac{1}{2}O_2(g) \rightarrow H_2O(l) + \text{electric energy} + \text{waste heat}$$

Reactants are transported by diffusion and/or convection to the catalyzed electrode surfaces where the electrochemical reactions take place. The water and waste heat generated by the fuel cell must be continuously removed and may present critical issues for PEM fuel cells.

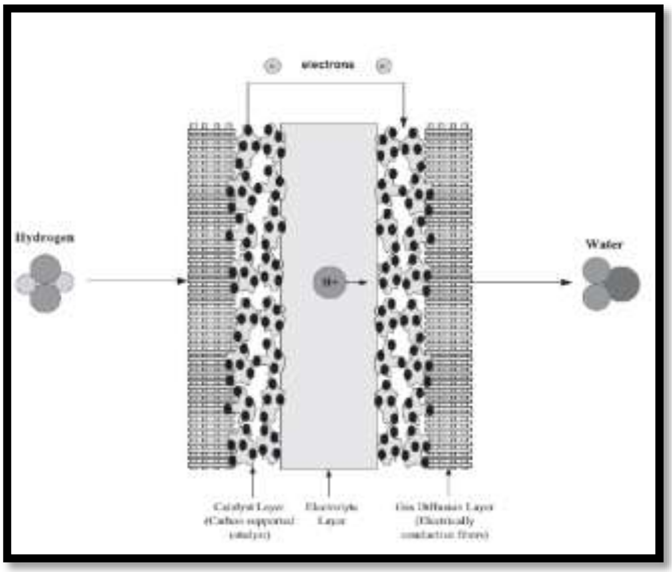

Fig 8-A single PEM fuel cell configuration

Some advantages of the fuel cell systems are as follows: -

- Fuel cells have the potential for a high operating efficiency
- There are many types of fuel sources, and methods of supplying fuel to a fuel cell
- Fuel cells have a highly scalable design
- Fuel cells produce no pollutants
- Fuel cells are low maintenance because they have no moving parts
- Fuel cells do not need to be recharged, and they provide power instantly when supplied with fuel.

Some limitations common to all fuel cell systems are as follows:

- Fuel cells are currently costly due to the need for
- Materials with specific properties. There is an issue with finding low-cost replacements. This includes the need for platinum and Nafion material.
- Fuel reformation technology can be costly and heavy and needs power in order to run.
- If another fuel besides hydrogen is fed into the fuel cell, the performance gradually decreases over time due to catalyst degradation and electrolyte poisoning.

VI. DC-DC CONVERTER

DC/DC converters are used in applications where an average output voltage is required, which can be higher or lower than the input voltage. The choice of the appropriate DC/DC converter for the implementation of both the MPPT system and its integration in the facility array has not been explicitly studied, despite its affecting significantly the optimum operation of the photovoltaic system. The aim of this work is to make a comparative of the photovoltaic system performance using the three basic topologies of three different DC-DC converters (Buck and Boost converter) and MPPT tracker, for that we require the study of characteristics and properties of DC/DC converters, especially as regards the input impedance that they present under certain operating conditions. So that it may be possible to make a decision on the best configuration to be used [2].

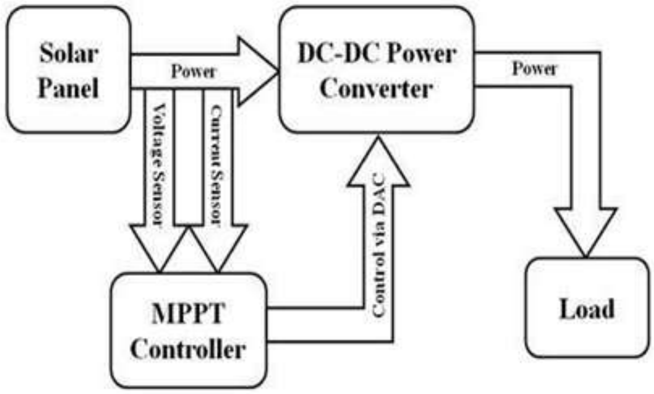

Fig 9: DC – DC converter for operation at the MPP

Few comparisons such as voltage, current and power output for each different combination has been recorded. Multi changes in duty cycle, irradiance, temperature by keeping voltage and current as main sensed parameter.

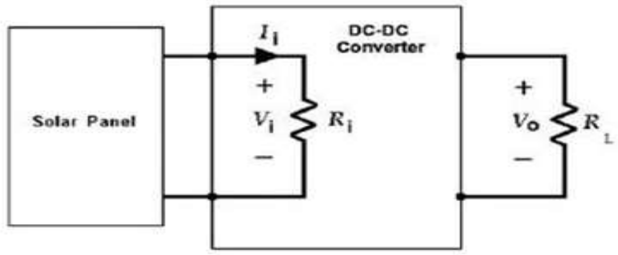

Fig 10: Panel–converter connection

Fig.10 shows the diagram of a solar panel connected to a DC/DC converter, where the resistance shown at the converter's input is represented by Ri (RL is the converter's load resistance). The ratio of the time interval in which the switch is on (TON) to the commutation period (TC) is called duty cycle (D) of the converter.

VII. PROPOSED WORK

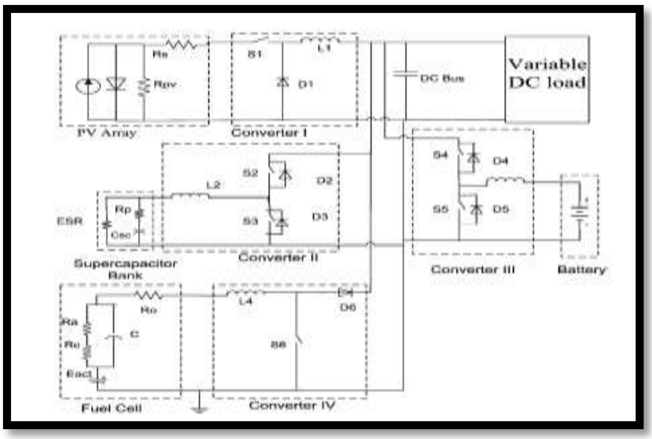

Fig. 11 Structure of proposed system of PV-FC hybrid system with boost converter

In this paper, a new three-input dc–dc boost converter is proposed for hybrid power system applications. As shown in Fig. 11, the proposed converter interfaces two unidirectional ports for input power sources, a bidirectional port for a storage element, and a port for output load in a unified structure. The converter is current-source type at the both input power ports and is able to step up the input voltages. The proposed structure utilizes only four power switches that are independently controlled with four different duty ratios.

Utilizing these duty ratios facilitates controlling the power flow among the input sources and the load. Powers from the input power sources can be delivered to the load individually or simultaneously. Moreover, the converter topology enables the storage element to be charged or discharged through both input power sources. Depending on utilization state of the storage element; three different power operation modes of the converter are defined. Besides, in order to design the control system, converter small-signal model is obtained in each operation mode. Due to multivariable nature of the control system, decoupling network is utilized in order to separately design closed-loop controllers.

VIII. MODELLING AND SIMULATION OF PV

Modelling and Results of Solar-PV System:-
A 30 KW panel is considered as consisting of 24,080 solar cells arranged in 344X70 combinations. The solar array consists of number of panels connected in series-parallel configuration and a panel consists of number of cells. The power characteristics of the solar cell are formulated using its equivalent circuit. The equivalent circuit of the cell is presented as a current source in parallel with diode and a parallel resistance with a series resistance.

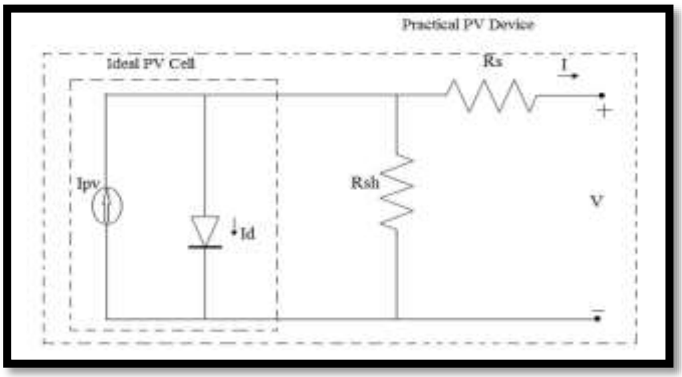

Fig-12: Equivalent circuit of a practical PV device [6]

The output current can be measured by subtracting the diode currents and current through resistance from the light generated current. From this circuit, the output current of the cell is expressed as,

$$I = Ipv - Id - I_{Rsh} \quad (1)$$

$$I = Ipv - I_0\left[\exp\left(\frac{V+IRs}{a}\right) - 1\right] - \left(\frac{V+IRs}{Rp}\right) \quad (2)$$

Where, $a = \frac{NS.A.K.Tc}{q} = Ns.A.V_T$

$$\frac{Isc + Kv * dT}{\exp\left(\frac{Voc+Kv*dT}{a*V}\right) - 1}$$

Where, ns are numbers of cells connected in series. The output current of the solar panel is I. The light generated current is Ipv. Saturation currents through diodes are I_0. The voltage at output of panel is V Series resistance of cell is Rs which represents the internal resistance of cell and it is considered as 0.55 Ω. The Boltzmann's constant is K (1.38 X 10^{-23} J/K). Ambient temperature (in Kelvin) is T and charge constant is q (1.607 X 10^{-19}C). A 30 KW solar-PV array is realized considering 24,080 cells (344×70 dimensions) using (1)-(2). A Matlab model for the same is developed.

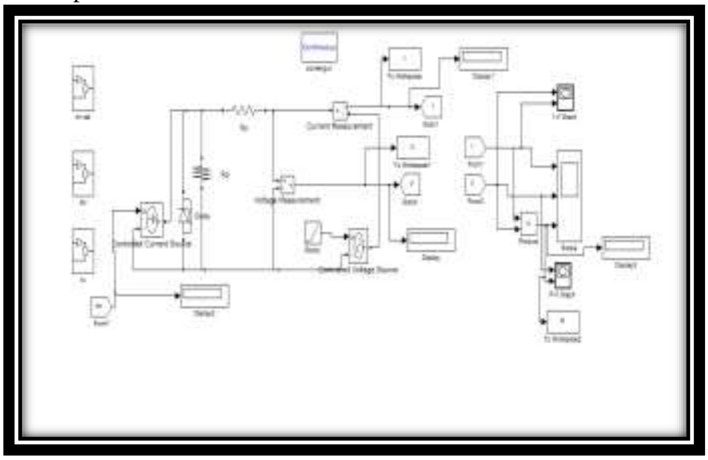

Fig 13: Simulink model of a PV device

Table 1: Parameters of the PV module at 25^0C, 1000 W/m^2 [6]

Imp	2.88 A
Vmp	17 V
Pmp	49 W
Isc	3.11 A
Voc	21.8 V
Rs	0.55 Ω
Kv	-72.5×10^{-3} V/K
Ki	1.3×10^{-3} A/K
Ns	36

IX. RESULTS

After the simulation, we obtained the following results,
Simulation Results of solar panel

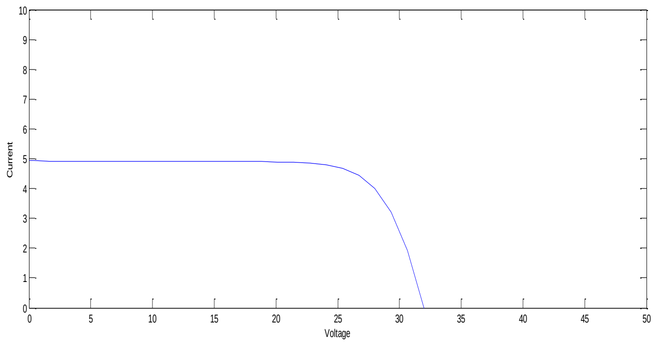

Fig 14-I-V Characteristic

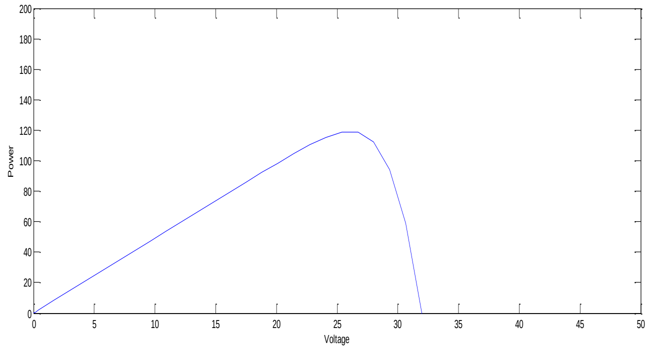

Fig 15-P-V Characteristic

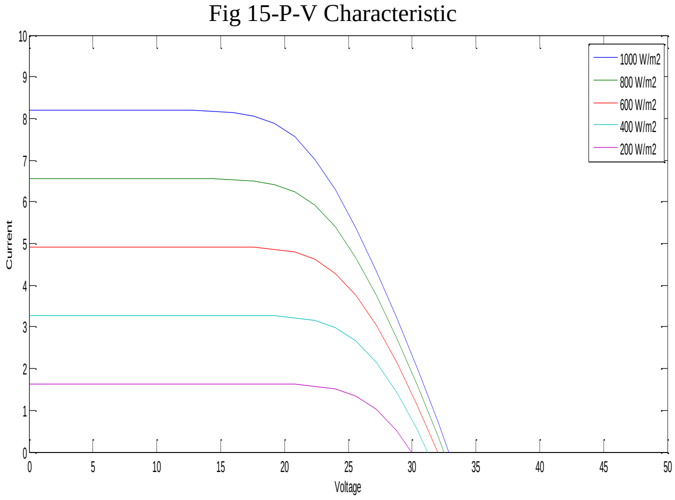

Fig 16-Diiferent Radiation I-V Characteristic

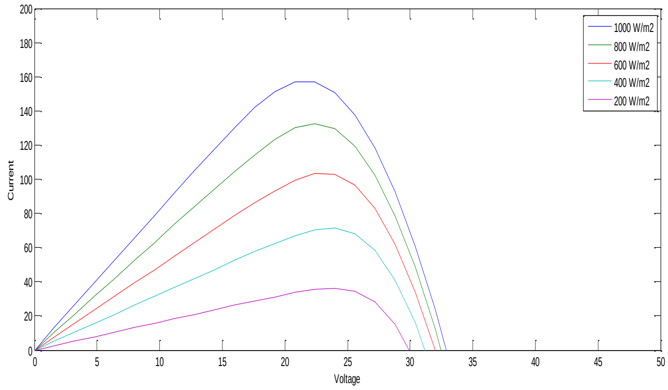

Fig 17-Diiferent Radiation P-V Characteristic

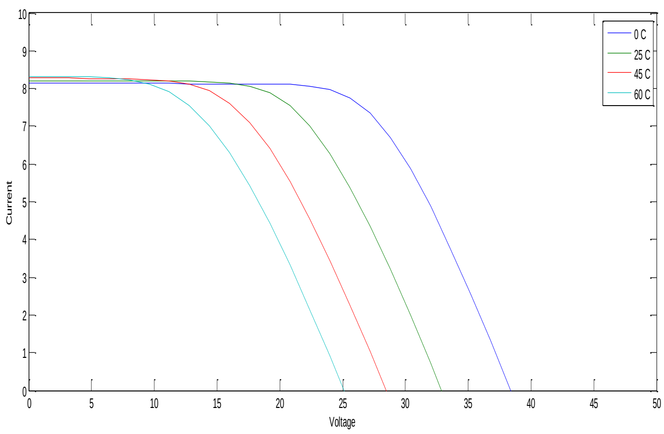

Fig 18-Diiferent Temperature I-V Characteristic

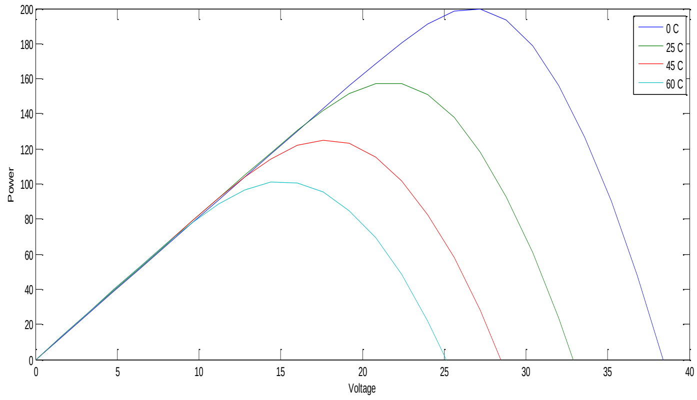

Fig 19-Diiferent Temperature P-V Characteristic

Modelling of Fuel Cell

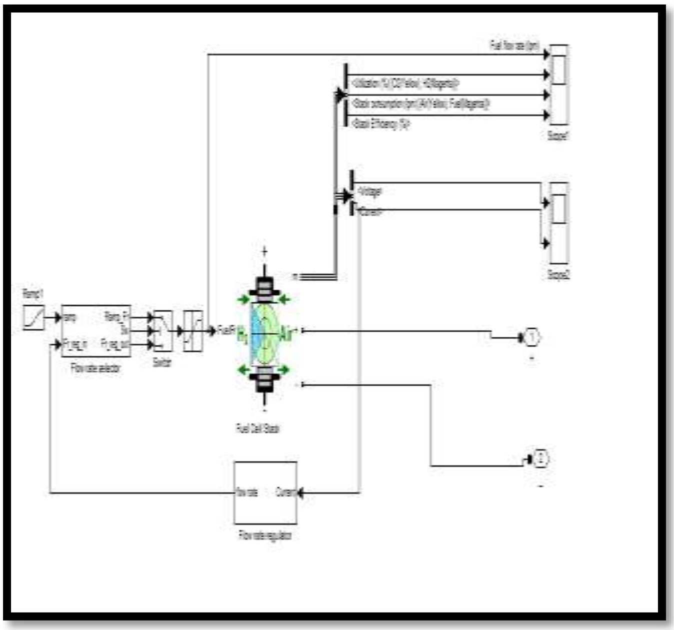

Fig-20 Fuel Cell Matlab model

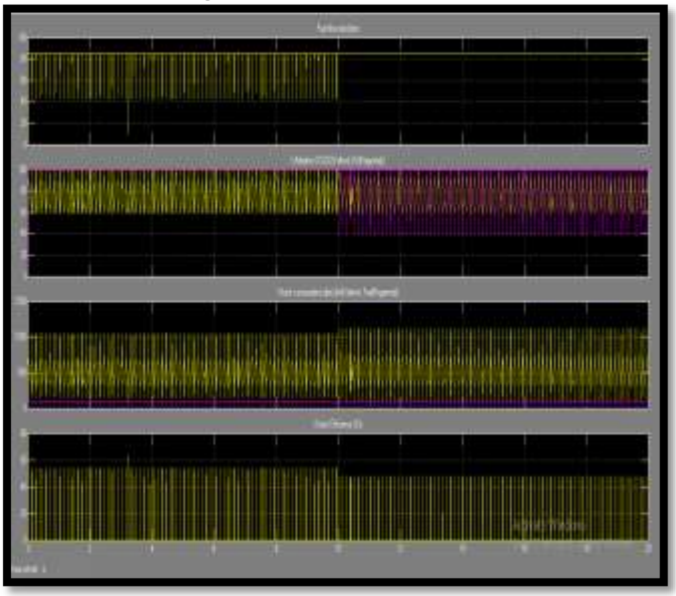

Fig 21- Fuel Cell mechanical output parameters

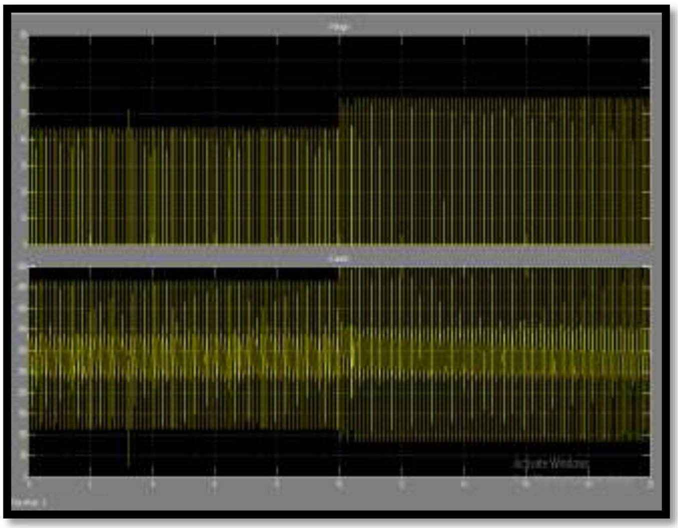

Fig 22- Output voltage and current of fuel cell

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