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Design and Developing of Converter for Integration of the Grid Connected Hybrid Energy Sources

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ABSTRACT

Hybrid converter is designed for energy management between different types of source, Grid and energy storage systems. The number of ports is varied based on number of sources, storage systems and Grid. The proposed isolated converter is accepting limitless, different types of sources and storage systems. Its operating mode is classified into different operating states. One ferrite core transformer with serial coupling capacitor is used to perform step up operation with reduced power switch. Proposed converter is designed for energy management between Photovoltaic (PV) array, Fuel Cell(FC), Super capacitor (SCAP) and load. PV array and Fuel Cell are connected in unidirectional port, super capacitor is connected in bi directional ports. Super capacitors are designed for transient load and Photovoltaic array, Fuel Cell designed for steady state load. Grid is connected to the converter throng 1:N ferrite core transformer and 3ø Voltage Source Inverter. Energy transferred to Grid based on the charging state of coupling capacitor. ANFIS based on MPPT gives the fast dynamic response with better accuracy. It's the controller works based on Neuro- Fuzzy for energy management between different ports with different load conditions. MATLAB simulation is done with different modes, the results shows super capacitor is discharging and charging in transient load conditions and mode of operations are performed based on charge states of coupling capacitor. The transient and steady state response is analyzed using different load conditions.

Keywords—Grid Connected System PV System, Hybrid energy storage, Charge parameter control, Transient and steady state power management

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I. INTRODUCTION

In recent years researchers are concentrate to produce electric energy from the sources of renewable energy likes solar, wind, and tidal etc. Out of these solar energy is viable to generate electrical energy for sustainable energy needs like Domestic and irrigation Water pumping, Petrol bunk, Street lights and etc. Street lights and etc. Series and Parallel connected solar photovoltaic (PV) devices are used for converting solar intensity to electricity. The Quality of electricity from solar PV system is depends on light intensity. Light intensity is affected various external disturbances, they are bird and cloud crossing; It's directly affect performance of the electrical system. Resultant solar electrical system is not suitable to constant power system.

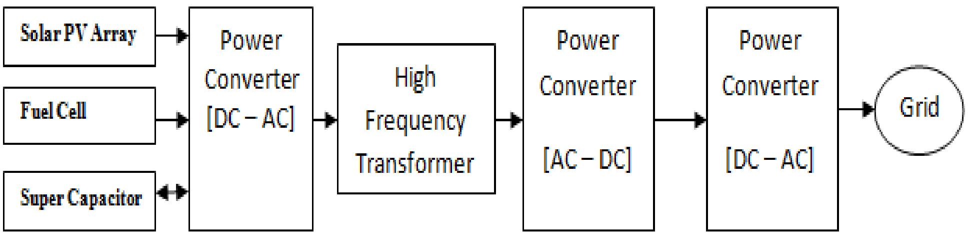


Fig. 1 Portrait of Proposed System

Adding secondary energy sources likes Wind energy systems, Fuel cells and storage system with solar electrical conversation system is solution for constant power output, Lead-Acid type of batteries are broadly used to manage power in transient and steady state period, But frequent charging and discharging affects the Battery life time and decrease the overall system efficiency and mostly increase the cost of the overall system. Here introduced super capacitor based energy storage system to mitigate issues generated by load variations. Super capacitor is used to fast charging and discharging in transient period. Partially isolated multi sources connecting DC–DC converters proposed [1]–[4]. Fig. 1 portrait proposed system. The introduced system is consist of the two stages, first one performed DC-DC operations and the Second one is used to convert DC-AC standalone solar based system with hybrid storage, which contains a partially isolated multiport DC–DC converter with an inverter. The partially isolated DC–DC converter having multiple input ports for connecting multiple energy sources such as solar panels and one bidirectional port for connecting multiple storage devices(Battery, Super capacitor and etc). One output port for connect load. Load port is electrically isolated from source and storage systems.

There are three different structure of multiport DC-DC converter is proposed earlier, Non-isolated structure is not feasible for high step up ratio. source, load and storage devices are not electrically isolated [3]-[6].Fully isolated structures need individual transformer winding for each ports, It's provide electrical isolation of each ports. All ports are operated in different ground[5]-[10].Partially isolated structure is providing common ground for input and storage ports and less number of transformer port is advantages of the structure[11]-[18].

There are four basic cells are discussed, they are half-bridge, full-bridge, boost half-bridge and canonical switching cell. A widely used basic cell is half bridge, It's used for storage port, which used 2S switches, where S is the number of storage devices[1]. Only one switch is used for all the input sources. Number of switches is reduced to 2S+1.Compare with exiting topology, the multiport converter having less number of switches and basic components. Availability of renewable energy sources light source are large quantity, has more power density and it in mass quantity. This energy conservation can be preferred in planning OFF Grid, ON Grid, or Hybrid systems Application implementation for autonomous system for load demands satisfactions. Among several Renewable energy sources, light energy which is called as light energy (SPV) system is developing very fast [2]-[12]. The generated power is modulated using power modulator for the purpose of maximum extraction of generated power at the generating unit of primary side .PV generation is becoming **most** important energy source in the current scenario due to it is inexhaustible and non-polluting. It has the many advantages than others, some of the low running, maintenance cost, and also noiseless in operation [19]. The details of PV system and their characteristics and maximum power point tracking controller (MPPT) given in [19] – [21].

The boosted voltage based on requirement changes from one status to another using a voltage source inverter. The power controllers using Fuzzy-Logic [23] or Neural-Network does not provide maximum power without any prior knowledge. So, it seems to be a black box. The Adaptive Neuro Fuzzy inference system (ANFIS) is the most interesting and powerful artificial intelligence technique, it integrates the neural network and also fuzzy logic to get the maximum power from the PV[23][24].

The proposed converter is capable of delivering power to load either separately (or) concurrently. It's also responsibility of the power management between source, load, and storage devices with less number of switches [25]. Compared with existing topology, there are no switches devices are used in transformersecondary part [9]. Least number of switches used in the converter, there by a less cost.

This paper is well organized as follows. The topology of isolated multiport converter is hosted with each mode of operation in Section-II. Modelling of energy source components solar PV, Fuel cell and Super capacitors discussed in Section –III. Proposed Control strategy for power modulators with various switching pulses for power modulator is discussed in section – IV. Various Modes of operation of system topology was discussed in detail in section V.

II. Proposed partially isolated Multiport DC-AC Converter Topology

Proposed partially isolated multilevel converter shown in Fig.-2. Sources and storage devices are connected in primary of high frequency transformer. Load is connected secondary of transformer through DC link and three phase inverter. Transformers core is made by ferrite core. The turns radio of transformer is defined by n=Ns/Np. Where, Ns - Number of secondary turns and Np - Number of primary turns. Primary side of transformer having buffer capacitor (CB).C_B is frequently charged and discharged for make bi directional current flow in primary of the transformer. Decoupling capacitor (Cs) is connected across the storage devices to avoid voltage fluctuation. Sources and Super capacitor are connected to primary of transformer through inductor (L1,L2 and L3), Reverse blocking diode (D1,D2 and D3) are connected series with sources and Super capacitors to restrict reverse power flow to sources and storage devices. The switch Ss and Sf and Ssd are control sources and super capacitor. The switch Ssc is used to charge the super capacitor.

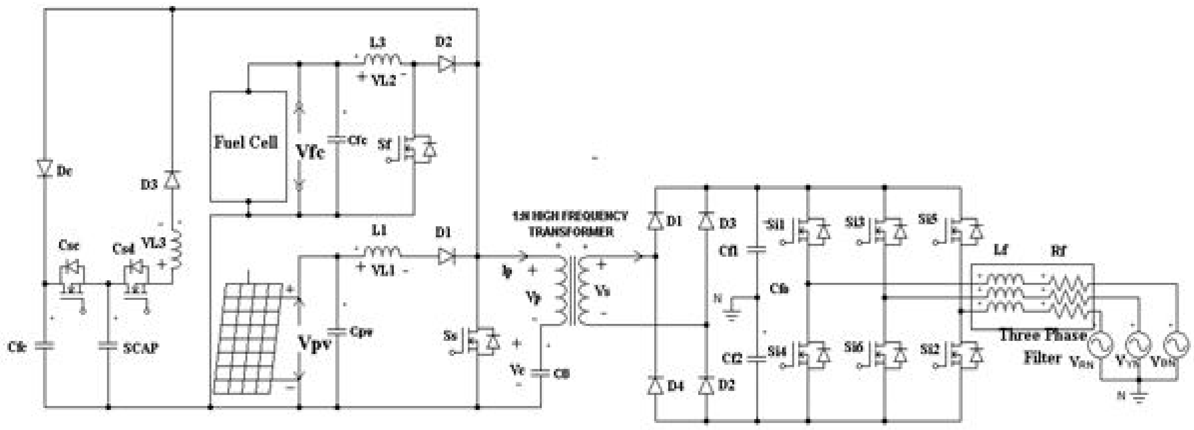


Fig.-2 Proposed Isolated Multiport Converter

Operating Modes:

The projected converter works on five operating modes. Source and load of each mode is listed in table-1.Each mode having two stage of operations, During Stage-I source (PV, Battery and SCAP) energy is stored in respective inductor and buffer capacitor CB is discharged through primary of the transformer.VP is negative and equal to VCB, Energy stored in C_B is transferred to load.When the converter in Stage-II operations, sources are connected to primary of transformer through boost inductor and buffer capacitor C_B. Voltage across transformer primary (V_P) and secondary (V_S) are positive. One portion of energy is transferred to load and remaining energy is stored in buffer capacitor C_B.Fig-3. Shows switching patterns of each mode with different states.

Table-1: Source and Load of each mode

Mode	Source	Load
Mode-1	Photovoltaic	Grid
Mode-2	Photovoltaic and Fuel Cell	Grid
Mode-3	Photovoltaic, Fuel Cell and Supercapacitor	Grid
Mode-4	Photovoltaic, Fuel Cell	Supercapacitor and Grid

III Modelling of Energy Source Components

A. Solar Photovoltaic (SPV Array)

In Renewable energy solar PV natural method of conventional energy source is selected for proposal work so the SPV with required specification was designed in simulink under Matlab environment. This parameter of solar is designed using user defined function as per the load design parameter; component parameter is table in follow;

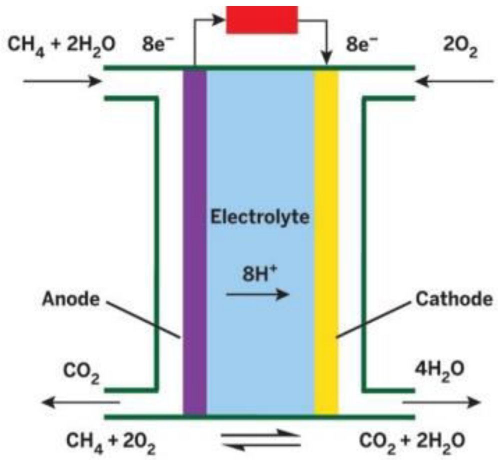
The simulation of solar PV Panel done in Matlab/Simulink environment with parameter specifications are shown above for preferred input power rating for satisfying Load power.

Table: 1 Parameters of solar PV Cell

Parameter name	Variable	Value
Maximum output power	Pm	60W
Maximum output voltage	Vm	17.1V
Current at the max power	Im	3.5A
Open circuit voltage	Voc	21.06V
Short circuit current	Isc	3.74A
No of cells in parallel and series	Np,Ns	1,36

B. Hydrogen Fuel-Cell:

Chemical reaction take place in-between the hydrogen fuel and oxidant (generally oxygen) to produce the electricity.Where, the water and heat are byproducts of the chemical reaction. Mostly, the efficiency of the fuel cells is ranges in-between 40%-60% and it can be improved up to 80%-90% by the co-generation process. The fuel cellsare one of the family of batteries because the structure and functioningare similar except that the hydrogen fuel continuously inject into the cell. The cell contains of two electrodes such as anode and cathode,it can be separated by the electrolyte. Due to potential difference take place due to chemical reaction. Due to difference current will flow through the wire.



In the above figure clearly shows the chemical reaction, based on that chemical reaction current going produce in fuel cell.

C. Super capacitor

The supercapacitor banksare always connected to the DC bus (bidirectional converter(DC-DC)). The supercapacitor power can be either positive or negative, which allows to transfer energy in both directions. It helps to minimize the transients in the system. This is used in circuits for managing reactive power. It observe the reactive power there was a excess flow of reactive power in the system and injects the reactive power when there was a demand in the system.

IV Proposed Control strategy for power modulators

A. POWER CONDITIONING UNIT (MPPT)

Maximum Power Point Tracking is necessary for various solar Photovoltaic energy sources for conditioning solar power. In order to overcome power quality issue this power conditioning unit is developed. MPPT will act as power conditioning unit will increasing the efficiency of the solar power by tracking to the maximum power from the solar PV and deliver maximum voltage irrespective of variation in solar irradiation. Without MPPT solar PV deliver power directly to the load the voltage will quickly reduced to zero. Clearly understood from the I-V characteristics curve obtained from the solar PV. A many types of MPPT Algorithms are available for power conditioning unit. Among all the available algorithms INC Algorithm lends itself well in FPGA controller.

In PV system, temperature varies from 10º C to 70 ºC at each step of 6 ºC. The solar irradiance varies from 50 to 1000W/sq.m at each step of 50 W/sq.m. By varying this two factors data is generated in Matlab/simulation. Hundredofdatasets used to train the ANFIS network [26] for MPPT. The training done in offline using Matlab tool box. The network trained for 30, 000 epochs.

The Fig. 4, shows the overall structure of neuro-fuzzy, which is a five-layer network [27]. The structures shows two inputs of one is solar irradiance and second is cell temperature. Which is translated into appropriate membership functions and three functions for solar irradiance and functions for temperature. These membership functions generated by the ANFIS controller based on the previous trained knowledge [28]. The membership function shape varies during the training stage and final shape obtained after the completion of the complete training. They are named as 'low', 'medium', and 'high'. The rule portrays the relationship and mapping in-between output and input membership function. It can be seen that, the temperature varies from the 10ºC to 70ºC. The solar irradiation varies from the 50 to 1000 W/sq.m and consistently the maximum power point voltage varies in the last column.

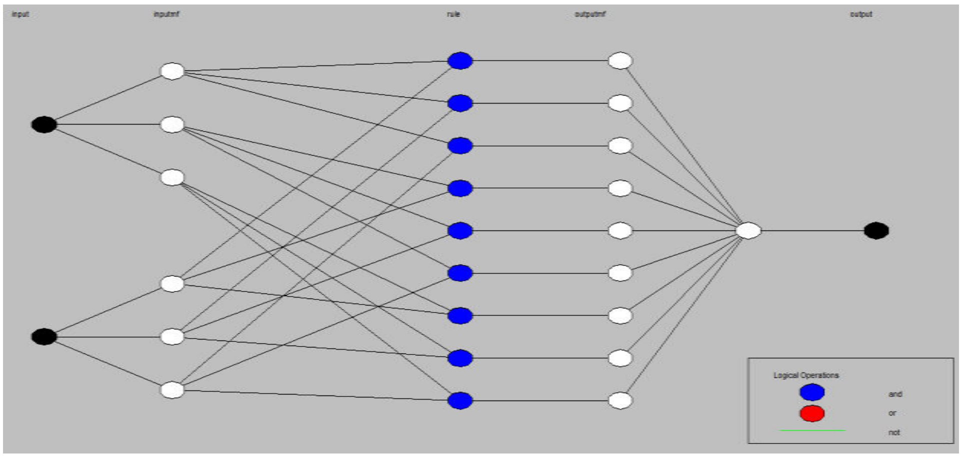


Fig : ANFIS-based MPPT structure

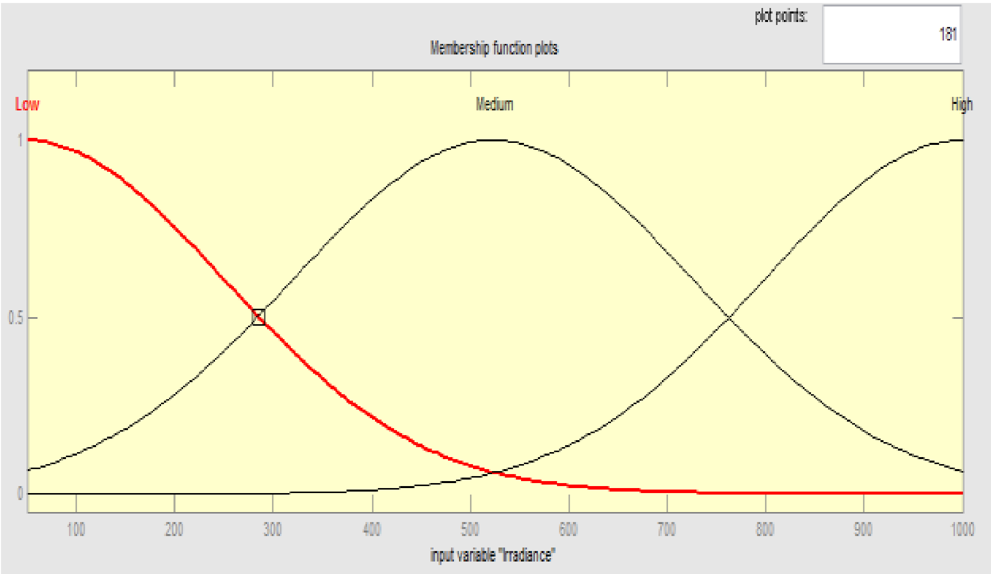


Fig : solar irradiance with MF

There are nine rules created, that rules can follows the conditions. More filled cells means that 'high' values and 'blank' means that low values. For example Rule8 can be read the temperature input is low means that solar irradiation is medium, then the maximum power point voltage become is 14.3V.

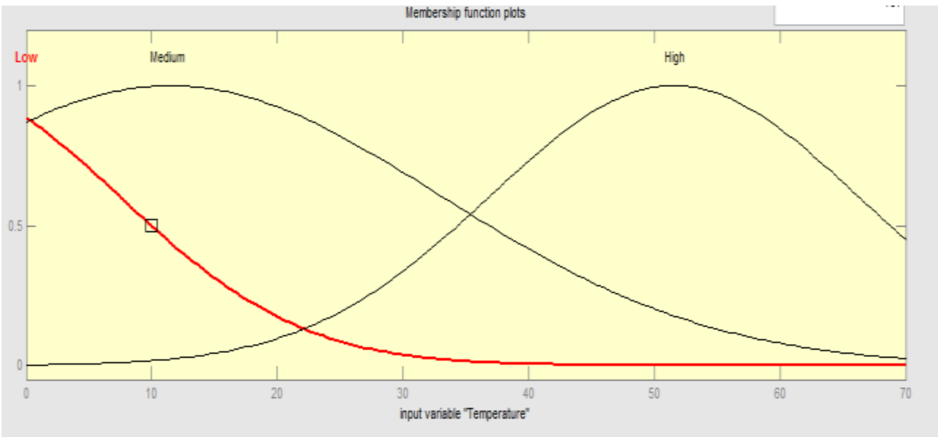


Fig: MF:PV-cell temperature

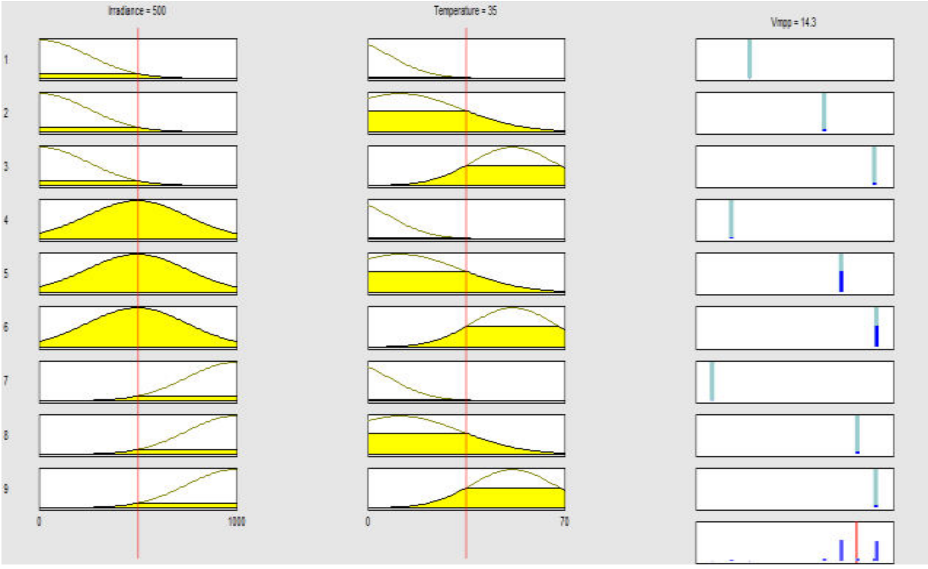


Fig : Rule base of ANFIS controller

The rulers such as red line in vertically clearly shows the solar temperature and irradiance. It can be moved and check the rules of other operating conditions. Fig7. Clearly shows the variation in MPP voltage (Vmpp) with changes in cell temperature and irradiance. The surface shown in Fig.8.portrays the typical behavior of system. The projected ANFIS with MPPT is suitable as well faster when compared to the other conventional MPPT algorithms [23]-[24].

Fig.- Switching pattern of each mode

V various Modes of operation of system topology

Mode-1 Photovoltaic as source and Grid as Load (t_1< t<t_2)

During state-1 switch S is on and S_{S1}, S_{S2}, S_{D1} and S_{D2} are off. PV current is flowing through respective inductor (L_1,L_2...L_N) and stored the harvested energy from PV and Stored energy in C_B makes reverse primary current. Voltage across the primary of transformer (V_P) is equal to voltage across the capacitor (V_C).Now V_P is negative. Vs is negative and secondary current I_{Se} makes D_{S3} and D_{S4} as forward bias and makes load current I_L. Voltage across capacitor C_S makes D_S as reverse bias. During this mode previous cycle energy stored in C_B is transferred to load. I_{SCAP} and I_{BAT} is equal to zero. state-II operation start with S is off. PV-1,PV-2...PV-N are connected to primary of transformer through Buffer capacitor C_B. Voltage across transformer primary (V_P) and secondary (V_S) are positive. Load current is flowing through DS1 and Ds2. One portion of energy is transferred to load and remaining energy stored in buffer capacitor C_B.

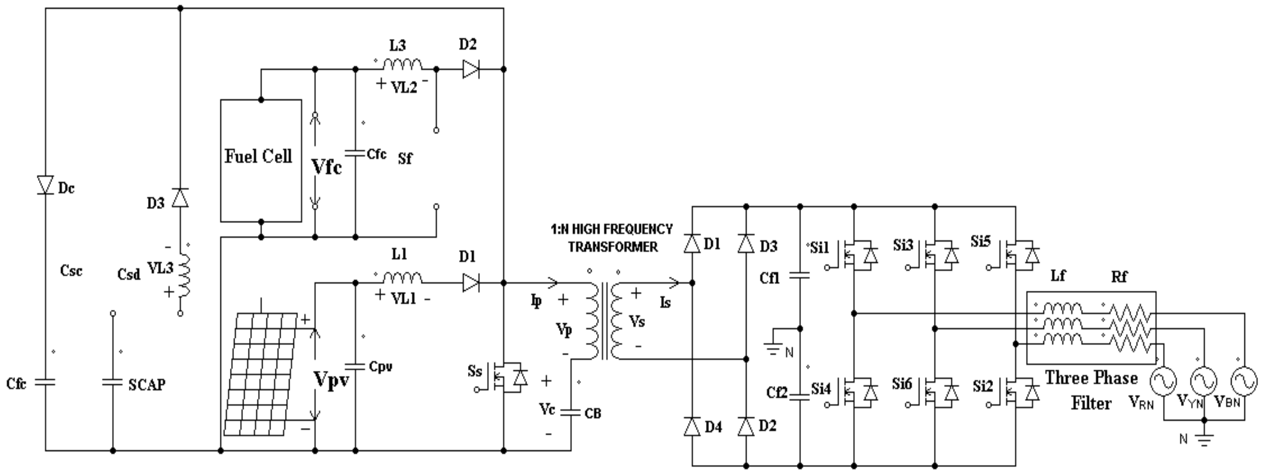


Fig.- Photovoltaic as source and Grid as Load (t_1< t<t_2)

Mode-2 Photovoltaic and Fuel cell as source and Grid as Load (t_2< t<t_3)

Switch S and S_{D1} is on and S_{S1}, S_{S2}, S_{Ds} are off in state-1. PV current are flowing through L1,L2...LN and BAT current flowing through LS. Stored energy in C_B is transferred to load. S is off and SD1 is remains on in state-II.PV and BAT are transferred energy to CB through primary of transformer. PV and BAT energy jointly operates load. This mode is enabled during insufficient PV energy and steady state load conditions.

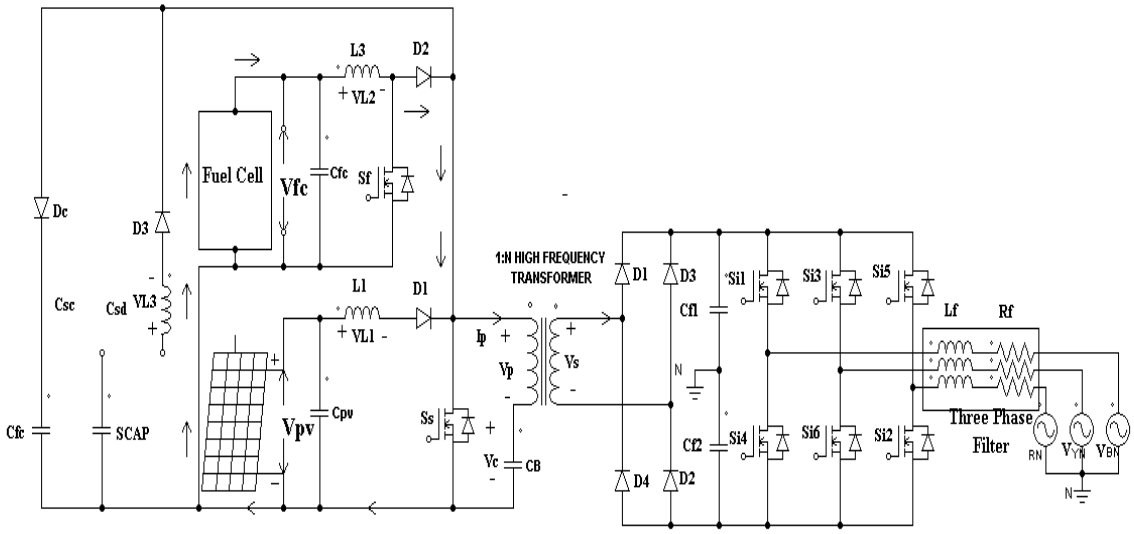


Fig.-Photovoltaic and Fuel cell as source and Grid as

Load ($t_2 < t < t_3$)

Mode-3 Photovoltaic and Fuel cell as source and Grid as Load ($t_3 < t < t_4$)

Switch S and SD2 is on and SS1, SS2, SD1 are off in state-1. PV and SCAP energy is stored in inductor. CB operates load. During state-2 S is off with SD2 on, SCAP and Battery energy is transferred to load and CB.Mode-3 is operates when the sufficient PV energy and fulfil the transient load.

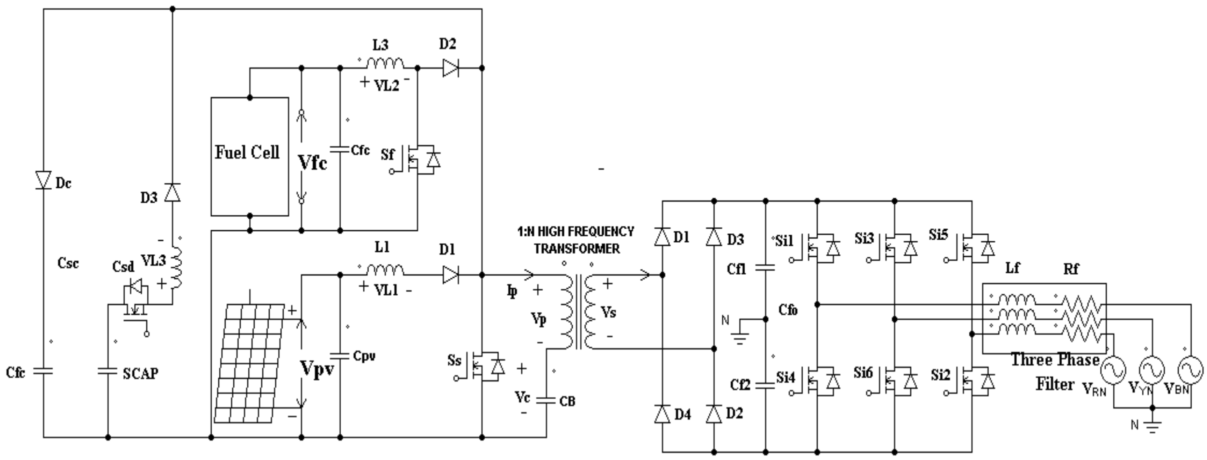


Fig.-Photovoltaic and Fuel cell as source and Grid as

Load ($t_3 < t < t_4$)

Mode-4 Photovoltaic and Fuel cell as source and Supercapacitor and Grid as Load ($t_3 < t < t_4$)

When PV energy is not sufficient and load is transient conditions the mode is activated. BAT is operated for steady state load requirements and SCAP is fulfilled for transient load. state-1 switch S,SD1 and SD2 is on and SS1, SS2 are off. PV energy transferred to, SCAP and BAT energy is transferred to LS. During state-II S is off with SD1 and SD2 is remains ON.PV,BAT and SCAP energy are transferred to CB through primary of transformer.

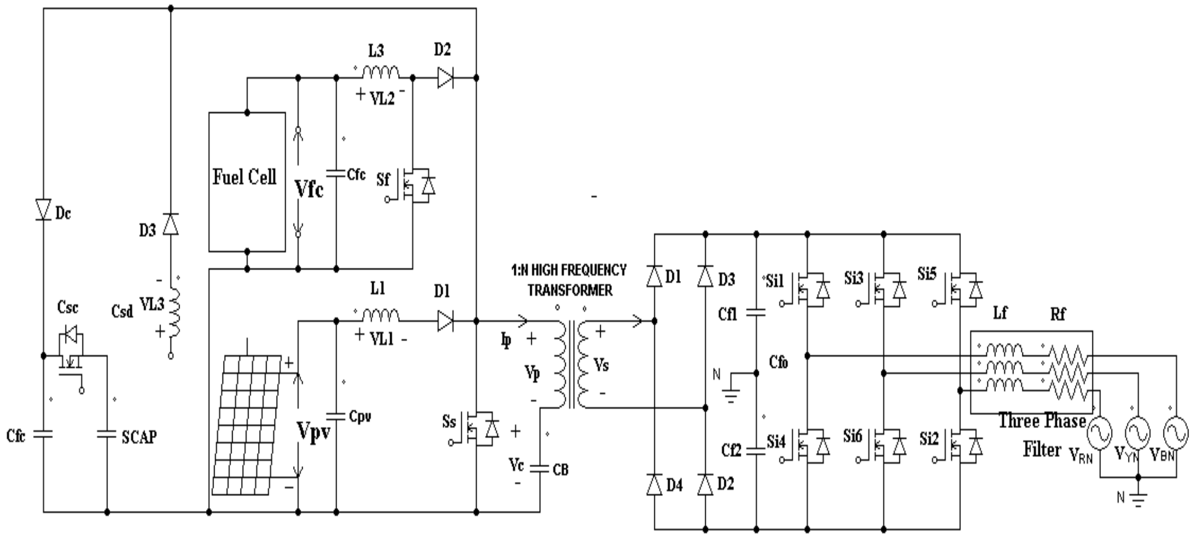


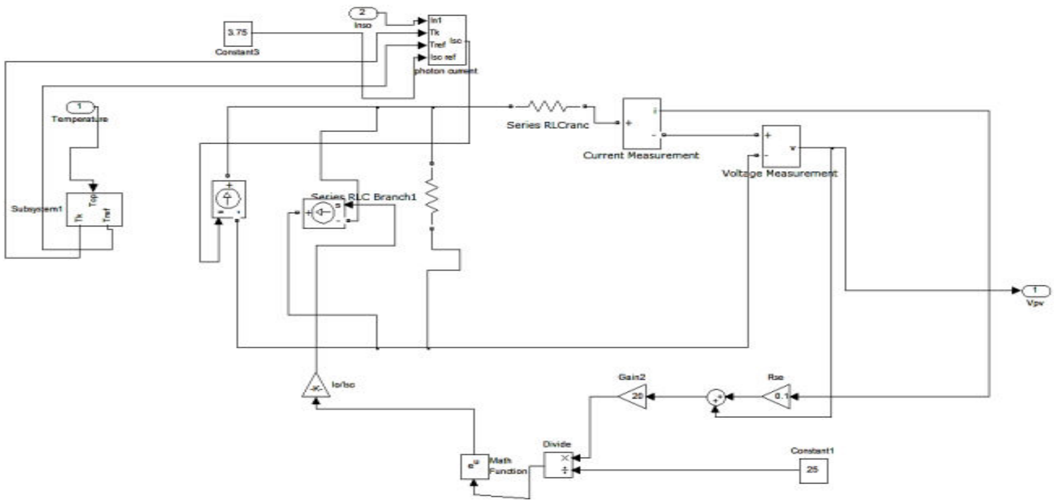
Fig.: Photovoltaic and Fuel cell as source and Supercapacitor and Grid as Load ($t_3 < t < t_4$)

When the harvested solar power is not sufficient to operate load, the mode is activated. Either Switches SD1 and SD2 or both theses switches are turned on in parallel with energy boost operation. Stored power in previous cycle is transferred to inductor through Dd. During this mode solar PV is providing load power in association with either battery, SCAP or both these storage devices. ISCAP and IBAT are positive. Battery current is flowing through SD1 and SCAP current is flowing through SD2.Load current is flowing through secondary of transformer, DS3 and DS4.

VI. RESULTS AND DISCUSSION

A. *PV Array model:*

The Simulink model of PV array designed in the Matlab Simulink tool box. It can clearly shows the P-V characteristic curves.



From the observation irradiance increasing with constant temperature. The output of the voltage from the PV cell decreases but output of the current increases slightly with respect to the voltage. Hence, the output power from PV array reduced.

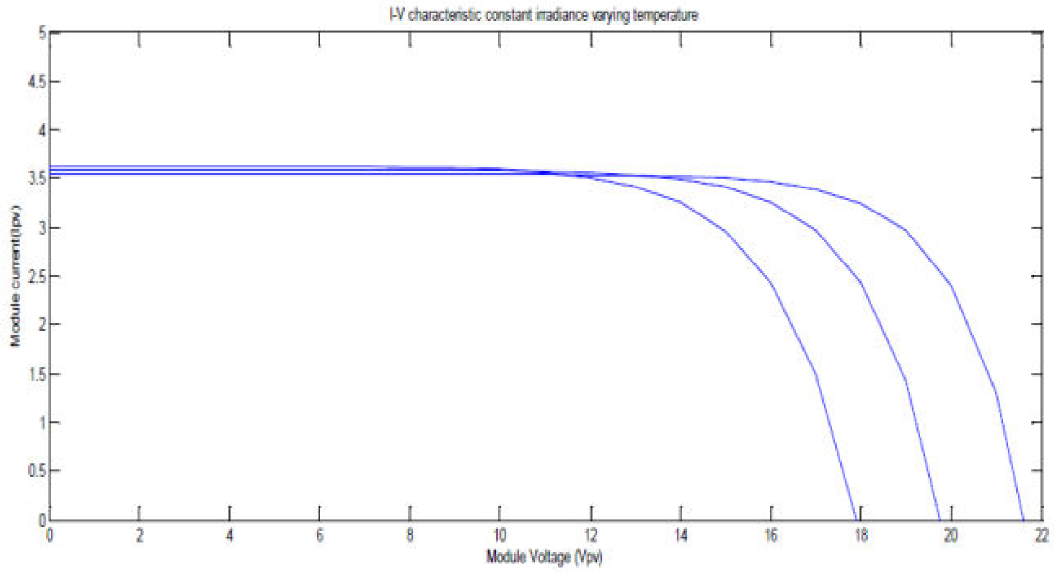


Fig: V-I Characteristic PV cell for varying temperature according with constant irradiation.

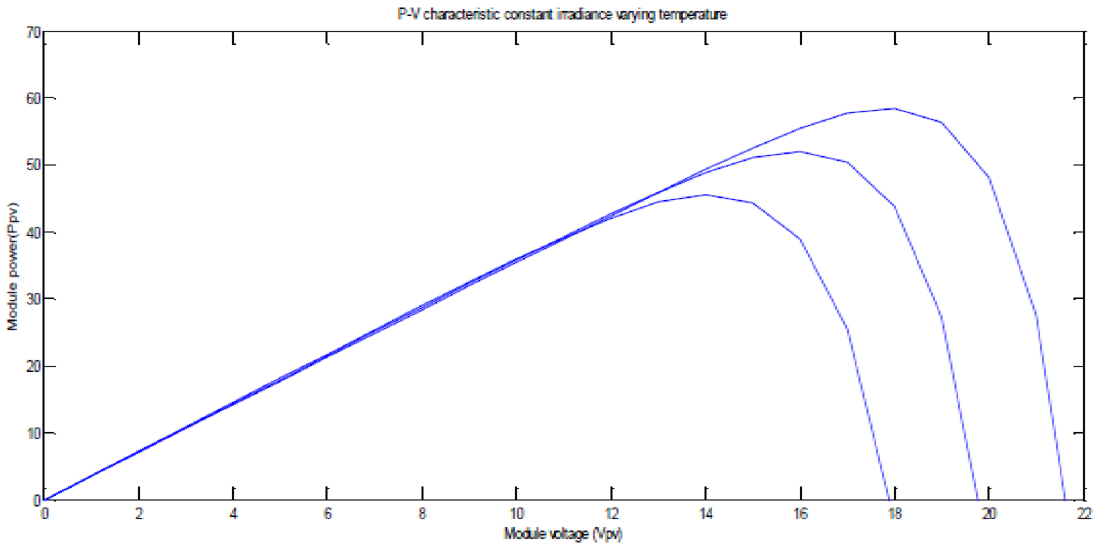


Fig : P-V characteristic: varying irradiance with constant temperature

To increasing the solar radiation in PV with the constant temperature the voltage and current in the array also increases. Hence, at higher insulation we are going to get the required voltage

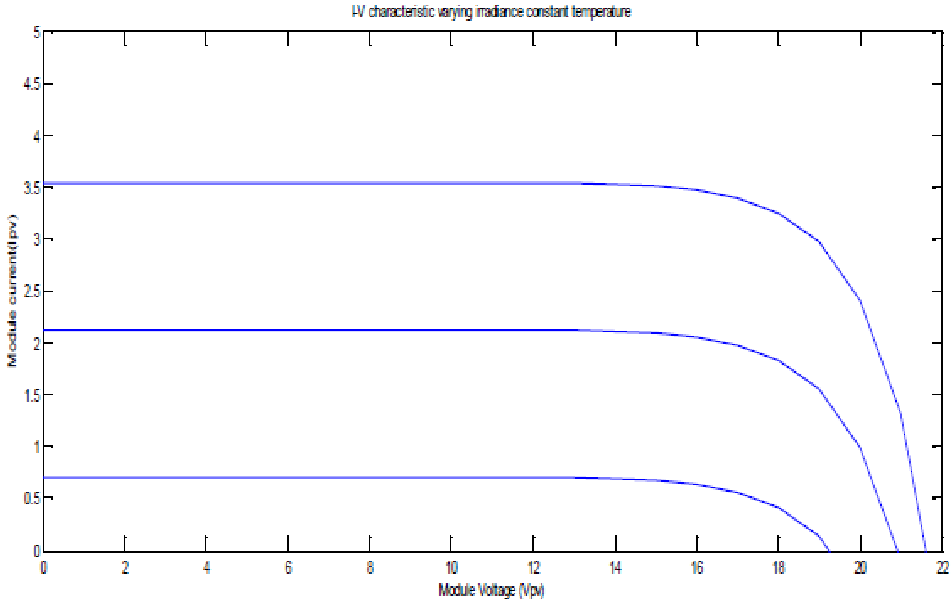


Fig : I-V characteristic: varying irradiance with constant temperature

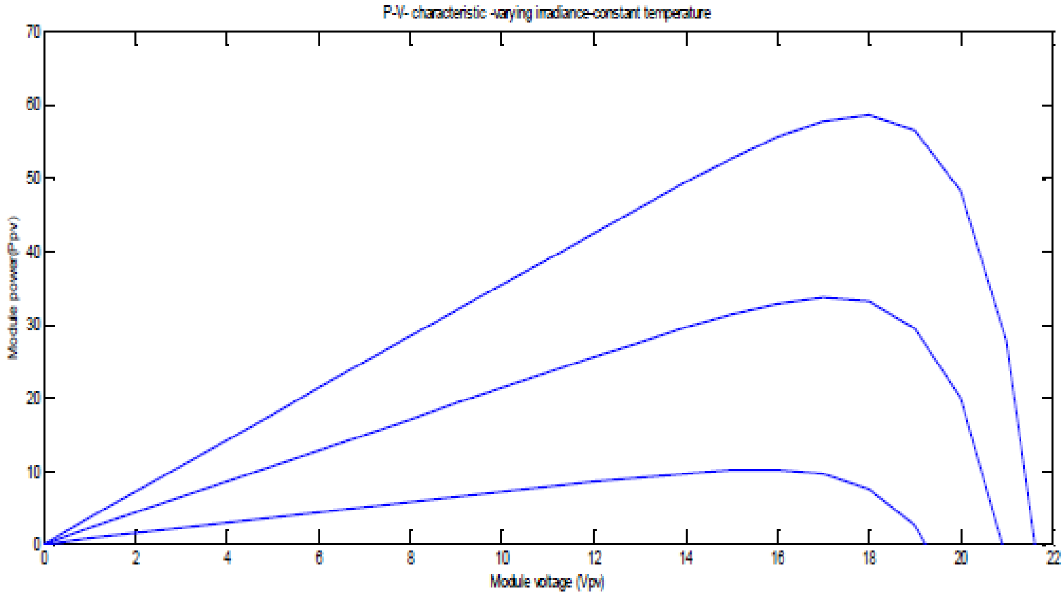
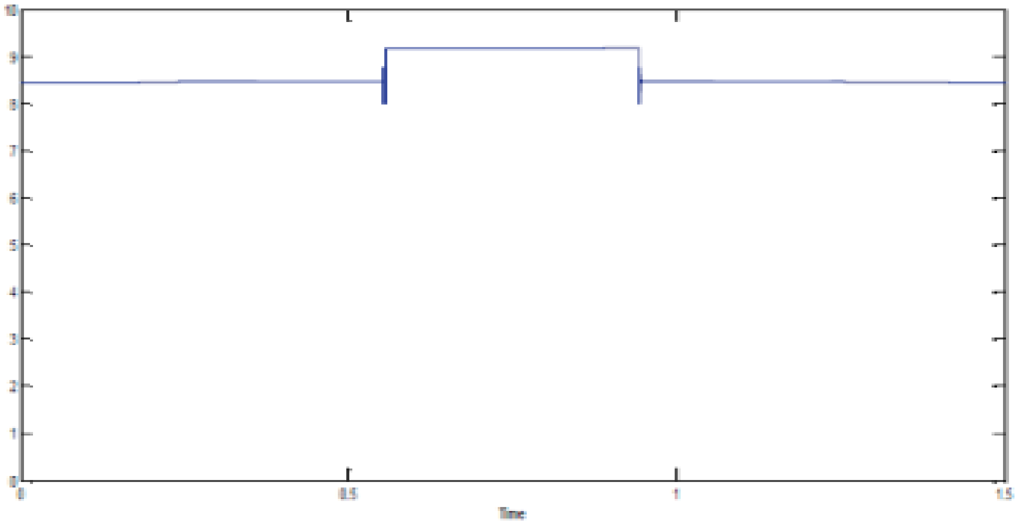


Fig : P-V characteristic: varying irradiance with constant temperature

The PV output voltage maximum obtained by using ANFIS controller. This technique is faster and stable, when compared to other conventional types of MPPT algorithms.



Output voltage (ANFIS):

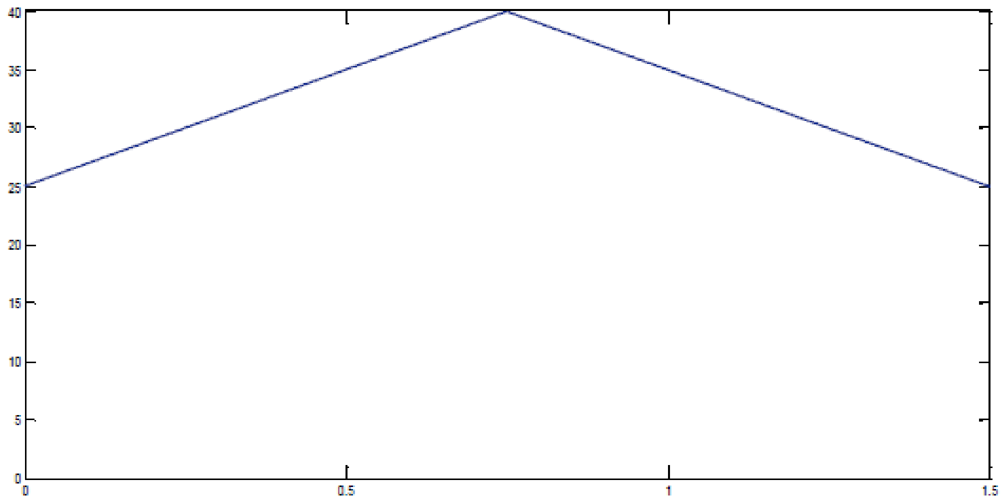


Fig..Variation of solar irradiation and temperature in simulation time.

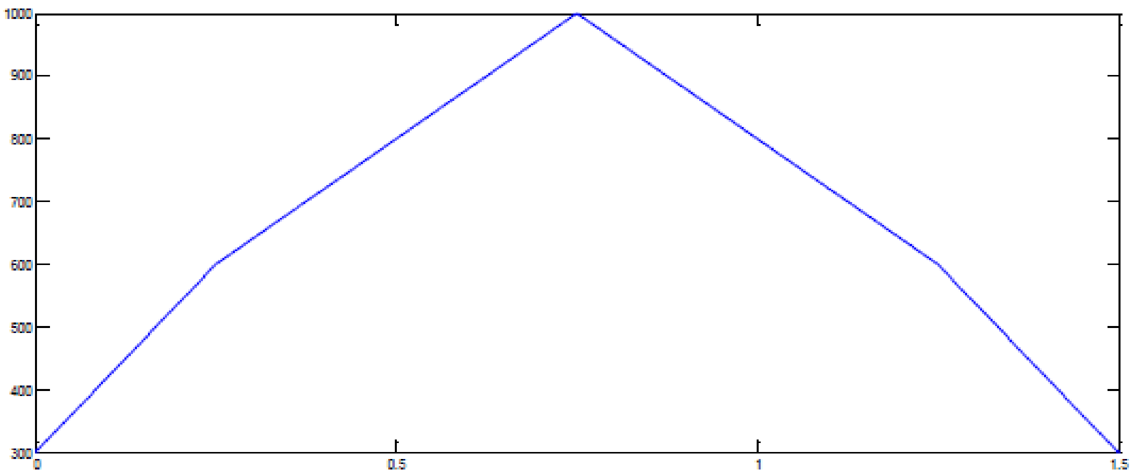


Fig..Curve for varying temperature and solar irradiation.

B. Fuel-Cells:

The Fuel Cells mainly contains the three parts. They are Anode, Cathode, and in-between the both of these two seats of chemical reactions And the FC core of conductive membrane we called as

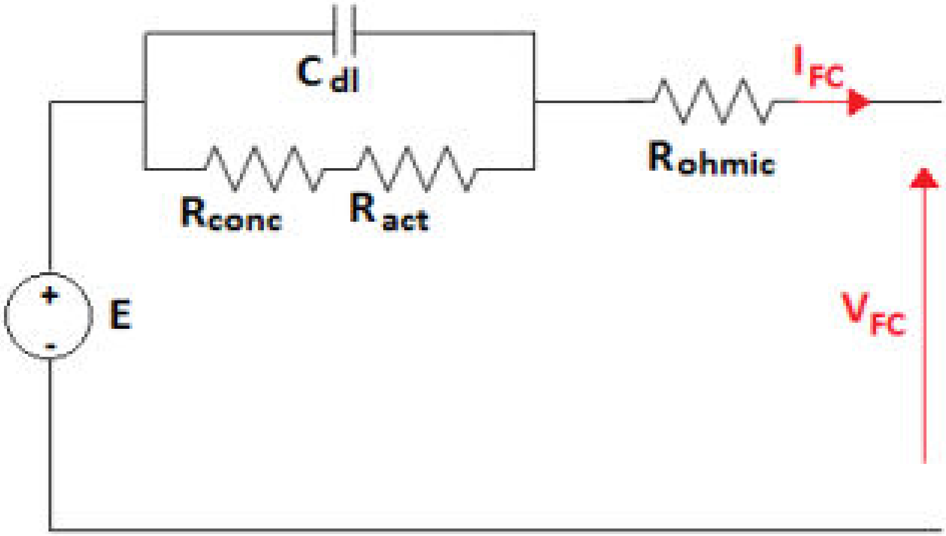
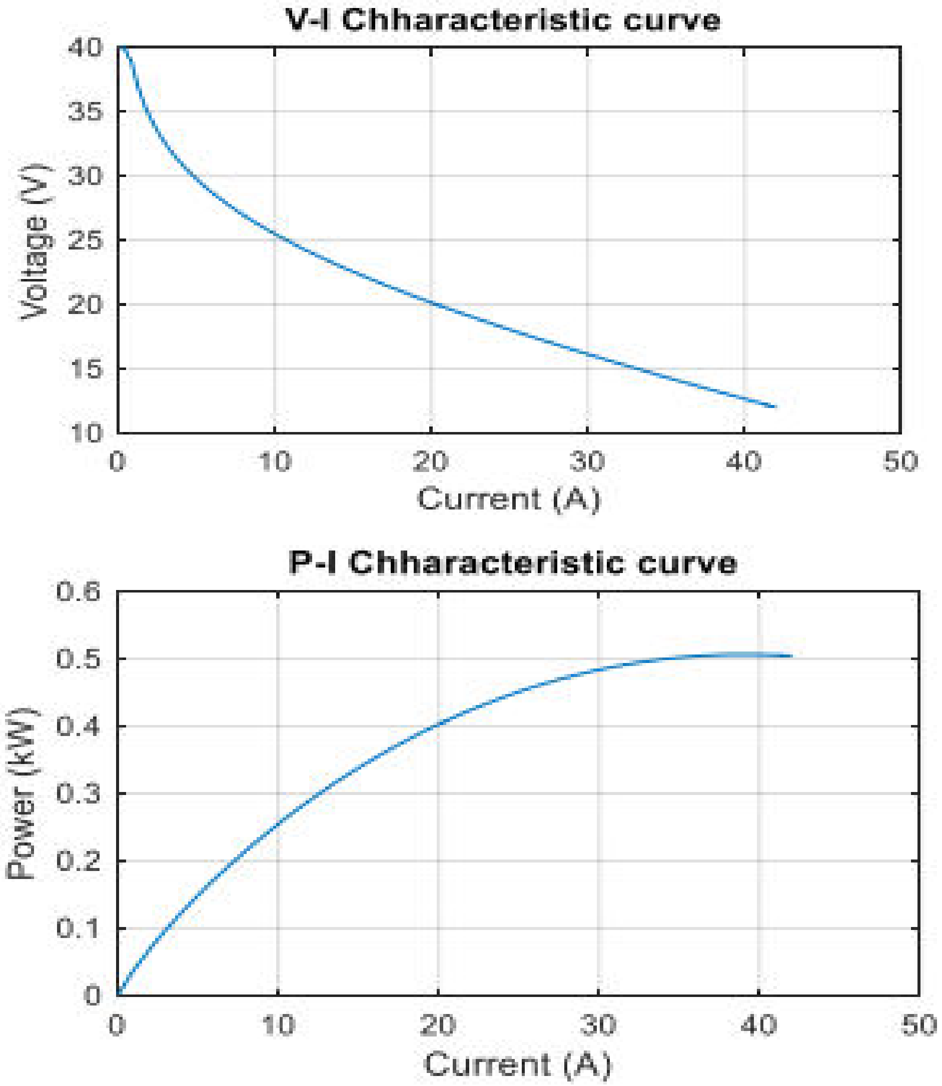


Fig. . FC electrical circuit equivalent model**.**

Electrolyte. We use the 500W PEM(Product code: H-500)type Fuel Cell model. This model features are given in below Table.

TABLE II. Features of H-500 PEM Fuel-Cell

Parameter	Value
Rated Power	500 W
Number of PV Cells	24 No.
Rate	14.4V at 35A
Max Temperature(Stack)	60ºC
Hydrogen Flow Rate(Maximum Output)	6.6 L/min
Pressure(Hydrogen)	0.46-0.56 bar
Purity (Hydrogen)	99.989 %
Time for Start-Up	<= 30.5 s



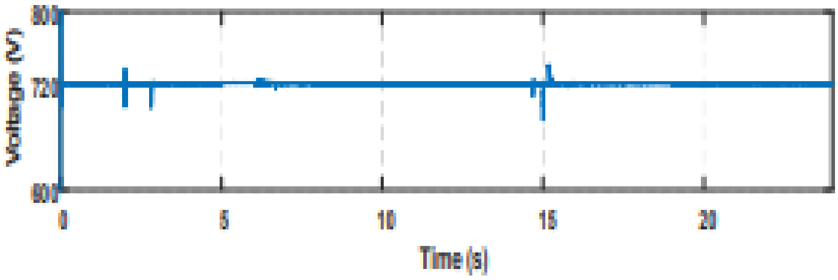
Figs. V-I and P-I characteristics of H-500 PEM type fuel-cell

C. Super-Capacitor:

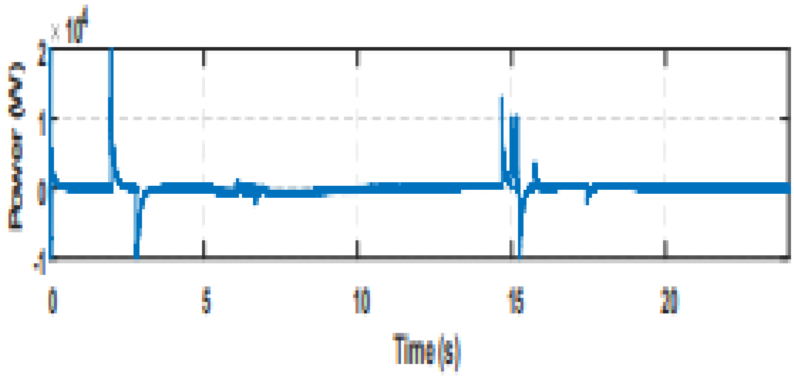
The energy source of super capacitor model Maxwell BMOD0006-E160-B02 165 V module type used in our system and its capability details given below.

TABLE .Module features for Maxwell 160v ultra-capacitor

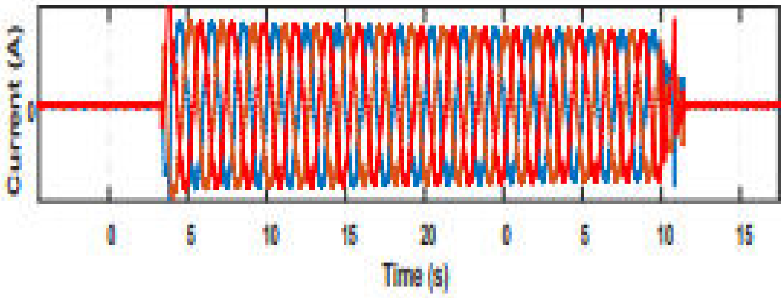
Parameter	Value
Capacitance	5.7 F
Voltage	165 V
Max. Voltage	175 V
Max. Current	170 A
Max. ESR	240 mΩ
Max. Stored Energy per Cell	0.35 Wh
No. of Cells	65



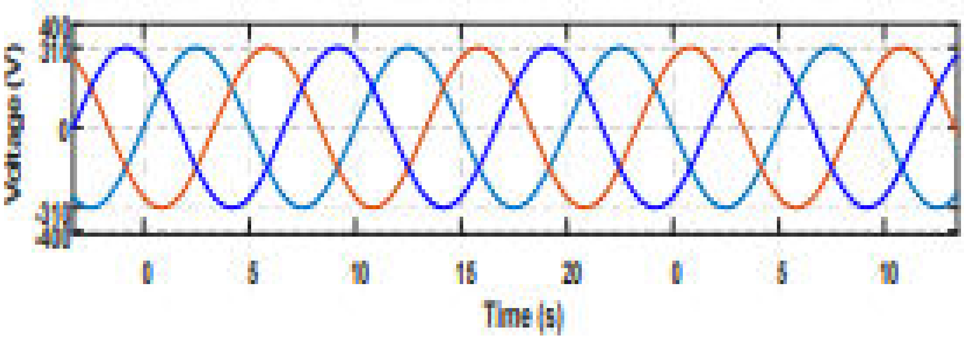
DC bus voltage



Super capacitor power



Grid Current



Grid Voltage

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