

Driving Sustainability: Multiport Power Electronics Converter (MPEC) Topologies for Efficient Electric Vehicles (EV) Charging

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Abstract

Electric vehicles are highly demand in recent years due to the deficiency of fuel, gas and no pollution emit. The various types are required different charging modes for EVs battery charging. The charging modes such power grid and renewable energies. Some EVs batteries, the utility grid mode is not suitable. Due to this the charging stations need the alternative method to operate both AC and DC. In this paper, the proposed multiport power electronics converter (MPEC) in controller unit has been operated in both modes. This proposed converter can convert the AC-DC for charging applications and DC-AC for domestic applications. RES are required the battery storage unit to store the energy in rest mode. The proposed work is designed and simulated using MATLAB and obtained the output power and voltages for all modes of operations.

Keywords - Electric vehicles (EVs), Photovoltaic (PV), Fuel-cell (FC), multiport power electronics converter (MPEC) and Resource Energy System (RES)

1. Introduction

The Climate changes, air pollution and Fuel disasters, many countries are research alternatives for conventional transportations. It is recognizable to Electric vehicles (EVs) for reduce this issues. There are Plug-in and pure Battery EVs are available commercially [1]. It can charge the battery from AC or DC power supply with certain voltage and current levels. For domestic purposes, the utility grid sources are preferred in charging locations. For on-road or dynamic charging, DC power supply is preferred to get the battery pack [2]. Using the renewable energy sources (RES) to saving and transfer the power for all charging applications and the excess energy also stored for future use [3]. The different energy sources from grid, solar systems and fuel cell systems. In EVs, it contains different sources, Compensation circuits with converter and load units. To access the various energy sources and transferred to EVs batteries are required a converter to control the power flow [4]. For this purpose, the bidirectional DC-DC converter has supported to overall isolated systems [5]. In these articles, there is a possible to use multiport power electronic converter (MPEC) with high frequency transformer to charge the multi applications through multiport [6]. It's called as an isolated converter. The EVs are preferred both isolated and non-isolated converters as per requirements [7].

Moreover, the system has been connected with RES (Renewable Energy Systems) to get the energy from different sources, due to the development of smart grid systems. Hence, the bidirectional data transfer method for wireless charging systems for all applications [8]. And also, to save the energy, the system has connected with RES and grid source for development of smart grid systems. It needs to distribute the energy from different sources and utilize the same through a central control unit. Hence the power flow has controlled control unit using power electronics converter [9]. Power electronic systems consist of one or more than one

power electronic converter also known as multiport power electronic converter (MPEC). The characteristics of the semiconductor devices and its control permit the converter to control the source as per output requirements [10]. In MPEC method has various type of converters: AC-DC, DC-DC, DC-AC; in AC-DC, the diode rectifiers are used to get the fixed DC voltage in output from AC source voltage for battery charging applications. In DC drives, the line voltages are used for transfer the energy, which is known as naturally commutated converter (AC-DC) [11]. Hence the RES act as a source, the DC-DC converters are used for variable DC output voltage from fixed input DC voltage. Various converter types are available depending on applications, such as DC drives, Battery vehicles. For AC load applications such as motors and UPS, the converter output is variable AC output voltage from the fixed DC voltage [12][13]. The controller can extract maximum energy from the source to transfer the batteries. Mostly the maximum power point tracking (MPPT) is approached to get the energy from PV cell. This approach is optimized with control the power for high accuracy in tracking systems [14]. For this purpose, the MPEC has been proposed to control the power flow in charging systems shown in Fig.1.

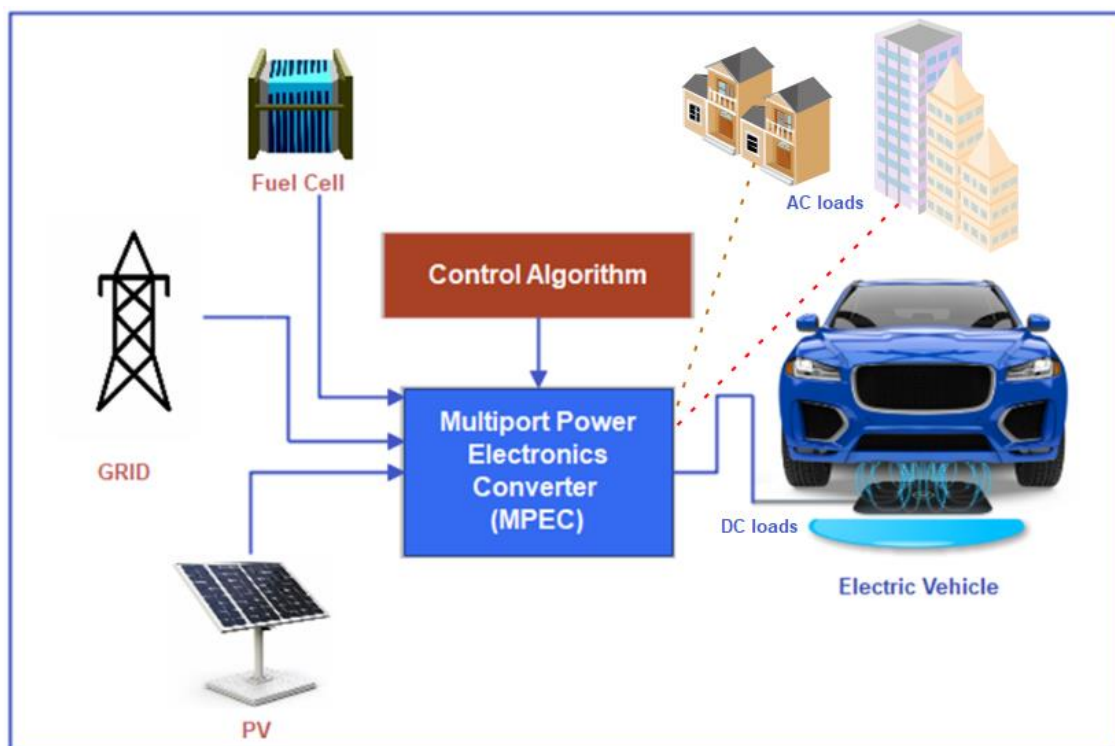


Fig. 1. Overview of Proposed MPEC topologies

The contribution of MPEC in the system size, efficiency and cost is prominent [15]. Henceforth the system has accessed to AC-DC-DC-AC, the MPEC is suitable for comprised with grid unit and also RES unit to control the power flow. In EVs batteries charging and discharging, the converter needs to change their modes immediately depending on the requirements. Here the grid and EVs are connected together and support by transfer the energy in electricity demanding and storing the surplus energy [16]. It's possible to transfer the energy directly to a domestic via vehicle-to-home (V2H), which allows the user can supply the energy to domestic purposes from battery backup. Same technologies in Vehicle to grid (V2G) provide various services, voltage and frequency regulation, balancing irregular energy [17]. In this method, the EV battery charging with different charging ratios have an important effect to the V2G applications. The V2G technologies to stabilise the irregular energy from RES, when the uncertain of EV charging at worst-case [18]. In this article discusses the main research areas of study in MPEC topologies for EVs battery charging systems, including interfaced with RES of research. Then the recent progresses are studied along with future visions [19][20]. To conclude, the major contributions of this article are as follows. To reduce the power loss, the MPEC topologies based EVs battery charging systems is analysed in detail. The organization of this article consists of an

overview of renewable energy source for EVs in section II, a discussion of converter topologies and their control methods in section III, results and discussions in section IV, and conclusions in section V.

Abbreviations

EV	Electricvehicle
PE	Powerelectronics
RES	Renewable Energy Sources
PV	Photovoltaic
PEMFC	ProtonExchangeMembraneFuelcell
MPEC	Multiport Power Electronics Converter
SOC	Stateofcharge
HHVH2	HigherHeatingValue of the hydrogen

2. Modelling of Energy Resources

2.1. Photovoltaic (PV) system

Solar PV system is one of the most viable one for EVs battery charging which is easily available in everywhere. In charging systems of a PV, batteries, and super capacitors are used for long-term power transfer and fast dynamic power regulation, respectively using MPEC methods. Depending on the load, the energy consumed from its battery bank. For this, the PV array capacity plays a major role in energy storage in day by day usage. Sometime there is a challenge of uncertain power supply issues in PV, its require the MPEC approach to control the systems. The PV system contains one and more series or parallel solar setups which are connected in series or parallel connection setups to compose with storage unit (batteries), and grid energy to charge the EV and to feed the load applications. For large power applications and high voltage, the system need the many number of devices connected in either series or parallel which is known as Module array.

2.1. PV modulesDesign:

For Open Circuits; when the PVs are connected in series and its obtained maximum power which is calculated by the summation of total PVs. The PV modules parameters are required to get the maximum power point (P_M) such as open circuit voltage (V_{oc}), Voltage at maximum power point (V_M), and Short circuit current (I_{sc}).

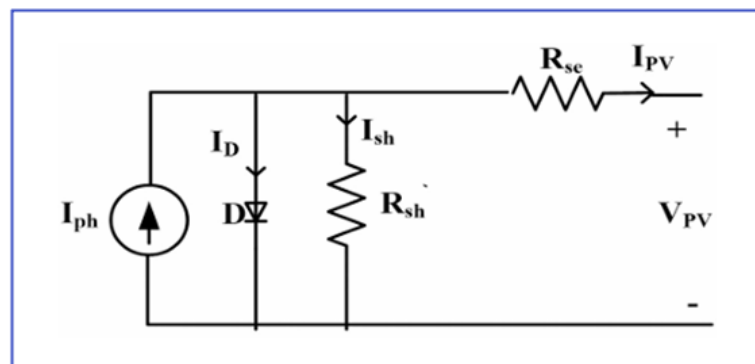


Fig. 2. Equivalent circuit of PV cell

From the circuit, the total power of PV modules (P_t) becomes,

$$P_t = N \times P_M ; \quad (1)$$

Power array,

$$P_a = V_M \times I_M ; \quad (2)$$

V_M – PV array Voltage;

I_M – PV array Current;

Source input voltage = 900 volts;

$$V_{MA} = 900 \text{ V};$$

$$V_{OC} = 35 \text{ v};$$

$$V_M = 29 \text{ v};$$

$$I_{SC} = 7.2 \text{ A};$$

$$I_M = 6.4 \text{ A};$$

$$P_a = V_M \times I_M;$$

$$= 29 \text{ V} \times 6.4 \text{ A};$$

$$P_a = 185.6 \text{ Watts}$$

Number of PV modules becomes,

$$N = V_{MA} / V_M; \quad (3)$$

$$N = 900 / 29;$$

$$N = 31.03 \text{ (Higher integer value 31)};$$

$$\text{From (3),} \quad V_{MA} = V_M \times N; \quad (4)$$

$$= 29 \times 31$$

$$V_{MA} = 899 \text{ Volts};$$

Total power of the PV array,

$$P_{MA} = N \times P_M; \quad (5)$$

$$= 31 \times 185.6$$

$$P_{MA} = 5753.3 \text{ Watts.}$$

The Total Efficiency,

$$\eta = P_M / (P_s \times A); \quad (6)$$

$$A = 100 \text{ cm}^2;$$

$$P_M = 5.75 \text{ W};$$

$$\eta = [5.75 \text{ W} / (1000 \text{ W/m}^2 \times 0.01 \text{ m}^2)];$$

$$\eta = 57.5 \%$$

When the PV modules are connected in series and their maximum voltage is added but the current is constant in each module which is shown in Table.1. And V_{OC} becomes zero, when the PV generating I_M (0.65 A) in short circuit. And the maximum Efficiency of PV system is obtained by, maximum of output power and input power with area of PV modules.

Table.1. Parameter values of Current, Voltage and Power

I_M (Amps)	V_M (Volts)	P_M (Watts)
0.6	9.54	5.72
0.61	9.39	5.73
0.62	9.27	5.75
0.63	9.08	5.72
0.64	8.72	5.58
0.65	0	0

2.2. Fuel cell (FC)

The energy is an electrochemical cell which is converts the chemical energy of a fuel into electricity. This module has leads flexible modular structure with high efficiency, high power density. It's categorized by the electrolyte used like alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), proton exchange membrane fuel cell (PEMFC) and molten carbonate fuel cell (MCFC). Due to high power density, low noise generation and very compact size, PEMFC is widely used in electrical circuit's applications.

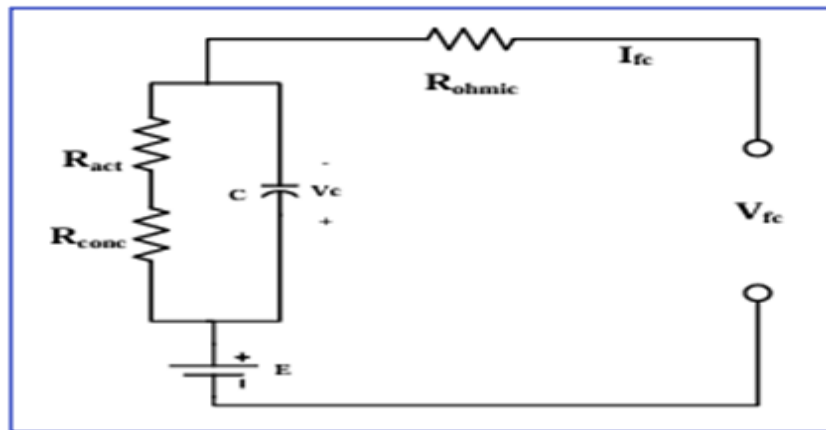


Fig. 3. Equivalent circuit of PEMFC

The resistances of ohmic, activation and concentration become like R_{ohmic} , R_{act} , R_{conc} and membrane capacitance C , then the membrane voltage equation is given,

$$V_{FC} = E - V_{act} - V_{\Omega} - V_{co}$$

$$P_{FC} = N \cdot V_{FC} \cdot I_{FC}$$

The efficiency is,

$$\eta = P_{FC} / M_{H_2} HHV_{H_2}$$

Nearly, a FC can yield 0.6–0.75 V and the power and voltage level can fluctuate from 2 kW to 50 MW and a couple of volts to 10 kV(10), individually relying upon the connections and picked arrangements plan. The important task in making FCs widely utilized in the DG market is to make them all the more financially serious with the innovations. Sometimes the electric load transients are not quickly responds for this FC, due to their slow progress in electrochemical and thermodynamic characteristics. And it's directly connected to utility through the interfacing units. It can control their performance by using these interfacing units. Each cells output cannot feed to grid directly. So the numbers of FCs are connected either in series or parallel connections to achieve high DC output voltage. When the numbers of FCs are connected, the system efficiency gets worse and system cost is high. Due to this reason, high voltage gain based MPEC converter design is used. It increased the voltage from low voltage with high duty cycle which reduces the overall low efficiency. This proposed MPEC which has high power transfer gain and efficiency with minimum duty ratio is suggested for FCs in EV applications.

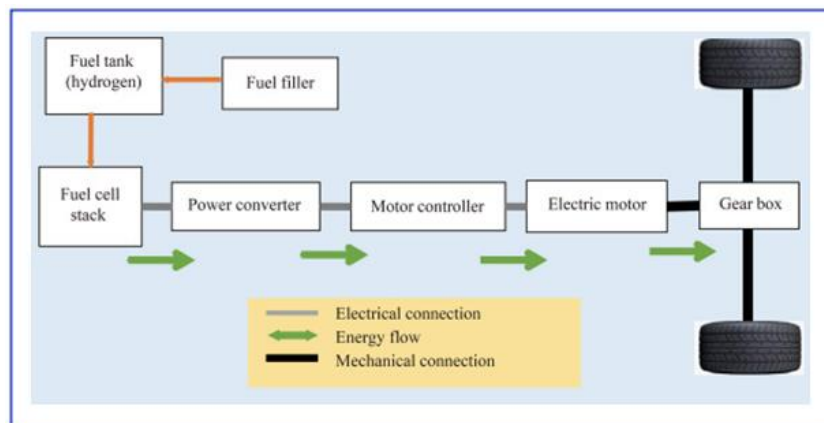


Fig.4. MPEC based FC system for EVs charging applications

3. Proposed MPEC Topologies

In this method, the main constrain is not only the energy sharing, the system efficiency is also important role in this module. To provide maximum efficiency in all converters for Utility AC grid, solar PV

modules, Batter storage unit, EVs charger. The MPEC has both isolated and non-isolated converters. An isolated as a self-defines or independent converter which is isolated by AC grid. On other hand, the non-isolated converters are dependent or the source is connected with load. The MPEC Buck- Boost converter has designed for all circuits applications which is depicts in Fig. 5.

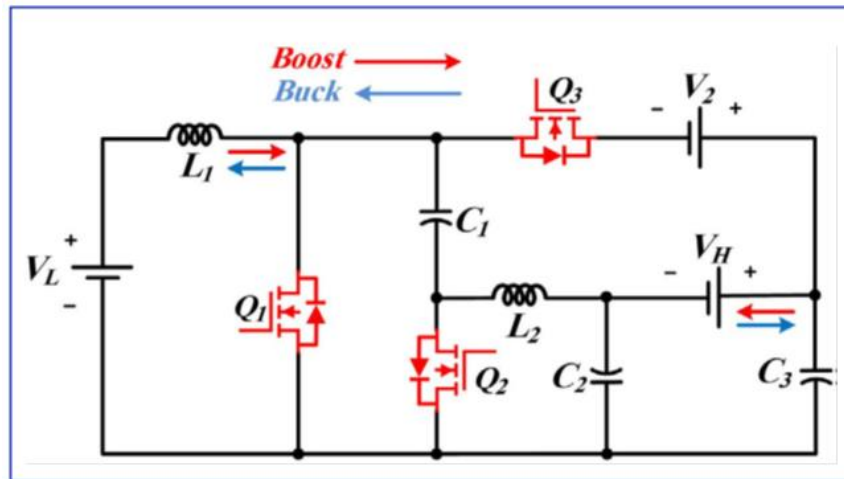


Fig.5. MPEC based system design

In this converter design has two inductors (L_1 , L_2), three capacitors and power switches (C_1 , C_2 , C_3) and (Q_1 , Q_2 , Q_3) respectively. The two source voltages (V_L) and (V_H) are low level and high level voltages respectively, both sources is connected as a bi directional port in MPEC design. Another source of voltage (V_2) connected across the capacitor for proposed MPEC design. This proposed design has two modes like step up and step down conversion modes. To analysis these modes and simplify its in steady state, all the semiconductor devices are maintained in an ideal and the capacitors in constant position. Depending on the step up or step down modes, the converter voltage (V_2) can produce the cumulative or diminishing output voltage for its applications. When the output voltage is high, the high energy can passed through the source voltage (V_L) and converter voltage (V_2) to the load applications in step-up mode. And the same for low energy level, it can pass through the source voltage (V_H) and converter voltage (V_2) to the load in step down mode.

A) BuckMode Converter:

The duty cycle $D_1 \gg D_2$ and D_3 , the energy is transferred from V_H to V_L . And the R_o is connected to the low level port. Due to this, the voltages across the inductors V_{L1} and V_{L2} are positive and inductor currents I_{L1} and I_{L2} increased which is presented in Fig. 6. The Q_1 is turned ON, when the Q_2 and Q_3 in OFF. The V_2 is detached from MPEC. The voltage remains constant. Due to this the inductor currents I_{L1} and I_{L2} decreased and C_2 is discharged, C_1 & C_3 are charged.

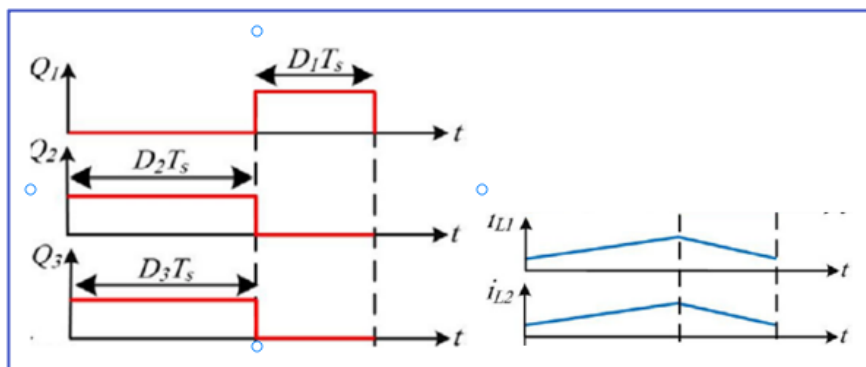


Fig. 6. MPEC waveform in Buck mode

B) Boost mode Converter:

From the equivalent circuit, the switch Q_1 is ON state, the switches Q_2 and Q_3 in OFF state. In this, the inductors currents L_1 and L_2 are increased and capacitors C_2 is charged, C_1 & C_3 are discharged. From the fig. 7. The V_2 is open circuited and its voltage is constant during first half stage. Now, the energy is transferred from V_L to V_H . The Q_1 is turned OFF, when the Q_2 and Q_3 in ON. The V_2 is connected through Q_3 to MPEC. Due to negative voltage across an inductor currents I_{L1} and I_{L2} decreased and C_2 is discharged, C_1 & C_3 are charged.

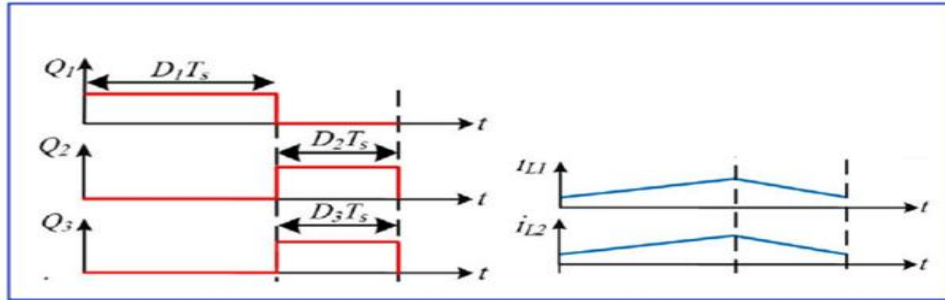


Fig. 7. MPEC waveform in Boost mode

$$\therefore D_2 = D_3 = (1 - D_1); \text{and}$$

$$D_1 = (1 - D_2) = (1 - D_3);$$

When the duty cycle of switch $Q_1 \gg D_2$ and D_3 , the duty cycles of switches are become, $Q_2 = Q_3$; and Duty cycles $D_2 = D_3$.

4. Results and Discussions

The MPEC controller unit based charging system operates under various resources can operate either an isolated and non-isolated mode. The converter can also change their modes depending upon the demand of energy sources. RESs are supported directly to the load applications while grid is not supported or engaged with another user. While charging, grid sources can detached completely. In results of PV and FCs are presented in Fig.9. and Fig. 10. This system model and its operations are designed using MATLAB/Simulink and its results are obtained in various source modes.

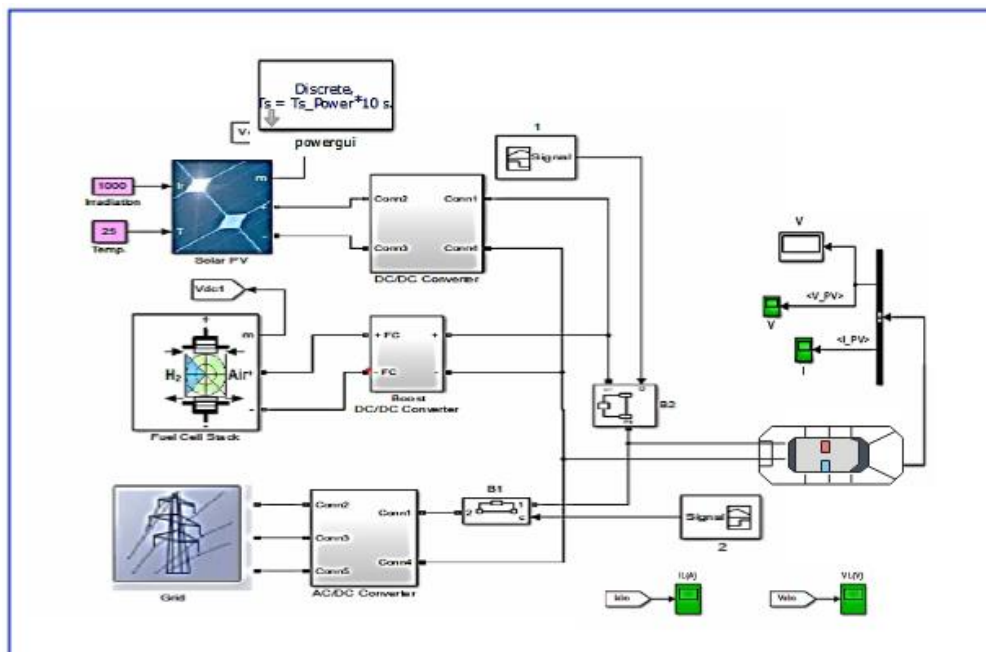


Fig 8. Simulation design of MPEC Topologies based Charging systems

4.1. Simulation design and results

The multiport power electronic converter based EV charging systems are modelled in MATLAB Simulink to appropriately characterise its dynamic operations and conditions. The MPEC has controlled by PID controller in demanding periods and the surplus energies are used to store the energy for back up.

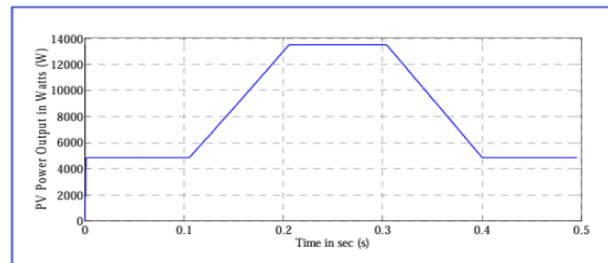


Fig. 9. PV array Output Power

The Simulink models can be customised based on the user's requirements and various resources such as PVs and FCs are chosen by its applications. This various resources with MPEC based EVs charging designed and obtained by MATLAB/Simulink Power System Toolbox software is presented in Fig. 8.

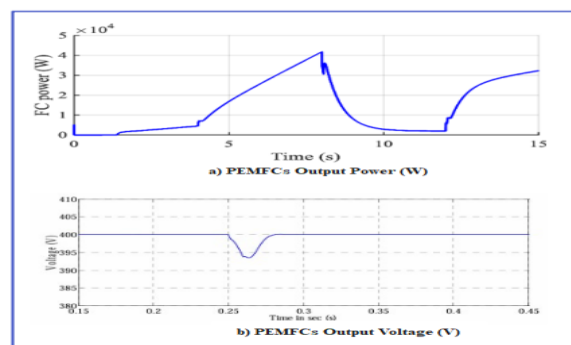


Fig. 10. PEMFCs Output Power and Voltage

The simulation results shows that how the all resources are connected and transfer the power and its output voltage with high efficiency. This scenario represents, how that each resources are operates under MPEC control unit for different applications. The power transfer from PV array cells responds to the converter control and generates the output power shown in Fig. 9. Another resource named FCs is operates under the various independent functions and its results of output power and voltage is presented in Fig. 10.

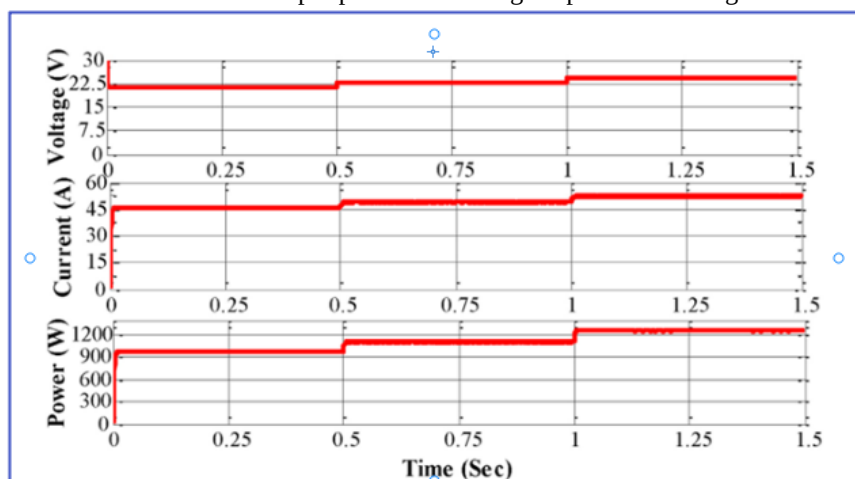


Fig. 11. Simulation results output Power, Voltage, and Current of PEMFCs

The grid source is accompanying in various mode of operation during peak hours, the grid connections are not sufficient to provide the energy or else the charging connections is completely occupied which creates the high demand. Generally, the utility grid sources are used to get the power while other resources are isolated and its simulation results shown in Fig. 11.

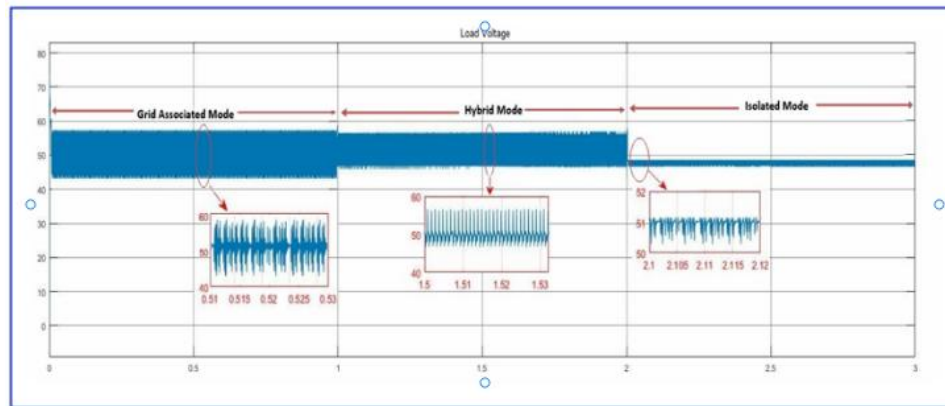


Fig. 11. Simulation results of output voltage in various modes

And the grid output voltage is high and rate of battery charging state is also high. Meanwhile, the other sources are isolated and it produce high voltage with low power charging rate up to 45-50%, at this moment grid source is completely detached. And both PV cells and FCs are connected together, when the grid power is not available. In hybrid mode, the system can operate in both isolated and non-isolated sources which makes the output voltage is more than 40 volts.

5. Conclusion

The multiport power electronic converter systems are proposed and comprehensively studied in this paper. The charging applications are required to transfer the power in fast mode. For this purpose the system can be connected with various power modes to get fast charging. AC grid source is connected through the MPEC controller to maintain the power transferring stability. And also other RESs are connected together with grid system for charging applications while utility not supported properly. The controller operates with multiport converter unit under various load applications. This control unit is incorporated with both grid and RES systems. Additionally the MPEC converter can operate in both buck and boost modes. The effectiveness of proposed converter based design operates on various sources, its operations are analysed by MATLAB/Simulink in each mode which is suitable for EVs charging applications. The suggested MPEC converter performance is highly suitable for all charging and discharging applications. The analysis of grid mode, PV and FC modes results are obtained.

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