POWER CONDITIONING OF SOLAR PHOTO VOLTAIC, BATTERY WITH FUEL CELL UNDER DYNAMIC SWITCHING OF LOADS

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ABSTRACT

The renewable sources integration with the DC micro grid is playing vital role in the current distribution system for providing the necessary clean power. The available of abundant renewable sources can be integrated through the DC link medium. The intermittent nature of renewable sources and dynamic switching of loads affects the quality of supply and DC link voltage respectively. It may fails to supply the power continuously. Reliability of power supply can be achieved with the use of integration of storage system. Here, the solar photovoltaic (SPV) array is fed with battery storage, fuel cell through the DC link medium. Utilizing SPV array maximum power is tracked using intelligent controller based maximum power point tracking (MPPT) technique. The battery storage with the DC link integration made through the bi-directional DC-DC converter with the help of the battery charge controller. Fuel cell is used as a base source and it's fed with the DC link system. Finally, the simulation of SPV array, battery storage with fuel cell integration is performed under dynamic switching of loads. The variations in the source and switching of load performance are simulated in the MATLAB/Simulation software.

Keywords: Battery storage systems, DC-DC Converter, fuzzy based MPPT controller, fuel cell, solar photo voltaic system

1.0 INTRODUCTION

Micro grid plays major role in the present power system due to development in modern technology and increasing the power usage because of more applications depends on the electrical power [1]. Due to this technology development and population growth in every day of life leads to increasing more use of power. On the other side, the most of the power supported from the conventional sources are drastically degraded [2]. This became a big challenge in the current power system for providing continuous power. Still in India 1398 MW power shortage occurs during the peak power as of 27th April 2019 [3, 4]. The exhaustion of fossil fuel leads attention on use of integration of renewable sources in the micro grid. The power usage demand can be fulfilled with micro grid distribution generation with use of integration of renewable energy sources [5]. Presently, this demand is met every year with the invention of renewable energy sources in the distributed generation system. SPV is the prime source among the other renewable sources. In India, the solar power is utilized with a capacity of 14,771.69MW as of 31 March 2017 [6]. The SPV generation is the pollution free and green economy that leads to motivate for installing the present power systems. The intermittent power from SPV is obtained with the use of various kinds of MPPT technique [7-8] and the SPV power is oscillated during the day.

In this work, for predicting the stochastic nature power of SPV is analyzed using fuzzy controller based MPPT technique. Fuzzy based MPPT technique predict the nature of solar power and is used for extracting the intermittent SPV power. The SPV power may not provide the supply continuously during the entire day due to stochastic nature. The power from SPV is efficiently utilized with the use of battery storage. Hence, the SPV combined with a storage and other sources [9].The reliable power can be availed at the DC link using SPV integration with battery. The use of wind, tidal other small scale renewable sources majorly cause the source variation and influence the load. The use of diesel power generation again influences the global warming [10].

To adequate the continuous supply, the SPV is integrated with the Battery and Fuel cell. In this paper, the SPV, battery, fuel cell integration with DC link performance through the DC-DC converter is simulated under dynamic switching of loads. The battery with fuel cell unit provides the supply without interruption to the sensitive load. The SPV, battery storage with fuel cell is stimulated in the isolated and integrated mode. The proposed hybrid model with dynamic switching condition of load simulation made using MATLAB/Simulation software is discussed in the following sections.

2.0 DESCRIPTION OF PROPOSED HYBRID SYSTEM

The SPV, battery storage with fuel cell power generation integration is shown in Fig.1 and the main module are: A) SPV array, B) Boost converter, C) Fuel Cell, D) Battery with bi-directional converter, E) DC loads. The SPV is fed with the 48V DC link system using a boost converter and with the help of intelligent based MPPT controller. The SPV maximum power is captured using solar tracking system and the output of SPV is fed with the input of boost converter. The switching pulses of converter is regulated using fuzzy based MPPT controller. The battery storage and fuel cell are also integrated with 48V DC link system for providing the continuous power supply.

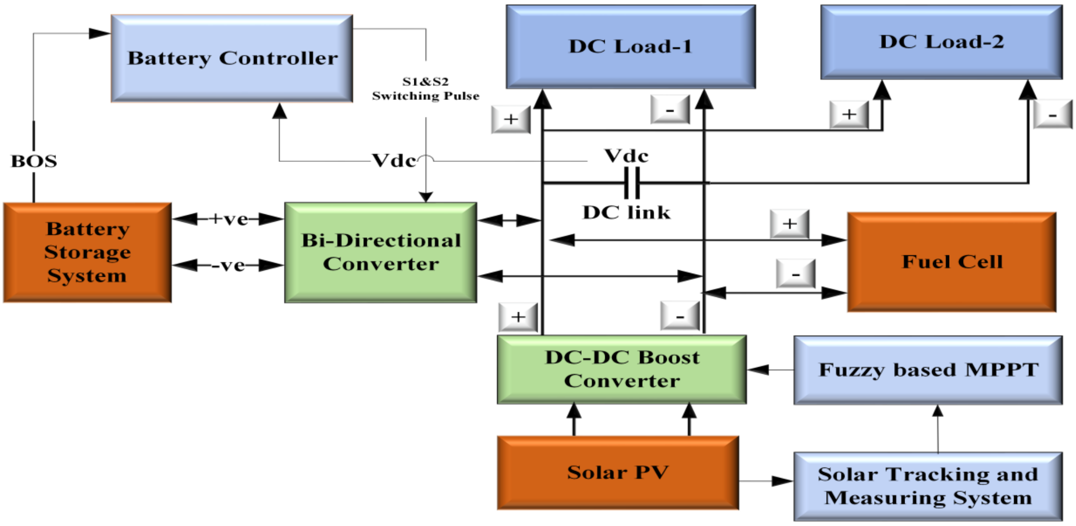

Fig.1: Layout of SPV, battery storage with fuel cell.

The battery storage integration is made using bi-directional converter. The battery charging and discharging is operated through the battery charge controller. The fuel cell is used as base load support and it’s connected with the DC link system for stabilizing the voltage. Two DC loads are considered for understanding the performance of dynamic switching of load. The proposed system is designed to accommodate the power continuously and prevents the sensitive load under dynamic condition of the load switching. The detail description of each module of proposed hybrid system is discussed in the next section.

2.1 Solar Photo Voltaic (SPV) System

The cell nonlinear characteristic of SPV basic circuit is shown in the Fig.2. SPV cell are framed in series to build the 24V and the required current is obtained using solar parallel array configuration.

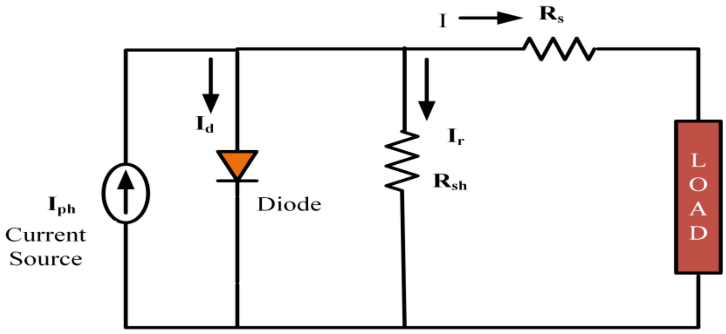

Fig.2: SPV equivalent circuit [11].

The SPV model voltage and current obtain using the equation 1 and 2.

$$V_{pv} = \frac{nKT}{q}\ln(\frac{I_{sc}}{I_{pv}}+1) \tag{1}$$

$$I_{pv} = I_x - I_{pvo}[\exp(\frac{q(V_{pv}+I_{pv}R_s)}{N_s KTn}-1)] - \frac{V_{pv}+I_x R_s}{R_{sh}} \tag{2}$$

The power from SPV system is obtained with the equation.3.

$$P_{pv} = V_{pv} * I_{pv} \tag{3}$$

Where *K*- Boltzmann constant, I_{PV}, – SPV current (A), V_{PV} – SPV voltage (V), *T*- cell temperature. The SPV power is obtained with the help of fuzzy based MPPT Controller.

2.2 Boost Converter

In this paper, boost converter framed in between SPV and DC link for stepping up the SPV voltage level into 48V DC voltage. The switching function is analyzed with fuzzy based MPPT technique, which is shown in Fig.3.

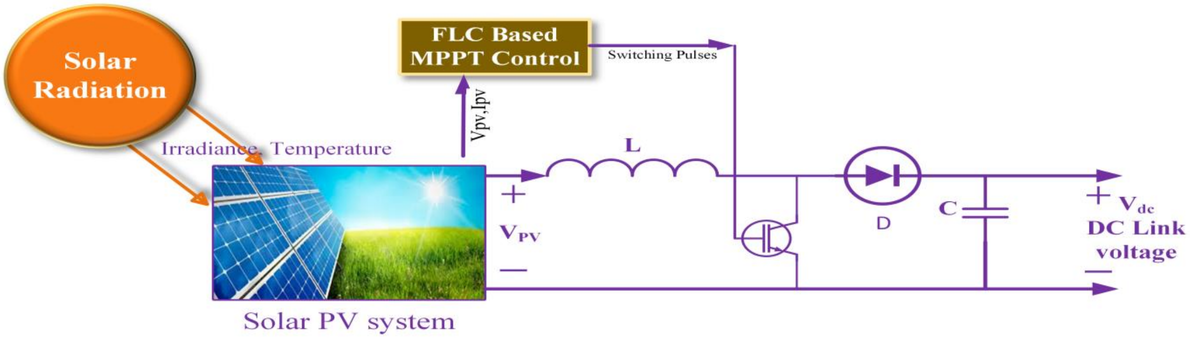

Fig.3: Boost converter with SPV system.

The output voltage is calculated using equation.4

$$V_o = \frac{V_{in}}{1-D} \tag{4}$$

Where, V_o, V_{in} – The output and input voltages of boost converter (V), D - duty ratio. The converter design is model using the following equation 5 and 6[12].

$$\Delta V_c = \frac{I_o * D}{C * F} \tag{5}$$

$$\Delta I = \frac{V_s * D}{L * F} \tag{6}$$

Where L (mH), C (μF) are the inductor and capacitor of boost converter. F-Temperature in ^oC, ΔV_c and ΔI are the ripple in voltage and current tolerable limits, V_s- input voltage (V).

2.3 Battery storage

Battery storage is used to stabilize the voltage within an instant at the DC link using a DC-DC bidirectional converter as shown in the Fig.4.

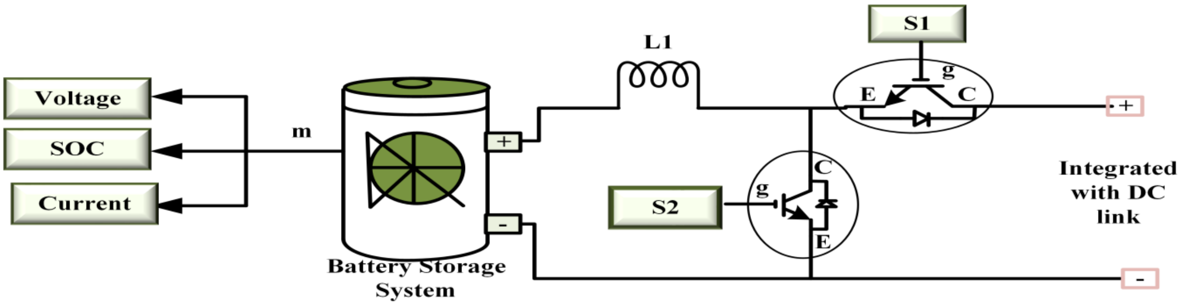

Fig.4: Battery with bi-directional converter.

It is used for energy back-up in the proposed hybrid system to make supply continuous. Depending upon the battery SOC, The converter switching function is operated through the charge controller. The DC bus voltage at the DC link is maintained using a PI (proportional and integral) controller based on the battery charging or discharging mode.

2.4 Fuel Cell

The fuel cell is working on electro-chemical action and it can be framed as a secondary source in the proposed system. It is integrated with 48V of DC link system is shown in the Fig.5.

Fig.5: Fuel Cell

The 48V Proton Exchange Membrane Fuel Cell (PEMFC) is used in the proposed system due to its fast response, high efficiency and the life-time. PEMFC is filled with the hydrogen and oxygen as shown in the Fig.5. PEMFC is one of the electrochemical devices, which turns chemical power into electrical power with the by-product of water. It contains fuel, oxidant electrode and an electrolyte squeezing between them [13].

2.5 DC loads

DC loads are considered for dynamic switching function. In this systems, two DC loads are framed in parallel and connected with the DC link system. These two load switching function can be determined in two ways. In the first case, one load is taken as constant load and another one is variable load. In the second case, both the loads are consider as variable load. In the both the cases SPV system is operated in dynamic nature.

3.0 CONTROL STRATEGY

The control strategy of proposed system mainly categorize into two parts namely:1. Fuzzy based MPPT method, 2. Battery charge controller. These two control strategy description are explained in the following sections.

3.1 Fuzzy based MPPT

The FLC based MPPT controller grasp the stochastic SPV power. The FLC is employed for solving the composite problem to attain the desired response. The FLC helps in obtaining the flexible output with the desired decision, which is used for the applications of a control systems. The FLC based MPPT is employed to boost converter for getting switching pulses and the layout is shown in Fig.6.

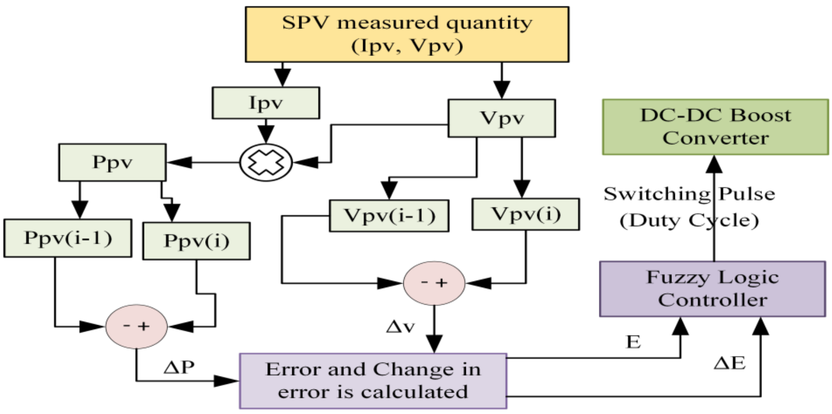

Fig.6: FLC based MPPT

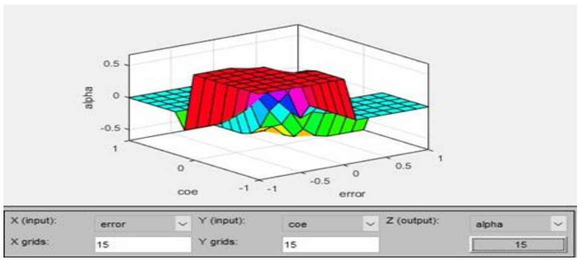

Fig.7: Surface view of fuzzy logic controller

In FLC MPPT, fuzzy factor is stated as instant change in the power into the voltage (ΔP/ΔV is defined as error signal). The input of fuzzy controller membership are shown in the Fig.8 (error) and Fig.9 (change error). It is obtained with the equations 7 and equation 8[14].

$$E(i) = \frac{P_{PV}(i) - P_{PV}(i-1)}{V_{PV}(i) - V_{PV}(i-1)} \quad (7)$$

$$\Delta E(i) = E(i) - E(i-1) \quad (8)$$

The stochastic change in the SPV power is estimated using FLC controller. E(i), ΔE – are the instant change in the ratio error, ΔV- small variation in voltage (V), ΔP- Change in power (W), E(i-1) is error signal in the previous state, $P_{PV}(i)$, $V_{PV}(i)$ – are the Instant power (W), Voltage (V) respectively, $P_{PV}(i-1)$, $V_{PV}(i-1)$ – are the previous instant power (W), voltage (V).

Table I: Fuzzy rule information

E/ΔE	**NH**	**NM**	**NS**	**Z**	**PS**	**PM**	**PH**
NH	PH	PH	PH	PH	NM	Z	PH
NM	PH	PH	PM	PH	PS	Z	Z
NS	P	PM	PS	PS	PS	Z	Z
Z	PH	PM	PS	Z	NS	NM	NH
PS	Z	Z	NM	NS	NS	NM	NH
PM	Z	Z	NS	NM	NH	NH	NH
PH	Z	Z	NM	NH	NH	NH	NH

The input of Fuzzy logic variable and the output surface view are shown in the Fig.7. The converter duty cycle maintain with fuzzy factor to obtain desired SPV power. The fuzzy set rules are framed in seven linguistic variable based on the input and output. These variables are positive hig (PH), positive medium (PM), positive small (PS), Zero (Z), negative high (NH), medium (NM), small (NS), and are presented as shown in Table 1.

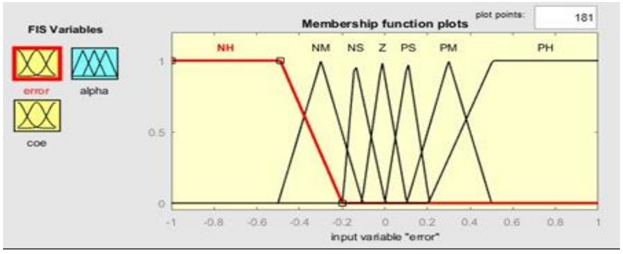

Fig. 8: Fuzzy input-1(error)

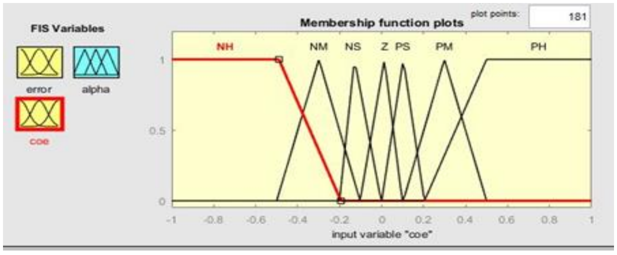

Fig. 9: Fuzzy input-2(Change in error)

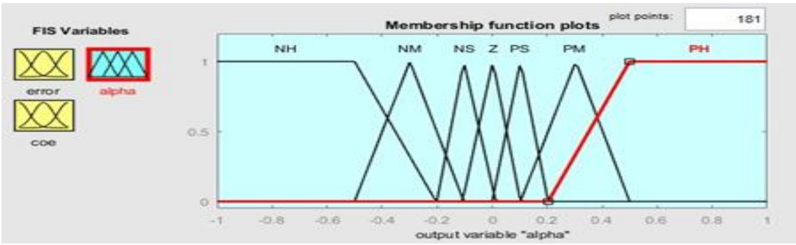

Fig.10: Membership function of fuzzy output

If E and ΔE membership function variables are NH then corresponding output of fuzzy membership function variable is PH. The fuzzy output variable is shown in the Fig.10. The fuzzy factor (E)is zero at the MPP. The fuzzy output is regulates the boost converter output and it mapping at the DC link voltage depends on the possibility of duty cycle variations. The control action of switching pulses achieve in obtaining required voltage at the DC link.

3.2 Charge controller

The Battery controller is used for regulating the SOC (state of the charge). The battery charge controller contains the two sections as shown in the Fig.11 and it works on the battery SOC. The first part of PI controller reference voltage (V_{dc}) and measured actual voltage (V_{dc_meas}) helps in maintaining the voltage within the limit. The PI second section charge controller maintain the battery SOC. The switching pulses of the battery maintain with the battery depth of the charge.

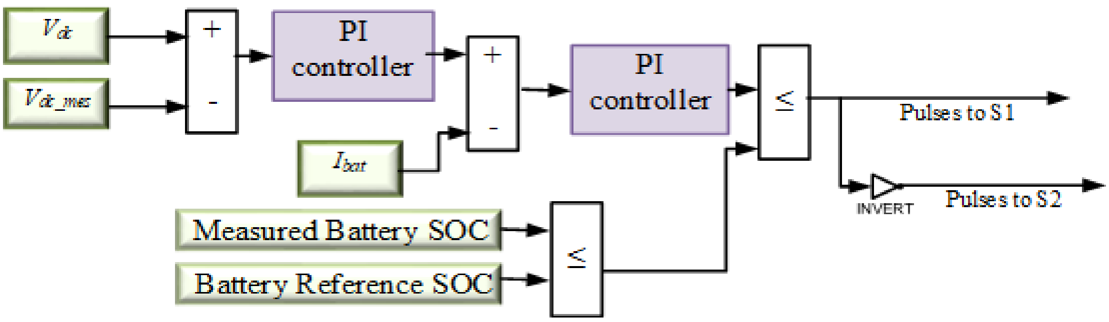

Fig.11: Charge controller

4.0 RESULT ANALYSIS

The SPV array is framed with the series and parallel strings. Each module is having 60 cell. Primarily in the simulation, the 24V of SPV voltage can be step-up with boost converter using fuzzy controller and the switching frequency is 5 kHz. It is implemented and synchronized with the 48V of DC link voltage. The battery with specification of 48V is connected with DC link. In the next stage, the fuel cell is synchronized with DC link voltage of 48V.

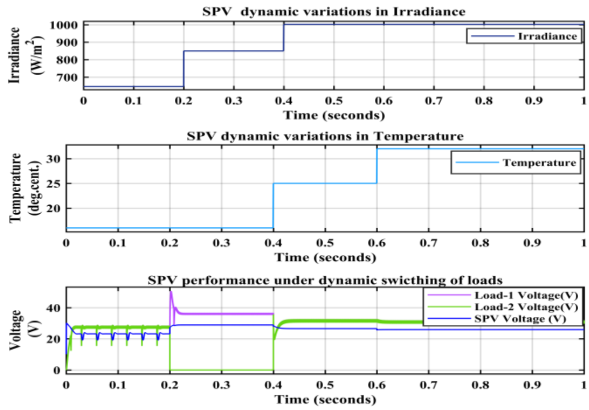

Fig. 12: SPV irradiance, Temperature and Voltages

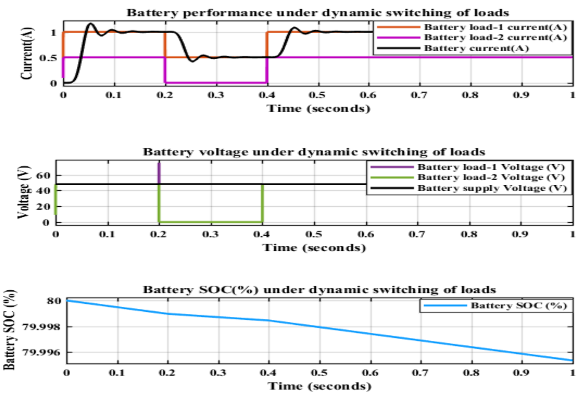

Fig. 13: Battery performance under dynamic switching of loads

The SPV, battery storage with fuel cell simulation is made in three different individual cases in MATLAB/SIMULINK software. In the first case, the SPV, Battery storage, fuel cell is simulations made individually during the dynamic switching of the load. In the second case, the SPV with battery is connected with the load through the DC link. In the third case, the SPV, battery and fuel cell fed with the load through the DC link system. The hybrid system simulation is done under variable temperature, irradiance condition as shown in the Fig.12. At t=0.2sec the irradiance varied from 650W/m^2 to 850W/m^2 and then at t=0.4 to t=1sec varied from 850W/m^2 to 1000W/m^2. Also the temperature changed from 16 ^{0}C to 25 ^{0}C during t=0.4sec to 0.6 sec and then finally reached to 35^{0}C at 0.6sec. The two resistive loads are integrated at the DC link system. Among that, the second load is operated in dynamic switching and it is switched during the t=0.2sec to 0.4sec interval. The output voltage also varied according to source and load switching as shown in the Fig.12. The battery performance during dynamic switching of loads and the battery SOC are shown in the Fig.13. During the second load switching the charging current and the battery supply is varied. Fuel cell with load performance is shown in the Fig.14 and not maintain constant voltage.

From Fig.12, Fig13 and Fig.14 observed that the SPV, Battery, Fuel cell individual performance and voltage are varied during the dynamic switching of loads. It also affects the quality of the supply during the interval t=0.2sec to 0.4sec. The integration of these source can reduce the effect of source and load.In the second case, SPV using battery performance is shown in the Fig.16, the corresponding voltage at the DC link is presented in the Fig.15. The battery storage stabilizes the voltage as compared to first case. The load-1 voltage is also stabilized with the 48V during the dynamic switching of second load. In this case, the load-2 is variable and corresponding load currents are shown in Fig.16.

In the third case, SPV with battery, fuel cell is considered under the dynamic switching condition of the load. In this case the first load is considered as a constant and the second load is operated under dynamic condition. The both load current drawn from the source is shown in the Fig.17. The second load alternatively switching at t=0.2sec to 0.4sec. The corresponding voltage of DC link is shown in the figure 18. The battery storage and fuel cell stabilize the voltage even dynamic condition of source and load-2. In the third case, the proposed hybrid system is considered with the variable condition of source and load.

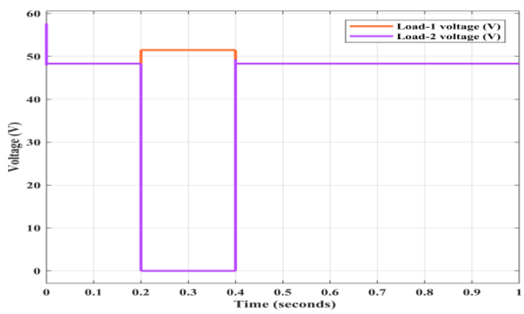

Fig. 14: Fuel cell under dynamic switching of loads.

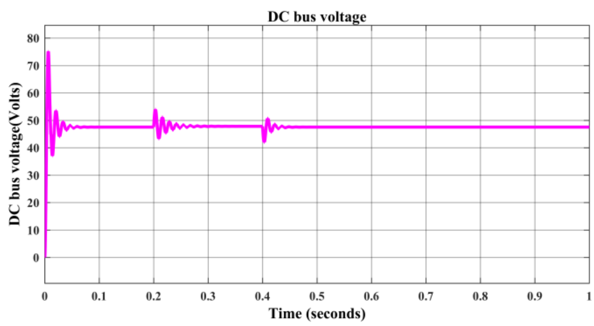

Fig. 15: SPV with battery storage DC link voltage.

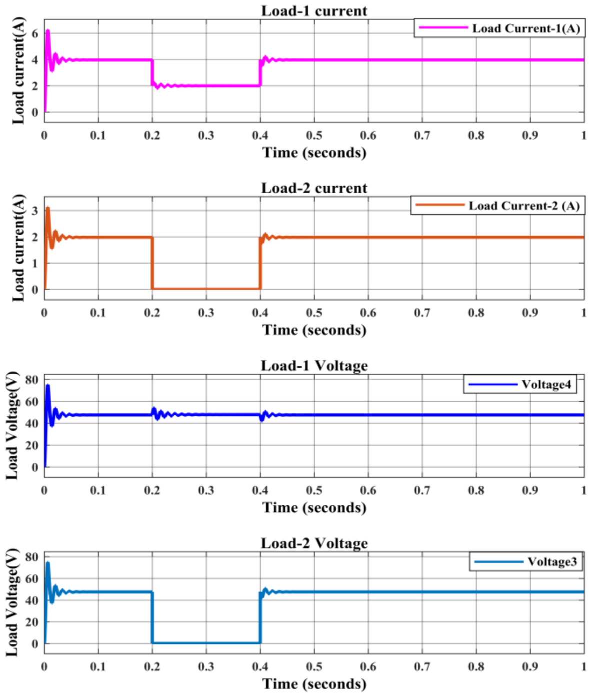

Fig. 16: SPV with battery storage under dynamic switching of load.

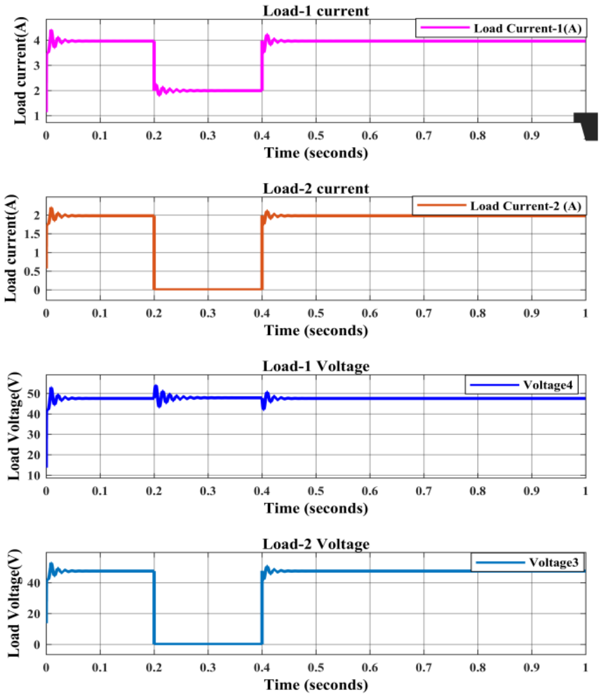

Fig. 17: Integration of SPV with Battery storage, fuel cell hybrid system.

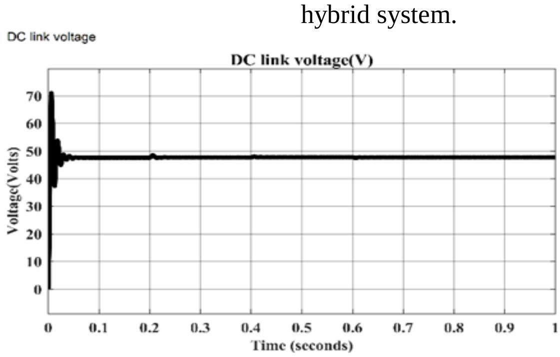

Fig.18: DC link voltage of proposed hybrid system

The simulation of different source and load variation is observed and the most of the cases the voltage is stabilized at the DC link with the use of battery, fuel cell. The battery and fuel cell stabilizes the DC link voltage even under variable nature of the SPV source, load.

5.0 CONCLUSION

The proposed SPV, battery storage with fuel cell integrated system is performed with different instant of load switching and variable condition of source. The dynamic condition of SPV with fuzzy controller is used to obtain 48V at the DC link. At the DC link, the voltage is maintain constant even during dynamics in the source and load by the use of battery and fuel cell. The solar PV, battery and fuel cell integration maintained the necessary voltage and supply the continuous power. The continuous power supply and necessary voltage is achieved by maintain constant at the DC link voltage.

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