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Fractional Open Circuit Voltage MPPT with Fuzzy Logic Controller for PV System Using Single Switch DC/DC Converter

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ABSTRACT: This paper explores the performance of a single stage single switch converter (SSC) for a photovoltaic (PV) system with fuzzy logic controller (FLC) based maximum power point tracking (MPPT) method. The proposed FLC based fractional open circuit voltage MPPT method uses an existing single switch converter. MPPT is achieved by pulse frequency modulation (PFM) with the help of the FLC concept incorporated fractional open circuit voltage method. Where as the load regulation is obtained by pulse width modulation (PWM) technique. The steady state dynamic performance of the system is improved by the FLC. A steady state dc-link voltage is given by the battery in the system which also helps to reduce the switching stress on the single switch. The outstanding feature of this converter is the reduced number of components.The performance of the proposed system with FLC is verified with MATLAB/SIMULINK.

KEYWORDS: Photovoltaic (PV) System, Single Stage Single Switch Converter (SSC), Maximum Power Point Tracking (MPPT), Fractional Open Circuit Voltage Method, Fuzzy Logic Controller (FLC), Pulse Width Modulation (PWM), Pulse Frequency Modulation (PFM)

I.INTRODUCTION

In the present scenario, global energy consumption is drastically increasing. Considering the fossil fuels that we consume and use on a daily basis, solar energy provides pollution free ,cost effective and a sustainable source of energy. The practice of solar energy offers pure and justifiable source of energy with immense environmental and financial benefits. A standalone PV-battery system can be used for various applications where the battery can be used for supplying the power in the absence of insolation or at partial shading condition. A suitable MPPT system assimilated in the PV system provides the maximum power at different environmental conditions with minimum losses. Photovoltaic (PV) systems provide a better solution to reduce the drastic demand on energy consumption. Which utilizes direct sunlight fallout and converts it to electric power. The most vital features in such systems are photovoltaic cells that are connected as an array to produce operational electric energy. These systems incorporate electronic converters to convert output current and voltage in an appropriate form when considering the conditions of the system's load and its needs. The most usually used electronic converter is the DC to DC converter where high voltage is produced from the lower solar cell voltage.

Renewable energy sources like PV system can be efficiently utilized with the help power electronic converters. A cost effective SSC topology proposed in [1] mitigates the number of components as well as the control circuitry. A single stage single switch converter can be degenerated from a multistage converter by replacing the active switches with a single switch at a common sharing node [2]. Hence, the complexity and the number of the control circuitry can be reduced. Exisisting SSC topology with the combination of buck and buck-boost converter is adopted with FLC based MPPT technique. This paper proposes a twofold control strategy on a single switch with combined fuzzy logic controller based PFM and PWM control. In order to achieve this control, the input side of the converter (buck stage) is operating in discontinuous conduction mode (DCM) and output side (buck-boost stage) is in continuous conduction mode (CCM) [3]. The voltage stress across the single switch can be reduced by a steady state voltage provided by the battery [4]. Combined double stage buck and buck- boost converter results in the single stage SSC by replacing the active switches with a synchronous switch. Dual control strategy in a single switch is adopted in this article.

The fractional open circuit voltage method in [3] with propotional integral (PI) controller has poor steady state response. Variable frequency along with duty ratio control can be obtained by incremental conductance [5] as well as perturb and observe (P & O) [6] MPPT method. But both of these have steady state oscillation around the maximum power point [7]. But the proposed method with fuzzy logic control is suitable for rapidly changing atmosphere with enhanced steady state response. It is a well supervisory system for PV source with the incorporated knowledge of the designer form the previous experience. The FLC has potential ability to improve the robustness of DC-DC converters than the usual proportional integral (PI) controller.

This paper is structured as follows;description of the converter is given in section II. Section III deals with the principle of operation with four distinctive modes of operation. Proposed system configuration is detailed in section IV. MATLAB/SIMULINK model of the proposed system is given in section V and the conclusion of this article is given in section VI.

II.DESCRIPTION OF CONVERTER

Combined buck and buck-boost stage double stage converter is degenerated to a single stage single switch converter as in fig 1.MPPT tracking is done by the front stage buck part and at the same time buck-boost stage regulate the load. The battery acts as a DC-link part which provides a steady dc-link voltage to reduce the switching stress. Capacitor C_1 across the battery removes the ripple component of battery current. Dual control in the switch is obtained by operating the buck (L_1) and buck-boost (L_2) stage inductors at two different modes such as DCM and CCM respectively. The front stage buck converter is used to track the MPP of the PV module by changing the input impedance of the converter. The battery voltage here is lower than the PV source input voltage. The second stage buck-boost converter is used to regulate the output voltage in order to maintain a desired flow rate of the pump. Two active switches S_1 and S_2 are controlled separately. The operation of the two converters would not be affected if both of the MOSFETS are moved to the return paths of the circuit in a double stage converter. By doing this, S_1 and S_2 share a common node, i.e., the drain of S_1 and the source of S_2 has a common node. The operation remains identical if S_1 and S_2 turn ON/OFF synchronously. Hence, S_1 and S_2 can be replaced by a synchronous switch. Diodes D_2 and D_3 are added to provide current paths when the currents through the original switches S_1 and S_2 in are different. Thus, the SSC is derived, as shown in fig 1.

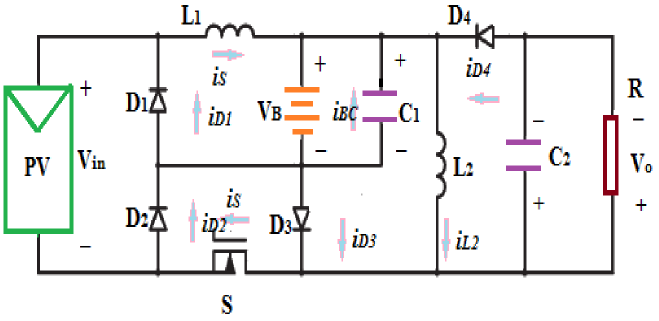

Fig.1 Circuit description of single switch converter.

Power switch makes the current path for the battery as well as the PV source. Positive and negative currents of the battery flow through the diodes D_1 to D_3 during different operation periods. Diode D_4 and capacitor C_2 sustain the output load. Battery is also helping to shrink the voltage stress across the MOSFET.

III.PRINCIPLE OF OPERATION

Since the fractional open circuit voltage control method is used for MPPT in this design, the PV input voltage is controlled to operate within a range by adjusting the switching frequency. To simplify the analysis of the operation of the converter in the steady-state high frequency domain, both the PV module and battery are assumed to be constant dc voltage sources within a switching period, under the assumption that the input capacitor is large enough to hold the PV source voltage when the switch is OFF. The simulation result for PV input voltage is illustrated in section V. The capacitance of C_2 is large enough so that the output voltage ripple is negligible and the output can be treated as a constant dc voltage source as well. All the semiconductor devices are assumed to be ideal. The input buck inductor L_1 works in discontinuous conduction mode (DCM), whereas the the dual control strategy is adopted in this paper, PV input voltage is controlled by varying the switching frequency using the modified FLC based MPPT method. Single switch converter has four steady state modes of operation. output buck-boost inductor L_2 operates in continuous conduction mode (CCM). The overall current i_{BC} is pulsating, but the current through the battery is in dc. The ac component of the current flows through the capacitor.. During the steady state, the converter shows four distinctive operation modes.

In Mode-1 switch S is ON and only the diode D2 is conducting. Inductor L_1 charges with inductor current, as in (1)

$$I_{L1} = \frac{V_{in} - V_B}{L_1} \int dt \qquad (1)$$

Inductor current L_1 is the summation of the inductor current in L_1 and the battery current i_{BC}, as in (2)

$$I_{L1} = I_{L2} + I_{BC} \qquad (2)$$

In Mode-2 the extra energy from the PV source is stored in the battery when I_{L1} is greater than I_{L2}. At time T_2 both of the inductor currents reach their peak value. Mode-3 occurs during the time interval T_2-T_3, when the switch S is turned OFF. Stored energy in the inductor L_1 discharges to the battery and the inductor L_2 withstands the load. The discharging current of L_1 and L_2 is given as in (3)-(4).

$$i_{L1} = -\frac{V_B}{L_1} \int dt \qquad (3)$$

$$i_{L2} = -\frac{V_o}{L_2} \int dt \qquad (4)$$

Switch S is OFF in Mode 4. Since inductor L_1 is in DCM, it resets. Inductor L_2 operates in CCM. Hence, it discharges to the load with current as in (4).

IV.PROPOSED SYSTEM CONFIGURATION

The consolidated block diagram of the closed loop control of the proposed system with a fuzzy logic controller is given as in fig. 2. In buck stage MPPT is done by the fractional open circuit method.76% of the open circuit voltage is taken as the maximum power point voltage. Variable frequency control with pulse frequency modulation is adopted here. Load regulation is obtained by the pulse width modulation technique at the buck-boost stage. Both PFM and PWM control are done with FLC which give zero error at the steady state response and fast dynamic response. The fuzzy controller takes error as inputs, the output of fuzzy controllers is given to PWM and PFM controller, which generates gating pulses of desirable pulse width to MOSFETS in the SSC. A fuzzy controller converts a linguistic control strategy into an automatic control strategy, and fuzzy rules are constructed by expert experience or knowledge database. Firstly, output voltage *Vrms* and the output reference voltage *Vrms-ref1* and *Vrms-ref2* have been given to the input of the fuzzy logic controller. To convert these numerical variables into linguistic variables, the following three fuzzy levels or sets are chosen at the input as: NE (negative), ZE (zero), PE (positive). The output fuzzy sets also include three levels: DE (decrease), NC (no change), IN (increase). Fuzzy system is developed based on the Mamdani method. The syntax of the rules of the fuzzy system is represented by the following linguistic conditional declarations:
Rule 1: If (Error is Negative), Then (output is decrease)
Rule 2: If (Error is Positive), Then (output is increase)
Rule 3: If (Error is Zero), Then (output is no-change)

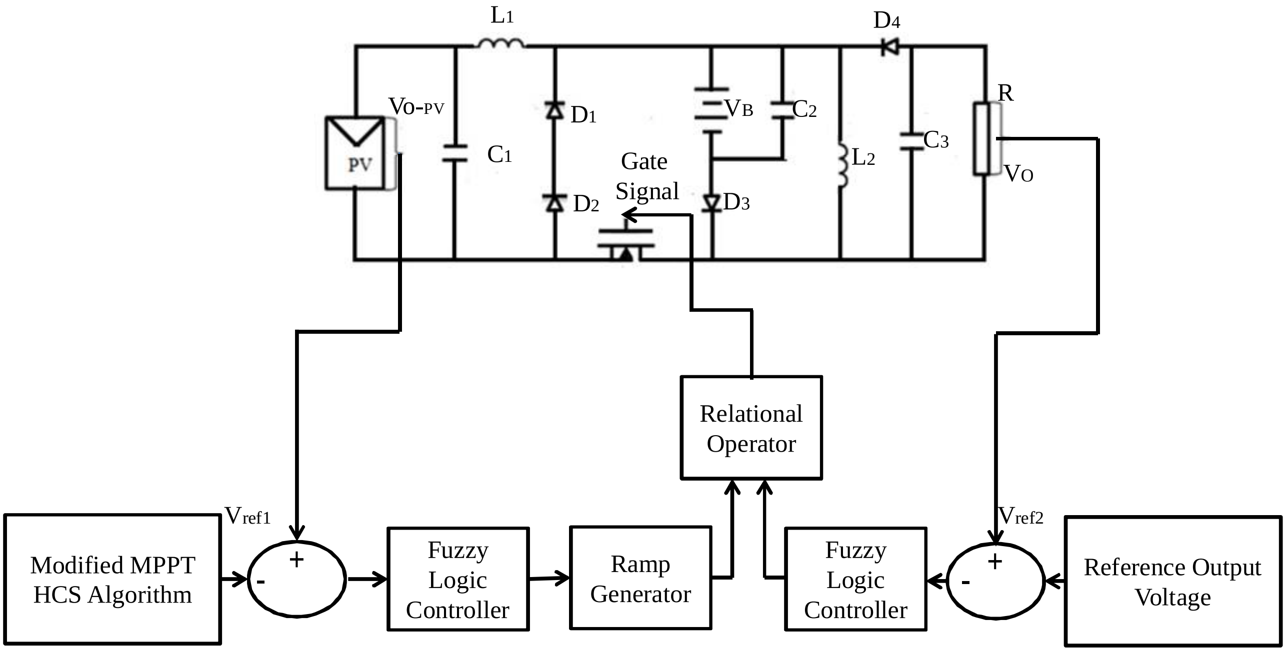

Fig.2 Closed loop control of the proposed system

The input membership function is given in fig 3 and output membership function is given at fig4.

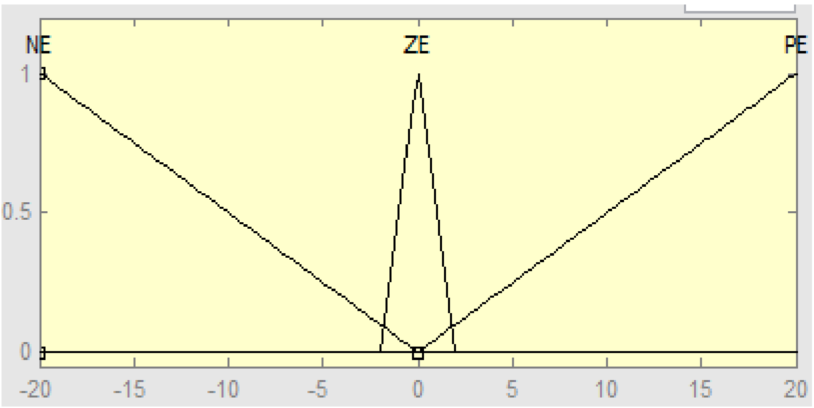

Fig 3. Input membership function

The fuzzy controller for PFM and PWM is characterized as follows:

(1) Three fuzzy sets for each input and output;
(2) Fuzzification using continuous universe of discourse;
(3) Implication using Mamdani's 'min' operator;
(4) De-fuzzification using the 'centroid' method.

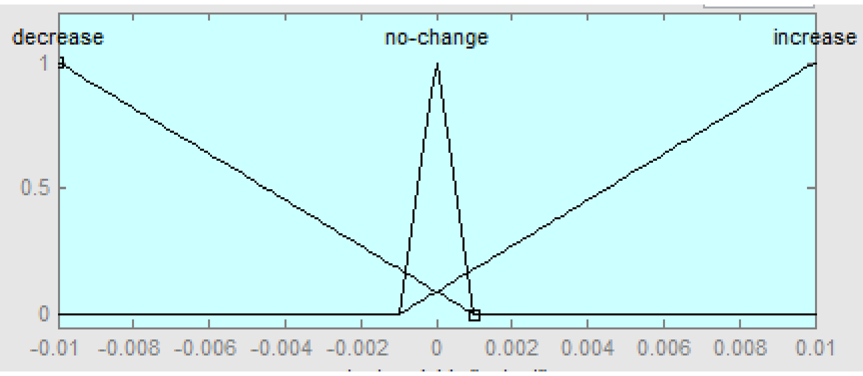

Fig.4 Output membership function

The rules are inferred in a parallel way, without considering the order in which they are implemented. The inference of each rule consists of the evaluation of the antecedent, followed by the application of the implication operator to determine the consequent fuzzy set. The defuzzification procedure obtains the FL's numeric value. The implication operator used was Mamdani's minimal operator; the aggregation of the consequents was performed by the maximum operator and the defuzzification method employed was the area center method (or centroid method).

V. SIMULATION AND RESULTS

The proposed system is validated with MATLAB/ SIMULINK. Fuzzy logic controller at the buck stage track the maximum power point, according to the rule base and inference of the system.. In fig. 7 PV system output voltage at MPP is given. Steady state response is enhanced compared to the PI controller response. The output PV system is studied at atmospheric condition of 25°C and 1000 W/m^2. The simulation outcomes show that FLC significantly lessens the time overhead and it advances the system dynamic response. The Simulink model of the proposed system is given in fig 5 and its control loop with fuzzy logic is given in fig 6.

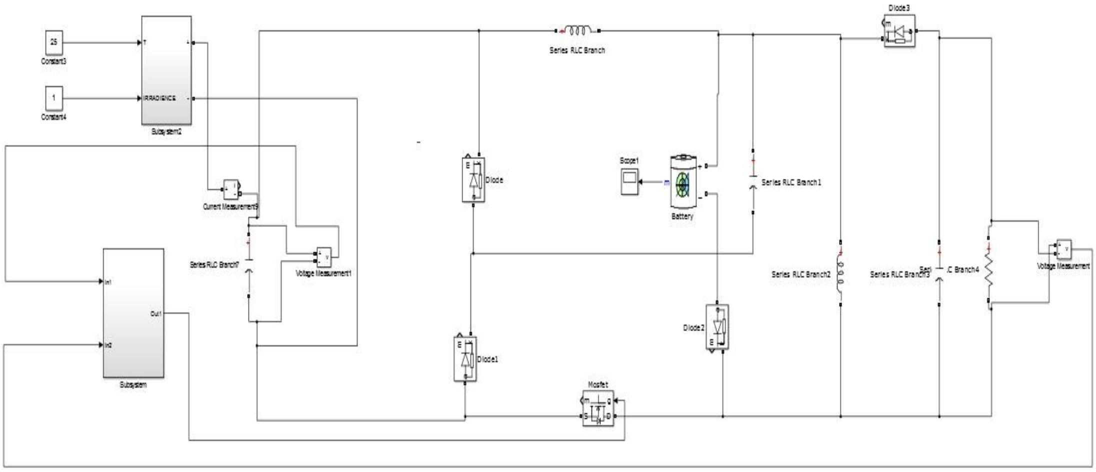

Fig.5 SIMULINK model of the proposed system

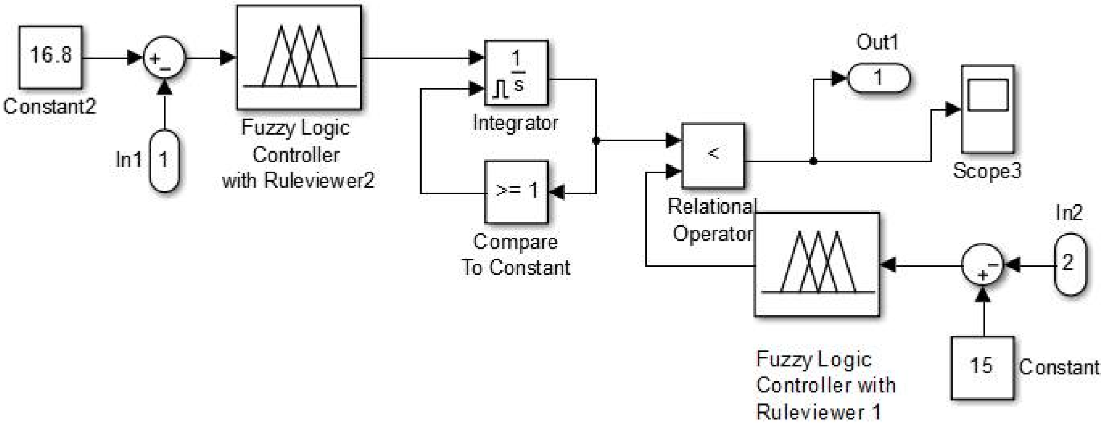

Fig.6 SIMULINK model of the fuzzy logic controller

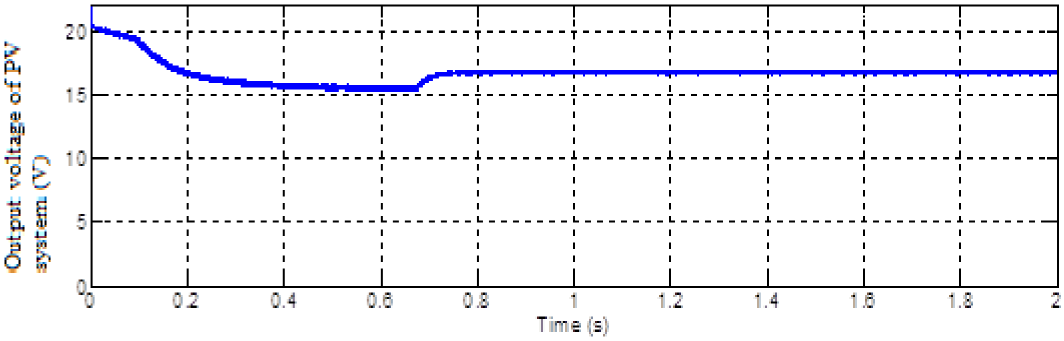

Fig.7 PV Output Voltage at MPP

PV output current at MPP is given in fig 8. FLC provides an enhanced response of steady state and transient performance.

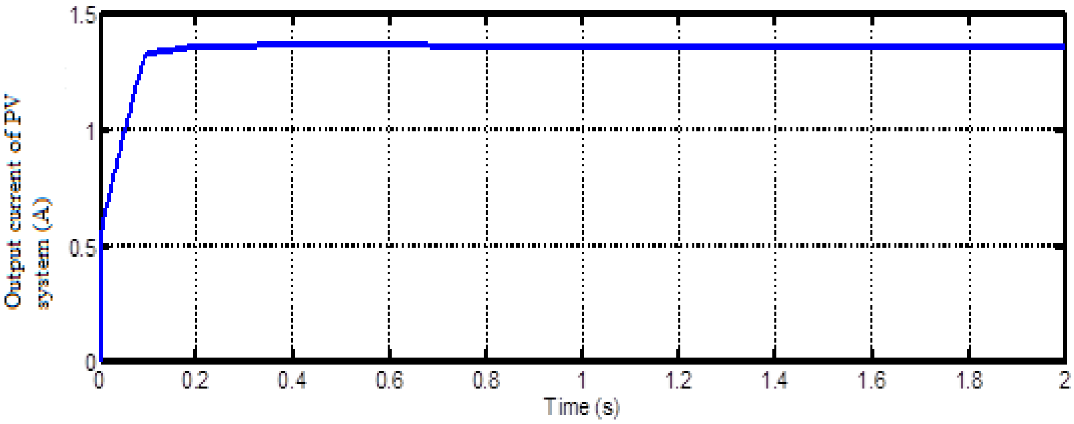

Fig.8 PV Current at MPP

Maximum PV system power at the above mentioed atmospheric condition is given in fig.9.

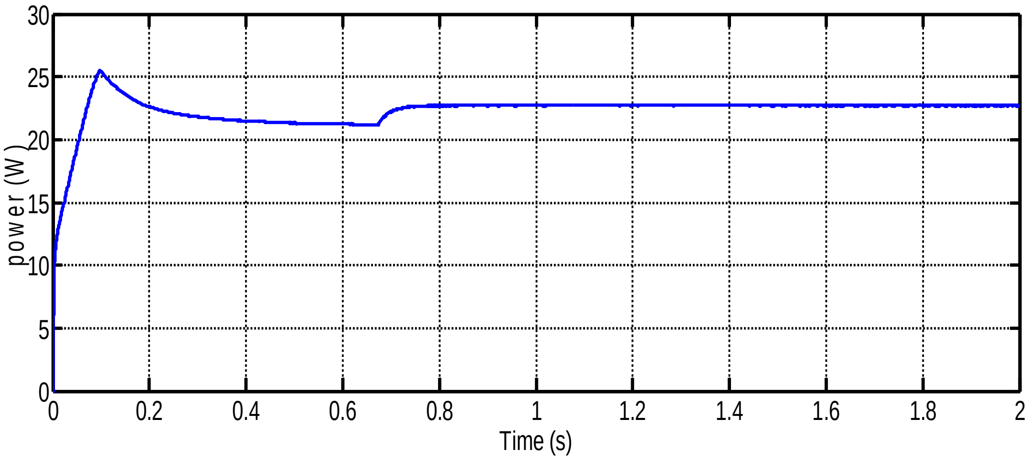

Fig. 9 PV Power at MPP

Output load regulation is done with the help of fuzzy logic based PWM technique. The output load is maintained at 15V by controlling the buck-boost stage. Battery maintained at 12V supplies to this stage. Output voltage regulation is given in fig 10.

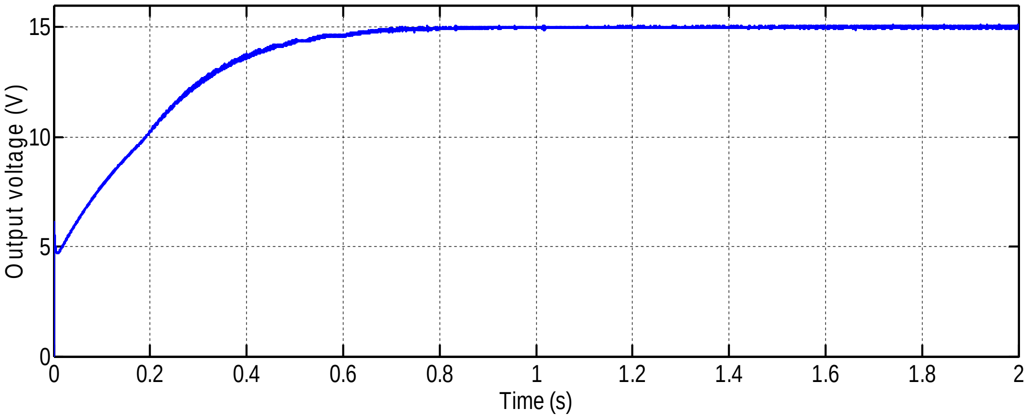

Fig.10 Output Voltage at MPP

VI.CONCLUSION

This paper has presented a SSC which is performing simultaneously three operations such as MPPT, load regulation and charging and discharging of battery with combined PFM and PWM controller using fuzzy logic. By using the variable frequency control, the main functions such as MPPT and load regulation is realized with a reduced number of active switches and without sacrificing the overall efficiency as compared to the conventional two-stage design. The voltage stress problem of the DC-link capacitor in conventional single-stage converters is eliminated when a battery is used. Reduced repeated power processing is achieved automatically during the operation. The fuzzy logic controller provides an enhanced steady state response of the system and robustness compared to the conventional PI controller.

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