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Design And Simulation of Low Power Charging Station for EV By Using Fuzzy Systems

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Abstract: - The depletion of fossil fuels and increased pollution has led to the invention of Electric Vehicles (EV). An Electric Vehicle requires an onboard charger (OBC) to charge the battery for its propulsion. The objective of this project is to present the design and simulation of unidirectional onboard charger that can charge the traction battery through the solar PV system Here, the OBC consists of PROJECT PUBLICATION PROJECT PUBLICATION PROJECT PUBLICATION converter and Buck type DC-DC converter to regulate the charging voltage and charging Current of the battery. And using fuzzy logic controller. A 210W charger is considered for the design with a lead- acid battery of nominal voltage of 48 V, 35 Ah. This paper presents a performance evaluation of a fuzzy logic controller-based solar photovoltaic (PV) fed low-power charging station for electric vehicles (EVs). The proposed system utilizes a solar PV array to generate electricity and a fuzzy logic controller to regulate the charging process of the EVs. The study investigates the effectiveness of the fuzzy logic controller in maintaining the charging voltage and current within the safe limits while also ensuring optimal utilization of the available solar energy.

Key Words: ***Buck converter, Current control, Grid to vehicle mode, on-board charging, Voltage control, Solar PV, Fuzzy Logic Controller.***

I. INTRODUCTION

The demand for Electric Vehicle (EV) is increasing because of its reduction in fuel usage and greenhouse gas emissions. EVs need a significant amount of energy storage systems for their continuous propulsion. The battery chargers play a vital role in the development of EVs, as the vehicle needs frequent charging. The charging station helps reduce on-board energy storage requirements and costs [1]. EVs have not yet gained full acceptance as the cost of batteries is high, and the life of the cells is low; at the same time, there is a lack of charging infrastructure.

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Another drawback is that the battery chargers can induce harmonics into the electric utility systems [2]. The Electric vehicle requires a battery bank that can be charged from the conventional or non-conventional sources. Mostly in the case of non-conventional source, the solar PV is widely used for electric vehicle charging because of reduced emission and pollution, which is more prominent in fuel cells [3].

Battery charging is done in two ways: On-board charging and Off-board charging. Further, they are classified as unidirectional and bidirectional chargers. The unidirectional load allows the operation in Grid -to-Vehicle (G2V) mode, in which the traction batteries can be charged from the utility grid. The main advantage of unidirectional charging is that it reduces the size, mass, and cost of charger and improves the reliability of the system [4]. The bidirectional chargers operate in both modes, Grid-to-Vehicle (G2V) mode for battery charging and Vehicle to Grid (V2G) mode to feed the power back to the grid. The main drawback in V2G method is the battery degradation caused due to cyclic charging and discharging [5].

The battery charger plays a significant role in utilizing the battery to its maximum capacity. Fig 1 shows the block diagram of the primary battery charging system for the electric vehicles. Basically, are divided into two different stages. The first stage comprises of AC-DC conversion, and the second stage contains DC-DC conversion. The ripple content at the output of AC-DC Converter is minimized by using a filter capacitor at the output of the bridge rectifier. The rectified voltage is given to the DC-DC converter, which steps down the voltage for battery charging. The amount of power transfer between input and the output is controlled by adjusting the duty cycle of the switch in the DC-DC convert.

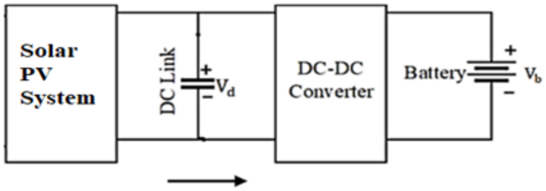

Fig.1. Basic block diagram of the battery charging system

Various topologies for the battery chargers of EVs operating in G2V mode is mentioned in the literature. Basically, there are two types isolated and non-isolated. The choice of topology depends on the power requirements of the charger and its suitability [6]. The non-isolated buck and boost converters are suitable for low power applications due to its simplicity and fewer components than other topologies.

Similarly, the buck-boost derived topologies like Cuk and SEPIC, are ideal for the power rating up to 500 watts [7].

The isolated topologies like Half-bridge, Full-bridge, and Push-pull have low Total Harmonic Distortion (THD) as compared to the non-isolated topologies and are suitable for power level up to 1000 watts. A cascaded buck-boost converter topology for an on-board battery charger with power factor improvement, and reduced distortion in the source current to ensure reliable operation of the converter has been proposed in [8-9]. The buck converter with variable width PWM switching is as proposed in [10] and the conventional method is then compared with the proposed method for parameters like THD, power factor, battery charging current and the voltage. Some soft switching techniques using Zero Voltage Switching (ZVS), and Zero Current Switching (ZCS) are explained in [11] that help in the reducing the complexity of control mechanism and number of components.

The battery charger operates in two modes. Firstly, the battery is charged under Constant Current (CC) mode, where there is an increase in the battery voltage depending upon the State of Charge (SOC). Later, when the battery voltage reaches the rated value, the battery goes to Constant Voltage (CV) mode where the battery voltage is kept at a reference value, and current is decreasing [12]. As far as the charging current of the battery is concerned, the ripple plays an important role in the performance of the battery. The different current ripple reduction methods are discussed and compared based on their performance for a 3 phase, 5 kW battery chargers in [13]. The production of lead-acid, as well as the lithium- ion batteries are analysed under both good as well as bad conditions, and the estimation of the parameters like SOC, charging rate (C-rate) are as explained in [14] by using experimental setup. The lead-acid battery using a pulse frequency technique [15] has prolonged battery life and improved charger efficiency. In the design and implementation of a bi-directional converter for electric bikes [16], the energy is recycled to improve the battery performance, and electrical capacity estimation strategy promotes the system reliability. A novel battery charging system for DC-DC converter with a micro-controller unit is as analyzed in [17], the system provides maximum energy transfer to the battery bank and increased life because of high SOC.

The design and simulation of the battery charging for low power applications is presented in this paper. The model comprises of a 210 W battery charger fed from a single-phase AC supply along with bridge rectifier and dc-dc buck converter for charging operation. The State of Charge (SOC), current and voltage of the battery is considered for analyzing the performance. The paper is divided into the following parts: Part II gives the detailed design of the battery charging system along with the control strategy. Part III presents simulation results of the battery charging system in Constant Current Charging (CC), and now, for determining the value of the capacitance (C), the output voltage ripple Part IV briefs the conclusion of the project.

II. LITERATURE REVIEW

*Longo, M., Yaici, W. & Foiadelli, F.*This paper aims to investigate the potential, the technical benefits and environmental aspects in terms of air pollutant emissions reduction using photovoltaic (PV) charging systems located in home's roof located in Ottawa in the context of electric mobility. The PV system evaluated was a solar roof combined with a charging system for electric vehicle. Different scenarios have been analysed considering different model of EVs and different state of charge. The results demonstrate that the PV systems are effective to feed EVs and eliminate emissions.

D. C. Erb, O. C. Onar, and A. Khaligh. The automotive industry is going through a major restructuring, and automakers are looking for new generations of hybrid vehicles called plug-in hybrid electric vehicles (PHEVs). In the event that PHEVs become more available and the number of PHEVs on the road increases, certain issues will need to be addressed. One vital issue is the method by which these vehicles will be charged and if today's grid can sustain the increased demand due to more PHEVs. Although these vehicles appear to pose a large liability to the grid, if executed properly, they can actually become an even larger asset. The grid can benefit greatly from having reserves that can store or release energy at the appropriate times. Enabling PHEVs to fulfill this niche will require a bi-directional interface between the grid and each vehicle. This bi-directional charger must have the capability to charge a PHEV's battery pack while producing minimal current harmonics and also have the ability to return energy back to the grid in accordance with regulations. This paper will first review some of the power electronic topologies of bi-directional AC-DC and DC-DC converters that fulfill these requirements and then discuss the best choice for combining two topologies to form a bidirectional charger.

S.Y. Kim, H.S. Song, and K.Nam, The battery charger and the dc-dc converter can be combined in a single unit with the three-port converter topology. In the three-port converter, one port is idling, while the other two are operating actively. To block power flowing into an idling port, a virtual isolation scheme is proposed. It is also illustrated by a phase analysis. Effectiveness of the proposed isolation scheme is verified by simulation and experimental results.

Radu P.V, &Szelag, A. This paper presents the design and simulation of an non isolated DC-DC Cuk converter. The input current control is provided with pulse-width modulation (PWM). A closed control loop is used with two proportional-integral (PI) controllers for the current and voltage. The DC-DC Cuk converter is used with Simulink cells for battery and supercapacitors (SC) to simulate the charging and discharging process for a stationary energy storage device (ESD). Simulations results are presented in Simulink.

A.V.J.S.Praneeth, Lalit Patnaik, Sheldon S Williamson. In this paper, we propose the use of cascaded converter in power factor correction (PFC) converters to achieve the wide DC link voltages for battery chargers. The primary focus of the paper is on the analysis and operation of boost-cascaded by buck (BoCBB) converter. The control implementation presented in the paper achieves a high input power quality, wide DC link voltages with universal input voltage ranges of 85-265 V. It also provides the degree of control freedom to operate even if the VNm (output voltage to the peak of Input) <; 0.5. Simulations of the proposed converter with 1 kW power rating are carried out in PSIM 11.0 software and the results with wide DC link voltage of 150-400 V are presented in the paper.

Chirag P. Mehta; Balamurugan P, this paper presents an informal and effective line frequency current shaping control arrangement used for achieving power factor nearer to unity. It also satisfies the harmonic compliance of source current in accordance to the IEEE519 recommendations. This objective is achieved by active power factor control circuit using continuous conduction mode (CCM) of buck-boost converter implementing adaptable duty cycle control scheme. The control is very simple and gives good performance. The performance of the control scheme is simulated for both open-loop and closed-loop control in Matlab/Simulink environment.

III. DC TO DC CONVERTERS

3.1 Introduction

DC to DC converters are electrical systems that transform a DC voltage level into another DC voltage level. These converters are extensively utilized in various applications such as power sources, battery charging, and voltage regulation.

There are several types of DC-to-DC converters, including:

Buck converter: This device reduces the input voltage to a lower output voltage and is often applied in battery-powered equipment and LED driver circuits.

Boost converter: This converter steps up the input voltage to a higher output voltage. It is commonly used in automotive and solar power applications.

Buck-boost converter: This converter can step down or step up the input voltage, depending on the design. It is commonly used in battery charging and LED drivers.

Flyback converter: This converter uses a transformer to step up or step down the input voltage. It is commonly used in low-power applications, such as USB chargers and small appliances.

Cuk converter: This converter is a type of buck-boost converter that uses capacitors and inductors to step up or step down the input voltage.

SEPIC converter: This converter is a type of buck-boost converter that uses capacitors and inductors to step up or step down the input voltage, while maintaining a constant output voltage.

DC to DC converters are essential components in many electronic systems and play a crucial role in enabling efficient power conversion and management.

3.2 Buck converter

3.2.1 Working

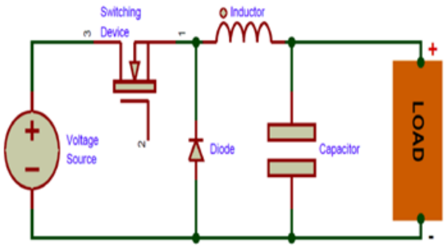

Fig.2. Buck converter

The working of a buck converter can be explained in the following steps:

During the first phase, the switching transistor in the buck converter is turned on, allowing current to flow from the input voltage source (usually a battery or power supply) through the inductor and to the output capacitor and load.

As the current flows through the inductor, it stores energy in the form of a magnetic field. The energy stored in the inductor increases with time as long as the switching transistor remains on.

In the second phase, the switching transistor is turned off, causing the magnetic field in the inductor to collapse. As the magnetic field collapses, the energy stored in the inductor is released and current continues to flow through the circuit, but now through the output capacitor and the load.

The output capacitor and load absorb the energy released by the inductor, which helps to regulate the output voltage and provide a steady supply of power to the load.

The switching transistor then turns back on, starting the first phase of the cycle again. The duty cycle, or the percentage of time that the switching transistor is on, determines the output voltage of the buck converter. By adjusting the duty cycle, the output voltage can be regulated to the desired level.

Overall, the buck converter converts a higher input voltage to a lower output voltage while maintaining a stable supply of power to the load. The efficiency of the buck converter is due to the inductor and capacitor, which store and release energy, reducing power loss and heat generation.

As headlights, sensors, and entertainment systems.

IV. PROPOSED METHOD

4.1 Design of Battery Charging System for Electric Vehicle

The necessary design formulas for the different components required for the battery charging have been presented in the following sub-sections. A. Design of AC-DC converter one of the most commonly used AC-DC converters is a diode bridge rectifier for low power applications. In this paper, the input AC voltage is converted to DC. The rectified output voltage contains a very high amount of AC ripples, which is reduced by using filters. A capacitor filter helps in reducing the output voltage ripple to 10% of the output voltage. The value of the capacitor is calculated using equation (1).

$$C = \frac{I_d}{2*f*\Delta V_d} = 4mF \qquad (1)$$

Where, ΔVd= ripple in output voltage of rectifier, Id = Output current of rectifier and f=fundamental frequency

4.2 Design of DC- DC converter

The detailed design of the buck converter [18] is as presented in this sub-section. The duty ratio of buck converter is obtained in equation (2). Considering battery voltage as 60 V and the input voltage of 160 V from the above calculation of equation (1).

$$D = \frac{V_o}{V_d} = 0.375 \qquad (2)$$

Where, D = duty cycle,

V_0= Output voltage of converter and

Vd= Input voltage of converter. The design of the inductor is considered assuming that the buck converter operates in Continuous Conduction Mode (CCM). Selecting the switching frequency of 20 kHz and generally, the inductor current ripple is considered to be 10% of the output current inductor value is calculated using equation (3).

$$L = \frac{(V_d - V_o)D}{\Delta i_L * f_s} = 2\ mH \qquad (3)$$

Where, fs=switching frequency in kHz and Δi_L = inductor current ripple.

is as given in equation (4). The output voltage ripple is considered as 10%, which maintains 60V DC as the optimum charging voltage for the battery.

$$\Delta V_o = \frac{T_S^2 V_o(1-D)}{8LC} \qquad (4)$$

The output voltage ripple ΔV0 obtained is 6 V. So, the value of output capacitor C is determined using equation (5).

$$C = \frac{T_S^2 V_O (1-D)}{\Delta V_O * 8L} = 2\mu F \tag{5}$$

4.2.1. Selection of Battery

A Lead Acid Battery of 48 V, 35 Ah (4 packs of 12V, 35Ah) rating is selected for analysing its State of Charge (SOC), current and voltage. The charging Current required for the battery is 3.5 Amp, considering C-rate of 0.1 C using Constant Current (CC) charging.

4.3 Control strategy for Battery Charging

The control strategy for the charging of lead acid battery using a Constant Current (CC) method through the PI controller. The battery reference current (I∗b) is generated and compared with the actual current (Ib thereby the error signal is obtained. This error can be minimized by using PI Controller. The signal from the PI controller is compared with the saw-tooth wave in the PWM generator to create the gate pulses for varying the duty cycle of the converter switch. The control loop is mainly responsible for controlling the current according to the switching of the converter. This type of control strategy is widely used for all types of batteries which are used in electric vehicle application and ensures reliable operation of the system. The simulation results for the battery charging system for the low power applications is illustrated in the next part. The performance of the battery charging system is analysed from the following results.

V. PROPOSED CONTROLLER

5.1 Fuzzy logic controller

5.1.1 Introduction

FLC is a type of control system that uses fuzzy logic to reason about uncertain or imprecise information. It is a type of expert system that can be used to control a wide range of systems, including industrial processes, consumer electronics, and robotics.

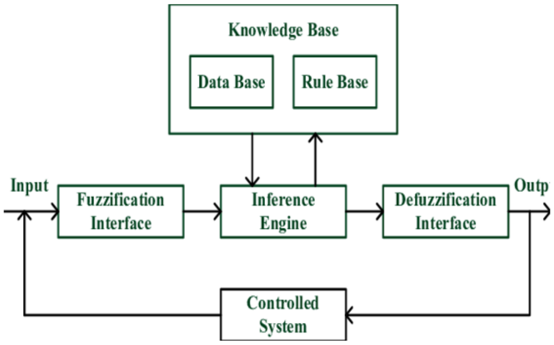

Fig.3. Fuzzy Logic Controller

Fuzzy logic is a type of mathematical logic that allows for reasoning with imprecise or uncertain information. It was introduced in the 1960s by LotfiZadeh, who recognized that many real-world problems involve imprecise and uncertain information that cannot be easily modelled using traditional logic. Fuzzy logic is based on the concept of fuzzy sets, which are sets that allow for partial membership, or degrees of membership, rather than the traditional binary set membership. FLCs are particularly useful in systems where the inputs and outputs are not well-defined or are subject to change over time. FLCs can reason about the uncertainty and imprecision in the input signals and produce control actions that are robust and adaptive to changes in the environment. FLCs are often used in control systems where traditional control methods are difficult to implement due to the complexity of the system or the lack of precise mathematical models.

One of the key advantages of FLCs is that they can be easily implemented using software or hardware, making them a popular choice for real-world control applications. FLCs have been successfully applied in a wide range of applications, including automotive engineering, robotics, consumer electronics, medical equipment, traffic control, and financial modeling.

VI. RESULTS AND DISCUSSION

6.1 With PI Controller

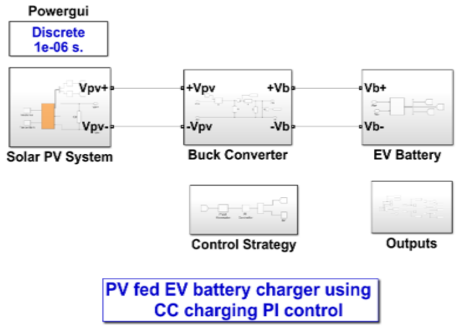

Fig.4. PI Controller

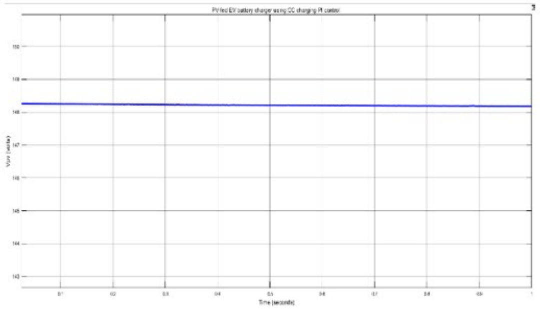

Fig.5. Vpv

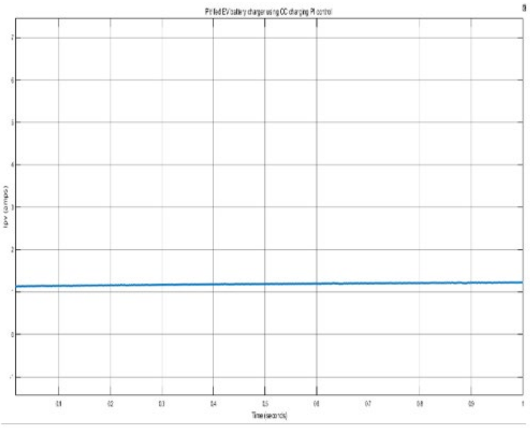

Fig.6. IPV

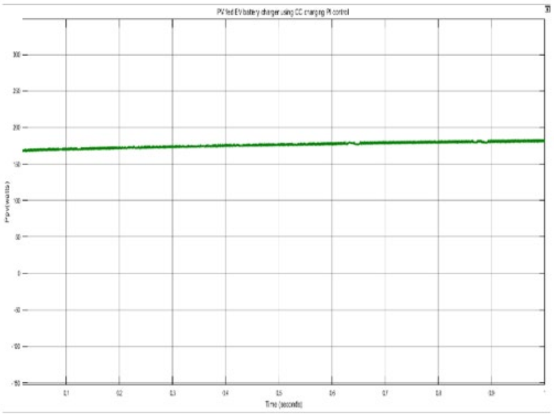

Fig.7. PPV

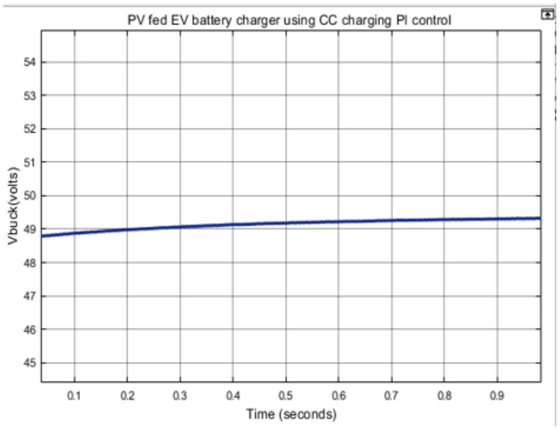

Fig.8. V-buck

The waveform of the output voltage of the buck converter is as shown in above. The output voltage ripple obtained is within the specified limit of 10% for an average output voltage of 49.5 volts. The output voltage ripple obtained is 2 Volts.

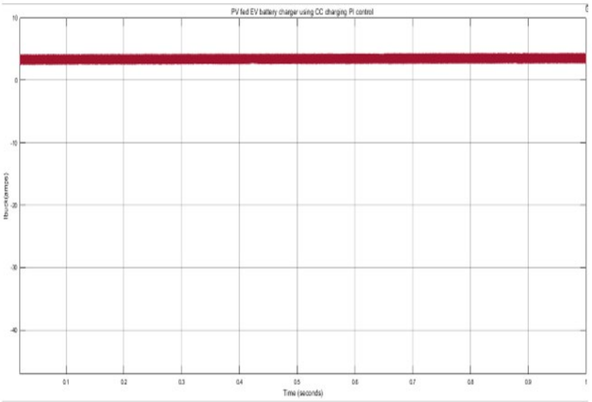

Fig.9. I buck

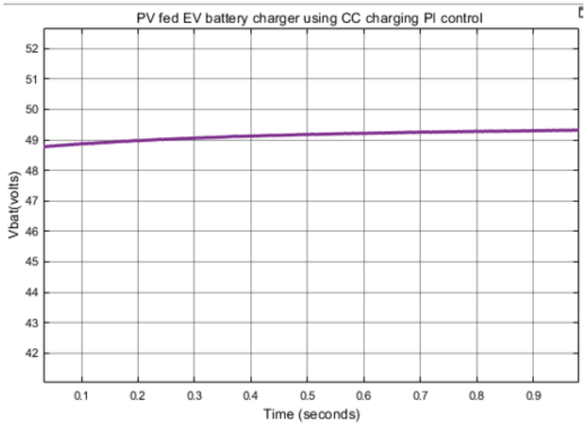

Fig.10. V battery

It has been observed that the output voltage rises from the nominal voltage remain constant at 48.8 V.

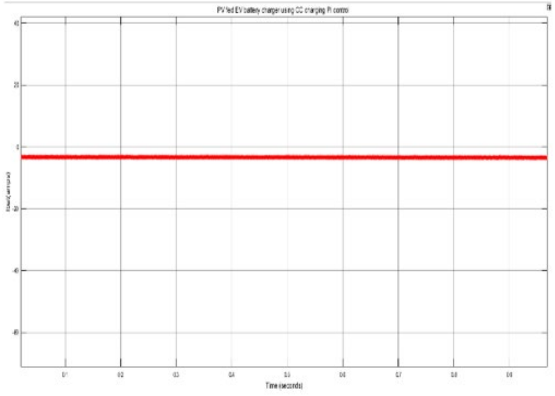

Fig.11. I battery

The battery current obtained is 3.68 A. The ripple observed in the battery current is 0.05 A which is approximately 1% of the charging current.

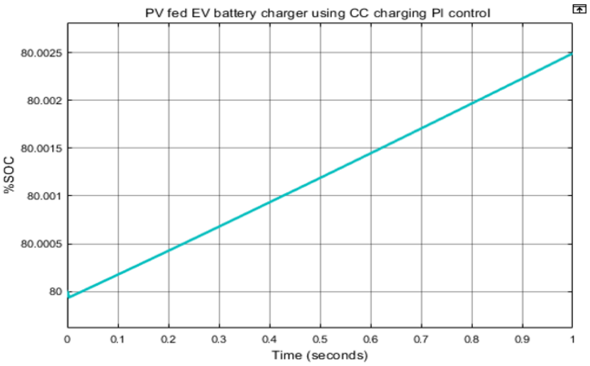

Fig.12. SOC

Above Fig shows the State of Charge (SOC) for the lead acid battery by considering SOC of 80%. The SOC increases gradually in this case with the increase in the charging voltage of the battery.

6.2 With fuzzy controller

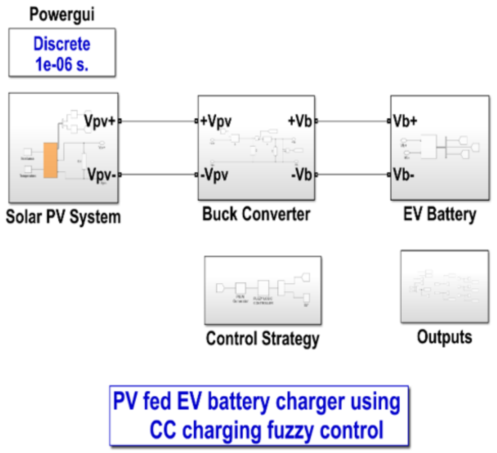

Fig.13. Fuzzy controller

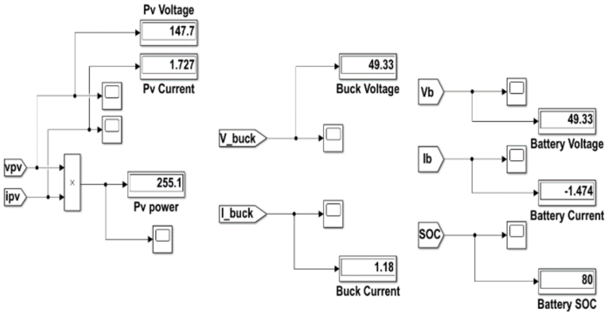

Fig.14. V and I buck

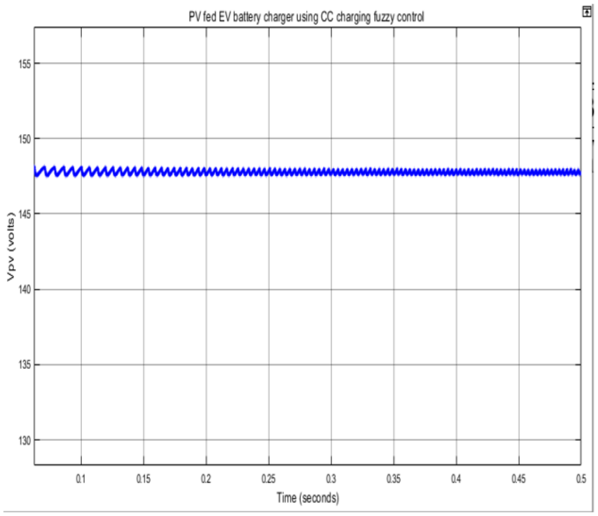

Fig.15. Vpv

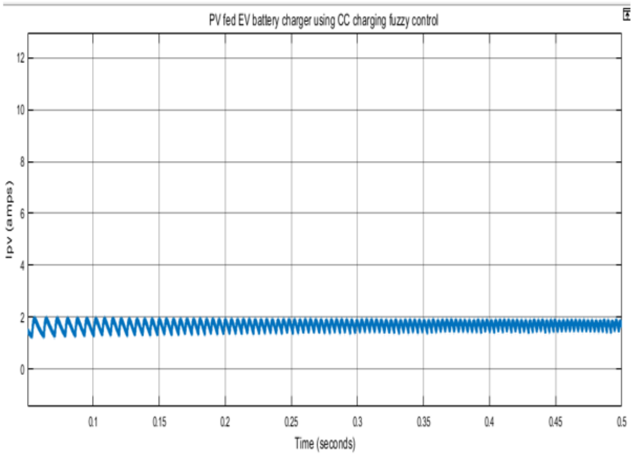

Fig.16. I-pv

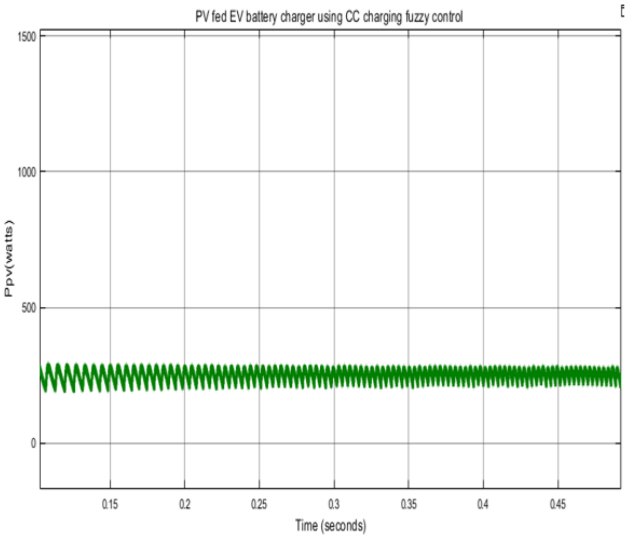

Fig.17. P-pv

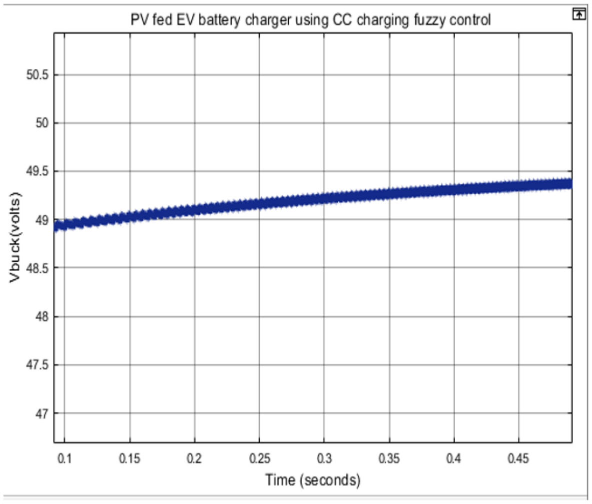

Fig.18. V-buck

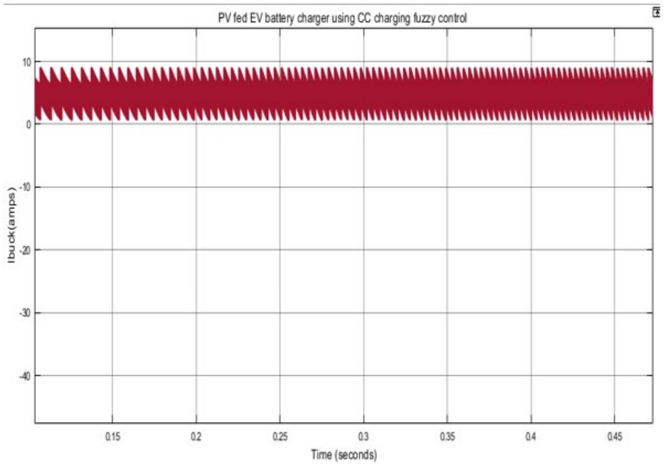

Fig.19. I-buck

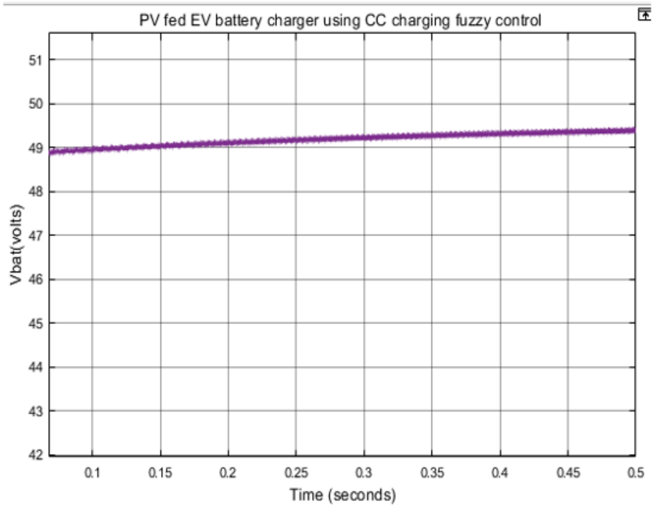

Fig.20. V-bat

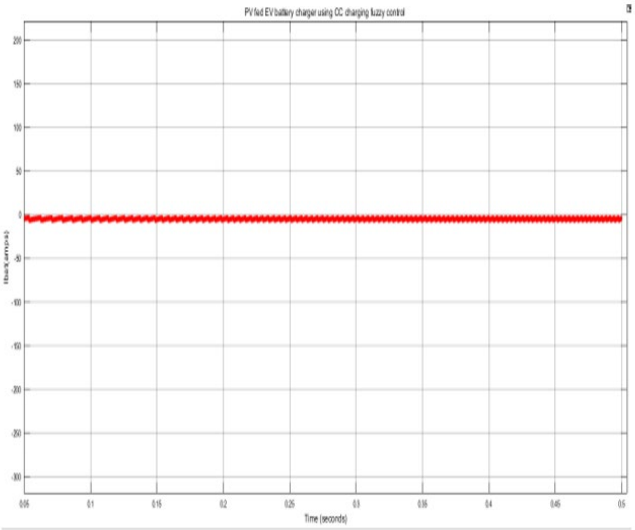

Fig.21. I-bat

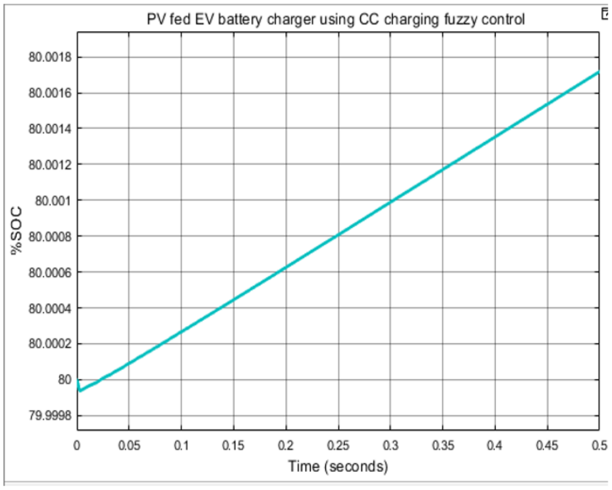

Fig.22. SOC

VII. CONCLUSION

In conclusion, the performance evaluation of the fuzzy logic controller-based solar PV-fed low power charging station for EV project has shown that it is a promising solution for sustainable and efficient EV charging. The system utilizes renewable energy sources, provides efficient and effective control of the charging process, has a higher charging efficiency, and ensures the safety of the EV and its components. The proposed system can optimize the charging time and improve the battery life of the EV, leading to a reduction in greenhouse gas emissions. Overall, the fuzzy logic controller-based solar PV-fed low power charging station for EV project is an innovative and practical solution for the future of EV charging.

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