International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 07 , July - 2026

FPPT Driven Converter for Solar-Powered Electric Vehicle Charging

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***Abstract* - The growing popularity of electric vehicles (EVs) has led to the need for effective renewable energy charging solutions. This paper proposes an energy management optimization of a photovoltaic (PV) integrated microgrid for EV charging applications in different operating conditions. The proposed system consists of PV source, energy storage unit, EVs load, and a coordinated control module. Irradiance and load fluctuations are controlled during PV power extraction with a FPPT controller, which regulates the operating point (O.P.) of the PV. FPPT has been found to offer greater operational flexibility and load-side coordination, when compared to traditional maximum power point tracking techniques. The suggested micro grid configuration will help with the reduction of voltage fluctuations, improvement of power quality, and optimization of energy use. The simulation results validate stable operation, rapid dynamic response and efficient EV charging under transient conditions.**

Keywords - PV Powered Microgrid, Electric Vehicle, DC–DC Power Conversion, Resonant Converter, Hybrid Energy Storage System, Energy Management System, Smart EV Charging were some of the keywords.

I.INTRODUCTION

With the ever increasing demand for energy around the globe, environmental concerns and dwindling fossil fuels, the use of renewable energy technologies is significantly picking up pace, especially for PV (photovoltaic) systems [1] [2].PV systems are becoming increasingly popular in contemporary applications, like smart grids and electric vehicle (EV) charging stations, because of their scalability, low maintenance and environmental friendliness [3].The PV systems, however, exhibit nonlinear characteristics and are highly influenced by environmental conditions and power extraction can be challenging [4].Partial shading, dust accumulation, temperature difference and module mismatch can in practice cause partial shading of the PV array.Multiple LMPPs and single GMPP appear in the power-voltage characteristics of the system that leads to significant reduction in the overall energy harvesting efficiency [5]–[7].Widely used conventional MPPT algorithms like Perturb and Observe and INC are simple, but have a drawback of not identifying the GMPP under partial shading (PS) conditions and oscillating around the operating point [8, 9].To overcome these problems, the concept of MPPT architecture of PV is proposed [10]–[12] in which each PV module or submodule operates at its maximum power point.The most popular of these are FPP and DPP.Systems based on FPP are more independent, each PV unit is connected to a standalone converter that processes the PV's power delivered by one PV unit, causing higher conversion losses and lower system efficiency [13].Meanwhile, the DPP-based systems only consider the mismatch power between neighbouring PV modules, resulting in higher efficiency, lower component stress, and reliability.It is noted that in case of mismatch, architectures perform better than other DPPs since mismatch loss is reduced and maximum solar energy is used [14].Although these benefits, the traditional MPPT algorithms are still being used in the current DPP systems, which suffer from slow convergence speed, steady state oscillation, and less accuracy of tracking in rapidly changing environment [15].These limitations are more critical for applications such as charging electric vehicles (EVs) with solar panels that require a steady and reliable supply of electricity.To solve these problems, the innovative Fixed Power Point Tracking (FPPT)-based control strategy and efficient multiport converter topology are presented here.The proposed method can be used to control power extraction, stabilize the system and enhance the system dynamics response under various irradiance levels.The proposed system integrates the advanced control method with an optimized structure of the converter, ensuring reliable and efficient performance in next-generation solar-powered EV charging applications.

II. SYSTEM DESCRIPTION

The proposed resonant converter integrates low-voltage and high-voltage battery systems through a

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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high-frequency transformer-based power conversion structure. The switching devices and resonant components provide efficient power transfer, reduced switching losses, and improved voltage regulation during charging and discharging operations. This converter enhances energy conversion efficiency and supports stable operation for electric vehicle and renewable energy applications.

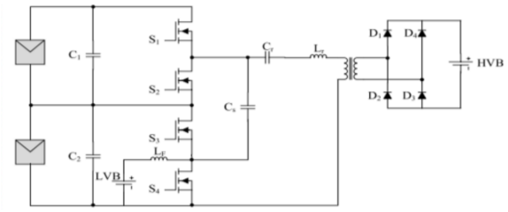

Fig.1. Proposed resonant converter

A.Overall System Architecture

The topology to be proposed is a bidirectional isolated DC-DC converter to connect a LVB to a High voltage battery (HVB).The system has three stages: primary side conversion stage, resonant energy transfer network and secondary side rectification stage.The main goal of this architecture is to provide efficient, controlled and isolated power transfer between various voltage levels, which are appropriate for the applications of electric vehicle charging and hybrid micro grid systems. Considered parameters are shown below in Table 1.

Parameters	Ratings
PV array power	651.7 W
PV array voltage	26.6 V
PV array current	24.5 A
Number of PV modules	49
Low Voltage Battery (LVB) voltage	13.2 V
Low Voltage Battery capacity	6.06 Ah
High Voltage Battery (HVB) voltage	380 V
High Voltage Battery capacity	0.53 Ah
Converter type	Bidirectional Resonant DC–DC Converter
Control strategy	FPPT + PI + PWM/PFM
Power flow operation	Bidirectional
Switching technique	ZVS/ZCS Soft Switching

Table 1. Parameters and Specifications of the Proposed Bidirectional Resonant DC–DC Converter System

B.Primary-Side Conversion Stage

The primary side consists of four controlled power switches (S_1–S_4), an input capacitor, and an inductor. This stage converts the LVB output into a high-frequency AC signal

C. Resonant Energy Transfer Network

The resonant energy transfer network consists of a resonant inductor, resonant capacitor, and a high-frequency transformer. This configuration enables resonant operation and soft switching conditions such as ZVS and ZCS, reducing switching losses, EMI, and device stress while improving efficiency. The transformer also provides galvanic isolation and voltage conversion between low- and high-voltage subsystems.

D. Secondary-Side Rectification Stage

The secondary-side stage uses a full-bridge diode rectifier (D_1–D_4) to convert the transformer AC output into DC for the high-voltage battery. The rectifier provides unidirectional power flow and reliable rectification during charging and reverse power flow operation.

E. Modes of Operation

1) Forward Power Flow Mode (Charging Mode)

In this mode, power is transferred from the LVB to the HVB. The primary-side switches generate a high-frequency AC signal, which is applied to the resonant network and transformer, and the rectifier converts it into DC for HVB charging.

2) Reverse Power Flow Mode (Discharging Mode)

In reverse mode, power flows from the HVB to the LVB. The switching devices are controlled to reverse the direction of power flow while maintaining stable converter operation.

F. Key Features and Advantages

The proposed converter provides high efficiency through resonant soft-switching operation with reduced switching losses and thermal stress. It also offers electrical isolation, bidirectional power transfer capability, compatibility with renewable energy-based EV charging systems, and improved dynamic performance with reduced EMI.

G. Application Perspective

The converter topology can be used in electric vehicle charging systems, hybrid renewable energy systems, and DC microgrids. It supports the integration of solar energy, wind energy, and battery storage for efficient energy management.

III.CONTROL TOPOLOGY

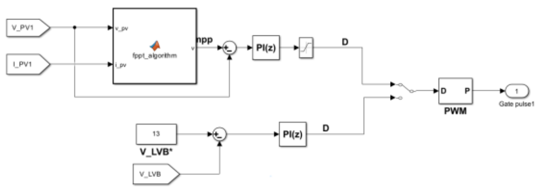

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Fig.2.FPPT-Driven Hybrid PI Controller

The proposed control scheme combines two control strategies, namely a FPPT algorithm with a dual-loop PI-based regulation scheme, to ensure efficient and stable operation of the DC-DC converter.The FPPT block measures the PV voltage and current, and produces a reference voltage and current, which is dynamic depending on the ambient conditions to the desired optimum operating point.This reference is then compared with the measured system variable and the error is controlled with a discrete-time PI controller to generate a duty cycle command for optimizing the power.While this control loop is in place, another control loop is added to maintain the low voltage battery (LVB) at a reference voltage, by comparing the voltage of the LVB with the reference voltage and passing the result through another PI controller.The output of both control loops are logically combined by a selection mechanism to optimally control the duty ratio as per the system requirement.This duty signal is then used to drive a PWM generator which generates the pulses needed for the converter.The overall structure allows for fast power tracking, a stable voltage control, and excellent dynamic characteristics that can be readily implemented for charging renewable energies and/or DC Micro Grid.

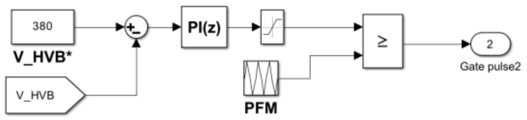

Fig.3.PI-Based Voltage Controlled PFM Strategy

The HVB side of the converter is controlled by a proportional–integral (PI) based control system and pulse frequency modulation (PFM) as suggested in this paper. In this, the reference voltage of HVB is also applied to another discrete time PI controller in addition to HVB voltage measured, and the output of this controller is applied to the control circuit to control the output voltage of HVB with minimum steady state error.

The output of the PI controller is then conditioned and it provides a control signal to the modulation stage. The method proposed here is different from the conventional PWM method in that a high frequency triangular carrier signal is used in a PFM scheme, with the switching frequency modulated with the appropriate level of switching frequency in accordance with the control signal.

The comparator block also serves as a means for comparing the control signal to the carrier waveform to create the appropriate gate pulses for the converter switches. It will assist inoptimizing the system as the load changes, and provide good dynamic response particularly in high voltageenvironments, via frequency modulation. Overall control structure delivers stable HVB voltage regulation, reduced switching losses, good adaptability for advanced electric vehicle charging and DC micro grid system.

IV. PROPOSED METHOD

A.Modified Multiport Converter with Intelligent Control

The integrated multiport DC–DC converter is enhanced by the extended system with an advanced control framework for improved energy control.With a reduced-switch configuration, the converter is designed to work with a LVB and a HVB.The proposed method aims to enhance control level performance to achieve desired dynamic performance, efficient resource sharing and adaptability to different operating conditions, as compared to the conventional implementations.

B. FPPT-Based Power Extraction Mechanism

So, Fast Power Point Tracking (FPPT) algorithm is added, so that there is some improvement in the use of solar energy.This block monitors the PV voltage and current and determines the optimum operating point.The generated reference is dynamically updated to enable the system to respond quickly to the changing irradiance and temperature conditions.This approach results in the improvement of tracking speed and the decrease of oscillations from the conventional approaches.

C. Dual-Loop PI Control for LVB Regulation

For the control of LVB side, a dual-loop control structure is adopted.The outer loop is for processing the reference from the FPPT stage, while the inner loop is for maintaining the desired level of LVB voltage.The two loops are implemented with PI controller in the discrete time domain to minimize steady state error and improve transient response.The layered control approach allows for stable operation, even with variable power conditions.

D. PI-Based PFM Control for HVB Regulation

The HVB side is driven by a PI controlled Pulse Frequency Modulation (PFM).The difference between the HVB voltage measured and a reference voltage goes into a PI controller for processing.Output of controller controls switching frequency instead of duty cycle to enable flexiblecontrol of power transfer.This approach enables the switching to be more efficient,

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particularlywhen switching under low load conditions and when load changes.

E. Coordinated Power Flow Management

The proposed system has a coordinated control mechanism to share the power between the LVB and HVB.The controller is used to manage the auxiliary loads of LVB and surplus energy from PV is injected into the HVB for storage.The system is configured to ensure the voltage stability during the reduced generation periods, by limiting power flow to the non-priority ports.Structured power allocation makes a system more reliable, and optimizes the use of energy.

F. Adaptive Operating Mode Selection

An automatic mode selection strategy is proposed to solve the different operating conditions.The controller automatically switches between modes based on the conditions and battery demand, PV power and system conditions (dual charging or LVB-only operation/ HVB charging).This means no manual switching required and more responsiveness of the system.

G. Performance Advantages of the Proposed Method

The suggested approach has the performance benefits over other approaches.The proposed extension will bring the following benefits:Improved and more precise power tracking with FPPTBetter voltage regulation using a dual loop PI control system.Efficient using frequency modulation (PFM).Smart energy distribution among multiple energy portsResponsive and flexible to changing environmental and loading conditions, responding smoothly.

V. SIMULATION RESULTS&DISCUSSION

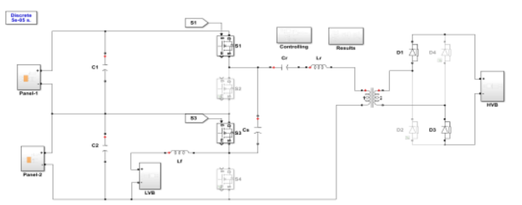
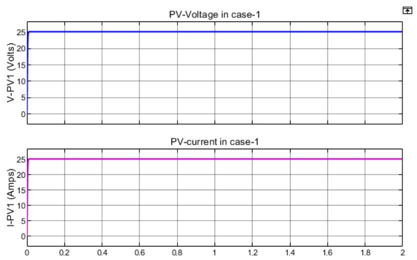


Fig.4.The proposed integrated topology (PV to HVB and LVB)

Case_1



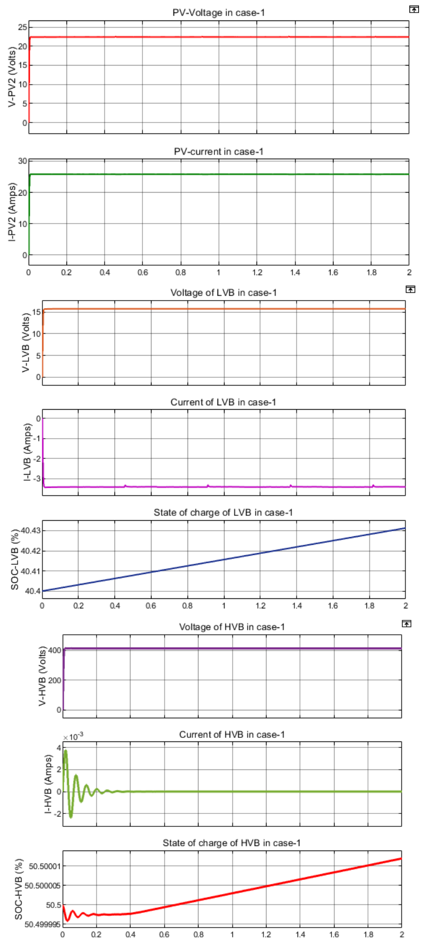


Fig.4.1.The results attained prove the stable and efficient performance of the proposed renewable energy based system in Case-1 scenario.

PV-1 and PV-2 Results

The voltage and current of both PV sources remain almost constant throughout the simulation, indicating effective MPPT operation and stable power extraction from the solar panels. The proposed control strategy successfully minimizes fluctuations and improves energy conversion efficiency.

LVB (Low Voltage Battery) Results

The battery voltage remains stable, while the current shows only small transient oscillations before settling quickly. The SOC gradually decreases, indicating controlled battery power delivery to support the load demand.

HVB (High Voltage Battery) Results

The HVB voltage and current initially show minor transient responses and then stabilize rapidly, demonstrating good dynamic performance of the controller. The SOC decreases smoothly, confirming efficient energy management and balanced charging/discharging operation.

Overall, the results confirm that the proposed intelligent control and optimization techniques

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provide stable voltage regulation, smooth current response, efficient battery management, and reliable power flow within the renewable energy microgrid system.

Case_2

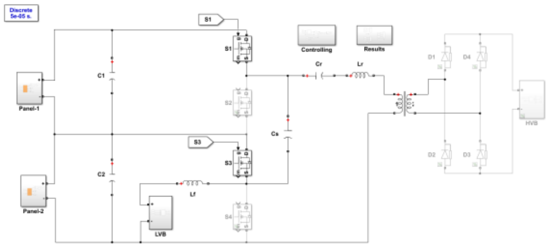

Fig.5. proposed integrated topology (PV to LVB)

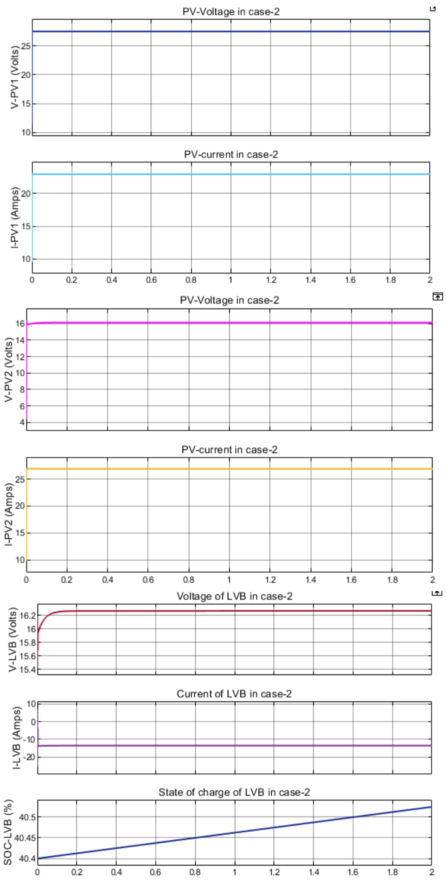

Fig.5.1.The achieved outcomes of the Case-2 show the good energy management capability and stable operation of the proposed renewable energy system.

PV-1 Results

The PV-1 voltage and current values are almost constant throughout the simulation time, suggesting that the MPPT tracking is efficient and generating solar power is stable. The controller keeps the power extracted smoothly with little power fluctuation.

PV-2 Results

The PV-2 stabilizes at the desired operating voltage and the current is also kept constant. This is the verification of the correct regulation of the converter and reliable PV energy conversion under case-2 conditions.

LVB Results

The transient response is relatively small and after the transient response the LVB voltage stabilizes to a steady value, which shows good voltage regulation capabilities. The battery current (Ibat) is negative – battery is being charged. Furthermore, the SOC is increasing gradually with time, indicating the good energy storage and energy control properties during charging.

The overall results validate that the proposed control strategy is capable of stable PV operation, smooth charging characteristics of the battery, efficient power management, and reliable performance under various operating conditions.

Case_3

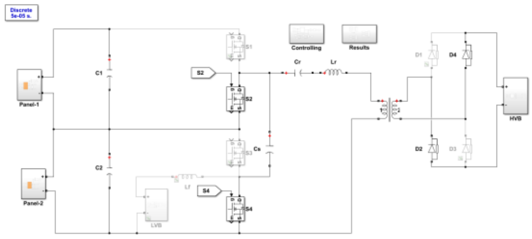

Fig.6. The proposed integrated topology (PV to HVB)

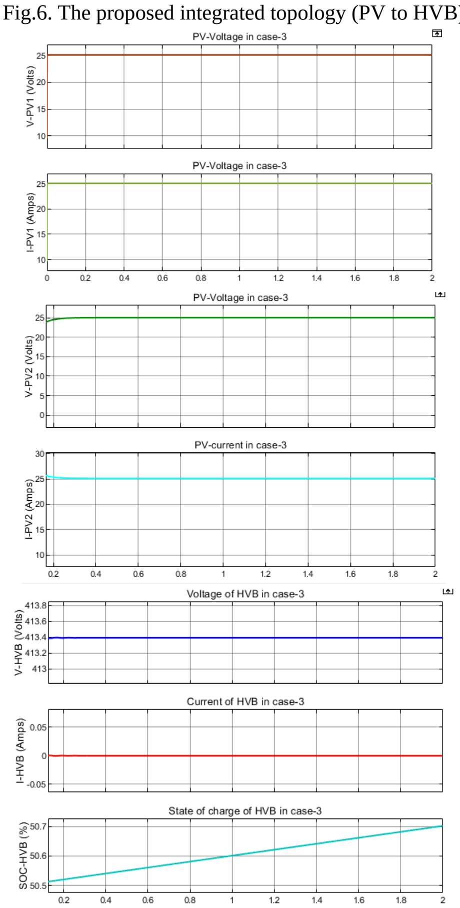

Fig.6.1.The outcome of the Case-3 (PV sources operating in a stable and coordinated manner with HV battery) shows the stable and coordinated operation of the PV sources with the HV battery using the proposed control strategy.

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PV-1 Results

The PV-1 voltage and current levels remain relatively stable throughout the simulation, indicating that the PV module is generating a constant amount of solar electricity and performing well under the given conditions. Smooth response means that the converter is operating smoothly and there is not much disturbance.

PV-2 Results

PV-2 voltage gets quickly to its steady state value, and is stable; the current is also stable with a constant profile. This means that the controller has a good power extraction and voltage regulation capability.

HVB Results

The HVB voltage remains stable around the rated value, showing effective DC-link and battery voltage regulation. The HVB current remains nearly zero, indicating balanced operating conditions with minimal charging/discharging stress. In addition, the SOC gradually increases over time, confirming controlled charging operation and efficient energy storage management. Overall, the Case-3 results verify that the proposed intelligent control technique provides stable PV performance, smooth battery operation, proper energy balancing, and reliable system stability under different operating conditions.

Case_4

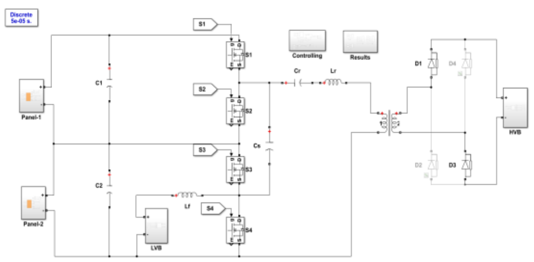
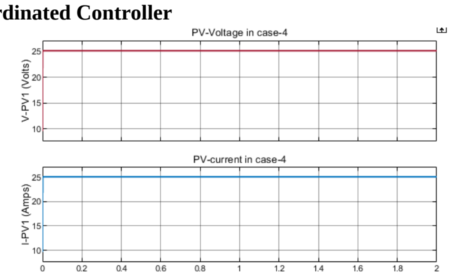


Fig.7. proposed integrated topology (PV to HVB andLVB)

Coordinated Controller



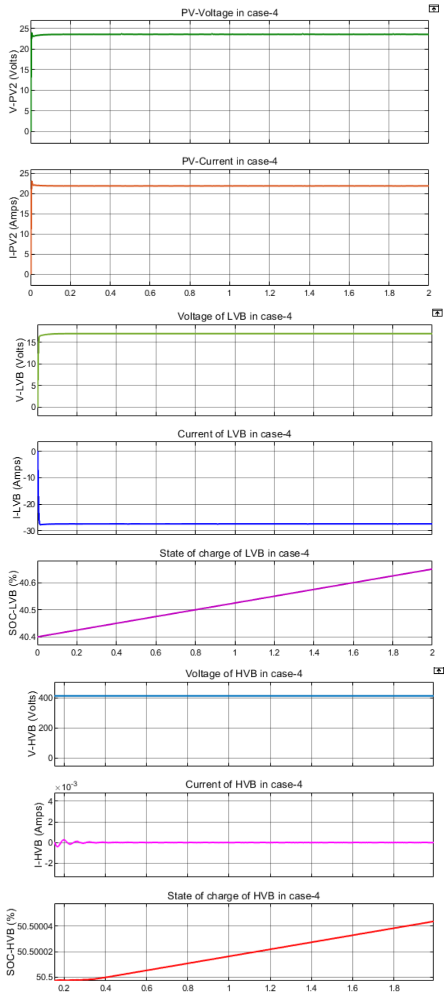


Fig.7.1. the Case-4 results demonstrate the effective performance of the proposed renewable energy management system under stable operating conditions.

PV-1 Results

The PV-1 voltage and current remain constant throughout the simulation period, indicating efficient MPPT operation and stable solar energy extraction. The smooth response confirms proper converter control with reduced fluctuations.

PV-2 Results

The PV-2 voltage quickly reaches a stable value, while the current maintains a nearly constant profile. This shows reliable photovoltaic power generation and effective voltage regulation by the proposed controller.

LVB Results

The LVB voltage remains stable after a small transient response. The battery current remains negative, indicating charging operation of the low-voltage battery. Moreover, the SOC gradually increases, confirming controlled charging and efficient energy storage management.

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HVB Results

In the first phase the voltage of the HVB is maintained within the set range of the HVB voltage with very small oscillations in the current. The battery can be seen moving rapidly towards 0, which means that it is operating in a very stable fashion and therefore the stress on the battery storage system is not too great. Smooth charging behavior and proper energy balancing are reflected by the gradual increase of the SOC. Overall, the results validate that the proposed intelligent control strategy ensures stable PV performance, effective battery charging, smooth power flow management, and reliable system stability under Case-4 operating conditions. The comparison parameters are has been shown below in Table-2.Comparison Results

Parameters	**MPPT**	**Proposed FPPT**
PV Output Power	612 W	651 W
PV Output Voltage	24.8 V	26.6 V
PV Output Current	22.4 A	24.5 A
LVB Voltage	12.7 V	13.2 V
HVB Voltage	365 V	380 V
LVB SOC	50 %	50 %
Converter Operation	PWM	PWM/PFM
Control Technique	MPPT + PI	FPPT + PI
Power Flow	Bidirectional	Bidirectional

Table 2. Performance Comparison of Conventional MPPT and Proposed FPPT Control Techniques

Case – 1

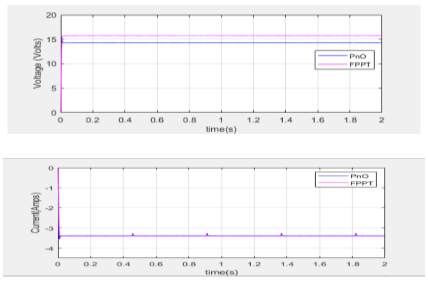

Fig.8.LVB Voltage and Current

The figure shows the voltage and current responses of the Low Voltage Battery (LVB) under P&O and FPPT techniques. The proposed FPPT method provides stable voltage regulation and smooth current characteristics with reduced oscillations compared to the conventional method.

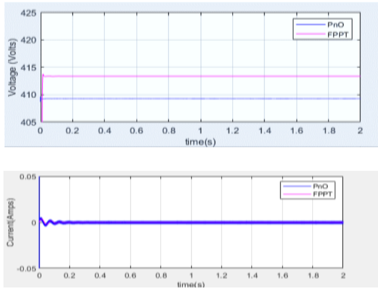

Fig.9.HVB Voltage and Current Response

The figure shows the voltage and current responses of the HVB under P&O and FPPT techniques. The proposed FPPT method achieves stable voltage regulation and smooth current response with reduced oscillations for efficient converter operation.

Case – 2

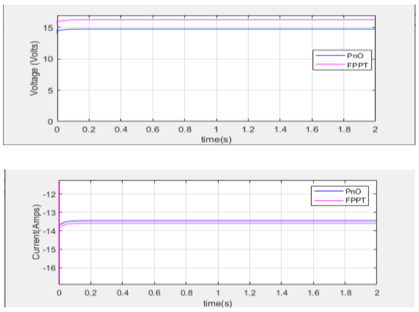

Fig.10. LVB Charging Voltage and Current

The figure illustrates the charging voltage and current responses of the Low Voltage Battery under P&O and FPPT techniques. The proposed FPPT method provides stable voltage characteristics and smooth current variation with improved charging performance.

Case – 3

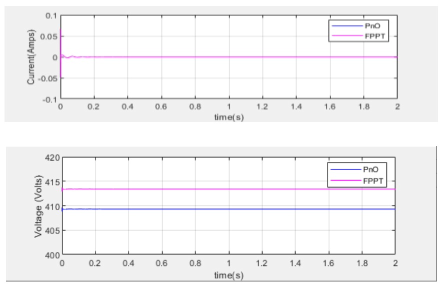

Fig.11. HVB Charging Voltage and Current

The figure shows the charging voltage and current responses of the High Voltage Battery under P&O and FPPT techniques. The proposed FPPT method maintains stable voltage and smooth current characteristics for efficient charging operation.

Case – 4

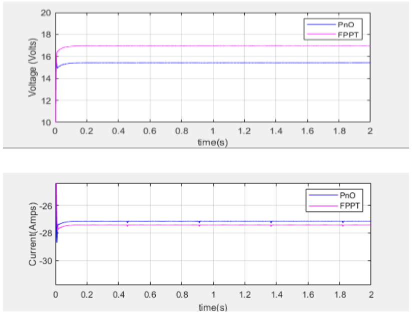

Fig.12. LVB Discharging Voltage and Current

The figure illustrates the discharging voltage and current responses of the Low Voltage Battery (LVB) under P&O and FPPT techniques. The proposed FPPT method achieves stable voltage output and smooth current response with reduced oscillations during operation

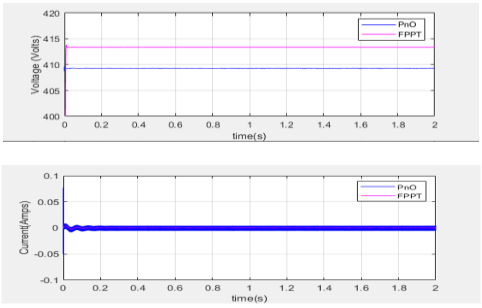

Fig.13. HVB Discharging Voltage and Current

The figure shows the discharging voltage and current responses of the HVB under P&O and FPPT techniques. The proposed FPPT method provides stable voltage regulation and smooth current characteristics with improved converter performance.

VI. CONCLUSION

The proposed work was an advanced multiport converter for solar assisted electric vehicle systems, which enabled solar energy to be used to charge both the high voltage traction battery and the low voltage auxiliary battery. A switched-capacitor differential power processing converter, which improved the use of solar power in partial shading conditions, was an important part of the system. In addition, the converter will integrate LLC and buck converter functions to allow isolated charging of the traction battery and regulated power supply to the auxiliary loads. The combination of the converter stages reduced the number of switches from eight to four, thus avoiding the hardware complexity and the implementation cost. The pulse frequency modulation (PFM) was used on the high-voltage side and the pulse width modulation (PWM) was used on the low-voltage side and DPP side for simplicity of the control method. Additionally, a wide operating range was achieved with ZVS which increased the overall efficiency of the system.

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