DESIGN AND ANALYSIS OF INTERLEAVED BOOST CONVERTER FOR EV BATTERY CHARGING APPLICATION

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Abstract - *This paper presents the design and analysis of an interleaved boost converter for EV battery charging applications, a basic boost converter converts a DC voltage to a higher DC voltage. Interleaving adds additional benefits such as reduced ripple currents in both the input and output circuits. Higher efficiency is realized by splitting the output current in both input and output circuits, substantially reducing I^2R losses and inductor ripple current losses.*

Keywords: Electric Vehicle (EV), Interleaved Boost Converter (IBC), Hybrid renewable energy systems (HRES), Photo Voltaic (PV), Power conditioning system (PCS), Perturb and observe (P&O), Maximum power point tracking (MPPT), Conventional Boost Converter(CBC), electromagnetic interference(EMI), boost converter(BC), Discontinuous conduction mode (DCM). Continuous conduction mode (CCM).

1. INTRODUCTION

The project's primary objective is to design an interleaved boost converter for efficient integration of HRES. The main aim of this project is to implement interleaved concept to the boost converter and improve its performances. IBC is used for reducing switching losses and switching stresses. PV panel is used as a source and MPPT algorithm is used to obtain maximum power from PV panels. This project involves theoretical derivations, simulations, and experimental demonstrations.

2. PROJECT OVERVIEW

PV generation is increasingly important due to its advantages, such as no fuel costs, no pollution, low maintenance, and no noise. However, PV modules have relatively low conversion efficiency due to nonlinear V-I and P-V characteristics, which depend on irradiance, temperature, and load conditions. To enhance efficiency, a power conversion system (PCS) is required to transfer power from the PV array to the load. A typical single-phase PV PCS consists of two conversion stages: DC-DC and DC-AC. The DC-DC converter, as the first stage, controls the maximum power point (MPP) by adjusting the duty ratio. The widely used Perturb and Observe (P&O) algorithm has limitations in tracking MPP quickly and reducing oscillations. To improve efficiency, an interleaved boost converter (IBC) is used for high-power applications due to its low conduction loss, high voltage step-up, reduced output voltage ripple, and faster transient response. Although IBC requires more inductors, increasing complexity compared to a conventional boost converter, it is preferred due to low ripple at both input and output. To reduce this complexity, a coupled IBC is considered. The proposed topology employs a Hill Climbing MPPT algorithm for better control and optimal energy harnessing. The IBC topology enhances output power with high efficiency, and steady-state voltage ripples at the output capacitors are minimized. The design and implementation of switching pulses and the MPPT algorithm are carried out using an Arduino microcontroller.

2.1 OBJECTIVES OF THE STUDY

The primary objectives of this study are to design, analyze, model, and control an interleaved-boost DC-DC converter. The objectives of the proposed work to analyse the performance of Interleaved boost converter using PV panel and MPPT technique for battery storage applications [4]. To develop the prototype model of an Interleaved boost converter for the EV battery storage applications

2.2 PROBLEM FORMULATION

A comparison between CBC and IBC is done based on various parameters like input current ripple, output voltage ripple, and gain of the converter, and the best one is chosen to be IBC. The main aim is to obtain a high-gain converter with reduced input current ripple and reduced output voltage ripple, ensuring better efficiency and performance to justify the selection of IBC for photovoltaic applications .This makes the IBC a more suitable choice for applications requiring stable power conversion, improved reliability, and enhanced overall system efficiency.

Table 1 Comparison between CBC & IBC

S.No	Conventional Boost Converter	Interleaved Boost Converter
1.	Efficiency is low	Improved efficiency
2.	Increase in ripple voltage	Reduced ripple voltage
3.	Increase in inductor	Reduced inductor

	current ripple	current ripple
4.	Slow switching speed as compared with IBC	Fast switching speed

2.3 IMPORTANCE OF WORK

The Efficiency of the converter is improved by reducing the input current ripple and switching losses. For Higher current applications, IBC are preferable, since the currents through the switches are just fractions of the input current. If the converters are still operated in hard switching, resulting in large switching losses and serious EMI problem. It will improve the efficiency and reduce the maintenance needed for any PV system. MPPT algorithm i.e., Hill climbing (P&O) technique implemented to extract more power from the PV panels through IBC.

3. Existing System

The EBC as shown in Fig.1 has various limitations in their parameters like input current ripple, output voltage ripple, gain of the converter and efficiency. So in order to overcome these issues, IBC The main aim is to obtain a high gain converter with reduced input current ripple and reduced output voltage ripple.

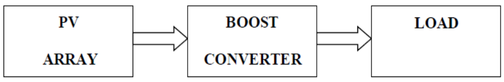

Fig.1 Existing boost converter system

3.1 Limitations of Existing System

The existing system has several limitations that hinder its performance. Firstly, the total current flows through a single switch, which increases the voltage stress across it. This design also results in high input ripple current and output voltage ripples. Furthermore, the system suffers from high switching losses and low voltage stability as well it fails to achieve maximum power output. These limitations collectively impact the overall efficiency and reliability of the system, making it less effective for practical applications.

4. Proposed System

IBC concept is used in this work for PV module applications as shown in Fig2. The advantages of IBC related to CBC are low input current ripple, high efficiency, and faster transient response, reduced EM emission and improved reliability. The design equations have been presented and performance parameters have been related using theoretical calculations and simulation. The operation principle and steady-state performance are analysed and finally the experimental results are given, moreover, the derivation of the proposed converter is also presented.

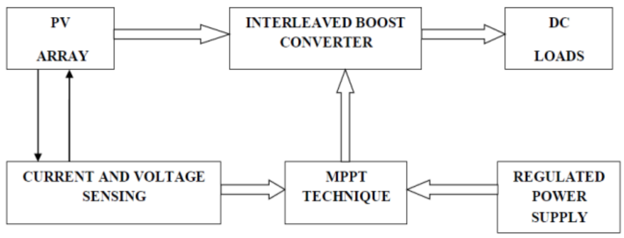

Fig.2 The proposed system operation sequence

5. MAXIMUM POWER POINT (MPP)

The entire system has been modelled on MATLAB/Simulink. The block diagram of the solar PV panel is shown in Fig3. and Fig.4. The inputs to the solar PV panel are temperature, solar irradiation, No. of solar cells in series and number of rows of solar cells in parallel. Different parameters of the standalone PV system are shown in Table 2.

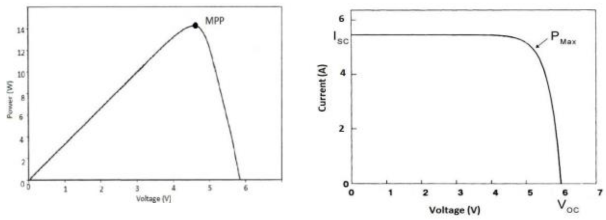

Fig.3 & 4 IV& PV characteristics

Table 2 Solar PV array specification

S No	Parameters	Simulation Values
1.	Maximum power (P_{max})	200W
2.	Open circuit voltage (V_{ocn})	32.9V
3.	Short circuit current (I_{scn})	8.21A
4.	Voltage at maximum power point (Vpm)	26.3V
5.	Current at maximum power point (Imp)	7.60A
6.	Cells per module	72

5.1 DESIGN OF AN IBC

A basic BC converts a DC voltage to a higher DC voltage. Interleaving adds additional benefits such as reduced ripple currents in both the input and output circuits. Higher efficiency is realized by splitting the output current into two paths, substantially reducing I^2R losses and inductor AC losses. Figure 5 shows the basic interleaved boost topology. When Q1 turns on, current ramps up in L1 with a slope depending on the input voltage, storing energy in L1. D1 is off during this time since the output voltage is greater than the input voltage. Once Q1 turns off, D1 conducts delivering part of its stored energy to the load and the output capacitor. Current in L1 ramps down with a slope dependent on the difference between the input and output voltage. One half of a switching period later, Q2 also turns on completing the same cycle of events. Since both power channels are combined at the output capacitor, the effective ripple frequency is twice that of a conventional single channel boost regulator.

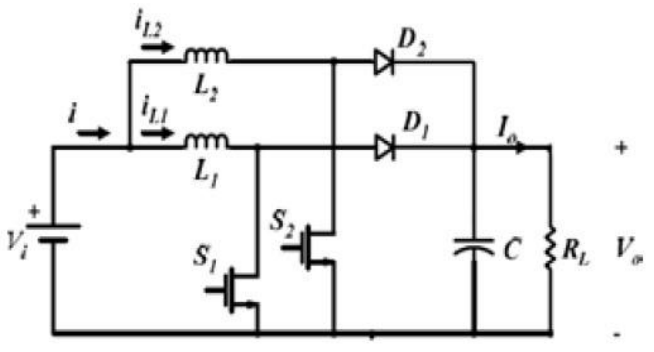

Fig.5 Circuit Diagram of Interleaved boost converter

6.MODES OF OPERATION

The mode of operation can be analyzed based on one channel. Since both power channels share current and because both inductors are identical, each power channel behaves identically. Based on the amount of energy that is delivered to the load during each switching period, the boost converter can be classified into continuous or DCM If all the energy stored in the inductor is delivered to the load during each switching cycle, the mode of operation is classified as DCM. In this mode the inductor current ramps down to zero during the switch off-time. If only part of the energy is delivered to the load, then the converter is said to be operating in CCM. Figure 6 shows the inductor current waveforms for both modes of operation. The mode of operation is a fundamental factor in determining the electrical characteristics of the converter. The characteristics vary significantly from one mode to other, affecting parameters such as efficiency, voltage ripple and transient response.

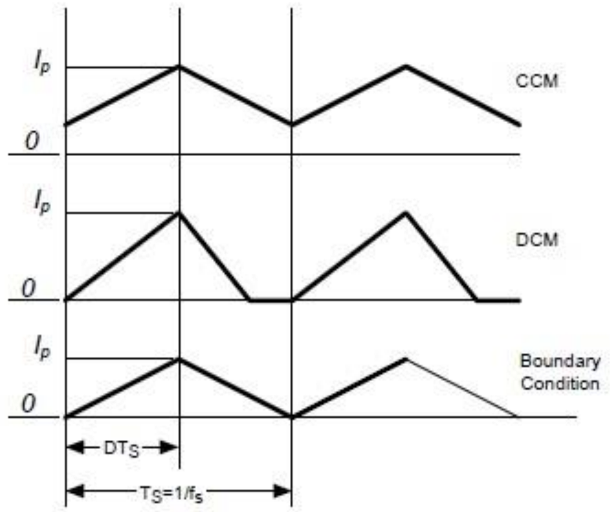

Fig.6 Inductor Current (IL) Waveforms

6.1. SELECTION OF IBC COMPONENTS

1. Input voltage ranges

Input Voltage $V_{in}(min)$ = 26.3 V

Input Voltage $V_{in}(max)$ = 32.9 V

Input Voltage $V_{in}(avg)$ = 29.6 V

2. Calculation of Duty Cycle

Duty cycle:

$$D = \frac{1\text{-Vin(min)Vout}}{\text{Vout}} = 80.01\ \%$$

3. Calculation of inductor ripples current:

Inductor Ripple Current:

$$\Delta IL = \frac{\text{Vin(min).D}}{\text{Fs.L}} = 1.350\ \text{A}$$

4. Calculation of inductor

Inductance

$$L = \frac{\text{Vin(avg). Vout-Vin(avg)}}{\Delta\text{IL.FS.Vout}} = 564\ \mu\text{H}$$

5.Output Capacitor selection

Output capacitance

$$Co = \frac{Io.D}{Fs.\Delta vout} = 24.5\ \mu f$$

Table 3 Hardware Specifications

S.No	Parameters	Values
1.	Input voltage $V_{in}(avg)$	29.6 V
3.	Efficiency of the converter (η)	99%
4.	Inductor (L_1=L_2)	564μH
5.	Capacitor (C_o)	24.5μF
6.	Switching frequency (F_S)	30kHz
7.	Duty cycle (D)	80%
8.	Load resistance (R_L)	70 Ω
9.	Output voltage ripple ($Vout$)	1.63 V
10.	Inductor ripple current (ΔI_L)	1.350 A
11.	Output voltage (V_{out})	162 V

7. Simulation Analysis

Simulink model of IBC and MPPT controller contain two inductors, one output capacitor and a resistive load as shown in Fig.7 The simulation has been done for the resistive load of 70 Ω, the inductor values has chosen to be *564* μ*H*, and output capacitor value taken to be *25* μ*F* Fig.8 shows the output voltage waveform of IBC, input of 30 V is boosted up to 162V for various irradiation conditions. Fig.9 shows the output current waveform of IBC. The value of current is 0.82 A. The power output is 138W as shown in Fig 10

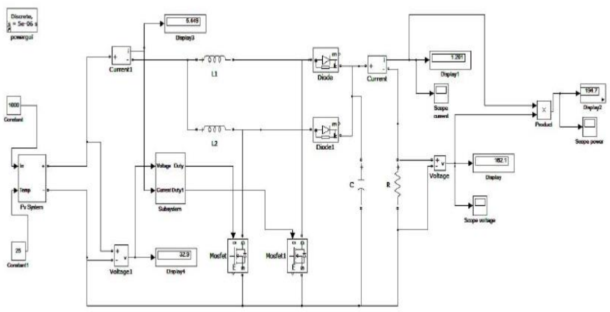

Fig.7 Simulink model of IBC with PV panel and MPPT controller

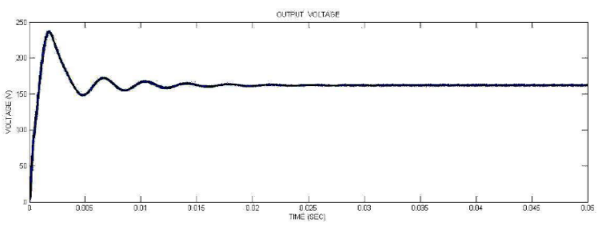

Fig.8 Simulink model of IBC with PV panel and MPPT controller- output voltage

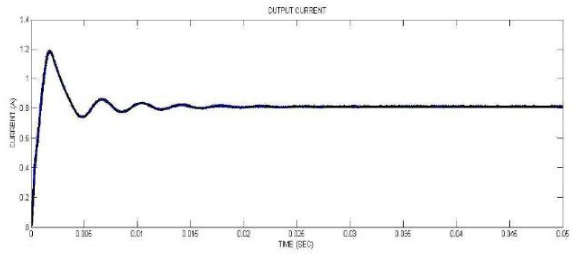

Fig.9 Simulink model of IBC with PV panel and MPPT controller- output current

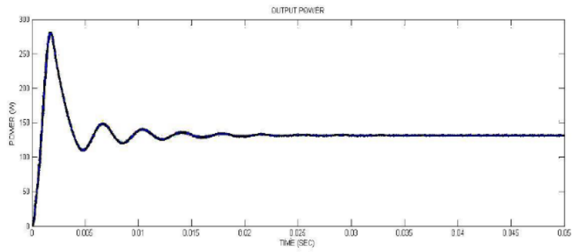

Fig.10 Simulink model of IBC with PV panel and MPPT controller- output power

When, comparing the IBC with and without MPPT controller in Simulink encouraging results were obtained.

S.NO	PARAMETERS	IBC WITHOUT MPPT CONTROLLER	IBC WITH MPPT CONTROLLER
1.	Input voltage V_{in}(avg)	26.3 V	26.3 V
2.	Output voltage V_{out}	139 V	162 V

Table 4 Comparison between without and with MPPT controller for IBC

8. Hardware Analysis

The **hardware implementation** of an IBC WITH HRES involves several crucial components and meticulous steps to ensure optimal performance. Switching devices, such as IGBTs or MOSFET are employed for their high switching speeds and efficiency, allowing for effective energy management between different ports. Control circuitry, including a microcontroller or DSP, generates the necessary PWM signals to operate these switches. Phase-shift control is then implemented to regulate power flow and minimize ripple currents, enhancing power transfer efficiency and reducing EMI. Passive components, such as inductors and capacitors, filter unwanted harmonics and smoothen output voltage and current, contributing to the converter's performance and stability.

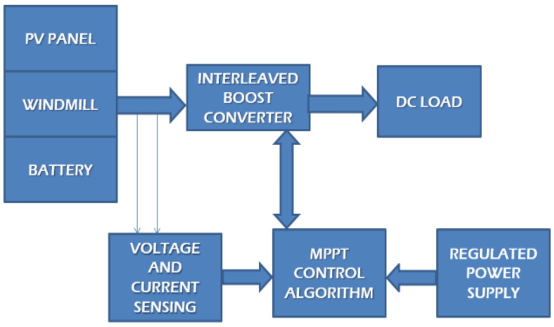

Fig.11 Block Diagram of the system

Fig.12 Hardware setup of the system

The hardware setup of an IBC involves several meticulous steps and components to ensure efficient and reliable operation. The first step is selecting appropriate switching devices such as IGBTs or MOSFETs. These are crucial for high-speed switching and efficient power conversion. The control circuitry, which includes a microcontroller or DSP, generates the necessary PWM signals to operate these switches. The control circuitry is typically programmed to manage phase-shift control, which helps regulate power flow and reduce ripple currents. Aswell, passive components such as inductors and capacitors are integrated into the system to filter out unwanted harmonics and smoothen the output voltage and current. These components must be carefully selected and placed to optimize the performance of the converter

9. RESULT

The following tabulations show the results from hardware system validation and simulation results from MATLAB – Simulink.

S.NO	PARAMETERS	VALUES
1.	Input voltage V	17.56 V
2.	Inductor L1-L2	564 µH
3.	Capacitor Co	22µF
4.	Switching frequency Fs	25kHz
5.	Duty cycle D	50%
6.	Load resistance R	1 kΩ
7.	Output voltage at unloaded V	153.41 V
8.	Output voltage at 1KΩ loaded	32.8 V

10. SUSTAINABLE DEVELOPMENT GOALS

Goal 7:Affordable and Clean Energy

The project aims to harness solar energy for charging EV batteries. Solar energy is a renewable and abundant resource, significantly reducing greenhouse gas emissions compared to traditional fossil fuels. By utilizing solar power, the project not only supports the adoption of clean energy but also makes EV charging more affordable for consumers, thereby encouraging the widespread use of sustainable energy sources.

Goal 11: Sustainable Cities and Communities

Encouraging the use of electric vehicles (EVs) supports cleaner and more sustainable urban development. EVs produce zero tailpipe emissions, leading to improved air quality and reduced noise pollution in cities. By reducing the carbon footprint of transportation, the project contributes to the development of smart and sustainable cities.

Goal 13: Climate Action

Reducing dependence on fossil fuels through the use of renewable energy sources helps mitigate climate change. The project addresses the urgent need to cut down on greenhouse gas emissions by promoting the use of solar energy for EV charging.

Goal 12: Responsible Consumption and Production

Promoting resource and energy efficiency within the project fosters sustainable consumption and production patterns. The use of solar energy for EV charging minimizes the depletion of non-renewable resources and reduces environmental impact. The project encourages responsible use of resources by optimizing energy consumption and promoting sustainable production practices.

11. CONCLUSION

In this work an IBC system is designed to tackle the switching losses and switching stresses efficiently. Although promising results are obtained from the prototype design, to validate the efficiency of the proposed converter is tested and simulation results were verified practically. The test result shows that the efficiency of the converter is improved by reducing the input current ripple and switching losses. In this work IBC was designed and the simulation results obtained for the proposed system and the performance of the same will be validated using experimental results. Aswell the experimental validation confirms the effectiveness of the proposed design in achieving high efficiency and stable operation under varying load conditions. The results demonstrate that the IBC system is well-suited for EV battery charging applications, ensuring reliable performance with minimized losses.

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