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Interleaved Buck Converter with Overvoltage Protection

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Abstract: Efficient DC–DC power conversion is essential in modern electrical and electronic systems such as electric vehicles, renewable energy setups, and industrial power supplies. Interleaved buck converter with overvoltage protection presents the design and implementation of a Two phase interleaved buck converter using a PI controller for stable and efficient voltage step down operation. The system converts a DC input of 30 V into a regulated 12 V DC output with improved performance and efficiency. By operating two buck converter phases at 180° out of phase, the design significantly reduces input and output current ripple, enhances thermal distribution, and efficiency. A digital PI control algorithm implemented on the DSPIC30F2010 microcontroller ensures precise voltage regulation and equal current sharing between phases. Additionaly an overvoltage protection mechanism is integrated to automatically detect and respond to overvoltage conditions by disconnecting the circuit, thereby preventing component damage and enhancing system reliability .The combined use of interleaving ,digital PI control with overvoltage protection makes the converter efficient, safe, and suitable for advanced applications in electric vehicles, solar energy systems, and industrial automation.

I. INTRODUCTION

Modern electrical and electronic systems require efficient and reliable DC–DC power conversion to ensure stable operation in applications such as electric vehicles, renewable energy systems, and industrial power supplies. Among the various converter topologies, the interleaved buck converter has gained significant attention due to its ability to reduce current ripple, improve efficiency, and distribute thermal stress across multiple phases. This paper presents the design and implementation of a two-phase interleaved buck converter with an integrated overvoltage protection mechanism for improved safety and performance. The converter operates with two phases shifted by 180°, which effectively minimizes input and output current ripple and enhances overall system efficiency. A digital PI controller implemented using a DSPIC30F2010 microcontroller ensures accurate voltage regulation and balanced current sharing between the phases. Additionally, an overvoltage protection circuit is incorporated to detect abnormal voltage conditions and automatically disconnect the system to prevent damage to components. This integrated approach improves reliability and makes the converter suitable for modern power electronic applications.

II. INTERLEAVED BUCK CONVERTER

A. Interleaved Buck Converter

An interleaved buck converter is an advanced form of the conventional buck converter designed to enhance efficiency and reduce current ripple. It consists of multiple buck converter phases connected in parallel, each operating with a fixed phase shift between them. This interleaving of switching signals allows the input and output currents to overlap in such a way that the total ripple current is significantly reduced. As a result, the converter experiences lower electromagnetic interference (EMI),reduced thermal stress on components, and improved transient response. The even distribution of load current among phases also enhances reliability and efficiency, making the interleaved buck converter highly suitable for high-current applications such as electric vehicles, battery charging systems, and renewable energy converters

B. *Circuit Diagram*

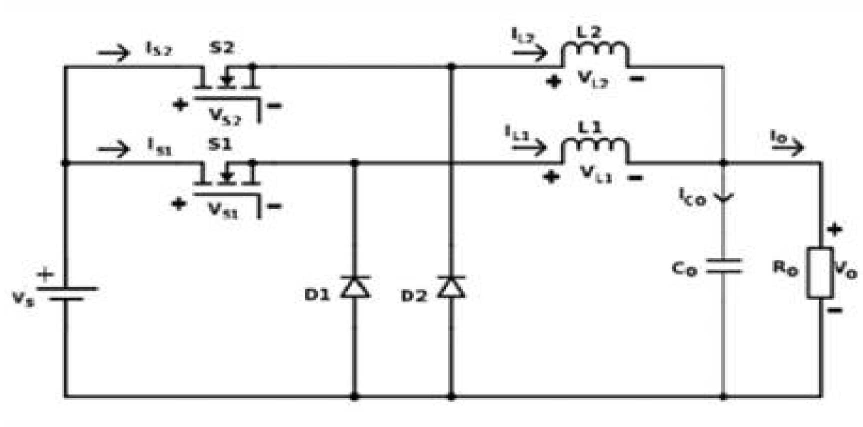

Figure 1 Circuit diagram of interleaved buck converter

figure 1 illustrates the circuit diagram of interleaved buck converter consisting of two buck converter phase connected in parallel each phase includes a switch(S_1,S_2), a diode(D_1,D_2),and an inductor(L_1, L_2).The two switches are driven by pulse-width modulation (PWM) signals that are phase-shifted by180°, allowing interleaved operation. This interleaving causes the inductor currents of each phase to overlap, which reduces the total output current ripple. The combined output from both inductors is filtered by the output capacitor (Co) and supplied to the load (Ro). The input voltage (Vs) is common for both converter stages. This configuration improves overall efficiency, minimizes electromagnetic interference (EMI), and ensures better thermal distribution compared to a single-phase buck converter

C. *Working*

An interleaved buck converter is formed by connecting two or more buck converter circuits in parallel, operating with equal load sharing but with a phase shift between their switching signals. The purpose of this interleaving is to improve efficiency, reduce current ripple, and distribute thermal and electrical stresses across multiple components. Each phase of the converter consists of a switch (MOSFET), diode, inductor, and a common output capacitor connected to the load. The switches in the different phases are driven by gate pulses that are phase shifted. This ensures that when one switch is ON and supplying power to the load, the other switch is either OFF or in the opposite part of its cycle, allowing its inductor to release stored energy. During the ON period of each switch ,the corresponding inductor stores energy from the input supply. When the switch turns OFF ,the inductor discharges through its diode to the load .Because the operation of each phase is interleaved ,the inductor currents from the different phases overlap, resulting in a lower total output current ripple. The combined current supplied to the load is smoother and more continuous compared to a single buck converter. This interleaving effect also leads to better transient response ,reduced input current ripple, lower EMI,and improved overall efficiency .Further rmore, as the load current is shared between multiple inductors and switches, component heating and stress are minimized, enhancing system reliability. In summary, by controlling the duty cycle (D) and maintaining proper phase shifting between the converter stages, the interleaved buck converter provides a stable, low ripple DC output and is ideal for high-current applications such as electric vehicles, battery charging systems, and renewable energy power converters.

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III. IBC WITH OVERVOLTAGE PROTETION

A. BlockDiagram

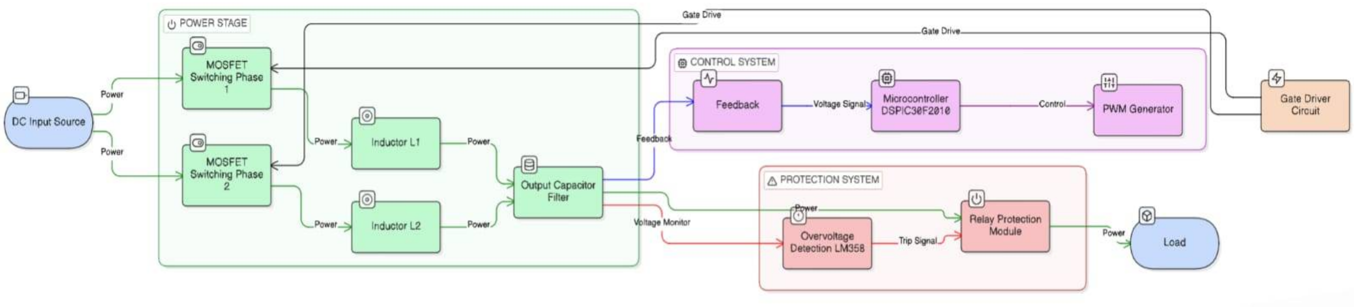

Figure 2 Block diagram of IBC with overvoltage protection

Figure 2 shows the block diagram of the interleaved buck converter it consists of two parallel buck converter phases operating 180° out of phase to achieve efficient DC voltage conversion. The high DC input is supplied to both phases, each containing a MOSFET, diode, inductor, and output capacitor. These two phases work alternately, reducing current ripple and improving overall efficiency. The combined output provides a regulated DC voltage. The sensed signals are fed to a PI controller that compares the output with the reference value and generates appropriate PWM signals to control the MOSFET switches. A microcontroller manages the PWM generation. The PWM signals are sent through a gate driver circuit to drive the MOSFETs safely. The fault detection unit continuously checks for abnormal conditions like overvoltage and provides protection by shutting down the system during faults.

IV. SIMULATION AND RESULT

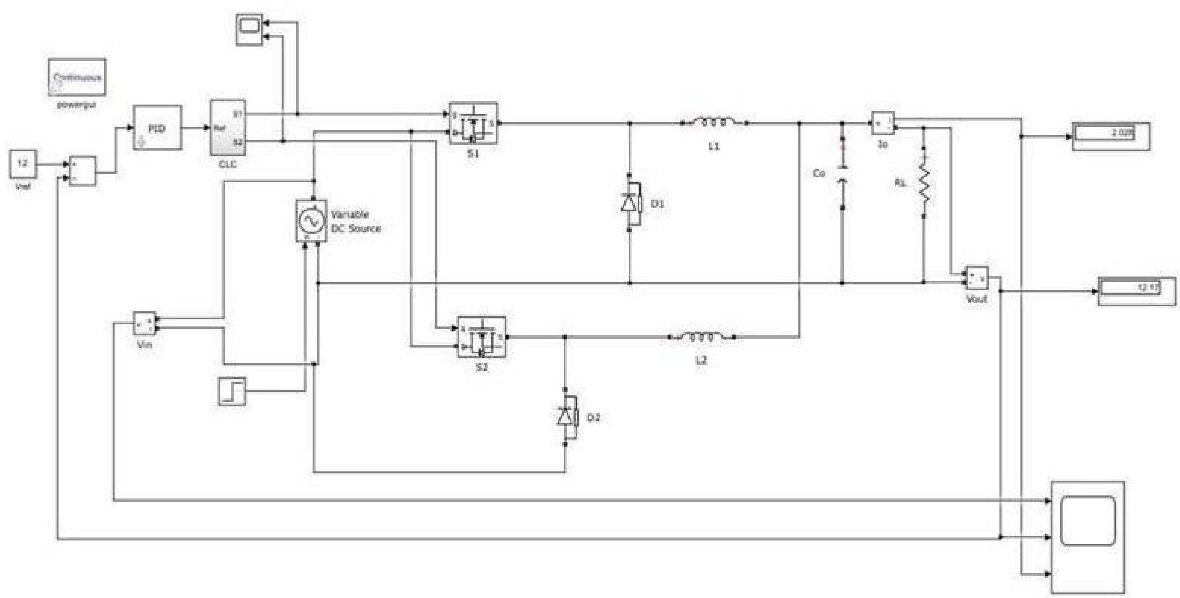

Figure 3 Simulation of IBC with PI

figure 3 shows the simulation model of an Interleaved Buck Converter implemented using a PI controlled feedback system. The controller generates PWM signals that are processed through PI controllers and gate drivers (TLP250) to drive the switching MOSFETs (S_1,S_2). The two buck converter phases operate in an interleaved manner, using inductors (L_1,L_2), diodes, and output capacitor (Co) to reduce current ripple and improve efficiency. The output voltage is continuously monitored and compared with a reference value, and the PI controller adjusts the duty cycle to maintain a regulated output voltage. The over-voltage protection mechanism ensures safe operation by preventing excessive output voltage, thereby protecting the load and power components

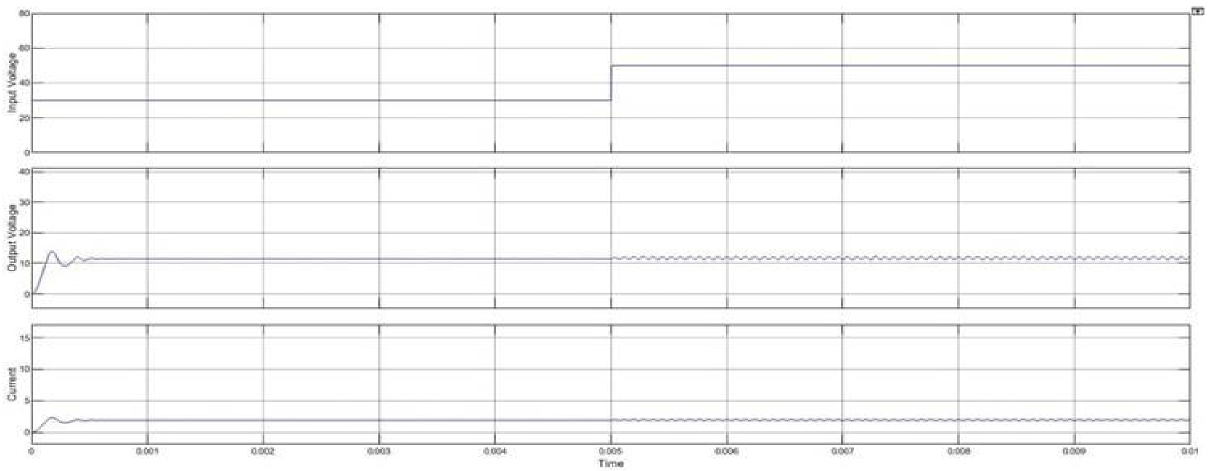

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Figure 4 Simulation result of Output voltage and input voltage

figure 4 shows the simulation results of the interleaved buck converter under dynamic load conditions. The graph represents the input voltage, which steps from a lower value to a higher value during operation. The middle graph shows the output voltage response, which initially exhibits a small transient and quickly settles to the desired regulated value with minimal ripple, demonstrating effective PI control. The bottom graph represents the output current, which increases smoothly corresponding to the input change and maintains a stable value with reduced ripple due to the interleaving effect. Overall, the results confirm stable operation ,fast transient response ,and good voltage regulation of the converter

V. IMPLEMENTATION

A. Schematic diagram

The proposed system is a microcontroller-based power electronic converter designed using the dsPIC30F2010 digital signal controller for controlled switching applications. The microcontroller generates high-frequency PWM signalsusinga6.144 MHz crystal oscillator, which are fed to TLP250H gate driver circuits. These drivers provide electrical isolation and amplify the PWM signals to properly drive the IRFP250 power MOSFETs. The MOSFETs perform high-speed switching of the DC source, enabling efficient power conversion. Fast recovery diodes (MBR20200) are used to provide protection and ensure proper current flow during switching operations. The circuit incorporates voltage regulation stages using LM317 and 7805 regulators to generate regulated +3.1 V, +5 V, and +12 V supplies required for control and driver circuits. An LM358 operational amplifier is employed for signal conditioning and feedback sensing, allowing the microcontroller to monitor system parameters and implement closed-loop control .Inductors and passive filter components are used to smooth the output, while a relay module provides load control and protection. Overall, the system integrates digital control, isolation, power switching, and feedback mechanisms to achieve efficient and reliable power conversion suitable for inverter or DC–DC converter applications.

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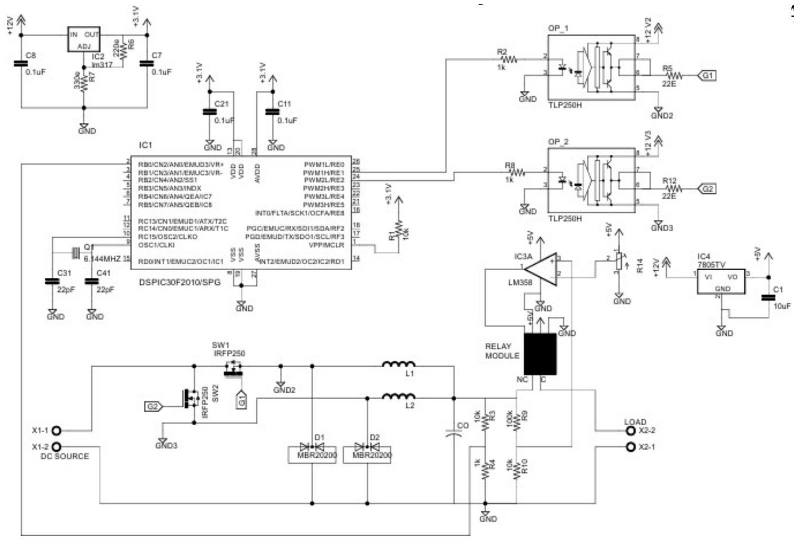

Figure 5 Schematic diagram

B. Inductordesign

Vin=30V Vo =12V

I out = 2A Fs= 25kHz

*Iripple=20%(assumed) I ripple = .2 *2=.4A……….(1)*

D=Vo/Vin……………………………………….………..(2)

*=12/30=.4=.4*100=40% D=40%*

*L=(Vo(1-D))/Fs*Iripple………………………………..(3)*

*=(12(1-.4))/(25*10^3)*.4*

=7.2/10,000=720uH

L=720uH

C. Capacitor design

*C=Iripple/(8*Fs*Vripple)……………………………….(4)*

Vripple=Vo.01=.12C=.4/(8*25*10^3*.12)………..(5)*

*=1.66*10^-5=16uF* ***C=16uF***

VI. HARDWARE

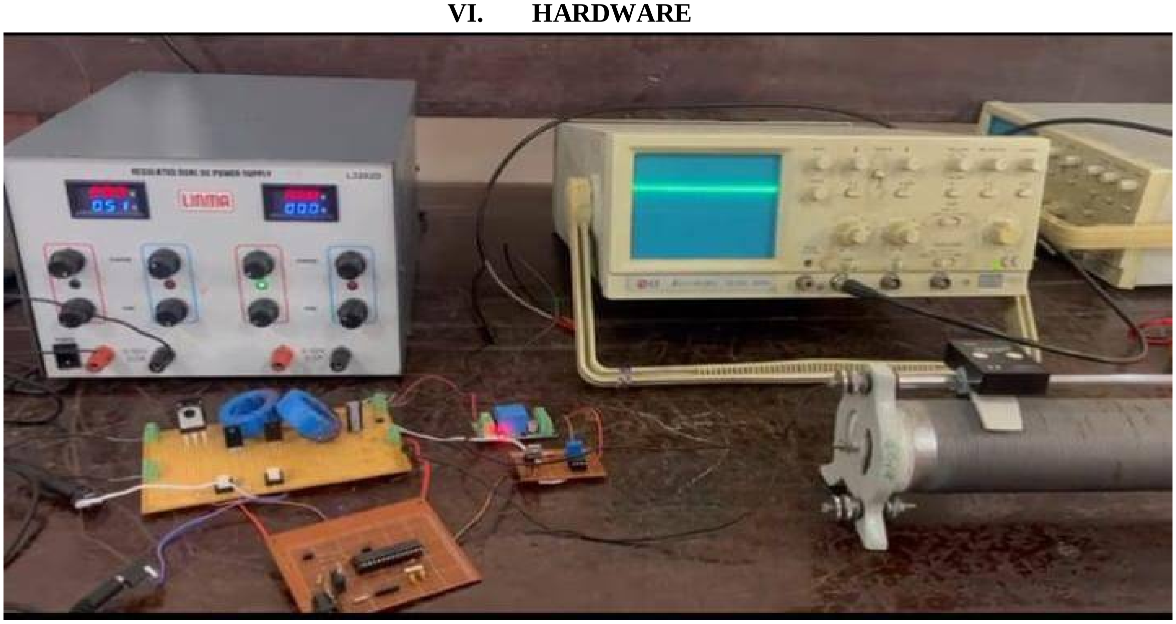

Figure 6 Hardware setup of IBC with overvoltage preotection

Figure 6 shows the experimental setup of the hardware implementation and testing of an interleaved buck converter system used for controlled DC power conversion. The circuit consists of two parallel buck converter phases operating in an interleaved manner to reduce input current ripple and improve efficiency. The power stage includes MOSFET switches, inductors, diodes, and filtering capacitors mounted on the PCB. A control circuit implemented on a separate board provides the required switching pulses for the MOSFETs, ensuring phase-shifted operation between the two converter stages. The setup is powered using a regulated DC power supply, while the output and switching waveforms are monitored using an oscilloscope and a digital multimeter. The motor or resistive load connected at the output demonstrates the converter's ability to supply regulated voltage. This arrangement allows observation of voltage, current, and switching characteristics, thereby validating the performance of the interleaved buck converter and its protection and control features under practical operating conditions.

VII. RESULTS

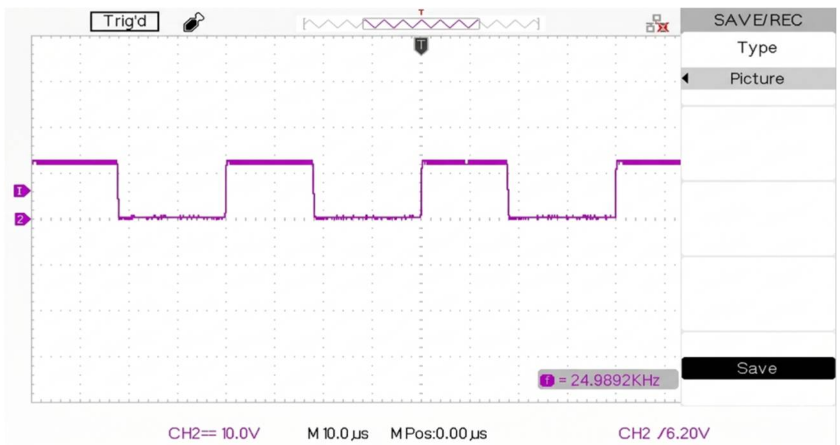

Figure 7 Output of MOSFET 1

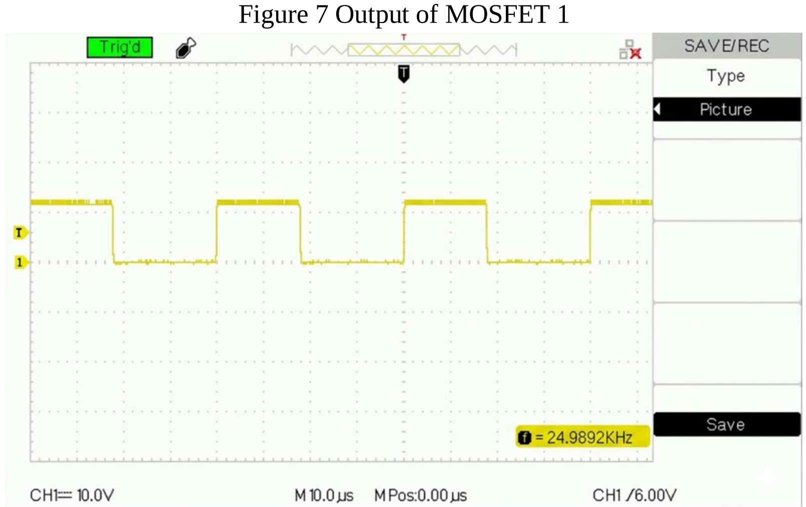

Figure 8 Output of MOSFET 2

Figure 7 and figure 8 shows the waveforms that represent the switching voltages across the two MOSFETs in an interleaved buck converter. The signals are complementary and phase-shifted (typically by 180°), meaning when one MOSFET is turned ON, the other is OFF. The voltage across each MOSFET alternates between a high value (approximately equal to the input voltage when the device is OFF) and a low value (near zero when the device is ON). The phase shift between the two switching waveforms ensures interleaved operation, which helps in reducing input current ripple and improving output voltage smoothness. These waveforms clearly indicate proper switching action and coordinated operation of the two MOSFETs for efficient power conversion.

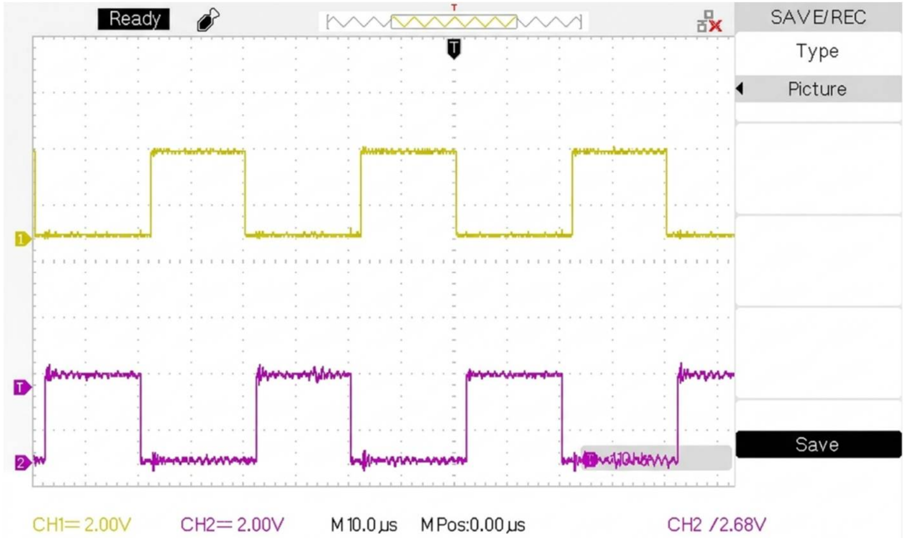

Figure 9 Output of signal generation

Figure 9 shows the waveform generation of a Pulse Width Modulation (PWM) signal using two channels. The yellow trace (CH1) represents a square wave with a fixed period, while the purple trace (CH2) shows another PWM signal with a similar frequency but a different duty cycle. PWM signals switch between a high level and a low level, and the duty cycle (the ratio of ON time to the total period) controls the average output voltage. In the graph, each pulse rises sharply to a high level and then falls back to a low level, indicating digital switching. The time scale of 10 µs/div shows that the pulses repeat at a high frequency, which is typical for PWM used in applications such **as** motor speed control, LED brightness control, and power regulation**.** The slight noise visible on the signal edges is due to measurement or circuit switching effects, but overall the waveform demonstrates a stable PWM generation with clearly defined high and low states.

Figure 10 Output of IBC

Figure 10 shows the waveform of the interleaved buck converter with overvoltage protection shows the switching pulses of the two phases operating with a 180° phase shift, which helps in reducing input and output current ripple. The inductor currents of each phase are interleaved, and when combined, they produce a smoother output current with lower ripple compared to a single buck converter. The output voltage initially rises and is regulated at the desired reference level. When an overvoltage condition occurs, the protection circuit activates by reducing or stopping the gate pulses, thereby preventing the output voltage from exceeding the safe limit. This ensures stable operation, improved efficiency, reduced ripple, and protection of the load from excessive voltage

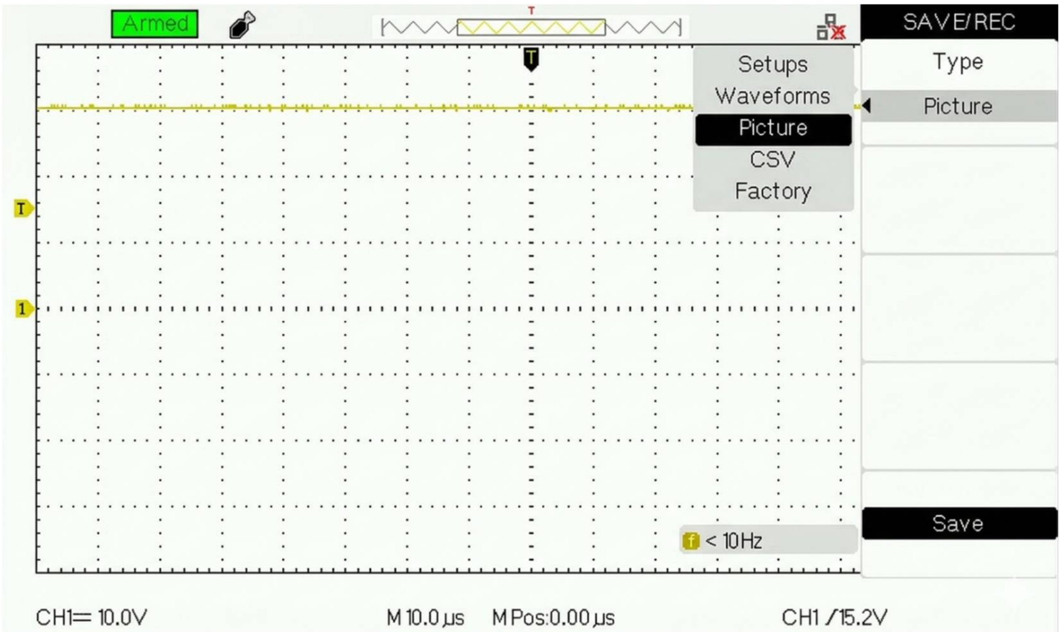

Figure 11 Output of IBC with overvoltage protection

Figure 11 shows the waveform of the interleaved buck converter shows two switching gate pulses that are phase-shifted (typically by 180°), indicating the operation of two buck converter phases in parallel. The inductor currents of the two phases are triangular and interleaved, meaning when one current is rising, the other is falling. When these currents are combined, the overall output current ripple is significantly reduced. The output voltage waveform appears smoother with lower ripple compared to a single-phase buck converter. This interleaving technique improves efficiency, reduces stress on components, and enhances overall performance by minimizing input and output current ripples.

VIII. CONCLUSIONS

The proposed two-phase interleaved buck converter with overvoltage protection demonstrates an efficient and reliable DC–DC power conversion system. By operating the two converter phases with a 180° phase shift, the design effectively reduces input and output current ripple, improves voltage regulation, and distributes thermal stress across components. The use of a dsPIC30F2010 microcontroller with PI-based control enables accurate PWM generation and stable closed-loop regulation of the output voltage from 30 V to 12 V. Simulation and experimental results confirm smooth switching operation, reduced ripple in inductor currents, and stable output voltage under varying conditions. The integrated overvoltage protection circuit successfully detects abnormal voltage levels and disconnects the load to prevent damage to power devices and the connected system. Overall, the proposed converter provides improved efficiency, enhanced protection, and reliable performance, making it suitable for applications such as renewable energy systems, battery charging units, electric vehicles, and other embedded power supply applications.

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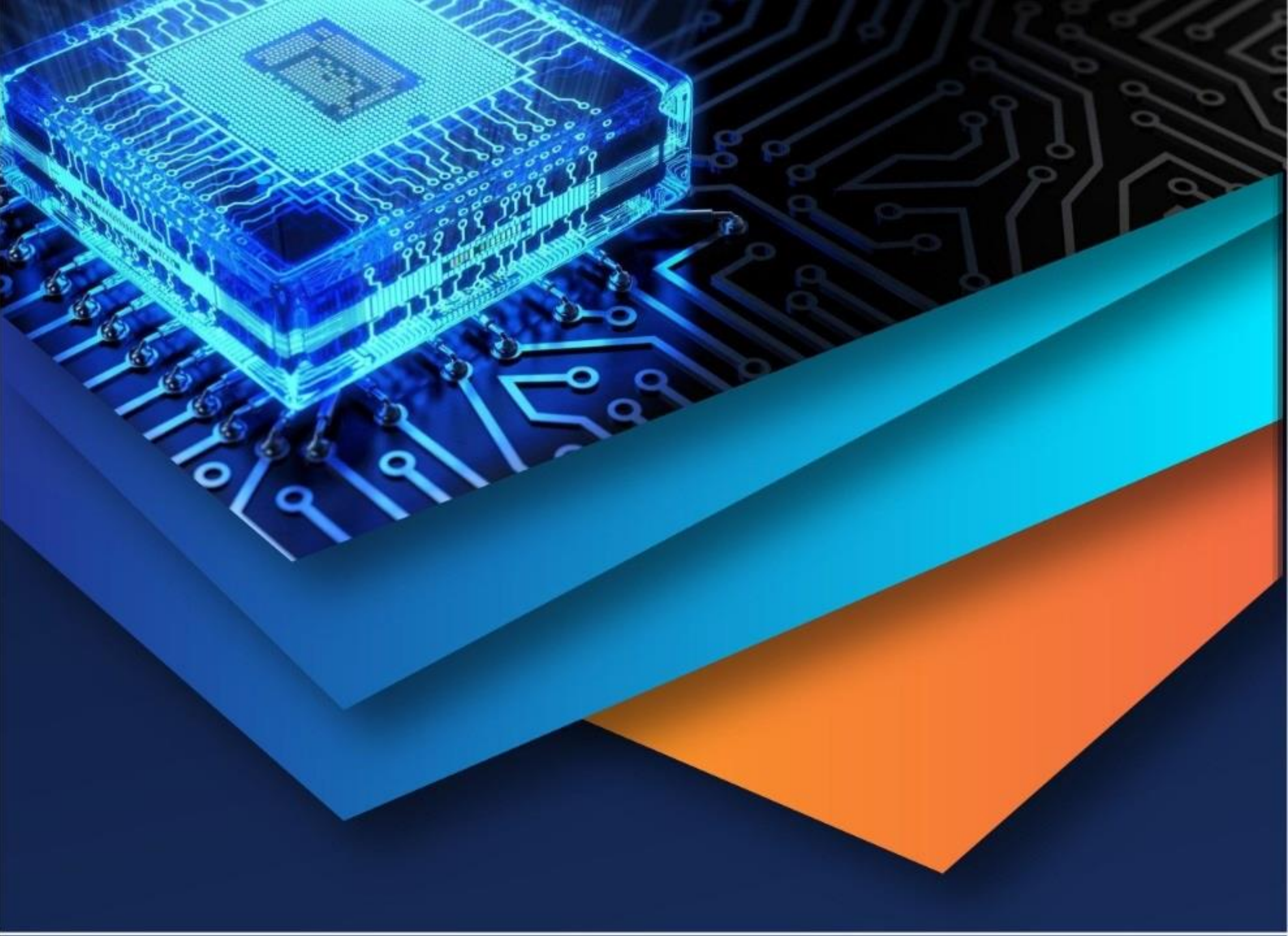

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