OPTIMIZED HYBRID SOLAR AND TRANSFORMER-POWERED MWJC FOR HIGH-VOLTAGE DC- DC CONVERTERS

Dr .M. Jegadeesan, Muhundana AR V, Sindhiya S, Tharani S K

Department of Electrical and Electronics Engineering, K.L.N. College of Engineering, Pottapalayam, Sivagangai, Tamil Nadu, India

---***---

Abstract - *In this project, a high-gain DC-DC converter is designed and implemented to step up a low input voltage of 24V to an intermediate voltage of 150V, which is further boosted to 350V. The proposed system utilizes a multi-stage conversion process with eight MOSFET switches to achieve high efficiency and voltage gain. The first stage of the converter provides an initial boost to 150V, followed by a secondary stage that increases the voltage to 350V. An experimental prototype was developed to validate the design, and extensive testing was conducted to evaluate its performance under different operating conditions. The results confirm the feasibility and effectiveness of the proposed system, making it suitable for applications requiring high voltage DC conversion.*

Key Words: **Power Conversion, Opto Coupler, Step-Up Converter, Switching Regulator, MWJC, DC-DC Converter, MOSFET, Boost Converter, Voltage Regulation, Micro Controller**

1. INTRODUCTION

DC to DC converters are integral components in power electronics, used in applications requiring the conversion of a DC voltage from one level to another. Common configurations of these converters include buck, boost, and buck-boost converters, which allow voltage step-up or step-down based on the needs of the system. However, certain applications demand a high voltage gain with stability, which presents challenges for traditional converters. The Watkins Johnson Converter (WJC) stands out for its ability to achieve high voltage gain with a minimal number of storage elements. While the WJC can deliver a positive output voltage by simply controlling the duty cycle, it does require multiple switches, which may introduce switching losses. The main advantage of the WJC is that it does not require any changes in topology when reversing the output polarity. This work focuses on enhancing the WJC by adding a third leg to its existing two-leg configuration, improving its voltage gain without using a tapped inductor. Instead, two separate, non-coupled inductors are utilized to avoid the complexity of magnetic coupling. The modified Watkins Johnson Converter (MWJC) is modeled using MATLAB SIMULINK, and the system's performance is analyzed through its transfer function, Bode plot, and Root Locus studies. Experimental validation is conducted with two power sources: a conventional power supply and a solar input, demonstrating the MWJC's potential for high-efficiency DC-DC conversion in renewable energy applications.

2. OVERVIEW

This project focuses on the development, simulation, and experimental validation of a novel high-boost DC-to-DC converter topology. The proposed design extends the existing two-leg Watkins-Johnson (WJC) converter by incorporating a third leg, along with additional inductors and capacitors, to achieve enhanced voltage gain. This modified converter, referred to as the Modified Watkins-Johnson Converter (MWJC), aims to improve the performance and efficiency of conventional converters. The study involves the design and simulation of the MWJC in the MATLAB SIMULINK environment to analyze the behavior and voltage gain under various duty cycles. An experimental prototype was developed to validate the simulation results. The system operates in an open-loop configuration to demonstrate the voltage gain improvement and provide insights for potential future control strategies.

2.1. DC-DC Converter

DC-DC converters are electronic devices used to change DC voltage levels efficiently. They are necessary because DC power cannot be transformed directly like AC power. These converters are used in various applications, such as stepping down 24V DC from a truck battery to 12V for a radio, or stepping up 12V DC to higher voltages in power supplies. The efficiency of these converters is crucial, as they aim to minimize power loss during conversion. A perfect converter would have no losses, but in practice, some energy is lost due to the converter's components. Efficiency is typically above 80-90% in modern converters, making them as efficient as AC transformers.

3. EXISTING SYSTEM

3.1 MODIFIED WATKINS JOHNSON CONVERTER

The topology of the existing two leg WJC. The WJC can be viewed to have two modes of operation. In mode 1 the Switch module SW1, the inductor L, Switch module

SW2 and the capacitor C are connected in series and the whole connected across the input voltage Vin. The voltage across the Capacitor C is the output voltage Vout. This mode of operation is maintained for a period D in a switching cycle. During the period 1 – D the switch modules SW3 and SW4 are turned on while SW1 and SW2 are turned off.

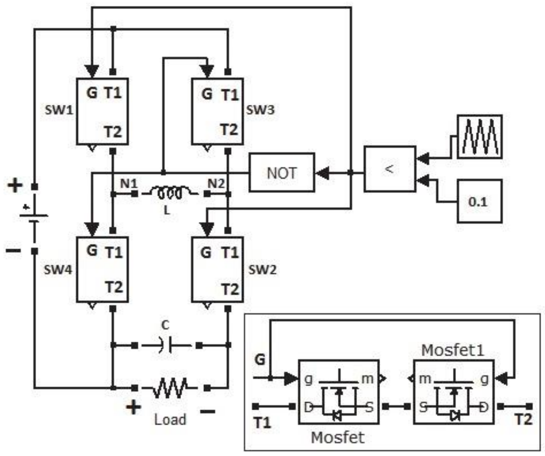

Fig 1 Existing Bridge type WJC

3.2 PROPOSED MWJC CONVERTER

The Modified Watkins Johnson Converter (MWJC) is an enhanced version of the basic Watkins Johnson Converter (WJC), featuring a three-leg topology. It includes two inductors (L1, L2) and two capacitors (C1, C2) compared to the original two-leg design. The load is connected across capacitor C2, and the converter operates with two sets of power electronic switch modules: SW1, SW6, SW5 in one set, and SW4, SW3, SW2 in the other. These switches are turned on and off in a complementary fashion, resulting in two operating modes. In the first mode, switches SW1, SW6, and SW5 are on, while the other three are off. In the second mode, switches SW3, SW4, and SW2 are on, while the remaining switches are off. This complementary switching mechanism leads to voltage buildup and contributes to the derivation of the voltage gain of the MWJC topology. The enhanced design improves the converter's performance over the basic WJC.

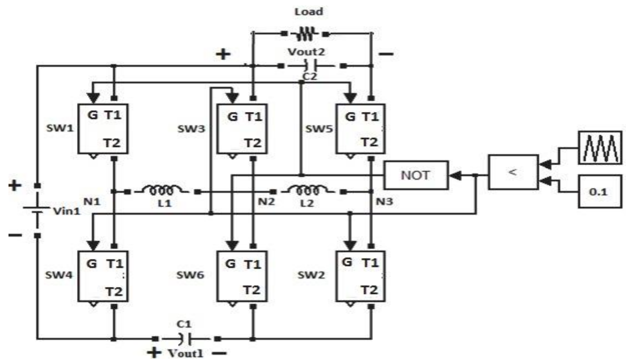

Fig 2 Block Diagram Of Proposed Method

Function in MWJC

1. Energy Storage: Stores energy when the MOSFETs are ON and releases it when the MOSFETs turn OFF.
2. Current Regulation: Helps in smoothing the current to prevent sharp spikes during switching.
3. Voltage Boost: Contributes to increasing the output voltage by regulating the flow of energy through the converter's stages.

Transformer-Based Power Source	Solar Power-Based Power Source
AC voltage is stepped up or stepped down to the desired level.	DC voltage is directly used or converted through a DC- DC converter
Moderate cost for the transformer and related components.	Initial setup cost of solar panels and inverter can be higher.
Highly reliable, with long operational life.	Dependent on weather and daylight; efficiency decreases in cloudy weather.
Low maintenance once installed.	Requires occasional cleaning and maintenance of panels.
Power supply systems, industrial use, home appliances, etc.	Off-grid power systems, renewable energy projects, remote areas.
AC mains (typically 110V, 220V AC)	Solar panels (DC from photovoltaic cells)

Table 1 comparison between Transformer and Solar - Based Power Source

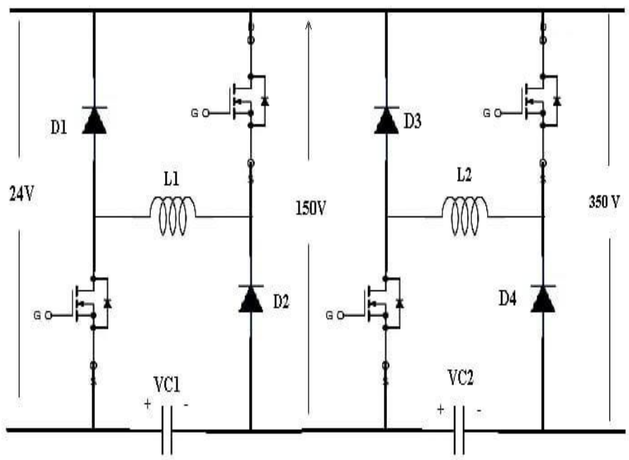

Fig 3 Schematic diagram

3.3 MOSFET(IRF840)

The IRF840 is an N-channel enhancement-mode MOSFET that remains off when no voltage is applied to the gate. When a positive voltage is applied (2-4V), it allows current to flow between the drain and source. With a high drain-to-source voltage rating of 500V and low on-state resistance (0.85 Ω), it is suitable for high-voltage, low-loss applications like DC-DC converters. The MOSFET switches quickly and efficiently, making it ideal for high-frequency circuits. It has an internal body diode for reverse current flow protection and requires minimal current to drive, making it suitable for low-power control circuits. The IRF840 is perfect for power conversion systems such as the Modified Watkins-Johnson Converter (MWJC).

3.4 OPTO COUPLER

The MCT2E is a phototransistor-based optocoupler that provides electrical isolation between two circuits. It is commonly used to protect low-voltage control circuits (such as microcontrollers) from high-voltage systems. The MCT2E consists of an LED on the input side and a phototransistoron the output side, encapsulated in a single package. When a current flows through the input LED, it emits infrared light. This light is detected by the phototransistor, which turns it on, allowing current to flow from the collector to the emitter of the transistor. The key advantage of the optocoupler is that the electrical connection is replaced by light transmission, ensuring complete isolation between the control and power sections. This prevents noise, voltage spikes, or faults in the high-voltage side from damaging the low-voltage control components.

3.5 MICRO CONTROLLER

The PIC 16F877A is an 8-bit microcontroller with multiple I/O pins, ADC, and PWM modules, running at up to 20 MHz. It generates PWM signals for MOSFET control and monitors voltages for precise power conversion. Programmable and versatile, it supports various control algorithms. In this project, it acts as the central controller for efficient energy conversion.

PORT-A	**RA-0 to RA-5**	**6 bit wide**
PORT-B	**RB-0 to RB-7**	**8 bit wide**
PORT-C	**RC-0 to RC-7**	**8 bit wide**
PORT-D	**RD-0 to RD-8**	**8 bit wide**
PORT-E	**RE-0 to RE-9**	**3 bit wide**

Table 2 INPUT/OUTPUT PORTS

3.5 POWER SUPPLY

3.5.1 TRANSFORMER BASED POWER SUPPLY

The mains voltage ac 230v is step down to 9 volt, using 9v step down transformer. The low value secondary voltage is fed to the rectifier is formed using four no. of IN 4007. For first half cycle, Diodes D1 & D2 come toaction and next half cycle diode D3 & D4 come to action, finally unidirectional dc supply is fed to the filter capacitor. The charging & discharging property of capacitor provide pure smooth dc is nearly peak value of the secondary voltage. The pure DC supply is fed to regulator IC's input terminal of IC7805. Due to the regulator action, finally, regulated 5 volts is available at output terminals. This supply is used for entire circuit.

3.5.2 SOLAR PANEL 24 V DC

The input voltage for this project is sourced from a 24V solar panel, providing renewable energy for the system. Solar panels with this voltage rating are common in medium-sized photovoltaic applications and are capable of delivering enough current to power the converter. This 24V DC input is fed into the circuit and regulated by the MOSFETs and other components to achieve the desired output. The use of a solar panel makes this system environmentally friendly and sustainable, aligning with modern energy trends toward renewable sources for clean power generationand efficiency .

4.WORKING

The 24V solar-powered Modified Watkins-Johnson Converter (MWJC) converts variable DC from a solar panel into a stable, high-voltage DC output. The solar panel generates electricity through the photovoltaic effect, but its output fluctuates with sunlight and temperature. The MWJC uses a three-leg configuration with inductors, capacitors, and MOSFET switches to step up the voltage. Pulse Width Modulation (PWM) control, managed by a microcontroller, adjusts the duty cycle of the MOSFETs to regulate the energy flow. A higher duty cycle boosts the output voltage, while a lower duty cycle reduces it.

The inductors store energy during MOSFET on-states, releasing it when the switches are off, stepping up the voltage. Capacitors smooth the output maintaining stability. This process ensures efficient energy conversion from solar power to high-voltage DC. The system adapts to fluctuations in the solar panel output. The MWJC delivers a reliable, stable high-voltage output for demanding applications.

SIMULATION

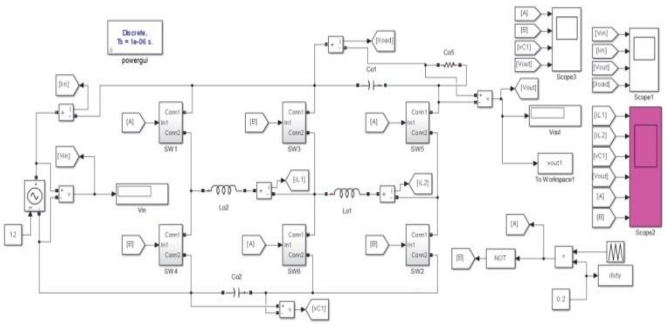

Fig 4 The complete circuit model in matlab Simulink

5.1 SIMULATION OUTPUT

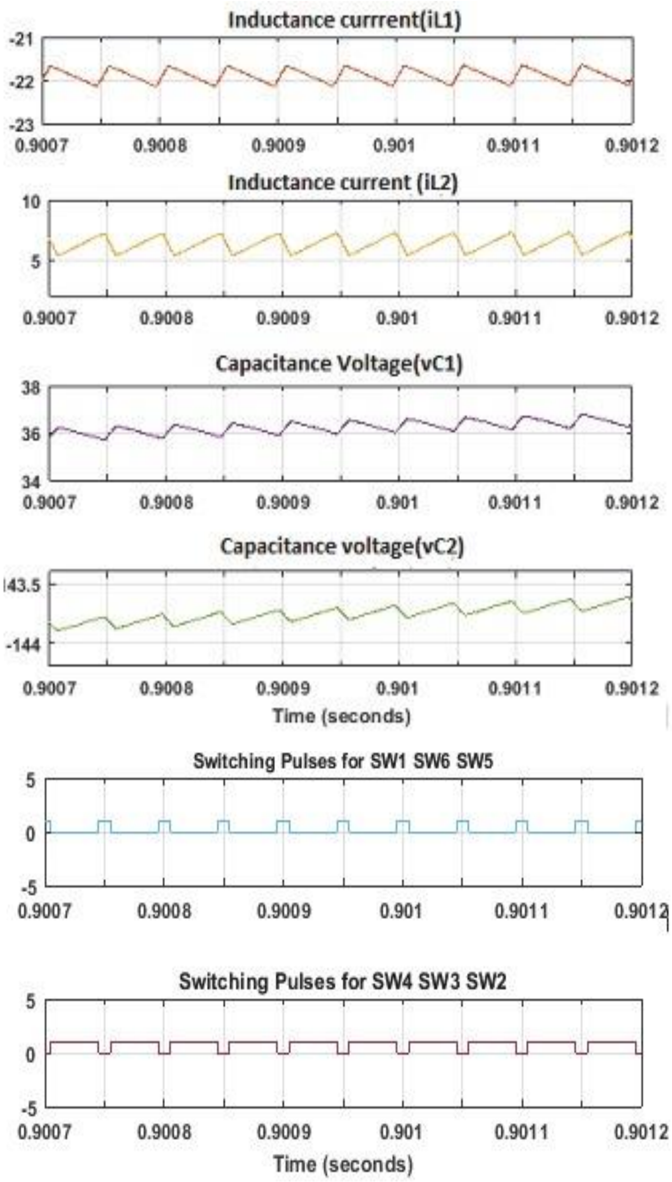

Fig 5 The waveforms obtained from simulation of the circuit model

5. HARDWARE DESCRIPTION

The hardware of the proposed system is implemented using Arduino. The software system like C++is used for the system design for coding the program.

5.1.SOFTWARE REQUIREMENT

In a solar-powered MWJC (Modified Watkins-Johnson Converter) converter system, microcontrollers play an essential role in optimizing and controlling power conversion. The microcontroller generates Pulse Width Modulation (PWM) signals to control the duty cycle of MOSFETs, enabling precise regulation of output voltage, such as maintaining a target of 350V. This PWM control allows the system to adjust dynamically based on real-time conditions. Additionally, microcontrollers enable Maximum Power Point Tracking (MPPT), which is crucial for maximizing energy harvested from the solar panel. By constantly monitoring and adjusting the panel's operating point, the microcontroller ensures the system operates at its optimal power level, which is especially valuable under changing sunlight conditions. Furthermore, the microcontroller monitors voltage and current at both the solar panel input and converter output, dynamically adjusting the duty cycle to protect against over-voltage, over-current, and other adverse conditions. Data logging capabilities allow it to store operational information, such as solar input voltage, output voltage, current, and temperature, which can be used for performance analysis and troubleshooting. The microcontroller also implements fault detection, identifying issues such as overheating, short circuits, and component failures, and can shut down or adjust the system to prevent damage. 34 In setups involving batteries, the microcontroller manages charging and discharging cycles, optimizing energy storage based on the state of charge and load requirements. This feature is essential for maximizing battery health and longevity in off-grid systems. For user interaction, the microcontroller can interface with displays, buttons, or wireless modules, enabling monitoring, remote control, and configuration through a smart phone or web application. Overall, microcontrollers make the MWJC system intelligent, adaptable, and efficient, providing critical functions such as power optimization, fault protection, and user accessibility, ensuring reliable operation in diverse solar power applications.

6.2 DATA STORAGE AND ANALYTICS

To optimize the performance of a 24V solar panel-based Modified Watkins Johnson Converter (MWJC), implementing a data storage and analytics system is essential. The microcontroller gathers critical data from the solar panel, converter, and battery (if applicable), which is then stored and analyzed to enhance system efficiency, detect potential faults, and predict maintenance needs. Data can be stored locally on the microcontroller using an SD card or EEPROM for small scale, off-grid systems, while cloud-based storage solutions, like IoT platforms (e.g., Thing Speak or Firebase), provide broader accessibility and larger storage capacity. Cloud databases, such as MySQL or InfluxDB, also enable advanced time-series data handling, essential for large-scale analytics. The key data points collected typically include solar panel voltage and current, converter output, duty cycle of PWM signals, and any temperature or energy usage data. Logging intervals are chosen based on the system's dynamics, with real-time data collected more frequently during peak operation. This information supports a range of analytics applications, including real-time monitoring and alerts for conditions like over-voltage or over-current. It also enables efficiency tracking by comparing the solar panel's input power with the converter's output, helping identify performance losses. Analytics further support system optimization by analyzing trends in the maximum power point tracking (MPPT) performance, 35 which can indicate if the MWJC system is effectively capturing solar energy. Historical data is used to understand energy production trends, battery health, and even correlations between weather patterns and system output. Visualization tools like Grafana and Power BI provide accessible dashboards for monitoring real-time performance and identifying issues at a glance. Together, data storage and analytics empower efficient, reliable operation of the MWJC system, using insights to refine control strategies, schedule timely maintenance, and maximize energy production over time.

6. CONCLUSION

In conclusion, the Modified Watkins-Johnson Converter (MWJC) presents a significant advancement in power conversion technology, particularly in enhancing voltage gain compared to traditional two-leg converters. By utilizing carefully selected components, including MOSFETs for efficient switching, a PIC microcontroller for precise control, and capacitors for voltage stabilization, the MWJC effectively manages energy flow and improves overall performance. The understanding of sensitivity and output characteristics is critical for optimizing the design and functionality of the converter. Sensitivity analyses help predict how the system will respond to variations in voltage, frequency, and temperature, while output parameters, such as voltage, current, and efficiency, are vital for assessing the converter's effectiveness in real-world applications. Overall, the MWJC showcases how innovative engineering solutions can lead to improved performance in power electronic systems, paving the way for more efficient and reliable energy management solutions in various applications.

7. SUSTAINABLE DEVELOPMENT GOALS

Goal 7: Affordable and Clean Energy: The MWJC enhances energy conversion efficiency and voltage gain, facilitating better energy management and utilization. By improving power converters, the project supports the development of affordable and reliable energy systems.

Goal 9: Industry, Innovation, and Infrastructure: By advancing power electronics technology, the MWJC promotes innovation and enhances the infrastructure of energy systems. The research and development involved in this project contribute to resilient and sustainable industrial practices.

Goal 12: Responsible Consumption and Production: The MWJC aims to optimize energy usage, encouraging responsible consumption patterns. By improving energy efficiency, it promotes sustainable production methods and resource conservation.

Goal 13: Climate Action: Efficient energy conversion technologies can reduce energy waste and greenhouse gas emissions, supporting efforts to combat climate change. The MWJC's design improvements can lead to lower carbon footprints in energy consumption.

8. REFERENCES

1. Jiawei, Z., Daolian, C., & Jiahui, J. (2021). Transformer less High Step-Up DC-DC Converter With Low Voltage Stress for Fuel Cells. IEEE Access, 19, 10228-10238. https://doi.org/10.1109/ACCESS.2021.3050546.

2. Zhiguo, Z., Mingyu, L., Dongrong, J., Xiaobin, Y., & Shan, L. (2021). High step-up isolated forward-fly back DC/DC converter based on resonance with pulse frequency modulation. Journal of Power Electronics., 21(2), 483-493. https://doi.org/10.1007/s43236-020001865

3. Liangyu, H., Yimin, L. (2021). Discrete Modeling and Period-Adding Bifurcation of DC–DC Converter Feeding Constant Power Load. IEEE Access, 9, 2773-52783. https://doi.org/10.1109/ACCESS.2021.3069633

4. Xingxing, P. & Changing, L. (2020). Designoriented fast response voltage mode buck converter with adaptive ramp control. Journal of Power Electronics, 20(5), 1273-1282.https://doi.org/10.1007/s43236-020-00114-7
The inductors store energy during MOSFET on-states, releasing it when the switches are off, stepping up the voltage. Capacitors smooth the output B. (2021).Composite Robust Quasi-Sliding Mode Control of DC-DC Buck Converter With Constant Power Loads. IEEE Journal of Emerging and Selected Topics in Power Electronics, 9(2), 1455-1464.
https://doi.org/10.1109/JESTPE.2020.302194

5. Raj kamal –Microcontrollers Architecture, Programming, Interfacing and System Design.

6. Geetha, E., Maddah, M., Mansouri, M., Khosravi, A. K., & Somavatian, V. (2020). Dynamic enhancement of interleaved step-up/step-down sDC-DC converters using passive damping networks. Journal of Power Electronics, 20(3), 657-663. https://doi.org/10.1007/s43236-020000720