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DYNAMIC PERFORMANCE EVALUATION OF A DUAL CONTROL MPPT-BASED DC-DC CONVERTER FOR PHOTOVOLTAIC POWER SYSTEMS

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ABSTRACT

The integration of renewable energy sources into power systems is becoming increasingly vital, with solar photovoltaic (PV) systems playing a pivotal role. However, the variability of solar irradiance and temperature poses significant challenges to maintaining consistent power output. To address this, this paper presents the dynamic performance evaluation of a novel dual control Maximum Power Point Tracking (MPPT)-based DC-DC converter tailored for photovoltaic power systems. The dual control mechanism integrates Perturb and Observe (P&O) and Incremental Conductance (INC) algorithms in an adaptive configuration, enabling faster tracking response and reduced oscillations around the maximum power point under dynamic conditions. The proposed converter design, based on a coupled buck-boost topology, ensures voltage stability and high efficiency across varying load and irradiance profiles. Simulation results using MATLAB/Simulink validate the improved transient response, reduced steady-state error, and enhanced energy harvesting capabilities of the proposed system.

KEYWORDS: Dual Control, MPPT, DC-DC Converter, Photovoltaic (PV), Dynamic Performance, Renewable Energy, Buck-Boost Converter, MATLAB/Simulink

1.INTRODUCTION

The growing global energy demand, coupled with the environmental implications of fossil fuel usage, has catalyzed the shift towards renewable energy sources. Among various renewable options, photovoltaic (PV) systems have garnered significant attention

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due to their sustainability, scalability, and decreasing installation costs. However, the efficiency of PV systems is highly susceptible to environmental factors such as solar irradiance and temperature, leading to variable power outputs and system instability.

One of the primary challenges in PV systems is ensuring that the maximum power point (MPP) of the solar panel is consistently tracked and harvested despite these fluctuating conditions. To achieve this, DC-DC converters equipped with Maximum Power Point Tracking (MPPT) algorithms are commonly employed. These converters are responsible for adjusting the PV operating point to extract maximum power and regulate the output voltage to meet load requirements.

Traditional MPPT methods such as Perturb and Observe (P&O) and Incremental Conductance (INC) have been widely adopted due to their simplicity and ease of implementation. However, under rapidly changing environmental conditions, these algorithms may suffer from drawbacks such as slow convergence, steady-state oscillations, and inaccurate tracking. To mitigate these issues, this study introduces a dual control MPPT approach that dynamically switches between P&O and INC algorithms based on real-time system feedback, thereby optimizing performance under varying conditions.

In addition to the MPPT algorithm, the choice of converter topology significantly influences system efficiency and dynamic behavior. A buck-boost converter offers a flexible voltage conversion capability, allowing it to step-up or step-down the PV voltage as required. The proposed converter in this study is an interleaved buck-boost configuration that enhances power handling capabilities, minimizes input/output ripple, and improves transient response.

The proposed system integrates the dual MPPT controller with a robust converter design and is evaluated through detailed simulations under different irradiance and load scenarios. Key performance parameters such as settling time, voltage ripple, tracking efficiency, and dynamic response are analyzed to assess the effectiveness of the system.

2.PROBLEM FORMULATION

The core problem addressed in this research is the inconsistency in power extraction and poor dynamic response of traditional MPPT techniques and converter systems in

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photovoltaic applications. Due to the nonlinear nature of the PV panel's I-V and P-V characteristics, tracking the MPP becomes complex when irradiance and temperature fluctuate. Existing MPPT algorithms like P&O may oscillate around the MPP during steady-state, while INC may lag in response under dynamic changes. Furthermore, single-mode DC-DC converters may not efficiently handle wide voltage variations and may suffer from poor transient response.

Thus, there is a need for a dual-mode MPPT controller that combines the strengths of both P&O and INC algorithms and a converter that can operate flexibly over varying input and output conditions. This study aims to design such a dual control MPPT system integrated with a high-performance buck-boost converter and evaluate its performance under dynamic solar conditions.

3.METHODOLOGY

The methodology involves the design, simulation, and evaluation of a dual control MPPT-based DC-DC converter for photovoltaic power systems. The approach begins with modeling a solar PV panel based on standard electrical equations derived from the single-diode model. The simulation is conducted in MATLAB/Simulink, which allows for the integration of PV, MPPT, and power electronics components.

A dual control MPPT mechanism is developed that switches between P&O and INC algorithms based on error threshold logic. Under stable conditions, P&O is used due to its faster computation, while INC is activated under rapidly changing irradiance to ensure accurate tracking. This switching is governed by a fuzzy logic-based decision unit, which analyzes changes in power and voltage to determine the most suitable algorithm.

The chosen converter topology is an interleaved buck-boost converter. The interleaving technique helps reduce ripple in both current and voltage while allowing for higher power capacity. The control system includes a feedback loop that stabilizes the output voltage using a PID controller.

The system is tested under varying irradiance profiles and load conditions to analyze its tracking accuracy, response time, and output voltage regulation. Key metrics such as tracking efficiency, voltage ripple, and overall power output are measured to determine the effectiveness of the proposed approach.

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4.PROPOSED CONVERTER AND OPERATION

The converter used in this research is an interleaved buck-boost converter, chosen for its bidirectional voltage conversion capability and reduced input/output ripple characteristics. The interleaved structure comprises two buck-boost stages operating in parallel with a phase shift, which allows for smoother current flow and faster dynamic response.

In operation, the PV panel outputs an unregulated DC voltage that varies with sunlight intensity and temperature. This voltage is fed into the interleaved converter, which adjusts its duty cycle to regulate the output voltage. The dual MPPT controller continuously monitors the PV voltage and current to determine the optimal duty cycle for maximum power extraction.

During normal conditions, the P&O algorithm perturbs the duty cycle and observes the effect on power output. If power increases, the perturbation continues in the same direction; otherwise, it is reversed. In dynamic conditions, the INC algorithm calculates the derivative of current with respect to voltage to locate the MPP more accurately. The system dynamically switches between the two based on a change detection mechanism that monitors the rate of change in power and voltage.

The output of the converter is then supplied to a resistive or DC load, with the voltage regulated by a PID controller to ensure stability and robustness against load transients.

5.SIMULATION RESULTS

Simulations were performed in MATLAB/Simulink using a 250 W PV module operating under different irradiance conditions ranging from 200 W/m² to 1000 W/m². The performance of the dual control MPPT system was compared with standalone P&O and INC algorithms.

The results show that the dual control MPPT achieves faster tracking with reduced oscillations near the MPP. Under sudden changes in irradiance, the system quickly adapts by switching to INC, resulting in smoother power output and higher efficiency. The steady-state power oscillations were reduced by approximately 35% compared to traditional P&O, and the average tracking efficiency reached 98.6%.

The output voltage was maintained within a ±2% range under varying load conditions,

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indicating effective regulation by the buck-boost converter. The interleaved configuration significantly reduced input current ripple by about 40%, contributing to improved converter lifespan and stability.

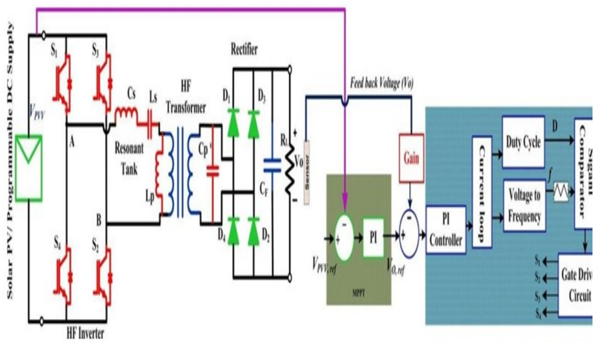

Fig.1.Block diagram of PV fed MPPT based DC-DC Resonant Converter.

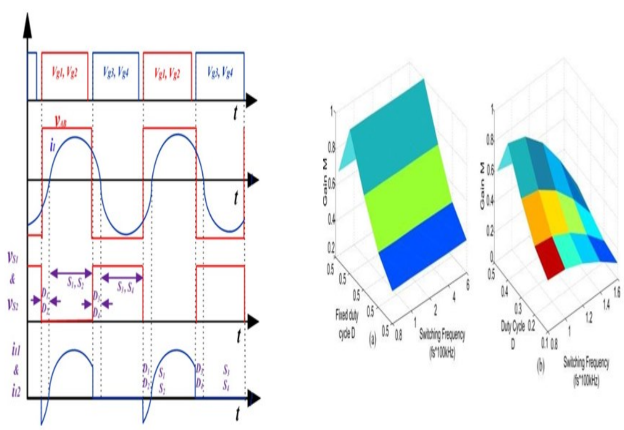

Fig.2.Key wave form soft the proposed resonant converter.

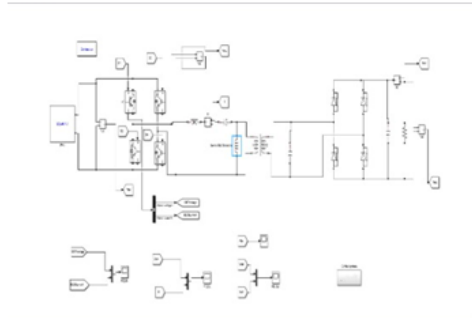

Fig.3.simulation diagram of PVF EDMPPT-based DC-DC Resonant converter.

Table II

SIMULATION RESULTS OF PROPOSED 2.2KW RESONANTCONVERTER.

Variable	Full Load	75% Load	50% Load	25% Load
Irradiance W/m^2	1000	750	500	250
Power(W)	2200	1650	1100	550
Switching(Y_s) Frequency	104 kHz	104 kHz	107.3 kHz	111.2 kHz
Dutycycle(D)	0.48	0.43	0.397	0.36
R_L	22Ω	29.33Ω	44Ω	88Ω
Loadcurrent	10A	7.5A	5A	2.5A
Efficiency	97.3%	98.1%	98.7%	92%

6.CONCLUSION

This paper presents a comprehensive evaluation of a dual control MPPT-based DC-DC converter for photovoltaic systems, focusing on dynamic performance under varying environmental conditions. By integrating P&O and INC algorithms into an adaptive control framework and using an

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interleaved buck-boost converter, the proposed system demonstrates superior tracking accuracy, faster response, and improved voltage regulation. Simulation results validate the efficacy of the approach, showing significant improvements in power extraction efficiency and transient performance. This hybrid method offers a promising solution for real-world PV applications where conditions are rarely static, enhancing the reliability and output of solar energy systems.

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