Using Model Predictive Control-Based MPPT Technique for Control the High Gain DC-DC Converter for Photovoltaic Systems

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Abstract **-** This article presents a novel approach to enhance the performance of a high-gain DC-DC converter in a photovoltaic (PV) system through the utilization of Model Predictive Control (MPC) combined with Maximum Power Point Tracking (MPPT). The primary objective is to ensure the continuous operation of the PV system at its MPP. To achieve this, a straightforward current-based Incremental Conductance (IC) MPPT algorithm is employed to generate a reference current for the Model Predictive controller. The system exhibited remarkable tracking dynamics and demonstrated autonomous grid current injection capabilities. Extensive simulations confirmed the feasibility and effectiveness of the proposed control techniques, showcasing their strong performance in tracking maximum power from the PV system.

Keywords **-** DC/DC converter, MPPT, MPC, PV system.

I. INTRODUCTION

The increase in the emission of harmful gases resulting from various human activities has had a significant impact on the Earth's atmosphere. This has prompted people worldwide to seek alternative, sustainable, and infinite sources of renewable energy. These sources include biomass, waste, hydroelectricity, geothermal energy, solar power, and wind energy [1]. Solar energy stands out as one of the most promising options for generating power across a wide range of applications. It enjoys a special place among renewable energy sources due to its consistent availability and the potential to meet global energy demands [2]. Solar photovoltaic PV technology is particularly popular among renewable energy sources, thanks to its simplicity, ease of installation, and durability.

In PV generation systems, the inclusion of a DC/DC converter is essential for bridging the gap between the low-voltage PV panel and the high-voltage DC link. To harness the full potential of the PV panel, it is necessary to implement MPPT control [3, 4]. The effectiveness of MPPT techniques is generally assessed based on several key criteria. These include high tracking accuracy, as well as stable transient and steady-state responses. Achieving these criteria is crucial for optimizing the performance of MPPT systems. As a result, various MPPT techniques have been extensively explored and documented in the literature [5].

The Perturb and Observe (P&O) algorithm is a traditional approach used to track the MPP of a PV panel by observing the slope of the PV curve. However, one of the issues with the P&O algorithm is that its output often exhibits undesirable oscillations around the MPP [6]. The IC method represents a step forward in addressing the oscillation problem associated with the P&O algorithm. This method effectively eliminates the oscillations around the MPP, resulting in a more efficient and stable operation of the PV system.

In systems that necessitate multi-variable control, the employment of finite-set model predictive control (FS-MPC) emerges as a highly appealing solution [7]. The use of MPC-based MPPT methodology proves to be highly efficient in effectively tracking the maximum power of PV modules across a range of environmental conditions. This approach offers a versatile and robust solution for optimizing the performance of photovoltaic systems. From this perspective, this paper proposes an MPC-MPPT algorithm to control a high-gain DC-DC converter.

II. HIGH GAIN DC-DC CONVERTER

The high-gain DC-DC converter suggested in [8] was employed in this work. It was selected due to its ability to achieve a substantial boost ratio while subjecting the diodes and switches to relatively lower voltage stress in comparison to other similar topologies. This converter, illustrated in Fig. 1, comprises three diodes, two power switches, three diodes, two inductors, and an output capacitor.

The converter operates in two distinct intervals, which are determined by the state of the switches, denoted as δ, where δ can be either 1 or 0, as shown in Fig. 2 (a) and (b).

During the δ = 1 state, the inductors L_1 and L_2 are charged by the DC source. In this state, energy is transferred from the source to the inductors. The characteristic equations for this state are expressed as follows:

$$\begin{cases} v_{L1}(t) = V_{PV} \\ i_{PV}(t) = C_{PV}\dfrac{dV_{PV}}{dt} + 2i_{L1} \\ v_{L2}(t) = V_{PV} \\ C_o\dfrac{dV_o}{dt} = i_{Co} = -V_o/R \end{cases} \quad (1)$$

Conversely, when the switches are in the δ = 0 state, the inductors L_1 and L_2 discharge their stored energy into the output capacitor. In this state, energy is released from the inductors and supplied to the output capacitor, which is an essential part of the energy transfer process in this converter. The characteristic equations for this state are expressed as follows:

$$\begin{cases} v_{L1}(t) = v_{L2}(t) = \left(\dfrac{V_{PV} - V_o}{2}\right) \\ i_{PV}(t) = C_{PV}\dfrac{dV_{PV}}{dt} + i_{L1} \\ C_o\dfrac{dV_o}{dt} = i_{Co} = i_{L1} - V_o/R \end{cases} \quad (2)$$

This is a topology capable of generating an enhancement ratio between input voltage, and output voltage :

$$V_o = \left(\frac{1+D}{1-D}\right)V_{PV} \quad (3)$$

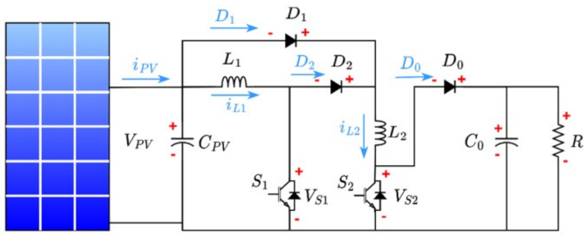


Fig. 1. Structure of high-gain DC-DC converter.

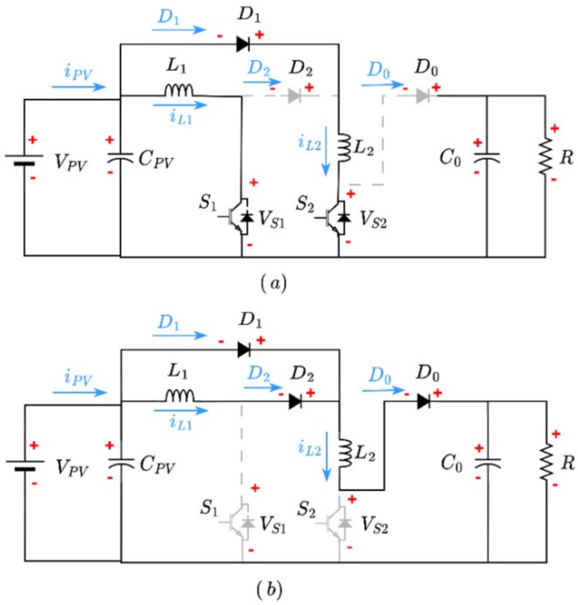


Fig. 2. (a) DC-DC converter for δ = 1. (b) DC-DC converter for δ = 0.

III. PROPOSED CONTROLLER

MPC offers an advanced control solution for complex systems, and in our specific application, the plant being controlled is the DC-DC converter. This converter, which is an integral component of a PV system, involves multiple state variables that require precise control. In the context of MPC, the plant is treated as a finite set of linear models, with each model corresponding to a specific switching state. MPC carries out predictions for each switching state, and the minimization process is employed through a cost function. The state that yields the minimal error is then determined and applied to the plant [9, 10].

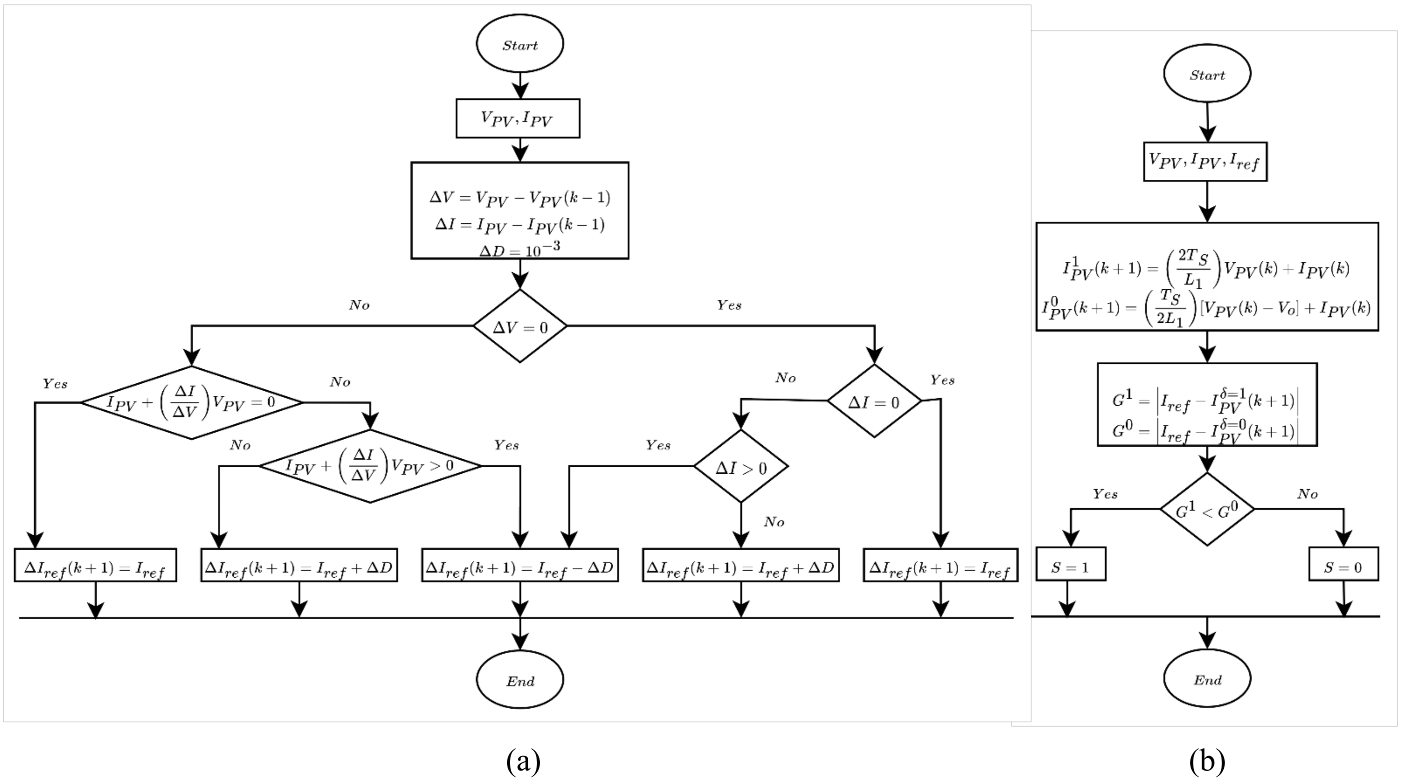


Fig. 3. (a) MPPT-based direct IC. (b) MPC.

In our application involving a PV system, the DC-DC converter is the focal plant. Due to its continuous conduction operation, it exhibits only two-state variables. Consequently, a discrete-time model for the proposed DC/DC step-up converter is derived by applying the forward Euler method to two conditions: when the switch is on and when the switch is off. This discrete-time model enables precise control of the DC-DC converter within the PV system.

$$I^{1}_{PV}(k+1) = \left(\frac{2T_S}{L_1}\right) V_{PV}(k) + I_{PV}(k) \tag{4}$$

$$I^{0}_{PV}(k+1) = \left(\frac{T_S}{2L_1}\right) [V_{PV}(k) - V_o] + I_{PV}(k) \tag{5}$$

Where $I_{PV}(k)$, $V_{PV}(k)$, V_O, L_1 Ts, $I^1_{PV}(k+1)$, and $I^0_{PV}(k+1)$ are the current of PV, a voltage of PV, output voltage, inductance, sampling time, predicted PV current if the switch is turned on, and predicted PV current if the switch is turned off, respectively.

The last phase of the MPC command focuses on optimizing potential future states and selecting the state that results in the minimum error. This optimization process is driven by the cost function, as described in Equation (3):

$$g^{\delta=\{0,1\}} = \left| I_{ref} - I^{\delta}_{PV} \right| \tag{6}$$

The cost function is represented by g, and I_{ref} signifies the reference current. The reference current I_{ref} is generated through an incremental conductance algorithm. The MPPT algorithm is illustrated in Fig. 3(a), while the MPC algorithm is depicted in Fig. 3(b). These algorithms work together to optimize the control of the system, with the incremental conductance algorithm providing the reference current for the MPC algorithm to act upon.

IV. RESULTS

The proposed control technique for the studied system has been validated through computer simulations using MATLAB/Simulink.

The system is analyzed to track the MPC-MPPT of the system, while also observing the dynamic response of the controlled parameters. The parameters of the simulation are presented in

Table. 1. Test parameters.

Parameters	Values
Voltage ($\boldsymbol{V_{MP}}$)	33.58 V
Current ($\boldsymbol{I_{MP}}$)	3.56 A
STC Power ($\boldsymbol{P_{MPP}}$)	120 W
Sampling Time ($\boldsymbol{T_s}$)	15 µs
DC Capacitors ($\boldsymbol{C_1}$&$\boldsymbol{C_2}$)	260 µF
Converter Inductors ($\boldsymbol{L_1}$&$\boldsymbol{L_2}$)	3 mH

The results of these analyses are verified based on the specified criteria and are presented in Fig. 4 to Fig. 6.

Fig. 4 presents the simulation results for steady-state operation. These results showcase the effectiveness of the MPC-MPPT algorithm, which guides the converter to operate at the MPP.

This incorporation of the MPC-MPPT algorithm into the generation of reference current is demonstrated in Fig. 4 (a), (b), and (c). In these figures, you can observe the precision and speed with which the maximum voltage V_{MP} and current I_{MP} values are reached, ultimately leading to the attainment of the maximum power of the solar panels P_{MPP} with exceptional efficiency and quality.

The MPC-MPPT algorithm's ability to swiftly and accurately reach the MPP ensures the optimal performance of the solar panel system.

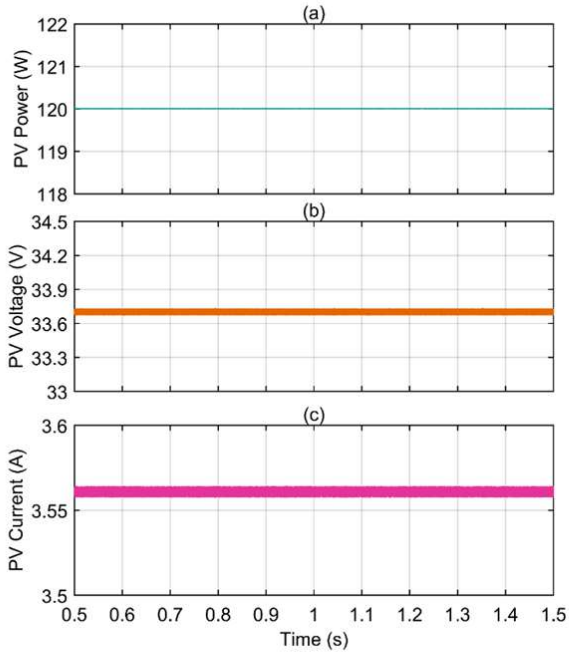
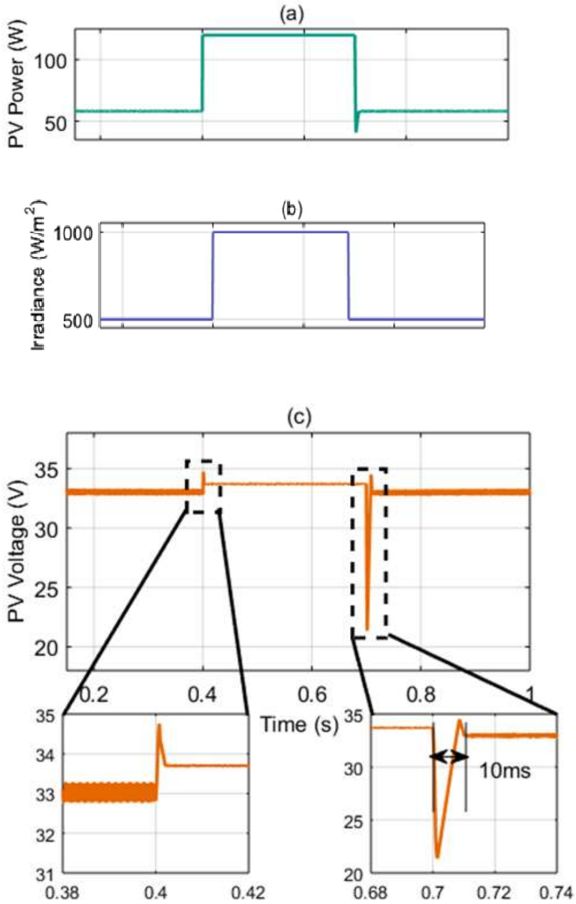


Fig. 4. Initiat condition for MPC-MPPT.

Fig. 5 illustrates how the proposed system responds to a sudden change in solar radiation levels, transitioning from 500 W/m² to 1000 W/m², and then back to 500 W/m². This rapid shift in radiation corresponds to a demanding and swift system response. The voltage V_{PV} and current I_{PV} experience rapid changes but quickly stabilize at the desired values within a mere 10 ms, as demonstrated in Fig. 5 (c) and (d). This ability to respond promptly and effectively to changes in solar radiation is a testament to the system's robustness and efficiency.



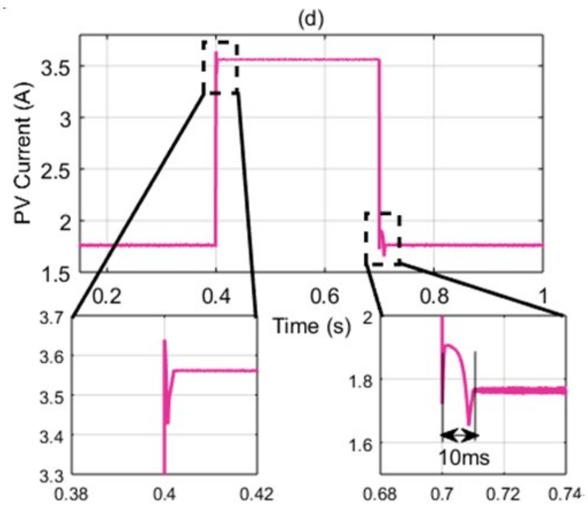
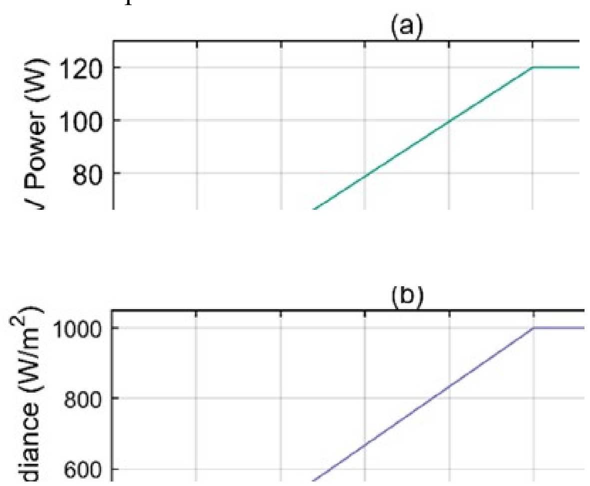


Fig. 5. Simulation results of the MPC-MPPT for an abrupt change in solar radiation from 500 W/m^2 to 1000 W/m^{2}and then to 500 W/m^2.

Fig. 6 illustrates the response of the proposed system to a gradual change in solar irradiation, specifically transitioning from 500 W/m² to 1000 W/m². In contrast to the abrupt changes, this gradual shift in irradiation leads to gradual changes in the system's voltage V_{PV} and current I_{PV}, as depicted in Fig. 6(c) and (d).

In this scenario, both the current and voltage changes stabilize smoothly and seamlessly at the desired values. This showcases the system's ability to adapt to and efficiently manage gradual variations in solar irradiation, ensuring consistent and stable performance.



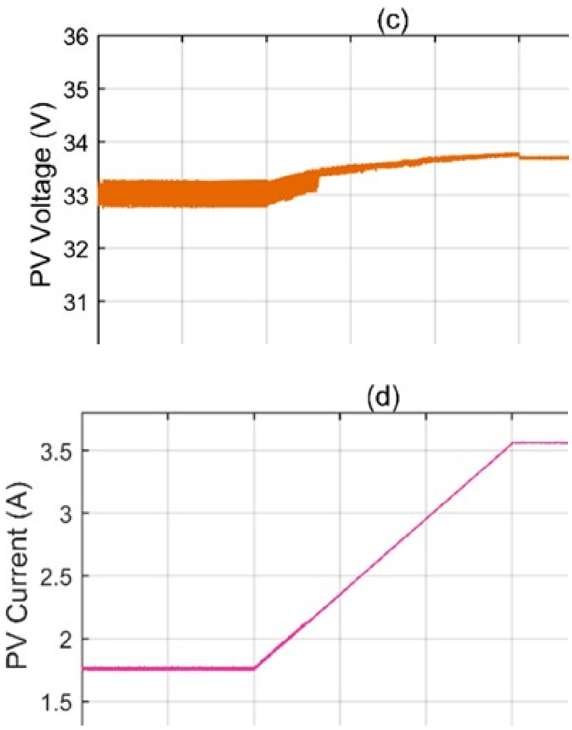


Fig. 6. Simulation results of the MPC-MPPT for a gradual change in solar radiation from (500 to 1000) W/m^2.

V. Conclusion

In this paper, a high-gain DC-DC converter was controlled using an MPC-MPPT. To achieve continuous operation of the PV system at its MPP, a straightforward current-based (IC) MPPT algorithm was employed to generate the reference current for the Model Predictive controller.

The system exhibited excellent capabilities in tracking and delivering maximum power from the PV source, characterized by rapid and efficient tracking dynamics. The simulation results verified the feasibility of the proposed system and the effectiveness of the implemented control techniques.

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