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Advancing Grid Integration: Maximum Power Point Tracking-Based Model Predictive Current Control Technique for Photovoltaic Systems

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Abstract

Tracking a PV system's maximum power point is necessary as demand for grid-connected solar systems rises, regardless of utility demand. Since the PV system's output is D.C., a converter serving as a middleman between the PV system and the D.C. link capacitor is necessary to track the maximum power at all loads. Since the firing angle of the IGBT in the boost converter is between 0 and 1 at maximum loads during MPPT, the boost converter often serves as a medium between the PV system and the dc link capacitor. Regardless of the grid utility, the dc link capacitor voltage needs to be kept constant for the inverter to operate smoothly. Since the grid will be supplying the reactive current, the reference reactive current must be kept at zero. To do this, the active current reference signal must be established by setting up the reference voltage across the dc link capacitor. A PI controller is utilised in this instance to create active reference current. Additionally, the reference voltage is determined using the inverter output voltage peak. A three-phase inverter fed by the PV system and connected to the grid was used to test the suggested control method under variable light and foggy circumstances.

Keywords: Photovoltaic system, converter, maximum power point tracking, model predictive current control, controller, reference active current, 3 phase inverters

INTRODUCTION

The use of solar systems has expanded due to the decline in renewable energy sources and the decrease in PV cell costs. MPPT techniques are used in PV systems to manage the power electronic converters [1]. Improved sensitivity and dynamic capability of control algorithms are achieved by using secondary control algorithms [1–5]. To enhance dynamic response, the sliding mode control (SMC) [6] and model predictive control (MPC) [2] algorithms are typically employed. Technological advancements in micro controllers have eliminated the need for powerful computation, even for these techniques.

To track the PV systems' maximum power at various loads, various techniques are put forth. For improved tracking of the maximum power, P&O MPPT algorithms and adaptive neuro fuzzy inference are integrated [7–10]. It will outperform the traditional MPPT techniques in terms of results. The maximum power from the PV system can also be tracked using mechanical trackers, however this

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method is impractical for high power rating PV systems. Sliding mode control's primary benefits are its resilience, quick dynamic response, and insensitivity to system conditions. However, this paper argues that the rapid dynamic reaction is generated by the model predictive control technique. Another technique with benefits akin to SMC is model predictive control. Combining the MPPT and MPC algorithms improves maximum power tracking efficiency. This combination performs well in settings with fluctuating radiation. A grid-connected Z-source inverter is controlled by this algorithm. One stage power converter is employed in this paper. To obtain additional dc bus voltage, however, a series linked PV panel group is required when employing a single stage power converter. Although there are various ways to raise the dc bus voltage, the most recommended model is one that combines series PV panels with a one-stage power layer. The voltage across the dc link capacitor in this grid-connected single-stage power converter is a crucial parameter that must be kept constant regardless of the load to ensure the Z-source inverter operates smoothly. Since the firing angle of the power electronic switch lies between 0 and 1 for maximum loads during MPPT, which is not the case with buck type converters or buck boost converters, boost converters are used in this study as the medium between PV systems and dc link capacitors. This study presents a comparison of various load resistance values for buck, boost, and buck-boost converters.

Maximum Power Point Tracking (MPPT)

The PV array's maximum power point (MPP) is constantly tracked by MPPT algorithms, which guarantee optimal power extraction across a range of temperature and sun irradiation circumstances. Fractional Open Circuit Voltage (FOCV), Incremental Conductance (INC), and Perturb and Observe (P&O) are examples of common MPPT approaches. These algorithms maximise energy yield by adjusting the PV system's operating point to maintain maximum power production.

Maximising the PV array's power output is the main function of MPPT in a VSI for PV systems. PV panels' operating point is continuously impacted by temperature changes and solar irradiation, which results in variations in the panels' output power. Under changing climatic conditions, MPPT algorithms constantly modify the PV system's operational parameters to keep it running at or close to its maximum power point (MPP). The PV system may maximise energy production and system efficiency by drawing the greatest power from the solar array through the use of MPPT, which continuously tracks the MPP.

Here, the boost converter is utilised to increase the inverter's input voltage while acting as a medium between the PV system and the DC link capacitor. Since the grid will supply the reactive current, the reference reactive current must be kept at zero. The active current reference signal must be generated by setting the reference vofltage across the DC link capacitor in order to maintain the constant DC link voltage [11]. A PI controller is utilised in this instance to create active reference current. Additionally, the reference voltage is determined using the inverter output voltage peak. A three-phase inverter fed by the PV system and connected to the grid was used to test the suggested control method under variable light and foggy circumstances.

Model Predictive Control (MPC)

This control technique makes use of the system's dynamic models to forecast future behaviour and maximise control actions within a limited prediction horizon. By considering system dynamics, restrictions, and objectives, MPC in the context of PV systems allows precise management of grid connected VSIs. When compared to conventional control systems, MPC performs better by optimising control inputs based on predictive models.

Model Predictive Current Control (MPCC)

In PV systems, MPCC integrates grid integration and efficient power generation by utilising both MPPT and MPC methods. To choose the best course of action for present control, MPCC forecasts the behaviour of the PV system in the future, considering changes in solar irradiance and grid conditions. MPCC ensures optimal power extraction through the PV array while preserving grid stability and operational limitations compliance by dynamically modifying the current reference in real-time.

Here, some operational characteristics of the PI controller should be considered.

That is, in accordance with the irradiation curve, PV irradiation will first be zero before beginning to increase. However, since there will be no power created during the zero-irradiation period, the converter is unable to provide any power to the DC bus. Despite this, the PI controller will continue to operate normally and attempt to get the DC bus voltage up to the reference voltage. It is not possible because there is no generated power and the PI controller will become saturated. As irradiation rises, voltage rises as well, but since the PI controller is already saturated, electricity cannot be sent to the grid via an inverter. Because of this, the PI controller must be reset by creating a reset condition when the DC bus voltage reaches an extremely high value. In this work, the PI controller will reset if the DC bus voltage is higher than 1.05 times the reference voltage. In the event that the direct reference current lacks a saturation threshold, it may rise to an extremely high value, triggering the overcurrent relay and causing annoying tripping. Thus, the PI controller's output should have a saturation point.

Modelling of PV Systems: The PV system is configured in many ways to evaluate the MPPT's performance. But when grid integration is considered, the boost converter is the most widely used converter [3]. Consequently, the boost converter is used by the PV system under investigation to connect the PV source and the load. This arrangement is just shown in Figure 1.

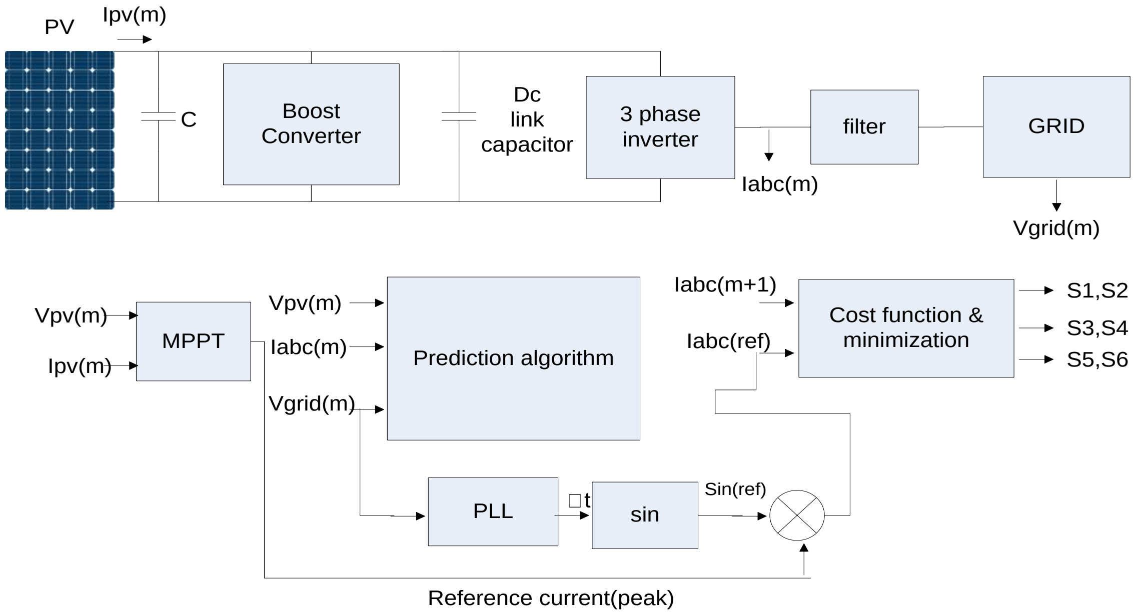

Figure 1. General schematic diagram of the system.

Examining MPPT-Based Predictive Control Models

Principles: MPPT-based Model Predictive Control combines the concepts of MPC, a control method that uses predictive models to optimise control actions over a finite prediction horizon, with MPPT, which attempts to track the maximum power point of the PV array. The control system may anticipate future changes in environmental variables and make preemptive adjustments to control actions to maximise energy yield while maintaining system stability and reliability by merging MPPT with MPC.

Developing predictive models of the PV system, encompassing PV panel characteristics, environmental variables, and system dynamics, is a prerequisite for implementing MPPT-based Model Predictive Control. In order to maximise the amount of electricity extracted from the PV array, these models are used to forecast future power generation and optimise control inputs, such as voltage and current references. To address the optimisation problem and produce the best control actions in real-time, a variety of optimisation approaches can be used, including quadratic programming and model predictive control algorithms.

Grid Integration: In PV systems that are connected to the grid, voltage sensing inverters (VSIs) are in charge of transforming DC power produced by photovoltaic arrays into synchronous AC electricity. With MPPT, you can be guaranteed that the PV system produces enough power to fulfil load demand without sacrificing grid quality or stability. MPPT enables the smooth integration of renewable energy into the grid by controlling the power output of the PV system in response to load demands and grid conditions. This enhances the overall stability and dependability of the electrical network.

Adaptability to Environmental Changes: The output power of photovoltaic (PV) panels can be greatly impacted by changes in temperature, partial shade, cloud cover, and solar irradiation. To lessen the effects of environmental fluctuations, MPPT algorithms continuously analyse the environment and modify the PV system's operational settings. MPPT optimises energy output throughout the day by dynamically adjusting to changing environmental circumstances and ensuring that the PV system functions at its greatest capacity independent of external influences.

Protection of the System: MPPT algorithms also help shield the PV system from possible harm or deterioration. The PV array's longevity and dependability may be jeopardised by overloading, overheating, and other negative impacts that MPPT helps to avoid by ensuring that it runs within its acceptable operating parameters. In order to safeguard utility workers' safety and avoid system damage, certain MPPT algorithms also include anti-islanding protection, which stops the PV system from delivering power into the grid during grid disruptions.

Benefits of MPPT-based MPCC include

- *Enhanced Energy Yield:* By continually tracking the MPP, MPPT-based MPCC maximises power extraction from PV panels, boosting energy yield and system efficiency.
- *Grid Stability:* By using predictive control algorithms, MPCC reduces harmonics and voltage fluctuations while guaranteeing the seamless and steady functioning of VSIs linked to the grid.
- *Quick Reaction:* The MPCC responds promptly to variations in solar radiation and grid circumstances, allowing for quick modifications to current control measures in order to preserve optimal performance.
- *Robustness:* Because MPCC is predictive, it performs well under a variety of operational situations, including as partial shading, cloud cover, and grid disruptions.

CONCLUSION

A combined control algorithm for PV systems is suggested in the paper. The MPPT and MPC algorithms are used in the suggested control strategy. The integrated algorithm provided efficient tracking under variable irradiance and foggy situations because of the quick and sensitive control capabilities of MPC. For grid-connected voltage source inverters in photovoltaic (PV) systems, the MPPT-based Model Predictive Current Control (MPCC) technology is a cutting-edge method. Maximum power point tracking (MPPT) and model predictive control (MPCC) are used to provide reliable performance across a range of grid and environmental conditions, smooth grid integration, and efficient power generation. With the growing demand for renewable energy, MPCC provides an advanced solution to optimise solar energy benefits while maintaining grid stability and dependability.

In addition to the combined algorithm performance testing, the step-change tests demonstrate that the MPC algorithm has a superior capability for current control. It has been done to analyze the efficiency of both control and power structures. The MPPT method's control efficiency is 98 percent, while the inverter efficiency is 92 percent.

Future Studies

Further research is encouraged to carry out more evaluations of the suggested control mechanism's efficacy. Specifically, a sensitivity analysis that considers how the system behaves when imbalanced or balanced faults cause low or high voltage to arise at the grid side. Analysing how the PV system behaves when reactive power is added to the grid to temporarily preserve grid stability would be fascinating.

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