Engineering and Technology Journal e-ISSN: 2456-3358
Volume 09 Issue 03 March-2024, Page No.- 3538-3642
DOI: 10.47191/etj/v9i03.11, I.F. – 8.227

Chaos-Based NMPC as a Novel MPPT Approach for Organıc Photovoltaıcs

Mohammad M. BORHAN ELMI[1], Osman YILDIRIM[2]
[1]Istanbul Aydin University, Turkey, https://orcid.org/0009-0007-1705-0214
[2]Prof. Dr. Istanbul Aydin University, Turkey, https://orcid.org/0000-0002-8900-3050

ABSTRACT: Environmental degradation, alongside the dire consequences of climate change such as the melting of glaciers and rising sea levels, highlight the severe challenges associated with reliance on fossil fuels. As such, the shift towards sustainable and clean renewable energy sources, like photovoltaic systems, is becoming increasingly critical. This paper introduces a novel approach leveraging a chaotic-based nonlinear model predictive control to maximize the power output from organic photovoltaic cells. This method is distinguished by its rapid tracking capabilities and its effectiveness in enhancing the distribution network's performance under fault conditions. Utilizing a feedback-driven recursive control strategy, this approach efficiently predicts and adjusts to the optimal operating state, thereby minimizing its cost function. It comprises two primary phases: estimating the reference point and subsequently adjusting the operating point in alignment with this reference. In this process, the Lagrange function plays a pivotal role in optimizing the estimator's performance, while a chaotic neural network model predictive controller manages the boost converter's operation. Implementing this chaos-based nonlinear model predictive controller has successfully reduced overvoltage incidents by more than 1.3%. Notably, in the absence of such control methods, the penetration of OPV panels leads to voltage fluctuations beyond acceptable limits. The findings demonstrate that, alongside a decrease in network losses, there is an increase in the capacity of distribution feeders and a notable enhancement in the system's overall efficiency.

KEYWORDS: MPPT, Algorithm, Organic Photo Voltaics, Energy Efficiency

INTRODUCTİON

There are many MPPT methods in the literature, such as VOC, ISC, P&O, INC, ANN, Fuzzy, MPC, and so on. The choice of MPPT method depends on several factors such as system size, required accuracy, environmental conditions and available computing resources. While simpler methods such as VOC and ISC offer ease of implementation, more sophisticated approaches such as ANN, Fuzzy, and MPC offer greater accuracy and adaptability at the cost of increased complexity and resource requirements.

Maximum Power Point Tracking (MPPT) methods are critical for optimizing the efficiency of photovoltaic (PV) systems by ensuring that they operate at their maximum power point (MPP) under varying environmental conditions. MPPT methods are including voltage open circuit (VOC), current short circuit (ISC), perturb and observe (P&O), and incremental conductance (INC), Artificial Neural Networks (ANN), Fuzzy Logic Controllers (Fuzzy), and Model Predictive Control (MPC).

VOC (Voltage Open Circuit) estimates the MPP by measuring the open circuit voltage of the PV module. It is easy to implement; no complex calculations are required. is less accurate and efficient because it requires temporary disconnection of the PV module from the load to measure the VOC, which can result in energy loss.

ISC (Current Short Circuit) determines the MPP by measuring the short circuit current of the PV module. This method is easy to implement with minimal calculations. Like VOC, it's less efficient due to the need for temporary disconnection, resulting in potential energy losses. P&O (Perturb and Observe) iteratively perturbs the voltage or current and observes the effect on power output to find the MPP. It is widely used because of its simplicity and ease of implementation, but it can oscillate around the MPP under steady state conditions and may not accurately track the MPP under rapidly changing conditions. INC (Incremental Conductance) is more accurate than P&O under rapidly changing conditions and can accurately track the MPP without steady state oscillations. It is more complex and requires more computational resources. ANN (Artificial Neural Networks) uses machine learning models trained on historical data to predict the MPP under various conditions. It can potentially provide high accuracy in predicting the MPP under various conditions without explicit mathematical modeling of the PV system. It requires extensive training data and computational resources; performance is highly dependent on the quality and range of the training data.

Fuzzy logic controllers use fuzzy logic rules to adjust the operating point toward the MPP based on inputs such as voltage, current, and temperature. It is robust to variations in temperature and irradiance and does not require an accurate mathematical model of the PV system. It designs the fuzzy logic rules can be subjective and requires expert knowledge.

MPC (Model Predictive Control) uses a model of the PV system to predict future power output and determine the optimal control actions to achieve the MPP. It can take into account constraints and future forecasts, potentially leading to optimal system performance. It requires a detailed model of the system, which can be complex to develop and computationally intensive.

Among the most important contributions of the proposed paper, the following can be mentioned:

- Designing an innovative nonlinear-MPC based MPPT approach to control the switching process of the converter from organic solar arrays with considering variable environmental conditions, network load changes and unwanted disturbances.
- Prediction of converter performance during fault occurrence in order to improve stability
- Using the chaos-based neural network to improve the quality of the reference point tracking
- Implementation of the proposed approach on the organic PVs as a new generation of solar panels with 100% recycling capability.

LİTERATURE REVİEW

Organic Photovoltaic (OPV) technology offers numerous benefits over traditional silicon-based photovoltaic systems. These advantages include its lightweight nature, the capacity for semi-transparency, and exceptional flexibility. OPVs are also noted for their cost-effectiveness and simpler manufacturing processes, which are characterized by lower energy requirements. Furthermore, OPV cells can be produced using 3D printing techniques on flexible substrates at reduced temperatures, facilitating their application on pliable surfaces. This technology is versatile, suitable for both indoor and outdoor settings, and boasts a complete recyclability rate of 100% (Bernard, 2007).

Emanuele et al. (2019) research focuses on presenting and experimentally validating a novel model designed for photovoltaic (PV) systems, specifically addressing the challenges posed by partial shading in the context of building-integrated applications.The research lies in the development of a model that accurately predicts the performance of PV systems under partial shading conditions, which is a significant issue for building-integrated PVs due to the variable nature of shading from surrounding structures and the building itself throughout the day and year.

Hongkun et al. (2021) research describes an innovative approach to enhancing the Low Voltage Ride Through (LVRT) capability of Modular Multilevel Converter (MMC) photovoltaic systems using a Model Predictive Control (MPC) strategy. The paper introduces a novel control scheme specifically designed for MMC-based PV systems to maintain stable operation during periods of low voltage, which are common in grid disturbances. This research addresses a critical need for renewable energy sources, like photovoltaics, to effectively withstand and quickly recover from grid voltage fluctuations, ensuring continuous power supply and supporting grid stability. The research findings of this paper potentially pave the way for more robust and efficient integration of solar energy into the power grid, highlighting its practical implications for the renewable energy sector, particularly in enhancing the grid compatibility of PV systems.

Rampradesh and Rajan (2021) research is based on an innovative assessment of a Nonlinear Model Predictive Control (NMPC) based Maximum Power Point Tracking (MPPT) controller, integrated with an Extended Kalman Filter (EKF), for optimizing the performance of a Wind/Photovoltaic (PV) hybrid energy system. The NMPC based MPPT controller is designed to dynamically adjust the operation of both wind and PV components to ensure they operate at their maximum power points despite the variable and unpredictable nature of wind and solar resources. In this research, the EKF is utilized to provide accurate and real-time estimation of the system states, which is critical for the effective implementation of NMPC and for handling the uncertainties inherent in wind and solar power generation.

Moliton and Nunzi (2006) research covers the discussion related to the optimization of various parameters which govern the behaviour of polymer based and organic photovoltaic cells. The paper by Moliton and Nunzi explores the development of a comprehensive model for understanding the behavior of organic photovoltaic (OPV) cells, particularly under conditions of partial shading, which is crucial for building-integrated applications. The methodology involves an in-depth analysis of the mechanisms leading to the generation of charge carriers in OPV cells and the factors contributing to loss, such as shunt resistance across the cell layers. This includes a detailed examination of photon absorption, exciton generation and diffusion, and charge separation at donor-acceptor interfaces, among other processes.

The Perturb and Observe (P&O) controller is a widely used algorithm in the field of photovoltaic (PV) systems for tracking the Maximum Power Point (MPP) under varying environmental conditions. The P&O method periodically perturbs the voltage or current of the PV system and observes the change in power. If the power increases, the perturbation continues in the same direction; if the power decreases, the direction of the perturbation is reversed. The P&O method is favored for its simplicity and ease of implementation, though it may suffer from oscillations around the MPP and can be slow to respond to rapidly changing conditions.

Taïssala et al. (2018) research paper presents a modified Perturb and Observe (P&O) maximum power point tracking (MPPT) algorithm designed for standalone single-phase photovoltaic systems employing a boost converter. The main goal is to enhance the efficiency of solar energy utilization, a challenge due to the low efficiency of photovoltaic solar energy conversion and its dependency on fluctuating environmental conditions. The proposed modification to the conventional P&O algorithm aims to reduce power oscillations and improve power extraction under varying conditions.

The optimizing the P&O MPPT algorithm addresses the inherent inefficiencies and power loss associated with the traditional method, especially under partial shading conditions or rapidly changing environmental factors. By focusing on reducing oscillations around the MPP and enhancing tracking speed, the modified algorithm offers a potentially significant improvement in the performance and reliability of PV systems, contributing to the broader adoption and efficiency of renewable solar energy sources (Ballaji, 2018).

For power-voltage curve prediction, the Lagrange polynomial transform function can be employed, with coefficients updated at each sampling step. The integration of a chaotic neural network with the NMPC system helps track reference values under dynamic environmental conditions. The control strategy can be tested on organic solar panels, chosen for their full recyclability and higher efficiency compared to silicon-based PV cells (Patel et al. 2016).

Femia et al. (2005) study presents an innovative approach to optimizing the Perturb and Observe (P&O) maximum power point tracking (MPPT) algorithm used in photovoltaic (PV) systems. The originality of this work lies in its detailed theoretical analysis and optimization of the P&O MPPT parameters, specifically tailored to the dynamic behavior of the PV system's specific converter. This optimization aims to mitigate two main drawbacks of the conventional P&O algorithm: the steady-state oscillation around the maximum power point (MPP), which leads to energy loss, and the algorithm's confusion during rapidly changing atmospheric conditions. The authors demonstrate that by customizing the P&O MPPT parameters—namely, the perturbation size and sampling interval—according to the converter's dynamics, it is possible to significantly enhance the efficiency of the MPPT control. The paper provides a comprehensive theoretical framework for selecting these parameters optimally, supported by experimental results that validate the proposed method's effectiveness (Femia et al. 2005). This optimization not only reduces the oscillations around the MPP, thus minimizing energy waste, but also improves the algorithm's adaptability to changing irradiance levels, ensuring more reliable tracking of the MPP.

METHODOLOGY

The variability in solar irradiation, temperature, and other influential factors introduces non-linearity to the I-V characteristic of photovoltaic (PV) curves, making the task of identifying the maximum power point (MPP) quite complex. Traditional methods like Perturb and Observe (P&O) or Incremental Conductivity (IC) have been deployed to establish reference values for this purpose. However, these methods struggle to effectively track rapid changes in environmental conditions and often lead to power fluctuations at the steady-state point, thereby increasing power losses. To address these challenges, the proposed method adopts a two-pronged strategy: initially estimating the reference point for each time interval and then adjusting the operating point of the converter accordingly. This approach aims to enhance the precision of MPP tracking under dynamic environmental conditions, thereby optimizing the efficiency of PV systems.

RESULTS EVALUATİON

When a module receives less light due to factors such as dust and shading, the voltage at that specific point decreases. This point then functions as a generator, referred to as a hotspot. Typically, a bypass diode is employed in parallel with each OPV module in this scenario to safeguard the module. Furthermore, a blocking diode is utilized at the end of each string (a grouping of series modules in a current path) to prevent reverse current resulting from voltage discrepancies between parallel strings. The voltage generated under these circumstances is illustrated in Figure 1. The extracted active power with reference point is compared and the results is shown in Figure 2.

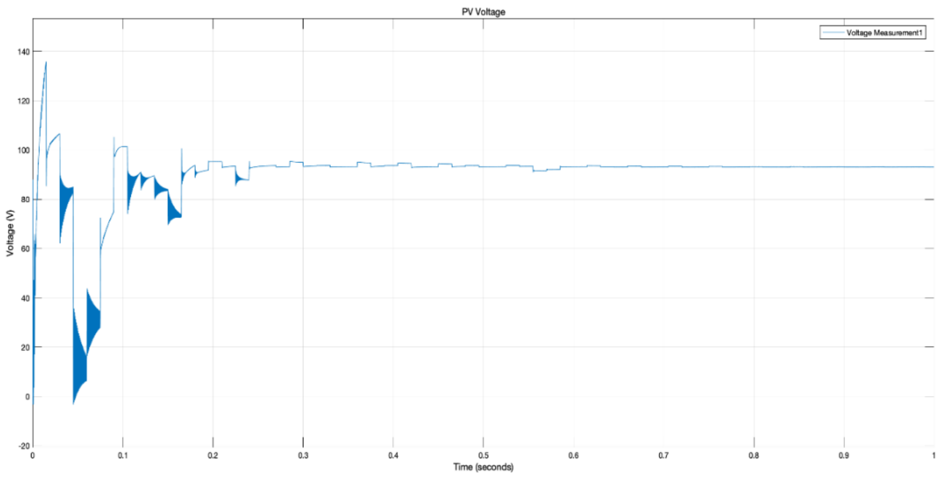

Figure 1. Output voltage signal of PV with considering noise

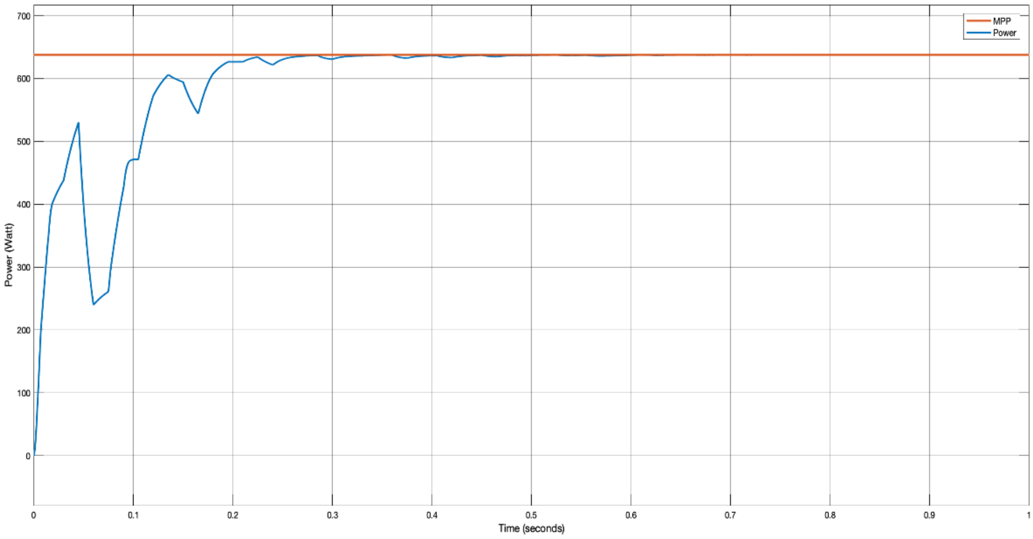

Figure 2. Comparing desired and real active power of PV system

Based on the information provided in Table 1, it is evident that the use of CNMPC (Chaotic Nonlinear Model Predictive Control) results in a reduction of overvoltage by more than 1.2%. This indicates that employing control methods such as CNMPC is effective in managing voltage levels, especially in scenarios where the penetration of OPV panels is increasing. Without the implementation of control methods, the voltage range surpasses permissible limits as the penetration of OPV panels rises.

Table 1. Comparison of the voltages drop in per unit (pu)

	Phase 1	Phase 2	Phase 3
OPV arrays not used	0.98	0.98	0.98
OPV + P&O controller	1.02	1.035	1.01
OPV + CNMPC controller	1.01	1.00	1.00

OPV: Organic Photovoltaic; CNMPC: Chaotic Nonlinear Model Predictive Control; P&O: Perturb and Observe

CONCLUSION

Reactive power injection serves as a method to mitigate voltage drops in distribution networks. This study employs a constant peak current control strategy to safeguard the converter system from overcurrent risks, allowing for the conversion of all injected power into reactive power if the voltage drop is below 50%. Although the primary role of the MPPT controller is to harvest the maximum possible power from solar panels, during faults, the active and reactive power reference values are determined by a predictive model, and converter operations are managed through a chaos-based NMPC controller.

This proposed method unfolds in two phases: first, estimating the reference point at each timestep, and second, adjusting the converter's operating point to optimize power extraction. For modeling the power-voltage curve predictor, the Lagrange polynomial transform function is utilized, with its coefficients updated at every sampling interval. Moreover, integrating a chaotic neural network with the NMPC system enables the tracking of reference values under changing environmental dynamics. Furthermore, this control approach has been modeled on organic solar panels, noted for their complete recyclability and superior efficiency compared to traditional silicon-based PV cells.

The key contribution of this work to the field of renewable energy and power electronics is the development of a more efficient, adaptable, and optimized MPPT algorithm that can be applied to various PV system configurations.

REFERENCES

1. Ballaji, A. (2018). Design and Implementation of Perturb and Observation Maximum Power point Transfer (MPPT) algorithm for Photovoltaic system', Journal of Engineering Research and Application, 8(5), 16 - 23, ISSN: 2248-9622.
2. Bernard, K. (2007). Organic photovoltaics, Optics and Photonics News 18, 10, 26-33.
3. Emanuele, P., Dama, A., Dolara,A. and Leva, S. (2019). Experimental validation of a model for PV systems under partial shading for building integrated applications, Solar Energy 183 (2019): 356-370.
4. Femia, N., Petrone, G., Spagnuolo, G. and Vitelli, M. (2005). Optimization of Perturb and Observe

Maximum Power Point Tracking Method, IEEE TRANSACTIONS ON POWER ELECTRONICS, 20(4), 963-973.

5. Hongkun,H., Jia, C., Fu, J. and Xiaoming Luan, X. (2021). Low voltage ride through control strategy for MMC photovoltaic system based on model predictive control, International Journal of Electrical Power & Energy Systems, 125, 106530.
6. Moliton, A. and Nunzi, JM. (2006). How to model the behaviour of organic photovoltaic cells, Polymer International 55(6):583 - 600. DOI: 10.1002/pi.2038.
7. Patel, G.R., Patel, D.B. and Paghdal, K.M. (2016). Analysis of P&O MPPT Algorithm for PV system', International Journal of Electrical and Electronics Engineering, IJEEE, Vol. 5, N°6, 2016, 1-10 ISSN(P): 2278-9944; ISSN(E): 2278-9952.
8. Rampradesh, T. and C. Christober Asir Rajan, C.C.A. (2021). Performance assessment of NMPC based MPPT controller and extended Kalman filter for a Wind/PV hybrid system, Fourth International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp. 1-4. IEEE.
9. Taïssala, A., Djongyang, N., Tom, A. and N. Nicodem, N. (2018). A modified perturb and observe maximum power point tracking algorithm for a standalone single phase photovoltaic system using boost converter, Journal of Renewable Energies, 21(4), 575 - 591.