

Maximum Power Point Tracking Implementation of Z-Source Inverter through Finite Step Model Predictive Control Strategy

Chirantan K¹, Mr. Mallikarjuna B²

M.Tech Student, Dept. of E&E, RNSIT, Bengaluru, India¹

Asst. Professor, Dept. of E&E, RNSIT, Bengaluru, India²

ABSTRACT: This paper presents a model predictive based Maximum Power Point Tracking (MPPT) method for a photovoltaic energy harvesting system based on a single-stage grid-tied Z-source inverter. First it provides a brief review of Z-source inverters, MPPT methods and Model Predictive Control (MPC). Next it introduces the proposed model predictive based MPPT method. Finally, it provides experimental results to verify the theoretical outcomes.

KEYWORDS: Text Impedance-Source Inverter, Model Predictive Control, Maximum Power Point Tracking, Photovoltaic Systems.

I. INTRODUCTION

Photovoltaic (PV) systems are one of the most promising electric power generation systems due to their low environmental impact and high availability of solar irradiation in most geographical locations [1, 2]. The energy generated by the PV systems is highly dependent on the environmental and ambient conditions such as the solar irradiance level and the module temperature. In order to ensure extraction of the maximum available energy in any ambient condition, MPPT for PV systems is essential [3]. The PV system efficiency can be degraded easily if the PV module is not forced to operate at its Maximum Power Point(MPP) at all times regardless of the environmental conditions.

Conventional grid-tied PV systems typically use a two-stage power conversion topology: an upstream dc/dc power conversion stage from the PV module to a dc link energy buffer (such as a capacitor), and a downstream dc/ac power conversion stage from the energy buffer to the grid. Several control techniques and analysis have been developed in literature for each of these conversion stages [4-8]. The general schematic of a conventional two-stage grid-tied PV system is illustrated in Fig. 1. The use of a two-stage topology is necessitated due to the inherent limitation of the dc/ac inverters for stepping up/down the voltage freely. Commonly, the conventional inverters classified as Voltage-Source Inverters (VSI) can only step-down the voltage while the Current-Source Inverters (CSI) can only step-up the voltage [9, 10].

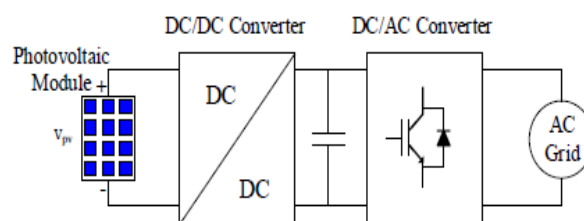


Fig. 1 Two stage grid tied PV system

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 4, April 2018

The MPP voltage of a PV module can be higher/lower than the grid voltage based on the environmental conditions, necessitating a power conversion system that can step up/down the voltage freely to track the MPP accurately. Recently a new converter topology, denoted as the impedance-source converter, is developed by the researchers that undermines the limitations with the conventional VSIs and CSIs [11-12]. In particular, a class of dc/ac inverters designed based on the concept of impedance-source conversion, denoted as Z-Source Inverter (ZSI), can step up/down the voltage freely, and thus is very well suited for designing single-stage PV harvesting systems. Fig. 2 demonstrates a single-stage PV harvesting system built around a ZSI.

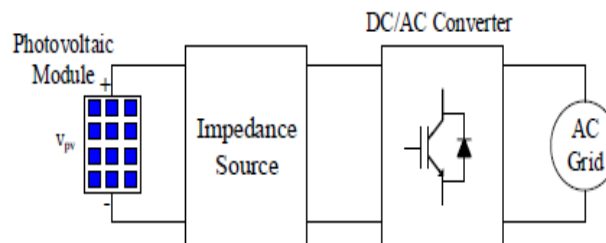


Fig. 2 Single stage impedance source grid tied PV system

This paper presents a new MPPT scheme for a ZSI based PV energy harvesting system based on the concept of Model Predictive Control (MPC). The MPC technique features simplicity and flexibility, and can be programmed to compensate for the inherent non linearities associated with power electronic converters. Comparing to classical control schemes, MPC delivers a fast dynamic response with a high stability margin, making it well suited for MPPT of PV systems operating under dynamic environmental conditions. A few research works have been recently published focusing on the MPPT for grid-tied PV system by MPC. The work presented by Shadmand et al uses a conventional Perturb and Observe (P&O) algorithm for identification of MPP. However, in the approach presented in this paper, the MPC method is used directly to predict the power generated by the PV panel, subsequent to possible changes to the PV voltage. Accordingly, in this paper, the decisions on the trajectory of the PV voltage are directly made by a MPC algorithm. This provides advantages to the MPPT process over the conventional methods. Unlike the previous works, the proposed method uses a fixed switching frequency and an adaptively predicted voltage step that can change according to the proximity to the MPP. This improves the tracking response caused by variations in solar irradiance level and minimizes the oscillation around the MPP. Thus, the proposed MPPT technique features high control effectiveness, fast dynamic response, and small oscillations around MPP without requiring expensive sensing devices to measure the solar irradiance level directly. Due to nature of MPC which predicts the system behaviour in a specified time horizon, the most significant advantage of the proposed technique is high accuracy tracking of gradually changing solar irradiance levels, a property absent in most well-known MPPT techniques such as P&O. Moreover, due to small oscillations around MPP, the proposed technique makes it possible to use a ZSI with small inductors/capacitors for the PV harvesting system. This is especially important because according to, one of the challenges of employing impedance source inverters such as ZSIs is the large size of the passive elements in the impedance network. Consequently, by using the proposed method, the foot print of a ZSI converter can be reduced significantly. Although the proposed method can be used in conjunction with other converters, its benefits will signify when used with a ZSI. This paper is structured as follows: Section II provides a review of the impedance-source converters, the MPPT methods and the MPC techniques. Section III presents the proposed model predictive based MPPT technique and the new PV harvesting system built around the ZSI. Section IV provides experimental results to validate the operation of the proposed system. Section V concludes this paper.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 4, April 2018

II. PROPOSED WORK

A. Impedance-Source Converters

The impedance networks can be utilized in a wide range of power conversion applications to provide a flexible means of conversion between different types of sources and loads. A simple impedance-source converter, denoted as a Z-Source Inverter (ZSI) is utilized as the PV harvesting interface in this paper. A distinctive characteristic of a ZSI is its capability to leverage shoot-through switching states for boosting the output voltage [11]. In shoot-through states both switches in one leg of the inverter are turned ON simultaneously. Due to inclusion of the shoot-through states, controlling ZSIs requires innovative modulation strategies. Several novel modulation strategies based on Pulse Width Modulation (PWM) method, have been proposed for ZSIs in the literature lately. Three notable modulation strategies for ZSIs are simple-boost, maximum-boost, and constant-boost techniques. In this paper, the simple boost strategy is chosen for generating the switching signals for the ZSI of Fig. 3.

The simple boost modulation strategy operates similar to a traditional carrier based PWM and its voltage gain is given by,

$$G = MB = \frac{V_{ac}}{V_o/2} = \frac{M}{2M-1} \quad (1)$$

Where M is the modulation index, B is the boosting factor of the impedance-network, V_{ac} is the amplitude of the output voltage of the inverter (equivalent to grid peak phase voltage when grid-tied), and V_o is the dc-link voltage. The boosting factor B is given by,

$$\beta = \frac{1}{1-2D} \quad (2)$$

Where “D” is the shoot through duty ratio.

B. MPPT Techniques

Fast convergence, small power ripples at MPP, accurate and robust tracking of MPP are the key desired properties of a MPPT technique. Several algorithms, architectures, and mechanisms for tracking the MPP of a PV module have been proposed in the literature in the past two decades. Some of the very well-known MPPT methods include: hill-climbing algorithm, power-matching scheme, curve-fitting technique, P&O algorithm, incremental conductance algorithm, and fractional open-circuit voltage (V_{oc}) control. In this work, the idea behind the P&O algorithm is used as grounds to develop the new model predictive based MPPT technique that features better energy harvesting efficacy can more effectively hedge against dynamic environmental conditions.

C. MPC for Power Electronic Converters

Power electronic converters are nonlinear systems with finite number of switching devices that need to be controlled according to stringent operational goals and constraints. Controlling power electronic converters with the mentioned characteristics demands for elaborated control schemes. As such, the MPC technique has been emerging lately as a promising new control strategy for control of power electronic systems. Comparing to classical control schemes, MPC techniques deliver a fast dynamic response with a high stability margin, making them well suited for MPPT of PV systems operating under dynamic environmental conditions.

The MPC techniques use the discrete-time model of the system to evaluate the predicted value of system states and use the predictions to determine an optimal switching schedule for the future steps that will minimize a pre-defined cost function. Designing an MPC scheme involves the following steps: (a) Identifying all possible switching configurations of the converter and deriving the discrete-time model of the converter for each configuration. The derived models allow to predict future values of the system such as output voltage or current; (b) Defining a cost function that upon minimization leads to the desired behaviour of the system; (c) Predicting the behaviour of the system states for all possible switching configurations; (d) Evaluating the cost function for each possible switching configuration and selecting the switching configuration for the next step that minimizes the cost function.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 4, April 2018

The grid-tied ZSI and the block diagram of the proposed MPPT system for this converter are illustrated in Fig. 3.

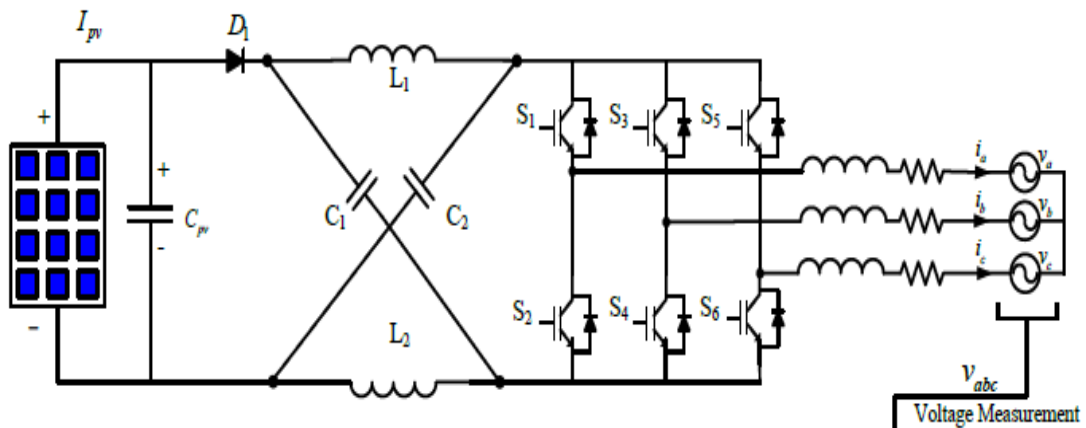


Fig.3. the grid-tied ZSI and the block diagram of the proposed control system

III. EXPERIMENTAL RESULTS

The proposed controller is implemented in MATLAB/Simulink. A unity power factor is targeted for the entire operation. The performance of the proposed model predictive based MPPT is evaluated by looking into three important merit criteria: the response to a step change in the solar irradiance level, operation in the event of gradually changing solar irradiance (*aka* clouds moving in sky), and operation in steady-state to evaluate the oscillation around MPP.

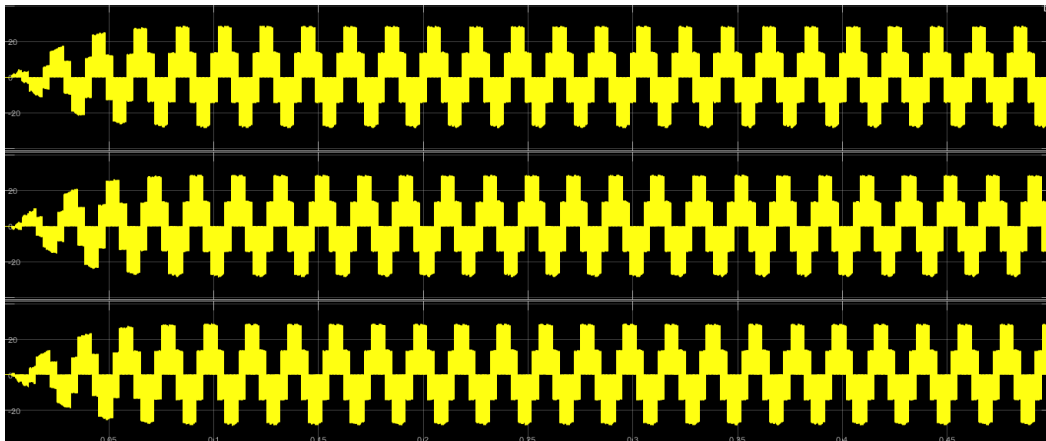


Fig.4. Z-source inverter output voltage waveform

The control efficacy of the proposed model predictive MPPT is calculated for several solar irradiance levels. To calculate the control efficacy, the actual captured power at the PV side for each solar irradiance level is measured and divided by the maximum available power at MPP determined from the P-V curves of the utilized PV module. The waveform for the power extracted from the PV cell is shown in the fig. 5.

International Journal of Innovative Research in Science, Engineering and Technology

(A High Impact Factor, Monthly, Peer Reviewed Journal)

Visit: www.ijirset.com

Vol. 7, Issue 4, April 2018

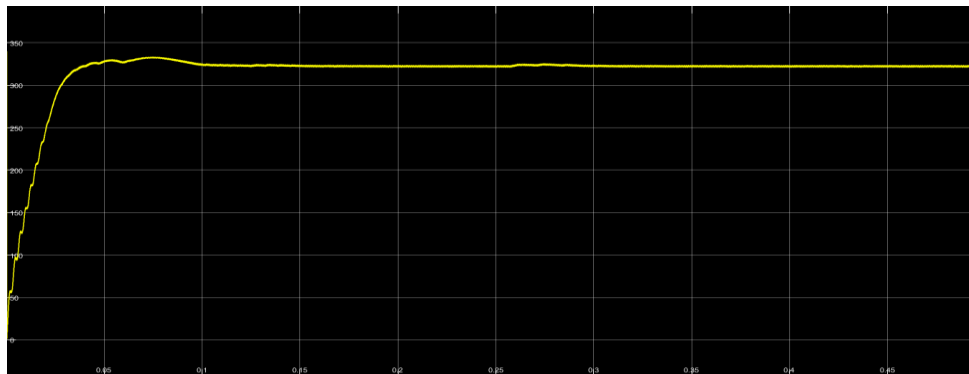


Fig.5. power extracted from PV cell

IV. CONCLUSION

This paper presents a highly efficient control scheme for a ZSI based grid-tied PV system. The presented control system has two components: the proposed model predictive based MPPT, and the grid side power injection controller. The experimental results demonstrate low THD of the grid side current that is within the IEEE 519 standards, fast dynamic response to a step change in solar irradiance level, and negligible oscillations around MPP under dynamically changing sky condition.

REFERENCES

- [1] H. Abu-Rub, M. Malinowski, and K. Al-Haddad, *Power electronics for renewable energy systems, transportation and industrial applications*: John Wiley & Sons, 2014.
- [2] S. Kouro, J. I. Leon, D. Vinnikov, and L. G. Franquelo, "Grid- Connected Photovoltaic Systems: An Overview of Recent Research and Emerging PV Converter Technology," *IEEE Industrial Electronics Magazine*, vol. 9, pp. 47-61, 2015.
- [3] T. Esmar and P. L. Chapman, "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques," *IEEE Transactions on Energy Conversion*, vol. 22, pp. 439-449, 2007.
- [4] J. Irwin, M. P. Kazmierkowski, R. Krishnan, and F. Blaabjerg, *Control in power electronics: selected problems*: Academic press, 2002.
- [5] S. Sajadian and E. C. d. Santos, "Three-phase DC-AC converter with five-level four-switch characteristic," in *Power and Energy Conference at Illinois (PECI), 2014*, 2014, pp. 1-6.
- [6] M. Peyvandi, M. Zafarani, and E. Nasr, "Comparison of particle swarm optimization and the genetic algorithm in the improvement of power system stability by an sssc-based controller," *Journal of Electrical Engineering and Technology*, vol. 6, pp. 182-191, 2011.
- [7] M. I. Chehardeh, H. Lesani, M. K. Zadeh, and E. M. Siavashi, "An optimal control strategy to alleviate sub-synchronous resonance in VSC-HVDC systems," in *Power Electronics and Intelligent Transportation System (PEITS), 2009 2nd International Conference on*, 2009, pp. 250-255.
- [8] N. Farokhnia, M. Ehsani, H. Vadizadeh, H. Toodeji, and M. Mohammad, "Fast closed-form solution of line-to-line voltage total harmonic distortion for three-level inverters," *IET Power Electronics*, vol. 6, pp. 581-591, 2013.
- [9] L. Poh Chiang, D. M. Vilathgamuwa, L. Yue Sen, C. Geok Tin, and L. Yunwei, "Pulse-width modulation of Z-source inverters," *IEEE Transactions on Power Electronics*, vol. 20, pp. 1346-1355, 2005.
- [10] S. Miaosen, A. Joseph, W. Jin, F. Z. Peng, and D. J. Adams, "Comparison of Traditional Inverters and Z -Source Inverter for Fuel Cell Vehicles," *IEEE Transactions on Power Electronics*, vol. 22, pp. 1453-1463, 2007.
- [11] P. Fang Zheng, "Z-source inverter," *IEEE Transactions on Industry Applications*, , vol. 39, pp. 504-510, 2003.
- [12] Y. P. Siwakoti, P. Fang Zheng, F. Blaabjerg, L. Poh Chiang, and G. E. Town, "Impedance-Source Networks for Electric Power Conversion Part I: A Topological Review," *IEEE Transactions on Power Electronics*, vol. 30, pp. 699-716, 2015.