Three-Level Neutral-Point-Clamped Quasi-Z-Source Inverter with Maximum Power Point Tracking for Photovoltaic Systems

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Abstract. This article is focused on a photovoltaic system based on the three-level neutral-point-clamped quasi-z-source inverter. The maximum power point tracking (MPPT) algorithm based on dP/dV feedback was used in the photovoltaic system to adjust the duration of the shoot-through states of power switches and achieve a maximum power. Proper system operation in the case of irradiance step is demonstrated by simulation in Matlab/Simulink software.

Keywords: three-level inverter, neutral-point-clamped inverter, quasi-z-source inverter, shoot-through, maximum power point tracking, photovoltaic system, dP/dV feedback.

1 Introduction

Continual focus of DoCEIS is on general topics of wide-scale importance that create opportunities for researchers to discuss their contribution to the challenges involved in their proposed subjects [1]. A current topic "Technological Innovation for the Internet of Things" is closely connected to the smart grid.

1.1 Smart Grid as Application of the Internet of Things

In some studies the application of the Internet of Things in the smart grid is gravely emphasized. But we should keep in mind that the Internet of Things is a rather broad concept. It may concern not only to the smart grid and therefore is not limited by it.

However discussing the contribution of this work to the development of the Internet of Things we will consider it in terms of the smart grid, since this paper is focused on the photovoltaic system as an element of the smart grid.

Smart grid can solve the problem of an energy alternative and compatible use, which integrates system data on the basis of building an open system and a shared information model to optimize the operation and management of the grid. The principal characteristics of the smart grid include self-healing, mutual operation and participation of the users, perfect electricity quality, distributed generations and demand response, sophisticated market and effective asset management [2].

Our conviction is that the greatest development of the mentioned concept can be achieved if attention is paid first to the objects of control, and then to the ways and methods of the management. Thus, renewable energy sources (fuel cells, photovoltaic arrays, wind turbines etc.) can be used as electrical sources for a smart grid supply. This work is devoted to the photovoltaic system based on the new topology of a quasi-z-source inverter (QZSI).

1.2 Quasi-Z-Source Inverter Based Innovative Approaches

Many studies propose the QZSI for use in PV systems. Some module architecture designs provide a high efficiency up to 98% [3]. Moreover, the output current of a QZSI based system has good quality (THD up to 3%) [4]. The QZSI also has necessary voltage boost properties and can be used for the MPPT in PV systems [5].

Since approaches for the MPPT implementation using QZSI have been required, a lot of new modifications of the MPPT have appeared. Some methods track the MPP without the current sensor [6]. Most of the studies suggest tracking by adjusting the shoot-through of the QZSI [7]. Methods to control shoot-through by artificial intelligence techniques are known. In [8] a method based on an adaptive neuro-fuzzy inference system (ANFIS) is proposed to harness the maximum power of the PV system based on the QZSI. It offers a very fast dynamic response with high accuracy.

A new QZSI topology was proposed and described in [9]. It is a combination of the QZSI and the three-level neutral-point-clamped (3L-NPC) inverter. The three-level neutral-point-clamped quasi-z-source inverter (3L-NPC QZSI) has advantages of both of these topologies. It can buck and boost the input voltage, it has short circuit immunity and due to the multilevel topology, high energy density is attainable. The 3L-NPC QZSI is especially suitable for renewable energy sources.

Since the mentioned topology is rather new, in all previous studies the 3L-NPC qZSI was considered as an isolated system [9], [12], [13]. The aim of the current work is to develop and study the capabilities of this topology assuming it as an integrated system. A wide range of problems should be considered (MPPT, anti-islanding methods, reactive power control). This article is focused on the MPPT.

The control system for the 3L-NPC qZSI can be built on the FPGA (Field Programmable Gate Array), as described in [9]. The FPGA makes it easier to implement a shoot-through mode. Using FPGA resources, it is sufficient to integrate the MPPT based on the same chip. Furthermore, we can use the FPGA to integrate a PV system in the smart grid and use the remote control of power converters. Sensor technology of the Internet of Things can form an interactive real-time network connection between the users, the corporation and power equipment, which will improve the overall efficiency of the integrated power grid [2]. Such control basis makes an excellent contribution to the furtherance of the Internet of Things.

2 Relationship to Internet of Things

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3 Description of the System

The general structure of the studied system is depicted in Fig. 1. Different models of the system were developed and implemented using Matlab/Simulink as a simulation tool. The power stage of the system is composed of a photovoltaic array and a three-level neutral-point-clamped quasi-z-source inverter with an output LC filter. The MPPT algorithm and a shoot-through pulse-width modulation (SPWM) technique compose the control stage of the system.

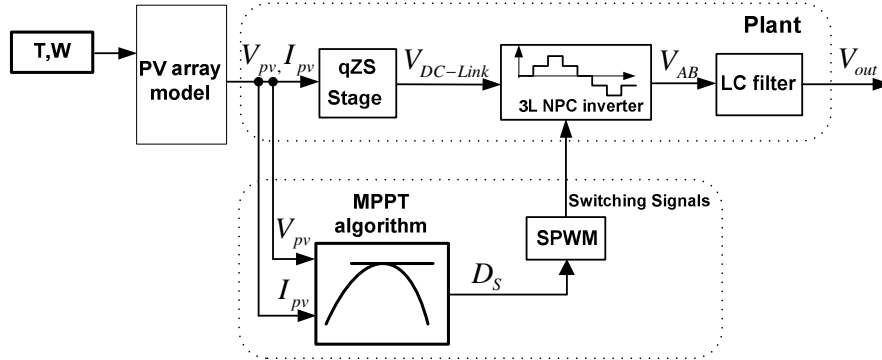All the mentioned components of the PV system will be described in detail in the following sections.

Fig. 1. General block-diagram of the analyzed photovoltaic system.

3.1 Photovoltaic Array Model

One of the principal components of the system is the PV array model. It is modelling the real photovoltaic module Shell SP150-P [10].

Several models for solar panel simulation are reported in the literature. Most of them are modelling the solar cell as an electrical equivalent circuit. Due to such representation some electrical parameters are required, such as junction resistance, dark current, effective cell area etc. Usually these parameters are not provided in the solar panel manufacturer datasheet. It makes such model use difficult for engineers and users.

In this work the model based on I-V exponential curve has been used for simulation. This model was proposed in [11], where detailed description of the model could be found. The influence of temperature and irradiance was also considered.

The simulated I-V curves in different irradiance conditions for the mentioned PV panel are shown in Fig. 2a. Proper work of the model was validated by the comparison of these curves with those provided by manufacturer for the solar panel Shell SP150-P (Fig. 2b).
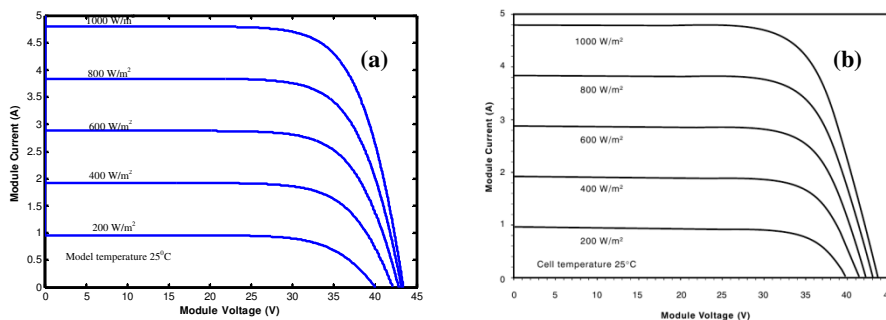

Fig. 2. I-V curves family of the photovoltaic array obtained using Matlab/Simulink model (a) and I-V curves family from the Shell SP150-P Product Information Sheet (b).

Suitable series-parallel associations of the single photovoltaic panels enable the necessary DC input voltage and the PV system power to be provided.

3.2 Three-Level Neutral-Point-Clamped Quasi-Z-Source Inverter

DC/AC conversion is based on the 3L-NPC qZSI proposed and described in [9]. It is depicted in Fig. 3.

Each leg of the converter consists of two complementary switching pairs of transistors and four anti-parallel diodes (Fig. 3). The required parameters of the passive elements of the QZS-stage were calculated according to the methodology proposed in [13].
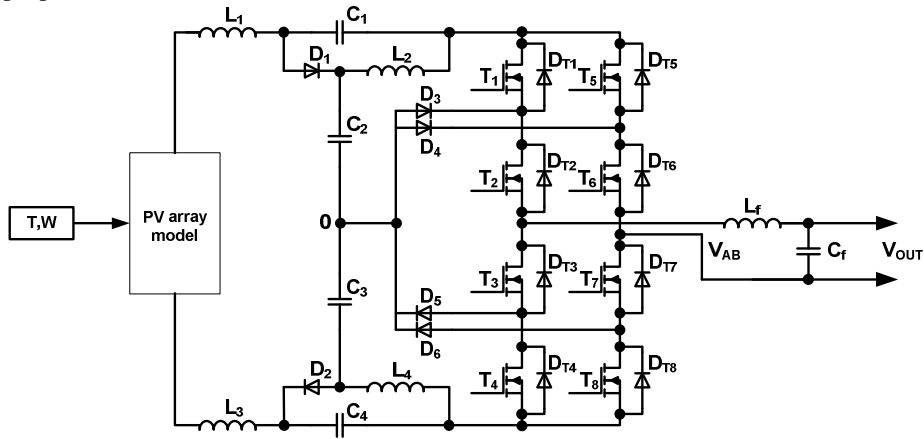

Fig. 3. Three-level neutral-point-clamped quasi-z-source inverter fed by a photovoltaic array.

This topology has such advantages as continuous input current, the possibility to use shoot-through, lower switching losses and balanced neutral-point voltage in comparison with the traditional two-level voltage source inverter. Due to the above features the neutral-point-clamped quasi-Z-source inverter is especially suitable for the PV systems.

3.3 Maximum Power Point Tracking Algorithm

The structure of the proposed MPPT algorithm is depicted in Fig. 4.

The input parameters of this stage are values of the voltage and current of the photovoltaic array. As can be seen from Fig. 4, this MPPT algorithm is based on dP/dV.
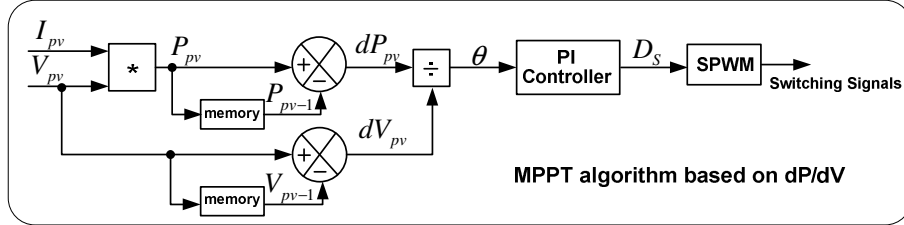
Fig. 4. The structure of the maximum power point tracking algorithm.

The novelty of this approach lies in the usage of the shoot-through state of power switches for maintenance of the maximum power. Using the value of the dP/dV, denoted as θ in Fig. 4, PI controller forms the necessary shoot-through duty cycle Ds to achieve the maximum power. Ds is used by the SPWM block to generate the control signals for all switches. Thus, the MPPT algorithm is adapted for the 3L-NPC qZSI in the PV system. In Figs. 5a and 5b, I-V and P-V curves show the MPPT.
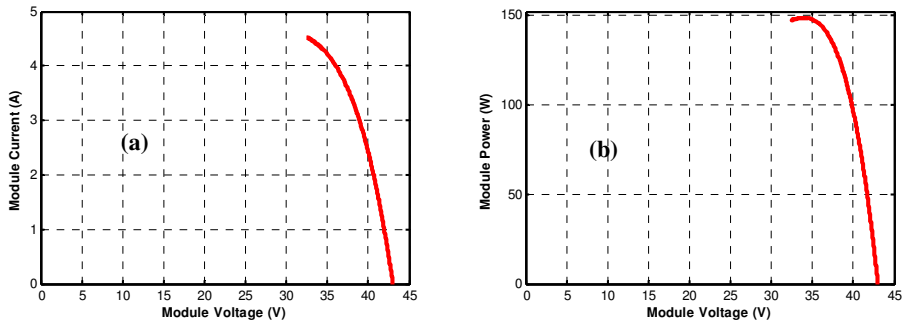

Fig. 5. Modelled I-V (a) and P-V (b) curves with maximum power point tracking.

3.4 Modulation Technique

A special shoot-through pulse-width modulation (SPWM) technique was implemented for the 3L-NPC qZSI. This modulation technique as well as the switching strategy are described in detail in [13].

The modulation technique differs from the classical modulation techniques for such converters. It has shoot-through states of the power switches distributed during the whole period of the output voltage, while in the classical approaches the shoot-through states are usually applied when the output voltage is equal to zero.

This modulation technique has several benefits. It significantly reduces the DC voltage pulsations and output voltage distortion. Thus it allows a decrease in the values of the passive elements used for the quasi-z-source stage and neutral point clamping. It also influences the output filter parameters.

In addition, the proposed modulation technique allows the boost factor that is needed to be easily achieved only by changes of the shoot-through duty cycle. Thus, it combines the necessary boost factor with acceptable quality of the output power.

4   Simulation Results

The photovoltaic system was simulated using MATLAB Simulink. All the parameters of the PV array model are presented in Table 1 under standard conditions (irradiance 1000 W/m^2 and temperature 25^{0}C).

Table 1. Simulation parameters

	Symbol	Description	Values
Parameters of the used photovoltaic array model	V_{OC}	Open circuit voltage	43.4 V
	I_{SC}	Short circuit current	4.80 A
	V_{MPP}	Maximum power point voltage	34.0 V
	I_{MPP}	Maximum power point current	4.41 A
	N_S	Number of panels connected in series	7
	N_P	Number of panels connected in parallel	1
	P_{MAX}	Maximum power	1050 W
Parameters of the used passive elements	L_1, L_2, L_3, L_4	Inductors of the quasi-Z-stage	160 µH
	C_1, C_4	Capacitors of the quasi-Z-stage	1180 µF
	C_2, C_3	Capacitors of the neutral point	940 µF
	L_F	Inductor of the output filter	2.2 mH
	C_F	Capacitor of the output filter	0.47 µF
	R_F	Resistor of the output filter	0.25 Ohm
	R_L	Resistor of the load	15 Ohm

In the PV system study it was necessary to validate its ability to track the maximum power point under nonstandard conditions. Thus, using the changes of irradiance the response of the system was observed and results are depicted in Fig 6.

At the initial time, irradiance was 1000 W/m^2 (Fig. 6a). The module voltage is about 240 V (Fig. 6b). So, the voltage of each of 7 panels was 34 V. Such panel voltage according to the I-V curves in Fig. 2a corresponds to the current 4.4 A in Fig. 6c. The PV module power was 1050 W (Fig. 6d).

At second 8, irradiance was gradually decreased to 900 W/m^2 (Fig. 6a). It caused a sharp decline of the module power (Fig. 6d). The MPPT block by changes of the shoot-through duty cycle (Fig. 6e) is looking for the new maximum power point in such conditions. Thus, when the transient process is finished, the voltage is near to 240 V (Fig. 6b). The voltage of a single panel is about 34 V. For such conditions, the current is 4.0 A (Fig. 6c). The power in a steady state is 960 W (Fig. 6d).

After second 16, the irradiance returns to its initial level. MPPT block by changes of shoot-through duty cycle (Fig. 6e) establishes the initial power. It allows all the variables get their original values.
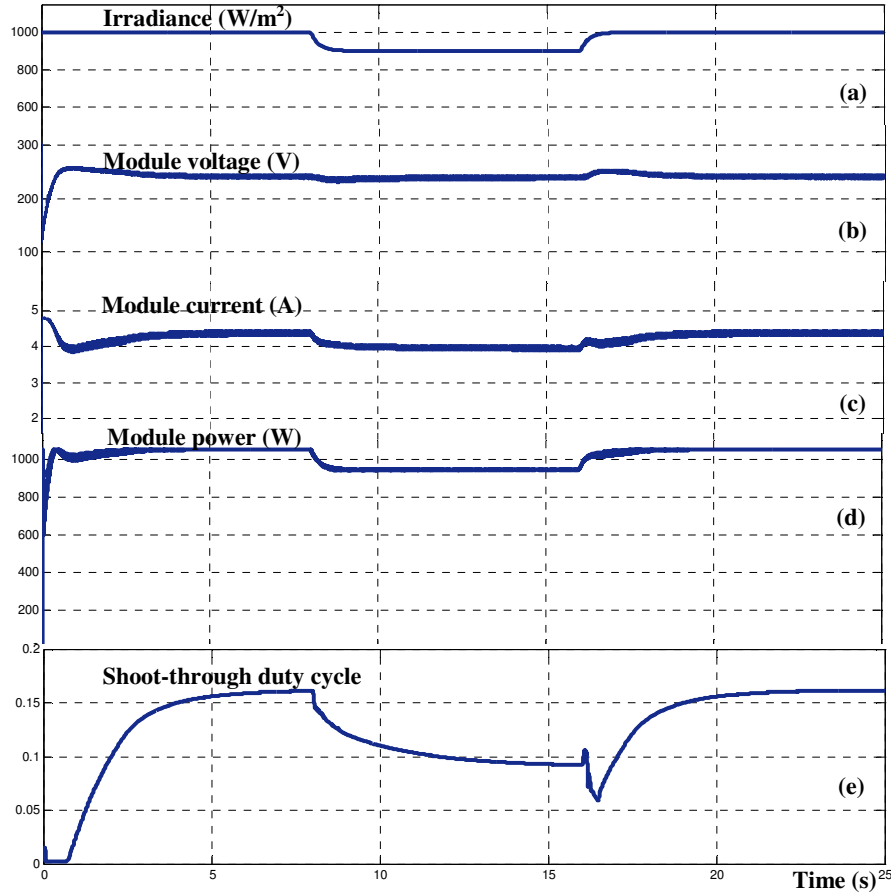
Fig. 6. Simulation results: irradiance (a), PV module average voltage (b), PV module average current (c), PV module average power (d), shoot-through duty cycle (e).

5   Conclusions and Further Work

A photovoltaic system based on three-level neutral-point-clamped quasi-z-source inverter with the maximum power point tracking has been modelled and described in this work.

The MPPT algorithm based on dP/dV is featured by the shoot-through duty cycle to achieve the maximum power. Simulation results proved the ability of the proposed system to track the maximum power point under irradiance changes.

Our further work will be devoted to detail analysis of the output voltage of the integrated photovoltaic system. Attention will be paid also to the features affect the output voltage and the ways of its improvement.

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