An Overview of ANFIS Based Quasi Z Source Inverter for Photovoltaic Power Generation

P.Lenin Pugalanthi
PG Student,
Dept of EEE,
Sri Krishna College of Engineering And Technology,
Coimbatore.
leninpugal@gmail.com

R.Parthasarathy
Assistant Professor,
Dept of EEE,
Sri Krishna College of Engineering And Technology,
Coimbatore.
parthasarathy@skct.ac.in

Abstract

Quasi-Z-source inverter (qZSI) is a new topology derived from the traditional Z-source inverter (ZSI). The paper proposes an artificial-intelligence-based solution to interface and deliver maximum power from a photovoltaic (PV) power generating system. The interface between the PV dc source and the load is accomplished by a quasi-Z-source inverter (qZSI). The maximum power delivery to the load is ensured by an adaptive neuro fuzzy inference system (ANFIS) based on maximum power point tracking (MPPT). The proposed ANFIS-based MPPT offers an extremely fast dynamic response with high accuracy. The closed-loop control of the qZSI regulates the shoot through duty ratio and the modulation index to effectively control the injected power and maintain the stringent voltage, current, and frequency conditions.

Keywords: quasi-Z-source inverter (qZSI), non shoot-through state, shoot-through state, solar power generation, total harmonic distortion (THD).

I. Introduction

The rapidly increasing environmental degradation across the globe is posing a major challenge to develop commercially feasible alternative sources of electrical energy generation. Thus, a huge research effort is being conducted worldwide to come up with a solution in developing an environmentally benign and long-term sustainable solution in electric power generation. The major players in renewable energy generation are photovoltaics (PV), wind farms, fuel cell, and biomass [1]. These distributed power generation sources are widely accepted for microgrid applications. However, the reliability of the microgrid relies upon the interfacing power converter [2]. Thus the proper power regulation from the interfacing power converter will ensure a stable and reliable microgrid system [3]. Thus this paper focuses on the proposal of a new class of interfacing inverter, the quasi-Z-source inverter (qZSI) for off-grid applications. There are several power converter topologies employed in PV systems; however, they differ by several characteristics: two stage or single-stage, with transformer or transformerless, and with a two-level or multilevel inverter [4]–[5]. Single-stage inverters are becoming more attractive in comparison to two-stage models due to their compactness, low cost, and reliability [15]. However, the conventional inverter has to be oversized to cope with the wide PV array voltage changes because a PV panel presents low output voltage with a wide range of variation based on irradiation and temperature, usually at a range of 1:2. To interface the low voltage output of an inverter to the grid, a bulky low-frequency transformer is necessary at the cost of a large size, decrease in efficiency, loud acoustic noise, and high cost [16].

The two-stage inverter applies a boost dc/dc converter instead of a transformer in order to minimize the required KVA rating of the inverter and boost the wide range of voltage to a constant desired value. Unfortunately, the switch in the dc/dc converter becomes the cost and efficiency killer of the system. For safety reasons, some PV systems have a galvanic isolation, either in the dc/dc boost converter using a high-frequency transformer, or in the ac output side of a line frequency transformer. Both of these added galvanic isolations increase the cost and size of the whole system, and decrease the overall efficiency.

Transformer less topologies especially deserves attention because of their higher efficiency, smaller size and weight, and a lower price for the PV system [16]. The Z-source inverter (ZSI), as a single-stage power converter with a step-up/down function, allows a wide range of PV voltages, and has been reported in applications in PV systems [15]–[17]. It can handle the PV dc voltage variation in a wide range without overrating the inverter, as well as implement voltage boost and inversion simultaneously in a single power conversion stage, thus minimizing system cost and reducing component count and cost, and improving the reliability.

Recently proposed qZSIs have some new attractive advantages that are more suitable for application in PV systems. This will make the PV system much simpler and lower its cost because the qZSI: 1) draws a constant current from the PV panel, thus no need for extra filtering capacitors; 2) features lower component (capacitor) rating; and 3) reduces switching ripples to the PV panels [01]–[03].

This paper employed qZSI for interfacing the PV generation system for the isolated load condition. Artificial intelligence (AI)-based methods are increasingly used in renewable energy systems [09]–[10] due to the flexible nature of the control offered by such techniques. The AI techniques are highly successful in nonlinear systems due to the fact that once properly trained they can interpolate and
extrapolate the random data with high accuracy. A review on the application of AI techniques in renewable energy generation system is presented in [05]. Some applications of artificial neural network in PV are presented in [06]–[11], and the use of fuzzy logic is available in [15] and [16], while the adaptive neuro-fuzzy inference system (ANFIS) is utilized in [06]. In [04], voltage and current are taken as the input to the ANFIS controller. In contrast, the presented technique utilizes the weather information as the input to the ANFIS.

The neural network is a powerful technique for mapping input–output nonlinear function; however, it lacks the heuristic sense and it works as a black box [12]. On the other hand, fuzzy logic has the capability of transforming heuristic and linguistic terms into numerical values through fuzzy rules and membership functions [13]. It also provides the heuristic output by quantifying the actual numerical data into heuristic and linguistic terms. However, the shortcoming of fuzzy computation is obtaining correct fuzzy rules and membership functions which heavily rely on the prior knowledge of the system. The ANFIS integrates the neural network and fuzzy logic, thus this synergy offers the most powerful artificial intelligence technique [14]. This paper thus uses ANFIS techniques to determine the maximum power capability of a photovoltaic module for variable solar irradiance and temperature conditions.

The other maximum power point tracking (MPPT) algorithms such as perturb and observe, incremental conductance and their improvements suffer from drawbacks such as oscillations at the operating point and lack in fast dynamic response. The speed of the algorithm in locating the correct operating point of PV is a crucial factor especially when operating in grid interactive mode. The proposed technique of using ANFIS-based MPPT offers highly precise and fast control with robust operation and is highly suitable for microgrid application in PV generation systems. This paper is organized in six different sections. Section II discusses the basic working principle of a qZSI.

II. Quasi-Z-Source Inverter-Circuit Topology and Control

Quasi-Z-source inverter (qZSI) topology has been introduced recently to overcome some of the shortcomings of the Z-source inverter. The qZSI offers several advantages over the Z-source inverter such as continuous input current, reduced components rating, higher reliability, and simple control strategy [16]–[18].

This topology of the inverter is identified as one of the most suitable power conditioning interface between the PV generation system and the grid. This paper presents an improved power circuit topology of qZSI where one capacitor of the quasi-Z-source network is replaced by storage batteries, as shown in Fig. 1, thus flexible power conditioning functionalities can be achieved. In the proposed structure, the load can be isolated or it can be a micro grid or a full scale grid. In order to capture the maximum solar energy, MPPT is necessary to draw the maximum power from the PV panels in PV applications, which is commonly implemented by regulating the PV voltage to follow a time-variant reference—the voltage of the maximum power point. The value of is continuously tracked by certain MPPT algorithms, such as the perturb and observe (P&O), incremental conductance (Inc-Cond), or ANFIS presented in this paper.

Fig. 2 Comparison of ZSI and qZSI

On the other hand, the output power is another concern of the PV system. For an isolated load condition (standalone PV system), the output voltage of the qZSI is regulated and the output power is determined by corresponding load demands. While for a grid-interactive condition (grid-tied PV system), the output power of the qZSI can be regulated by controlling the current injected to the grid accordingly.

Notice that no matter the case, the input power from PV panels, the output power to loads (isolated load or grid), along with the power absorbed or released by energy storage battery in the proposed topology, should be matched to maintain a stable and sustainable operating approach, and it is the battery that provides an energy buffer zone for both input and output sides of the PV system. Given the condition that the battery is within its valid charge or discharge status, MPPT can be accomplished by sending the captured extra power to the battery, or the output power can be maintained for period of time by extracting absent power from the battery.

The second case is of essential importance for large-scale PV systems interfacing the power grid, where stable and sustainable energy supply is always demanded, while contrastively PV cell's output power varies accordingly with temperature and solar irradiation. With the proposed topology in this paper, the state-of-charge (SOC) of the battery is taken into consideration with the following concerns: 1) To choose a proper shoot-through duty ratio for regulating, and the battery is charged or discharged through a desired current, which is determined by the power difference of input and output together with the battery
voltage, and also is limited by the maximum acceptable value according to the battery. 2) Once the battery has been adequately charged, the voltage of the battery in the circuit should be regulated as little current (theoretically no current) charging the battery any longer. Notice in this situation MPPT may not be achieved because the energy is unable to absorb extra power.

3) If the battery is exhausted where the battery voltage drops below one threshold and there is still a shortage of power from PV panels, load shading needs to be executed. 4) For all the above-mentioned statuses, a sufficient dc bus voltage should be kept for a valid output (as in another point of view, capacitor voltage needs to be kept above a certain value). In order to satisfy this requirement, MPPT may be sacrificed for the sake of an adequate voltage boost. The whole operation of a qZSI is divided into two distinct modes called the shoot-through and non shoot-through or active mode and their equivalent representation is given in Fig. 3. From Fig. 3(a), the inverter operated during the interval of the Non shoot-through states and in Fig. 3(b).

Hence, the qZSI can buck or boost input dc voltage, it can handle wide variation of the input voltage, particularly for the PV system, and produce a desired voltage for the isolated load or for the grid in a single stage. This feature results in the reduced number of switches involved in the power electronics of the PV system and, therefore, the reduced cost and the improved system efficiency and reliability. When the solar irradiance is low and the PV panel produces low voltage, the qZSI boosts the voltage, which helps to avoid redundant PV panels for higher dc voltage or unessential inverter overrating. As mentioned previously, it is able to handle the shoot-through state; therefore, it is more reliable than the conventional VSI. Additionally, for the qZSI, there is a common dc rail between the source and inverter, which is easier to assemble and causes less EMI problems.

III. Proposed Control Structure

It is assumed that the PV power generating system is feeding an isolated load. The objectives to be achieved by the proposed control system are

1) Maximum power point tracking.
2) Desired stable output power to the isolated ac load.

The output power of the inverter should be controllable and adjustable on the basis of users’ demand in case of the isolated load conditions. The MPPT is achieved using ANFIS. It is known from literature that the PV system needs to be operated at a specified voltage for extracting maximum available power [15], [16]. The ANFIS is trained for giving voltage output crisp value corresponding to the maximum power delivery from the PV panels. The inputs to the ANFIS are given as environmental conditions, i.e., the solar irradiance and temperature. There are two control variables for this qZSI control system, i.e., the shoot-through duty and modulation index.

Both control variables should cooperate to achieve the above set goals. In the proposed control strategy, a closed-loop control of the input voltage is combined with the trained ANFIS to implement the MPPT control, as shown in Fig. 4. A proportional and integral regulator with feed forward will adjust the shoot-through duty of the qZSI. In general, the battery voltage depends on its SOC, instead of its current, and has a little change in a suitable range of the SOC. At constant temperature, the change of solar irradiation will result in a great change of PV current at the maximum power point (MPP), when compared to the resultant change of PV voltage. The MPPT control could ensure a stable peak dc-link voltage with little variation at a constant temperature. On the other hand, the change of temperature will result in a great change of PV voltage at the MPP, when compared to the resultant change of PV current, which will make the peak dc-link voltage change greatly.

In the load side, the closed-loop control is employed to keep the output voltage magnitude and frequency constant regardless of the change in the input conditions, as shown in Fig. 4(a). The modulation signals are adjusted to ensure a constant output voltage, thus the change of load impedance will cause a change of output power in the isolated loading conditions, where the storage batteries are employed to meet the load demand. The solar irradiance is measured using standard industrial solar pyranometer and the temperature and other weather data are collected using weather transmitters arrangements. The outputs of the solar

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**Fig.3** Equivalent circuit of the qZSI with battery. (a) Shoot-through state. (b) Non Shoot-through state.

**Fig.4.** (a) Proposed control scheme with ANFIS-based MPPT. (b) Schematic outline for ANFIS controller.
irradiance and temperature transducers are current/voltage signals which are logged in real time using standard data loggers. These data are then be transferred to the PC for further processing or implementation of real-time control system using the ANFIS controller. The schematic outline for the ANFIS controller is shown in Fig. 4(b).

IV. Simulation Diagram and Results

The solar irradiance varies from a certain minimum value to the maximum value. The time scale is taken as 1.5s due to the limited memory of the digital computer. A lithium ion battery pack with the nominal voltage of 100v and 5 Ah. It is used as the energy storage. The initial SOC of the battery pack is taken as 50%. The dc link voltage depends on the value of input voltage due to the almost constant voltage of the battery based energy storage. The pv voltage is 85V. The average duty D only depends on the input voltage, regardless of input power and output power.

Fig.5 Main Proposed Simulink Model

Fig.6 ANFIS Output and Training Data

Fig.7 SPWM battery voltage

Fig.8 Active Reactive Inject Power

Fig.9 Active Reactive Load power

Fig.10 Power factor correction
The fig.11 represents a comparison of P&O, Z source and Quasi response. When compare to the other methods, the quasi z source inverter based ANFIS system having high voltage. So it is best suitable for renewable energy systems in power electronic devices.

The fig.12 shows the power factor improvement. It having 0.9352 PF value. It is suited interface for renewable energy system and could prove to be highly efficient, when implemented with the improved power factor.

From the fig.13, The grid current value is 30 amps and grid side voltage is 200v. so the ANFIS based qZSI technique is best suitable for microgrid applications.

V. Conclusion

The paper proposes ANFIS-based PV power generation system. The interface stage between the generation source and the load is accomplished by a qZSI. This magnitude of lower order harmonics and total harmonic distortion (THD) in the output voltage is found to be reduced. Simulation results presented verifies the analysis of the control method. The QZSI is capable of handling a wide range of input voltage fluctuations. It provides single stage power conversion, features low component rating and cost, and is more reliable. QZSI is best suited interface for renewable energy system and could prove to be highly efficient, when implemented with the improved control techniques proposed.
References


