

Using ANFIS Controller Energy Usages Quasi-Z-Source Inverter in PV Power System

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ABSTRACT: The quasi-Z-source inverter (QZSI) with battery operation can balance the stochastic fluctuations of photovoltaic (PV) power injected to the grid/load. Two strategies are used to control the new energy-stored QZSI when applied to the PV power system. They can control the inverter output power, track the PV panel's maximum power point, and manage the battery power, simultaneously. The voltage boost and inversion, and energy storage are integrated in a single-stage inverter. The QZSI draws a constant current from the PV panel, and thus, there is no need for extra filtering capacitors. The QZSI features a lower component (capacitor) rating and reduces switching ripples seen by the PV panels. It injects the active/reactive power into the grid by the inverter and regulates the battery state of charge (SOC). It controls the PV panel output power (or voltage) to maximize energy production. QZSI is best suited interface for photovoltaic power generation system and could prove to be highly efficient, when implemented with the improved space vector control techniques. This technique reduces the harmonics especially third and fifth order harmonics.

KEYWORDS: Energy storage, photovoltaic (PV) power generation, power conversion, Quasi-Z-source inverter (QZSI).

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 and long-term sustainable solution in electric power generation. The major players in renewable energy generation are photovoltaic (PV), wind farms, fuel cell, and biomass.

Photovoltaic (PV) are arrays (combination of cells) that contain a solar voltaic material that converts solar energy into electrical energy. PV cell is a basic device for Photovoltaic Systems. Such systems include multiple components like mechanical and electrical connections and mountings and various means of regulating and (if required) modifying the electrical output. The current and voltage available at the PV device terminals can be directly used to feed small loads like lighting systems or small DC motors. Energy sources such as solar, fuel cell, and wind have a wide voltage change.

The Z-source inverter (ZSI) presents a new single-stage structure to achieve the voltage boost/buck character in a single power conversion stage. This type of converter can handle the PV dc voltage variations over a wide range without over rating the inverter. As a result, the component count and system cost are reduced, with improved reliability due to the allowed shoot through state. Recently proposed quasi-Z-source inverters (QZSI) have some new attractive advantages more suitable for application in PV systems. Quasi-Z-source inverter (QZSI) is a power conversion technology suitable for interfacing of renewable sources. Two strategies are with the related design principles to control the new energy-stored QZSI when applied to the PV power system. They can control the inverter output power, track the PV panel's maximum power point, and manage the battery power, simultaneously. QZSI draws a constant current from the PV panel, and thus, there is no need for extra filtering capacitors. The voltage boost and inversion, and energy storage are integrated in a single-stage inverter.

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In addition, the intermittent and unscheduled characteristics of solar power limit the applicability of PV systems. Therefore, much of the literature suggests the addition of an energy storage system (ESS) to work in conjunction with PV power generation to make its output power continuous, stable, and smooth. Moreover, when applied as a grid-connected system, it implements other important auxiliary services normally provided by special and expensive equipment. Most of the existing ESS technologies employ bidirectional dc/dc converter to manage the batteries which makes the system complex, increases its cost, and decreases its reliability.

A. Quasi-Z-Source Inverter

The quasi z-source inverter (QZSI) is a single stage power converter derived from the Z-source inverter topology, employing a unique impedance network. The conventional VSI and CSI suffer from the limitation that triggering two switches in the same leg or phase leads to a source short and in addition, the maximum obtainable output voltage cannot exceed the dc input, since they are buck converters and can produce a voltage lower than the dc input voltage.

Both Z-source inverters and quasi-Z-source inverters overcome these drawbacks by utilizing several shoot-through zero states. A zero state is produced when the upper three or lower three switches are fired simultaneously to boost the output voltage. Sustaining the six permissible active switching states of a VSI, the zero states can be partially or completely replaced by the shoot through states depending upon the voltage boost requirement.

Quasi-Z-source inverters (QZSI) acquire all the advantages of traditional Z source inverter. The impedance network couples the source and the inverter to achieve voltage boost and inversion in a single stage. By using this, the inverter draws a constant current from the PV array and is capable of handling a wide input voltage range. It also features lower component ratings, reduces switching ripples to the PV panels, causes less EMI problems and reduced source stress compared to the traditional ZSI.

B. QZSI Network

The QZSI circuit differs from that of a conventional ZSI in the LC impedance network interface between the source and inverter. The unique LC and diode network connected to the inverter bridge modify the operation of the circuit, allowing the shoot-through state which is forbidden in traditional VSI. This network will effectively protect the circuit from damage when the shoot through occurs and by using the shoot-through state, the (quasi-) Z-source network boosts the dc-link voltage.

The impedance network of QZSI is a two port network. It consists of inductors and capacitors. This network is employed to provide an impedance source, coupling the converter to the load. The dc source can be a battery, diode rectifier, thyristor converter or PV array. The output voltage of the QZSI is regulated and the output power is determined by corresponding load demands.

C. Operating Principle of QZSI

The two modes of operation of a quasi z-source inverter are:

- (1) Non-shoot through mode (active mode).
- (2) Shoot through mode.

1) Active mode

In the non-shoot through mode, the switching pattern for the QZSI is similar to that of a VSI. The inverter bridge, viewed from the DC side is equivalent to a current source, the input dc voltage is available as DC link voltage input to the inverter, which makes the QZSI behave similar to a VSI. A continuous current flows through the diode D_1 .

2) Shoot Through Mode

In the shoot through mode, switches of the same phase in the inverter bridge are switched ON simultaneously for a very short duration. The source however does not get short circuited when attempted to do so because of the presence LC network, while boosting the output voltage. The DC link voltage during the shoot through states, is boosted by a boost factor, whose value depends on the shoot through duty ratio for a given modulation index. The diode D_1 is turned off due to the reverse-bias voltage.

By connecting the battery in parallel with capacitor C_2 of the QZSI, as shown in Fig. 2, this system is able to do the following simultaneously: 1) produce the desired output ac voltage to the grid/load; 2) regulate the battery state of charge (SOC) and 3) control the PV panel output power (or voltage) to maximize energy production. In fact, the

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battery in Fig. 1 has a big discharging power limitation due to the existence of the DCM, which limits the inverter output power. The battery paralleled with the capacitor makes the circuit quite different.

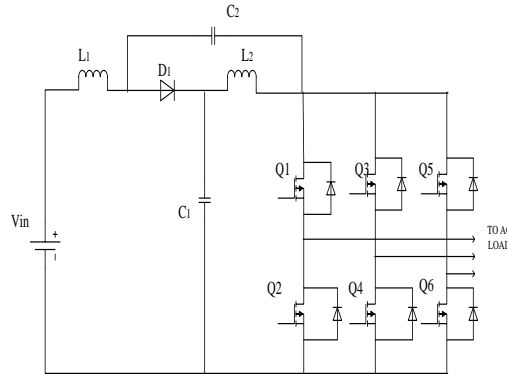


Fig.1. Quasi Z source inverter

For example, the inductor currents are no longer equal during battery charging and discharging, and the capacitor voltage is clamped by the parallel battery. It limits the ability to achieve a constant dc-link peak voltage. When the solar irradiation and the PV panel's temperature change randomly, the dc-link peak voltage will fluctuate accordingly. Also, it faces a challenge to simultaneously control three independent variables, i.e., the output power, the MPPT of the PV panel, and the dc-link peak voltage, using only two degrees of freedom, i.e., the shoot-through duty cycle and the modulation index.

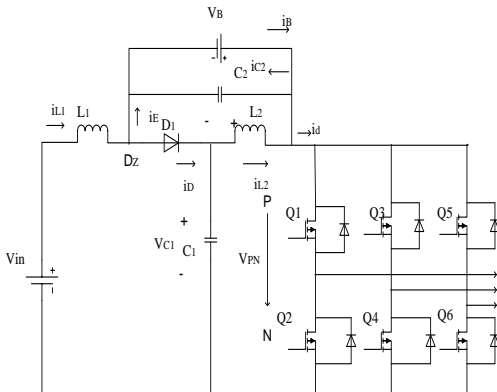


Fig.2. Existing QZSI with battery for PV power generation

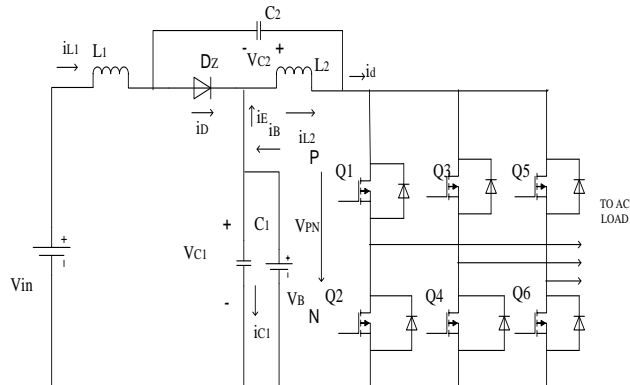


Fig.3. New energy-stored QZSI for PV power generation

II. NEW QZSI-BATTERY TOPOLOGY AND COMPARISON

Fig. 2 shows just one of the energy-stored QZSI topologies, where the battery is connected in parallel with the capacitor C_2 . As a counterpart, we connect the battery in parallel to the capacitor C_1 , leading to a new topology in Fig. 3. They have common points: 1) There are three power sources/consumers, i.e., PV panels, battery, and the grid/load, and 2) as long as controlling two power flows, the third one automatically matches the power difference, according to the power equation

$$P_{in} - P_{out} + P_B = 0 \quad (1)$$

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where P_{in} , P_{out} , and P_B are the PV panel power, the output power of the inverter, and the battery power, respectively. The power P_{in} is always positive because the PV panel is single directional power supply, P_B is positive when the battery delivers energy and negative when absorbing energy, and P_{out} is positive when the inverter injects power to the grid.

There are three operating states of the battery. When the battery is charging, thus $i_b > 0$, $i_{L2} > i_{L1}$, $P_{battery} > 0$, and $P_{PV} > P_{load}$; when the battery is discharging, $i_b < 0$, $i_{L2} < i_{L1}$, $P_{battery} < 0$, and $P_{PV} < P_{load}$; no charging and discharging, $i_b = 0$, $i_{L2} = i_{L1}$, $P_{battery} = 0$, and $P_{PV} = P_{load}$.

The grid-injected active power is changed to achieve the designed operating modes. Three cases have been investigated:

- 1) Battery charging mode
- 2) Neither charging nor discharging mode
- 3) Battery discharging mode

A. Battery Charging Mode

The PV panel received high solar irradiation. With the MPPT algorithm, the PV panel outputs high output current i_{L1} and power P_{in} to the energy-stored inverter. Light grid-injected power P_{out} results in $P_{in} > P_{out}$. The power difference ($P_{in} - P_{out} = P_b$) presents the superfluous PV power that is charged into the battery in the negative battery current.

B. Battery Neither Charging Nor Discharging Mode

The PV panel received low solar irradiation. As a result, the PV panel produced low output current i_{L1} and power P_{in} to the energy-stored inverter. The grid-injected active power is adjusted to match the PV power, i.e., $P_{in} = P_{out}$. For this case, there is no active power difference inputted into the battery, i.e., $P_b = P_{in} - P_{out} = 0$ W. The battery will be neither charging nor discharging for the zero battery current.

C. Battery Discharging Mode

The PV panel received low solar irradiation, leading to low current i_{L1} and power P_{in} . The grid-injected active power is increased to a high level, such that $P_{in} < P_{out}$. The grid requires much more active power than that PV panel could provide to track the desired value. For this situation, the battery will discharge, providing a positive current to supply the power shortfall. Finally, the grid injected active power reaches its desired value through the combination ($P_{out} = P_b + P_{in}$) of the PV panel and battery powers.

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.

Maximum power point tracking, frequently referred to as MPPT, is an electronic system that operates the PV modules such that the modules produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves" the modules to make them point directly at the sun. It only varies the electrical operating point of the modules so that they deliver the maximum available power.

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. 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.

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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. 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.

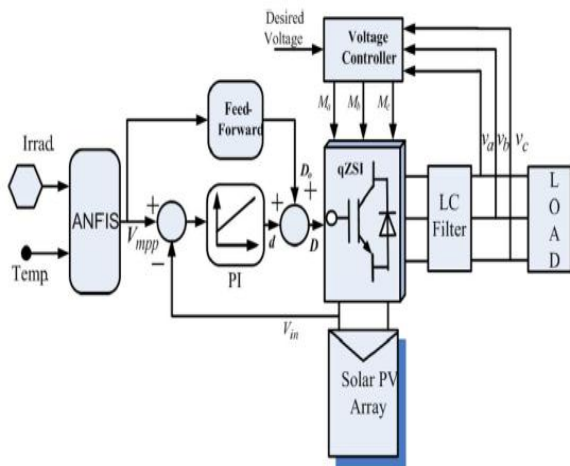


Fig.3. Control scheme with ANFIS-based MPPT

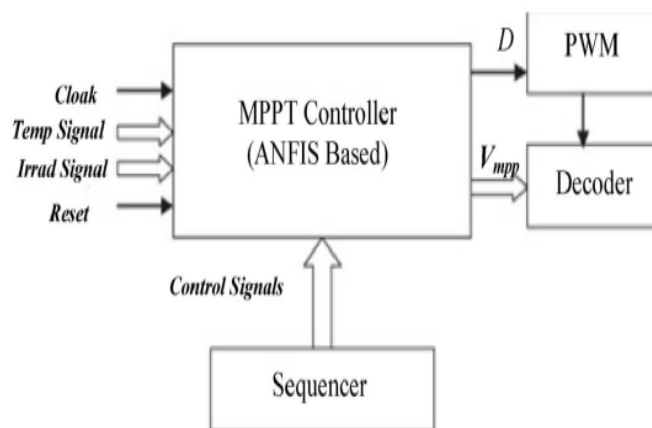


Fig.4. Schematic Outline for ANFIS Controller

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. 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 irradiance and temperature transducers are current/ voltage signals which are logged in real time using standard data loggers. These data are then transferred to the PC for further processing or implementation of real-time control system using the ANFIS controller. The maximum power delivery to the load is ensured by an adaptive neuro-fuzzy inference system (ANFIS) based on maximum power point tracking. It offers an extremely fast dynamic response with high accuracy.

IV. SIMULATIONS AND RESULTS

MATLAB Simulink (Fig.5) consists of PV panel using MPPT technique and QZS with battery. PV panel uses MPPT technique, which produces duty ratio for the switching of the QUASI-Z-Source inverter. Here battery is connected across the capacitor C_2 . Duty ratio is obtained by using ANFIS controller. Output is taken from the battery.

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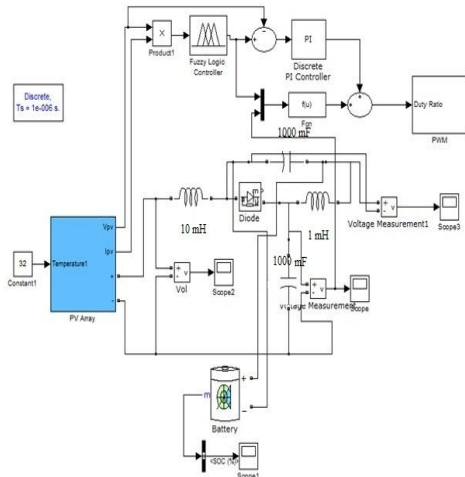


Fig.5. QZS with battery across C_2

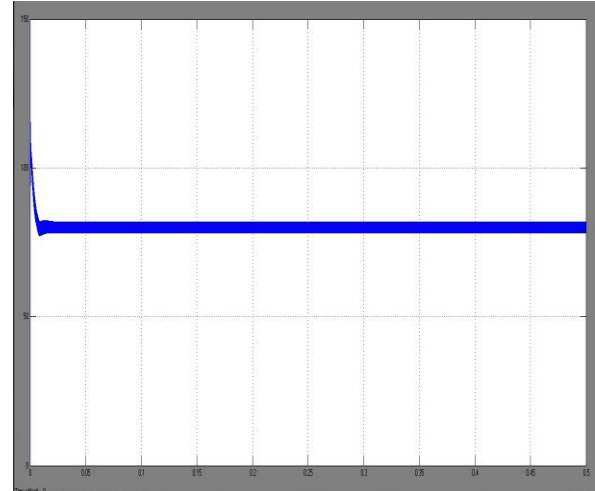


Fig.6. Output voltage waveform

Output voltage waveform of Fig.6 is 80V. It is obtained when battery is connected across C_2 .

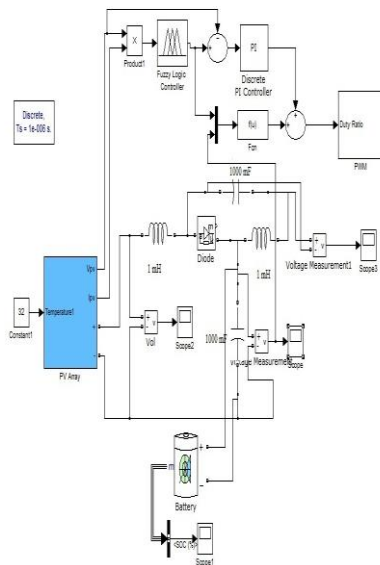


Fig.7. QZS with battery across C_1

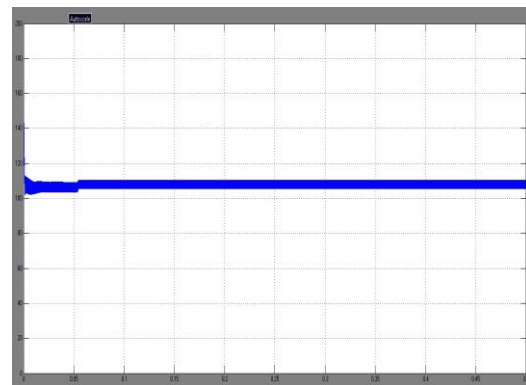


Fig.8. Output voltage waveform

MATLAB Simulink (Fig.7) consists of PV panel using MPPT technique and QZS with battery. PV panel uses MPPT technique, which produces duty ratio for the switching of the QUASI Z source inverter. Here battery is connected across the capacitor C_1 . Duty ratio is obtained by using ANFIS controller. Output is taken from the battery.

Output voltage waveform of Fig.8 is 110V. It is obtained when battery is connected across C_1 .

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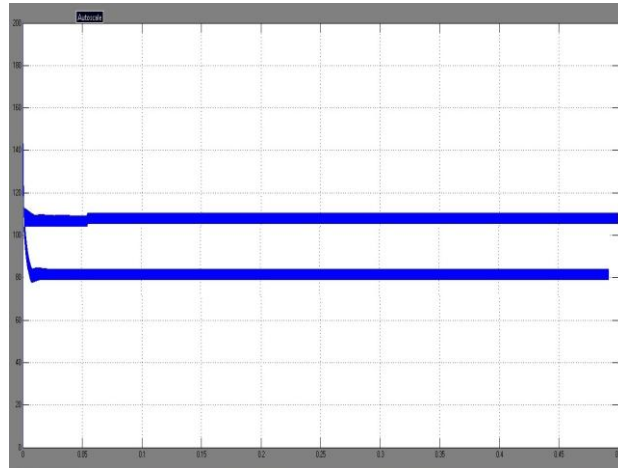


Fig.9. Comparative graph about the output voltage waveform

Output voltage waveform of Fig.5.2 is 80V and Output voltage waveform of Fig.5.4 is 110V, hence battery connected across C_1 provides more voltage than battery connected across C_2 .

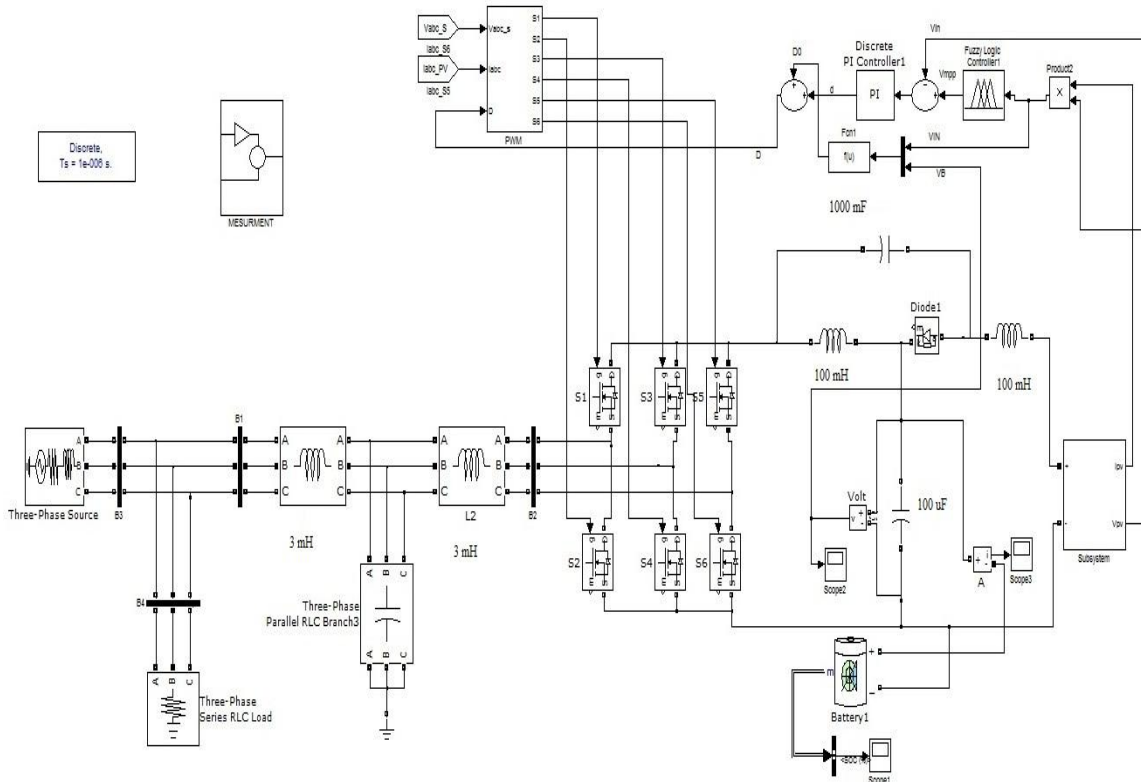


Fig.10. Energy-stored QZSI for PV power generation

Fig.10. shows just one of the energy-stored QZSI topology, where the battery is connected in parallel with the capacitor C_1 . Output voltage of PV panel is 200 V dc, which is given to the QUASI-Z-source, that boost the voltage and given to

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the inverter. Inverter converts the dc voltage into ac voltage, obtaining ac contain ripples which is filtered by LCL filter. Output voltage obtained is 200 V three phase ac, which is given to the ac grid or to the load. Output also contains the power factor, active power and reactive power. PV panel uses MPPT technique, which produces duty ratio for the switching of the QUASI-Z-Source inverter. Duty ratio is obtained by using ANFIS controller.

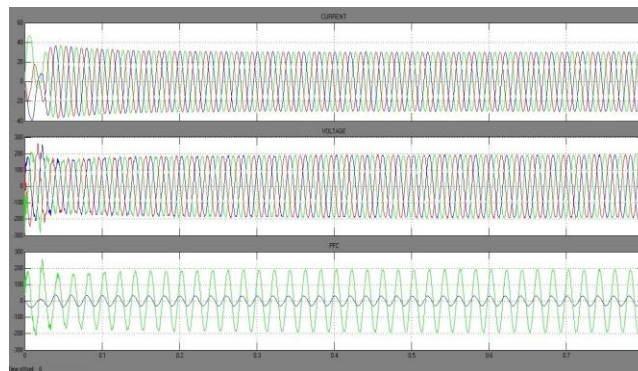


Fig.11. Output voltage, current, PFC waveforms

In Fig.11 output voltage is 200V three phase ac voltages and output current is 35 Ampere three phase current. In power factor correction the voltage and current of any one phase is taken, and are almost in phase with each other.

V. CONCLUSIONS

PV array has been simulated and integrated to the QZSI with maximum power point tracking algorithm (ANFIS method). The QZSI inherits all the advantages of the ZSI and features its unique merits. It can realize buck/boost power conversion in a single stage with a wide range of gain that is suited well for application in PV power generation systems. Furthermore, QZSI with battery has advantages of continuous input current, reduced source stress, and lower component ratings when compared to the traditional ZSI. Battery connected across C_1 in QZSI provides more voltage than battery connected across C_2 . It can effectively track the MPP in the PV module and inject the active/reactive power into the grid by the inverter, independently, as well as control the battery power flow. Energy-stored QZSI for PV power generation was simulated in MATLAB/SIMULINK, the output of simulated diagram was observed and analysed.

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