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## Research Paper

# RENEWABLE ENERGY SOURCES USING QUASI-Z-SOURCE INVERTER WITH DISTRIBUTION LEVEL POWER-QUALITY IMPROVEMENT

E Babu<sup>1</sup>, T Sasikumar<sup>1\*</sup>, S Nithyaprabu<sup>1</sup> and R Yogaraj<sup>1</sup>

\*Corresponding Author: **T Sasikumar** ✉ [Sasikumar92eee@gmail.com](mailto:Sasikumar92eee@gmail.com)

Quasi-Z-source inverters (QZSI) acquire all the advantages of traditional Zsource inverter. The impedance network couples the source and the inverter to achieve voltage boost and inversion in a single stage. By using this new topology, 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. The quasi-Z-source inverter (QZSI) is a single stage power converter derived from the Z-source inverter topology, employing an impedance network which couples the source and the inverter to achieve voltage boost and inversion. A new carrier based pulse width modulation (PWM) strategy for the (QZSI) which gives a significantly high voltage gain compared to the traditional PWM techniques is implemented. This technique employs sine wave as both carrier and reference signal, with which the simple boost control for the shoot-through states is integrated to obtain an output voltage boost. The conventional triangular wave carrier used in simple boost control technique is replaced by sine wave, which improves the shoot-through duty ratio for a given modulation index. The conventional perturb and observe maximum power point tracking algorithm is modified for QZSI and used along with the PWM technique for tracking the maximum power from PV. All the simulations are done using MATLAB. Hardware implementation and Microcontroller programming are done in the lab. All of these functions may be accomplished either individually or simultaneously. The combination of grid-interfacing inverter and the 3-phase linear/non-linear unbalanced load at point of common coupling appears as balanced linear load to the grid. This new control concept is demonstrated with extensive MATLAB/Simulink simulation studies and validated through digital signal processor-based laboratory experimental results.

**Keywords:** Distributed generation (DG), distribution system, grid interconnection, power quality (PQ), renewable energy.

## INTRODUCTION

Electric utilities and end users of electric power

are becoming increasingly concerned about meeting the growing energy demand. Seventy

<sup>1</sup> Jay Shriram Group Of Institutions, Tirupur.

five percent of total global energy demand is supplied by the burning of fossil fuels. But increasing air pollution, global warming concerns, diminishing fossil fuels and their increasing cost have made it necessary to look towards renewable sources as a future energy solution. Since the past decade, there has been an enormous interest in many countries on renewable energy for power generation. The market liberalization and government's incentives have further accelerated the renewable energy sector growth. Renewable energy source (RES) integrated at distribution level is termed as distributed generation (DG). The utility is concerned due to the high penetration level of intermittent RES in distribution systems as it may pose a threat to network in terms of stability, voltage regulation and power-quality (PQ) issues.

Therefore, the DG systems are required to comply with strict technical and regulatory frameworks to ensure safe, reliable and efficient operation of overall network. With the advancement in power electronics and digital control technology, the DG systems can now be actively controlled to enhance the system operation with improved PQ at PCC. However, the extensive use of power electronics based equipment and non-linear loads at PCC generate harmonic currents, which may deteriorate the quality of power.

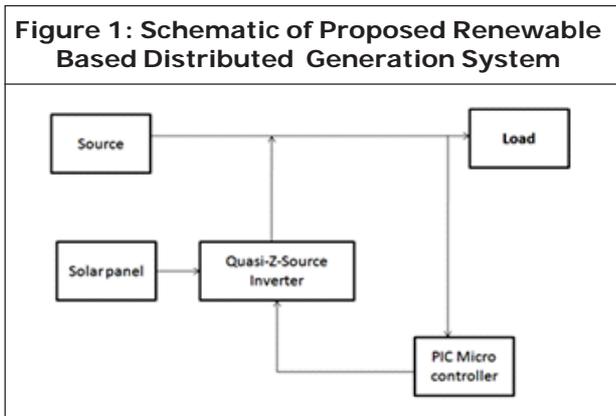
Generally, current controlled voltage source inverters are used to interface the intermittent RES in distributed system. Recently, a few control strategies for grid connected inverters incorporating PQ solution have been proposed. In an inverter operates as active inductor at a certain frequency to absorb the harmonic current. But the exact calculation of network inductance in real-time is difficult and may deteriorate the

control performance. A similar approach in which a shunt active filter acts as active conductance to damp out the harmonics in distribution network is proposed. In a control strategy for renewable interfacing inverter based on theory is proposed. In this strategy both load and inverter current sensing is required to compensate the load current harmonics.

The non-linear load current harmonics may result in voltage harmonics and can create a serious PQ problem in the power system network. Active power filters (APF) are extensively used to compensate the load current harmonics and load unbalance at distribution level.

This results in an additional hardware cost. However, in this paper authors have incorporated the features of APF in the, conventional inverter interfacing renewable with the grid, without any additional hardware cost. Here, the main idea is the maximum utilization of inverter rating which is most of the time underutilized due to intermittent nature of RES. It is shown in this paper that the grid-interfacing inverter can effectively be utilized to perform following important functions: 1) transfer of active power harvested from the renewable resources (wind, solar, etc.); 2) load reactive power demand support; 3) current harmonics compensation at PCC; and 4) current unbalance and neutral current compensation in case of 3-phase system. Moreover, with adequate control of grid-interfacing inverter, all the four objectives can be accomplished either individually or simultaneously. The PQ constraints at the PCC can therefore be strictly maintained within the utility standards without additional hardware cost.

The paper is arranged as follows: Section II describes the system under consideration and



the controller for grid-interfacing inverter. A digital simulation study is presented in Section III. Extensive experimental results are discussed in Section IV and, finally, Section V concludes the paper.

### SYSTEM DESCRIPTION

The proposed system consists of RES connected to the dc-link of a grid-interfacing inverter. The voltage source inverter is a key element of a DG system as it interfaces the renewable energy source to the grid and delivers the generated power. The RES may be a DC source or an AC source with rectifier coupled to dc-link. Usually, the fuel cell and photovoltaic energy sources generate power at variable low dc voltage, while the variable speed wind turbines generate power at variable ac voltage. Thus, the power generated from these renewable sources needs power conditioning (i.e., dc/dc or ac/dc) before connecting on dc-link. The dc capacitor decouples the RES from grid and also allows independent control of converters on either side of dc-link.

#### A. DC-Link Voltage and Power Control Operation

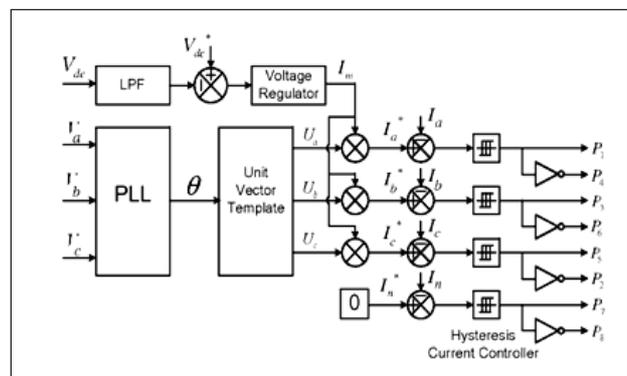
Due to the intermittent nature of RES, the generated power is of variable nature. The dc-

link plays an important role in transferring this variable power from renewable energy source to the grid. RES are represented as current sources connected to the dc-link of a grid-interfacing inverter. The systematic representation of power transfer from the renewable energy resources to the grid via the dc-link. The current flow on the other side of dc-link can be represented as, where and are total power available at grid-interfacing inverter side, active power supplied to the grid and inverter losses, respectively.

#### B. Control of Grid Interfacing Inverter

The fourth leg of inverter is used to compensate the neutral current of load. The main aim of proposed approach is to regulate the power at PCC during:

- 1)  $P_{RES} = 0$ ; 2)  $P_{RES} < \text{total load power (PL)}$ : While performing the power management operation, the inverter is actively controlled in such a way that it always draws/ supplies fundamental active power from/ to the grid. If the load connected to the PCC is non-linear or unbalanced or the combination of both, the given control approach also compensates the harmonics, unbalance, and neutral current.



The regulation of dc-link voltage carries the information regarding the exchange of active power in between renewable source and grid.

Thus the output of dc-link voltage regulator results in an active current. The multiplication of active current component with unity grid voltage vector templates ( $U_a$ ,  $U_b$  and  $U_c$ ) generates the reference grid currents. The reference grid neutral current is set to zero, being the instantaneous sum of balanced grid currents. The grid synchronizing angle obtained from phase locked loop (PLL) is used to generate unity vector template.

$$\begin{aligned}
 U_a &= \text{Sin}(\theta) \\
 U_b &= \text{Sin}(\theta - \frac{2\pi}{3}) \\
 U_c &= \text{Sin}(\theta + \frac{2\pi}{3}).
 \end{aligned}$$

The actual dc-link voltage is sensed and passed through a first-order *low pass filter* (LPF) to eliminate the presence of switching ripples on the dc-link voltage and in the generated reference current signals. The difference of this filtered dc-link voltage and reference dc-link voltage is given to a discrete-PI regulator to maintain a constant dc-link voltage under varying generation and load conditions. The dc-link voltage error at the sampling instant is given as:

$$V_{dcerr}(n) = V_{dc}^*(n) - V_{dc}(n).$$

The output of discrete-PI regulator at the sampling instant is expressed as

$$\begin{aligned}
 I_m(n) &= I_m(n-1) + K_{PV_{dc}}(V_{dcerr}(n) - V_{dcerr}(n-1)) \\
 &\quad + K_{IV_{dc}}V_{dcerr}(n)
 \end{aligned}$$

Proportional and integral gains of dc-voltage regulator. The instantaneous values of reference three phase grid currents are computed as

$$\begin{aligned}
 I_a^* &= I_m \cdot U_a \\
 I_b^* &= I_m \cdot U_b \\
 I_c^* &= I_m \cdot U_c.
 \end{aligned}$$

The neutral current, present if any, due to the loads connected to the neutral conductor should be compensated by forth leg of grid-interfacing inverter and thus should not be drawn from the grid. In other words, the reference current for the grid neutral current is considered as zero and can be expressed as

$$I_n^* = 0.$$

The reference grid currents ( $I_a^*$ ,  $I_b^*$ ,  $I_c^*$  and  $I_n^*$ ) are compared with actual grid currents ( $I_a$ ,  $I_b$ ,  $I_c$  and  $I_n$ ) to compute the current errors as

$$\begin{aligned}
 I_{aerr} &= I_a^* - I_a \\
 I_{berr} &= I_b^* - I_b \\
 I_{cerr} &= I_c^* - I_c \\
 I_{nerr} &= I_n^* - I_n.
 \end{aligned}$$

These current errors are given to hysteresis current controller. The hysteresis controller then generates the switching pulses ( $P_1$  to  $P_8$ ) for the gate drives of grid-interfacing inverter. The average model of 4-leg inverter can be obtained by the following state space equations

$$\begin{aligned}
 \frac{dI_{Inva}}{dt} &= \frac{(V_{Inva} - V_a)}{L_{sh}} \\
 \frac{dI_{Invb}}{dt} &= \frac{(V_{Invb} - V_b)}{L_{sh}}
 \end{aligned}$$

Where,  $V_{Inva}$ ,  $V_{Invb}$ ,  $V_{Invc}$ , and  $V_{Invn}$  are the three-phase ac switching voltages generated on the output terminal of inverter. These inverter output voltages can be modeled in terms of instantaneous dc bus voltage and switching pulses of the inverter as

$$\begin{aligned}
 \frac{dI_{Invc}}{dt} &= \frac{(V_{Invc} - V_c)}{L_{sh}} \\
 \frac{dI_{Invn}}{dt} &= \frac{(V_{Invn} - V_n)}{L_{sh}} \\
 \frac{dV_{dc}}{dt} &= \frac{(I_{Invad} + I_{Invbd} + I_{Invcd} + I_{Invnd})}{C_{dc}}
 \end{aligned}$$

Similarly the charging currents for  $I_{Invad}, I_{Invbd}, I_{Invcd}$ , on dc bus due to the each leg of inverter can be expressed as

$$\frac{dI_{Invc}}{dt} = \frac{(V_{Invc} - V_c)}{L_{sh}}$$

$$\frac{dI_{Invn}}{dt} = \frac{(V_{Invn} - V_n)}{L_{sh}}$$

$$\frac{dV_{dc}}{dt} = \frac{(I_{Invad} + I_{Invbd} + I_{Invcd} + I_{Invnd})}{C_{dc}}$$

### SIMULATION RESULTS

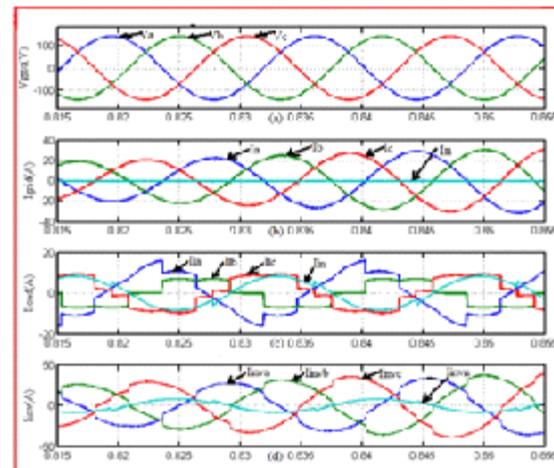
In order to verify the proposed control approach to achieve multi-objectives for grid interfaced DG systems connected to a 3-phase network, an extensive simulation study is carried out using MATLAB/Simulink. A 4-leg current controlled voltage source inverter is actively controlled to achieve balanced sinusoidal grid currents at unity power factor (UPF) despite of highly unbalanced nonlinear load at PCC under varying renewable generating conditions. A RES with variable output power is connected on the dc-link of grid-interfacing inverter. An unbalanced 3-phase 4-wire nonlinear load, whose unbalance, harmonics, and reactive power need to be compensated, is connected on PCC.

The experimental results for simultaneous active power filtering and RES power injection mode are In this case study it is considered that the generated power at grid-interfacing inverter is more than the total load power demand. Therefore, after meeting the load power demand, the additional RES power flows towards grid.

Positive values of grid active-reactive powers

and inverter active-reactive powers imply that these powers flow from grid side towards PCC and from inverter towards PCC, respectively. The active and reactive powers absorbed by the load are denoted by positive signs. Thus, this mode of operation validates the concept of utilization of grid-interfacing inverter as shunt APF when there is no power generation from the RES. The experimental results demonstrate the effective compensations of load current unbalance, harmonics and reactive power.

**Simulation results: (a) Grid voltages, (b) Grid Currents (c) Unbalanced load currents, (d) Inverter Currents**



Experimental results for the active power filtering and renewable power injection mode ( $P_{RES} > P_L$ ) (a) phase A performance, (b) phase B performance, (c) phase C performance, (d) grid currents (e) load, grid and inverter neutral currents. The total active and reactive powers of grid, load and inverter. In the APF mode of operation, the inverter consumes a small amount of active power to maintain the dc-link voltage and to overcome the losses associated with inverter, while most of the load reactive power need is supported by inverter effectively.

## Dynamic Performance of Proposed Control Approach

The experimental results to validate the dynamic performance of proposed control approach under different modes of operation. Initially, it is considered that the system is working under mode-A operating condition (i.e., non-linear load current harmonics and reactive power compensation). After few cycles, the power at dc-link is initially increased and then decreased, which can be noticed from the amplitude of injected inverter current profile. The corresponding decrease (for increased power level at dc-link) and increase (for decreased power level at dc-link) in grid current magnitude can also be noticed from Fig. 10, under constant load conditions. Thus, the proposed controller precisely manages any variation in real power at dc-link and effectively feeds it to the main grid. A smooth changeover from mode-A operating condition.

Experimental results: Dynamic performance of proposed approach

## CONCLUSION

This paper has presented a novel control of an existing grid interfacing inverter to improve the quality of power at PCC for a 3-phase DG system. It has been shown that the grid-interfacing inverter can be effectively utilized for power conditioning without affecting its normal operation of real power transfer. The grid-interfacing inverter with the proposed approach can be utilized to: i) inject real power generated from RES to the grid, and/or, ii) operate as a shunt Active Power Filter (APF). This approach thus eliminates the need for additional power conditioning equipment to improve the quality of power at PCC. Extensive MATLAB/

Simulink simulation as well as the DSP based experimental results have validated the proposed approach and have shown that the grid-interfacing inverter can be utilized as a multi-function device. It is further demonstrated that the PQ enhancement can be achieved under three different scenarios: 1)  $P_{RES}=0$ , 2)  $P_{RES}<P_{Load}$ , and 3)  $P_{RES}>P_{Load}$ . The current unbalance, current harmonics and load reactive power, due to unbalanced and non-linear load connected to the PCC, are compensated effectively such that the grid side currents are always maintained as balanced and sinusoidal at unity power factor. Moreover, the load neutral current is prevented from flowing into the grid side by compensating it locally from the fourth leg of inverter. When the power generated from RES is more than the total load power demand, the grid-interfacing inverter with the proposed control approach not only fulfills the total load active and reactive power demand (with harmonic compensation) but also delivers the excess generated sinusoidal active power to the grid at unity power factor.

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