ABSTRACT

A total power control scheme including DC link voltage and PWM control for Quasi Z-source inverter based grid-tie single phase photovoltaic power system is proposed. The DC link voltage control is employed to control the voltage of the inverter H-Bridge and provides a solution to the voltage imbalance problem. Independent MPPT is employed to control the shoot through states of the Quasi Z-source inverter and also the phase shifted PWM is employed for conventional non shoot through pulses to the inverter switches. For MPPT, the Perturb and Observe algorithm has been used. The Phase shift sinusoidal PWM technique has been implemented for generating the pulses to which the shoot through from the independent MPPT will be added. The PV module, the impedance network and the output filter has been designed for the inverter with output power of 0.6 kW. The Phase shift triangular carrier PWM has been implemented to add with shoot through states from the independent MPPT. The detailed design of the total power controlling action is disclosed in this paper. Simulations were carried out using MATLAB/SIMULINK and the simulation results are discussed.

Key words: Quasi Z-Source inverter, DC link voltage, MPPT, Double carrier PWM & Multilevel inverter, Photovoltaic system.

INTRODUCTION

As the renewable energy usage has been increasing day by day we need to efficiently trap it. So at every step of designing the stand-alone PV systems care must be taken to reduce the system size and cost without compromising its performance. As so many researches have been focused on the source and load side of the PV systems, we have taken our investigation towards the Quasi Z source inverter (QZSI) topology. The QZSI is a sub topology of Z-Source inverters. These inverters are gaining attention in the PV systems as they can boost the output voltage in a single stage and draws continuous current from the source. The QZSI topology allows independent control of power delivery with high reliability and distributed MPPT can be employed for this topology [4]-[7]. It has so many advantages compared with traditional voltage source inverters and are very suitable to PV systems. As the solar power fluctuates stochastically, it will be difficult to control the output voltage and power that is fed to grid. In this paper, a total power control scheme has been discussed for controlling the power of the PV based single phase grid tied QZSI. To effectively control the QZSI, independent control of DC link voltages and the pulse width modulation (PWM) are necessary [9]. The maximum power point tracking (MPPT) of the PV source has been employed with perturb and observe (P & O) algorithm for generating shoot through states and PWM has been employed with Phase shift triangular carrier PWM. The DC link voltage control and the grid injected power control is studied.

Topology Of Quasi Z-Source Inverter:

Figure 1 shows the circuit configuration of Quasi Z-Source inverter (QZSI). As like any other
inverter, the QZSI has a DC or PV source. Instead of connecting the voltage source directly to the inverter H-bridge, an impedance network is connected in between. It has certain significance over conventional voltage source inverters. By employing the unique impedance network between the voltage source and the inverter bridge, the following advantages can be achieved.

1. The AC output voltage will be more than the input DC rail voltage.
2. The upper and lower devices can be gated simultaneously without creating short circuit with the source.
3. Overdrive can be achieved without additional converter stages to obtain the required output which reduces the system cost and reduces efficiency.
4. They are less vulnerable to EMI noise.

**Fig. 1:** Quasi Z-source Inverter

*Operating States Of The Quasi Z-Source Inverter:*

There are two operating states in a QZSI. They are non-shoot through state and shoot through state. The equivalent circuits of the two states are shown in fig.2 and 3. With the QZSI, the unique LC and diode network connected to the inverter bridge modify the operation of the circuit, allowing the shoot-through state. This network will effectively protect the circuit from damage when the shoot-through occurs and by using the shoot-through state, the QZS network boosts the dc-link voltage. The non-shoot through state consists of usual active and zero states of any VSI. In boost mode some or all of the zero states are replaced by shoot-through states depending on the PWM technique used.

**Fig. 2:** QZSI in non-shoot through state

**Fig. 3:** QZSI in shoot through state

*Impedance Network Design Of QZSI:*

The inductance and capacitance values of the QZSI are calculated as follows.

\[
L_1 = L_2 = \frac{\Delta T V_L}{\Delta I} = \frac{T_{m}m V_{in}}{2 J_{L} R_{c}}
\]

(1)

\[
\text{Inductance:}
\]

\[
\text{Capacitance:}
\]
\[ C_1 = C_2 = \frac{2 \Delta T J_e}{\Delta (V_{C1}+V_{C2})} = \frac{T_o m I_L}{2 B V_{oc} R_s} \]  

(2)

Where,

\[ T_o \] - Shoot-through Interval, \( M \) - Modulation Index, \( R_c \) - Peak current ripple in \%, \( R_v \) - Peak voltage ripple in \%.

\[ I_L \] - Rated Load current and \( f_s \) - Switching frequency

**Photovoltaic cell equivalent electrical circuit** is shown in figure 4.

\[ \text{Fig. 4: Equivalent circuit of photovoltaic cell} \]

The I-V and P-V characteristics of the solar cells are non-linear in nature. The solar cell characteristics mainly depend on the existing atmospheric conditions such as temperature and irradiance. The P-V characteristics of solar cell are shown in figure 5. The I-V curve shown in figure 6 is for the PV module under sunlight and dark conditions.

\[ \text{Fig. 4: P-V characteristics of a PV cell} \]

\[ \text{Fig. 5: P-V characteristics of a PV cell} \]

The PV cell can be mathematically modelled using the following equations.

The load current is given by the following equation

\[ I = I_L - I_D \left[ e^{\frac{Q V_{oc}}{k T}} - 1 \right] - \frac{V_{oc}}{R_s} \]  

(5)

Where,

\[ I_D \] - Diode saturation current, \( Q \) - Charge of an electron = \( 1.6 \times 10^{-19} \) C, \( A \) - Curve fitting constant, \( k \) -
Boltzmann constant = $1.38 \times 10^{-23}$ J/K, $T$ – Absolute Temperature in K.

**Independent MPP Control:**

Perturb and Observe algorithm has been implemented for tracking maximum power point. It is a very simple algorithm which requires the measurement of solar panel’s output voltage and current. The perturbation at each step is used to find out the maximum power. The flow chart of the P & O algorithm is shown in figure 6.

**Fig. 6:** Flow chart of P & O MPPT algorithm

Figure 7 shows the simulation circuit of designed PV module along with MPPT implemented using P and O algorithm.

**Fig. 7:** Simulation of PV Module with MPPT

The simulation parameters for the PV module has been listed in table 1.

**Table 1:** Simulation parameters of PV array

<table>
<thead>
<tr>
<th>PV Parameters</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open circuit voltage $V_{oc}$</td>
<td>105.1 V</td>
</tr>
<tr>
<td>Short circuit current $I_{sc}$</td>
<td>2.55 A</td>
</tr>
<tr>
<td>No of cells $N_s$</td>
<td>36</td>
</tr>
<tr>
<td>Insolation $G$</td>
<td>1000 W/m²</td>
</tr>
<tr>
<td>Ideality factor $A$</td>
<td>1.5</td>
</tr>
<tr>
<td>Operating temperature $T$</td>
<td>298 K</td>
</tr>
</tbody>
</table>

Figure 8 represents the shoot through pulses generated from the independent MPPT control.
Depending upon the variations in the PV output, the Perturb and observe algorithm tries to always operate the PV in its maximum power point by changing the reference wave for shoot through pulse generation.

**Phase Shift Carrier Pwm:**

The reference wave generated from the DC link voltage control will be used to generate PWM pulses using phase shifted triangular carriers. The resulting output pulse will be added along with the shoot through pulses produced from the independent MPPT. The Phase shift technique has been chosen out of the other carrier amplitude PWM techniques such as PD, POD, APOD because it has balanced switching action and there is no difficulty in implementing shoot through states. Figure 9 represents the PS-PWM carriers.

**Total Power Control And Dc Link Voltage Control:**

The power injected to the grid is the PV string output power. Let the power reference be \( P_n^* \).

The peak value of the grid current is

\[
I_{\text{grid max}} = \frac{2P^*_n}{V_{\text{grid peak}}}
\]

(6)

To ensure unity power factor operation, the phase locked loop (PLL) is used to measure the phase of the grid voltage. The grid current is measured and fed back to the current loop. The output voltage \( V_{\text{total}} \) is given by the current loop to produce the modulation index. With the modulation index and the shoot-through duty ratio from the MPPT, the required gating signals are produced for the QZSI [9]-[10]. Figure 10 and 11 shows the control scheme and power control of the QZSI.

**Fig. 8:** Shoot through pulses generated from MPPT

**Fig. 9:** Phase shift triangular carrier PWM

**Fig. 10:** Control scheme of the QZSI
Simulation Results of The Total Power Control Scheme:

Simulation of the QZSI with total power control and DC link voltage control has been carried out using MATLAB/Simulink.

The simulation parameters of the QZSI has been listed in table 2. The gating pulses for the QZSI are shown in figure 13.

Table 2: Simulation parameters of QZSI

<table>
<thead>
<tr>
<th>QZSI Parameters</th>
<th>Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>105 V</td>
</tr>
<tr>
<td>Inductors $L_1, L_2$</td>
<td>3 mH</td>
</tr>
<tr>
<td>Capacitors $C_1, C_2$</td>
<td>2200 µF</td>
</tr>
<tr>
<td>Boost Factor B</td>
<td>1.66</td>
</tr>
<tr>
<td>Switching frequency $f_s$</td>
<td>5kHz</td>
</tr>
</tbody>
</table>

Fig. 11: Power control of the whole system

Fig. 12: Simulation of QZSI with Power control of the whole system

Fig. 13: Gating pulses for the QZSI
The output current, output voltage and output power fed to the grid from the PV sourced QZSI has been shown in figure 14.

![Figure 14: Grid current, Grid Voltage and output power of the QZSI](image)

The grid voltage and grid current was obtained as 230 V and 2.55 A respectively. So the total output power was found to be 600 W in the simulation result.

**Conclusion:**

The total power control of QZSI grid tie single phase photovoltaic system has been discussed clearly. The PV system acts as source for the QZSI and it was modeled mathematically using equations in MATLAB/Simulink. Also independent MPPT is employed with Perturb and Observe algorithm to control the shoot through states of the QZSI when there are drastic variations in PV source. With an input voltage of 105 V obtained from PV, the QZSI is designed to boost the voltage to 230 V. A grid current controller controls the grid current and the DC link voltage is controlled by DC link voltage control. The phase shifted carrier PWM has also been implemented for adding its advantages to the QZMLI. As a whole the total power of the system was controlled by controlling the modulation index and the shoot through of the QZSI. The controllers were simulated using MATLAB/Simulink and the grid voltage obtained was 230 V. The grid current of 2.5 A and the power output was around 600 W.

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**References**