MPPT for Single Phase Five Level Quasi-z-source Photovoltaic Inverter with Fuzzy Controller

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Abstract. The fast growth of PV system has led to the development of power electronics devices which come along with lots of challenges. One of these is the structure design including the choice of different elements involved. This paper presents an advanced off grid photovoltaic (PV) system with less components and high efficiency. The structure shows a multilevel cascaded inverter (CHB) with the advantage of less harmonics and high voltage level, quasi-z source inverter (Q-ZSI) which plays the buck/boost function for efficient operation of power electronic devices. Hence, reducing the cost and the volume of the whole system. The buck/boost operation is implemented by simple boost control (SBC) method for shoot through insertion. The pulse width modulation technique (SPWM) used is phase shift technique (PS-SPWM). This paper also compares the performance of fuzzy logic controller (FLC) with incremental conductance (Inc cond) algorithm for MPPT by focussing on their adaptability, speediness and precision despite the changes in solar irradiance. The overall system is implemented in matlab-simulink environment for simulation. Thereby confirming the feasibility and efficiency of the system.

Keywords: MPP; Q-Z source inverters (Q-ZSI); Simple boost control (SBC); Phase shift technique (PS-SPWM); FLC; shoot through; irradiance; Inc cond.

1. Introduction
In the near future, it is obvious that renewable energy will be substituted to the classical ones because of its availability and pollution free. Photovoltaic system (PV) is one of the upcoming alternatives in this situation. But the development of PV system is coming along with lots of challenges ahead since meteorological factors (such as solar irradiance, temperature etc.) have great impact on PV output systems [1-2]. Research is aimed at mitigating these problems related to the utilization of PV system. When dealing with the photovoltaic system, the interface converter plays a vital role. Conventionally two stage converter is being. But due to the well-known drawbacks, new PV system structures came out such as single stage with Q-ZSI as interface. Hence, reducing the cost and the volume of the whole system [3-4]. In order to get the entire benefit of buck/boost quality of Q-ZSI, proper shoot through insertion must be done using the techniques commonly applied such as simple boost control (SBC) [1], maximum boost control (MBC) [2], maximum constant boost [MCBC] [3]. Multi-level inverter is also another trend of power electronics development. There are mainly divided into two major groups [1-2]. The one using multi DC source (neutral point clamp and flying capacitor) and the other with single DC source cascaded H Bridge (CHB). CHB is preferred because it provides series of
combination yielding voltages from level three up to N-level and low harmonics under both balanced and unbalanced DC source. For efficient use of power converter in PV system, proper algorithm for maximum power point tracking (MPPT) is of great importance. Previously, classical methods were used such as perturb and observe (P&O) [2], Incremental conductance (Inc Cond) [3], Nowadays, intelligent control is more and more applied in PV system to overcome the limitations of the above mentioned methods due to its speed and precision of tracking the maximum power point (MPP). Fuzzy controller has shown its performance [5]. This paper presents single stage multilevel inverter off-grid system. First, different modes of Q-ZSI is analyzed; second, the PS-PWM technique and shoot-through insertion are explained; third, both fuzzy and inc cond controllers are designed for targeting the maximum power point (MPP); Then simulation and discussion will follow and lastly conclusion will be made.

\[ V_{ij} = V_{in} - V_{cl} \]  
\[ V_{i2} = V_{c2} + V_{in} \]
\[ V_{out} = 0 \]  

2. Quasi Z Source Inverter

Due to the limitations shown by the traditional ZSI (Z source inverter) such as current discontinuity during boost mode and high capacitor voltage and in some cases control complexity, Q-ZSI (quasi-z source inverter) was developed to overcome those drawbacks. Q-ZSI exhibits two operating modes Figure 2 exhibits the traditional six active states and two zero states. While figure 3 which is the special feature of Q-ZSI allows shoot-through insertion for boosting purpose. Shoot-through state is not allowed in conventional voltage source inverter since it causes short circuit. Thus, destroying the device.

\[ V_{out} = V_{cl} - V_{i2} = V_{ij} = V_{cl} + V_{c2} \]  
\[ V_{diode} = 0 \]  

\[ V_{ij} = V_{c2} + V_{in} \]  
\[ V_{i2} = V_{cl} \]  
\[ V_{out} = 0 \]
\[ V_{\text{diode}} = V_{c1} + V_{c2} \]  

(8)

The average voltage of the inductors over one switching period at steady state is zero. From equation (5) and equation (6) we derive:

\[ V_{i1} = \frac{T_0 (V_{c2} + V_{in}) + T_1 (V_{in} - V_{c1})}{T} = 0 \]  

(9)

\[ V_{i2} = \frac{T_0 (V_{c1}) + T_1 (-V_{c2})}{T} = 0 \]  

(10)

\[ V_{c1} = \frac{T_1}{T_1 - T_0} V_{in} \]  

(11)

\[ V_{c2} = \frac{T_0}{T_1 - T_0} V_{in} \]  

(12)

From the above equation (8), equation (11) and equation (12), we obtained the peak voltage across the converter

\[ V_{\text{out}} = V_{c1} + V_{c2} = \frac{T_0}{T_1 - T_0} V_{in} = \frac{1}{1 - \frac{2T_0}{T}} V_{in} = B V_{in} \]  

(13)

B is the boost factor. We observe that by adjusting D in the range of [0 0.5], we can boost the voltage from any value to infinity. As far as PV system is concerned, Vin is equaled to Vpv obtained from PV array. By adjusting the duty shoot-through (or boost factor B), one can boost Vpv thereby obtaining the MPP since Vmpp = Vpv.

3. PWM Technique and Shoot through Insertion

Conventionally PWM exhibits eight states when applied to the traditional VSI (voltage source inverter). This paper utilizes phase shift technique shown in Figure 4. This technique is implemented using bipolar sine wave combined with high frequency carrier with the aim of reducing harmonics. The phase shift modulation scheme is composed of carrier’s signals having the same characteristics but displaced by 90 degree between each other. The phase shift difference is obtained according to the levels of the inverter using equation (14) below. The above mentioned shifted carriers have each its opposite carrier (180 degree out of phase). The gating scheme at any time is executed by two opposite switches for each single module of CHB. The control of each CHB module is independent. For the voltage to be boosted, an extra technique has to be used to deal with the special feature of Q-ZSI. In this paper simple boost control method is used as depicted in Figure 4. Two straight lines are introduced at the top and the bottom. The shoot-through is inserted into the circuit right at the traditional zero state whenever the carrier signal is greater or lesser than the straight lines mentioned above. Thereby bringing change to the traditional PWM technique. This shoot-through is done without disturbing the active states.

\[ \theta_{\text{carrier}} = \frac{360^\circ}{n-1} \]  

(14)
4. Fuzzy and Incremental Conductance Controller Design

Fuzzy controller is one of the latest control algorithms called intelligent control. It has shown its performance by using imprecise inputs. This technique is made of three stages: fuzzification, rules evaluations and defuzzification. This paper uses FLC in combination with PS-PWM technique to catch speedily the maximum power point (MPP) with less oscillation. The FLC uses two inputs error and change on error and their membership functions are designed and plot using 25 rules as shown by table I.

\[
E(K) = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \quad (15)
\]

\[
CE(K) = E(K) - E(K-1) \quad (16)
\]

Both P and V are respectively power and voltage of the PV module. E(k) is the P-V curve slope. Hence, defining the position of the MPPT. Figure 5 shows the membership functions of the error E(K) designed using 25 rules. The same explanations hold for CE(K) shown in figure5 (b). The change in error rather tells us whether the operating point is on the right path and from the output value which is the duty ratio, one can notice whether the operating point is located on the right or left of the MPPT. The output duty is fed to the SP-PWM for proper triggering of Q-ZSI.

Incremental conductance algorithm is implemented by sampling both voltage and current and using PID controller to generate shoot through duty using algorithm in figure 8.

| Fuzzy Rules | E(k) | CE(K) |
|-------------|------|-------|
| NB          | NB   | NS    |
| NS          | PS   | PB    |
| ZE          | ZE   | NB    |
| PS          | PB   | PS    |
| PB          | ZE   | NS    |
| PB          | NS   | ZE    |
| PB          | PS   | PB    |
| PB          | NB   | NS    |
| PB          | ZE   | NS    |
| PB          | NS   | ZE    |

Table 1. Fuzzy rules.

![Figure 5. Membership functions (a) P-Vslope (b) change of error.](image-url)
5. Simulation Analysis
The schematic diagram is shown above in figure 1. To confirm the feasibility of the proposed fuzzy and incremental conductance controllers, simulation is carried out in matlab/Simulink. Taking into account both the voltage and current ripple of capacitors and inductors of Q-ZSI, parameters of table 2 are obtained. Due to similarity and to avoid redundancy, we will be using in case of necessity one
branch of the schematic diagram. Figure 2 and figure 3 explain the working principles of Q-ZSI through two known modes that are shoot-through and non-shoot-through leading to the boosting of the PV input voltage. Figure 6 displays the P-V curve with three distinct shapes according to different values of irradiance. Figure 9 shows fuzzy controller with constant irradiance of 1000w/m² up to 0.7s. Power oscillates tightly around 50 watts which is in conformity with Table 2. When solar irradiance decreases to 800w/m² from 0.7s to 1s, power drops to 40W and finally to 20W, with 500w/m² as irradiance from 1s to 2s. Meanwhile, inc cond exhibits 45W at MPP and the remaining shape of the curve follows the fuzzy one with slight deviations. Figure 10 confirms the advantages of multilevel inverter by exhibiting 35.57V with 1000w/m² as solar irradiance which is almost twice the cell voltage. Fuzzy technique yields low THD of 1.31% as displayed in figure 12, whereas inccond yields a THD of 1.38 as shown in figure 11. Figure 7 displays the fuzzy searching path to locate the MPP. The voltage starts from 9V and moves quickly towards Vmpp (18.4V) and sharply to the MPP (50W) which means the operating point is kept at the vicinity of the MPP with FLC. This demonstrates that the simulation results agree with the ideas that guided the conception of fuzzy rules.

Table 2. Electrical characteristics of PV module and system parameters.

| Parameter                        | Value     | Element       | System parameters |
|----------------------------------|-----------|---------------|-------------------|
| Power                            | 50 W      | L1=L1         | 1mH               |
| Open circuit voltage(Voc)        | 21.5V     | C1=C2         | 1000µf            |
| Short circuit current(Isc)       | 2.95A     | Switching frequency | 10KHZ             |
| Voltage at MPP(Vm)               | 18.4      | R-load        | 7ohms             |
| Current at MPP(Im)               | 2.72A     | L-load        | 0.5 mH            |
| Test irradiance                  | 1000W/m²  | L-filter/C-filter | 20 mH/495µF       |

![Figure 9. Controllers’ performa.](image)

![Figure 10. Fuzzy output voltage.](image)

![Figure 11. Incremental conductance THD.](image)

![Figure 12. Fuzzy THD.](image)
6. Conclusion
This paper presents single stage multilevel inverter with Q-ZSI which improves the utilization of PV system. This topology also shows increase in voltage which in this case is twice the PV module output and less harmonics with THD equals to 1.31% when FLC is used. Whereas inc cond catches less power with THD equals to 1.38%. The higher the irradiance the higher the PV output vice versa. Simulation has also strongly demonstrated that phase shift PWM combined with well-designed fuzzy rules can track efficiently the MPP with less oscillation around the operating point and less harmonics compared to incremental conductance algorithm. This research can be used in stand-alone system to supply energy to remote area as well as in grid-connected system. When connected to the grid, not only it supplies power to the grid but also improves power quality.

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