Solar Smart Inverter using Multi-Cell Cascaded Inverter Topology and Closed Loop Boost Converter with Load Detection without using Microcontroller

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Abstract

The term solar smart inverter has become very important in the electronics industry. It is a combination of multi-level inverter and solar charging. Inverters are primarily classified as single level and multilevel inverters. Minimum harmonic distortion, reduced EMI generations are the major advantages of multilevel inverters as compared to single level inverters. Multilevel inverters can operate on various voltage levels and its applications, such as active power filters. By using sinusoidal pulse-width modulation (SPWM) control, within the inverters we can control the gain of inverters more effectively. One of the most forthright methods of describing voltage source modulation is a SPWM scheme that can be conceived by the intersection of a modulating signal with triangular carrier waveforms. In this paper, we have designed a Solar Multilevel Pulse Width Modulator inverter using SPWM and cascade 2H-bridge topology which increases the efficiency and reliability of the system.

Keywords: Multilevel Inverter, Sinusoidal Pulse-Width Modulation, 2 H-Bridges, Closed Loop Boost Converter, Load-Detection, Integrator, Differentiator, Comparator

I. INTRODUCTION

Due to extensive usage of fossil fuels, the greenhouse effect and its gases are generated. Price of fossil fuels is increasing and it has made us to utilize solar energy. This paper emphasis on Solar Smart Inverter which is made up of solar charging through closed loop boost converter and multi-cell inverter topology. In next few years, the power inverter will change more than its past few years. New technology basically focuses on inverter stability and its improvement. Multilevel Inverter Topology includes 2 H-Bridge inverters, Triangular and Square wave generator for generation of Sinusoidal Pulse Width Modulation (SPWM) and basic circuits of comparator, integrator and differentiators, NOT gate IC and IR2110 red band ICs. We have used Sinusoidal Pulse Width Modulation (SPWM) for controlling the switching of the H-Bridge Topology. Along with multi-cell inverter, closed loop boost converter and charging constitute Solar Smart Inverter (SSI). [6][7]

II. PROPOSED TOPOLOGY

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![Diagram](image-url)

Fig. 1: Proposed Solar Smart Inverter
Figure 1 shows the Proposed Solar Smart Inverter. Solar Smart Inverter can be divided into two sections. First section is boost converter and second is Multilevel Inverter and load detection and charging. Switching section and Control section are major divisions of Multilevel Inverter. We cannot charge all batteries at a time because of common ground problem. Common ground problem arises when multilevel charging is employed. Multilevel charging needs separate ground for each battery.

III. SYSTEM DESIGN

A. Closed Loop Boost Converter

In this closed loop boost converter the given supply from the solar panel is boosted and regulated to charge the batteries. Primarily the inductor stores the energy and that stored energy is added to the final output of the converter and by using the voltage divider rule, some desired voltage is obtained and that voltage is compared with the reference source as shown in figure 2. Then that compared output is given to the integrator or the PID controller (if needed) which integrates the amplitude of the given input and again its output is compared with the triangular carrier waveforms and that output is given as the gate pulses of the used switches like IGBTs, MOSFETs, etc. [1][5][6][7].

![Closed Loop Boost Converter](image)

**Fig. 2 : Closed Loop Boost Converter**

![Output waveforms of current & voltage for Boost Converter](image)

**Fig. 3 : Output waveforms of current & voltage for Boost Converter**

By applying this closed loop converter in the scheme, one can reduce the output voltage ripple, controlled output magnitude and an efficiency of the converter also increases. The schematic diagram for the closed loop boost converter and its output current & voltage waveforms are shown in the figures 2 and figures 3 respectively. As we change the values for the inductor or capacitor, one can see the reduction in the output voltage ripple. For designing the boost converter [5][6]. For designing the Boost Converter following equations are used respectively:

The first step to calculate the switch current is to determine the duty cycle, \(D\), for the minimum input voltage. The minimum input voltage is used because this leads to the maximum switch current.

\[
D = 1 - \frac{V_{\text{in}}(\text{min}) \cdot \eta}{V_{\text{out}}} \quad (1)
\]

\(V_{\text{in}}(\text{min})\) = minimum input voltage

\(V_{\text{out}}\) = desired output voltage
η = efficiency of the converter, e.g. estimated 80%. The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

The next step to calculate the maximum switch current is to determine the inductor ripple current. In the converters data sheet normally a specific inductor or a range of inductors is named to use with the IC. So either use the recommended inductor value to calculate the ripple current, an inductor value in the middle of the recommended range or, if none is given in the data sheet, the one calculated in the Inductor Selection section of this application note.

\[ \Delta I_l = \frac{V_{\text{in(min)}} \times D}{F_s \times L} \]  
\[ (2) \]

Vin (min) = minimum input voltage
D = duty cycle calculated in Eq.1.
Fs = minimum switching frequency of the converter
L = selected inductor value

Now it has to be determined if the selected IC can deliver the maximum output current.

\[ I_{\text{max out}} = \left[ I_{\text{lim(min)}} - \frac{\Delta I_l}{2} \right] \times (1 - D) \]  
\[ (3) \]

The inductor ripple current cannot be calculated with Equation 1 because the inductor is not known. A good estimation for the inductor ripple current is 20% to 40% of the output current.

\[ \Delta I_l = (0.2 \text{ to } 0.4) \times I_{\text{out(max)}} \times \frac{V_{\text{out}}}{V_{\text{in}}} \]  
\[ (4) \]

For the output capacitor, with internally compensated converters, the recommended inductor and capacitor values should be used or the recommendations in the data sheet for adjusting the output capacitors to the application should be followed for the ratio of L × C. With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple:

\[ C_{\text{out(min)}} = \frac{I_{\text{out(max)}} \times D}{F_s \times \Delta V_{\text{out}}} \]  
\[ (5) \]

Where, Cout(min) = minimum output capacitance, Iout(max) = maximum output current of the application, D = duty cycle calculated with Eq.1, Fs = minimum switching frequency of the converter, ΔVout = desired output voltage ripple The ESR of the output capacitor adds some more ripple, given with the equation:

\[ \Delta V_{\text{out(ESR)}} = ESR \times \left[ \frac{I_{\text{out(max)}}}{1 - D} + \frac{\Delta I_l}{2} \right] \]  
\[ (6) \]

B. Multi-cell 2 H-bridge Cascaded Inverter

Two H-bridge circuit to get five levels of AC voltage by SPWM switching scheme powered by two separate DC sources together constitute multilevel inverter. A single-phase structure of an m-level cascaded inverter is illustrated in Figure 4. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge inverter. Each inverter level can generate three different voltage outputs, +V dc, 0, and -V dc.

By connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, and S4. To obtain +V dc, switches S1 and S4 are turned on, whereas -V dc can be obtained by turning on switches S2 and S3. By turning on S1 and S2 or S3 and S4, the output voltage is 0. For designing this inverter go through the [2] [3] [4] [6]. In this inverter the carrier triangular waves are made using square wave generator and integrator which is Compared with common sine wave for the gate pulses of inverters, Reference[7].

![Fig. 4: m-level multicell cascaded inverter](image-url)
The AC outputs of each of the different Full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels \( m \) in a cascade inverter is defined by \( m = 2s + 1 \), where \( s \) is the number of separate dc sources. For an example phase voltage waveform for an 11-level cascaded H-bridge inverter with 5 SDCSs and 5 full bridges is shown in Figure 5. The phase voltage
\[
V_{an} = v_{a1} + v_{a2} + v_{a3} + v_{a4} + v_{a5}.
\]

For a stepped waveform such as the one depicted in Figure 5 with 5 steps, the Fourier Transform for this waveform follows:
\[
V(wt) = 4V_{dc}X_n\{\cos(n\theta_1) + \cos(n\theta_2) + \ldots + \cos(n\theta_5)\}\sin(nwt) \ldots \text{where } n = 1, 3, 5, 7, \ldots
\]

This waveform in figure 5 shows the output wave for each stage for five H-bridge 11 level multi-cell cascaded inverter for reference. As we increase the number of bridges, the accuracy for the sine wave increases. I have made this inverter for two full bridges cascaded inverter using sinusoidal pulse-width modulation (SPWM). By using SPWM, we get the different width of pulses in the output waveforms as illustrated in the figure 7. Below are the simulation waveforms of the multi-cell 2 H-bridge inverter and the circuit diagram for the 2H-Bridge Cascaded Inverter in figure 6.
Now, the load detection is incorporated with the help of optocoupler IC or relay in order to detect load-variation. The current transformer detect load variation and feedback to battery to connect or disconnect the system.[4].

If unendurable load variation occurs then the system will automatically shut down. We can minimize problem caused by the adverse effect of weather disasters by interfacing this with the grid. Furthermore efficiency of switching scheme can be improved by implementing space vector sinusoidal pulse-width modulation.

IV. CONCLUSION

Solar power continues to demonstrate its potential as a breakthrough for renewable energy. As companies continue the research into solar power, the technology for them is becoming more and more useful. After the capstone design, we designed a DC-DC converter with MMPT function which is for specific application. Solar Smart Inverter has a great significant to energy saving and utility system integration. Of course there can be some future work and we are going to continue our work in combining the design with building, cars and many other places where it can be useful.

REFERENCES