Experimental study of Bipolar PV Inverter for nonlinear load

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Abstract – One of the attractive options for converting solar PV DC/AC modules is a bipolar inverter as bipolar technique provide easy control and theoretically low-priced technology. A few drawbacks to this bipolar method, since it has a high voltage DC-link ripple, which can cause high harmonic inverter distortion. A smooth DC voltage is then needed to preserve the unstable voltage of the PV device in such a way that the overall harmonic distortion of the inverter is preserved at the regular stage. This paper will demonstrate the impact of unstable voltage from PV and connecting to the nonlinear load. The performance of the converter in term of efficiency and THD performance are monitored and reported.

1. Introduction

From the embryonic stage of renewable energy, the solar photovoltaic (PV) system plays a significant role in sustaining electricity demand due to its many peculiarities, such that the inverter-associated photovoltaic system is commonly used in several applications [1]-[2]. This renewable energy sources such sunlight, wind and water can be harness with a specific topology and it is getting even better when the harness energy can be stored into back up power supply such as battery and supercapacitor [3]-[10]. Most of power electronics engineers developing the relevance power circuits that supports the variant type of power either in AC power or DC power [3]. Working with these free energies that are totally uncertain depending on the situation such as the shaded condition of sky lead to the poor irradiation of sunlight and the unstable wind resulting a poor capturing at the wind turbine blade [4],[7]. Although all these problems are countered with the current technologies such intelligent solar capturing using sensor and advance magnetic levitation (MAGLEV) vertical axis wind turbine (VAWT) to ensure the stability of the harness energy [4],[7], it is still having some losses and not getting the optimum power.

In this paper, the full bridge inverter with the bipolar switching will drive the nonlinear load directly from the solar PV supply. The bipolar switching strategy is the simplest inverter control strategy as it can drive the four units of MOSFETs with a lesser command from the main controller [11]. The bipolar inverter is consisting of fours that works in a pair of two, together with the capacitor and filter for the filtering purposes as in Figure 1(a). Another capacitor will be place in the input section where it will function as the DC-link voltage stabilizer and provide a very small ripple voltage even though the supply from PV panels is in unstable [12]. The process of converting the straight DC voltage from Solar PV started from the voltage flow from the PV panel thru the MOSFET drain terminal and will flow through the source terminal after the pulsation from the controller complete it one cycle [13]-[14]. The voltage that passes through the source terminal will flow through the load and forming the
alternation of \(+\)Dc voltage and \(-\)Dc voltage at the load as in Figure 1(b). This one complete cycle was known as alternating Ac voltage.

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1a.png}
\caption{Fig 1(a). Bipolar Inverter topology}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1b.png}
\caption{Fig 1(b). Bipolar Switching strategy}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=0.4\textwidth]{fig1c.png}
\caption{Fig 1(c). Comparison of unfiltered and filtered bipolar inverter}
\end{figure}

2. System Configuration

The bipolar inverter system was first tested at the simulation stage using MATLAB Simulink as to testify its circuit functionality and behaviour towards the nonlinear load. The load use in this paper is the AC motor with the rated power of 50W for 24 Vrms maximum output voltage. The parameter for this project are mention as in Table 1.

\begin{table}[h]
\centering
\caption{Bipolar Inverter parameters}
\begin{tabular}{|l|l|}
\hline
Parameter & Value \\
\hline
Fundamental frequency & 50 Hz \\
Load & 50 W (24 Vrms, 460 ohms) \\
Capacitor, C & 470 \mu F \\
Inductor, L & 1200 \mu H \\
Switching Frequency & 20 kHz \\
Input voltage & 36 V\text{DC} \\
\hline
\end{tabular}
\end{table}

For the hardware section, the controller use for this project is the ezDSP controller for generating the pulsation for the MOSFETs to drive the bipolar inverter. The selection of component will be depending on the calculation and its suitability on handling the conversion.
3. Problem formulation and Harmonic study

The general waveform of bipolar inverter as in Figure 1(b) were formed by intersection of carrier frequency, \( f_c \), with the reference frequency, \( f_r \). A discrete pulsation for G2 is inverted from the G1 as to avoid the short circuit occurrence between the inverter leg [14]-[16]. The ratio of the switching points is defined thru modulation ratio formula as in equation (1). The sampling rule of the switching points can be determined by using equation (2).

\[
m_j = \frac{f_c}{f_r} \tag{1}
\]

\[
\alpha_k = \frac{\pi}{2m_f} \left\{ 2k - 1 + (-1)^k m_j \left( \frac{\pi}{m_f} (k + m) \right) \right\} \tag{2}
\]

Where :
\( k = 1, 2, \ldots, 2m_j \)
\( \alpha_k \) = switching point

A The output voltage of the bipolar inverter is in quarter symmetric before the filtering process of LC filter as in Figure 1(a) and it contains the fundamental harmonic contents where it can be express as in equation (3) [17]-[20]. The equation is in Fourier series of output voltage and it can be used to understand the harmonic study and can be further expanded for the harmonic elimination purposes.

\[
v(t) = \sum_{n=1}^{\infty} v_n(t) = \sum_{n=1}^{\infty} (a_n \cos nt + b_n \sin nt) \tag{3}
\]

4. Results

The experimental results for bipolar inverter have been tested for both in the lab and the outdoor testing. Figure 2(a) shows the testing was done in the lab with the artificial light while Figure 2(b) was the testing at the outdoor lightning. The solar PV used can produce up to 36 VDC with rated power of 80W. For laboratory testing method, the inverter will be tested with the standard artificial light and observed the performance of bipolar inverter for nonlinear load testing.

![Fig 2(a). In lab artificial light testing](image_url)

![Fig 2(b). Outdoor testing](image_url)
The measurement of results is measured through the digital oscilloscope TPS2024 for both input and output voltage. For the outdoor measurement, the setting of the oscilloscope is set to logging mode as to track and ensure the unstable voltage received from the solar PV system as in Figure 3(b). Figure 3(a) were the measurement using the artificial light in the lab. This procedure is compulsory as to ensure that the switching element of the bipolar does not interrupt the behaviour of input voltages.

Next, the inverter was tested with the real load applications by connecting the AC motor directly to the inverter. The first experimental test by connecting the nonlinear load from the solar PV under the artificial light condition. The generated voltage from the artificial light is in stable and there is no voltage spike during the measurement. The result of bipolar inverter from the artificial light as in Figure 4(a). Based on the results, the bipolar inverter can handle the nonlinear load well with the stable voltage injection from the artificial light solar PV. However, the value of harmonic quite moderate as the bipolar inverter naturally comes with high switching state condition.

Next, the experimental will be tested on the outdoor light condition to the nonlinear load. Figure 5(a) shows the condition of bipolar inverter before and after filter and Figure 5(b) shows the THD performance of the nonlinear load condition under the unstable solar PV voltage. The condition now are far distort and very high in noise disturbance especially the waveform for after filter. While for the total harmonic reading, the value of harmonic raise tremendously from 29.4% to 55.4%.
The nonlinear load experimental is done by setting up a manual disturbance at the motor as to let the motor operate unusual and imbalanced. It can be said that the almost irrelevant for a basic open loop of bipolar inverter to handle this nonlinear load.

5. Summary

Based on the results above, the nonlinear load has been tested for both cases under artificial light and outdoor testing directly from the sunlight. It can be observed that the stable Dc voltage is important for handling the converter that deals the conversion from straight Dc voltage into alternate Ac voltage. It is because the switching of alternation involves the rise and fall condition which will impact the value of charging whenever the value of input voltage is not stable. This research can be improved by adding the closed loop control such PI control or PID control to ensure the stability of voltage injection to the inverter even though the supply is in unstable condition.

6. References

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