Optimization and Simulation of IGBT Inverter Using PWM Technique

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ABSTRACT

This paper proposes a special pulse-width modulation (PWM) technique to stabilize a non-stable D.C Input by using an H-Bridge IGBT (Insulated Gate Bipolar Transistor) -inverter which is adaptive and able to send and receive messages quickly. The output voltage of this inverter is a stable A.C output of V_{rms}=220 V and f=50 Hz. The application of such inverters is important for systems fed by photovoltaic panels where their output can fluctuate over short periods. The design circuit consists of a voltage measuring circuit, a PIC micro-controller, a gate driver, and an H-Bridge IGBT inverter. The desired stable output is achieved even for rapid changes in the input by tracking the input and regulating the output for every (0.02) seconds.

Keywords: IGBT-Inverter, Pulse-width Modulation, PIC Micro controller

1. INTRODUCTION

In recent years, photovoltaic (PV) systems are widely used in contemporary societies; this is related to the increased environmental awareness, and the fact that photovoltaic energy has a low cost compared to fossil fuels [1]. Whether a grid-connected or a stand-alone PV system is used, the output power lacks the stability due to the fact that the sun emissions vary during the day which results in a non-stable electric output power. For Stand-alone PV systems, this problem can be over passed by storing the generated electric power in storage elements, and then converting it to a suitable electric power form, however, storage elements suffer from having a short-life period, and high electric power losses. A problem rises with grid-connected PV systems is the resulting harmonics when connecting them through power inverters to Medium Voltage Distribution (MVD) networks [2, 5, 6].
Inverters are essential components in many electrical systems, since conversion of D.C voltage to A.C voltage is becoming more desired. Basic Inverters such as H-bridge inverters convert applied D.C voltages to A.C voltages of a desired frequency and amplitude using a convenient controlling method, but if the input is unstable, the output will be unstable as well, whether the output voltage is a pure sine wave or a modified sine wave [3, 4].
This paper, introduces a novel methodology of eliminating the before-mentioned harmonics by designing a inverter whose output (220V/50Hz) is always stable for a variable input even without including any storage elements in the system.

2. SYSTEM DESIGN DESCRIPTION

The system applied in this work includes a PIC-16f877A micro-controller, a voltage measuring circuit, a gate driver, and an H-Bridge inverter. The PIC micro-controller is the key component of this system; it reads the unstable input using the measuring circuit, then it makes the necessary PWM calculations and drives the main inverter through the gate driver. These duties are done by the micro-controller every (0.02) second to insure a stable output is continually available even for rapid changes in the input. Figure 1 shows the block diagram of the system used in this work.

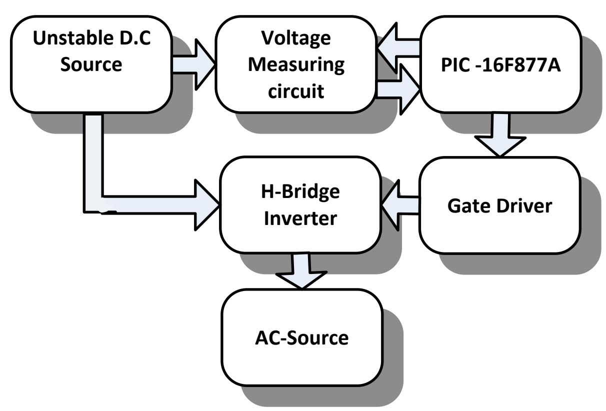

Figure 1: Block diagram of the system

3. METHODOLOGY AND DISCUSSION

The methodology used in this paper is explained in the flowchart as shown in figure 2.

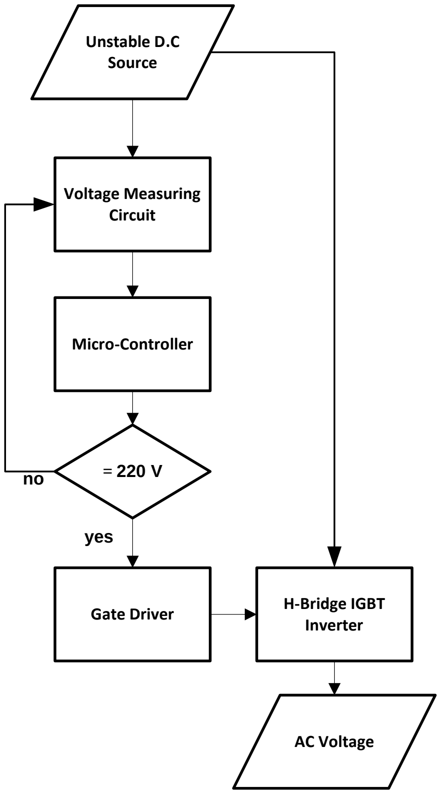

Figure 2: Methodology flowchart

The inverter is designed to give a 100% stable output power from the first instant, so it is important to calculate the non-stable input accurately. Based on voltage-divider law, Figure 3 shows the voltage measuring circuit, it uses two resistors of 2W rating to express input voltages up to 500V in a small voltage range (0 – 5)V; which is acceptable to be read by the micro-controller. The voltage measuring circuit is connected in parallel with the input and the inverter.

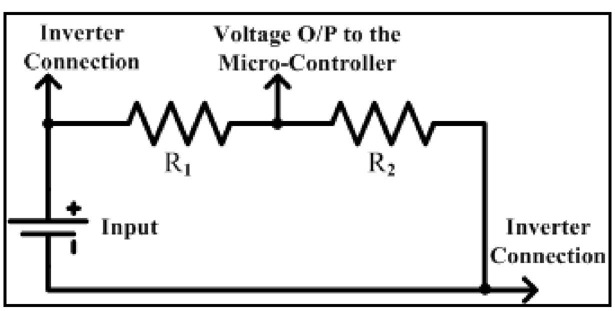

Figure 3: Voltage measuring circuit

The PIC-16F877A micro-controller is the heart of this design; it reads the unstable input using the measuring circuit, then makes the necessary PWM calculations and drives the main Inverter.

PIC-16F877A is a 40 pin, 8-bit micro-controller. It is chosen due to the variety of input/output ports it offers, the ability to work with frequencies up to 20MHz, and the fact that it has 8 bits, which is widely available [7]

To generate a low A.C effective voltage from a higher D.C Voltage, pulse-width modulation (PWM) technique is used, in which the conduction time in each A.C half-cycle is shortened, this time is called conduction time or delay time depending on the used PWM technique. With deriving a suitable equation for a specific PWM technique, the result will be lower A.C output effective voltage. The following PWM technique seen in Figure 4 is applied as the control method in the inverter to generate a 50Hz, 220V stable A.C output. The variable α represents the delay time during which, the voltage is prevented from being applied to the load, and thus, the result is a lower A.C effective output voltage.

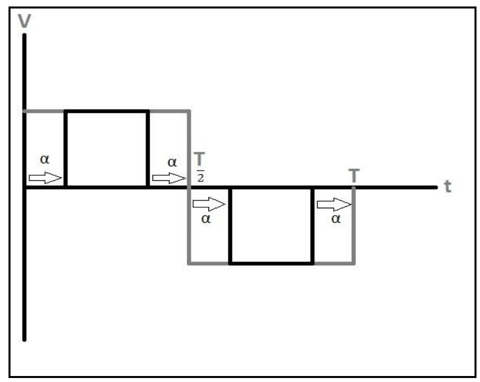

Figure 4: PWM technique

To derive this delay time as a function of the input voltage, the definition of the RMS value is used:

$$Vrms^2 = \frac{1}{T}\left[\int_{\alpha}^{\frac{T}{2}-\alpha} Vp^2 dt + \int_{\frac{T}{2}+\alpha}^{T-\alpha} Vp^2 dt\right] \tag{1}$$

$$Vrms^2 = \frac{Vp^2}{T}[-4\alpha + T] \tag{2}$$

Where T is the cycle time (0.02 second), Vrms is the output effective voltage, and α is the delay time. As na example; for a 220V(rms), 50Hz output, the delay time will be:

$$\alpha = 0.005 - \frac{242}{Vp^2} \tag{3}$$

Figure 5 illustrates the PWM method used in this paper by applying the result of equation (3). It can be concluded that for α = 0, the resulting Vrms will be maximum whereas for α = T/4, the resulting Vrms will be minimum.

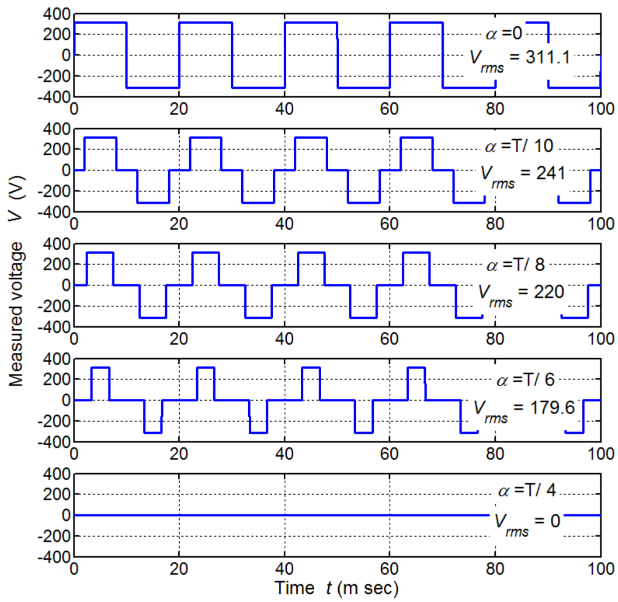

Figure 5: Measured voltage for different values of time delay α and the resulting effective value V_{rms}.

The main inverter is constructed as an H-bridge using IGBT semiconductor. IGBT was chosen over other semiconductors due to its numerous advantages; such as it can be used in high power applications, voltage controlled device, and low on-state voltage drop [8].

A Gate drive circuit is required to interface control signals provided by the micro-controller with IGBTs of the main inverter, and in the same time, it is needed to isolate the micro-controller circuit from the main inverter circuit; which will handle voltages up to 500V. IR2110 gate driver I.C by "International Rectifier" corp. is used as a drive circuit. It is a high speed MOSFET and IGBT gate driver, with the compatibility to work with input driving signals in the logic range (0-5V).[9]

Another important feature it offers is the ability to drive the upper side IGBTs of the H-bridge inverter; the inverter may be exposed to voltages up to 500V, and IGBTs with the capability of bearing such voltages require high Gate to Emitter voltage (10-20 VGE) in order to be switched on. That is also the case for the lower side IGBTs but the difference between the two sides is that in the upper side case, the load is located between the Emitter and the system's ground, so the voltage on the Emitter of the upper side IGBTs can be as high as 220V for a regulated output, thus about 235 Gate to Emitter voltage is required to switch on the upper side IGBTs in a proper way; otherwise, a lower Gate to Emitter voltage will cause a high voltage drop across the IGBTs and thereby, a high power dissipation will occur causing their temperatures to exceed the maximum ratings.

Application note provided by "International Rectifier" corp. suggests a convenient way to drive the upper IGBTs with the IR2110 I.C, which is to include a capacitor and a diode to the gate drive circuit (also called bootstrap capacitor and diode). An external power source up to 20V (VCC) is connected to the gate driver circuit through the bootstrap diode as shown in figure (6), while the bootstrap capacitor is connected between (Vb) and (Vs) pins of the IR2110 I.C as shown in the same figure. Now when the upper IGBT is switched off, the bootstrap capacitor will charge from the external power supply through the bootstrap diode, providing the IR2110 I.C driving output (HO) an additional Voltage (equal to the external source used) above the Emitter Voltage, thus, make sure that the upper IGBTs is being switched on with a convenient Gate to Emitter voltage.[10]
Design tip provided by "International Rectifier" corp. includes an equation to calculate the required bootstrap capacitor;[11]

$$C \geq \frac{2\left\{2Qg + \frac{Iqbs(max)}{f} + Qls + \frac{Icbs(leak)}{f}\right\}}{Vcc - Vf - V_{LS} - V_{Min}} \qquad (4)$$

Where:

Qg	Gate charge of high side IGBT
f	frequency of operation
Icbs(leak)	Bootstrap capacitor leakage current
Qls	level shift charge required per cycle
Vf	Forward voltage drop across the bootstrap diode
VLS	Voltage drop across the load
VMin	Minimum voltage between Vb and Vs

As for the bootstrap diode, it must be able to block the input voltage across the inverter (up to 500V), and also it must block any charges that may leak back from the bootstrap capacitor to the external supply.[11] Figure 6 represents the integration between IR2110 I.C, PIC microcontroller, and the main inverter

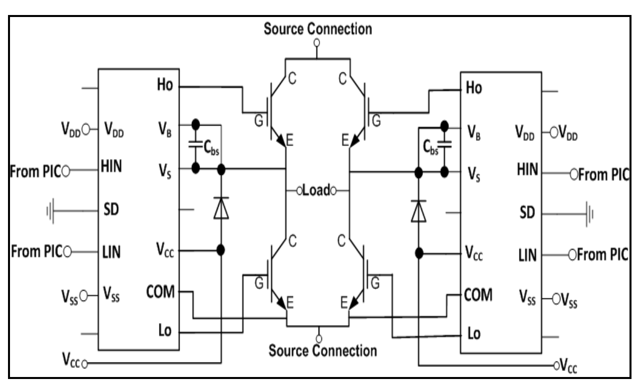

Figure 6: Gate Driver/Main Inverter Connection

Where:

Symbol	**Description**
V_{dd}	Logic Supply
HIN, LIN	Logic input for high and low side gate driver outputs (HO,LO)
SD	Logic Input for Shutdown
C_{bs}	Bootstrap Capacitor
V_{SS}	Logic Ground
V_B, Vs	High Side Floating supply and return
HO, LO	High and low Side Gate Drive Outputs
V_{CC}, COM	Low Side Supply and return

4. SYSTEM SIMULATION AND RESULTS

The micro-controller, in real-time, reads the input, drives the inverter, and makes the necessary calculations. Figure 7 shows the flow chart of the code, which is applied to insure a 100% stable output at all times;

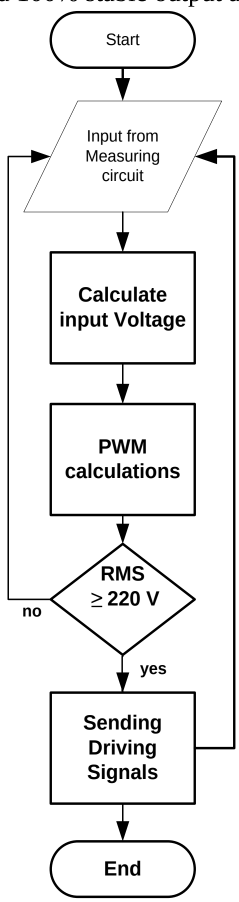

Figure 7: Flow chart of the code

The code was written using "MicroC PRO for PIC" in a way which the PIC micro-controller does not drive the inverter unless the conduction/delay time is calculated, and there is no delay for driving the inverter after applying the input voltage. The PIC micro-controller reads and stabilizes the input frequently every 0.02 second without any delay on the output; in other words, there will be no high or unstable voltage on the load.

A simulation of the driving signals is done using (PROTEUS 8 Professional) software [12], which supports micro-controllers simulation, including PIC Micro-Controllers.

To test the accuracy of the code, the following values are considered:

- The real value of the unstable D.C Input.
- The Measured Value of the unstable D.C Input by the PIC.
- The calculated and generated Conduction/ Delay time by the PIC (in reference to equations (2)).
- Output RMS Voltage and Output Frequency.

The following readings are obtained:

Table 1, PWM Simulation Results

D.C Input (V)	Calculated Input (V)	Input Error (V)	Delay Time (µs)	Output Voltage (V)	Output Error (V)	Frequency (HZ)
50	50.2929	0.293	N. O.	N. O.	N. O.	N. O.
125	124.999	0.000	N. O.	N. O.	N. O.	N. O.
208	208.008	0.008	N. O.	N. O.	N. O.	N. O.
221	220.703	0.297	31	220.314	0.3138	49.998
222	222.168	0.168	97	219.836	0.1639	49.998
223	223.144	0.144	139	219.879	0.1215	49.998
224	224.121	0.121	182	219.885	0.1146	49.998
250	249.999	0.000	1127	220.028	0.0284	49.998
253	252.930	0.071	1217	220.066	0.0664	49.998
256	255.859	0.141	1303	220.130	0.1302	49.998
259	258.789	0.211	1386	220.196	0.1957	49.998
280	279.785	0.215	1908	220.188	0.1876	49.998
286	286.133	0.133	2044	219.904	0.0959	49.998
292	291.992	0.008	2161	220.029	0.0293	49.998
298	297.851	0.149	2272	220.117	0.1169	49.998
301.3	301.269	0.031	2333	220.052	0.0522	49.998
301.6	301.269	0.331	2333	220.271	0.2713	49.998
301.9	301.758	0.142	2342	220.118	0.1180	49.998
302.2	302.246	0.046	2350	220.005	0.0049	49.998
350	350.098	0.098	3025	219.972	0.0284	49.998
360	359.863	0.137	3131	220.101	0.1011	49.998
370	370.117	0.117	3233	219.956	0.0444	49.998
380	379.883	0.117	3323	220.072	0.0722	49.998

The readings obtained from the simulation show the codes high accuracy in calculating the unstable Input; the highest error in the readings was 0.3306V and the smallest error was 0.0001V. That is also the case for the Calculated Delay Time, the Output Frequency, and the Output Voltage; the highest error in the output voltage was 0.3138V and the smallest error was 0.0049V.

Stable output frequency is found in the simulation output as shown in Figure 8 where the yellow and the blue lines represent the driving signals for the positive and negative half cycles of the stable output.

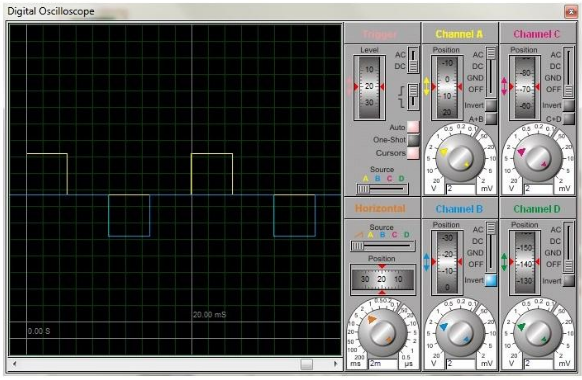

Figure 8: Simulation output

5. CONCLUSION

This paper introduced a design of a IGBT-inverter which was a very fast (regulates the unstable input every 0.02 second) and accurate (small errors obtained) in stabilizing the D.C input. These advantages alongside with the stable output frequency make the IGBT-inverter an ultimate method in generating a stable A.C power and emitting harmonics resulted from unstable power supplies.

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