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Implementation of a Single-phase Unipolar Inverter Using DSP TMS320F241

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Abstract

This paper presents the design and implementation of a single-phase inverter that produces a symmetric ac output voltage of desired magnitude and frequency. A diode bridge rectifier is used to rectify the ac line voltage. Unipolar PWM technique is employed to control the output voltage magnitude and frequency. The digital signal processor (DSP) of Texas Instruments TMS320F241 is used for the implementation of the inverter

Keywords: *Single-phase inverters, digital signal processor (DSP), unipolar-switching scheme, output voltage control of single-phase inverters, Matlab simulation.*

1. Introduction

Single-phase inverters are widely used in industrial applications such as induction heating, standby power supplies and uninterruptible supplies. A block diagram representation of a single-phase inverter is given in Fig.1-1. The inverter consists of four switching devices (represented as ideal switches) connected in the form of a bridge. The control scheme is implemented using TMS320F241 DSP controller (Techakittiroj *et al.* 2003)

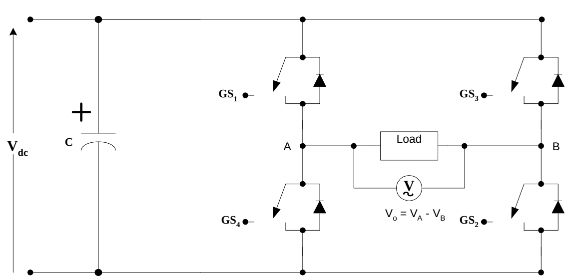


Fig. 1-1. Single-phase inverter

In the unipolar switching scheme (Ned *et al.* 1995), the output voltage changes between positive and zero, or between zero and negative voltage levels. To produce a sinusoidal output voltage waveform of variable frequency and amplitude, a sinusoidal reference signal (V_{ref}) is compared with the triangular waveform (V_{tri}). The amplitude modulation index (m_a), which controls the rms value of the output voltage, is defined as

$$m_a = \frac{\hat{V}_{ref}}{\hat{V}_{tri}} \qquad (1.1)$$

The $\hat{V}_{ref}$ and $\hat{V}_{tri}$ in equation (1.1) refer to the peak amplitudes of the signals.

Leg A and B of the full-bridge inverter are controlled separately by comparing V_{tri} with V_{ref} and V_{tri} with $-V_{ref}$. The resulting waveforms are used to control the switches as follows:

In leg A: (1.2a)

$V_{ref} > V_{tri}$ *: GS1 on* and

$V_{ref} < V_{tri}$ *: GS4on*

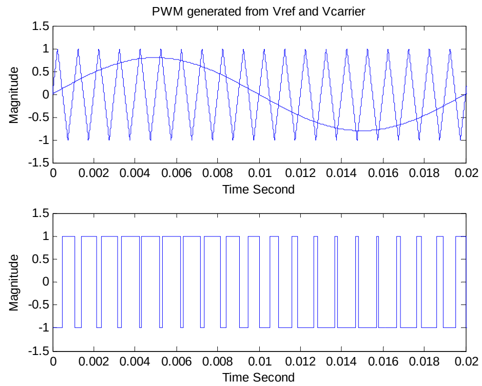
and

In leg B: (1.2b)

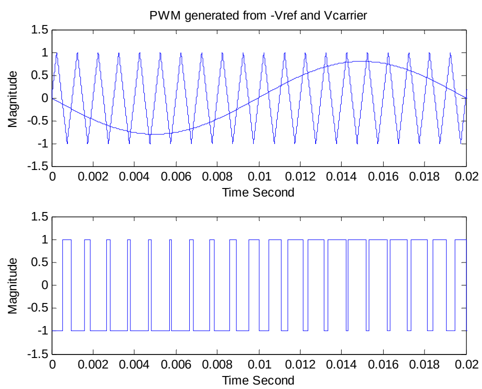
$-V_{ref} > V_{tri}$ *: GS3 on* and

$-V_{ref} < V_{tri}$ *: GS2 on*

The PWM signals obtained are shown in Figs. 1-2a and 1-2b. Note that GS4 and GS2 will be automatically created as the inversion of GS1 and GS3, respectively.



(a)



(b)

Fig. 1-2 PWM signals (a) For leg A
(b) For leg B

The comparison of the reference sinusoidal signal with the triangular waveform is done in the PWM generator of the DSP to generate the control signals for the switching devices along with the inverted signals with the required dead band. A 16-bit counter register is used to measure the frequency of the triangular wave. A centered symmetric PWM signal is used which has maximum count up of 2^{16} and count down 2^{16}. The PWM signals and the control signals generated are given in Fig. 1-3. Count up, count down, switching time and dead band are calculated as shown by Aphiratsakun (2004) and TI (2000):

Count up = Count down = PWMA_PERIOD

$$T_{sw} = 2\text{xPWMA\_PERIODxCPU clk} \quad (1.3)$$
$$= 2\text{xPWMA\_PERIODx50 ns}$$

The dead band (T_{dead}) calculated by Aphiratsakun (2004) and TI (2000):

$$T_{dead} = \text{Period x Dead Band Prescaler xCPU clock} \quad (1.4)$$

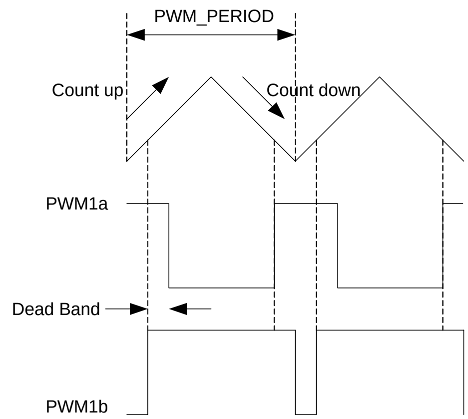


Fig. 1-3. Symmetric PWM waveform generation

2. Circuit Description

The schematic diagram of the inverter circuit implemented is given in Fig. 2-1. It has two parts, the control circuit and the power circuit. The shaded part is the control circuit containing the DSP controller TMS320F241 that generates the PWM signals and also provides soft start function.

Set point for the modulation index and frequency are set by a computer through serial interface. The low pass filter was designed in such way that the output voltage waveform of the inverter is sinusoidal.

To start with, the single-phase inverter with the unipolar switching scheme is simulated using simulink in Matlab and its performance is studied. Later on, the single-phase inverter was implemented using DSP TMS320F241 and its performance was studied. A comparison is made of the results obtained through simulation and experimental work under the same operating conditions.

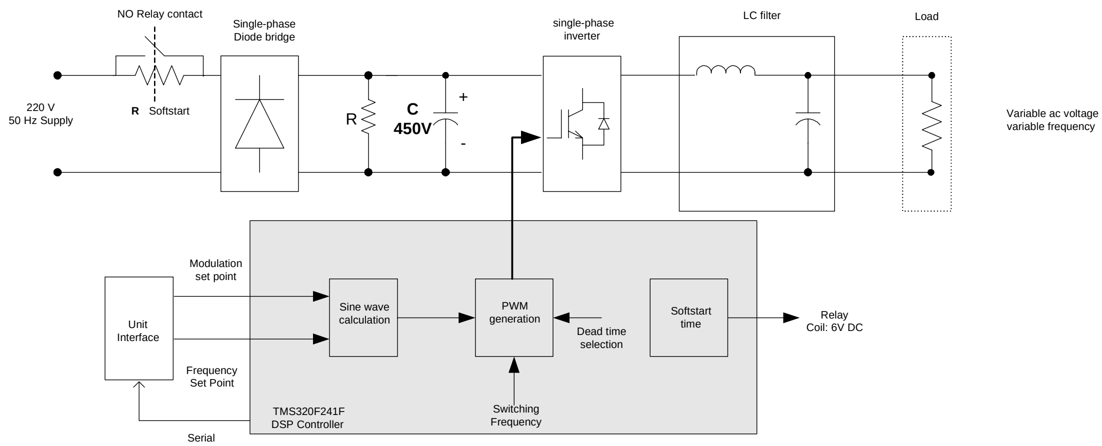


Fig. 2-1: Overall schematic diagram of single-phase inverter

The tested conditions for the simulation and experimental work are:

P_{rated} : 1.5 kW
V_{LN} : 220 V
C_{dc} : 1000 μF
L : 2 mH
C : 1.5 μF
m_a : 0.8
V_{ref} : 50 Hz
V_{tri} : 7.5 kHz
T_{dead} : 5.6 μs

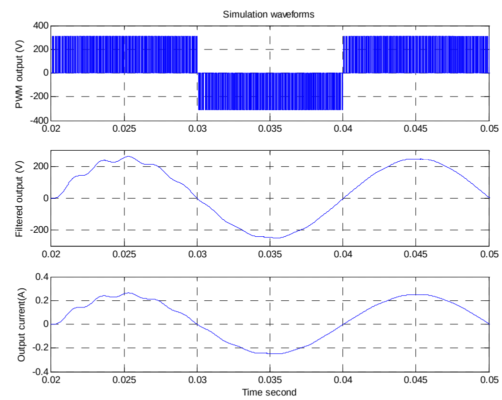


Fig. 3-2. PWM waveforms of unipolar inverter (simulation)

3. Simulation Study

The schematic for the simulation of unipolar single-phase inverter is given in Fig. 3-1. The waveforms of PWM output, filtered output voltage and filtered output current, obtained through simulation are shown in Fig. 3-2.

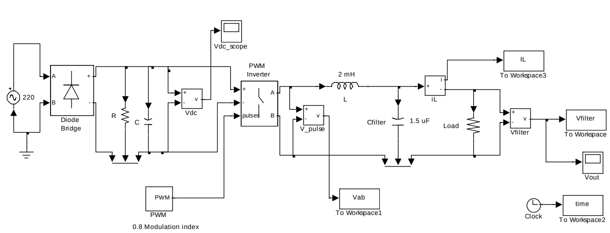


Fig. 3-1. MATLAB simulation of single-phase inverter

4. Experimental

The schematic diagrams for the power circuit and control circuit are shown in Figs.4-1 and 4-2, respectively. TMS320F241 DSP controller (Techakittiroj *et al.* 2003) with PWM and output ports is used for the implementation. The four PWM signals have been fed to the optocoupler (6N137) for the isolation of gate drivers. Four discrete MOSFETs (IRFP450) are used as switching devices. IR2110, IC gate driver is used to drive the MOSFETs in the upper and lower legs of the inverter. In the power circuit of Fig. 4-1 the single-phase diode bridge rectifier (6A6 GW) with a 1000μF DC link capacitor (C_{dc}) is connected to the single-phase ac power supply, 220V, 50 Hz to provide

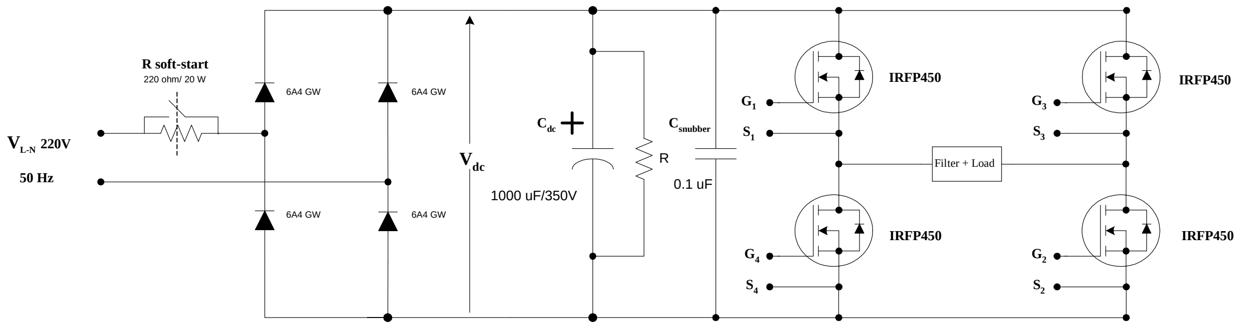


Fig. 4-1. Power circuit

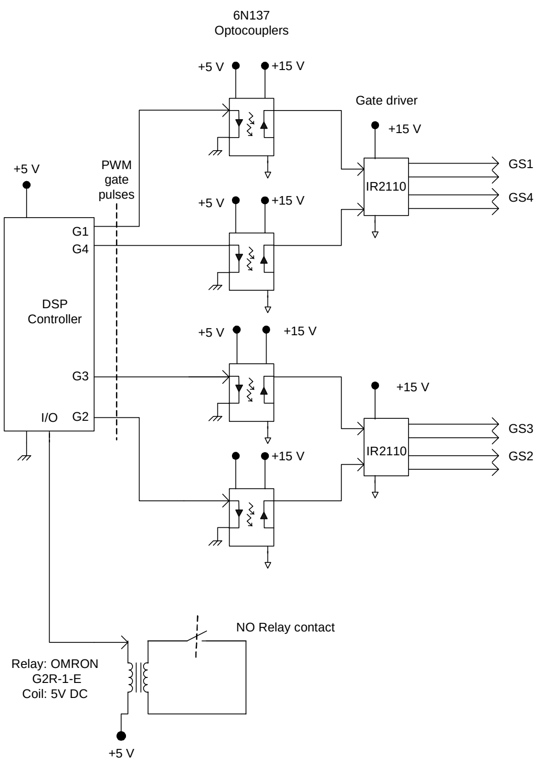
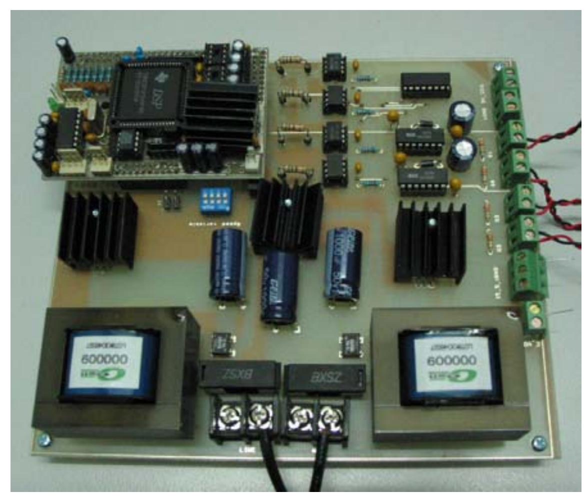


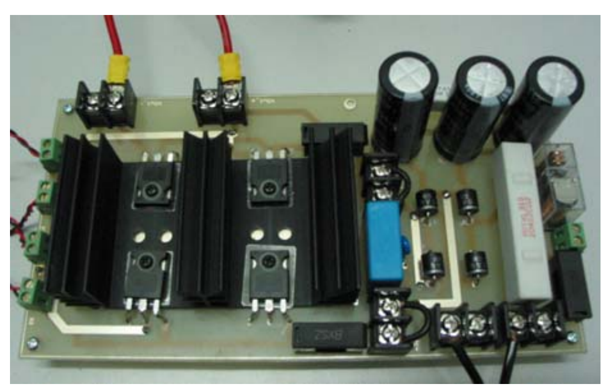
Fig. 4-2. Control circuit

a constant dc source to the inverter. The C_{dc} must have high voltage rating (greater than 350 V). A snubber capacitor of 0.1μF is connected across the inverter to protect it from high surge voltages. A soft start resistor is used to reduce the peak inrush currents, thereby reducing the stress on rectifier diodes and C_{dc}.

Photographs of the unipolar single-phase bridge inverter constructed in the laboratory are shown in Figs. 4-3 (a) and (b). Fig. 4-4 shows the recorded waveforms of unfiltered sinusoidal PWM, filtered output voltage and current. The rms output voltage is measured by rms meter and is found to be 220 V.



(a)



(b)

Fig. 4-3. Laboratory unipolar inverter board (a) control circuit (b) power circuit

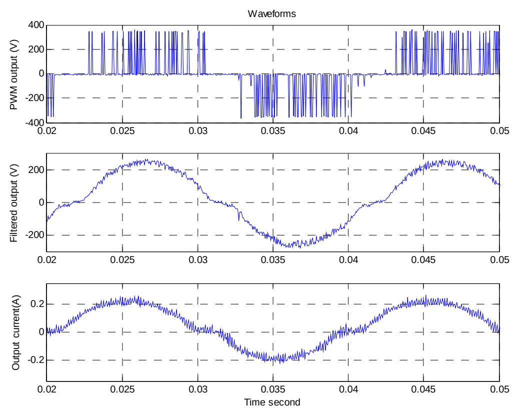


Fig. 4-4. PWM waveforms of unipolar inverter obtained through experimental work

Conclusion

A laboratory model of a unipolar single-phase inverter was successfully implemented using DSP TMS320F241 and tested. The inverter unit consists of four, discrete MOSFETs connected as a bridge and drive with a low cost driver. The experimental result matched with simulation results. Although any parameters are adjusted for giving fundamental frequency rms output voltage of 220V at 50 Hz. With this unipolar inverter unit, further research on single-phase inverters can be carried out such as soft switching inverters, single-phase UPS and single-phase induction motor drives.

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