DSP Based Control for Single Phase Induction Heating System using SPWM Technique

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Abstract—*This paper present the design of DSP standalone evaluation board and implementation of DSP based algorithm to generate SPWM signal, used to drive the gate driver of IGBT. The preferred method of controlling the heat inside Induction Heating Systems, is to vary the frequency of the AC voltage driving the Induction Heating Systems. The DSP provides variable frequency (PWM) signal that controls the applied voltage on the gate driver, which provides the required PWM frequency with less harmonics at the output of the power inverter. The algorithm development methodology and the experimental results are presented.*

1. INTRODUCTION

The electromagnetic induction heating technology, are increasingly being used in areas of industrial production and civil application. Induction heating power is a kind of inverter device which converts alternating current power to the middle frequency alternating current, high frequency, or ultrasonic frequency alternating current by electromagnetic induction principle to change electrical energy into heat energy [1]. The higher efficiency, very short heating times and local heating capabilities of induction heaters have made it superior to other heating devices . The high temperature is particularly important for precious metals. This paper introduced a DSP based algorithm to generate Sinusoidal PWM signal used for driving the IGBT gates of Induction Heating System. Finally experimental results have been shown followed by conclusion [2].

2. PRINCIPLE OF INDUCTION HEATING SYSTEM

Single Induction Heating is based on the principle of electromagnetic induction [2]. Due to the impedance of conductive substance, the power on the impedance is converted into heat energy. So it achieves the heating of the work piece, as shown in Figures 1 and 2. According to Maxwell’s electromagnetic equation the induction electromotive force is as follows when the alternating magnetic flux, $\Phi = \Phi_m \sin \omega t$:

$$e = -N\, d\Phi / dt = -N\Phi \cos \omega t, \qquad (1)$$

Where N is the coil number of turns, Φ is the flux, and e is the inductive electromotive force. And then we can calculate the effective value of eddy current in the cross section,

$$I_2 = E/Z = E \surd (R^{\wedge}2 + X_L{}^{\wedge}2), \qquad (2)$$

Where R is the equivalent resistance of the heated metal work piece and is the equivalent impedance of eddy current circuit. The role of induction coil is electricity transmission, which transfers the electrical energy into heat energy within the metal artifacts [5]. Its power can be expressed as,

$$P = 0.24 I_2{}^{\wedge}2R = (4.73N^{\wedge}2f^{\wedge}2\Phi_m{}^{\wedge}2R)/(R^{\wedge}2 + X_L{}^{\wedge}2), \qquad (3)$$

When the load is fixed, the heating power depends on the magnetic field intensity and frequency. So we can increase the current amplitude in the coil and frequency to enhance the heating effect. In addition, the cross-sectional shape of the metal, section size, permeability, and conductivity can also influence induced eddy current [3-4]. So we can adjust the frequency to control the heating of the work piece thickness.

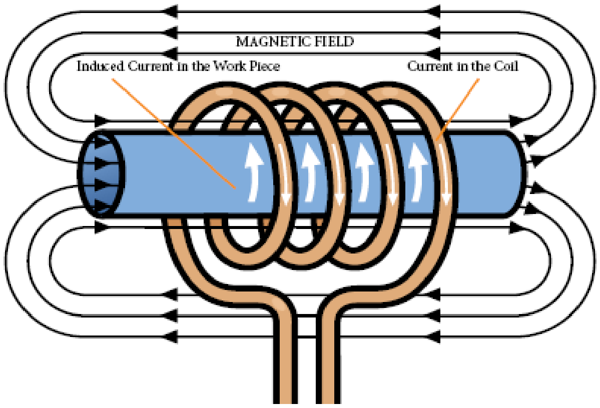


Fig. 1: The principle of single-sided heating.

Fig. 2: Induction heating effect.

3. INDUCTION HEATING SYSTEM

The A.C supply The AC supply which may be single phase or three phase depending upon the scale of the application, is converted to DC by using rectifier and filter. The DC voltage thus obtained is given to inverter which converts DC to AC. The inverter output is given to a coil which is to be heated, also called as work-piece or work-coil in which the object to be heated is placed without any contact [5].

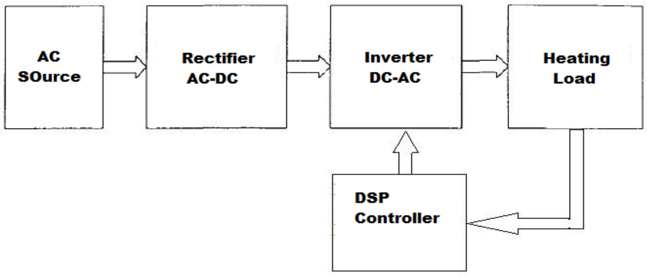


Fig. 3: A basic block diagram of IHS.

4. SINGLE PHASE FULL BRIDGE INVERTER

An inverter An inverter is basically a device that converts electrical energy of DC form into that of AC. The purpose of DC-AC inverter is to take DC power from a battery source and converts it to AC. For example the household inverter receives DC supply from 12V or 24V battery and then inverter converts it to 240V AC with a desirable frequency of 50Hz or 60Hz. It consists of two arms with a two semiconductor switches on both arms with anti parallel freewheeling diodes for discharging the reverse current. In case of resistive-inductive load, the reverse load current flow through these diodes. These diodes provide an alternate path to inductive current which continue so flow during the Turn OFF condition [6].

The switches are G1, G2, G3 and G4. The switches in each branch is operated alternatively so that they are not in same mode (ON /OFF) simultaneously .In practice they are both OFF for short period of time called blanking time, to avoid short circuiting. The switches G1 and G2 or G3 and G4 should operate in a pair to get the output. These bridges legs are switched such that the output voltage is shifted from one to another and hence the change in polarity occurs in voltage waveform. If the shift angle is zero, the output voltage is also zero and maximal when shift angle is π [7-9].

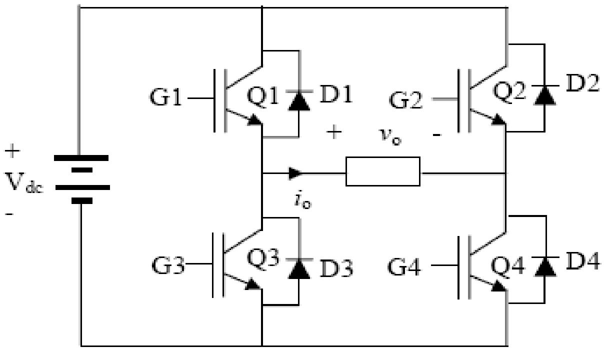


Fig. 4: Single Phase Full wave Bridge Inverter.

5. SINUSOIDAL PWM

There are many different ways that pulse-width modulation can be implemented to shape the output to be AC power. A common technique called sinusoidal-PWM will be explained. In order to output a sinusoidal waveform at a specific frequency a sinusoidal control signal at the specific frequency is compared with a triangular waveform (See Fig. 5). The inverter then uses the frequency of the triangle wave as the switching frequency [10]. This is usually kept constant. The triangle waveform, Vtri, is at switching frequency fs; this frequency controls the speed at which the inverter switches are turned OFF and ON. The control signal, Vcontrol, is used to modulate the switch duty ratio and has a frequency f1. This is the fundamental frequency of the inverter voltage output [11].

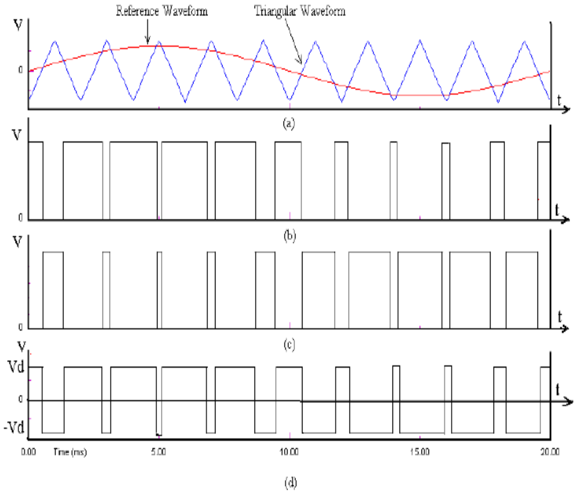


Fig. 5: SPWM with Bipolar voltage switching (a) Comparison between reference waveform and triangular waveform (b) Gating pulses for Q1 and Q4 (c) Gating pulses for Q2 and Q3 (d) Output waveform.

6. DSP SIGNAL GENERATION METHODOLOGY

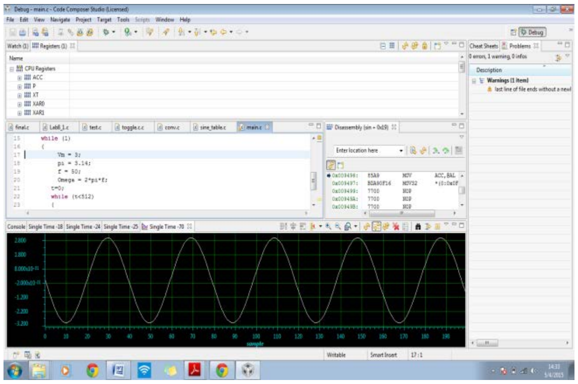
The DSP TMS320F28335 is well equipped with PWM, Capture & QEP (Quadrature Encoder Pulse) module, which provides a broad range of function and features that are particularly useful in motion control applications, control of switching pulses for digital power supply system & Analog voltage generators [9-10]. A unique feature of an ePWM / HRPWM module is its ability to start ADC converts without software interaction directly from an internal hardware event. Each ePWM is capable of controlling half H-bridge, when each bridge require a complementary PWM pair of control [10].

7. CODE GENERATION

A 16 bit Time Base Counter module, which repeats a counting period equal to PWM period is used to generate the triangular carrier signal. A 16 bit compare register is used to hold the modulating sine wave values. The value of the compare register present inside ePWM Time Base module is constantly compared with the value of the Time Base counter register. Whenever the values matches, a transition happens on the output. This matching of values & transition happens continuously and an output pulse is generated whose ON (or OFF) duration is proportional to the value in the compare register. This process is repeated for each timer period, with different values in the compare register. And hence a PWM signal is generated at the output pin of ePWM module [11-12].

8. PWM MODULATING SIGNAL

The algorithm to generate sinusoidal SPWM, CCSv4 is used which is an IDE (Integrated Development Environment) tool for from Texas Instruments (TI) that allows editing, debugging and compiling C/C++ coded programs in addition to real time interaction between PC and different TI digital signals processors [12]. A reference sine wave is generated and the calculated sine value for single phase is stored in an array. To achieve less deformed output waveform, large no. of sine values must be taken in consideration.Fig1 shows a graph of the sine wave modulating signal generated by the program. The program to generate the sine wave is given below:



```
    while (1)
    {
        Vm = 3;
        pi = 3.14;
        f = 50;
        Omega = 2*pi*f;
      t=0;
      while (t<512)
      {
```

Fig. 6: Single Phase Sine modulating signal

9. PWM CARRIER SIGNAL

The module to control the active phase of a pulse pattern and the position of the switching pulses in a PWM module is called the "Compare Unit". Compare registers A & B i.e CMPA & CMPB are handling the values to sine wave values.

Inside ePWM Time Base Unit, register TBPRD defines the length of a period of an output signal, in multiples of the time period of the input signal.

TBPRD=T(pwm)/(2*CLKDIV*HSPCLKDIV*T(sysclkout)) (4)

For TMS320F28335:
SYSCLKOUT= 150MHz
CLKDIV=1;
HSPCLDIV=2;
F(pwm)=1kHZ

Hence, TBPRD= 37500;

We will have to initialize ePWM1, by calling a new function, "Setup_ePWM1A();

```
Void Setup_ePWM1A(void);
```

The following register must be initialized to generate carrier signal of 1kHz.

```
EPwm1Regs.TBCTL
EPwm1Regs.TBPRD
EPwm1Regs.AQCTLA
```

An instruction to setup the operating mode to "up/down" mode would be

```
EPwm1Regs.TBCTL.bit.CTRMODE=2;
EPwm1Regs.TBCTL.bit.CLKDIV=1;
EPwm1Regs.TBCTL.bit.HSPCLKDIV=2;
EPwm1Regs.TBCTL.bit.CTRMODE=2;
EPwm1Regs.TBPRD=37500;
```

10. DSP SIGNAL GENERATION FLOW CHART

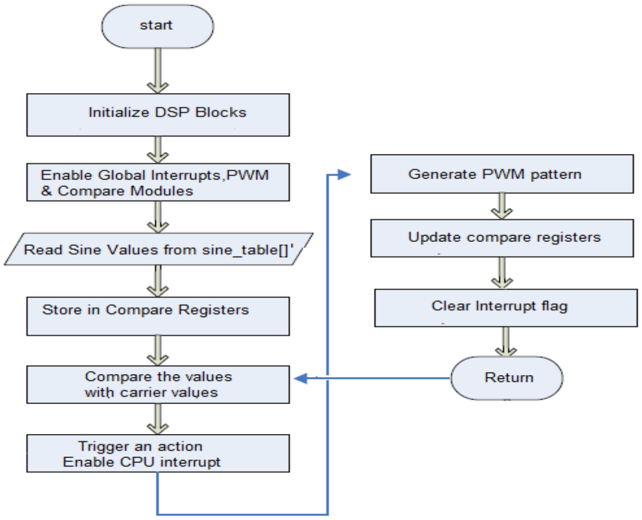


Fig. 7: DSP signal generation flowchart

The systematic flow chart is given in fig above. The first part of the algorithm (initialize DSP Block) initializes System control registers, clocks and PIE(Peripheral Interrupt Expansion control) registers to their default state. This can be done by calling the following function.

```
InitSysCtrl();
InitPieCtrl();
```

The DSP TMS320F28335 is driven externally by a much slower clock generator to reduce EMI. An internal PLL ckt generates the internal speed. To achieve the internal frequency of 100MHz, we have to use the multiply by a factor of 10,followed by a divide by 2.

```
EALLOW;
SysCtrlRegs.PLLCR.bit.DIV=0x10;
SysCtrlRegs.PLLSTS.bit.DIVSEL=0x2;
EDIS;
```

To disable the watch dog timer,

```
EALLOW;
SysCtrlRegs.WDCR.WDDIS=0x1;
EDIS:
```

Adding a new global variable “sine_table[512]” of data type “_iq30”.

```
#pragmaDATA_SECTION(sine_table,“IQmathTables”);
_iq30 sin_table[512];
```

This pragma statement is a derivative for the compiler to generate a new data section for sine_table. The linker command file “28335_RAM_lnk.cmd” will connect the section “IQmathTables” to the physical address, which is where our lookup table stored in ROM.

ePWM Compare unit consisting of registers CMPA & CMPB, which are used per period to trigger an action. An ISR is used to update compare registers, where a new sine value from the lookup table is assigned to its corresponding register at each interrupt.

```
interrupt void ePWM1A_compare_isr(void);
PieVectTable.ePWM1_INT=&ePWM1A_compare_isr;
PieCtrlRegs.PIEIER3.bit.INTx1=1;
```

Changing register IER to allow interrupt.

```
IER|=4;
```

Define the function of “ePWM1A_compare-isr()”. Also define a static variable “index” and initialize it to zero. This variable will be used as an index into lookup table “sine_table[512]”:

```
Static unsigned int index=0;
```

Now, calculation of a new value for register CMPA,

```
EPwm1.Regs.CMPA.half.CMPA=
EPwm1.Regs.TBPRD-
IQsat(_IQ30mpy((sine_table[index]+_IQ30(1))/2,EPwm1Regs.TBPRD),EPwm1Regs.TBPRD,0);
```

Increment variable “index” and to reset it, if we are at the end of the sine_table:

```
Index+=1;
If (index>511)index=0;
```

Finally we have to clear the interrupt flag of the event trigger module and the PIE-unit:

```
EPwm1.Regs.ETCLR.bit.INT=1;
PieCtrlRegs. PIEACK.all=4;
```

11. EXPERIMENTAL RESULTS

Fig.8 illustrates a pair of Complementary PWM signal generated using SPWM technique. The amplitude of the generated single phase signals is 3.3V so they are amplified and sent to the three phase inverter’s IGBT driving circuit, which operates at 12V. Fig. 9 illustrate respectively the inverter output current waveforms for given frequency:

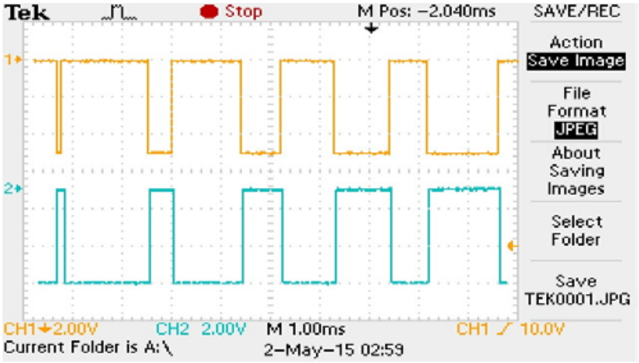


Fig. 7: PWM Pattern

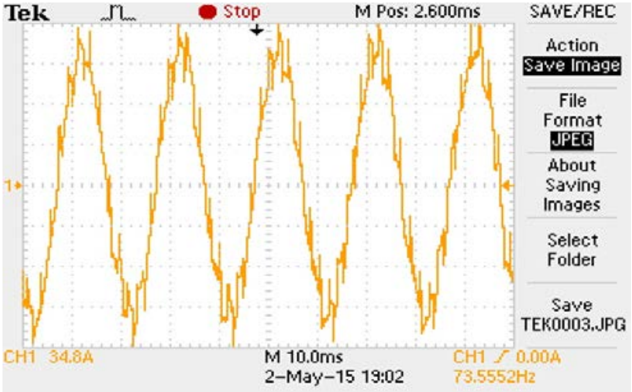


Fig. 8: Output Current waveform

12. CONCLUSION

This paper presented an algorithm to generate sine modulated PWM signals for Single phase inverters using Texas Instruments TMS320F28335 DSP. Step-by-step program development, algorithm and flowchart are detailed. The sinusoidal PWM generation algorithm is written in C language because of its flexibility, it provides in terms of changing the fundamental frequency of the inverter output voltage. Output SPWM signal and current signal are successfully generated. Experimental results prove the algorithm functionality and the validity of the experimental setup for single phase inverter applications including electric drives. Implementing sensorless direct field oriented control algorithm based on the presented structure is the subject of future work.

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