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Full Length Article

Design of a single-phase SPWM inverter application with PIC micro controller

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ABSTRACT

The goal of this study was to investigate low level harmonic content with unipolar voltage switching and bipolar voltage switching methods. Hence, we designed a single-phase full-bridge inverter application with Pulse Width Modulation (PWM) technique by using Peripheral Interface Controller (PIC) microcontroller. To obtain sinusoidal control signal and control of the inverter parameters, a PIC16F877 microcontroller was utilized in conjunction with an inverter to perform these two different techniques. The LCD control display and PIC Basic Pro programming language were used for the user interface and to program the microcontroller, respectively. Due to the application of PIC based control technique, total harmonic amount was decreased and a smaller size inverter was designed with very high realibility, safety, and low cost. In this study, an appropriate algorithm for the control software was obtained and approved for the supervision. Software was utilized to control the inverter, scalar control and ramp function as well as to obtain sine signal control of many parameters. The operation principle of the applied system and designed circuits is reported.

In conclusion the measurements with the applied system's operating status were discussed and evaluated with respect to their value for the education of electrical engineering students.

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1. Introductıon

Different control methods together with the development of semiconductor switching elements are being developed continuously. Sinusoidal pulse width modulation is one of the most preferred pulse width modulation techniques and widely used in industry. The pulse width modulation technique functions on the basis of a comparison of the carrier wave with the reference sine wave. The comparison process cannot be realized as a natural sampling on the microprocessors. This problem can be overcome by making regular sampling of the reference sine wave. "Symmetric Regular Sampling" is the sampling state at each full switching of the reference sinusoidal wave period; also "Asymmetric Regular Sampling" is understood as the sampling state at each half switching period [1].

This study mainly aimed to control the output frequency and voltage of a full bridge inverter. Two different control technique were used for Sinusoidal Pulse Width Modulation (SPWM), such as unipolar voltage switching and bipolar voltage switching.

Application of these two control methods was performed between the system and the user interface. PIC Basic Pro programming language was used for the sine signal and control of the output voltage. As a result of our experiments, the most appropriate algorithm was obtained for the control software and deemed suitable for the control. Control signals have been applied to the switches in the arms of the full bridge inverter.

The scalar control for mono phase motor torque which is connected to the output of the inverter is controlled with the open loop method. The main purpose of scalar control is to keep the v/f ratio constant. Inverter output voltage and frequency values were adjusted between 0 and 220 Volts and 0–400 Hz. The inverter was programmed for the experimental measurements. Implementation of this ratio is taken as 220/50 = 4,4. The inverter output voltage was adjustable. The output voltage was calculated based on this factor.

Triangle wave frequency per cycle determines the number of switching semi-conductors. The inverter output frequency is equal to the frequency of the reference wave [2]. When the modulation frequency was increased, the output voltage consist of high-frequency harmonics to be filtered easily. In addition,

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switching losses are increased due to high frequency. However a drawback occurs between 6 and 20 kHz switching frequency values. Switching in this range is undesirable due to the fact that the human ear hears this range of sound as a noise.

2. Step modulatıon method

There are two different methods to the PWM switching strategies. The first of these, natural sampling technique, is widely implemented in digital and analog systems. The highly advantageous technique used in digital or microprocessor applications is called regular sampling technique.

In this method, the reference signal was in the form of steps such as those shown in Fig. 1. The reference signal comprised from the steps was approximately similar to the sine wave. However, the sine signal was obtained by a division into determined intervals. First in order to obtain a sinusoidal signal, the number of steps was determined; later the control signal steps for its defined angle values were increased. For example, to obtain a sine voltage in 18 steps for the period 20 ms and frequency 50 Hz values; the angular step increment was equal to $\frac{360^\circ}{18} = 20^\circ$.

Amplitude of the control signal is calculated by multiplying peak value of the control signal by the sine value of angle in the same step. Thus, in each step the amplitudes of the control signals are calculated [3]. The output voltage of this method has a lesser harmonic than staircase Modulation Method.

3. Full brıdge ınverter

This section describes the operating principle of the implemented system. Comparison of the output voltage harmonics during operation with unipolar voltage switching and bipolar voltage switching of the inverter was investigated. The system, ease of installation, inspection and circuits were revised again [4]. In this case the circuits can be operated with different type of cards that have been designed. The circuits also represent blocks in Fig. 2.

4. Sıne oscıllator card

It is known that there is a certain ratio between carrier signal and the control signal in the Sinusoidal Pulse Width Modulation (SPWM). In the application this rate for the maximum output frequency of sine signal of 400 Hz value has been reduced to 12.

$$M_f = \frac{fc}{fs} = \frac{4800}{400} = 12$$

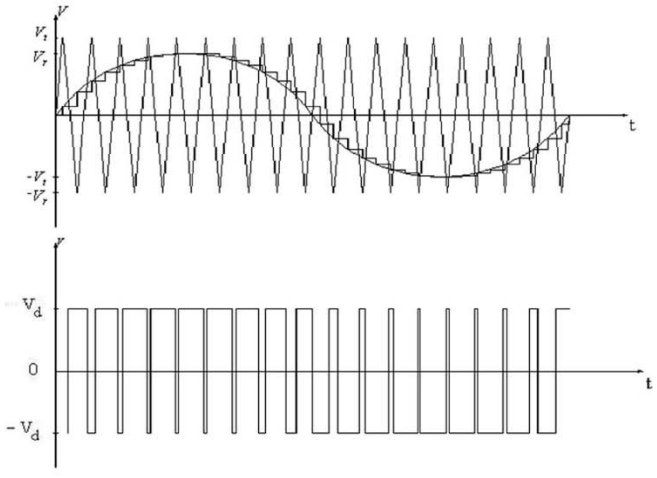


Fig. 1. Step Modulation.

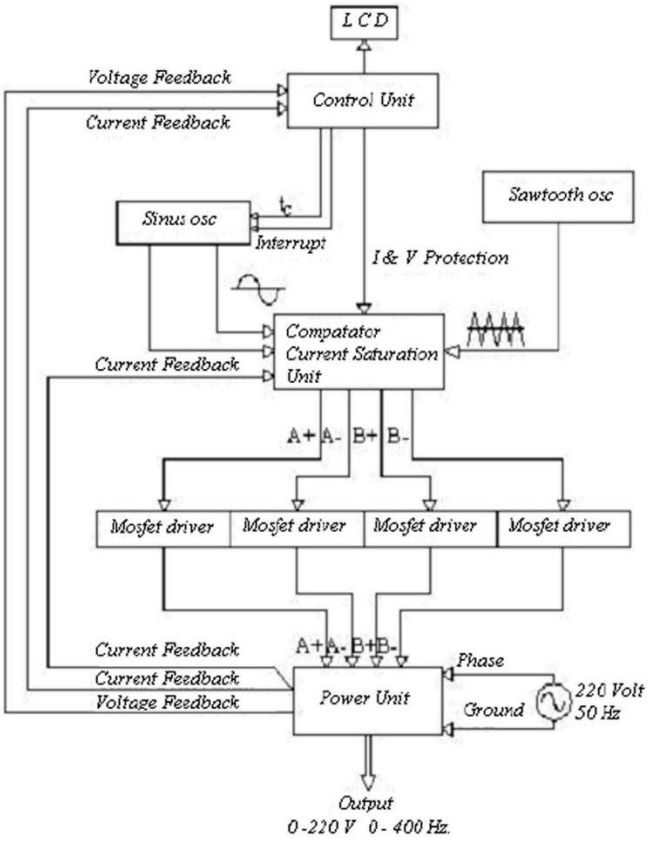


Fig. 2. Block circuit diagram.

The frequency of a generated control signal for adjusting to the desired value was created with the help of the microcontroller and Stepped Modulation method [5]. The number of steps of sine signal was determined as 30 steps. The output value of the control signal was obtained digitally from microcontrollers and converted to the analog value with the IC DAC-MC1408.

SPWM technique with unipolar voltage switching is used for two different signals with 180° phase difference; the output voltage is inverted and two different signals are obtained [6].

This card only produced the sine wave in Fig. 3. Control of the frequency and voltage were performed by the control board. While

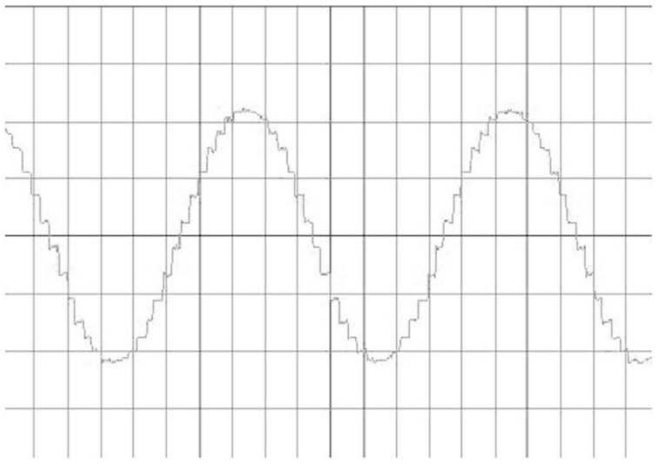


Fig. 3. Obtained sinusoidal signal. (This figure shows number of steps of sine signal was determined as 30 steps with $M_f = 12$).

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sine wave was generated, a numerical value at that step of desired sine was found by applying an interruption to the PIC. This value is transferred as an output to port B of the PIC. Obtained digital value of sinusoidal voltage is converted to the analog signal by DAC. In this system, the amplitude of the sine signal was performed by means of this integrated circuit. Maximum peak value of the output signal can be adjusted by means of Pin 14, so adjustment of sinus wave of the inverter output voltage is carried out via this pin.

The required other sine signal with 180° phase difference in the unipolar voltage switched PWM inverter was obtained by means comparator. These two signals are transmitted to the current saturation and gate comparison cards [7].

5. Triangle oscillator card

The Schmitt trigger circuit U1D is diagrammed in Fig. 5. U1A works as an integrator. Square wave was obtained from output of the U1D. The square wave signals have been converted to the triangular wave signals by applying to the input of U1A, which is working as an integrator [8]. Frequency of the output signal is set with adjustable resistor R6. In order to change amplitude of the signal by adjusting the gain of the U1C opamp, the peak voltage of triangular wave signal is set to desired value (Figs. 6 and 7).

6. Current saturation and gate comparison card

The first sine control signal comes from the sine oscillator card which is used as the principal control signal to form SPWM (Fig. 4). Also, besides normal sine wave, a second sine signal phase difference with 180° is used for unipolar switching in SPWM [9]. As a

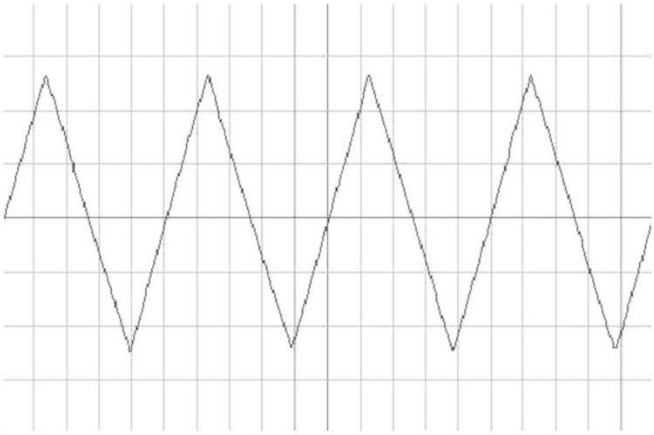


Fig. 6. Obtained triangular wave signal.

result of the comparison of the triangle wave with both sine 1 and sine 2, SPWM1 and SPWM2 signals are created and transmitted to the current-mode PWM controller SG3843. That controller's duty is to switch off the circuit in case of over load [10]. The current feedback in the circuit was provided with process variable (pv) pin.

Threshold value of the current limit of the controller SG3843 was 1 Volt, the this value is present pin 3. This voltage value is specified by the manufacturer. Because of this feature of the controller, the requested limit current value is determined by calibrating according to this value. Current control in this circuit is realized with pulse to pulse current control [11]. Pulse to pulse current control system allows the flow of a certain threshold current. When the controller current is increased to the over value, the controller

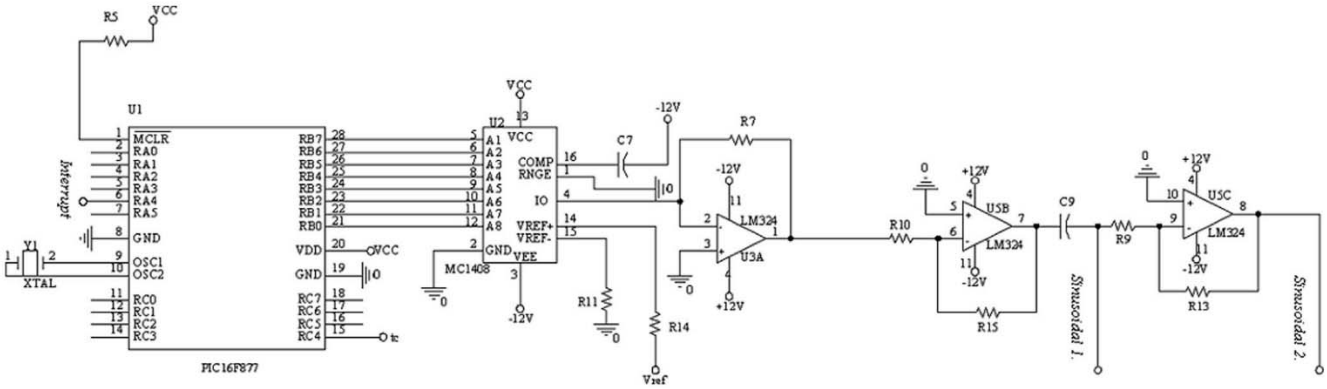


Fig. 4. Sine oscillator card.

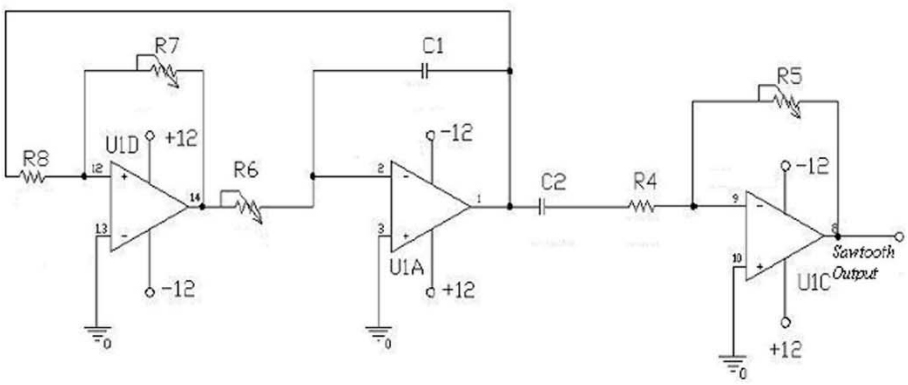


Fig. 5. Triangle oscillator card.

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switches turn off for a certain period of time, and at the end of this period the controller switches again. The controller does not intervene in the SPWM signal until a specified limit value.

After controller SG3843 outputs the SPWM signals, dead time has been generated by integrated circuits (U3D-U4D). In practice this period of time was counted $2\mu sn$. Unipolar switching or bipolar switching options is selected by means of relay contacts. After the generation of dead time, the control signals that are obtained from the gates of U6 have been applied to the mosfet drivers. Digital signals in the system switch off via the enable pin of the integrated circuit U6 [12].

7. Control card

The control board in Fig. 8 takes on the many tasks in the system. PIC16F877 microcontroller is used to carry out these tasks. However, when performing the protection process, the processing speed of the microcontroller is insufficient to safeguard the operation. For this reason, such cases limiting a possible short-circuit current or over current are preferred so as to realize this systematic process as analog. In case of a short circuit failure in the system microcontroller a possible short circuit condition is reported to the user [13] (Figs. 9–12).

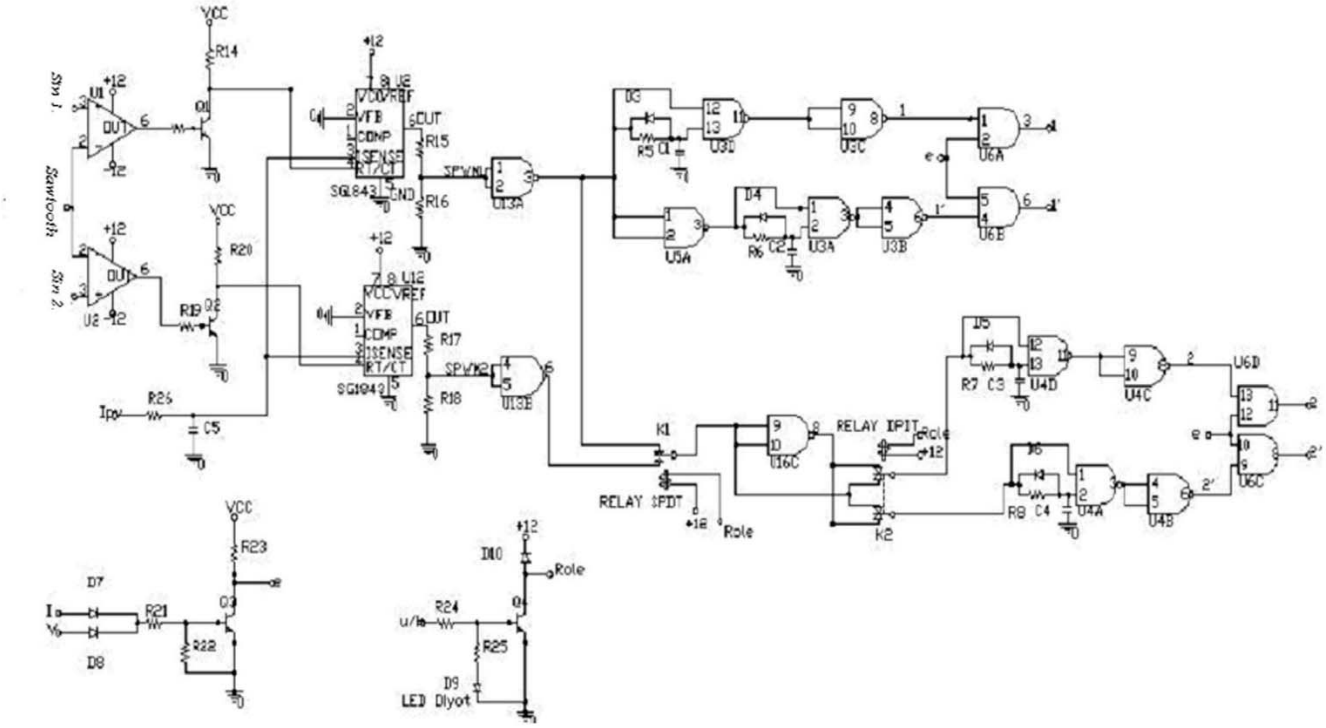


Fig. 7. Current saturation-gate & comparator circuit.

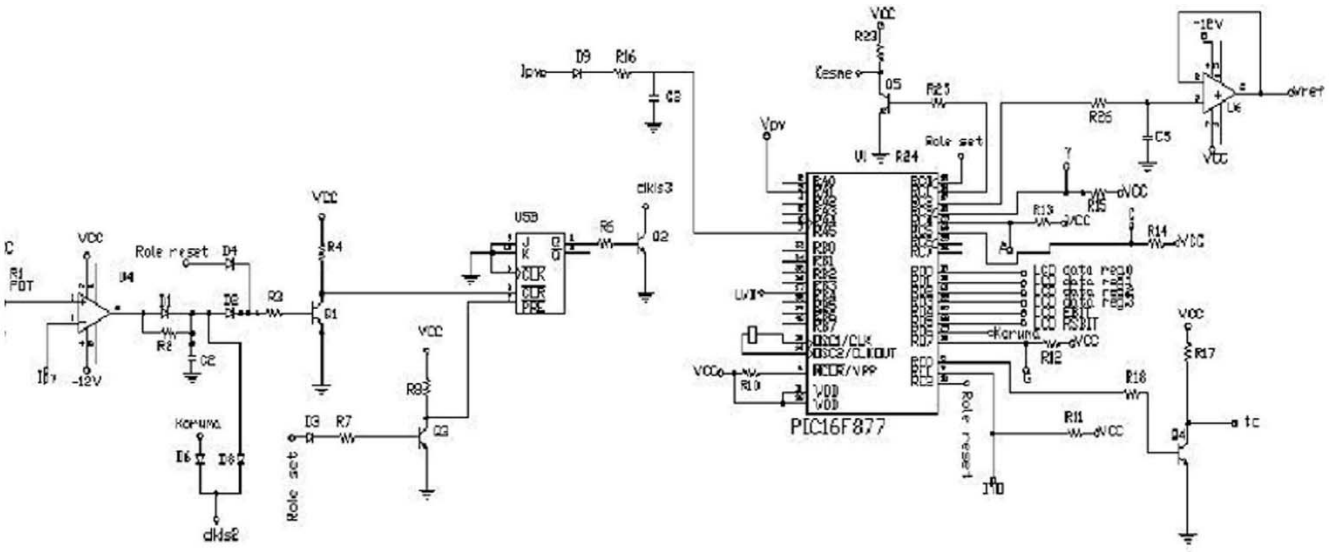


Fig. 8. Control card circuit.

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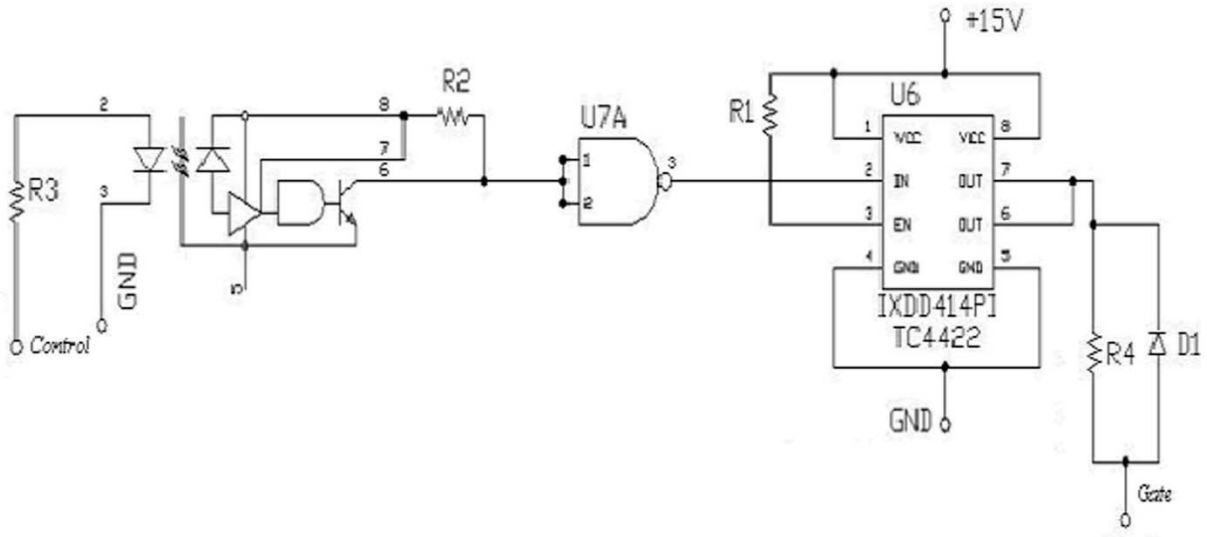


Fig. 9. Mosfet driver circuit.

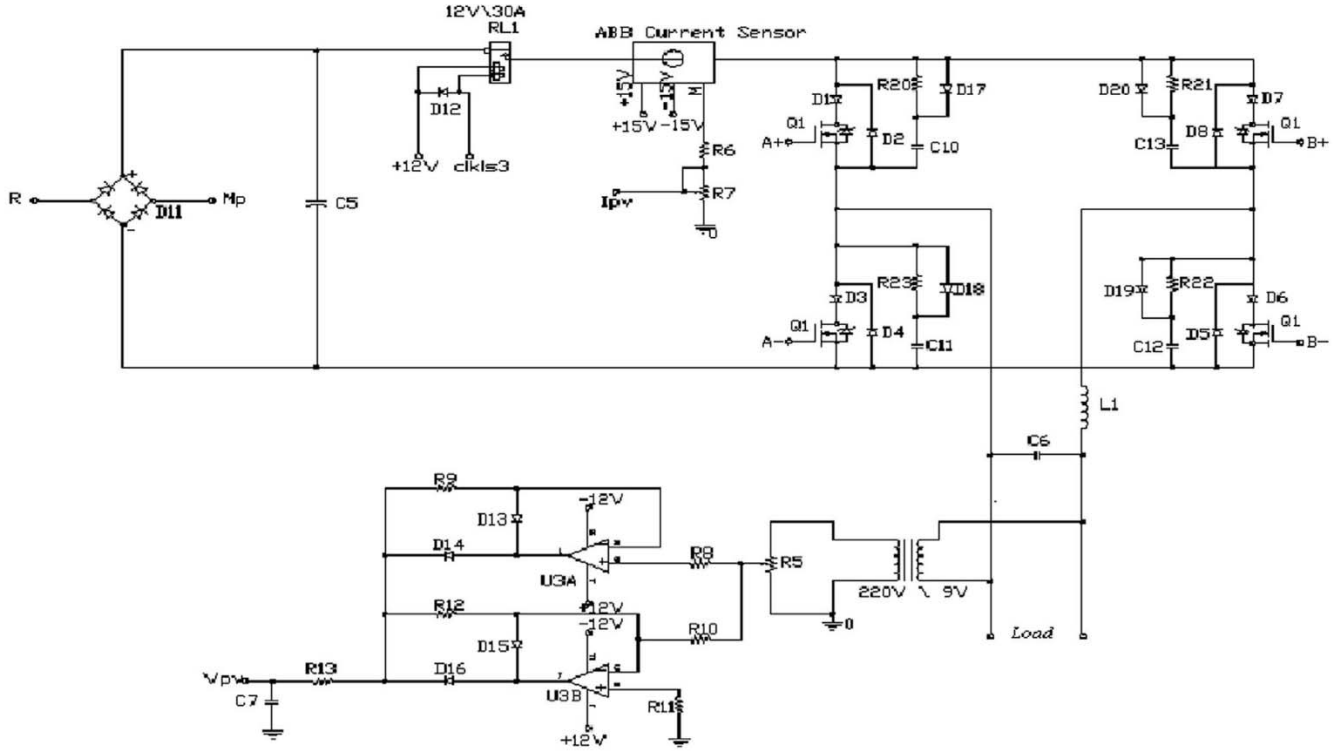


Fig. 10. Power circuit card.

Control board in the system;

- Necessary interface for operation between the user and the inverter has been performed.
- According to the required frequency value, an interrupt signal has been sent from pin PORTC.1 to the sine oscillator board by control card. During the programming of the control card, programmed PWM signal frequency in the hardware has not been changed. Desired sine signal of the frequency has been produced by using open loop control.
- The inverter generates the output voltage. To this, pin 14 sine oscillator card of inverter MC1408DAC is fed by using PWM signal from pin PORTC.2.
- For voltage control feedback, a signal is read as analog from PORT 2 pin with 8-bit resolution [14].
- v/f provides scalar control of inverter.
- An optional way was used for an inverter via unipolar or bipolar switching PWM technique.
- Soft start feature prevents the system from withdrawing over surge current from the network.

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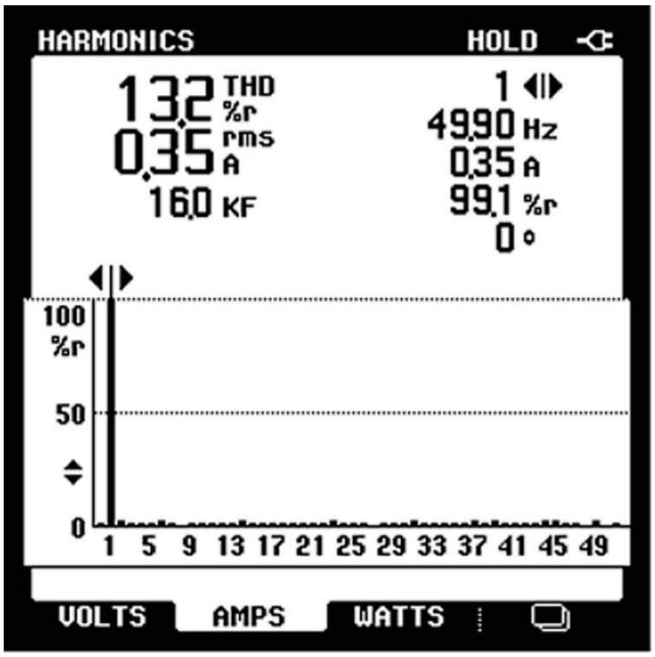


Fig. 11. The amount of total harmonic distortion (in the inverter output current).

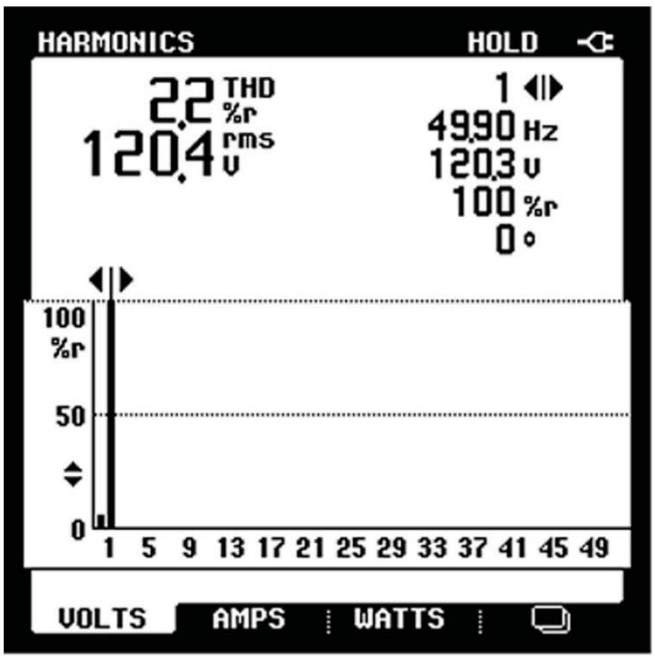


Fig. 12. The amount of total harmonic distortion (in the inverter output voltage).

- The status of a possible short circuit has been indicated on the LCD screen.

8. Mosfet driver card

To turn on Mosfet, an adequate level of positive voltage must be applied between gate and source tips. This voltage is called the threshold voltage. Mosfet IRFP460 uses threshold voltage ranging between 2 and 4 Volts [15]. Mosfets are used as voltage-controlled switches. Mosfet gate-source capacity must be taken into account during the control. In practice, integrated circuits are produced in order to control the TTL level of MOSFETS. In this application, IXYS Microchip company produced IXDD414PI and TC4422 mosfet drivers by were used [16]. The leg connections of integrated circuits are the same. The only difference between them is that IXDD414PI in pin 3, EN must be left idle, while in the TC4422 it remains constant. For this purpose it is sufficient to remove resistance R1.

To isolate the power circuit from the control circuit, 6 N137 optocoupler is used. The Logic control signal is inverted with opto-coupler, then reverted, and mosfets are thereby driven. In practice, four pieces of driver board for MOSFETs A+, A−, B+, B− are used separately [17].

9. Power driver card

Bridge rectifier connected to the network is filtered with capacitor C5. Obtained DC voltage in the full bridge is connected by means of relay. This relay will remain in the off position until the soft starting time of the inverter. Thus, while the inverter was switched off, its condition is left de-energised in order to protect against the mosfets' possibly turning on.

The information the circuit receives from the current sensors must be necessary DC measurement in the microcontroller and analog circuit. The current sensor is a product of the ABB company. The output signal is obtained as one way. The sensor does not have any structure that can transfer the value of the current flowing in the opposite direction. Thus the current information is connected to the DC busbar. To the easy calibration of the current value a potentiometer is connected between the chasis and tip M [18].

Required electrical insulation is provided by using a 220/9V voltage transformer, and the necessary voltage is obtained for the measurement as well. Another external diode has 30A/600 V values. DSEI30-06 i"s connected parallel to the Mosfet IRFP460.

10. Experimental measurements

The effective value of the inverter output voltage was increased up to 120 V and 50 Hz, the frequency values measured from the

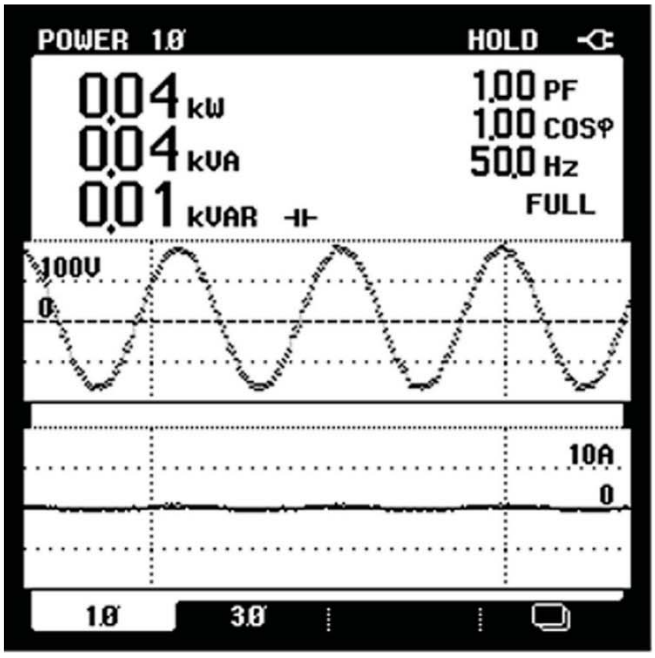


Fig. 13. Inverter output voltage waveform.

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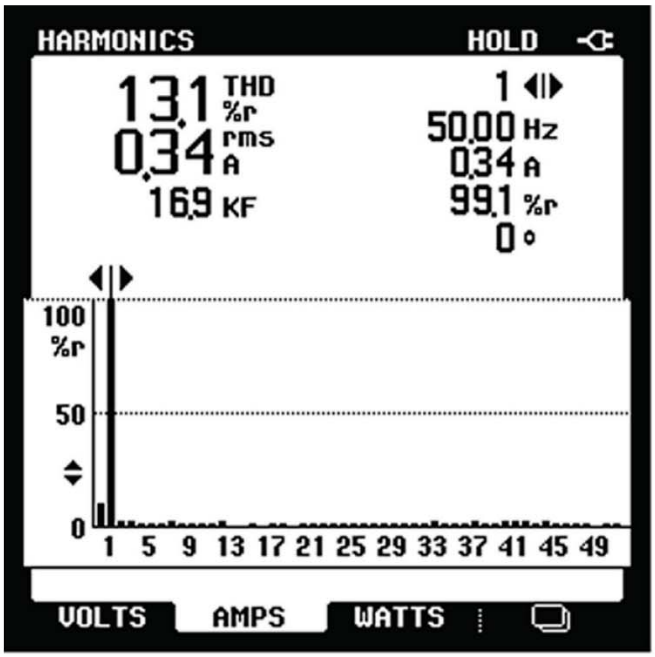


Fig. 14. The amount of total harmonic distortion (in the inverter output current).

experimental waveforms. 300Ω as a resistive load was connected to the inverter's output. Operating waveforms from the real circuits were measured by using harmonic analyzer (Figs. 13 and 16).

Step 1: Bipolar voltage switching PWM operation with a resistive load.

Frequency:50 Hz

Voltage:120 V

Step 2: Unipolar voltage switching PWM operation with a resistive load.

Frequency:50 Hz Voltage:120 V

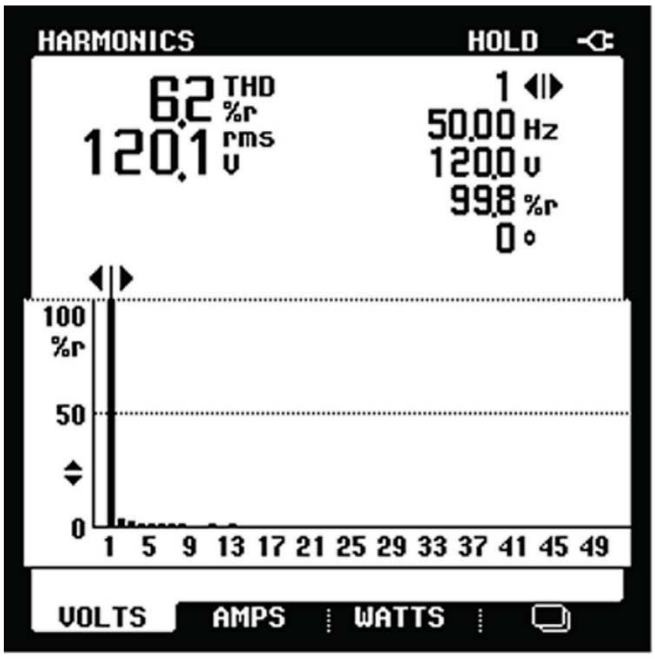


Fig. 15. The amount of total harmonic distortion (in the inverter output voltage).

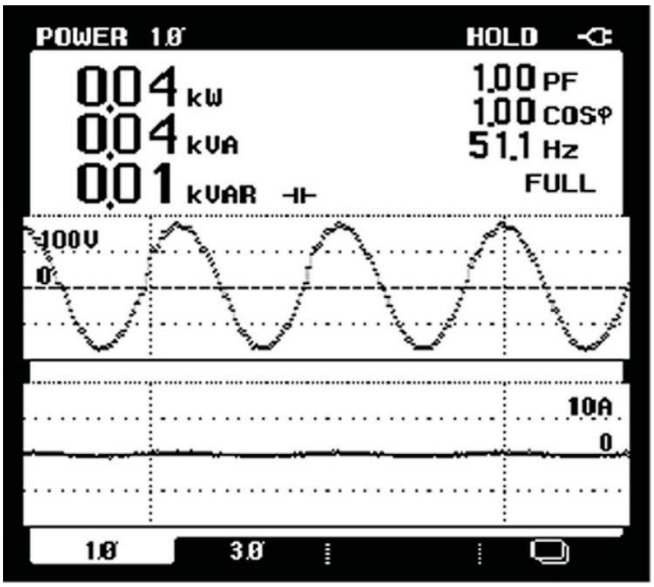


Fig. 16. Inverter output voltage wave form.

11. Conclusions

This study encompasses full-bridge inverters, which have a wide application in industry. The working principles and characteristics of different control methods are emphasized. Two different control algorithm were created and implemented for full bridge inverter function. Output frequency and voltage control of full-bridge inverter were focused. The objective of the experiments was a comparetion of the two techniques and the implementation of two different control methods (Figs. 14 and 15).

As the first control method bipolar, PWM switching had been applied to the output of full-bridge inverter. Output waveform of bipolar PWM switching is formed as the same value switching frequency as positive and negative alternations. The switching frequency of the system is the same as the triangular wave carrier signal.

Fig. 13 shows the harmonics of the output voltage versus the amplitude modulation index *ma*. The fundamental voltage increases linearly with *ma*. The dominant harmonic has a high magnitude, which is even higher than the fundamental voltage.

This harmonic along with its sidebands can be eliminated by the unipolar pulse width modulation scheme.

The second control method, inverter output, is operated as a unipolar voltage switching PWM. Output waveform at unipolar switching, unlike bipolar switching of PWM, is not the same as carrier frequency. Positive and negative alternations with equal frequency to the control signal have been obtained from output. In this switching technique, even though value of the mosfets' switching frequency is the same as the carrier frequency, SPWM signal frequency at output waveform is double that of the switching frequency.

Circuit design, implementation and, at the end of the experiments both techniques (unipolar-bipolar) were found to have pro and con properties relative to each other. Operation in bipolar voltage switching of inverter output waveform compared to unipolar voltage switching contained higher order harmonics. This also means that the amount of the total harmonic distortion is greater. SPWM with Unipolar voltage switching scheme has a better harmonic profile than Bipolar voltage switching. Hence, SPWM with Unipolar voltage switching technique is often used as a switching scheme for the single phase inverters.

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In the experiments, the amount of total harmonic distortion of output voltage varies between 0,7% and 6,2% (at experiment 14). The amount of the inverter output voltage total harmonic distortion is little more than 5%; so application could be considered successful. The 100 W power rate of inverter prototype was tested with the 50Watt resistive load and 50Watt shaded pole motor as a load.

Control of the full-bridge inverter with the development of high-speed processors has recently begun to be operated by digital implementation. However, the microcontroller PIC16F877 has been determined as not fast enough in practice to be used to control the system. For this reason, a fast control circuit application was necessarily applied as analog. PIC16F877 microcontroller used in the system is not sufficient to control the system as described previously. Industrial inverters with high processing capacity microcontrollers have been used for industrial purposes. In addition, the microcontroller is sensitive against interference in the system. For this reason, the output of the system was prevented from reaching high currents.

Compared previous applications utilizing electronic circuit diagrams and complicated. Integrated electronic circuits, the PIC microcontroller is better suited to electrical engineering pedagogy. Students can more easily comprehented the creation of sinusoidal inverter through the 18 steps thet proceed in increments of 20° via PIC microcontroller. Because of the importance of sinusoidal wave form with low harmonic content in industry, at the beginning of their education it is crucial for electrical engineering students to compare unipolar and bipolar switching of inverter switches, and need to learn the technique by the most efficient pedagogy possible.

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