

The Design and Implementation of a Microcontroller-Based Single Phase On-Line Uninterrupted Power Supply With Power Factor Correction

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Abstract

In this study, the design and implementation of a microcontroller-based single phase on-line UPS (Uninterrupted Power Supply) with PFC (Power Factor Correction) were made practically. SP-320-24 SMPS (Switch Mode Power Supply) module was used to correct the input power factor. Input power factor value was held at the desired value in uninterrupted power supply topologies. In the realized system, two PIC16F876 were used as microcontroller. One of them was used to generate sinusoidal PWM (Pulse Width Modulation) signals that are used to drive n-channel MOSFETs in push pull inverter and to assure feedback control. Other one was used to control and display units. Harmonics were eliminated and output filter was simplified by using sinusoidal PWM technology.

1. Introduction

The safety problem of the generators of electricity energy has been considered important because it was used commonly in devices and systems that should work permanently and has vital important. All preventive measures for safety in the AC network that supply 95 % of used electricity energy are not enough. For this reason, devices and systems known as critical load must be fed by UPS (Uninterruptible Power Supply). UPSs are separated into two groups according to structural difference as dynamic and static. And UPSs are separated also into three groups according to the running principle as off-line, line interactive and on-line. Especially UPSs that use PWM method with microprocessor and microcontroller have common usage due to their skill on eliminating harmonics and simplifying filters on the output stage. For this reason, there are works in the literature on them.

In [1], performance analysis has made on a degraded switching on-line UPS. This power supply consists of a new UPS system, a rectifier or boost converter with power factor regulating ability and two legs inverter with connected to the separate DC line. In [2], output voltage of a mono phase inverter in the UPS is filtered with LC filter in order to obtain sinusoidal output voltage. In this study, a mono phase resonance snubber inverter was developed to apply in UPS. In [3], a new method is proposed for real time digital feedback control of PWM inverter that has voltage control with voltage variation compensation. In this study, although sampling frequency of inverter was applied as an half of carrier frequency, it is also convenient for higher carrier frequencies. In [4], basic structure and elements of a UPS system were introduced and the basic features that desired in UPS systems were explained. It is shown that off-line and line

interactive UPS systems have less protection, they have common usage due to low price and losses. However on-line UPSs are preferred on the systems that have importance of safety. In [5], it is shown that a new control schema depend on two stage structure in PWM unit of an UPS can has either fast dynamic response and low harmonic disturbance. In [6], PWM inverters that control digitally with dead-beat response, for UPS applications, are reviewed. To improve the output waveforms of the PWM inverter, several modern control techniques are applied together with the deadbeat control. This paper describes the evolution of PWM inverters deadbeat control technique, and discusses practical considerations for the implementation of this digital control. In [7], the purpose of a voltage controller for UPS inverters is to produce stable output voltage with low distortion under all loading conditions, especially under nonlinear loads and dynamic loads. This paper presents the design of a novel digital robust feedback controller for single-phase UPS inverters based on pole-placement method. To eliminate the effect of the time delay caused by sampling and calculation, a modified PWM technique is introduced. Results of simulations and experiments show that the proposed controller can achieve very low total harmonic distortion (THD) and fast dynamic response under various loads with low switching frequency.

In our study, single phase on-line microcontroller-based UPS with PFC was realized practically. The responses of the system, input and output signals were examined for different loads by experiments.

2. The System Structure

UPS that is realized in this study charges 24 V batteries continuously by SMPS with PFC from 220 V AC input and supplies on-line power into system by converting 24 V DC to 220 V AC via inverter and control units. Block schema of realized UPS is shown in Figure 1.

UPSs are used to eliminate power quality problems and to supply the power into system in case network energy was interrupted. The inverter part of UPS is controlled by using PWM method that is used commonly in controlling AC energy system. Sinusoidal PWM is obtained by commonly used PIC16F876 microcontroller.

In realized UPS, SMPS module is used to regulate input power factor, and over 0.95 power factor is obtained. Using of the designed boost converter will be more economical to control PFC and to decrease cost.

The number of eliminated harmonics increases and output filter of inverter becomes simplified by switching many times

MOSFETs in the push pull inverter in an half period which assures wave form with lower harmonics.

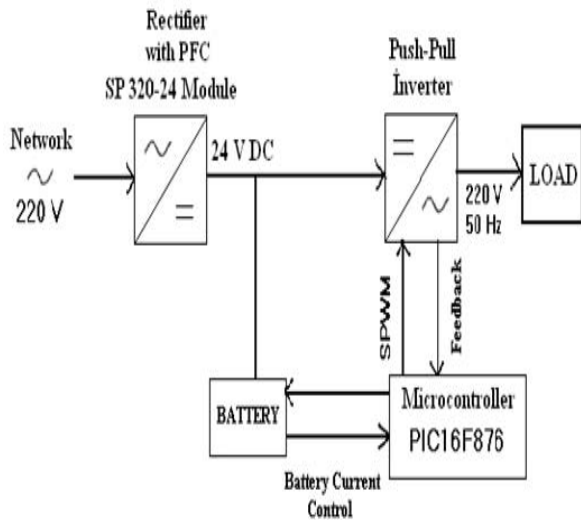


Fig. 1. Block schema of realized microcontroller-based single phase on-line UPS with PFC.

Eliminating undesired harmonics at the output of UPS is also superior specialty of PWM. This method that known as harmonic elimination is convenient especially for microprocessor based PWM and it controls also amplitude of the fundamental component. Generating process of PWM with microcontroller decreases physical dimension of the circuit in the big amount. Furthermore, output values gets more ideal case by this control and the control process is done easier.

Elimination until 15. harmonic is obtained with used 16 pulses sinusoidal PWM and it is seen that THD (Total Harmonic Distortion) is under 5 % in the calculations that is done with odd numbered harmonics coefficients by obtained Fourier series analysis. This is already one of the desired important features in UPS topologies. In UPS with this feature, filters that are used at the output to eliminate harmonics become simplified in a big amount.

In the realized UPS, two microcontroller were used. One of them was used in order to generate sinusoidal PWM and to assure feedback control. The other was used for controlling and measurement aim. It can be possible also to use just one microprocessor by using interrupt subroutines.

Sinusoidal PWM frequency is 1.6 KHz and 16 pulses in one alternance. PWM frequency can be increased by improvement in the software. However transformer in the inverter output is a low frequency transformer. If the PWM frequency is high, transformer at the output must be high frequency transformer. Transformer dimension can be reduced by increasing the switching frequency.

Realized UPS is on-line, so it feeds the loads continuously through itself. So power quality problems don't effect the sensitive loads. However the UPS is low power, the power can be increased by selecting bigger power elements without any software changes.

2.1. Functional Features of Module SP-320-24 SMPS

In the realized UPS, SP-320-24 SMPS was used to convert the AC input voltage to the DC output voltage and to control the

charge of the battery, and PFC control was assured as making power factor 0.95. SP-320-24 320W is a module that has one output PFC function. It has short circuit, over load and over voltage protections. It works at 100 KHz switching frequency.

2.2. Push-pull Inverter

In all UPS systems, main goal is to generate ideal output voltage for every kind of load and temporary case. 50- 400 Hz sinusoidal output is generally necessary in the UPS systems. Modern inverters work with PWM strategy. Load impedance in the system can be 0-150 % of the nominal load values and also it can be resistive, inductive or capacitive. The feedback is used to assure output voltage at the desired value. Adjusting the output voltage as depends on control strategy is the most important features of the system.

Push-pull inverter circuit is shown in Figure 2. Two MOSFETs in the push-pull inverter are switched sequentially. MOSFETs run as static switch. Both MOSFETs must have the same characteristic.

Sinusoidal PWM signals that are generated with PIC16F876 was used to drive MOSFETs in the push-pull inverter. When SPWM is applied to first MOSFET, other one is in off condition. Current flows through the first MOSFET and transformer. In the reverse condition, current flows through the second MOSFET and transformer. Applied sinusoidal PWM to the MOSFETs is assured as synchronous to prevent being ON condition of both MOSFETs in the same time.

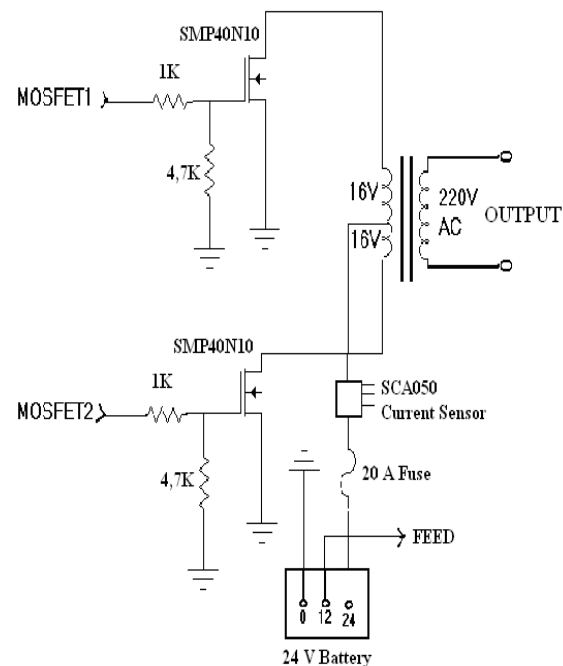


Fig. 2. Push-pull inverter circuit which is controlled by sinusoidal PWM

2.3. Obtaining the Sinusoidal PWM

Changes in the frequency and output voltage are done only with software changes. Generation of the sinusoidal PWM for MOSFETs that are used in the inverter is made for two aim. First aim is to control conduction sequence and conduction

duration, second aim is to control conduction time of each MOSFET. In the generation of PWM signal as depends on software, first function is realized by software, second function is realized by hardware timer. In this system, operations such as calculation of conduction time and selection of semiconductor are determined by software system. The control system is constructed by microcontroller as being standard with a clock pulse generator.

Sinusoidal PWM that is used to drive MOSFETs in the push-pull inverter is generated by PIC16F876 via software. Timing interval is increased by using 20 MHz oscillator in the microcontroller. A look-up table is occurred by sampling 50 Hz sinusoidal signal with 11.250 degree intervals with PIC microcontroller. 16 pulses sinusoidal PWM signal is obtained by sampling 16 times in the one alternance of 50 Hz sinusoidal signal. Obtained SPWM signal is 1.6 KHz. So, MOSFETs are switched at 1.6 KHz frequency. Obtained SPWM with PIC16F876 microcontroller is one channel PWM. PWM signal is taken from 12. pin (C1) of PIC16F876. This one channel PWM is applied to the MOSFETs in 10 ms with logical gates connected to 11. pin. Feedback control to the 3. pin of microcontroller is made in order to hold fixed decreasing output due to loading inverters at 220 V. It is assured that output voltage is fixed by adjusting the conduction durations of SPWM in case of change in output voltage. Circuit schema in order to generate sinusoidal PWM is shown in Figure 3.

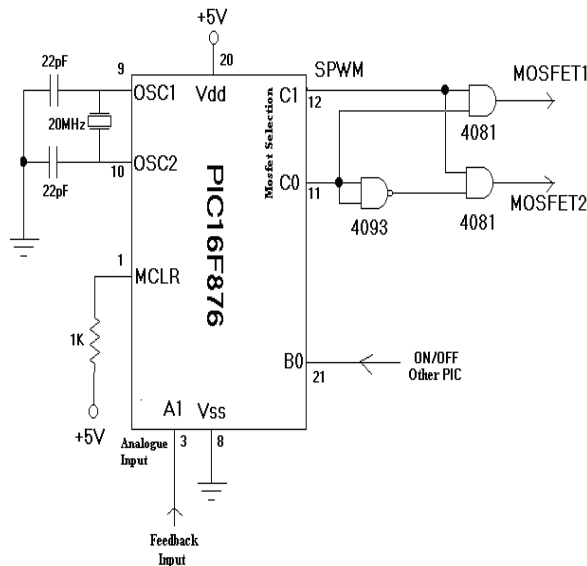


Figure 3. PIC16F876 microcontroller that generates SPWM

2.4. The Control, Display and Warn Unit

The reading process for LCD takes approximately 4 ms and this duration can cause the interruptions at the generating SPWM routines. For this reason, second microcontroller is used for control unit. The circuit schema of control, display and warn unit is shown in Figure 4.

ON/OFF process of the system are assured by the control unit. Input voltage, battery current, output voltage and output power are measured and they are displayed at the 2x16 LCD display. Communication with LCD is assured by reading 4 bits data with microcontroller. A SCA050 50A current sensor is used to read battery current.

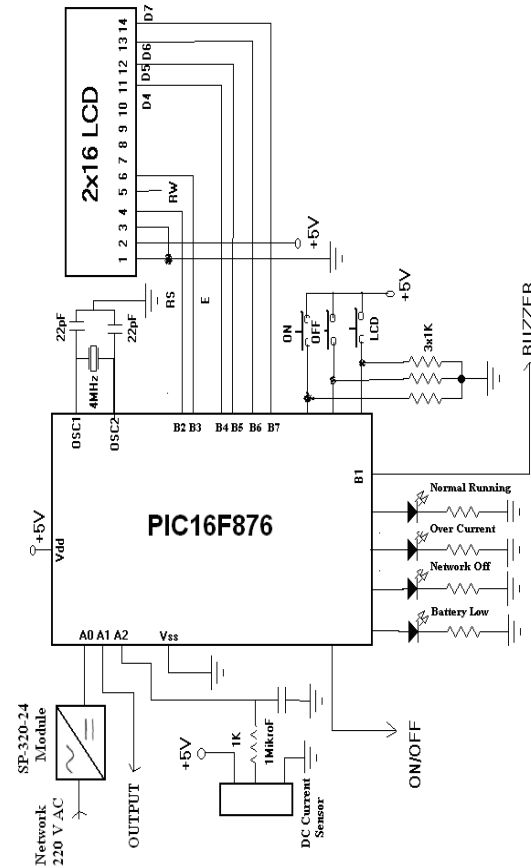


Fig. 4. The circuit schema of control, display and warn unit

3. Experimental Results

The experimental works were done on realized UPS and its performance was examined. A 1.6 KHz sinusoidal PWM signal was applied to the MOSFETs. There are 16 pulses with 1.6 KHz in each alternance. These signals were applied to the MOSFETs in each 10 ms respectively. This input signal is shown in figure 5.

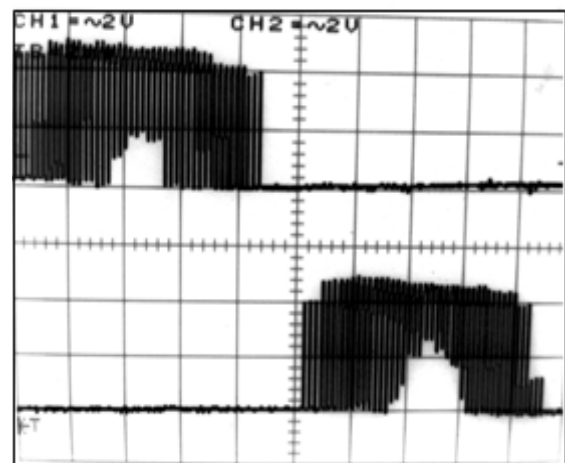


Fig. 5. Sinusoidal PWM signals that are applied to the MOSFETs gate

The oscilloscope view is shown in Figure 6 for 100 W resistive load without filter. This signal is not sinusoidal because there is not filter at the output. Capacitive filter was used at the output to make output signal as in the sinusoidal form. This is a simple filter due to used PWM. In this way, total harmonic distortion of the system was made under 5 %.

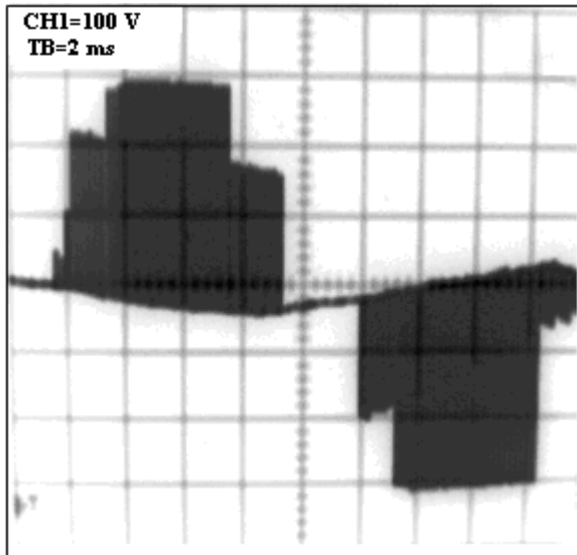


Fig. 6. The output voltage for 100 W resistive load without filter

The capacitive filter that is used at the output of UPS made the output signal in the sinusoidal form. The variations of output voltage and current for 100 W resistive load are shown in Figure 7. As it seen, this output signal is pure sinusoidal. This signal has done with simple capacitive filter due to used sinusoidal PWM. Generally in most UPS, normal PWM is used and for this reason, more complex output filter is necessary.

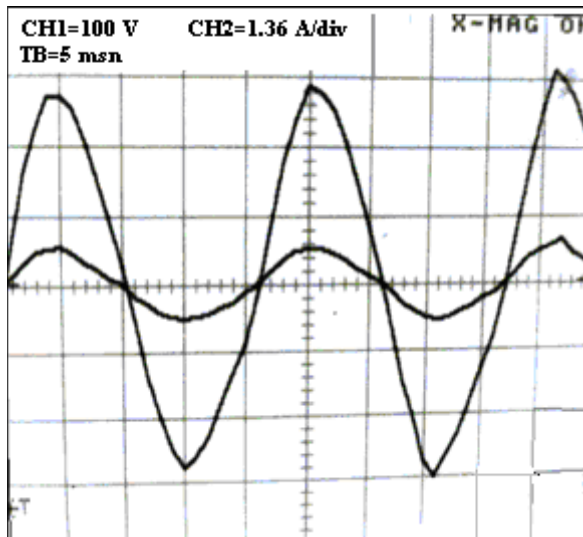


Fig. 7. The variations of output voltage and current for 100 W resistive load

The variation of the output voltage and current for resistive-inductive load is shown in Figure 8. Generally practically loads are in that type. Phase difference can occur between voltage and

current due to effect of the inductive load. In our UPS, there is no phase difference between output voltage and current and they are certainly in the sinusoidal form. In the output signals especially in the current, disturbance doesn't appear.

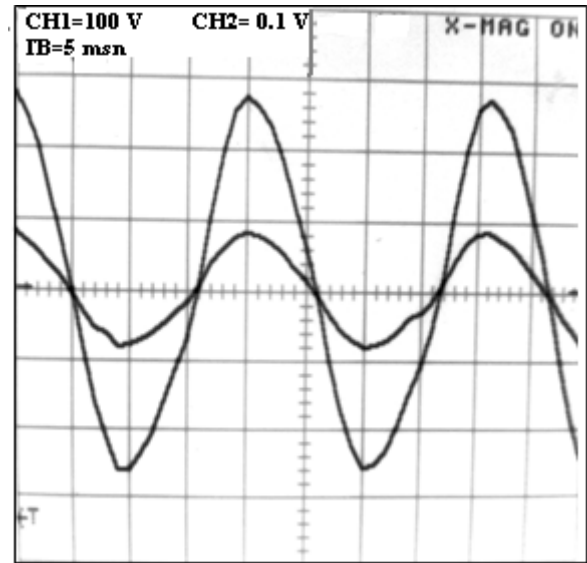


Fig. 8. The variation of the output voltage and current for resistive-inductive load

The variation of output voltage and current in case 135 W universal motor is connected to the output of UPS is shown in Figure 9. It is shown that output voltage and current are certainly sinusoidal without disturbance with inductive load. This is advantage of SPWM technique. It means also that feedback signal is processed very well in the microcontroller.

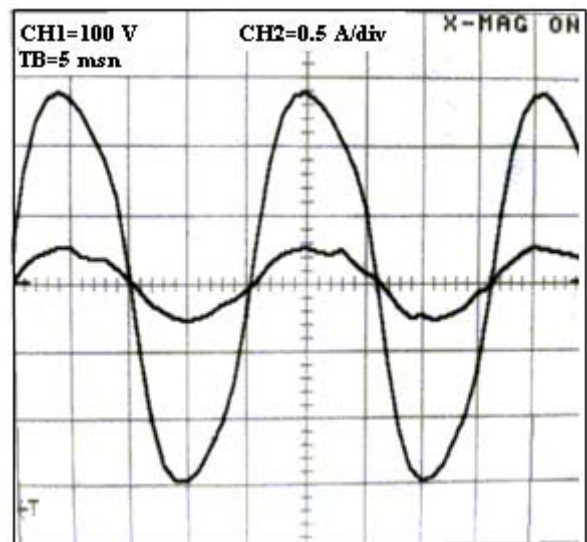


Fig. 9. The variation of output voltage and current in case 135W universal motor is connected to the output of UPS

The variation of input voltage and current is shown in Figure 10. It is seen that there is no phase difference between input current and voltage, it means that at the input of the realized system, PFC is high. At the same time, input current is certainly

sinusoidal and it means that it doesn't effect negatively the AC network and active/ reactive power consumption balance.

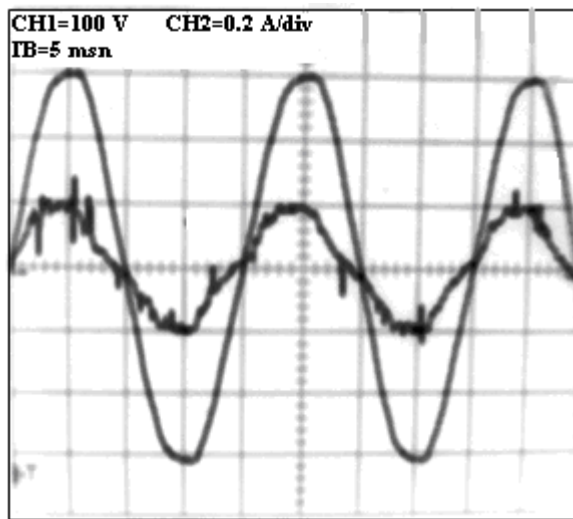


Fig. 10. The variation of input voltage and current of UPS

4. Conclusions

The solution for necessity of the qualified power for the devices that are known as critical load recently is assured with UPSs. In this study for this solution, design of single phase on-line microcontroller-based UPS with PFC was aimed. AC network was protected from negative effects by making input current sinusoidal as holding power factor at desired value at the UPS topologies. Negative effects of devices are eliminated by UPS with high power factor. The amplitude of fundamental component of the signal at the output of UPS is certainly sinusoidal as eliminated from harmonics by controlling with used sinusoidal PWM method that is made with microcontroller. This assures qualified power necessity for critical loads. The system has high voltage gain because the sinusoidal PWM technique is used. The various experimental results of the system were given in order to determine effectiveness of the system.

5. References

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