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Design and Implementation a Single-Phase UPS Based on Microcontroller with AVR at Input and Full-Bridge Inverter at Output for Improving Sinusoidal Output Voltage

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Abstract

In this paper, a novel application that uses the broadband noise from a ship-of-opportunity to estimate the scattering from underwater objects is reported. The propagation is based on the normal-mode model. The source localization (location of propeller) is initially realized using incoherent broadband matched-field processing. Then, by utilizing an estimator that relies on Normal-Modes, the target echo below the sea surface is calculated to evaluate the location of the target. The proposed idea is illustrated using simulation and then verified using the acoustic data from a 2019 underwater communication trial in Grand Passage, Nova Scotia in Canada. Experimental results show that the proposed technique can be a reliable signaling method and environmentally friendly that can be applied to the fields of underwater communication and ocean monitoring for a shallow water environment.

Keywords: Bistatic Echolocation, Normal-Mode Model, Matched-Field Processing, Underwater Localization, Ship-Of-Opportunity.

1. INTRODUCTION

Energy is a basic need for continued economic development, social welfare, improving the quality of life and security of society [1-6].

One of the important issues is the extent of the human need for energy resources so that the effort to achieve permanent energy resources is one of the long-standing goals of human beings [7-9]. Expansion of energy resources and control along with their

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protection are important studies in recent years [10,11]. In the meantime, uninterrupted energy production has become very important [12,13].

An uninterruptible power supply (UPS) is an electrical apparatus that is able to supply power to electrical equipment during a power outage for a certain amount of time [14-16].

A UPS is typically used to feed critical loads where an unexpected power disruption could cause fatalities, injuries, serious business disruption, or data loss [17,18]. The construction of a UPS, usually includes at least the following components: (a) energy storage, which provides the energy for emergency loads, (b) an inverter, which converts the DC voltage into the required AC voltage, and (c) mains voltage monitoring which detects critical conditions and activates the UPS [19,20].

Several control methods have been applied to UPS inverters [21,22].

A multi-input high step-up inverter suitable for photovoltaic power conditioning systems is proposed in [23], which is based on isolated soft-switching DC-DC converter blocks and each of these blocks can provide zero-voltage and zero-current switching through its semiconductors. The study of various sliding modes is presented in [24] that integral terminal attractor performs satisfactorily in regulating the output during load perturbations. This method can be regarded as a viable controller for PWM inverter applications, such as photovoltaic inverter, wind power inverter, and fuel cell inverter.

UPS with a high-power factor and two conversion stages is suggested in [25], which dual conversion configuration has three stages, but typically, only two stages work simultaneously. Also, the first stage of the proposed scheme includes the power factor correction step and the battery charger with dual conversion configuration and obtains a two-stage UPS.

The online UPS is technically the most advanced power supply of the power supply product line [26,27]. It always has a backup power source in the power flow path. They require no transfer time from the utility power supply during power failure to the backup sources [28,29]. There are several types of research in various fields of online UPS such as the structure, application, and design and control [30,31]. A single-phase transformer-less online UPS is proposed in [32]. The UPS system is composed of a four-leg-type converter, a battery charger/ discharger, and an inverter, the control of the dc-link voltage enhances the transient response of the output voltage and the utilization of the input power. An online UPS inverter that eliminates the inrush current phenomenon caused by the switching-in of the load transformers is proposed in [33], which in the system a fast flow control program is used to regulate the load current during all energizing conditions of the load transformer connected to the UPS system. A high-frequency isolated online UPS system, consists of a single-stage ac/dc converter, boost dc-dc converter, and an inverter, for low power applications is proposed in [34], which regulates the output voltage of the inverter at both linear and non-linear loads and is controlled by cascaded slide mode and proportional-resonant. A multi-input high step-up inverter suitable for photovoltaic power conditioning systems is proposed in

[35], which is based on isolated soft-switching DC-DC converter blocks and each of these blocks can provide zero-voltage and zero-current switching through its semiconductors. A no-isolated online UPS system consists of a bridgeless PFC boost rectifier, battery charger/discharger, and an inverter is proposed in [36] which the controller exhibits excellent performance during transients and step changes in load.

Based on the analysis of the problems related to the topologies of the UPS, this paper presents a new topology of UPS system as shown in Figure 1. It is important to note that no battery banks are needed to hold high voltage DC link in the proposed scheme, and the number of batteries is practically decreased. Therefore, it is appropriate for applying resources with low power consu-mption, high efficiency, low weight, and less volume and cost. Implementation of the proposed UPS shows high performance in the experimental results; the overall system efficiency is between 85% and 90% (for a power range of 200 to 350 W). It includes PFC incremental rectifier, buck converter as a battery charger, push-pull converter to increase battery voltage for DC voltage link and a full bridge inverter.

A single-phase UPS based on microcontroller with AVR at the input and a full-bridge inverter at the output for improving sinusoidal output voltage is designed and implemented. The main advantages of the proposed system are high power factor correction (PFC) by rectifiers, effective control of DC link voltage, decreasing the effect of output load, high efficiency, a significant reduction in the number of batteries, and improvement of the inverter PWM signal which provides a favorable sinusoidal voltage at the output.

2. SYSTEM STRUCTURE

The UPS system specifications designed in this paper are as follows: (a) Power factor correction to greater than %95, (b) THD less than %5, (c) Automatic adjustment of the appropriate voltage, (d) Inverter with an ideal sine output, (e) Effective output voltage with change of 2% (220 V±2%), (f) Frequency is 50 Hz, and (g) 350W continuous active power and 550 W instantaneous active power.

The SPWM pulse generated by the microcontroller is used to drive power MOSFETs in the inverter. The control of the various parts of the system is done by a microcontroller. Also, it is used to display parameters.

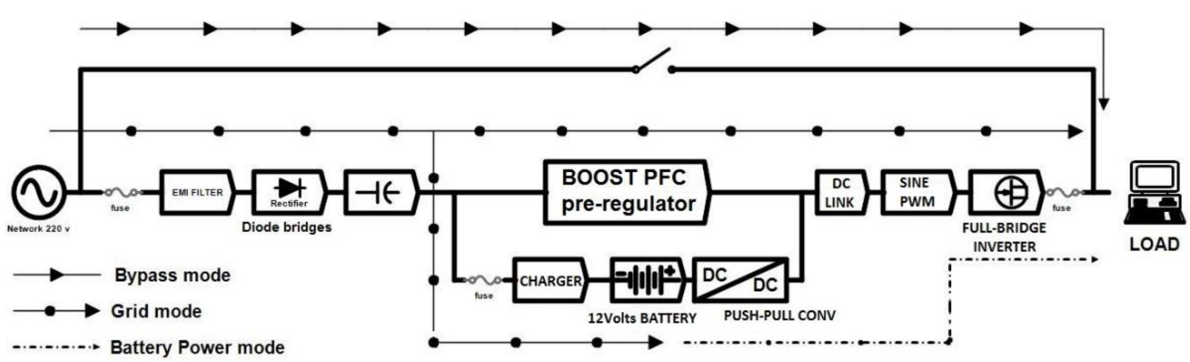


Fig. 1. UPS system functional modes

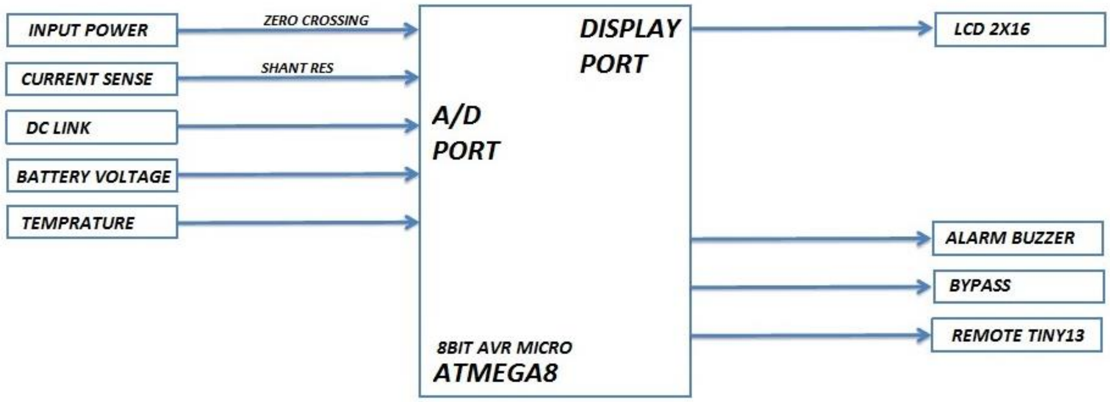


Fig. 2. Control, display and alarm unit.

The high frequency technique for increasing efficiency is used in output UPS to derive MOSFETs. Therefore, the switching speed is increased and a small output filter is necessary. Also, two PWM pulses are produced by a microcontroller with the frequency of 20 kHz. For charging batteries, a converter with a current controller is designed. A 3 A current is required and the converter is of the step-down Buck type. A Push-Pull converter was designed by soft starter to increase the battery voltage level. It can prevent moments of current flowing during system startup.

Two EMI filters are located at the input and output of the system because the UPS works at high frequency and generates noise.

2.1. System Performance Specifications

Three performance modes of the UPS in the block diagram are:

The grid mode is activated, if the network input power exceeds 85% of its power or the network input power it is not interrupted. During this state, a rectifier with power factor correction activates the buck converter to charge the battery and the output inverter. using the boost rectifier convert, the ac input voltage converts to dc voltage. Then output sinusoidal voltage is created by the inverter. The voltage needed to charge the batteries is supplied by the step-down converters in DC link.

Battery mode: This mode is activated by the sudden and rapid decrease of DC link. This may be due to the mains voltage drop or the input voltage drop. Therefore, the Push-Pull mode is activated in this case and converts the battery voltage to the DC link voltage. Also, the ac output voltage is supplied by the inverter.

Bypass mode: When the UPS system defects, the system is quickly bypassed by a high-performance relay. Its failure will be notified by alerting and alarms.

2.2. Automatic Voltage Regulator

To have a constant output without fluctuations, a stable regulated DC voltage should be supplied for the inverter. For this purpose, a Boost module is designed by the IC L6562. This IC is a current mode PFC controller with excellent performance and high linear coefficient which allows to significantly reduce input current distortion. Also, it has a very low THD at a wide range of its connected loads. In the designed module, by changing the input voltage range between 160 V and 280 V, a constant regulated DC voltage of 400 V is supplied.

2.3. Battery Charger

The designed charger circuit constantly charges the batteries to store sufficient energy when the system is in battery mode [37]. Thus, this design should have little power consumption. In addition, low-input, IC UC3845 has a high efficiency and fewer auxiliary elements. Unique features of this IC are: high gain of the error range, high output current, having oscillator, temperature compensated reference and current comparator [38,39].

2.4. DC to DC Converter

Two MOSFETs are switching sequentially, MOSFETs act as static switches, both MOSFETs must have the same properties. To have the constant DC voltage under load, a high-performance circuit design is needed.

The IC SG3525 is a pulse width controller with high performance. It requires little spare parts to design, and it's good for switching power supplies. This IC, has the proper flow to drive the MOSFETs, the capacitors have a soft drive to charge slowly, prevents amps on startup, and has shut-down input to interrupt DC voltage of circuit [40].

2.5. Full-Bridge Inverter

The main role of any UPS system is to provide short-term power and ideal output voltage when the input power source fails for a variety of different loads. The frequency of the UPS output (in 50-60 Hz range) must match the requirements of the load. The inverter does not produce any power; the power is provided by the DC source.

The modern inverter is operated with a PWM strategy. The impedance of the load system is a combination of resistance, inductive reactance, and capacitive reactance. It can be between 0 and 150% of the rated load. SPWM signal is generated by the microcontroller. Two SPWM signals are generated by ICATTINY13 that are NOT relative to each other. Also, at the moment of change of pulse mode, a moment is considered, so that the MOSFETs are not lit at the same time. The switching pulse frequency is selected 20 kHz. This choice of switching frequency will increase the efficiency of the inverter and it requires a smaller output filter. The selected MOSFETs must be able to switch at this frequency and provide the output power. In a 20-millisecond period, 360 pulses of PWM are generated from the look table by ATTINY13, to produce high quality sine wave at the output. The pulses produced by the microcontroller are applied to four high frequency opt-couplers. These opt-couplers, switch the DC voltage of 10-35 V to ±1.5A by receiving a PWM signal with a 5 V from the microcontroller. With these opt-couplers, the steering circuit is completely isolated from the power circuit. After the MOSFETs, by placing the LC filter on two LEGs, a completely sinusoidal output is produced without noise.

2.6. Control, Display and Warn Unit

The microcontroller used in this part is ATMEGA8. The process of switching on and off the system is done by the control unit.

This unit measures the following and displays on a 2×16 LCD: input mains voltage, battery charging voltage, device temperature, output voltage, and output power of the device. Detection, display, and alert operations are also performed by the control unit. The block diagram of the control unit is shown in Figure 2.

3. DESIGN CONSIDERATIONS

According to system quality parameters such as reliability reduction and centralized emergency network costs, the small UPS is a more appropriate option in comparison with a centralized UPS. to design the UPS system with small dimensions (85*210*320 mm), low cost, and high system capability, are a number of points which are considered below.

3.1. Technical Specifications

Technical features of the designed UPS are mentioned in Table 1. The switching frequency is 20 kHz. The system is completely intelligent. It has a full package of protection options such as short circuit protection, overload protection, and battery discharge protection. It also has a visual and sound alarm for fault condition and operation mode (grid connected) indicator. The system can also be connected to external batteries or solar cells.

3.2. Power Factor Correction

For designing the Boost converter with the current controller and PFC, the equations presented in [41] were used. The boost converter provides a fixed DC voltage on DC link. If the overall efficiency of the system is considered eff, the inductor value for PFC with the following relationship is obtained:

$$L = \frac{\tau_{on}(\sqrt{2}v_{in})^2(eff)}{2p_{out}} \tag{1}$$

3.3. Charger Design

The resistance Rt and capacitance Ct are selected as 22 KΩ and 1 nF, respectively, to select the oscillator frequency and duty cycle of output voltage, by reading the MOSFET source current from the CS leg, MOSFET switching is controlled by control feedback. A potentiometer is used for arranging the charging of the battery voltage.

If the switching frequency of UC3845 IC is considered f_{sw}, the inductor value of the charger circuit can be estimated by (2).

$$L_{\min} = \frac{(v_{in(\min)} - v_{out})(1 - v_{out}/v_{in(\min)})}{1.4 I_{out(\min)} f_{swt}} \tag{2}$$

After the voltage reaches the charged voltage, IC reduces the PWM pulse width which leads to charge current limitation. The pulse current of the battery is provided by the signal of the PWM to gate-source of the MOSFET. The resistor connected to PIN3 of UC3854, senses the charge current.

Table 1. ***Technical specifications of the UPS.***

Input voltage	160~280V ac
Output voltage	220V ac
DC Link Voltage	400V
Grid Frequency	50~60 Hz
Output Power Capacity	350W
Output Frequency	50Hz
Output Power Factor	0.95
Number of Battery	2x12V(parallel)

3.4. Push-Pull DC to DC Converter Design

For switching circuits, the SG3525 IC is used since it has good capability. The SOFT-START capacitors are used to start up slowly to charge DC link capacitors. By using resistance (Rt) and capacitance (Ct) the oscillator frequency is determined. The resistor (100 Ω) connected to the 7th leg controls the dead-time of the output pulse. When the system fails, to disconnect the DC voltage the shut-down IC leg is used, which is controlled by the microcontroller ATMEGA8. simultaneous switching of the switches is prevented using the creation of dead time by IC. By using output current feedback and dead time adjustment, the transformer saturation is avoided. Also, the core is prevented from being saturated by creating a gap between the ferrites. If the transformer is saturated, the IC control unit will increase the current flowing through MOSFETs and turn off.

3.5. Full Bridge Inverter Design

Filter inductance value is obtained by $V_L=L d(\Delta i_L)/dt$. The angle of the input voltage considering LC filter is $\theta=\omega t=\frac{\pi}{2}$. The value of inductance is obtained:

$$L_{fi}=\frac{v_b}{4h'f_s} \tag{3}$$

where, h', V_b, and f_s are hysteresis band, dc link voltage, and switching frequency, respectively. In this paper, the hysteresis band may be very small, due to the high current ripple, inductance value is selected. h′is 50% of load current at the highest value of output voltage. The hysteresis band is:

$$h'=\frac{\frac{1}{2}p_o}{v_o} \tag{4}$$

The inverter's apparent power is P_O. The value of filtering capacitor with considering resonance frequency is:

$$f_{fi}\le\frac{2f_s}{10}=\frac{1}{2\pi\sqrt{L_{fi}C_{fi}}} \tag{5}$$

3.6. Control System Structure and Strategy

The proposed UPS system is based on providing a stable DC voltage link to have a regulated output voltage. As mentioned before, a boost rectifier has been used. As shown in the block diagram of the proposed system, a push-pull converter has been used to feed the DC voltage link. Since in the configuration with two DC voltage sources connected in parallel (battery and grid), the one having a higher value of voltage supplies the load; the generated voltage from 5-volts battery is always less than the boost converter voltage. Using this method, UPS output would always be supplied by the grid. One of the advantages of this method is that in overload condition battery voltage will help the DC voltage link and prevents voltage variation. Moreover, having the batteries supplying the load, grid disconnection will not affect the output. Grid disconnection sharply reduces the voltage of DC link but as the voltage reaches to defined the value of the battery mode, an appropriate voltage is provided for DC link.

For the control system, the basic unit is ATMEGA8 microcontroller. The system is continuously controlled and monitored using feedback signals. A feedback signal is obtained from the voltage drop on a resistor, that helps the system by determining and handling an overload condition. Charging of the battery is controlled by sensing battery voltage. The control system alarmed the over charge or battery damage condition. The variations of network voltage are displayed on LCD. The alarm signal and the remaining time for battery usage are displayed during network disconnection. NTC sensor controls the device temperature. To prevent damage to the load, any faults in the system are notified using the feedback signal.

4. EXPERIMENTAL RESULTS

To analyze the proposed method, a laboratory prototype model as shown in Figure 3 was developed with a nominal power of 350 W, and its performance was evaluated. A printed circuit board (PCB) layout of the system is shown in Figure 4. Practical parameters and values of components designed for each part of the system are given in Tables (2) to (5). The changes of the output voltage and output current for a linear-resistor load (100-watt lamp) are shown in Figure 5. The figure shows that the output signal is all-sinusoidal.

The changes of the voltage and output currents for nonlinear load by connecting a universal motor (135 W) at UPS output are shown in Figure 6. As can be seen in this figure, the output voltage is completely sinusoidal and without disturbing the induction load, which is one of the benefits of using the SPWM method.

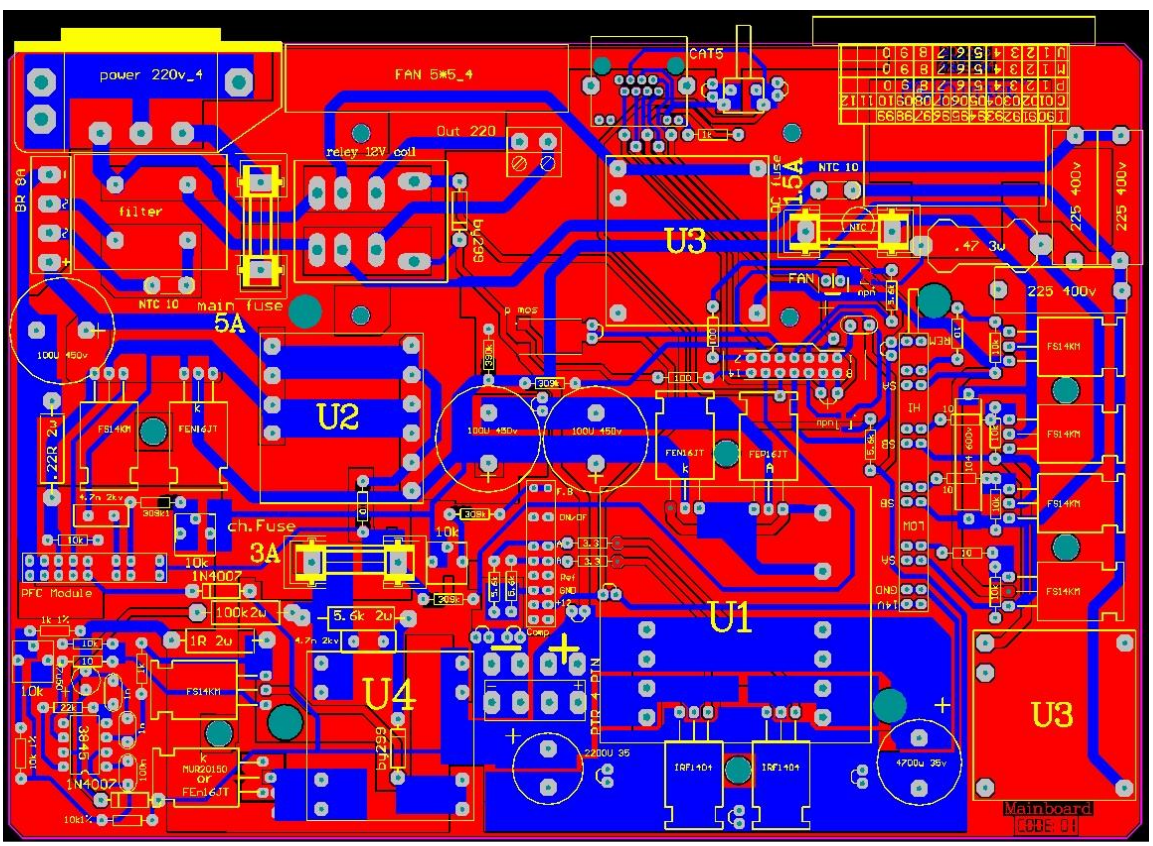


Fig. 3. PCB designed for mainboard.

Table 2. ***PFC circuit practical parameters*.**

Inductance in the output	765 uH
Capacitance in the output	100uF-450V
Double Diode	FEN16JT
Switch-type (MOSFET)	FS14KM
IC Controller	L6562

Table 3. ***Charger circuit practical parameters.***

Inductance in the output	144uH
Capacitance in the output	2200uF-25V
Double Diode	FEN16JT
Switch-type (MOSFET)	FS14KM
IC Controller	UC3845

Table 4. ***Push-pull circuit practical parameters.***

Number of turnings in transformer	N1/N2 =8/215
Capacitance in the output	2x100uF-450V
Double diode with common cathode	FEN16JT
Double diode with common anode	FEP16JT
Switch-type (MOSFET)	2xIRF1404
IC Controller	SG3525

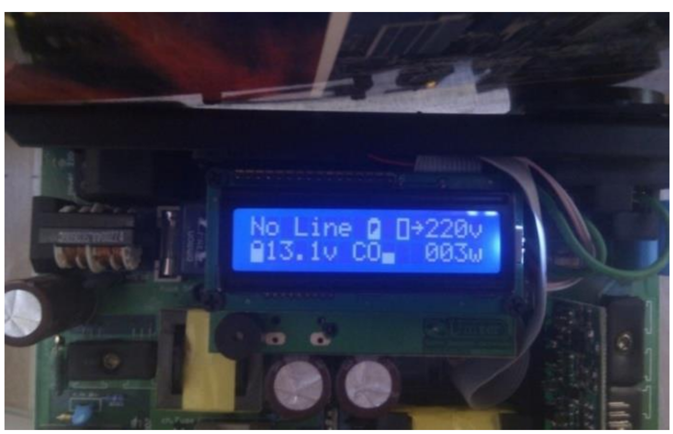
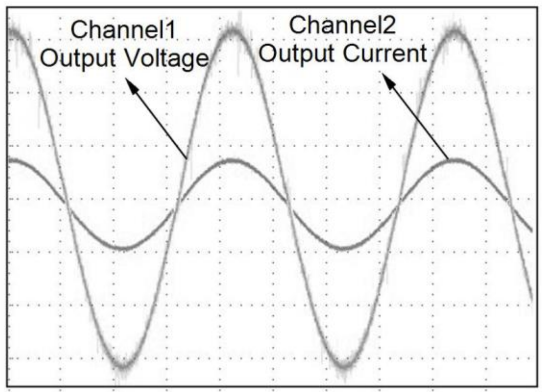


Fig. 4. Laboratory sample of proposed UPS implementation.

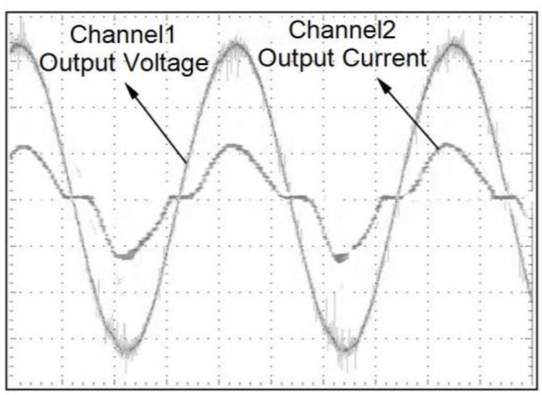
Table 5. Inverter circuit experimental parameters.

Inductance in the output	2x2mH
Capacitance in the output	4x2.2uF-400V
Double diode	FEN16JT
IC Controller	TINY13
Opti-coplayer	4xTLP250
Switch-type (MOSFET)	4x FS14KM



(Ch1:100V/div. ; Ch2:750mA/div. ; 4ms/div.)

Fig. 5. Output voltage and current for 100 W linear load.



(Ch1:100V/div. ; Ch2:750mA/div. ; 4ms/div.)

Fig. 6. Output voltage and current for a nonlinear load (135 W).

Similar laboratory results for the full-load (350 W) are given in Figure 7. The changes of the input voltage and input current are shown in Figure 8. As it is seen the phase difference between the input voltage and the input current is very small. In other words, in the applied input, PFC performance is high, at one moment, the input current is completely sinusoidal, which means it has no negative effect on the AC network and there is a balance between active power and reactive power consumption. The measured efficiency of the pre-regulator as a function of the output power is shown in Figure 9.

According to IEC61000-3.3.24 standard, THD is calculated as the ratio of the effective value of the harmonics to the base component. According to this standard, as shown in Fig. 10, the harmonics were less than the limited value of this standard and have fallen below that. The proposed UPS system is portable and designed for low power applications. In order to use it for higher power applications, the nominal power of the elements should be increased but the program code remains changeless.

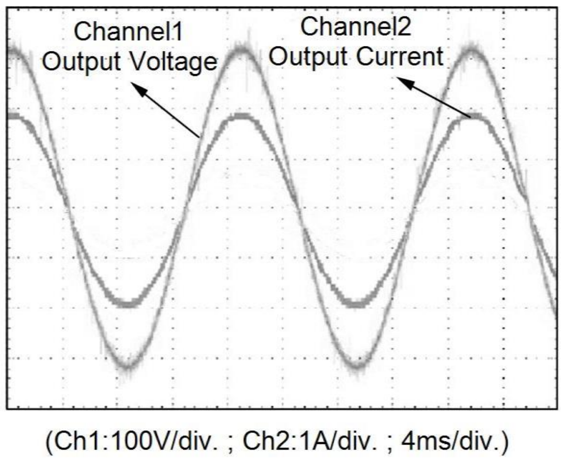


Fig. 7. Output voltage and current for full-load (350 W).

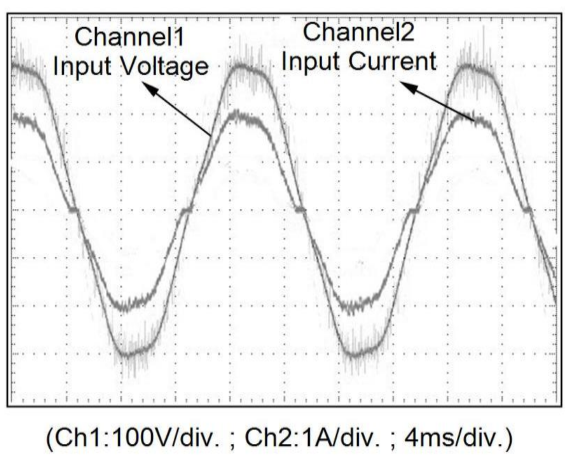


Fig. 8. Phase difference in input voltage and current.

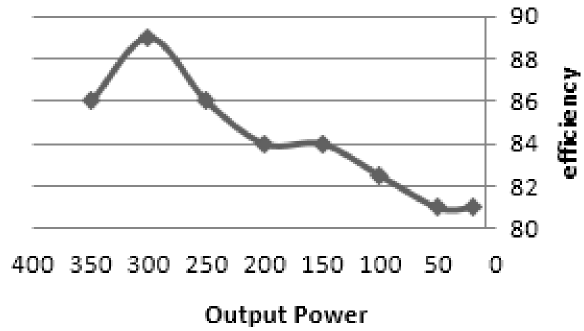


Fig. 9. Efficiency against output power variation of UPS.

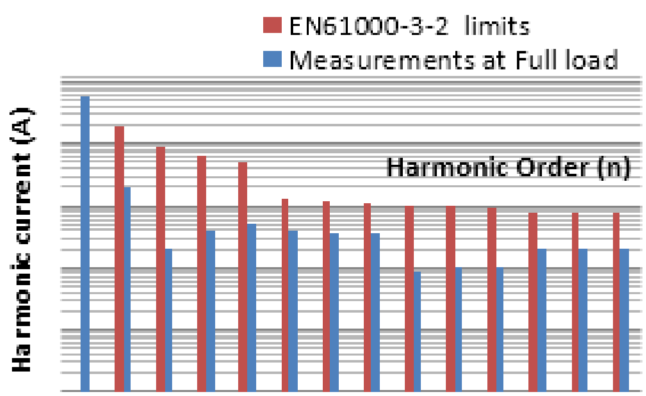


Fig. 10. Harmonics spectrum at full load.

5. CONCLUSION

A single-phase online UPS based on the microcontroller with PFC has been designed and implemented in this paper. The amplitude of the basic component of the UPS output signal is completely sinusoidal with the elimination of harmonics by the SPWM method and is controlled by the micr-ocontroller. This technique guarantees the necessity of high-quality power for critical and sensitive loads. The system has a high voltage gain because it uses the SPWM technique. In the proposed model of UPS, the weight, volume, and cost of the system are reduced while the overall system efficiency is improved. To upgrade the rectifier performance in order to regulate the DC link, the PFC method is used. The DC link voltage control method is used for reducing transient spikes, therefore the dynamic response of the output voltage is improved. Practical results show that the proposed system has a high efficiency that is approximately 80% to 90%.

Moreover, created resonance between the inductance of the system and power factor correction capacitors were eliminated and harmonics were significantly decreased. Therefore, the total harmonic distortion is reduced to the desired level.

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