Design and Construction of an Intelligent Uninterruptible Power Supply (IUPS), 500VA, 220V, 50Hz

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Abstract: *An Uninterruptible Power Supply is a system connected between the electric grid and the consumer, comprising electric hardware and rechargeable batteries. The fundamental purpose/aim of this project - Design and Construction of an Intelligent Uninterruptible Power Supply (IUPS) - is to provide an* uninterruptible (continuous, steady, non-stop) and clean (*qualitative) source of power supply of 500VA, 220V, 50Hz for domestic equipment it supplies and protects. This is achieved by basically designing and constructing a battery charging circuit and an inverter circuit. An inverter is a power electronics device which converts DC (in this case, from a 12V DC battery) power to AC power (500VA) at the required output voltage (220V) and frequency level (50Hz). The salient features are: Firstly, upon power outage (from the mains power supply) a square wave is generated through the means of an AT89C51 microcontroller. The program controlled microchip device (AT89C51) forms the basis of realization of this project. Bipolar Junction Transistors are applied as switching system connected to the oscillating output pins of the chip. An inverter drive MOSFETs pairs are incorporated with a 12V~220V, center tapped transformer working to transform the oscillating signal to pure AC signal. This project takes its power from two power sources which automatically switch between each other: the utility mains and a DC lead acid battery. The experimental results conformed to the desired design analysis with acceptable and negligible errors. The results of this project research show that the AT89C51 microcontroller (an intelligent device) can be used as a square wave generator (oscillator) as well as to control the working conditions of the system in which it is used.*

Keywords: Uninterruptible Power Supply**,** Operating Time, Switching Stage

1. Introduction

The continuous supply of quality and emergency power is critical, seeing that electrical energy is very important in many applications, commercial and industrial process installations (such as in tunnels, supermarkets and office buildings), networking, etc. A power failure, or even minor disturbances in the power supply, will interrupt the process chain and eventually result in system shutdown. This could cause substantial financial losses or even jeopardize the safety of human lives. Also, unfiltered electrical power supplied by utilities to consumer's wall sockets is not clean and may contain harmonics, surges, sags, spikes or other noise; and most times it is frequently interruptible. Under the best conditions, power interruptions can be an inconvenience. At their worst, they can cause loss of data in computer systems or damage to electronic equipment.

Thus, we need a system for reliable and protected electrical power supplies to installations (that is, consumers or loads), which cannot tolerate even the slightest voltage interruption or inconsistencies. So, introducing an ***Uninterruptible Power Supply*** (UPS) system along the power supply chain will effectively eliminate these kinds of disturbances. Most importantly, during power failure conditions, the UPS will bridge the critical power supply gap. In these instances, the system automatically switches to large battery banks to draw the required electrical power until mains are again available. This occurs without affecting the load performance. It is also the function of an uninterruptible power supply (UPS) to act as a buffer and provide clean, reliable power to vulnerable electronic equipment. The basic concept of a UPS is to store energy during normal operation (through battery charging) and release energy (through DC to AC conversion) during power failure. [1]

This project - *design and construction of an intelligent uninterruptible power supply (IUPS)* - has been realized taking advantage of power electronic components like MOSFET, BJT, relays, etc., incorporated with AT89C51 microcontroller (a microchip) as an intelligent device**.**

2. Materials and Methods

2.1 The Block Diagram

This chapter presents the development of an intelligent uninterruptible power supply system (IUPS) with a hybrid power source that comprises the electricity utility mains and a lead-acid cell. Specifically, the hybrid IUPS comprises of electricity input from utility mains supply, a 12V dc lead-acid cell, an ac-dc battery charger, a half bridge dc-ac inverter, a single chip microcontroller AT89C51 as an intelligent device to implement a digitized control of the proposed system and electromechanical switching relays. The diagram below represents the block diagram of the IUPS.

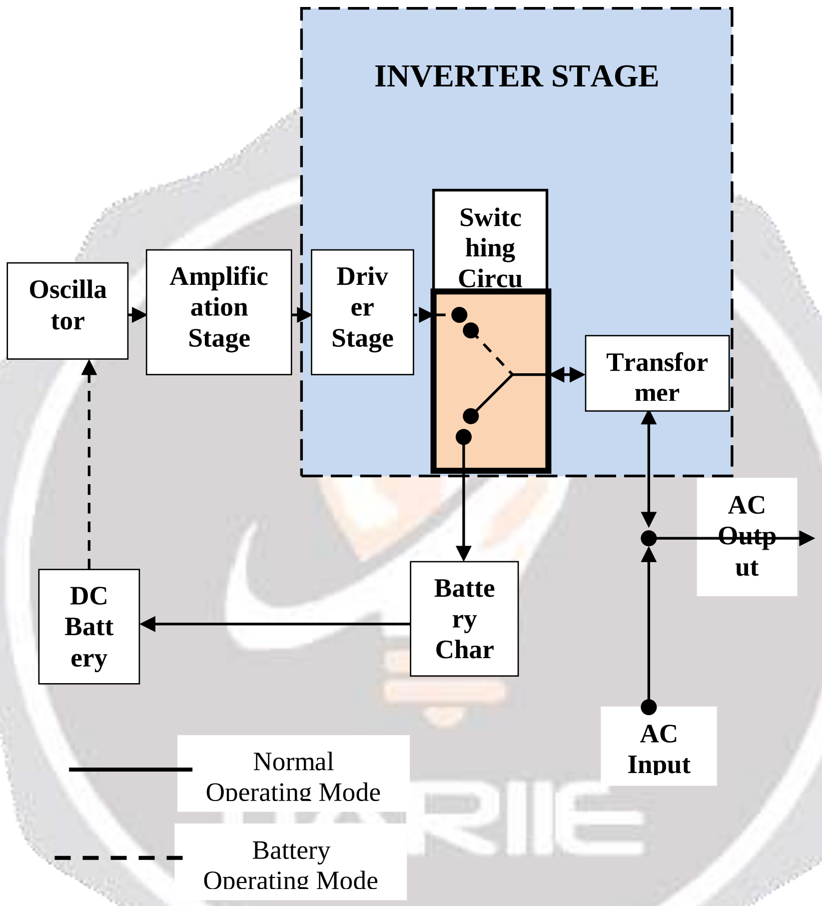

Fig. 2.1: Block diagram of the IUPS

2.2 System Mode of Operation

As earlier stated, this project work is implemented based on the principle of an off-line UPS. AC power from the utility mains into the system is supplied directly to the output load and at the same time part of it goes into the transformer where it is stepped down (24V in this case). The stepped down power (24V) now goes into the battery charger where it is rectified by a full-wave bridge rectifier, filtered and regulated to 12V DC; the output of this battery charger is now suitable and charges the battery. The charger supplies the battery with the charging current as long as the input mains are on, until it is fully charged. But the moment the supply from utility mains fails, the switching circuit instantly disconnects from the battery charger and switches to the driver stage. The battery now discharges via the oscillator, the signal is amplified and it comes out as pure AC signal (supply).

Hence, during power failure conditions, the IUPS will bridge critical power supply gap. In these instances, the system automatically switches to the dc battery to draw the required electrical power until mains are again available. The on-battery runtime of the IUPS is about 15-20 minutes typical for smaller units but sufficient to allow time to bring an auxiliary power source on line or to properly shot down the protected equipment.

2.3 Block Details and Functions

The IUPS on-battery run time circuit is achieved by a simple control device, a single microcontroller AT89C51 chip which serves as the oscillator. It is illustrated in the block diagram in Figure 2.1.

2.4 The Oscillator Circuit

The major content of the oscillator circuit is the AT89C51 microcontroller. The AT89C51 is an integrated circuit (IC). It is also used on the motherboard of computer systems, where it was developed to control peripheral devices alleviating the load from the main Central Processing Unit (CPU). The AT89C51, like the CPU has calculation functions and memory, and is controlled by a program written and burnt into its memory .The AT89C51 requires an external oscillator circuit. The oscillator circuit usually runs at a default frequency of about 12MHz, although the AT89C51 (depending on which specific model) is capable of running at a maximum of 40MHz. Each machine cycle in the AT89C51 is 12 clock cycles, giving an effective cycle rate at 1MHz (for a 12MHz clock) to 3.33MHz (for the maximum 40MHz clock). The oscillator circuit generates the clock pulses so that all internal operations are synchronized.

2.4.1 Working Principle of AT89C51

The microchip device as earlier defined is a programmable intelligent hardware used in electronic circuit for control when properly programmed. The AT89C51 can be programmed using C, C++ or assembly languages as the case may be. For this project, it is programmed using C language. The working of the AT89C51 microcontroller depends on the written program (encoded instructions) burnt into the memory of the chip.

The aim as used in this project is to generate a square wave whose frequency depends on a set of instructions (program). The program direct the chip to use two pins - 1 and 2 - as output slots alternately at a frequency of 50Hz, thereby producing a square wave to the external circuit. It is worth noting that the alternation of the time of output between the two pins cannot be visually observed, this is because of the high frequency (50Hz) at which the chip oscillates. The output waveform of each of these pins is shown below:

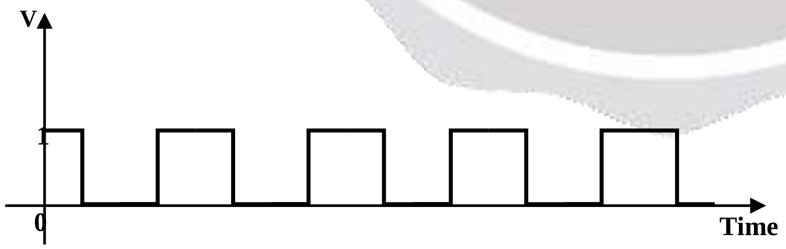

Fig. 2.4: Output waveform of the AT89C51

2.5 THE TRANSFORMER

A transformer is a static (or stationary) piece of apparatus by means of which electric power in one circuit is transform into electric power of the same frequency in another circuit. It can raise or lower the voltage level in the circuit, but with a corresponding decrease or increase in the current. Its job as applied in the circuit is to step down the AC supply voltage to suite the requirement of the solid state electronic devices and circuits as well as step up the inverted DC when the main supply is out.

2.6 The Battery Charger

When the system is connected to the AC mains, it supplies directly to the output while it also charges the battery incorporated in the system. But DC batteries cannot be charged directly by AC voltage, so the AC supply from the mains need be converted to a form that is safe and compatible with the DC battery. Therefore a battery charger is designed and implemented in the system.

A battery charger is an electrical device that is used for putting energy in a battery. It changes the AC from the power line into DC suitable for charger [2].

2.6.1 Working Principle

The mains-operated battery charger consists basically of the following elements:

- **i.** A Transformer.
- **ii.** A full wave rectification bridge (for converting A.C. to D.C.)
- **iii.** A charger-current limiting element for preventing the flow of excessive charging current into the battery under charge.
- **iv.** A battery voltage-monitor which acts as an over-voltage protection circuit which protects the battery, because an incorrect charging can cause premature deterioration thereby shortening the life of the battery.

As listed above, the charger consists of a power supply transformer that steps down AC power from 220/240V to a lower AC voltage (24V) closer to that of the battery. There is a rectifier that smoothens out the existing sinusoidal AC signal into a constant voltage DC signal. There is also a filter circuit element used to remove the fluctuations, pulsations or ripples present in the D.C. voltage to be supplied by the rectifier. A 12V D.C. regulator is also incorporated in the circuit to keep the terminal voltage of the D.C. supply to the battery nearly constant even when the input voltage to the transformer varies or the load varies. An automatic turn-off feature is also designed into the charger so that a maximum charge voltage could be obtained using a pair of transistor-driven relays circuit.

When the predetermined battery voltage level is reached, the charger circuit will automatically turn-off. As shown in Figure 2.7, when the output voltage is below the trip point level, transistors Q_2 is turned ON and relay R_L is closed applying full output voltage to the charge terminals and the battery voltage increases. When the preset battery voltage level is reached, the Zener diode D_1 conducts thereby turning ON transistor Q_1 and turning off the relay. The D.C. power source is then disconnected from the battery preventing over-charging. If the battery voltage goes below the threshold voltage by any small amount, the relay will automatically be reconnected across the battery again, hence charging it. Thus, with this mechanism in place, the charger can be left connected to the battery without fear of over-charging it.

2.7 THE INVERTER STAGE

If the A.C. mains voltage is not detected, the battery charger is disabled and the IUPS switches to the inverter mode. During inverter mode of operation, the system runs on D.C. battery but produces a clean A.C. at the output so that critical electronics can continue operation without interruption.

The AT89C51 is used as an oscillator to generate square waves and the BJTs Q_3, Q_4, Q_5 and Q_6 are used for switching to drive the Metal Oxide Semiconductor Field Effect Transistors (MOSFET) Q_7 and Q_8 into conduction. Pins 1 and 2 of the AT89C51 microcontroller are programmed as output pins which come ON and turn OFF alternatively (that is, when pin 1 is ON, pin 2 will be OFF and vice versa) at a frequency of 50Hz. By the principle of using transistors for switching, transistors Q_3 and Q_5 are used in pair for switching pin 1, and transistor Q_4 and Q_6 for switching pin 2. When pin 2 is OFF the base voltage V_{BB} from the microcontroller output (i.e. pin 2) is approximately zero volt. The transistor Q_3 is in cut-Off mode and the output is high, almost equal to V_{CC}. This now becomes input voltage V_{BB} to transistor Q_5 hence, turns ON transistor Q_5. If on the other hand the input is high due to output voltage from pin 2 when it is on, transistor Q_3 will now be driven into saturation with output voltage equal to $V_{CE\ (Sat)}$ hence, transistor Q_5 will be turned OFF. Similar pattern of switching takes place in the second transistor pair Q_4 and Q_6 switching pin 1 (as in Fig. 3.1).

This oscillation produced by the AT89C51 depends on the program instruction in its memory. When transistor Q_5 is ON, the output voltage at its collector (which is equivalent toV_{CC}) is used to drive the gate of the MOSFET (i.e. transistorQ_7). By this way, current flows through the top half of the primary winding of the transformer. On the next half circuit of the microcontroller oscillator, using the same principle, transistor Q_6 turns ON as pins 1 is OFF and current flow through the lower half of the transformer primary. In this way, an alternating current is setup in the primary and this induces an AC voltage in the secondary of the transformer.

2.8 THE BATTERY

Among the many types of battery system that exist, two of the secondary cell type namely, the lead-acid type and the alkaline type are commonly used. However, because of its higher ampere-hour efficiency and lower cost as compare to the later, the lead-acid is preferred for UPS application and has been considered in this project as the DC source. The battery draws small amount of current during charging, which helps in keeping it in fully charged state. The capacity of the battery is expressed in ampere-hour; this rating is equal to the product of the constant discharge current and the duration above which the battery falls below a certain level called the final discharged voltage.

2.9 THE SWITCHING CIRCUIT

This is basically a relay. It automatically switches between the battery charger and the inverter at times when the system is connected to the mains and when it is off-line. When the system is connected to the mains, the A.C. relay switches and connects to the battery charger, thereby charging the battery. However, immediately there is a cut-off at the mains, the switch now switches to its normally closed state, thereby connecting the inverter through which the battery discharges to the output.

2.10 DESIGN SPECIFICATIONS.

The DC input voltage: $V_1 = 12\text{V}$

The AC output voltage: $V_2 = 220\text{V}$

The operating frequency: $\text{f} = 50\text{Hz}$

The output power: $P_{out} = 500\text{VA}$

2.11 THE IUPS OPERATING TIME.

By power balance: Power input = Power output

$$P_{in} = P_{out} \quad \textbf{(3.1)}$$

But,

$$\text{P} = \text{IV} \quad \textbf{(3.2)}$$

Substituting for P into **3.1,**

$$V_1 I_1 = V_2 I_2 \quad \textbf{(3.3)}$$

Where:

$$P_{in} = P_1 = V_1 I_1 \quad \textbf{(3.4a)}$$

And

$$P_{out} = P_2 = V_2 I_2 \quad \textbf{(3.4b)}$$

From equation **3.2**, it follows that:

$$I_1 = \frac{V_2 I_2}{V1} \text{ ……………………… } (\mathbf{3.5})$$

Substituting the data specification as stated in section **3.1** above into equation **3.5,** which is

$V_1 = 12V$

$V_2 = 220V$

$P_{out} = 500VA$ and

$V_1 I_1 = P_{out},$

Thus:

$$I_1 = \frac{500\text{VA}}{12\text{V}} = \mathbf{41.67A}$$

This design uses a battery with standard battery rating of 12V, 7A-Hr. But from the relationship:

Ampere – Hour = Current x time

$$A - Hr = I_1 \text{x}\, t \text{ …………..…………… } (\mathbf{3.6})$$

So that:

$$t = \frac{A-Hr}{I_1} \text{…………………………….…… } (\mathbf{3.7})$$

$$\text{t} = \frac{7}{41.67} = 0.168 \text{ Hr.}$$

$$\text{t} = 0.168 \text{ x } 60$$

$$\mathbf{t = 10.08\ minutes}$$

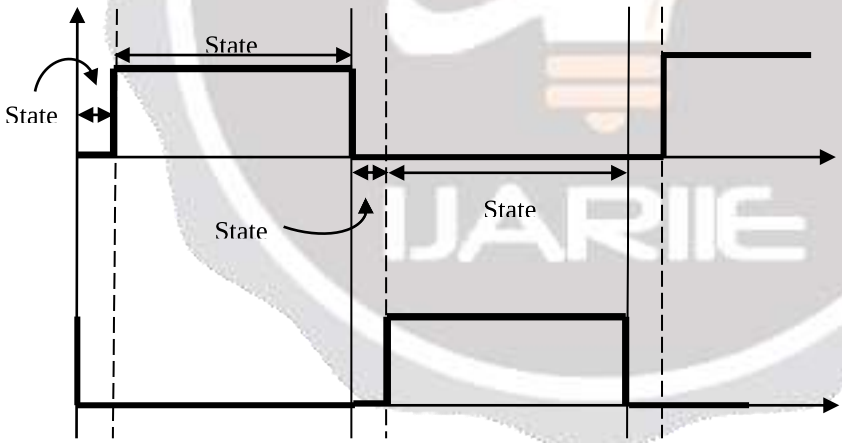

Fig. 3.5: Square wave of the switching states

This is the time for which the IUPS will supply energy to the load connected to it before it will finally run down.

3.7 SOFTWARE DESIGN

3.7.1 AT89C51 Programming

The AT89C51 microcontroller for this project was programmed using C programming, after looking at other programming language options such as Assembly, Basic and C++ programming languages due to the following considerations.

i. It is easier and less time consuming to write in C than Assembly
ii. C is easier to modify and update
iii. You can use codes available in function libraries

iv. C code is portable to other microcontrollers with little or no modification

3.7.2 C Programming Procedure

The inverter circuit as used in this project works with the principle of single-phase inverter driven by the perfect square wave generated by the AT89C51 microcontroller. In the AT89C51 program written in C language, we created a square wave of 50% duty cycle (with equal portions of high and low) on the two AT89C51 output pins (1 and 2). In other words, the ON and OFF states or the HIGH and LOW portions of the pulse have the same length. Therefore, we toggled pins 1 and 2 with a single delay in between each state. The ON and OFF states of the two output programmed pins produced two states with a time delay introduced in between each of the states making it four states for a cycle to avoid the two states coming on or off at the same time.

Aaaaa

All the time delays are equal (i.e. 1 second for states 1 and 3). Similarly, the time for the ON states (i.e. states 2 and 4) are equal. This is further explained with the switching table shown in Table 3.1.

Table 3.1: Transistors switching states

States / Transistors	State 1	State 2	State 3	State 4
Q_7	OFF	ON	OFF	OFF
Q_8	OFF	OFF	OFF	ON

The AT89C51 output pins switching table is also shown in Table 3.2 for more clarity.

Table 1.2: Pins switching states

States / Pins	State 1	State 2	State 3	State 4
Pin_1	O	1	O	O
Pin_2	O	O	O	1

The C language program was developed for the four states as could be seen in Fig. 3.5, Table 3.1 and Table 3.2 our delays for each of the four states was deduced from the Atmel89C51 crystal oscillator which in this case an 8MHz crystal.

3.9.1 Programming the Microcontroller

To program a microcontroller one must have two basic tools. One is the hardware-programmer board and the second is the software for burning the program into the microcontroller. The programmer board is used to hold the chip and enable the computer to burn the program into the microcontroller. The programmer board is connected via a USB cord to the computer. The software needed to program a microcontroller is in two fold. One is the compiler and the other to download the program written. The compiler program automatically checks for errors in your program and then compiles it into a *hex* file. This *hex* file is stored in the same directory in which you have stored your original program file. The compiler software used here is ASEM software in M-IDE for MCS-51. The downloading software used here is TOPWIN software. The software is user friendly and can be operated easily.

4.2 SIMULATION AND MEASUREMENTS.

The simulation process for this project was carried out using advanced circuit design software, PROTEUS 7 professional. It is Computer Aided Design (CAD) software. It has advanced simulation facilities, such as the digital oscilloscope, DC/AC voltmeter, DC/AC ammeter and other measurement tools. The circuit development from the most essential (i.e. Microcontroller IC's) to the common components (e.g. resistors, diodes, etc) are all found in the components library under different subdivisions and classes according to the models and chip makers. The interconnections and circuit links (i.e. wires and connection nodes) are all available minor circuit accessories in the CAD software.

The software is user friendly and easy to draw and modify circuits and its properties. The PROTEUS software installation process and use is as easy as any other regular software in use. The screen shot for the circuit simulation for the microcontroller output square wave is shown in Figure 4.1. This is seen clearly with the delays in between the two ON and OFF states.

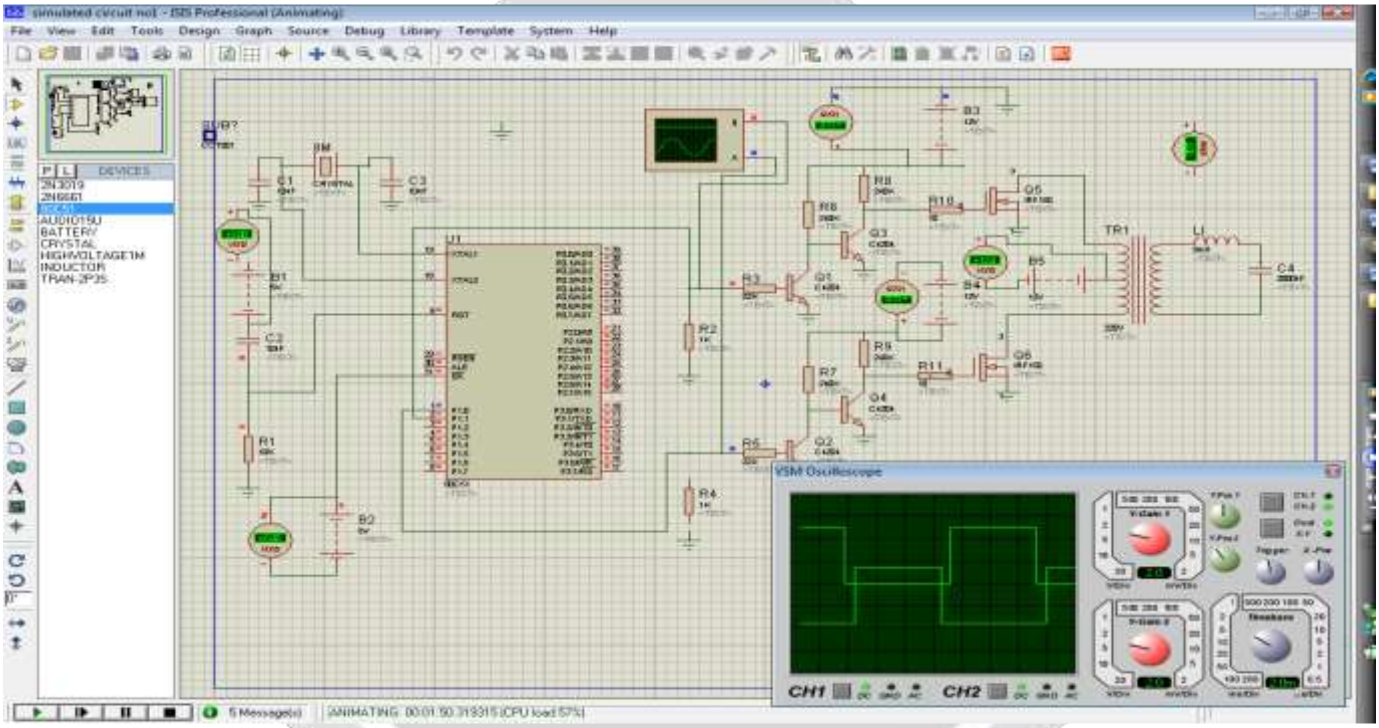

Fig. 4.1: Screen shot of square wave from the circuit simulation of the microcontroller output.

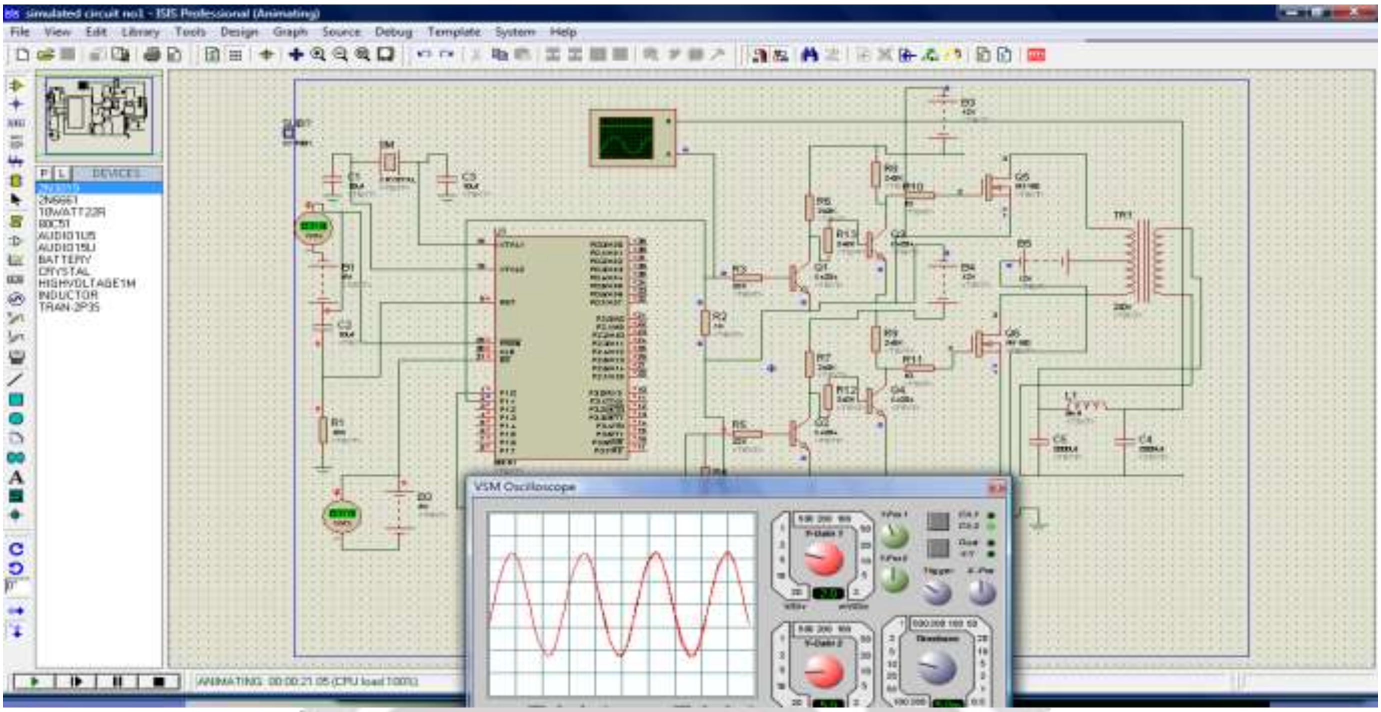

Fig. 4.2: The Screen Shot of Circuit Simulation Showing Sinusoidal Waveform after Filtering

4.4 TEST RESULTS

The construction was completed and testing done. The screen-shot of the output wave form as viewed from an oscilloscope is as shown in Figure 4.3

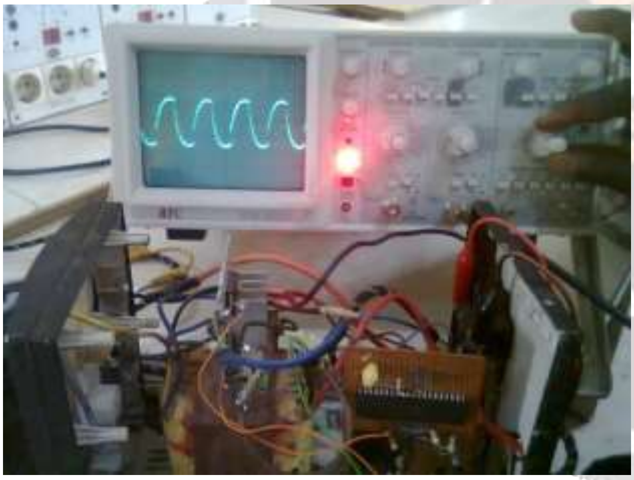

Fig. 4.3b: Complete IUPS device (front view)

5.2 CONCLUSION

The work, design and construction of an intelligent uninterruptible power supply was carefully designed, developed and implemented under close supervision of the project supervisor in line with project specifications required for the project. With the careful selection of materials, step by step development, testing and final implementation, the overall goal for the design and construction of an intelligent uninterruptible power supply, 500VA, 220V, 50Hz was achieved with 95% efficiency under an acceptable negligible error range.

5.3 RECOMMENDATION

With the design specification for this project, we recommend it for use in low power appliances not exceeding 500VA. For high power requirement, larger transformers and batteries could be used. The overall test performance of the device showed considerable efficiency and safety assurance for use in low power devices hence, it is recommended for use in any appliance within its capacity. Reference could be made to this work for further study or research in the future.

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