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SCHOOL OF ENGINEERING

**DEPARTMENT OF ELECTRICAL AND ELECTRONIC
ENGINEERING**

**CONSTRUCTION AND EVALUATION OF A
MICROCHIP DESIGNED UPS**

BY

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November 2005

Acknowledgement

I would like to appreciate appreciate and give praise to my heavenly father for the breath that I have from him.

My thanks to my project supervisor Mr. S. Namukolo for giving me an opportunity to work with him.

Special thanks to the Necor Customer Service engineers for the time they used to allow me do my download for data I needed.

Special thanks to my family and friends for the help and moral support they render in my studies.

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Notation

AC	Alternating Current
AD	Analog to Digital
BB	Battery Boost
D	Diode
FDBK	Feedback
IGBT	Insulated Gated Bipolar Transistors
FRC	Free Running Chopper
UPS	Uninterruptible Power Supply
DC	Direct Current
IC	Integrated Chip
NEG	Negative
PWM	Pulse Width Modulation
POS	Positive
Q	Transistor
SYNCH	Synchronization

Summary

Reliable power supply results in the overall efficiency of organizations. Providing standby power supply when the utility power fails helps in switching of most equipments in the normal way. An analysis of the operation of the Uninterruptible Power Supply helps in understanding of the operation of these devices. The various circuits in these devices perform different functions. Thus, these circuits must be analyzed individually so as to make a good understanding of these devices. The principle operation of the Uninterruptible Power supply is the conversion of DC voltage from batteries to AC voltage and output these to the equipment they are connected to.

Chapter 1

1.0 Introduction

Utility power supply is not always reliable as is subject to spikes, surges and complete blackouts. This is not good for most electrical and electronic equipment. In the event of power failure, equipment such as computers and most telecommunication equipment, tend loose data, which was not stored. For computers the machine can even be corrupted, as the equipment was not properly shut down. To allow for proper shutdown of such computers, it is therefore required that power from some other source be available.

The need for uninterruptible power supply is thus vital for smooth operation of computers and other electronic equipment. In order to achieve this, a UPS is installed between the computer and the main utility power supply. UPS simply stands for Uninterruptible Power Supply. A UPS stores energy in the batteries, which it uses to supply to the equipment connected to it. This ability to provide power to a system during power failure allows the systems to be properly shutdown and in the case of computers the files to be stored. In cases where the system is connected to another stand by generator, the UPS will allow for the transient period the generator needs before it can reach the voltage of the utility supply.

There are basically two types of UPSes. The first type is the Online UPS, which always monitors the utility power supply. This is done by monitoring the voltage level. Once the voltage from the utility goes below a certain level, the UPS starts to supply power until the minimum allowable value is reached by the supply from the utility. During normal power supply by the mains, the UPS is in the charging mode. Thus, this type of UPS also acts as a filter in times of spikes and surges. The other type of UPS is a Standby UPS. This type of UPS only comes on when there is a complete power failure in the utility supply.

Since UPSs use batteries for their supply of energy, it can thus be seen that, this unit has some energy conversion. The utility supply is an alternating current (AC) whilst batteries produce direct current (DC).

The UPSs use batteries are easily get drained after some time. These batteries thus can only give power for a certain period time. Thus the maximum rating of a given UPS in use will

determine for how long it will supply power. The UPS is always rated in VA. In cases where the load connected to the UPS are exceeding the maximum rating, the life span of batteries in the ups is reduced which is a common problem in UPSs.

The UPS is made of many single electronic circuits that have to be incorporated together to achieve its prime function of being a standby power supply. With the advancements in the solid state electronics hardware-based UPSs are gradually being replaced by microprocessor or microcontroller-based counterparts, with significant improvement in ease of design, flexibility of the control software and overall reduction in development cost. Since a UPS incorporates a relatively large number of detection, protection and control functions the many analog components from which the UPS is made can easily be incorporated by the use of microcontrollers.

1.1 Background

Due to the many circuits present in the UPS, it is thus required it is divided into parts. Each part must constitute major circuits or classes of circuits that perform similar functions. Each of these circuits has its own various voltages for input and output. Thus, the different voltages at each circuit terminals result in different currents being fed into a particular component. Its these various circuits which are incorporated together form a UPS that performs its function of supplying uninterruptible power to a system that is connected to it.

In the analysis of the various circuits of the UPS, it is important that a sequential approach is used. By sequential approach its meant that, the circuits that perform similar functions and connected together they must be analyzed together so as to see the effect of changing any of the parameters on other parts of the circuits. Each UPS has its own unique arrangement of circuits. Despite having various UPSs on the market, all the UPSs look at having the same function and that is to supply power when the utility fails. Thus different UPSs look at only having enhancements.

The above consideration of dividing the UPS circuits into groups only takes into consideration of the UPS hardware system. The UPS is mainly divided into two parts namely the Hardware

Features of particular importance in the UPSs are the transient time of switching from the utility to the UPS. Thus in the design of the UPS, this time is reduced to milliseconds or even microseconds so that the equipment does not see any power changes in the supply.

The principle of operation of the UPS is based on the conversion of the energy stored in batteries and uses this energy to supply power to the equipment connected to it. The power from the batteries is direct current voltage while utility supply is alternating current. Thus conversion of this dc source of batteries to ac for the equipment is of particular importance. Energy conversion in most electrical circuits requires that, losses be minimized for maximum efficiency of the electrical systems that are using the converted energy. In UPSs, the conversion of energy results in low energy losses.

Conversion of the dc voltage from the batteries to ac voltage requires that, the output voltage (ac voltage) should be as smooth as any ac voltage from the utility. Thus, the conversion process, the converters used should be able to produce a purely sinusoidal voltage. To obtain a purely sinusoidal output from dc voltage involves a use of many electrical circuits. Thus a need to understand the operation of these different circuits arises for the would be designers of the UPS. The understanding of the circuits of the UPS can thus be learnt from the use of already made UPSs. Thus the different voltages in the various circuits of the UPS system can be measured and analyzed. The values of the voltages of the various circuits depend largely on the rating of the UPS being used.

1.4 Methodology

A complete and thorough analysis of the given UPS is the main objective of this project. To achieve this, it was necessary to divide the UPS into two parts as mentioned earlier the Hardware and Software.

The hardware part of the UPS is the circuitry part. This was further divided into the following main circuits namely input power, power factor correction and rectifier, battery boost and

charging, free running chopper, inverter and the microcontroller. An analysis of these individual circuits was to be done. The work on the analysis of these circuits was to identify which part of the circuit controls what other part of the UPS as these circuits are connected together via the microcontroller voltage buses.

The software of the UPS is the programming of the microcontroller that was done during the design of the UPS. The software embedded into the microcontroller determines on how the controls of the hardware will be done. Thus a thorough study of this package was to be done.

After the analysis of the UPS hardware and software is done, the UPS was to be constructed from these circuits. Its this constructed UPS whose voltages were to be measured and the all operation of the UPS evaluated.

1.5 Scope of work

The work that was involved in this project to realize the UPS:

1. Studying the various circuits of the given UPS.
2. Studying the various IC's used for the circuits that have them incorporated.
3. Studying the software package of the UPS.
4. Building the UPS from the given circuits.
5. Measuring the various voltages on the main voltage buses of the UPS.

1.6 Problem statement

To analyze the various circuits of the UPS and to understand the basic principle of operation of the UPS .To make recommendation on the redesign of certain parts of the UPS. This will give an opportunity of third world countries to venture into high technology.

Chapter 2

2.1 UPS overview

The UPS under study is online. Figure 2.0 gives the basic block diagram of a UPS [1]. A UPS basically has the parts shown which include the battery, rectifier and the inverter. The battery is for energy and the rectifier for the conversion of the ac voltage input to dc voltage. The inverter is for converting dc voltage from the rectifier and the battery to ac voltage that is output voltage fed to the load. Thus during normal operation of the UPS, energy is stored in the batteries which is later used whenever there is power failure in the utility supply. The rectifier unit receives its input from the utility supply. From this basic UPS circuit certain features can be added to develop UPS whose functions maintain the basic principles of the UPS

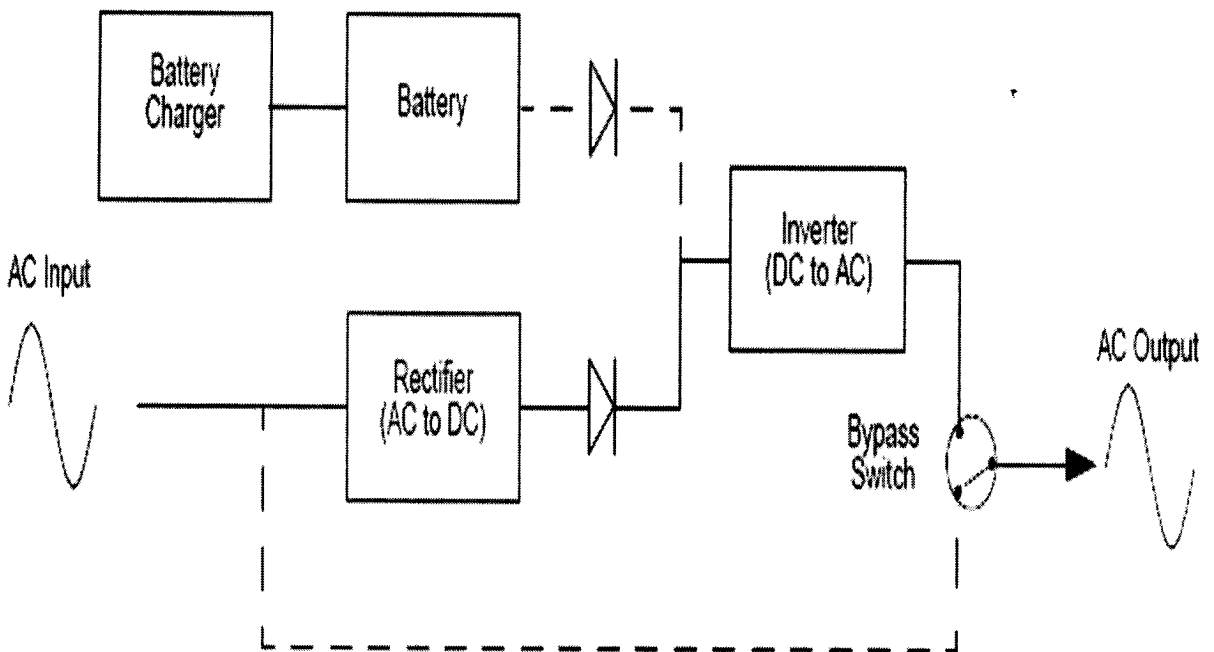


FIGURE 2.1 Basic Ups Block Diagram

2.2 System overview and operating principle

The UPS under study has the system lay out as shown in figure 2.2. The system has the following main parts namely the Input power protection, power factor correction and rectifier, and battery charging and battery boost, free running chopper, H-bridge (inverter), IGBT drivers, Hardware protection, A/D (analog to digital converter), output filtering and the microcontroller the PIC17C43. To fully understand the principle operation of each circuit is important before the UPS could be built for studying the voltage characteristics of the whole UPS. The UPS was divided into the various circuits and each circuit analyzed separately.

The power flow in this UPS is as follows [2]. For utility power that is available, power enters through the input filter and is filtered of spikes and surges, this is done by the input power protection. The filtered power then flows into the power factor correction and rectifier unit. The rectified (ac converted into dc) is fed into the free running chopper. The free running chopper is also fed by the battery boost. The free running chopper feeds the inverter (H-bridge). The dc is converted into ac by this inverter and the filtering of this done by the output filter and this power is fed to the load. The H-bridge is controlled by the microcontroller. The main power flow in this Uninterruptible Power Supply is shown below.

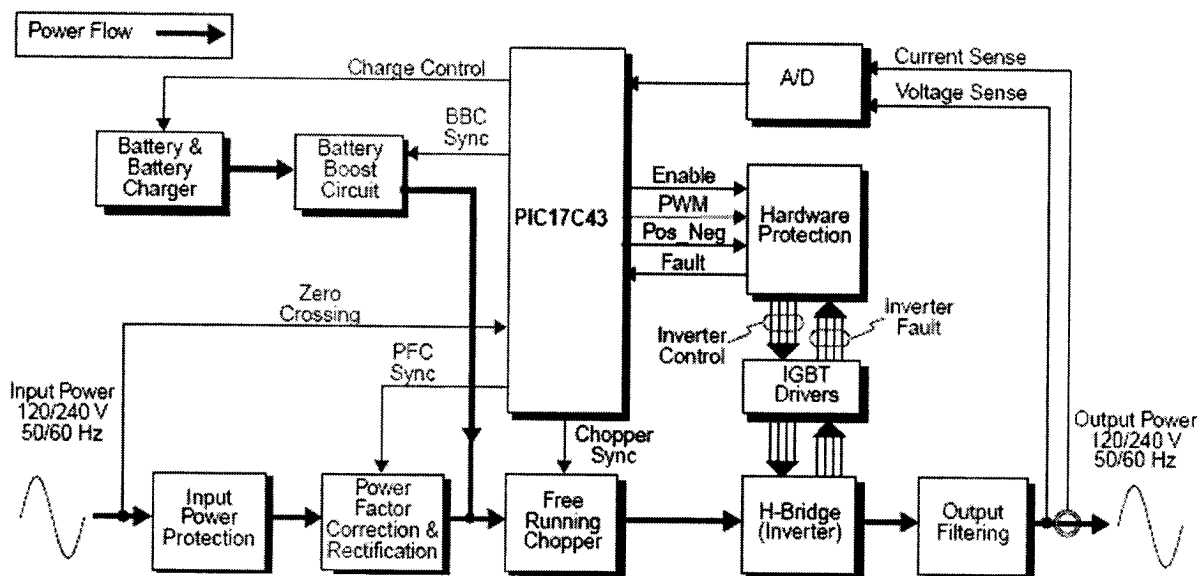


Figure 2.2 Uninterruptible Power Supply Block Diagram

2.3 BATTERY

The battery is the source of the energy in the UPS. The battery rating of the UPS is about 40volts. The energy is stored as DC voltage. Since the battery drains when the UPS is supplying energy when the utility has failed it is thus the required that the battery is recharged using the battery charging unit. This unit in this UPS has not installed hence the need of designing the circuit. The charging of the battery is supposed to be determined by the microcontroller

2.4 BATTERY BOOST

The battery boost is divided into two parts namely the battery boost circuit and the battery boost control card.

2.4.1 Battery Boost Circuit

The output voltage from the UPS is either 120V or 240V. From the battery only 48V is available. Thus if 240V is to be obtained from the batteries, it would mean that six such batteries have to be used. This would make the UPS very heavy and above all the cost would very high. The purpose of this unit is to raise the voltage from the battery. The battery boost circuit is given in the figures2.4.1.

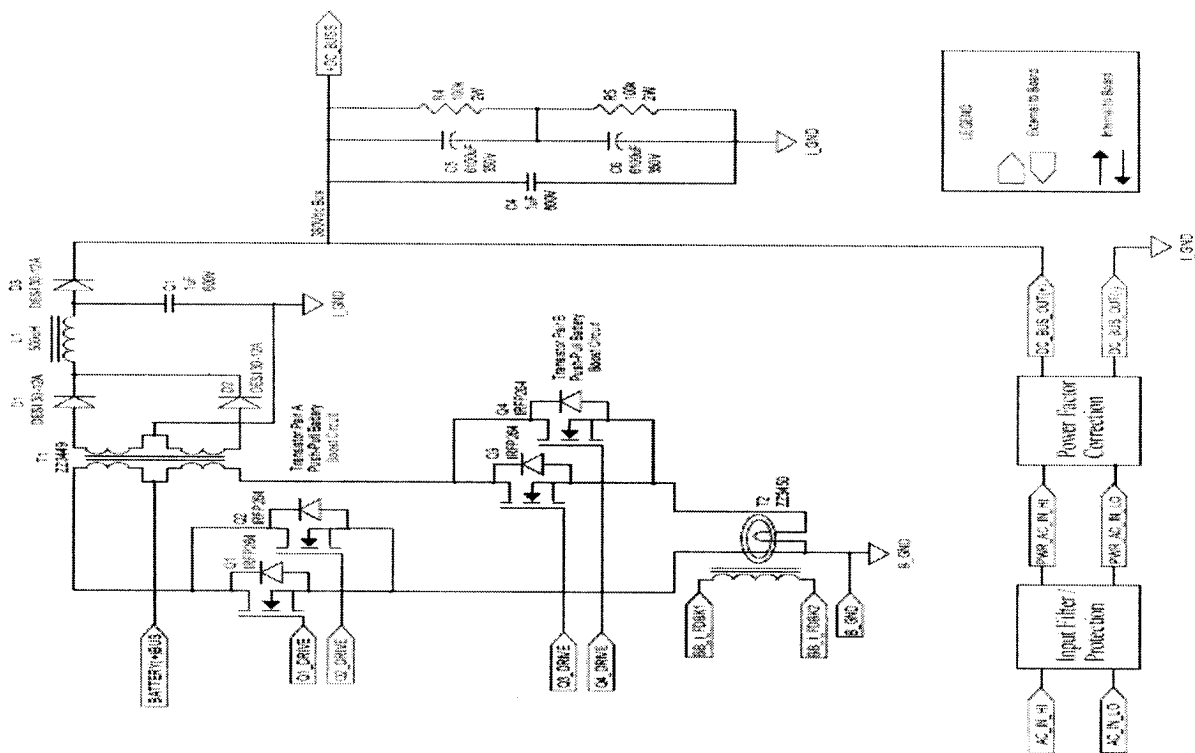


figure2.4.1 Battery Boost Circuit

The push pull transistors (Q1 and Q2) and the transistors (Q3 and Q4) are used for switching the DC voltage ON and OFF. The transistors have been paralleled for each limb so as to reduce the amount of the current carried by each transistor and to ensure that should one transistor fail then the other one should continue operating. These transistors have been ensured they have the capabilities of handling the entire load current. The transistors of each limb are turned ON and OFF simultaneously. The drive to these transistors from the control card figure shows that drive for Q1 and Q2 (Q1-drive and Q2-drive) both are connected to the logic drive chip the TSC429CPA which is drive A and the transistors Q3 and Q4 are driven from the drives Q3-drive and Q4-drive respectively which are connected to the drive B from the TSC429CPA chip. The battery(+) is connected to the center of a step-up transformer T1. The switching ON and OFF of the transistors produce a varying field across the transformer which results in a stepped up alternating current voltage. The voltage from battery is about 48volts and its stepped up to 360volts a value below that from the rectifier which is 380volts. The purpose of stepping the voltage from the 40V to 360V and not 380V

The battery boost control card has an integrated circuit UC3825AN. This chip is a high speed pulse width modulation (PWM). The feedback loop of the battery boost control card is fed from the current transformer T2 that monitors the current in the battery boost circuit. The two feedbacks namely BB-1-FDBK1 and BB-1-FDBK2 are fed into the rectifier unit thus providing a direct current through resistor R12 into the Ilim of the UC3825AN chip. This pin is an input into the current limit comparator. The purpose of this is to provide a means of monitoring the amount magnitude of the output voltage from the battery boost circuit thus monitoring the maximum current that has to be used in the UPS. From the same rectifier unit, the ramp pin (pin7) is fed through resistor R13. The ramp pin is the non-inverting input to the PWM comparator that uses the Ct as the feed-forward for the voltage function. The Ct is also fed through resistor R13, capacitor C8 and resistor R11. The purpose of the capacitor C9 and C8 connected to the Ct are for determining the oscillator frequency of the UC3825AN.

The battery (+) terminal is also connected to the LM139 operational amplifier. The operational amplifier has two inputs to it the battery(+) terminal and the Vref from the UC3825AN chip. The Vref from the UC3825AN has a value of 5.1volts. The battery(+) terminal supplies a voltage of 40volts or more. The voltage reaching the operational amplifier is about 5.2volts. Thus the output from the operational amplifier is a negative voltage as the operational amplifier is operating in the inverter mode[4]. Since this negative voltage is applied to the transistor Q1, the transistor does not conduct any current. The moment the voltage of the battery(+) is below the 40volts, the output from the operational amplifier becomes positive thus turning the transistor Q1 ON. The moment the transistor turns on, the LOW BATTERY signal is sent to the microcontroller that in turn switches the battery charging circuit on. This results in the battery being charged if the utility supply is on. In cases where the utility power is completely shut down the turning on of the battery charging unit also triggers the battery alarm. During the time the UPS is supplying power from the battery, the charging unit should not come on so that the battery does not carry an extra load of charging the battery apart from the equipment connected to the UPS.

The soft start pin(ss pin8) of the UC3825AN is a control pin for the reset of the UC3825AN. The other pins of interest in the way this chip has been used are C, INV, Ct, OUTA and OUTB. The OutA and OutB have been mentioned earlier in the battery boost section.

The UC3825 chip requires power for it to carry out the functions mentioned above. The powering pin of this chip is the Vcc pin. This requires a minimum voltage of 12V. The power circuit of this chip is given in the inverter control card section. The transformer terminals labeled X1 and X2 of the transformer T6 of the rectifier circuit from the free running chopper output supply the transformer terminals of this transformer. This alternating voltage is rectified through a full bridge rectifier and the output from the rectifier is stabilized by the capacitor C1. The voltage regulator U1 7815 then regulates the stabilized voltage. This thus gives the 12V required by the UC3825 chips. Note should be taken that the same 12V for the UC3825 of the battery boost circuit is also used to supply the UC3825 of the free running chopper circuit.

The synchronization of the battery boost circuit in the UPS is done through the Ct pin of the UC3825AN. The battery boost circuit synchronizing input to this circuit is given as BB-SYN1. The BB-SYN1 terminal is controlled by the PIC17C43 (Microcontroller). The Microcontroller handles the synchronization of the battery boost.

To protect the battery boost circuit, the UC 3825 has a current limit comparator with a 1V threshold. The soft start pin has the capabilities of doubling as the duty cycle clamps. The logic of this chip is fully latched so that jitter free operation and multiple pulses at the outputs. When the voltages for the inputs that are voltage based are low the outputs are designed to have high impedances. The pins OUTA and OUTB are output pins that are designed to source and sink high peak currents from loads that are highly capacitive. Such loads include the MOSFET gates that are connected to them for their switching. Such transistors are the ones shown in the figure of the battery boost section; eg the push-pull transistors. These have their gates connected to the OUTA and OUTB.

2.5 Power Factor Correction Circuit

The power factor correction circuit has the responsibility of adjusting the power factor of the UPS. The purpose of this circuit is to raise the power factor. A high power factor results in

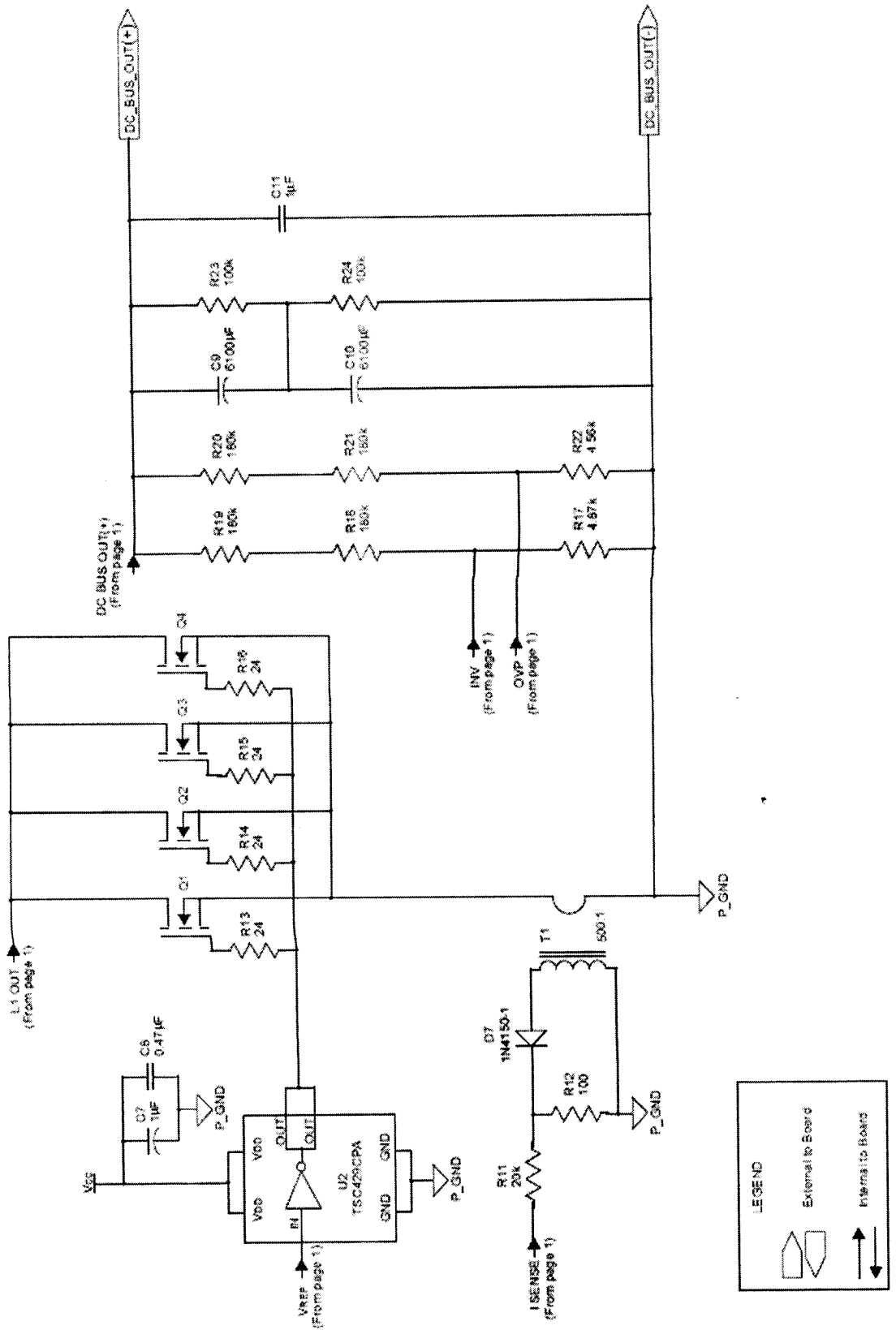


Figure2.5(b) Power Factor Correction Circuit

The power factor correction circuit has a high power factor pre-regulator integrated chip the UC3854. This integrated circuit (UC3854) is a 16 pin chip[5]. The different pins can be used for various activities. The powering on of this chip is through the Vcc pin which takes a voltage of about 17volt. The UC3854 for its proper operation, an operating frequency must be determined through the pin CT. The value of the capacitor connected to this pin determines the operating frequency of this IC. Since the UPS is designed to operate at 50Hz and 60Hz, the frequency used must accommodate both of these frequencies. But the desired operating frequency is that of the transistor switching which is 100kHz.

The input current is monitored by the UC3854 through the I(sin) pin. The current is tapped from the rectifier output terminals. The value of the voltage at the point where the current is tapped from is very high but the I(sin) pin is high current pin hence the voltage is scaled down through the high resistors R1 and R2. (Fig2.5a) . The output current is also monitored through the I(sense) of the UC3854. Thus the power factor correction circuit has two feedback loops. The inner feedback loop monitors the input current waveform. The outer loop monitors the output current from the UC3854.

The control inputs to the UC3854 are the following: I(sin)(pin6) , I(sense)(pin1) OVP(Output voltage pin,pin5) and the INV(Input voltage pin4). The I(sin) senses the input current from the rectifier output .The waveform of the input current is monitored so as to compare it with the input voltage waveform. This comparing of the two waveforms brings about the reduction in the phase difference between the two waveforms. The I(sense) monitors the output current from the transistors Q1,Q2,Q3 and Q4 (Figure2.5b) which are controlled by the Vref through the chip TSC429CPA. These transistors have placed in parallel in order to reduce the amount of current flowing through each transistor thus reducing the stress in them. The switching frequency of these transistors is very low hence noise is greatly reduced in this circuit. The switching is controlled by the Vref, the output current is thus compared to the input current sensed through I(sin) .I(sense) current is determined from the transformer T1(Figure2.4a) which is a current transformer. Like the I(sin) pin, I(sense) is also a high current pin hence the voltage scaled down through R11 and R12. As the current LI is controlled by the Vref ,it is forced to have the same waveform as the input voltage and the phase displacement is reduced thus raising the power factor.

The OVP(output voltage pin) and INV (input voltage) monitors the outer current loop. The outer current loop monitors the DC output current magnitude. The dc output voltage is monitored by the OVP pin. The output voltage feedback through this pin controls the magnitude of the output current. As the input current controls V_{ref} , the output current through this outer current loop ensures that a correct output current is forced into the L1.

Since the output current from L1 is forced to have the same value as the input current to the UC3854 and the input current waveform is matched with the input voltage waveform, the power factor of the UPS is thus raised as required. The purpose of raising the power factor in the UPS is to reduce on the amount of the current that has to be drawn from the main power supply. To meet a given load at lower power factor would require a large current as compared to a higher power factor which would draw a lower current.

The V_{ref} , which controls the transistor switching, is controlled from the pin12 of the UC3854. The pin12 controls the switching of the transistor Q5. Pin 12 is a gate drive pin which is internally clamped to a voltage of 15volts. The V_{ref} from the UC3854 is set to magnitude of 7.5volts which when the V_{cc} is below the 17volts. The EA pin is for ensuring that the UC3854 is coming on this pin is enabled. The enabling of this pin is by stiffening the internally supplied 2.5volts through the capacitor connected to the INV pin which is used to monitor the output voltage magnitude. The mult (pin2) of the UC3854 is current output pin for the non-inverting input current from the rectifier. This pin has not been used in it being connected to the input current but has been connected to the ground through the resistor R3. the purpose of this is to use this pin as means of grounding the noise that arises from the UC 3854 switching effects of the various controls. The pin SHUT (pin10) is a pin that is controls the switching off of the UC3854 in case of any malfunctions. Thus, the synchronization of the power factor correction circuit in the all UPS. This is done through the microcontroller. In cases of the malfunction of the UC3854, the R(T) pin is used to control the frequency at which the UC3854 should oscillate before complete shut by the SHUT pin. The oscillation frequency of the UC3854 is thus controlled using the C(T) and R(T) pins. The frequency at which the UC3854 operates usually should be much higher than the frequency of the utility power supply. A very simple relation between the oscillation frequency and the C(T) capacitor to be used is given below

$$C_t = 1.25/F * R_t \quad (2.1)$$

The switching of the transistors is such that the two transistors placed diagonally are switched at the same time. The transistors of the bridge are namely Q5, Q6, Q7 and Q8. The transistors to be switched simultaneously are Q5 and Q8 then Q6 and Q7. The commutative switching of the transistors results in the production of alternating current voltage, which has a square waveform. These transistors are desired to have a high switching frequency. The switching frequency of the transistors determines the quality of the waveform from the H-bridge. These transistors have been set to switch very high frequencies so that pulse width of the waveform to the transformer T6 are good enough for it give the correct voltage. This square voltage appears across the transformer T6. Each H-bridge limb has a current transformer namely T4 and T5 (fig2.6.1). The current transformers are used for the feedback loop of the free running chopper.

The transformer T6 is a center tap transformer. The voltage that has to be the output for the load must be the same as the input. To select the correct voltage for the output, the relays RYL1 and RYL2 have been placed for this purpose. The relay switches are designed to be controlled by the microcontroller. Thus the software program has to handle this part.

The square wave produced by this circuit has a duty cycle of about 45% and the free running chopper is set to a frequency of 100kHz. This is determined from the control circuit. This square wave is generated for the purpose of comparing it with the input voltage from the utility. The aim of comparing the two voltages is to ensure that the voltage fed to the H-bridge from the free running chopper corresponds to that of the mains supply. This square waveform is rectified to give a duty cycle 90-92%. The duty cycle is raised so that the ripple and stress on the components is minimized. Noise due to the high switching frequency of the transistors also arises. The filter circuit reduces the noise and currents from the parasitic capacitance of the inductor and voltage spikes are removed by this part of the circuit. This all occur during the of state of the duty cycle

The control card of the free running chopper is given in figure2.6.2. The circuit has the UC3825AN as the controlling chip. The UC3825 has been used for its high pulse width modulation capabilities. The powering of the UC3825 is that mentioned in the section of the battery boost control card. The frequency of oscillation for the free running chopper was determined from the value of R_t used and thus determining the value of C_t .

TSC429CPA chip that has its output connected to the transformer T2. The Out b is also connected to the chip TSC429CPA that too is connected to the other end of the transformer T2. The secondary of transformer T2. The polarity marking for the transistors Q5 and Q8 are on the same side just as those for Q6 and Q7 are in the same direction. The secondary of transformer T2 have resistors so as to reduce the amount of current reaching the gates of the transistors. Since the polarity markings for the transistor Q5 and Q8 are on the side, transistors are switched on simultaneously just as transistors Q6 and Q7 are equally switched together. Thus square wave is generated from this arrangement.

The feedback loops are namely CH-1-FDBK1 and CH-1-FDBK2 from the current transformers T4 and T5 respectively. The current transformers are used to measure the value of the output currents in the H-bridge(of the FRC). The feedbacks are both connected to diodes D8 and D9 (fig). The output from these diodes are connected together and provide the current to the current limit pin of UC3825AN. The current limit pin controls the maximum value of the current that should pass through the UPS. The same current from the diodes D8 and D9 is connected to the ramp pin through the resistor R6. The UC3825AN in this circuit is operating in the current mode. Hence the current going to the ramp is used as the slope compensation input. Due to this reason, the current that flow through the UPS is monitored for any fluctuations.

The DC buss is connected to the three zeiner diodes connected in series that are joined to the transistors that are connected to the soft start pin. The soft start pin monitors the duty cycle of the waveform from the H-bridge of this section of the UPS. The soft start pin has the capacity of doubling as the maximum duty cycle clamps. Due to the doubling effect of the soft start, the duty cycle of the square wave is raised to about between 90-92%. Hence the output voltage square wave has this duty cycle as compared to the square wave produced by this H-bridge is at a duty cycle of 45%.

2.7 Inverter

2.7.1 The inverter circuit

The inverter commonly called the H-bridge is used to convert the DC voltage into ac. The DC voltage conversion to AC is for the use by the loads which require AC current. The DC voltage from the rectifier is filtered through the power factor correction and the DC from the battery are both filtered through the free running chopper then fed into the H-bridge. The H-bridge circuit generates separate positive and negative cycles that are needed for the sinusoidal output voltage for the load. The circuit for the H-bridge is shown in figure2.6

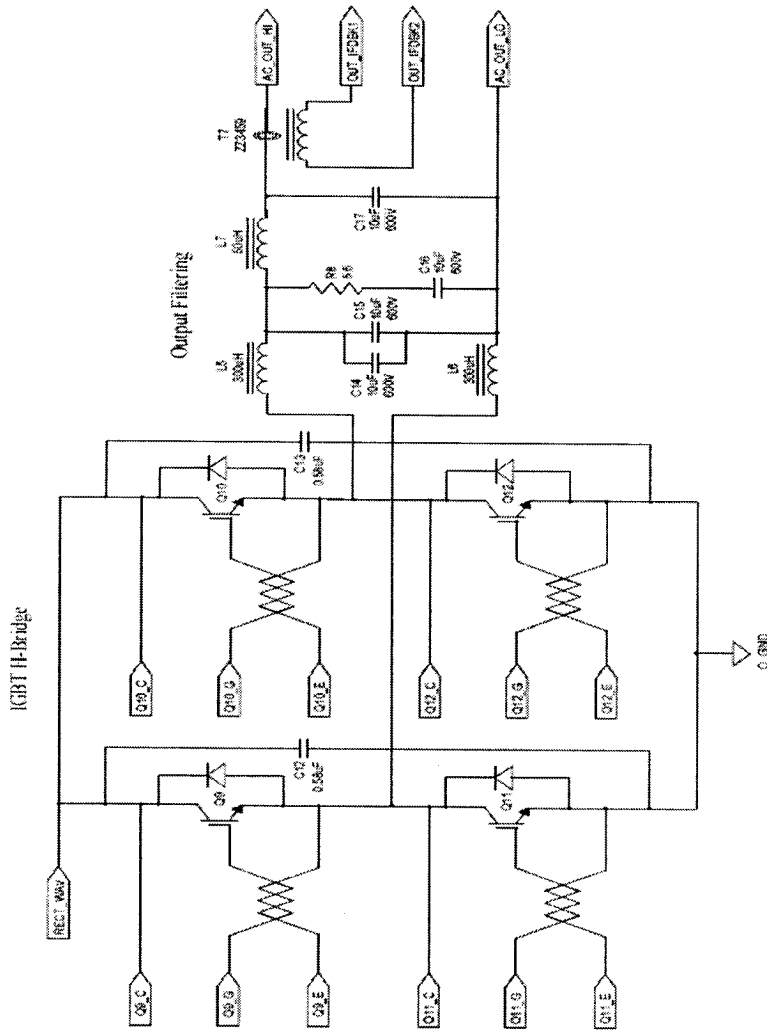


Figure2.7 Inverter Circuit

The inverter is made of four transistors which make up the two limbs which form the H-bridge. The transistors are labelled Q9, Q10, Q11 and Q12. The transistors for this particular bridge are Insulated Gated Bipolar Transistor (IGBT). These transistors have a low ON resistance and low operating frequency. MOSFETs can also be use but these have very high ON impedance for this particular application.

The drives to these transistors are given as Q9-DRIVE, Q10-DRIVE, Q11-DRIVE and Q12-DRIVE respectively. The control drives to these transistors are controlled from the logics gates given in the inverter control drive card. Each transistor has its own drive circuit. Transistor switching mode is given in the table shown in table2.7.1. The mode of switching for the transistors gates is such that Q9 and Q12 are switched at the same time whilst Q10 and Q11 are also switched at the same time. The equation for the relationship of switching of the transistors in each limb is such that, if S9 and S11 are the switching logics for the gates of the transistors Q9 and Q11 respectively then:-

$$S9 + S11 = 1 \quad (2.2)$$

The same applies for transistors Q10 and Q12 for the

$$S10 + S12 = 1 \quad (2.3)$$

This mode of transistor switching is determined from the pulse width modulation for the H-bridge to generate the square wave. From the relationship above it could thus be seen that the transistors in each limb cannot be switched ON at the same time. Thus transistor switching relation is given in table

Table2.7.1 Transistor Switching

S9	S10	S11	S12
1	0	0	1
0	1	1	0

This circuit is referred to as the inverter drive card. There are connected to the two parallel logics circuits. From the logic outputs it could be seen that for the PWM high and the POS-NEG low, the transistors Q9 and Q12 have their drives high hence they do not conduct but transistors Q10 and Q11 have their drives low hence they conduct. From this it follows that the transistors Q9 and Q12 have their drives low when the PWM is high and the POS-NEG is high.

Four control logics from the PIC17C43 (microcontroller) that control the inverter gates are namely the POS-NEG (pin RC2/AD2), ENABLE (pin RC0/ADO), FAULT (pin RC1/AD1) and the Pulse Width Modulation (pin RB2/PWM1). The pin selection of the PIC17C43 is discussed in the PIC17C43 section. The other control input to the drive is the saturation state of the transistors. The fault logic is the logic that detects the fault in the functions of the H-bridge.

The inverter control card is a logic circuit. This circuit is made of NAND and Exclusive OR gates the inputs to these gates are the Out of saturation, Enable, PWM, and the POS-NEG (Positive-Negative, this is for determining the reference voltage waveform for the positive and negative cycles). The Out of saturation logic is determined from the saturation state of the transistors, thus for normal operation, the transistor have to be in the saturation state. When any of the transistors is out of saturation, the out saturation state is low enabling the fault NAND gate. The fault logic being enabled, enables the PIC17C43 which disables the H-bridge. The out of saturation for the transistors occurs when there is a high short current drawn by the any of the transistors. The Enable logic from the PIC17C43 controls the flip-flop made from the two 74AC400 NAND gates. A high on the enable resets the H-bridge to initialise again. The resistor is connected to the Enable so that the system does not initialise the H-bridge due to stray signals. The PWM and POS-NEG logic inputs it follows that Q9 and Q12 are turned ON when their drives are low. This occurs when the PWM is high and the POS-NEG low. The PWM is always high for both the states of the transistor switches. This occurs because the PWM is needed to generate the duty cycle value for the square wave produced by the H-bridge. The PWM is internally generated by the PIC17C43 depending on the frequency of the input power source. The input power source frequency is captured by the zero crossing line shown in the UPS over view block diagram (figure 2.1). This, thus ensures that the output waveform is purely determined by the input power voltage form.

From the four logic inputs for the switching on of the transistors, the logic combination for the PWM and POS-NEG for transistor switching is given in table 2.7.2

Table 2.7.2 Inverter Control Signals

POS-NEG	PWM	Q9 Drive	Q10 Drive	Q11 Drive	Q12 Drive
0	0	0	0	1	1
0	1	1	0	0	1
1	0	0	0	1	1
1	1	0	1	1	0

It should be noted that a low on the transistor gate drive means the transistor is ON and a high the transistor is OFF.

2.7.3 Inverter drive card

The drives (Q9-drive, Q10-drive, Q11-drive and Q12-drive) from the inverter control card feed into the inverter drive card. There are four circuits for the inverter drive card one for each transistor but only one has been shown in figure 2.7.3. The drive signals for Q# drive feeds into the chip EXB840. The EXB840 chip is a Insulated Gated Bipolar Transistor driving hybrid chip [6]. The chip controls the switching ON and OFF of the IGBT. The switching frequency of this chip is as high as 40 kHz. The series resistor connected from pin 1 of this chip to the IGBT is provided for ensuring that the IGBT is protected from large spikes that are generated at the collector terminal.

The EXB840 has an inbuilt Overcurrent Protection Circuit (OVP). This monitors the current that flows through of the IGBT and thus the switching ON of the optoisolator H11L1 that has a logic output. A large current flow through the collector is detected from the relation of the gate drive signal and the voltage at the collector. A large current is considered present whenever the collector voltage is higher than the gate drive voltage. This optoisolator is powered from the separate power source and is fed into the OVP of the EXB840. The flow of a large current through the collector of the IGBT triggers the flow of current in the OVP consequently turning the H11L1 ON. This results in the Q#-OC ALARM for the respective IGBT ON. The capacitors placed across the pin 1 and 2 of the EXB840 are used absorbing the

2.8 Hardware Protection

The hardware protection logic has to automatically disable the inverter's power stage in the event any of the IGBT's have gone out of saturation, i.e., an external short was placed on the H-Bridge which was so severe that an appreciable voltage was developed across one of the switches that was on. This feature prevents a short from immediately destroying the switching devices. As long as none of the out-of-saturation signals (Q9/Q10/Q11/Q12 OC Alarm) are LOW, the power stage can be enabled. When the PIC17C43 is first powered up, the ENABLE line (PORTC, bit0) will be in a high impedance state. A pull-down resistor keeps the ENABLE line held LOW so that any spurious signals which may be generated while the system is initializing will not drive the H-Bridge. If any of the out-of-saturation signals go LOW, the FAULT signal goes HIGH, reporting to the PIC17C43 that an external fault occurred. This will disable the H-Bridge. The inverter may be re-enabled by cycling the ENABLE line LOW and then HIGH to reset the flip-flop and allow the PIC17C43 to drive the H-Bridge again. The PIC17C43 microcontroller and hardware protection circuits are found on the Inverter Control Card. IGBT driver circuits are found on the Inverter Drive Card.

2.9 Analog to Digital converter

Feedback of the output AC sine wave is accomplished through the use of an external 8-bit A/D converter. An 8-bit A/D is considered adequate based on the speed of operation of the PIC17C43 and the resolution needed for 120V. Both the output current and output voltage are monitored through the A/D converter. The voltage is sensed at the output stage and is fed to the A/D through an op amp circuit. The voltage is attenuated to the A/D input range. An op amp is used so that any DC offset components remain with the signal and can be measured. The current is monitored through a current transformer (refer to figure 2.1)

2.10 PIC17C43 (microcontroller)

2.10.1 Description of the microcontroller

The PIC17C43 is a single-chip 40 pin microcontroller/microprocessor with an EPROM of 4 kilobytes and a RAM of 454 bytes. It's a 16 bit wide word instruction and 8-bit wide data it has a clock input frequency of 33 MHz and 121 nanoseconds instruction cycle with 33

input/output pins. Pin RA2 and RA3 are the open drain high voltage pins. The pulse width modulation (PWM) pin which gives advantage of using this microcontroller in devices that require PWM applications and thus its use in this UPS for the control the inverter. The PWM resolution is 1 to 10 bit. The high RAM and EPROM provide a large memory capacity for programming. This microcontroller has a macro assembler, software simulator, an inbuilt emulator, a universal programmer and 'C' compiler .[7]

2.10.2 Pin description

The most important feature for the use of this microcontroller is its programmability. Thus pin configuration is important to understand. The pins are classified by the manufacturer into parts namely PortA, PortB, PortC, PortD and PortE. Table 2.8.2 shows the classification of these pins. Ports A and B are multiplexed with peripheral features of the chip which are the timer module, capture module and PWM module.

Interrupt handling of the PIC17C43 is done through four registers namely peripheral interrupt enable register (PIE), interrupt status register (INTSTA), peripheral interrupt register request (PIR). The INTSTA records the individual interrupts. This is used to control most of the interrupts to be handle by this microcontroller.

The Ports B, Port C, and Port D due to their properties are used for programming of the microcontroller. The software used determines the configuration of ports and pins. The other pins of interest are the PWM pins used in determining the quality of the output voltage for the H-bridge. This microcontroller has two PWM. These pins use the TMR1 and TMR2 for their generation.

Table2.10.2 Pin Description

Name	DIP No.	PLCC No.	QFP No.	I/O/P Type	Buffer Type	Description
OSC1/CLKIN	19	21	37	I	ST	Oscillator input in crystal/resonator or RC oscillator mode. External clock input in external clock mode.
OSC2/CLKOUT	20	22	38	O	—	Oscillator output. Connects to crystal or resonator in crystal oscillator mode. In RC oscillator or external clock modes OSC2 pin outputs CLKOUT which has one fourth the frequency of OSC1 and denotes the instruction cycle rate.
MCLR/VPP	32	35	7	I/P	ST	Master clear (reset) input/Programming Voltage (VPP) input. This is the active low reset input to the chip.
RA0/INT	26	28	44	I	ST	PORTA is a bi-directional I/O Port except for RA0 and RA1 which are input only. RA0/INT can also be selected as an external interrupt input. Interrupt can be configured to be on positive or negative edge. RA1/T0CKI can also be selected as an external interrupt input, and the interrupt can be configured to be on positive or negative edge. RA1/T0CKI can also be selected to be the clock input to the Timer0 timer/counter. High voltage, high current, open drain input/output port pins. High voltage, high current, open drain input/output port pins. RA4/RX/DT can also be selected as the USART (SCI) Asynchronous Receive or USART (SCI) Synchronous Data. RA5/TX/CK can also be selected as the USART (SCI) Asynchronous Transmit or USART (SCI) Synchronous Clock.
RA1/T0CKI	25	27	43	I	ST	
RA2	24	26	42	I/O	ST	
RA3	23	25	41	I/O	ST	
RA4/RX/DT	22	24	40	I/O	ST	
RA5/TX/CK	21	23	39	I/O	ST	
RB0/CAP1	11	13	29	I/O	ST	PORTB is a bi-directional I/O Port with software configurable weak pull-ups. RB0/CAP1 can also be the CAP1 input pin. RB1/CAP2 can also be the CAP2 input pin. RB2/PWM1 can also be the PWM1 output pin. RB3/PWM2 can also be the PWM2 output pin. RB4/TCLK12 can also be the external clock input to Timer1 and Timer2. RB5/TCLK3 can also be the external clock input to Timer3.
RB1/CAP2	12	14	30	I/O	ST	
RB2/PWM1	13	15	31	I/O	ST	
RB3/PWM2	14	16	32	I/O	ST	
RB4/TCLK12	15	17	33	I/O	ST	
RB5/TCLK3	16	18	34	I/O	ST	
RB6	17	19	35	I/O	ST	
RB7	18	20	36	I/O	ST	
RC0/AD0	2	3	19	I/O	TTL	PORTC is a bi-directional I/O Port. This is also the lower half of the 16-bit wide system bus in microprocessor mode or extended microcontroller mode. In multiplexed system bus configuration, these pins are address output as well as data input or output.
RC1/AD1	3	4	20	I/O	TTL	
RC2/AD2	4	5	21	I/O	TTL	
RC3/AD3	5	6	22	I/O	TTL	
RC4/AD4	6	7	23	I/O	TTL	
RC5/AD5	7	8	24	I/O	TTL	
RC6/AD6	8	9	25	I/O	TTL	
RC7/AD7	9	10	26	I/O	TTL	

[7]

2.10.3 Inverter Control Card

The inverter control card is made of four circuits that are given in the figures 2.10.2. The inverter control card is mainly centered on the PIC17C43 microchip. The circuit is referred to as the inverter control card though it controls all the circuits in the UPS. The other main features of this control card are the ADC10154CIN (analog to digital control) for monitoring the output current and voltage magnitudes, the CXT171 (clock setting) and the 74HC4040 ripple counter for setting the frequency for the synchronizing circuits. The CTX171 determines the frequency of the microcontroller as well as the ripple counter 74HC4040. The microcontroller and the ripple counter are set to the same frequency so that they work in synchronous.

waveform and this results in the determination of any DC offsets needed to correct the magnitude of the output voltage and current magnitude. The LM158 monitoring the A/D voltages for the output, has a minimum voltage of $-5V$. The voltage from the A/D that is compared with this Lm158 voltage is the V_{rout} voltage which is used as feedback voltage for the output voltage loop.

2.11 Software Overview

The PIC17C43 embedded software controls the operation of the AC sine wave generation. It is imperative that the loop response be fast enough to minimize distortion on the output wave. Therefore, the throughput of the microcontroller is a critical parameter. The architecture of the PIC17C43 provides enough throughput to execute the control algorithm with a minimum distortion. The architecture is efficient enough to support the device running at 33 MHz (121 ns instruction cycle), so can easily support 25 MHz (160ns instruction cycle) to meet the distortion requirement.

The main software function looks for the zero crossing point and calculates the input frequency. Based on the calculation, the appropriate look-up table is indexed[8]. The SW checks for violation of maximum conditions and sets the appropriate flags. The loop continues indefinitely based on the zero crossing detect. Information on how the look-up table is generated is provided in the first subsection. The interrupt is set up to occur periodically based on the output frequency of the wave. The interrupt period is initialized so that 32 interrupts occur within the half-wave period. During the interrupt, there must be sufficient margin to perform two A/D conversions (current and voltage), calculate offsets and errors, and adjust the output duty cycle. Adjusting the AC output waveform requires adjusting the PWM that controls the inverter circuitry (H-Bridge).

To do this, compensator coefficients need to be determined. That is, in pseudocode:

$$X = (\text{Output_V}) - V_{ref};$$

$$Y = c * Y_{old} + d(X + X_{old});$$

$$Y_{old} = Y;$$

$$X_{old} = X;$$

Where

$$Y = \text{output}; X = \text{error}.$$

The error in the output is used to also determine the Dc offsets

Chapter3

Expected results

The voltages from the main busses expected are as follows. The DC bus which is the main bus from the battery boost circuit is designed to carry a voltage of 360V. This voltage is lower than that from the rectifier which is 380V. The purpose of this is to ensure that during normal operation the UPS supplies power from the utility.

The free running chopper is designed to produce the square wave that is twice in magnitude that from the battery boost hence the magnitude is 720V. The duty cycle of this wave is set at 45%.

The results expected from the inverter is a sinusoidal wave. A purely resistive load has current waveform that is similar to the input. The input voltage to the UPS is a sine wave hence the current should follow the same pattern.

Chapter 4

4.1 Discussion

The major challenges in the analysis of the UPS circuits functions are largely dependent on the integrated components used. The various circuits require an intensive study of the data sheets of the particular ICs used. The designers thus follow a systematic approach. Thus to fully understand the given UPS one must read through the specifications of the system so that when the UPS is fully developed its these specifications against which the results obtained should be compared. The UPS was not developed hence the performance of the UPS could not be evaluated.

4.2 Conclusion

Analysis of the circuits in the UPS requires a huge investment in reading the data sheets of particular components present in the circuits. The various circuits may employ certain integrated circuits which are same but are performing different functions depending on the circuit in which they have been used.

The design of UPS system requires that the system responds to the utility power failure in a short period of time. The design always ensures that high frequency switching devices are used. This could be seen from the use of many chips which have high operating frequencies. The micro controller based UPS has advantages of reducing on the number of components to be used. Micro controllers have a high control of the circuits using the software embedded in them. Alterations of the functions of certain circuits can be achieved through changing the software.

Reference

1. Powerware, Prestige 6000 Operators Manual

2. Microchip Technology PICREF-1

www.microchip.com/stellent/idcplg?IdcService

3. Texas Instruments UC3825 Data Sheets

www.alldatasheet.com/datasheet

4. Linear Technology. Data Sheets

www.chipdocs.com/datasheets

5. Texas Instruments UC3854 Data Sheets

www.alldatasheet.com/datasheet

6. Agilent Technology Data Sheets

www.home.agilent.com/USeng

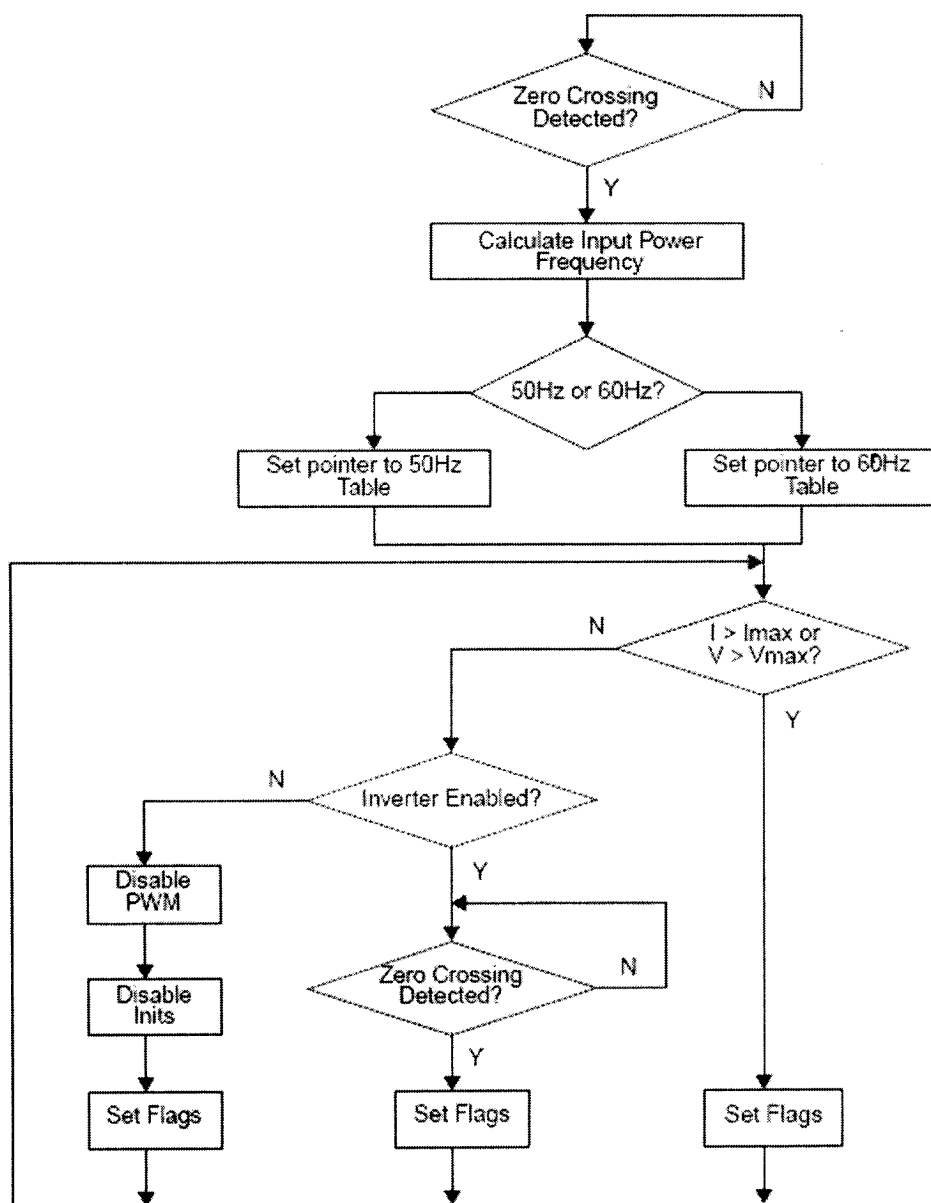
7. Microchip Technology PIC17C43 Data Sheets

www.microchip.com/stellent/idcplg?IdcService

APPENDICES

APPENDIX A

Program Flow Chart



Appendix B

```

main()
*
* Description: The main routine initializes the registers and loops
* forever. All control is handled in the TMR0 INT
* routine.
*
*
* Input Variables: NONE
*
* Output Variables: NONE
// This table yields Full VRMS input
unsigned char const pwmtab[32]={0,25,50,74,98,120,142,162,180,197,212,
225,235,244,250,254,255,254,250,244,235,
225,212,197,180,162,142,120,98,74,50,25};
#endif
#ifdef FEEDBACK
// This table yields slightly less than Full VRMS input
unsigned char const pwmtab[32]={0,20,40,60,79,97,114,131,145,159,171,
181,189,197,202,205,206,205,202,197,189,
181,171,159,145,131,114,97,79,60,40,20};
#endif
long read_ad(unsigned char); // Prototype for A/D converter function
unsigned char index; // Index into the sinewave reference table
unsigned char sign; // Flag used to unfold sinewave reference table
long reference; // Value of the sinewave refrence after unfolding
unsigned char reference_lo @ reference; // V1.21 of Compiler does not type cast unsigned
// char to long so we will write to low byte separately

```

```

long out_volt; // Magnitude of the output voltage;
long y; // Variables used in compensation routine
long yold;
long x;
long xold;
long ad_value; // A/D Converter Value
void main(void)
{
CLRWDT();
PORTC = 0; // Zero out portc latches
DDRC = 0x22; // Set up Data direction register for C
DDRB = 0; // Set up Data direction register for B
PR1 = 0xFF; // Setup PR1 register (24.4Khz @ 25Mhz clk)
PW1DCL = 0; // Set low bits of PWM to 0
PW1DCH = 0; // Init PWM duty cycle to 0
T0STA = 0x20; // Configure Timer0 prescaler
INTSTA.T0IE = 1; // Enable Timer 0 interrupt
TCON1.TMR1CS = 0;
TCON1.T16 = 0;
TCON2.TMR1ON = 1; // Start timer 1 (PWM timer)
TCON2.PWM1ON = 1; // Turn on the PWM
CPUSTA.GLINTD = 0; // Unmask the interrupts
index = 0; // Initialize variables
sign = 0;
y = 0;
yold = 0;
x = 0;
xold = 0;
PORTC.0 = 1; // Enable the Inverter
while(1); // Loop forever, execute in INT Routine
}
#ifdef FEEDBACK
__TMR0() // Timer interrupt

```

```

{
T0STA.T0CS = 0; // Stop timer
PORTB.7=1;
#ifdef 60Hz
TMR0L=0xA5;
TMR0H=0xF9; // Make Timer0 interrupt at 3.84KHz for 60Hz output
#endif
#ifdef 50Hz
TMR0L=0x5F; // Make Timer0 interrupt at 3.20KHz for 50Hz output
TMR0H=0xF8;

#endif
T0STA.T0CS = 1; // Start timer
CLRWDT();
reference = 0; // Clear Reference Value
reference_lo = pwmstab[index]; // Lookup the value of the sinewave reference
if (!index) // Toggle Sign Every Cycle Through table
sign = ~sign;
++index; // Increment index
if (index == 32) // If end of table, reset counter
index = 0;
if (sign) // If negative going wave
{
reference = ~reference; // V1.21 of Compiler negate (-ref) doesn't work for
reference = reference + 1; // ref<=0
}
ad_value = read_ad(0);
out_volt = ad_value - 512; // Read output voltage (512 counts=0 volts out)
// Form the expression  $y = yold + (0.09261 * (x + xold))$ 
// Where yold, xold is the value of y, x from the previous sample
// x is the <error signal>, formed by the difference between the output
// of the inverter and the reference signal.
x = out_volt - reference;

```

```

y = ((x + xold) * 24);
y = y / 256;
y = y + yold;
if (y >= 0)
{
PORTC.2 = 0; // Set positive going cycle
} else
{
PORTC.2 = 1; // Set negative going cycle
y = ~y;
y = y + 1;
}
if (y > 255)
y = 255; // Limit y
PW1DCH = y; // Update duty cycle
xold = x; // Store previous sample's state
yold = y;
PORTB.7=0;
}
#endif

#ifdef OPEN_LOOP
// The inverter runs in an open loop mode with OPEN_LOOP defined.
__TMR0() // Timer interrupt
{
T0STA.T0CS = 0; // Stop timer
#ifdef 60Hz
TMR0L=0xA5;
TMR0H=0xF9; //Make Timer0 interrupt at 3.84KHz for 60Hz output
#endif
#ifdef 50Hz
TMR0L=0x5F; //Make Timer0 interrupt at 3.20KHz for 50Hz output
TMR0H=0xF8;
#endif
#endif

```

```

T0STA.T0CS=1; //Start timer
CLRWDT();
PW1DCH = pwmtab[index];
if (!index)
{
PORTC.0 = 0; // Gate Drive off

PORTC.2 = ~PORTC.2; // Flip Pos/Neg bit
PORTC.0 = 1; // Gate Drive on
}
++index;
if (index == 32)
index = 0;
PORTC.3 = ~PORTC.3; // Toggle bit to test freq.
}
#endif
long read_ad(unsigned char channel)
{
long result;
PORTC.6 = 1; // Write bit high
PORTC.7 = 1; // Read bit high
PORTC.4 = 1; // Chip select high
DDRD = 0; // Make PORTD an output
PORTD = 0x04; // Single ended mode signed 10 bit chan 0 Right justified
PORTC.4 = 0; // Select chip
PORTC.6 = 0; // latch command word int A/D
PORTC.6 = 1; // Start conversion
PORTC.4 = 1; // Deselect chip
while (PORTC.5); // Wait for conversion to complete
DDRD = 0xFF; // Make PORTD an input
PORTC.4 = 0; // Select chip
PORTC.7 = 0; // Read high byte
*((unsigned char*)&result + 1) = PORTD;

```

```
PORTC.7 = 1;
PORTC.4 = 1;
PORTC.4 = 0;
PORTC.7 = 0; // Read low byte
*((unsigned char*)&result) = PORTD;
PORTC.7 = 1;
PORTC.4 = 1; // Reset chip select lines
return (result); // Return data
}
```