CHAPTER 6

HARDWARE IMPLEMENTATION

6.1 GENERAL

The hardware circuit implementation of the pulse width modulated AC chopper fed single phase induction motor is explained in this chapter.

6.2 HARDWARE DESCRIPTION

The available AC voltage of 230 V is fed to the primary of the transformer from the source. The transformer steps-down the voltage to 6 V, which is given to the Zero Crossing Detector Circuit (ZCD). A 5 V DC input voltage is given to the microcontroller using a rectifier having diodes (IN4007), capacitor and regulator ICs (7812 and 7805). The output of the microcontroller is fed to the driver circuit consisting of IR2110, and that output is given to the gate terminal of the IGBTs. The hardware involves the following sections-

- Power supply unit
- ZCD circuit
- Microcontroller circuit
- Driver circuit
- AC chopper power circuit
6.3 POWER SUPPLY UNIT

The circuit consists of the following components

- Transformer
- Bridge rectifier
- Filter
- IC regulator

The main source section of hardware unit is shown in the Figures 6.1 and 6.2. In the ZCD power supply unit, the rectifier is given an input voltage of 6 V AC, which is obtained from a step-down transformer. This 6 V AC is converted into DC and regulated by means of regulator ICs 7805 and 7905 to get +5 V and -5 V respectively. The output is given to the ZCD.

![ZCD power supply circuit diagram](image)

**Figure 6.1 ZCD power supply unit**

In the power supply unit shown in Figure 6.2, the rectifier is given an input voltage of 15 V AC, which is obtained from a step-down transformer. This 15 V AC is converted into DC and regulated by means of
regulator ICs 7812 and 7805 to get +12 V and +5V supply which is given as input to driver circuit and microcontroller respectively.

![Power supply unit diagram](image)

**Figure 6.2 Power supply unit**

### 6.3.1 Transformer

It is used to step-up or step down the AC supply voltage to suit the requirement of the electronic devices and the circuit fed by the power supply. It also provides the isolation from the supply line. The input voltage to the transformer primary is 230 V AC. The output (step down) voltage of 15 V AC and 6 V AC are used.

### 6.3.2 Bridge Rectifier

A diode bridge or bridge rectifier is an arrangement of four diodes connected in a bridge circuit as shown in Figure 6.2, which provides the same polarity of output voltage for any polarity of the input voltage, when used in its most common application, for conversion of alternating current (AC) input into direct current (DC) output, it is known as a bridge rectifier. The bridge rectifier provides full wave rectification from a two wire AC input (saving the cost of a center tapped transformer) but has two diode drops rather than one, reducing efficiency over a center tap based design for the same output voltage.
When the input connected at the left side is positive with respect to the one connected at the right side, current flows to the right along the upper path to the output, and returns to the input supply via the lower one.

When the right side is positive relative to the left side, current flows along the upper path and returns to the supply via the lower path.

In each case, the upper right output remains positive with respect to the lower right one. Since this is true whether the input is AC or DC, this circuit not only produces DC power when supplied with AC power, it also provides “reverse polarity protection”. That is, it permits normal functioning when batteries are installed backwards or DC input-power supply wiring “has its wires crossed” (and protects the circuitry and it powers against damage that might occur without this circuit in place).

6.3.3 Filter

The function of the filter is to remove the fluctuations or pulsations (ripples) present in the output voltage of the rectifier. It cannot completely eliminate the ripples as that of a DC battery, but it approaches so closely that the power supply performs so well.

Capacitors provide a low impedance path to the AC component of the output, reducing the AC voltage across, and AC current through the resistive load. In less technical terms, any drop in the output voltage and current of the bridge tends to be cancelled by loss of charge in the capacitor. This charge flows out as additional current through the load. Thus the change of load current and voltage is reduced relatively to what would occur without the capacitor. Increase in the voltage correspondingly store excess charge in the capacitor, thus moderating the change in output voltage/current.
6.3.4 Voltage Regulator

The main function of voltage regulator is to maintain the terminal DC voltage constant even when

- AC input voltage to the transformer varies
- The load varies
- It is impossible to get 100% constant voltage but minor variation is acceptable

A voltage regulator (also called as “regulator”) has only three legs and appears to be a comparatively simple device but it is actually a very complex integrated circuit. A regulator converts varying input voltage into a constant “regulated” output voltage. Voltage regulators are available in a variety of outputs, typically 5 V, 9 V and 12 V. The last two digits in the name indicate the output voltage. The “LM78XX” series of voltage regulators are designed for positive input. For applications requiring negative input the “LM79XX” series is used.

Voltage regulators are very robust. They can withstand over-current drawn due to short circuits and also due to over-heating. In both cases the regulator will shut down before damage occurs. The only way to destroy a regulator is to apply reverse voltage to its input. Reverse polarity destroys the regulator almost instantly. To avoid this possibility diode protection of the power supply is used. This is important while using nine-volt battery supplies, as it is common for people to ‘test’ the battery by connecting it one way or the other. Even this short ‘test’ could destroy the regulator if a protection diode is not used. Protection diodes connected to the power supply circuit prevent damage due to incorrect polarity. Generally a IN4001, 1 A power diode is connected in series with the power supply. If the supply is connected the wrong way around, the regulator will be protected from damage.
With the exception of shunt regulators, all voltage regulators operate by comparing the actual output voltage to some internal fixed reference voltage. Any difference is amplified and used to control the regulation element. This forms a negative feedback servo control loop. If the output voltage is too low, the regulation element is commanded to produce a higher voltage. For some regulators if the output voltage is too high, the regulation element is commanded to produce a lower voltage. In many cases, it stops sourcing current and depends on the current drawn and it pulls the voltage down. In this way, the output voltage is held roughly constant.

6.4 ZERO CROSSING DETECTOR

The zero crossing detector shown in Figure 6.3, is also called the sine to square wave generator. The IC 741 operational amplifier (op-amp) is used for this conversion. A fixed reference voltage is applied to the non-inverting input, and the inverting input is grounded. The output is obtained from the pin number 6. The +5V supply is given to the pin number 7 and -5V supply is given to the pin number 4. The generated square wave is given to the pin number 12 of the microcontroller.

Figure 6.3 Zero crossing detector circuit
6.5 MICROCONTROLLER BASED PULSE GENERATING UNIT

The microcontroller is a programmable IC manufactured by Very Large Scale Integration (VLSI) technique, and capable of performing arithmetic and logical operations.

The microcontrollers are similar to microprocessors, but they are designed to work as a true single chip system by integrating all the devices needed for a system on a single chip. The basic functional units of a microprocessor are Arithmetic and Logic Unit (ALU), a set of registers, timing and control unit. The microcontroller have these functional blocks and in addition may have I/O ports, programmable timer, Random Access Memory (RAM) memory and Erasable Programmable Read Only Memory (EPROM) and Electrically Erasable Programmable Read Only Memory (EEPROM) memory. Some of the microcontrollers have internal Analog to Digital Converter (ADC) and/or Digital to Analog Converter (DAC).

The ALU is the computational unit of the microcontroller which performs arithmetic and logical operations. The various conditions of the result are stored as status bits called flags in the flag register. The register array and internal RAM memory are used as temporary storage device for storing temporary data during execution of a program.

All arithmetic and logic operations will be carried out in accumulator. The PC is a sixteen-bit register. The register points to the address of the next instruction to be executed. As the CPU fetches the op-code from the program memory, the program counter is incremented automatically by one, two or three based upon the length of the instruction being executed.

The Data Pointer (DPTR) is a sixteen-bit register to hold 16 bit address. It can be used as separate two eight bit registers, DPH and DPL. The
DPTR register is used as a pointer to hold the address of external memory location to access. The DPH register holds high order eight bit address and DPL register hold low order eight bit address.

The program codes and permanent data are stored in EPROM/EEPROM. In microcontroller based systems, external memory is provided only when internal memory is not sufficient and so in most of the microcontroller based systems, the program and data are stored in the internal memory of the microcontroller itself.

The program counter generates the address of the instructions to be fetched from the memory and send through internal bus to the memory (If the instruction to be fetched is stored in external memory then the address is send through I/O ports).

ROM is the least expensive means of storing a program in microcontroller, especially for high volume manufacturing. EPROM technology is used to place the programmable memory in the microcontroller chip for limited production purposes, a less expensive version of EPROM chip called one time programmable chip is used. Another technique called EEPROM is also used for storing program data in a microcontroller. Some data that are generated and saved for later use are usually stored in RAM. In more microcontrollers, the amount of RAM is usually 60 to at most a few hundred bytes. The amount of ROM, EPROM, EEPROM usually runs from 1000 bytes upwards to a few tens of thousand of bytes. Currently flash ROM are available in the microcontroller, hence it is easy to transfer the program form computer into the microcontroller through serial port.

The memory will send the instruction codes, which are decoded by instruction decoding unit and send information to timing and control unit. The
timing end control unit will generate the necessary control signals for internal and external operation of the microcontroller.

The parallel and serial I/O ports are used for interfacing I/O devices like switches, keyboard, ADC, DAC, etc., and also for any other I/O operations.

The microcontrollers do not have dedicated external address and data bus. Therefore for interfacing any additional peripheral devices, the external address and data buses are formed only by using port lines.

The microcontrollers with internal ADC can directly accept analog signals for processing. Likewise the microcontrollers with internal DAC can directly generate analog signals for controlling analog devices. The programmable timer can be used for time based operations and it can also be used as a counter.

In microcontrollers, each I/O device input and output registers, its control registers and status registers are mapped into memory locations. I/O transactions require no special computer instructions.

Interrupts are used whenever it is necessary for a program to respond as quickly as possible to external events. Interrupts from various sources can occur at any time during the program execution, which makes their programming and debugging complex.

When an interrupt occurs, and the 8051 is programmed to respond to it, the program jumps to the routine that meant for the interrupt. To make sure that the ‘interrupted’ main program can continue without problem when the interrupt routine is finished, the interrupt routine must not contain instructions that change the registers used by the main program. This is
usually ensured by pushing the necessary SFRs right at the start of the interrupt service routine, and popping them back again on returns to the main program. To protect the registers, the register bank is swapped. This requires a clear-cut subdivision to be defined for the register banks and the stack, and it is readily seen that errors may creep-in at any stage, and may not come to light after a good deal of debugging. To return from an interrupt subroutine to the main program, the last instruction in the subroutine must be RET.

The hardware is implemented using the ATMEL 89C2051 microcontroller. The circuit diagram of microcontroller based pulse generating unit is shown in Figure 6.4. The line-interfacing unit gives the information about the supply to the microcontroller. A suitable program is written in the microcontroller to generate square pulses. The driving pulses required for the IGBTs are obtained from the microcontroller.

![Figure 6.4 Microcontroller based pulse generating unit](image-url)
Criteria for choosing microcontroller are as follows.

- Meeting the computing needs of the task at hand efficiently and cost effectively.
- Availability of software development tools such as compilers, assemblers and debuggers.
- Wide availability and reliable sources of the microcontroller.

6.6 DRIVER CIRCUIT

A driver circuit shown in Figure 6.5, is used for the purpose of isolating the negative current from the microcontroller, for amplification of voltage and to create constant voltage source. The square pulse should have a constant voltage of 5 V. This voltage is connected to the isolator for isolation purposes. Isolation refers to the separation of the power circuit from the microcontroller.

![Diagram of the driver circuit](image)

**Figure 6.5 Driver circuit**
The gate drive requirements for a power IGBT utilized as a high-side switch driven in full enhancement (i.e., lowest voltage drop across its terminals) can be summarized as follows:

- Gate voltage must be 10 V to 15 V higher than the source voltage. Being a high-side switch, such a gate voltage would have to be higher than the rail voltage, which is frequently the highest voltage available in the system.
- The gate voltage must be controllable from the logic, which is normally referenced to the ground. Thus, the control signals have to be level-shifted to the source of the high side power device, which, in most applications, swing between the two rails.
- The power absorbed by the gate drive circuitry should not significantly affect the overall efficiency.

When voltage is applied to the IR2110 IC, the output voltage will have an increased magnitude that will be sufficient for driving the IGBTs.

### 6.7 POWER CIRCUIT OF AC CHOPPER

An optimal control strategy for selecting firing and commutation angles in pulse width modulated (PWM) AC chopper-type, single phase controller is used. The method minimizes output voltage harmonic distortion through numerical techniques, and can also eliminate certain chosen harmonics. Best results are obtained when no harmonics are completely eliminated, but are allowed to have small residual values.

Figure 6.6 shows the schematic representation of the single phase PWM AC Chopper. The circuit can operate directly from a single phase line, and the voltage across each switch is limited to the line voltage. The circuit consists of two IGBTs and diodes.
The forward switch $S_1$ is used periodically to connect and disconnect the load to the supply, i.e. it regulates the power delivered to the load. The parallel switch $S_2$ provides a freewheeling path for the load current to discharge the stored energy of the load inductance when the forward switch $S_1$ is turned off.

The switching patterns of a controlled switch are decided by the polarity of the source voltage and the load current in such a way so as to provide a path for the load current whatever be its direction. Table 6.1 gives the sequence of closure and opening of switches.

![Figure 6.6 Pulse width modulated AC chopper circuit](image)

**Table 6.1 Switching sequence of driving signal**

<table>
<thead>
<tr>
<th>State</th>
<th>Switch $S_1$</th>
<th>Switch $S_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_S&gt;0, I_L&gt;0$</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$V_S&lt;0, I_L&gt;0$</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>$V_S&lt;0, I_L&lt;0$</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>$V_S&gt;0, I_L&lt;0$</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Switch state: 0-Open, 1-Closed
When the supply voltage and the load current are of equal polarity, normal switching takes place in which switch S₁ is completely turned on and switch S₂ is turned off. When the supply voltage and the load current are of different polarity, switch S₂ is turned on and switch S₁ is turned off. By such switching patterns a continuous current path always exists regardless of the load current direction. The operating modes are divided into two: active mode and freewheeling mode. The active mode is defined when the switch S₁ is turned on. The freewheeling mode is defined when the switch S₂ is turned on and the inductor current paths can be formed by the direction of the load current. In the free wheeling mode, the load current free wheels and naturally decays. Using the AC chopper, the pulse width modulated voltage is obtained and it is applied to the induction motor.

6.8 EXPERIMENTAL VERIFICATION

The experimental setup of the hardware implemented is shown in Figure 6.7. For the experimental verification, a 746 W, 230 V single phase induction motor is used.

![Experimental setup](image)

Figure 6.7 Experimental setup

The hardware is implemented using the AT89C2051 microcontroller. It consists of a small capacitor of 11 μf, as a voltage
suppressor, placed across the freewheeling path, in order to avoid problems of high-voltage transients that can occur if both the switches are turned off in the presence of a reactive load. The hardware circuit of the pulse width modulated AC chopper fed drive is shown in Figure 6.8. The main part of the control circuit is the microcontroller. The line-interfacing unit gives the information about the AC supply to the microcontroller. A program is written in the microcontroller to generate the driving pulses. Thus the gating pulses required by the switches are obtained from the microcontroller.

From the experimental set-up, the readings are noted and tabulated as given in Table 6.2. The saving in energy in a no-load and partial load conditions are calculated for various duty-ratio values using Equation 5.11.

<table>
<thead>
<tr>
<th>Load condition</th>
<th>Voltage in Volts</th>
<th>Current in Amps</th>
<th>Power in Watts</th>
<th>Energy saving in %</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-load</td>
<td>230</td>
<td>4.1</td>
<td>228</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>47</td>
<td>1.2</td>
<td>87</td>
<td>62</td>
</tr>
<tr>
<td>Partial load</td>
<td>10%</td>
<td>230</td>
<td>4.8</td>
<td>340</td>
</tr>
<tr>
<td></td>
<td>115</td>
<td>1.7</td>
<td>210</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>20%</td>
<td>230</td>
<td>5.2</td>
<td>440</td>
</tr>
<tr>
<td></td>
<td>161</td>
<td>2.3</td>
<td>330</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>230</td>
<td>5.9</td>
<td>550</td>
</tr>
<tr>
<td></td>
<td>209</td>
<td>4.3</td>
<td>517</td>
<td>6</td>
</tr>
</tbody>
</table>

The flowchart to obtain the driving pulses for the two switches is given in Figure 6.9. The oscillogram of gate pulses with the duty-ratio of 50% and 20% are shown in Figures 6.10(a) and (b) respectively. The oscillogram of output voltage is shown in Figure 6.10(c).
Figure 6.8 The hardware circuit of PWM AC chopper fed drive
Figure 6.9 Flowchart for the generation of control pulses
(a) Driving pulse for 50% duty-ratio

(b) Driving pulse for 20% duty-ratio

(c) Output voltage of the system

Figure 6.10 Experimental results

It is found that with reduced voltage, 62% of the energy can be saved in a no-load condition. The energy-saving decreases with the increase in
the load. i.e 38%, 25% and 6% of energy can be saved at 10%, 20% and 30% of the load.

6.9 CONCLUSION

The hardware is implemented using an ATMEL 89C2051 microcontroller and the experimental results are presented. The experimental results and the simulation results are given in Table 6.3. The experimental results are almost similar to the simulation results.

Table 6.3 Comparison of saving in energy

<table>
<thead>
<tr>
<th>Load condition</th>
<th>% saving in energy</th>
<th>Simulation Results</th>
<th>Experimentation Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>No-load</td>
<td>58%</td>
<td>62%</td>
<td></td>
</tr>
<tr>
<td>Partial load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>35%</td>
<td>38%</td>
<td></td>
</tr>
<tr>
<td>20%</td>
<td>23%</td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td>30%</td>
<td>5%</td>
<td>6%</td>
<td></td>
</tr>
</tbody>
</table>