Power Control Board using Integer and Fractional Cycle Power Controls and Selectable Control Profile

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Abstract

There are various kinds of loads, some of which function better with Integer Cycle Power Control (ICPC) while others under Fractional Cycle Power Control (FCPC). The designed product provides the user the option of selecting either ICPC or FCPC, for each of the four loads controlled by it. To make this regulator commercially viable and attractive alternative to normal regulator, features like selectable control profile and compensation for fluctuation in mains voltage have been added. Additionally, Real Time Clock with an alarm clock has been implemented. User-friendly interface in the form of LCD display, keypad and serial interface has been integrated in the design.

1. Introduction

The objective of our design project is to build a power control board, which implements Integer Cycle Power Control (ICPC) as well as Fractional Cycle Power Control (FCPC) for load regulation of the 4 loads controlled by the circuit. The board shall give the user the option of selecting either ICPC or FCPC for each load. It also provides regulation against input power supply voltage variation. In addition to this, the product also contains a clock and alarm system implemented with the help of a Real Time Clock (RTC). The designed board should permit the settable profile feature for one load. In case of speed control of fan, the user comfort can be largely increased if the board facilitates setting the profile for varying the speed with time, to best suit the user requirement. For example, in the night, one may set a profile of higher initial speed and lower final speed so that in the morning when the atmospheric temperature has dropped the fan speed is low.

2. Design Approach

2.1 Software Approach

The designed board controls four loads simultaneously using either ICPC or FCPC, polls the user-interface for inputs, reads the time from the RTC and maintains a user set profile for one load. Proper execution of all these tasks without affecting the load requires an efficient software control. The process flow for the microcontroller is implemented using a finite state machine. Events like a zero crossing signal, key press, serial/timer interrupts cause execution of particular set of instructions depending on the present state. The software is divided into five keyboard states and eight timing states. At any given instant the microcontroller can be in any of these forty states. The microcontroller waits in its current state until an event occurs. The events and their corresponding actions are described below.

Zero Crossing Signal: This event is generated every time the instantaneous ac voltage becomes zero. When this signal is received, the microcontroller calculates the outputs for the loads controlled by ICPC, polls the keyboard for key press and reads current time from the RTC.
Timer Interrupt: When a timer interrupt is received, the microcontroller jumps to the next timing state. It also generates the trigger pulses for the triacs of loads depending on the speed set.
Key Press: Whenever a key is pressed for more than 20 milliseconds, the key press signal is generated. The microcontroller decodes the pressed key and executes the set of instruction depending on its present keyboard state and the key pressed. After executing the instructions it jumps to the next keyboard state.
Serial Interrupt: When this signal is received, the microcontroller fetches the byte received serially and generates a 'key press' signal. The byte received indicates the instructions to be executed by the key press subroutine.
Timing States: Each half sine wave cycle of the ac mains is divided into 8 timing states. For fractional cycle control the trigger pulses for the triacs are generated at the start of each timing state.
Keyboard States: A keyboard state indicates the sequence of keys pressed till now and hence indicates the steps to be performed when the next key is pressed.

2.2 Algorithms

Integer Cycle Power Control

The speed set by the user is achieved by passing integer number of cycles so that the average of the cycles passed lies close to the user specified speed. In our program, we have implemented a low pass IIR filter [10] to calculate the running average of the duty cycle.

$$Y(n) = \alpha C(n) + (1- \alpha)\, Y(n-1)$$

where $Y(n)$ is the running average after the n^{th} cycle and $C(n)$ is the input to the filter. When a cycle is passed, '1' is applied on filter input $C(n)$. This increases the average $Y(n)$. While for an off cycle, '0' is applied and it reduces the average. The increase or decrease in average corresponding to a particular cycle is determined by the filter coefficient α. The input to the filter is decided by whether the average $Y(n-1)$ lies within a tolerance limit (6%). If it is below the required limit, the input $C(n)$ is forced to be 1 and 0 if it is above the limit. In case it lies within the tolerance limits, the input is decided by generation of a random number.

$$C(n) = \begin{cases} 0 & \text{if } Y(n\text{-}1) > \text{speed} + \text{tolerance} \\ 1 & \text{if } Y(n\text{-}1) < \text{speed} - \text{tolerance} \\ \text{random} & \text{otherwise} \end{cases}$$

The value of $C(n)$ is used for controlling the triac in the given cycle.

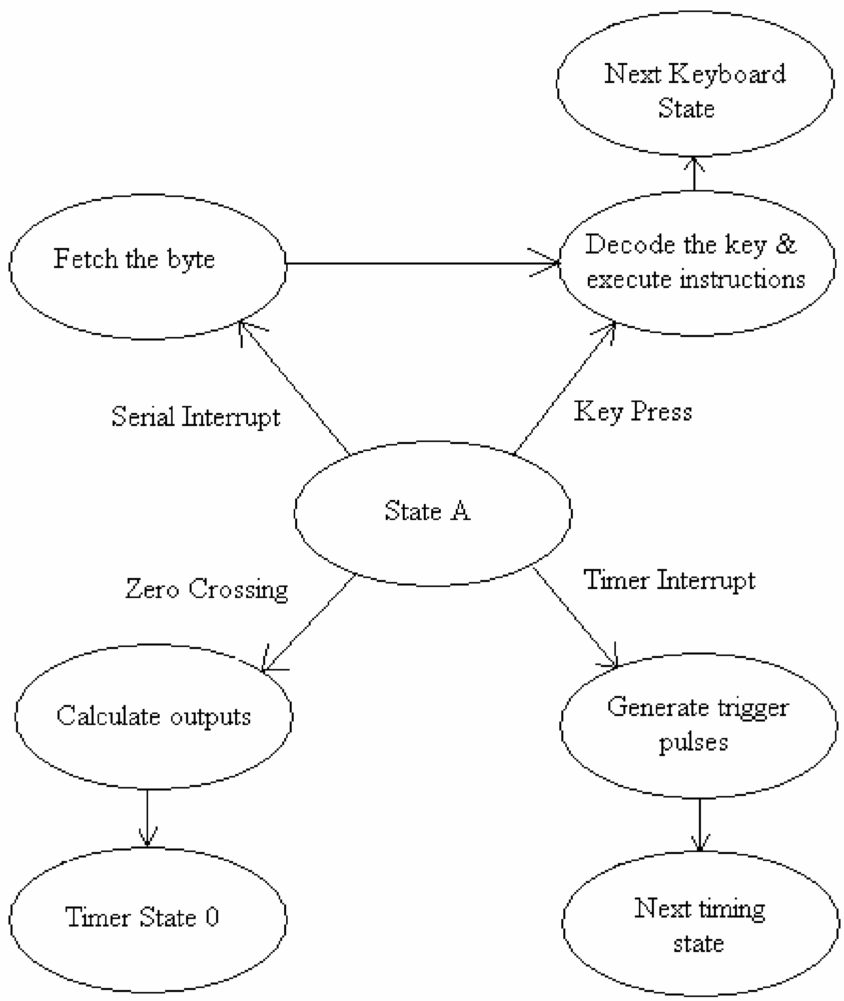

Fig 1 Process Flow Diagram

Random Number Generation

The random number is generated using 8-bit Linear Feedback Shift Register (LFSR) algorithm [11]. In this the bit-values in a register are shifted left and the incoming LSB is decided by taking XOR of bits at positions 1, 2, 3 and 7 of the previous value. This generates a pseudo random sequence. If this number is greater than 127 the input to the filter is 1, otherwise 0.

Fractional Cycle Power Control

The speed set by the user is achieved by passing requisite fraction of each cycle. Each load is controlled through the Triac circuit, by the pulses generated by the microcontroller. Here, speed can vary from 0-8. Suppose the period of the supply is '2T'. Then, triggering Triac circuit at nT/8 interval from the zero-crossing (where n=0-8) will vary the speed according to FCPC. Higher n value means smaller speed as the load will be powered for smaller fraction of the cycle.

Speed Compensation Due To Voltage Fluctuation

The fluctuation of voltage causes the load output to vary. So we continuously monitor the power supply peak voltage using an ADC. Whenever the voltage differs from its usual value the duty cycle is varied correspondingly to keep the power input to the load constant. The voltage regulation needed for ICPC and FCPC is different. This is due to the fact that random switching of the load in ICPC causes energy loss. For the ICPC case the number of cycles to be added or subtracted is obtained from a look up table. For the fraction cycle control the time interval between two timing states is varied to regulate the load output.

User Set Linear Profile

The initial speed, final speed and time duration readings are taken from the user, through keypad input. Using these values we set a linear profile, in which speed is updated after regular time intervals depending upon the difference in speeds and time duration.

2.3 Hardware

User Interface Circuit

User interface consists of a 4X4 keypad (for input), LCD display and a serial interface through MAX232.

Keypad

This 4X4 keypad takes following inputs from the user: load select, speed for selected load, user-selectable profile and setting of a clock and an alarm. It has 0-9 digits and separate buttons for “ENTER”, “UP”, “DOWN”, “SET TIME” and “LOAD SELECT”,”SET PROFILE”. Microcontroller checks for debouncing to avoid multiple inputs.

LCD

This is a 16 character, 2 line display which is driven by the microcontroller. LCD displays the current time on first row and the last updated load with its speed on second row, in the idle state. It also outputs error messages warning user to input correct values.

Serial Interface

The circuit can receive input from both the keyboard as well as the serial interface. The serial interface is provided with the thought that a remote control module can be externally attached to make the device remote controlled. The level shifting of RS232 input for interfacing to the microcontroller has been carried out using MAX232. The byte sent over serial input should be in the range (0-15). These values correspond to the 16 keyboard keys.

ADC 0809

We are using 8 bit Analog to Digital Converter to read the supply voltage. The filtered, unregulated D.C. is given to a potential divider to step it down to 2V. This is fed to the ADC channel which is read by the microcontroller. The voltage varies over a span of 1.4V (corresponding to 160V mains supply) to

2.6V (300V mains). The clock to the ADC is given by the microcontroller ALE pin (2 MHz) through JK flip-flop which acts as frequency-divider and brings down the frequency to 1 MHz, as needed for ADC to function. The start pulse to the ADC is given from the microcontroller pin P3.4.The microcontroller polls for the EOC signal on the pin P3.5 to detect the end of conversion thereafter output enable is given through pin P3.6 and the data is read from port 1.

Power supply

The power supply to the circuit is provided through a (230V/9V) step-down transformer. A bridge rectifier rectifies the sine wave; a 1000 μF capacitor filters this rectified sine wave to give a nearly constant DC supply with a 60 mV ripple. This is fed to a voltage regulator (LM7805) which

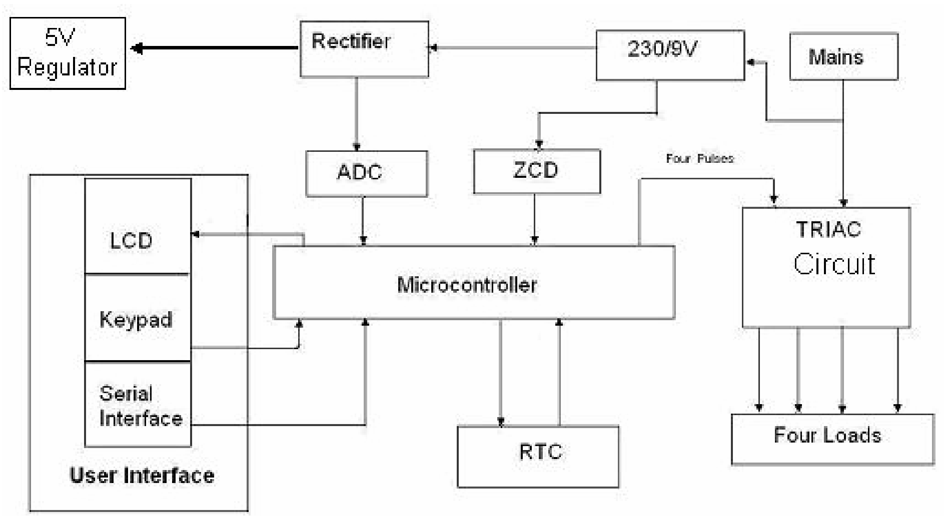

Fig 2 Circuit Block Diagram

provides 5 Volt output, which is used to power all the ICs in the circuit.

Zero Crossing Detector

The two ends of the low voltage side of the step down transformer are connected to resistor potential dividers. The voltage across the two legs of the resistor potential divider is fed to the inverting and non-inverting terminals of op-amp in LM324 [5]. The output pin of the LM324 [5] is connected to P3.7 of the microcontroller, to generate zero crossing pulses.

Triac Circuit

TRIAC is equivalent to two Silicon Controlled Rectifiers (SCRs) connected in opposite directions with their gates shorted. Hence it can conduct in both the directions when a pulse is given to its gate. In our circuit a low pulse from the microcontroller switches on the LED inside the opto-coupler, which in turn shorts the gate and the supply terminal of the TRIAC. The 2 ms pulses from the microcontroller pins P2.4-7 are connected to the pin 2 (the cathode of the LED) of the opto-couplers MOC 3020 [7] and the anode is connected to the V_{cc} of the circuit. When the microcontroller gives a low pulse, the LED inside the opto-coupler turns ON and makes the photo-triac conducting. In this part the pulses are in optical form hence providing the optical isolation between the TRIAC load circuit and the electronic circuit. . As we are driving an inductive load an additional resistor-capacitor circuit is needed to drive the TRIAC using the opto-coupler. The MOC 3020 [7] drives the gate of the TRIAC The live wire of the power supply is fed to the load and the TRIAC is connected in series with it between the load and the neutral. Minimum holding current must be maintained in order to keep a TRIAC conducting.

RTC Circuit

A Real Time Clock DS1302 [8] is used to for clock and alarm. Back-up power supply of 3V is provided for the RTC to retain the memory and run the clock when the power is switched off. Scratch-pad memory of RTC has been used to store the current settings for different loads. This helps in retaining the correct settings for various loads in case of power failure.

3. Test Results and Plots

3.1 Duty Cycle

The table below gives the duty cycle observed for each speed set by the user. These readings were taken for the value of $\alpha = 0.2$ at normal voltage, for the ICPC. The duty cycle average is calculated over a period of 0.8s (40 cycles).

Sr.No	Speed	Duty Cycle (%)
1.	0	0
2.	1	12
3.	2	22
4.	3	37
5.	4	52
6.	5	65
7.	6	76
8.	7	84
9.	8	100

Table1. Variation of Duty Cycle with Load Speed

We tested the operation of fan under various values of α. The inertia of the fan decides the best value of α. From our experiments we could conclude that the value at which the fan vibrations were least and the duty cycle accuracy over a given period was maintained is 0.2.

3.2 Voltage Regulation

We tested the circuit for the varying power supply voltages using an auto-transformer. The microcontroller changed the duty cycle to compensate for the speed loss/gain due to the voltage fluctuation. A look up table was made for voltage regulation in the case of ICPC by recording the fan speed at various voltages.

4. Conclusion

The above product is able to control the load output using integer cycle power control and fractional cycle power control. It incorporates features like user selectable profile and immunity against voltage fluctuation, which add to the user comfort. Control of four loads through a single unit cuts down cost significantly.

Add-on features like alarm-clock, serial interface and LCD display make it a commercially viable alternative to existing products.

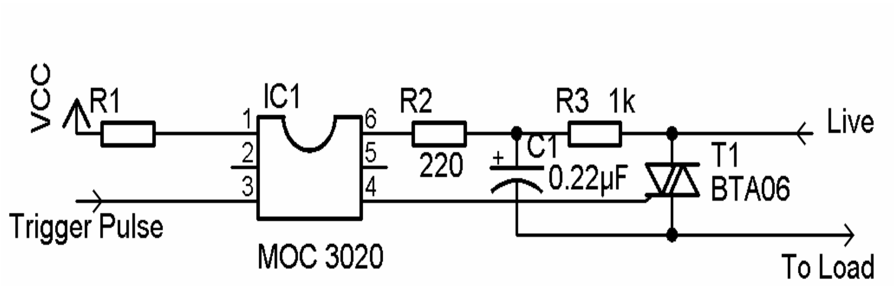

Fig 3.Circuit Diagram (Opto-coupler and Triac)

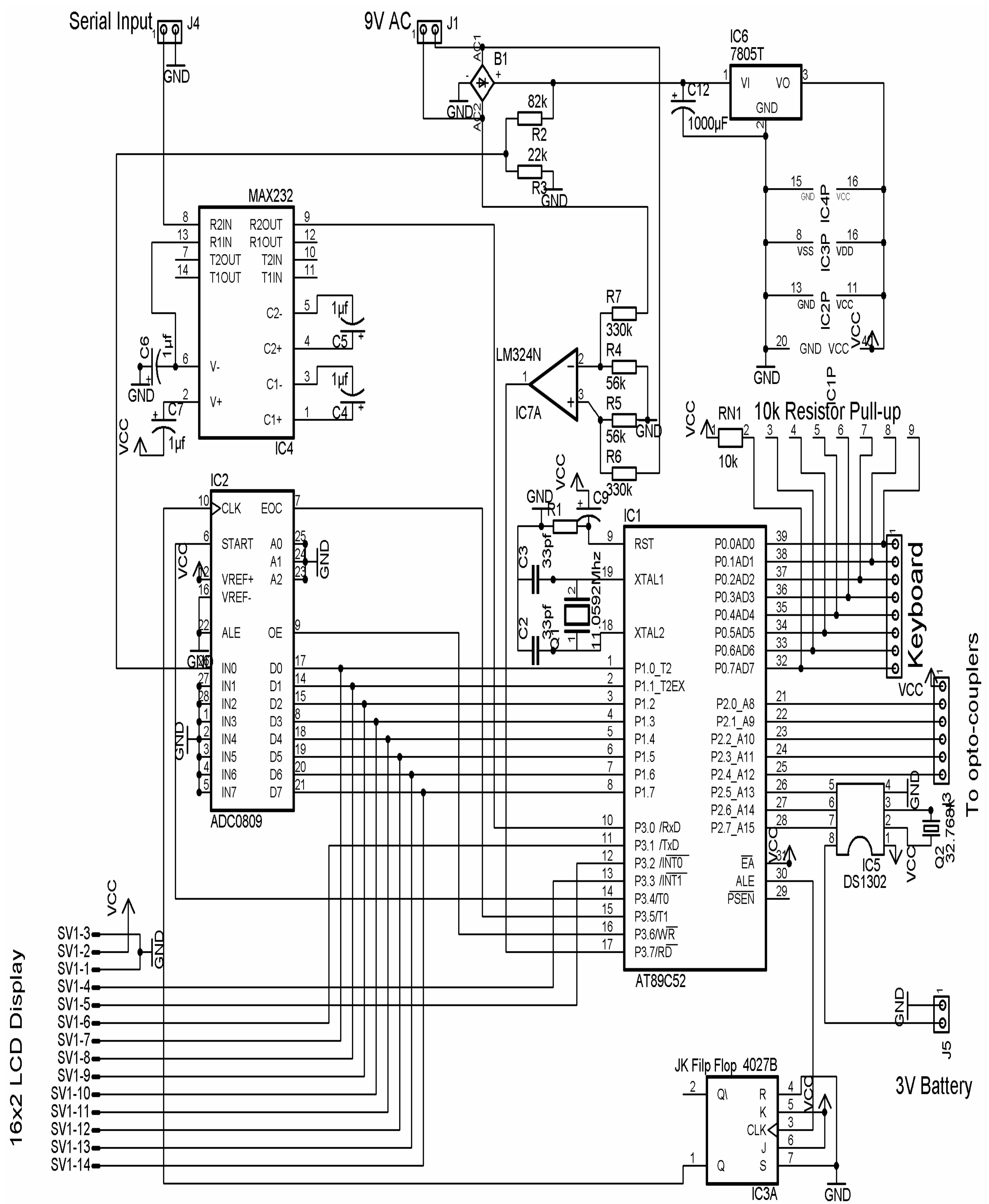

Fig 4. Circuit Diagram (Digital)

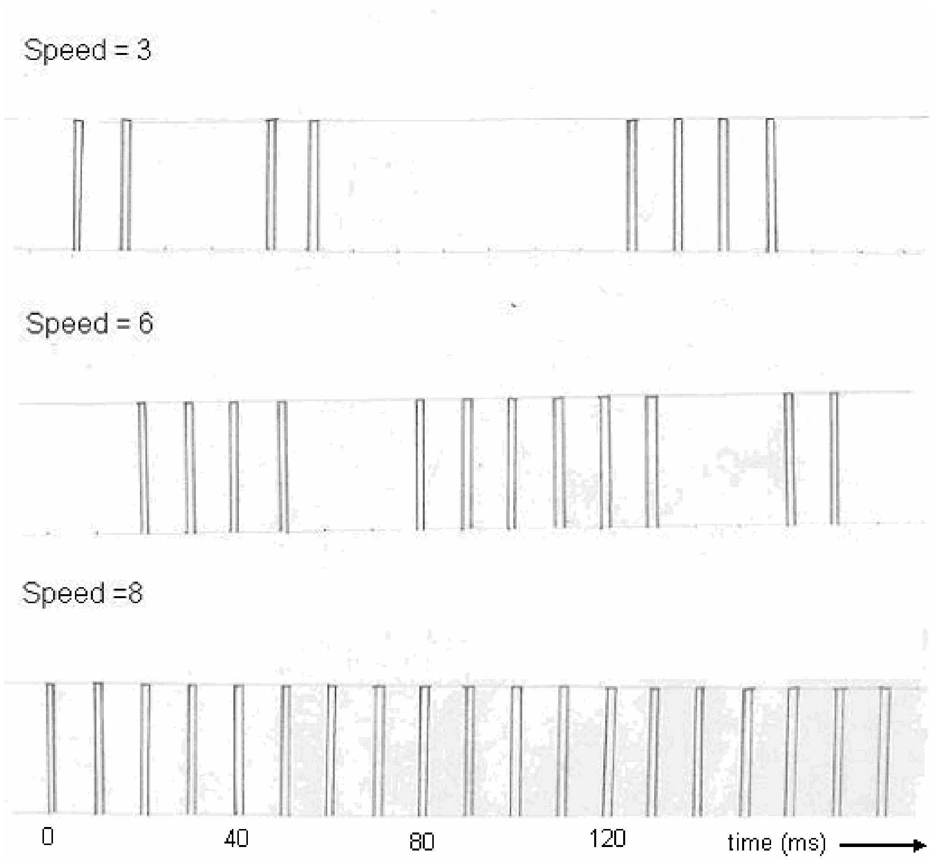

Fig 5. Waveforms (Microcontroller pulses to triac in ICPC)

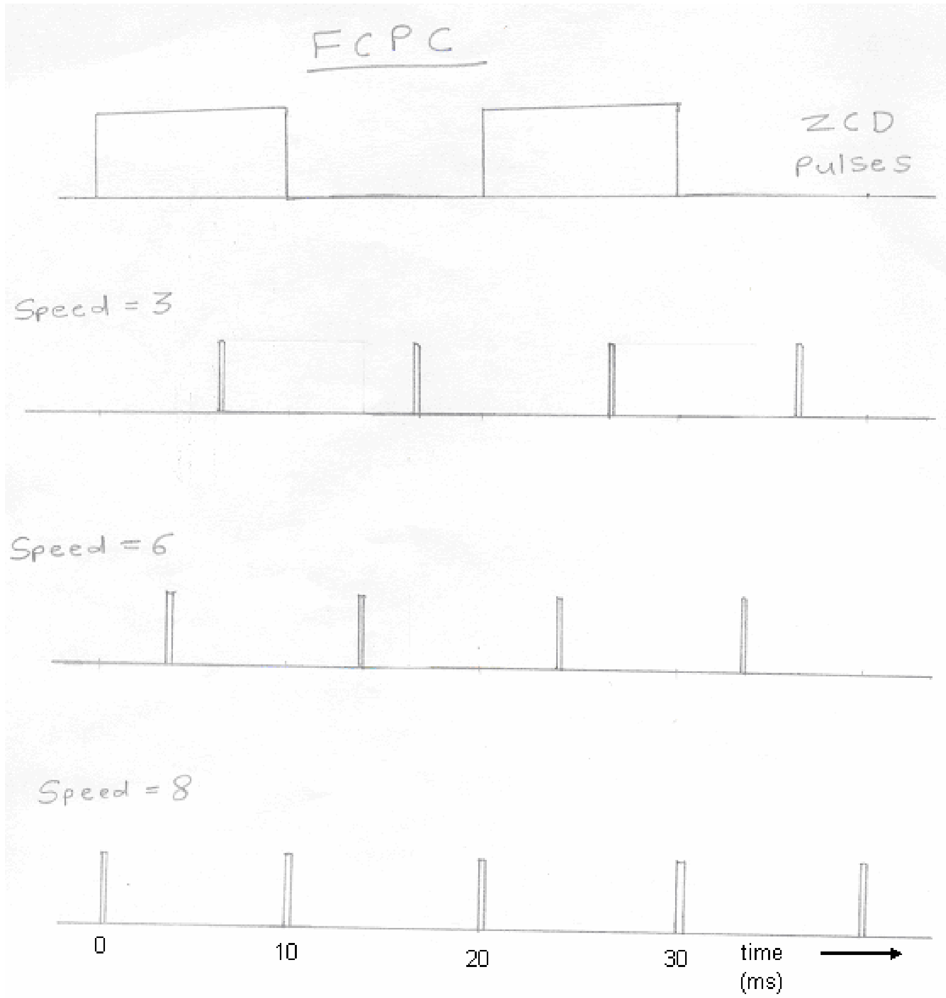

Figure 6 (Microcontroller pulses to triac in FCPC)

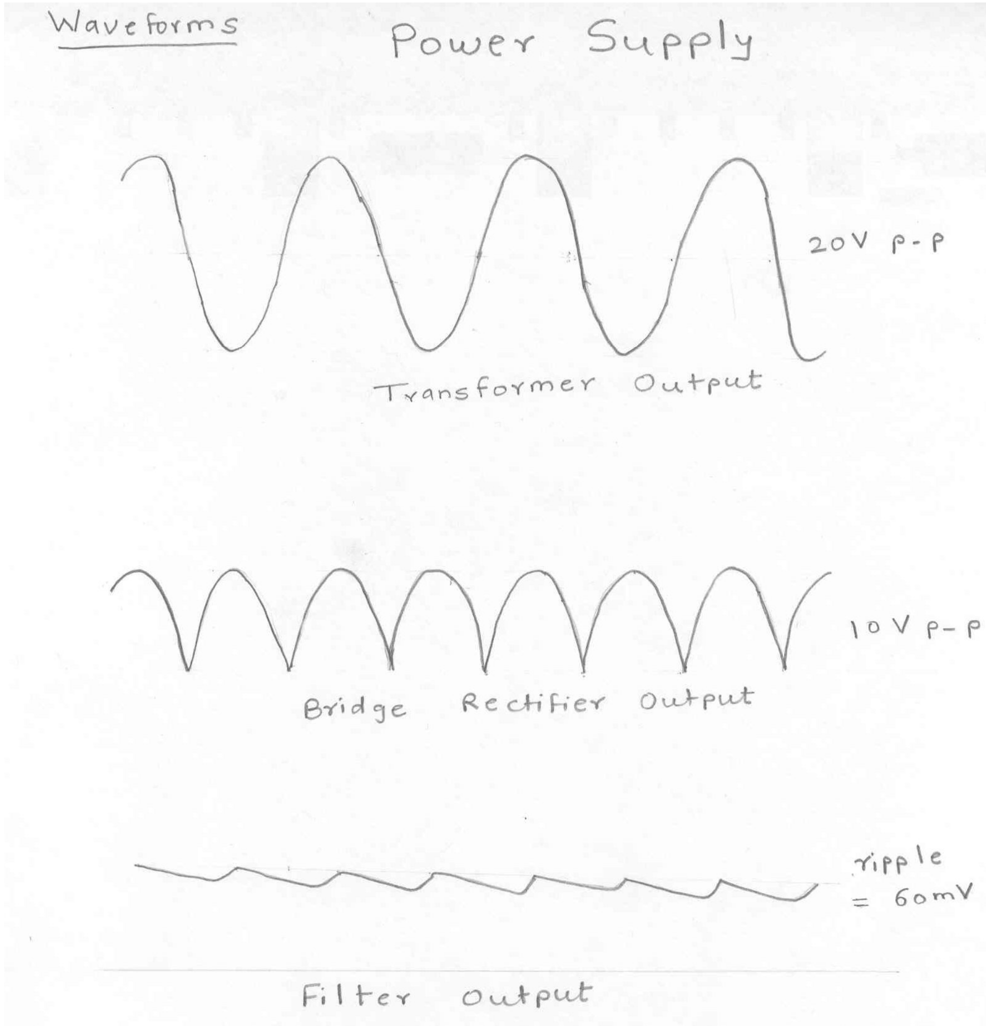

Fig 7.Waveform (Power supply)

5. Future Work

The integer cycle power control algorithm presently treats all loads independently. The algorithm can be modified so that the power cycles are distributed to the loads in a way that no cycle is blocked and during each cycle only one load is switched on. This would reduce the harmonics generated considerably. Also the free memory in RTC could be used to provide features like multiple alarms and digital diary.

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APPENDICES

A. User Manual

The figure below shows the layout of keys for the 4X4 keypad provided. Their usage has been described.

Load 1 UP	Load 2 UP	Load 3 UP	Load 4 UP
Load 1 DOWN	Load 2 DOWN	Load 3 DOWN	Load 4 DOWN
-	-	-	UP
MENU	-	-	DOWN

Load Up: The Load Up key increases the corresponding load level by one.

Load Down: The Load Down key decreases the corresponding load level by one.

Menu: The Menu key is used to display the menu for configuring the board.

Up/Down: The Up and Down keys are used to scroll the menu and adjust the input values for each menu option.

Other keys are reserved for future use.

The Liquid Crystal Display (LCD) displays the following in idle mode.

7 5 6 0	13:59
1 2 3 4	Time

First row displays the current load levels and the current time in hh:mm format. The numbers below the load levels indicate the load number. When menu key is pressed the menu option appears on the second line. The menu can be scrolled using the up and the down keys. The displayed menu option can be selected by pressing the menu key.

The procedure for setting level, time and profile is described below:

Setting Level: The level for each load can be set using the ‘Load Up’ or ‘Load Down’ keys for the corresponding load. The load level increases or decreases by one on each key press.
Setting Clock: The clock time can be set using the ‘Clock Set’ menu option. The hours and minutes for the clock can be set using the ‘Up’ and ‘Down’ keys. Pressing ‘Menu’ key saves the changes.
Setting Alarm: The alarm time can be set using the ‘Alarm Set’ menu option. A sub-menu appears on selecting the ‘Alarm Set’ option. Select ‘Adjust’ to set the alarm time, else select ‘Off’ to switch off the alarm. The hours and minutes for the clock can be set using the ‘Up’ and ‘Down’ keys. Pressing ‘Menu’ key saves the changes.
Setting Profile: A control profile can be set using the ‘Set Profile’ menu option. When this option is selected it asks for the initial and the final speed desired. The speed can be set using the ‘Up’ and ‘Down’ keys. Pressing ‘Menu’ key saves the changes. Now the board asks for time of variation. This can be in the range 00:08 hrs to 23:59 hrs. If the variation time is set to less than 8 minutes the profile is not activated and the speed would not vary.
Fractional/Integer Cycle Control: The type of power control can be set using the ‘Power Control’ menu option. The board prompts for the load for which the power control needs to be set. The load can be selected using the ‘Up’ and the ‘Down’ keys. After selecting the load, pressing ‘Menu’ key brings up a sub-menu to select the type of power control, fractional or integer. ‘Menu’ key selects the displayed option.

B. Cost Analysis

Component	Chip Number	Cost/piece	Quantity	Total Cost
Voltage Regulator	LM7805	6.00	1	06.00
Microcontroller	AT89c52	48.00	1	48.00
ADC	ADC0809	70.00	1	70.00
Bridge Rectifier	-	4.00	1	4.00
Op-amp	LM324	15.00	1	15.00
TRIAC	BTA 06A	15.00	4	60.00
RTC	DS1302	40.00	1	40.00
Serial Driver	Max232	20.00	1	20.00
Opto-coupler	MOC3020	18.00	4	72..00
Transformer	-	30.00	1	30.00
Crystal(12 MHz)	-	6.00	1	6.00
Crystal(32.76 kHz)	-	6.00	1	6.00
Keypad	-		1	50.00
LCD Display	-	150	1	150
Total				577

List of Figures