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Fan Regulation using Integer Cycle Power Control

Group D02
Ameya Chaudhari (03d07001) <ameyac@ee.iitb.ac.in>
R.Anand (03d07019) <anandr@ee.iitb.acin>
Sanish Mahadik (03d07023) <sanish@ee.iitb.ac.in>

Supervisor: - Prof. P.C.Pandey and Mr. V.K.Tandon

Abstract

This report discusses the use of integer cycle power control(ICPC) for fan speed regulation. Conventional fan regulators use fractional cycle power control for controlling fan speed. This causes higher power loss as switching occurs at a non-zero voltage. This also introduces harmonics in the power supply. ICPC is aimed at reducing these shortcomings of a normal regulator, by passing integer number of cycles. Randomization of cycles passed reduces the sub harmonics in power supply. To make this ICPC regulator commercially viable and attractive alternative to normal regulator, features like selectable user profile and immunity against fluctuation in power supply have been added. The circuit has been tested for effective fan speed control under voltage variation and with the user defined profile.

1. Introduction

The objective of our design project is to build a fan regulator which implements integer cycle power control to vary the fan speed, follows a user programmable linear profile, and provides regulation against input power supply voltage variation.

In normal regulators, fan-speed is controlled by passing fraction of a sine wave which involves switching at non-zero voltages. This causes significant power loss as large current is drawn during switching Also, the speed set by the user is fixed and does not vary according to the later conditions. Also it does not adjust itself to voltage variations after it is set to the present level. User comfort is largely increased if the regulator can be programmed to follow a particular profile and also adjust itself against power variations.

So in our regulator, we propose to take in a profile from the user in the initially in terms of speed variation required by him and the time interval over which he requires the speed variation. We then use ac regulation controlled by a microprocessor to follow the user defined profile independent of input voltage of power supply.

We implement a linearly varying speed profile, so we would require the initial speed, final speed and time duration from the user. The user input will have three potentiometers to set initial speed, final speed and time over which profile will vary. One RESET switch is provided to activate the new profile.

2. Design Approach

2.1 Software Approach

The speed of the fan is varied by passing an integer number of cycles which is decided by the speed set by user. The ratio of the number of cycles passed to the load to the total number of cycles which occur during that period determines the speed. Depending on power supply voltage, the microcontroller is programmed to generate pulses to the gate of TRIAC to get the required duty cycle. The profile parameters which are the initial speed, final speed and the time duration of the profile are set by user using three potentiometers. The speed can be varied continuously from zero to the maximum while the time period of variation of speed can be chosen from zero to eight hours. For the maximum speed all the cycles will be passed while for zero speed no cycle will be passed. For intermediate speeds the number of cycles passed will be such that the running average lies within a tolerance limit of the speed set. The tolerance limit has been set at 6% .That is for a speed of 7 (on a scale of 0-9) the average would lie between 0.74 and 0.86. Once the user sets the three parameters and presses the RESET switch, the microcontroller starts on the new profile. The microcontroller scans for the user inputs from the ADC and starts the timer to implement the speed variation with time.

2.1.1 Process Flow

When the power is switched on, the microcontroller initializes the duty cycle to 50% until some profile is set by the user. When the RESET switch is pressed, the microcontroller reads inputs one by one from the multiplexed ADC and initializes the timer. When the timer interrupt occurs, the duty cycle is changed to follow the linear profile.

After that, it waits for signal from Zero Crossing Detector. Once this signal is received, it fires the triac depending upon the output determined from the earlier cycle. Thereafter, it reads the power supply voltage from the ADC and adjusts the duty cycle appropriately. It is followed by calculation of the new running average and the output for the next cycle.

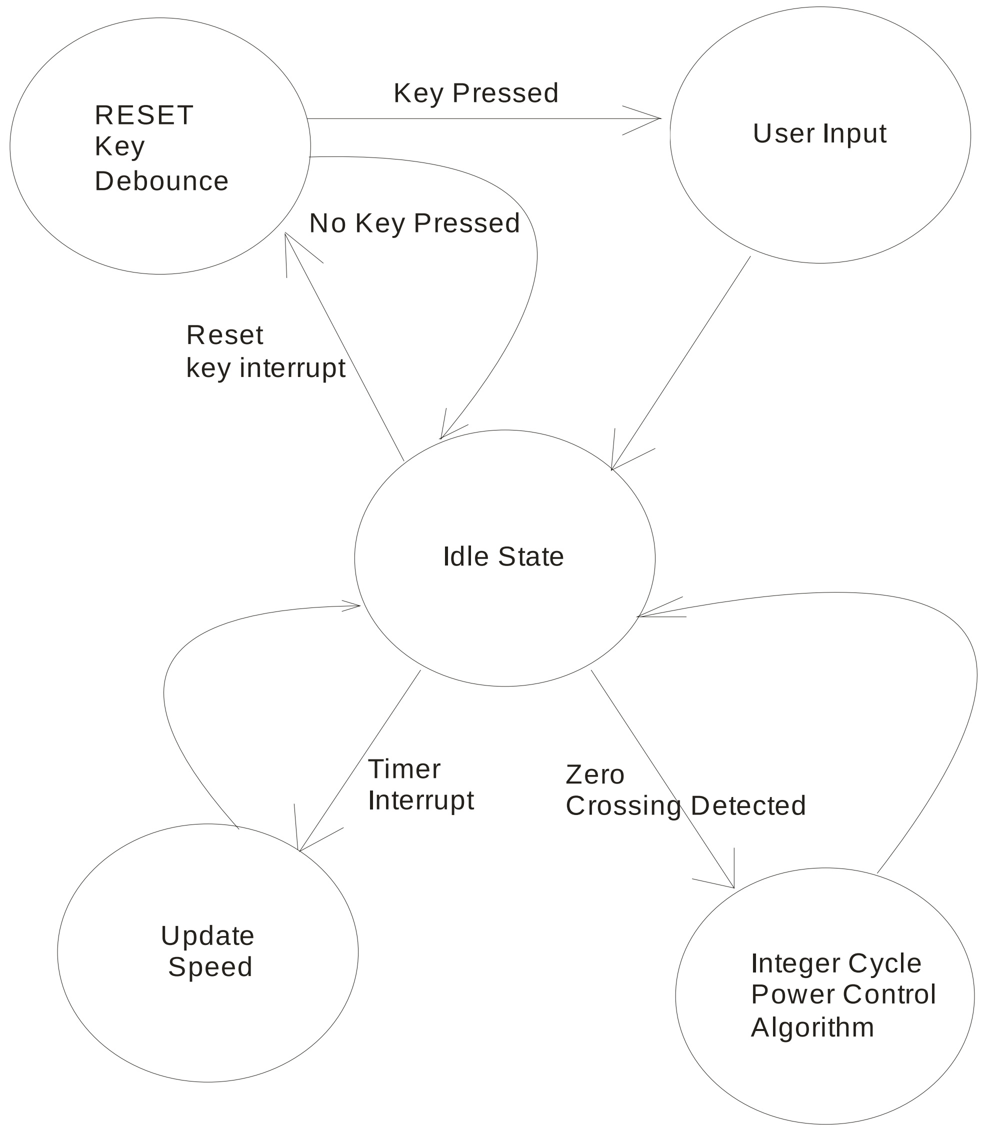

Fig 1 Process Flow Diagram

2.1.2 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 digital filter to calculate the running average of the duty cycle. When a cycle is passed '1' is fed into the filter(C(n)). This increases the average. While for an off cycle the '0' passed reduces the average. The increase or decrease in average corresponding to a particular cycle is determined by the slope of the filter (α). The following equation implements the filter.

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

Here Y (n) is the running average after the n^{th} cycle and C(n) is the input to the filter.

The input to the filter is decided by whether the average Y (n-1) lies within the 6% tolerance limit. 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. This input is given to the triac.

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

Random Number Generation

The random number is generated using 8-bit Linear Feedback Shift Register (LFSR) algorithm. 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.

Speed Compensation Due To Voltage Fluctuation

The fluctuation of voltage causes the fan speed 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 number of cycles passed is varied inversely with square of the voltage. Therefore for small voltage changes the duty cycle is decided by

$$N_2 = N_1 (1 - 2(\Delta V/V))$$

where N_2 is the compensated duty cycle N_1 is the duty cycle corresponding to the normal voltage. ΔV is the change in the supply voltage, V is normal voltage (230 V).

When the voltage goes below 160 V or above 300 V the fan is automatically switched off to prevent damage.

User Set Linear Profile

The initial speed, final speed and time duration readings are taken from the potentiometers using an ADC. 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.

2.2 Hardware Approach

User Interface Circuit

User interface consists of three 10 kΩ potentiometers to input speeds (initial and final) and time duration. The RESET switch is an interrupt to the microcontroller which is also checked for the debouncing. The current implemented fan speed in the range 0-9 is displayed to the user on a seven segment display.

ADC 0809

We are using 8 bit 8 channel Analog to Digital Converter to read the values from the three potentiometers (Channel 4, 5, 6) used in the user interface as well as the power supply voltage (Channel 7). The filtered output of the capacitor 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(1 MHz).The pins P3.0 and P3.1 provide the channel address to the ADC and the Address Latch Enable is given through the pin P3.4. The start pulse to the ADC is given from the microcontroller pin P0.0.The microcontroller polls for the EOC signal on the pin P0.2 to detect the end of conversion thereafter output enable is given through pin P0.1 and the data is read from port 1.

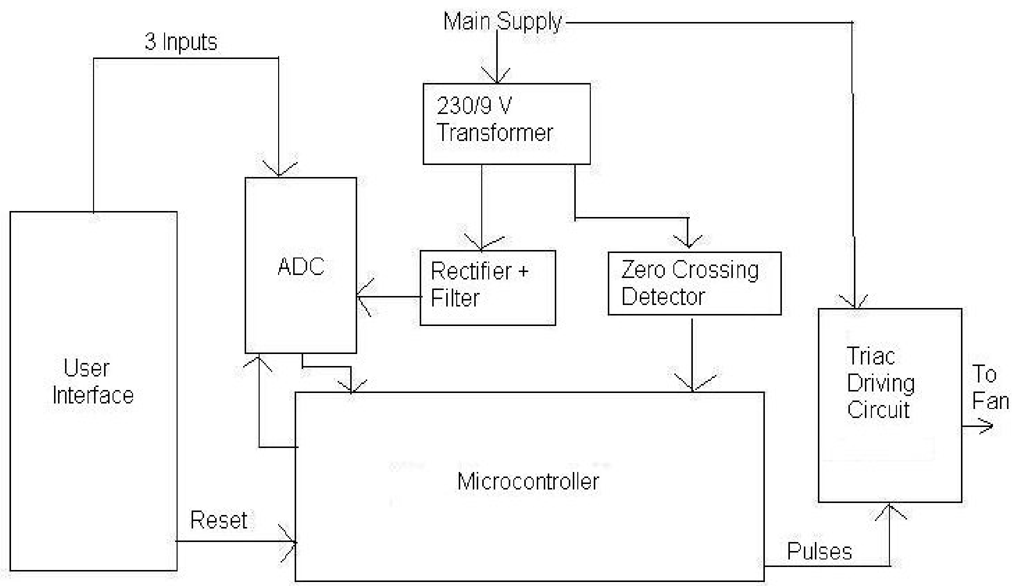

Fig 2. Circuit Block Diagram

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 capacitor of value 1000 µF filters this rectified sine wave to give a nearly constant DC supply with a 60 mV ripple. This is fed into a voltage regulator (LM7805) which provides a 5V voltage output. It 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 are connected the inverting and non-inverting terminals of op-amp in LM324[5]. The output pin of the LM324[5] is connected to P3.2 of the microcontroller.

Triac Circuit

TRIAC is a combination of two 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 pin P0.7 are connected to the cathode of the LED of the opto-coupler 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 (snubber) is needed to protect the TRIAC. The MOC 3020 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.

3 Test Results and Plots

Duty Cycle

The following table 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 The duty cycle average is calculated over a period of 0.8 s(40 cycles).

Sr.No	Fan Speed	Duty Cycle(%)
1.	0	0
2.	1	21.4
3.	2	29.2
4.	3	41.0
5.	4	49.6
6.	5	59.0
7.	6	67.44
8.	7	76.7
9.	8	84.0
10.	9	100

Table 1. Implemented Duty Cycle

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.

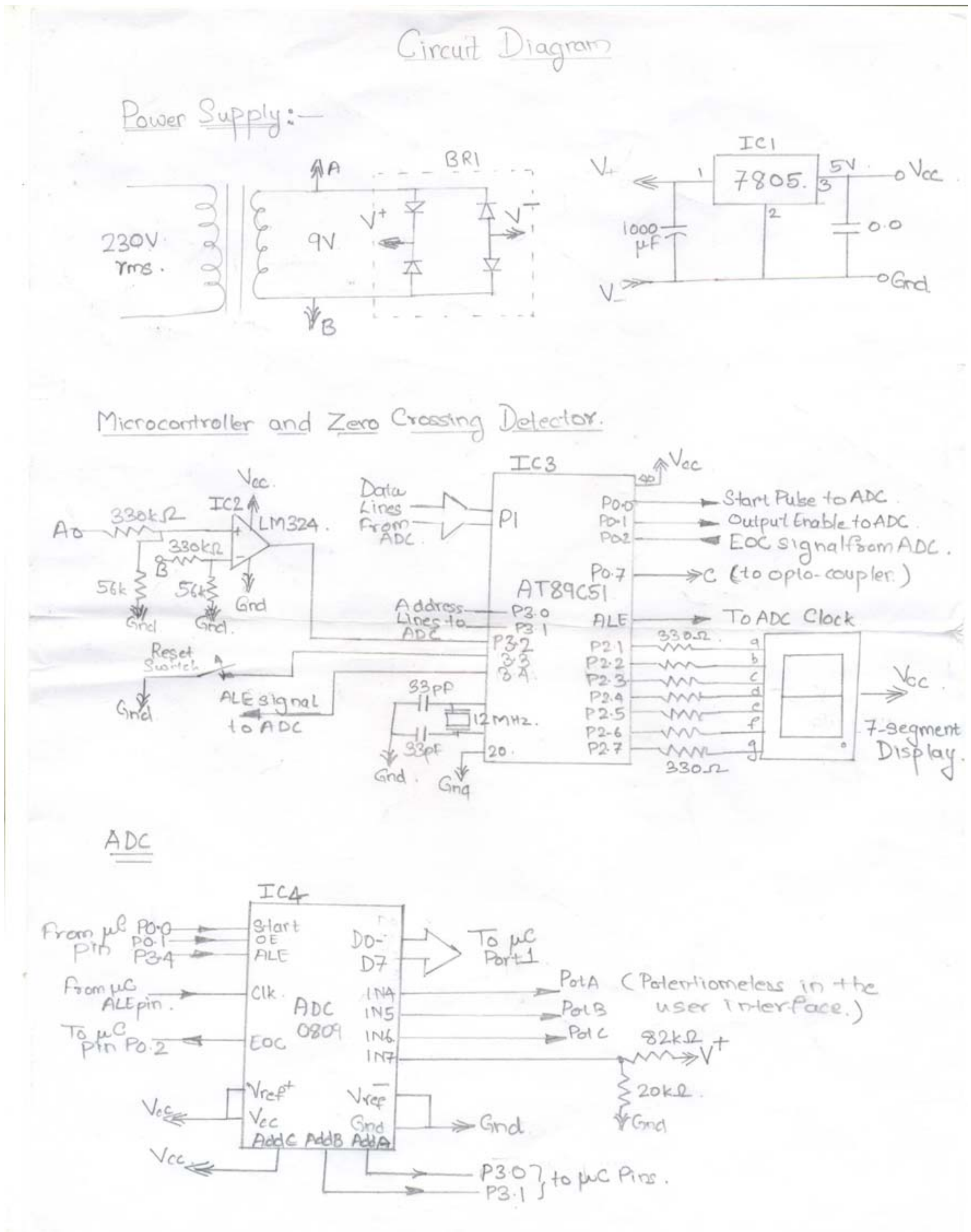

Fig 3. Circuit Diagram(1)

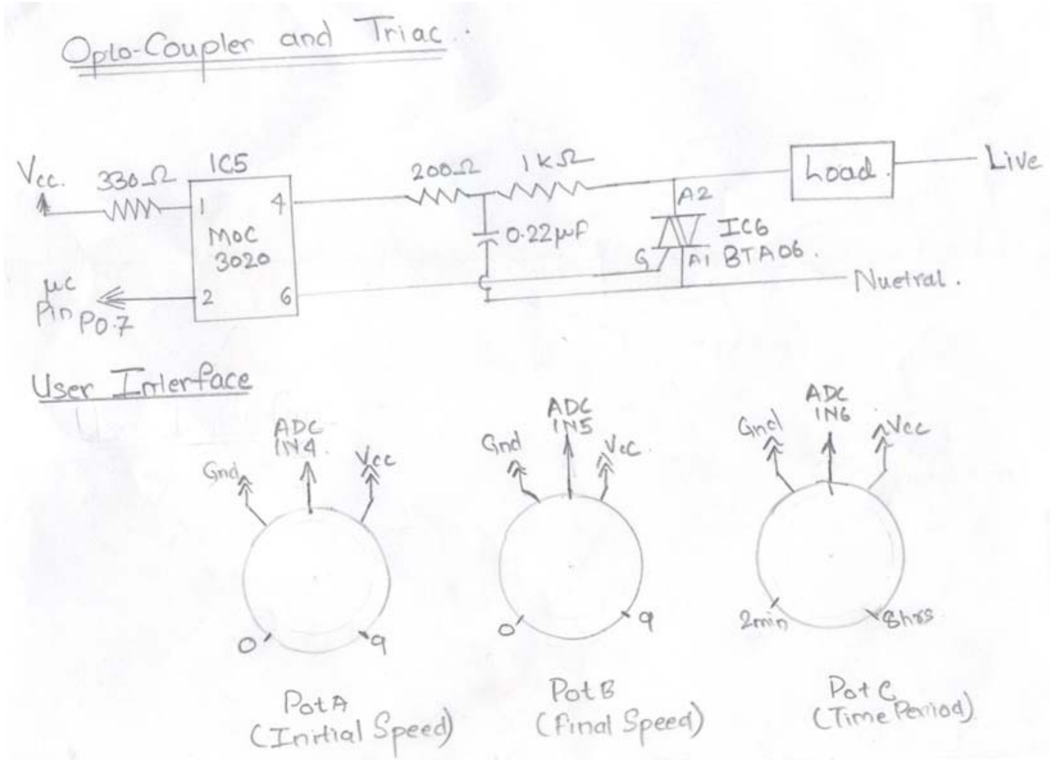

Fig 4. Circuit Diagram(2)

Voltage Regulation

We tested the circuit for the varying power supply voltages using an variac. The microcontroller changed the duty cycle to compensate for the speed loss/gain due to the voltage fluctuation. The following table indicates the speed at normal voltage corresponding the changed duty cycle for the given power supply voltage. At normal power supply voltage (230 V) the speed input was 4.The voltage was varied from 160 V to 240 V. Below 160 V the microcontroller automatically switches the fan off.

Sr.No	Power supply Voltage	Implemented Speed
1.	240	3
2.	215	5
3.	190	6
4.	170	7
5.	160	0

Table 2. Implemented speed with varying supply voltage

Linear Fan Speed Variation

We set the time period to 30 minutes, initial speed to 9 and final speed to zero. The speed decreased by one in every 3 minutes.

4 Waveforms

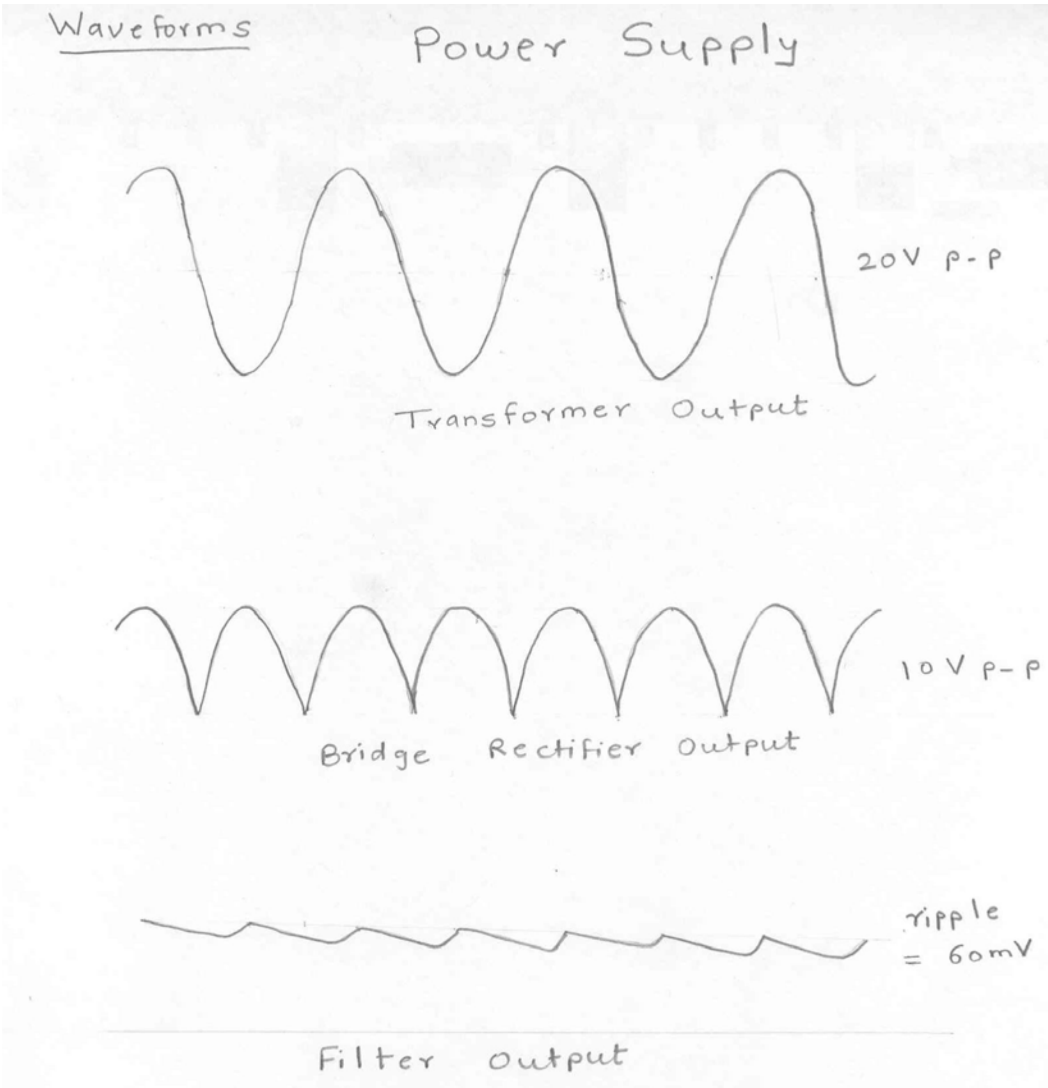

Fig 5.Waveform (Power supply)

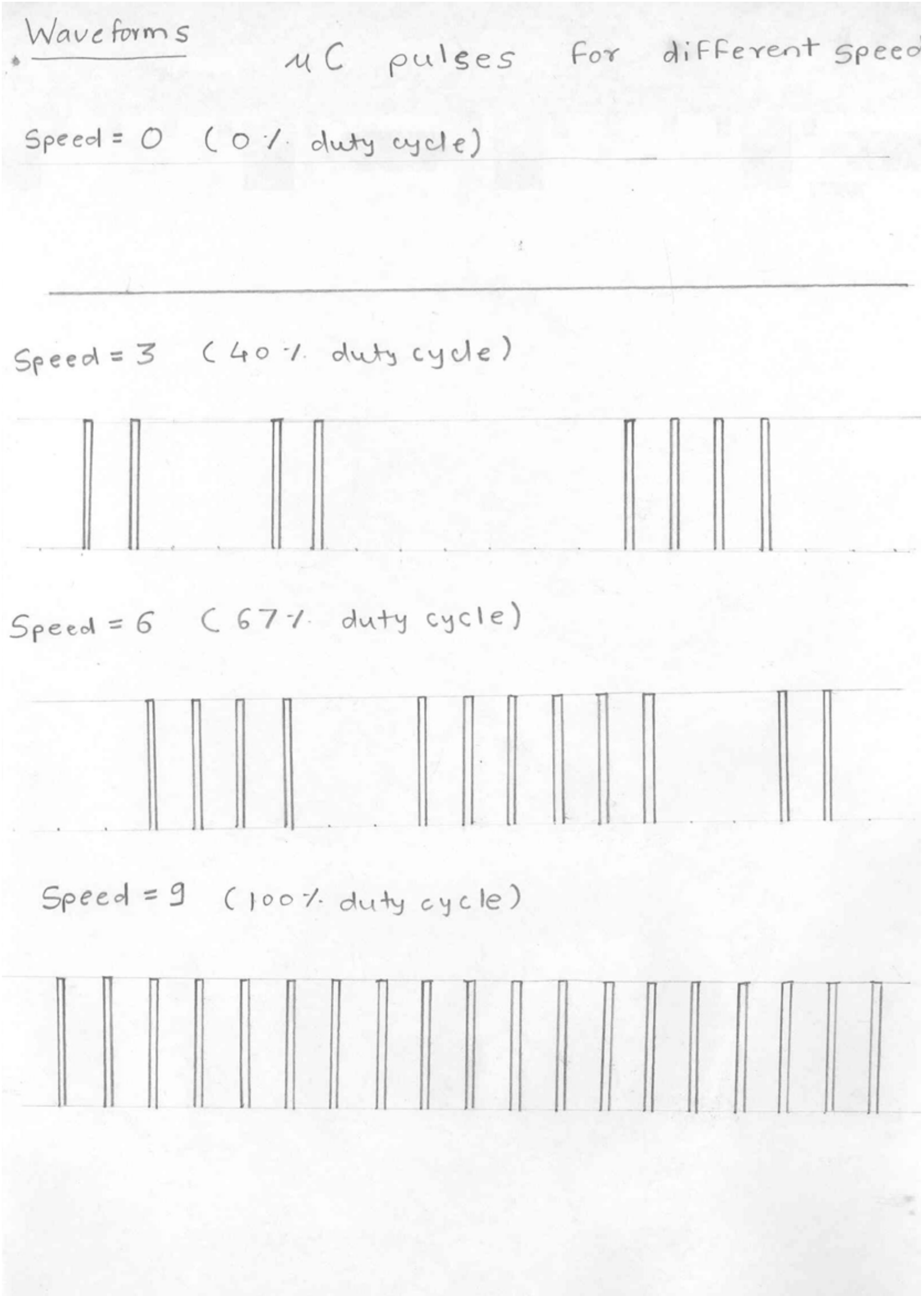

Fig 6. Waveforms (Microcontroller pulses to triac)

5 Component Description

1. Microcontroller: AT89c51[2]

The AT89c51[2] is a low-power, high-performance CMOS 8-bit microcomputer with 4K bytes of Flash programmable and erasable read only memory (PEROM), 128 bytes of RAM, 32 I/O lines (four ports of 8 bits each – Port 0, Port 1, Port 2, Port 3), two 16-bit timer/counters, a six-vector two-level interrupt architecture, a full-duplex serial port, on-chip oscillator, and clock circuitry. Port 0 is an 8 bit open drain bi-directional I/O port. Each pin as output port can sink 8 TTL inputs. Port 1, Port 2 and Port 3 are 8 bit bi-directional I/O port with internal pull-ups and their output buffers can sink 4 TTL inputs.

Absolute Maximum Ratings
Maximum Operating Voltage: 6.6 V, DC Output Current: 15.0 mA, Voltage on any pin with respect to Ground: -1.0V to 7.0V

2. LM324
[5]: Low Power Quad Operational Amplifiers

Features: Wide Power Supply Range, Single Supply: 3V to 32V, Dual supplies: $\pm$ 1.5V to $\pm$ 16V, Large Voltage Gain 100dB, Supply Voltage: 32V, Input Voltage: -0.3V to 32V

3. ADC0809:

The ADC0809[3] data acquisition component is a monolithic CMOS device with an 8-bit analog-to-digital converter,8-channel multiplexer and microprocessor compatible control logic. The 8-bit A/D converter uses successive approximation as the conversion technique. The converter features a high impedance chopper stabilized comparator, a 256R voltage divider with analog switch tree and a successive approximation register. The 8-channel multiplexer can directly access any of 8-single-ended analog signals.

Easy interfacing to microprocessors is provided by the latched and decoded multiplexer address inputs and latched TTL Tri-state outputs.

Absolute Maximum Ratings

Supply Voltage (V_{cc}) 6.5V
Voltage at Any Pin −0.3V to (V_{cc}+0.3V) (Except Control Inputs)

Voltage at Control Inputs −0.3V to +15V (START, OE, CLOCK, ALE, ADD A, ADD B, ADD C)

4. Triac BTA06 [6]

Absolute Maximum Ratings
RMS on-state current : 6 A
dI/dt Critical rate of rise of on-state current: - 50A/µs
Peak gate current : 4 A

6 Cost Analysis:

Component	Chip Number	Cost/piece	Quantity	Cost (Rs)
Voltage Regulator	LM7805	6.00	1	6.00
Microcontroller	AT89c51	40.00	1	40.00
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	1	15.00
Opto-coupler	MOC3020	18.00	1	18.00
Transformer	-	30.00	1	30.00
7 segment display	LT542	10.00	1	10.00
Crystal(6 MHz)	-	6.00	1	6.00
Button Switches	-	1.00	1	1.00
Resistor + Capacitors	-	5.00	-	5.00
10 kΩ Potentiometers	-	10.00	3	30.0
Total				250.0

Table 3 Cost Analysis

7 **Conclusion**

The circuit developed is able to control the fan speed using integer cycle power control and incorporates features like user selectable profile and immunity against voltage fluctuation, which add to the user comfort. This provides a power efficient alternative to the conventional regulators, which would be cost effective over the long run.

This product can be made commercially viable by adding features like remote controlling and power monitoring over LAN. It can also be used to control multiple fans/motors simultaneously which would bring down the cost per appliance and would save power at the same time.

References

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[2]Atmel Corporation, “At89C51 Datasheet”, www.atmel.com/dyn/resources/prod_documents/doc0313.pdf, April 2006

[3] National Semiconductor, “ADC0808/ADC0809 Datasheet” http://cache.national.com/ds/DC/ADC0809.pdf, April 2006

[4] ST Microelectronics, ”BTA06 series datasheet”, http://www.st.com/stonline/books/pdf/docs/2936.pdf, April 2006

[5] National Semiconductor, “Low Power Quad Operational Amplifiers”, http://cache.national.com/ds/LM/LM124.pdf, April 2006

[6] Fairchild Semiconductor, “LM78XXE 3-Terminal 1A Positive Voltage Regulator” http://www.fairchildsemi.com/ds/LM%2FLM7805E.pdf, April 2006

[7]Fairchild Semiconductor,”6-Pin DIP Random-Phase Optoisolator TRIAC Driver”, http://www.fairchildsemi.com/ds/MO%2FMOC3021-M.pdf, April 2006

APPENDIX A

User Manual

This device is used for setting a user profile for fan regulation and then operating according to the profile set up by the user. It works independent of the voltage of the supply (to a limit of 70 volts on either side of the nominal voltage i.e., 230 V). The speeds can be varied from 0(off) to 9(max.).The time of variation can be set in the range of 0 - 8 hours. The initial speed, final speed and the time can be set using the respective knobs. Once the speed and time levels are chosen this profile can be activated by pressing the RESET switch.

The 7-segment LED display displays the current speed of the fan.

APPENDIX B

List of Figures