ELECTRICALLY VARYING TENSION POWER GENERATING (EVAT GEN) EXERCISE BICYCLE

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ABSTRACT

In this project we seek to build an exercise bicycle that, as you pedal, will generate power for the electric grid. The speed of pedaling and the tension produced by the power generating machine will change the amount of power produced. In this design, the tension is to be controlled by changing the electric parameters of the motor, effectively removing the need for excessive mechanical components present in other exercise bikes.

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CHAPTER 1

INTRODUCTION

1.1 Purpose

In this project, I want to create a stationary bicycle that will allow its owner to save electricity while at the same time exercising. This design will have simplified functionality by using an induction machine. This is because this type of machine allows the power generated to be put directly back into the electric grid, in 3-phase, without the necessity of an inverter. It also allows for the physical resistance against pedaling to be changed by modifying the voltage at its terminals. A variac[1] is used to control this voltage. It takes on one side the 230V line-line from the grid and steps down the voltage to its other side, connected to the induction machine. The variac's knob, in turn, is moved by a small DC motor. Once the induction machine is powered, its shaft can then be driven above its synchronous speed to generate power. An average person should be able to generate continuously 100W or more [1].

1.2 Functionality

An induction machine's synchronous speed in this project is 1800 RPM. However, most human beings can pedal at no more than 110 RPM [2]. To make the machine's speed more reasonable to a user, its shaft is connected to the pedals through a 30:1 gear-box, which will convert that synchronous speed into 60 RPM.

A PIC micro-controller controls the direction of rotation of the DC motor that turns the variac. The motor turns the variac in increments of 10% of the maximum possible voltage at the induction machine. The duration of

[1] A variable transformer.

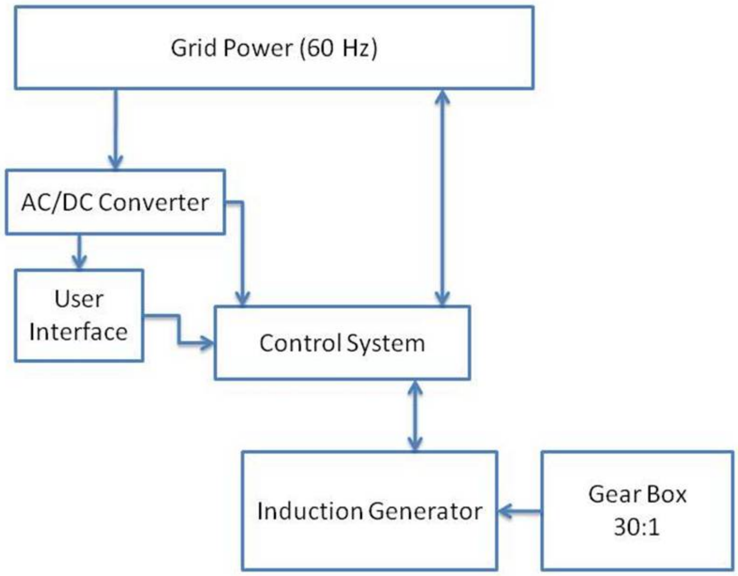

Figure 1.1: System Block Diagram.

the "on" state of that motor is determined by an internal counter, which is increased or decreased based on '+' or '-' signals received from the User Interface. The resistance level that this counter represents is also indicated by an LED array on the interface, each LED powered by a signal from the PIC, one for each 10% increment.

For safety, when the bicycle is not in use, the variac is set to 0%. At this moment, changes can be made to the resistance level. When the user begins to pedal, the variac is turned to desired voltage, based on resistance level. While in use, the resistance level cannot be changed. Once the user stops pedaling, the speed drops below synchronous, and the variac gets turned back down to 0%, powering off the induction machine. Since the machine functions as a motor below synchronous speed, a ratchet is installed on its shaft to keep it from driving the pedals and possibly causing injury to the user. The speed is calculated with the help of a hall-effect sensor.

1.3 Blocks

The following are brief descriptions of each block as seen on the block diagram of this project (See Fig. 1.1).

1.3.1 Grid Power

This is the 3-phase power from the grid, in 60Hz, 230V line-line.

1.3.2 AC/DC converter

This block takes one phase from the grid as line-neutral. This voltage is rectified and regulated to supply 5V and 12V DC power to different parts of the User Interface and the Control System.

1.3.3 User Interface

The resistance control of this block consists of two push buttons, which output 0V or 5V. There is one button for each of increasing or decreasing functions. These signals are sent to the control system, where they are processed by the PIC. This module also has a 10x1 LED array which serves as a resistance level indicator. It receives, from the control system, one signal for each LED.

1.3.4 Control System

The system control signals are all managed by a PIC. The resistance control signals from the User Interface modify a counter, which sets the level indicator, as well as determine the voltage that is to be fed to the induction machine, by changing how much the variac knob is to be turned. The speed of the machine tells the PIC when to turn the variac and when to accept changes in resistance level. The PIC also decides when to set these outputs, based on the speed of the machine.

1.3.5 Induction Machine

I used a 1/3 HP 3-phase 208-230V induction machine that has a synchronous speed of 1800 RPM. When voltage is first applied to the machine, it will drive itself as a motor. Then, when pedaling, the shaft will be driven over synchronous speed, which will cause electric power to be generated. As a generator, the higher the speed at which the machine is turned, the greater will be the torque required to maintain this speed. Changes in voltages also change this torque proportionally.

1.3.6 Gear Box

A 30:1 gear box is used to connect the induction machine to the pedals. This brings down the synchronous speed from 1800 RPM to 60 RPM.

CHAPTER 2

DESIGN

2.1 Design Procedure

2.1.1 AC/DC Converter

The first step here is to take one phase from the grid power and step it down to about 30V. The voltage values are then made all positive by passing the wave through a bridge rectifier (see Fig. 2.1). The input capacitance, $C_I = 400\mu F$, reduces the fluctuations of the wave so the values are within operating range of the voltage regulator. The regulator's output (with $C_O = 0.1\mu F$) should be 5VDC (or 12VDC), and have fluctuations no more than 0.1V. The regulators used are LM7805 and LM7812 for 5V and 12V, respectively.

2.1.2 User Interface

The User Interface consists of two push buttons (see Fig. 2.2), increase and decrease physical resistance, which send their signals to the PIC, and a 10x1 LED array, which serves as a resistance level indicator. Each LED (see Fig. 2.2) represents a 10% voltage increment on the variac, and is powered from

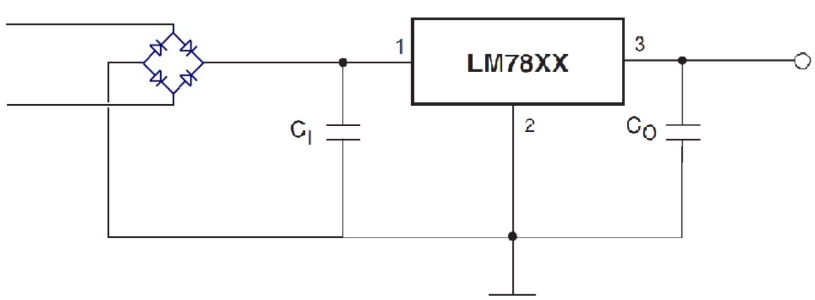

Figure 2.1: AC/DC Converter Circuit Diagram.

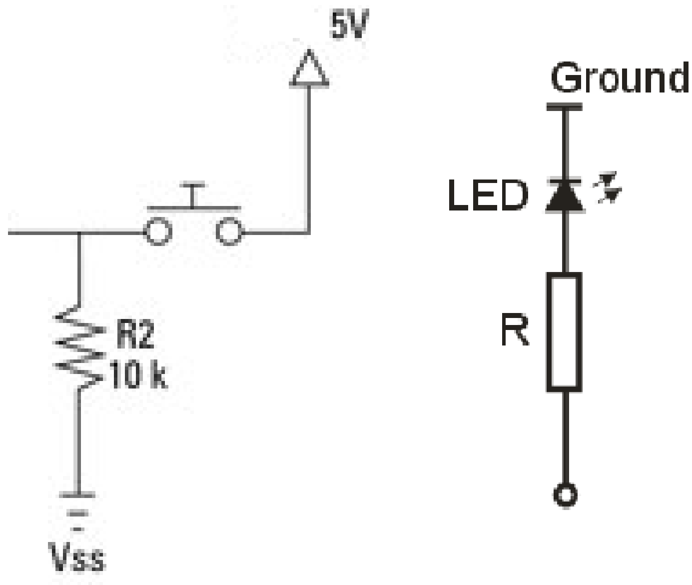

Figure 2.2: Push Button and LED Circuit Diagrams.

the PIC.

2.1.3 Control System

The control system is managed by a PIC. Every time the output of a push button goes from 0V to 5V the processor records a change in the resistance counter[1]. Immediately following, the PIC turns an LED on or off in the level indicator, depending on whether an increase or a decrease was pressed. These resistance level updates can only occur when the induction machine is powered off.

A hall-effect sensor (see Fig. 2.3) is mounted on the induction machine, along with a magnet mounted on the shaft. The sensor detects each time the magnet passes by. The PIC then measures the time between detections, and uses this measurement to calculate the speed of the machine.

The DC motor turning the knob on the variac is fitted with a slotted wheel and an optical sensor, which outputs a specific signal when a slot is passing by it. When the PIC "sees" a non-zero speed on the induction machine it powers on the motor, through an H-bridge, to turn the knob. It then counts the amount of slots passed to determine how much the knob has turned (ie.

[1]This counter is kept in software

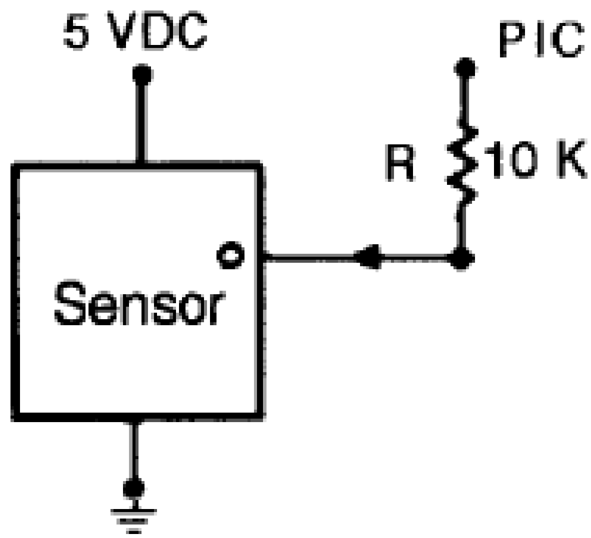

Figure 2.3: Hall-Effect Sensor Circuit Diagrams.

What the voltage is at the terminals of the machine). When the user stops pedaling, the PIC will calculate a speed below synchronous. At this moment it turns the knob again in the same way, reversing the direction of rotation until voltage at induction machine is 0V. (see Fig. 2.4)

2.2 Design Details

2.2.1 Control System

The hall-effect sensor is mounted on the induction machine to detect the passing of a magnet mounted on the machine's shaft. When the magnet comes near the sensor, its output rises above 0.5V, signifying one revolution. The PIC measures the time that has passed since the last magnet detection, and uses it to calculate the speed (see eq. 2.1).

$$\omega_r = (\frac{1}{\Delta t})(\frac{1000}{1})(\frac{60}{1}) \tag{2.1}$$

where ω_r is in RPM and Δt is in ms.

The time is maintained with a timer that causes an interrupt every 0.5ms to update a time variable. This variable is accessible in the code. During each

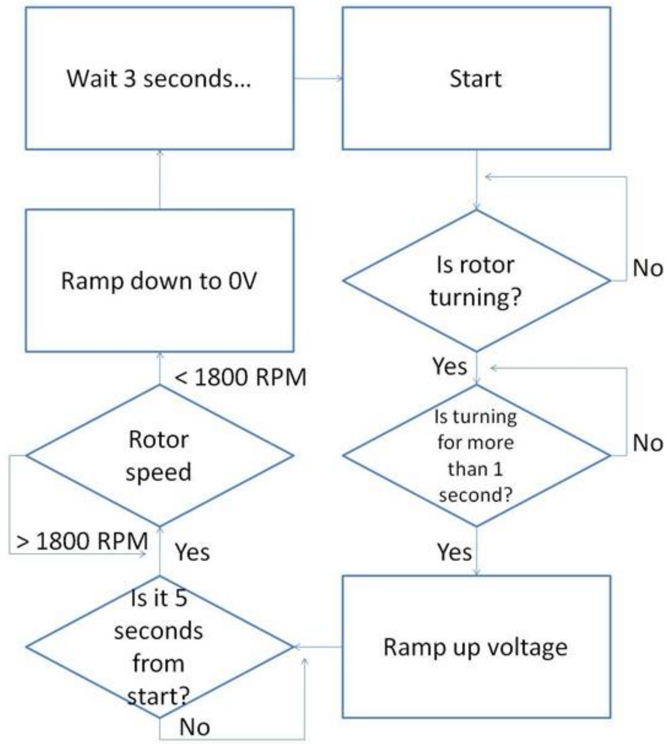

Figure 2.4: Flow Chart of Control System.

magnet detection the time measurement is recorded. On the next detection the new time is recorded and compared against the old time to find the time difference. After this calculation the old time is free to be written over by the next time measurement.

When the system is first started, the induction machine is off. Once a user begins to pedal, the speed is detected by the PIC, which stops accepting changes in resistance level and powers the DC motor that turns the variac to the current level specified by counter. The motor is controlled through a H-bridge and powered with 12VDC. It is fitted with a slotted wheel and an optical sensor, which sends a signal to the PIC every time a slot passes by it. The PIC counts the number of slots to determine the position of the variac. Once desired level is reached, the DC motor is powered off. Meanwhile the induction machine is driven above synchronous speed and generates power.

The moment the user stops pedaling, the speed of the induction machine will drop below synchronous. This will be calculated by the PIC, which will signal the H-bridge to power the DC motor in the opposite direction as before (by inverting voltage polarity), counting the slots again until 0V is reached and the machine is off. At this point, initial state is reached and changes to the resistance level are again allowed.

CHAPTER 3

VERIFICATIONS

This section presents the results obtained from testing the different components involved in this project. For more detailed information on the tests realized and the requirements for these tests to pass see the table in. The gear box was tested by turning the pedals by hand and counting about 30 rotations of the shaft of the induction machine for one full rotation of the pedals. The AC/DC converter (Fig. 2.1) was first tested with $C_I = 33\mu F$, causing the voltage to drop when applying any load to the output of the regulator. This problem was fixed by changing the capacitance to $C_I = 400\mu F$. The User Interface was then tested by connecting the push buttons and the LED array to the PIC and programming it so that with each press of the '+' or '$-$' push buttons an additional LED was turned on or off, respectively. This functionality was observed during the tests as expected. The tests that now follow are for the induction machine and the control system.

3.1 Induction Machine

For testing, the shaft of the induction machine is connected to the shaft of a dynamometer, which is controlled from the computer. The dynamometer takes readings of speed and torque, while the 3-phase power is connected to the induction machine through two watt-meters in line-line setup. The watt-meters measure the voltage, current, and power to the machine. After connecting the power the dynamometer is set to drive the induction machine at different speeds above synchronous. Table 3.1 shows the results of how the power generated increases with speed, as well as the torque required to drive the shaft at that speed. The final test is mounting the induction machine on the exercise bicycle and confirming increasing physical resistance, while pedaling, at increasing voltages. This test was also successful.

Table 3.1: Induction Machine Generator Operation with Torque levels.

Speed (RPM)	T (Nm)	Ptotal (W)
1798	0.125	62.5
1804	0.355	22.7
1808	0.570	-10
1814	0.735	-42.5
1818	0.955	-78.3
1824	1.150	-106.4

3.2 Control System

The DC motor itself was tested by applying 12VDC in both possible polarities, showing that its turns clockwise and counterclockwise as expected. However, having switched to this design from the original concept of turning the knob of the variac by giving a PWM signal to position a servo, resulted in not having enough time for integration of this device to the system. The PWM part was made to work, but the servo obtained did not have the torque necessary to turn the knob.

After mounting the hall-effect sensor and magnet on the induction machine, the sensor's output is connected to an oscilloscope. It was observed that, as the pedals were turned on the bicycle, the signal on the oscilloscope jumped whenever the magnet passed by the sensor, demonstrating proper detection of each revolution of the machine's shaft. However, due to the time it takes for the A/D converter to setup for each reading and the high speed of the induction machine, the integration of this part resulted in very unreliable behavior. This could be fixed by passing the sensor output through a comparator, whose output will be 0V or 5V, thus removing the delay from setting up the A/D converter followed by the conversion of the signal to a digital variable. To further avoid problems relating to time, the PIC could also be programmed to create an interrupt as soon as this signal changes so it is not missed.

CHAPTER 4

COSTS

Ideal salary: \$30/hour Hours spent: (15 hours/week) * (11 weeks) = 165 hours Labor: (\$30/hour) * (165 hours) * 2.5 = \$12375.00 Total cost (see Table 4.1): \$12672.70

Table 4.1: Estimate of costs of parts.

Part no.	**Description**	**Price per unit (\$)**	**Qty.**	**Total (\$)**
---	Frame	100.00	1	100.00
MTR-P33-3BD18	3-phase 0.33HP 1800RPM 208-230/460V Induction Machine	96.00	1	96.00
MSP430F47196	Micro Controller	7.70	1	7.70
13435	NEW # 264 Hub City 25:1 Gear Box	85.00	1	85.00
---	Red LED	0.12	2	0.24
MV57 164 821 H	10x1 LED array	1.95	1	1.95
W02G 220C	Rectifier	0.48	1	0.48
LM7805AC	5V regulator	0.40	1	0.40
S41 908	Hall effect sensor	1.93	1	1.93
---	Push button	2.00	2	4.00
TOTAL				297.70

CHAPTER 5

CONCLUSION

At the end of this project we have successfully used an induction machine on an exercise bicycle, generating electric power while at the same time exercising. As intended, the physical resistance to the pedals increases as the magnitude of the voltages at the terminals of the machine also increase. This design also allows the generated power to be put directly back into the electric grid. A functioning user interface was incorporated into the system to help communicate with the control system, intended to automate the voltage setting to the induction machine. Unfortunately, the control system itself was not completely integrated. A last-minute addition to the system, time did not suffice to integrate the DC motor intended to adjust the voltages, while a timing issue made the speed calculations of the machine shaft too unreliable. This last problem could be fixed by passing the hall-effect sensor's output through a comparator, whose output, in turn, could be set to trigger an interrupt in the PIC. Applying these changes should be enough to make the system fully functional.

5.1 Ethical Considerations

There are two main considerations of ethics in this project, having to do with the safety of the user of this project and the welfare of the public. The first is that, under synchronous speed, the induction machine drives itself as a motor, until power is turned off. If the machine were to drive the pedals it could cause injury to the user. To avoid this problem, a ratchet was installed on the shaft of the induction machine, which allows the pedals to drive the shaft, but does not let the motor drive the pedals. The second is that, to protect the grid, the voltage magnitudes and phases at the terminals of the machine must be matched with those of the grid. To make sure no mismatch occurs, the control system is programmed to not accept changes in resistance level (changes in voltage) as long as the induction machine is running. These considerations are linked with the commitment from the IEEE Code of Ethics that agrees "to accept responsibility in making decisions consistent with the safety, health and welfare of the public, and to disclose promptly factors that might endanger the public or the environment ".

REFERENCES

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