TEMPERATURE MONITORING SYSTEM FOR MEDIUM-SIZED MOTOR DRIVEN MACHINERY

by

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PROJECT DISSERTATION

Submitted to the Electrical & Electronics Engineering Programme
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CERTIFICATION OF APPROVAL

TEMPERATURE MONITORING SYSTEM FOR MEDIUM SIZED MOTOR DRIVEN MACHINERIES

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Approved:

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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Nabilah binti Saripan

ABSTRACT

This project is a temperature monitoring system for medium size motor driven machineries. A lab model was constructed to endure the problems mentioned. This monitoring system will alert a personnel doing surveillance round to identify any motors abnormalities without the need to have a direct contact with the motor as it will be very dangerous to be in contact with a running motor It will alert the personnel in charge for any unwanted changes such as extreme temperature change and diagnose for any possible problems that cause the alarm to turn on. This monitoring system is very useful for earlier stage problem detection method. Earlier detection definitely will be important in order to sustain the production of a particular product by prolonging the machine's Mean time between failures (MTBF).

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LIST OF ABBREVIATIONS

MTBF	Mean Time between Failures
DC	Direct Current
AC	Alternating Current
HVAC	High Voltage Alternating Current
RPM	Revolutions per Minute
RTD	Resistance Temperature Detector
PRTD	Platinum Resistance Temperature Detector
PTC	Positive Temperature Coefficient
NTC	Negative Temperature Coefficient

CHAPTER 1
INTRODUCTION

1.1 Background of study

Machines will not be complete without a motor because motor is one of its most essential parts. The use of the machine in any industries is very important and it cannot be taken lightly. As important as it seems to be, if these machines fail because of motor problems, all the productions will stop. Because of that, long working hours of these motors must be taken seriously. Any risks of having big problems should be minimized. Another major effect is the cost of the maintenance of the motor. The bigger the problem is, the higher the cost to repair the fault. Many companies nowadays do not notice the abnormalities of their machines in the earlier stages, thus suffering from a greater problem to solve including total plant shutdown due to the misbehave of the motors.

The project “Temperature Monitoring System for Medium Sized Motor Driven Machinery” involves constructing a system that can detect increase in temperature in a particular motor that may cause a more serious damage. This monitoring system will detect any extreme temperature changes and alert the personnel in charge immediately. The principle of the monitoring system will depend on its working principle designed. Although it is not as detail and accurate as the other system, this monitoring system gives time for the maintenance personnel to figure out the actual problem and its solution as it will alert him in the problem’s earliest stage in a safe manner.

1.2 Problem Statement

Having a lot of motors available in the industries, they are being divided into a few types and this project will only be applicable to the medium sized motor with the voltage ratings ranging 3.3kV to 6.6kV [1] .This monitoring system will be more effective for a three-phase type motor. These motors will have abnormal changes if they encounter an extreme heat excess and this situation should be taken seriously to avoid bigger problems to occur. Thus a monitoring system is vital in order to keep track and alert the personnel in charge on any abnormalities of the motor.

1.3 Objective / Scope of Study

1.3.1 Objective

The objectives of this project are to:

1) Design a temperature monitoring system to detect and alert operators on the early signs of a medium sized motor's unusual behavior.
2) Reduce the hazards for the operators to do inspection in their surveillance round to keep track with the motor's health condition in its earlier stage.

1.3.2 Scope of study

This project is limited to the following principle:

1. Motor Theory

   In order to have a monitoring system about the 3 phase medium sized motor, the motor theory is needed to be understood.

2. Gate Logic and Control system

   Both of the concepts are important to be implemented in the project flow of the designing stage. Every step forward in the working flow depends on the control of the system.

3. Circuit Theory and design

   Basic circuit theory and knowledge is needed to design the system.

CHAPTER 2
LITERATURE REVIEW

2.1 Motor Driven Machinery Theory

In any industries, various types of motors are being used and these motors are divided according to its category:

1) DC motor

2) Single-phase AC motor

3) Three-phase AC motor (3-phase)

A DC and AC motor serve different use due to certain reasons. DC motors have a smaller packaging but with same horsepower, and produces high torque at low speed in comparison with AC motors. But above all else, AC motors are more in demand by the industries. An AC motor driven machinery is used in mostly the HVAC (High Voltage Alternating Current) motors and industrial application because they have easier installation and maintenance procedures. The maintenance costs of the AC motors are minimum compared to the DC motors because of the brushes that is needed to be replaced, while for AC motors, it does not need any brush to operate. An AC motor also improves torque control and able to produce faster speed even it is above its nameplate.

An AC motors then can be classified as a single phase motor or a 3 phase motor. A single phase motors are mostly used in a smaller industries facilities and also residential facilities. A few example of a single phase motors are the furnace, blowers, refrigerators, dryers and cooling fan. A bigger industries application usually will be using the 3-phase motors. This makes possible to use a high voltage facilities which is necessary in any industries for its operations process.

These high voltages for industry usage motors are being divided into 3 types mainly small, medium and large motors. The minimum and maximum ratings and system voltages are being stated in PETRONAS Technical Standards (PTS). These classifications are made based on the rating in relation with system voltage in Table 1.

Table 1 : Motor classification on size [1]

Size	Rating	System voltage
Small	110 kW – 132 kW	0.6 kV – 3.3 kV
Medium	132 kW – 200 kW	3.3 kV – 6.6 kV
Large	Above 200 kW	Above 6.6 kV

2.2 3-phase AC Motor Problems Identification

The variety of the ratings and system voltages between each motor size will cause a difference in the methods and techniques to identify its faults and failures. This project focused on the monitoring system for medium sized of a 3-phase AC motor only. There are many problems that can occur to a particular motor especially after long hours of running. The problems will be reflected by any abnormalities on the motor. The abnormalities may show as an excess temperature rise, higher noise production, slower starting and lower than rated speed (rpm) or even discharge of a strange compound such as dirt.

Due to the diversity of fault characteristics that may be shown by the 3-phase medium size motor driven machinery, this project focused only on the temperature of the motor. The temperature abnormalities can actually give a rough view of a problem that might be encountered by the machine.

2.2.1 Motor Overheating

Having to detect any unusual changes to the temperature of the motor will alert the personnel in charge to further investigate the reasons of the abnormal changes. An excess temperature release has the biggest possibility for the motors to breakdown. For every 10°C increase of temperature from its rated maximum operating temperature, the insulation system life of that particular motor is reduced by one-half. Moreover, the bearing and gear lubricant life is halved by every 25°C temperature rise. The excess heat will cause leakage and the failures in the lubrication system due to increase in friction. The problems that cause temperature rise are [2, 3, 7] :

1) Over voltage / low voltage / overload

According to the worldwide standards, usually the only allowable voltage deviations are ±10% of their rated voltage. Over voltage can cause this overheating problem. Low voltage also contributes to the temperature rise. In fact, the motor will run slowly than its rated rpm. Technically it is actually overloaded and this scenario will cause the motor to increase its temperature and eventually fails. Usually the low voltage problem is possible to occur if there is any problem on capacitors from the incoming supply of the transmission lines. The task of the capacitors is to adjust and correct the power factor of the supply lines due to the inductance that accumulates.

2) Phase unbalanced

This problem occurs when the phase difference are not 120º apart. Phase unbalances may happen when a single phase load is applied causing one of the 3 lines bear the extra load than the other 2. The greater the phase unbalance, the higher the temperature rise will be and the motor might burn if the overheating is too high.

3) Voltage unbalanced

This problem takes place when the voltages between the phases are not equal. One of possibility that it will happen is due to the excess load on one of the 3 phase when a fuse is blown. A serious voltage unbalanced will cause the stator to be blackened. Apart from having an extreme temperature rise, voltage unbalanced is the source of a current unbalance. A current unbalance may result to an insulation failure. Once the current unbalance is establish, the condition will be more severe as the ratio of a voltage unbalance to a current unbalance is about 8:1.

4) Single phasing

The single phasing problem is an operation of a 3 phase load on 2 phases only due to the deterioration of one of the phase. This is the maximum condition for voltage unbalance. One of the phases will deteriorate until there are only 2 phases available. Apart from that, the single phasing also causes from a blown fuse or lightning that knocks out one of the lines.

5) Worn bearing and uneven air gap

Uneven air gap will happen due to worn bearings. Both of the problems do contribute to the overheating of the motor. More heat will be produced if a higher friction takes place.

6) Dirt, excess oil and grease on the cooling fins and motor housing

This causes heat to be stored in the housing and prevent it from break out causing the temperature to keep increasing.

7) Improper ventilation, high ambient temperature

2.3 Different Problems Definition between Large and Small Motors

Motors available nowadays either in the market or industry are in various ratings. This rating will later on specify the size of the motor; large, small. Large motors that use High Voltage AC (HVAC) are usually being used in the industry or plants to operate on a larger load. In the other hand, the smaller rating motor with low voltage is usually being used in our daily life. Even though they differ in a way that the rating sizes might be far apart between the motor types, the problems that might occur to both of the motor types can be considered similar between each other. This is due to the same operational principle of both of the motors. The differences are only on the numerical values if any data is being collected because the larger the rated values of voltage for 1 motor, the values of other perimeters or variables also should be larger from the smaller rating's motor. [10, 11, 12]

2.4 Abnormalities Detection

Every abnormality can be detected in various ways. It can be detected according to its own characteristics which it embodies.

2.4.1 Temperature Detection

Temperature detection for motors or large system with high temperature value can be done using certain sensors. Among the sensors are the Resistance Temperature Detector (RTD) and thermistor. RTDs and thermistors are different indeed. RTDs are usually made from pure metal; nickel and platinum where as the logic goes, the higher the temperature is, the larger the value of their electrical resistance. The most common RTDs in the industries are the platinum RTD (PRTD) where the sensor can detect temperature ranges from -200°C to 600°C. For application above 600°C, this sensor is not in great demand due to the possibility of contamination with impurities. Even though RTDs are very stable, the biggest disadvantage is that they are not sensitive to small changes.

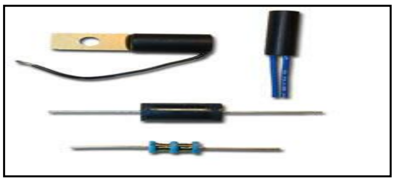

Figure 1 : Resistance Temperature Detector (RTD)

Apart from the RTD, thermistors can detect the small changes as they are very sensitive sensors. Thermistors are divided into Positive Temperature Coefficient (PTC) and Negative Temperature Coefficient (NTC). PTC is common for electric current control and NTC is common for temperature detection such as the engine temperature. [13, 14, 15, 16, 17]

Table 2 : PTC and NTC temperature range [17]

Thermistor type	Minimum temperature	Maximum temperature
PTC	60°C	180°C
NTC	-200°C	1000°C

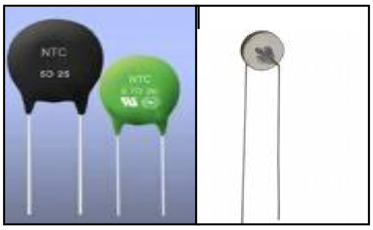

Figure 2 : Thermistors (NTC and PTC)

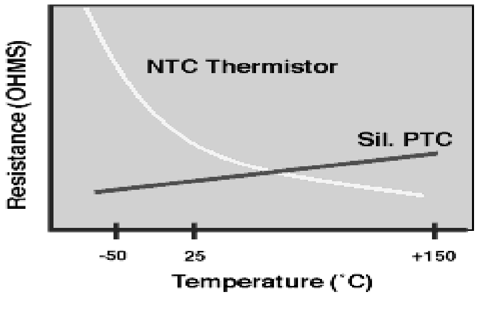

Figure 3 : NTC and PTC graphical difference [18]

As being claimed before, NTC is more suitable in temperature detection application and for NTC, when its temperature goes up, the resistance goes down.

2.5 Comparisons with other study on monitoring system

A study entitled "Acoustic Emission Techniques for Condition Monitoring and Diagnosis of Rotating Machines" [19] focused specifically on the bearings of the motors where the bearings represent the commonly used part in all rotating machines and equipments. To detect the problems of the bearings, acoustic emission (AE) technique is being used. The AE signals are collected from the rotation of a healthy bearing and unhealthy bearing and then being compared to diagnose the problems that occur, thus providing valuable information about the motor's health condition. The statistical methods are used to demonstrate a clear difference in the signal of acoustic emission signal between the normal and the defective bearings of motors.

As for this project, the study is conducted more onto monitoring the motor's health on temperature. Detection of high temperature increase more that its rated temperature that is up to certain extend, will reflect the motor's condition whether it is healthy or not. The detection mechanism used for this project is a surface temperature sensor. This project is meant for early detection of temperature abnormalities of a motor, thus this is considered a basic monitoring system that can assist the involved personnel to notice any motor's temperature increase using a much cheaper monitoring system for cost effective alternative.

2.6 Project Application

This project was initiated by the idea the keeping motors healthy thus this system is needed to detect extreme temperature changes to occur to medium sized motor driven machineries but with a lower cost. Being different from the usual monitoring systems available in the industries, this particular project stressed on the importance of safety by minimizing any personnel direct contact with a running motor in order to check if any misbehaviour occurs.

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

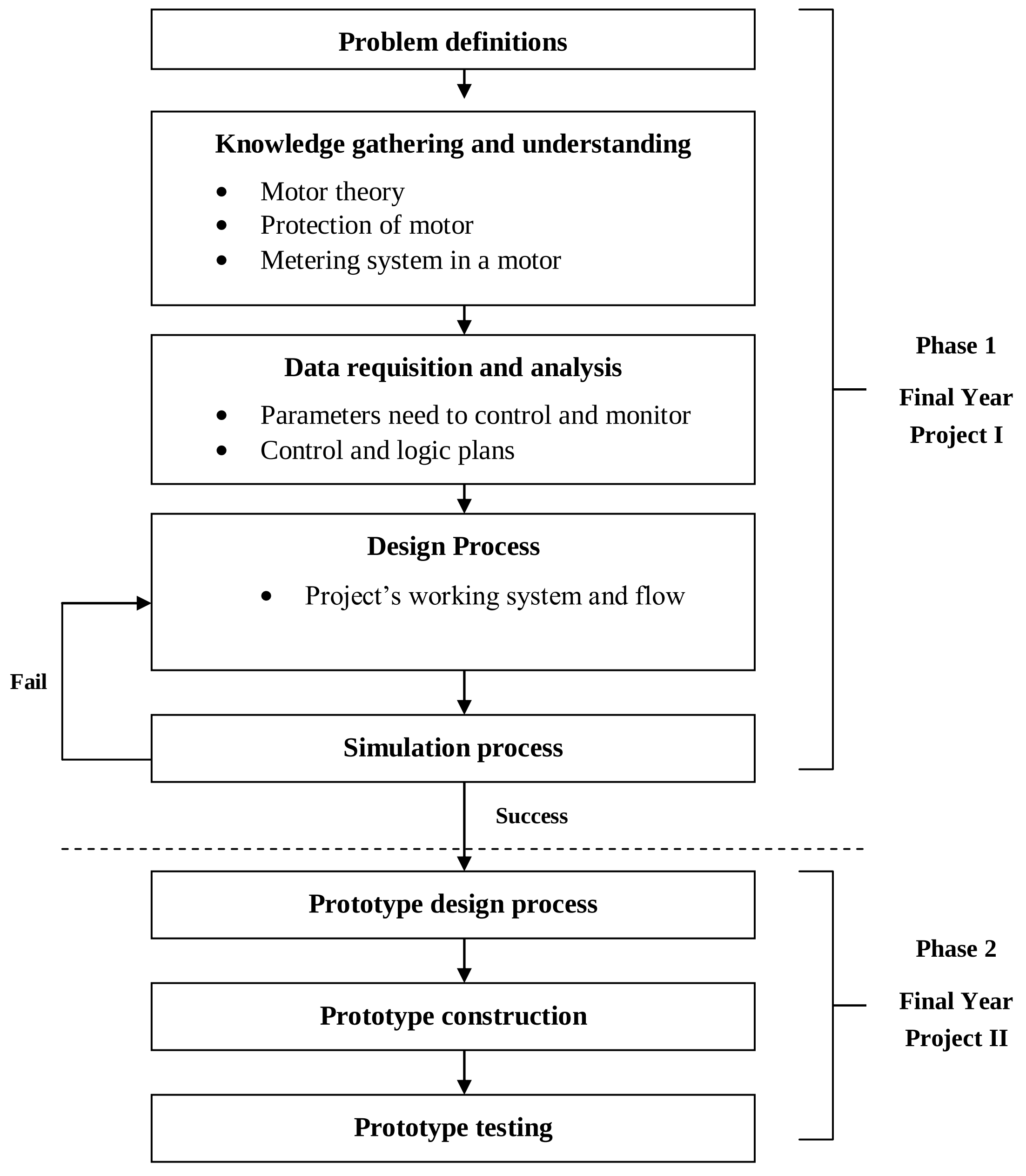

Figure 4: Work flow chart

The project's Gantt chart is in APPENDIX A. Figure 4 shows the flow chart in completing this project. This flow chart is a brief about the process of completing the project from the designing stage to prototype testing to ensure that the prototype is a working prototype. The simulation is based on the logic and algorithm design. All the design stages will be referring to the data gathered from the theory and the on-site information.

Step 1 :

Researches through books, journals and internet are crucial to facilitate the study.

Step 2 :

The parameter that can to be monitored using this monitoring system is set by looking for constraints that will be encountered. After the decision on the parameter is confirmed, the flow continues to the logic design where it needs to obey the system's requirement.

Step 3 :

The system flow is then transferred to the suitable designs using a suitable tool.

Step 4 :

Then, simulation will take part in order to ensure that the designed circuit is working properly. If the simulation fails, the flow will return to step 3. If the simulation is successful, then the flow moves on to step 5 (phase 2).

Step 5 :

The Circuit designing step takes place concurrently with some alterations.

Step 6 :

The circuit construction will be based on the circuit designed. The circuit designed in step 5 will be the backbone of the circuit that will be constructed but if there is any changes and modifications that might be done, it will be done during this stage.

Step 7 :

Circuit testing will be done when the circuit construction is finally constructed. But there are limitations on the testing stage that will be explained later.

3.2 Tools Required

3.2.1 Hardware

1) Electronic components – resistors, LED, buzzer, SCR, Op-Amp, etc

2) Circuit board

3) Surface temperature sensor – thermistor-typed NTC

4) Science workshop 750 Interface by Pasco Scientific

5) K-type sensor

6) Digital Multimeter

7) Heating element

3.2.2 Software

1) OrCad PSpice

2) Lab-volt oscilloscope

3) Data Studio 1.9.0

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 Results

4.1.1 Testing Result: Voltage Unbalanced and single phasing waveform

As mentioned in **Chapter 2**, there are a lot of internal motor problems that will cause excess temperature. From the experiment and testing done, two out of the mentioned problems; the voltage unbalanced and single phasing phenomenon waveform can be produced to act as evidence to the theoretical knowledge. This experiment is using the lab-volt facilities. This waveform was obtained by varying the voltage load at 1 out of the 3 phases.

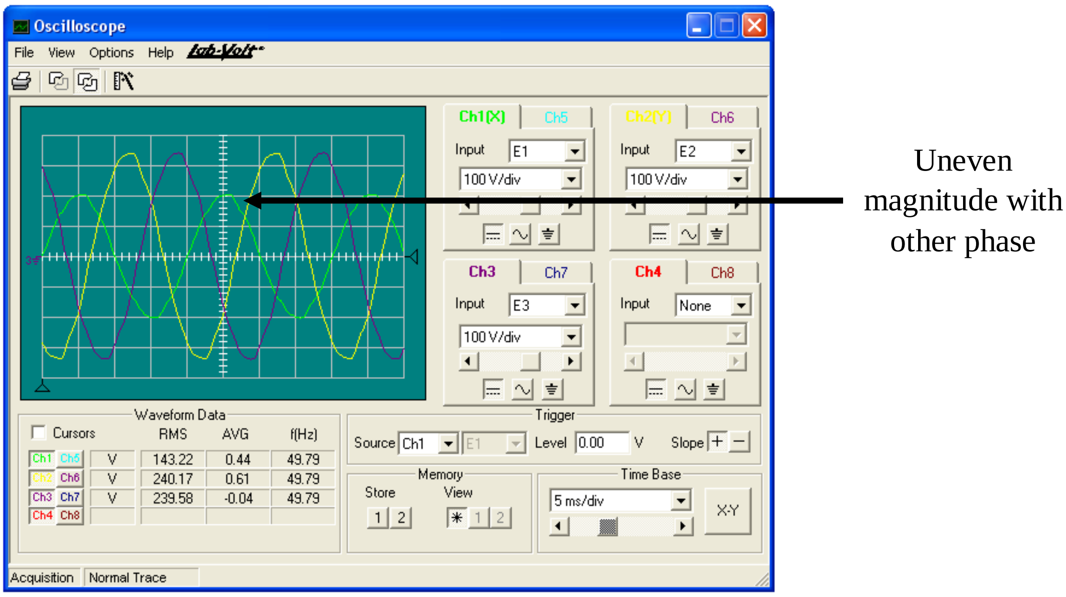

Figure 5: Voltage unbalanced waveform

The magnitude of the overload phase will keep on deteriorate if the load keeps increasing.

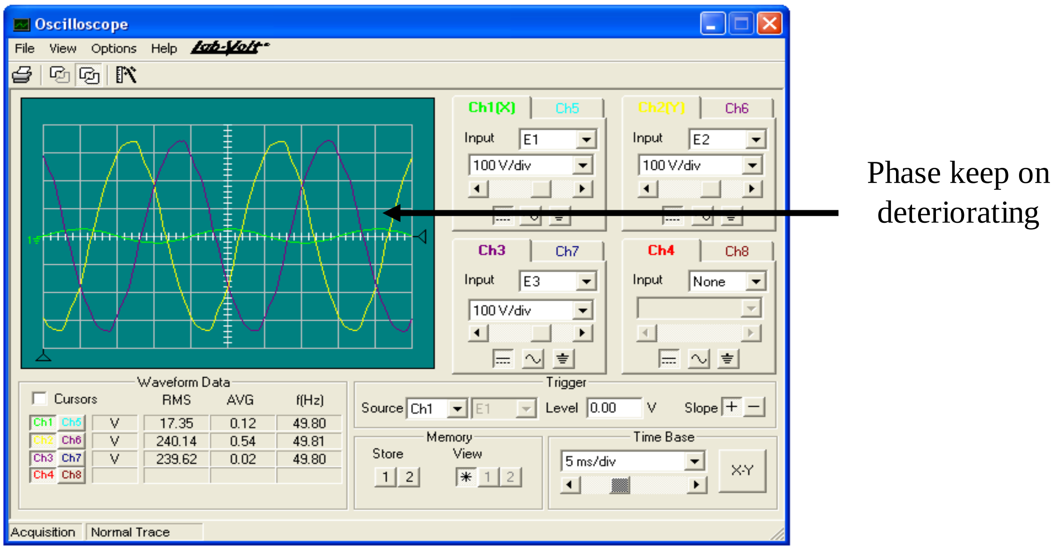

Figure 6 : Voltage unbalanced towards maximum condition

The maximum condition of the voltage unbalanced with cause single phasing where one of the phases will totally deteriorate

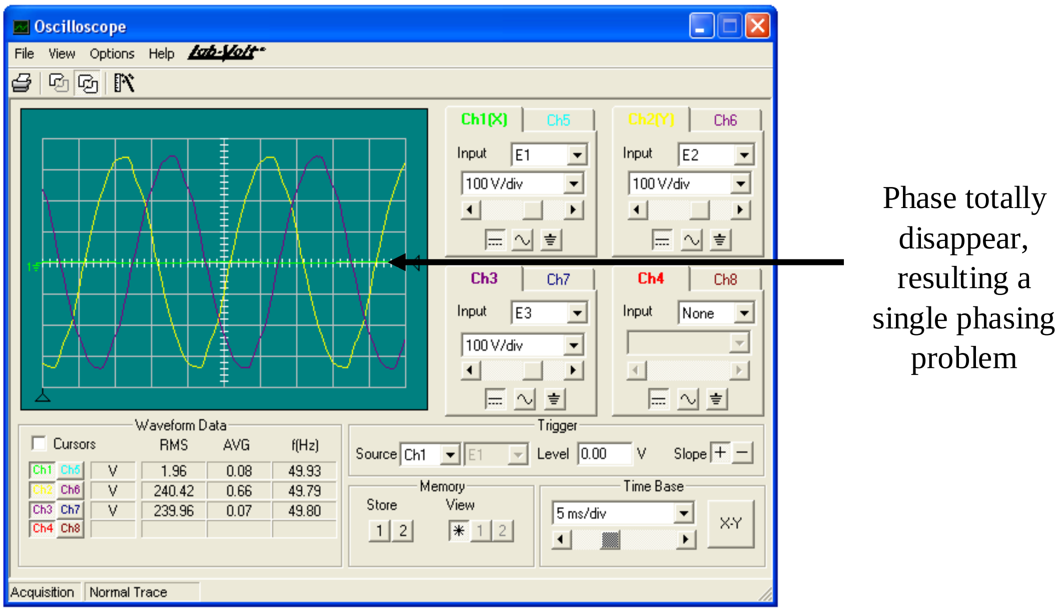

Figure 7: Single phasing waveform

4.1.2 *Monitoring system circuit*

The circuit designed for the prototype of the monitoring system is as below.

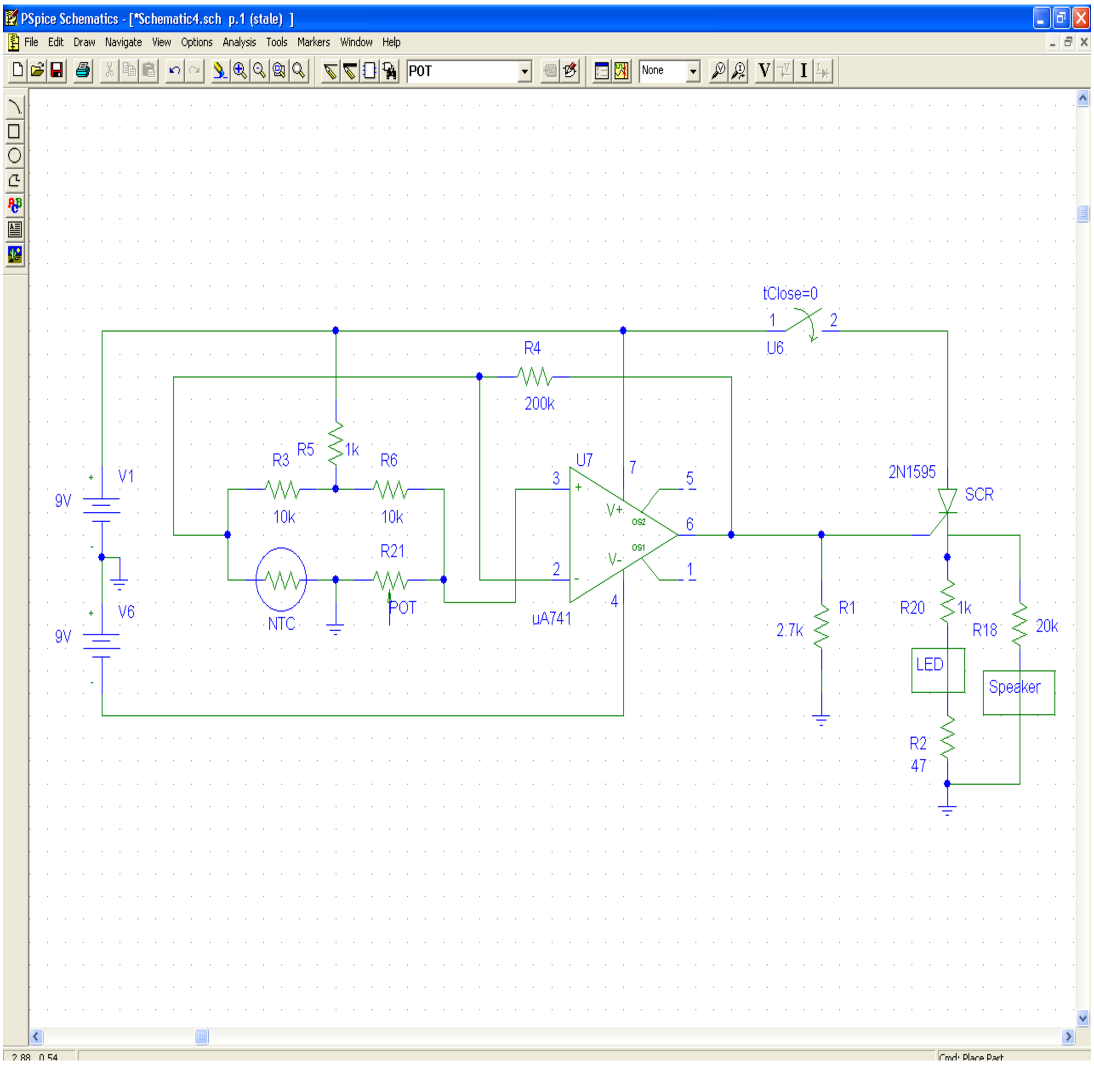

Figure 8: System circuit diagram

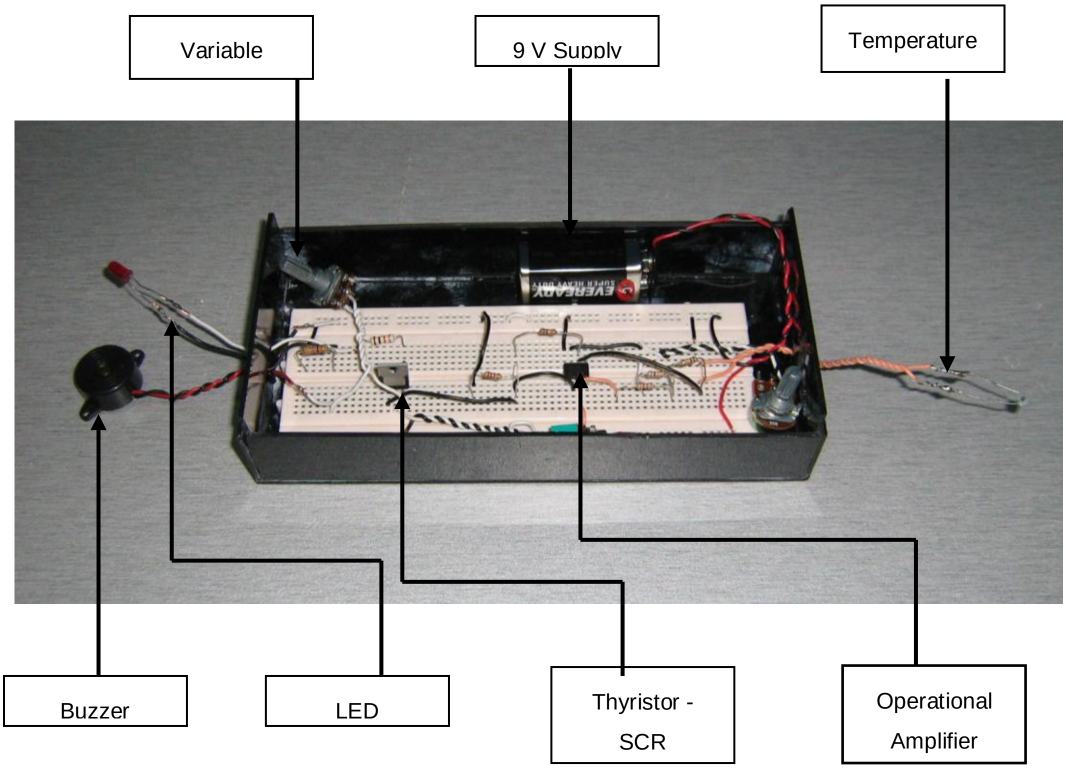

Figure 9: System circuit on circuit bread board

This automatic system will turn the alarm ON for any extreme increase in temperature, hence reducing the frequency of the operators to be in direct contact with the running machine along with keeping the motor's health in observation to ensure that the motor is working in order. This will reduce the risks of injuries because any unsafe act and unsafe conditions will be kept low due to the reduced frequency of the workers to go directly inside the unsafe zone while the motor is running.

4.1.3 Circuit Simulation Results

From Orcad PSpice, the simulated values of the circuit can be obtained. The simulated circuit diagrams are shown in Appendix B. The table below is the summary of the values obtain with respect to the NTC resistance value.

Table 3 : Orcad PSpice simulation result summary

NTC Resistance value (Ω)	**Variable resistor value (Ω)**	**OpAmp Output value (V)**	**LED / Buzzer**
5k	4.5k	-8.447	Off
4.8k	4.5k	-4.365	Off
4k	4.5k	8.611	On
1k	4.5k	8.614	On

4.1.4 Experiment to determine suitable resistance of NTC for different motor heat classes for real life application

Motor's health on the temperature aspect depends on the heat dissipation where too high heat discharge will damage the motor up to the severe part i.e. motor downtime. LED and speaker inside this circuit turn on when the temperature is high up to certain extend, in order to alarm to operators. An experiment has been conducted to determine the resistance value of the variable resistor that must be set as certain maximum level of allowable heat dissipation for certain motor. According to NEMA, thermal classes for motors are in table 4:

Table 4: Thermal classes for motors [20]

Class	**Maximum Temperature**
A	105°C
B	130°C
F	155°C
H	180°C

The most common class for medium sized motor is class B and F and this project will be designed according to the thermal classes of motor. The experimental tools are:

- Science workshop 750 Interface by Pasco Scientific
- K-type sensor
- 68kΩ thermistor (NTC)
- Digital Multimeter
- Heating element
- Data Studio 1.9.0

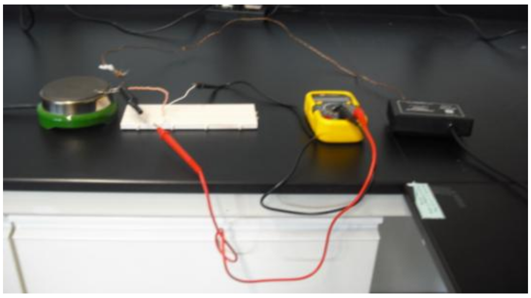

Figure 10: Tools arrangement

Figure 11: Pasco Scientific Interface

The experimental result is as table 5:

Table 5: Resistance value for temperature

Temperature (°C)	NTC Resistance (Ω)
60	1200
70	620
80	308
90	200
100	115
105	54
120	30
130	21
140	16
150	13
155	10
160	7
170	5
180	1

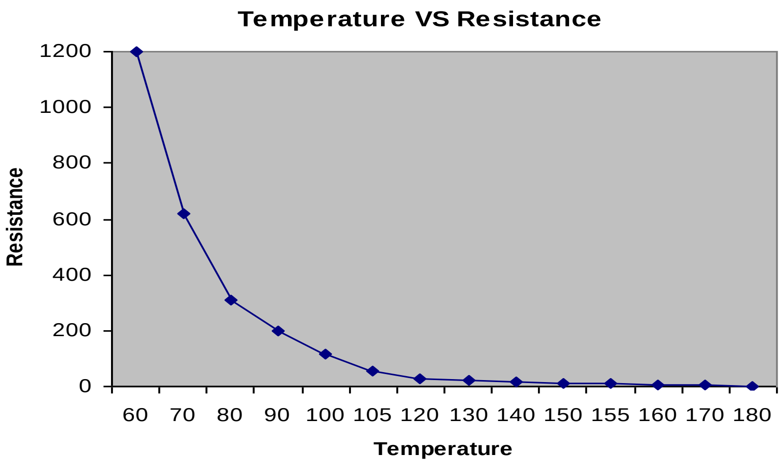

Figure 12: Temperature vs. resistance graph

The system's comparative resistance will be depending on the NTC resistance. From the experiment above, Table 6 is developed.

Table 6: System design specification for variable resistor values

Class	Maximum Temperature	System detection temperature	NTC resistance	Suggested variable resistor value
A	105°C	90°C	200 Ω	220 Ω
B	130°C	100°C	115 Ω	120 Ω
F	155°C	130°C	21 Ω	25 Ω
H	180°C	150°C	13 Ω	15 Ω

The value of temperature that will trigger the system should be lower than the maximum thermal capacity of each class. This is for the purpose of early detection pf temperature rise. When NTC resistance is lower than the variable resistor value, the alarm will trigger.

4.2 Discussions

4.2.1 Circuit flow

The circuit acts as the controller of the system. The main circuit is using NTC for the sensor and having variable resistor to have the Resistors Bridge slightly unbalanced. This is important to have the operational amplifier (Op-Amp) produce a negative voltage when the temperature condition is below the alarm level due to the voltage at the inverting input of the Op-Amp is greater than its non-inverting input. The variable resistor resistance is made lower than the resistance of the NTC. When NTC detects heat, the resistance of NTC will decrease until the resistance is lower than the variable resistor resistance. The comparisons will be done in the bridge and being sent to the Op-Amp input. This phenomenon will give out a positive Op-Amp input, and turn on the alarm on the LED and the buzzer. This alarm can only be turned off with a manual switch. The reason why this system is using manual operator switch is to attract attention of the personnel in charge on the motor abnormalities, thus the small abnormalities can be noticed and immediately can be taken into action.

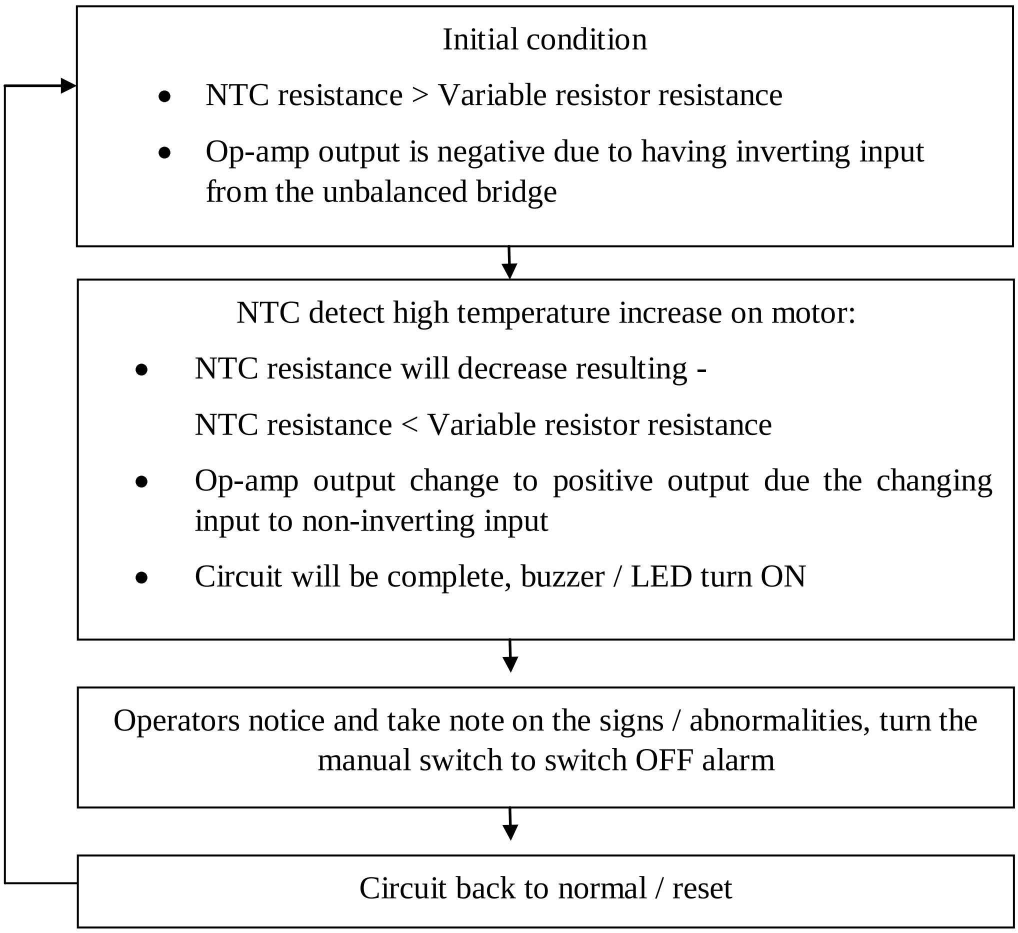

Figure 13: Circuit operation flow

4.2.2 Limitation on prototype testing

In this project, the motor ratings are according to the industrial motors are very high compared to the residential or university facilities ratings. Due to this, there is some limitation on the testing of the prototype because the machines with the rating as per this project are only available on-site. Apart from that, the hands-on testing of the prototype might risk of the motor available in the. Thus, to decrease any unwanted risks, the testing was conducted in the campus lab using a heating element. As being mentioned before, the problem that might occur is similar for a different size motor with a same type of motor due to the similarities of the construction.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This 'Temperature Monitoring System for Medium Size Motor Driven Machinery' was designed for early detection of high temperature to minimize downtime. Even though this monitoring system did not provide an accurate diagnosis of a certain problem, this system facilitated the detection of a fault in its earlier stage. An early detection can bring all the difference where the costs of maintenance are minimized and the risks of having production deferment cam be reduced. Besides taking the motor's health into account, safety is crucial in order to keep the workers and work place safe. The function of this system will alert operators and minimize their direct contact to the running machine thus decreasing the hazards risks. Apart from that, this system is lower in cost alternative for 3-phase medium size motor thus it is cost effective for economical themed properties.

5.2 Recommendations

The system can be upgraded to detect speed, vibration problems and rotations problems. Apart from that, this system can also be upgraded to provide an accurate diagnose of problems to the abnormalities detected. The implementation of this system is suggested to be done by clamping the NTC part to the motor's housing using a non-magnetic clamp with high melting point.

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APPENDICES

APPENDIX A
GANTT CHART

Gantt chart for Phase 1 – Final Year Project I

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Selection of Project Topic	■														
	- Propose Topic	■														
	- Confirmation of Topic Selection		■													
2	Preliminary Research Work		■	■	■											
	- Data collection			■	■											
	- Literature review motor, its major concepts and faults			■	■	■	■									
3	Submission of Preliminary Report															
4	Project Work				■	■	■	■								
	- Data reduction and presentation					■	■	■								
5	Submission of Progress Report								●							
6	Project work continue / simulation								■	■	■	■	■			
7	Submission of Interim Report Final Draft													●		
8	Submission of Interim Report														●	
9	Oral Presentation															●
		●	Milestone													
		■	Process													

Gantt chart for Phase 2 – Final Year Project II

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continue	■	■	■							Mid-Semester Break						
2	Submission of Progress									●							
3	Seminar (compulsory)											■	■				
4	Project work continue								■	■		■	■				
5	Poster Exhibition												●				
6	Submission of Dissertation														●		
7	Submission of Project																●

● Suggested milestone

■ Process

APPENDIX B

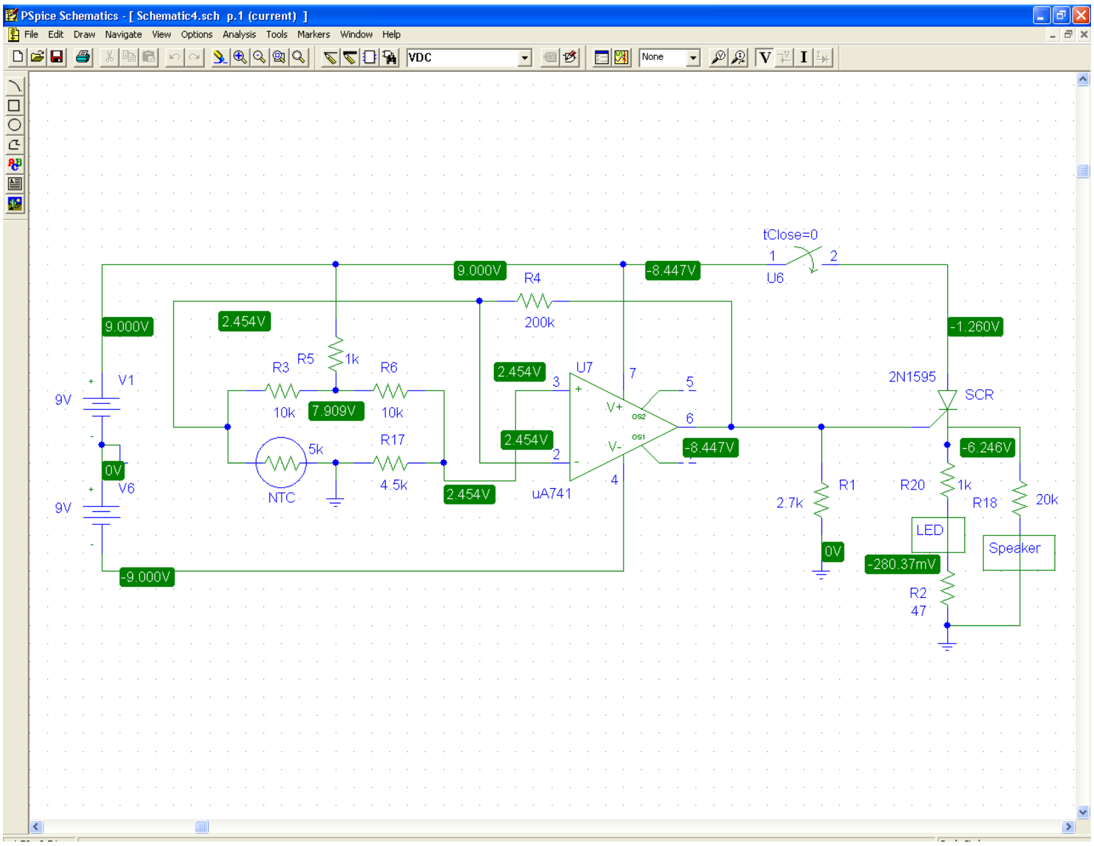
ORCAD PSPICE SIMULATION CIRCUITS

<u>Case 1</u>

NTC Resistance: 5k Ω

Potentiometer Resistance: 4.5k Ω

OpAmp output: -8.447 V

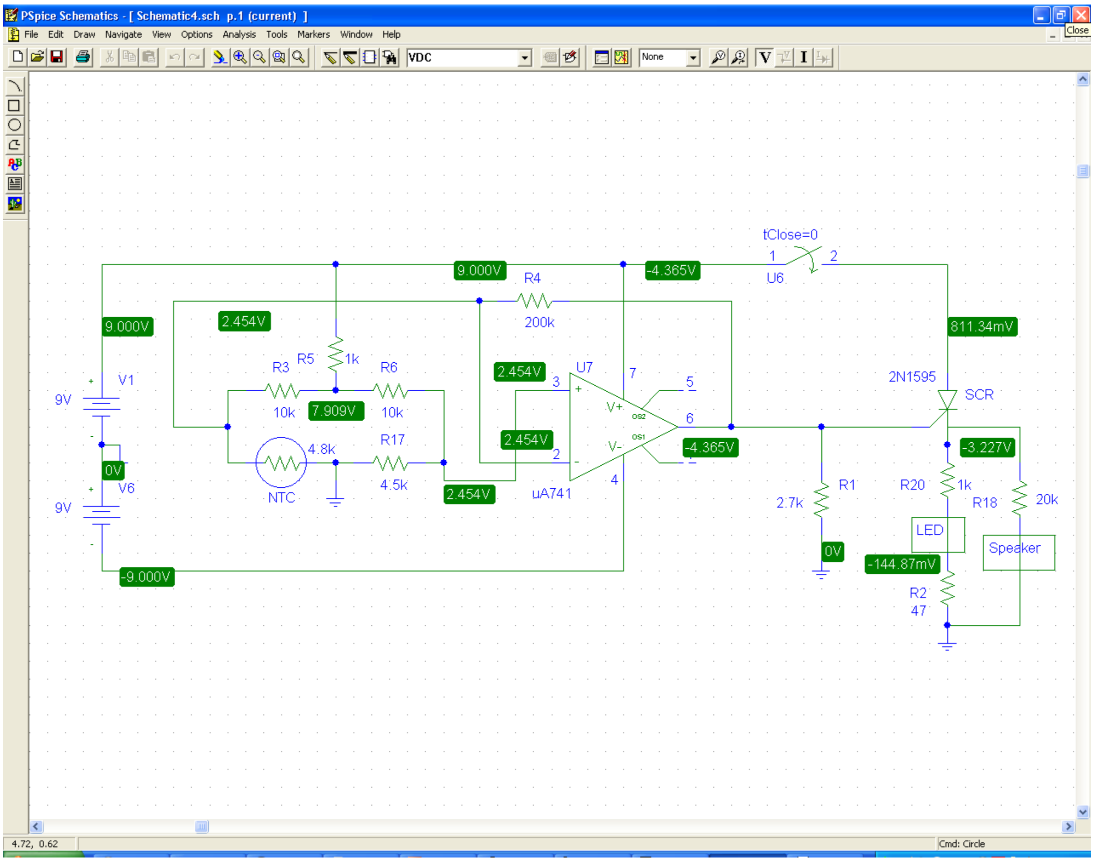


Case 2

NTC Resistance: 4.8k Ω

Potentiometer Resistance: 4.5k Ω

OpAmp output: -4.365 V

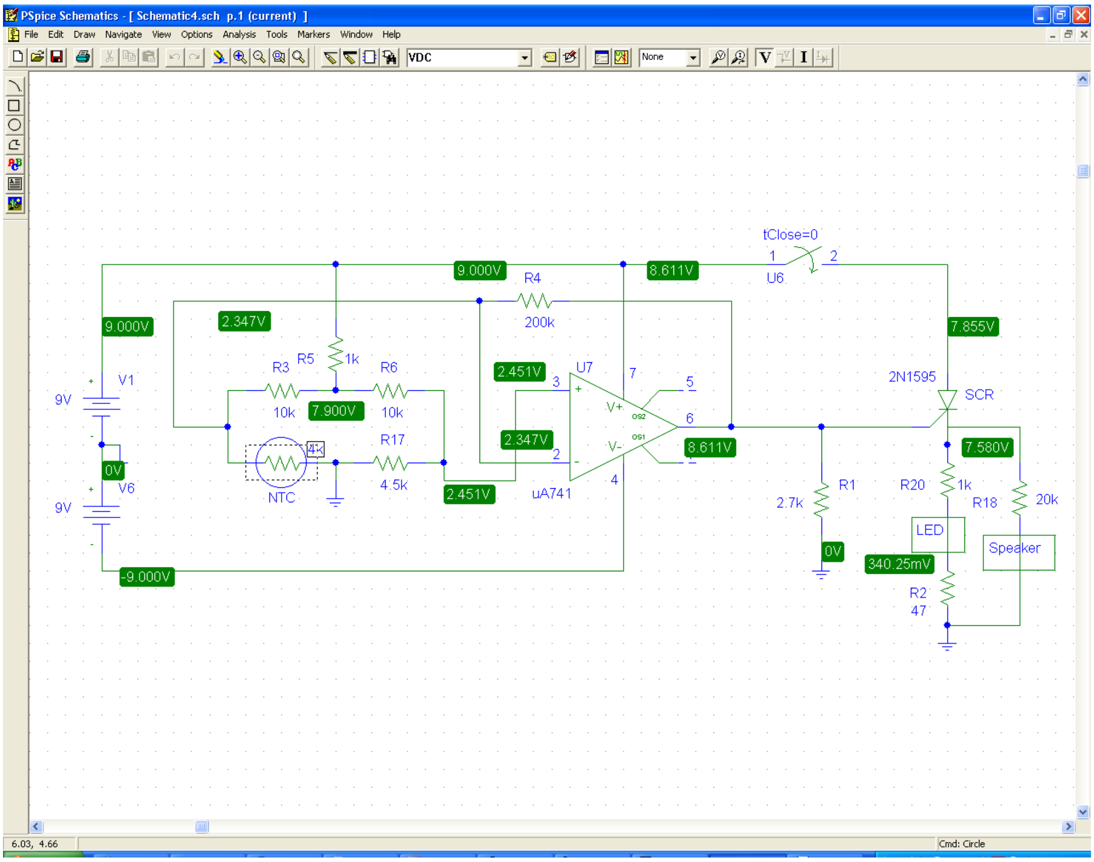


Case 3

NTC Resistance: 4k Ω

Potentiometer Resistance: 4.5k Ω

OpAmp output: 8.611 V

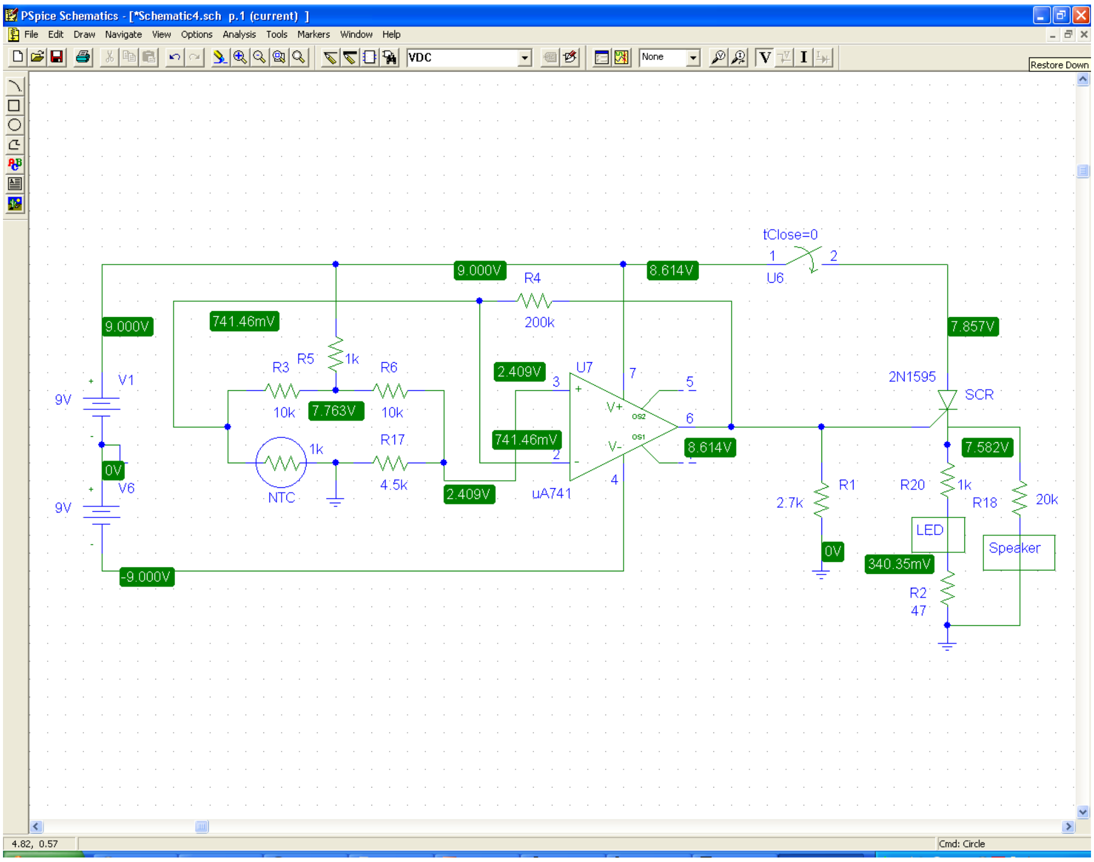


Case 4

NTC Resistance: 1k Ω

Potentiometer Resistance: 4.5k Ω

OpAmp output: 8.614 V



APPENDIX C

SIMILAR PRODUCTS IN INDUSTRY

There are a lot of manufacturers and service provider offered the monitoring systems for motor driven machineries in their product range including:

- GE Digital Energy
- Siemens
- ABB

Most of the products from these companies are very complicated and very precise in motor's health diagnosis. Being very complicated and accurate, the monitoring system for one (1) motor may cost thousands of dollars. Few examples of monitoring system for medium sized motor protection from GE Digital Energy: [20]

1) 239 Motor Protection System

239 Motor Protection System (GE Digital Energy)

The 239 Motor Protection relay is designed to provide protection and control to small to medium size motors. The additional monitoring features include in this system is to protect associated mechanical equipment from damage resulting from motor abnormalities.

Cost: $2,910.15 / system

2) M60 Motor Protection System

M60 Motor Protection System (GE Digital Energy)

The M60 is a full featured relay designed for the protection and management of medium and large horsepower motors which incorporates advanced features such as an enhanced thermal model, standard and custom thermal limit curves, and current unbalance biasing, running and stopped exponential cooling curves, optional RTD modules, and hot/cold motor compensation.

Cost: $6,950.00 / system

3) 469 Motor Protection System

469 Motor Protection System (GE Digital Energy)

The 469 Motor Management Relay is intended for protection and management of medium and large horsepower motors and driven equipment.

Cost: $5,757.79 / system