Generator Status Monitoring System

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A project report submitted to the Department of Electrical Engineering, University of Cape Town, in partial fulfilment of the requirements for the degree of Bachelor of Science in Engineering.

Cape Town, October 2005

Declaration

I declare that this project report is my own, unaided work. It is being submitted for the degree of Bachelor of Science in Engineering in the University of Cape Town. It has not been submitted before for any degree or examination in any other university.

Signature of Author . . . .

Cape Town

18 October 2005

Abstract

The purpose of this project is to design and install part of the monitoring electronics required to monitor the status of a Dassaults 400Hz generator system. The temperature of the generator casing heatsink and pressure of the generator air cooling system need to be monitored. The results must be transmitted from the generator by wireless connection to a lab where the monitored characteristics are to be displayed. Research was done to find the most suitable and available components to satisfy the requirements.

The temperature of the generator casing heatsink is fully installed and operational, producing an accurate temperature output reading which is displayed to the user. The air pressure monitoring is designed and operational but not installed because the cooling system has not arrived at UCT yet. Further research and design was done to complete other areas of the monitoring system not stated in the scope of the project.

Acknowledgements

I would like to extend a special thanks to Professor Mike Inggs who supervised the progress of the project. His invaluable advice was of great assisstance.

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List of Symbols

Hz	Hertz
MSc	Master of Science
^{o}C	Degrees Celcius
Pa	Pascals
A	Ampere
AC	Alternating Current
LCD	Liquid Crystal Display
RF	Radio Frequency
ADC	Analog-to-Digital Converter
UHF	Ultra High Frequency
Comms	Communications
LSB	Least Significant Bit
I/O	Input/Output
+ve	Positive

Nomenclature

Potential products—The products that satisfy the minimum criteria.

Asynchronous communication—Serial communication without the use of a clock line.

Multiplex—To combine multiple signal lines into a single line where the input lines can be individually recovered.

Chapter 1

Introduction

Status monitoring of machines forms an essential part of machine operation. It helps to maintain the safe operation of the machine and protect its immediate surroundings. Operating characteristics can be logged over time to produce a history of the machine. The operating history is analysed for patterns in component failure. This helps to determine where faults are or will most likely occur next. This allows necessary maintenance to be planned and performed before component failure. In the event of an unexpected fault detected by the monitoring electronics, a user or computer can take the necessary action to fix the problem or prevent damage from occurring. The monitoring of a machines status is therefore a vital safety and maintenance requirement.

1.1 Background

A Dassaults 400 Hz generator was removed from an aircrafts fuselage. Its purpose is to provide power to aircraft flight instrumentation and radar systems on the ground. The generator needs to be constantly monitored for changes in chassis temperature, ventilation cooling air pressure and electrical outputs. The monitoring equipment did not accompany the generator on exchange of ownership and needs to be redesigned and installed. A cooling system is also being designed and installed as an MSc dissertation.

The Dassaults generator is currently being kept in the Machines lab, 3rd floor, Menzies building, and is soon to be moved into a wooden shed outside room 609, 6th floor, Menzies building. The generator will be susceptible to rain leaks and dampness in the shed. The generator load will also be located on the 6th floor, in the Microwave lab. The generator status needs to be displayed to viewers in the Microwave lab, while the monitoring is done in the shed. The communication method between the shed and Microwave lab is not important, however the reliability of the communication link is essential.

1.2 Requirements Review

The aim of this project is to design and build part of the monitoring electronics for the Dassaults 400 Hz generator. The monitoring electronics monitors the status of the generator and conveys the information with minimal error to the user in the Microwave lab. The microcontrollers interpret the generator status and react accordingly to ensure that the generator operates within its safe limits. The standards by which the generator is monitored are:

- The operating temperature of the generator is measured and displayed to the user in the Microwave lab. The temperature limits are 0 ^{o}C & 80 ^{o}C with a ± 2 ^{o}C tolerance.
- The cooling air pressure (gauge pressure) of the cooling system is measured and displayed to the user in the Microwave lab. The pressure limits are 500 & 3700Pa with a $\pm$10Pa tolerance.
- The current supplied to the prime mover and load circuitry is monitored and displayed to the user. The current limits are 29 - 35A and 40 - 45A respectively. (Completion of the current circuit implementation is not required for this project).

Suitable temperature, pressure and current sensors are chosen that range more than the acceptable limits of the generator. The sensors are reliable, robust, consistent and stable in their output readings and have a relatively quick response time. The sensors measure the temperature of the generator casing heatsink, the cooling air pressure inside the ventilation ducting and the AC current that supplies the prime mover (induction motor) and load circuitry.

The generator is kept in an outside shed where the possibility of rain leaks and dampness pose a potential problem. The sensing hardware is therefore suitably protected from possible water leaks (see sections 2.1.1 to 2.1.3 for details on how the sensors are protected). The installation and operation of the sensors and the accompanying electronics do not affect the running of the generator. Vibrations of the generator do not affect the hardware and measured results.

The output temperature, pressure and current readings are displayed to the user in the lab on an LCD screen. In the event of an excursion, where the temperature, cooling pressure or current exceeds their limits, the controllers interpret and shut down the generator system. In addition, a buzzer will sound and the LCD screen will inform the user of the parameter that caused the shutdown.

Two circuit breakers are required to complete the generator monitoring system. Research and purchase of the circuit breakers and current sensors are not required for this project.

1.3 Concept Study

Most of the hardware is kept in the shed. The sensor readings are transmitted to the Microwave lab where the user can view them. A systems flow diagram (refer to Figure 1.1) shows how the system is arranged.

The mains voltage provides power to the prime mover (induction motor) via a circuit breaker. The prime mover drives the rotor of the generator, which provides power to the load via a second circuit breaker. An air-cooling system cools the generator. The microcontroller in the shed controls the monitoring and transmission of the sensor data to the RF transmitter. The data is received by the RF receiver in the lab. The data is converted into decimal format by the second microcontroller before it is displayed on the LCD screen in the lab. The microcontrollers also control the starting and stopping of the entire system.

A collection of reliable sensors is used to convert the physical variables: temperature, pressure and current, into electrical signals. These analog signals are amplified where necessary to produce an appropriate voltage that is fed into the ADC of the microcontroller. The microcontroller interprets the digital signals and if they exceed the preset limits it will cause a sequential shutdown of the generator.

The shutdown sequence can be seen in Figure 1.2. First the user is informed that the shutdown process is about to begin by sounding a buzzer and displaying that the system is shutting down. The cooling system is turned off first by applying logic 0 to its power supply. The load circuitry is then isolated from the generator by opening the load circuit breaker. Finally opening the mains circuit breaker isolates the mains supply to the prime mover and stops the generator. There is a 5 second time interval between the shutdown of each component. It is important that the shutdown is performed in this sequence to prevent damage to the machinery.

The microcontrollers have separate power supplies from the system being turned off so that they can:

- Inform the user that the shutdown procedure has begun
- Show the user what reading caused the system to shutdown.

Inspection and tests can then be performed to the suspected faulty area to determine the cause of the malfunction. Maintenance is then administered where required.

If however, the digital signals are within their limits, the system will not shutdown. Instead they will be multiplexed to the RF transmitter, where they are broadcasted via an antenna in the shed. The receiver antenna picks up the signal in the lab and sends it to the second microcontroller. The final temperature, pressure and current values are scaled and reproduced in this microcontroller and displayed on an LCD screen.

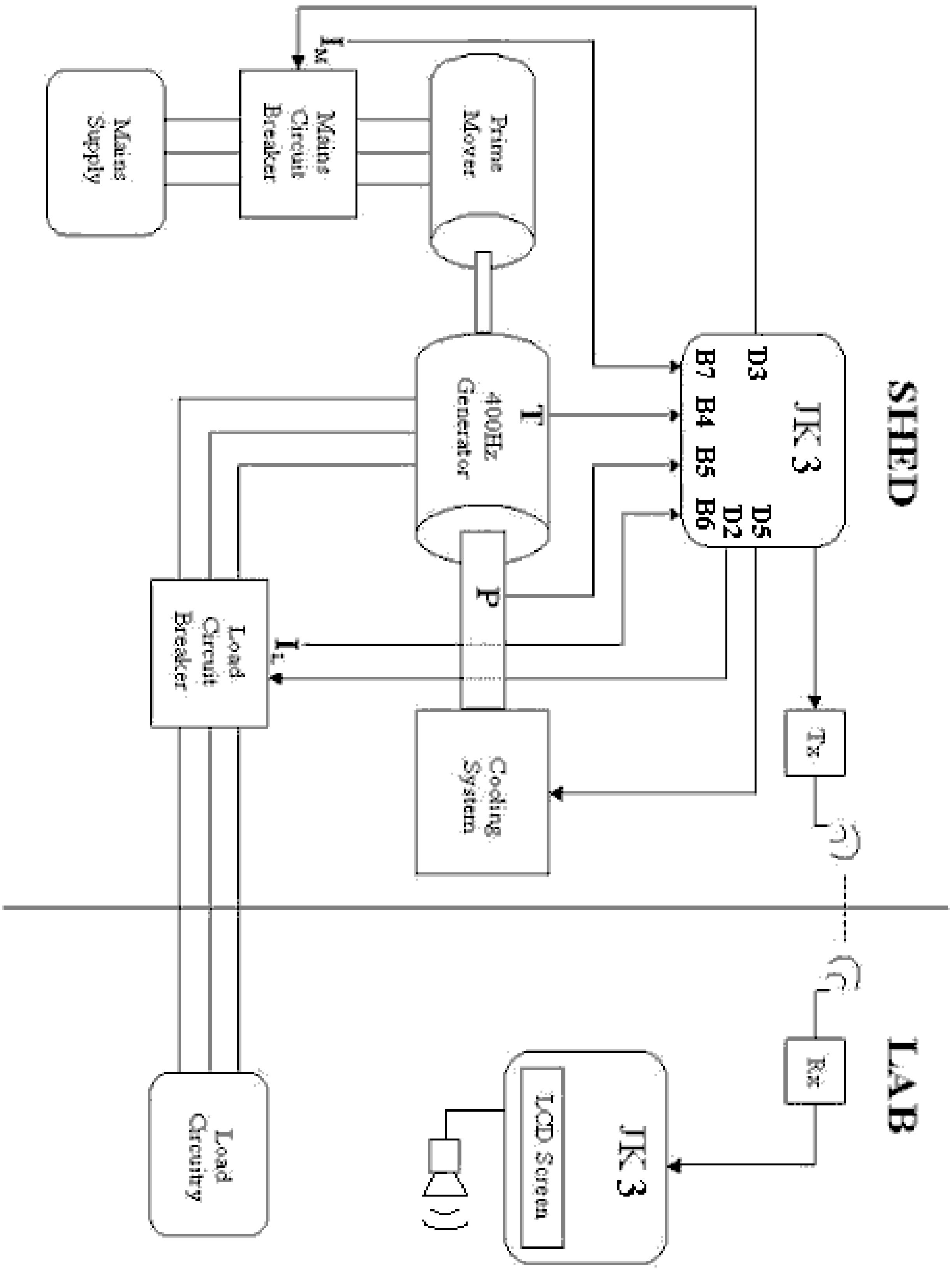

Figure 1.1: Systems Flow Diagram

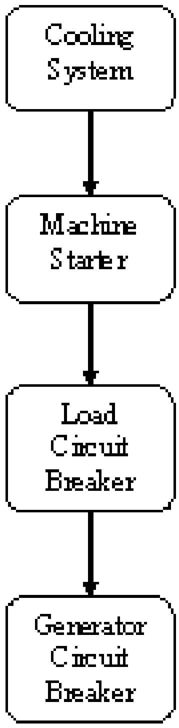

Figure 1.2: Shutdown Sequence

1.4 Project Plan

A brief description of each chapter follows:

Chapter 2: The literature review deals with the investigation into the selection of suitable components to satisfy the design requirements. The system requires that reliability and consistency be of utmost importance. A selection of possible options is explored for specific components. The most appropriate device is then selected. Possible errors are also researched and detailed in this chapter.

Chapter 3: This chapter details the software design implementation. An overview of the code and flow chart is carried out. The microcontrollers are programmed using assembler code.

Chapter 4: The hardware implementation of the sensors, their circuitry and the testing and calibration therein are discussed in this chapter.

Chapter 5: The results of the tests performed on the sensors and microcontrollers are detailed in this chapter.

Chapter 6: Possible future improvements are discussed in the recommendations chapter.

Chapter 7: The conclusion summarizes the achievements and important findings in this project.

Chapter 2

Literature Review

The hardware selection process is fundamental for implementing a system that provides accurate information that is efficiently controlled and communicated with minimal error. Thorough research forms a vital part of assessing what components are locally available and whether they are the most suitable part for the system. For this project, location and availability of the components are the most concerning factors. Once the potential products are researched, they are assessed and filtered to ascertain which component is the most suitable. The components required for this project are listed below:

- 4 Sensors
- 2 Microcontrollers
- ADC
- LCD
- Buzzer
- Wireless data transmitter and receiver
- 2 Circuit breakers

2.1 Sensors

The generator and cooling system have four critical characteristics that are monitored to ensure safe operation. These are the:

- Generator operating temperature
- Cooling system air pressure

- Load circuit breaker current
- Mains circuit breaker current

The safe operation limits for these four sensors are determined in the *Auxilec Technical Generator Manual, section 1, Characteristics* [2] (Refer to section 1.2 for the safe operation limits).

When deciding on what sensors to use, characteristics such as the reliability, robustness, protection, accuracy, linearity and stability are considered. These help pro-long the life of the sensor and produce better quality results.

It is important to remember that all sensors have errors. One such avoidable error is the calibration history of the sensor. A preferable sensor is one that does not need to be calibrated, but this is not always possible. Without the knowledge of the last calibration date, it is not possible to tell how close the reading obtained is to the actual value on the system. It is also important to know the standard against which the sensor is calibrated [8].

2.1.1 Temperature Sensor

The essential criteria for the temperature sensor measuring the generator operating temperature are:

- Range: 0°C - 80°C
- Minimum ± 2°C accuracy

A large number of sensors satisfy the essential criteria stated above, so a list of additional favourable features is drawn up to help filter out the less appropriate sensors for this system. The additional favourable features are as follows:

- No calibration
- Stable output
- Protection from water leaks and dampness
- Minimum heat transfer loss
- Immunity to vibrations
- Reliability

The additional features filtered out the temperature sensing ICs LM75, LM78, DS1621, LT1392, MAX1617 and the standard probe PT100 sensor. The two most suitable sensors that are extensively researched are the LM35 and the TS2229.

The TS2229 is a specialised PT100 temperature sensor that is specifically designed for measuring the casing temperatures of electric machines. The datasheet is available in Appendix B. The advantage that the TS2229 sensor has over the LM35 with reference to this project is that it has PUR cables that protect it from coolants and lubricants. This is particularly important considering the environment in which the generator is stored.

The LM35 is the ideal component because it satisfies all of the above criteria, with the exception of the cable protection. The legs of the sensor are covered with shrink-wrap after the wires have been soldered on. This prevents liquids from interfering with the measured temperature result. The LM35's output voltage is linearly proportional to the temperature measured in °C. For every 1°C increase in temperature, the output voltage increases by 10mV. This is convenient because no circuitry is required before inputting the analog signal into the ADC (For further explanation refer to section 3.3.3). Furthermore, the software required to convert from a digital signal to a BCD representation of the temperature is simple. The LM35 does not require external calibration. It comes in 3 different packages (refer to Figure 2.1): the hermetic TO-46 transistor package, the plastic TO-92 transistor package and the plastic TO-220 package. The TO-46 package is the least suitable option. The temperature is determined by the entire metal body in this package. This is not suitable for connecting to a heatsink because the surrounding air temperature will manipulate the temperature measurement. The TO-92 package is very common and is available in the white lab at UCT, and although the TO-220 package is not readily available, it is the preferable option. It can be purchased from the manufacturer. The datasheet is available in Appendix B.

The TO-220 package has a hole in its backing-plate so that it can be screwed onto the mounting surface, providing a good heat conduction interface. Another option commonly used is to glue the sensor onto the mounting surface. The thermal path of the TO-220 package is through its metal backing-plate. The TO-92 package provides its thermal path through its leads, which are glued to the heated surface. The leads provide a small thermal conduction surface which means that it is not very sensitive to changes in temperature. The TO-220 package is more sensitive to temperature changes because it has a larger thermal conduction path that comes in direct contact with the heatsink.

The measured temperature error of the LM35DT (TO-220 package) varies between a guaranteed maximum value of 1.5 - 2°C as the temperature changes over its range of 0 - 100°C (refer to Figure 2.2). The typical error value obtained from testing is ± 0.8°C over its full range (refer to the datasheet in Appendix B). This guarantees accuracies within the acceptable limits.

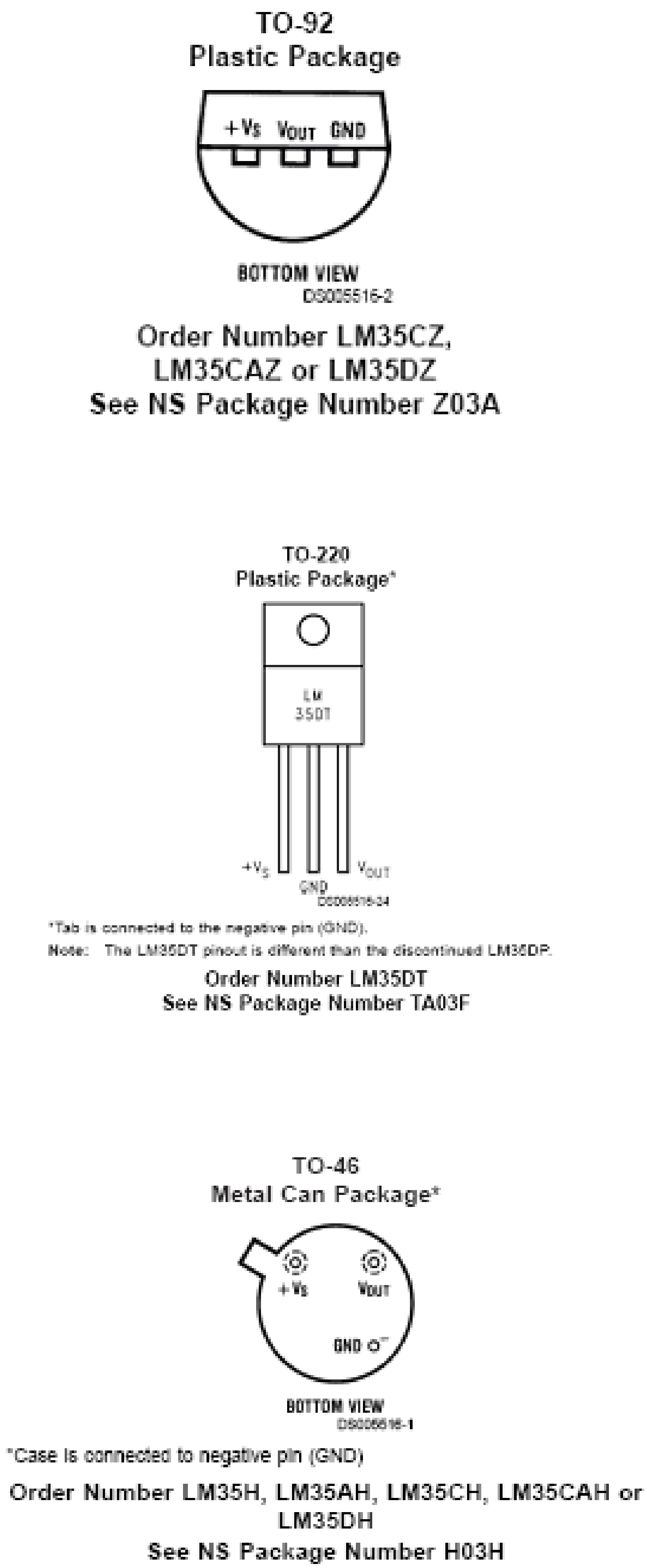

Figure 2.1: LM35 Packaging

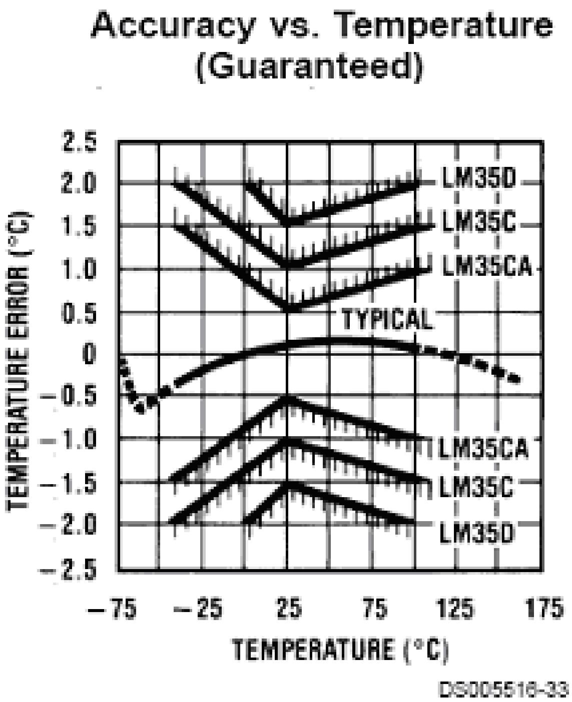

Figure 2.2: Accuracy vs. Temperature (Guaranteed)

2.1.2 Pressure Sensor

The pressure sensor measures the cooling air pressure of the cooling system. The cooling duct is designed to accommodate the pressure sensor. The sensor is firmly mounted onto the inside wall of the duct and safe from possible vibration or leakage damages. The fundamental criteria required of the pressure sensor are:

- Range: 500 - 3700Pa Gauge pressure
- Minimum $\pm$10 Pa tolerance

The two most suitable pressure sensors that are readily available from *RS Components, Cape Town* [4] are the 24PCAFA6G and the 26PCAFA6G gauge pressure sensors. They have a silicon diaphragm and unique conductive seal to increase reliability. They both have ranges of 0 - 1 psi (= 0 - 6900 Pa) and require a supply voltage of 10V DC. Neither of them require external calibration. Their data sheets is available in Appendix B.

The 26PCAFA6G has better guaranteed specifications than the 24PCAFA6G. It has guaranteed long-term stability, low hysteresis effects, and high output repeatability. It is therefore the preferable sensor for this application. The 26PCAFA6G pressure sensor has an output voltage of 0 - 16,7mV over its full range. This is very small and is therefore amplified 488 times to increase the range before it is fed into the ADC. The reason for this is explained in section 3.3.4. Figure 2.3 is a picture of the pressure sensor.

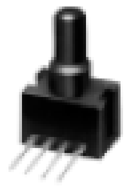

Figure 2.3: 26PCAFA6G Pressure Sensor

2.1.3 Current Sensor

The research, design and implementation of the current sensing electronics is not required for this project, although some research was done into finding a suitable current sensor. The requirements for the sensor are:

- Measure AC current
- Ranges: 29 - 35A and 40 - 45A

A current sensor, the LAH 50-P (LEM Module), is suitable for this application. It measures AC current and provides a galvanic isolation between the primary and secondary circuits. The primary circuit is the load and mains current and the secondary circuit is the electronic circuitry that produces the sensor output. The LAH 50-P has a measuring range of 0 - 50A and requires a supply of ± 12 or ± 15V. An output current of 0 - 25mA represents the input current. Other relevant features are:

- Excellent accuracy
- Very good linearity
- Low temperature drift
- High immunity to external interference

No external calibration is required for the LAH 50-P. It will be protected from water when installed by placing it inside a sealed case, which will have holes for cables. The datasheet is available in Appendix B. A graphical representation of the current sensor is shown in Figure 2.4.

2.2 Circuit Breakers

The research, design and implementation of the two circuit breakers is not required for this project. However, the required criteria for the circuit breakers are:

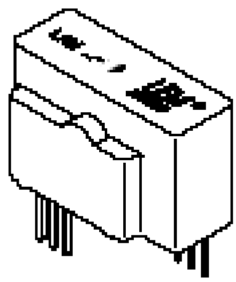

Figure 2.4: LAH 50-P Current Sensor

- Withstand a current of up to 50A
- Have digital interface
- High reliability

The circuit breakers are activated and de-activated by the microcontroller so they need to have a digital interface through which they can be controlled. Reliability is very important. The circuit breakers are safety equipment and therefore must operate properly at all times. They will need to be protected from water.

2.3 Transmitter & Receiver

The transmitter and receiver pair is an important feature of the monitoring electronics system. The transmitter and receiver are required to transmit and receive the digital sensor data between the shed and Microwave lab. The transmission link is a section where possible data loss and modification can occur. Therefore reliability of transmission is the most important characteristic required. The requirements are:

- Reliability of transmission
- Minimum range of 20m indoors
- Have TTL logic compatability

The Radiometrix TX2 and RX2 radio transmitter and receiver pair is suitable for this application because of its high reliability history [1]. The datasheet is attached in Appendix B. The operating frequency is 433.92 MHz, which is in the UHF band. The transmitter and receiver are powered by a 5V supply. The frequency used does not interfere with the other equipment. An average range of 50m indoors is achieved [1] and the data is transmitted at 14kbps. The input to the transmitter accepts a serial stream of TTL logic data and outputs the same stream from the receiver.

The transmitter and receiver require a pair of antennae to broadcast the data. The 3dB PW Series $\frac{1}{4}$-wave whip antennae, available with the transmitter and receiver pair, are suitable for this project. The datasheet is available in Appendix B.

2.4 Microcontroller

Two microcontrollers are required in this project. This first one receives the digitized sensor data and process' it to ascertain whether the generator system is operating within its safe limits. It then outputs a serial data stream to the second microcontroller via the wireless RF connection. The second microcontroller receives the transmitted data, converts the data into decimal format and displays it on the LCD screen.

The requirements of the first microcontroller are:

- ADC with multiplexer
- 4 input pins
- 7 output pins
- Serial communication

The requirements for the second microcontroller are:

- An LCD
- 1 input pin
- 7 output pin
- Serial communication

The function of the I/O pins is detailed in Chapter 3, Table 3.1.

The 20-pin Motorola MC68HC908JK3 is the chosen microcontroller. It is ideal because it satisfies all of the above requirements and is available at UCT. It has 4096 bytes of flash memory, which is sufficient to accommodate the software. There are 15 I/O pins on ports B and D, and an 8-bit ADC multiplexed over 12 channels. The datasheet is available in Appendix B. The Motorola board designed by Mr. S Ginsberg is designed to accomodate the MC68HC908JK3. It has a built-in ADC with multiplexer, LCD screen and compiler with the relevant electronics. This board will thus be used.

2.5 Errors

The wires are kept as short as possible to reduce errors when transmitting the sensor outputs to the ADC.

2.5.1 Analog-to-Digital Converter Errors

Resolution: The resolution of an ADC indicates the number of digital values it can produce. The ADC on the Motorola board is 8-bit therefore it can produce 256 digital values, since $2^8 = 256$. Each of the digital values represent an equal voltage of 0.01953125V, because the ADC range is 0 - 5V.

Quantization: Quantization is the process where the continuous range of values of an analog signal is sampled and divided into subranges by an ADC. A unique digital value is assigned to each subrange [6]. Figure 2.5 represents the quantization of x using Q(x) = floor((Lx) / L). This introduces a small error known as the quantization error. Quantization error is defined as the difference between the analog voltage and its digital representation [7].

Accuracy: The accuracy of an ADC is specified in terms of its total error. If the digital output of the ADC ideally changes from state (k-1) to state (k) when VIN = kδV (where δV is the voltage represented by each ADC increment), then the total error is the maximum difference between the actual VIN and the theoretical VIN [3]. In Figure 2.5, the total error is the maximum deviation of the digital output from the ideal straight line.

Linearity: Figure 2.5 shows the linearity line. This line represents the voltage deviation of each incremental step from the theoretically calculated voltage. The voltage deviation of the linearity line from the ideal line is called the linearity error [3].

2.5.2 Wireless Transmission Errors

Data corruption occurs if an interfering signal collides with the original signal. This results in an insufficient signal-to-noise ratio at the receiver. Error detection techniques are used to reduce the amount of noise. An example of this is cyclic redundancy checking. This detects a limited amount of transmission corruption and causes the signal to be sent again. This method causes considerable delays [9].

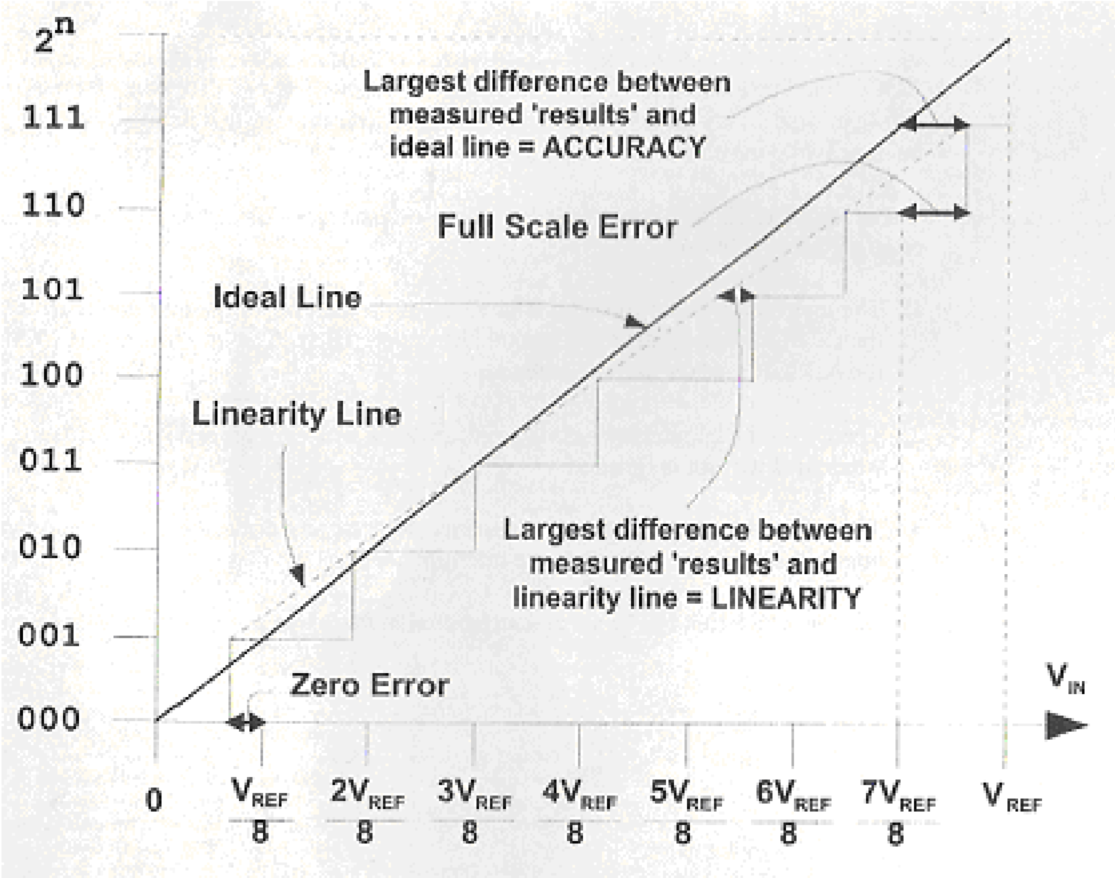

Figure 2.5: Quantization Process

2.6 Summary

A summary of the components chosen is displayed in Table 2.1.

Table 2.1: Summary of Components

	Name	Range	Output
Temperature Sensor	LM35DT	0 - 100°C	10mV/°C
Pressure Sensor	26PCAFA6G	500 - 6900Pa	0 - 16.7mV
Current Sensor	LAH 50-P	0 - 50A	0 - 25mA
Transmitter & Receiver	Radiometrix TX2 & RX2	50m indoors	NA
Microcontroller	MC68HC908JK3	NA	NA

All the above components have been purchased with the exception of the RF transmitter and receiver pair and their antennae. Therefore, as a substitute, a cable link is implemented between the two microcontrollers. The data is now serially transmitted across the cable instead of being transmitted via a wireless system.

Chapter 3

Software Design

The microcontroller software forms the control section of the monitoring system. Its function is to analyze and react to the data received from the sensors. It decides whether the system is operating within its safe limits and causes a sequential shutdown if it is not. The two microcontrollers, Motorola MC68HC908JK3s, are programmed using assembler code. Copies of the code are attached in Appendix A.

The wireless link is not installed because the order for the components was not processed by RF Design, so a serial communications link is installed. The serial communications link between the two microcontrollers works by sending a byte of data across a cable. This method is known as bit banging. 9 Bits of data are transmitted. The first bit is a start bit represented by pulling the serial line high. The start bit is required to indicate to the receiver that the data byte is following. The receiving pin loops infinitely until it has received the start bit and the data byte before exiting the *get_serial* subroutine. There is no stop bit. The communication link is asynchronous, so the serial transfer only works if the receiving microcontroller is waiting in its *get_serial* subroutine for the data transfer. The sending subroutine, *put_serial*, is then run to send the data to the receiver. They both exit their routines after sending or receiving the data. This disadvantage complicates the program slighty, but is solved by placing a 1 second delay before the *put_serial* subroutine. This gives the receiving end enough time to run the *get_serial* subroutine before the data is transmitted.

3.1 Microcontroller 1

This microcontroller is in the shed with the generator system. Table 3.1 provides information on the location and function of the I/O pins utilized. On port B, bits 4 - 7 are the sensor output signal inputs. These pins are multiplexed to the 8-bit ADC that converts the 0 - 5V input signal into a digital number. The serial communications output is port B bit 0. The control outputs, which turn the generator system on and off, are port bits D2, D3 and D5. The ADC module requires three pins, which are allocated to port B, bits 1 - 3.

Figure 3.1 shows the software flow diagram for microcontroller 1. The software starts by turning on the generator system. First the cooling system is activated and then the load and mains circuit breakers are opened respectively. The program delays for 1 second to ensure that the receiving microcontroller is waiting in the *get_serial* subroutine for the start bit to arrive. A code is then sent to the receiving microcontroller to tell it which sensor data is about to be sent across. The hexadecimal number 01_{16} indicates that the temperature data is following, 02_{16} indicates pressure, 03_{16} indicates load current and 04_{16} indicates mains current. If 05_{16} is sent then the receiving microcontroller will know that the shutdown sequence is activated and can inform the user. The relevant data is then converted into a digital signal and sent to the receiver, depending on what code was sent. After the data is transmitted across, it is compared to its limits (Refer to section 1.2) to see if the system is still operating safely. If it is, then the program sends the next code to the receiver and the next set of data. After the mains current signal code, 04_{16}, and signal are sent, the software begins the loop again with the temperature code, 01_{16} .

If the safe operating limits are exceeded, the shutdown sequence is initiated. Initially the code 05_{16} is sent to the receiver and the cooling system is turned off. The load circuit breaker is then activated and finally the mains circuit breaker is activated. The program waits in this state until the reset button is pressed to begin the program again.

Table 3.1: I/O Functions and Allocations

	Microcontroller 1 (Shed)			**Microcontroller 2 (Lab)**		
		Port	**Pin**		**Port**	**Pin**
Inputs	Temperature	PTB4	11	Serial Comms	PTB0	15
	Pressure	PTB5	8	——-	—	—
	Load Current	PTB6	7	——-	—	—
	Mains Current	PTB7	6	——-	—	—
Outputs	Serial Comms	PTB0	15	Buzzer	PTD3	16
	Cooling System	PTD5	18	LCD	PTD6	10
	Load Circuit Breaker	PTD2	17	LCD	PTD7	9
	Mains Circuit Breaker	PTD3	16	LCD	PTB4	11
	ADC Load	PTB1	14	LCD	PTB5	8
	ADC Clock	PTB2	13	LCD	PTB6	7
	ADC Data	PTB3	12	LCD	PTB7	6

3.2 Microcontroller 2

This microcontroller is in the lab. Table 3.1 provides information on the location and function of the I/O pins utilized for this microcontroller. The serial communications input is port B bit 0 and the buzzer output is port D3. The LCD screen occupies port B bits 4 - 7 and port D bits 6 and 7.

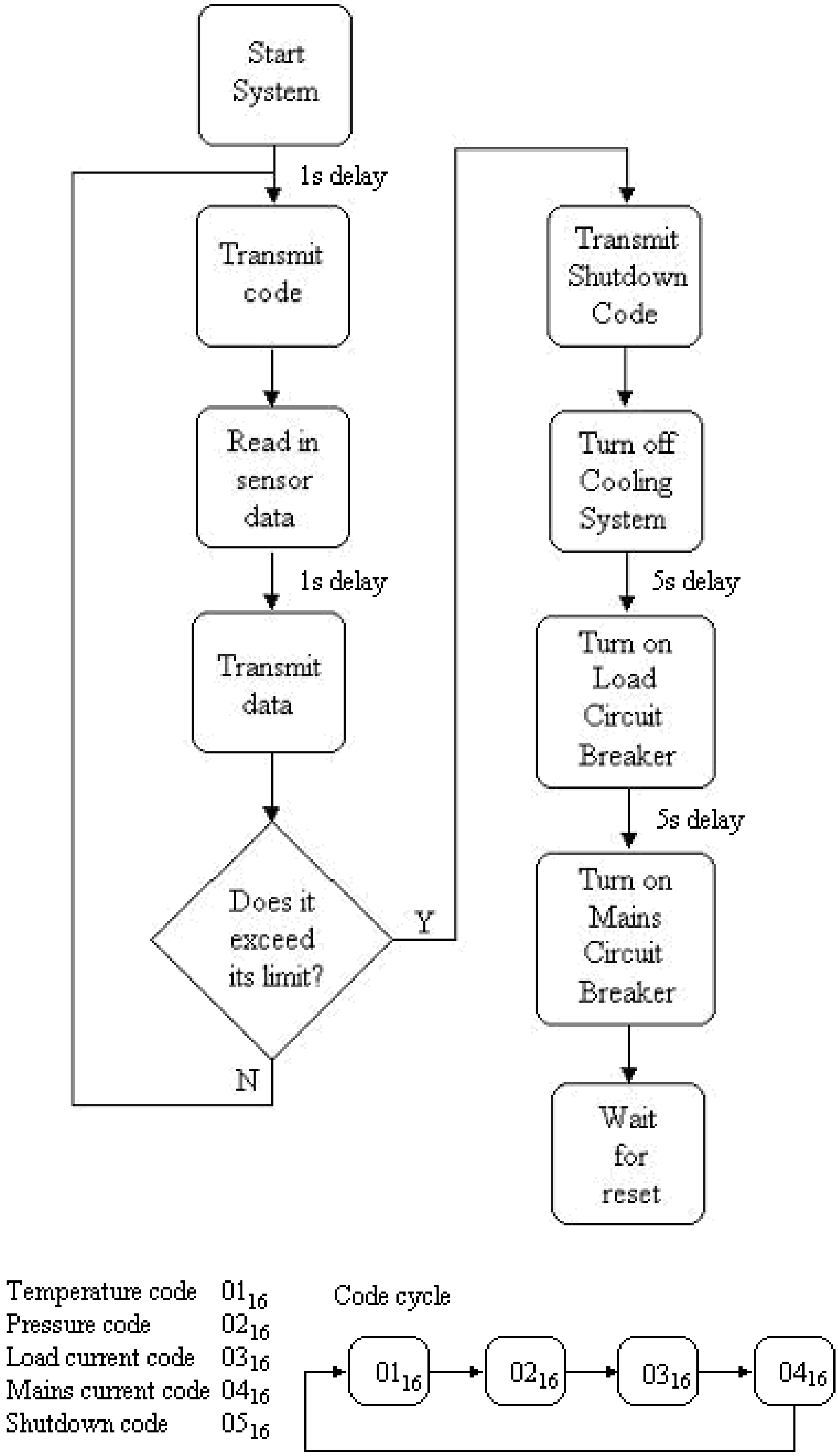

Figure 3.1: Microcontroller 1 Software Flow Diagram

Figure 3.2 shows the software flow diagram for microcontroller 2. The software starts by entering the *get_serial* subroutine and waiting for the code signal to be sent across. Once it has received the code it compares it to the 5 possibilities that it could be, namely 01_{16} to 05_{16}. The code value received determines which subroutine is run. If sensor data is to be received next, the respective routine is run. In each of the sensor data input subroutines, the *get_serial* subroutine is run. The program waits in this state until the data is sent. The amount of code executed between the receiving of the code data bit and the sensor data bit is kept to a minimum. This ensures that the time taken to execute the code is well under 1 second, which is the delay time between each signal transmission. Once the data is received, it is decoded and displayed to the user. The decoding process is explained in section 3.3. If the code is 05_{16}, the program informs the user of the shutdown and the statistic that caused the shutdown. A buzzer is activated and the program waits in this state until it is reset.

If the received signal does not match any of the 5 options, the LCD tells the user that the code data was not sent properly and returns to wait for the next data byte. Whether the code is sent properly or not, the next byte received will most likely be the sensor data and will produce another code error, after which a code byte is sent again and the program returns to its normal operation.

3.3 Decoding the data

Decoding the data is a complex process. It needs to be as accurate as possible to provide output readings with minimal errors. Certain limitations reduce the accuracy of the result. The first limiting device is the ADC.

3.3.1 The Analog to Digital Conversion

The ADC is an 8-bit successive approximation converter. It has 255 equal voltage increments over a voltage input range of 0 - 5V. This means that every 0.01953V increases the digital value by 1, starting at 0 and ending at 255. Therefore the sensor output voltage, after being scaled where necessary, ranges from 0 - 5V and is divided into 256 different numbers. To increase the accuracy, the sensor outputs are scaled by external electronic circuitry. Table 3.2 shows the sensor outputs, their corresponding scaled voltages and the error produced. The error is the change in sensor value for each increment in the ADC.

3.3.2 The Digital to Decimal Conversion

After the sensor output value is sent to the 2nd microcontroller in the lab as a digital number, it needs to be converted into decimal format before it is displayed on the LCD.

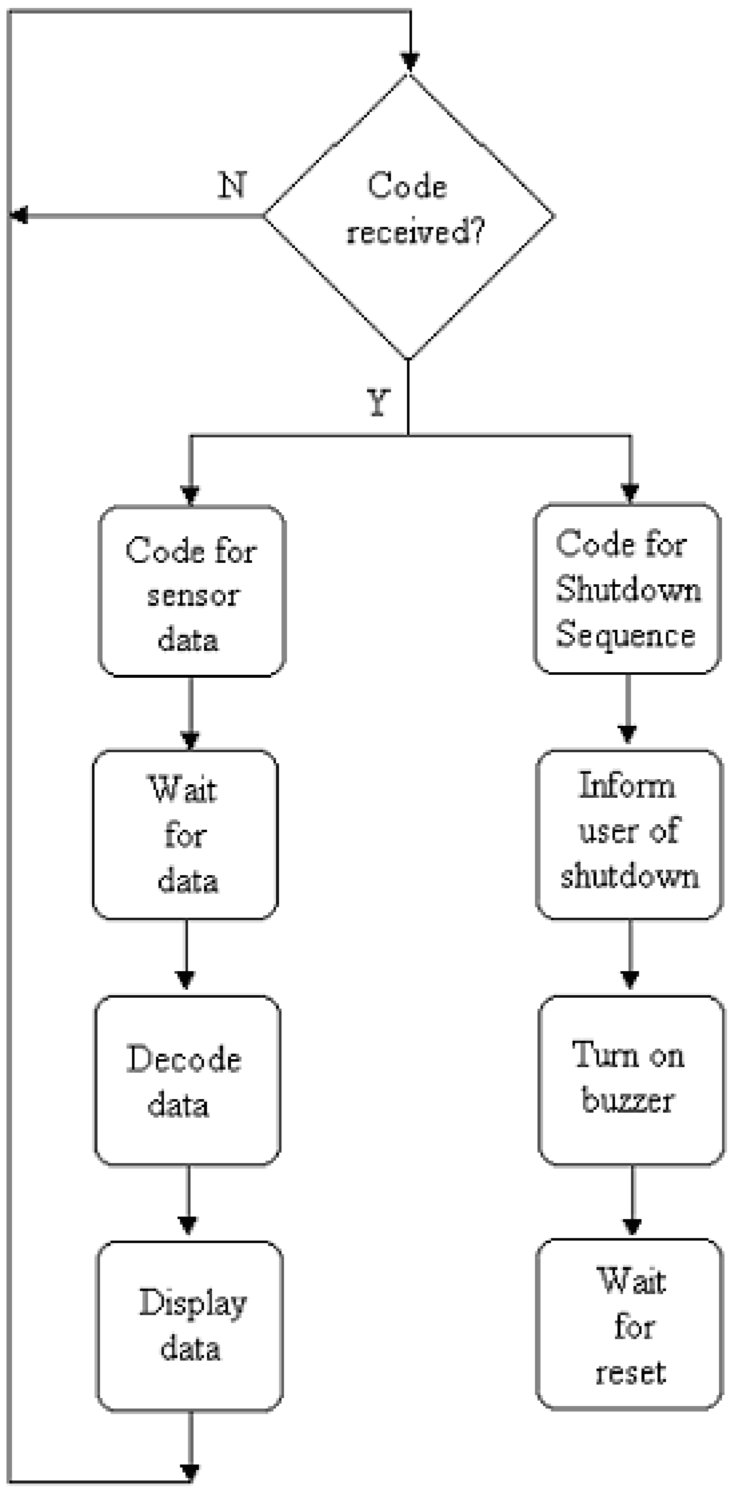

Figure 3.2: Microcontroller 2 Software Flow Diagram

The temperature conversion is simple, whereas the pressure and current conversion is more complicated. The method used in the pressure and current conversion is known as the bin method. It is explained in section 3.3.4.

3.3.3 Temperature

The temperature output voltage is fed directly into the ADC. Therefore, the total temperature range measured by the ADC is 0 - 500°C. The maximum temperature limit is set at 80°C (≡0.8V) in microcontroller 1. The operating temperature of the generator should never reach this upper limit. Thus only 16% of the ADC is being used. If the signal is amplified, a larger ADC input voltage range will result and the accuracy of the result will increase (i.e. each increment in the ADC will represent a smaller change in °C. e.g. If the input voltage signal is multiplied by 2, then each ADC increment will now represent a change of 1°C.) A non-linearity error is introduced by amplifying the sensor output signal. The amplification is never exactly equal over the entire range of input values, thus for an increase in accuracy of the result, a non-lineararity error is introduced, especially at the input boundaries. Thus, the option of amplifying the sensor output voltage is not implemented and the output voltage is fed directly into the ADC.

The binary to decimal conversion is simple because every 1°C increase in temperature causes the output to increase by 10mV. Therefore every increment of the ADC, approximately 20mV, represents a 2°C increase in temperature. Thus the digital number represents half the actual temperature. To solve this, multiply the digital number by 2 by using the ASL command. An error of 2°C results. The error introduced by assuming that each increment represents 20mV is very small and produces no significant deviation of the result from the ideal temperature.

3.3.4 Pressure

The pressure output voltage signal is amplified before it is fed into the ADC. Therefore the total pressure range measured by the ADC is 0 - 4204Pa. By measuring only a part of the full pressure sensor range, the accuracy increases. The maximum pressure limit, 3700Pa, now corresponds to 4.4V due to a gain of 488 by the external circuitry. Every increment of the ADC corresponds to 16Pa. This is explained in section 4.2.2. The ADC output digital number, multiplied by 16, produces the correct decimal result that is displayed on the LCD screen. The bin method is used to do this.

The bin method is based on the method of converting a binary number to a decimal number. To convert from a binary number to a decimal number, take the sum of 2^n, where n is the number of the bit that is set and the LSB is bit 0.

E.g.

- 0011 = $2^0 + 2^1$ = 3
- 0100 = 2^2 = 4
- 1010 = $2^3 + 2^1$ = 10

Four bins are used, one for units, tens, hundreds and thousands. Each bin is initially empty. Each bit of the binary number is checked to see if it is set or not. If it is set then a certain number is put into each bin. For example, if bit 0 (decimal number equals 2^0 = 1) of the pressure binary number is set then the pressure is 16 Pa, because each digital increment represents 16Pa. Therefore 6 is added to the units bin and 1 is added to the tens bin. If bit 1 is set then 2 is added to the units bin and 3 is added to the tens bin. If bit 2 is set then 4 is added to the units bin and 6 is added to the tens bin. If a bin reaches a value of 10 or more, then the next larger bin is incremented by 1 and 10 is reduced from the overflowing bin. In the example, if bits 0 and 2 are set (= 05_{16}), then the units bin overflows and becomes 0 and the tens bin becomes 8, which is equal to 80 = 16 + 64. Therefore the final pressure is 80Pa because the digital number was 05_{16}.

3.3.5 Current

The entire sensor current range, 0 - 50A, is measured by the ADC. The 25mA sensor output is fed into a 200Ω resistor and non-inverting buffer opamp circuit to produce a 0 - 5V output, which is fed into the ADC.

The bin method is used for the current conversion, except that each ADC increment represents a 200mA increase in the current. The digital signal, multiplied by 200, produces the output current value in mA. Refer to section 4.3.2 to find out how to calibrate the current sensors.

Table 3.2: ADC Incremental Error

	Operating Limits	**Corresponding ADC Input Voltage**	**No. of Incremental Steps**	**Error**
Temperature	0 - 80°C	0 - 0.8V	40	2°C
Pressure	500 - 3700Pa	0.53 - 4.4V	198	16Pa
Load Current	40 - 45A	4 - 4.5V	25	0.2A
Mains Current	29 - 35A	2.9 - 3.5V	30	0.2A

Chapter 4

Hardware Implementation

The implementation stage involves securing the sensors to the generator system, installing the microcontrollers and electronic circuitry, and performing initial testing and calibration of the devices.

4.1 Temperature Sensor Implementation

The temperature sensor is fastened to the casing heatsink using epoxy glue so that the metal backing plate touches the surface. Three wires are sent from the sensor to the microcontroller board. The wires are ground, +5V and the output voltage signal. The pin-out configuration is shown in Figure 2.1. The legs of the sensor are covered with shrink-wrap for protection. A 1μF polarized electrolytic capacitor is connected between the output signal and ground. This stabilizes the output signal.

The temperature sensor output signal is not scaled before it is sent to the microcontroller. The sensor does not require regular calibration, although it is tested for accuracy on installation. Two tests are performed, the results of which are discussed in section 5.1.

Test1:

Aim: To compare the temperature sensor output voltage to the temperature reading diplayed on the LCD screen.

Method: Convert the output voltage to its corresponding temperature by multiplying it by 100. Compare this reading with the temperature value displayed on the LCD screen. Turn on the generator system to increase the temperature of the heatsink and monitor the output voltage and temperature display changes. Determine the error between the sensor output voltage and the temperature displayed on the LCD screen.

Test2:

Aim: To compare the temperature reading on the LCD screen to that of the heatsink, where the temperature of the heatsink is obtained by a thermometer.

Method: Hold the thermometer on the heatsink until its temperature is that of the heatsink. (This is not a very accurate way of determining the temperature of the heatsink because the thermometer is not designed to read the temperature of a flat or finned surface. Nevertheless, this test is performed to attain some standard of accuracy.) Compare the temperature reading on the LCD to the temperature of the thermometer. Turn on the generator system and monitor the temperature changes. Determine the offset of the measured temperature to the actual temperature of the heatsink.

4.2 Pressure Sensor Implementation

The cooling duct has a designated hole in which the pressure sensor is placed. Although there are 4 legs on the sensor, only three wires are necessary. They are: ground, +10V and the output voltage. The pin configuration is displayed in Figure 4.1. The output (-) pin is connected the ground pin. This means that the output (+) pin is referenced to ground.

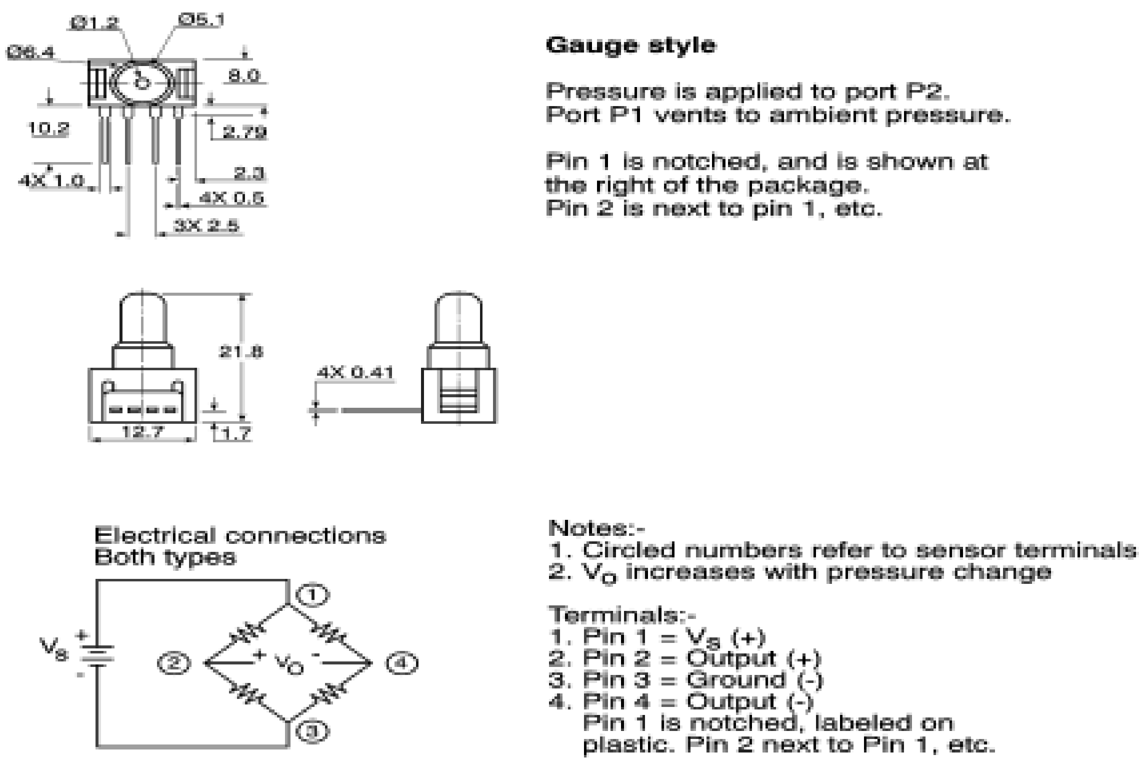

Figure 4.1: 26PCAFA6G pin configuration

4.2.1 The Non-Inverting Opamp Circuit

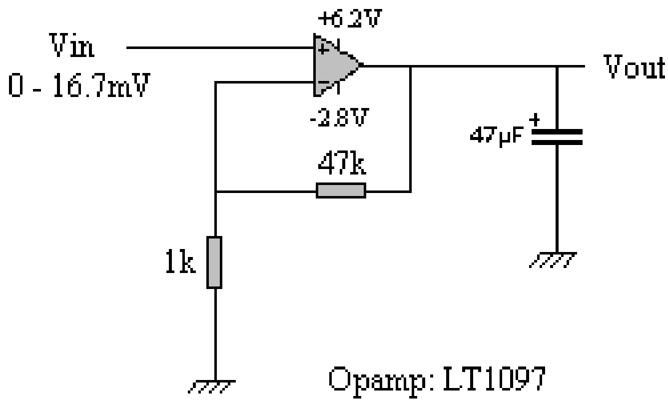

Figure 4.2: Non-Inverting Opamp Circuit

The sensor output voltage (Vin) is fed into a circuit to produce an amplified output. The circuit, Figure 4.2, is a non-inverting opamp. An LT1097CN8 opamp is used because of its low offset voltage. This is very important because the low input voltage signal from the pressure sensor is fed into the +ve input of the opamp. The opamp has a typical offset voltage of 10μV. The offset voltage, when amplified by the gain circuitry, outputs 4.88mV. This voltage is to small to have any major affect on the analog to digital conversion. The theoretical gain of the opamp is calculated as $\frac{470+1}{1}$= 471. In practise the measured gain is 488. The 47μF polarised capacitor is required to stabilize the output voltage. The opamp needs to be able to output any voltage including and between 0V and 5V. A split supply is required (if a single 0 - 5V supply is used the opamp would not be able to saturate at the required 0V and 5V because of the transistor output design of an opamp). The opamp is thus powered by +6.2V and -2.8V. This voltage is obtained from the +9V supply that powers the microcontroller board.

Figure 4.3 shows the power supply circuit. A reference point is taken at 3.2V. In practise this voltage is 2.8V. The reference point is driven through a buffer opamp. An LM351 is used. The buffer opamp is essential to sink or source current. The 3.2V reference point is the ground used in the non-inverting opamp circuit. Therefore the +5.8V and -3.2V rails are created with reference to the 3.2V (in practise the rails are +6.2V and -2.8V). These rails contain noise because of the large output capacitor. The noise on the supply rails is the sacrifice made to have a stable output voltage, which is more important because it is being fed into the ADC.

This power supply method has resulted in a problem that has been resolved, but not implemented. The problem is that the ground against which the pressure output signal is measured is the 3.2V reference point. Furthermore the pressure sensor requires a +10V supply with reference to its ground, which is 3.2V. Therefore a +13.2V supply is needed. This is currently not availabe. A recomendation is made in Chapter 6 on a suitable so-

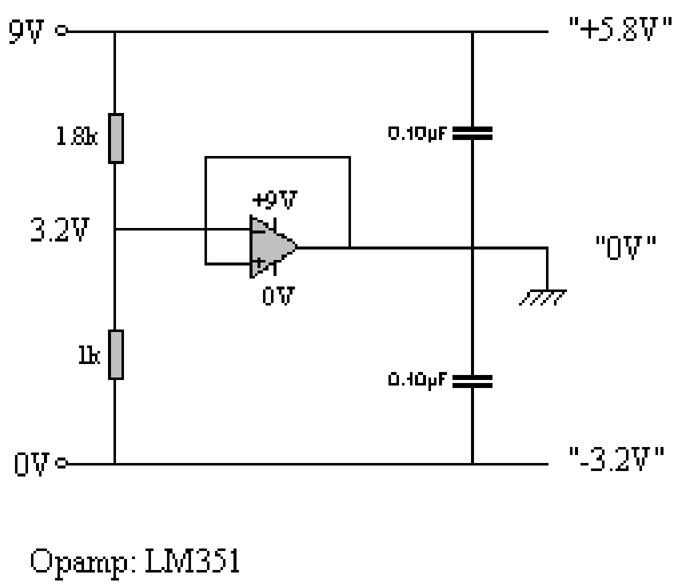

Figure 4.3: Power Supply Circuit

lution to the problem. Another problem that prevents this power supplying method from working is that the output voltage of the opamp must be fed into the ADC. The opamp output voltage is referenced to the 3.2V ground. The microcontroller sees 0V (as opposed to the 3.2V) as ground because the 9V supply for the pressure sensor and circuitry comes from the power supplying the microcontroller board. Therefore the opamp output voltage will be 3.2V larger than it should be. This problem cannot be solved using this power supply method. The recommended solution has to be inplemented to solve this problem.

Non-linearity errors occur in the non-inverting amplifier circuit. This was discussed in section 3.3.3. Testing is performed to determine the effects of the non-linearity. The results of the test are discussed in section 5.2

Test1:

Aim: To determine the practical gain of the non-inverting opamp circuit and to determine the impact of the non-linearity effect caused by the circuit on the input voltage.

Method: Build a circuit to simulate the pressure sensor output voltage, 0 - 16.7mV, by using a simple resistor-divider circuit. Refer to Figure 4.4. Feed this voltage into the non-inverting opamp circuit and read the output of the opamp. Apply different voltages to the circuit and observe their output readings. Determine the practical gain of the circuit.

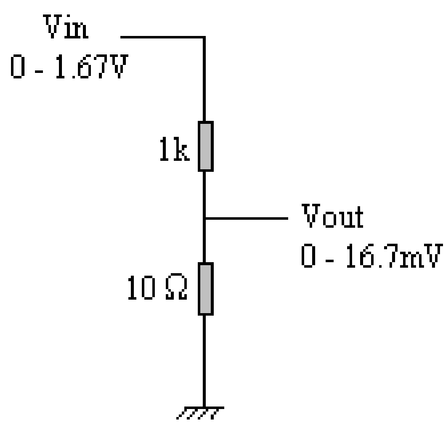

Figure 4.4: Resistor-Divider Circuit

4.2.2 Calibration

The microcontroller LCD display pressure is calibrated with the ADC input pressure after installation. This is done by answering the following questions:

1. What are the required pressure range limits? 500 - 3700Pa
2. What is the corresponding sensor output voltage? 1.21 - 9mV
3. What is the voltage equivalent after the amplifying electronics? 0.53 - 4.4V
4. What is the amplification? 488
5. What is the limit voltage difference input to the ADC? 3.87V
6. Each ADC increment is 0.01953V; therefore calculate the number of increments in the voltage difference. 198
7. What is the difference between the pressure limits? 3200Pa
8. Finally calculate the number of Pascals for each ADC increment. 16 Pa/increment

Therefore 16 is the number by which the digital signal is multiplied to get the correct decimal number. The numbers that are inputted into the *mult* subroutine are as follows:

If bit 0 is set: 16

If bit 1 is set: 32

If bit 2 is set: 64

If bit 3 is set: 128

If bit 4 is set: 256

If bit 5 is set: 512

If bit 6 is set: 1024

If bit 7 is set: 2048

The LCD displayed pressure is now calibrated.

4.3 Current Sensor Implementation

The current sensors have been purchased but are not connected to the generator system because they do not form part of the scope for this project.

4.3.1 The Current-to-Voltage Conversion Circuitry

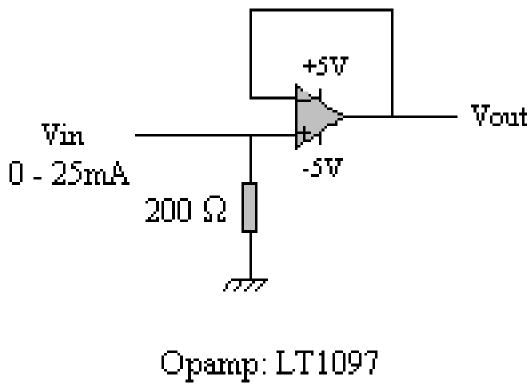

Figure 4.5: Non-Inverting Buffer Opamp

A circuit is required to convert the 0 - 25mA output current into a voltage that is fed into the ADC. The proposed circuit is displayed in Figure 4.5. This circuit is self explanatory. An important error-determining factor is the input bias current of the opamp. An LM351 is suitable because it has an input bias current of 50pA. It also has an offset voltage of 10mV which might interfere with the output result. It is therefore recommended that an LT1097CN8 opamp is used because it has a low input bias current of 25pA and a low offset voltage of 20μV. An advantage of using this circuit is that the sensor output current is isolated from the voltage being fed into the ADC.

4.3.2 Calibration

The binary to decimal conversion software is complete. Testing is performed to determine whether the software is functioning correctly. The results are discussed in section 5.3.

Test1:

Aim: To determine whether the current conversion software is functioning correctly.

Method: Use the ADC on the microcontroller board to produce a 0 - 5V output. Set the ADC is to continuous conversion. Control the voltage level with the onboard potentiometer. Feed the variable 0 - 5V into the current input ports of microcontroller 1. The current output value is displayed on the LCD screen of microcontroller 2. Convert the input voltage into its current value in amps by multiplying by 10. Compare this intputted current value to the LCD displayed current value and determine whether the LCD displayed current value is a true reflection of the inputted current.

The calibration of the LCD current output value with the actual measured current is the same as that described for the pressure sensor.

4.4 Circuit Breaker Implementation

Research has not been conducted on what circuit breakers are suitable for this system because they do not form part of the scope of this project.

4.5 The Microcontrollers

The microcontrollers are situated next to the generator. When the generator system moves to the 6th floor the microcontrollers will be seperated and placed in their respective rooms. Microcontroller 1, which measures the sensors output values will be kept in the shed with the generator system. Microcontroller 2, which displays the sensor reading to the user will be kept in the Microwave lab. A test is performed prior to the installation the microcontrollers to their respective allocations. The results of the test are discussed in section 5.4.

Test1:

Aim: To ensure that the microcontroller software is functioning correctly.

Method: Connect the two microcontrollers together as they would be connected in the generator system. Adjust the software of microcontroller 1 to accept the temperature only. Set the ADC of microcontroller 2 to output a 0 - 5V signal.

Set the ADC to continuous conversion. Adjust the voltage with the potentiometer. Feed the voltage into the temperature input pin of microcontroller 1. Check that the LCD screen of microcontroller 2 is functioning properly and displaying the correct temperature. Change the software to read in the pressure. Feed the voltage into the pressure pin. Perform the same individual functionality test with the load and mains currents. Finally allow the software to read in multiple sensor values. Feed the voltage signal into the respective pins and ensure that the software is functioning properly.

Chapter 5

Results

The results of the tests performed are discussed in this chapter.

5.1 Temperature Testing

Two tests are performed to determine the functionality and accuracy of the temperature sensor and the temperature sensor software.

Test1:

Aim: To compare the temperature sensor output voltage to the temperature reading diplayed on the LCD screen.

Results: The LCD displayed a temperature of 18^{o}C when the generator was off. The output from the sensor was 200mV, which corresponds to a temperature of 20^{o}C. The test has not yet been performed while the generator is running due to shortage of time.

Test2:

Aim: To compare the temperature reading on the LCD screen to that of the heatsink, where the temperature of the heatsink is obtained by a thermometer.

Results: The LCD displayed a temperature of 18^{o}C when the generator was off. The thermometer, after being left on the heatsink for half an hour, read 23^{o}C. The temperature of the thermometer end and the heatsink was still different after being left in contact for half an hour. This was tested by touching the heatsink and the end of the thermometer. The heatsink was distinctly colder than the thermometer. The test has not yet been performed while the generator is running due to shortage of time.

It can be concluded that the temperature sensor is fully operational and functioning correctly. The error is minimal when the generator is off. Table 5.2 provides more information on the accuracy of the displayed result for a given input voltage.

5.2 Pressure Testing

One test is performed on the pressure sensing circuitry. The pressure sensor could not be tested on the generator system because the cooling system has not been installed yet.

Test1:

Aim: To determine the practical gain of the non-inverting opamp circuit and to determine the impact of the non-linearity effect caused by the circuit on the input voltage.

Results: The results of the test are tabluated in table 5.1. The graph in Figure 5.1 shows the output voltages of the non-inverting opamp circuit for their input voltages as tabulated. (This test was performed using a $\pm$9V split supply in the white lab at UCT.) The practical gain is slightly different from the theoretically calculated gain of 471. This is expected. Three values are omitted from the calculations of the average practical gain result. This is because their results are unstable and are not an accurate reflection of the average gain of the circuit. It is important to notice that the output voltage does not increase as the input voltage rises above 14mV. This is due to the saturation of the opamp. The opamp is supplied by a noisy +6.2V and -2.8V and therefore allows the output voltage to saturate at 6.5V. Another important result is the non-linearity effect at the high and low sensor output voltages. This is shown by the large gain deviations from the average gain at the sensor output boundaries. This means that as the pressure approaches its limits, the pressure reading becomes unstable and will oscillate. This will cause premature shutdown of the system as the pressure approaches 0Pa. The system remains stable untill after it has crossed the upper pressure limit of 3700Pa so the unstability problem does not affect the pressure readings as the generator approaches its upper pressure limit. It is important to ensure that the opamp output voltages for the inputs of 1.2mV and 9mV (the boundary voltages) are converted into their respective digital numbers and entered into the software as the pressure limits.

5.3 Current Testing

One test is performed to test the functioning of the current conversion software.

Table 5.1: Pressure Test Results

Number of readings	Pressure Sensor Output (mV)	Opamp Output Voltage (V)	Practical Gain
1*	1.21	0.53	438
2	2	0.97	485
3	3	1.45	483
4	4	1.97	492
5	5	2.45	490
6	6	2.96	493
7	7	3.4	486
8*	8	3.9	487
9	9	4.4	489
10	10	4.9	490
11	11	5.35	486
12	12	5.9	491
13	13	6.3	485
14	14	6.5	464
15	15	6.5	433
Average Practical Gain			**488****

* These readings represent the pressure limits

** This average does not include the 1st,14th and 15th reading.

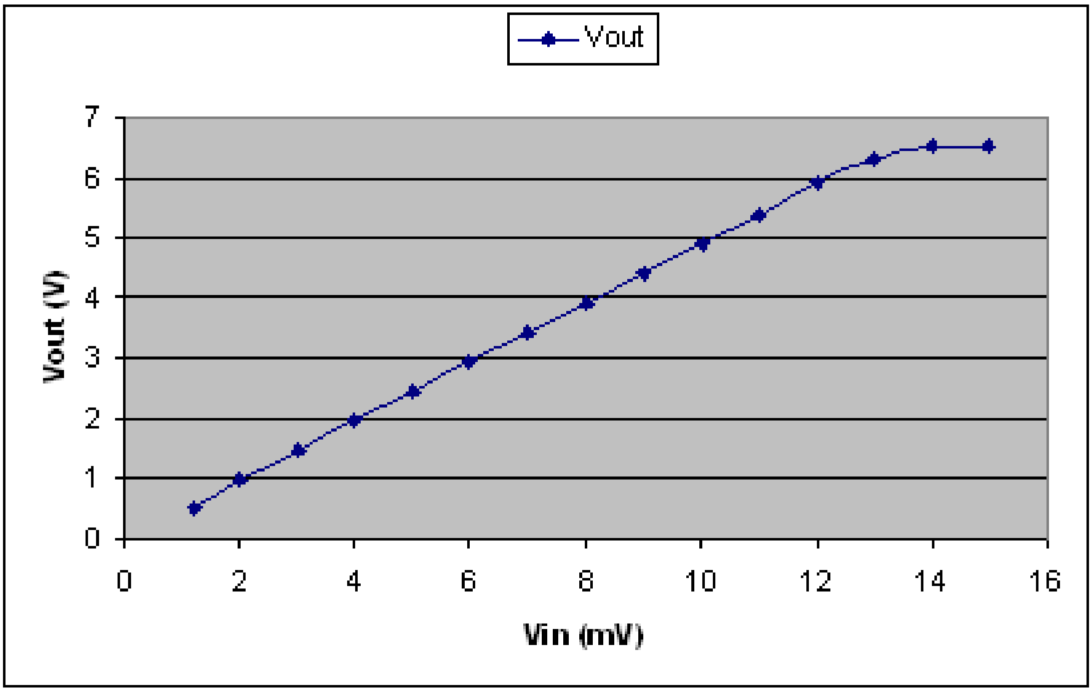

Figure 5.1: Pressure: Vin vs. Vout

Test1:

Aim: To determine whether the current conversion software is functioning correctly.

Results: Tables 5.4 and 5.5 contain the results of the current tests. The current software functions as it should but is subject to errors.

5.4 Microcontroller Testing

5.4.1 Microcontroller Temperature Test

Aim: To determine whether the displayed voltage corresponds to the voltage inputted to microcontroller 1 from the ADC of microcontroller 2.

Results: The results are tabulated in Table 5.2. The corresponding temperature of the input voltage is calcultaed by multiplying the voltage by 100. The displayed temperature is linear at low temperatures. As the temperature rises the displayed temperature deviates from the ideal temperature output. This error is due to slight non-linearity in the ADC and human error. Figure 5.2 displays the deviation of the real output temperature from the ideal output temperature. This error needs to be taken into account when the generator system is running. Table 5.2 can be used as a guideline to the actual temperature of the generator system.

Table 5.2: Microcontroller Temperature Test Results

	Input Voltage (V)	**Corresponding Ideal Temperature (°C)**	**Display (°C)**
Temperature	0.1	10	10
	0.2	20	20
	0.26	26	26
	0.32	32	32
	0.44	44	46
	0.51	51	56
	0.64	64	72
	0.68	68	Shutdown

5.4.2 Microcontroller Pressure Test

Aim: To determine whether the displayed pressure corresponds to the voltage inputted to microcontroller 1 from the ADC of microcontroller 2.

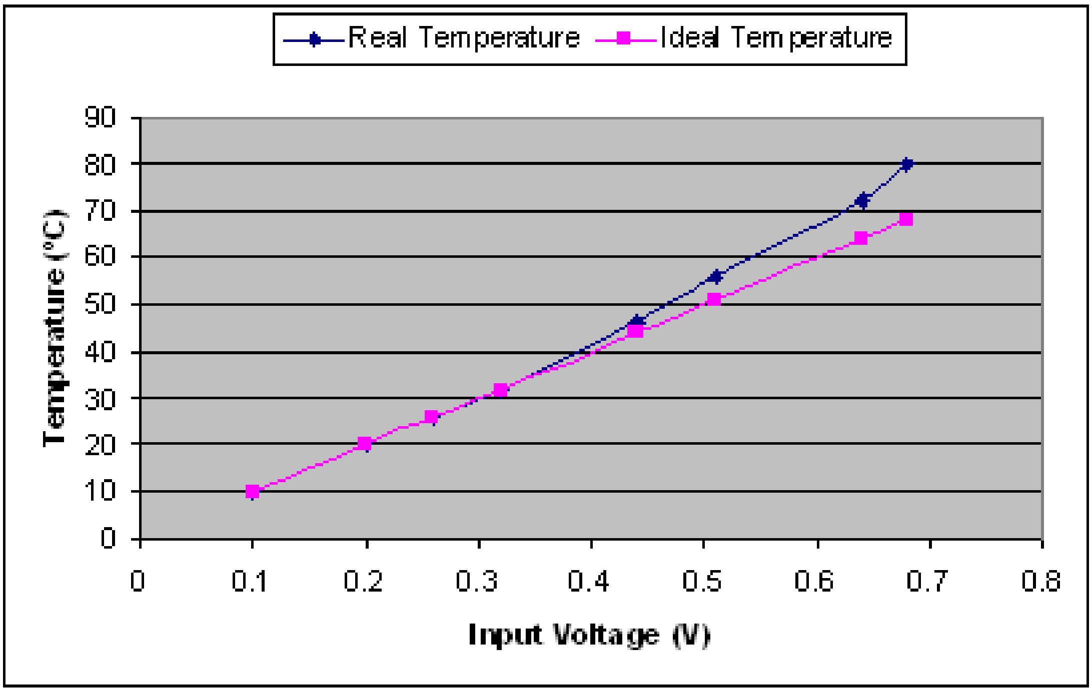

Figure 5.2: Temperature Deviation

Results: The results are tabulated in Table 5.3. The corresponding ideal pressure of the input voltage is calcultaed by multiplying the voltage by 1000. The displayed pressure oscillates over a range of 300Pa because the input voltage source is not stable. The displayed result in Table 5.3 is the maximum recorded oscillating pressure result. This result is used because it is more accurate than the average displayed pressure.

Table 5.3: Microcontroller Pressure Test Results

	Input Voltage (V)	**Corresponding Ideal Pressure (Pa)**	**Display (Pa)**
Pressure	0.69	690	656
	0.86	860	854
	1	1000	998
	1.5	1500	1446
	2	2000	1990
	2.5	2500	2502
	3	3000	3030
	3.5	3500	3526
	3.63	3630	3622
	3.7	Shutdown	Shutdown

5.4.3 Microcontroller Load Current Test

Aim: To determine whether the displayed load current corresponds to the voltage inputted to microcontroller 1 from the ADC of microcontroller 2.

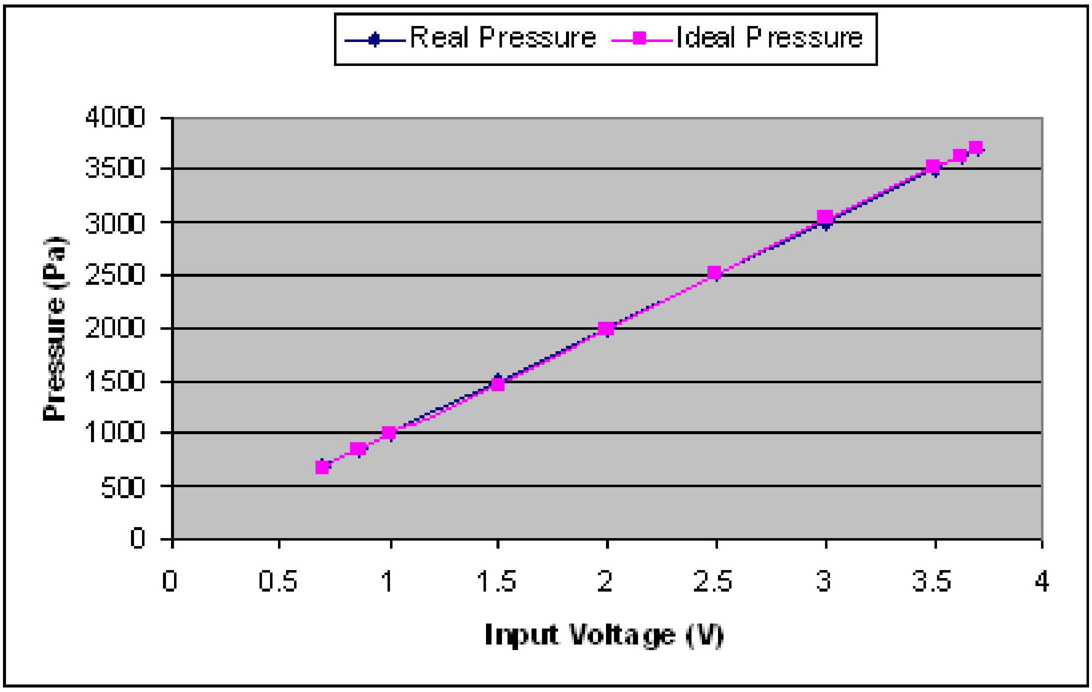

Figure 5.3: Pressure Deviation

Result: The results are tablulated in Table 5.4. To convert the input voltage to its corresponding ideal current, multiply it by 10. The input voltage is reduced when connected to the input pin on microcontroller 1 by 0.3V. This has not been taken into account in the recording of the input voltage. The output current oscillates so an average value is recorded.

Table 5.4: Microcontroller Load Current Test Results

	Input Voltage (V)	**Corresponding Ideal Load Current (A)**	**Displayed Load Current (A)**
Load Current	3.7	37	Shutdown (45)
	3.5	35	40
	3.35	33.5	Shutdown (38)

5.4.4 Microcontroller Mains Current Test

Aim: To determine whether the displayed mains current corresponds to the voltage inputted to microcontroller 1 from the ADC of microcontroller 2.

Result: The results are tablulated in Table 5.5. To convert the input voltage to its corresponding ideal current, multiply it by 10. The input voltage is reduced when connected to the input pin on microcontroller 1 by 0.3V. This has not been taken into account in the recording of the input voltage. The output current oscillates so an average value is recorded.

Table 5.5: Microcontroller Mains Current Test Results

	Input Voltage (V)	**Corresponding Ideal Mains Current (A)**	**Displayed Mains Current (A)**
Mains Current	2.5	25	Shutdown (29)
	2.85	28.5	33
	2.95	29.5	Shutdown (35)

Chapter 6

Recommendations

This chapter provides future recommendations that could not be performed due to shortage of components and time. The following recommendations are made:

1. The implementation of the current sensing hardware and circuitry, together with the circuit breakers, are the most important addition required by the system. They will complete the generator monitoring system. The current sensing hardware required has been purchased and the software has been written (refer to section 3.1). The required circuitry needs to be built and installed with the current sensing hardware (refer to section 4.3.1). Suitable circuit breakers need to be researched and purchased. The requirements for the circuit breakers are listed in section 2.2.

2. The purchase and installation of the wireless communication system. The most suitable and available components have been researched for this modification. The installation will increase the mobility of the system by removing the serial data transfer cable from the system. The software will have to be modified slightly to accommodate the new data transfer method. The data is currently serially transmitted and needs to be serially transmitted for the wireless devices, so the software modification will be small.

3. Further tests should be performed to attain better results as to the accuracy of the temperature sensor reading compared to the temperature displayed by another device. A device or method needs to be obtained to get an exact reading of the heatsink so that it can be compared to the displayed reading. Refer to test 2, section 4.1.

4. The temperature error is currently 2^{o}C and can be improved to 1^{o}C by adding an electrical circuit of gain 2 to the temperature output voltage signal before it is fed into the ADC. This is not essential but is an option that can be implemented easily.

5. Minimization of the practical errors produced and unstability in the monitoring electronics needs to be reduced.

6. A power supply problem was explained in section 4.2.1. A simple solution and future recommendation would be to obtain a +15V supply. A 5V regulator can be used to produce a 5V rail. This can then become the reference point, creating the -5V and +10V rails required to power the pressure sensor and the non-inverting opamp.

7. The monitoring system has not been set up to control the turning on and off of the generator system. This needs to be implemented to complete the generator monitoring electronics system.

Chapter 7

Conclusions

The monitoring system is vital for ensuring safe operation of the generator system. The design, installation, reliability and accurate operation of each part is essential. The following important achievements have been accomplished:

1. The temperature sensing part of the system has been designed, successfully installed and is functioning properly. The design is reliable and robust. The results of the tests that assessed the error in the final displayed temperature show that the error is insignificant at low temperatures, but increases as the temperature rises. The temperature displayed on the LCD screen is therefore reliable in preventing the generator from overheating because the error introduced as the displayed temperature increases will result in a premature shutdown of the generator.

2. The pressure sensing part of the system has been designed but is not installed because the cooling system has not arrived at UCT yet. The software and circuitry are functioning properly. The power supply solution in the recommendations chapter must be implemented to power the circuitry. The results of the tests show that the pressure displayed on the LCD screen will be a reliable indication of the pressure in the cooling system except when the pressure approaches 0Pa. The pressure reading becomes unstable and oscillates as the reading approaches 0Pa.

3. The current sensing part of the system has been successfully designed but not fully implemented because it is not included in the scope of this project. The current detecting and converting software is complete and functioning properly, with an offset error. The sensor output circuitry is designed but still needs to be built. The current sensors and circuit breakers then need to be installed and the sensors calibrated as described in section 4.3.2.

4. The researched RF transmitter and receiver pair, and accompanying antennae, have not yet been purchased because the order was not processed by RF Design. Therefore a cable is installed to transmit the data between the microcontrollers. The serial cable data transfer system is functioning correctly with no errors.

5. The microcontrollers are functioning correctly. The software is currently programmed to only accept a temperature reading input. The software for the microcontroller accepting the sensor outputs must be adjusted and the microcontroller re-programmed on installation of the pressure or current sensors. The software is available on the accompanying cd.

6. The monitoring system has not been set up to control the turning on and off of the generator system.

The section of the generator monitoring system required to be completed as stated in the scope of the project is completed to the full extent possible. On completion of the recommendations stated in Chapter 6, the entire generator monitoring system, including those part not included in the scope of the project, will be complete.

Appendix A

Software Source Code

The code written for both of the microcontrollers is saved on the accompanying cd. Refer to the *readme.txt* file for instructions.

Appendix B

Datasheets

The datasheets are saved on the accompanying cd. Refer to the *readme.txt* file for instructions.

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