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Control System Design for Utilizing Natural Gas in Diesel Engines Using Microcontroller

تصميم نظام تحكم لإستخدام الغاز الطبيعي في ماكينات الديزل بإستخدام المتحكم الدقيق

A Thesis Submitted in Partial Fulfillment of the Requirements of M.Sc. in Electrical Engineering (Control and Microprocessor)

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الآيـــــــــة

قَال تَعَالَى:

وَمَا لأَحَدٍ عِنْدَهُ مِنْ نِعْمَةٍ تُجْزَى (19) إِلاَّ ابْتِغَاءَ
وَجْهِ رَبِّهِ الأَعْلَى (20) وَلَسَوْفَ يَرْضَى (21)

سورة الليل

DEDICATION

I want to dedicate this thesis to

My mother

Whom her dawn prayers are the origin of all the happiness, joy and blessing of the family

My father

Who taught me the values of hardworking, devotion and patience by setting himself as an example

My wife

Who spared no effort to make me feel comfortable and focus

My brothers and sisters

For their whole-hearted support throughout my entire life

And to my lovely little three kids

Basil, Sally and Samar

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ABSTRACT

With the increasing concern regarding diesel engine emissions, including Nitrogen Oxides (NOX) and Particulate Matter (PM), and the rising of energy demand as well, the utilization of alternative fuels in diesel engine has been found to be an attractive solution. Natural gas is a very promising and highly attractive fuel because of its low cost and clean-burning qualities. Natural gas/diesel bi-fuel is an operation mode in which natural gas is introduced into the intake air upstream of the manifold and then ignited by the direct injected diesel into the cylinder. The aim of this research is to build a gas delivery system to supply the natural gas to the diesel engine, and without any modification on engine design. And to design a control system that ensure proper operating conditions for both engine and bi fuel system. An electronic control panel based on ATMega32 microcontroller that monitors and displays critical engine and Bi-Fuel System parameters is used. Various sensors were involved. Based on input from the sensors and user programmed limits, the Microcontroller will activate or deactivate Bi-Fuel mode as required. The (Bascom) software program for generating the code that programs the microcontroller is used, beside the Proteus software for simulation. It has been found that the bi fuel mode has a lower fuel consumption rate of almost one third (1/3) compared to the normal 100% diesel mode. According to the data collected from the literature, the application of bi fuel mode significantly decreases the NOX, carbon dioxide (CO_2) and PM emissions. However, the HydroCarbon (HC) and carbon monoxide (CO) emissions may increase by several times in comparison to normal diesel combustion. Moreover the life time of the diesel engine parts is increased as well as the life time of the lubricating oil.

مستخلص

نتيجة لتزايد الإهتمام بالقضايا المتعلقة بإنبعاثات ماكينات الديزل مثل اكاسيد النتروجين والملوثات الأخرى، بالإضافة لتزايد الطلب المتطرد على الطاقة، وجد ان استخدام أنواع اخرى من الوقود وخصوصا" الغاز الطبيعي في ماكينات الديزل يمكن ان يكون حلا" مناسبا".

يعتبر الغاز الطبيعي وقود واعد جدا" لما يحتويه من مميزات عديدة منها على سبيل المثال توفره بكميات كبيرة في الطبيعة وطبيعه احتراقه النظيفة بالإضافة لتكلفته القليلة.

الوقود الثنائي (غاز طبيعي و ديزل) هو نمط تشغيل يتم فيه خلط الغاز الطبيعي مع الهواء الداخل للماكينة ليتم الإحتراق بعد ذلك بالحقن المباشر للديزل داخل الأسطوانة، خلط الغاز الطبيعي بالديزل يقلل من إستهلاك الديزل، وتتحسن عملية الإحتراق تبعا" لذلك.

تهدف هذه الدراسة لتصميم نظام للتحكم في توصيل الغاز الطبيعي لماكينة الديزل بصورة تضمن تشغيل آمن ومستقر للنظامين (الوقود الثنائي والماكينة) ، حيث تم فيها تصميم لوحة تحكم تعتمد على المتحكم الدقيق الذي يعمل على مراقبة المتغيرات المختلفة بواسطة مجموعة من الحساسات الموصولة معه وإعتمادا" على قيم هذه الحساسات وحدود التشغيل المرغوب بها يقوم المتحكم الدقيق بتشغيل أو إيقاف النظام،و يتم عرض المتغيرات بصورة مستمرة بإستخدام شاشة عرض.

تم إستخدام برنامج (باسكوم) لكتابة الكود، وبرنامج (بروتوس) لعمل محاكاة للنظام الذي تم تصميمه.

وجد أن إستخدام الغاز الطبيعي في ماكينات الديزل يمكن أن يقلل من إستهلاك الديزل بنسبة قد تصل إلى 70% كحد إقصى، الشئ الذي يقود بدوره إلى زيادة عدد ساعات تشغيل الماكينة، بالإضافة إلي إطالة عمر الزيت المستخدم. وطبقا" للمعلومات التي تم الحصول عليها من الدراسات السابقة تبين أن إستخدام الغاز الطبيعي يقلل بصورة ملحوظة من إنبعاثات أكاسيد النتروجين، وثاني أكسيد الكربون والمواد الصلبة الأخرى، على الرغم من الزيادة المحتملة لأول أكسيد الكربون وبعض الهايدروكربونات الأخرى.

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LIST OF ABBREVIATIONS

ADC	Analog to Digital Converter
AP	Air pressure
AT	Air Temperature
BTE	Brake Thermal Efficiency
BTU	British Thermal Unit
CCD	Charged Couple Device
CFD	Computational Fluid Dynamics
CI	Compression-Ignition
CMOS	Complementary Metal Oxide Semiconductor
CNG	Compressed Natural Gas
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPU	Central Processing Unit
DC	Direct Current
DPI	Diesel Pilot Ignition
DTL	Diode-Transistor Logic
ECV	Electronically Controlled proportioning Valve
EMF	Electro-Motive Force
E/T	Exhaust Temperature
GEG	Gas Equivalent Gallon
GP	Gas Pressure
GPH	Gallon Per Hours
GSP	Gas Supply Pressure
HC	HydroCarbon
HHV	Higher Heat Value

HMI	Human Machine Interface
IC	Integrated Circuit
IPS	Inches Per Second
Kpa	Kilo pascal
KW	KiloWatt
LCD	Liquid Crystal Display
LED	Light Emitting Diode
LEL	Lower Explosive Limit
LPG	Liquid Petroleum Gas
LSB	Least Significant Bit
MCF	volume of 1000 Cubic Feet
MOSFET	Metal Oxide Semiconductor Field-Effect Transistor
MPS	Millimeters Per Second
MSB	Most Significant Bit
MVA	Mega Volt Ampere
NOX	Nitrogen Oxide
Pa	Pascal
PLC	Programmable Logic Controller
PLIF	Posterior Lumbar Interbody Fusion
PM	Particulate Matter
PSI	Pound per Square Inch
PMOS	Positive-channel Metal Oxide Semiconductor
TTL	Transistor-Transistor Logic
RCCI	Reactivity Controlled Compression Ignition
RPM	Revolution Per Minute
SCF	Stander Cubic Feet

CHAPTER ONE

INTRODUCTION

1.1 Overview:

Diesel engines are widely used in the world due to their high combustion efficiency, reliability, adaptability and cost-effectiveness. However, diesel engines are one of the major contributors to environmental pollutions. The main harmful pollutants from diesel engines are NOX and PM. NOX emission is one of the major causes of photochemical smog. And it is also a cause of acid rain. Primary PM from diesel engines consists of various types of chemical components such as elemental carbon, organic carbon, inorganic ions, trace elements etc. These particles have extremely harmful effects on human health and environment. Numerous studies have proved that these particles cause respiratory and cardiovascular health problems and neurodegenerative disorders. Furthermore, the exhaust emissions of diesel engine have been identified as carcinogen by the World Health Organization in June 12, 2012. Therefore, emission regulations become increasingly stringent to reduce these harmful emissions. On the other hand, energy demand is increasing but the oil resources are diminishing. In order to ease the contradiction between the need for increased energy and the decreasing oil resources while at the same time reduce pollutant emissions, the utilization of alternative fuels has been found to be an attractive solution. Among the various alternative fuels, natural gas is very promising and highly attractive in the industrial sector. Firstly, natural gas is available in several areas worldwide at encouraging prices. Beside the oil fields and natural gas fields, the natural gas industry is producing gas from increasingly more challenging resource types: sour gas, tight gas, shale gas, coal-bed methane, and methane gas hydrate. Secondly, although the main component of natural gas, namely methane, is a greenhouse gas, natural gas still is an eco-friendly fuel. It can contribute to the reduction of CO2 emission because it exhibits the lowest carbon-to-hydrogen ratio of all the fossil fuels. Natural gas can also substantially reduce the NOX emission and at the same time produce almost zero smoke and PM, which is extremely difficult to achieve in conventional diesel engines. But on the other hand, in order to avoid its own environmental pollution, we should try to reduce the leakage of natural gas. Thirdly, natural gas is not prone to knock due to its high methane number under normal circumstances. Therefore, it can be used in engines with relatively high compression ratio and obtain a higher thermal efficiency compared with that of normal gasoline engine. Natural gas has been employed as a supplementary fuel widely in diesel engine for its economic and environmental benefits.

1.2 Problem Statement:

There is a trade-off between using natural gas generators and diesel generators.
Natural gas generators, though common in the under 150 kW market, are limited in larger kW applications due to significantly higher capital costs. Even so, natural gas generators offer numerous advantages compared to diesel solutions. The most noticeable is the extended run time offered by an endless supply of natural gas.

Diesel generators, on the other hand, are the market norm above 150 kW, but system designers must plan for the limitations associated with utilizing on-site diesel fuel. Moreover, diesel fuel is likely to continue to rise in price besides, keeping liquid fuel in good condition also adds cost. Further, emissions from diesel engines operating long hours on diesel fuel only may exceed federal, state or local air quality standards.

1.3 Proposed Solution:

The bi-fuel system is a system that allows diesel engines to operate on a mixture of diesel fuel and natural gas. Conversion to bi-fuel requires no major changes or modifications of the engine and allows the engine to operate on gas mixtures ranging from 30% to almost 70% of total fuel consumed. This is achieved through a system that is installed externally of the engine. This research is thus aimed at the designing of a control system for utilizing the natural gas in diesel engines using microcontroller.

1.4 Objectives:

The following objectives are set for the research:

- To propose a control system design for utilizing the natural gas in diesel engines.
- To simulate the designed system software simulation.
- To evaluate the system performance.
- To utilize both diesel and natural gas (or other available gases) to operate industrial diesel engines.
- To reduce the on-site diesel fuel storage for industrial diesel engine.
- To reduce the emissions due to both burning gas in flare and engine exhaust.

1.5 Methodology:

The control system will be designed using an electronic control panel based on ATmega32 microcontroller. The controller will be installed in CATERPILLAR diesel engine model 3516B PM that has power of 1600KW and constant speed of 1500 Revolution Per Minute (RPM). Throughout the process the microcontroller continuously monitors a variety of the engine and bi fuel system parameters including air pressure, engine exhaust temperature, intake manifold air temperature and pressure, and engine vibration at each cylinder. Based on input from various sensors and user programmed limits, the microcontroller will activate or deactivate Bi Fuel mode as required. Bascom software will be used for generating the code that programs the microcontroller, beside Protoes software for simulation.

A gas delivery system to supply the natural gas to the diesel engine will be involved. The gas is supplied to the engine with the use of an air-gas mixing device. And in order to ensure proper operation, the bi fuel system is supplied with a “gas train” consisting of a gas filter, gas pressure regulator, electrically activated gas solenoid valve, and control valve.

1.6 Thesis Outlines:

The thesis is organized into five chapters. The outline of this chapters as follows: chapter one presents brief overview to bi-fuel system and its advantages when introduced to diesel engines and the chapter also include the problem statement, the research objectives and the general methodology. Chapter two is divided into two sections; section one covers literature reviews and previous studies. Section 2 presents a detailed description of all the components used in the research. Chapter three starts with the system block diagram followed by the circuit design, the components function and performance and the methodology. In chapter four the system design is discussed and evaluated. Finally, the conclusion and recommendations are presented in Chapter five.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview:

Diesel and natural gas fueled generators have been common solutions for industrial standby power applications for decades. Each has its advantages and disadvantages. As end users search for ways to improve the reliability of their standby power systems, increased interest has been directed toward mainly two issues one of them is the on-site diesel fuel storage. How much fuel is enough? How much is too much? The other is the emissions they produce.

Microcontrollers are used in automatically controlled products and devices, such as automobile engine control systems, remote controls, office machines, appliances, power tools, toys, and other embedded systems. By reducing the size and cost compared to a design that uses a separate microprocessor, memory, and input/output devices, microcontroller make it economical to digitally control even more devices and process, For that reason among others the ATMega32 microcontroller is used in this research to control fuel supply gas to a 3516 Caterpillar diesel engine. Various sensors are utilized by the microcontroller to ensure the safety of the system and control the gas flow to the engine.

2.2 Related Studies:

In view of energy depletion and environmental pollution, dual-fuel technology has caught attention of many researchers. It is an ecological and efficient combustion technology.[1] This group of researchers, Present a literature review and simulation of dual Fuel diesel-Compressed Natural Gas (CNG) Engines that summarizes a review of recent research on dual-fuel technology and future scope of research. Paper also throws light on present limitations and drawbacks of dual-fuel engines and proposed methods to overcome these drawbacks. A parametric study of different engine-operating variables affecting performance of diesel-CNG dual-fuel engines vis-à-vis base diesel operation is also summarized. Chemical kinetic and Computational Fluid Dynamics (CFD) simulation of dual-fuel diesel-CNG engine combustion has been carried out based on available literature data. Thereafter, experimental results of effect of gas supplement ratio (fraction of natural gas in total fuel) on mass basis, on emission and performance characteristics of a six-cylinder heavy-duty compression ignition engine have been discussed with an aim of understanding the engine behavior under dual-fuel operating mode [1].

Another group [2], have published a paper discussing "A numerical Study on Controllability of Natural Gas and Diesel Dual Fuel Combustion in a Heavy-Duty Engine". They proposed that in order to achieve high efficiency and low emission combustion in a practical diesel engine over a wide range of operating conditions, understanding the performance responses to engine system parameter variations is needed. The controllability of two combustion strategies, Diesel Pilot Ignition (DPI) and single injection Reactivity Controlled Compression Ignition (RCCI), were evaluated using the multi-dimension CFD simulation. DPI is a strategy that premixed natural gas is ignited by a direct injection of diesel fuel near the compression top dead center, and RCCI employs earlier diesel injection to customize a desired in-cylinder fuel reactivity gradient to achieve a sequential, staged combustion. Their research indicates RCCI generally has higher fuel efficiency and lower HC, CO and NOX emissions relative to DPI combustion. Its combustion phasing and fuel efficiency can be significantly influenced by the fuel and air system parameters including injection timing. The highly sensitive responses to these parameters also suggest that RCCI should be carefully controlled to avoid misfire or undesired operation. While these parameters have a smaller effect on the combustion phasing and fuel efficiency of DPI except injection timing when compared to RCCI. For real applications, injection timing and PES should be considered the better parameters to control combustion on a cycle to cycle basic for both RCCI and DPI. A major challenge for DPI combustion is balancing the trade-off between NOx and HC. [2]

LijiangWei and Peng Geng [3]. Have presented "A review on natural gas/diesel dual fuel combustion, emissions and performance". This paper is aimed to identify the potential use of natural gas/diesel dual fuel on diesel engine. In the review, the combustion, emission and performance characteristics of natural gas/diesel dual fuel combustion mode published mainly in scientific journals have been collected and critically analyzed. A wide range of natural gas mass ratio which represents the mass fraction of natural gas in the total fuel and different types of engines were involved. It has been found that dual fuel mode has a lower compression pressure and a longer ignition delay compared with normal diesel mode. The application of dual fuel mode significantly decreases the NOX, carbon dioxide CO2 and PM emissions. However, the hydrocarbon HC and carbon monoxide CO emissions may increase by several times or even more than 100 times in comparison to normal diesel combustion. And there appears a trade-off relationship between NOX and HC emissions with dual fuel mode. The engine power is decreased up to 2.1% at dual fuel mode, but the power loss can be reduced or recovered by changing some of the operating parameters. The Brake Thermal Efficiency (BTE) of dual fuel mode is lower at low and intermediate loads, while under high engine load conditions it is similar or a little higher when compared with normal diesel mode, and the maximum increase is about 3%. The COVIMEP seems to be generally higher than normal diesel mode and it decreases with the increasing engine load [3].

Nicolas Dronniou and others, [4] Have Proposed an Optical Investigation of Dual-fuel CNG/Diesel Combustion Strategies to Reduce CO2 emissions. They have carried out an investigation to explore the fundamental combustion phenomena occurring when methane is ignited with a pilot injection of diesel fuel. Experiments were performed on a single-cylinder optical research engine which is typical of modern, light-duty diesel engines. A high-speed digital camera recorded time-resolved combustion luminosity and an intensified Charged Couple Device (CCD) camera was used for single-cycle. Experiments were performed for a wide range of equivalence ratios of the premixed charge. At low equivalence ratios, optical engine results revealed that combustion of the premixed charge of methane gas was dominated by spray entrainment and mixture stratification of diesel fuel. At higher equivalence ratios particularly close to stoichiometry, time-resolved natural luminosity images revealed significant modifications in combustion behavior indicating some evidence of flame propagation. Corresponding rates of heat release support the optical measurements in terms of revealing a significant impact on combustion following an increase of equivalence ratio. PLIF-tracer experiments were also performed in order to investigate the influence of in-cylinder fuel distribution on dual-fuel ignition [4].

An applicable and comprehensive control strategy of a natural gas/diesel dual fuel engine is presented by Yeo, J, Rochussen, J, among others [5]. In this research "Control Strategy Development of Natural Gas/Diesel Dual Fuel Engine for Heavy Duty Vehicle"[5], the dual fuel engine is converted from a conventional mechanical pump, turbo charged, and heavy duty diesel engine. In the dual fuel mode, the pedal position is explained as demanded total fuel quantity, the quantity of pilot diesel and natural gas are calculated in order to provide the equal energy with the original diesel engine at the same operation condition, the proportion of the natural gas is primarily determined by the load rate and the speed of the engine. When the engine is working under light or moderate load, the intake air is throttled in order to improve the brake mean effective pressure and reduce the hydrocarbon emissions of the dual fuel engine, according to target excess air ratio and the quantities of the two fuels, the desired air mass per cycle can be obtained. After that a mean value model based feed-forward control is adopted to calculate the electronic throttle position, with a universal exhaust gas oxygen sensor, a proportional-integral controller is designed, therefore feedback control is introduced to the air/fuel ratio control system to enhance its accuracy and robustness. Verification test results show that: the engine which employs the control strategy in this paper can work stably and reliably with less calibration data; the air/fuel ratio is regulated accurately and quickly, dual fuel engine has better fuel economy even though its brake thermal efficiency is lower due to the comparatively low price of natural gas; intake throttling has significant effect on improving the economy and hydrocarbon emission of the dual fuel engine under light and moderate load [5].

Based on the above literature reviews, it is clear that all the authors reported obviously increase of CO emission under natural gas/diesel bi fuel combustion mode in comparison with normal diesel mode. They also reported that CO emission increased with the increasing natural gas mass ratio in a certain extent and with the further increase of natural gas CO emission started to decrease.

Natural gas is considered to be a good alternative fuel for its good environmental effect. Numerous studies have been conducted by researchers around the world to explore the improvement of natural gas on the engine emissions. These investigations were carried out in different test engines and operation conditions. The emission characteristics with natural gas/diesel dual fuel were reviewed and summarized in some of the literature reviews above.

2.3 Types of Microcontroller:

There is the question of which microcontroller to use for a given application. Since costs are important, it is only logical to select the cheapest device that matches the application’s needs. As a result, microcontrollers are generally tailored for specific applications, and there is a wide variety of microcontrollers to choose from. The first choice a designer has to make is the controller family; it defines the controller's architecture. All controllers of a family contain the same processor core and hence are code-compatible, but they differ in the additional components like the number of timers or the amount of memory. There are numerous microcontrollers on the market today, and it can easily be confirmed by visiting the webpages of one or two electronics vendors and browsing through their microcontroller stocks. There are many different controller families like, for instance, 8051, PIC, HC, ARM to name just a few, and that even within a single controller family a choice may again have to be made of many different controllers [6].

Table 2.1 Comparison of AVR 8-bit controllers (AVR, ATmega, ATtiny).

Controller	Flash (KB)	SRAM (Byte)	EEPROM (Byte)	I/O-Pins	A/D (Channels)	Interfaces
AT90C8534	8	288	512	7	8	
AT90LS2323	2	128	128	3		
AT90LS2343	2	160	128	5		
AT90LS8535	8	512	512	32	8	UART, SPI
AT90S1200	1	64		15		
AT90S2313	2	160	128	15		
ATmega128	128	4096	4096	53	8	JTAG, SPI, IIC
ATmega162	16	1024	512	35		JTAG, SPI
ATmega169	16	1024	512	53	8	JTAG, SPI, IIC
ATmega16	16	1024	512	32	8	JTAG, SPI, IIC
ATtiny11	1		64	5+1 In		
ATtiny12	1		64	6		SPI
ATtiny15L	1		64	6	4	SPI
ATtiny26	2	128	128		16	SPI
ATtiny28L	2	128		11+8 In		

Table 2.1 shows a selection of microcontrollers of Atmel's AVR family. The one thing all these controllers have in common is their AVR processor core, which contains 32 general purpose registers and executes most instructions within one clock cycle. After the controller family has been selected, the next step is to

choose the right controller for the task. As you can see in Table 1.1 (which only contains the most basic features of the controllers, namely memory, digital and analog (Input/Output), and interfaces), the controllers vastly differ in their memory configurations and (Input/Output). The chosen controller should of course cover the hardware requirements of the application, but it is also important to estimate the application's speed and memory requirements and to select a controller that offers enough performance. For memory, there is a rule of thumb that states that an application should take up no more than 80% of the controller's memory – this gives some buffer for later additions. The rule can probably be extended to all controller resources in general; it always pays to have some reserves in case of unforeseen problems or additional features. Of course, for complex applications before-hand estimation is not easy.

The basic internal designs of microcontrollers are pretty similar. Figure 2.1 shows the block diagram of a typical microcontroller. All components are connected via an internal bus and are all integrated on one chip. The modules are connected to the outside world via I/O pins [6].

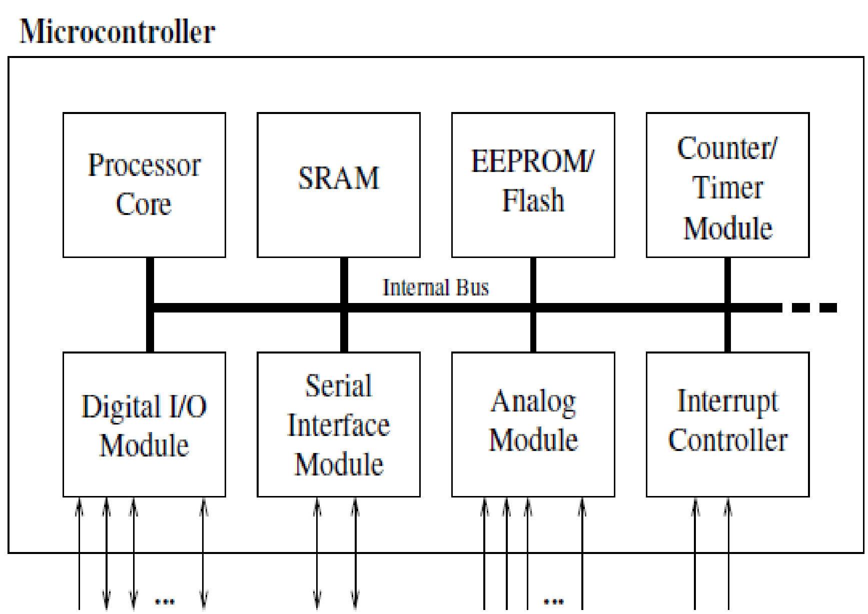


Figure 2.1 Basic layout of a microcontroller.

2.4. Atmega32:

In recent days, there have been much advancement in the field of electronics and many cutting edge technologies are being developed every day, but still 8 bit microcontrollers have its own role in the digital electronics market dominated by 16, 32 and 64 bit digital devices. Although powerful microcontrollers with higher processing capabilities exist in the market, 8bit microcontrollers still hold its value because of their easy-to-understand-operation, very much high popularity, ability to simplify a digital circuit, low cost compared to features offered, in addition to many new features in a single Integrated Circuit (IC) that it is of interest of both manufacturers and consumers.

Today's microcontrollers are much different from what it was in the initial stage, and the number of manufacturers are much more in count than it was a decade or two ago. At present some of the major manufacturers are Microchip (publication: PIC microcontrollers), Atmel (publication: AVR microcontrollers), Hitachi, Phillips, Maxim, NXP, Intel etc. Our interest is upon ATmega32. It belongs to Atmel's AVR series micro controller family. And here are some of its features.

2.4.1 PIN count:

Atmega32 has 40 pins. As shown in figure 2.2, two for power (pin no.10: +5v, pin no. 11: ground), two for oscillator (pin 12, 13), one for reset (pin 9), three for providing necessary power and reference voltage to its internal ADC, and 32 (4×8) I/O pins [7].

2.4.2 About I/O pins:

ATmega32 is capable of handling analogue inputs. Port A can be used as either Digital I/O Lines or each individual pin can be used as a single input channel to the internal ADC of ATmega32, plus a pair of pins AREF, AVCC & GND (refer to ATmega32 datasheet) together can make an ADC channel.

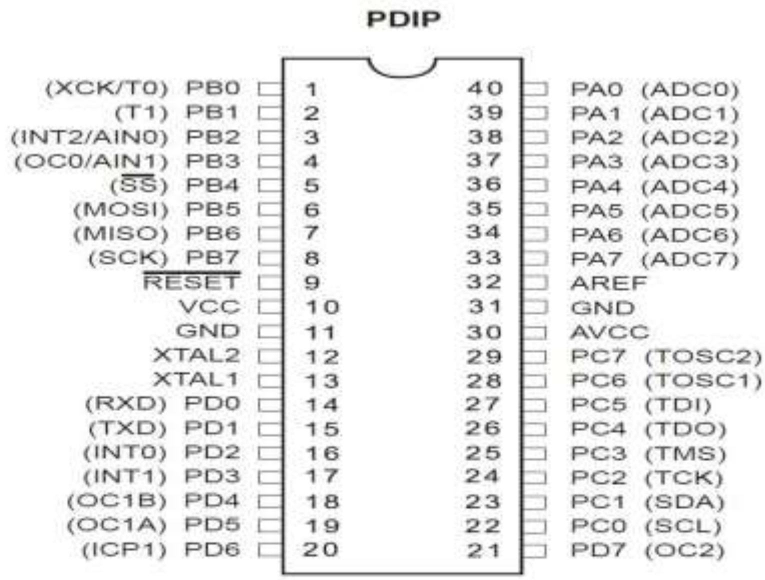


Figure 2.2 Atmega32 I/O pins

No pins can perform and serve for two purposes at the same time (for an example: Port A pins cannot work as a digital I/O pin while the internal ADC is activated) at the same time. It’s the programmer's responsibility to resolve the conflict in the circuitry and the program. Programmers are advised to have a look to the priority tables and the internal configuration from the datasheet [7]. Table 2.2 shows the pins configuration of the ATMega32 microcontroller.

Table 2.2 ATMega32 pins description

Pin No.	Name	Description	Alternate Function
Pin no. 1	PB0(XCK/T0)	Pin 0 PORT B	T0(Timer0 External Counter Input) XCK(USART External Clock I/O)
Pin no. 2	PB1(T1)	Pin 1 PORT B	T1(Timer1 External Counter Input)
Pin no. 3	PB2(INT2/AIN0)	Pin 2 PORT B	AIN0(Analog Comparator Positive I/P)

			INT2(External INTERRUPT 2 Input)
Pin no. 4	PB3(OC0/AIN1)	Pin 3 PORT B	AIN1(Analog Comparator Negative I/P) OC0(Timer 0 Output Compare Match Output)
Pin no. 5	PB4(SS)	Pin 4 PORT B	SS (SPI Slave Select Input). This pin is low when controller acts as slave [Serial Peripheral Interface (SPI) for programming]
Pin no. 6	PB5(MOSI)	Pin 5 PORT B	MOSI (Master Output Slave Input). When controller acts as slave, the data is received by this pin. [Serial Peripheral Interface (SPI) for programming].
Pin no. 7	PB5(MOSI)	Pin 6 PORT B	MOSI (Master Input Slave Output). When controller acts as slave, the data is send to master by this controller through this pin. [Serial Peripheral Interface (SPI) for programming].
Pin no. 8	PB7(SCK)	Pin 7 PORT B	SCK (SPI Bus Serial Clock). This is the clock shared between this controller and other system

			for accurate data transfer.[Serial Peripheral Interface (SPI) for programming].
Pin no. 9	RESET	Reset Pin, Active low Reset	Pulled High to Reset Controller.
Pin no. 10	Vcc	Vcc = +5V	
Pin no. 11	GND	GROUND	
Pin no. 12	XTAL2	Connected to Crystal Oscillator	
Pin no. 13	XTAL1	Connected to Crystal Oscillator	
Pin no. 14	PD0 (RXD)	Pin 0 PORT D	RXD (USART Input Pin). USART Serial Communication Interface [Can be used for programming]
Pin no. 15	PD1 (TXD)	Pin 1 PORT D	TXD (USART Output Pin). USART Serial Communication Interface [Can be used for programming]
Pin no. 16	PD2 (INT0)	Pin 2 PORT D	External Interrupt INT0
Pin no.	PD3(INT1)	Pin 3 PORT D	External Interrupt INT1

17			
Pin no. 18	PD4 (OC1B)	Pin 4 PORT D	PWM Channel Output
Pin no. 19	PD5 (OC1A)	Pin 5 PORT D	PWM Channel Output
Pin no. 20	PD6 (ICP)	Pin 6 PORT D	Timer / Counter1 Input Capture Pin
Pin no. 21	PD7 (OC2)	Pin 7 PORT D	Timer / Counter2 Output Compare Match Output
Pin no. 22	PC0 (SCL)	Pin 0 PORT C	TWI Interface
Pin no. 23	PC1 (SDA)	Pin 1 PORT C	
Pin no. 24	PC2 (TCK)	Pin 2 PORT C	JTAG Interface
Pin no. 25	PC3 (TMS)	Pin 3 PORT C	
Pin no. 26	PC4 (TDO)	Pin 4 PORT C	
Pin no. 27	PC5 (TDI)	Pin 5 PORT C	
Pin no. 28	PC6 (TOSC1)	Pin 6 PORT C	Timer Oscillator Pin 1
Pin no. 29	PC7 (TOSC2)	Pin 7 PORT C	Timer Oscillator Pin 2
Pin no. 30	AVcc	Vcc For Internal ADC	

		Converter	
Pin no. 31	GND	GROUND	
Pin no. 32	AREF	Analog Reference Pin for ADC	
Pin no. 33	PA7 (ADC7)	Pin 7 PORT A	ADC (Analog to Digital Converter) Channel 7
Pin no. 34	PA6 (ADC6)	Pin 6 PORT A	ADC (Analog to Digital Converter) Channel 6
Pin no. 35	PA5 (ADC5)	Pin 5 PORT A	ADC (Analog to Digital Converter) Channel 5
Pin no. 36	PA4 (ADC4)	Pin 4 PORT A	ADC (Analog to Digital Converter) Channel 4
Pin no. 37	PA3 (ADC3)	Pin 3 PORT A	ADC (Analog to Digital Converter) Channel 3
Pin no. 38	PA2 (ADC2)	Pin 2 PORT A	ADC (Analog to Digital Converter) Channel 2
Pin no. 39	PA1 (ADC1)	Pin 1 PORT A	ADC (Analog to Digital Converter) Channel 1
Pin no. 40	PA0 (ADC0)	Pin 0 PORT A	ADC (Analog to Digital Converter) Channel 0

All the internal components and I/O pins can be illustrated using the block diagram shown in Figure 2.3.

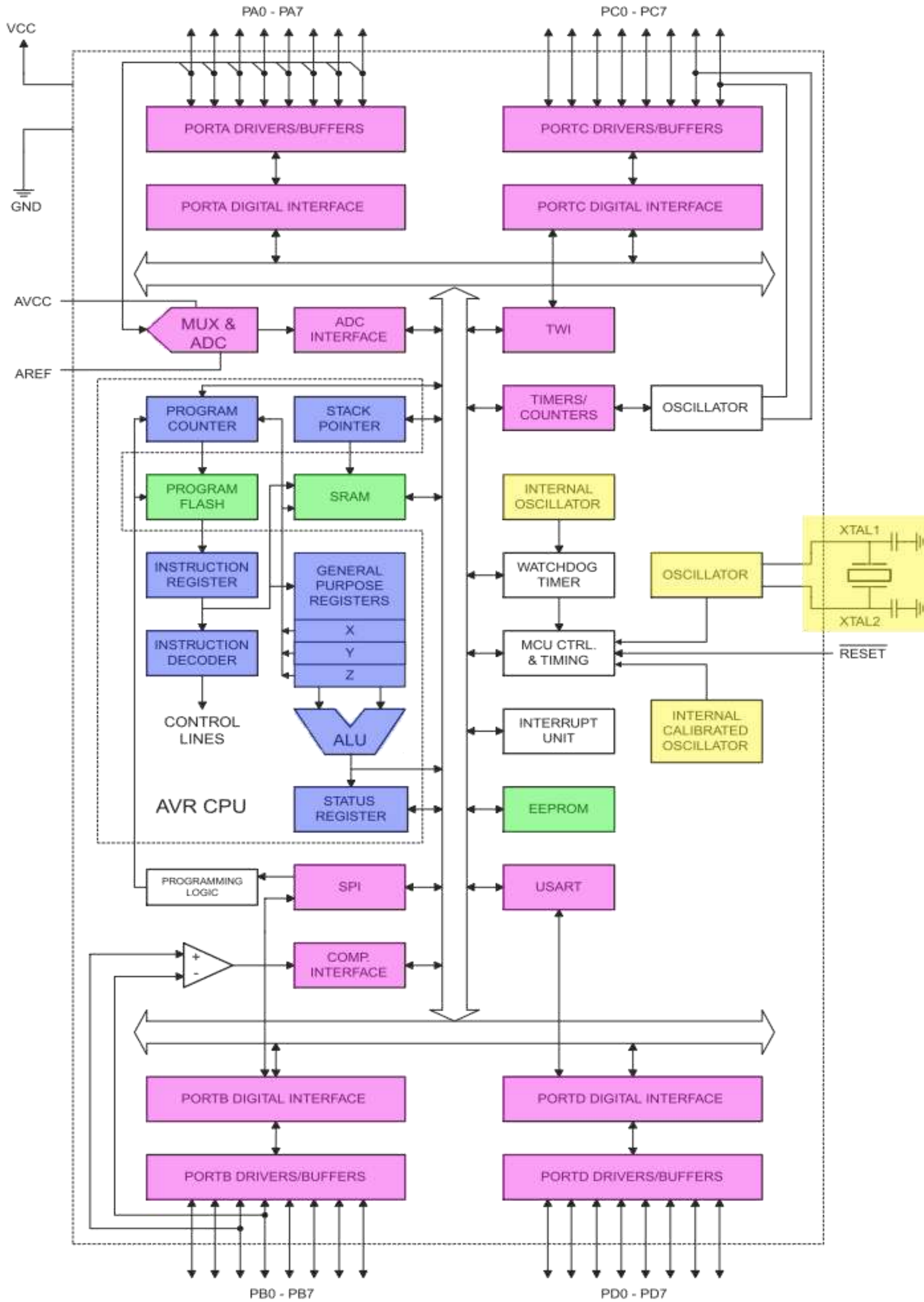


Figure 2.3 Block diagram for ATMega32

2.5 Stepper motor:

A stepper motor is a unique type of Direct Current (DC) motor that rotates in fixed steps of a certain number of degrees. Step size can range from 0.9 to 90° [8]. Figure 2.4 shows a typical stepper motor, it is basically consists of a rotor and stator. Normally, the rotor is a permanent magnet, and the stator is made up of electromagnets (field poles). The rotor will move (or step) to align itself with an energized field magnet. If the field magnets are energized one after the other around the circle, the rotor can be made to move in a complete circle.

Stepper motors are particularly useful in control applications because the controller can know the exact position of the motor shaft without the need of position sensors. This is done by simply counting the number of steps taken from a known reference position. Step size is determined by the number of rotor and stator poles, and there is no cumulative error (the angle error does not increase, regardless of the number of steps taken). In fact, most stepper motor systems operate open-loop that is; the controller sends the motor a determined number of step-commands and assumes the motor goes to the right place. A common example is the positioning of the read/write head in a floppy disk drive.

Steppers have inherently low velocity and therefore are frequently used without gear reductions. A typical unit driven at 500 pulses per second rotates at only 150rpm. Stepper motors can easily be controlled to turn at 1rpm or less with complete accuracy. There are three types of stepper motors: permanent magnet, variable reluctance, and hybrid. All types perform the same basic function, but some differences among them may be important in some applications [8].

A stepper motor cannot be directly connected to the microcontroller due to many reasons, for instance, the microcontroller cannot supply the current required to drive the motor, ATmega32 can source or sink current up to 40mA, but the motor needs much more current than that, another reason is the difference in the operating voltage between the two, Also the negative voltage created due to the back EMF of the motor may affect the proper functioning of the microcontroller, moreover, reversing the direction of the motor will not be possible if the motor is directly connected to the microcontroller because changing direction means changing the polarity of the supply. To solve these problems a transistorized H-bridge may be brought into action in which freewheeling diodes used to avoid the problems due to back EMF, a readymade IC L293D contain four h-bridge may be used. However, ULN2003A is used in this research as motor driver because the advantages they offer and shall be discussed later in this chapter.

Figure 2.4 Stepper motor

2.6 Pressure Sensors:

Pressure is defined as the force per unit area that one material exerts on another. For example, consider a 10lb cube resting on a table. If the area of each face of the cube is 4 in^2, then 10lb is distributed over an area of $4in^2$, so the cube exerts a pressure on the table of 2.5lb/in2 (10lb/4 in2 = 2.5lb/in2, or 2.5psi). In SI units, pressure is measured in Newton per square meter (N/m^2), which is called a Pascal (Pa). For a liquid, pressure is exerted on the side walls of the container as well as the bottom. Pressure sensors usually consist of two parts: The first converts pressure to a force or displacement, and the second converts the force or displacement to an electrical signal. Pressure measurements are made only for gases and liquids. The simplest pressure measurement yields a gauge pressure, which is the difference between the measured pressure and ambient pressure. At sea level, ambient pressure is equal to atmospheric pressure and is assumed to be 14.7psi, or 101.3 kilo Pascals (kPa). A slightly more complicated sensor can measure differential pressure, the difference in pressure between two places where neither pressure is necessarily atmospheric. A third type of pressure sensor measures absolute pressure, which is measured with a differential pressure sensor where one side is referenced at 0psi (close to a total vacuum) [9].

2.6.1 Semiconductor pressure sensor (MPX4115):

Some commercially available pressure sensors use the piezoresistive property of silicon such as MPX4115A (Figure 2.5). The piezoresistive element converts pressure directly into resistance, and resistance can be converted into voltage. These sensors have the advantage of “no moving parts” and are available in pressure ranges from 0-1.5psi to 0-5000psi. An example of a commercial semiconductor pressure sensor is the ST2000 series from Sen Sym Inc. This unit can be used with fluids or gases, has an internal amplifier, and outputs a voltage that is directly proportional to absolute pressure. The pressure sensor used is the MPX4115, it uses a silicon piezoresistive sensor element. If a material called "piezoresistive" it means that the resistance of the material will change when a mechanical stress is applied. In this case the piezoresistive material is silicon. The changes of resistance for silicon are far greater than for example silicon, making this material very useful to use as a sensor element in a pressure sensor [9].

2.6.2 MPX4115 PIN Configuration:

MPX4115A has six pins as shown in the figure 2.6 below. Pin 1 is V_{out} and it is noted by the notch in the lead. Pin 2 and 3 are ground and Vs respectively. Pin 4, 5, and 6 are internal device connections, and they must not be connected to external circuitry or ground.

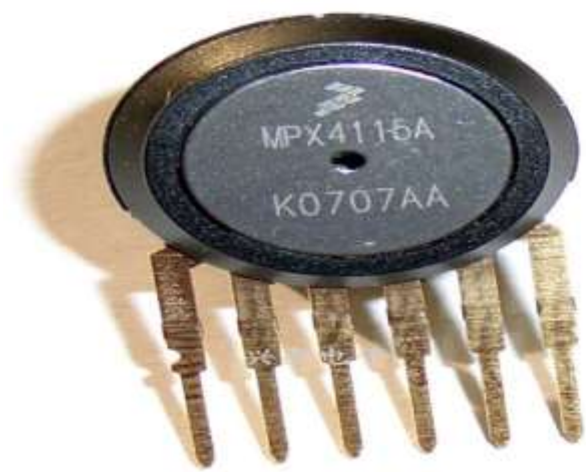


Figure 2.5 MPX4115A

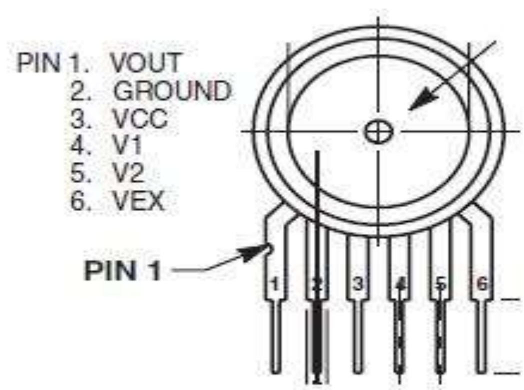


Figure 2.6 MPX4115A PIN Configurations

Table 2.3 MPX4115A Pin configurations

PIN NUMBER			
1	Vout	4	N/C
2	GND	5	N/C
3	Vs	6	N/C

2.7 ULN2003A:

The ULN2001, ULN2002, ULN2003 and ULN2004 are high voltage, high current Darlington arrays each containing seven open collector Darlington pairs with common emitters. Each channel rated at 500mA and can withstand peak currents of 600mA [10]. Suppression diodes are included for inductive load driving and the inputs are pinned opposite the outputs to simplify board layout. The ULN2003A is shown in Figure 2.7, as well as the pin connection diagram in Figure 2.8. The versions interface to all common logic families: ULN2001 (general purpose, Diode-Transistor Logic (DTL), Transistor-Transistor Logic (TTL), Positive-channel Metal Oxide Semiconductor (PMOS), Complementary Metal Oxide Semiconductor (CMOS); ULN2002 (14 - 25 V PMOS); ULN2003 (5 V TTL, CMOS); ULN2004 (6 - 15 V CMOS, PMOS).These versatile devices are useful for driving a wide range of loads including solenoids, relays, DC motors, LED displays filament lamps, thermal print-heads and high power buffers. In this research ULN2003A is used to drive two stepper motors. The ULN2001A/2002A/2003A and 2004A are supplied in 16 pin plastic Dual In Package (DIP) packages with a copper lead-frame to reduce thermal resistance. They are available also in small outline package (SO-16) as ULN2001D1/2002D1/2003D1/ 2004D1 [10].

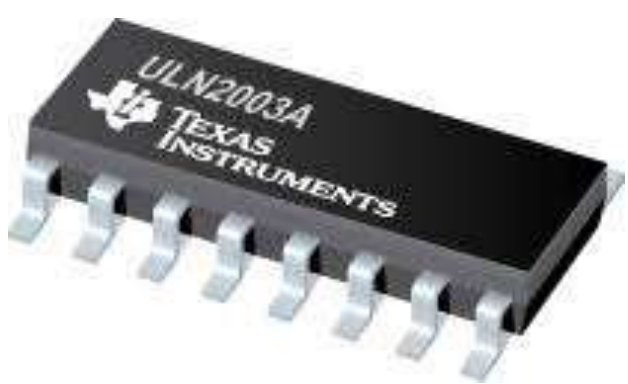


Figure 2.7 ULN2003A

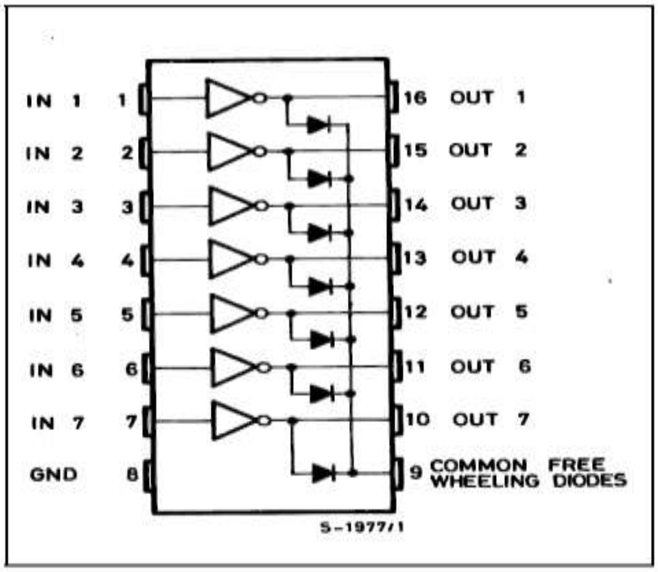


Figure 2.8 ULN2003A pin connection diagram

2.8 Gas Sensor (MQ-9):

A gas detector is a device that detects the presence of gases in an area, often as part of a safety system. This type of equipment is used to detect a gas leak or other emissions and can interface with a control system so a process can be automatically shut down. A gas detector can sound an alarm to operators in the area where the leak is occurring, giving them the opportunity to leave. This type of device is important because there are many gases that can be harmful to organic life, namely humans and animals.

Semiconductor sensors detect gases by a chemical reaction that takes place when the gas comes in direct contact with the sensor. Tin dioxide is the most common material used in semiconductor sensors, and the electrical resistance in the sensor is decreased when it comes in contact with the monitored gas. The resistance of the tin dioxide is typically around 50kΩ in air but can drop to around 3.5kΩ in the presence of 1% methane. This change in resistance is used to calculate the gas concentration. Semiconductor sensors are commonly used to detect hydrogen, oxygen, alcohol vapor, and harmful gases such as carbon monoxide. One of the most common uses for semiconductor sensors is in carbon monoxide sensors. They are also used in breathalyzers, because the sensor must come in contact with the gas to detect it, semiconductor sensors work over a smaller distance than infrared point or ultrasonic detectors. MQ-9 is a semiconductor sensor. Sensitive material of MQ-9 gas sensor is SNO2, which with lower conductivity in clean air. It make detection by method of cycle high and low temperature, and detect CO when low temperature (heated by 1.5V). The sensor's conductivity is higher along with the gas concentration rising. When high temperature (heated by 5.0V), it detects methane, Propane etc. MQ-9 gas sensor Figure 2.9 has high sensitivity to carbon monoxide, methane and Liquid Petroleum Gas (LPG). The sensor could be used to detect different gases contains CO and combustible gases; it is with low cost and suitable for different applications [11]. Figure 2.9 shows the MQ-9 gas sensor.

Figure 2.9 MQ-9 Gas Sensor (Top and Bottom view)

MQ-9 has four pins as illustrated in the figure 2.10.

Figure 2.10 MQ-9 Pin Configuration

Table 2.4 MQ-9 Pin Configurations

Pin No	Pin Name
1	Vcc (+5v)
2	Ground
3	Digital Out
4	Analog Out

2.9 Analogue switch (4066):

The analogue switch, also called the bilateral switch, is an electronic component that behaves in a similar way to a relay, but has no moving parts. The switching element is normally a pair of Metal Oxide Semiconductor Field-Effect Transistor (MOSFET) transistors, one an N-channel device, the other a P-channel device. The device can conduct analog or digital signals in either direction when ON and isolates the switched terminals when OFF. Analogue switches are usually manufactured as integrated circuits in packages containing multiple switches (typically two, four or eight). These include the 4016 and 4066 from the 4000 series [12]. The control input to the device may be a signal that switches between the positive and negative supply voltages, with the more positive voltage switching the device on and the more negative switching the device off. Other circuits are designed to communicate through a serial port with a host controller in order to set switches on or off. The signal being switched must remain within the bounds of the positive and negative supply rails which are connected to the Positive-channel Metal Oxide Semiconductor (P-MOS) and Negetive-channel Metal Oxide Semiconductor (N-MOS) body terminals. The switch generally provides good isolation between the control signal and the input/output signals. They are not used for high voltage switching.

4066 contains four analogue bilateral switches as depicted in Figure 2.11, each with an active enable input (A) and two input/output (x and y). When the enable input is set high, the x and y terminals are connected by low impedance; this is the ON condition. When the enable is low, there is high impedance path between x and y, and the switch is off. The 4066 is pin-compatible with the 4016, but has a significantly lower on impedance and more constant on resistance over the full range of input voltage. The 4066 is preferable to the 4016 in most cases [12].

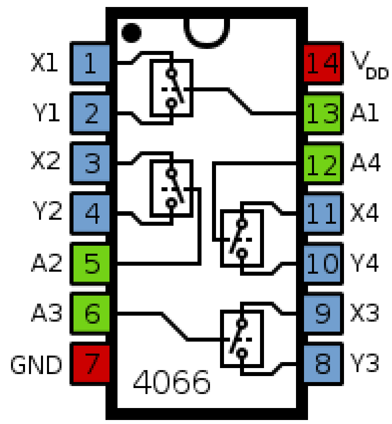


Figure 2.11 Analogue switch (4066)

2.10 Vibration Sensor SW-420:

Vibration sensor is used originally as vibration switch because of its high sensitivity; it is sensitive to environment vibration, and generally used to detect the ambient vibration strength. Vibration Switch Sensor Module is shown in Figure 2.12, when module did not reach the threshold in shock or vibration strength, D0 port output gets high level and when external vibration strength exceeds the threshold, D0 port output gets low level. Small digital output D0 can be directly connected to the microcontroller, for the microcontroller to detect low level, thereby to detect the ambient vibration. Small digital output D0 can directly drive the relay module, which can be composed of a vibration switch [13]. The module Specifications are as follows:

- The default state of the switch is open

- Digital output
- Supply voltage:3.3V-5V
- On-board LM393 voltage Comparator chip and Vibration sensing probe
- Signal detection sensitivity can be adjusted.
- Dimension: 3cm x 1.5cm.

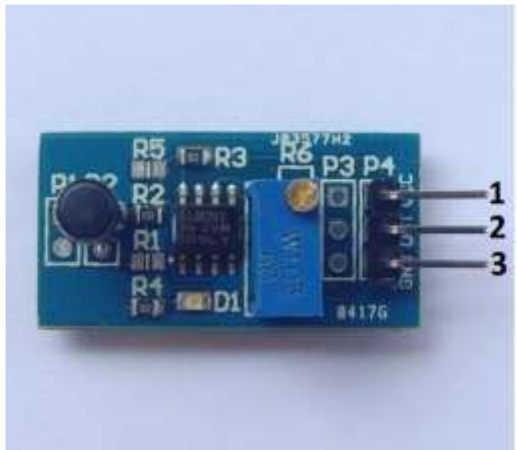


Figure 2.12 Vibration switch sensor module

Table 2.5 SW-420 PIN Configuration

Pin No	Pin Name
1	Vcc (+5v)
2	Digital Out
3	Ground

2.11 LM 35 precision centigrade temperature sensors:

The LM35 series are precision integrated-circuit temperature sensors, whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. The LM35 thus has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from its output to obtain convenient Centigrade scaling. The LM35 does not require any external calibration or trimming to provide typical accuracies of ±1⁄4°C at room temperature and ±3⁄4°C over a full −55 to +150°C temperature range [14]. Low cost is assured by trimming and calibration at the wafer level. The LM35's low output impedance, linear output, and precise inherent calibration make interfacing to readout or control circuitry especially easy. It can be used with single power supplies, or with plus and minus supplies. As it draws only 60 µA from its supply, it has very low self-heating, less than 0.1°C in still air. The LM35 is rated to operate over a −55° to +150°C temperature range, while the LM35C is rated for a −40° to +110°C range (−10° with improved accuracy). The LM35 series is available packaged in hermetic TO-46 transistor packages, while the LM35C, LM35CA, and LM35D are also available in the plastic TO-92 transistor package. The LM35D is also available in an 8-lead surface mount small outline package and a plastic TO-220 package. The LM35 can be applied easily in the same way as other integrated-circuit temperature sensors. It can be glued or cemented to a surface and its temperature will be within about 0.01°C of the surface temperature [15]. A typical LM35 sensor is shown in figure 2.13 below.

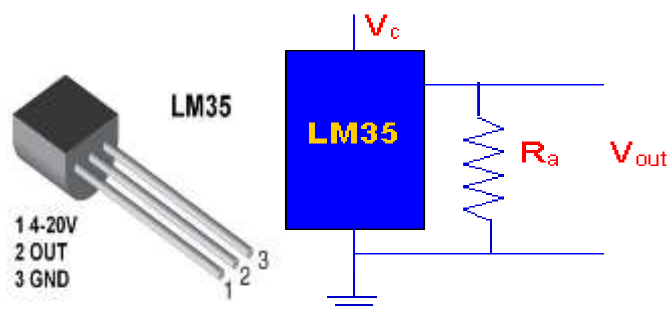


Figure 2.13 LM 35 Precision Centigrade Temperature Sensors

2.12 Liquid Sensor (Oil detector):

There are many choices for monitoring liquid level, and selecting the ideal sensor for any application can be challenging simply due to the number of good options. The challenge is determining the best option based on the application and design goals. Electro-optic sensors as shown in Figure 2.14, integrate an optical prism (a transparent glass) tied to solid-state circuitry that combines an infrared light emitter and receiver with transistorized switching. They are low cost and compact level sensors with built-in switching electronics. With no moving parts, these small units are ideal for a broad variety of point level sensing applications, especially where dependability and economy are a must. Electro-optic sensors are suitable for high, low or intermediate level detection in practically any tank, large or small. Installation is simple and quick through the tank top, bottom or side. Performance can be limited by reflected light, such as in a small reflective tank, bubbles, or coating fluids. Although they protrude very little into a container, they still require an entry through the container wall and must come into contact with fluids [16].

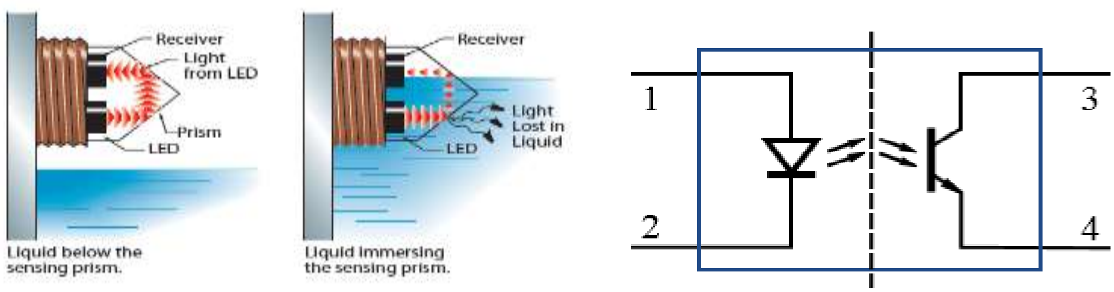


Figure 2.14 Electro-optic sensor

2.13 Flow Control Valve:

An electronically controlled proportioning valve (ECV) shown in figure 2.15 will take an electrical input signal (usually 4-20mA) and proportion to the amount of flow through a pipe from fully closed to fully open. These valves are used in industrial automation control as proportional actuators. The ECV valve features are reverse or direct acting control. Direct acting means that, as the current signal rises, the valve allows more flow, while reverse acting will decrease the flow rate with an increasing current signal [16].

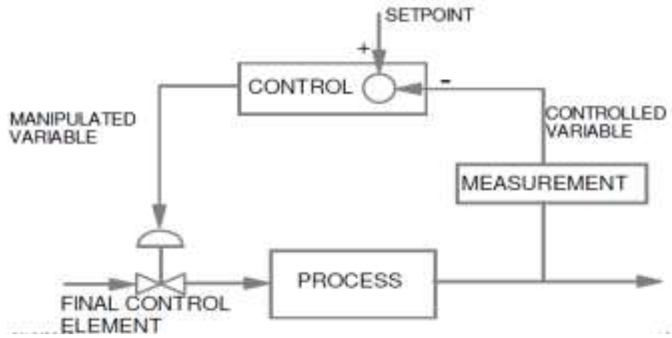


Figure 2.15 Flow control valve

2.14 LM041L "16 x 4":

Liquid Crystal Display (LCDs) provide a cost effective way to put a text output unit for a microcontroller, LEDs or 7 segments do not have the flexibility to display informative messages. The most commonly used LCDs found in the market today are one Line, two Line or four Line LCDs which have only one controller and support at most of 80 characters [17].

The LCD used in this research is LM041L (16*4), Figure 2.16 shows this display, and it has four lines and can display 16 characters on each line. Nonetheless, when it is interfaced with the microcontroller, we can scroll the messages with software to display information which is more than 16 characters in length.

Figure 2.16: LCD (LM041L)

Most LCDs with 1 controller has 14 pins and LCDs with two controllers has 16 pins. Pins description is shown in the Table 2.6. It is easy to interface with a microcontroller because of an embedded controller. This controller is standard across many displays (HD 44780), that is, many microcontrollers (including the one used here) have libraries that make displaying messages as easy as a single line of code [17].

Table 2.6 LM041L LCD (16*4) pins description

Pin No.	Name	Description
Pin no. 1	VSS	Power supply (GND)
Pin no. 2	VDD	Power supply (+5V)
Pin no. 3	VEE	Contrast adjust
Pin no. 4	RS	0 = Instruction input 1 = Data input
Pin no. 5	R/W	0 = Write to LCD Module 1 = Read from LCD module
Pin no. 6	EN	Enable signal
Pin no. 7	D0	Data bus line 0 (LSB)
Pin no. 8	D1	Data bus line 1
Pin no. 9	D2	Data bus line 2
Pin no. 10	D3	Data bus line 3
Pin no. 11	D4	Data bus line 4
Pin no. 12	D5	Data bus line 5
Pin no. 13	D6	Data bus line 6
Pin no. 14	D7	Data bus line 7 (MSB)

CHAPTER THREE

SYSTEM DESIGN

3.1 Overview:

The bi-fuel system is a system that allows diesel engines to operate on a mixture of diesel fuel and natural gas. This is achieved through a system that is installed externally of the engine. Conversion to bi-fuel mode requires no major changes or modifications of the engine and allows the engine to operate on gas mixtures ranging from 30% to almost 70% of total fuel consumed. After conversion to bi-fuel, the engine can still be operated on 100% diesel fuel without loss of power or efficiency. The bi-fuel system has been designed to allow for switching of fuel modes during full or part load conditions, without interruption in engine speed, power or stability.

The bi-fuel system utilizes a fumigation gas delivery method whereby gas is delivered to the cylinders via the standard engine air-intake system and is then ignited by a diesel "pilot" which acts as ignition source for the air-gas mixture. The system requires precise regulation and control of the fuel supply gas. In order to ensure nominal operation and proper functioning, the System should be supplied with gas train consisting of gas filter, gas pressure regulator and gas solenoid valve.

As the mechanical part of the system is beyond the scope of this research, we will only discuss the electrical and electronic part of the system that is used to enable the diesel engines to operate on a mixture of diesel fuel and natural gas. We shall discuss in this chapter the circuit design, the components and their function, as well as the components connections to the microcontroller. Figure 3.1 shows the complete block diagram of the bi-fuel system.

Block Diagram:

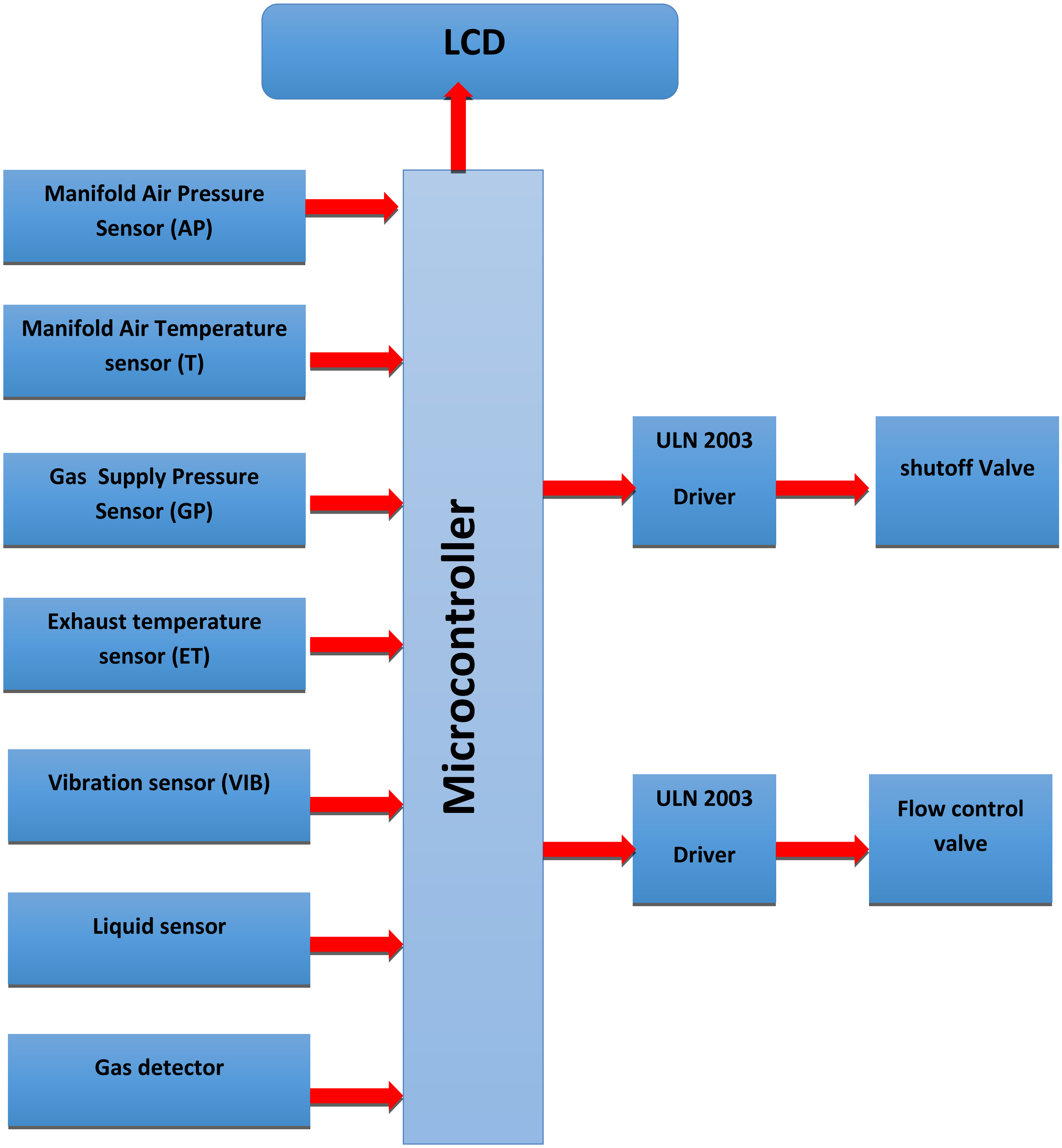


Figure 3.1 Complete block diagram of the bi-fuel system

3.2 Circuit Design:

The circuit was designed using Protoes software for simulation as shown in Figure 3.2.

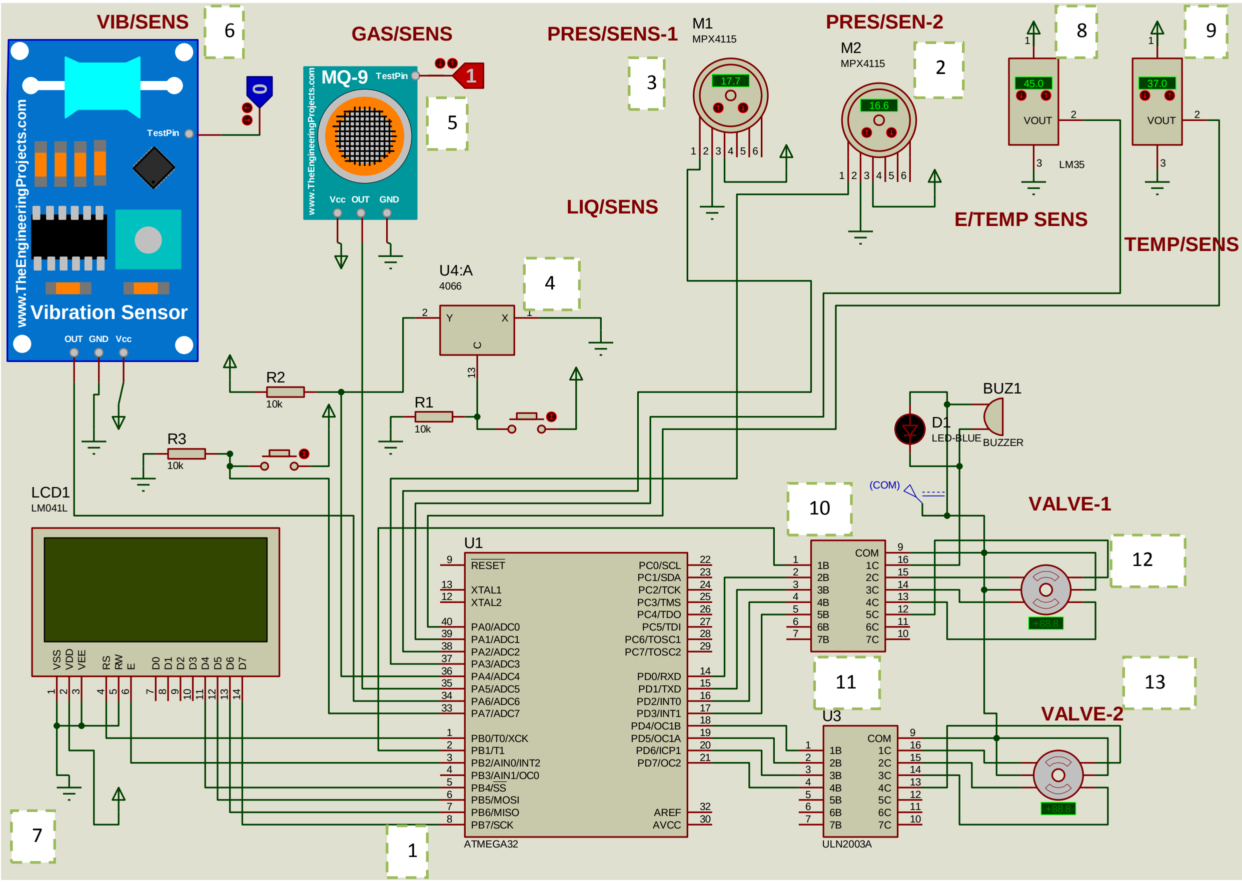


Figure 3.2 Circuit Design using Proteus software

The main parts of the circuit design are:

1- Microcontroller (ATmega32).

2- MPX4115 pressure sensor 1.

3- MPX4115 pressure sensor 2.

4- Liquid detector (4066).

5- MQ-9 gas sensor.

6- Vibration sensor SW-420.

7- LM016 L (LCD 16 x 2).

8- LM35 precision centigrade temperature sensors 1.

9- LM35 precision centigrade temperature sensors 2.

10- ULN2003A motor driver 1.

11- ULN2003A motor driver 2.

12- Stepper motor (valve 1).

13- Stepper motor (valve 2).

3.3 The Basic Design and Requirements:

The designed system can be divided into four major parts as follows:

1. Central Processing Unit (CPU) (microcontroller ATmega32).
2. Monitor (LCD)
3. Inputs (sensors).
4. Outputs (stepper motors and their drivers).

Throughout the process the microcontroller continuously monitors a variety of the engine and bi-fuel system parameters including air pressure, air temperature, gas pressure, engine exhaust temperature, and engine vibration. The microcontroller also receives signals from oil or (liquid) detector and gas sensor. Based on input from various sensors and user programmed limits, the microcontroller will activate or deactivate the system as required. In the event a programmed limit is exceeded the microcontroller will deactivate the system and return the engine to 100% diesel fuel operation. To activate or deactivate the system, the microcontroller sends signals to open or close two valves. The two valves are represented by the two stepper motors in the simulation. The user can continuously monitors the system parameters through the display LM041, and in case the microcontroller receive any abnormal reading from any of the sensors, a message corresponds to that abnormal condition will appear in the display.

3.4 Microcontroller Pin Connection:

The microcontroller is the brain of the system, so it has connections to all the parts of the system; sensors, LCD, and stepper motors.

3.4.1 Sensors connection:

ATmega32 has 40 pins as shown in Figure 3.3. Two for power (pin No.10: +5V, pin No. 11: ground), two for oscillator (pin 12, 13), one for reset (pin 9), three for providing necessary power and reference voltage to its internal ADC, and 32 (4×8) I/O pins. ATmega32 is capable of handling analogue inputs. Port A can be used as either digital I/O lines or each individual pin can be used as a single input channel to the internal ADC of ATmega32. Each pin in this port is assigned to one sensor, that is, the designed system has a total of seven sensors and one switch, the seven sensors are connected to pins PA0 to PA6, and the switch is connected to PA7.

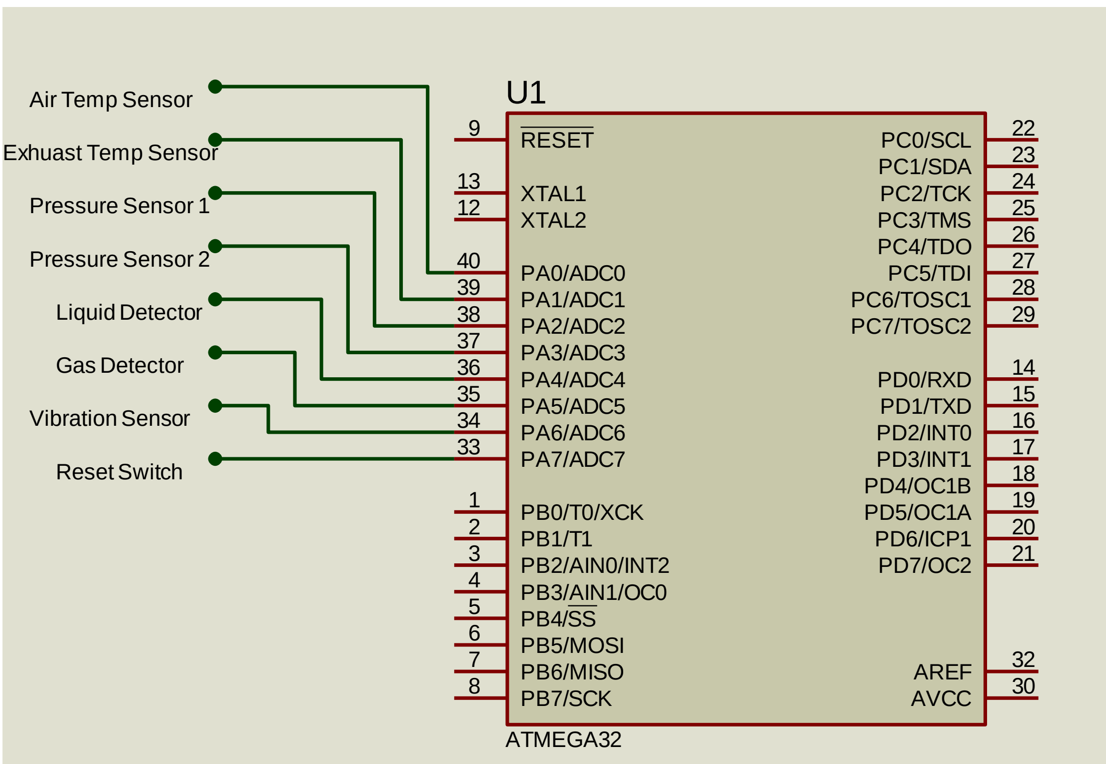


Figure 3.3 Sensors to microcontroller pins connection

3.4.2 ULN2003A connections:

Port D is assigned to the two ULN2003A motor drivers, PD0 to PD3 are connected to the first ULN2003A, whereas PD4 to PD7 are connected to the other one, one pin, namely, pin (1B) in the first ULN2003A is used to drive the buzzer. The buzzer function will be explained when we discuss the gas sensor. The connection between the microcontroller and the ULN2003A is illustrated in Figure 3.4. ULN2003A is basically a relay driver IC and it is a Darlington array having high voltages and high currents. Its pins are designed so that the input pins are at the left of the IC, whereas the output pins are on the right of it in front of the corresponding input pin. ULN2003A has 16 pins in total out of which there are; 7 inputs pins (pin 1 to pin 7), 7 output pins (pin 10 to pin 16), 1 COM pin (pin 9) and 1 ground pin (pin 8). ULN2003A is used as an interface between the microcontroller and the stepper motor (load), because the microcontroller cannot handle the high currents associated with the stepper motor.

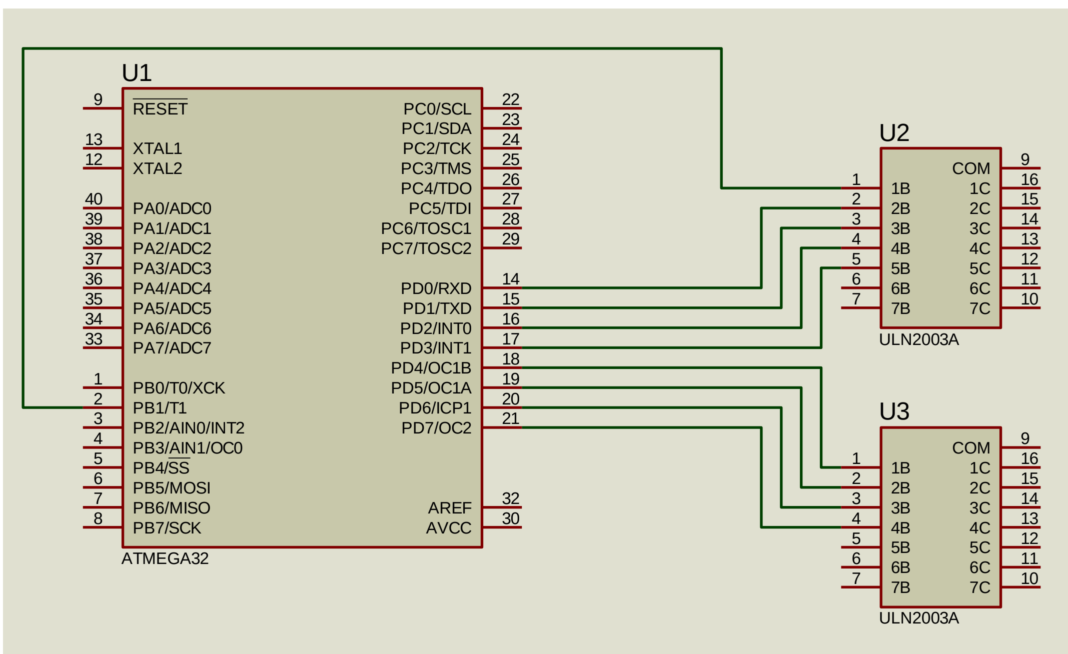


Figure 3.4 ULN2003A to microcontroller pins connection

3.4.3 LM041L connections:

The LCD used in this research is LM041L (16*4), Figure 3.5 shows this display, and its connection to the microcontroller. It has 4 lines and can display 16 characters on each line. Nonetheless, when it is interfaced with the microcontroller, we can scroll the messages with software to display information which is more than 16 characters in length. The LCD has power pins for the display to be able to function in the first place. There is a VDD pin for 5 volts and a VSS pin for ground. There is a VEE for the adjustment of the LCD contrast. And just like the microcontroller, the LCD has a row of 8 pins to serve as its output, in which only 4 of them are connected to the microcontroller D4 to D7. For the LCD to accept information from the microcontroller, or send information, the enable pin must be turned ON or OFF while the information is presented

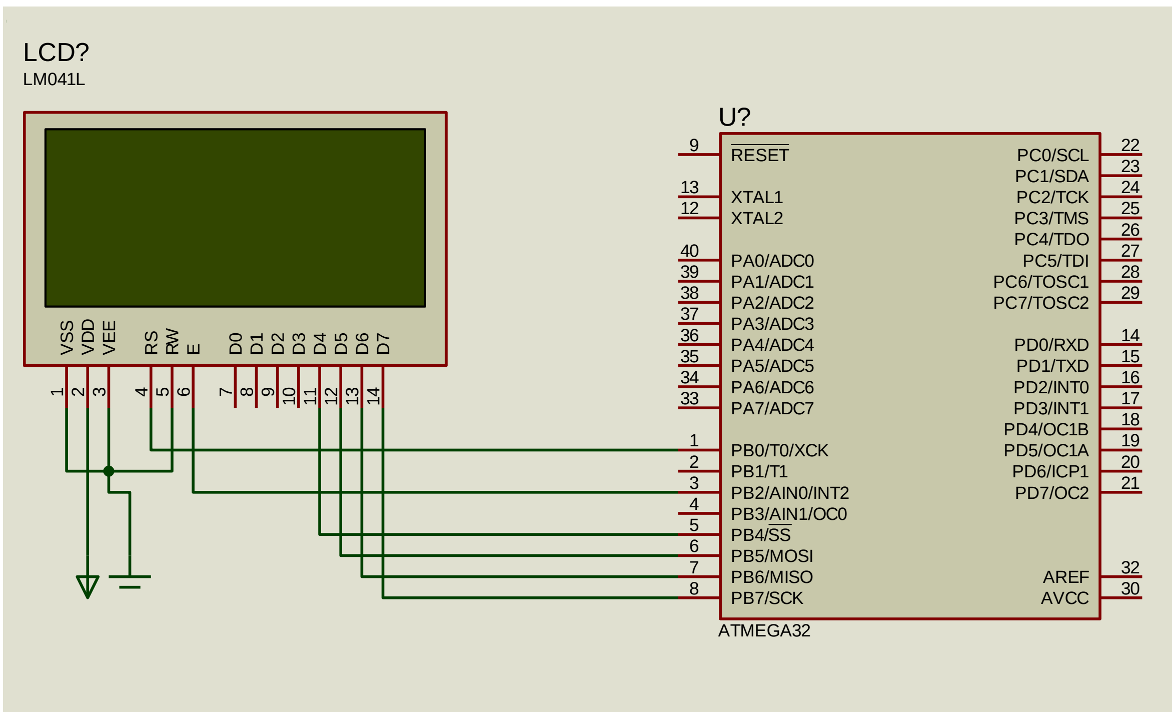


Figure 3.5 LM041L to microcontroller pins connection

3.5 Sensors:

The devices that inform the control system about what is actually occurring are called sensors (also known as transducers). As an example, the human body has an amazing sensor system that continually presents our brain with a reasonably complete picture of the environment—whether we need it all or not. For a control system, the designer must ascertain exactly what parameters need to be monitored—for example, position, temperature, and pressure, and then specify the sensors and data interface circuitry to do the job. Most sensors work by converting some physical parameter such as temperature or position into an electrical signal. This is why sensors are also called transducers, which are devices that convert energy from one form to another. The sensors used in the study includes, pressure sensors, temperature sensors, vibration sensors, liquid sensors and gas sensors. Detailed description of their function and their connection to the microcontroller is given below.

3.5.1 Air temperature sensor (AT):

Air Temperature (AT) is monitored by the microcontroller to protect against excessive temperature increases that could lead to a knocking condition in bi-fuel mode. The air temperature sensor is represented by LM35 precision centigrade temperature sensor in the simulation (temp/sensor). If the temperature increases above 40°C the sensor sends a signal (5V) to the microcontroller to stop the stepper motors. AT is displayed in Celsius units, and it has three pins, two of them are connected to power supply and ground, the third one, which is its output, is connected to the microcontroller pin A.0.

3.5.2 Exhaust temperature sensor (E/T):

The microcontroller monitors Exhaust Temperature E/T to protect against excessive combustion temperatures while operating in bi-fuel mode. The exhaust temperature sensor is represented by LM35 precision centigrade temperature sensor in the simulation (E/Temp SENS). If the temperature increases above 50°C the sensor sends a signal (5V) to the microcontroller to stop the stepper motors. E/T is displayed in Celsius units. Its pins connection is discussed in section 2.11. Figure 3.6 illustrates the connections of the two LM35 which represent the exhaust temperature sensor and the air temperature sensor to the ATmega32 microcontroller.

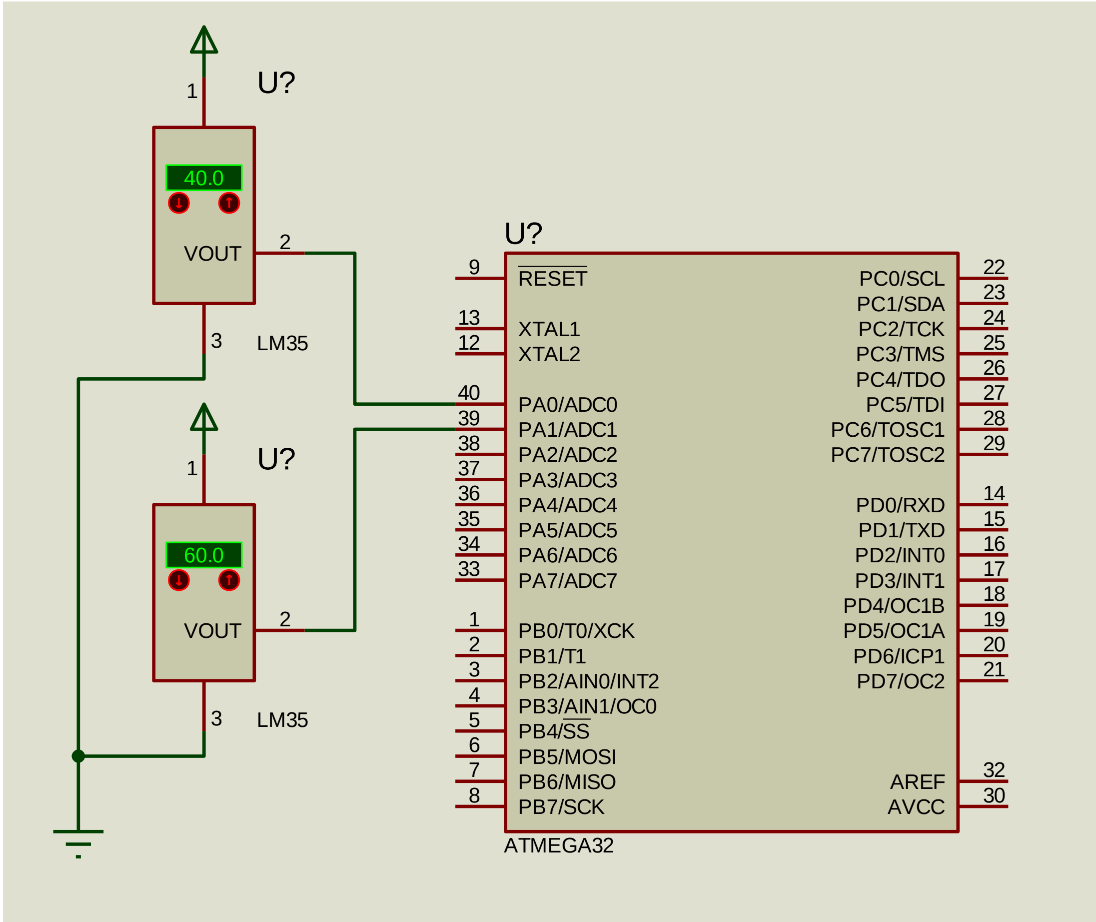


Figure 3.6 LM35 to Microcontroller pin connections

3.5.3 Air pressure sensor (AP):

Air Pressure sensor (AP) is monitored by the microcontroller to determine engine load window in which bi-fuel operation will be allowed. The user programs minimum value for AP .The minimum value sets the minimum engine load limit for bi-fuel operation. Once this value is programmed, the engine will only operate on bi-fuel mode when the load is above the programmed minimum value. The minimum value is set to 0Kpa, above this value the system operation is normal and at 0Kpa, due to a sudden drop in engine load or any other reason, the microcontroller deactivate the system by stopping the two stepper motors. AP is measured in kPa units. Mpx4115 semiconductor pressure sensor is used in the simulation, it has six pins out of which there are only three are used, one for power, one for ground and one for the output to the microcontroller.

3.5.4 Gas pressure sensor (GP):

Programmed set-point are defined as either control or safety shutdown. Gas Pressure sensor (GP) is the only control set-point and is used to protect against variations in gas supply pressure. The user programs a minimum value for GP. GP is monitored at the inlet to the bi-fuel supplied gas train. In the event GSP exceeds the programmed limit value the microcontroller automatically switches the engine fuel mode to 100% diesel operation. In case the gas supply pressure drops under 50Kpa the microcontroller stops the second stepper motor and consequently the gas flow to the engine stops. When the gas pressure increases above 50Kpa again, the system resumes its operation normally. Unlike the other sensors which defined as safety shutdown sensors, GP sensor requires no intervention by any external means to reset the system or to put it back to work except for one case, the gas's pressure drops to zero, in this case the two valves close and the system wait for operator response . Figure 3.7 below illustrate the pins connection between the MPX4115 and the microcontroller. MPX4115 pins configuration is discussed in 2.7.2.

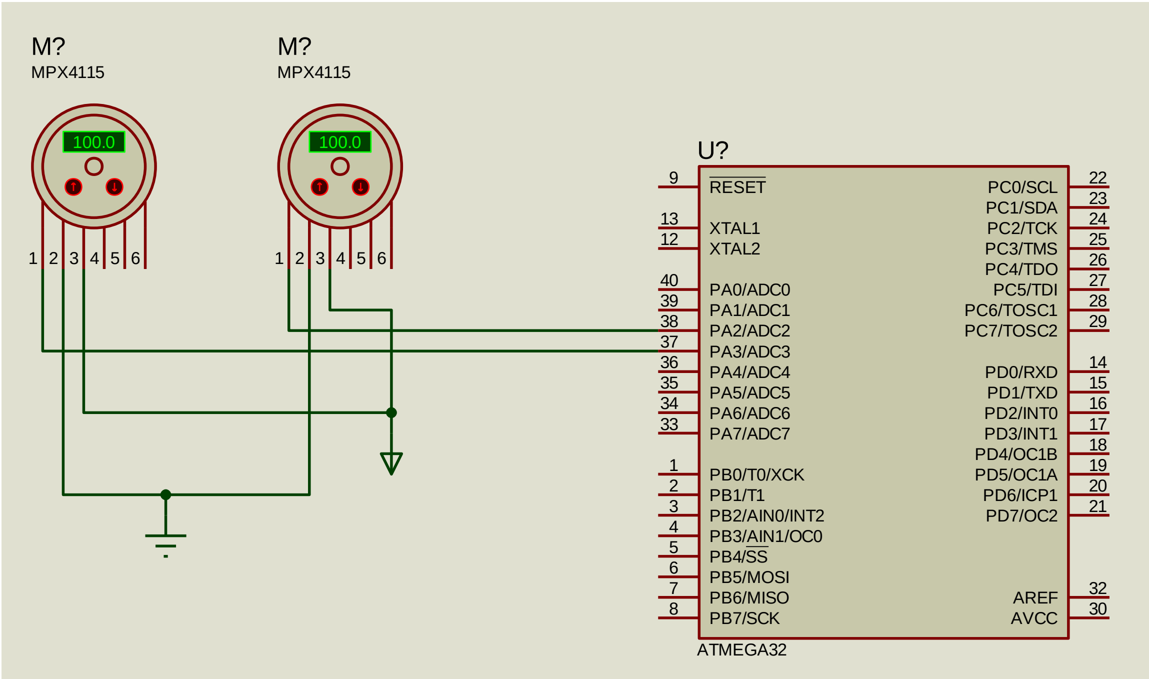


Figure 3.7 MPX4115 to Microcontroller pin connections

3.5.5 Engine vibration:

Vibration (VIB) is monitored by the microcontroller to protect against excessive engine vibration. Excessive engine vibration during bi-fuel operation may indicate a knocking condition or other combustion related abnormality. The maximum allowable value for VIB is set according to the engine manufacturer designer. In the event VIB exceeds the programmed limit value the control panel automatically switches the engine fuel mode to 100% diesel operation. VIB is measured in either Inches Per Second (IPS) or Millimeters Per Second (MPS) units and is monitored using a vibration sensor SW-420. The pin configuration of SW-420 is simple; it has only three pins VCC, ground and output. Figure 3.8 depicts the pin connection between the VIB sensor and the microcontroller.

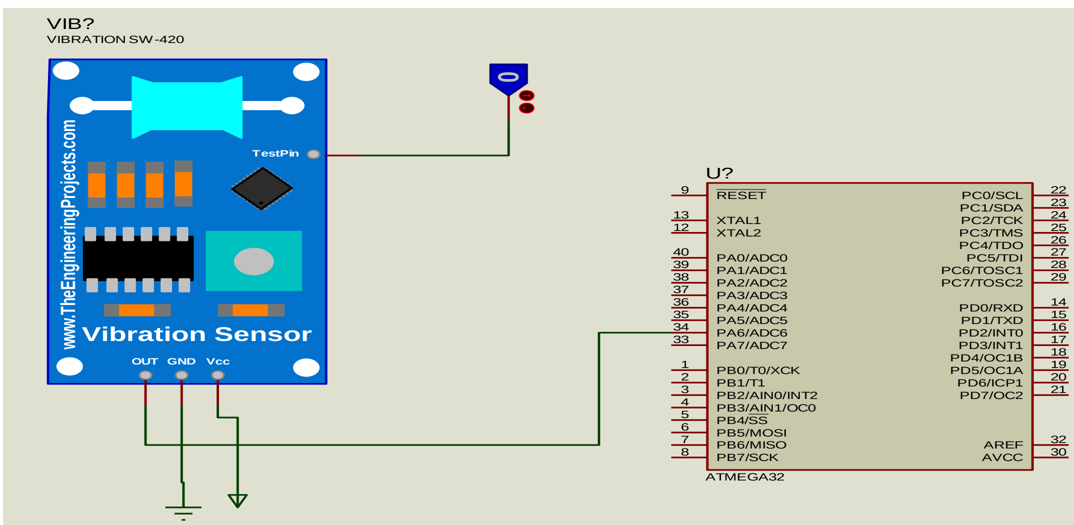


Figure 3.8 ULN2003A to Microcontroller pin connections

3.5.6 Gas sensors (MQ-9):

Semiconductor sensor MQ-9 is useful for gas leakage detecting in home and industry. Sensitive material of MQ-9 gas sensor is SNO2, which with lower conductivity in clean air. It make detection by method of cycle high and low temperature, and detect CO when low temperature (heated by 1.5V). The sensor's conductivity is higher along with the gas concentration rising. When high temperature (heated by 5.0V), it detects methane, Propane etc. MQ-9 gas sensor has high sensitivity to carbon monoxide, methane and LPG. The sensor could be used to detect different gases contains CO and combustible gases. Based on its fast response time, measurement can be taken as soon as possible. Also the sensitivity can be adjusted by the potentiometer. It is with low cost and suitable for different application [11]. It has three pins VCC, ground and output, and the pin connections to the microcontroller and the gas sensor is illustrated in figure 3.9. In the event that the gas sensor detects any presence of gas, it sends signal (5V) to the microcontroller, the microcontroller close the two valves (stepper motors) immediately to stop the flow of gas to the engine, and activate the buzzer alarm, to warn the operator with the gas presence.

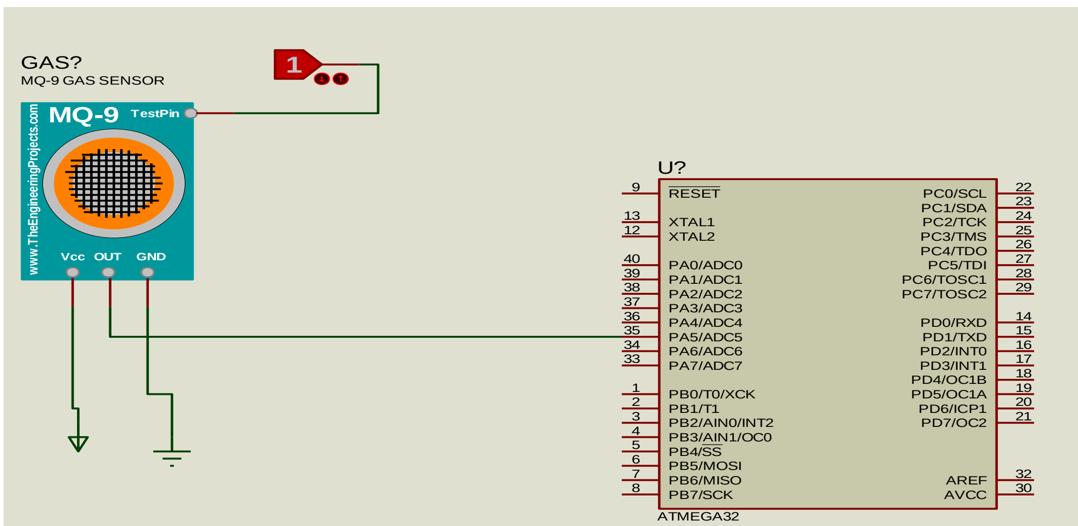


Figure 3.9 ULN2003A to microcontroller pins connection

3.5.7 Liquid detector:

Liquid detector or liquid sensor is monitored by the microcontroller in order to protect against liquid entrance to the engine manifold. In the oil and gas, petrochemical and oil refining industries, liquid-gas coalescers (filters) are widely used to remove water and hydrocarbon liquids (plus particulate matter) from natural gas to ensure natural gas quality and protect downstream equipment such as compressors and gas turbines and diesel engine in our case. The analogue switch (4066), also called the bilateral switch is used to represent the liquid detector in the simulation. 4066 contains four analogue bilateral switches, each with an active enable input (A) and two input/output (x and y). When the enable input is set high, the x and y terminals are connected by low impedance; this is the ON condition. When the enable is low, there is high impedance path between x and y [12], and the switch is off. In the event that the liquid detector detects any liquid presence it sends a signal (0V) through output (y) to the microcontroller. The microcontroller then stops the stepper motors, and prevent liquid to enter the engine. In the event that no liquid is detected, the microcontroller receives a signal of (5v) through a 10KΩ pull up resistor connected to pin A.4 and the output of the switch (y) to keep the system in normal operation. A pull down resistor is also connected to common of the 4066 so the system will function normally when there is no liquid. Figure 3.10 below shows the pins connection of the analogue switch 4066 to the microcontroller, the switch attached to the switch 4066 is used to simulate the presence or absence of liquid, when it is pressed there is liquid detected, and there is no liquid when it is released.

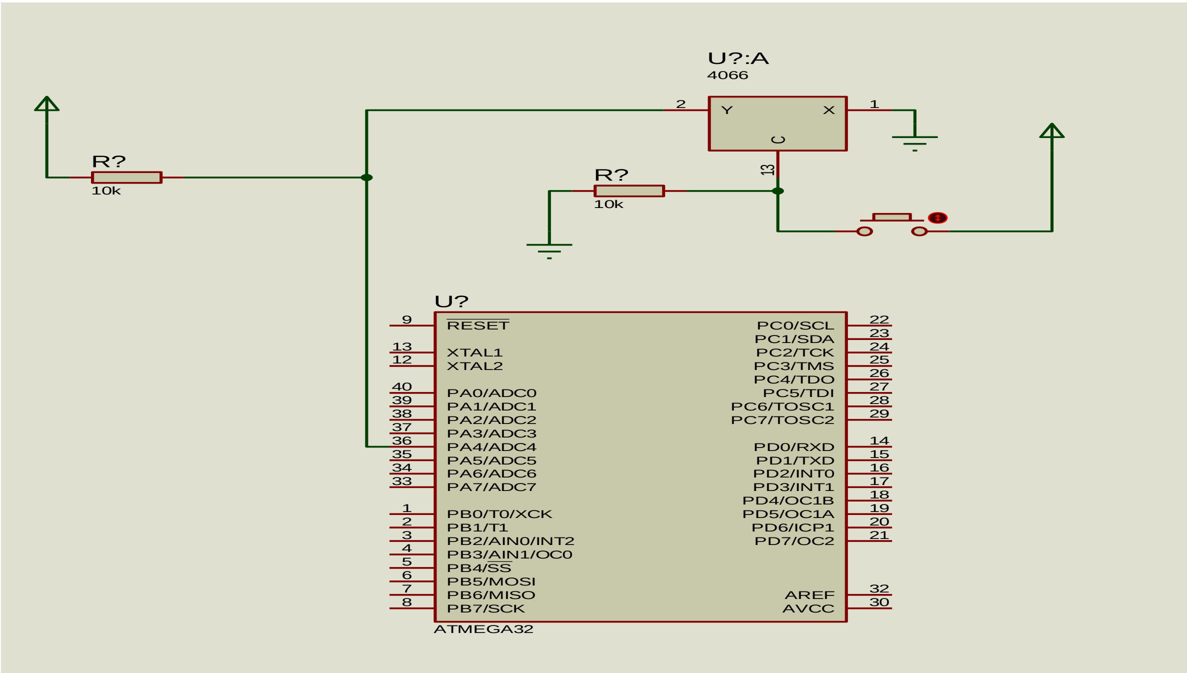


Figure 3.10 ULN2003A to Microcontroller pin connections

3.6 System Outputs (stepper Motors and Drivers):

As discussed earlier in this chapter, the microcontroller cannot provide the necessary current which is required to drive the stepper motors, thus ULN2003A is used as interface between the microcontroller and the stepper motors. ULN2003A motor driver receive signals from the microcontroller, process the signals, and then use the signals to drive the stepper motor. The stepper motor, in the actual application, is supposed to control a final control element such as control valve which controls the flow of the natural gas to the engine.

The Pins connection of the two stepper motors and their drivers is illustrated in figure 3.11 below.

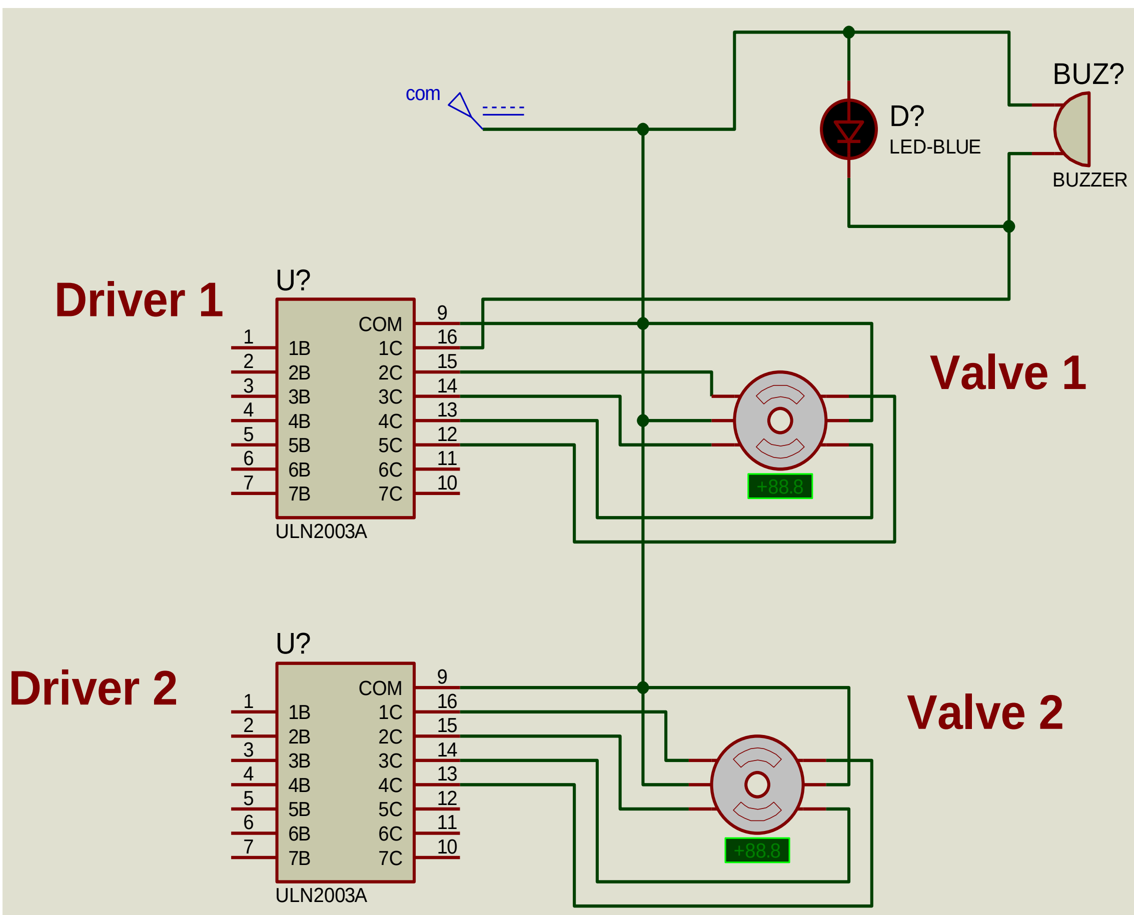
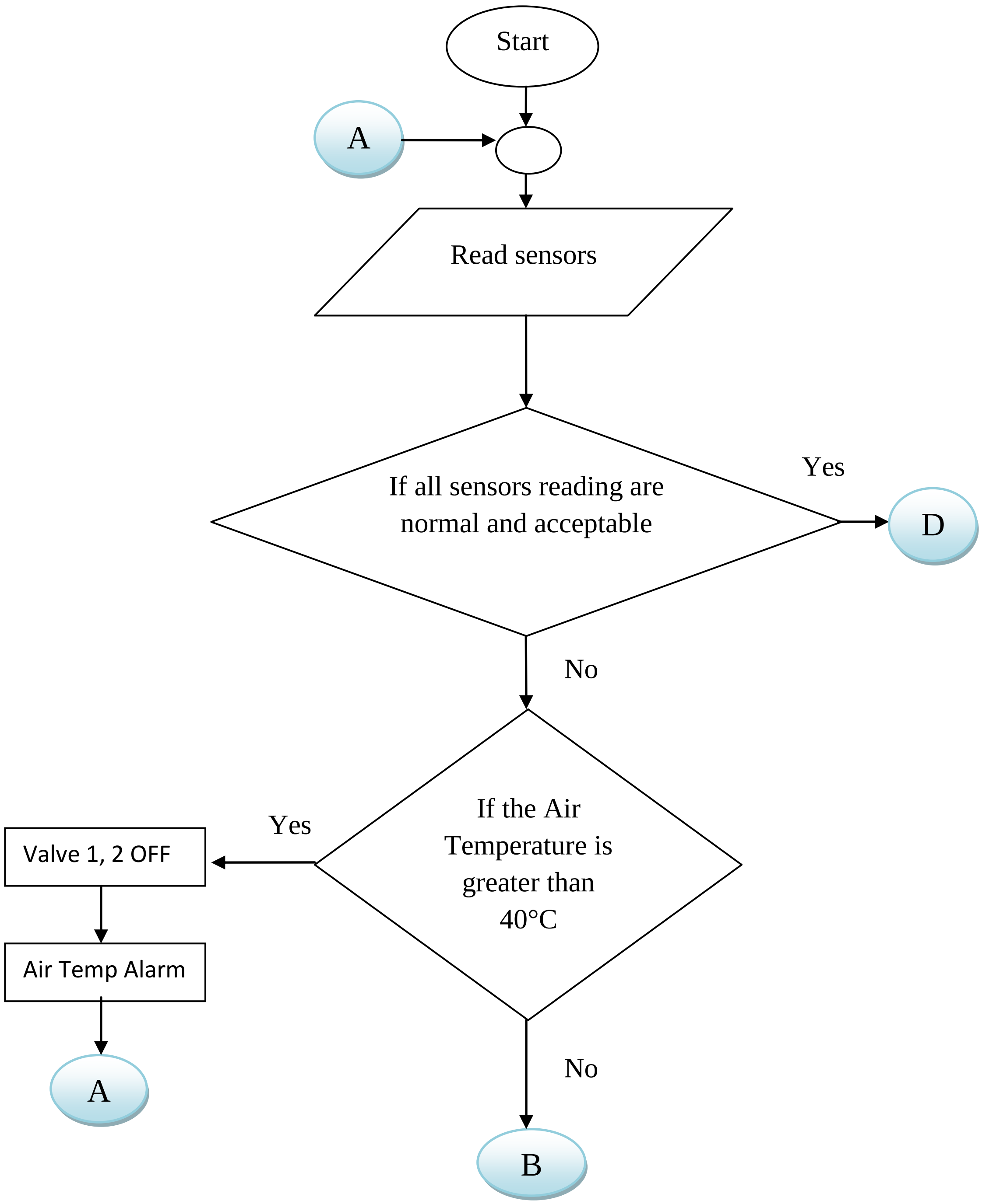
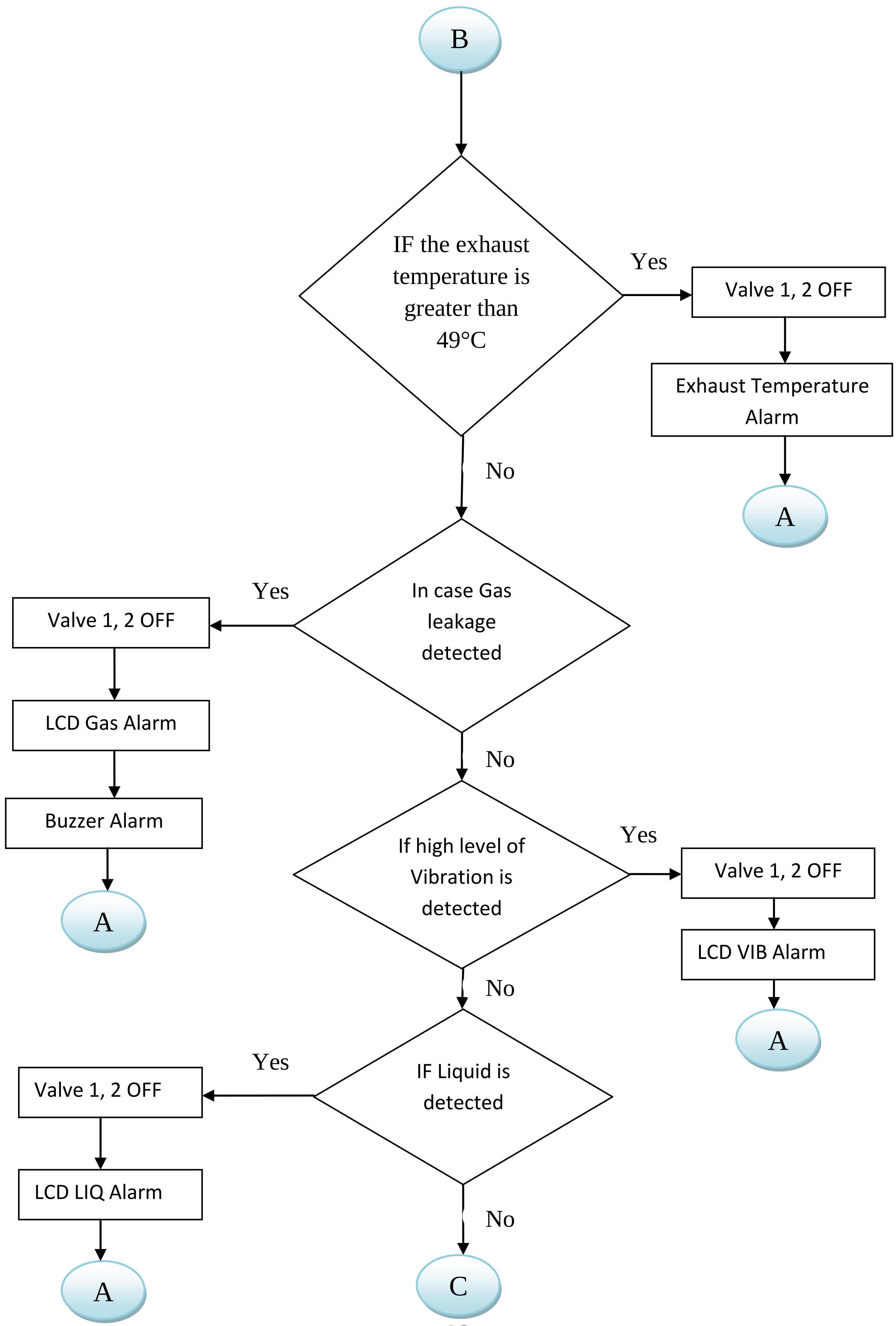


Figure 3.11 ULN2003A to stepper motors pin connections

3.7 Flow Chart:

Figure 3.12 illustrates the flow chart process in which the designed system introduces natural gas to the diesel engine safely and effectively. The flow chart also shows the set-point value of each sensor, and how the system will behave in case of an unacceptable reading from one of the sensors.




B
IF the exhaust temperature is greater than 49°C
Yes
Valve 1, 2 OFF
Exhaust Temperature Alarm
A
No
In case Gas leakage detected
Yes
Valve 1, 2 OFF
LCD Gas Alarm
Buzzer Alarm
A
No
If high level of Vibration is detected
Yes
Valve 1, 2 OFF
LCD VIB Alarm
A
No
IF Liquid is detected
Yes
Valve 1, 2 OFF
LCD LIQ Alarm
A
No
C

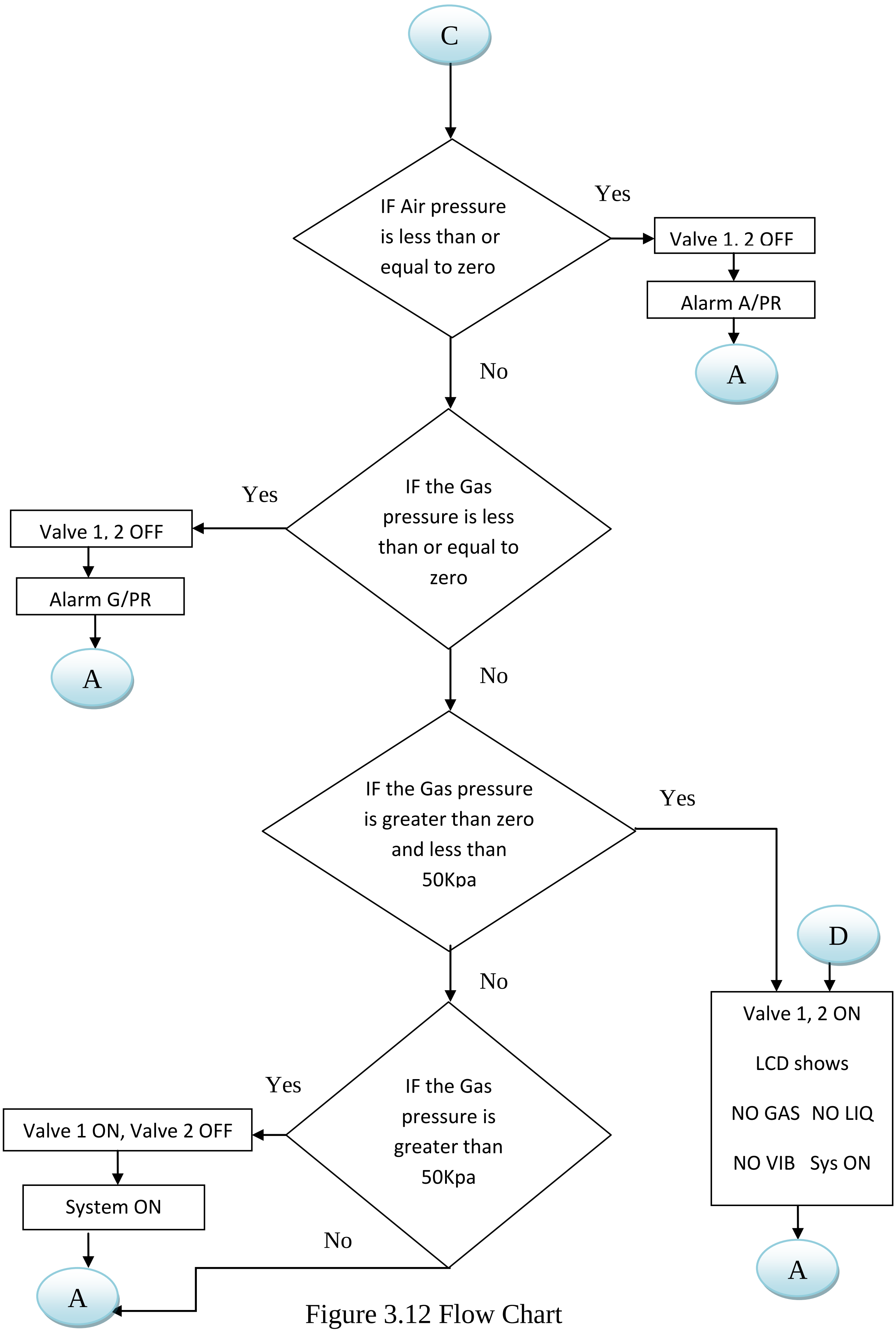


Figure 3.12 Flow Chart

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results:

In this chapter the operation of the system being designed will be discussed in detail. This section is organized into two divisions: one discusses the system startup and the other deals with the cases when the programmed limits have been exceeded.

4.1.1 System Startup:

The system commence with a welcome massage on the LCD, as shown in Figure 4.1.

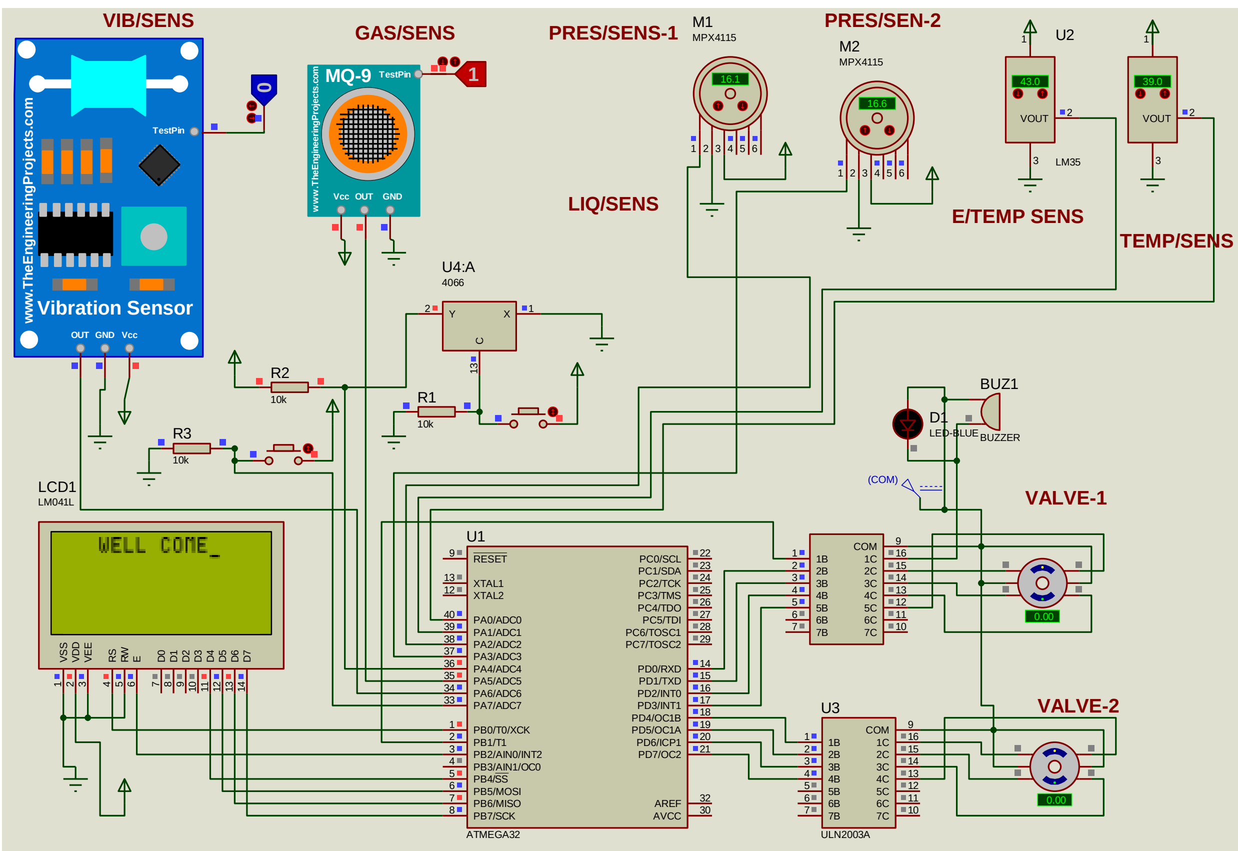


Figure 4.1 System startup screen

The microcontroller then scans port A for signals from the sensors. Port A in the microcontroller is capable of handling analogue and digital inputs. Seven sensors and one switch are connected to port A, four out of the seven are analogue sensors and the rest are digital sensors. The readings of the four analogue sensors are displayed in the LCD. Figure 4.2 shows the four analogue sensors reading in the display.

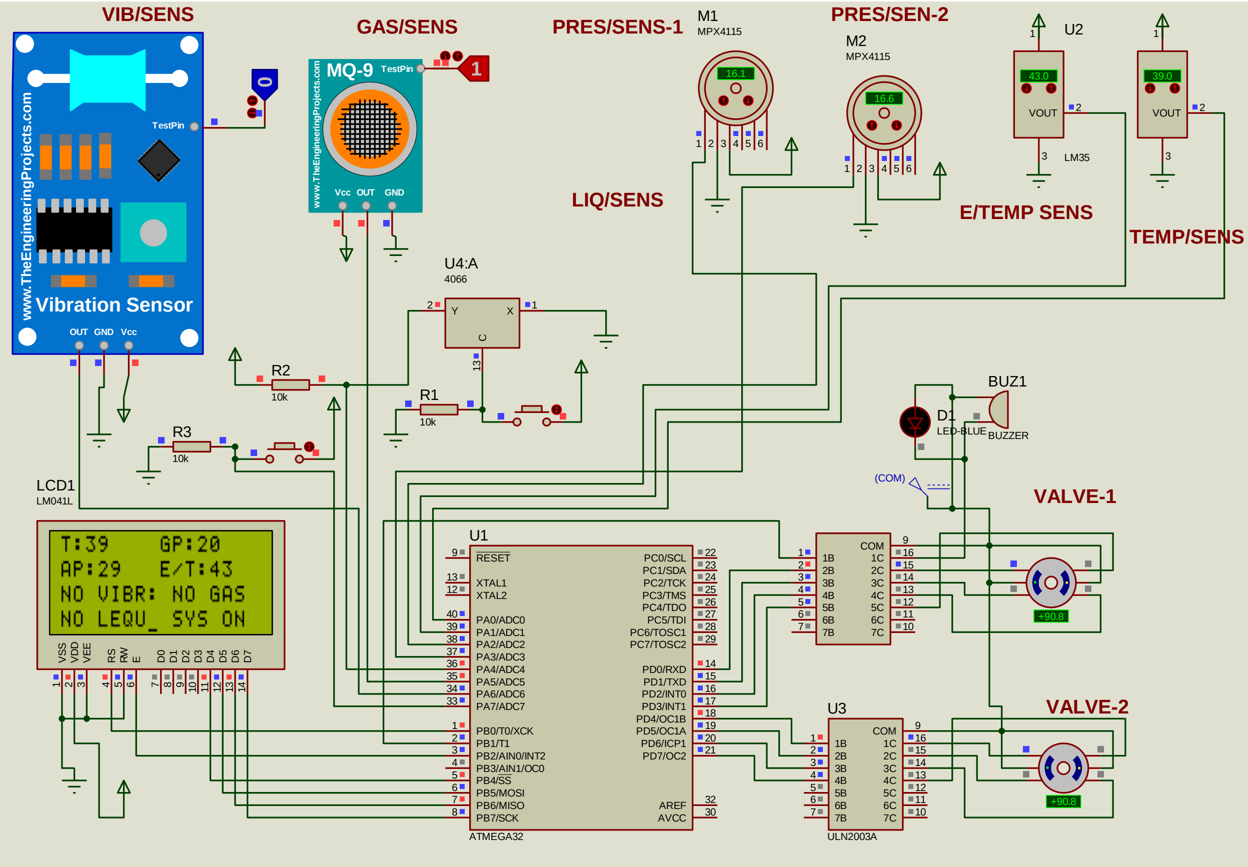


Figure 4.2 sensors reading

Figure 4.2 also shows on the display the condition of each of the three digital sensors.

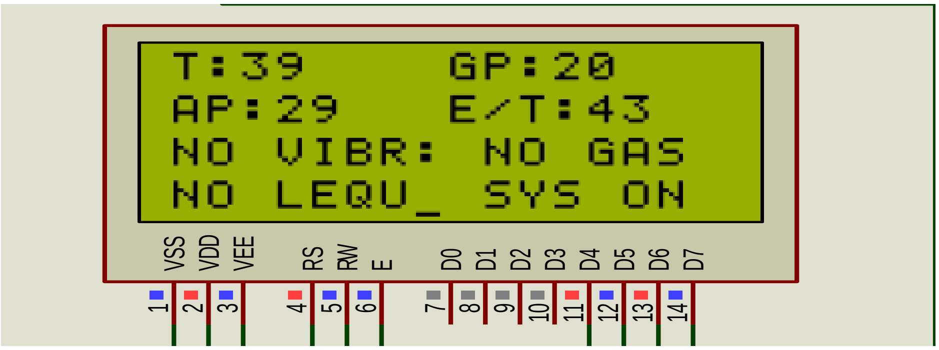


Figure 4.3: LM041L display

The first and second lines are reserved for the readings of the four analogue sensors. The first line on the display is reserved for the air temperature sensor (T) and the GP. On the second line the AP and the E/T are displayed. The three digital sensors are displayed in the third and the fourth lines. The gas detector and vibration sensor are displayed on the third line, and the liquid detector is on the fourth line of the display. The display also shows in the fourth line (SYS ON) to indicate that all parameters are within acceptable minimum and maximum limits and the system is working properly. In this case the three sensors show normal conditions, the display shows, NO VIBR for normal vibration, NO LIQU for normal liquid or no liquid and NO GAS for normal concentration of the targeted gases. The word NO may also stand for (Normal). Providing that all parameters are normal, the microcontroller sends signals to the two ULN2003A motor drivers, which in turn command the two stepper motors to turn in a clockwise direction, hence opening the two valves and allow natural gas to flow into the engine. The engine is now running in bi-fuel mode until one or more of the programmed limits are exceeded, the microcontroller will then deactivate the bi-fuel mode and return the engine to its normal operation with diesel fuel only. As this discussion progresses, an insight into the behavior of the system when the programmed limits are exceeded will be provided. There are seven cases associated with the seven sensors.

Case 1 (Air Temperature Sensor):

The programmed limit for the air temperature sensor is less than or equal to 40°C, in figure 4.4 below the air temperature sensor (LM35) senses a rise in the air temperature, the temperature exceeded the programmed limit and record 41°C, in this case the microcontroller instantly closes the two valves (two stepper motors), and the LCD display two messages; ALARM TEMP, to indicate the air temperature limit has been exceeded, and SYS OFF, to state that the valves are closed and the engine is returned to 100% diesel fuel operation.

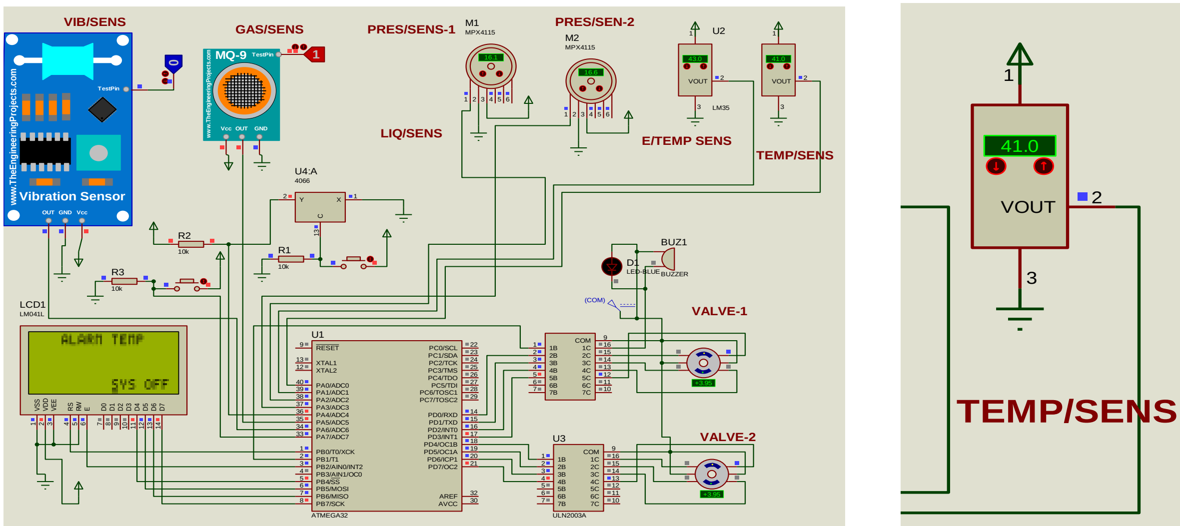


Figure 4.4 High air temperature

Case 2 (Gas Pressure Sensor):

As mentioned in the previous chapter the gas pressure sensor is the only control set point among all other sensors, however it will deactivate the system in one case, and that is when the gas pressure drops to zero. Figure 4.5 shows this case in the display (GP: 0). MPX4115 is used to measure the pressure and it shows (15.0) for (0Kpa), the range is programmed to be 15.0 = 0Kpa, and 20.0 = 90Kpa, that is, every 1% increase in the pressure sensor MPX4115 correspond to 1.8Kpa increase in the pressure.

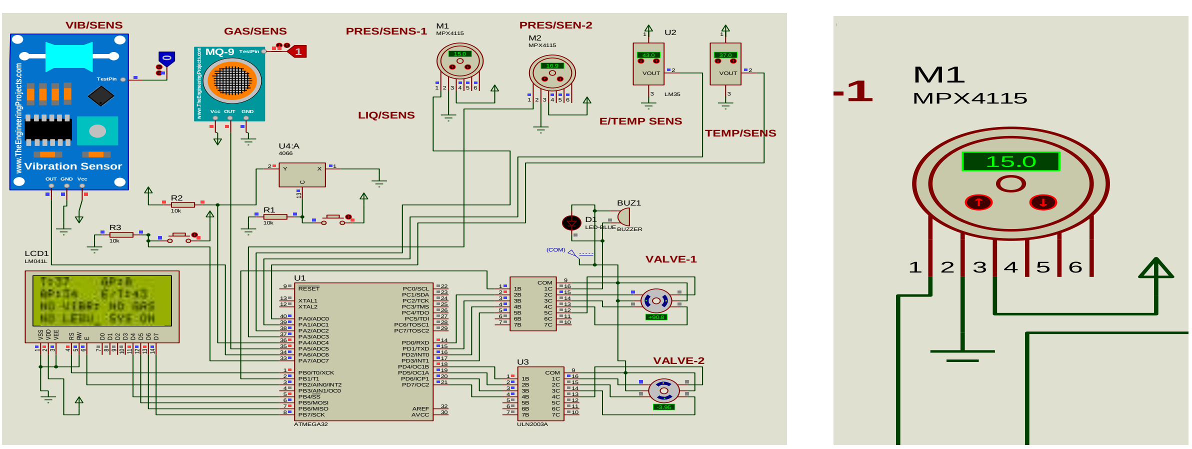


Figure 4.5 Gas pressure drop to zero

Figure 4.6 shows the system alarm when the gas pressure drops to zero.

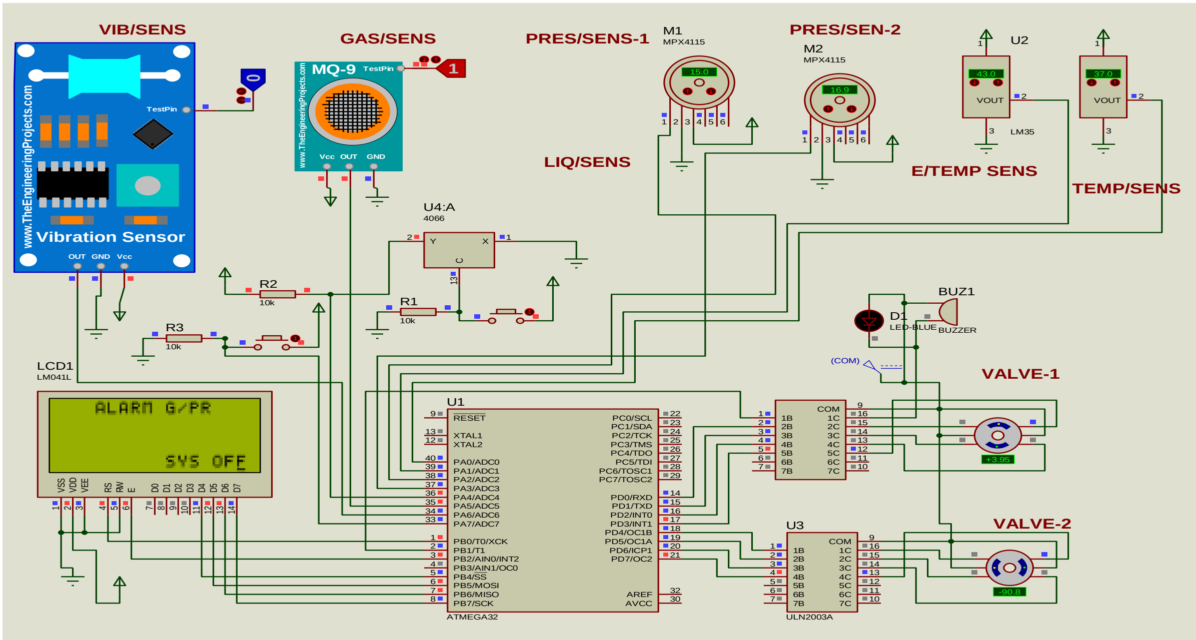


Figure 4.6 Alarm gas pressure

Case 3 (Air pressure Sensor):

The microcontroller will deactivate the system when the air pressure drops to zero. Air pressure sensor is used to determine the engine load; zero air pressure is an indication of no load. The system is designed so that the gas would not be allowed into the engine, if the engine is not loaded. The display shows in figure 4.7 below the case when pressure is zero and the system is off. The equation governing the MPX4115 has been discussed in case 2.

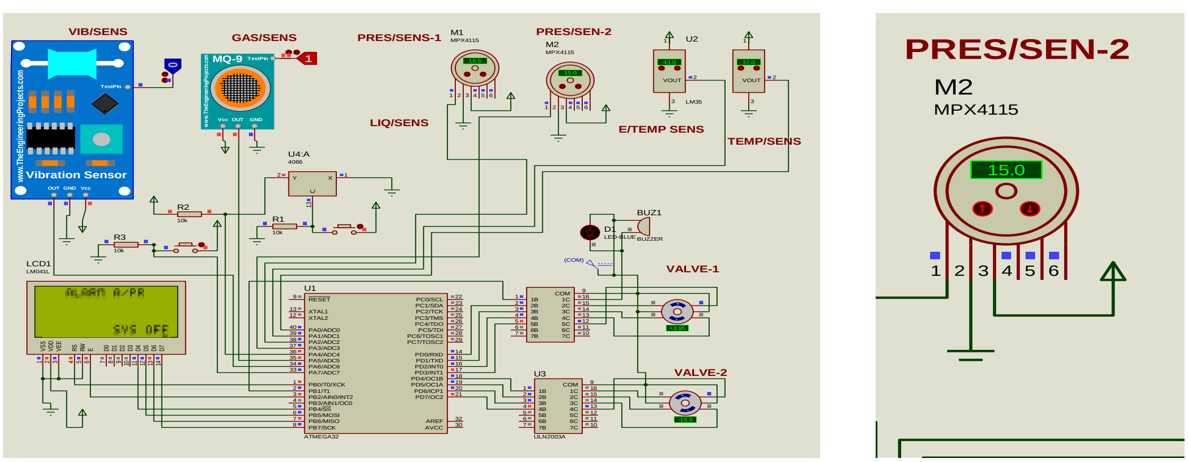


Figure 4.7 Alarm air pressure

Case 4 (Exhaust Temperature Sensor):

The programmed limit for the exhaust temperature sensor is less than or equal to 49°C, in Figure 4.8 the exhaust temperature sensor (LM35) senses a rise in the exhaust temperature, the temperature exceeded the programmed limit and record 50°C, in this case the microcontroller instantly closes the two valves (two stepper motors), and the LCD display two messages; ALARM E/TEMP, to indicate the exhaust temperature limit has been exceeded, and SYS OFF, to state that the valves are closed and the engine is returned to 100% diesel fuel operation.

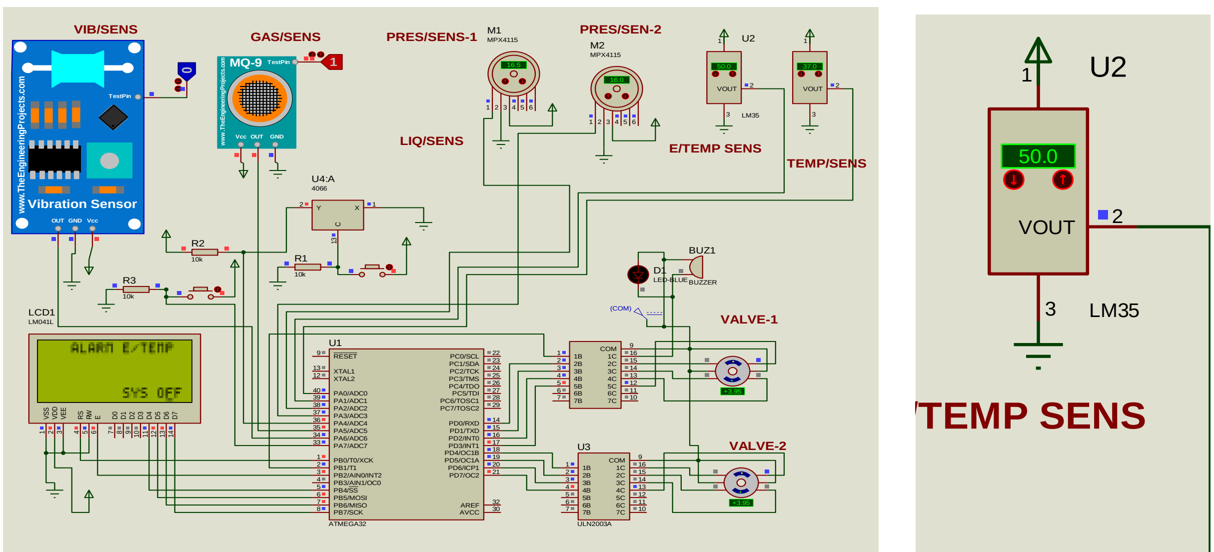


Figure 4.8 Alarm exhaust temperature

Case 5 (Liquid Detector):

The liquid sensor is one of the three digital sensors and it is used to detect the accumulation of liquids. 4066 switch is used to represent the sensor. The switch attached to 4066 shown in Figure 4.9 has been pressed to indicate that liquid is detected at this time.

In the case of any liquid detected, the microcontroller will instantly close the two valves (two stepper motors), and the LCD shows the message (ALARM LIQU) and (SYS OFF) as shown in Figure 2.10.

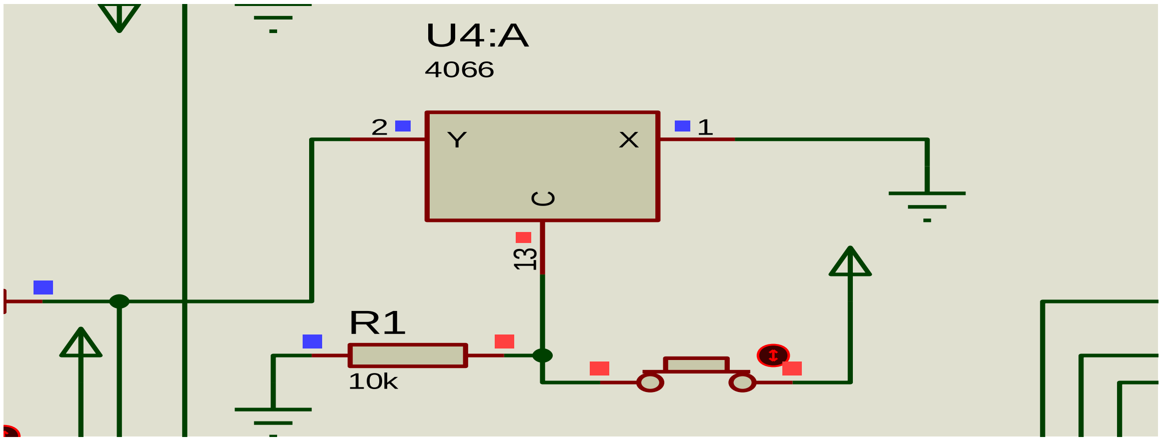


Figure 4.9 Liquid detection

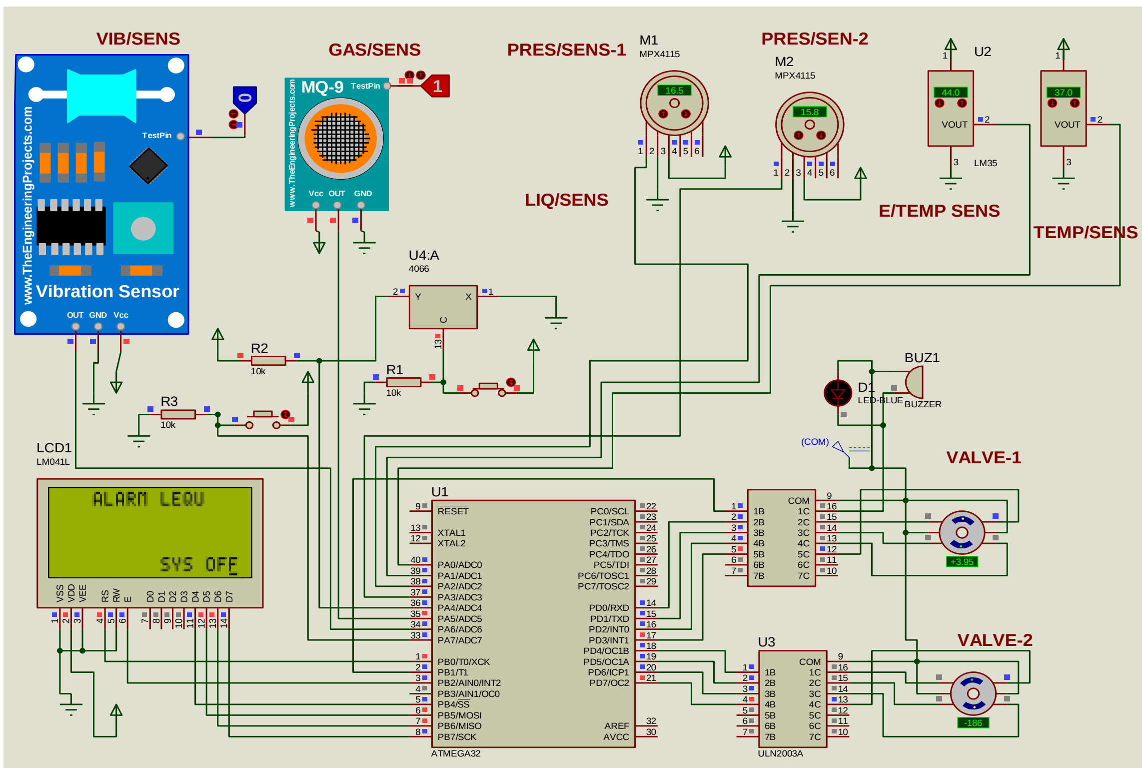


Figure 4.10 Liquid alarm

Case 6 (Gas Sensor):

MQ-9 gas sensor is used to detect high concentrations of natural gas in the area where the system has been installed. Gas leakage can result in fire or explosion. Extreme care must be taken in order to ensure that no gas leakage will occur and the bi-fuel mode is deactivated as soon as possible. Figure 4.11 shows the case when a gas leakage has been detected.

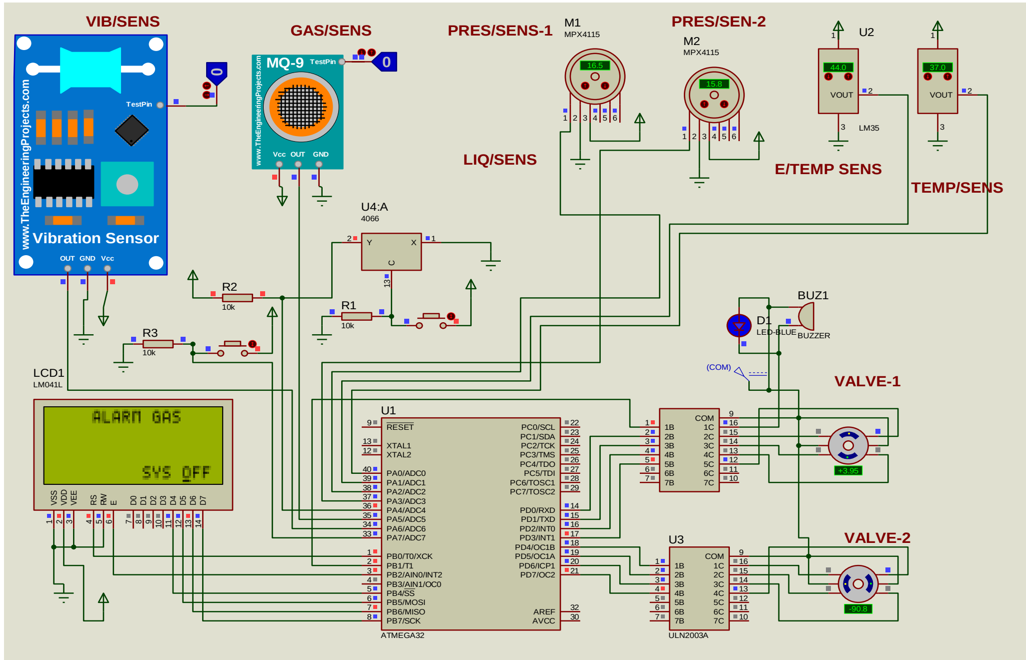


Figure 4.11 Gas leakage alarm

The LCD shows (Alarm gas) to indicate that gas presence in the atmosphere has exceeded the normal level (programmed set point). As a result the microcontroller de-energizes the two stepper motors and consequently interrupts the flow of gas into the engine.

Figure 4.12 Buzzer Alarm and LED Indicator

The microcontroller also initiates buzzer alarm along with LED indicator as shown in figure 4.12 above to inform the user that abnormal level of gas is detected.

Case 7 (Vibration Sensor):

Vibration sensor is used to detect high vibration levels that may indicate a knocking condition or other combustion related abnormality. In figure 4.13 below a high level of vibration is sensed using SW-420 vibration sensor, the message (ALARM VIBR) is displayed on the LCD and the microcontroller deactivate the bi-fuel mode and return the engine to 100% diesel operation.

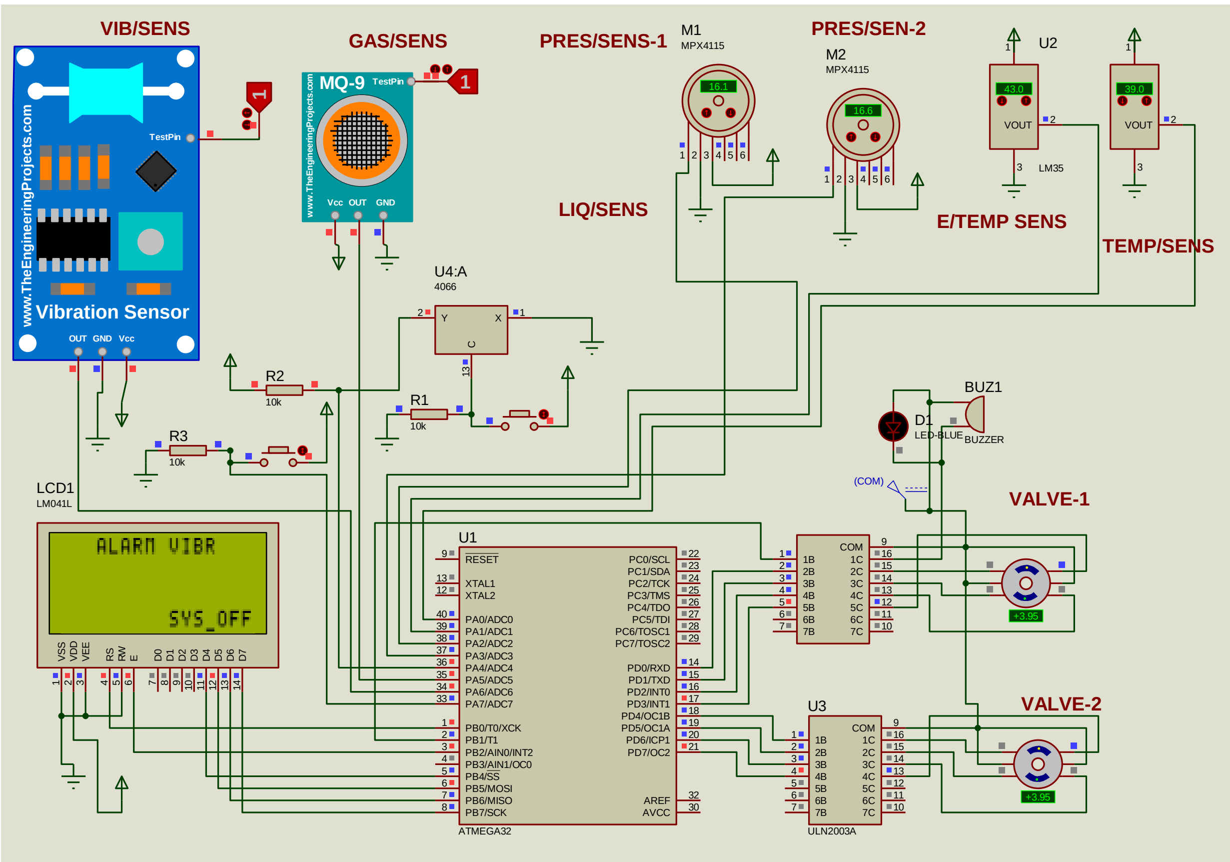


Figure 4.13 Vibration Alarm

4.2 Discussion:

4.2.1 Overview:

The system is designed so that diesel engines can run on a mixture of diesel and natural gas together. We have chosen the name (Bi fuel) for the system to imply that when the natural gas is introduced to a diesel engine, the engine will be running on two different kinds of fuel. When the bi-fuel mode is activated the engine would be running on diesel fuel and natural gas with different proportion. When it is activated, all bi-fuel system critical factors are continuously monitored in order to ensure that the engine is working properly and safely. This process is controlled through microcontroller which provides a single point of control for all sensors. The microcontroller monitors various parameters such as air pressure, air temperature, exhaust temperature, gas pressure, gas and liquid presence as well as the level of vibration. These inputs determine whether is it safe to let the bi-fuel system working or it is better to deactivate it.

4.2.2 Practical results:

The bi-fuel system has been designed for constant speed applications such as engine-driven electric power generators, compressors and other industrial applications. Variable speed applications may also be converted to bi-fuel depending on the governing system used and the method of engine operation. The bi-fuel system has been designed for continuous-duty operations such as prime power generation and oil field pumping operations. The bi-fuel system is typically applied to high speed (>1200 rpm) diesel engine ranging in size from 100 horsepower (75 kW) to over 4000 horsepower (3000kW) [18].

4.2.3 Compatible fuel types:

The bi-fuel system is compatible with methane-based fuels such as natural gas, wellhead gas, and bio-gas. Hydrocarbon gasses such as propane and butane are not compatible with bi-fuel operation (in pure form) due to unfavorable combustion characteristics of these fuels. Gas quality and composition are critical factors of bi-fuel operation. Ideally, pipeline supplied gas will have a high concentration of methane and a low overall concentration of heavier hydrocarbon gasses (see table 4.1). For lower quality gasses (pipeline supplied or other), reductions in engine performance and or gas substitution rate may be required [19].

Table 4.1 High quality pipeline gas/composition in volume%

Methane	Ethane	Propane	Butane	Nitrogen	Carbon
97.09	0.88	0.26	0.09	1.41	0.12

4.2.4 Physicochemical properties of natural gas and diesel:

The physicochemical properties of natural gas are very similar to methane. The properties of natural gas in comparison to diesel fuel and gasoline are given in Table 4.2 below. Natural gas is an environmentally friendly alternative fuel for use because it contains less carbon per unit of energy than any other fossil fuel and thus produces lower CO2 emission [19].

Table 4.2 Physicochemical properties of natural gas and diesel

Fuel properties	Natural gas	Diesel
Low heating value (MJ/kg)	48.6	42.5
Heating value of stoichiometric mixture (MJ/kg)	2.67	2.79
Cetane number	–	52.1
Octane number	130	–
Auto-ignition temperature (°C)	650	180–220
Stoichiometric air–fuel ratio (kg/kg)	17.2	14.3
Carbon content (%)	75	87

4.2.5 Air-fuel ratio:

Operation in Bi-Fuel mode does not appreciably change engine air fuel ratio. At the maximum allowable gas substitution rates (70%), the gas concentration in the intake air is typically less than 3.0% by volume, which is substantially below the 5.0% Lower Explosive Limit (LEL) of methane. Due to the lean condition of the air-gas charge, the possibility of ignition in the engine air-intake system due to backfire or other causes is minimized [20].

4.2.6 Combustion process:

Combustion in Bi-Fuel mode follows the normal Compression-Ignition (CI) sequence. The air-gas mixture is admitted to the combustion chamber through the intake valve and then compressed during the compression cycle. The high auto-ignition temperature of the lean air-gas mixture prevents ignition of the charge until the diesel injector is activated. The injected diesel fuel provides the necessary ignition source for the air-gas mixture which then combusts at a similar speed and pressure compared to 100% diesel operation. It is also providing a portion of the total energy needed for combustion based on the set gas-diesel mixture [21].

4.2.7 Engine governing:

The bi-fuel system allows the original engine governing system to control engine speed. As gas is introduced to the engine the governor detects a slight increase in engine RPM as the engine temporarily has more fuel than needed for the current load condition. In order to maintain the preset speed the governor quickly adjusts the position of the diesel fuel "rack" thereby maintaining engine speed and allowing the substitution of natural gas. No interface or tie-in is required between the Bi-Fuel system and the engine governor. The bi-fuel system is compatible with electro-mechanical and hydro-mechanical governors as well as electronic injection based governing systems [21].

4.2.8 Engine operating temperatures:

Engine heat rejection rates while operating in Bi-Fuel mode are largely similar to 100% diesel performance. Engine exhaust gas temperature, coolant temperature, oil temperature and manifold air temperature levels remain within the limits set by the engine manufacturer [21].

Table 4.3 shows the comparison of engine governing between bi-fuel and 100% diesel operation.

Table 4.3 Comparison of Engine Governing: between bi-fuel and 100% Diesel

Engine Parameter	100%Diesel Mode	Bi-Fuel @ 70% Gas
Power	1000 KW	1000 KW
Speed	1500 RPM	1500 RPM
Diesel Rack Position (%)	90%	27%

4.2.9 Engine efficiency:

Because the bi-fuel System utilizes a low restriction air-gas mixing device and maintains the excess-air operation of the diesel engine, net fuel efficiency (specific fuel consumption) is normally equivalent to 100% diesel operation. For each unit of diesel fuel displaced during bi-fuel operation, a calorically equivalent unit of natural gas will be needed to maintain engine power [22].

4.2.10 Bi-Fuel Emissions:

Bi-Fuel operation will typically reduce production of nitrogen oxides, sulfur oxides, reactive hydrocarbons, carbon dioxide and particulates. Exhaust capacity levels (visual emissions) are also typically reduced [22].

4.2.11 Economic benefits:

Fuel cost savings resulting from operation in bi-fuel mode will vary according to the respective cost of each of the fuels. If there is a significant cost differential between the cost of diesel fuel (per gallon, liter, etc.) and the equivalent quantity of natural gas (heat value basis) in favor of the natural gas, significant fuel cost savings would result. The closer the fuels are in price, the lower the fuel cost savings will be during Bi-Fuel mode. In addition to fuel cost savings, engine maintenance savings (life time of engine part increased), and (life time of lubrication oil increased) may also contribute to the economic benefit of Bi-Fuel operation [23]. The savings realized by running the Bi-Fuel System is directly related to the cost of diesel fuel, cost of gas, and the number of hours of operation. The following is an example of a cost comparison between running a

1000 kW generator on 100% diesel and on Bi-Fuel with a 65% gas-to-diesel ratio in continuous operation. A number of assumptions are made in this example which is clearly stated in order to clarify the calculations.

4.2.12 Calculations:

Table 4.4 Calculation of diesel consumption in 100% diesel operation and Bi fuel

FACTS AND ASSUMPTIONS	
Fuel consumption @ 1000 kw:	69 gph (100% diesel)
Hours Per Year	8000
Gas/Diesel Ratio	65%
Diesel Cost ($/gal)	$2.33 per gallon
Natural Gas Cost ($/Mcf)	$8.11 per mcf
Hhv Of #2 Diesel	140,000 btu/gal
Hhv Of Natural Gas	1,000 btu/scf
Gas Equivalent Gallon (Geg)	140 scf/gal
100% Diesel Operation	
Diesel Consumption Rate Per Hour	69 gph
Diesel Cost Per Hour	$160.77 (69 x $2.33)
Diesel Cost Per Year	$1,286,160 ($160.77 x 8000)
Bi-Fuel Operation	
Diesel Use Per Hour	24.15 gph (69 x 0.35)
Diesel Cost Per Hour	$56.27 (24.15 x $2.33)
Gas Use Per Hour	6279 scf (69 x 0.65 x 140)
Gas Cost Per Hour	$50.92 (6279/1000 x $8.11)
Total Fuel Cost Per Hour	$107.19 ($56.27 + $50.92)
Savings	
Bi-Fuel Savings Per Hour	$53.58 ($160.77 -$107.19)
Bi-Fuel Savings Per 8000 Hours	$428,640 ($53.58 x 8000)

One gallon = 3.785 liter.

Diesel gallon price = $2.33.

Natural Gas cost ($/mcf) = $8.11.

Figure 4.14 illustrates the consumption of diesel fuel in Lit/day. The data has been obtained from five CAT diesel engines 2MVA each, through a designated software program.

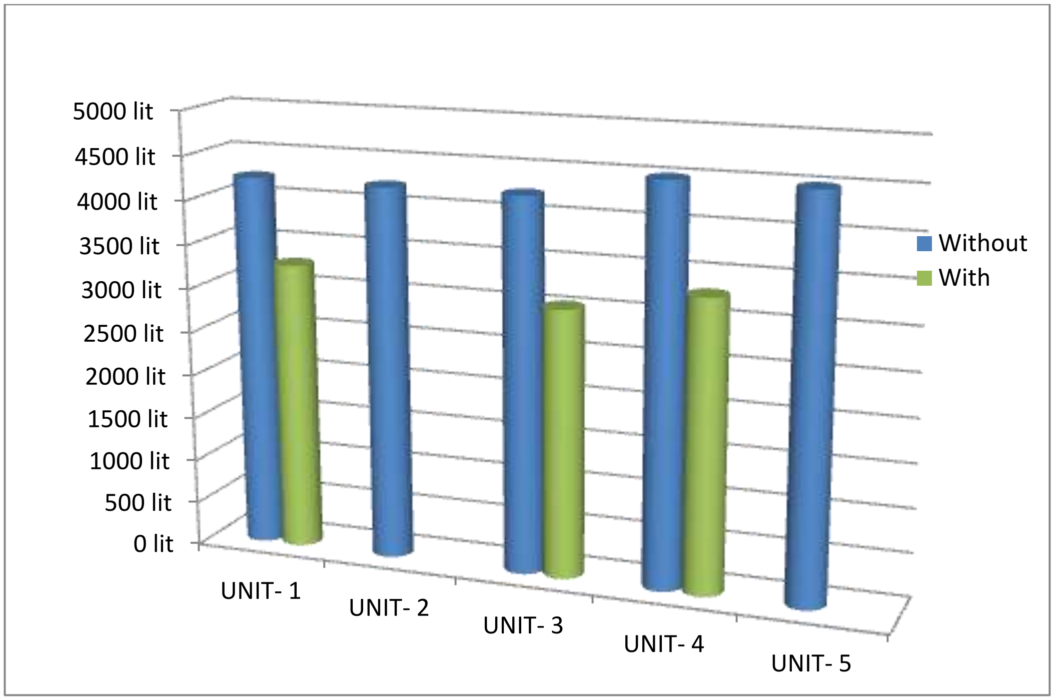


Figure 4.14 Consumption Rate of Diesel in Lit\day

* Units 1, 3 and 4 with bi-fuel systems

* Units 2 and 5 diesel only (no bi-fuel system)

This chart shows CAT engine running with 30% gas (consumption of diesel in Lit\day).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion:

The introduction of bi-fuel technology represents a tremendous advancement in the standby power industry. System designers have continually struggled with issues of fuel system reliability, too much fuel and it goes bad, too little fuel and it runs out. With tremendous increases in run time and the minimal use of diesel fuel, bi-fuel generators address these major fuel reliability issues and offer environmental advantages.

Because of the growing environment and energy issues, natural gas has been considered as a promising alternative fuel. Natural gas/diesel bi-fuel mode is a more practical and low cost mean of using natural gas in diesel engine. Therefore, this method has been given a lot of attention by many researchers in order to improve the engine performance, reduce the diesel consumption, as well as significantly decrease the NOX, CO_2 and PM (particulate matter) emissions. However gas unlike diesel is very explosive fuel and this means it needs careful and close monitoring during system operation, Accumulation of gas caused by undetected leaks can result in high energy explosions that can damage or destroy structures and cause injury or death to nearby personnel. Due to that an appropriately automatic rated fire extinguisher must be kept in a readily accessible location during installation and operation, beside adequate ventilation in work area is required.

At the maximum allowable gas substitution rates the gas concentration in the intake air mustn't exceed LEL, increasing above the limit of LEL can cause vibration that may develop to knocking, which could result in engine parts damage. Also the gas supplied to the engine must be in a good fuel grade quality and sufficiently treated to prevent engine damage.

5.2 Recommendations:

Because the PLCs have many advantages over microcontrollers in terms of scalability, Modularity, and reliability, and the PLCs are rugged and tough to use in industrial environment. A microcontroller used in this project can be replaced with a PLC. Using a PLC would also provide a means of adding separate Temperature control module just by adding another communication module to the PLC, which can increase the efficiency of the control system. A Human Machine Interface (HMI), instead of the ordinary LCD, alongside keypad, can be used to enable the program user to change the set points.

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Appendix A

Source Code

```
regfile = "m32def.dat"
$crystal = 8000000

Config Lcd = 16 * 4
Config Lcdpin = Pin , Db4 = Portb.4 , Db5 = Portb.5 , Db6 = Portb.6 , Db7 = Portb.7 , E =
Portb.2 , Rs = Portb.0

Config Adc = Single , Prescaler = Auto , Reference = Internal

Cls

Dim I As Word
Dim Time1 As Word

Time1 = 20
Dim T As Word
Dim Temp As Word

Dim T1 As Word
Dim Temp1 As Word

Dim P1 As Word
Dim Pres1 As Word

Dim P2 As Word
Dim Pres2 As Word

Config Pina.3 = Input
Config Pina.4 = Input
Config Pina.5 = Input

Config Pina.7 = Input                    'reset
```

```
Config Portb.1 = Output                          'buzzer

Config Portd = Output

Cls
Locate 1 , 4
Lcd "WELL COME"
Waitms 100
Cls
V:
Gosub Ml1

Do
S:

 Gosub Sensor
  If P1 >= 1 And P1 <= 50 Then
   Gosub Ml2
  Waitms 100
      Gosub Ss
  End If



   Waitms 200
  Loop

  ''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
 Sensor:

 Cls
```

```
Temp = Getadc(0)
T = Temp
T = T / 4

Locate 1 , 1
Lcd "T:" ; T

Temp1 = Getadc(1)
T1 = Temp1
T1 = T1 / 4

Locate 2 , 9
Lcd "E/T:" ; T1

Pres1 = Getadc(2)
P1 = Pres1
P1 = P1 - 107

Locate 1 , 9
Lcd "GP:" ; P1

Pres2 = Getadc(3)
P2 = Pres2
P2 = P2 - 107

Locate 2 , 1
Lcd "AP:" ; P2

If Pina.6 = 0 Then

Locate 3 , 1
Lcd "NO VIBR"
```

```
  End If

  If Pina.5 = 1 Then
    Portb.1 = 0
  Locate 3 , 8
  Lcd ": NO GAS "

  End If
     Locate 4 , 10
  Lcd "SYS ON"

  If Pina.4 = 1 Then

  Locate 4 , 1
  Lcd "NO LEQU"

  End If
    Waitms 300

  If T > 40 Then
  Cls
  Locate 1 , 4
  Lcd "ALARM TEMP"
Gosub Ml12
  Waitms 300
  End If

  If T1 > 49 Then
  Cls
  Locate 1 , 4
  Lcd "ALARM E/TEMP"
```

```
Gosub Ml12
Waitms 300
End If


If Pina.6 = 1 Then
Cls
Locate 1 , 4
Lcd "ALARM VIBR"
Gosub Ml12
Waitms 300
End If

If Pina.5 = 0 Then
Portb.1 = 1
Cls
Locate 1 , 4
Lcd " ALARM GAS "
Gosub Ml12
Waitms 300
End If

If Pina.4 = 0 Then
Cls
Locate 1 , 4
Lcd "ALARM LEQU"
Gosub Ml12
Waitms 300
End If

If P2 <= 0 Then
Cls
```

```
  Locate 1 , 4
  Lcd "ALARM A/PR"
  Gosub Ml12
  Waitms 300
  End If

  If P1 <= 0 Then
  Cls
  Locate 1 , 4
  Lcd "ALARM G/PR"
 Gosub Ml12
  Waitms 300
  End If
Return

Do
Ss:
 Gosub Sensor
  If P1 >= 51 Then
      Gosub Mr2
  Waitms 100
     Gosub S
  End If
  Waitms 200
  Loop
''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''''
  Res:

  Do

    Locate 4 , 10
  Lcd "SYS OFF"
```

```
  If Pina.7 = 1 Then
  Portb.1 = 0
  Gosub V
  End If

  Loop

  Return

  Mr1:
For I = 1 To 3
Portd.0 = 1
Portd.1 = 0
Portd.2 = 0
Portd.3 = 0
Waitms Time1
Portd.0 = 0
Portd.1 = 1
Portd.2 = 0
Portd.3 = 0
Waitms Time1

Portd.0 = 0
Portd.1 = 0
Portd.2 = 1
Portd.3 = 0
Waitms Time1

Portd.0 = 0
Portd.1 = 0
Portd.2 = 0
Portd.3 = 1
```

```
Waitms Time1
Next I
Return

Ml1:
For I = 1 To 3
Portd.0 = 0
Portd.1 = 0
Portd.2 = 0
Portd.3 = 1
Waitms Time1
Portd.0 = 0
Portd.1 = 0
Portd.2 = 1
Portd.3 = 0
Waitms Time1

Portd.0 = 0
Portd.1 = 1
Portd.2 = 0
Portd.3 = 0
Waitms Time1

Portd.0 = 1
Portd.1 = 0
Portd.2 = 0
Portd.3 = 0
Waitms Time1
Next I
Return

Mr2:
```

```
For I = 1 To 3
Portd.4 = 1
Portd.5 = 0
Portd.6 = 0
Portd.7 = 0
Waitms Time1
Portd.4 = 0
Portd.5 = 1
Portd.6 = 0
Portd.7 = 0
Waitms Time1

Portd.4 = 0
Portd.5 = 0
Portd.6 = 1
Portd.7 = 0
Waitms Time1

Portd.4 = 0
Portd.5 = 0
Portd.6 = 0
Portd.7 = 1
Waitms Time1
Next I
Return

Ml2:
For I = 1 To 3
Portd.4 = 0
Portd.5 = 0
Portd.6 = 0
Portd.7 = 1
```

```
Waitms Time1
Portd.4 = 0
Portd.5 = 0
Portd.6 = 1
Portd.7 = 0
Waitms Time1

Portd.4 = 0
Portd.5 = 1
Portd.6 = 0
Portd.7 = 0
Waitms Time1

Portd.4 = 1
Portd.5 = 0
Portd.6 = 0
Portd.7 = 0
Waitms Time1
Next I
Return

Ml12:

    Locate 4 , 10
  Lcd "SYS OFF"
For I = 1 To 3
Portd.0 = 1
Portd.1 = 0
Portd.2 = 0
Portd.3 = 0

Portd.4 = 1
```

```
Portd.5 = 0
Portd.6 = 0
Portd.7 = 0
Waitms Time1
Portd.0 = 0
Portd.1 = 1
Portd.2 = 0
Portd.3 = 0

Portd.4 = 0
Portd.5 = 1
Portd.6 = 0
Portd.7 = 0
Waitms Time1

Portd.0 = 0
Portd.1 = 0
Portd.2 = 1
Portd.3 = 0

Portd.4 = 0
Portd.5 = 0
Portd.6 = 1
Portd.7 = 0
Waitms Time1

Portd.0 = 0
Portd.1 = 0
Portd.2 = 0
Portd.3 = 1

Portd.4 = 0
```

```
Portd.5 = 0
Portd.6 = 0
Portd.7 = 1
Waitms Time1
Next I
 Gosub Res
Return

Mr12:
For I = 1 To 3
Portd.4 = 0
Portd.5 = 0
Portd.6 = 0
Portd.7 = 1

Portd.0 = 0
Portd.1 = 0
Portd.2 = 0
Portd.3 = 1
Waitms Time1
Portd.4 = 0
Portd.5 = 0
Portd.6 = 1
Portd.7 = 0

Portd.0 = 0
Portd.1 = 0
Portd.2 = 1
Portd.3 = 0
Waitms Time1

Portd.4 = 0
```

```
Portd.5 = 1
Portd.6 = 0
Portd.7 = 0

Portd.0 = 0
Portd.1 = 1
Portd.2 = 0
Portd.3 = 0
Waitms Time1

Portd.4 = 1
Portd.5 = 0
Portd.6 = 0
Portd.7 = 0

Portd.0 = 1
Portd.1 = 0
Portd.2 = 0
Portd.3 = 0
Waitms Time1
Next I

Return
```

Appendix B

ATMega32 Data Sheet