MONITORING AND CONTROL OF 3-TIER POWER SUPPLY

BY

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FACULTY OF ENGINEERING
UNIVERSITY ON NIGERIA,
NSUKKA

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APPROVAL PAGE

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF MASTER OF ENGINEERING (DIGITAL ELECTRONICS AND COMPUTER OPTION) IN THE DEPARTMENT OF ELECTRONIC ENGINEERING, UNIVERSITY OF NIGERIA, NSUKKA.

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CERTIFICATION

Egbuchulam Ekenna, a Master's degree postgraduate student in the Department of Electronic Engineering, University of Nigeria, Nsukka, with registration number **PG/M.ENG/09/50877**, has satisfactorily completed the requirements for the award of a Master of Engineering (M.Eng) in Electronic Engineering.

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DECLARATION

I, Egbuchulam Ekenna, a postgraduate student of the Department of Electronic Engineering, University of Nigeria, Nsukka, declare that the work embodied in this thesis is original and has not been submitted by me in part or in full for any other diploma or degree of this University or any other Universities.

…………………………………………………… ………………………………………..

EGBUCHULAM EKENNA **DATE**

(STUDENT)

DEDICATION

I fondly dedicate this work to God Almighty, who made it all happen, and to the memory of my mum, Mrs. C. B. Egbuchulam, whose concern to see me stand never failed, till her very last breath.

Acknowledgement

Firstly, I want to give thanks to Almighty God for His sustained guidance, protection and provision throughout the course of this work. This project couldn't have been completed but for the blessings of God.

I wish to appreciate profoundly my supervisor and teacher, Professor O. U. Oparaku, not only for getting me started on this work, but for his endless contribution of ideas and direction all the way through.

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And last, but by no means the least, my lovely wife Nkechi, for her understanding and unremitting care while I was on this project.

Abstract

Reliable electricity supply is essential for development. As a result, demand for electricity has continued to increase globally, occasioned by the fact that electricity is highly portable and can be transformed from one form to another to meet needs. In Nigeria and most developing countries, electricity supply from the public utility is not only insufficient but highly erratic. The effect of this is adverse on critical and sensitive infrastructure that depend on uninterrupted power supply. Hence, many domestic, industrial and commercial consumers are compelled to acquire one form of alternative source of power supply or another.

With this however, when different power schemes are interconnected, there arises the challenge of switching between the power sources not only smoothly, but in a manner that optimizes their use. Solving these challenges forms the focus of this work. This design monitors three independent power sources: Utility Grid of Power Holding Company of Nigeria (PHCN), solar and generator and engages them following preset conditions in a microcontroller. A software program in assembly language drives the microcontroller. Preference is given to the PHCN line, but in the event of failure or abnormal conditions in the PHCN line, the system will effect a changeover automatically to the solar source through contactors, provided the output of the solar source is acceptable, else the system will initiate the starting of the generator and transfer of load to same. This system finds application wherever there is unreliable power supply and interconnected power schemes.

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CHAPTER ONE

INTRODUCTION

1.0 Project Background

Electricity is of enormous importance to the society today. It is indispensable to social and economic development. Modern industrial systems depend on regular supply of electricity. Quality of life and standard of living today depend much on electricity. People need energy in one form or the other (heat, light, sound etc) and electricity is most convenient in that it can be converted with ease from one form to another.

However, in many developing nations steady availability of electricity is yet to be realized. In Nigeria, for instance, the supply of electricity from the public utility (PHCN) is unreliable, marked by incessant outages, and therefore inadequate for any meaningful advancement in industrial, commercial and domestic activities.

Generators are commonly used in Nigeria but the cost of running diesel or other fuel for running generators all the time is not feasible for both home and business concerns. Renewable sources like solar are also used but so far there is yet room for improvement before solar power can be utilized without some form of backup. Thus, multi-tier power supply, a system of more than one power source, has gradually become the norm in our society.

This project "**Monitoring and Control of 3-tier Power Supply"** provides a way of monitoring and switching between three different power sources in order to optimize their use.

1.1 Statement of Problem

The demand for energy especially electrical energy is on the increase globally and power utilities strive to match supply with demand. A lot of large-scale industrial critical loads suffer from voltage interruptions and sags which can cause a significant financial loss [1]. In Nigeria the actual generating capacity falls short of the installed capacity and the country's peak demand due to problems in the power systems network [2]. The country requires over 6000 MW of electricity to meet present demand. Current output is around 3000MW, much of which is not put to use due to poor power transmission and distribution infrastructure [3]. The effect is that supply from the national grid has been very low and unsteady over the years with the result that people have resorted to integrating multiple power sources as a remedial measure.

The problem is the need to monitor these power sources and switch between them in a manner that ensures safety of personnel and equipment. There is also a need to optimize their use by setting the preferred power source as default through some device.

1.2 Project Objectives

The objectives of this project include:

1. To monitor and control a three tier power supply system.
2. To automate the power changeover process to ensure a smooth transfer of load for the purpose of safety and convenience.
3. To implement a system of power change over with minimal time wastage.
4. To optimize power use in a system of 3 power sources by setting the most economical power source as default in the system.

1.3 Significance of the Project

Electricity which is an essential tool to development and indeed civilization is a necessity that should be readily available. As stated earlier the demand for electricity is on the increase globally. However, the shortfall in supply from the national grid creates a need which this project seeks to fill.

This project is significant because it seeks to provide a cost effective way of using multitier power supplies which are common in developing societies like Nigeria. In addition, it ensures a smooth and safe means of power changeover during outages through an automated process.

Further it is expected that this work will benefit power system managers, public policy analysts, policy makers, scholars and the general public.

CHAPTER TWO

LITERATURE REVIEW

2.0 Electricity in Nigeria

Electricity generation in Nigeria started in 1896 although it was not until 1929 that the first utility company, the Nigerian Electricity Supply Company was established [4].

In the 1950s and 1960s the Nigerian government created the Electricity Corporation of Nigeria to control all existing diesel/coal fired isolated power plants across the country and the Niger Dams Authority to develop hydroelectric power in Nigeria. These two entities were amalgamated into the National Electric Power Authority (NEPA) in 1972, and in 2004, the need to reform the Electricity industry necessitated the transformation of NEPA into Power Holding Company of Nigeria (PHCN).

Electricity generation, transmission and distribution in Nigeria account for less than one per cent of the Gross Domestic Products (GDP) [5]. Until the recent unbundling and handover of PHCN to successor companies, PHCN dominated Nigeria's electricity sector, supplying most of the electricity consumed in Nigeria, supplemented with power generated from privately-owned plants. There is still a high incidence of privately-owned plants usually referred to as 'captive power plants'. This in most cases is in response to irregular public power generation and transmission.

2.0.1 Nigeria's Electricity Sector in Retrospect

Electric Power development in Nigeria started toward the end of 19th century when the first generating plant of 30KW was installed in the city of Lagos in 1898 [6]. From this date onwards and until 1950, the pattern of electricity development was in form of individual electricity undertaking set up in various towns somewhere by Native or Municipal authorities.

In 1946, the Nigerian Government Electricity undertaking was established within the then Public Works Department (PWD) to take over the responsibility for electricity in Lagos State.

In 1950 the Government passed the Electricity Corporation of Nigeria Ordinance No.1 of 1950 to integrate power development and make it effective. This ordinance brought all the electricity undertakings and the electricity sections of PWD under control. The Electricity Corporation of Nigeria (ECN) then became the statutory body responsible for Generation, Transmission, Distribution and Sales of Electricity to all consumers in Nigeria.

In 1962, the Niger Dams Authority was established by an Act of the Parliament. The Authority was responsible for the construction and maintenance of Dams and other works on the river Niger and elsewhere, generating electricity by means of water, improving navigation and promoting fisheries and irrigation.

The Electricity Corporation of Nigeria (ECN) and the Niger Dams Authority (NDA) were merged to become National Electric Power Authority (NEPA) by decree No.24 of 1972. The Authority was to develop, maintain and co-ordinate an efficient economic system of electricity supply for all parts of the Federation. The

Authority generates electricity through two major sources: Hydro and Thermal. The Hydro Power stations are Kainji Hydro Power station with capacity of 760MW, Jebba Hydro Power station with 578.4MW capacity, Shiroro Hydro Power Station 600MW. The Thermal Power stations are: Afam Thermal Power station with 696MW, Lagos thermal power station, Delta IV thermal Power station with 600MW and Sapele Thermal Power station 1020MW. The existing power stations in Nigeria are shown in appendix A.

However, the need to reform the Electricity industry necessitated the transformation of NEPA into Power Holding Company of Nigeria (PHCN) in 2004.
Today, non-availability of spare parts and poor maintenance have been identified as major problems of PHCN. Also, a poorly-motivated workforce, vandalisation, theft of cables and other vital equipment, accidental destruction of distribution lines, illegal connections and resultant over-loading of distribution lines, are additional major problems of the sector. These have been responsible for unannounced load shedding, prolonged and intermittent outages which most consumers of electricity in Nigeria have had to contend with over the years. It is apparent that the poor performance of the electricity power sector in Nigeria since inception has been a significant obstacle preventing private investment, the overall development and economic growth in the country [7].

The Electricity Reform Act of 2005, unbundled PHCN into 11 Distribution companies, 1 Transmission Company and 6 Generation companies.

2.0.2 Nigeria's Power sector Reform

Through the Electric Power Sector Act of 2005 (EPSA 2005), the Federal Government began the unbundling of the power industry for the eventual deregulation and privatisation of the power generation and distribution in Nigeria in a bid to make it more efficient in meeting existing and prospective consumption demand [8]. As a result, the Power Holding Company of Nigeria (PHCN) was established with an intended strategy to privatise core functions of the power company such as generation and distribution, whilst transmission operations would be retained by the government.

Prior to the enactment of the Electricity Power Sector Reform Act (EPSRA), 2005, the Federal Government was responsible for policy formulation, regulation, operation, and investment in the Nigerian power sector. However, EPSRA Act became law in 2005, providing legal backing to the power sector reform programme, leading to the launch of the Power Sector Roadmap by President Goodluck Jonathan in August 2010 [9].

In order to attract private sector investment and sustain the development of the power sector to ensure uninterrupted and efficient power supply in the country, the National Council on Privatization (NCP) defined the objectives for power sector reform as follows.

1. To promote competition and facilitate more rapid provision of service throughout the country;
2. To create a new legal and regulatory environment for the sector that establishes a level playing field, encourages private investment and expertise,

and meets social goals;

3. To restructure and privatize the National Electric Power Authority (NEPA); and,
4. To encourage the successors to NEPA to undertake an ambitious investment program [10].

On November 1, 2013, the assets of Power Holding Company of Nigeria (PHCN) were physically handed over to their new owners. The Nigerian Electricity Regulatory Commission (NERC) and the Bureau of Public Enterprises (BPE) were saddled with the responsibility to monitor the operations of the successor companies. Currently, NERC is facing challenges in addressing the near failure in generation as a result of acute shortage in gas supply to most of the thermal stations. Similarly, the NERC also appears not to have panacea to estimated billing, one of the issues that have pitched consumers against the distribution companies. Indeed, the Commission is at crossroads dealing with high ineptitude in the value chain [11].

2.0.3 Electricity Power Sector after Privatization

The privatization exercise involved the sale of eleven distribution companies (DISCOS), seven generation companies (GENCOS) and the appointment of Manitoba Hydro International of Canada to manage the Transmission Company of Nigeria (TCN).

There has been a period for teething problems, more so as some of the generation companies, such as Afam, Kaduna and Sapele experienced late completion of their privatisation. It is expected that it would take some time before the new private operators would fully take over and begin to make the much expected difference [12].

Meanwhile, the power supply has fallen, while many consumers from across the country are groaning over new "crazy" bills which no one appears to be available to explain the rationale for them.

The operational methods of the new owners and operators of the nation's power system is quite different from what took place in the telecoms sector, where competition, promos and avalanches of public enlightenment invaded the media. Private operation of telecoms took a life of its own from the onset and established a bridge to the public that helped shape the industry to esteemed position it has attained today.

The enormous challenges of weak electricity transmission network and low generation capacity inherited from the defunct government-owned Power Holding Company of Nigeria (PHCN) is putting the brakes on the investment drive of new owners of the distribution companies (Discos) [13].

The Discos which are the closest to the customers on the electricity value chain, have been grappling with revenue collection from customers since the take-over late last year, when power supply in many parts of the country declined.

Some of the Discos that have already invested in upgrading their power assets, it was gathered, are now very wary of making further investments pending when transmission and generation capacities would increase [14].

Also, some of the generation companies (Gencos) which were planning to increase capacity are being constrained by gas supply shortages. Generation, which peaked at 4,517 megawatts (MW) in December 2012, is now hovering between 3,000MW and 3,500MW, no thanks to gas supply shortages.

Added to this problem is the issue of revenue collection which would require that strategies be put in place to optimise. Capacity expansion will be gradual and will remain subject to considerable risks and delays. While significant demand for electricity undoubtedly exists, disputes over tariffs, gas shortages and concerns about the country's business environment could all weigh on investment.

The challenge of gas supply to power plants and system collapse have continued to limit generation capacity, with massive investment required to upgrade dilapidated power generation and transmission facilities, some of which have become problematic due to their age and years of neglect. There is need for the new investors to drive the government to do its part particularly in the areas of gas supplies and transmission. Power that does not reach the consumers does not translate to money.

Beyond revenue collection, the market is still very unstable. Generation capacity has not radically improved. Nigeria's daily electricity generation capacity is currently fluctuating between **4,400** and **4,500 megawatts** [15], and the transmission network is also weak. Even if generation improves, the transmission network is not strong enough to evacuate generated power. There is an urgent need to expand the transmission network.

In what is an acknowledgement of the need to expand the transmission capacity, the Federal Government in its 2014 budget proposal allocated about N25 billion to the Transmission Company of Nigeria (TCN), out of the N62 billion to the power sector.

2.0.4 Electricity Production and Consumption in Nigeria

Electricity production is the annual electricity generated expressed in kilowatt hours. In Nigeria, electricity production has varied from gas-fired to hydroelectric power to coal-fired stations, with hydroelectric power systems and gas fired systems taking precedence [16]. Renewable energy penetration in Nigeria is still at its nascent stage, presently the only renewable energy source supplying the commercial grid is hydro. Wind and solar have only been deployed in minuscule amount [17]. The table below highlights Nigeria’s annual electricity production and consumption expressed in kilowatt-hours from year 2000-2012 as compared to South Africa.

Table 2.1: Nigeria's electricity production/consumption (billion KWh) compared to South Africa

Country / Year	Nigeria		South Africa	
	Production	Consumption	Production	Consumption
2000	14.75	13.72	192.02	174.49
2001	18.7	17.37	186.9	172.39
2002	15.9	14.77	194.38	181.52
2003	15.67	14.55	195.6	181.2
2004	15.67	14.55	195.6	181.2
2005	19.85	18.43	202.6	189.4
2006	15.59	14.46	215.9	197.4
2007	19.06	17.71	227.2	207
2008	22.11	15.85	264	241.4
2009	22.11	15.85	264	241.4
2010	21.92	19.21	240.3	215.1
2011	21.92	19.21	240.3	215.1
2012	20.13	18.14	238.3	212.2

Source: [18]

The discrepancy between the amount of electricity generated and consumed is accounted for as loss in transmission and distribution.

Electricity consumption per capita is defined as the total electricity consumed in a country divided by its total population. According to World Bank data [19], Nigeria's population as at the year 2012 stood at 168.8 million while South Africa's population for the same year was 51.19 million. From Table 2.1 above, total electricity consumption for the same year for both countries are 18.14 and 212.2 billion KWh respectively.

Therefore, electricity consumption per capita, for Nigeria and South Africa are **107.5 KWh** and **4145.3KWh** respectively.

From the above, a South African citizen enjoys **38.6** times more electricity than a Nigerian. Hence, since availability of electricity in modern times translates to economic and social development (all other factors considered), it can be argued that South Africa has 38.6 times more potential to develop than Nigeria.

2.1 Electricity from Solar

In view of the growing demand for environmentally friendly technologies for electricity generation, coupled with the finite nature and rising cost of fossil fuel for conventional electricity generation, global attention has shifted to the harnessing of renewable technologies for electricity generation [20]. Photovoltaic solar electric generation technology is one of the best means to provide electricity in a clean manner virtually everywhere around the world. Photovoltaic systems are modular, producing electricity directly from sunlight and do not give rise to emissions harmful to health or climate.

Advantages

-Environmentally friendly and pollution free (emission free).

-No use of fuels and water.

-Requires minimum maintenance and low running cost.

-Long lifetime, up to 30 years.

-Modular or “custom made” energy, can be designed for any applications from low power to a multi-megawatt power plant.

-No restriction on harvesting as far as there is light.

Drawbacks

-High initial cost.

-PV cannot operate without light.

-PV generates DC current: energy storage, like batteries, and inverters are needed.

-Large area needed for large scale applications.

-Cannot always generate stable output with ever-changing weather conditions.

In the generation of energy from solar irradiation, the PV-arrays trap the photons of solar light and convert the light energy into electrical energy. The energy obtained from the PV-systems can be utilized in different applications. DC power is the direct output of PV-arrays and this DC form of power can be directly used with DC appliances. For AC appliances, this DC power has to be changed into AC form using power electronic inverters.

2.1.0 Components of a PV system

Photovoltaic (PV) systems consist of solar panels in addition to other hardware usually referred to as balance of system components. The balance of system (BOS) encompasses all components of a photovoltaic system other than the photovoltaic panels. This includes the inverter, battery bank, charge controller, mounting structures as well as switches, fuses, grounding equipment, combiner boxes, wires, etc. These components are arranged and interconnected to set up a working PV system. The system may sometimes include a solar tracking system to improve the system's overall performance.

Solar panels or modules

Solar panels are made up of interconnected solar cells or photovoltaic cells that convert the energy of light directly into electricity through a phenomenon known as photovoltaic effect. The solar cells are the building blocks of solar panels, otherwise known as photovoltaic modules. Each module is rated by its DC output power under standard test conditions (STC), and typically ranges from 100 to 320 watts. The efficiency of a module determines the area of a module given the same rated output [21]. For instance, a 16% efficient 230 watt module will have half the area of an 8% efficient 230 watt module.

Figure 2.1: An array of solar panels

Usually, a single solar module can produce only a limited amount of power; most installations contain multiple modules. The lifetime of the panels is typically 20 to 25 years, which is considered the lifetime of the total system.

Inverters

The inverter converts the Direct Current (DC) electricity produced by the solar panels to the Alternating Current (AC) form that is required for the operation of most electrical appliances. The converted AC can be at any required voltage and frequency with the use of appropriate transformers, switching, and control circuits. The inverter performs the opposite function of a rectifier.

In PV systems the inverter also provides a fail-safe link between the solar generator and the mains electricity network. If there is a problem with the PV system or (more usually) a fault on the electricity network, the inverter would make the system safe. There are three types of Inverters, based on the output waveforms. These are Square wave inverter**,** Modified Sine wave and Sine wave inverter. Of these three, the **Sine wave inverter** has the best output waveform obtainable from an inverter and is therefore the most suitable for all appliances. Some of its advantages are as follows:

- Output voltage waveform is pure sine wave with very low harmonic distortion.
- Inductive loads like microwave ovens and motors run correctly, quieter and cooler.
- Reduces audible and electrical noise in fans, fluorescent lights, audio amplifiers, TV, Fax, and answering machines.
- Prevents crashes in computers, unreadable print outs, and glitches and noise in monitors.

- They have high surge capacity which means they are able to exceed their rated wattage for a limited time, enabling them to withstand power motors which can draw up to seven times their rated wattage during startup.

However, Sine wave inverters are more expensive than Modified Sine wave and Square wave inverters. For less sensitive devices (e.g resistive loads) that do not require high quality waveform, the Modified Sine wave inverter is the more cost-effective option. Square wave inverters are seldom used because of their poor quality power output and limited applications.

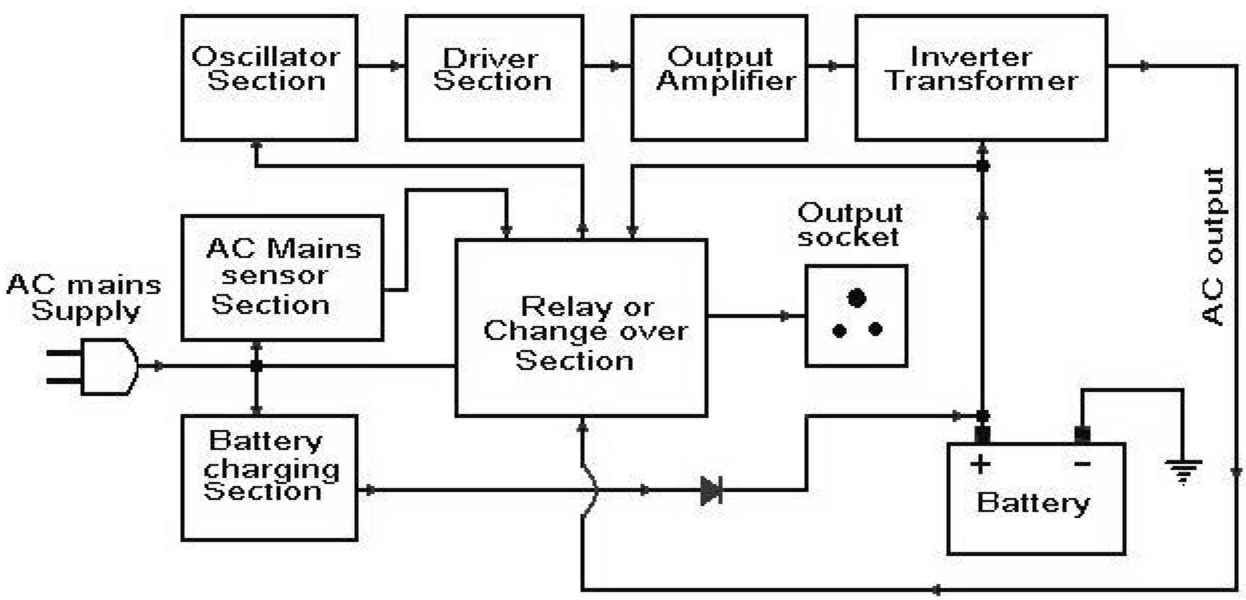


Figure 2.2: Block diagram of a basic inverter

Batteries

Batteries are used in PV systems for the purpose of storing energy produced by the PV array during the day, and to supply this energy to electrical loads when the source is unavailable, for instance at night or during cloudy weather. Batteries are rated in amp-hours. The amp-hours (AH) indicates how much energy can be stored in by the battery. Two types of batteries can be used, deep-cycle and starter batteries. Deep-cycle batteries are more efficient and most commonly used, but starter batteries are widely available in Nigeria due to their use in cars. Although not recommended for most PV applications, SLI (Starting, Lighting and Ignition) batteries may provide up to two years of useful service in small stand-alone PV systems where the average daily depth of discharge (DOD) is limited. SLI batteries are designed to produce a high amount of current in a very short time.

Deep cycle batteries on the other hand are designed to produce less current than an SLI type battery, yet they produce that current for longer periods of time. Deep cycle batteries can be discharged up to 80 percent DOD without damage depending on the model. In order to increase battery life, manufacturers recommend discharging deep-cycle batteries only down to 50 percent in order to increase battery life. A deep-cycle battery lasts between three and eight years.

Charge Controller

A charge controller is used to maintain the proper charging voltage on the batteries in order to maximize the battery lifetime. It prevents overcharging and may protect against overvoltage, which can reduce battery performance or lifespan and may also pose a safety risk. Further, in order to protect battery life, some charge controllers have additional features, such as a low voltage disconnect (LDV), a separate circuit which powers down the load when the batteries become overly discharged. The two major types of charge controllers in use are: PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking) charge controllers.

Mounting structures

The principal aim of the mounting structures is to hold the PV modules securely in place. Arrays are most commonly mounted on roofs or on steel poles set in concrete. In certain applications, they may be mounted at ground level or on building walls. On roof-mounted systems, the PV array is typically mounted on fixed racks, parallel to the roof for aesthetic reasons and stood off several inches above the roof surface to allow airflow that will keep them as cool as possible. In addition to cost considerations, a key requirement of mounting structures is that they should be such that there is easy access to the modules for the maintenance or repair.

Switches

Switches ensure that the system can be safely shut down and system components can be removed for maintenance and repair. For grid-connected systems, a switch ensures that the generating equipment is isolatable from the grid, which is important for the safety of personnel. In general, a switch is needed for each source of power or energy storage device in the system

Grounding equipment

Grounding equipment provides a well-defined, low-resistance path from your system to the ground to protect your system from current surges from lightning strikes or equipment malfunctions. Grounding also stabilizes voltages and provides a common reference point. All system components and any exposed metal, receptacles and frames should be grounded. The grounding harness is usually located on the roof.

Combiner box

Wires from individual PV modules or strings are run to the combiner box, typically located on the roof. These wires may be single conductor pigtails with connectors that are pre-wired onto the PV modules. The output of the combiner box is one larger two-wire conductor in conduit. A combiner box typically includes a safety fuse or breaker for each string and may include a surge protector.

Surge protection

Surge protectors help to protect your system from power surges that may occur if the PV system or nearby power lines are struck by lightning. A power surge is an increase in voltage significantly above the design voltage.

2.1.1 Design Considerations

The design of a photovoltaic system must balance the rate of solar energy deposition on a given area with the power required by the load. The measure of total solar irradiance commonly used to assess the input for photovoltaic panels is daily “peak sun hours”. The number of daily peak sun hours is equal to the value in kWh of the total amount of direct and diffuse solar radiation incident on a square meter in a day. As one moves northward through Nigeria, average irradiance increases, despite Nigeria’s location in the northern hemisphere. This gradient is explained by the movement of the Guinea trade winds and the associated geographic variation in intensity and duration of the rainy and dust storm seasons. (A study by the U.S. National Academies and the Nigerian Academy of Science (2007) suggests that battery replacement occur during the rainy season, in order to bolster customers’ interest in their systems when capacity is at its lowest. In order to maintain optimal system functioning during the opposite season of dusty Harmattan winds, it is important that customers wipe the dust off their panels daily. Lagos and the rest of the coast in the south of Nigeria receive between 3.5 and 4.0 peak sun hours at minimum. The northern region of the country receives between 5.0 and 5.5 peak sun hours at minimum.

2.1.2 Energy from the PV module

The output power generated from the PV module, with respect to the solar radiation, can be calculated using the following formula [22]:

$$P^{t}_{pv} = S_{pv}\,\eta_{pv}\,P_{f}\,\eta_{pc}\,G^{t} \qquad t=0,..,T-1$$

where S_{pv} is the solar cell array area, η_{pv} is the module reference efficiency, P_f is the packing factor η_{pc} is the power conditioning efficiency, and G^t is the hourly irradiance.

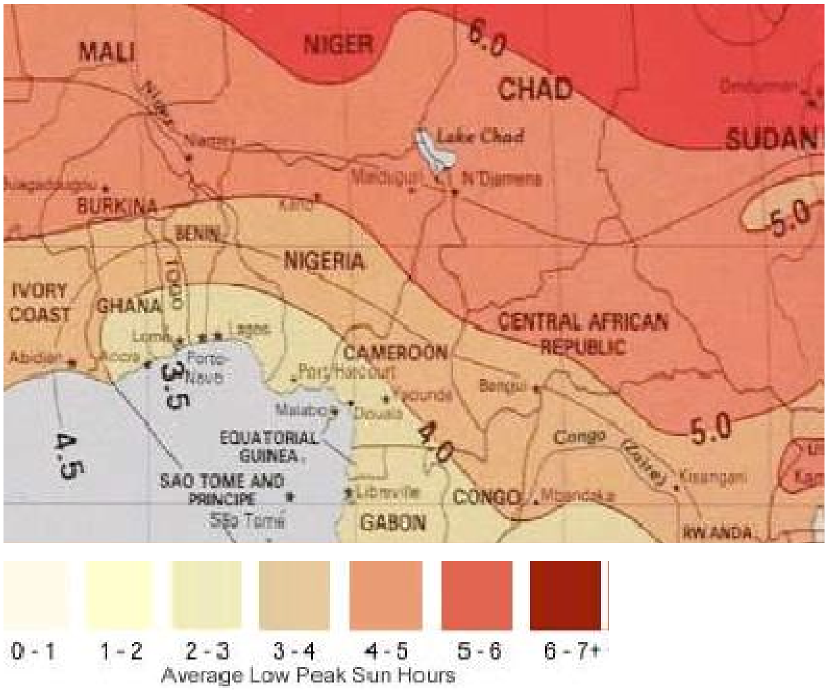


Figure 2.3: Yearly minimum Peak Sun Hours

Source [14]

2.2 Use of Generators

Due to the lack of reliable electricity, many people and companies supplement the electricity provided by the grid system with their own generators. According to one approximation, well over 90% businesses have generators. The World Bank survey of Nigerian firms in the year, 2002 shows that 95.7, 98.2 and 98.2% of business firms located in the north, east and south of Nigeria respectively owned private generators. In average, about 97.1% of business firms located in Nigeria owned and operate private generator.

Generators are used not only by rural households but also by grid connected households and industries as a more stable supplement to grid power. The rural incidence of diesel generators is difficult to estimate, but 96 to 98% of the grid-connected firms surveyed reported ownership of private generators [23].

For these systems, the value of the generator's kVA rating should equal or exceed the wattage of estimated load. The estimated lifetime of a generator is between 10 and 13 years. When calculating the present value of the lifetime costs of fuel, one must consider not only the rising cost of petrodiesel due to Nigeria's limited refining capacity, but also the disparity in Nigeria's official, subsidized price of diesel and the significantly higher price that can be obtained in practice, which ranges from 1.5 to 4 times the official price.

The actual market price of diesel is likely highest for the most remote regions. (See Oparaku (2003) for a sensitivity analysis of the life-cycle cost of the entire system with variation in fuel price).

2.3 Transfer Switches

Transfer (or changeover) switches allow switching from a primary power source to a secondary or tertiary power source and are employed in some electrical power distribution systems; most often transfer switches can be seen where emergency power generators are used to back up from the utility source. The transfer switching allows safe switching from utility power to emergency generator power while maintaining isolation of each source from the other. The switch may be a manual switch, an automatic switch or a combination of manual and automatic. In a home, for example, during power outages, the power transfer switch allows isolation of the owner's critical circuits (e.g. cooling, refrigerator, lighting) from the utility service, hence allowing for operation of the generator without back feeding to the utility which can damage utility equipment [24].

Standby generation systems in low- and medium-voltage applications connect to the utility power system in a number of different ways. Typically, an automatic transfer switch is a part of most power system connections. **Automatic transfer switches** (ATS) continually monitor the incoming utility power automatically. Any anomalies such as voltage drops, brownouts spikes, or surges will cause the internal circuitry to signal a generator to start. This will then transfer to the generator when additional switch circuitry determines that the generator has the proper voltage and frequency. When utility power returns and no anomalies occur for a certain time, the transfer switch will then transfer load back to the utility line and initiate the turn off of the generator.

2.3.0 Types of Transfer Switches

1. **Open Transition Transfer Switch (OTTS)**

An Open Transition Switch is also called a 'break before make' transfer switch. A 'break before make' transfer switch breaks contacts with one source of power before it makes contacts with another, and therefore it prevents back feeding from an emergency generator back into the utility line, for example. One example is an open transition automatic transfer switch (ATS). During the slip second of the power transfer the flow of electricity is interrupted.

2. **Closed Transition Transfer Switch (CTTS).**

A Closed transition transfer switch is also called a 'make before break' transfer switch. In a typical emergency system, there is an inherent momentary interruption of power to the load when it is transferred from one available source to another. In most cases this outage is inconsequential, particularly if it is less than 1/6 of a second. There are some loads however, that are affected by even the slightest loss of power. There are also operational conditions where it may be desirable to transfer loads with zero interruption of power when condition permit. For these applications, closed transition transfer switches can be provided. When transferring loads in this manner, during a test or when re-transferring to normal after primary power has stabilized, the switch will operate in a make-before break mode provided both sources are acceptable and synchronized. Typical parameters determining synchronization are: voltage difference less than 5%, frequency difference less than 0.2Hz and relative phase angle between the sources of 5 electrical degrees. Since the maximum frequency difference is 0.2Hz, the engine will generally be required to be controlled by an isochronous governor.

It is generally required that the closed transition, or overlap time, be less than 100 milliseconds. If either source is not present or not acceptable (such as when normal power fails) the switch must operate in a break before make less mode (standard open transition operation) to ensure no back feeding occurs. Closed transition transfer makes code-mandated monthly testing less objectionable because it eliminates the interruptions to critical loads, which occur during traditional open transition transfer.

2.3.1 Applications of Closed Transition Transfer Switch (CTTS)

Typical load switching application for which closed transition transfer is desirable includes data processing and electronic load. Certain motor and transformer loads, curtailment systems, or anywhere load interruptions of even the shortest duration are objectionable. It should be understood that a CTTS in a system is not a substitute for a UPS (uninterrupted power supply). In addition to providing line conditioning, a UPS has a built-in stored energy that provides power for a prescribed period of time in the event of a power failure. A CTTS by itself simply assures that there will be no momentary loss of power when the load is transferred from one live power source to another.

2.4 Uninterruptible Power Supplies (UPS)

In today's mission-critical applications, where the end-use equipment cannot tolerate even a momentary power outage and, even relatively minor disturbances in the power system can cause computer systems to re-boot, uninterruptible power supplies are used to provide continuous, conditioned power to sensitive loads, thereby preventing operational down-time.

UPS's use stored energy, usually chemical energy in the form of batteries or mechanical energy in the form of a rotating flywheel, and use it to "bridge the gap" from the time the normal source of power (i.e., the utility) fails and the time the alternate source of power (standby generators, solar) can be brought on-line.
In addition, many UPS systems provide power conditioning, further isolating the sensitive loads from disturbances on the system. However, the UPS stored energy source cannot operate indefinitely, and typically requires re-charging from the system normal or alternate power source.

2.5 Microcontroller and Embedded systems

A microcontroller is a small computer on a single integrated circuit containing a processor core, memory, and programmable input/output peripherals. It can be considered as a microcomputer built on a single integrated circuit or *chip* [25]. Microcontrollers are designed for embedded applications, in contrast to the microprocessors used in personal computers or other general purpose applications. Modern high-performance embedded processors are capable of a great deal of computation in addition to I/O tasks [26]. Dramatic advances in computer and communication technologies have made it economically feasible to extend the use of embedded systems to more and more critical applications [27].

2.5.0 The 89C52 Microcontroller

The AT89C52 used in this design is a low-power, high-performance CMOS 8-bit microcomputer with 8K bytes of Flash programmable and erasable read only memory (PEROM) manufactured by Atmel. It is compatible with the industry-standard 80C51 and 80C52 instruction set and pinout. The on-chip Flash allows the program memory to be reprogrammed in-system or by a conventional nonvolatile memory programmer. By combining a versatile 8-bit CPU with Flash on a monolithic chip, the Atmel AT89C52 is a powerful microcomputer which provides a highly-flexible and cost-effective solution to many embedded control applications.

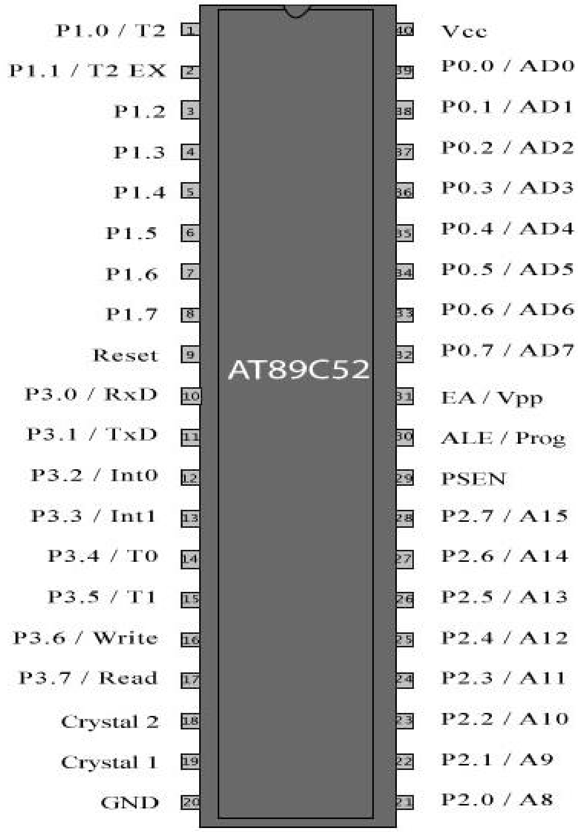


Figure 2.4: Pin designation of AT89C52 microcontroller

The AT89C52 provides the following standard features: 8K bytes of Flash, 256 bytes of RAM, 32 I/O lines, three 16-bit timer/counters, a six-vector two-level interrupt architecture, a full-duplex serial port, on-chip oscillator, and clock circuitry. In addition, the AT89C52 is designed with static logic for operation down to zero frequency and supports two software selectable power saving modes. The Idle Mode stops the CPU while allowing the RAM, timer/counters, serial port, and interrupt system to continue functioning. The Power-down mode saves the RAM contents but freezes the oscillator, disabling all other chip functions until the next hardware reset.

Pin Description

VCC

Supply voltage.

GND

Ground.

Port 0

Port 0 is an 8-bit open drain bi-directional I/O port. As an output port, each pin can sink eight TTL inputs. When 1s are written to port 0 pins, the pins can be used as high impedance inputs. Port 0 can also be configured to be the multiplexed low order address/data bus during accesses to external program and data memory. In this mode, P0 has internal pull-ups. Port 0 also receives the code bytes during Flash programming and outputs the code bytes during program verification. External pull-ups are required during program verification.

Port 1

Port 1 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 1 output buffers can sink/source four TTL inputs. When 1s are written to Port 1 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 1 pins that are externally being pulled low will source current (IIL) because of the internal pull-ups. In addition, P1.0 and P1.1 can be configured to be the timer/counter 2 external count input (P1.0/T2) and the timer/counter 2 trigger input (P1.1/T2EX), respectively, as shown in the following table. Port 1 also receives the low-order address bytes during Flash programming and verification.

Port 2

Port 2 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 2 output buffers can sink/source four TTL inputs. When 1s are written to Port 2 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 2 pins that are externally being pulled low will source current (IIL) because of the internal pull-ups. Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @ DPTR). In this application, Port 2 uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOVX @ RI), Port 2 emits the contents of the P2 Special Function Register. Port 2 also receives the high-order address bits and some control signals during Flash programming and verification.

Port 3

Port 3 is an 8-bit bi-directional I/O port with internal pull-ups. The Port 3 output buffers can sink/source four TTL inputs. When 1s are written to Port 3 pins, they are pulled high by the internal pull-ups and can be used as inputs. As inputs, Port 3 pins that are externally being pulled low will source current (IIL) because of the pull-ups. Port 3 also serves the functions of various special features of the AT89C51, as shown in the following table. Port 3 also receives some control signals for Flash programming and verification. Reset input. A high on this pin for two machine cycles while the oscillator is running resets the device.

ALE/PROG

Address Latch Enable is an output pulse for latching the low byte of the address during accesses to external memory. This pin is also the program pulse input (PROG) during Flash programming. In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency and may be used for external timing or clocking purposes. Note, however, that one ALE pulse is skipped during each access to external data memory. If desired, ALE operation can be disabled by setting bit 0 of SFR location 8EH. With the bit set, ALE is active only during a MOVX or MOVC instruction. Otherwise, the pin is weakly pulled high. Setting the ALE-disable bit has no effect if the microcontroller is in external execution mode.

PSEN

Program Store Enable is the read strobe to external program memory. When the AT89C52 is executing code from external program memory, PSEN is activated twice each machine cycle, except that two PSEN activations are skipped during each access to external data memory.

EA/VPP

External Access Enable. EA must be strapped to GND in order to enable the device to fetch code from external program memory locations starting at 0000H up to FFFFH. Note, however, that if lock bit 1 is programmed, EA will be internally latched on reset. EA should be strapped to VCC for internal program executions.

This pin also receives the 12-volt programming enable voltage (VPP) during Flash programming when 12-volt programming is selected.

XTAL1

Input to the inverting oscillator amplifier and input to the internal clock operating circuit.

XTAL2

Output from the inverting oscillator amplifier.

Special Function Registers

A map of the on-chip memory area called the Special Function Register (SFR) space is shown in Table 2.2. Note that not all of the addresses are occupied, and unoccupied addresses may not be implemented on the chip. Read accesses to these addresses will in general return random data, and write accesses will have an indeterminate effect. User software should not write 1s to these unlisted locations, since they may be used in future products to invoke new features. In that case, the reset or inactive values of the new bits will always be 0.

Table 2.2: AT89C52 SFR Map and Reset Values

0F8H									0FFH
0F0H	B 00000000								0F7H
0E8H									0EFH
0E0H	ACC 00000000								0E7H
0D8H									0DFH
0D0H	PSW 00000000								0D7H
0C8H	T2CON 00000000	T2MOD XXXXXX00	RCAP2L 00000000	RCAP2H 00000000	TL2 00000000	TH2 00000000			0CFH
0C0H									0C7H
0B8H	IP XX000000								0BFH
0B0H	P3 11111111								0B7H
0A8H	IE 0X000000								0AFH
0A0H	P2 11111111								0A7H
98H	SCON 00000000	SBUF XXXXXXXX							9FH
90H	P1 11111111								97H
88H	TCON 00000000	TMOD 00000000	TL0 00000000	TL1 00000000	TH0 00000000	TH1 00000000			8FH
80H	P0 11111111	SP 00000111	DPL 00000000	DPH 00000000				PCON 0XXX0000	87H

Timer 2 Registers Control and status bits are contained in registers T2CON (shown in Table 2.3) and T2MOD (shown in Table 2.5) for Timer 2. The register pair (RCAP2H, RCAP2L) are the Capture/Reload registers for Timer 2 in 16-bit capture mode or 16-bit auto-reload mode.

Table 2.3: T2CON – Timer/Counter 2 Control Register

T2CON Address = 0C8H Reset Value = 0000 0000B

Bit Addressable

Bit	TF2	EXF2	RCLK	TCLK	EXEN2	TR2	$C/\overline{T2}$	$CP/\overline{RL2}$
	7	6	5	4	3	2	1	0

Symbol	Function
TF2	Timer 2 overflow flag set by a Timer 2 overflow and must be cleared by software. TF2 will not be set when either RCLK = 1 or TCLK = 1.
EXF2	Timer 2 external flag set when either a capture or reload is caused by a negative transition on T2EX and EXEN2 = 1. When Timer 2 interrupt is enabled, EXF2 = 1 will cause the CPU to vector to the Timer 2 interrupt routine. EXF2 must be cleared by software. EXF2 does not cause an interrupt in up/down counter mode (DCEN = 1).
RCLK	Receive clock enable. When set, causes the serial port to use Timer 2 overflow pulses for its receive clock in serial port Modes 1 and 3. RCLK = 0 causes Timer 1 overflow to be used for the receive clock.
TCLK	Transmit clock enable. When set, causes the serial port to use Timer 2 overflow pulses for its transmit clock in serial port Modes 1 and 3. TCLK = 0 causes Timer 1 overflows to be used for the transmit clock.
EXEN2	Timer 2 external enable. When set, allows a capture or reload to occur as a result of a negative transition on T2EX if Timer 2 is not being used to clock the serial port. EXEN2 = 0 causes Timer 2 to ignore events at T2EX.
TR2	Start/Stop control for Timer 2. TR2 = 1 starts the timer.
$C/\overline{T2}$	Timer or counter select for Timer 2. $C/\overline{T2}$ = 0 for timer function. $C/\overline{T2}$ = 1 for external event counter (falling edge triggered).
$CP/\overline{RL2}$	Capture/Reload select. $CP/\overline{RL2}$ = 1 causes captures to occur on negative transitions at T2EX if EXEN2 = 1. $CP/\overline{RL2}$ = 0 causes automatic reloads to occur when Timer 2 overflows or negative transitions occur at T2EX when EXEN2 = 1. When either RCLK or TCLK = 1, this bit is ignored and the timer is forced to auto-reload on Timer 2 overflow.

Table 2.4: Timer 2 Operating Modes

RCLK +TCLK	$CP/\overline{RL2}$	TR2	MODE
0	0	1	16-bit Auto-reload
0	1	1	16-bit Capture
1	X	1	Baud Rate Generator
X	X	0	(Off)

Interrupt Registers The individual interrupt enable bits are in the IE register. Two priorities can be set for each of the six interrupt sources in the IP register.

Data Memory

The AT89C52 implements 256 bytes of on-chip RAM. The upper 128 bytes occupy a parallel address space to the Special Function Registers. That means the upper 128 bytes have the same addresses as the SFR space but are physically separate from SFR space. When an instruction accesses an internal location above address 7FH, the address mode used in the instruction specifies whether the CPU accesses the upper 128 bytes of RAM or the SFR space. Instructions that use direct addressing access SFR space. For example, the following direct addressing instruction accesses the SFR at location 0A0H (which is P2).

MOV 0A0H, #data

Instructions that use indirect addressing access the upper 128 bytes of RAM. For example, the following indirect addressing instruction, where R0 contains 0A0H, accesses the data byte at address 0A0H, rather than P2 (whose address is 0A0H).

MOV @R0, #data

Note that stack operations are examples of indirect addressing, so the upper 128 bytes of data RAM are available as stack space.

Table 2.5: T2MOD – Timer 2 Mode Control Register

T2MOD Address = 0C9H — Reset Value = XXXX XX00B

Not Bit Addressable

	–	–	–	–	–	–	T2OE	DCEN
Bit	7	6	5	4	3	2	1	0

Symbol	Function
–	Not implemented, reserved for future
T2OE	Timer 2 Output Enable bit.
DCEN	When set, this bit allows Timer 2 to be configured as an up/down counter.

Timer 0 and 1

Timer 0 and Timer 1 in the AT89C52 operate the same way as Timer 0 and Timer 1 in the AT89C51.

Timer 2

Timer 2 is a 16-bit Timer/Counter that can operate as either a timer or an event counter. The type of operation is selected by bit C/T2 in the SFR T2CON (shown in Table 2.3). Timer 2 has three operating modes: capture, auto-reload (up or down counting), and baud rate generator. The modes are selected by bits in T2CON, as shown in Table 2.4. Timer 2 consists of two 8-bit registers, TH2 and TL2. In the Timer function, the TL2 register is incremented every machine cycle. Since a machine cycle consists of 12 oscillator periods, the count rate is 1/12 of the oscillator frequency. In the Counter function, the register is incremented in response to a 1-to-0 transition at its corresponding external input pin, T2. In this function, the external input is sampled during S5P2 of every machine cycle. When the samples show a high in one cycle and a low in the next cycle, the count is incremented. The new count value appears in the register during S3P1 of the cycle following the one in which the transition was detected. Since two machine cycles (24 oscillator periods) are required to recognize a 1-to-0 transition, the maximum count rate is 1/24 of the oscillator frequency. To ensure that a given level is sampled at least once before it changes, the level should be held for at least one full machine cycle.

Capture Mode

In the capture mode, two options are selected by bit EXEN2 in T2CON. If EXEN2 = 0, Timer 2 is a 16-bit timer or counter which upon overflow sets bit TF2 in T2CON.

This bit can then be used to generate an interrupt. If EXEN2 = 1, Timer 2 performs the same operation, but a 1-to-0 transition at external input T2EX also causes the current value in TH2 and TL2 to be captured into RCAP2H and RCAP2L, respectively. In addition, the transition at T2EX causes bit EXF2 in T2CON to be set. The EXF2 bit, like TF2, can generate an interrupt.

Auto-reload (Up or Down Counter)

Timer 2 can be programmed to count up or down when configured in its 16-bit auto-reload mode. This feature is invoked by the DCEN (Down Counter Enable) bit located in the SFR T2MOD (see Table 4). Upon reset, the DCEN bit is set to 0 so that timer 2 will default to count up. When DCEN is set, Timer 2 can count up or down, depending on the value of the T2EX pin.

Baud Rate Generator

Timer 2 is selected as the baud rate generator by setting TCLK and/or RCLK in T2CON (Table 2.3). Note that the baud rates for transmit and receive can be different if Timer 2 is used for the receiver or transmitter and Timer 1 is used for the other function.

The baud rate generator mode is similar to the auto-reload mode, in that a rollover in TH2 causes the Timer 2 registers to be reloaded with the 16-bit value in registers RCAP2H and RCAP2L, which are preset by software. The baud rates in Modes 1 and 3 are determined by Timer 2's overflow rate according to the following equation.

$$\text{Modes 1 and 3 Baud Rates} = \frac{\text{Timer 2 Overflow Rate}}{16}$$

The Timer can be configured for either timer or counter operation. In most applications, it is configured for timer operation (CP/T2 = 0). The timer operation is different for Timer 2 when it is used as a baud rate generator. Normally, as a timer, it increments every machine cycle (at 1/12 the oscillator frequency). As a baud rate generator, however, it increments every state time (at 1/2 the oscillator frequency). The baud rate formula is given below.

$$\frac{\text{Modes 1 and 3}}{\text{Baud Rate}} = \frac{\text{TimeOscillator Frequency}}{32 \text{ x } [65536 - (\text{RECAP2H}, \text{RECAP2L})]}$$

where (RCAP2H, RCAP2L) is the content of RCAP2H andRCAP2L taken as a 16-bit unsigned integer. Timer 2 as a baud rate generator is shown in Figure 4. This figure is valid only if RCLK or TCLK = 1 in T2CON. Note that a rollover in TH2 does not set TF2 and will not generate an interrupt. Note too, that if EXEN2 is set, a 1-to-0 transition in T2EX will set EXF2 but will not cause a reload from (RCAP2H, RCAP2L) to (TH2, TL2). Thus when Timer 2 is in use as a baud rate generator, T2EX can be used as an extra external interrupt. Note that when Timer 2 is running (TR2 = 1) as a timer in the baud rate generator mode, TH2 or TL2 should not be read from or written to. Under these conditions, the Timer is incremented every state time, and the results of a read or write may not be accurate. The RCAP2 registers may be read but should not be written to, because a write might overlap a reload and cause write and/or reload errors. The timer should be turned off (clear TR2) before accessing the Timer 2 or RCAP2 registers.

2.6 Comparator

A comparator is similar to an op amp which is arguably the most useful single device in analog electronic circuitry [28]. It has two inputs, inverting and non-inverting and an output. But it is specifically designed to compare the voltages between its two inputs. Therefore it operates in a non-linear fashion. Comparators generally have more flexible output circuits than op-amps. Whereas an ordinary op-amp uses a push-pull output stage to swing between the supply voltages, a comparator chip usually has an open-collector output with grounded emitter [29]. The comparator operates open-loop, providing a two-state logic output voltage. These two states represent the sign of the net difference between the two inputs (including the effects of the comparator input offset voltage). Therefore, the comparator's output will be a logic "1" if the input signal on the non-inverting input exceeds the signal on the inverting input (plus the offset voltage, Vos) and a logic "0" for the opposite case. A comparator is normally used in applications where some varying signal level is compared to a fixed level (usually a voltage reference). Since it is, in effect, a 1-bit analog-to-digital converter (ADC), the comparator is a basic element in all ADCs [30].

Because comparators have only two output states, their outputs are near zero or near the supply voltage. Bipolar rail-to-rail comparators have a common-emitter output that produces a small voltage drop between the output and each rail. That drop is equal to the collector-to-emitter voltage of a saturated transistor. When output currents are light, output voltages of CMOS rail-to-rail comparators, which rely on a saturated MOSFET, range closer to the rails than their bipolar counterparts.

On the basis of outputs, comparators can also be classified as open drain or push–pull. Comparators with an open-drain output stage use an external pull up resistor to a positive supply that defines the logic high level. Open drain comparators are more suitable for mixed-voltage system design. Since the output is high impedance for logic level high, open drain comparators can also be used to connect multiple comparators on to a single bus. Push pull output does not need a pull up resistor and can also source current unlike an open drain output.

The pin diagram of **LM339** is shown in figure 2.5 below. LM339 is a comparator IC with four inbuilt comparators.

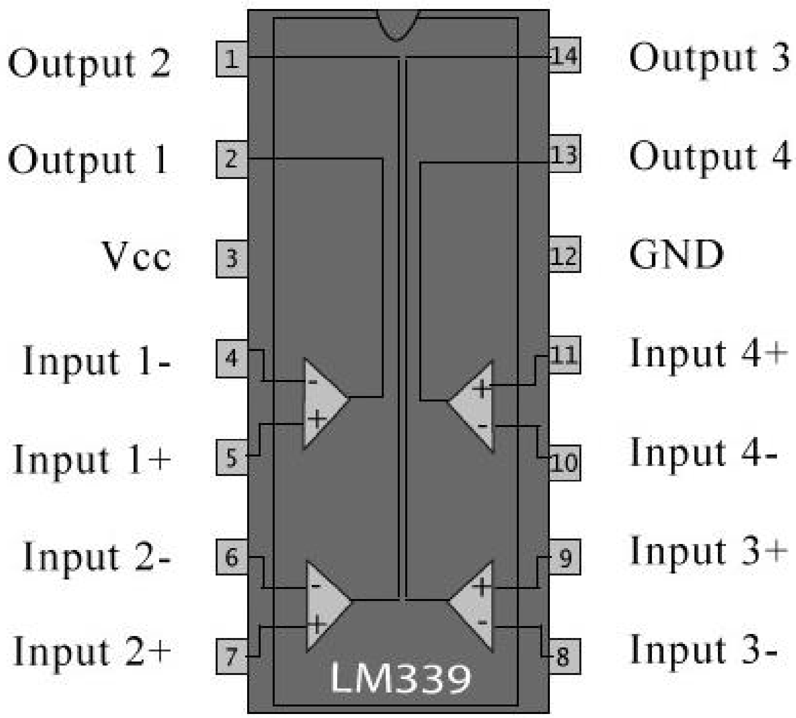


Figure 2.5: LM339 Pin Configuration

2.6.0 Comparator parameters

The major comparator parameters include the following: Propagation delay, Current consumption, Output stage type (open collector/drain or push-pull), Input offset voltage, hysteresis, Output current capability, Rise and fall time, Input common mode voltage range.

- **Propagation Delay**

  Propagation delay T_{PD} is one of the key parameters for many applications because it limits the maximal input frequency which can be processed. Voltage comparison of analog signals requires a minimum amount of time.

  Propagation delay is defined as the time difference between the moment the input signal crossing the reference voltage and the moment the output state changes (usually when the output signal crosses 50% of V_{CC}, if nothing is specified).

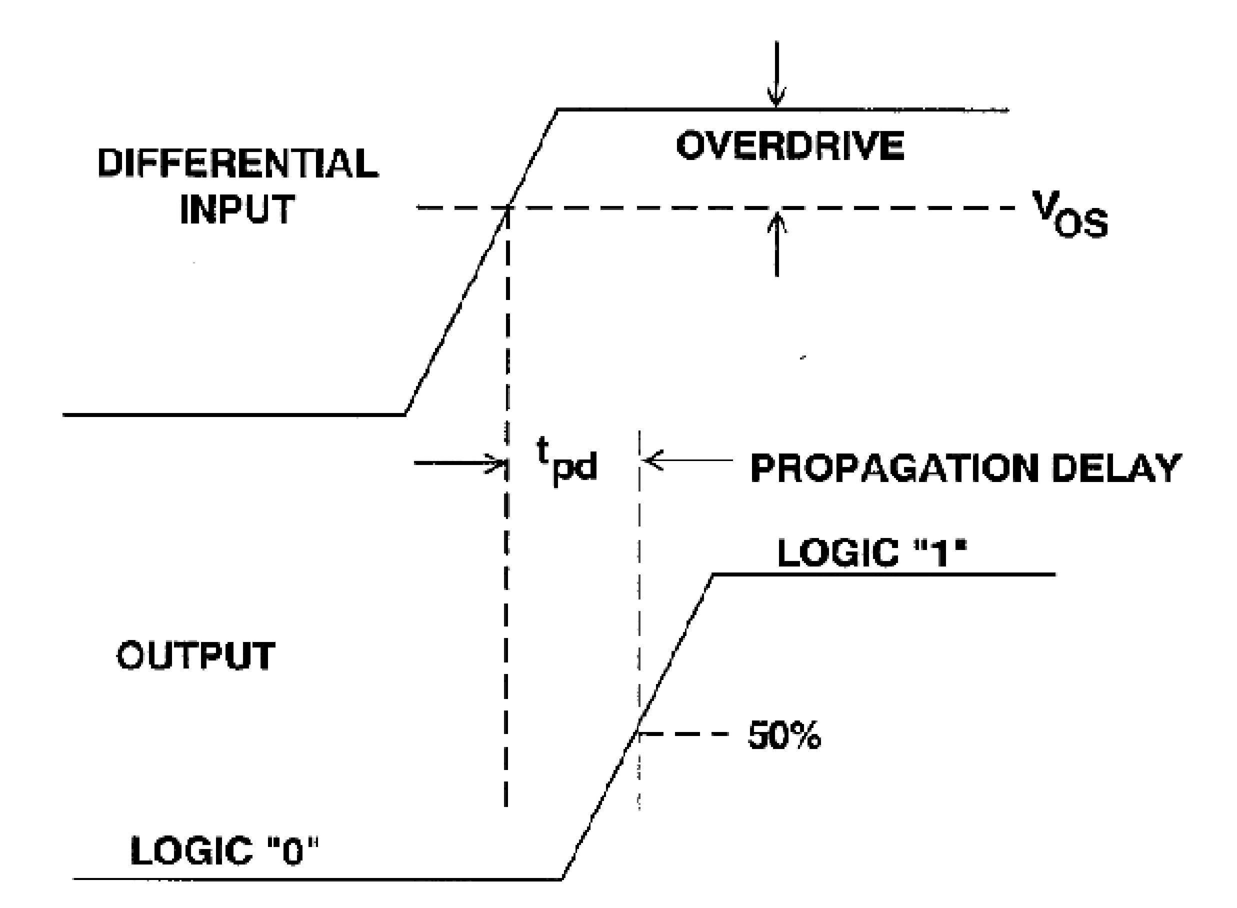


Figure 2.6: Comparator Propagation Delay

The propagation delay in practical comparators decreases somewhat as the input overdrive is increased. This variation in propagation delay as a function of overdrive is called dispersion.

- **Voltage Gain**

Voltage gain A_{VD} indicates the overall device gain. Higher gain means better small input signal resolving capability which can be an advantage in certain applications. Common comparators have an A_{VD} in the range of 200 V/mV (106 dB). 1 mV input signal amplified by 106 dB leads to theoretical amplitude of 200 V. In reality, the output signal swing is limited by V_{CC}. Note that the A_{VD} doesn’t affect external hysteresis as the output is always in high or low state and never between (unlike an operational amplifier, a comparator is not used in its linear region).

- **Input Offset Voltage**

The input offset voltage (V_{IO}) can be defined as the differential input voltage to apply in order to be at the toggling level. Input offset voltage limits the resolution of comparators. Therefore, for very small signals (in the same order as the V_{IO}), the comparator toggles at an undesired value or does not toggle at all.

Speed and Power

While in general comparators are "fast," their circuits are not immune to the classic speed-power tradeoff. High speed comparators use transistors with larger aspect ratios and hence also consume more power. Depending on the application, select either a comparator with high speed or one that saves power. For example, nano-powered comparators in space-saving chip-scale packages (UCSP), DFN or SC70 packages such as MAX9027, LTC1540, LPV7215, MAX9060 and MCP6541 are ideal for ultra-low-power, portable applications. Likewise if a comparator is needed to implement a relaxation oscillator circuit to create a high speed clock signal then comparators having few nano seconds of propagation delay may be suitable. ADCMP572 (CML output), LMH7220 (LVDS Output), MAX999 (CMOS output / TTL output), LT1719 (CMOS output / TTL output), MAX9010 (TTL output), and MAX9601 (PECL output) are examples of some good high speed comparators.

Hysterises

A comparator normally changes its output state when the voltage between its inputs crosses through approximately zero volts [31]. Small voltage fluctuations due to noise, always present on the inputs, can cause undesirable rapid changes between the two output states when the input voltage difference is near zero volts. To prevent this output oscillation, a small hysteresis of a few millivolts is integrated into many modern comparators. For example, the LTC6702, MAX9021 and MAX9031 have internal hysteresis desensitizing them from input noise. In place of one switching point, hysteresis introduces two: one for rising voltages, and one for falling voltages. The difference between the higher-level trip value (VTRIP+) and the lower-level trip value (VTRIP-) equals the hysteresis voltage (VHYST).

If the comparator does not have internal hysteresis or if the input noise is greater than the internal hysteresis then an external hysteresis network can be built using positive feedback from the output to the non-inverting input of the comparator. The resulting Schmitt trigger circuit gives additional noise immunity and a cleaner output signal. Some comparators such as LMP7300, LTC1540, MAX931, MAX971 and ADCMP341 also provide the hysteresis control through a separate hysteresis pin. These comparators make it possible to add a programmable hysteresis without feedback or complicated equations. Using a dedicated hysteresis pin is also convenient if the source impedance is high since the inputs are isolated from the hysteresis network. When hysteresis is added then a comparator cannot resolve signals within the hysteresis band.

2.6.1 Comparator applications

Null detectors

A null detector is one that functions to identify when a given value is zero. Comparators can be a type of amplifier distinctively for null comparison measurements. It is the equivalent to a very high gain amplifier with well-balanced inputs and controlled output limits. The circuit compares the two input voltages, determining the larger. The inputs are an unknown voltage and a reference voltage, usually referred to as v_u and v_r. A reference voltage is generally on the non-inverting input (+), while v_u is usually on the inverting input (−). (A circuit diagram would display the inputs according to their sign with respect to the output when a particular input is greater than the other.) The output is either positive or negative, for example ±12 V. In this case, the idea is to detect when there is no difference between in the input voltages. This gives the identity of the unknown voltage since the reference voltage is known.

When using a comparator as a null detector, there are limits as to the accuracy of the zero value measurable. Zero output is given when the magnitude of the difference in the voltages multiplied by the gain of the amplifier is less than the voltage limits. For example, if the gain of the amplifier is 10^6, and the voltage limits are ±6 V, then no output will be given if the difference in the voltages is less than 6 µV. One could refer to this as a sort of uncertainty in the measurement.

Zero-crossing detectors

For this type of detector, a comparator detects each time an ac pulse changes polarity. The output of the comparator changes state each time the pulse changes its polarity, that is the output is HI (high) for a positive pulse and LO (low) for a negative pulse squares the input signal.

Relaxation oscillator

A comparator can be used to build a relaxation oscillator. It uses both positive and negative feedback. The positive feedback is a Schmitt trigger configuration. Alone, the trigger is a bistable multivibrator. However, the slow negative feedback added to the trigger by the RC circuit causes the circuit to oscillate automatically. That is, the addition of the RC circuit turns the hysteretic bistable multivibrator into an astable multivibrator.

Level shifter

This circuit requires only a single comparator with an open-drain output as in the LM393, TLV3011 or MAX9028. The circuit provides great flexibility in choosing the voltages to be translated by using a suitable pull up voltage. It also allows the translation of bipolar ±5 V logic to unipolar 3 V logic by using a comparator like the MAX972.

Analog-to-digital converters

When a comparator performs the function of telling if an input voltage is above or below a given threshold, it is essentially performing a 1-bit quantization. This function is used in nearly all analog to digital converters (such as flash, pipeline, successive approximation, delta-sigma modulation, folding, interpolating, dual-slope and others) in combination with other devices to achieve a multi-bit quantization.

Window detectors

Comparators can also be used as window detectors. In a window detector, a comparator used to compare two voltages and determine whether a given input voltage is under voltage or over voltage.

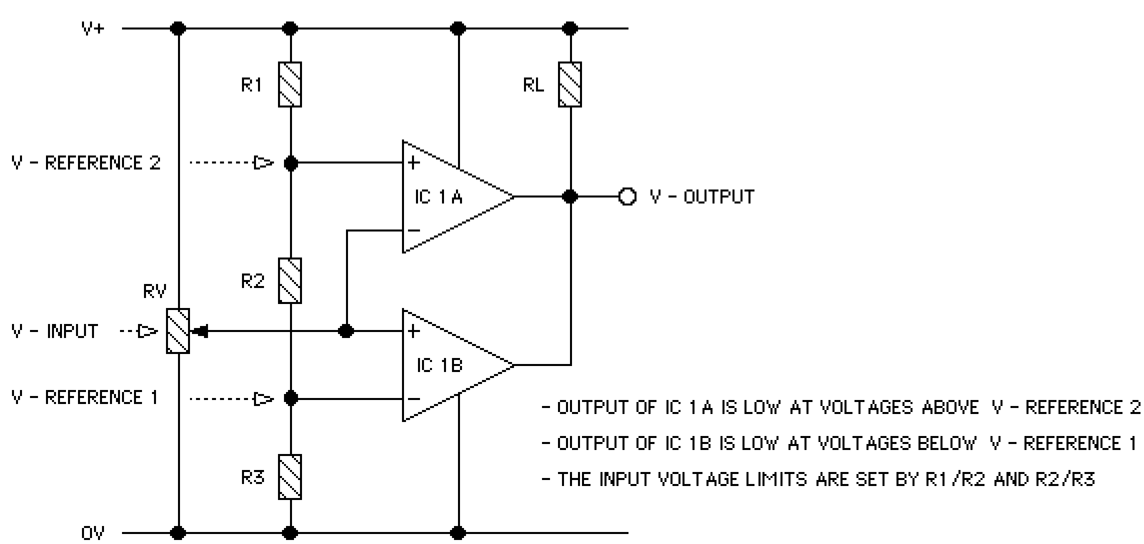


Figure 2.7: Voltage window detector circuit using comparator

2.7 Relay

A relay is an electrical switch that opens and closes under the control of another electrical circuit. It is used to turn on/off high-power devices such as motors, transformers, heaters, bulbs, etc. In many applications the relay is used to switch a contactor in order drive higher output currents. There are various types of relays, but all of them operate in the same way. When current flows through the coil, the relay is operated by an electromagnet to open or close one or more sets of contacts. Similar to optocouplers, there is no galvanic connection (electrical contact) between input and output circuits. Relays usually demand both higher voltage and higher current to start operation, but there are also miniature ones that can be activated by low current directly obtained from a microcontroller pin.

Figure 2.8: Relays

2.8 Contactor

A contactor is a control device that uses a small control current to energize or de-energize the load connected to it. They operate like relays but are capable of switching large electrical loads. Contactors are operated by applying a voltage to the coil of an Electro-magnet, which will cause a switch, (or several switches) to close. The circuit that applies the voltage to the coil is referred to as the **control circuit**, because it controls the main device that the contactor or relay is switching. Figure 2.9 below shows an AC contactor.

Figure 2.9: AC contactor

Contactors come in many forms with varying capacities and features. Unlike a circuit breaker, a contactor is not intended to interrupt a short circuit current. Contactors range from those having a breaking current of several amperes to thousands of amperes and 24 V DC to many kilovolts.

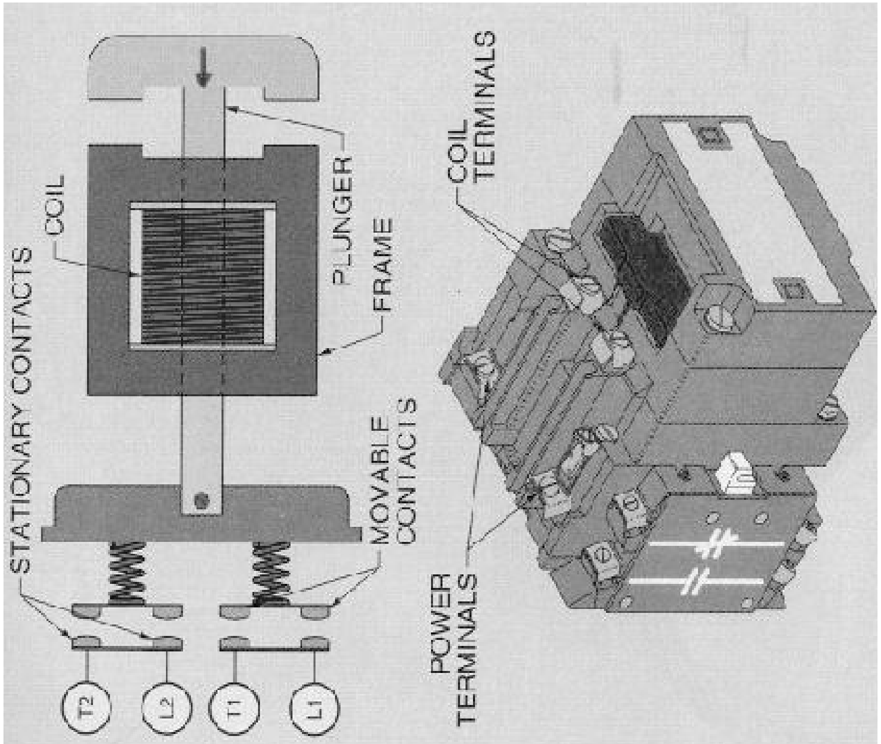


Figure 2.10: Internal mechanism of a contactor

As shown in figure 2.10 a contactor has a frame, plunger, and a solenoid coil. The action of the plunger is used to close (or open) sets of contacts. Contactors do not include overload protection. The closing of the contacts allows electrical devices to be controlled from remote locations.

2.8.0 Contactor Operation

When current passes through the electromagnet, a magnetic field is produced, which attracts the moving core of the contactor. The electromagnet coil draws more current initially, until its inductance increases when the metal core enters the coil. The moving contact is propelled by the moving core; the force developed by the electromagnet holds the moving and fixed contacts together. When the contactor coil is de-energized, gravity or a spring returns the electromagnet core to its initial position and opens the contacts.

Because arcing and consequent damage occurs just as the contacts are opening or closing, contactors are designed to open and close very rapidly; there is often an internal tipping point mechanism to ensure rapid action.

2.9 Step down transformer

A transformer is a static (or stationary) piece of apparatus by means of which electric power in circuit is transformed into electric power of the same frequency in another circuit [32]. They consist of two or more coils of wire coupled together by means of electromagnetic induction. It is based on two principles; firstly, electric current can produce a magnetic field and secondly electromagnetic induction. Current variation in the primary winding changes the magnetic flux that is developed, thereby inducing a voltage in the secondary winding. The primary winding is connected to the power source and the other windings are known as secondary windings, which connected to the load. The behavior of a transformer is strongly affected by the nature of the core upon which the two coils are wound. If the core is made from some non- magnetic material (air), the component is referred to as an air- cored transformer. If the core is made from magnetic materials, the two windings have very much increased magnetic coupling and the component is known as iron-cored transformer. The equation of an ideal transformer is given as:

$$\frac{\square\square}{\square\square} = \frac{\mathrm{Ns}}{\mathrm{Np}}$$

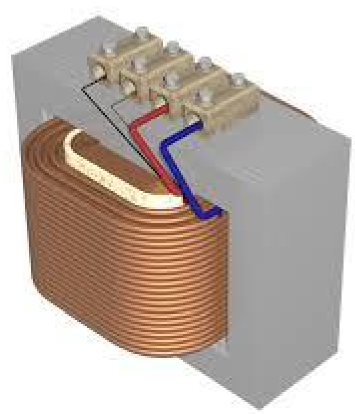


Figure 2.11: Voltage transformer

A step down transformer is designed to reduce electrical voltage. Step down transformers are made from two or more coils of insulated wire wound around a core made of iron. When voltage is applied to primary winding, it magnetizes the iron core, which induces the voltage at secondary winding. The turn's ratio of the two sets of windings determines the amount of voltage transformation. In an ideal transformer, the induced voltage in the secondary winding (V_S) is proportional to the primary voltage (V_P), and is specified by the ratio of the number of turns in the secondary (N_S) to the number of turns in the primary (N_P).

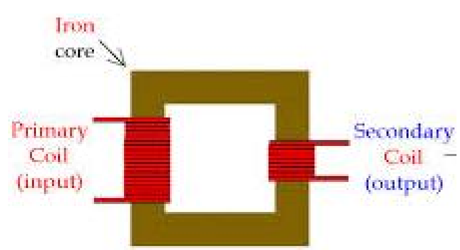


Figure 2.12: Step down transformer

Losses in transformers are generally low and thus efficiency is high. Being static they have a long life and are very stable [33].

CHAPTER THREE

METHODOLOGY

3.0 Introduction

The system design is such that three interconnected power sources: PHCN, solar and generator are constantly monitored with the aim to engage and utilize the preferred power source following preset conditions in the microcontroller. In addition to the microcontroller, the project employs the use of contactors, relays, comparators and overloads devices which are all readily available in the market. The design employs a priority based Automated Switching system using the microcontroller to give preference in the desired order. Shown below is the Priority Table for automatic input selection.

Table 3.1: Automatic Input Selection Priority Table

INPUTS			OUTPUT
PHCN	SOLAR	GENSET	
√	√	√	PHCN
√	√	X	PHCN
√	X	√	PHCN
√	X	X	PHCN
X	√	√	SOLAR
X	√	X	SOLAR
X	X	√	GENSET
X	X	X	NO POWER

The priority order for the system is as shown in Table 3.1, namely: PHCN-SOLAR-GENERATOR. The system is set by default to engage the PHCN line and in the event of failure or abnormal conditions in the PHCN lines, the system will effect a changeover automatically to the solar source provided the output of the solar supply is acceptable, as determined by the comparator circuit, else the system will initiate the starting of the generator and transfer of load to same. The block diagram of the system is as shown in the figures below.

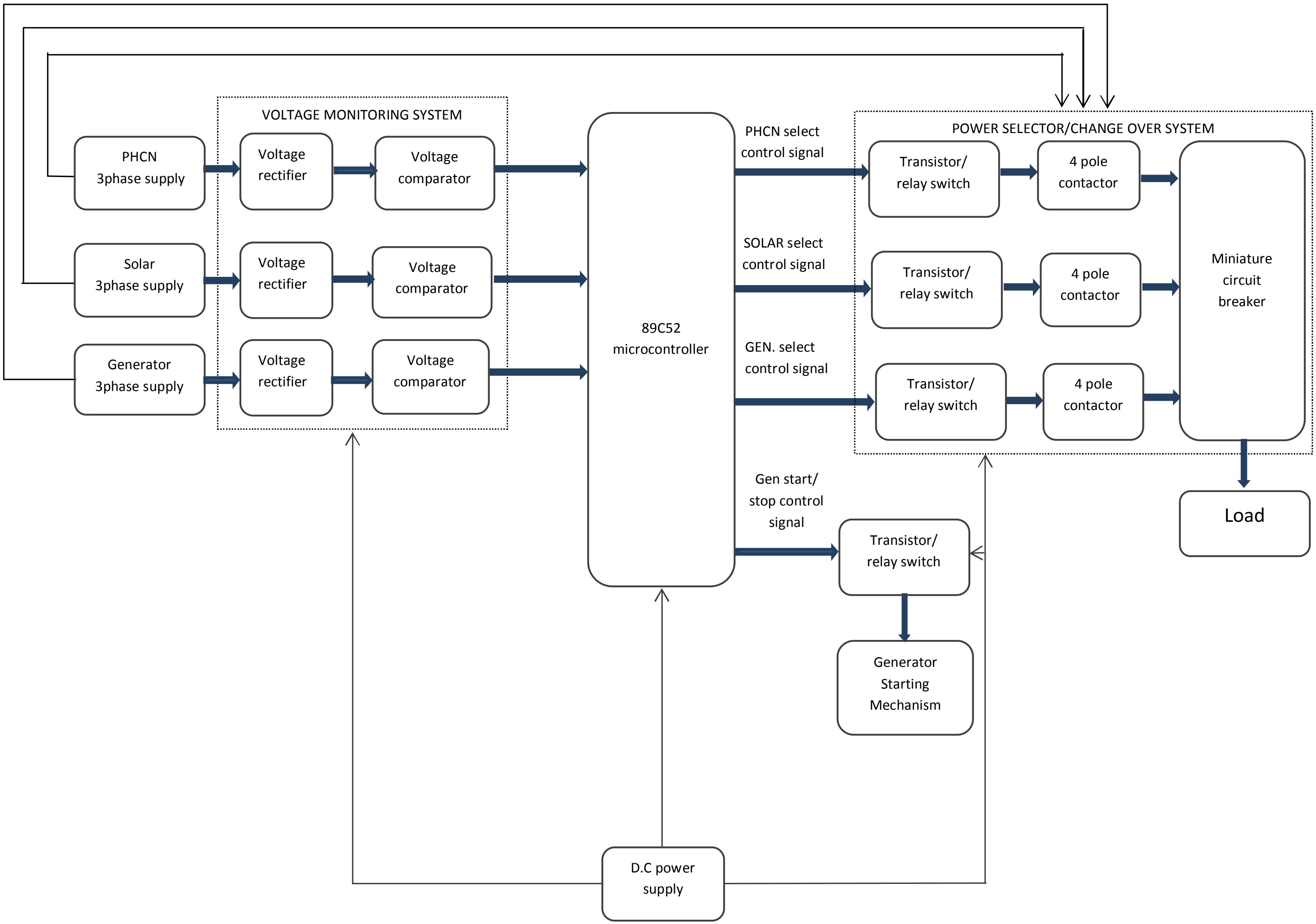


Figure 3.1: System Block Diagram

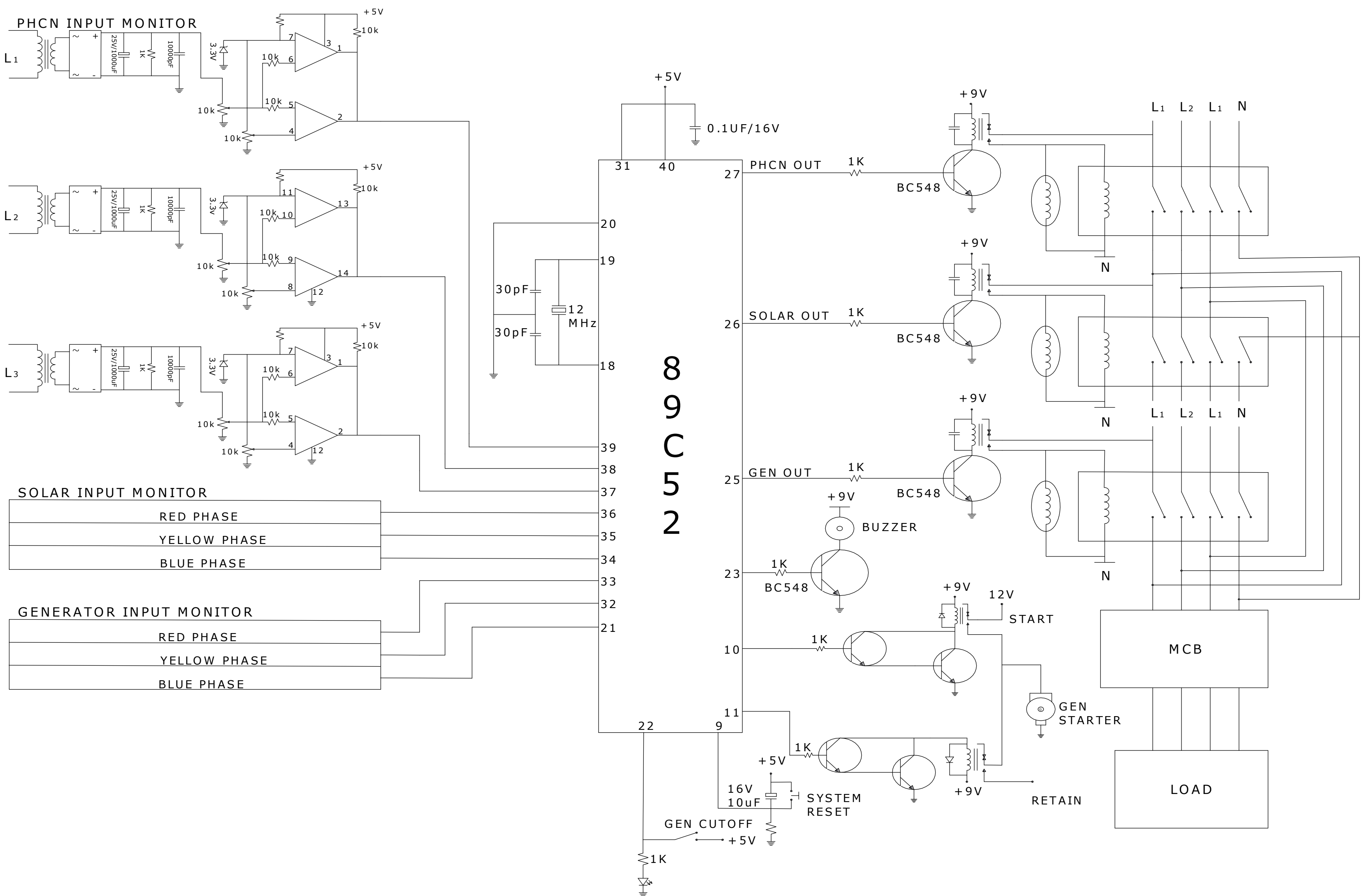


Figure 3.2: System Circuit Diagram

Materials and technical information for this work was gathered from textbooks, data books, the internet as well as staff of experienced companies such as JohnHolt Engineering and Enugu Electricity Distribution Company (EEDC).

3.1 Design Stages: Circuit Simulation

To achieve the design, the circuit was first simulated using **PROTEUS**. PROTEUS is a software for microprocessor simulation, schematic capture and PCB (Printed Circuit Board) design. The simulation of the project was just as important as the hardware implementation. It helped in observing and understanding the function of the key circuits in detail before the hardware implementation. The circuit simulation dealt with observing the response of the different components that make up the design, checking the output of various indicators before implementing into hardware. All the desired functionality was observed to be working using PROTEUS simulation software.

DESIGN SIMULATION WITH PROTEUS

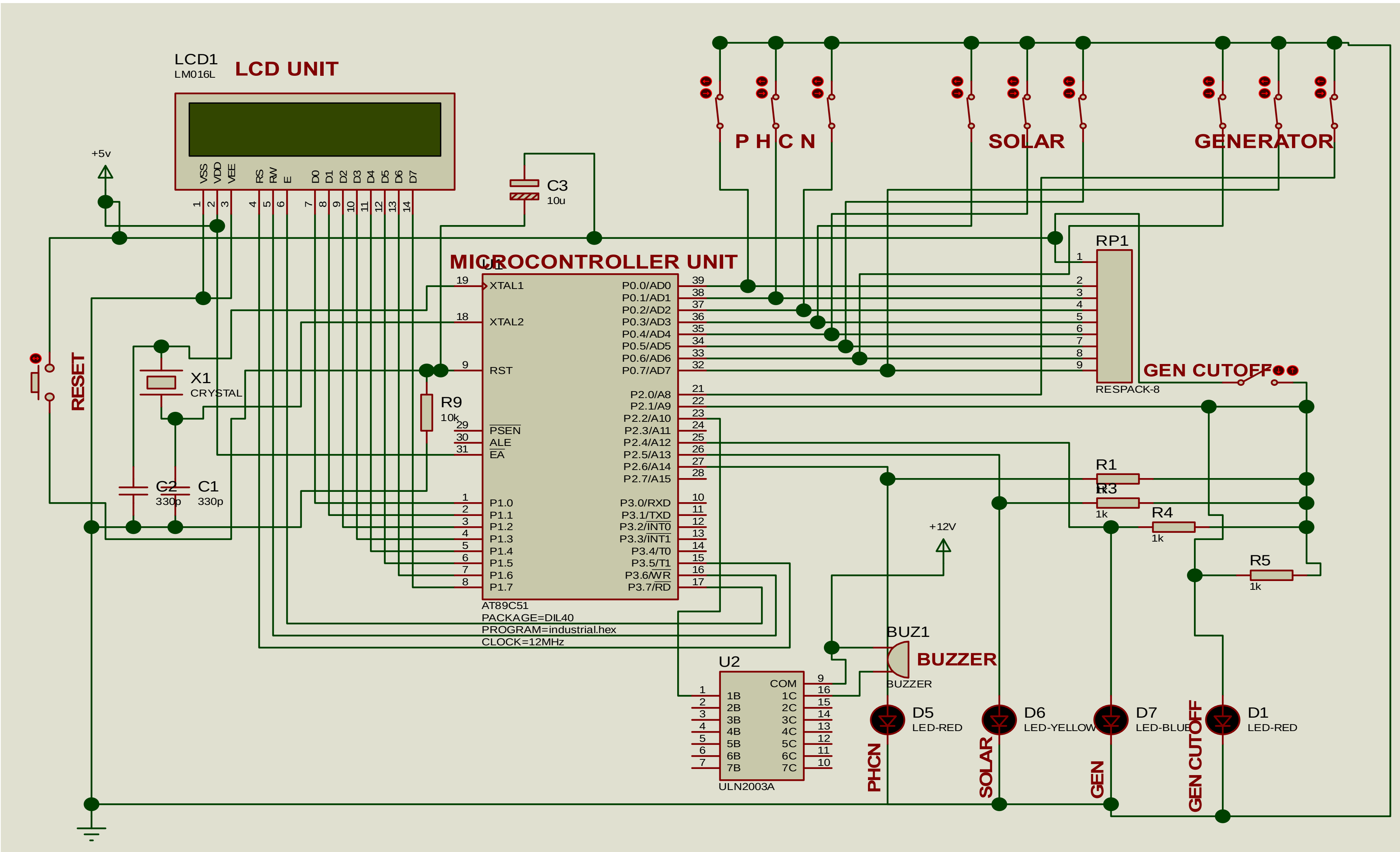


Figure 3.3: Schematic showing simulation of the design using PROTEUS

3.2 Voltage Monitoring

The voltage monitoring system consists of step down transformer, rectifying circuit, filtering and smoothing circuit and voltage detection circuit.

3.2.0 Step down transformer

The first step in the project design is to step down the voltage received from each output line of the three power sources from 220V to 6V using a 6V transformer. The input voltage applied to a transformer is linearly converted to lower suitable voltage in order to protect the components from extreme voltage and ensure that the voltage applied to the voltage detection circuit is in the suitable range. Transformers transform voltages by means of two or more coils of wire coupled together via electromagnetic induction. Current variation in the primary winding changes the magnetic flux that is developed, thereby inducing a voltage in the secondary winding. The primary winding is connected to the power source and the other windings known as secondary windings are connected to the load. After the voltage has been stepped down, it is then fed through rectifiers for rectification.

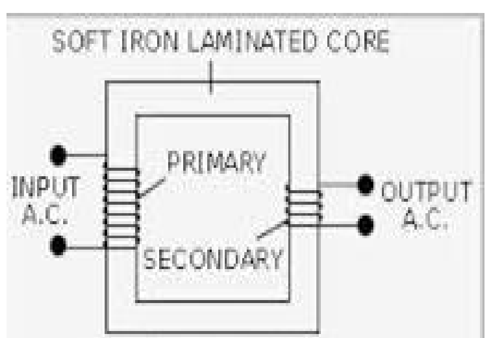


Figure 3.4: Step down transformer

3.2.1 Rectifying circuit

Rectification is the process of converting an alternating (a.c) voltage into one that is limited to one polarity. A rectifier is a circuit which converts the *Alternating Current* (AC) input power into a *Direct Current (*DC) output power [34]. The input power supply may be either a single-phase or a multi-phase supply with the simplest of all the rectifier circuits being that of the **Half Wave Rectifier**. Full-wave rectifiers allow two halves of the dipole peak voltages or currents compared to half-wave ones [35]. Diode is useful for rectification because of its nonlinear characteristics. Current flows for one voltage polarity, and for the opposite polarity the current is essentially zero. Rectification can either be half wave or full wave depending on the number of diodes used. For this project, full wave rectification was used for the efficiency.

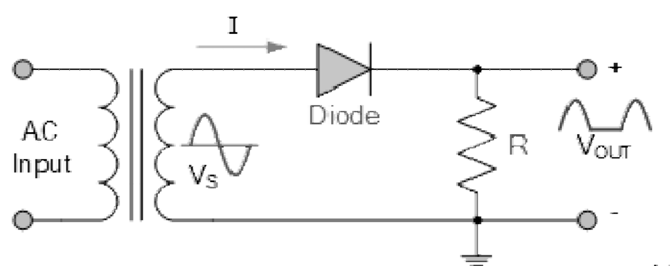


Figure 3.5: Half wave rectifier circuit

Rectified output voltage is given as:

$$V_{d.c.} = \frac{V_{\max}}{\pi} = 0.318V_{\max} = 0.45V_S$$

Where V_{max} is the maximum or peak voltage value of the AC sinusoidal supply, and V_S is the RMS (Root Mean Squared) value of the supply.

The full wave rectifier inverts the negative portions of the sine wave so that a unipolar output signal is generated during both halves of the input sinusoid. For the purpose of this project, a **bridge rectifier** is used to achieve the desired full wave rectification. This type of single phase rectifier uses four individual rectifying diodes connected in a closed loop "bridge" configuration to produce the desired output. The main advantage of this bridge circuit is that it does not require a special centre tapped transformer, thereby reducing its size and cost. The single secondary winding is connected to one side of the diode bridge network and the load to the other side as shown below.

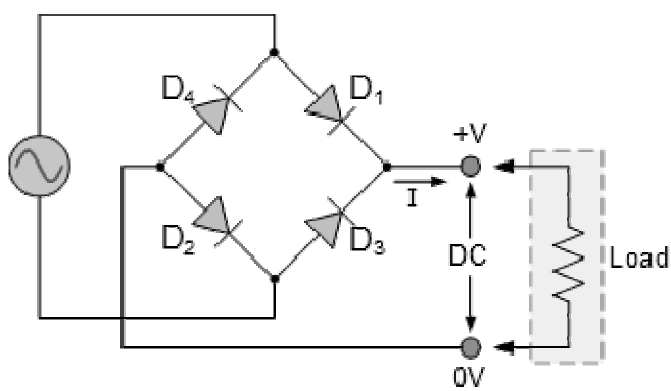


Figure 3.6: Full wave rectifier circuit employing bridge rectifier

The four diodes labelled D_1 to D_4 are arranged in "series pairs" with only two diodes conducting current during each half cycle. During the positive half cycle of the supply, diodes D1 and D2 conduct in series while diodes D3 and D4 are reverse biased. During the negative half cycle of the supply, diodes D3 and D4 conduct in series, but diodes D1 and D2 switch "OFF" as they are now reverse biased. The current flowing through the load is the same direction as before. A key advantage in using the bridge rectifier is that it does not require a transformer with center- tapped secondary winding.

3.2.2 Filtering and smoothing circuit

To make the output of the bridge rectifiers as smooth as possible after the rectification process, an electrolytic capacitor of appropriate capacitance value was added at the output of the bridge rectifier network. A simple filter circuit is constructed by adding an appropriate capacitor parallel with the load resistor of the rectifier. This is to eliminate the ripple effect in the output of the rectifier circuit. The simple principle behind smoothing and filtering as that the capacitor charges to its peak voltage value when the input signal is at its peak value. As the input decreases, the capacitor discharges through the output resistance to fill up the gap created by the dropping voltage. In this design a 25V 1000µF capacitor was used to achieve this as shown in figure 3.7a below.

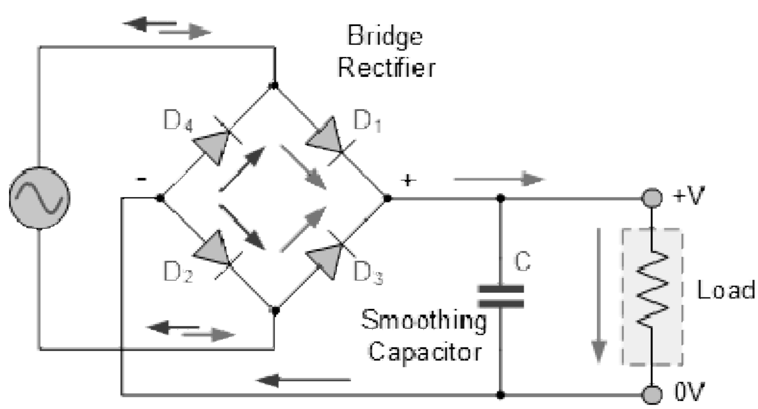


Figure 3.7a: Rectifier with smoothing capacitor

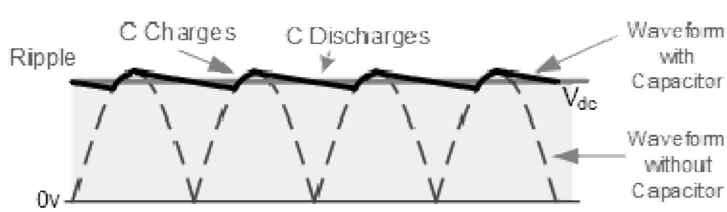


Figure 3.7b: Output waveform of rectifiers with and without smoothing capacitor

The smoothing capacitor converts the full-wave rippled output of the rectifier into a smooth DC output voltage. Generally for DC power supply circuits the smoothing capacitor is an Aluminium Electrolytic type that has a capacitance value of 100µF or more with repeated DC voltage pulses from the rectifier charging up the capacitor to peak voltage. There are two important parameters to consider when choosing a suitable smoothing capacitor and these are its ***working voltage***, which must be higher than the no-load output value of the rectifier and its ***capacitance value***, which determines the amount of ripple that will appear superimposed on top of the DC voltage.

Too low a capacitance value will have little effect on the output waveform. But if the smoothing capacitor is sufficiently large and the load current is not too large, the output voltage will be almost as smooth as pure DC. A general rule is to have a ripple voltage of less than 100mV peak to peak.

The maximum ripple voltage present for a **Full Wave Rectifier** circuit is not only determined by the value of the smoothing capacitor but by the frequency and load current, and is calculated as:

$$V_{ripple} = \frac{I_{load}}{f \times C}$$

Where I is the DC load current in amps, ƒ is the frequency of the ripple or twice the input frequency in Hertz, and C is the capacitance in Farads.

3.2.3 Voltage detection circuit

The main focus of this project lies on the voltage detection circuit. This circuit is to detect three different ranges of voltage which are overvoltage, undervoltage and normal operation. It was suitable to use comparators for this purpose as they are simple to use and affordable. Secondly because the comparator is a nonlinear circuit, it is not necessary to include a compensating capacitor as is the case in a typical op-amp like the 741. The effect of this is an enhanced slew rate (maximum voltage change per unit time) that offers a better time response and gives a superior performance than a typical op- amp. The slew rate for the 741 is 0.5V/microsecond compared to 100V/microsecond for a high-speed op-amp [36].

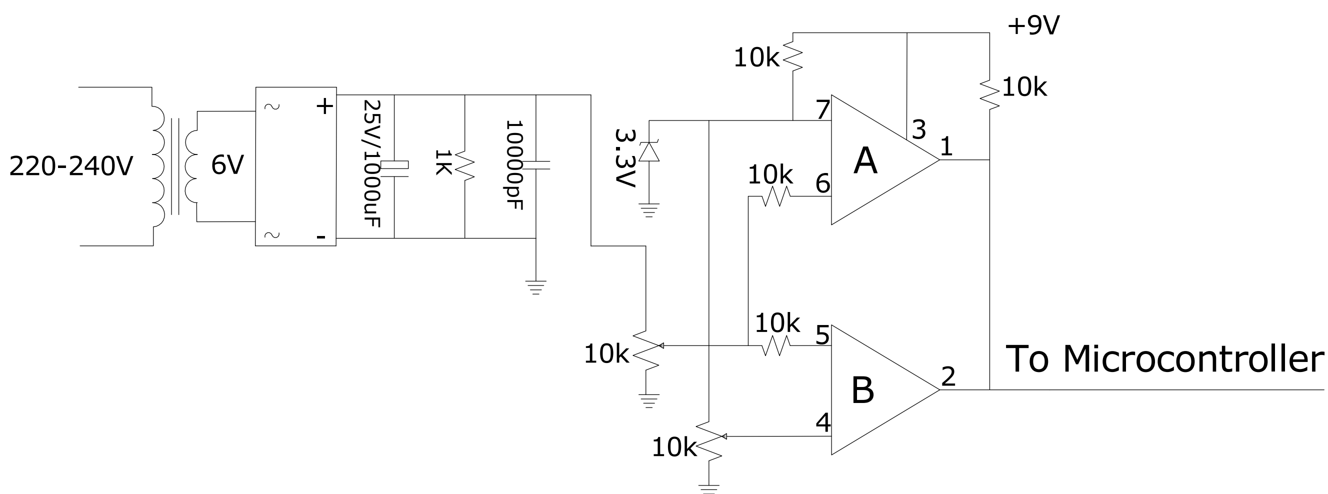


Figure 3.8: Voltage detection circuit using LM339 comparators and variable resistors

Using variable resistors in combination with a zener diode as shown in figure 3.9, two LM339 comparators are biased with the appropriate input and reference voltages in order to monitor the voltage variations on each line of the power sources. The basic operation of the comparator is as follows: When the non-inverting input (+ve input) is more positive than the inverting input (-ve input), the output voltage is high and equal to the V+. In contrast, when the non-inverting input is less than the inverting input, the output voltage is low, approximately in mV. Thus, Comparator A which is set up for inverting operation monitors over voltage while Comparator B monitors under voltage. The output of the comparators for each line is sent to the microcontroller. This is as shown in figure 3.9 below.

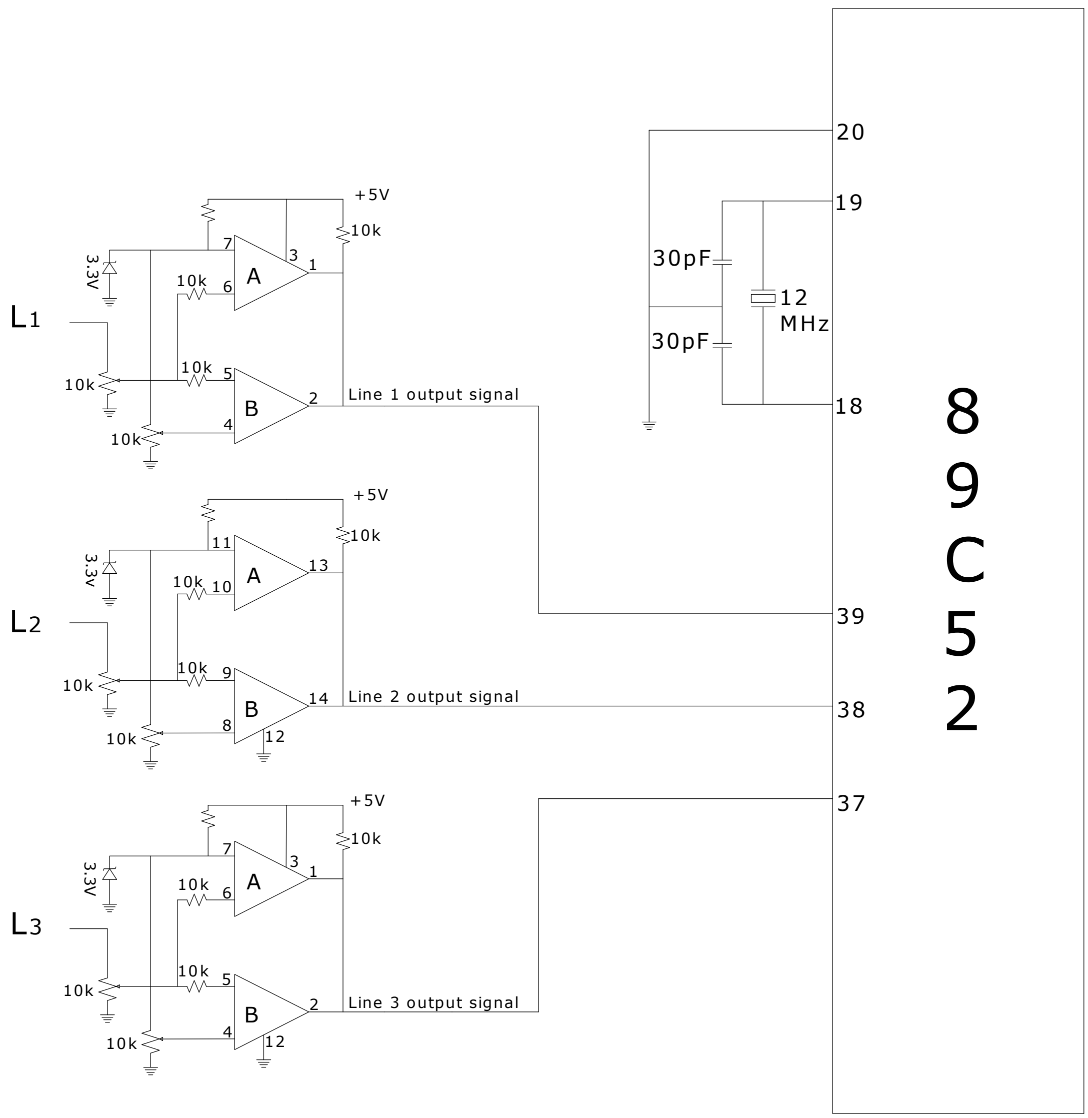


Figure 3.9: Output of LM339 comparators to the microcontroller

Under normal conditions at the output of the power sources, the comparator output will be HIGH, so the microcontroller assumes abnormality anytime it senses a LOW at the output of the comparators.

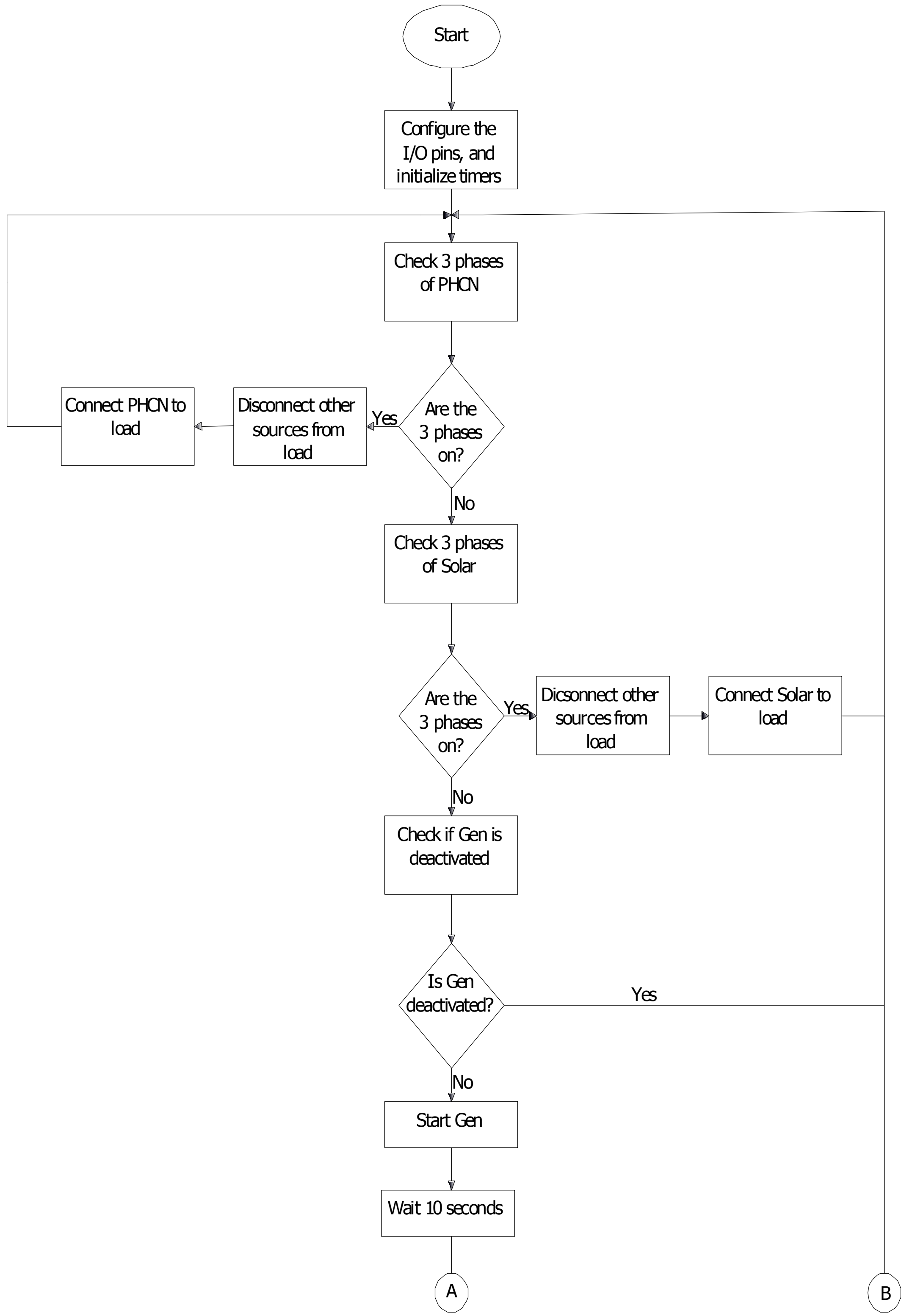
3.3 Realizing the Software

The software program for this project was written with 8051 Assembly language program using the 8051 instruction set. An **Assembly language** program is a series of statements, or lines, which are either assembly language instructions such as ADD and MOV, or statements called derivatives [37]. The **instruction set** of a microcontroller is a set of instructions recognized by the microcontroller. The instruction set of the 8051 microcontroller is shown in appendix B.

The software for this project work was written in modular form. Subroutines were extensively used to achieve most of the desired functionality. Each subroutine served a particular function, for instance the delay subroutine will delay the microcontroller for an interval. The aim achieved through the use of subroutines was that it made the program concise compared to the functionality.

Once the system is powered up the microcontroller configures the port pins. Some pins will be configured as input pins and some as output pins. Port 0 of the microcontroller was used as input port for the output of the comparators monitoring the power sources. Once the microcontroller is done with initializing, it starts sampling the signals from the power sources beginning with the PHCN line. The software code that drives the system is shown in appendix C.

Programme Flowchart



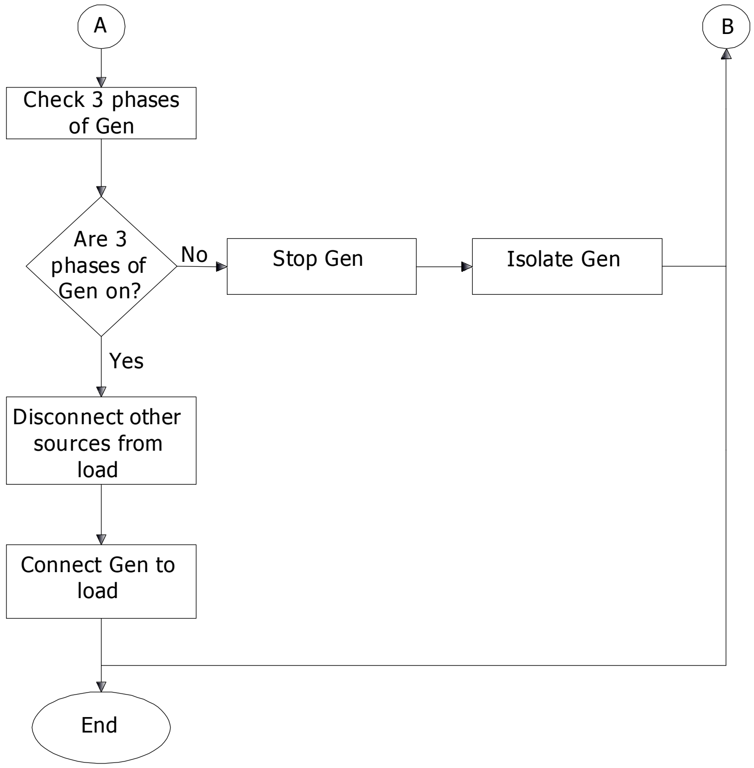


Figure 3.10: Programme Flowchart

3.4 Switching circuit

This is the circuit that does the actual switching of the load from the mains to the secondary power sources and vice-versa. It consists of relays which energize or de-energize contactors depending on the signal received from the control circuit. The coil of the relays are connected to the output of the microcontroller through appropriate transistors. Once there is need to engage a particular power source, the microcontroller will send a pulse to the coil of the necessary relay. This will close the Normally Open (NO) contacts of the relay which in turn will energize the corresponding contactor to engage that line.

In the event of disruption of power or abnormal conditions (under or overvoltage) on the line, the microcontroller will send a LOW pulse that will de-energize the contactor through its relay before it begins to check the other power sources.

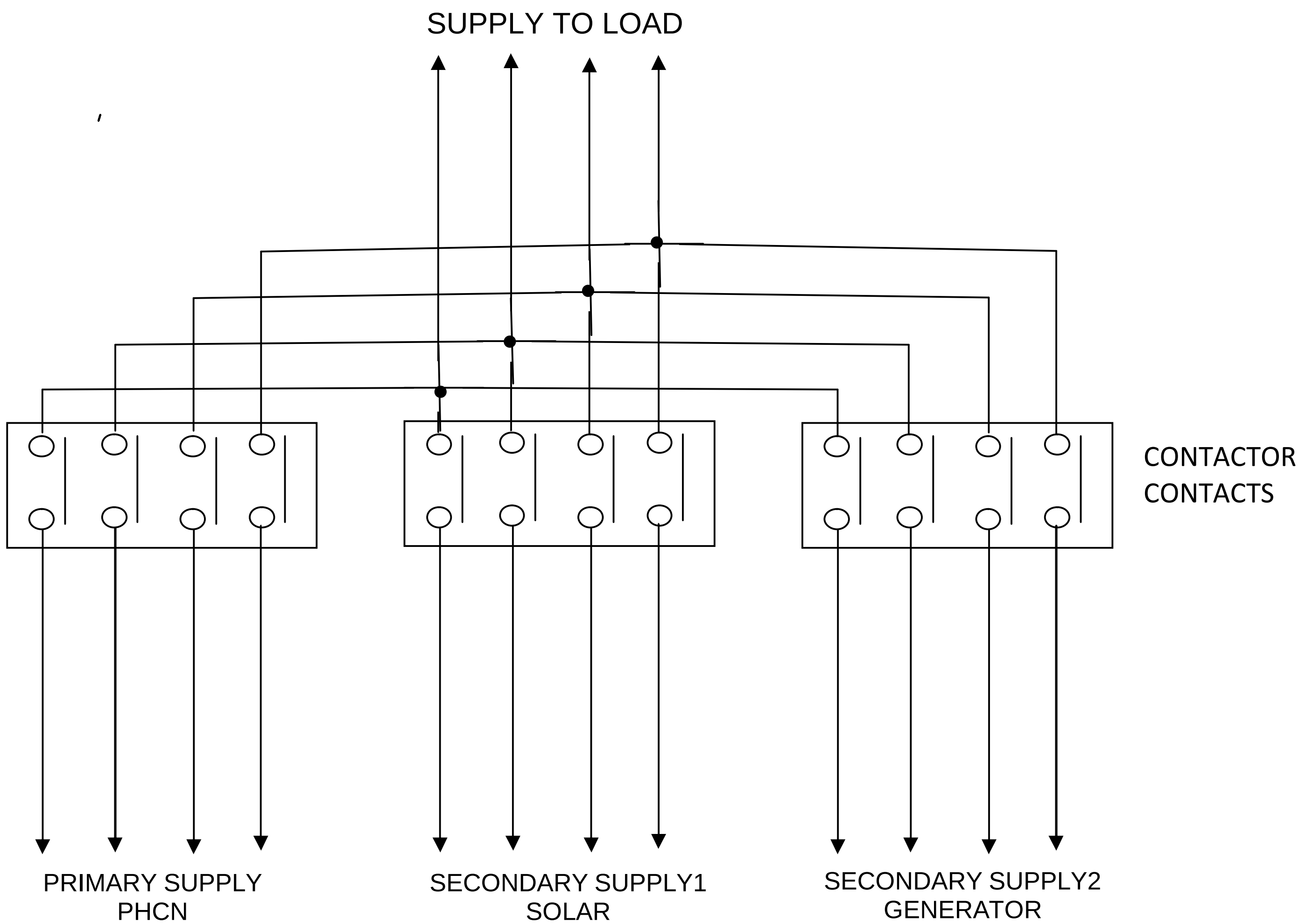


Figure 3.11: Power output diagram of the circuit

CHAPTER FOUR

SYSTEM DESIGN AND IMPLEMENTATION

4.0 Selection Of Components

The system is intended to handle a load of 20KVA.

Therefore using the power equation for a 3 phase supply;

$P = \sqrt{3} VI \cos\Theta$ ……………………………..………………………….. **Equation 4.1**

Where;

V = Line Voltage = 415V

I = Full Load Current

CosΘ = Power Factor = 0.8

P = 20KVA

Therefore full load current,

$$I = \frac{P}{\sqrt{3} V \cos\Theta}$$ ……………………………………………………..…. **Equation 4.2**

Assuming power factor of 0.8

$$I = \frac{20000}{\sqrt{3} \times 415 \times 0.8} = 34.78\text{A}$$

Therefore current capacity of system at full load = 34.78 amps

4.1 Contactor Design

In choosing the contactors the full load current was considered. From calculations the full load current was 34.78 A. Therefore contactors must be rated above 35A. For the purpose of this work, three 40A 4-pole (3 phase) contactors were used, one for each of the three power sources.

4.2 Voltage Monitoring Circuit

LM339 Quad comparator IC was used for voltage monitoring. The design is as described below.

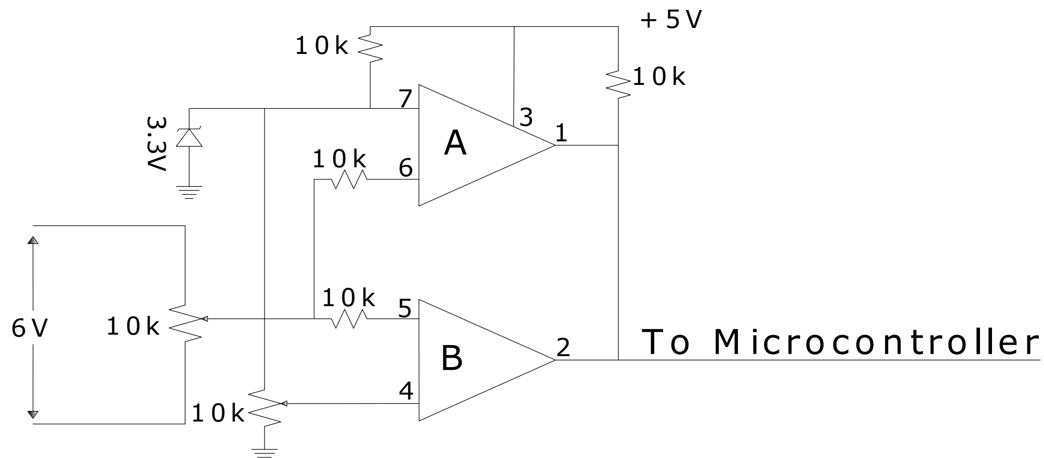
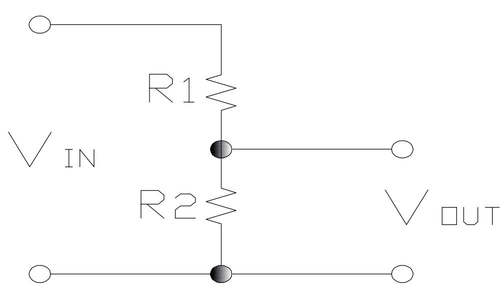


Figure 4.1: Voltage monitoring network

Voltage Divider

The 10k variable resistors in Figure 4.1 function as resistive voltage dividers. A resistive voltage divider is commonly used at the input to a comparator to set threshold voltage [38]. The threshold voltage is set by the ratio of the two resistors in the divider.



$$V_{OUT} = \left(\frac{R_2}{R_1 + R_2}\right) V_{IN} \quad \text{..........Equation 4.3}$$

Figure 4.2: Voltage Divider Circuit

The ratio of R1 to R2 determines V_{OUT}, allowing any voltage within V_{IN} to be obtained.

Using equation 4.3, the values of R1 and R2 for the 10K variable resistor connected to 6V are determined as follows:

$$V_{OUT} = \left(\frac{R2}{R1+R2}\right)V_{IN}$$

We want to apply 3.3V to pins 5 and 6, thus:

$V_{OUT} = 3.3V$

$R1 + R2 = 10k$

$V_{IN} = 6V$

Therefore from equation 4.3,

$$3.3 = \left(\frac{R2}{10K}\right)6$$

:. $R2 = 5.5K$

$R1 = 10 - R2 = 4.5K$

As shown in Figure 4.1, the 6V applied across the 10k variable resistor is the output of each line of the power sources after being stepped down and rectified. This is the voltage to be monitored, thus the 6V represents incoming 240V AC.

The comparators A and B shown are configured as window detectors. While comparator A is used to set the high voltage limit, comparator B is used to set the low voltage limit. When the voltage on the non-inverting input (pins 7 and 5) is greater than that on the inverting input (pins 6 and 4), the output is a High. In contrast, when the voltage on the non-inverting input drops below that on the inverting input, the output goes low.

By connecting a 3.3V zener diode as shown, the reference voltage for comparator A was set at 3.3V. The variable resistor feeding pins 6 and 5 was then adjusted until 3.3V was gotten. The effect is that at 240 V, which is equivalent to 6V across the 10k variable resistor, input pins 6 and 5 will see 3.3V. Therefore, when the voltage exceeds 240V, input to pin 6 will exceed 3.3V which is the reference voltage of comparator A, thus the output will go Low.

Then to set the low voltage limit (185V ac), transformer equation was first applied to get the dc voltage equivalent of 185V:

$$\frac{V_p}{V_s} = \frac{N_p}{N_s} \text{ .... Equation 4.4}$$

Therefore,

$$\frac{240}{6} = \frac{N_p}{N_s} = 40$$

Therefore,

$$\frac{185}{y} = 40; \ \ y = 4.625V$$

Therefore at 185V ac, output voltage = 4.625V dc

By comparison, if 6V ≡ 3.3V

$$\therefore 4.625V \equiv \frac{3.3}{6} \times 4.625 = 2.5V$$

Thus at 185V, which is equivalent to 4.625V, input pins 6 and 5 will see 2.5V. This is the low voltage reference to be applied to pin 4. So using equation 4.3 again, the values of R1 and R2 for the 10K variable resistor connected to 3.3V are determined as follows:

$$V_{OUT} = \left(\frac{R2}{R1 + R2}\right)V_{IN}$$

We want to apply 2.5V to pin 4, thus:

V_{OUT} = 2.5V

R1+ R2= 10k

V_{IN}= 3.3V

Therefore from equation 4.3,

$$2.5 = \left(\frac{R2}{10K}\right)3.3$$

:. R2= 7.6K

R1 = 10-R2= 2.4K

Therefore the 10K variable resistor attached to pin 4 was adjusted to obtain 2.5V, which is the low voltage reference, such that when supply voltage drops below 185V, the voltage at input to pin 5 will drop below 2.5V, thus driving the output of comparator B to a Low state. However, if the supply voltage falls within the required range (185V to 240V ac) both comparator outputs will be high signifying normal voltage supply.

The LM339 comparator has an open collector configuration, therefore the 10K resistor attached to the output is a pullup resistor ensuring that the output is pulled up to +5V that the microcontroller can sense. In this way the microcontroller monitors the output of the power sources.

4.3 Circuit Breaker Design

In order to avoid loading the system beyond its capacity, considering full load current of 34.78 Amps, a 30 Amps 4 pole (3-phase) circuit breaker will be used.

This ensures that the current drawn is kept safely below the full load current capacity of the system.

4.4 Relay Design

Standard SPDT relays rated 6V with high reliability and stable performance were used. The transparent housing of the relays used makes for ease of maintenance through inspection.

4.5 Pilot and Indication Lamps

The pilot and indication lamps work with single phase voltages. Their operating voltage should be the line voltage divided by $\sqrt{3}$:

$$\frac{\text{Line Voltage}}{\sqrt{3}}$$

$$= \frac{415}{\sqrt{3}} \approx 240\text{V}$$

4.6 Conductor Design

The following approximation used sometimes for design of copper conductor is followed:

25mm × 25mm of the conductor handles approximately 1000A of current.

Full load current of system = 34.78 A

Therefore conductor dimension

$$\frac{625\text{mm}^2 \times 34.78\text{A}}{1000\text{A}} = 21.74\text{mm}^2$$

$$r = \sqrt{\frac{A}{\pi}}$$

$$r^2 = \left(\frac{21.74}{\pi}\right) = 6.92$$

$$r = \sqrt{6.92} = 2.63mm$$

Therefore cable diameter $d = 2r = 2 \times 2.63 = 5.23$mm.

This is in order following the American Wire Gauge (AWG) specification shown in appendix D.

4.7 Testing and results

Various tests were carried out to ensure that the system functioned as expected. These include relay and contactor switching test. This was done to be sure the relays and contactors switch with the signal from the microcontroller. The generator start/stop function was also tested and confirmed to be working well. Also the voltage variation test was done to be sure that when the output voltage is within permissible limit which is between 185V and 241V, the system sees a normal voltage and sends the appropriate signal, and in the event of power disruption, overvoltage and undervoltage, the system sees an abnormal voltage and also sends the right signal. The delay was also observed to be working properly. The tests carried out are summarized below:

- **Continuity of conductors**: this test was conducted to ensure that the control conductors used for the wiring had no break in them.

- **Continuity of normally closed contacts**: the normally closed contacts gave continuous reading when tested to indicate a closed contact. When manually operated a discontinuous reading was attained to indicate opened contact.
- **Continuity of protective devices**: all the protective devices where tested by closing the contacts and using continuity tester to test for continuity. When the protective devices such as the three phase line controller were closed, the instrument gave a continuous signal indicating closed contacts, meaning the electrical device is in good working condition.
- **Operation of contactors, relays, timers, protective devices and interlocks**: the contactors, relays and the timers were energized to observe their opening and breaking operation. They were found to be in good working condition.
- **Polarity checks**: this was done to ensure that live and neutral polarity was connected to the respective terminal block to prevent electrical hazards.
- **Protection by electrical separation**: this test was carried out by isolating the breakers/switches and then tested to observe if there were leakages.

All the components were found to be in good working condition and the control system performed satisfactorily.

4.8 Cost Analysis

Description	Quantity	Unit Price (NAIRA)	Total (NAIRA)
4 Pole 40 Amps contactor :Telemecanique	3	2,000.00	6,000.00
4 Pole 40 Amps miniature circuit breaker	1	2,500.00	2,500.00
Pilot lamps	3	500.00	1,500.00
Indicator Lamps	9	100.00	900.00
Reset switch	1	500.00	500.00
On-Off switch	1	500.00	500.00
Push button switch	1	100.00	100.00
6V/300ma step down transformer	9	200.00	1,800.00
12V D.C fan	1	250.00	250.00
Big Light Emitting Diode	2	20.00	40.00
Liquid Crystal Display	1	800.00	800.00
12V/1000ma power pack	1	1,000.00	1,000.00
6V D.C rechargeable batteries	2	600.00	1,200.00
6V D.C relay	5	60.00	300.00
6V buzzer	1	100.00	100.00
Casing	1	5,500.00	5,500.00
Painting for casing	-	-	1,000.00
BC548 transistor	4	20.00	80.00
D438 transistor	2	50.00	100.00
C828 transistor	2	20.00	40.00
IN4001 rectifier diode	2	10.00	20.00
Block diodes	9	20.00	180.00
LM339	6	60.00	360.00
74LS132	3	150.00	450.00
89C52 microcontroller	1	350.00	350.00
7805 voltage regulator	2	30.00	60.00
7809 voltage regulator	2	30.00	60.00
3.3v zener diode	9	20.00	180.00
8.2KΩ, 1/4W resistor	1	5.00	5.00
1KΩ, 1/4W resistor	32	5.00	160.00
10k potentiometer	18	20.00	360.00
10kΩ, 1/4W resistor	12	5.00	60.00
220Ω, 1/2W resistor	2	5.00	10.00
330Ω, 1/2W resistor	9	5.00	45.00
25V/1000uf electrolytic capacitor	10	20.00	200.00
30pf ceramic capacitor	2	5.00	10.00
16V/10uf electrolytic capacitor	3	10.00	30.00

10000pf ceramic capacitor	9	5.00	45.00
14pin DIL IC socket	9	15.00	135.00
40 pin DIL IC socket	1	40.00	40.00
Big dotted vero board	3	120.00	360.00
Connecting cables (assorted types)		1,500.00	1,500.00
Roll of soldering lead	1	500.00	500.00
Miscellaneous		4,000.00	4,000.00
Labour		6,000.00	6,000.00
Total			**39, 330.00**

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.0 Conclusion

This project provides a means of cushioning the consequences of unreliable power supply that pervade developing societies like Nigeria by offering a cost effective way of using multitier power supplies. Owing to the fact that modern industrial systems depend on regular supply of electricity, and quality of life as well as standard of living today depend much on electricity, this project is very relevant in our society today.

5.1 Recommendation

This device is recommended for use in homes, industries and facilities where power supply from the grid is unreliable, and uninterrupted 3 phase power supply is essential. Further, based on the experience gathered in the course of the design, the following recommendations are suggested**:**

1. The machine should be made more robust, efficient and exportable by using PCB (Printed Circuit Board) technology to develop the electronics control board.
2. As an improvement the system can include a computer interface that will link it to a Wide Area Network to facilitate advanced features like data logging and remote sensing.

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Appendix A: Existing Power Stations in Nigeria

Existing Plants	**Types**	**Capacity**	**Status**	**Year Commissioned**
AES Barge	Gas	270 MW	Operational	2001
Aba Power Station	Gas	140 MW	Taking off (1 quarter 2013)	2012
Afam IV-V	Gas	726 MW	Partially Operational	1982 (Afam IV)- 2002 (Afam V)
Afam VI	Gas	624 MW	Operational	2009 (Gas turbines) 2010 (Steam turbines)
Alaoji Power Station	Gas	1074 MW	Partially operational (225MW)	2012 - 2015
Calabar Power Station	Gas	561 MW	Under Construction	2014
Egbeme Power Station	Gas	338 MW	Under Construction	2012-2013
Egbin Thermal Power Station	Gas	1320 MW	Partially operational (994 MW)	1985-1986
Geregu I Power Station	Gas	414 MW	Unknown	2007
Geregu II Power Station	Gas	434 MW	Taking off (I quarter 2013)	2012
Ibom Power Station	Gas	190 MW	Partially Operational (60MW)	2009
Ihovbor Power Station	Gas	450 MW	Under Construction	2012-2013
Okpai Power Station	Gas	480 MW	Operational	2005
Olorunsogo Power Station	Gas	336 MW	Partially Operational	2007
Olorunsogo II Power Station	Gas	675 MW	Partially Operational	2012

Table 2 continued

Existing Plants	Types	Capacity	Status	Year Commissioned
Omoku Power Station	Gas	150 MW	Operational	2005
Omoku II Power Station	Gas	225 MW	Under Construction	2013
Omotosho I Power Station	Gas	336 MW	Operational	2005
Omotosho II Power Station	Gas	450 MW	Operational fully by NDPHC . The Nation Partially operational (375MW) By China Machinery Engineering Corporation:BusinessDay.	2012
Sapele Power Station	Gas	1020 MW	Partially Operational (135 MW)	1978 - 1981
Delta - Ughelli Power Station	Gas	900 MW	Partially Operational (360 MW)	1966-1990
Itobe Power Plant	Coal	1200 MW	Planned	2015-2018 (first phase 600 MW
Kainji Power Station	Hydroelectric	800 MW	In service	1968
Shiroro Power Station	Hydroelectric	600 MW	In service	1990
Jebba Power Station	Hydroelectric	540 MW	In service	1985
Zamfara Power Station	Hydroelectric	100 MW	In service	2012
Total Capacity		**14353 MW**		

Under Construction or Proposed

Plants	Type	Capacity	Year of completion
Kano Power Station	Hydroelectric	100 MW	2015
Kiri Power Station	Hydroelectric	35 MW	2016
Zamfara Power Station	Hydroelectric	100 MW	2012
Mambilla Power Station	Hydroelectric	3050 MW	2018
Total Capacity		**3285 MW**	

Source: [39]

Appendix B: 8051 Instruction Set

Arithmetic Operations

Mnemonic	Description	Bytes	Cycles
ADD A,Rn	Add register to A	1	1
ADD A,direct	Add direct byte to A	2	1
ADD A,@Ri	Add indirect RAM to A	1	1
ADD A,#data	Add immediate data to A	2	1
ADDC A,Rn	Add register to A with Carry	1	1
ADDC A,direct	Add direct byte to A with Carry	2	1
ADDC A,@Ri	Add indirect RAM to A with Carry	1	1
ADDC A,#data	Add immediate data to A with Carry	2	1
SUBB A,Rn	Subtract register from A with Borrow	1	1
SUBB A,direct	Subtract direct byte from A with Borrow	2	1
SUBB A,@Ri	Subtract indirect RAM from A with Borrow	1	1
SUBB A,#data	Subtract immediate data from A with Borrow	2	1
INC A	Increment A	1	1
INC Rn	Increment register	1	1
INC direct	Increment direct byte	2	1
INC @Ri	Increment indirect RAM	1	1
DEC A	Decrement A	1	1
DEC Rn	Decrement register	1	1
DEC direct	Decrement direct byte	2	1
DEC @Ri	Decrement indirect RAM	1	1
INC DPTR	Increment Data Pointer	1	2
MUL AB	Multiply A and B (A x B => BA)	1	4
DIV AB	Divide A by B (A/B => A + B)	1	4
DA A	Decimal Adjust A	1	1

Logical Operations

Mnemonic	Description	Bytes	Cycles
ANL A,Rn	AND register to A	1	1
ANL A,direct	AND direct byte to A	2	1
ANL A,@Ri	AND indirect RAM to A	1	1
ANL A,#data	AND immediate data to A	2	1
ANL direct,A	AND A to direct byte	2	1
ANL direct,#data	AND immediate data to direct byte	3	2
ORL A,Rn	OR register to A	1	1
ORL A,direct	OR direct byte to A	2	1
ORL A,@Ri	OR indirect RAM to A	1	1
ORL A,#data	OR immediate data to A	2	1
ORL direct,A	OR A to direct byte	2	1
ORL direct,#data	OR immediate data to direct byte	3	2
XRL A,Rn	Exclusive-OR register to A	1	1
XRL A,direct	Exclusive-OR direct byte to A	2	1
XRL A,@Ri	Exclusive-OR indirect RAM to A	1	1
XRL A,#data	Exclusive-OR immediate data to A	2	1
XRL direct,A	Exclusive-OR A to direct byte	2	1
XRL direct,#data	Exclusive-OR immediate data to direct byte	3	2
CLR A	Clear A	1	1
CPL A	Complement A	1	1
RL A	Rotate A Left	1	1
RLC A	Rotate A Left through Carry	1	1
RR A	Rotate A Right	1	1
RRC A	Rotate A Right through Carry	1	1
SWAP A	Swap nibbles within A	1	1

Data Transfer Operations

Mnemonic	Description	Bytes	Cycles
MOV A,Rn	Move register to A	1	1
MOV A,direct	Move direct byte to A	2	1
MOV A,@Ri	Move indirect RAM to A	1	1
MOV A,#data	Move immediate data to A	2	1
MOV Rn,A	Move A to register	1	1
MOV Rn,direct	Move direct byte to register	2	2
MOV Rn,#data	Move immediate data to register	2	1
MOV direct,A	Move A to direct byte	2	1
MOV direct,Rn	Move register to direct byte	2	2
MOV direct,direct	Move direct byte to direct byte	3	2
MOV direct,@Ri	Move indirect RAM to direct byte	2	2
MOV direct,#data	Move immediate data to direct byte	3	2
MOV @Ri,A	Move A to indirect RAM	1	1
MOV @Ri,direct	Move direct byte to indirect RAM	2	2
MOV @Ri,#data	Move immediate data to indirect RAM	2	1
MOV DPTR,#data16	Load Data Pointer with 16-bit constant	2	1
MOVC A,@A+DPTR	Move Code byte relative to DPTR to A	1	2
MOVC A,@A+PC	Move Code byte relative to PC to A	1	2
MOVX A,@Ri	Move External RAM (8-bit addr) to A	1	2
MOVX A,@DPTR	Move External RAM (16-bit addr) to A	1	2
MOVX @Ri,A	Move A to External RAM (8-bit addr)	1	2
MOVX @DPTR,A	Move A to External RAM (16-bit addr)	1	2
PUSH direct	Push direct byte onto stack	2	2
POP direct	Pop direct byte from stack	2	2
XCH A,Rn	Exchange register with A	1	1
XCH A,direct	Exchange direct byte with A	2	1
XCH A,@Ri	Exchange indirect RAM with A	1	1
XCHD A,@Ri	Exchange low-order Digit indirect RAM with A	1	1

Single Bit (Boolean Variable) Operations

Mnemonic	Description	Bytes	Cycles
CLR C	Clear Carry flag	1	1
CLR bit	Clear direct bit	2	1
SETB C	Set Carry flag	1	1
SETB bit	Set direct bit	2	1
CPL C	Complement Carry flag	1	1
CPL bit	Complement direct bit	2	1
ANL C,bit	AND direct bit to Carry flag	2	2
ANL C,/bit	AND complement of direct bit to Carry flag	2	2
ORL C,bit	OR direct bit to Carry flag	2	2
ORL C,/bit	OR complement of direct bit to Carry flag	2	2
MOV C,bit	Move direct bit to Carry flag	2	1
MOV bit,C	Move Carry flag to direct bit	2	2

Program Flow Control

Mnemonic	Description	Bytes	Cycles
ACALL addr11	Absolute subroutine call	2	2
LCALL addr16	Long subroutine call	3	2
RET	Return from subroutine	1	2
RETI	Return from interrupt	1	2
AJMP addr11	Absolute Jump	2	2
LJMP addr16	Long Jump	3	2
SJMP rel	Short Jump at relative address	2	2
JMP @A+DPTR	Jump indirect relative to DPTR	1	2
JZ rel	Jump if A is Zero	2	2
JNZ rel	Jump if A is Not Zero	2	2
JC rel	Jump if Carry flag is set	2	2
JNC rel	Jump if No Carry flag	2	2
JB bit,rel	Jump if direct Bit is set	3	2
JNB bit,rel	Jump if direct Bit is Not set	3	2
JBC bit,rel	Jump if direct Bit is set and Clear bit	3	2

CJNE A,direct,rel	Compare direct to A and Jump if Not Equal	3	2
CJNE A,#data,rel	Compare immediate to A and Jump if Not Equal	3	2
CJNE Rn,#data,rel	Compare immediate to register and Jump if Not Equal	3	2
CJNE @Ri,#data,rel	Compare immediate to indirect and Jump if Not Equal	3	2
DJNZ Rn,rel	Decrement register and Jump if Not Zero	2	2
DJNZ direct,rel	Decrement direct byte and Jump if Not Zero	3	2
NOP	No operation	1	1

Appendix C: System Firmware

```
ORG 0000H

SENSOR1_OUT BIT P2.6

SENSOR2_OUT BIT P2.5

SENSOR3_OUT BIT P2.4

IGNITIONA BIT P3.0

IGNITIONB BIT P3.1

IGNITION_CONTROL BIT P2.1

BUZZER BIT P2.2

SENSOR1A BIT P0.0

SENSOR1B BIT P0.1

SENSOR1C BIT P0.2

SENSOR2A BIT P0.3

SENSOR2B BIT P0.4

SENSOR2C BIT P0.5

SENSOR3A BIT P0.6

SENSOR3B BIT P0.7

SENSOR3C BIT P2.0

LCD EQU P1

EN BIT P3.7

RW BIT P3.6

RS BIT P3.5

MOV R4,#00H

AJMP MAIN
```

```
INTCODE:DB 038H,00EH,001H,006H,081H,0

WRTOVER: DB 081H,0

LINE2: DB 0C1H,0

LCD_WRT: CLR A

MOVC A,@A+DPTR

MOV LCD,A

SETB RS

CLR RW

SETB EN

NOP

CLR EN

ACALL DELAY

INC DPTR

JZ CMD

SJMP LCD_WRT

CMD:RET


LCD_CMD: CLR A

MOVC A,@A+DPTR

MOV LCD,A

CLR RS

CLR RW

SETB EN

NOP
```

```
CLR EN
ACALL DELAY
INC DPTR
JZ CMD1
SJMP LCD_CMD
CMD1:RET

MAIN: MOV P0,#0FFH
    MOV P1,#0FFH
    MOV P2,#00H
    MOV P3,#00H
    SETB P3.0
    SETB P3.1
    clr ignitiona
    clr ignitionb
    clr sensor3_out
    CLR IGNITION_CONTROL
    SETB P2.0
CLR SENSOR1_OUT
CLR SENSOR2_OUT
CLR SENSOR3_OUT
START: MOV DPTR,#INTCODE
ACALL LCD_CMD
MOV DPTR,#INTCODE
```

```
ACALL LCD_CMD
MOV DPTR,#TABLE1
ACALL LCD_WRT
ACALL WAST_TIME2
MOV DPTR,#WRTOVER
ACALL LCD_CMD
MOV DPTR,#CHECKING_OUT
ACALL LCD_WRT
ACALL WAST_TIME
BEGIN1:CLR SENSOR1_OUT
clr ignitiona
clr ignitionb
clr sensor3_out
SENSOR1:
JB SENSOR1A,sensor2
se1: JB SENSOR1B, sensor2
se2: JB SENSOR1C,SENSOR2
CLR SENSOR2_OUT
CLR SENSOR3_OUT
SETB SENSOR1_OUT
CLR IGNITIONA
CLR IGNITIONB
MOV DPTR,#WRTOVER
ACALL LCD_CMD
```

```
MOV DPTR,#STRING1

ACALL LCD_WRT

MOV DPTR,#LINE2

ACALL LCD_CMD

MOV DPTR,#STRING1B

ACALL LCD_WRT

BLOOP:MOV R3,P0

JB SENSOR1A,SENSOR2

JB SENSOR1B, SENSOR2

JB SENSOR1C,SENSOR2

    CJNE R3,#00011111B,B1

B1:   CJNE R3,#00000011B,B2

B2:   CJNE R3,#00H,BEGIN1

B3:   SJMP BLOOP


SEC30:ACALL WAST_TIME2

ACALL WAST_TIME2

ACALL WAST_TIME2

AJMP SENSOR1


BEGIN2: CLR SENSOR2_OUT

SENSOR2:JNB SENSOR1A,SEC30

     JNB SENSOR1B,SEC30

     JNB SENSOR1C,SEC30
```

```
 s20:   JB SENSOR2A,route
 s21:   JB SENSOR2B,route
 s22:   JB SENSOR2C,route
        CLR IGNITIONA
        CLR IGNITIONB
        CLR SENSOR3_OUT
        CLR SENSOR1_OUT
        SETB SENSOR2_OUT
        MOV DPTR,#WRTOVER
        ACALL LCD_CMD
MOV DPTR,#STRING2
ACALL LCD_WRT
MOV R3,#0FFH
BLOOP2:JNB SENSOR1A,SEC30
       JNB SENSOR1B,SEC30
       JNB SENSOR1C,SEC30
       MOV R3,P0
       CJNE R3,#11100011B,B12
B12:   CJNE R3,#11100000B,BEGIN2
       SJMP BLOOP2
amen:     ajmp resd

ROUTE:
DIS: MOV DPTR,#WRTOVER
```

```
ACALL LCD_CMD
MOV DPTR,#STRING5
ACALL LCD_WRT
   MOV DPTR,#LINE2
ACALL LCD_CMD
MOV DPTR,#STRING5B
ACALL LCD_WRT
jb ignition_control,amen
ok:
    setb IGNITIONA
    setb IGNITIONB
    acall wast_time
    acall wast_time
     CLR IGNITIONA
     INC R4
     JNB SENSOR3A,SENSOR3
     JNB SENSOR3B,SENSOR3
     JNB SENSOR3C,SENSOR3
CO1:  ACALL WAST_TIME2
     CJNE R4,#3h,ok
     MOV R4,#00
     AJMP resd

sec30x: ajmp sec30
```

```
SENSOR3: JB IGNITION_CONTROL,MON1
        JNB SENSOR2A,SEC31
        JNB SENSOR2B,SEC31
        JNB SENSOR2C,SEC31
        JNB SENSOR1A,SEC30x
        JNB SENSOR1B,SEC30x
        JNB SENSOR1C,SEC30x
        JB SENSOR3A,COMPLETE
        JB SENSOR3B, COMPLETE
        JB SENSOR3C,COMPLETE
        CLR SENSOR2_OUT
        CLR SENSOR1_OUT
        SETB SENSOR3_OUT
        MOV DPTR,#intcode
ACALL LCD_CMD
MOV DPTR,#STRING3
ACALL LCD_WRT
MOV DPTR,#LINE2
ACALL LCD_CMD
MOV DPTR,#STRING1B
ACALL LCD_WRT
        ACALL WAST_TIME
        CLR IGNITIONA
MON1:JB IGNITION_CONTROL,SWG
```

```
        JNB SENSOR2A,SEC31
        JNB SENSOR2B,SEC31
        JNB SENSOR2C,SEC31
        JNB SENSOR1A,SEC30x
        JNB SENSOR1B,SEC30x
        JNB SENSOR1C,SEC30x
        JB SENSOR3A,COMPLETE
        JB SENSOR3B, COMPLETE
        JB SENSOR3C,COMPLETE
        SJMP MON1
SWG:
CLR SENSOR3_OUT
CLR IGNITIONA
AJMP SENSOR1
COMPLETE:CLR SENSOR3_OUT
        JNB SENSOR1_OUT,RESD
        JNB SENSOR2_OUT,RESD
        JNB SENSOR3_OUT,RESD
RETURN:  AJMP SENSOR1
SEC31:ACALL WAST_TIME2
ACALL WAST_TIME2
ACALL WAST_TIME2
AJMP SENSOR2
RESD: MOV DPTR,#intcode
```

```
ACALL LCD_CMD
MOV DPTR,#STRING4
ACALL LCD_WRT
SJMP ALARM

ALARM:MOV R3,P0
clr sensor3_out
clr ignitiona
clr ignitionb
return1:
ACALL BUZZER_OUT
mov r3,p0
cjne r3,#0ffh,next3
ajmp  alarm
next3: AJMP sensor1

; SUB ROUTINGS COUNTS
WAST_TIME: MOV R7,#00
HERE: INC R7
ACALL DELAY
CJNE R7,#60,HERE
MOV R7,#00
RET
```

```
WAST_TIME2: MOV R7,#00

HERE2: INC R7

ACALL DELAY

CJNE R7,#200,HERE2

MOV R7,#00

RET


DELAY: MOV R0,#255

       MOV R1,#10

       MOV R2,#1

LOOP: DJNZ R0,LOOP

   DJNZ R1,LOOP

DJNZ R2,LOOP

RET


TABLE1: DB 'WELCOME',0

CHECKING_OUT: DB 'SCANING BUTTON',0

BUZZER_OUT: jb ignition_control,rest

SETB BUZZER

ACALL WAST_TIME2

CLR BUZZER

ACALL WAST_TIME2

rest: RET
```

```
STRING1: DB 'PUBLIC POWER ',0

STRING1B:DB 'SUPPLY',0

STRING2: DB 'SOLAR POWER     ',0

STRING3: DB ' GENERATOR ......',0

STRING4: DB 'LOSS OF POWER',0

STRING5: DB 'BACKUP GEN   ',0

STRING5B: DB '  LOADING  ',0


          END
```

Appendix D: American Wire Gauge (AWG) Sizes and Current Limits

AWG	**Diameter** [inches]	**Diameter** [mm]	**Area** [mm^2]	**Resistance** [Ohms / 1000 ft]	**Resistance** [Ohms / km]	**Max Current** [Amperes]	**Max Frequency** for 100% skin depth
0000 (4/0)	0.46	11.684	107	0.049	0.16072	302	125 Hz
000 (3/0)	0.4096	10.40384	85	0.0618	0.202704	239	160 Hz
00 (2/0)	0.3648	9.26592	67.4	0.0779	0.255512	190	200 Hz
0 (1/0)	0.3249	8.25246	53.5	0.0983	0.322424	150	250 Hz
1	0.2893	7.34822	42.4	0.1239	0.406392	119	325 Hz
2	0.2576	6.54304	33.6	0.1563	0.512664	94	410 Hz
3	0.2294	5.82676	26.7	0.197	0.64616	75	500 Hz
4	0.2043	5.18922	21.2	0.2485	0.81508	60	650 Hz
5	0.1819	4.62026	16.8	0.3133	1.027624	47	810 Hz
6	0.162	4.1148	13.3	0.3951	1.295928	37	1100 Hz
7	0.1443	3.66522	10.5	0.4982	1.634096	30	1300 Hz
8	0.1285	3.2639	8.37	0.6282	2.060496	24	1650 Hz
9	0.1144	2.90576	6.63	0.7921	2.598088	19	2050 Hz
10	0.1019	2.58826	5.26	0.9989	3.276392	15	2600 Hz
11	0.0907	2.30378	4.17	1.26	4.1328	12	3200 Hz
12	0.0808	2.05232	3.31	1.588	5.20864	9.3	4150 Hz
13	0.072	1.8288	2.62	2.003	6.56984	7.4	5300 Hz
14	0.0641	1.62814	2.08	2.525	8.282	5.9	6700 Hz
15	0.0571	1.45034	1.65	3.184	10.44352	4.7	8250 Hz
16	0.0508	1.29032	1.31	4.016	13.17248	3.7	11 k Hz
17	0.0453	1.15062	1.04	5.064	16.60992	2.9	13 k Hz
18	0.0403	1.02362	0.823	6.385	20.9428	2.3	17 kHz

19	0.0359	0.91186	0.653	8.051	26.40728	1.8	21 kHz
20	0.032	0.8128	0.518	10.15	33.292	1.5	27 kHz
21	0.0285	0.7239	0.41	12.8	41.984	1.2	33 kHz
22	0.0254	0.64516	0.326	16.14	52.9392	0.92	42 kHz
23	0.0226	0.57404	0.258	20.36	66.7808	0.729	53 kHz
24	0.0201	0.51054	0.205	25.67	84.1976	0.577	68 kHz
25	0.0179	0.45466	0.162	32.37	106.1736	0.457	85 kHz
26	0.0159	0.40386	0.129	40.81	133.8568	0.361	107 kHz
27	0.0142	0.36068	0.102	51.47	168.8216	0.288	130 kHz
28	0.0126	0.32004	0.081	64.9	212.872	0.226	170 kHz
29	0.0113	0.28702	0.0642	81.83	268.4024	0.182	210 kHz
30	0.01	0.254	0.0509	103.2	338.496	0.142	270 kHz
31	0.0089	0.22606	0.0404	130.1	426.728	0.113	340 kHz
32	0.008	0.2032	0.032	164.1	538.248	0.091	430 kHz
33	0.0071	0.18034	0.0254	206.9	678.632	0.072	540 kHz
34	0.0063	0.16002	0.0201	260.9	855.752	0.056	690 kHz
35	0.0056	0.14224	0.016	329	1079.12	0.044	870 kHz
36	0.005	0.127	0.0127	414.8	1360	0.035	1100 kHz
37	0.0045	0.1143	0.01	523.1	1715	0.0289	1350 kHz
38	0.004	0.1016	0.00797	659.6	2163	0.0228	1750 kHz
39	0.0035	0.0889	0.00632	831.8	2728	0.0175	2250 kHz
40	0.0031	0.07874	0.00501	1049	3440	0.0137	2900 kHz