Low cost solution to optimize generator running hours in off-grid mobile base stations by analysing load parameters

WMSC Wijekoon

139187C

Faculty of Information Technology
University of Moratuwa

June 2018

Declaration

We declare that this thesis is our own work and has not been submitted in any form for another degree or diploma at any university or other institution of tertiary education. Information derived from the published or unpublished work of others has been acknowledged in the text and a list of references is given.

WMSC Wijekoon

Signature of Student

Date: 08/02/2018

Supervised by :

Mr. Saminda Premarathne

Senior Lecturer

Faculty of Information Technology

University of Moratuwa

Signature of Supervisor

Date

Acknowledgements

It is with great gratitude I would like to mention the support given by my project supervisor Mr.Saminda Premarathna, senior lecturer, Faculty of Information Technology, University of Moratuwa for his encouragement, guidance and support extended to complete this project.

My sincere gratitude also goes to Mr.Palitha Herath, Head of network operations at Etisalat Lanka Pvt Ltd for giving me the opportunity and encouragement to complete the project successfully.

I would also like to thank all the academic and none academic staff members of faculty of information technology, University of Moratuwa for the support given during the MSC IT degree program.

It is my family members and friends who encouraged me to complete this project and Thank you all for the support.

WMSC Wijekoon

Abstract

Telecommunication industry has also evolved at a very high rate during the last decade and mobile communication now plays a major role in economic, social and environmental aspects.

Green concept is one of the most dominant topic discussed in the 21st century due to rapid development on technology and adverse impact on the environment caused by the same. There are so many areas still opened to address. Power generation is one of the kay areas that influence most and many researches are being carried out in the power related areas.

Telecom operators are among the highest users of electricity in modern world. They use electricity to power up their base stations. Majority of base stations are used grid power to their operations and still considerable number of base stations are isolated from grid and powered separately from other sources such as generators, solar and wind power, hybrid solutions etc.

This research addresses to develop a software based low cost generator controller to be used at off-grid base stations. This will focus on the off-grid sites running only with generator power and a method to optimize the generator running hours. It is expected to minimize environmental impact caused by the generators running on 24x7 basis as well as provide financial benefit to the mobile operators by reducing the fuel consumption.

Proposed solution will be based on hardware designed with the help of a microcontroller and a software system which analyze the load parameters and control the generator. Web based software system will eliminate the problems associated with standalone generator controllers such as lack of keeping records, difficulty in remote monitoring, minimizing fuel theft and fraud etc.

Table of Contents

List of Figures

List of Tables

List of Acronyms

AC	Alternating Current
CEB	Ceylon Electricity Board
BS	Base Station
ACID	Atomic, Consistent, Isolated, Durable
CO_2	Carbon Dioxide
DC	Direct Current
DG	Diesel Generator
GHG	Green House Gases
GSM	Global System for Mobile
IC	Integrated Circuit
IoT	Internet of Things
KWh	Kilowatt Hour
LECO	Lanka Electric Company
NILM	None Intrusive Load Monitoring
O&M	Operation and Maintenance
PC	Personal Computer
SMS	Short Message Service

Chapter 01

1 Introduction

1.1 Background

Telecommunication sector has evolved at a very high rate in the recent past which is now plays a significant role in business and global economy [1]. This includes wired communication media such as optical fiber communication and high speed LANs etc. Mobile communication (GSM, 3G and LTE) in parallel has an exponential growth in the recent past in terms of data rates, coverage and network quality

As the demand for usage and quality of the network performance also increases, mobile operators are tend to deploy many mobile base stations which in return increases the power requirement for their operation as well. As per the research carried out by Lambert and colleagues, there is approximately 10% increase in total power consumption worldwide for telecommunication equipment and estimated that this will further increase by additional 10% in 2018 [2]. This makes the telecom operator networks the most electrical energy-intensive consumer within the telecommunication networks that is responsible for the amount of greenhouse gas (GHG) emissions it emits into the environment. In a comprehensive report on GHG emissions reported by the well-known SMART (Standards, Monitoring, Accounting, Rethink, Transform) 2020, Feshke et al. [7] elaborated that the GHG emissions produced by the telecommunication networks in 2020 will increase by a factor of three when compared to 2007[3]. It is also estimated that mobile data usage will increase in parallel three times faster that fixed data line connections.

Wireless telecommunication networks are becoming more popular due to the capacity that can be provided in a given geographical area [4]. There are different types of base stations that are available such as macro, micro, and small (e.g., pico and femto) cells. Different type of cells are developed to cater specific coverage capabilities and are having different energy consumption rates, deployment arrangements, performance and costs. High power consumption of the Base station can be compensated by macro, micro and small cells yet reduces the quality of service of the coverage. Therefore the mobile operators are more focused on deploying base stations with high capacity and coverage and consequently the demand for power is also much higher.

Power requirement of off-grid Base stations are more often provided by diesel generators, photo voltaic cells, wind turbines and hybrid solutions. Diesel generators are widely used for powering, yet, over the time, the idea of using diesel generators as a primary or back-up power supply has become less favorable due to the challenges linked to their reliability, availability, high operational and maintenance (O&M) costs and their significant environmental impacts such as noise and high GHG emission.

1.2 Motivation

Etisalat Lanka (Pvt) Ltd is one of the largest mobile operator in the globe and it is currently holds the number three position in Sri Lankan market considering the coverage and market share[5]. There are more than 2000+ base stations located island wide to provide the mobile coverage across the country.

More than 30% of the total operational cost of the company is spent over power requirement of its base stations and core switch locations. Power requirement of the base stations are fulfilled by the commercial power suppliers namely Ceylon Electricity Board (CEB) and Lanka Electric Company (LECO) whilst there are 30 base stations operating with full time generators running at off grid sites. More than 80% of the operational expenses on generator fuel is spend to run off grid generators which is a huge cost to the company comparing the revenue of these sites. These generators are currently operated manually by using an operator which is not efficient due to various reasons.

1. Operating time may vary and therefore difficult to trace the status of DG
2. Difficult to keep records on running hours, maintenance, fuel consumption etc.
3. DG is continuously running without a rest if the operator fails to manually operate. (Could be due to site access issues, etc)
4. Generator is continuously running even though the backup batteries are fully charged.

Impact to the environment caused by a running DG is comparatively high as it runs more than 20 hours per day.

A rough comparison is given in below table if the generator running hours can be reduced by 5 hours per day and the impact on fuel consumption and GHGs emission [6]

Daily basis	Running hours	Fuel consumption per hour	Fuel consumption	Cost	CO_2 emission
Normal running (Daily)	20	2	40	4680.00	105.2
Optimized running (Daily)	15	2	30	3510.00	78.9

Monthly basis	Running hours	Fuel consumption per hour	Fuel consumption	Cost	CO_2 emission
Normal running (Monthly)	600	2	1200	140400.00	3156.00
Optimized running (Monthly)	450	2	900	105300.00	2367.00

Table 1-1- CO2 emission by diesel engine

By implementing a system which can remotely monitor the generator running hours or energy consumed during the period could enable a new payment schemes based on units consumed which could be an additional saving to the company as well.

As a network operations Engineer of the Etisalat Sri Lanka, it was noticed that generators which are running at off-grid sites are not optimized and running for about more than 20 hours per day which is a waste of fuel and money. It also causes to emit larger amount of GHGs and need to minimize the impact to the environment as well. It was also noted that there is no proper control and records over the fuel consumption of the generators. When considering these aspects, it was started to think about a solution to overcome the major issues highlighted above and one solution was to implement hybrid power system which are commonly available worldwide. These hybrid systems have DG, photo voltaic cells, primary battery backup, and some even with wind turbine as well. These systems are capable of recording running hours, fuel consumption, alarm history ect. Even though there are many hybrid controllers have developed by many vendors across the world, the company is not interested in implementing them due to higher capital cost to be spent on implementing them.

When further analyzing the requirement, it was noticed that these off-grid generators could be controlled by analyzing various external factors such as the system voltage, load current, equipment temperature, fuel level etc to optimize the running pattern while having the DG as the only power source and utilizing the primary battery backup. Different type of sensors can be used to collect required data and they could be analyzed by using various algorithms and system controller could then decide whether the generator to be run or not. Primary battery back will then take over the power requirement until the DG start to run in the next cycle.

1.3 Aim of the research

Aim of this research is to implement a low cost solution to optimize the running hours of off-grid generators with the help of web based system which is capable of collecting and analyzing data related to various parameters and decides the running status of the generator in real-time. Intended system will be a web based system which is capable of controlling the DG by analyzing various parameters, identifying load patterns, daily, weekly and monthly running hours, forecasting of fuel requirement etc.

1.4 Objectives of the research

In order to reach the aim of the project, below objectives have identified in the research.

1. To design and implement hardware required to collect data and controlling the generator.
2. Implement a communication media between the measuring devices, controller and a web server.
3. Develop a web based system to log, analyze and process data.
4. Use data mining techniques to analyze load patterns.
5. Integrating the sub systems to generate automatic notifications from SMS's and emails. (Daily, Weekly alerts, alarms etc.)

Chapter 02

2 Research Area

Josip Lorincz and his team have done an in depth research to identify the relationship between the base station power consumption and traffic pattern [7]. They have confirmed that the instantaneous power consumption of base stations varies in accordance with the traffic load.

They have developed for each of the analyzed base stations a linear power consumption model. The proposed model with a significant percentage of confidence follows the results obtained through precise on-site measurements. Therefore, linear power consumption model can be accepted as a model for precise expression of the interdependence between instantaneous base station power consumption and traffic load. This interdependence is important for the future studies focused on improving the energy efficiency of already installed base stations.

L. Decreusefond and the team have done a research on modeling energy consumption in cellular networks [8]. They have identified two major parts of energy consumed by cellular base station namely the additive part and the broadcast part. It was found that by efficient power controlling mechanisms, the energy can be saved in broadcast part. This could be achieved by optimizing the cell radius so that required transmission power could be reduced. This research also enabled to model the power requirement in order to design the battery capacity of off-grid sites where permanent commercial power is not available.

N. Faruk and team proposed hybrid power systems to the off-grid mobile base stations which includes PV energy, diesel generator and storage battery banks [9]. PV energy plays a key role in hybrid power systems yet the cost of implementation is much higher and therefore many mobile operators are not interested in deploying the same. DG and storage battery banks are the primarily focused power source in most of the off-grid sites due to simplicity and low capital cost involvement yet the impact on the environment is much higher.

Two critical factors that are to be considered in designing a power system for off-grid base station are reliability and continuousness to make sure mobile users and telecom operators do not experience any service outages. Over the years, powering off-grid BS sites has been done using typical power supply solutions such as diesel and petrol generators either alone or together with renewable energy sources (e.g., hybrid PV-diesel power supply systems with or without energy storage). Such power supply solutions are particularly favorable in areas where either extending the grid connection to power the BS site is not economically attractive or the existing grid electricity is not uninterruptedly available to guarantee a continuous power supply [10]. Off-grid base stations also deployed in other instances such as available grid power is not up to the standard voltage specially in developing countries and regulatory requirements to avoid negative impacts to the general public by connecting base stations to grid power in lightening prone areas. Following the emerging concept of green telecommunication networks, the realization of powering the BS sites using sustainable solutions has started to receive significant attention. Because of that, various studies and developments have been done in order to help the telecom operators to shift away from using diesel generators as their primary power supply solution for off-grid BSs. It is being realized that by moving away from diesel generators, the unreliability factors and the high O&M costs usually associated with this solution can be avoided.

Different type of power supply and storage systems developed for off-grid base stations are discussed in the next few sections of this chapter.

2.1 Diesel generators

Diesel generators are among the earliest technologies used to power up off-grid base stations and still to continue in developing countries. Size of the diesel generator is determined by the total load of the base station and typical capacity is varying from 10 KVA to 20 KVA. Main advantage of deploying diesel generator is the easy deployment according to the load demand. There is a major concern with the reliability of the DGs as the probability of failure in startup of DG is approximately around 0.5% which means it fails 5 times in 1000 starting attempts [1]. This is a critical factor when the concern for availability is much higher and in such instances, a backup unit is also needs to deploy. Even though by adding extra generator increases the availability by 200% it doubles the deployment and operational cost which is a major hit in economic point of view. As per the report "SMART 2020: Enabling the low carbon economy in the information age", using diesel generators to power up base stations can add significant GHG to environment [11]. As per the same report, GHG emissions in the telecommunication sector between 2002 and 2020 shows that an increment from about

150 Mt CO_2e in 2002 to 350 Mt CO_2e in 2020 is expected and mobile network dominates the highest amount of GHG emissions and 103 Mt CO_2e is estimated to be released in the environment in 2020 if there is no regulatory action taken in order to achieve green telecommunication networks. Another major drawback of power off grid base stations by diesel generator is that low efficiency which around 30% as rest of the energy generator is lost as heat [12]. This, on the other hand, greatly contributes to the high operation and maintenance costs of the BSs powered by these generators. In a specific case of BSs in remote Kenya, it takes more than 100 trucks to supply enough fuel to the BS sites and a lot of full-time technicians are required to overcome the service outages, leading to various economic disadvantages (e.g., additional unnecessary labor, fuel, and transportation costs) [12]. Another example shows that a telecom operator like Vodacom has to spend more than $5 million per year for all of their 157 diesel-powered BS sites (about $32,000 per year per BS) located in the Democratic Republic of Congo (DRC), mainly for O&M purposes [12]. Additionally, it is noteworthy that there are also other common issues related to the deployment of diesel generators such as noise emission, oil spillage, theft risk, and limited shelf life [12]. This figure is around LKR 3.6 million per year as per the records available in Etisalat Sri Lanka network.

2.2 Renewable Energy Solutions

Using renewable energy sources such as solar and wind to power base stations is not a new concept. The components in solar- and wind-based systems are usually modular, which makes the design, expansion, and deployment of these types of systems for the BS sites very feasible. Yet, due to the unpredictable and intermittent nature of wind and solar, the systems running on these sources typically need to be integrated with other means of renewable or non-renewable power supply and/or energy storage solutions in order to ensure the continuity of power supply in a BS site.

In a study conducted by the GSMA, which is a mobile trade organization, 320,100 renewable-based off-grid BS sites have been rolled out in 2014 in regions like South Asia, Sub-Saharan Africa, Latin America, East Asia, the Pacific, and the Caribbean [13]. This number is expected to increase further in 2020 with about 389,800 sites. Paudel et al. highlighted that conducting a feasibility assessment is essential when designing renewable energy systems [14]. This is to mitigate any poorly designed power supply system that is inefficient for powering a BS site. As is often the case, the renewable energy systems are usually over-sized, and this imposes high capital and O&M costs to the telecom operators. In the same study, they also claimed that 99.99% reliability can be achieved if solar and wind are deployed concurrently as a power supply solution.

2.3 Hybrid Power Supply Systems

Why Hybridization?

Hybrid power supply systems are designed to combine two or more power sources (e.g., PVs and diesel generator) in order to provide reliable and environment friendly power supply. The deployment of a hybrid power supply system is able to reduce the intermittency of power supply and, accordingly, the need for a larger size of energy storage solution (e.g., batteries or hydrogen storage system) [9]. The selection of a hybrid power supply solution for a particular BS site is highly dependent on the availability of resources at the location. Currently the most common type of hybrid power supply systems are PV-wind, PV-diesel-battery, PV-wind-diesel, and PV-fuel cell systems.

2.3.1 Conventional Hybrid Power Supply Systems

PV-Wind Systems

A hybrid PV-wind system generates energy to through the effect of wind speed and solar radiation. Due to variation nature of solar and wind energy, a good storage method such as battery banks need to be implemented in parallel with PV-Wind system to supply power in case of solar or wind power unavailability or when not enough to cater the power requirement.

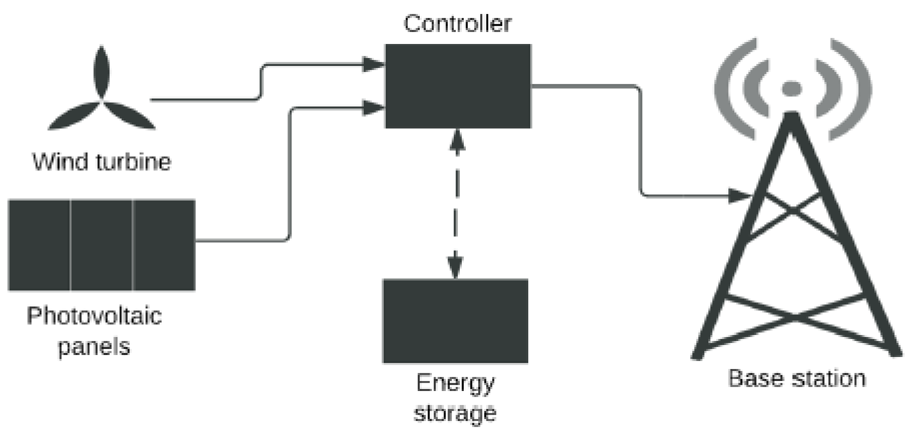


Figure 2-1 - Typical configuration of a hybrid PV-wind system in a base station site.

In a research carried on a BS site in Yonaguni Island, Japan, they proposed an optimal sizing of a hybrid PV-wind system and studied the possibility of service outages in three scenarios of battery capacity. The results showed that the system required a three-day backup battery in order to maintain zero hours of service outages. This is a large cost and consumes more space in base station site making the deployment more complex. Sometimes additional cost to be borne for even for the extra space occupied by infra-structure sharing sites.

2.3.2 PV-Diesel Systems

The hybrid PV-diesel system (typically with battery energy storage) is a comprehensive power supply system that works based on the complementary roles of the key components of the system; for instance, the high capital cost of the PV is compensated by the low capital cost of the diesel generator while the high O&M costs of diesel are compensated by the low O&M costs of PV. In most cases, the energy generated by the diesel generators is fairly available during the absence or shortage of the PV's power output [15]. Additionally, while the existence of diesel as a back-up power supply increases the reliability of the hybrid PV-diesel systems, the overall capital and O&M costs can be further decreased by employing a much smaller size of PVs and batteries [15].

It is important to note that factors such as high emissions from diesel usage, possible future increased cost of diesel prices, and unreliability suggested by the service outages (e.g., due to poor supply of fuel or fuel theft) are some of the limitations that prevent the hybrid PV-diesel system to be favorably deployed for powering off-grid BS sites. In the hybrid PV-diesel systems, the power is primarily supplied by the PV system and the diesel generator acts as a complementary power supply system to overcome the intermittency of solar energy. During periods when the PVs are able to generate excess energy, the energy storage is used to store the excess energy as a short-term energy storage option. Nevertheless, due to the non-existence of reliable long-term energy storage, the PV-diesel system is not reliable enough to power the off-grid BS sites. Figure 2.2 illustrates the PV-diesel hybrid system.

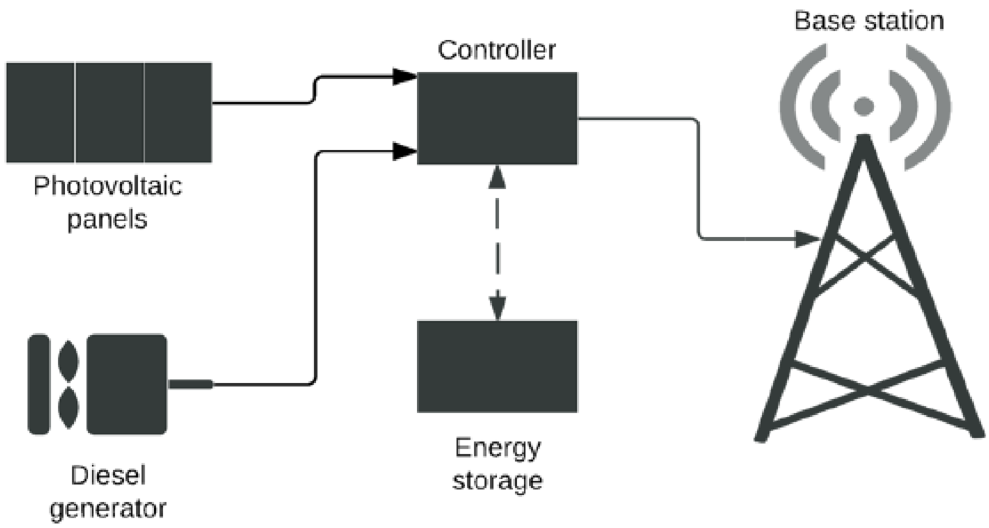


Figure 2-2 - PV-diesel hybrid system

2.3.3 PV-Wind-Diesel Systems

Primary power is supplied by solar and wind energy in PV-Wind-Diesel systems where DG act as secondary power source in case of unavailability of PV or Solar energy or when the energy produced by regenerative source is in sufficient to run the base station. In a study carried out by Bitterlin, it is suggested that PV-Wind-Diesel Systems are most suitable for power large capacity base station sites where the power requirement is more than 4 KWh [16]. A study showes that desirable outputs such as low emissions, low operating costs, low net present cost (NPC), etc can be achieved when deploying a hybrid PV-wind-diesel system to the BS site rather than a diesel-only power supply system. They also showed that the deployment of such a hybrid system is more viable, both technically and economically, when used for larger load demands [17].

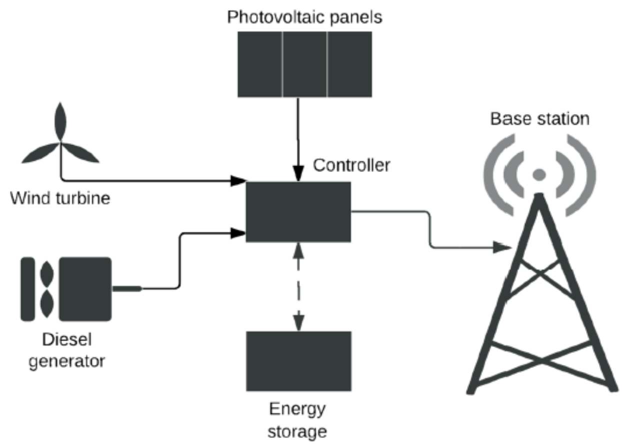


Figure 2-3 - PV, Wind, Diesel hybrid system

2.3.4 PV-Fuel Cell Systems

A hybrid PV-fuel cell system is a sustainable solution (if hydrogen is produced and supplied sustainably) that can be used to power an off-grid BS site based on the attractive features of the PV and fuel cell technologies, such as high efficiency, modularity, and fuel flexibility [49]. Figure 5 shows the typical configuration of a hybrid PV-fuel cell system used for powering a BS site. Generally, the fuel cell system is used to back up the power supply system by covering the intermittency of the PV system, particularly when the energy storage of the system is unable to supply enough electricity to meet the BS demand. The preferred fuel cell option for this purpose is Proton Exchange Membrane Fuel Cell (PEMFC) due to its low operating temperature (e.g., 60–100 °C), rapid start-up, and rapid response to variable loads [18].

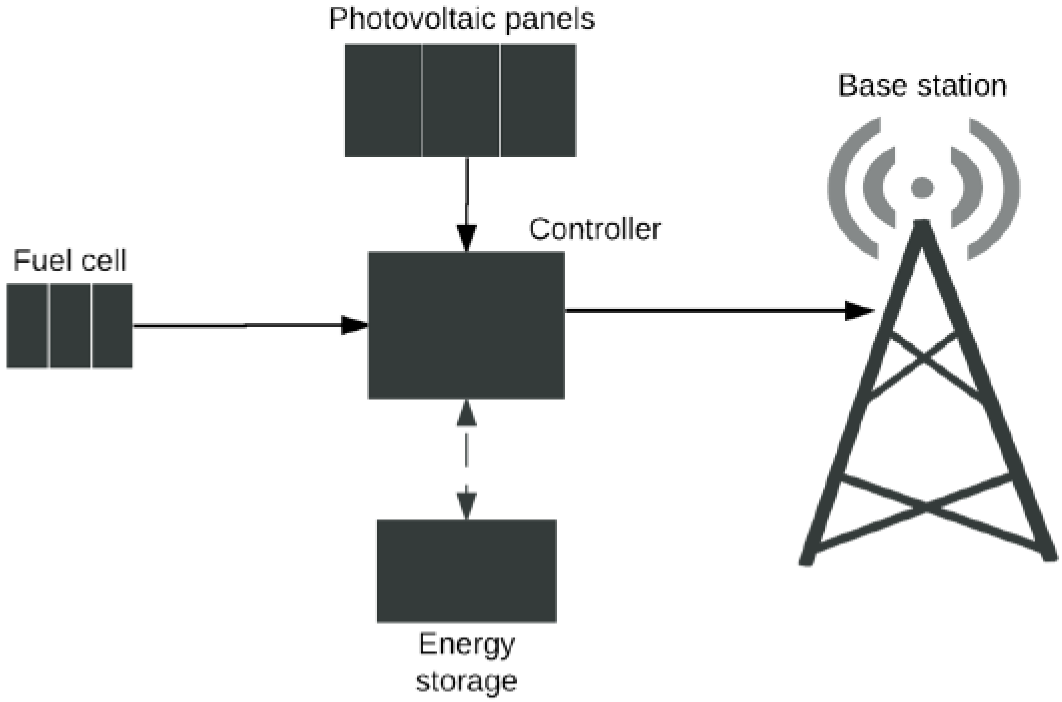


Figure 2-4 – PV-Fuel cell hybrid system

2.4 Energy Storage

Energy storage is an important element in a hybrid power supply system, simply to fill the gaps of supply when utilizing intermittent renewables (e.g., during the absence of sufficient wind and/or PV power output or during unexpected or irregular load consumption) [19]. In addition, the energy storage system stores surplus energy during the periods when the energy generation is more than the demand and releases this energy when the load demand is more than the energy generation [20]. The energy storage also acts as an energy buffer by compensating the imbalances found between the energy generation and the demand and it improves the system's reliability so that any power interruption within the telecommunication networks can be mitigated [20]. Energy storage systems are categorized in to four main categories namely, mechanical, Electrical, thermal and chemical. Most widely used energy storage system in off-grid base stations is electrochemical type which falls into chemical type category [20]. This includes batteries, hydrogen systems, and hybrid energy storage systems.

2.4.1 Batteries

A battery is a type of electrochemical energy storage device that can convert stored chemical energy into electrical energy and vice versa during its recharge process [54]. Typically, the battery can be classified into two categories, which are low-temperature internal storage and high-temperature external storage. The low-temperature internal storage is an energy storage system that can optimally perform at room temperature (e.g., 25 °C) and some examples of this are lead acid (PbO2), nickel cadmium (NiCd), lithium ion (Li-on), sodium metal-halide, and nickel metal hydride (NiMH) batteries [55]. Using these batteries at extreme cold or hot conditions can negatively affect their charging and discharging performance. Lead acid batteries are having the most advanced technology and widely used for most power supply systems. The Li-ion and NiCd batteries seem to emerge in the latest development in battery technology due to their smaller size, low weight, and ability to offer a high energy density and storage efficiency of close to 100%. Major drawbacks of these types of batteries are high cost and incapability of handling deep discharge cycles. For off-grid BS applications, the sizing of the battery is very much dependent on the following system requirements: voltage and current; charge and discharge rates and duration; operating temperature during charge and discharge; life in number of charge and discharge cycles; as well as cost, size, and weight constraints.

There are other energy storage systems like Hydrogen-Based Energy Storage Systems, Hybrid energy storage systems etc yet not discussed in the report as they are not commonly used in Sri Lankan context.

2.5 Voltage dependent timers (VDT)

Voltage dependent timers are used to control generators by referring the output voltage of the DC load. This is a closed loop control system where the input (the generator) is controlled by output voltage reference value. This is a primary method of controlling a generator in base station site to save fuel by minimizing the running hours. This operates by using a DC relay module where the generator on/off signal is controlled. Voltage sensing is achieved by using microcontroller based circuit [21]. Some of the feature comes with commercially available VDT timer are as follows [21].

- Fully digital & automatic.
- User Volt calibration facilities.
- Built in temperature sensor with display.
- Running battery voltage display.
- Built in watch dog timer.
- Over temperature alarm
- Soft touch key pad.
- Thundering protection.
- Auto By pass facility.
- Easy connection & replicable.
- Reverse polarity protection.
- Feature programmable without changing hardware.
- Microcontroller based circuit

Above analysis shows that there are many researches had been carried out to model the power requirement of off-grid mobile base stations and hybrid power systems. Most researches are focused on hybrid power solutions by considering the low impact to the environment as the GHG emission could be minimized by using the same technology. Most of the telecommunication operators are more focused on low cost and easy solutions to deploy and their concern for the environment impact is minimal as there is no regulatory constraints available with regard to powering off-grid base stations. Further it was noted that there are very limited researches carried out to identify how the existing off-grid sites with the generator as its only power source could be optimized if the hybrid power solutions could not be deployed due to various reasons. The only such method could found was the voltage dependent timer which can be installed at base station site and it is operated as standalone device. Its major limitation is that it

does not provide the facility to remotely control or monitor the device, storing data collected by the sensors and analyze the data for prediction on fuel, running hours etc.
This research is focused to develop more advanced generator controller with remote access, data collection and recording such as running hours, fuel consumption, operation and maintenance which can be used to optimize the generator running hours at off-grid mobile base stations.
In a research carried out by Pavlos S. Georgilakis, Decision support systems (DSS) has deeply studied and mainly focused on renewable energy sources [22]. Decision making process are analyzed in different viewpoints to find the best combination and to compromise from different solutions available. This will enable to address trade-offs between reliability, economical factors, financial benefits and risks and even environmental impacts to improve the quality and transparency of decision making.

Characteristics of DSS are summarized in five major categories as follows.

1. Support decision making process in complex problems
2. Integrate decision analysis techniques with data access and management.
3. Focused on user friendliness where no sophisticated analysis methods are used.
4. Flexibility to adapt in changing environment
5. Operate in an interactive mode for real time decision making.

Basic components of DSS

There are three major components identified in DSS namely,

1. The database
2. The model
3. User interface

The database

All necessary information and data required to analyze the issue are entered, stored and accessed through the database management system.

The model

Decision analysis tools that are used to support decision making is included in the model.

The user interface

This enables the communication of the system with the users.

Abu Taha in his research has identified multi criteria analysis can provide technical and scientific decision making support tool with high accuracy and consistence [23]. This model can handle both quantitative as well as qualitative criteria.

Chapter 03

3 Research plan – Technology adapted

Technology that is going to be used with the proposed system development will be described in this chapter. This will be focused on hardware, software and communication media of the modules.

IoT (Internet of Things) is an emerging technology that can be adopted in wide variety of applications in the modern world [24]. The IoT covers many areas ranging from enabling technologies and components to several mechanisms to effectively integrate these low level components. Software is then a discriminant factor for IoT systems. IoT operating systems are designed to run on small scale components in the most efficient way possible, while at the same time providing basic functionalities to simplify and support the global IoT system in its objectives and purposes. Middleware, programmability – in terms of application programming interfaces (APIs) – and data management seem to be key factors for building a successful system in the IoT. Management capabilities are needed in order to properly handle systems that can potentially grow up to millions of different components. In this context, self-management and self-optimization of each individual component and/or subsystem maybe strong requirements. In other words, autonomics behaviors could become the norm in large and complex IoT systems. Data security and privacy will play an important role in IoT deployments. Because IoT systems will produce and deal with personally identifiable information, data security and privacy will be critical from the very beginning. Services and applications will be built on top of this powerful and secure platform to satisfy business needs. So many applications are envisioned as well as generic and reusable services. This outcome will require new, viable business models for IoT and its related ecosystems of stakeholders. Above described concepts and features of the IoT technology is adapted to the development of the generator controller system. It will comprises with an IoT device at the base station premises and software component running on a server. Modules in the proposed system and technology used to develop these modules are described in next few paragraphs.

Proposed generator control system will have three separate modules, namely,

- Hardware module at the base station site

- Web based software module running on a server
- Communication module

3.1 Hardware module at the base station site

Hardware module at base station site is consist of a controller unit, voltage and current sensing devices, generator control unit and the communication device. The controller unit will be a PIC microcontroller. There are many reasons for selecting a PIC microcontroller as the main hardware controller. PIC microcontroller is an integrated chip which consists of RAM, ROM, CPU, TIMERS, COUNTERS, ADC (analog to digital converters) and DAC (digital analog converter), etc. It also supports the protocols like CAN, SPI, UART for interfacing with other peripherals. PIC mainly use modified Harvard architecture and also supports RISC (Reduced Instruction Set Computer) by the above specification RISC and Harvard it can decide that PIC is faster than the 8051 based controller which is made-up of Von-Newman architecture [25].

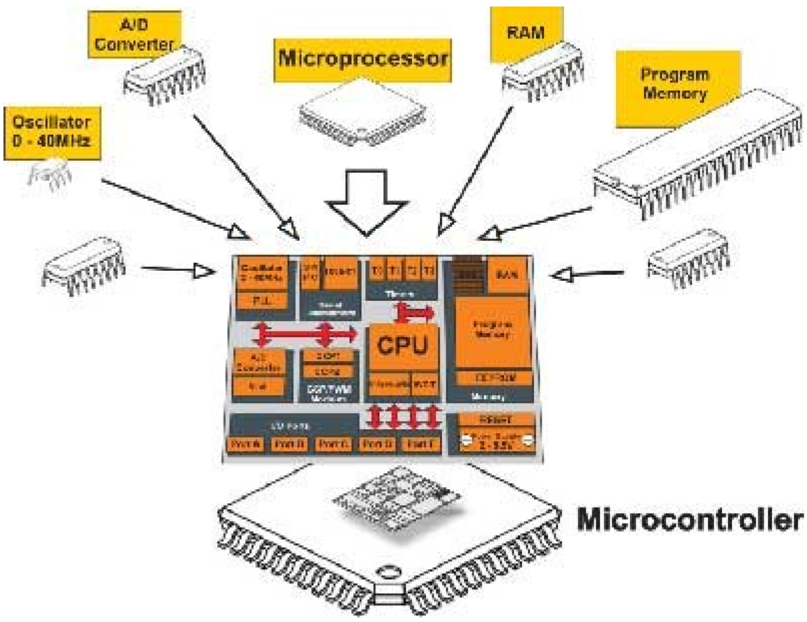


Figure 3-1- PIC microcontroller architecture

Advantages of PIC microcontrollers

- Low time required for performing operation.
- The processor chips are very small and flexibility occurs.
- Due to their higher integration, cost and size of the system is reduced.
- The microcontroller is easily to interface additional RAM, ROM and I/O ports.

- Once microcontrollers are programmed then they cannot be reprogrammed.
- At the same time many task can be performed so human effect can saved.
- Without any digitals parts it can be act as microcomputer.
- It is easy to use, troubleshooting and systems maintain is simple

There are some tradeoffs as well in PIC microcontrollers such as,

- The microcontroller cannot interface high power devices directly.
- It has more complex structure as compared to microprocessor.
- It only performed limited number of executions simultaneously.
- It is generally used in micro equipment.

How the advantages and disadvantages of microcontrollers impacts to the proposed system

One of the major reason for selecting PIC micro controller is because it is much easier to interface with Input / Output ports. In the proposed system, the controller to be interfaced with Inputs such as system voltage and system current as well as generator control signal which is an output port. Also it is needed to interface with UART module for transmitting data from the device to the web server. All these interfacing can easily be achieved with PIC microcontrollers. In addition, it is much easier to program the chip using micro basic language. Since the proposed system has only few I/O devices, it is very flexible to use. It also requires very small power to operate and reliable as well. PIC 16F877A micro controller is used as the controller in the proposed system which is a 40 pin 8 bit device [26]. Additional details of the 16F877A micro controller is shown in the table 3.1 [26].

Key Features	PIC16F873A	PIC16F874A	PIC16F876A	PIC16F877A
Operating Frequency	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz	DC – 20 MHz
Resets (and Delays)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)	POR, BOR (PWRT, OST)
Flash Program Memory (14-bit words)	4K	4K	8K	8K
Data Memory (bytes)	192	192	368	368
EEPROM Data Memory (bytes)	128	128	256	256
Interrupts	14	15	14	15
I/O Ports	Ports A, B, C	Ports A, B, C, D, E	Ports A, B, C	Ports A, B, C, D, E
Timers	3	3	3	3
Capture/Compare/PWM modules	2	2	2	2
Serial Communications	MSSP, USART	MSSP, USART	MSSP, USART	MSSP, USART
Parallel Communications	—	PSP	—	PSP
10-bit Analog-to-Digital Module	5 input channels	8 input channels	5 input channels	8 input channels
Analog Comparators	2	2	2	2
Instruction Set	35 Instructions	35 Instructions	35 Instructions	35 Instructions
Packages	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN	28-pin PDIP 28-pin SOIC 28-pin SSOP 28-pin QFN	40-pin PDIP 44-pin PLCC 44-pin TQFP 44-pin QFN

Table 3-1– Key features of PIC microcontroller

3.1.1 System current sensing

Hardware module is also responsible to collect real time data at the base station site power system. There are two variables measured at the initial development of the system which are system voltage and system current. Also this module is responsible to handle the generator control signals, which sends the on/off signal to the generator. This module also include the communication device which sends and receives data to/from web server where the processing and decision making will be done. Different type of sensors can be used to measure current in a power system. Current measurement can be done in three methods. Namely, Resistive, Transistor and magnetic [27]. The type which is going to be used in an application depends on the requirements such as whether the isolation is needed, accuracy etc. Comparison of each method is illustrated in the table 3.2 [27].

MEASUREMENT METHOD	ACCURACY	ISOLATION	EMI (TAMPER RESISTANCE)	ROBUST	SIZE	COST
RESISTIVE (DIRECT)						
Sense resistor	High	No	High	High	Small	Low
TRANSISTOR (DIRECT)						
$R_{DS(ON)}$	Low	No	Moderate	Moderate	Small	Low
Ratio metric	Moderate	No	Moderate	Moderate	Small	Moderate
MAGNETIC (INDIRECT)						
Current Transformer	High	Yes	Moderate	High	Large	Moderate
Rogowski coil	High	Yes	Moderate	High	Large	Moderate
Hall effect	High	Yes	High	Moderate	Moderate	High

Table 3-2 - Comparison of current measuring techniques

In the proposed hardware module, resistive method is used with a current sensing chip. Output of the current sensor is given to the PIC microcontroller as an input signal.

3.1.2 System voltage sensor

There are two ways that can measure the system DC voltage. It can be used a voltmeter to measure the voltage and output of the voltmeter can be given as an input to the PIC microcontroller. It can also use the PIC microcontroller itself as a voltmeter with the help of voltage divider circuitry which is to be designed as per the required voltage levels. Output of the voltage divider circuity can be fed into the PIC microcontroller as an input and it can convert the value in to a digital signal for further processing. This method will be used in the proposed system as it is much easier to implement and high in accuracy as well.

3.2 Communication module

System controller should communicate with the server to exchange data and control signals. This could be done in two ways.

1. By using WiFi
2. By using GSM technology

In both cases, the interfacing will be done by using the UART port available in the PIC microcontroller. UART stands for "Universal Asynchronous Receiver and Transmitter" [28]. A communication device such as Wifi or GSM could be easily connected via this protocol with very minimum hardware requirement and chip programming.

As most of the off-grid sites are located in remote locations, connectivity to WiFi network is far beyond practical hence GSM module is used as the communication media. GSM module will work with the GSM network infrastructure. Data could be transferred by means of packet with the help of GPRS technology or as text messages by using GSM technology. Text messages will be used in this case to transmit data and control signal messages. As the intended system is developed for the off-grid mobile base stations, accessing the GSM network is not a critical aspect to think of. There are many applications that are currently been developed using SMS technology.

3.3 Web based software module

Main controller module was developed as a web based software program. Major development tools that were used to developed the software was PHP programming language, MySQL package for database handling, HTML scripting for web page designing and apache server as the web server. In order to understand the major coding listed in this thesis, it is required to have knowledge in PHP, MySQL and HTML. Java script was also used in developing the pages. UML is used to model the software.

Microsoft Office front page 2003 (ver. 11.5516.5606) was used as the scripting editor for this software in development stage. WAMP5 (Version 1.6.5) was used as the Apache and MySql server package.

3.3.1 Why PHP?

It is also possible to use programming language such as java, ASP and ASP.net to accomplish the same task but there are many advantages of PHP over other programming languages.

- PHP works in combination of HTML to display dynamic elements on the page. PHP only parses code within its delimiters. Anything outside its delimiters is sent directly to the output and not parsed by PHP.
- PHP can run on variety of servers, including Apache, which is native to it, Microsoft's IIS, and others such as AOLserver and Roxen. The best part is that PHP is the most efficient with the most popular server Apache.
- PHP also has powerful output buffering that further increases over the output flow. PHP internally rearranges the buffer so that headers come before contents.
- PHP can be used with a large number of relational database management systems, runs on all of the most popular web servers and is available for many different operating systems.
- PHP5 a fully object oriented language and its platform independence and speed on Linux server helps to build large and complex web applications. MySQL is used with PHP as back-end tool.

- MySQL is the popular online database and can be interfaced very well with PHP. Connection to external modules is very simple with PHP. It is easy to embed other file formats such as pdf and macromedia to the web page easily with PHP.
- PHP and MySql are both open source hence the software is freely available.
- Most of web applications are built with PHP and MySql and therefore, it is easy to get reusable components from other previously developed software.

3.3.2 Reason for selecting MySql as the database server

Flexibility and Scalability

The MySQL database server provides the ultimate in scalability, having the capacity to handle deeply embedded applications with a footprint of only 1MB to running massive data warehouses holding terabytes of information. Platform flexibility is another feature of MySQL which support Linux, UNIX, and Windows. The open source nature of MySQL allows complete customization for advanced users those wanting to add unique requirements to the database server.

High Performance

A unique storage-engine architecture allows database professionals to configure the MySQL database server specifically for particular applications, with the end result being amazing performance results. Whether the intended application is a high-speed transactional processing system or a high-volume web site that services a billion queries a day, MySQL can meet the most demanding performance expectations of any system. With high-speed load utilities, distinctive memory caches, full text indexes, and other performance-enhancing mechanisms, MySQL offers all the right ammunition for today's critical business systems.

High Availability

Solid reliability and constant availability are also key features of MySQL, with customers relying on MySQL to guarantee around-the-clock uptime. MySQL offers a variety of high-availability options from high-speed master/slave replication configurations, to specialized Cluster servers offering instant failover, to third party vendors offering unique high-availability solutions for the MySQL database server.

High Transactional Support

MySQL offers one of the most powerful transactional database engines on the market. Features include complete ACID (atomic, consistent, isolated, durable) transaction support, unlimited row-level locking, distributed transaction capability, and multi-version transaction support where readers never block writers and vice-versa. Full data integrity is also assured through server-enforced referential integrity, specialized transaction isolation levels, and instant deadlock detection.

Web and Data Warehouse Strengths

MySQL is well suited for high-traffic web sites because of its high-performance query engine, tremendously fast data insert capability, and strong support for specialized web functions like fast full text searches. These same strengths also apply to data warehousing environments where MySQL scales up into the terabyte range for either single servers or scale-out architectures. Other features like main memory tables, B-tree and hash indexes, and compressed archive tables that reduce storage requirements by up to eighty-percent make MySQL a strong standout for both web and business intelligence applications.

Strong Data Protection

Because guarding the data assets of corporations is the number one job of database professionals, MySQL offers exceptional security features that ensure absolute data protection. In terms of database authentication, MySQL provides powerful mechanisms for ensuring only authorized users have entry to the database server, with the ability to block users down to the client machine level being possible. SSH and SSL support are also provided to ensure safe and secure connections. A granular object privilege framework is present so that users only see the data they should, and powerful data encryption and decryption functions ensure that sensitive data is protected from unauthorized viewing. Finally, backup and recovery utilities provided through MySQL and third party software vendors allow for complete logical and physical backup as well as full and point-in-time recovery.

Comprehensive Application Development

One of the reasons MySQL is the world's most popular open source database is that it provides comprehensive support for every application development need. Within the database, support can be found for stored procedures, triggers, functions, views, cursors, ANSI-standard SQL, and more. For embedded applications, plug-in libraries are available to embed MySQL database support into nearly any application. MySQL also provides connectors and drivers (ODBC, JDBC, etc.) that allow all forms of applications to make use of MySQL as a preferred data management server. It doesn't matter if it's PHP, Perl, Java, Visual Basic, or .NET, MySQL offers application developers everything they need to be successful in building database-driven information systems.

Management Ease

MySQL offers exceptional quick-start capability with the average time from software download to installation completion being less than fifteen minutes. This rule holds true whether the platform is Microsoft Windows, Linux, Macintosh, or UNIX. Once installed, self-management features like automatic space expansion, auto-restart, and dynamic configuration changes take much of the burden off already overworked database administrators. MySQL also provides a complete suite of graphical management and migration tools that allow a DBA to manage, troubleshoot, and control the operation of many MySQL servers from a single workstation. Many third party software vendor tools are also available for MySQL that handle tasks ranging from data design and ETL, to complete database administration, job management, and performance monitoring.

Open Source Support

Many corporations are hesitant to fully commit to open source software because they believe they can't get the type of support or professional service safety nets they currently rely on with proprietary software to ensure the overall success of their key applications. The questions of indemnification come up often as well. These worries can be put to rest with MySQL as complete around-the-clock support as well as indemnification is available through MySQL Network. MySQL is not a typical open source project as all the software is owned and supported by MySQL AB, and because of this, a unique cost and support model are available that provides a unique combination of open source freedom and trusted software with support.

Lowest Total Cost of Ownership

By migrating current database-drive applications to MySQL, or using MySQL for new development projects, corporations are realizing cost savings. Accomplished through the use of the MySQL database server and scale-out architectures that utilize low-cost commodity hardware, corporations are finding that they can achieve amazing levels of scalability and performance, all at a cost that is far less than those offered by proprietary and scale-up software vendors. In addition, the reliability and easy maintainability of MySQL means that database administrators don't waste time troubleshooting performance or downtime issues, but instead can concentrate on making a positive impact on higher level tasks that involve the business side of data.

Chapter 04

4 Requirement analysis of low cost generator control system

4.1 Chapter overview

This chapter describes the major requirements of the system in the perspective of system users and administrators. It also describes the hardware requirements which includes in the off-grid base station site hardware.

4.2 User requirements

Overall requirement is to develop an automated generator controller which is capable of optimizing the running hours in off-grid mobile base station. Below listed are the functional requirement of the system.

- Measuring real time data in the base station power system.
- Sending the data real time to the web server
- Fetching data to the database.
- Data analysis
- Decision making
- Report generation

4.2.1. Measuring real time data in the base station power system.

As the initial stage of the development of the system, only two parameters are measured in the power system which are voltage and the current. These two parameters can be treated as most critical parameters when designing such a system. In addition, it is also possible to extend the system with additional parameters such as temperature, fuel level, etc.

4.2.2. Sending the data real time to the web server

After measuring the real time parameters, these figures should pass to the web server where the processing will be done. Measured data will be sent in the form of SMS (text format) and system will decode the text message to separate the variables.

4.2.3. Fetching data to the database

Once the variables are separated, they will be passed in to the data base. This data could later queried for processing and analyzing. MySql will be used as the database for the proposed system.

4.2.4. Data analysis and decision making

Data fetched in to the database will analyze to determine the base station power system status such as whether the backup batteries are charging, System voltage is at desired level, whether generator is running etc. By analyzing these parameters, the software system will take the decision whether the generator to run or stopped and control signal will be sent via a SMS to the controller module at base station to execute.

4.2.5. Report generation

It is also important to create various reports on the aspects such as generator running hours in a given time frame, how the system voltage and current changes over the time, whether there are any suspected frauds of fuel supplier, generator maintenance records, etc.

4.3 None functional requirements of the system

Reliability

As the generator controller is directly related to the power system of the base station, reliability is a critical factor to be maintained. Failure in the system could impact total power loss to the base station causing huge impact to the customers and quality of service. Therefore, every possible action to be taken to maintain the reliability of the system.

Portability

System should be able to deploy to any type of generator set and irrespective of the location to be deployed. This should be easily integrated with the existing generator only sites without much modifications and complex wiring. Configuration and integration of a new site in the system should also be done easily.

Usability of the system

The system should be designed in such a way that it is more user friendly to use. The GUI is well organized so that the user is able to retrieve information and analyze the data and performance of their base stations with respect to external environment factors. The system can be introduced to the users with minimal training. The users are only to be aware of general windows applications specially internet browser.

Chapter 05

5 Designing of low cost generator controller

5.1 Design methodology

The nature of facilitating multiple dimensions was the major reason to select UML as the main system design methodology. As described in the system analysis level, Use Case diagrams were drawn and gathered the requirements. In the preliminary stage of design phase, system has viewed in three-layered structure, which is also named as vertical visualization. Then the system was further divided in to separate logical and functional areas called subsystems, which gives the horizontal visualization of the system. The main benefit made available with this technique is that it is extensible. Enhancement to the system could be added where necessary because each subsystem is independent. Lines of communication between subsystems (known as interface) must be formally defined to ensure the integrity of data and the execution of operations. Each subsystem can be tested independently, assisting the parallel implementation and testing of different subsystems.

5.2 Proposed system overview – High level design

Special hardware (IoT device) will be implemented to capture real time data such as DC voltage and current in electrical circuit.

Data will be transmitted to a web server via the GSM network as text messages. Data will be collected and analyzed as per the algorithms to determine status of the power system and decides whether the generator to be run or not and send back the control signal via the GSM module to the local controller to operate the generator. System will analyze and process the data to predict the future fuel requirement and load consumed by devices etc.

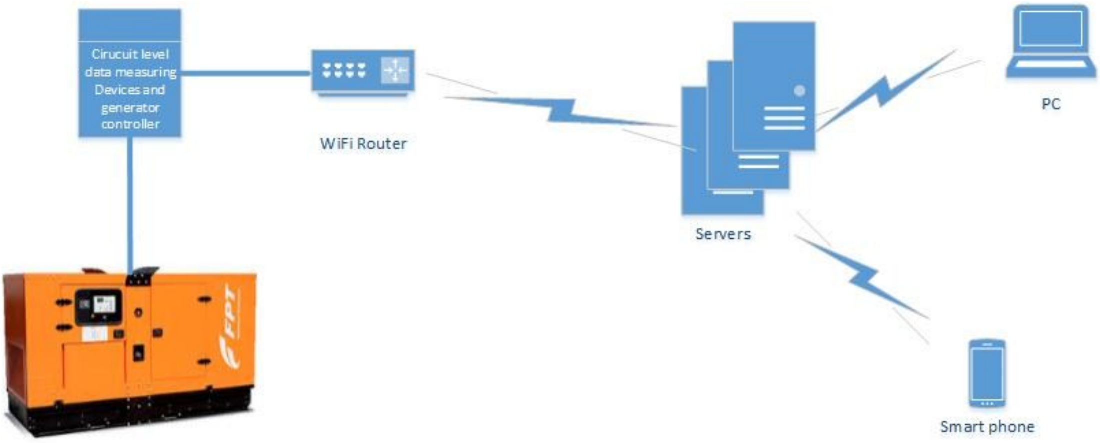


Figure 5-1 - Hi level design

5.2.1. Designing the IoT device

A PIC microcontroller will be used as the IoT device which will be used as the local controller. It will interface with the Input and output devices, UART device as well as the backup controller device which will take over the control of the gen set in case of unavailability of the main system. This will make sure the power system will keep running without interruptions due to system issues. This approach will double the reliability of the system which is a critical none functional requirement in an application of this nature.

Inputs to the PIC microcontroller will be the system voltage, system current and the clock signal. Clock signal will be connected to the designated port of the microcontroller while other two input signal will be connected to the analog input ports which are capable to convert the analog signal into digital signal. This process in known as analog to digital conversion. There a designated ports which can handle the ADC (Analog to digital conversion).

GSM module will be interfaced with the PIC microcontroller through the UART port which is a designated port which can only use for the serial communication between two devices. UART port is having a Tx and Rx ports which should cross connect with the communicating device.

Main output of the PIC microcontroller will be the generator control signal which will be change its state to active high or low states depending whether generator needs to run or stopped. This output signal will be connected to a relay module using an opto-coupler.

Activity diagram shown in the figure 5.1 describes the activities carried out by the IoT device.

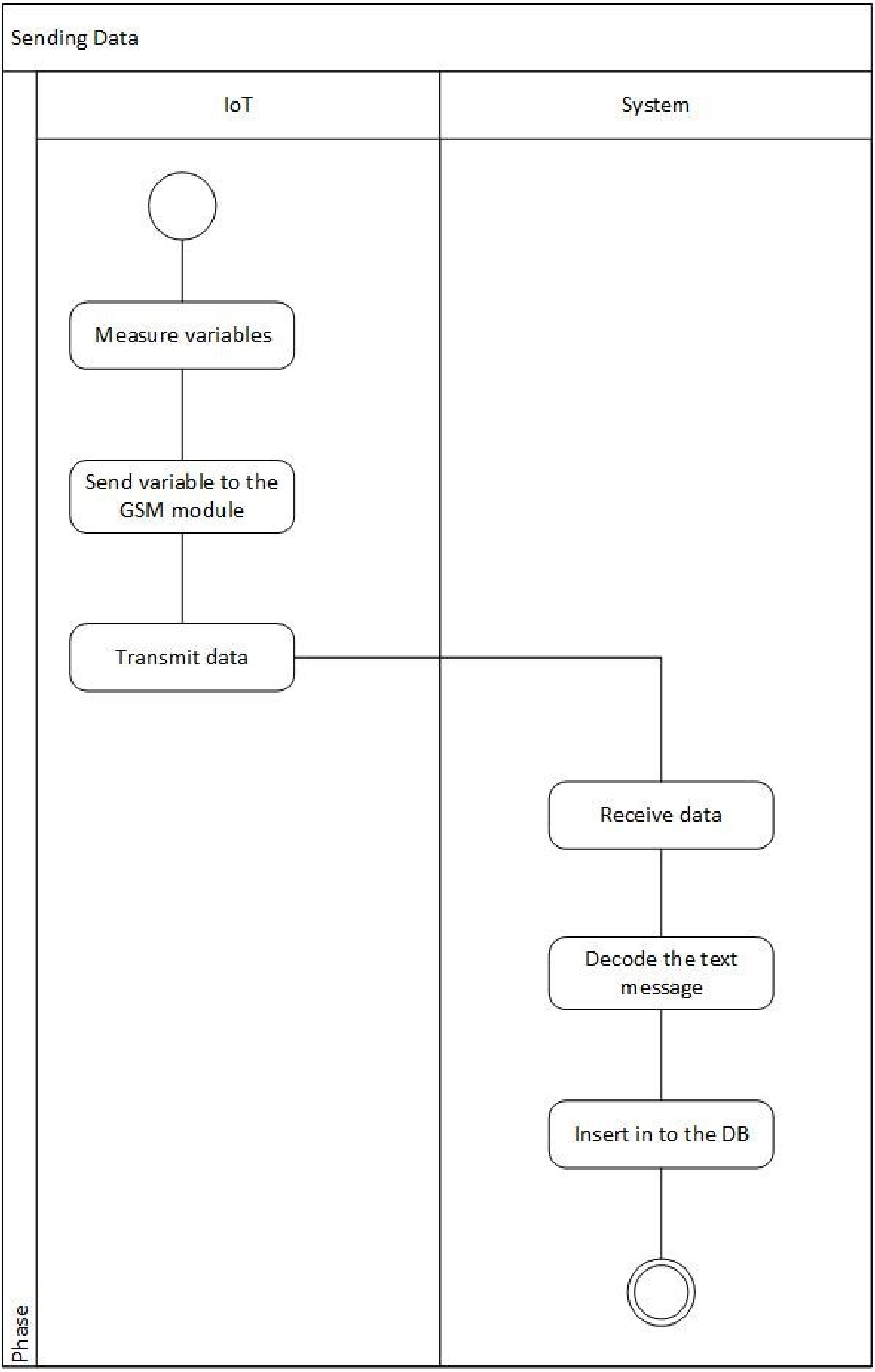


Figure 5-2 – Activity diagram of IOT device

After inserting the variables to the database, the system should analyze them and decision to be taken whether the generator to be run or not. Activity diagram with regard to decision making and sending back the control signal is given in below diagram.

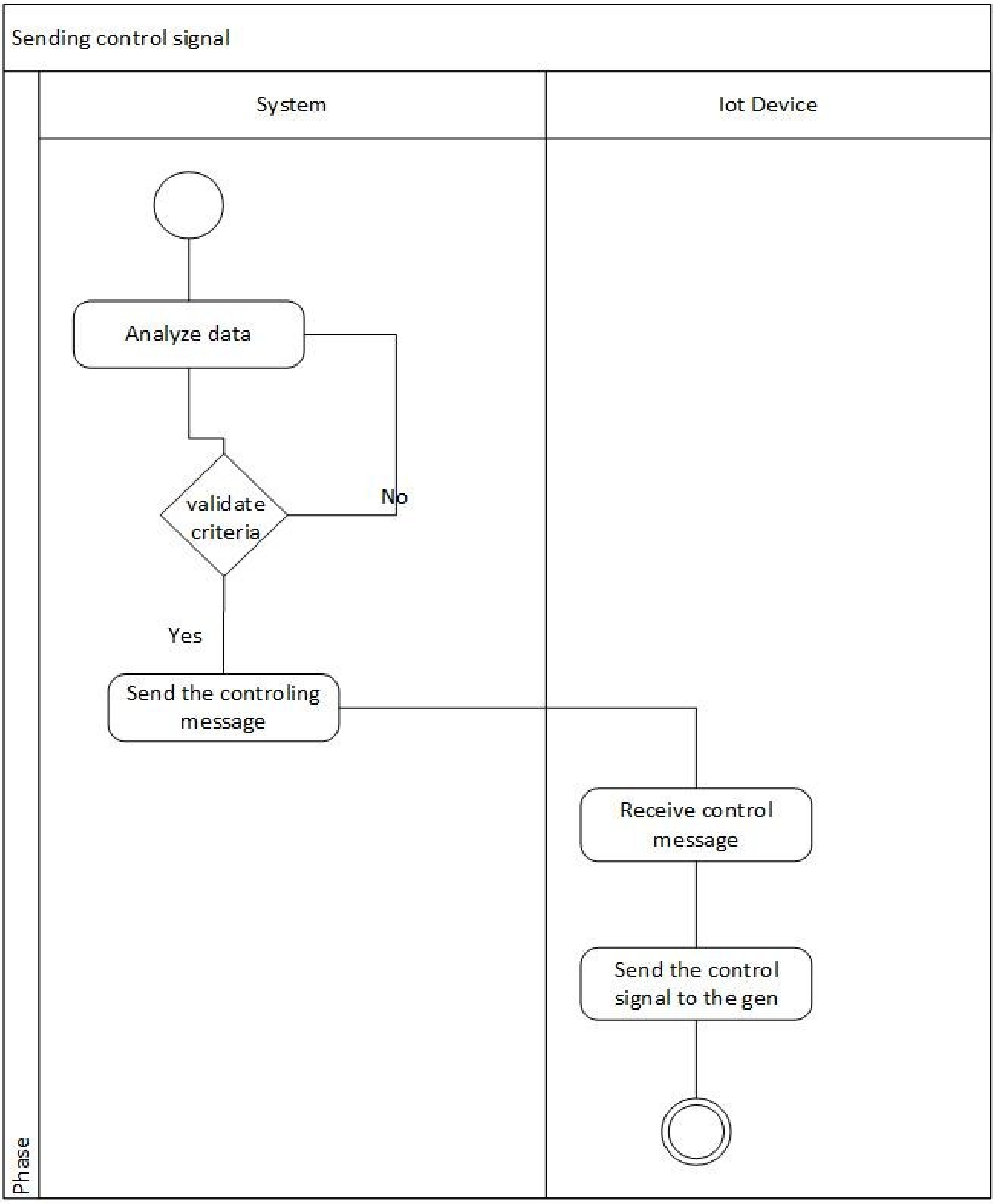


Figure 5-3 – Activity diagram of sending data

5.3 Designing the software module

Use case diagrams are used to describe the system users and their roles in a graphical way. This enables the clear understanding of the system. Use case diagram shown in figure 5.1 illustrates the proposed system's use cases.

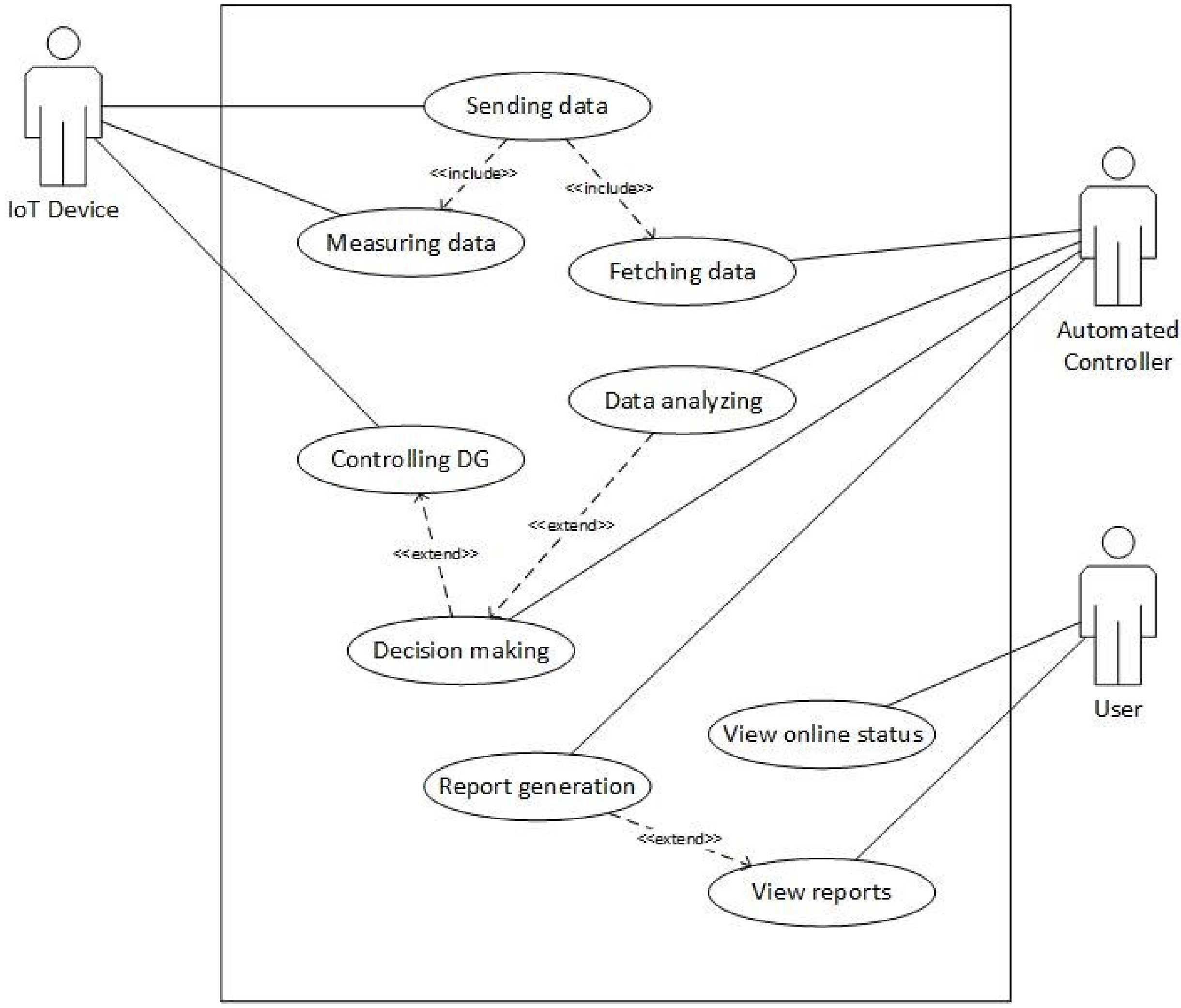


Figure 5-4 – Use case diagram

System user should also be able to view the online status of the generator running condition as well as the previous running records (History records). Below activity diagram describe the scenario of viewing the gen running status and reports.

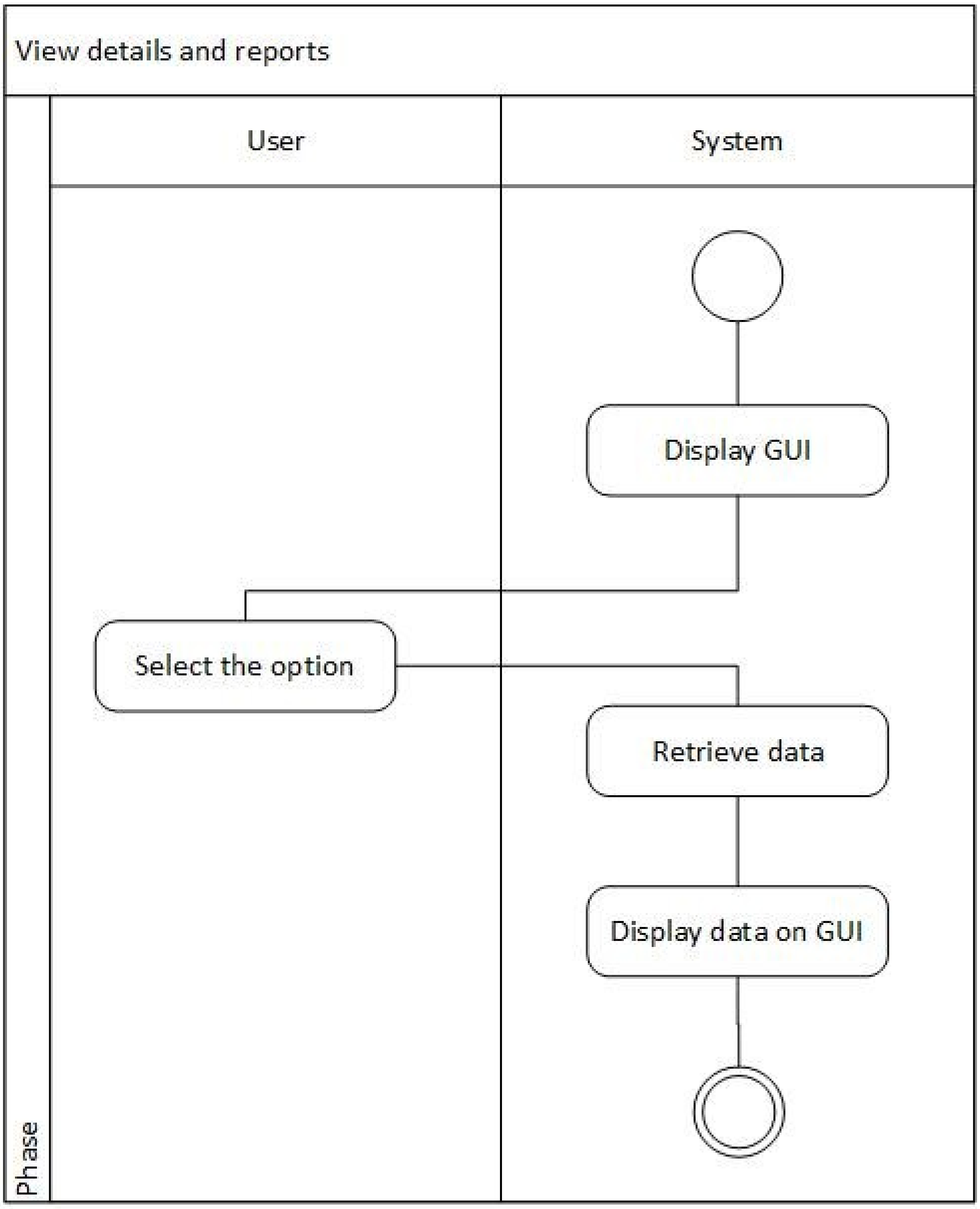


Figure 5-5 – Activity diagram of viewing reports

Chapter 06

6 Implementation

6.1 Hardware implementation

16F877A PIC micro controller is the main controlling unit of the IoT and top level design of the IoT device is shown in figure 6.1.

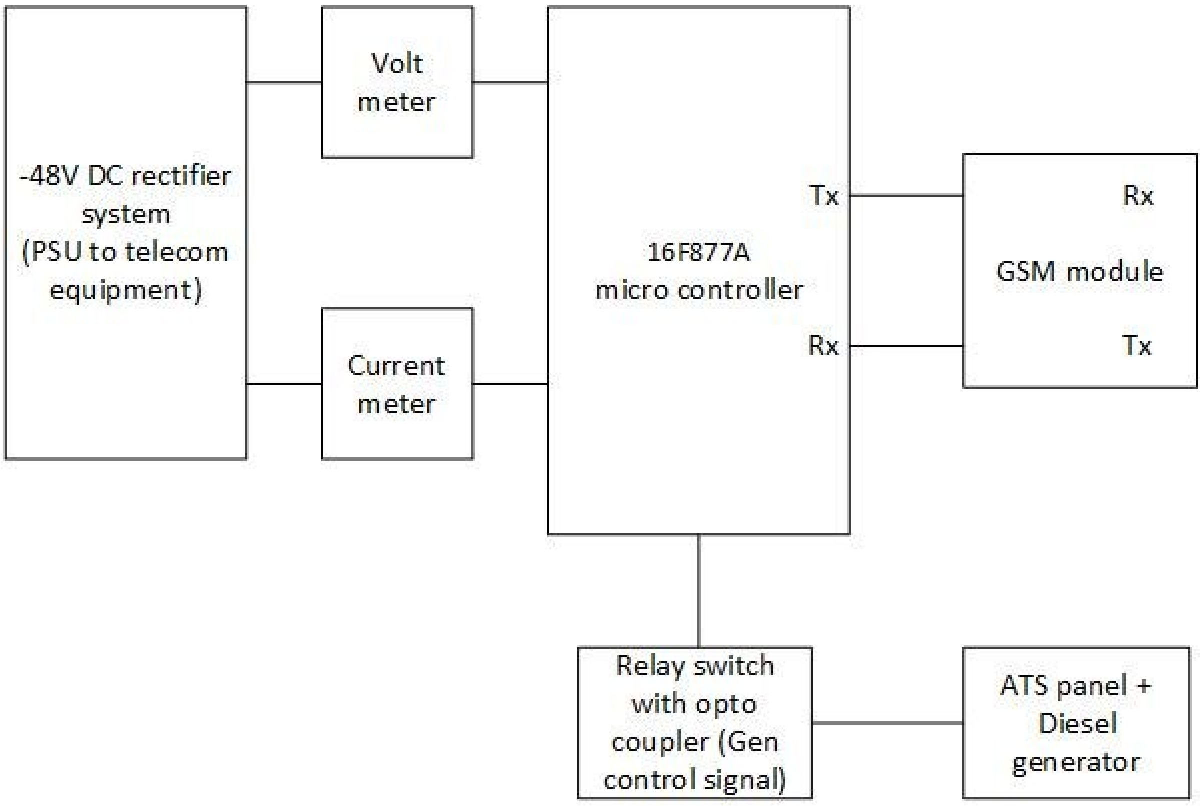


Figure 6-1– IoT device overview

6.1.1. PIC 16F877A micro controller

This is a 40 pin micro controller out of which 33 pins can be configured as Input and Output ports. This enables developers to use this chip in vast range of products easily. This has many applications in digital electronics such as remote sensors, security and safety devices, home automation and in many industrial instruments.

This micro controller is one of the mostly used version in the industry due to various reasons. It is very convenient to use and coding (programming) is much easier. It can be write-erase as many times as possible because it use FLASH memory technology. An EEPROM is also featured in it which makes it possible to store some of the information permanently like transmitter codes and receiver frequencies and some other related data. The cost of this controller is low and its handling is also easy. It's flexible and can be used in areas where microcontrollers have never been used before as in co-processor applications and timer functions etc.

6.1.2. Pin configuration and description of PIC 16F877A micro controller

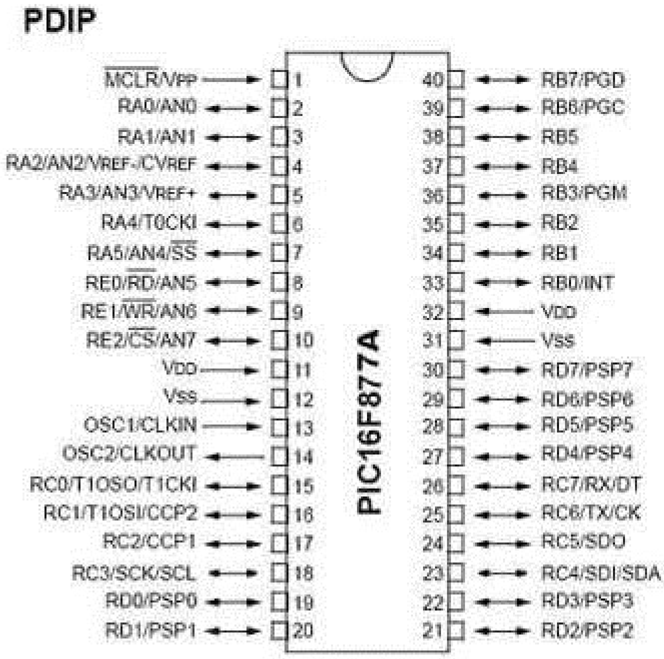


Figure 6-2– PIC16F877A micro controller

Main parameters are the system DC voltage and Battery charging current. These parameters are captured by using voltmeter and Ammeter with a current transformer. 16F877A PIC micro controller is used to determine the voltage and current values and control the generator locally and GSM module is used to communicate with the system in real time. AT commands are used to program the PIC to operate with SMS commands. 12V 4 channel relay module with Opto coupler is used to control the generator on/off function. Main parameters are sampled at 5 minutes interval at design stage and will be used optimized values when the system implemented in real time.

PIC programming and AT commands were used at this level as the hardware description language and GSM module control.

System voltage is measured by converting the analog voltage signal into digital value. A voltage divider circuit is used to drop down the voltage to PIC operational voltage range and circuit diagram of the voltage divider is shown in figure 6.3.

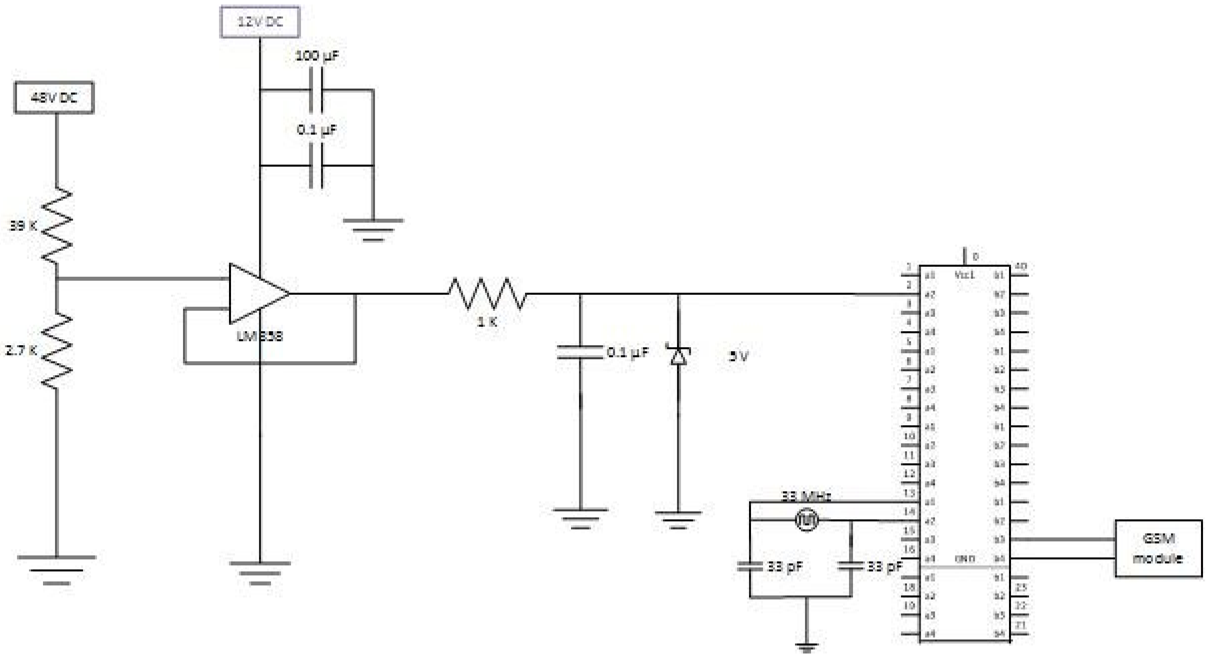


Figure 6-3– Voltage divider circuit to measure system voltage

Sample coding is given below where the ADC is done.

```
{
    INTCON = 0;
    ADCON0 = 0x00;                // Pin RA0 is configured as an analog i/p
    ADCON1 = 0x82;          //Right justified selected

    for (j = 4; j > 0 ;j--) {
    rect_voltage = ADC_Read(0);  // A/D conversion. Pin RA0 is an input.
    tlong = (long) rect_voltage * 76500; // Convert the result in //millivolts
    tlong = tlong / 1023;       // 0..1023 -> 0-5000mV
    rect_v = rect_v + tlong;
    Delay_ms (100);
    }
```

GSM module is interfaced with the PIC microcontroller using the UART interface port. This port having Tx and Rx terminals and should be cross connected with the GSM module Tx/Rx ports. Sample coding for interfacing GSM module through UART port is given in the code segment below.

```
char UART_Init(const long int baudrate)
{
unsigned int x;
x = (_XTAL_FREQ - baudrate*64)/(baudrate*64);
if(x>255)
{
x = (_XTAL_FREQ - baudrate*16)/(baudrate*16);
BRGH = 1;
}
if(x<256)
{
        SPBRG = x;
        SYNC = 0;
        SPEN = 1;
          TRISC7 = 1;
          TRISC6 = 1;
          CREN = 1;
          TXEN = 1;
        return 1;
      }
      return 0;
}
char UART_TX_Empty()
{
 return TRMT;
}

char UART_Data_Ready()
{
  return RCIF;
}
```

```
char UART_Read()
{

  while(!RCIF);
  return RCREG;
}

void UART_Read_Text(char *Output, unsigned int length)
{
   int i;
   for(int i=0;i<length;i++)
               Output[i] = UART_Read();
}

void UART_Write(char data)
{
  while(!TRMT);
  TXREG = data;
}
void UART_Write_Text(char *text)
{
  int i;
  for(i=0;text[i]!='\0';i++)
  UART_Write(text[i]);
}
```

6.2 Implementation of the main software module

Software tools used during the implementation phase were selected as per the requirement, availability and easiness to use. Eclipse IDE was used to develop the PHP code segments which is an open source software tool. MySQL workbench was used for database designing and implementation.

There are some functions, which can be considered as major components in the system. Some functions are used for user activities while some others are used for system activities. Inputs to the system are generated by the IoT device, hence possibility for errors during the input process is minimized.

Connection to the database is done using a re-usable code segment as listed below.

```
<?php
$conn = mysqli_connect('localhost','root','1010');
        if (!$conn) {
        $error = true;
        die ("Sorry server is not responding. </br> Please try again later.</br>");
    }
?>
```

Major component of the software is the SMS receiving, decoding and storing the data in a database. SMS related functions are handled by code segments provided in annexure A.

Decision of whether the generator to be running or not will be determined by below algorithm. Both voltage and current values will be considered for the decision making to make it more accurate.

```
if ($current_voltage <= 48){
        //$sender->sendMessage("On",$address);
        $state = "on";
}else if (($current_voltage > 48 && $current_voltage <= 53) && $current_current >= 10){
        //$sender->sendMessage("Off",$address);
        $state = "off";
}else if (($current_voltage > 48 && $current_voltage <= 53) && $current_current < 10){
        //$sender->sendMessage("Off",$address);
```

```
        $state = "on";
}else{
        $state = "off";
}
```

To make the software more efficient, AJAX is used. This enables to refresh some segments of the web pages without reloading the full page.

Code segments with related to important implementation techniques are available in the annexure A.

6.3 Implementation of user interface (UI)

User interface is the final outcome of a software product that enables the interface between the user and the software system. It determines the usability of the system. A software system could be failed even though how much complicated and critical the system is yet the use interface is poor. Therefore, special attention was given to design an effective user interface to the system.

Key features of user interface - Simplicity

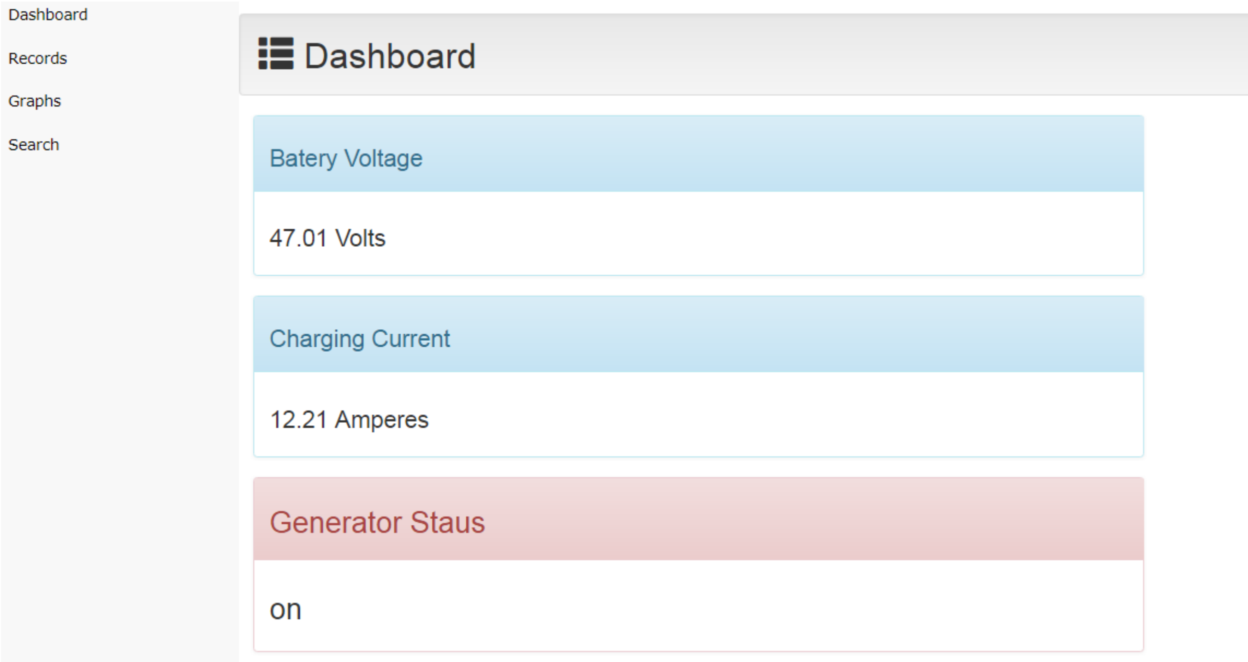


Figure 6-4 – Example of a simple GUI

Chapter 07

7 Testing and Evaluation of the system

7.1 Testing

Testing is a key factor in any software project. A proper test plan to be maintained from the beginning of the project to make sure the software (and hardware) is thoroughly tested throughout the development process. Proper test plan will enable to test all aspects of the software system and make sure the intended functions are working properly.

Since this project consist of specially implemented hardware components, the test plan was developed separately for the hardware and software modules.

7.1.1 Hardware testing

Modular testing approach was followed and below test plan was implemented with regard to hardware testing.

Unit / Module	**Test case**
IOT device – Software	When the programming was completed, the devices was simulated using the software to make sure the ports and logic is configured as per requirement.
IOT device – Hardware	It was initially tested whether the operating voltage of the IoT device is within the desired limits.
Voltage divider circuit	Tested whether actual voltages with respect to calculated voltage during the design stage are aligned.
Current meter output	Tested whether actual current value is reflected in the output of the current meter.
GSM module	Operating voltage SIM registration with the network Tx/Rx ports status
Opto coupler device	Relay function.

Table 7-1– Hardware test cases

7.1.2 Software testing

Standard testing procedures were followed to test the system and its functions during the implementation phase and also after the whole system were integrated. Main testing procedures were followed was black box testing and white box testing. White box testing was used in implementation phase to test the functions and the coding while black box testing was used to test the modules and integrated system. Proper testing was carried out throughout the project in-order minimize errors of the final system which is to be delivered to the client. Description of major steps in black box testing used are described in below paragraphs and all other tests cases are included in tables under each sub sections. Test plan was prepared in such a way that it tests all functions of the system. Unit testing was done during implementation of the project to identify whether each simple component is working properly. Functions of the system were tested by using functional testing which was carried out during the completion of adding each function. Final integrated system was tested to make sure the systems is free of errors and bugs.

Test case 1

Verify that each valid user can login to the system successfully	
Input	Valid username and a valid password
Expected Results	User should be able to log in to the system without any error.
Actual outcome	Success

Test case 2

Verify that each invalid user cannot login to the system and error message is displayed	
Input	Combination of invalid username and a invalid password
Expected Results	User should be blocked at the login and error message should display
Actual outcome	Success

Test case 3

Receive SMS and insert data into the database	
Input	SMS in the format “generator 00.00v00.00a”
Expected Results	Voltage value and current value should insert into the database with the receiving time taken by the system.
Actual outcome	Success

Test case 4

Send control signal SMS	
Input	Current system voltage and ampere values
Expected Results	If the generator running status needs to be changed as per the desired algorithm, a controlling signal message should generator and send via the system. Message format “on / off”. i.e: If the average voltage of the last 3 records is less than 48, a controlling message should generator as “on”
Actual outcome	Success

Test case 5

Dashboard, Records, Graphs, Search functions	
Input	User should select the desired function from a menu
Expected Results	User should directed to the relevant page and display the results correctly
Actual outcome	Success

7.1.3 System testing

After testing the hardware and software components separately a complete system test was carried out in order to make sure the integration was properly done. At this stage, the IoT device was connected to the live system and data was generated automatically by the system and transmitted them to the web server.

Test case 6

Complete system testing with automated data collection and transmission	
Input	Automatically collected data from the base station power supply unit
Expected Results	System should automatically collect the system information and transmit through the GSM module in the form of SMS, decode the SMS and insert values to the database, analyze the values and send the control signal.
Actual outcome	Success

7.2 Evaluation of the project with respect to its original goals

It is important to evaluate the system against the objective of the project. There are five major objectives of the project developing the low cost generator controller project. Achievements of the each goal at the end of the project are described below.

Design and implement hardware required to collect data and controlling the generator.

It was able to develop a hardware module with the help of microcontroller and using the theories of electronic to make sure it is capable of gathering system voltage and current, send the data through GSM module to a web server, send the controlling signal to the generator and so on.

Implement a communication media between the measuring devices, controller and a web server.

A communication device was implemented which is capable of communicating the data between the IOT device and the web server where the main software module is running.

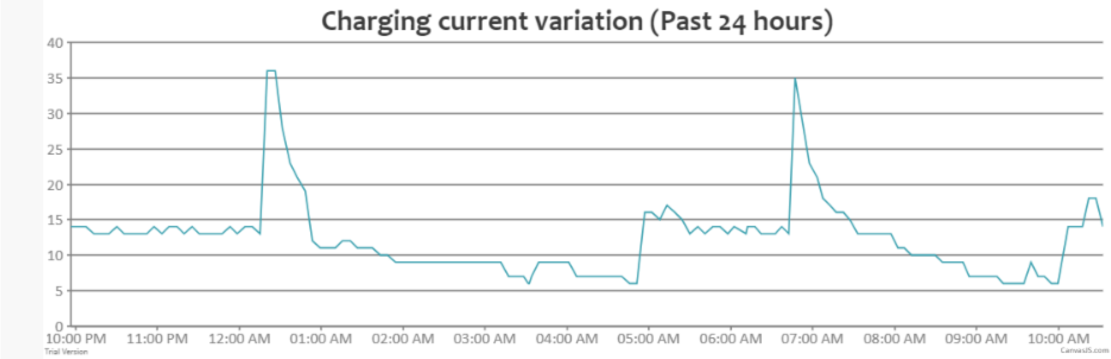
Develop a web based system to log, analyze and process data.

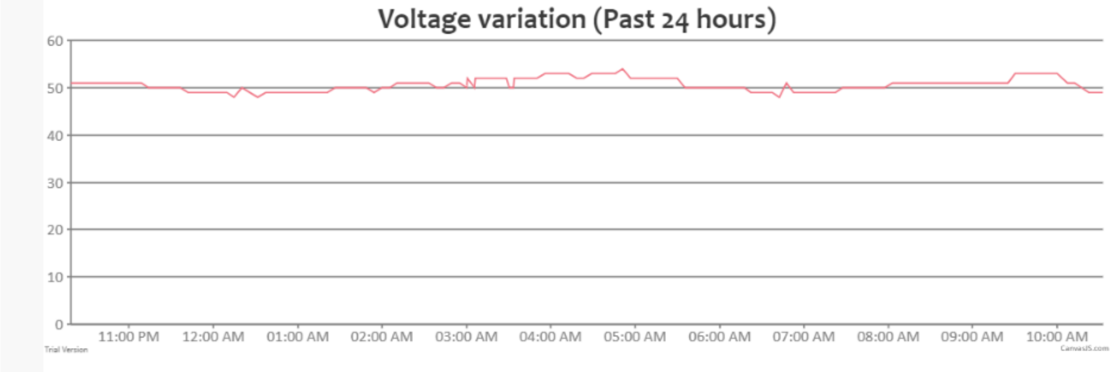
Developed software system was capable of storing the data with regard to base station power system such as voltage and current, analyze and process them. This objective was also successfully achieved.

Integrating the sub systems to generate automatic notifications from SMS's and emails (Daily, Weekly alerts, alarms etc.) was also successful.

It is clear that objectives related to the main project were successfully achieved.

7.3 System validation





The system was running for a test period and parameters (Charging current and voltage) are presented in a graphs to identify the charging and discharging patterns where in other words shows the generator running and stop cycles.

Charging current variation graph clearly shows the charging and discharging cycle and voltage variation graphs shows the voltage fluctuation is in between the desired floor and ceiling values which is 48V DC and 54V DC. (Operating voltage of the telecom equipment)

There were no outage reported during the test period due to power failures.

Validation of data within 24 hours period in a test site

Comparison of 24 hours running report is shown in table 7.1.

After implementation of the system	
Test duration	24 hours
Total generator running hours during the period	17.42 hrs
Total generator off hours during the period	6.58 hrs
Number of on/off cycles during the period	5

Manual operation	
Test duration	24 hours
Total generator running hours during the period	20 hrs Approx
Total generator off hours during the period	4 hrs Approx
Number of on/off cycles during the period	2

Technical details of the sample site

Number of BTS	1
TRX configuration	2/2/2
BTS type	Outdoor
Average load current	12 Ampere
Battery bank capacity	310 AH
Battery condition at the time of test period	Good

Above analysis shows that running hours of the generator has reduced approximately by 3.5 hours after implementing the system in the test site. This figure could be vary when considering long run and more accurate figure could be obtain after running the system for about 1 month.

Performance of the solution is highly depending on the condition of the primary battery bank which the load will be connected during the off period of the generator. The time taken to discharge battery bank up to the threshold levels is higher if the battery bank is healthy.

Chapter 08

8 Conclusion & Further work

8.1 Conclusion

After analyzing the results obtained from the test sites, it was shown some improvement in the running hours of the generators which is the main objective of the project. When considering the environmental and economic factors, even a reduction of few hours of running in diesel generator per day benefits a lot. This makes huge impact when considering the longer run and multiple number of off-grid sites. There are around 30 off-grid sites available only in Etisalat Lanka Pvt ltd network in Sri Lanka and the number could be much higher when considering other operators as well. It can be concluded that main objective of the project could achieved and it opens many areas to do research on future to further improve the project.

8.2 Further work

Since it shows positive results from the initial project work carried out, further testing and improvements could be added to the system.

- Since the test period is very short in a given location, the system should run for a longer during to obtain more accurate results. It is suggested that at least a one month test period should cover in one location for better results.
- This system should also tested with different locations where each having different loads in order to determine the behavior with the change of loads available in base station sites.
- Generator off time is purely depending on the capacity of the battery bank and the loads catering by the battery bank. Higher the battery bank capacity, it is higher the off period of the generator. Yet is should still evaluate the factors such as required capacity of the generator, battery charging current settings etc in order to determine the optimum battery bank capacity and generator capacities. Further testing to be carried out in this are for optimization.
- As the number of charging / discharging cycles are increased by introducing the system, the effect on the battery bank should be properly evaluated in terms of its life time and capacity degradation. Analysis to be carried out to compromise the reduced running hours with reduced battery life time. One method to overcome this impact is to introduce deep cycle type batteries which are

specifically designed for such type of systems and longer run effect to be further evaluated.

- This concept can also be used in backup generators as well in order to optimize running hours in case of backup running of the generator. Further testing to be carried out in this area. This will be beneficial in the areas where there are frequent and longer duration commercial power failures which is common scenario in rural areas of the country.
- The hardware module could be re-design by encapsulating the internal components to make it more attractive and easy to fix at any given location.

9 References

[1] A. Aris and B. Shabani, “Sustainable Power Supply Solutions for Off-Grid Base Stations,” *Energies*, vol. 8, no. 10, pp. 10904–10941, Sep. 2015.

[2] S. Lambert, W. Van Heddeghem, W. Vereecken, B. Lannoo, D. Colle, and M. Pickavet, “Worldwide electricity consumption of communication networks,” *Opt. Express*, vol. 20, no. 26, pp. B513–B524, 2012.

[3] A. Fehske, G. Fettweis, J. Malmodin, and G. Biczok, “The global footprint of mobile communications: The ecological and economic perspective,” *IEEE Commun. Mag.*, vol. 49, no. 8, 2011.

[4] C. R. Murthy and C. Kavitha, “A survey of green base stations in cellular networks,” *Int. J. Comput. Netw. Wirel. Commun. IJCNWC*, vol. 2, no. 2, pp. 232–236, 2012.

[5] “Etisalat web.”

[6] “Ecoscore.html.” .

[7] J. Lorincz, T. Garma, and G. Petrovic, “Measurements and Modelling of Base Station Power Consumption under Real Traffic Loads,” *Sensors*, vol. 12, no. 12, pp. 4281–4310, Mar. 2012.

[8] L. Decreusefond, T.-T. Vu, and P. Martins, “Modeling energy consumption in cellular networks,” in *Teletraffic Congress (ITC), 2013 25th International*, 2013, pp. 1–7.

[9] N. Faruk, A. A. Ayeni, M. Y. Muhammad, A. Abdulkarim, and O. Moses, “Hybrid power systems for cell sites in mobile cellular networks,” *Cyber J. Multidiscip. J. Sci. Technol. J. Sel. Areas Renew. Sustain. Energy JRSE January Ed.*, 2012.

[10] J. Lorincz and I. Bule, “Renewable energy sources for power supply of base station sites,” *Int. J. Bus. Data Commun. Netw. IJBDCN*, vol. 9, no. 3, pp. 53–74, 2013.

[11] “Smart2020Report.pdf.” .

[12] K. Kusakana and H. J. Vermaak, “Hybrid renewable power systems for mobile telephony base stations in developing countries,” *Renew. Energy*, vol. 51, pp. 419–425, Mar. 2013.

[13] International finance coperation, a world bank group, “Green power for mobile bi annual report 2014.” .

[14] S. Paudel, J. N. Shrestha, F. J. Neto, J. A. Ferreira, and M. Adhikari, “Optimization of hybrid PV/wind power system for remote telecom station,” in *Power and Energy Systems (ICPS), 2011 International Conference on*, 2011, pp. 1–6.

[15] D. Bezmalinović, F. Barbir, and I. Tolj, “Techno-economic analysis of PEM fuel cells role in photovoltaic-based systems for the remote base stations,” *Int. J. Hydrog. Energy*, vol. 38, no. 1, pp. 417–425, 2013.

[16] E. F. F. Ribeiro, A. J. Marques Cardoso, and C. Boccaletti, “Uninterruptible energy production in standalone power systems for telecommunications,” *Renew. Energy Power Qual. J.*, vol. 1, no. 07, pp. 351–356, Apr. 2009.

[17] S. Goel and S. M. Ali, “Hybrid energy systems for off-grid remote telecom tower in Odisha, India,” *Int. J. Ambient Energy*, vol. 36, no. 3, pp. 116–122, May 2015.

[18] K. Ranjith Kumara, , P. Sruthib, and and M. Surya Kalavathi, “Power Management in Standalone Hybrid Power System.” 29-Nov-2017.

[19] P. Lehman, C. Chamberlin, J. Zoellick, R. Engel, and D. Rommel, “Fuel cell/photovoltaic integrated power system for a remote telecommunications repeater,” in *Proceedings of the 14th World Hydrogen Energy Conference, Montreal, QC, Canada*, 2002, pp. 9–14.
[20] G. Koutitas and P. Demestichas, “A review of energy efficiency in telecommunication networks,” *Telfor J.*, vol. 2, no. 1, pp. 2–7, 2010.
[21] http://massiveelectronicsbd.com/client.php, “Voltage dependent timers for generator controllers.” .
[22] P. S. Georgilakis, “State-of-the-art of decision support systems for the choice of renewable energy sources for energy supply in isolated regions,” *Int. J. Distrib. Energy Resour.*, vol. 2, no. 2, pp. 129–150, 2005.
[23] “Abu Taha and Daim - 2013 - Multi-Criteria Applications in Renewable Energy An.pdf.” .
[24] iot.ieee.org, “Towards a definition of the Internet of Things (IoT).” .
[25] http://www.polytechnichub.com/advantages-disadvantages-microcontroller/, “Advantages and disadvantages of microcontroller - Polytechnic Hub.html.” .
[26] J. J. Grimm, “Electromagnetic linear actuator-design, manufacture and control,” 2009.
[27] B. Yarborough, “Components and Methods for Current Measurement,” *Power Electron.*, 2012.
[28] Texas instruments, “Universal Asynchronous Receiver/Transmitter (UART).” .

10 Annexure A

Sample code listing - Ajax

```
<?php
include("dbconnection.php");
if(isset($_REQUEST["fromT"]) && isset($_REQUEST["untilT"])){
	$from = $_REQUEST["fromT"];
	$until = $_REQUEST["untilT"];
	$query1 = "SELECT msg_id from details where (mili_time>='$from' && mili_time<'$until')";
	mysqli_select_db($conn,"manjitha0717_db");
	$res = mysqli_query($conn,$query1);
	$ret = 0;
	$ids = array();
	if($res){
		while($row=mysqli_fetch_array($res,MYSQLI_ASSOC)){
			$id = $row['msg_id'];
			array_push($ids,$id);
		}
	}
	foreach ($ids as $id) {
		mysqli_select_db($conn,"genny");
		$query2 = "select * from details where msg_id='$id'";
		$res = mysqli_query($conn,$query2);
		$row=mysqli_fetch_array($res,MYSQLI_ASSOC);
		if($row['state'] == 'on'){
			$ret++;
		}
	}
	echo $ret*5 ;
	exit();
}
```

```
if(isset($_REQUEST["fromDTime"]) && isset($_REQUEST["untilTime"])){//give two milisecond vlues to $from and $until
        $from = $_REQUEST["fromDTime"];
        $until = $_REQUEST["untilTime"];
  $query1 = "SELECT msg_id from details where (mili_time>='$from' && mili_time<'$until')";
  mysqli_select_db($conn,"manjitha0717_db");
  $res = mysqli_query($conn,$query1);
  $ret = 0;
  $ids = array();
  if($res){

    while($row=mysqli_fetch_array($res,MYSQLI_ASSOC)){
      $id = $row['msg_id'];
      array_push($ids,$id);
    }
    }
  foreach ($ids as $id) {
    mysqli_select_db($conn,"manjitha0717_db");
    $query2 = "select * from details where msg_id='$id'";
    $res = mysqli_query($conn,$query2);
    $row=mysqli_fetch_array($res,MYSQLI_ASSOC);
    if($row['state'] == 'on'){
      $ret++;
    }
  }
  echo $ret*5;
  exit();
}
if(isset($_REQUEST["fromMTime"]) && isset($_REQUEST["untilTime"])){//give two milisecond vlues to $from and $until
        $from = $_REQUEST["fromMTime"];
```

```
        $until = $_REQUEST["untilTime"];
  $query1 = "SELECT msg_id from details where (mili_time>='$from' && mili_time<'$until')";
  mysqli_select_db($conn,"manjitha0717_db");
  $res = mysqli_query
($conn,$query1);
  $ret = 0;
  $ids = array();
  if($res){

    while($row=mysqli_fetch_array($res,MYSQLI_ASSOC)){
      $id = $row['msg_id'];
      array_push($ids,$id);
    }
  }
  foreach ($ids as $id) {
    mysqli_select_db($conn,"manjitha0717_db");
    $query2 = "select * from details where msg_id='$id'";
    $res = mysqli_query($conn,$query2);
    $row=mysqli_fetch_array($res,MYSQLI_ASSOC);
    if($row['state'] == 'on'){
      $ret++;
    }
  }
  echo $ret*5;
  exit();
}
?>
```

11 Annexure B

Sample records

Time duration Minutes between two records	System Voltage	System current	Gen running Status
5	47	37	On
5	48	35	On
5	49	19	On
5	49	12	On
5	49	12	On
5	50	12	On
5	50	12	On
5	50	11	On
5	50	12	On
5	51	11	On
5	51	12	On
5	51	11	On
5	51	11	On
5	51	11	On
5	51	11	On
5	51	11	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	8	On
5	51	9	On
5	52	8	On
5	52	8	On
5	52	9	On
5	52	8	On
5	52	8	On
5	52	7	On
5	52	7	On
5	53	6	On
5	53	6	On
5	53	6	On
5	52	6	On
5	52	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	54	6	Off
5	50	14	Off
5	50	14	Off
5	50	13	Off
5	50	14	Off
5	50	14	Off
5	50	13	Off
5	50	14	Off
5	50	13	Off
5	50	14	Off
5	49	14	Off
5	49	13	Off
5	49	13	Off
5	49	13	Off
5	49	14	Off
5	49	12	Off
5	49	14	Off
5	49	13	Off
5	49	12	Off
5	48	13	Off
5	48	14	Off
5	47	39	On
5	50	37	On
5	50	35	On
5	50	21	On
5	50	18	On
5	50	12	On
5	50	12	On
5	50	12	On

5	50	12	On
5	50	11	On
5	50	11	On
5	50	11	On
5	50	10	On
5	51	10	On
5	51	10	On
5	51	11	On
5	51	10	On
5	51	10	On
5	51	9	On
5	51	9	On
5	51	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	53	7	On
5	53	7	On
5	53	7	On
5	53	8	On
5	53	7	On
5	53	7	On
5	53	7	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	53	6	On
5	54	6	Off
5	52	14	Off
5	51	14	Off
5	51	13	Off
5	51	13	Off
5	50	13	Off
5	50	14	Off

5	50	13	Off
5	50	13	Off
5	50	13	Off
5	50	13	Off
5	49	14	Off
5	49	13	Off
5	48	14	Off
5	48	14	Off
5	47	35	On
5	51	35	On
5	49	27	On
5	49	18	On
5	49	17	On
5	49	17	On
5	49	12	On
5	49	11	On
5	49	11	On
5	50	10	On
5	50	11	On
5	50	9	On
5	50	9	On
5	50	9	On
5	50	9	On
5	50	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	7	On
5	51	7	On
5	51	7	On
5	51	7	On
5	51	7	On
5	51	6	On
5	53	6	On
5	53	6	On

5	53	6	On
5	53	9	On
5	53	7	On
5	53	7	On
5	53	6	On
5	53	6	On
5	52	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	On
5	54	6	Off
5	52	14	Off
5	52	14	Off
5	52	13	Off
5	51	13	Off
5	51	13	Off
5	51	14	Off
5	51	13	Off
5	51	13	Off
5	51	13	Off
5	51	13	Off
5	51	14	Off
5	51	13	Off
5	51	14	Off
5	50	14	Off
5	50	13	Off
5	50	14	Off
5	50	13	Off
5	50	13	Off
5	49	13	Off
5	49	13	Off
5	49	14	Off
5	49	13	Off
5	49	14	Off
5	49	14	Off
5	49	13	Off
5	50	13	On
5	49	13	On

5	48	38	On
5	49	33	On
5	49	23	On
5	49	19	On
5	49	12	On
5	49	11	On
5	49	11	On
5	49	11	On
5	49	12	On
5	49	12	On
5	50	11	On
5	50	11	On
5	50	11	On
5	50	10	On
5	50	10	On
5	49	9	On
5	50	9	On
5	50	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	51	9	On
5	50	9	On
5	50	9	On
5	51	9	On
5	51	9	On
5	52	9	On
5	52	9	On
5	52	9	On
5	52	7	On
5	52	7	On
5	52	7	On
5	52	7	On
5	52	9	On
5	52	9	On
5	52	9	On
5	53	9	On
5	53	9	On
5	53	7	On
5	53	7	On
5	52	7	On
5	52	7	On

5	53	7	On
5	53	7	On
5	53	7	On
5	53	6	On
5	54	6	On
5	54	16	On
5	54	16	On
5	54	15	On
5	54	17	On
5	54	16	Off
5	52	15	Off
5	52	13	Off
5	50	14	Off
5	50	13	Off
5	50	14	Off
5	50	14	Off
5	50	13	Off
5	49	13	Off
5	49	13	Off
5	48	14	Off
5	49	13	Off
5	49	13	Off
5	49	13	Off
5	49	13	Off
5	49	14	Off
5	48	13	Off
5	47	14	On
5	50	36	On
5	49	29	On
5	49	21	On
5	49	18	On
5	49	13	On
5	49	13	On
5	49	13	On
5	49	14	On
5	49	13	On
5	49	14	On
5	50	14	On
5	50	12	On
5	50	13	On
5	50	13	On
5	50	12	On
5	50	13	On
5	50	11	On