THE APPLICATION OF INTERNET OF THINGS (IoT) TO THE TRADITIONAL POWER GRID

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A thesis submitted to the Department of Electrical and Electronic Engineering in partial fulfillment of the requirements for the degree of

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Declaration

It is hereby declared that

1. The thesis submitted is our own original work while completing degree at Brac University.
2. The thesis does not contain material previously published or written by a third party, except where this is appropriately cited through full and accurate referencing.
3. The thesis does not contain material which has been accepted, or submitted, for any other degree or diploma at a university or other institution.
4. We have acknowledged all main sources of help.

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Abstract

The use of Internet of Things (IoT) in the traditional power grid has the potential to pave the way for the deployment of modernized Smart Grid in Bangladesh. This integration of IoT will not only cater for the exponential rise in demand for energy, but also to improve the reliability of the data sent to the control station. The system is used to prioritize effectiveness and security as it gives consumers a way to track their power usage and manage electricity better. This intelligent infrastructure is used to analyze the accuracy of data transmission after it is passed through the Additive White Gaussian Noise (AWGN) channel. The data is collected and converted into binary digits via a transmitter and then sent to the receiver. The main purpose of this paper is to methodically examine the coherence and integrity of the data by comparing the information at the transmitter and receiver sides and evaluating the signal-to-noise ratio (SNR) to estimate the percentage error in the system. We observed approximately 20% more packet loss for the same SNR values in the 1 second delay case than the 0 second delay case. Hence, the feasibility of the IoT was determined.

Keywords: Smart Grid, SNR, AWGN, IoT

Dedication

DEDICATED TO OUR PARENTS

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Chapter 1

Introduction

1.1 Introduction to Smart Grid

For the last 150 years, the traditional power grid has managed to outgrow all of our electrical demands, and has stood strong in the face of multiple natural calamities and human interventions. However, despite the technological advancements in the reliability, efficiency and security domains of the traditional power grid, the upcoming energy challenges and digitalization beg for a newer, better, and a more modern version of the traditional grid that lives up to all the niches of the modern world. This growing demand also calls forth for a change in the way the power is communicated and thus, the customers want more transparency in what they are getting and at what rates. A two way communication has thus far been implemented as part of the Smart Grid, which helps the consumers with their usage data as well as data on on-peak and off-peak hours and rates thus providing efficient consumption, generation and monitoring process during power generation and distribution.

The idea of two-way communication presented above can be executed by using Smart Meters. Smart meters are electronic devices that record consumption of electric energy and communicate the information to the electricity supplier for monitoring and billing. Smart meters potentially assist us in the collection of data through which power generation plants can predict the peak demand periods. Europe already plans on replacing 80% of their traditional electricity measuring meters by Smart meters by 2020. This will reduce the annual emission and also unnecessary electricity consumptions in households by roughly 9%. A survey by export.gov predicts that approximately 1.7 billion people are expected to be connected to the traditional electric grid by 2030. This calls for an immediate proactive action to implement smart meters for the electric grids since generation and consumption will be at an all-time high. Moreover, Canada has been the leading advocate of Smart Grid in the world, closely followed suit by Japan and Saudi Arabia. India and China are currently leading the role of actively participating in the digitalization of the electric grid into Smart Grid for the Asian countries. The outlook for Smart Grid looks as good as ever, and the requirements for digitalization of the 150 year old electric grid are now coming to fruition.

As smart grid is getting recognized and acknowledged globally its market value has seen an exponential growth over the years. Since smart grid provides a systematic communication between consumers and suppliers, it gives a chance for both the parties to have a strategic operational plan in terms of willingness to pay and energy price set, respectively. Smart grids provide us with real time values with its automated infrastructure that determines the amount of energy used during peak time and off peak time. This technological advancement allows the conservation of energy and in turn gives people a chance to utilize energy with flexibility. Due to its growing recognition and shift in paradigm, the use of smart gird has taken the market by storm. Its significant transformation has made several governments to implement its use in their respective countries. The Market Research Future (MRFR) has published a report stating how the global market of smart grid is booming and expected for further gain over the forecast period. The market value is expected to rise approximately around USD 52 billion by 2023 with a Compound Annual Growth Rate (CAGR) of 20%.

On the other hand, some factors such as large initial investment cost with the classification of technology solutions for smart grid infrastructure and other safety concerns related to cyber security and vulnerabilities in the energy industry can obstruct the market growth. The development of low technological products can counterfeit the use of smart grid, restraining its growth in the global market during forecast period. Despite these, the tremendous projected market size of SG over the course of 6 years is show in figure 1.1 below

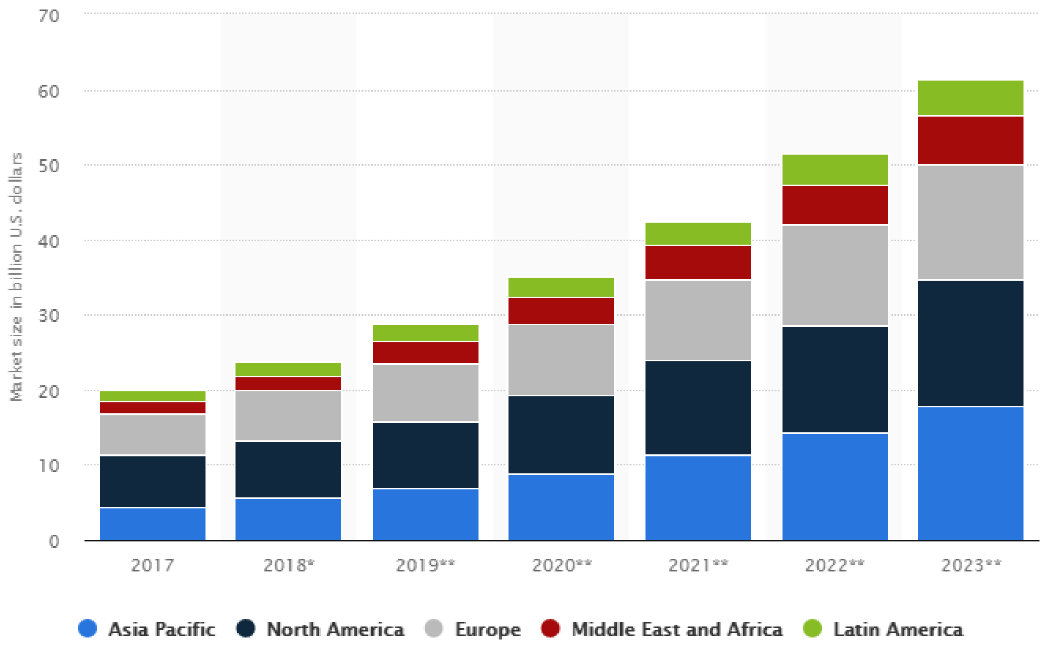


Fig. 1.1: The projected market size of SG over a 6-year period [16]

1.2 Feasibility of Smart Grid in Bangladesh's perspective

Most developed countries have already implemented a form of the Smart Grid into their power and energy infrastructure. This made the charging of hybrid Plug-in vehicles even more feasible than ever, since these can be charged during off-peak hours. The charging of these vehicles is known to be power hungry and thus put considerable stress on the overall electricity generation. The step forward to digitalizing the power infrastructure is easier in those countries given how they have already made the effort to introduce and implement Bi-directional power, smart homes and consumer flexibility. However, the step onto Smart Grid from traditional grid for Bangladesh would, at face value, still prove to be quite the hurdle for the initial part of the implementation. Despite the hurdles, the journey towards this particular goal can be smoothened out by eradicating the major grid problems that Bangladesh faces right now. Some of these are:

1) Poor planning of distribution network
2) Severe power sector corruption
3) Severe power theft
4) Little to no reactive power identification and regulating services
5) Overloading of already aging system components
6) Lackadaisical maintenance of the systems in general

Smart Grid, even in its infancy, can rectify a large portion of the above problems. The planning required to device the Smart Grid infrastructure would require a different planning of distribution network which will overthrow the earlier poor planning of the distribution network. Moreover, automation of the grid generation, usage and loss will provide and secure all energy usage data to outstanding accuracy, and as such, manipulation of any data for corruption or theft is little to impossible. Furthermore, smart meters can identify and monitor the reactive power consumed and generated, and so the billing can be made appropriately. With newer infrastructure, older components will now be replaced by newer and more efficient components. The current power lines are in an entangled mess and as such, proper power lines are very difficult to identify and diagnose in the case of power cuts, and considerable resources and time are wasted locating these transmission line faults. All these can be eliminated by Smart Meters as they use sensors and hence can monitor both the type as well as the nature and severity of the faults. With the self-healing and fast switching characteristics of Smart Grid, the faults can easily be located and cleared automatically

Table 1.1 portrays the current power condition of Bangladesh against the benefits that SG can bring to Bangladesh in the long run. From the table, it is clear that the current power grid is in dire need of SG implementation, and a huge plethora of problems can be resolved upon the application of this initiative.

Table 1.1: The Current power condition vs the Benefits that SG can bring [17]

Current power condition in Bangladesh	**Benefits of SG Implementation in Bangladesh**
Current power generation is highly Centralized.	Power generation will be centralized and distributed.
If there is a fault in Transmission and distribution system the fault can be identified automatically but it can’t recover automatically. So manual intervention is necessary.	Smart grid technology can recover the fault automatically. It can also reduce additional transmission lines.
Distribution system is not atomized. Mostly fragmented and divided.	Atomized and it processes real-time information from sensors and meters for fault location, automatic reconfiguration of feeders with voltage and reactive power Optimization.
No modern technology to reduce transmission loss.	Smart grid can reduce the reactive power flow and maximize the amount of real power to minimize transmission losses and maintain a proper power factor (pf).
Load shedding is due to sufficiency of circuit breakers (CB) in the distribution network. These CBs are not remotely operable.	Smart grid requires digital radios to wirelessly control the distribution network. Under this system the area will be divided into two very small regions and if fault occurs the entire area is not affected.
Most meters are electromechanical and the security system of these meters is very manipulable and poor.	Most meters are digital. They can detect defective and bypassed meters.
Only distributed sources are implementable.	Both renewable energy and distributed sources are implementable on the SG framework.
Billing problem is a major concern. Meter readers are not concerned about bill collection but very much concerned about harassment and corruption with consumers.	It can eliminate billing error, detect dues in bills, remotely disconnect for non-paying consumers and reconnect after payment. These can all be done automatically.
Many transformers are lost each year to theft and authorities fail to find them due to limited technology.	With the appropriate sensors, theft detection of transformer level is possible.
Communication is not present, or if present it is one way and not real time.	Both two way and real time.
Control of power flow is limited and uni-directional.	Power flow is automated, comprehensive and multiple power flow pathways exist.

However, the above steps for rectification are definitely not easy for a country like Bangladesh that is still in its developing stages. A proper re-planning of distribution network from scratch and implementation would be quite expensive to get started. According to the Bangladesh Power Development Board (BPDB), the power sector ran on a net loss of 3,963tk Crore in the financial year 2009-2010. It is only recently that the power sector has seen the light of profit for perhaps the first time. Table 1.2 shows the total revenues and the total expenses for the financial year 2016-2017 and 2017-2018. A profit of 6,207.47tk Crore was made in the last financial year, 2017-2018 and roughly 1,577.87tk Crore the year before. However, despite the profits, the complete implementation cost of SG would be nearly impossible for Bangladesh to bear alone. In addition to the obvious lack of financial grounding, the automation of the entire grid system as well as the installations of consumer side meters would require a massive scale initiative to install smart meters and radio communication technologies. This also involves going into consumer's homes and installing these meters under their full acknowledgement. This would mean that the consumers need to be fully aware of such a grid system and its necessities in their lives, and this would require mass awareness programs which can prove to be quite time and resource consuming.

Table 1.2 Total revenues and expenses for the financial years 2016-2018 (Crore) [18]

Particulars	Financial Year (FY) 2017-2018	Financial Year (FY) 2016-2017
Operating Revenue	**30,604.41**	**281295.22**
Operating Expense	**36,811.89**	**29,873.09**
Fuel Cost	6,122	3,499.89
Generation Expenses	2406.33	2,115.27
Electricity Purchase from IPP	10,410.59	8,733.87
Electricity Purchase from Rental	6,281.73	6,001.41
Electricity Purchase from Public Plant	7,289.54	5,340.11
Electricity Purchase From India	2,812.58	2,592.55
Wheeling charge to PGCB	182.92	255.20
Distribution Expenses	923.53	955.29
General & Administrative Expenses	382.68	379.49
Operating Profit	**6,207.47**	**1,577.87**

1.3 Literature Review

Faheem *et al.* (2018) provides a comprehensive idea about the use of smart in the perspective of industry 4.0.The industry 4.0 also known as the fourth industrial revolution has improved the development of Power grid (PG) also known as Smart grid (SG). Even though SG provides immense opportunities, many challenges are lurking in the context of Industry 4.0. Hence this paper gives an overview about the comprehensive use of smart grids with its international standards and also an idea about it benefits, applications and different features. This paper also explores both wired and wireless communication technologies and also the areas for further future development. The main approach for Industry 4.0 is to reduce faults significantly and to adapt to higher productivity to increase benefits economically. This article mainly focuses on the communication technologies, its applications and the components used in smart grid in the context of industry 4.0. [1]

Husain *et al.* (2018) aimed to utilize the renewable energy resources by using Smart grid which is also known as the next generation electricity grid that combines information and communication technologies and control system. The use of renewable energy resources (RER) has been desired for electricity generation due to the rise in energy costs, global environmental changes, nuclear power generation risks and loss in present day electricity grid. The object of this article is to shift demand from non-renewable resources such as fossil fuel based generator to RER. The goal is to move smart gird towards a hundred percent electricity generation from RER in order to reduce greenhouse gas emissions and gain economic benefits. However the widely distributed geographic nature of the RER has made it complicated to incorporate RER into SG. Hence this paper uses communication networks to integrate RER into SG and supports it by using ongoing research papers. [2]

Govinda *et al.* (2018) wrote about the integration of smart grid on the electricity power grid and ICT since it is sustainable, reliable and provides green electricity energy with advanced technologies and communication system. This provides flexibility and management but the infrastructure of smart grid is critical since large scale ICT must be augmented. Regardless smart grid is the best infrastructure used for the management system since its can handle a large set of it. Furthermore, the service providers face tremendous problems due to theft identification which makes a huge loss for the power management and provider. Hence, in this paper a new model has been introduced to secure power management and to handle the power loss in the system. [3]

Chin *et al.* (2017) surveys the security and energy big data analytics issues on Smart Grid based on Internet of Things and also demonstrates a new energy big data that employs a replay approach with both DC and AC state estimations which is verified by using simulations. Due to the increased intelligence and automation in smart grid we get demand response with increased efficiency and reliability with fault recovery. However, problems such as public communication infrastructure and Internet-based protocols arise in smart grids. In order to deal with security threats and other blackouts a warning should be provided at an early stage. In this paper, replay scheme is used to avoid big data attacks stealthily and to geometrically figure out how to eradicate those attacks by detecting bad data successfully using DC or AC state estimations. [4]

Mekkaoui *et al.* (2017) introduce the global use of renewable energy sources such as solar and wind energy in the context of two way communication and power flow. The integration of smart grid will provide the efficiency in utilizing resources to optimize the consumption of energy. The use of wired and wireless communications has led to the two way communication system using smart grid. As a result, a large amount of data can be handled with the reduction of commutation protocols since the evolution of smart grid. Hence, this paper states how Matlab Simulink is used to design a smart grid in order to approach the analysis of Active Power which in turn gives the idea of the range of maximum permissible load so that it can be connected to their relevant bus bars. This paper also presents the change in value of Active Power in small scale analysis by varying load angle. [5]

Rana (2017) organizes the paper by talking about the architecture and future prospects of Internet of energy (IoE) communication, introduces the state-space microgrid model and it estimated algorithm and then gives the results simulated from the research. The renewable energy resources such as wind turbines are integrated into the grid due to environmental crisis such as global warming and also loss of energy production. An AC microgrid that generates energy units, local loads and electronic devices is modeled and needs to be located on isolated areas so that it can be monitored on real time. In this paper the writer elaborates on the framework that would be used to create a suitable and efficient microgrid which will in turn provide efficient dynamic state estimations. [6]

Gore *et al.* (2016) wrote about the WAMS (IoT) deployment in smart grid and the large amount of data that needs to be processed in real time. The use of Internet of things have paved the way to make it easier and beneficial for businesses by providing a way for data to be utilized in decision making and visualization. The traditional ways have been far more challenging to operate for the power industry to cope with the instability and blackouts etc. Since electricity grids are expanding with increasing power demands it is becoming more complex to protect and monitor the grid. Hence, this paper introduces the WAMS or the Internet of Things deployment in grid and the challenges it faces using Big Data. A better idea of the problems are provided with in the context of India by using the Indian grid case studies. [7]

Hidell *et al.* (2016) talked about the challenges in using Internet of Things on Smart Grid, IoT architecture and communication models used for SG, examines the functions of it and then talks about its future prospects. Even though the use of IoT is crucial and necessary for smart grids the fact that it has a limited amount of responsiveness cannot be ignored since there might be a time sensitive issue of smart grid and this drawback may cause a communication delay. Hence, to facilitate this problem the deployment of IoT is considered in domestic environment with a small scale and easily programmable direct current (DC) grid with the use of low-power hardware and limited capacity. The aspects of communications in IoT are considered for control and monitoring functions. Furthermore, even though the use of DC-DC converters is relatively cheap with low power consumption there are still possibilities of processing delays. In order to mitigate this problem sending bursts of commands with scheduled responses seem to reduce the response time delay significantly as identified by the researchers of this paper. [8]

Cacciapuoti *et al.* (2015) talked about the attractiveness of the characteristics of TV White Space which is used to enable multiple and independently-operated secondary networks using Cognitive-Radio. However, as there is still no coexistence among heterogeneous secondary networks over TVWS their mutual interference is therefore severe. This problem becomes even more challenging in areas of multiple Neighborhood Area Networks (NAN) with tight latency and energy requirements. Therefore, in this paper this challenge among multiple NANs is addressed with the objective to maximize its data rate. Furthermore, the sensing time value with maximized expected data rate is derived so that the analytical results can be validated by theoretical values. [9]

Zafar *et al.* (2014) talks about the efforts of using smart grids in order to improve the existing security efforts. It is crucial to be concerned about the system security in the development of an SG. This paper focuses on how system security analysis can help elicit, categorize and specify the security requirements of the smart grid. The Security Quality Requirements Engineering (SQUARE) method is used as an analysis method to represent security system. This research tackles the lack of smart grid system security requirements specification using the applications of SQUARE and analyses the results of the system-of-systems representation and the interactions of the design in the smart grid. [10]

Wang *et al.* (2013) proposed the communication infrastructure of cognitive radio networks for SG in order to efficiently support the wireless transmission of a huge amount of multimedia data which happens to be based on bandwidth. Even though smart grids have a high reliability and low latency requirements they still face harsh environmental conditions since large chunks of data are being transmitted over the smart grid using wireless communication with increased interference and congested radio spectrum. Therefore the requirements of smart grid communications in the growing needs of multimedia applications can be fulfilled by the vast features of cognitive radio networks. In addition, this paper introduces the problems and solution of cognitive radio networks with multimedia application for smart grid communications and presents its future prospects. [11]

Deng *et al.* (2013) introduce the importance of the applications of cognitive-radio with spectrum sensing into a smart grid to improve communication reliability, the control performance of DRM is accessed to check the communication quality and the problem in sensing- performance of tradeoff is evaluated to provide both theoretical analysis and verified simulation. The best way to balance real-time load and shift peak-hour load is by using demand response management (DRM) as a control unit for smart grid. This paper focuses on the use of cognitive-radio into smart grid to upgrade communication quality. Communication outage can be reduced by means of spectrum sensing and channel switching. Hence, this paper analyzes the DRM on control performance and uses energy detector to confirm the existence of optimal sensing time which helps to yield maximum tradeoff revenue with the constraint that licensed channel are protected with numerical results to back up the theoretical analysis. [12]

Chang *et al.* (2013) basically gives us an insight about how cognitive radio protocol can be used for the two way communication of advanced metering infrastructure (AMI). AMI is a mesh network which utilizes Zigbee protocol due to its low cost and low power requirements. But the Zigbee has a number of limitations, like limited range of communication in a single hop. Even the use of Ethernet in smart grid has proven to have restriction in its establishment of wired system. Hence cognitive radio (CR) can be used to overcome these restrictions as it has the capability of acknowledging the surrounding radio environment and also operate on unused channels without interfering with primary users. Despite being integral part of communication CR also has some constraints. CR has the problem of self-interference which restricts its performance. This happens due to the correlation and connection of an unplanned system that simultaneously desires to access the same signal bands together. In order to mitigate this problem the concept of beam forming is introduced which uses the minimum mean squared error (MMSE) method in smart meters. This method provides the accurate estimations of channel and also provides the noise-interference power estimation. Hence in this paper, beamforming is used to mitigate the limitations of cognitive radio. [13]

Zhang *et al.* (2011) presents key issues and solutions to cognitive radio-based communications infrastructure for the smart grid, with the architecture. The emergence of new challenges in infrastructure and environment caused by the increased usage in technology is bringing about a drastic change. In order to increase the efficiency, effectiveness and reliability of communication technology, internet-connected power grids also known as smart grids play an important role to increase sustainability and improve stability. This article identifies the basic challenges faced in the data communication of smart grid and finds out a method to standardize ongoing efforts in the industry. The idea of the unparalleled cognitive-radio-based communications architecture is presented for smart grid. The suggested architecture is divided in to three subareas: cognitive home area network, cognitive neighborhood area network and cognitive wide area network depending on the potential of the applications and their service ranges. Constructive identification has been made to achieve network scale performance optimization in order to decompose NAN and WAN in geographic subareas. [14]

Liu *et al.* (2011) lays out the requirements of Internet of Things (IoT) in smart grid, the architecture used to present IoT and discuss important technologies of IoT in smart grid. Furthermore, this paper also studies the communication networks of IoT in smart grid and outlines its applications. This paper reviews the applications of smart grid in China as smart grids can be used to create various intelligent services with the help of IoT. There are three layers: the perception layer, the network layer and the application layer to introduce the layout of China’s smart grid architecture. To add to that, the applications and solutions of IoT are explained in details for power transmission line monitoring, smart patrol, smart home and electric vehicle management. [15]

1.4 Objective of Thesis

The purpose of this thesis is to evaluate the performance of small scale smart grid in Bangladesh's perspective and analyze the integrity of transmission of data from the transmitter to the receiver end. To reach our target goal, we have identified the following objectives:

1. To setup a small scale micro grid connected to a large power system
2. To analyze the load and power curves of the system components
3. To observe the behaviors of every components over a 24 hour period
4. To compare the data values from the transmitter and receiver sides and checks the error rate and the packet loss for a given SNR.

1.5 Organization of the Thesis

This thesis is organized into 4 chapters as follows:

Chapter-1 is the introduction of the thesis. It contains the discussion about the condition of the traditional grid in the world, the necessity of a new power grid infrastructure to replace the old, the feasibility of SG and its advantages and disadvantages in Bangladesh's perspective; and finally the impressive market value of SG. This chapter was concluded with the inclusion of the literature to briefly discuss the significant previous works on SG and its respective communication systems

Chapter-2 has three parts. Firstly, we discussed the entire IoT applied to SG infrastructure that we have designed, from the generation all way to transmission and ultimately distribution to the consumers. Secondly, it contained the system models with designs of the load and PV sides of the Simulink model and their explanations. Thirdly, the IoT prototype and the entire process of conversion, transmission, reception and ultimately the error calculation of the data was explained and articulated.

Chapter-3 contains the essential discussion of the results and graphs that we generated in chapter 2, from the load side consumption all the way to the power consumption and transmission of the battery for the entire duration of the simulation. This also contained the necessary graphs portraying the integrity of data being transferred over the IoT network.

Chapter-4 highlights the concluding remarks of all the chapters and proposes some further work and development in this area of research

Chapter 2

IoT based Smart Grid

2.1 Power Generation

2.1.1 Gas Turbine Generator

The power grid and the corresponding transmission line model is shown in Fig. 2.1. The model consists of 5 major Simulink blocks used to simulate a basic electric power grid from Generation to Transmission. The Gas Turbine Generator is simulated as being a 3 phase Non ideal Voltage source in series with an RL circuit. The resistor and inductor in series model the internal resistance and inductance of the generator armature coils, respectively. The generator is modeled as a 3 phase Wye connected source with the neutral grounded. Furthermore, the phase to phase voltage is generated at 19KV RMS at 50Hz with phase A being at 0 degrees. The 3-phase short-circuit level at base voltage (VA) is taken to be 279MW, which is the rated power generated at the New Haripur Power Plant in Bandar, Narayanganj. The base voltage is 25KV phase-phase at RMS. In compliance with the IEEE standard, the X/R ratio is taken to be 7.

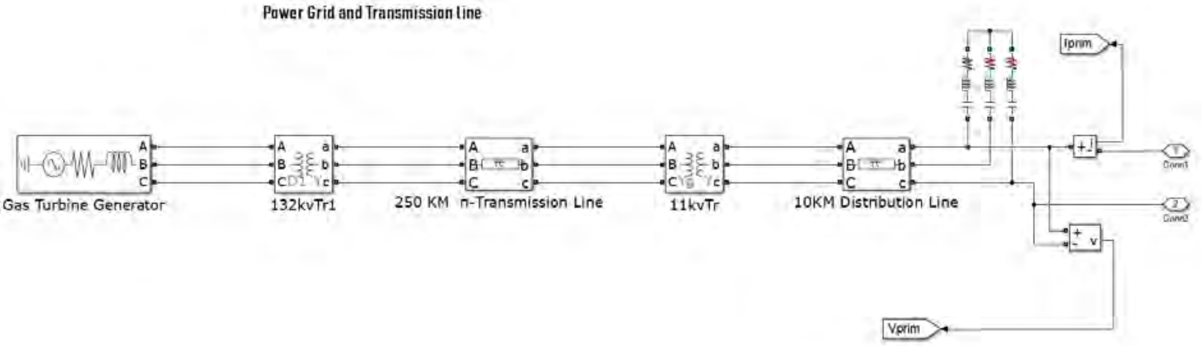


Fig. 2.1: An overview of the entire Power Grid and Transmission Line [19]

2.1.2 19/132KV Step up transformer

Subsequently, the 19KV voltage at the generator side is stepped up to 132KV by a Delta-Wye 3 phase, 2 winding transformer. The step up transformer has a nominal power of 120MVA at a frequency of 50Hz. The series resistances of the primary and secondary windings are 0.002 Per Unit (PU), and series inductance is 0.08PU. The magnetizing resistance and inductance are both 500 PU. The transformer steps up the voltage to a standard value of 132KV for the long distance power transmission. This high voltage results in a very small current in the transmission line and thus the I^2R losses are reduced in the transmission lines.

2.1.3 250KM Pi-transmission line

The 132KV on the secondary side of the step-up transformer block is now fed into the transmission line block of the Simulink model, which simulates a three-phase transmission line with a single PI section. This block of PI section represents a transmission line of length 250Kilometer (KM), which can be classified as a long line. Thus, we have decided to use the long line pi model of the transmission line. This model consists of one set of RL series elements connected between input and output terminals and two sets of shunt capacitances lumped at both ends of the line. The RLC elements are computed using hyperbolic corrections yielding an ‘exact’ representation in positive and zero sequence at specified frequency only. The frequency used for the RLC part is again, 50Hz. The positive and zero sequence resistances are 0.01273 ohm/km and 0.3864 ohms/km, respectively. The inductances for the positive and zero sequence are 0.9337e-3, and 4.1264e-3 H/km, respectively. The shunt capacitance for positive sequence is 12.74e-9 F/km and for zero sequence is 7.751e-9 F/km.

2.1.4 132/11KV Step down transformer

The transmission line section of the model ends with the 250KM PI section. The voltage in the transmission line block diagram was 132KV from the secondary side of the Step up transformer. But, since long distance transmission has already been carried out, this voltage must be stepped down and made ready for the distribution side. So the next block diagram is that of a step down transformer. This transformer is a wye-wye connected 132KV/11KV 3 phase two winding transformer with a nominal power of 25MVA. Winding 1 has a series resistance value of 0.002PU and a series inductance of 0.08PU with the phase-phase voltage being 132KV. Winding 2 has the same parameters with the voltage being 11KV. The magnetizing resistance and inductance are 500PU each

2.1.5 10KM Distribution Line

A second block of a PI section of transmission line is again used to depict a 10KM distribution line model. This model also consists of one set of RL series elements connected between input and output terminals and two sets of shunt capacitances lumped at both ends of the line .The parameters for positive and zero sequence are the same as they were in the 250KM long line model.

2.1.6 Wye-Connected RLC Load as a Filter

Three RLC loads, each with an active power of 10KW and a nominal voltage of 11kV RMS, are star-connected to act as a filter for the microgrid. The inductive reactive power QL(positive var) is 100var. The capacitive reactive power QC (negative var) is 100var

2.1.7 Current Measurement

Output of phase a of the Distribution Line block is fed into an Ideal Current Measurement block of the Simulink library. This block computes and outputs the Magnitude-Angle of the Current output of the 10KM Distribution Line. The phasor simulation is activated by a Powergui block placed in the model. The result of this block is taken by the GoTo block 'Iprim' and is sent to the Scope VI_prim.

2.1.8 Voltage measurement

The output of phase c of the Distribution Line block is fed into an Ideal Voltage Measurement block of the Simulink library. Similar to the Ideal Current measurement block above, this block computes and gives an output of the Magnitude-Angle of the voltage output of phase c of the Distribution Line. The result of this block is also sent to the GoTo block 'Vprim' and to the scope VI_prim.

2.1.9 Pole-Mounted Transformer

The 11,000V of the distribution line is now made suitable for distribution of households and PV cells by stepping the voltage down to 100v per winding of the 3 winding linear pole mounted transformer. This transformer operates at a nominal power of 75Kilovolt amps (KVA) at 50 HZ. Winding 1 takes the 11KV voltage at rms, with the series resistance being 0.00005PU and series inductance being 0.0002PU. Winding 2 and 3 have the exact same parameters except for the voltages being 100V. The magnetization resistance and inductance are both 50 per unit.

2.2 Load and PV Side

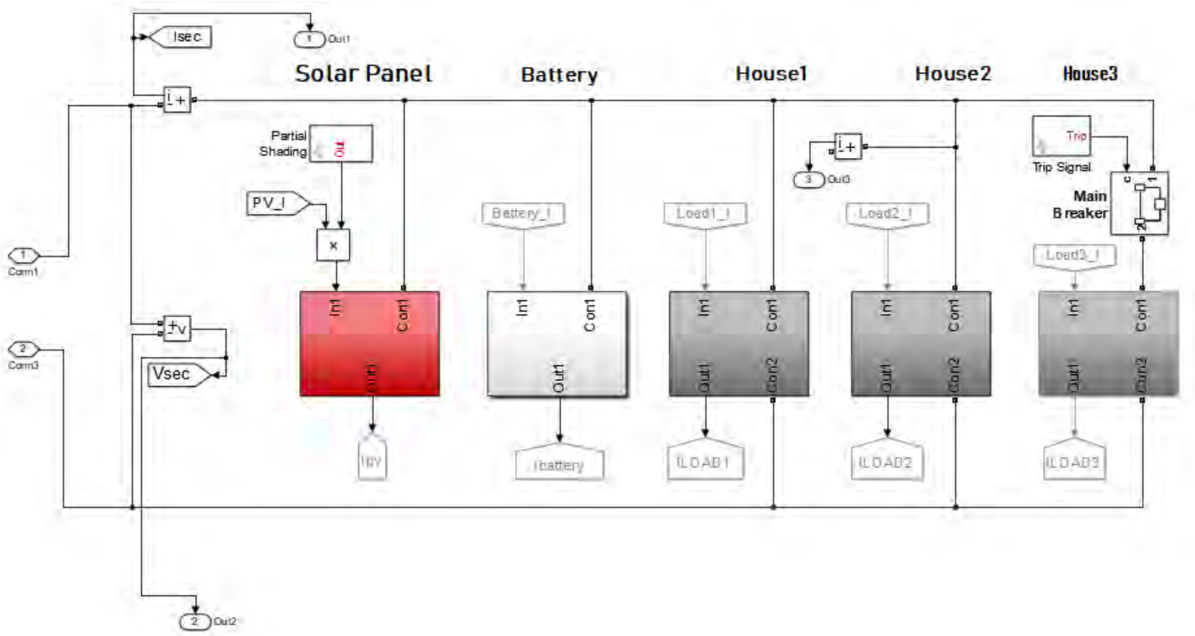


Fig. 2.2: An overview of the Load and PV side [19]

2.2.1 Solar panel (PV)

The components of the load side and the PV side of the model are as shown in Fig.3a. The pole mounted transformer stepped the voltage down to acceptable distribution values so that the loads and other components can function properly. The constituents of the Solar panel is shown in Fig.3b.

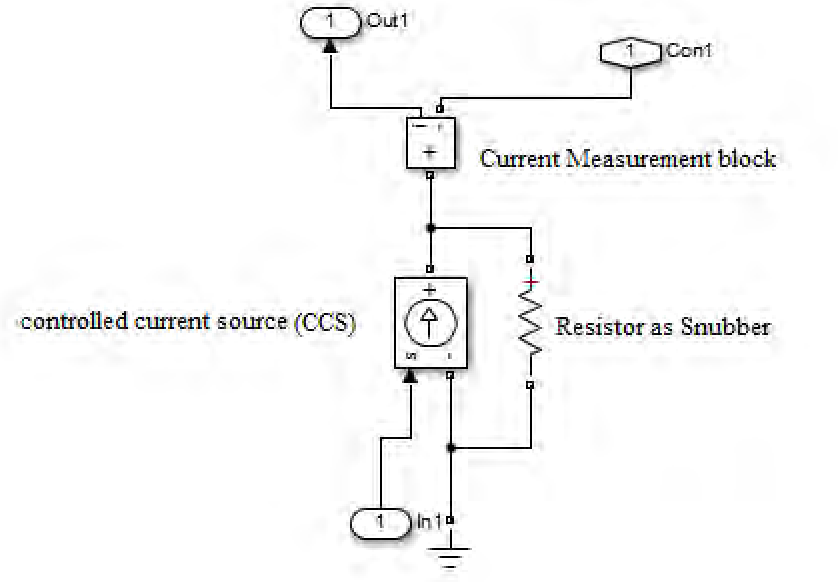


Fig. 2.3: Constituents of the Solar Panel (PV) block [19]

The Controlled Current Source converts the Simulink input signal into an equivalent current source. The generated current is driven by the input signal of the block. The source is Alternating Current (AC) with an initial amplitude of 0A. The initial phase is set to 30 degrees and frequency to 50HZ. The input to this controlled current source is the product (through the product block 'X') of the PV_I values and the Signal Disturbance mask. The PV_I values are computed in the 'Scenario' block that we will look into later. The signal disturbance block simulates a partial disturbance in the supply at the 11th hour of the day. This disturbance has duration of 20 seconds, and drops the output to a factor of 0.3 of the total output. The snubber is basically a resistor with a resistance value of 1 MΩ connected in shunt across the Controlled Current Source (CCS). This snubber suppresses any voltage transients that occur across the CCS block. This does this by limiting the rate of rise in voltage across the CCS. These voltage transients can improperly turn on the Current Source block, and show anomalous results in the model. The output of the CCS is fed into an Ideal Current Measurement block along with the current supplied by the distribution grid. The result of the measurement is then sent to the scopes.

2.2.2 Battery

Connected in shunt with the Solar panel (PV cell) is the Battery. This battery is modeled by a Controlled Current Source (CCS) that is Alternating in nature, which takes its input from the 'Battery_I' GoTo block. A snubber is again connected in parallel to the CCS with a rating of 1MΩ to reduce any transients capable of untimely triggering of the battery block. The output of the CCS is then compared with that of the distribution grid by a Current Measurement block and the output is labeled 'Out1'. The output is ultimately linked to the GoTo block 'Ibattery' which is then shown on the Scopes.

2.2.3 House 1

The schematic used to model a house (load) is shown in Fig.2.2.3

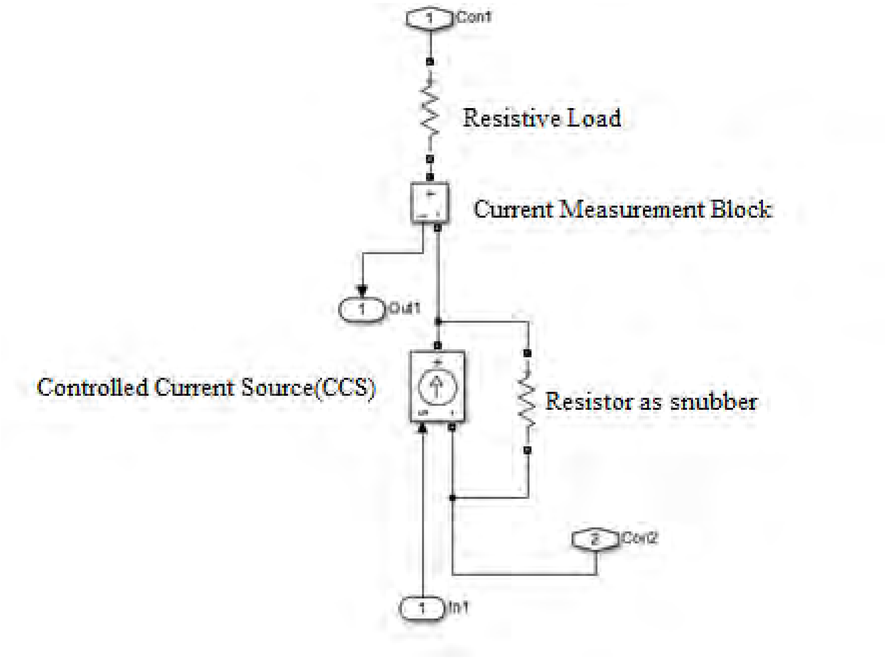


Fig.2.4: Constituents of the House 1 load [19]

The load is modelled in such a way that it represents the characteristics of an ordinary house over the period of 24 hours. Unlike the PV cells and the Battery, the difference is that the inputs to the CCS come from the 'Load1_I' GoTo block and one of the live distribution grid lines. The shunt snubber prevents transients from triggering and eventually rendering the simulation results useless. The output of the CCS is fed to a current measurement block along with a live line of the distribution grid. However, a resistive load, Load 2 is connected in series to represent the load data of the House. This resistor has a resistance of 16Ω.

2.2.4 House 2

House 2 is identical in nature to House 1. House 2 also employs the exact same circuit set up and has the exact same job in the Simulink model as House 1. Fig 2.2.4 below shows the block diagram for House 2.

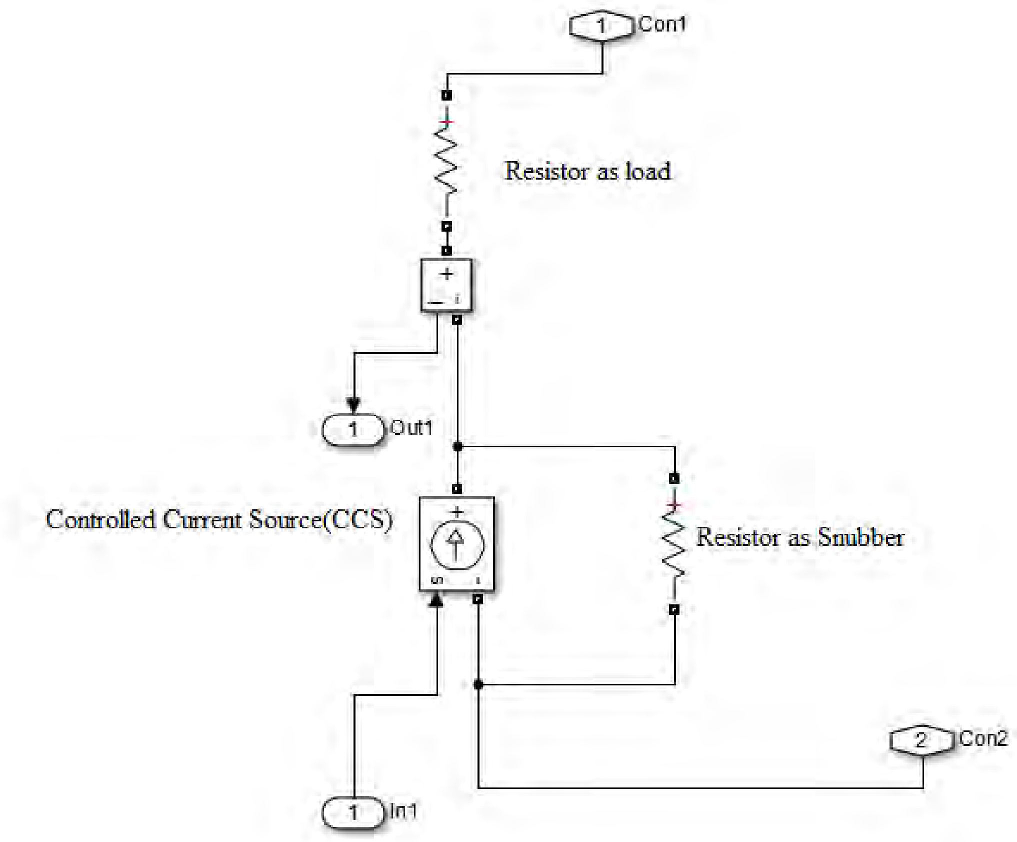


Fig 2.5: Constituents of the House 2 load [19]

2.2.5 House 3

House 3 is identical to both House 1 and House 2 and so does not need its separate definition. Fig 2.3 and Fig 2.4 can be referred to for House 3 also.

2.2.6 The Trip Signal block and the Main Breaker

The Trip Signal block and the Main Breaker are shown in Fig 2.2.6. The two aforementioned blocks serve to simulate a fault condition at a specific hour and time of the day, mainly at exactly 8am in our case. The fault introduced into the load of House 3 is made to last 10 seconds. The Main Breaker implements a circuit breaker with a breaker resistance of 0.001 Ω and a snubber resistance of 1 MΩ. The switching option of the breaker is set to ‘external’ as the tripping signal is externally applied to it by the Trip Signal block. When it receives a logical signal, the circuit breaker can be controlled appropriately.

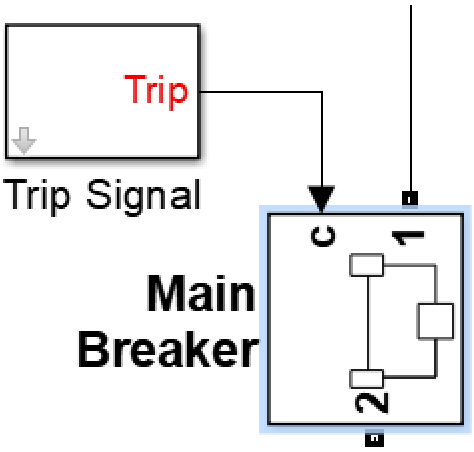


Fig 2.6: Trip Signal block and the Main Breaker [19]

2.3 IOT

2.3.1 The conversion of I_secondary into a complex value

The output from the Isec Go to block, representing the current in the Load and PV side, is taken out as OUT1. The OUT1 is then fed into a Complex-to-Real/Img block that outputs the real and/or imaginary components of the input. This is then sent into a 2x1 Multiplexer and the output is amplified with a gain of 10,000 brought about by the Gain block. Moreover, a 1x2 Demultiplexer is used to select one input and further convert that from Real to complex by using the Real-Imag to Complex Simulink block. The resulting complex value is then displayed on a display.

2.3.2 Integer to Bit conversion

The Gain block's output is also fed into a Data Type Conversion block of the Simulink library. This converts the input to the data type and scaling of the output. The output data type of the block is set to int8 and the input and output were set to have equal Real World Value (RWV). Integer rounding mode has been set to convergent. The subsequent output is now sent to an Integer To Bit Converter block with the following parameters; The number of bits per integer is set to 8; The input value is treated as an unsigned number and the output bit order and the output data type are MSB and Boolean, respectively.

2.3.3 Transmitter and the AWGN Channel

A 1x2 de-multiplexer splits the output of the Integer To Bit Converter block into 2 signals, which are then fed into two Rate Transition blocks as shown in Figure 2.6

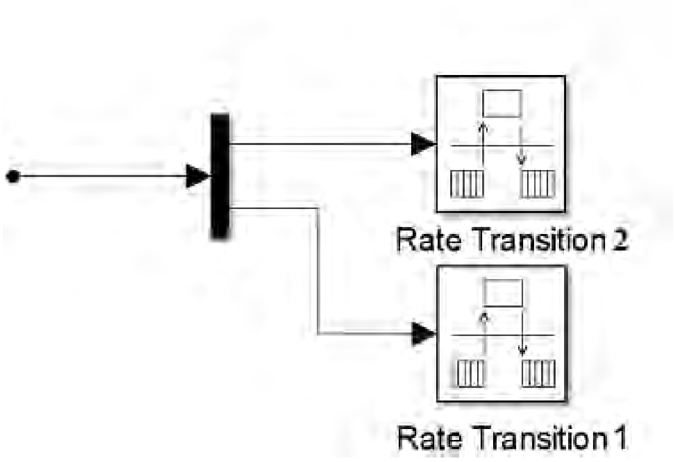
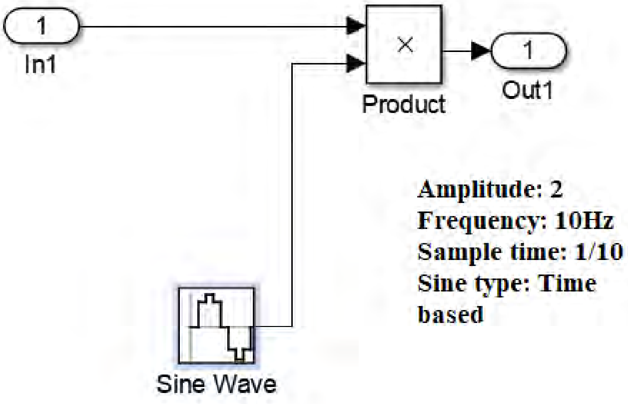


Fig 2.7: The two Rate Transition blocks preceding the transmission of the data

A rate transition block handles transfer of data between ports operating at different rates. Configuration options allow us to trade off transfer delay and code efficiency for safety and determinism of data transfer. Initial condition is set to 0 and output port time sample time is set to 1/10. Rate transition block 1 is connected to a transmitter block, shown in Figure 2.7 which takes the input signal from the rate transition and multiplies it with a Sinusoidal signal with the help of a product block.



Amplitude: 2
Frequency: 10Hz
Sample time: 1/10
Sine type: Time based

Fig 2.8: The transmitter block constituents

The output is then fed into an AWGN channel, which mimics the many random processes that occur naturally and contribute to the total system noise during transmission. The noisy output of the AWGN is now set for reception, and is given as an input to the Receiver block.

2.3.4 Receiver

The receiver block is constructed in much the same way as the transmitter block above. The only difference being the inclusion of a Digital Filter and a Comparator, as shown in figure 2.8

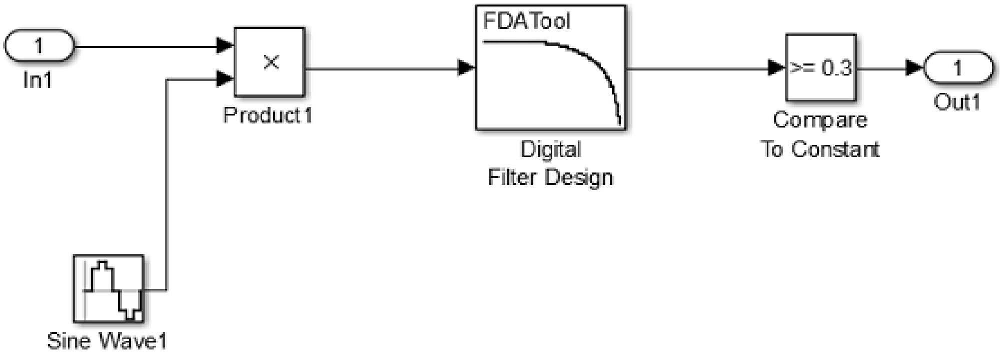


Fig 2.9: The receiver block constituents

The Sine wave generator shown above uses the same configuration settings as the one used in the Transmitter in section 2.3.3. The Digital Filter shown above is used to replicate a 4^{th} Order, Direct-Form FIR, low-pass filter. Following the Low-pass filter is a comparator block, called the compare to constant block. This block of the Simulink library determines how the signal compares to a constant. Signals with amplitudes larger than and equal to 0.3 are allowed to pass and those below are restricted. The output data type is integer type or ‘int8’, with zero-crossing enabled.

2.3.5 Bit to Integer Converter Block

The Bit to Integer Converter block maps a vector of bits to a corresponding vector of integer values, as defined by Matlab. The number of bits per integer is set to 8. Input bit order is MSB (most significant bit) first and the output data type is integer type.

2.3.6 Data transmission and Reception

The above few sections discussed the steps involved after the Rate Transition 1 block of the above model of IoT. However, the subsequent steps for Rate Transition 2 block was omitted due to the fact that the two blocks lead to exactly the same process of transmission (with the help of a transmitter) and reception (with the help of the receiver) and employ the exact same parameters in each case. This can be observed in Figure 2.9 below.

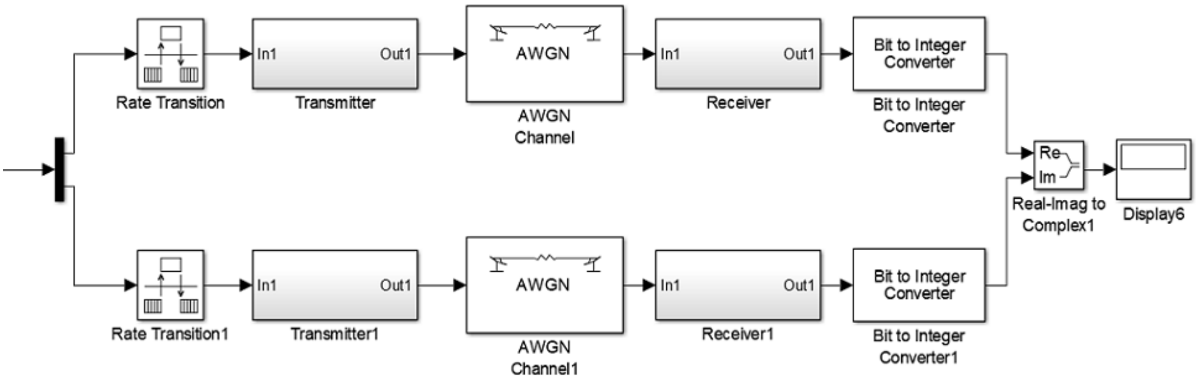


Fig: 2.10: An overview of data transmission and reception

As shown above, the output of the Bit to Int Converter 1 is taken as the Real value and the output of the Bit to Int Converter 2 is taken as the Imaginary value to the Real-Imaginary to Complex block, to output a complex value

2.4 Battery Dynamics

2.4.1 Battery Controller

The battery controller manages and controls the battery that we implemented back in Load and PV side. An overview of the entire Battery Dynamics is shown in Figure 2.10

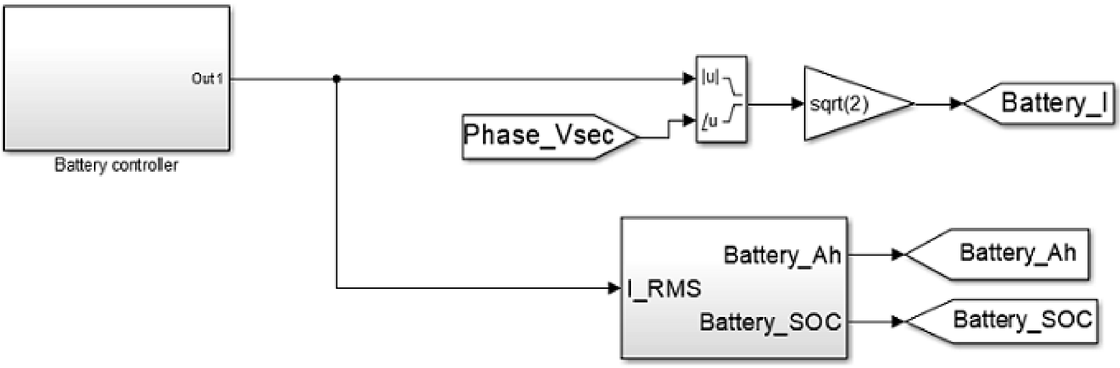


Fig 2.11: An overview of the entire Battery Dynamics block

Inside the battery controller block are 3 inputs Vsec, Isec and Control, taken from the secondary sides of the Pole Mounted Transformer and the Scenario block that we will look into later, respectively. Figure 2.11 shows the constituents of the battery controller block.

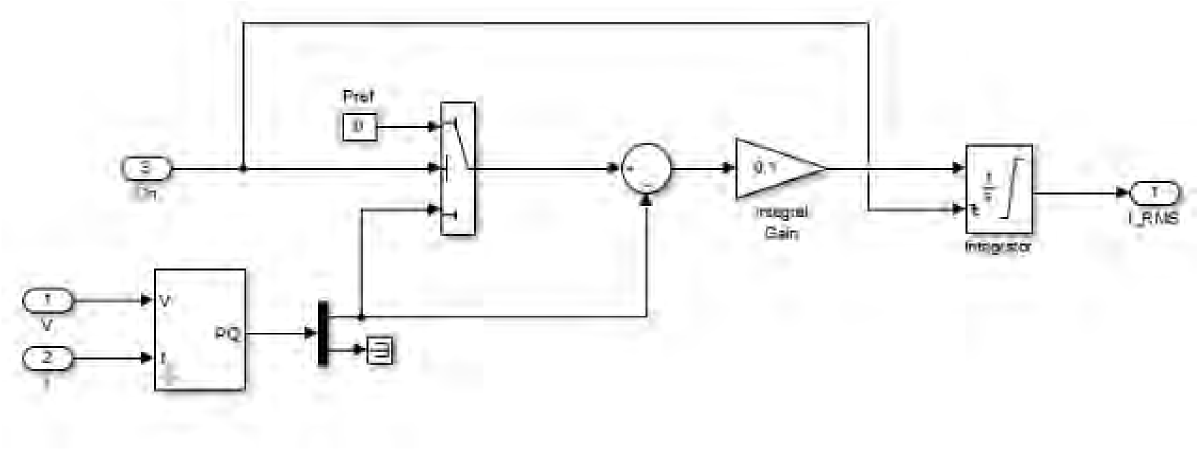


Fig 2.12: The constituents of the Battery Controller block

The V and I values are taken in at the Active & Reactive Power block and outputted into a 1x2 De-multiplexer, one output of which is terminated. The other output of the Demux is split into two, one being sent to a switch above and the other to a Summation block. The switch also switches between 3 values; one from the battery control signal from the Scenario block, a constant zero value, and of course the output of the demux as stated above. The summation block is met with an Integral Gain block with a gain of 0.1. The integrator takes the integral gain value and the control signal from the Scenario block and performs a continuous-time integration on them. The output is labelled as I_Rms. The Magnitude Angle to Complex block takes in the phasor value of Vsecondary from the Scenario block and the I_rms output of the battery controller, and computes the complex value which is then Squarerooted to be sent to the Battery block from 2.2.2. The I_RMS from the battery controller is sent as input to a subsystem, the constituents of which are shown in figure 2.12

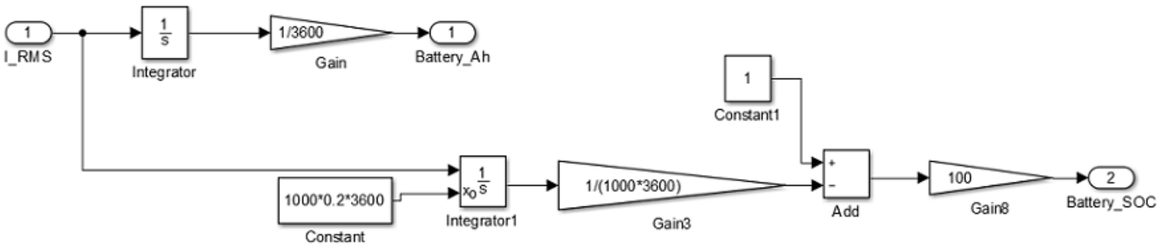


Fig 2.13: The building blocks of the subsystem

The I_RMS is integrated and then exposed to a gain of 1/3600, for a per-second computation of 1 hour of battery charge. The output is sent to the GoTo block Battery_Ah. The I_RMS is also split and sent to be integrated again, this time with a constant 1000*0.2*3600. A gain 1000 times smaller than the Battery_Ah gain is set next. An adder block subtracts the output of the Gain3 block from 1. When this value is multiplied by 100, we get a percentage charge of the battery, known as the State of Charge of the battery, or SOC for short. When the output of the integrator is zero, the adder outputs 1, and so the percentage charge is 100%. For larger values of the integrator, we get values less than 1 and hence an SOC of less than 100%. The output is sent to a GoTo block named conveniently as Battery_SOC.

2.5 Scenario

To simulate a real world time of 24 hours, we called upon the built in Matlab Clock. This clock outputs the current simulation time for 24 hours with a decimation of 1. Since the entire thesis revolves around the model simulating a 24-hour period of power flow analysis, this clock is one of the most crucial blocks we have used thus far. The Scenario block provides a real world-like simulation by using generic load data and generic solar data over a 24-hour period. The building blocks of the entire Scenario block is shown in figure 2.5 below.

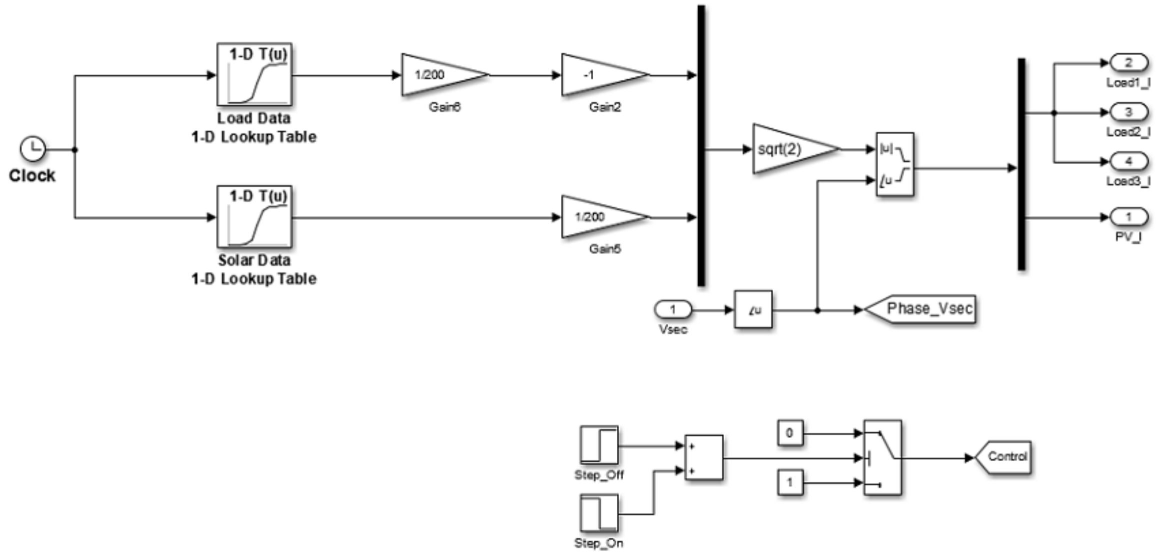


Fig. 2.5: Overview of the entire 24-hour period scenario

2.5.1 Load data and Solar data lookup table

The Load Data 1-D Lookup Table of Matlab Simulink and its solar counterpart have been used to provide a consistent set of data of our choice to mimic a typical day load curve and solar power. The flexibility of the two blocks in question allow us to input any data in the form of an Excel Spreadsheet. The load data lookup block plots a load value for every 60 seconds for a total of 86,400 seconds. It then uses interpolation to plot a graph of this data for an entire 24 hour period. The Load Data values are then taken through a gain of 1/200 followed by a gain of -1 to make its values negative. The Solar Data Lookup also uses the same principle of interpolation to plot a graph of solar power generated against time in seconds, where the interval is ever 60 seconds for 86,400 seconds. The solar data is also exposed to a gain of 1/200 before being introduced to a Multiplexer. The multiplexer data is then square-rooted. The Secondary side voltage data of the Pole Mounted Transformer is transformed from complex to its phase angle and inputted together with the square-rooted value. These two signals are then recombined into complex form, where Vsec takes the phase angle and the Square-rooted output of the multiplexer is taken as the magnitude for the complex value

2.5.2 Control signal

Two step signals, one up and the other down, are added through a summation block and consequently passed through a switch, which operates between 0 and 1 and the added signal. The signal that we thus attain from the switch is used as a control signal, which controls the battery controller as we have seen in chapter 2.4

Chapter 3

Results and Discussion

3.1 Solar PV output

The entire system model of the IoT controlled Smart Micro Grid discussed in chapter 2 yields 5 graphs over the 24 hour period that we have selected for the simulation. The graphs for the magnitudes of the various load changes and battery SOC are looked at first, followed closely by the data gathered by the IoT network. The entire map of the outputs that we have generated thus far for the load and SOC sides is shown in Figure 3.1

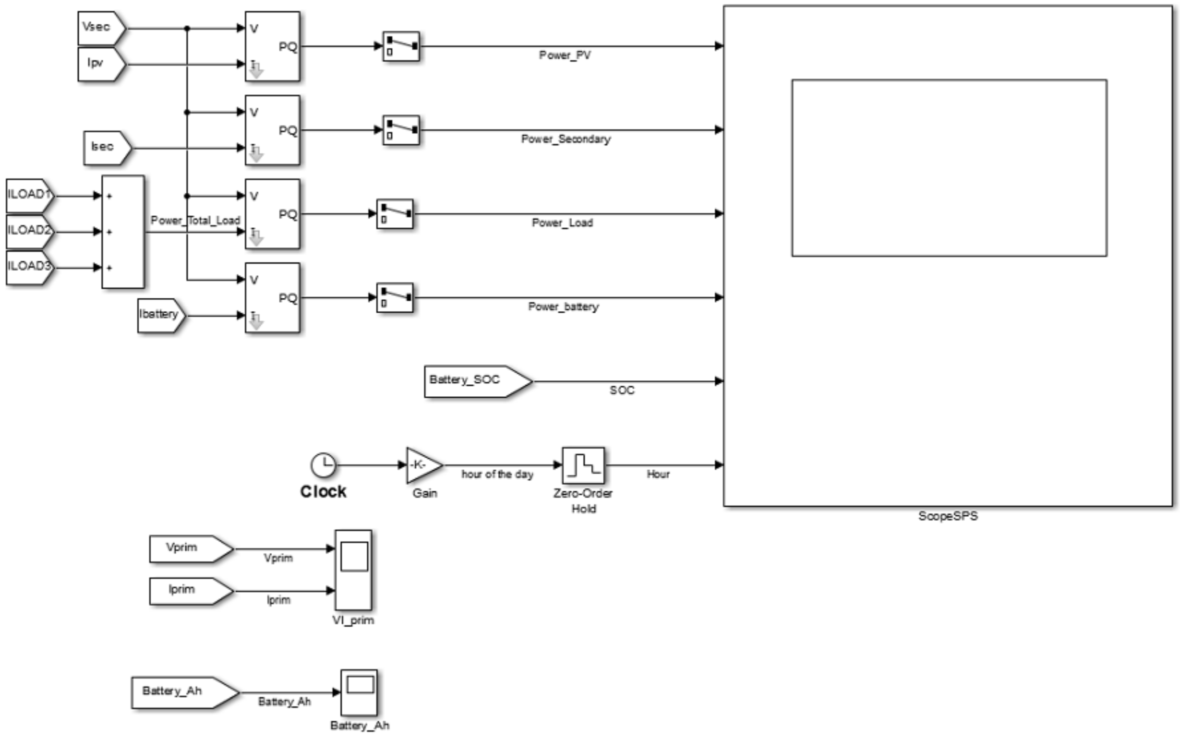


Fig. 3.1: Entire map of the outputs for the loads and battery SOC

The first result we look at is the one for the solar panel side we labelled Power_PV earlier. The solar panel first starts to output any significant power at the 18000th second or at the 5th hour of the day. This curve follows a typical per day graph of solar power output over the course of 24 hours. It reaches a peak value of 4.122 kilowatts (KW) only once at the 54000th second. After reaching the peak power output, the total power output of the panels starts to decrease over the course of the day as the day progresses towards late afternoon. The power drops very nearly to zero at the 69500th second or the 19th hour and continues on till sunrise at 5 again. The graph for the entire event can be seen in Figure 3.2 below.

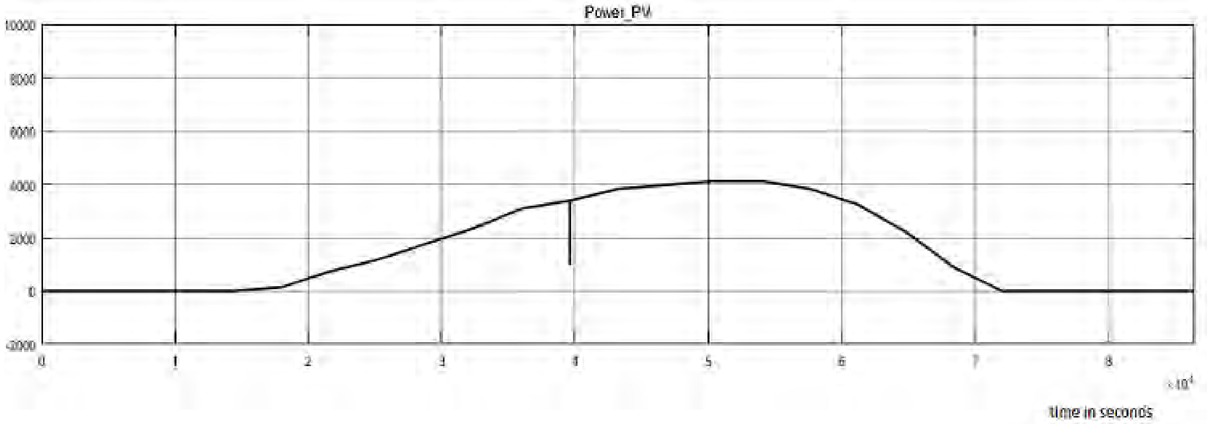


Fig 3.2: Solar power output over the 24-hour period

3.2 Secondary Power output from the Grid

The Power_Secondary is the power that the system takes in from the main power grid when the solar PV and the battery system prove to be not enough. It can be seen that the power consumed from the grid is minimal, as the entire solar PV and battery system is taken to be marginally sufficient for the Small Scale Micro Grid at all times. However, during peak hours, some power might be required from the grid. We have taken the peak time for the maximum solar power and the max power required from the grid to be the same for simplicity, as both occur during the mid-day. As per the graph, the power taken in from the grid only starts to go up at the 43200th second or at the 12th hour of the day. The graph continues to steepen up until a peak at the 5400th second, or the 15th hour and reaches the peak value of 3.316 KW. The load consumption from the microgrid decreases and reaches practically zero at 61800th second or at the 17th hour. However, it can be seen that the graph reaches a negative value of -2.582 KW at the 64700th second or the 18th hour. This negative value implies that power is supplied to the grid from the Solar PV. Even though, the bi-directional exchange of power lasts a short while, the power consumed by the grid goes to zero quickly as the battery takes control of the requirements of the houses (loads). The part where battery takes over, which is at the 61900th second on the Power_Secondary graph below in figure 3.3, will be shown in the subsequent sections when we describe the battery power graphs

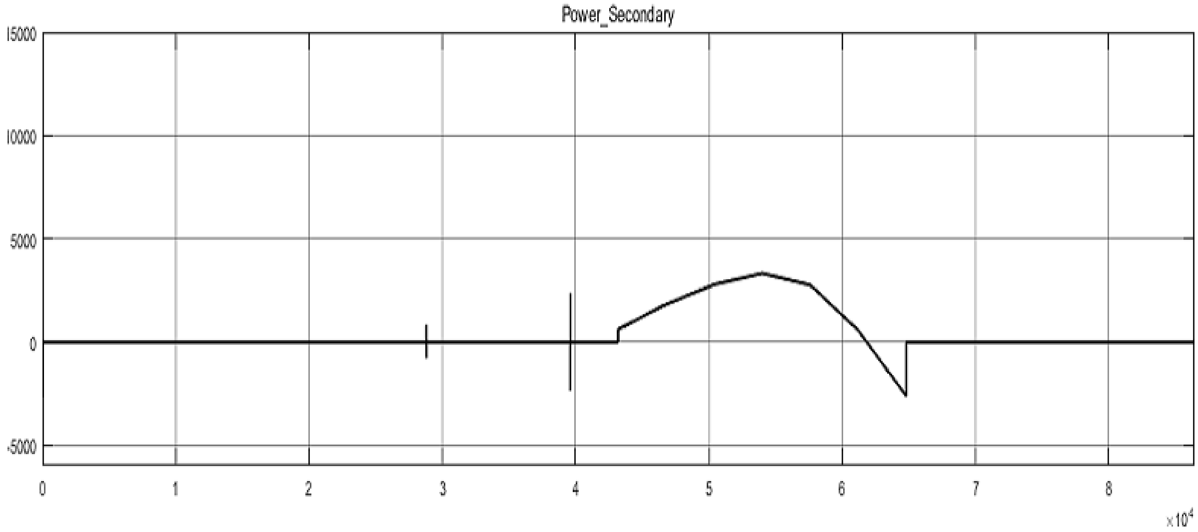


Fig 3.3: Secondary power output of the Grid over a 24-hour period

3.3 The power consumed by the loads

The total power consumption of the individual houses are added together to produce one graph. The typical load curve of a typical moderate home is assumed here, and the curve varies accordingly. Figure 4.4 below shows how the load varies over the entire day.

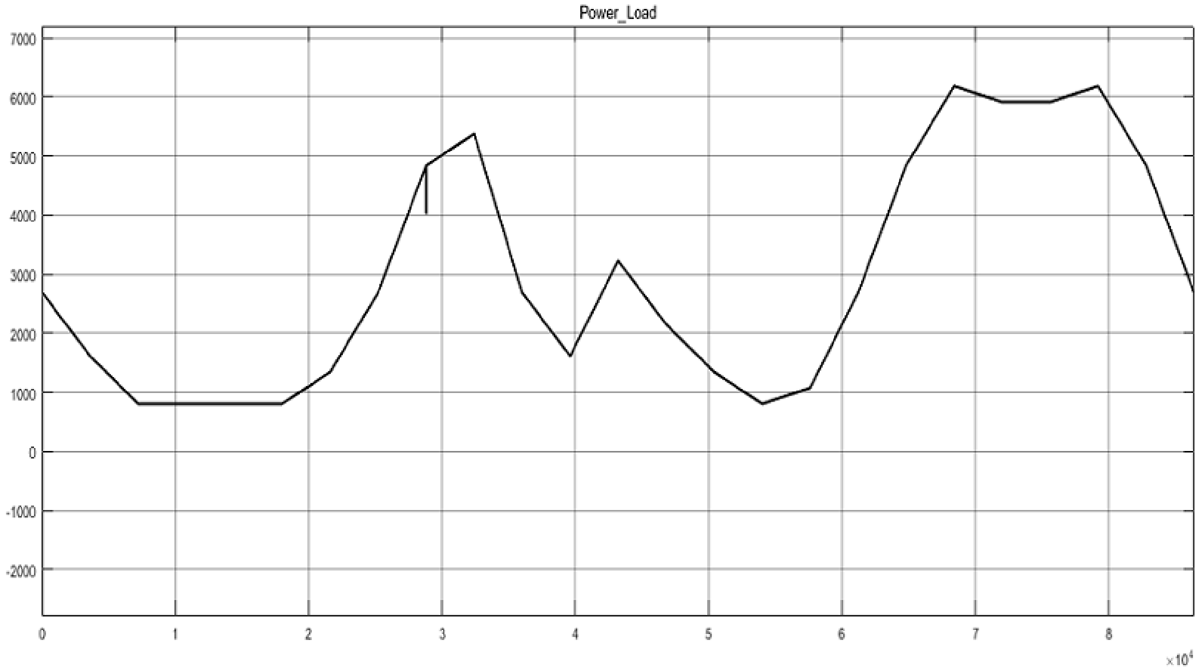


Fig 3.4: The power consumed by the loads

From the early hours of the day, the curve follows a typical decrease in load as the night progresses and reaches a constant in the early morning hours. There is a steep increase in the load until the 32600th second, the 9th hour of the day, when it reaches 5.224 KW of consumption. The load varies with various ups and downs throughout, reaching the peak value of 6.183 KW twice, at the 68400th and the 79200th seconds, 19th and 22nd hours of the day, respectively. The second portion of the graph where it reaches its two peaks are taken care of solely by the battery. This is the same portion where the power consumed from the grid dies down to zero, and most of the power is supplied by the battery alone

3.4 The power curve of the Battery

At the 0th hour, or the start of the day, both the power supplied by the Solar PV and the power consumed from the grid are zero. But Figure 3.4 above shows clearly that there's a net consumption of power by the 3 houses (loads), and so this power must be supplied by the battery. During the start of the day, the battery supplies 2.640 KW of power, the exact power that is consumed by the cumulative loads. However, at the 18000th second or 5th hour of the day, battery power consumption by the load decreases slightly due to an influx of solar power seen at the terminals of the PV. From this point onwards, the loads are shared by the solar PV as well as the battery and so the stress on the battery starts to go down. At the 35000th second, the power supplied by the battery goes down to zero. The load consumption also starts to decrease at a steady rate. Hence the combined effect of the decrease in load and the periodic increase in the Solar PV power output drives the battery controller to make the battery charge up. This point is where the battery power is shown to be negative (consuming power). We call this the charging period of the battery. At the 43200th second, the battery is neither charging nor discharging, and its SOC is stuck at 75%. This uniformity in the State of Charge of the battery or SOC, is largely due to the fact that the now decreasing load is now completely taken care of by the grid and the Solar PV. At the 64700th second, battery power output shoots up again to take care of the sudden increase in load power consumption. In this period of time, neither the Solar PV nor the grid fulfils any significant power demand from the loads, and much of the load is now taken care of by the battery, again. This causes the SOC of the battery to follow a downward trend.

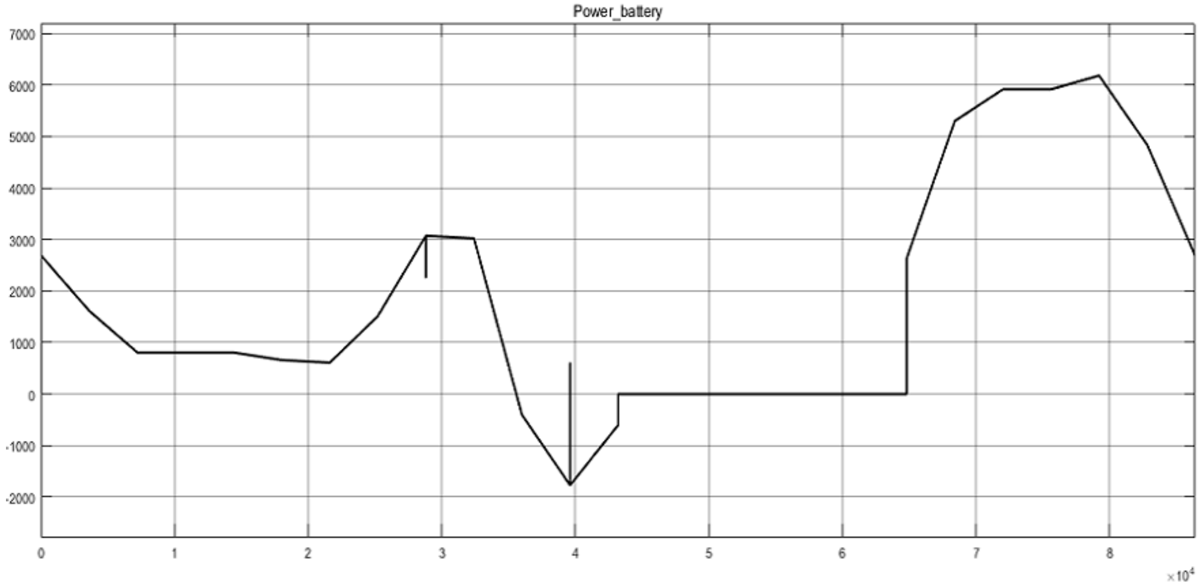


Fig 3.5: The power supplied and consumed by the battery

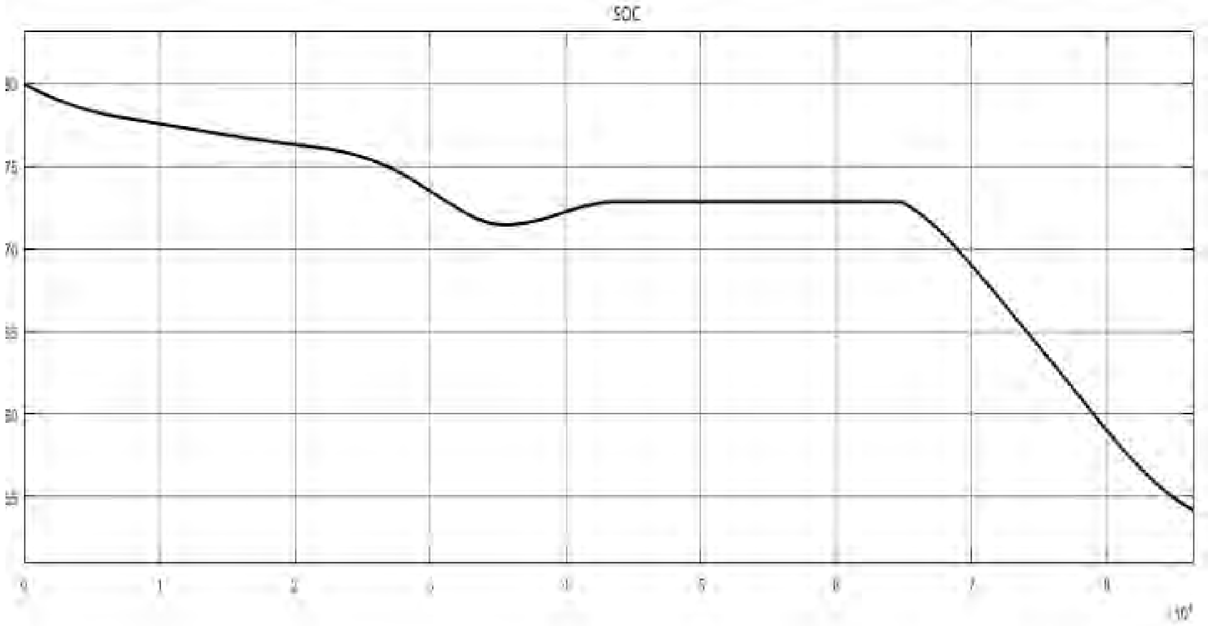


Fig 3.6: The state of charge (SOC) of the battery

3.5 Comparison of Packet loss against SNR for the IoT Devices

The 3 IoT devices we have implemented on our Simulink model of the Small Scale Microgrid used AWGN block to represent the inherent signal noise present naturally in all transmission. We have simulated to further enhance the reliability of the data transmission through these IoT devices. This is to ensure maximum reliability and security since the proper and timely interpretation of power and load data is crucial to making the appropriate decisions on load switching. We have plotted Packet Loss against the SNR values (in Decibel) for all 3 devices and made comparison with 1 second and 0 second delays, respectively. Graphs for IOT_I, IOT_V and IOT_H, respectively, are shown below.

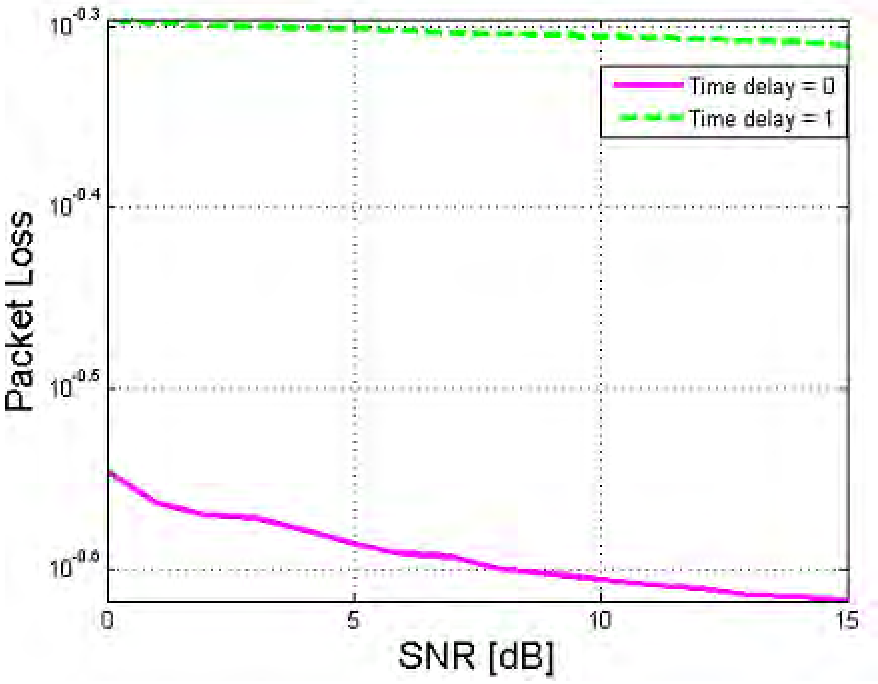


Fig 3.7: Packet Loss against SNR for 0 sec and 1 sec delays of IOT_I (Measured Current)

It can be seen above in Figure 3.6 that the packet loss with a time delay of 1 second is significantly higher for the same SNR value, and decreases in magnitude as the SNR increases. For 0 second delays, the packet loss goes practically to zero from 0.285. However, for the 1 second delays, the packet loss decreases very marginally from 0.51 to 0.49, as the SNR increases

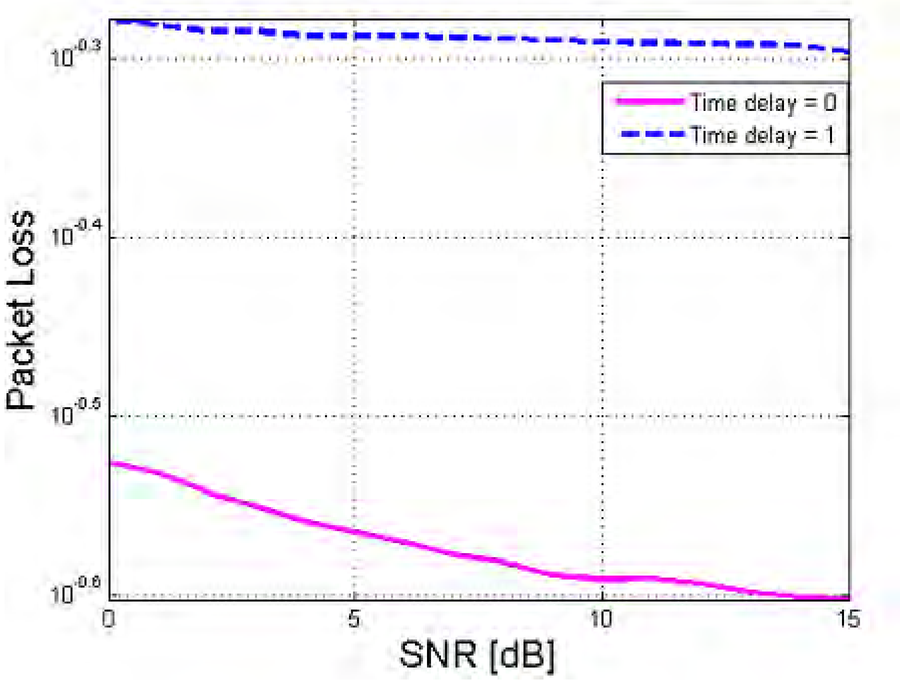


Fig 3.8: Packet Loss against SNR for 0 sec and 1 sec delays of IOT_V (Measured voltage)

Figure 3.7 above shows how the packet loss with a time delay of 1 second is significantly higher for the same SNR value, and decreases in magnitude as the SNR increases. The decrease in SNR for the 1 second delay, however is much more drastic for IOT_V than for IOT_I seen previously.

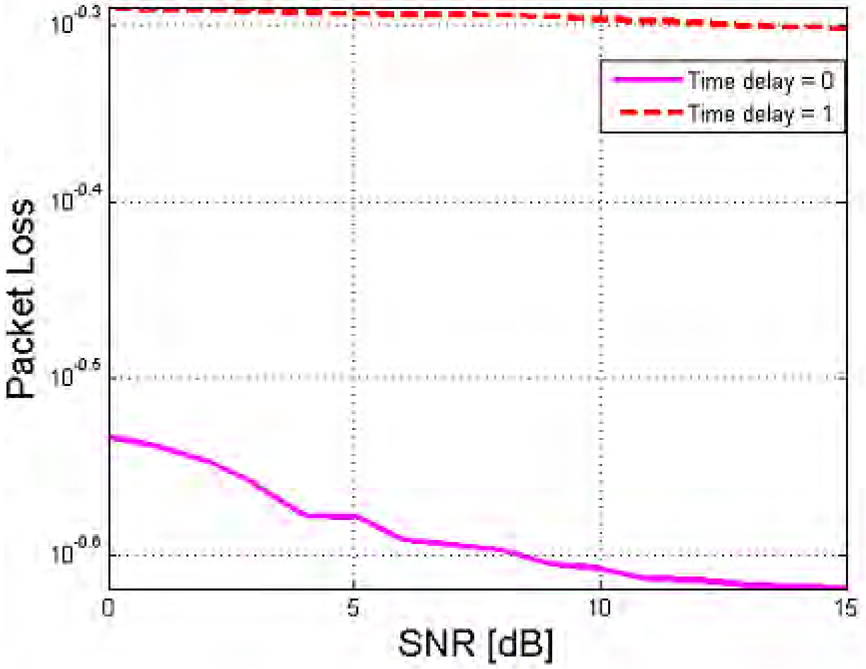


Fig 3.9: Packet Loss against SNR for 0 sec and 1 sec delays of IOT_H (House 3)

There are more bumps in the 0 second time delay curve for the power data of house 3. But like the rest of the devices we have looked at so far, the packet loss for higher SNR values approaches zero from 0.2925 for 0 second delay. For a delay of 1 second, the packet loss reduces from 0.515 to 0.5 as SNR increases beyond 15 Decibels (dB)

Chapter 4

4.1 Conclusion

We have set up a small-scale self-sufficient microgrid and hooked it up with IoT devices to transfer the load and power data from the components and the distribution sides all the way to the control station that could theoretically be situated hundreds of miles away. We have also managed to include what we call Solar Homes, the growing trend of which can be felt significantly in the rural areas of Bangladesh, and setting up IoT devices can greatly accentuate the effectiveness of such homes as well as the prosumers. To reach this milestone, we started with our generation side. The main features of the generation and transmission sides are noted below:

- Generation side used a 279MW generator to represent the combined cycle Steam Turbine generator of the new Haripur Power Station. Step up transformer was subsequently used to amplify the transmission voltage and decrease transmission line loss.
- The PI model of the long line model was used to implement our transmission line. This bridged the gap between the step up and step-down transformers. The line voltage was further lowered at the pole mounted transformer to make it fit for regular household distribution.

The load side saw the use of an array of solar photovoltaic (PV) cells compounded together for maximum power generation.

- This Solar PV array was simulated by a single Simulink block to reduce the clutter that would have resulted if we used a Simulink block for every solar cell to generate the amount of power we needed.

- A battery was subsequently used that both transferred and consumed power from both the grid and the Solar PV. This self-sufficient grid is capable of generating and maintaining power for the majority of the day and rely on the power grid very minutely during heavy demand

- We used 3 identical loads to represent the typical per day load curve of a typical household in Bangladesh. They consumed identical power throughout the day and their total consumption was cumulated together. It was then seen that the loads were mostly dependent on the Solar PV and the Battery, while only occasionally needing the support from the grid. It was also noted that the battery supplied power back to the grid when it could

The setup used for the IoT devices converted the data into binary, and multiplexed it into Code-Division Multiple Access (CDMA) signal before sending it over an Additive White Gaussian Noise (AWGN) channel. We used a receiver at the proposed control station to receive this data. The integrity of this data was subsequently tested, and a graph of the packet loss against the SNR for each IoT device was plotted. The graph also featured both zero delay and 1 second delay channels. We noted clear distinction in performance for each version of the delays. From the analysis we noted the following:

- The Packet loss decreases with an increase in SNR. However, this decrease is even more substantial as the delay increases from 0 second to 1 second.

- The decrease in packet loss looked more substantial for IoT devices IoT_V and IoT_H even though it may as well be within the uncertainty.

4.2 Future Works

The salient feature of the Simulink model that we have put forth is that it is very modular and flexible. For this reason, we can add any amounts of loads or solar PV cells in parallel to the current load side. We also have a substantial amount of power on the Generation side (279MW) and so this can be utilized as we add more homes to the model. And hence we can utilize this in our future work by introducing industries that consume reactive power, and also use industrial IoT devices for them to enable industrial participation in the digitalization of the typical electric power grid

We can also extend the current IoT infrastructure to include Cognitive Radio that will enable seamless detection of available channels in a wireless spectrum, and effectively change the transmission parameters to account for a better and smoother communication across all users.

Due to the availability of multiple sensors and communication devices we can implement, with slight changes in the model, Power Line Communication or PLC. This will enable data as well as power to be transmitted across a transmission line

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