WiMAX Implementation of Smart Grid Wide Area Distributed Generation and Demand Side Load Protection Model in MATLAB/SIMULINK

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DECLARATION

We do hereby declare that the thesis titled "WiMAX Implementation of Smart Grid Wide Area Distributed Generation and Demand Side Load Protection Model in MATLAB/SIMULINK", a thesis submitted to the Department of Electrical and Electronics Engineering of BRAC University in partial fulfillment of the Masters of Engineering in Electrical and Electronics Engineering. This is our original work and was not submitted elsewhere for the award of any other degree or any other publication.

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Abbreviation

ADC	-Analog to Digital Converter
ADSL	-Asymmetric Subscriber Line
BANs	-Business Area Networks
BPSK	-Binary phase shift keying modulation
CP	-Cyclic Prefix insertion
CRN	-Cognitive Radio Network
DLC	-Data Link Control
DSL	-Digital Subscriber lines,
EHV	-Extra High Voltage
EPON	-Ethernet PON
FEC	-Forward Error Correction
FFT	-Fast Fourier Transform
GF	-Galois field
GPRS	-General Packet Radio Service
HAN	-Home Area Network
HV	-High Voltage
IANs	-Industrial Area Networks
ICI	-Inter channel interference
ICT	-Information & Communication Technology
IFFT	-Fourier Transform
IQ	-Quadrature phase vector
ISI	-Inter symbol interference
LFSR	-Linear Feedback Shift Register
LL	-Line to Line
LLG	-Double Line to Ground
LOS	-Line of sight propagation
LRWPAN	-Low-rate wireless personal Area networks
LTE	-Long Term Evolution
LV	-Low Voltage
MV	-Medium Voltage
MNOs	-Mobile network operators
MVNO	-Mobile Virtual network operators
NAN	-Neighborhood Area Networks
OCR	-Over Current Relay
OPGW	-Optical Power Ground Wire
P2MP	-Point-to-multipoint
PLC	-Programmable Logic Controller
PLC	-Power line communication

PON	-Passive optical networks
PRBS	-Pseudo Random Binary Sequence generator
PSK	-Phase shift keying modulation
PU	-Primary user
QAM	-Quadrature amplitude modulation
QPSK	-Quadrature phase shift keying
RES	-Renewable energy sources
RFIDs	-Frequency Identification Devices.
SLG	-Single Line to Ground
SM	-Smart Grid
SUs	-Secondary users
TBP	-Transient Based Protection scheme.
WAN	-Wide Area Networks

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Abstract

Smart grid plays a vital role to protect electrical load and utilities among electrical power consumers due to its wide range of advantages which in turn made up its growing demand in current world. Mostly, electrical loads are venerable to fault current in the system results in sudden failure of expensive loads which is needed to be detached for safety reason. Therefore, this paper mainly focuses on designing the circuit in generating a fictitious fault current and its detection through WiMAX communication so as to detach the load from power generation unit using Matlab Simulink. In order for transmission of fault or trip current through wireless communication system, a WiMAX transceiver IEEE STD 802.16d has been designed, implemented and optimized for trip current transmission and receiption to certain distant places circuit breakers located in different HV and LV distribution system. Moreover, an automatic back-up system has been proposed to provide an uninterruptable power to the utilities/load during when the fault current occurs. Finally, the simulation result shows a successful transmission and detection of fault signal along with its impact in load end is evaluated for overall performance of the designed system.

Chapter 1
Introduction

In this chapter, we first introduce the topic of smart grid and describe the problem statement related to the availability of simulation environment. Then, the main research objectives are outlined followed by the research contributions. Finally, a general overview of the thesis is presented.

1.1 Literature review and problem statement

The smart protection system is the subsystem in SG that provides advanced grid reliability analysis, failure protection, and security and privacy protection services. By taking advantage of the smart infrastructure, the SG must not only realize a smarter management system, but also provide a smarter protection system which can more effectively and efficiently support failure protection mechanisms, address cyber security issues, and preserve privacy.

Smart Grid encompasses different types of controller and relay to optimize its goal. In fact, reaching out to consumers expectations eventually explores more convenient and logical solution for Smart Grid system. One of which is to design such relay by which the load isolation can be taken place while flowing any fault current through the system. There have been few researches done regarding design and application of fault relay or even differential relay to identify and isolate the load from power generation side. In this regard, a suitable digital differential relay has been designed using Matlab Simulink environment considering different operating condition's current pattern for transformer protection intelligently. The result of the simulation works properly and helps in determining new algorithm for the improvement of transformer protection system [1]. Another protection model has been proposed as digital over current relay with details explanation of its functionality OCR (digital over-current relay) effectively. It is systematically developed model which acts as a guide line to further idea of modeling new relays for protection system [2].

Moreover, in order to protect the power transformer, a differential relay for small power system is proposed where test probes are placed in to work with four different cases of fault and operation. To the first case, the inrush current makes the digital relay was not able to release the trip signal considering circuit breakers for primary side of power transformer getting close to evaluate the behavior of entire system. In second case, during the closing of circuit breakers of secondary side, the starting current will flow in the load eventually it is found that the components of inrush current disappears and trip signal was not released from digital relay. However, in third case, the internal fault is created inside of the protected zone results in trip signal for a particular CBs having a relay respond time of 10.7 msec in order for isolating the power transformer. The relay was not able to release the trip signal when an external fault is created outside of protected zone. To conclude the findings, a satisfactory result was found in third case when 10.7 msec was needed for the isolation of transformer ultimately ensures the algorithm to be true for fair degree and decision in applied case [3]. On the other hand, protecting control gears in sub-station grid, an automatic control mechanism has been proposed which can automatically detect the fault and detach the load in case to temporary fault but detach the load when it is a permanent fault and an automatic restore system is adopted for simple and temporary fault [4].

Special types of relay has been designed in ability of recognizing the types of fault by the measurement to impedance as the impedance get changes in terms of the changed fault location. Here, it is shown that, the model behavior is depended on the impedance path verifying the conditions for single line to ground (SLG) fault, double line fault (LL), double line to ground fault (LLG) and three phase fault including all other types of fault. It is found that, according to the fault for different reason, the relay is operated. In understanding the distance relay, MATLAB/SIMULINK environment was used clarify the proposed system [5]. On the other hand, studies has been made which dealt with communication of these fault current from demand side to generation side as the crucial requirements of smart gird application. In this regard, a conceptual idea is presented before going to discuss and design the reference model of smart grid. The communication systems are basically two types such as wire line and wireless system. Here, both wire line and wireless communication system are discussed in brief considering the progression of its advancement in current world. Finally, for the reason of smart grid application, a proposal was come for end to end communication architecture for Home Area Networks (HANs), Neighborhood Area Networks (NANs) and Wide Area Networks (WANs) [6].

The power line communication (PLC) as wire line communication has advantages in power management and load relief, it has few disadvantages such as network limitation in regard of scattered data, and loads are predefined priority, excessive load shedding for the reason of decision making and high time required for response. On the other hand, most demanding substations applications such as line and bus differential protection, precision time synchronization are not getting sufficient support in spite of very powerful priority-tagged Ethernet network [7].

Smart grid components are regarded to protection mechanism, privacy, security, reliability and cyber-attacks. Protection mechanism of smart grid and AC and DC micro grids are almost same except some additional facilities for consumers and suppliers. The isolation of fault facilitates active management and adaptive protection system where this isolation or islanding detection methods can be the categories for active, passive and communication-based approaches. Due to high expensive implementation, a promising islanding detection system should have to meet the requirements of smart grid [8].

1.2 Motivation of Work

The most fundamental requirement in any electrical system is proper over current protection to prevent the load from overheating and electrodynamics interactions. A smart grid is not only a bidirectional system of exchanging the information from load to power generation but also it facilitated to respond as per demand side power availability during fault current generation. Throughout our literature survey, we have found that, efforts have been made to identify the fault current from distribution generation and sending this fault current to islanding operation of load. Moreover, the procedure of communication in smart gird has been found to be two types: wire line and wireless. In this regard, we have seen the study those are done in sending fault current through wireless communication system to circuit breakers or in controller were not considerably elucidated for practical application. Therefore, it has become an important matter to clarify these terms with real time simulation for wide area Smart Grid network and focus on over current Power System Load Protection implementation in MATLAB/SIMULINK using WIMAX. The paper also highlights WIMAX transmitter and receiver model for desired wide area monitoring and control.

1.3 Research Objective

1. To have a clear concept of smart grid control operation and its application in power system.
2. Design a real time smart grid system using matlab simulink tools.
3. Design a fault generating circuit and automatic power backup to understand their behavior on power transmission and distribution system.
4. Fault signal optimization to transfer through WiMAX Transiver using simulink simulation tools.
5. Finally, evaluation of the overall performance of the smart grid control system.

1.4 Contribution of the Research

The main contributions of this thesis are as follow:

1. Using Matlab simulink environment, a complete guide is provided in designing the proposed smart grid load protection system with automatic power backup system through WiMAX communication system.
2. In order for that, a factious fault current is created having definite time duration to check the performance of fault detection and discretization of load from power generation.
3. Regarding transmission of fault current through wireless communication system, a WiMAX transceiver has been designed and implemented in terms of IEEE 802.16d.
4. Designed transceiver has been optimized to obtain the fault signal as trip signal to different HV and LV circuit breakers.
5. An ideal automatic power backup system has been proposed during fault current generation and it performance has been justified.
6. An overall smart grid performance has been evaluated successfully which could be an innovative concept for future smart grid system.

1.5 Thesis Organization

The rest of the dissertation is organized as follows:

Chapter 2: *Background and Related Work*

In this chapter, the definition of electrical smart grid system has been presented along with its characteristics. Besides, it also put a clear view of functional difference between traditional and smart grid system. At the end of this chapter, brief discussions of smart grid communication systems are done.

Chapter 3: *WiMAX Communication System*

This whole chapter is based on the discussion of WiMAX communication system in details. Moreover, the reason why this communication system has been adopted to communicate with different section of smart grid system has been presented in terms of advantages. The elements of WiMAX transmitter and receiver have been gone into in depth to have a clear understanding of this communication system.

Chapter 4: *Smart Grid Load Protection Model Using Simulink*

In this chapter, the concept of different types of three phase fault is presented before going to designing process of simulink based load protection model. The protection model includes, three phase fault circuit, differential fault current circuit, automatic power backup circuit, automatic fault generation circuit, bypass circuit while fault current occurs to get the power form automatic power back or inverter circuit and designing WiMAX transmitter and receiver for smart grid fault signal transmission and receiption using simulink.

Chapter 5: *Simulation Results*

In this chapter simulation result of the entire project is presented in terms of analytical context. To the last chapter, we have tested the simulink circuits individually but here we have accumulated all those circuits to make the whole project effective and analyze them in order for their performance and justifications.

Chapter 8: *Conclusions and Future Work*

In this last chapter the main results of this dissertation is summarized, and some concluding remarks and identify potential directions for future research has been given.

Chapter 2

Smart Grid and Communication Networks

An electrical grid is an interconnected network for delivering electricity from supplier to consumers. It consists of generating stations that produce electrical power, high-voltage transmission lines that carry power from distant sources to demand centers, and distribution lines that connect individual customers.

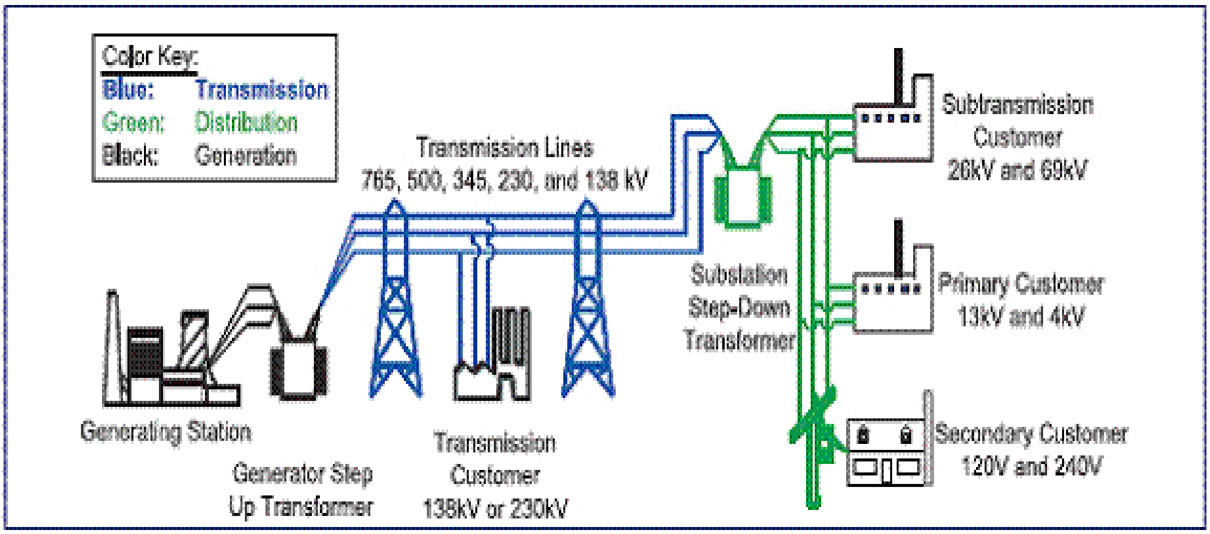


Figure 01: Electrical Grid System

The electrical grid [9] has been designed as a passive network. It had to collect large amounts of energy from power stations and distribute them to a large number of consumers. This has led to the employment of a centralized control, with unidirectional power flows from the power stations to the high voltage (HV) transmission grids, and then, through the transformer stations, up to the medium and low voltage passive distribution grids, that allow the consumers to get the amount of energy they need.

2.1 Basic Concept of Electrical Smart Grid [9]

With the advent of diffused generation, mainly produced from renewable energy sources (RES), this classical view of the electrical grid must be completely revised. The distribution grid, in fact becomes active: the small producers (mainly based on photovoltaic and wind power plants) generate energy and inject it into the distribution system, reversing the direction of power flow, which now goes to the transformer stations. Therefore, the electrical utilities must be ready to handle both the power flows coming from the large power stations (thermoelectric, hydroelectric, etc), and those coming from small producers (mainly solar, wind, thermal) connected to the distribution grid. To do this, grid management cannot anymore be centralized, it must become distributed in the territory: the power flows has to be locally monitored and controlled in order to guarantee both the stability of the grid and the maximum penetration of the distributed generation. Thus the power grid is not anymore only a channel to transmit and distribute energy from large power stations to end users, but an intelligent network, a "Smart Grid", that is able to interact with producers and consumers, in order to adapt with flexibility and instantaneously the energy production to the consumption request. It had to evolve toward a network composed of many small networks connected together, that are able to communicate each other, exchanging information on the power flows, managing with efficiency the energy demand and avoiding services interruption by reducing the load consumption when it is needed. Lines, switches and transformers are not enough anymore for the management of the medium and low voltage distribution grid. A new control system, which integrates electronics and telecommunications, is now required. Authors have already worked on topics related to Smart Grid operation optimization, such as Power Line Communication (PLC) in Medium Voltage (MV) smart grids, metrological characterization of networks, design and realization of innovative transducers and smart meters for power networks and fault detection. In this paper they present the first obtained research results relating the development of a measurement and diagnostic smart network for electric grids with distributed generation from renewable energy sources. They regard the implementation of a new smart network for optimization of electrical grid operation: it is composed of innovative smart meters, able to measure energy, power and power quality, to execute algorithms for fault detection identification. The network nodes are able to communicate among them and with the control centers of the electrical system, covering wide geographical areas. In section II, the design and implementation of the smart meter are reported. Section III discusses the communication network and section IV some details about fault identification technique are given.

What Are its Components?[10]

The grid can be viewed as having two main components, system and network.

System Component:

The major system components in smart grid are Electrical Household Appliances, Renewable Energy resources, Smart Meter, Electric Utility Operation Center and Service Providers. Electrical Household Appliances (smart and legacy) are assumed to be able to communicate with smart meters via a Home Area Network (HAN) facilitating efficient power consumption management to all home devices. Renewable Energy Resources are solar and wind energy that supply home appliances with local generate electricity. Smart Meter is a stand-alone embedded system. Each smart meter contains a microcontroller that has non-volatile and volatile memory, analog/digital ports, timers, real-time clock and serial communication facilities. Smart meters register the power consumption periodically and transmit it to the utility server, connect or disconnect a customer power supply and send out alarms in case of abnormality. Some smart meters are equipped with relays that can be interfaced directly with smart home appliances to control them; for example, turn OFF the air conditioner during peak periods. Furthermore, the smart meter can be used in demand side management. Electric Utility Center interacts with smart meters to regulate power consumption. It also sends consumption related instructions to smart meters and collects sub-hourly power usage reports and emergency/error notifications using General Packet Radio Service (GPRS) technology. Service Providers establish contracts with users to provide electricity for individual devices. Service providers interact with internal devices via messages relayed by the smart meter. To establish such interaction, service providers should register with the electric utility and obtain digital certificates for their identities and public keys. The certificates are then used to facilitate secure communications with users.

Network Component:

Smart grid incorporates two types of communication: Home Area Network (HAN) and Wide Area Network (WAN). A HAN connects the in-house smart devices across the home with the smart meter. The HAN can communicate using Zigbee, wired or wireless Ethernet, or Bluetooth. A WAN, on the other hand, is a bigger network that connects the smart meters, service providers, and electric utility. The WAN can communicate using WiMAX, 3G/GSM/LTE, or fiber optics. The smart meter acts as a gateway between the in-house devices and the external parties to provide the needed information. The electric utility manages the power distribution within the smart grid, collects sub-hourly power usage from smart meters, and sends notifications to smart meters once required. The smart meter receives messages from devices within HAN and sends them to the appropriate service provider. Note that while HANs are used in residential homes, Business Area Networks (BANs) and Industrial Area Networks (IANs) are used within business offices and industrial sites, respectively.

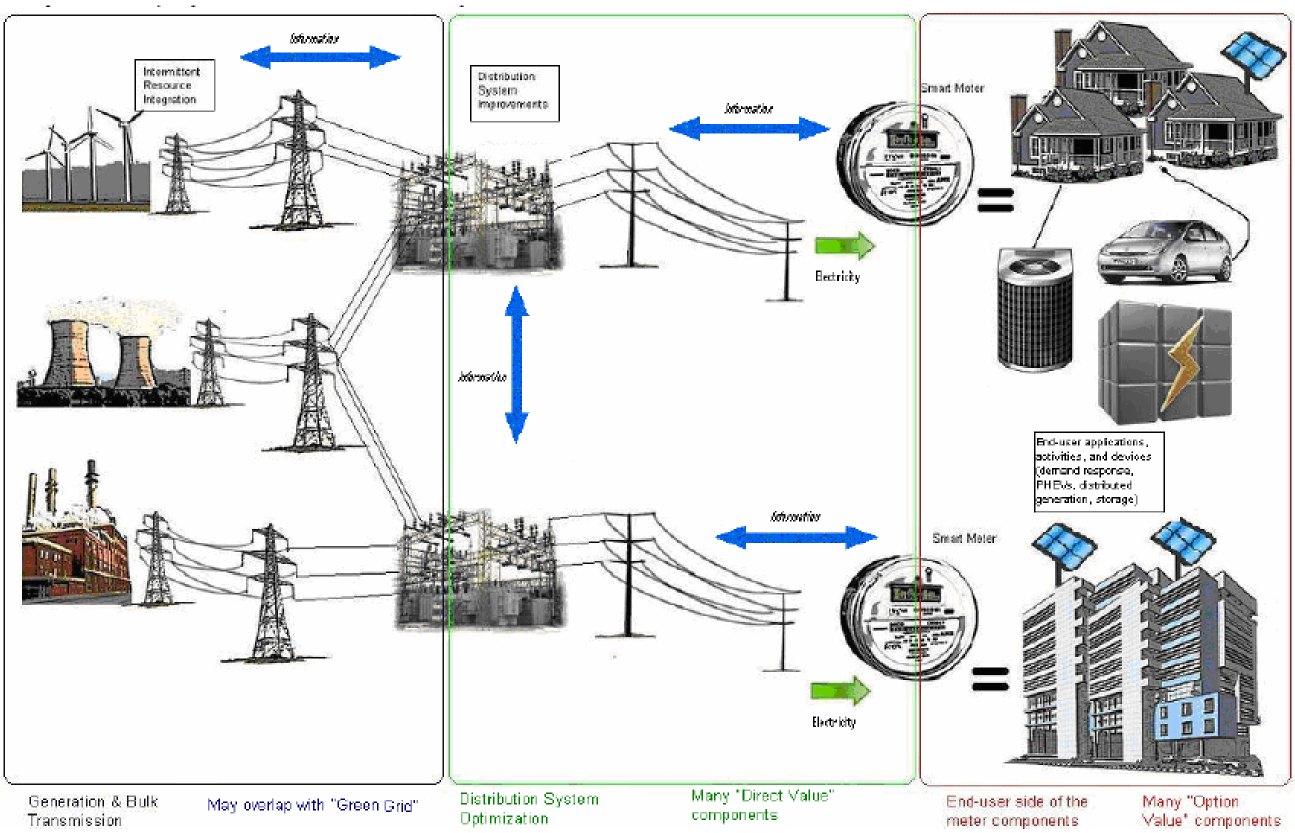


Figure 02: Smart Grid Components.

2.2 Characteristics of Smart Grid

- Enabling informed participation by customers
- Enabling new products, service, and markets
- Accommodating all generation and storage options
- Provide the power quality for the range of needs in the 21st century economy
- Optimizing asset utilization and operating efficiency Addressing disturbances through automation, prevention, containment, and restoration
- Operating resiliently against various hazards

2.3 Functional difference between Traditional and Smart Grid System [11]

Smart Grids deployment must include not only technology, market and commercial considerations, environmental impact, regulatory framework, standardization usage, ICT (Information & Communication Technology) and migration strategy but also societal requirements and governmental edicts. Table 1 shows a comparison between the traditional or current electric grid and the smart grid.

TRADITIONAL GRID	SMART GRID
Ist power generation system is centralized	Distributed power generation system
Electromechanical	Digital
Failures and Blackouts	Adaptive and Islanding
Lack of real time monitoring	Extensive real time monitoring
Slow Reaction time	Extremely quick reaction time
Manual Restoration	Self-healing
One way Communication	Two way communication
No energy Storage	Energy Storage
Total control by Utility	Increased customer participation

Table1. Comparison of Traditional Grid and Smart Grid

2.4 Technology used for Smart Grid Communication [6]

A. Wired Communication technologies for smart grid

A.1 Power Line Communication (PLC)

The power line communication technology consists of introducing of the modulated carrier over the power line cable in order to establish two way communications, it is composed of two major categories Narrowband PLC and Broadband PLC, this technique permit utilities to utilize the power infrastructure to exchange data flows and monitoring control messages, and so far it is considered as a cost-effective smart grid communication means, and it is widely used in AMR applications deployment. However PLC technology is deployed in several smart grid domains from bulk generation to distribution and end consumers. Therefore PLC can be considered as a practical solution for smart grid communication infrastructure. In HAN environment PLC is not - until now- a suitable solution, because of the lack of interoperability and standards, the multi-protocol and the multi-vendor environment in HAN networks. PLC technologies are preferred by utility operators because their reliability advantage compared with other communication techniques.

A.2 Fiber communication

Optical communication has been widely used to connect substations to operation and control centers in the backbone network. Thanks to its multiple advantages such as robustness against radio and electromagnetic interferences making it a suitable choice for high voltage environs, and its capacity to transmit over large distances with very high bandwidth. We believe that fiber optic communication will performance a crucial role in smartgrid infrastructure, according to the authors in the use of Optical Power Ground Wire (OPGW) technology in the distribution and transmission lines will be suitable in smart grid context since the combination of grounding and optical communications allow long distance transmissions with high data rates. Another application of fiber-optic technology would be to provide services to customer domain with the use of passive optical networks (PON) since they use only splitters to collect optical signals and do not require switching equipment. EPON for Ethernet PON is also interesting grid operators and seems to be suitable technology for smart grid access segment meanwhile its enable using interoperable IP based Ethernet protocols over optical networks technology.

A.3 DSL

DSL for Digital Subscriber lines, it is a suit of communication technologies permitting data transfer over telephone lines. Its main advantages consist of its simple utilization in the smart grid context since electric utilities can make immediate advantage of them without any extra cost for additional deployment. There are number of DSL alternatives like ADSL for Asymmetric DSL that supports up to 8 Mbps for downstream and 640 Kbps for upstream, the ADSL 2+ with up to 24 Mbps and 1 Mbps for downstream and upstream respectively. And VDSL (for Very high bit DSL) providing up to 52 Mbps for downstream and 16 Mbps for upstream but only for short distances.

B. Wireless Communication technologies for smart grid

B.1 IEEE 802.11 (WIFI)

IEEE 802.11 standard refers to the collection of wireless communication technology known as WIFI used for WLANs networks. This technology has proved its success due to its simple access structure based on CASMA/CA and its operation in unlicensed frequency bands (2.4 GHz and 5 GHz). IEEE 802.11 is a standards family; the latest release is the IEEE 802.11n which supports the highest data rates up to 150 Mbps while IEEE 802.11a/g supports maximum 54 Mbps. Other standard like 802.11e appears to be important for SG applications because its QOS features, and the 802.11s standard allowing multi-hop and mesh networks over physical layer and finally 802.11p standard for wireless networks for V2G systems.

B.2 IEEE 802.16 (WiMAX)

The IEEE 802.16 standard known as WiMAX supports long distance up to 10 Km broadband with up to 100Mbps of data rate; WiMAX was designed to handle thousands of synchronized users over large distances. The 802.16j standard is the recent version of WiMAX supporting multicast and broadcast multi-hop technique with seamless handover for mobile users item powers flexible distribution and higher coverage which make it suitable choice for NAN and AMI applications. The WiMAX under development version named 802.16 m will provide a greater mobility up to 350 km/h with 100 Mbps data rate , supporting handover with LTE and WIFI. The authors in demonstrate with a simulation based on metering capacities and QOS that WiMAX technology is the most suitable than cellular and wired solutions in the distribution domain for the SG.

B.3 GSM, GPRS and EDGE

The cellular technology main advantages over wireless technologies is the larger coverage area, that why utilities have used them especially in AMR systems and SCADA but the high cost of this technology with problems such latency if a large number of users are served by the same base station has to be solved. Cellular technologies are endorsing great evolution in the few recent years with the development of 3G standards such high packet access standard (HSPA+) providing data rates up to 168 Mbps in the downlink and 22Mbps in the uplink.

B.4 Long Term Evolution (LTE)

The 4G standard or LTE for long term evolution advanced is a wireless communication standard providing an enhancement of the LTE standard deployed today introducing capabilities like bandwidth, easing handover between different networks and advanced networking proficiencies. LTE has multiple advantages that make it a good choice for NAN networks such as end to end quality of services, peak upload rates near 75 Mb/s, and download rates reaching 300 Mb/s. The implementation of LTE technology in smart grid framework can be done in two ways, the first one is the most simple for immediate implementation, it is an efficient and a cost effective way it consist of carrying the data over the actual mobile network architecture of MNOs (Mobile network operators) with piggybacking technique from smart grid end devices in the HANs over the NAN network to the WAN until the utility. The second approach consist of utilization of a special network architecture for data transfer, and the implementation of this approach is similar to the MVNO (Mobile Virtual network operators) method it can be done by the rental of a portion of the MNO core network by the smart grid utility, or it can be done also by the implementation of the core network architecture by smart grid utility using the LTE technologies like the MNOs but totally disconnected from the MNO core network. The cost effectiveness security and the simple implementation make LTE a good choice as a communication technique for NAN networks.

B.5 IEEE 802.15.4

The IEEE 802.15.4 is a standard for physical and MAC layers for low-rate wireless personal Area networks (LRWPAN) it offers up to 250 kbps over 10m. Several network topologies are supported like star, tree or mesh multi-hop. IEEE 802.15.4 is the basis radios for many other standards for monitoring and control applications; the most important are ISA 100.11a standard, Zigbee standard and wireless HART standard. These standards replace 802.15.4 MAC protocol with TDMA based scheme. Zigbee is widely adopted for WPANs for both commercial and industrial environments; further information about this standard will be given in section

B.6 ZigBee

ZigBee is a standard and a communication technology which specifies the physical layer and the medium accesslayer it is based on the IEEE 802.15.4 standard and commonly known as the low-rate wireless personal area networks (LR-WPANs). In ZigBee network we have two types of devices: FFD for full function devices and RFD for reduced function device, the FFD perform the network establishment, management and routing while RFD support FFD functionalities .The network is composed of three types of nodes: the coordinator, the router and the end device .RFD is always the end device while FFD can make any device type. The role of the coordinator is to establish and manage the network, the router routes the traffic between coordinator and end device. Coordinators and routers are battery powered devices, they are usually not allowed to go to sleep mode, and they are capable of communicating with all the rest of intelligent devices in the network. The end devices are permitted only to interconnect with the router or the coordinator and not with each other. End devices are awakening periodically to checks the parent node for their tasks and sends the data and then they go to sleep mode. The sleep mode in Zigbee network nodes make the network energy efficient and low power comparing with other communication technologies. Zigbee most strong feature is its capability of creating application profiles empowering multi-vendor interoperability, in this profile we found a description of different parameters like data formats, application supported devices, message types etc.

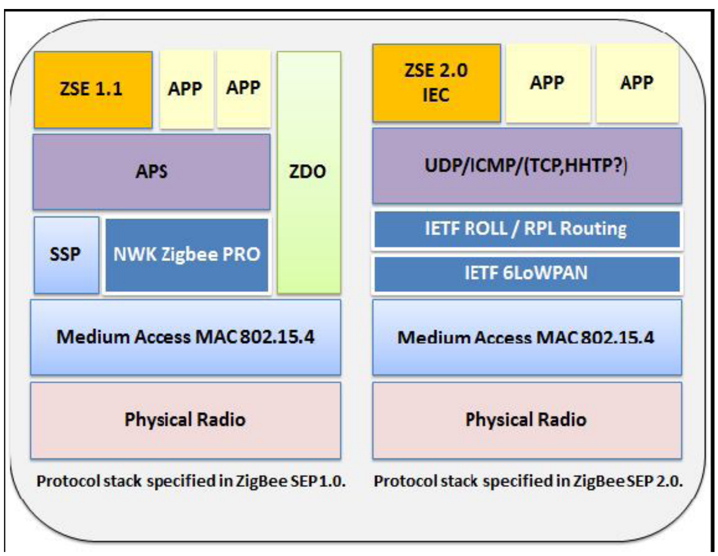


Figure 03 **:**Evolution of ZigBee Protocol Stack for SG new

Requirements: The ZigBee SEP 2.0 smart energy profile provides interfaces to manage, control and monitor energy use. As described by figure 3, the ZigBee IP protocol stack specified in SEP 2.0 compresses the packet structure specified in SEP1.0 within IPV6 packets. This will provide an independent interface between network and MAC layers tolerating smooth communication with IP based network.

B.7 Cognitive radio Networks

Cognitive radio technology is a stand-alone radio based on IEEE 802.22; it is a key technology for optimizing the underutilization of spectrum due to spectrum increasing demands caused by advancement of wireless technologies. CR networks enable to secondary users (SUs) the spectrum access when it is not used by the primary licensed user efficiently without causing any interference with PU. This spectrum sensing technique could be widely deployed in SG WAN, backhaul and distributions networks over large geographic area. The CR technique consists of opportunistic access to unused spectrum, we believe that this technique will have a great future for SG since it delivers a high performance, high speed data transmission, scalability and fault tolerant broadband access. A Cognitive Radio Network Testbed is built in Tennesee Technological University in order to attain convergence between CR technique and Smart grid. Cognitive radios make the smart grid “smarter” and provide to it more security, scalability, robustness, reliability and sustainability

B.8 DASH7

Dash 7 is a technology for wireless sensors networks based on ISO/IEC 18000-7 standard and promoted by Dash 7 alliance. It is made for Active radio Frequency Identification Devices or RFIDs. Dash 7 operates at a 28 kbps rate up to 200 kbps and it has coverage of about 250 m extendable to 5 km . It is a low power technology, with tiny sensors stacks and long live battery’s up to several years which make it cost effective solution. The dash 7 uses very small amount of energy for wake up signal up to 30-60 mW and it is low latency with around 2.5-5 s. Its several advantages like interoperability, robustness and cost effectiveness made it widely deployed for military application and also commercial applications such as building automation, smart energy, smart home, PHEVs, logistics control and monitoring. In the context of smart grid, Dash 7 seems to be respectable alternative to ZigBee, allowing several advantages like its wide range avoiding the multi-hop technique for HAN solution, permitting less number of nodes and less communication time.

Chapter 03

WiMAX Communication System

3.1 Fundamental Concept of WiMAX

WiMAX (Worldwide Interoperability for Microwave Access) is a connection-oriented wide area network. It supports high bandwidth and hundreds of users per channel at speeds similar to currently seen for DSL, Cable or a T1 connection; Promises to provide a range of 30 miles as an alternative to wired broadband like cable and DSL. It could potentially provide broadband access to remote places. Use point-to-multipoint (P2MP) architecture. It is designed for delivering broadband seamless quality multimedia services to the end users. “WiMAX combines the familiarity of Wi-Fi with the mobility of cellular that will deliver personal mobile broadband that moves with you”.

3.2 Advantage of WiMAX Communication [12]

1. It provides full utility of products, Provides greatest features and functions on the lowest cost. Advantages over PLC (Programmable Logic Controller), DLC (Data Link Control) and Mesh Network are significant.
2. The biggest reason for using WiMAX for the smart grid is its high bandwidth compared to other wireless network topologies. Data transfer rate ranges from 1Mbps to 15Mbps.
3. High speed for real time application and fast response.
4. WiMAX signals at a 2 mile radius area, which is well enough to include the effective sites on and off the campus area, where the intelligent system has been installed.
5. The WiMAX based smart grid networks has inbuilt feature of the security the data transmission i.e. a secure communication throughout the network through smart grids.
6. This is essentially the same as cellular phone service and WiMAX is one of the technologies being used for 4G implementations by the cellular providers.

3.3 WiMax Transmitter [13]

The MAC Payload Data Units (PDUs2) are fed into the randomizer which randomize/scrambling the data. The randomized data is coded by using channel encoder as, which consist of Reed Solomon, convolution encoder and puncture.

The coded data is interleaved by interleaver and mapped into QAM symbol. Afterwards, the mapped data enter into the OFDM modulation which consist of assemble OFDM frame, 256 IFFT and cyclic prefix insertion. Then the data is transmitted over AWGN channel.

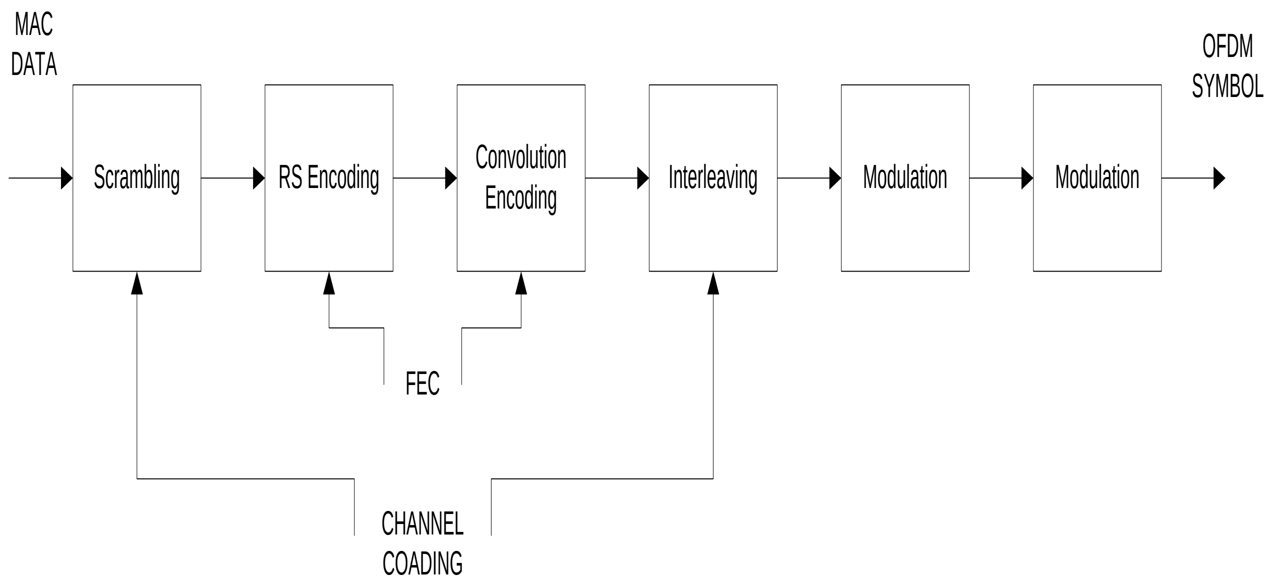


Figure 04: 802.16d transmitter block diagram for the OFDM PHY[14]

3.3.1 Randomizer/Scrambling Unit[13]

The information bits are randomized before the transmission. The randomizer, which is the first block in the transmitter, performs randomization of input data on each burst on each allocation to prevent a long sequence of 1's and 0's. This is implemented by using a Pseudo Random Binary Sequence (PRBS) generator, which is made of a 15 bits shift register and two XOR gates as shown in figure-05.

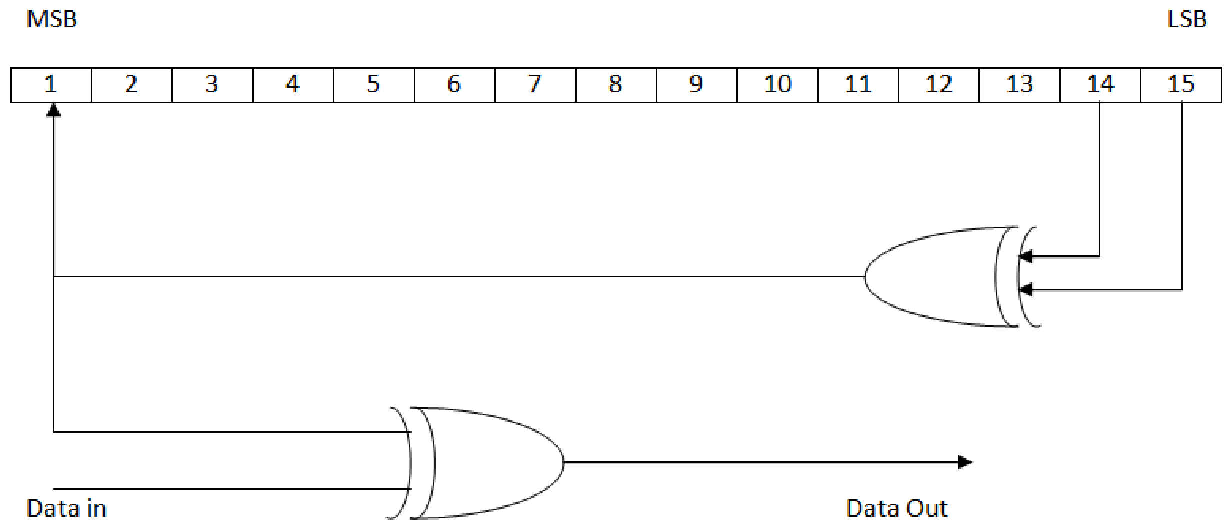


Figure: 05 Point PRBS for data randomization.

For downlink burst the initial vector for the shift register (Linear-Feedback Shift Register (LFSR) possessing characteristic polynomial (1+ +) is 100101010000000 and the scrambler should be reset at the start of each burst. The vector, which is shown in figure 2.3, is placed at the start of subsequent bursts. We utilize frame number for referring to the frame in which the downlink burst is transmitted. [4]

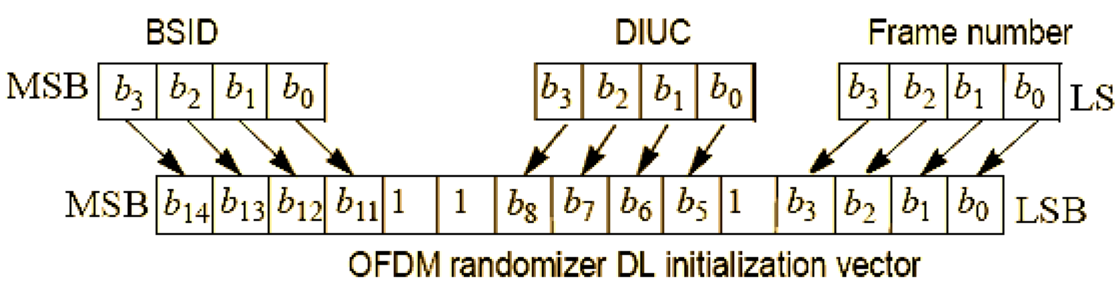


Figure 06: OFDM randomizer downlink initialization vector for burst #2...N.

3.3.2 Channel Encoder

The channel encoder consists of an FEC scheme (i.e. a concatenation of an outer RS code and an inner CC), puncturing and interleaving as shown in [6]. The randomized data passes to the RS encoder and then passes to CC encoder. After this, the encoded data is punctured and interleaved.

3.3.2.A Outer Reed Solomon [13]

The RS code is special kind of linear block codes, which is suitable for correcting burst errors. The RS encoder adds redundancy to the data sequence in order to correct the errors, which occurred during transmission. This RS code is derived from a systematic RS (= 255,= 239, =8) code using a Galois field specified as $GF(2^8)$, with is the number of bytes after encoding, is the number of data bytes before encoding and is the number of data byte that can be corrected.

The following polynomials are used for the systematic code:

Code Generator Polynomial: $g(x) = (x+\lambda^0)(x+\lambda^1)(x+\lambda^2)\ldots.(x+\lambda^{2T-1})$

Field Generator Polynomial: $p(x) = x^8 + x^4 + x^3 + x^2 + 1$

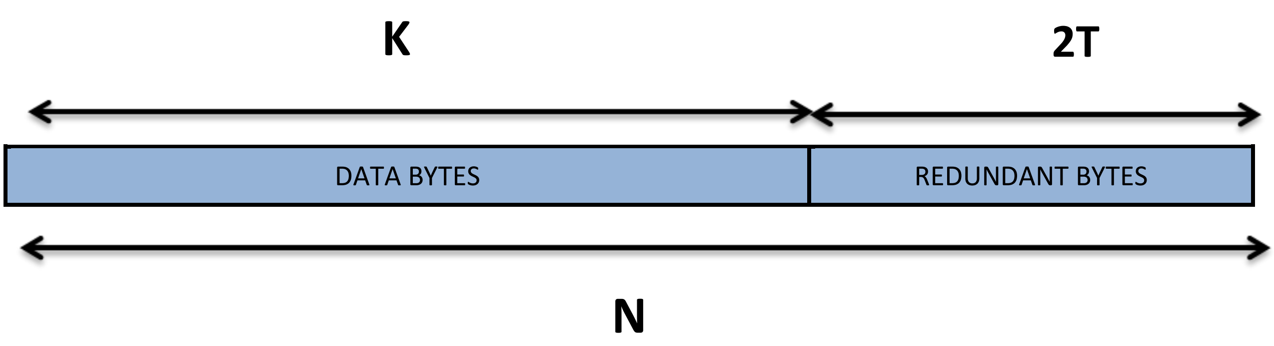


Figure 07: The Reed Solomon Code.

A Reed-Solomon code is specified as RS (n, k, t) with l-bit symbols. This means that the encoder takes k data symbols of l bits each and adds 2t parity symbols to construct an n-symbol codeword. Thus, n, k and t can be defined as:

n: number of bytes after encoding,

k: number of data bytes before encoding,

t: number of data bytes that can be corrected.

The error correction ability of any RS code is determined by $(n - k)$, the measure of redundancy in the block. If the location of the erroneous symbols is not known in advance, then a Reed-Solomon code can correct up to t symbols, where t can be expressed as $t = (n - k)/2$.Here we have used n=255, k=239 and t=8 because this values are standard.

Padding and Selector:

The Reed-Solomon Encoder is mainly work with integer values. So here we have first convert the bit into integer format using bit to integer converter then reorder the vector using zero padding then operate RS encoding process Then we have use a selector to select the data from our vector then convert it to the bit format again using integer to bit converter block.

3.3.2.B Inner Convolutional Encoder[13]

The purpose of a convolution encoder is to take a single or multi-bit input and generate a matrix of encoded outputs. One reason why this is important is that in digital modulation communications systems (such as wireless communication systems, etc.) noise and other external factors can alter bit sequences. By adding additional bits we make bit error checking more successful and allow for more accurate transfers. By transmitting a greater number of bits than the original signal we introduce a certain redundancy that can be used to determine the original signal in the presence of an error [16].

After the RS encoding process, the data bits are further encoded by a binary convolutional encoder. It converts the single or multi bit into matrix form. It is use to discard noise from the main signal. It is another process of error correction. It deals with bit data. It is work using poly2trellis function[16].

A convolutional encoder accepts messages of length k_0 bits and generates Code words of n_0 bits. Generally, it is made up of a shift register of L segments, where L denotes the constraint length. The binary convolutional encoder that implements the described code is shown in figure. A connection line from the shift register feeding into the adder means a "one" in the octal representation of the polynomials, and no connection is represented by a "zero“ [16] .

We have used here a convolutional encoder block for convolutional encoding.

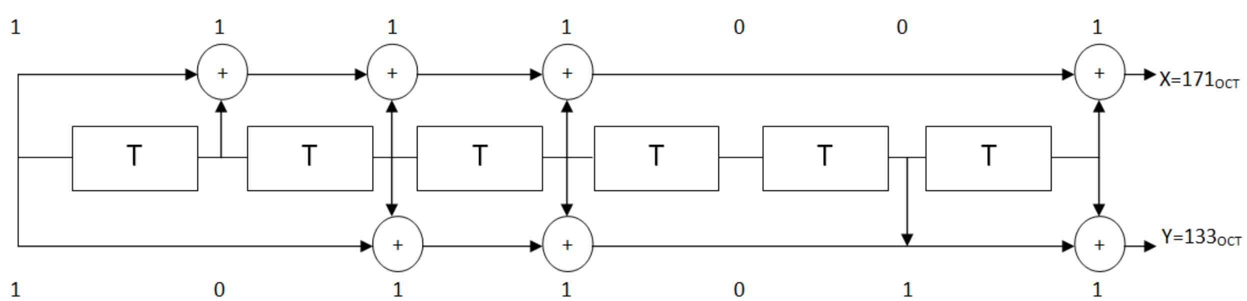


Figure 08: Convolutional encoder of rate ½ [16].

The RS encoded bits are encoded by the binary convlutional encoder, which has native rate of 1/2, a constraint length equal to 7 and a polynomial description [171 133] as shown in equation (2.3), (2.4) to produce its two code bits. The generator is shown in figure.

$$G1 = 171_{OCT} \qquad For\ X \qquad (2.3)$$

$$G2 = 133_{OCT} \qquad For\ Y \qquad (2.4)$$

In fact, encoding consist two types of process for distortion less transmission of data.

A. Puncturing process B. Interleaver

Puncturing process

Puncturing process is mainly used to convert a long bit stream data into short bit stream. It compress the long bit data. Puncturing is the process of systematically deleting bits from the output stream of a low-rate encoder in order to reduce the amount of data to be transmitted, thus forming a high-rate code. The bits are deleted according to a perforation matrix, where a "zero" means a discarded bit. The process of puncturing is used to create the variable coding rates needed to provide various error protection levels to the users of the system. There are different types of puncturing process like as ½ rate, 2/3 rate, ¾ rate, 5/6 rate. Here is the scenario of puncturing vector [16].

Interleaver

Interleaving is done by spreading the coded symbols in time before transmission. The incoming data into the interleaver is randomized in two permutations. First permutation ensures that adjacent bits are mapped onto nonadjacent subcarriers. The second permutation maps the adjacent coded bits onto less or more significant bits of constellation thus avoiding long runs of less reliable bits [13].

Error detection and correction is carried out by forward error correction block which is composed of Reed-Solomon encoder, convolutional encoder and puncture (used to adjust different data rate).These are the mandatory blocks on the standard FEC, consisting of the concatenation of a Reed-solomon outer code and a rate-compatible convolutional inner code. The modulation used in 802.16d is integer-mapped 4 QAM, 16 QAM, 64 QAM [14].

3.3.3 Modulation Mapper

Once the signal has been coded, it enters the modulation block. All wireless communication systems use a modulation scheme to map coded bits to a form that can be effectively transmitted over the communication channel. Thus, the bits are mapped to a subcarrier amplitude and phase, which is represented by a complex in-phase and quadrature-phase (IQ) vector. The IQ plot for a modulation scheme shows the transmitted vector for all data word combinations. Gray coding is a method for this allocation so that adjacent points in the constellation only differ by a single bit. This coding helps to minimize the overall bit error rate as it reduces the chance of multiple bit errors ocurring from a single symbol error [16].

The modulation constellation used in WiMAX is two types of phase shift keying (PSK) modulation (binary (BPSK) and quadrature (QPSK)) and two types of quadrature amplitude (QAM) modulation (16QAM and 64QAM). The complex constellation value is scaled by factor (Normalization constant), such that the average transmitted power is unity, c equals 1 √2⁄ for QPSK, 1 √10⁄ for 16-QAM, 1 √42⁄ for 64-QAM (if we assume that all symbols are equally likely) [15].

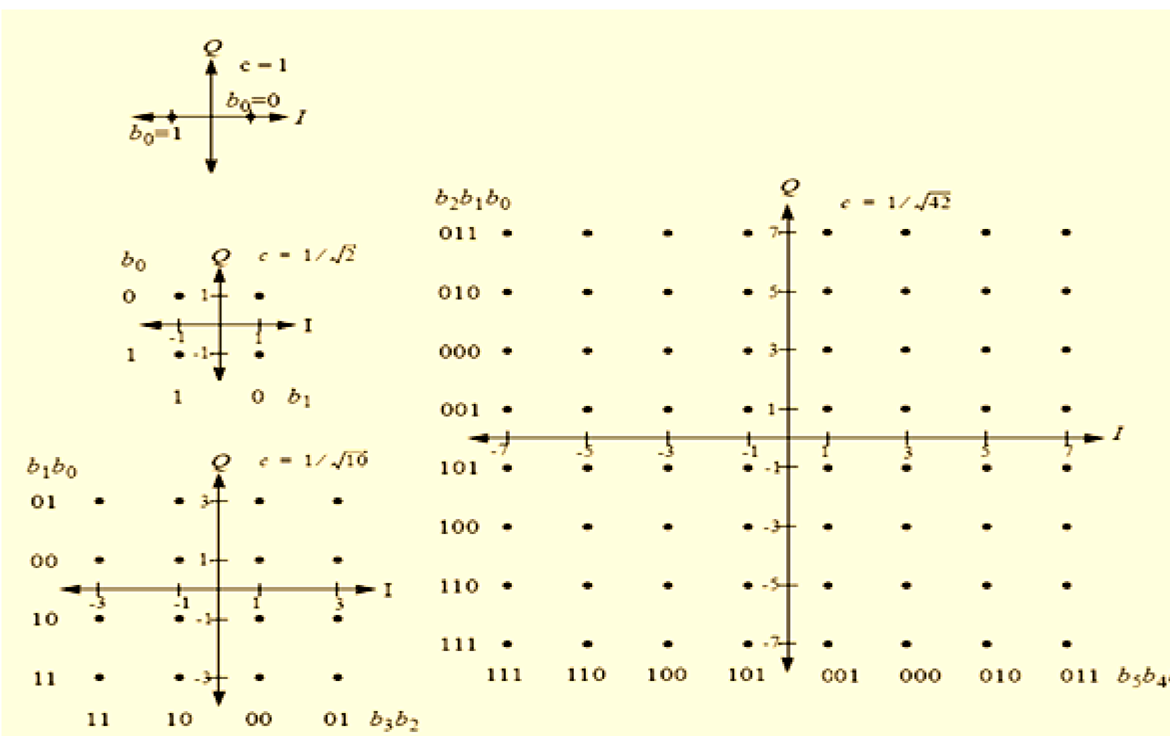


Figure 09: BPSK, QPSK, 16-QAM and 64-QAM constellations [15]:

3.3.4 OFDM Modulator

Orthogonality

The key to OFDM is maintaining orthogonality of the carriers. If the integral of the product of two signals is zero over a time period, then these two signals are said to be orthogonal to each other. Two sinusoids with frequencies that are integer multiples of a common frequency can satisfy this criterion. Therefore, orthogonality is defined by [17]:

$$\int_0^T \cos(2\pi n f_o t)\cos(2\pi m f_o t)dt = 0 \quad (n \neq m)$$

Where n and m are two unequal integers; f0 is the fundamental frequency; T is the period over which the integration is taken. For OFDM,T is one symbol period and f0 is set to 1/T for optimal effectiveness.

OFDM modulation

In WiMAX, each OFDM symbol consists of 256 subcarriers as shown in figure [10]. They can be divided into.

1. 192 data subcarriers that are used for conveying data.
2. 8 pilot subcarriers that are used for conveying pilot symbols.
3. 56 null subcarriers that have no power allocated to them, including the DC subcarrier

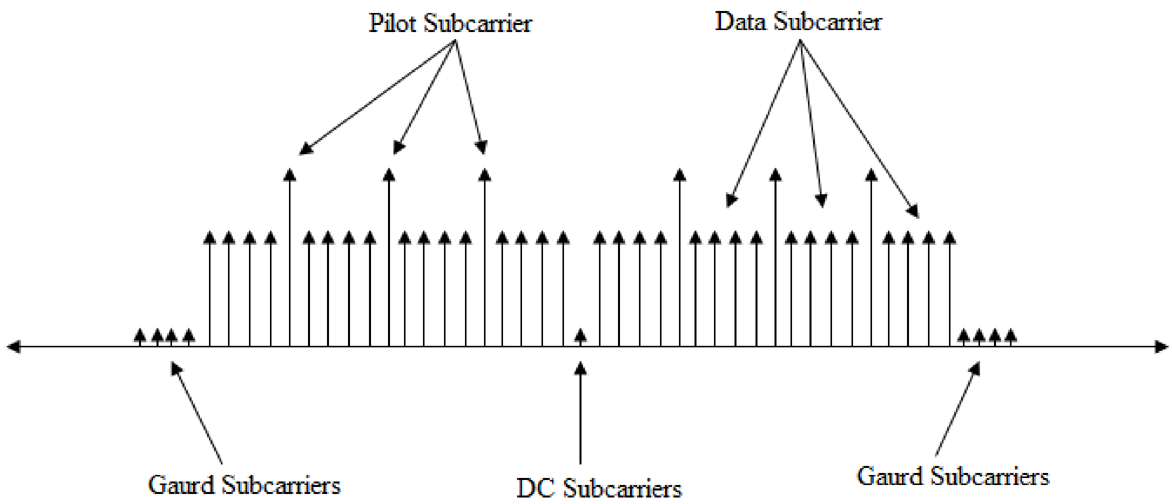


Figure 10: Frequency domain representation of OFDM symbol [18].

Pilot modulation

Before inserting a pilot to its specified position, as shown in figure 10, it has to be modulated. Pilots can be generated by Pseudo Random Binary Sequence (PRBS) generator as shown in figure 11.

	MSB										LSB
Initializatin DL:	1	1	1	1	1	1	1	1	1	1	1
UL:	1	0	1	0	1	0	1	0	1	0	1

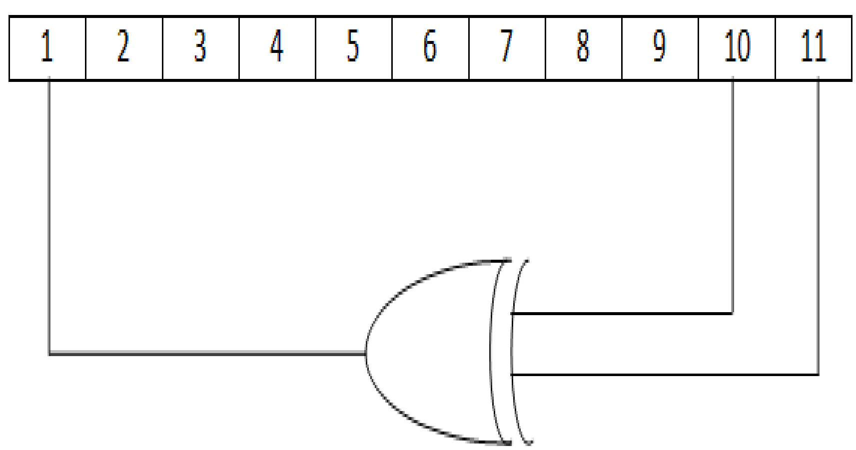


Figure 11: PRBS for pilot modulation [15].

The polynomial of PRBS generator is:

$$g(x) = x^{11} + x^{9} + 1$$

Pilot subcarriers are used for various estimation purposes.

Inverse Fast Fourier Transform (IFFT)

To convert mapped data, which is assigned to all allocated data subcarriers of the OFDM symbol, from frequency domain into time domain, the IFFT is used. We can compute time duration of the IFFT time signal by multiply the number of FFT bins by the sample period Zeros are added at the end and beginning of OFDM symbol. These zero carriers are used as guard band to prevent inter channel interference (ICI) [13].

Cyclic Prefix insertion (CP)

To avoid inter symbol interference (ISI) a cyclic prefix is inserted before each transmitted symbol. That is achieved by copying the last part of an OFDM symbol to the beginning as shown in figure [10] WiMAX supports four different duration of cyclic prefix (i.e. assuming G is the ratio of guard time to OFDM symbol time, this ratio is equal to 1/32, 1/6, 1/8 and 1/4).

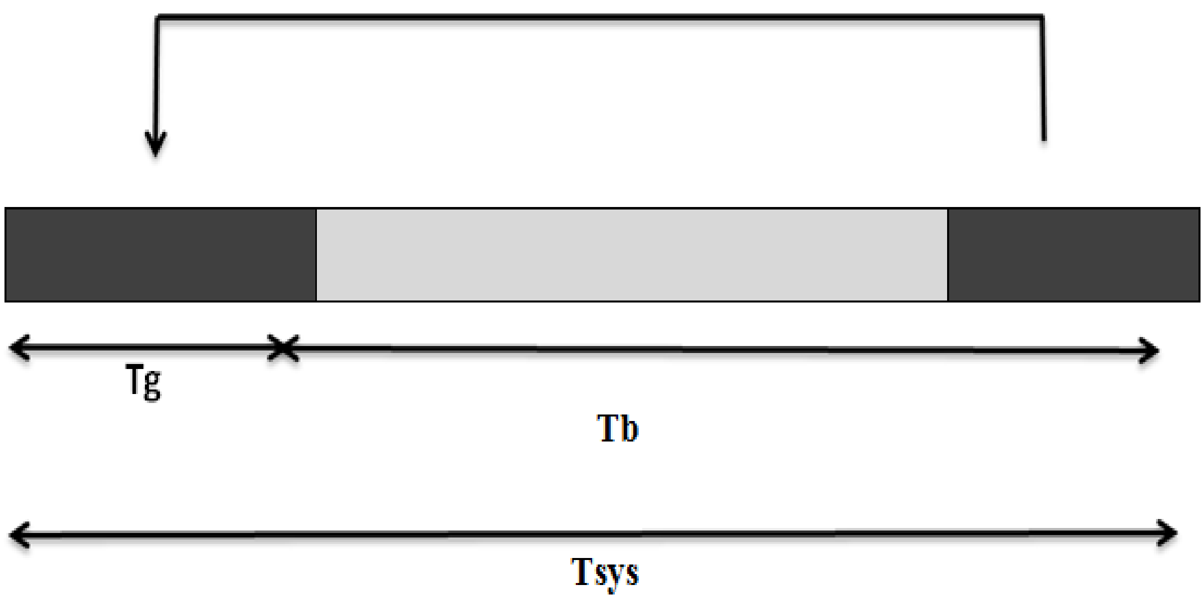


Figure 12: OFDM symbol with the cyclic prefix. [13]

Now we have to convert our data into OFDM symbol. For this reason we have to take the data as row format then add pilot signal and training signal with our data then use a vertical concatenation to make an OFDM symbol consists of data, pilot signal and training sequence and guard band.

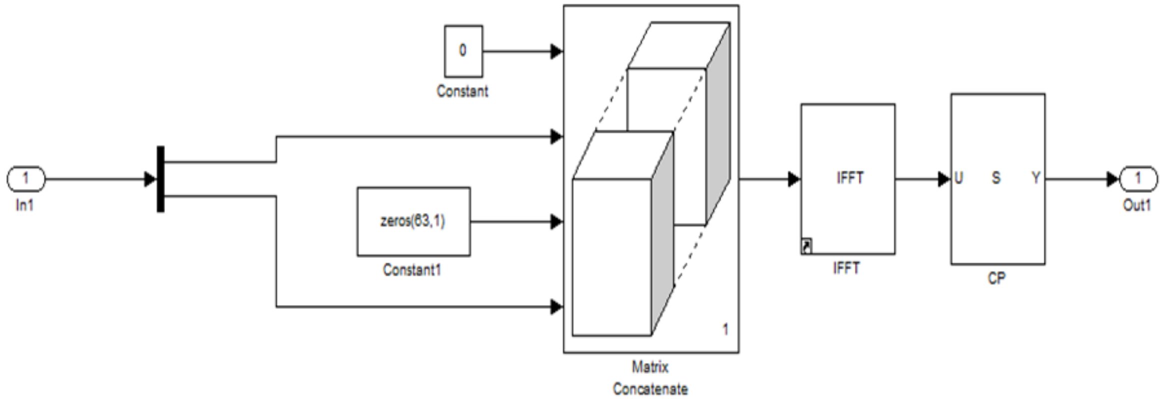


Figure 13: Simulink block of OFDM Transmitter

3.4. Channel

AWGN or Additive-White Gaussian Noise is assumed to be one of the simplest environment uses for the communication of wireless based system. AWGN is very common during transmission of signal travel through channel considering as a background noise. It is basically add the white Gaussian noise so as to pass through the channel with the actual signal. In short, it is known be a basic communication channel model for standard channel model. In order to disturb the actual signal which is intended to transmit through the channel, this additive white goussian noise is added [19].

Our WiMAX network is based on line of sight (LOS) propagation. So simulation supports 2 types of channel. They are –

1. AWGN channel
2. Rician Fading channel

But here we have used AWGN channel because it is the commonly used channel in wireless communication. On the other hand in Rician Fading channel the signal is distorted. And when no signal is transmitted a huge garbage value is received by the receiver as a result the signal is totally changed.

3.5. WiMAX Receiver

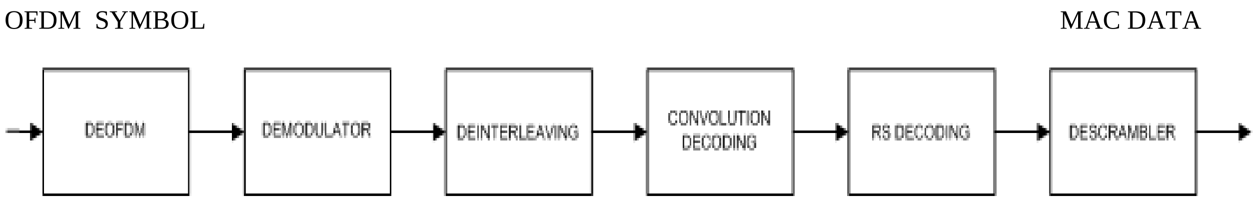


Figure 14: 802.16d WiMAX Receiver [14]

The received data coming from AWGN channel is fed into the OFDM demodulation, which consist of removal of CP, Fast Fourier Transform (256 FFT) and disassemble OFDM frame. Then, the data is performed by de-mapper and afterwards the demapped data enter the channel decoder. Channel decoder consists of de-interleaver, de-puncture, convolutional decoder and finally RS decoder.

3.5.1 OFDM Demodulation

The OFDM demodulation is the reverse operation of OFDM modulation. Here, the signal is converted back from time domain to frequency domain. The first step in OFDM demodulation is to remove the CP. Then FFT is performed. Afterwards the OFDM frame is disassembled.

Removal of CP

The first step after the arrival of data is to remove CP as shown in figure 15. We know that CP has no effect in case of using AWGN channel. It is useful when the multipath channel is used. If CP larger than the delay multipath the ISI is completely removed [13].

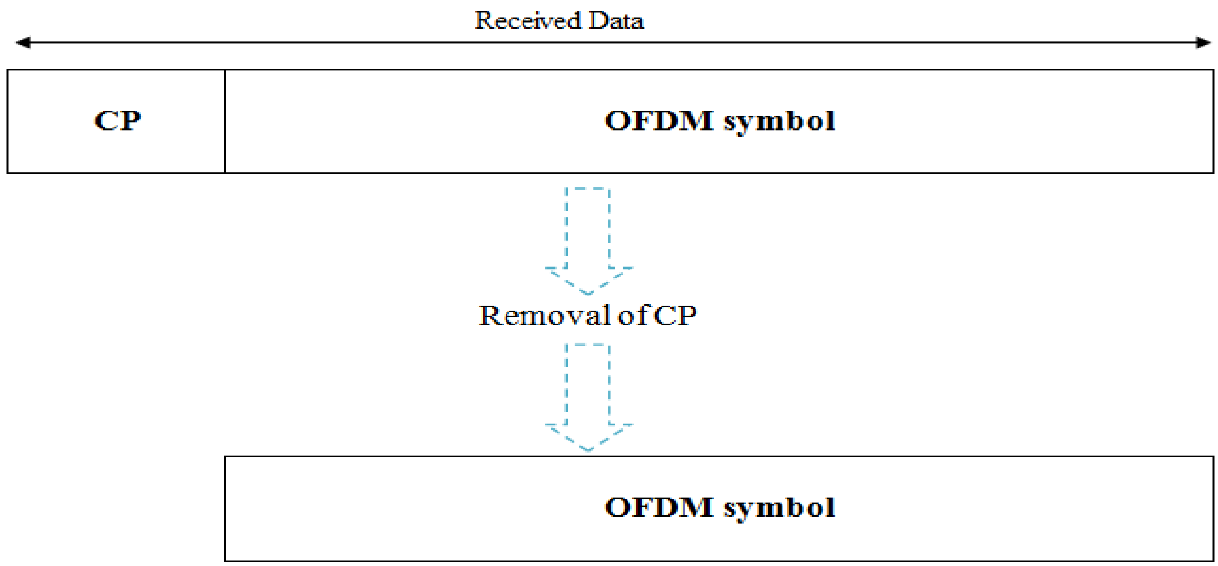


Figure 15 : Removal of CP [13]

Remove cyclic prefix is the same as add cyclic prefix. Here we have used a selector to add cyclic prefix with the data. Here we have use vector as input and define one based index to initialize the vector from one.

Fast Fourier Transform (FFT)

The IFFT algorithm represents a rapid way for modulating a group of sub carriers in parallel. Either the FFT or the IFFT are a linear pair of processes, therefore the FFT is necessary to convert the signal again to the frequency domain. It is needed because the decoding processes are work on frequency domain based signal. It is same as IFFT. The details of FFT are discussed in IFFT part [16].

To convert received data from time domain to frequency domain, the FFT is used. Afterward, the zeros, which were added at the end and beginning of OFDM symbol (guard bands) at the transmitter are removed from the assigned places.

3.5.2 Demodulator

Demodulator is the same as modulator. Here we have used QPSK modulation technique. So in receiver part to demodulate the data we have used QPSK demodulator to demodulate the data. It is the same as modulator but it’s the reverse process of modulation. Here is the eye diagram of the signal after demodulation.

Decoding:

After demodulating the signal we have to decode the signal. Then we have to decode the signal to recover the main signal from the demodulated signal. We have to pass through some step. They are:

a) Deinterleaver
b) Inserting zero
c) Viterbi Decoder/Convolutional decoder
d) Reed Solomon decoder

3.5.3 Deinterleaver

The matrix deinterleaver performs block deinterleaving by filling a matrix with the input symbols column by column, and then, sending its contents to the output row by row. The parameters used in both blocks are the same as those ones used in the interleaving process. This matrix deinterleaving process is done by the code [16].

To remove the effect of interleaving process achieved at the transmitter, the deinterleaving is used. Deinterleaver in WiMAX is defined by two-step permutation.

The first permutation is defined by equation :

$$m_j = s \cdot floor(j/s) + \left(j + floor(12 \cdot j/N_{cbps})\right)_{mod(s)} \qquad j = 0,1,\ldots,N_{cbps} - 1$$

The second permutation is defined by equation :

$$k_j = 12 \cdot m_j - (N_{cbps} - 1) \cdot floor(12 \cdot m_j/N_{cbps}) \qquad j = 0,1,\ldots,N_{cbps} - 1$$

With $s = ceil(N_{cpc}/2)$, and is the number of coded bit per carrier, N_{cbps}

is number of coded bits per OFDM symbol (received block), j is the index of a received bit before the first permutation, Mj is the index of that bit after the first and before the second permutation and Kj is the index of that bit after the second permutation [15].

Inserting Zero/Depuncturing:

The block named "Insert Zeros" deals with the task of reversing the process performed by the "Puncture" block. The receiver does not know the value of the deleted bits but it can know their position from the puncturing vectors. Thus, zeros are used to fill the corresponding hollow of the stream in order to get the same code rate as before performing the puncturing process. The inserted zeros can also be seen as erasures from the channel. They have no influence on the metric calculation of the succeeding Viterbi decoder [16].

3.5.4 Convolutional Decoder

To decode the bit stream coming after depuncturing, the convolutional decoder is used. The Viterbi algorithm is the one of methods, which is commonly used for decoding the convolutional codes. The Viterbi algorithm performs the maximum likelihood decoding. It is described by using the trellis diagrams as shown in figure [16]. The algorithm computes the distance between the received sequence at certain time and each trellis paths entering each state at the same time. When two paths met in single state, the algorithm chooses the one, whose better metric (i.e. smaller Hamming distance). And so on, till remain a single path which represents the received data (the surviving path). Comparing the received sequence with every possible code sequence is the best way to detect the random errors. [20]

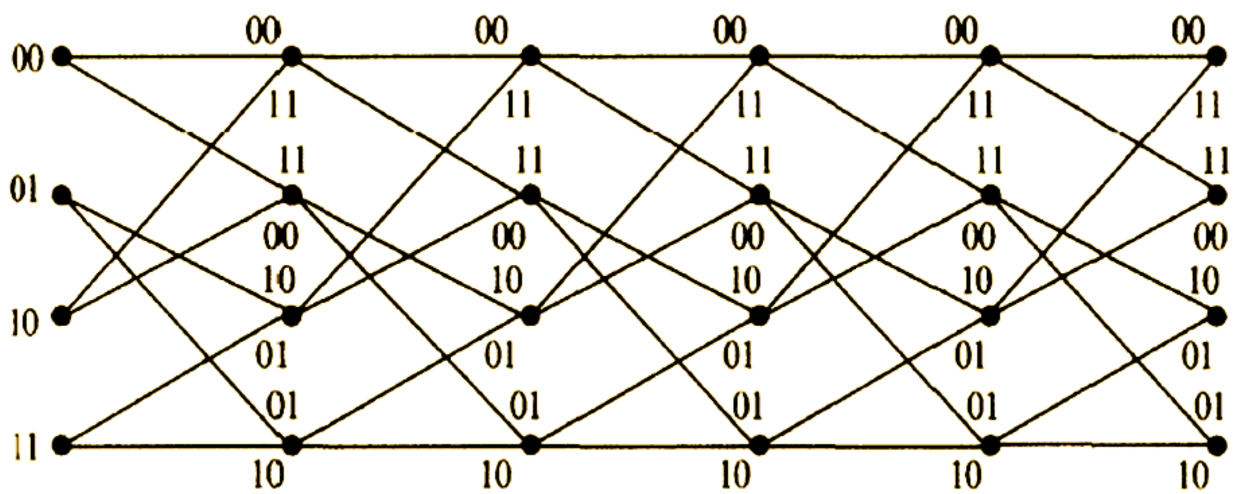


Figure 16.The trellis diagram [20].

3.3.5 Reed-Solomon Decoder

It performs the necessary operations to decode the signal, and get, at the end, the original message sent by the source. Thus, the RS decoder takes code words of length n, and, after decoding the signal, it returns messages of length k, being n = 255 and k = 239, the same as the ones described in the RS encoder[16].

3.5.6 Derandomizer

The stream of bits coming from RS decoder is forwarded to the de-randomizer. The structure and the operation of the de-randomizer is the same of randomizer.

Chapter 04
Smart Grid Load Protection Model (SGLPM) Using Simulink

In order to go before the depth of smart grid load protection system, it is required to know about the types of fault occurs in three phase system. There are different types of fault is taken place for numerous number of reason. However, those faults can be identified as three phase to ground fault, line to line fault, line to ground fault, double/two line ground fault, single line to ground fault and influential fault [21] [22]. Considering the frequency of occurring these fault, it is about 85% fault which is known to be line to ground fault but relatively less serious. On the other hand, the symmetrical (all phase a affected equally) faults are taken to be consider as very dangerous where the percentage is estimated to not more that 2%. To the followings, these faults are discussed with brief analytical method.

4.1 Three Phase Fault: [21]

When the individual phases gets contact with other remaining phases or get the contact with all phases unexpected is known to be as three phase fault. The example is shown in figure 17.

The equation of the voltage makes as follows when all three phase get into contact with each other:

$$V_{ax} = V_{bx} = V_{cx} = 0 \qquad (2.6)$$

According to the current law of Kirchhoff's:

$$I_a + I_b + I_c = 0 \qquad (2.7)$$

4.1.1 Three-Phase-to-Ground Fault

Three-Phase-to-Ground Fault is taken place provided that the phases of all individual lines have a contact with the ground of the circuit as shown in figure 18.

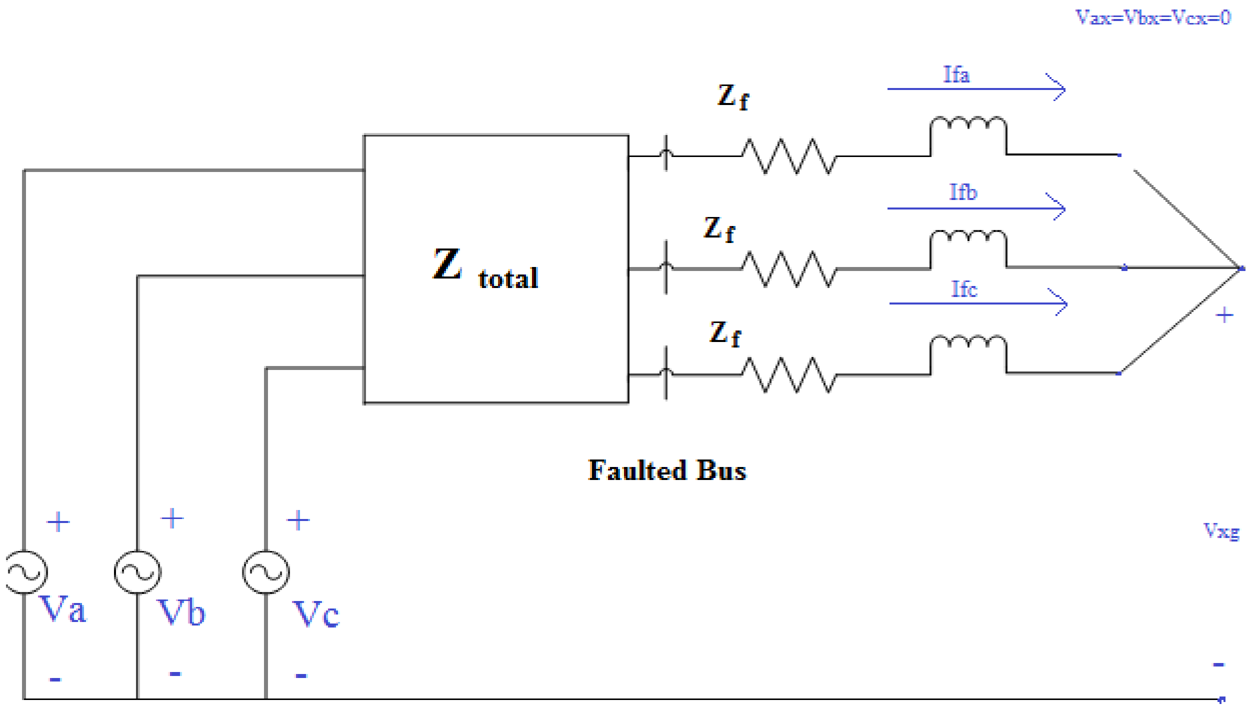


Figure 17: Thevenin Equivalent of three-phase fault

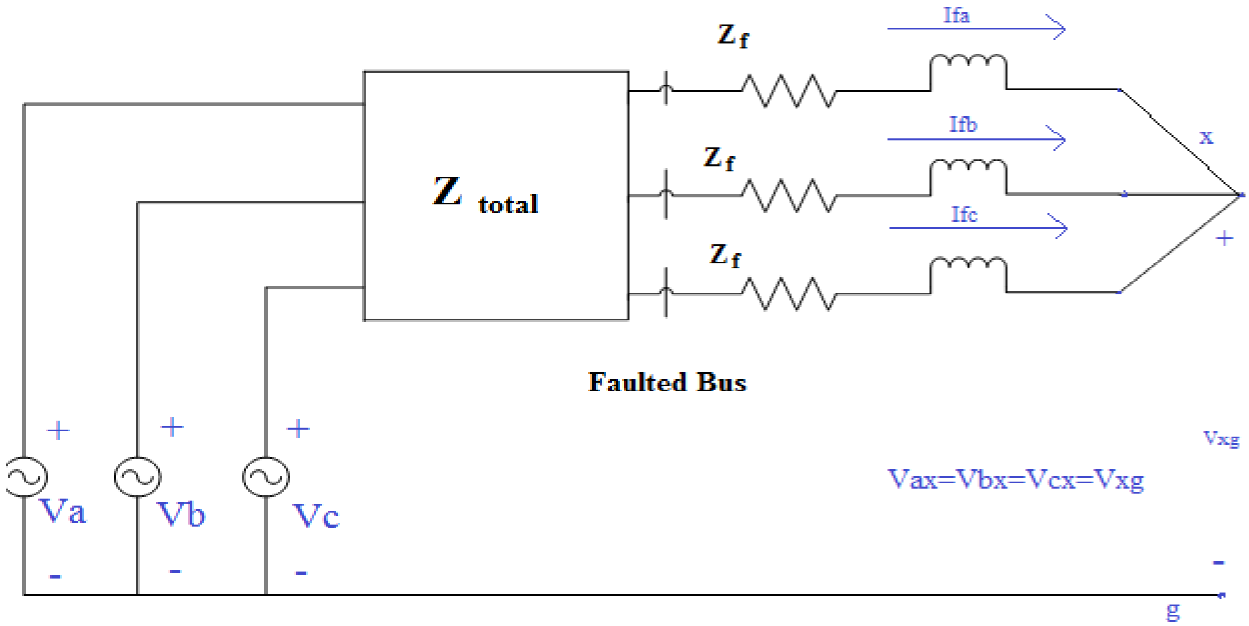


Figure 18: Thevenin Equivalent of three-phase-to-ground fault

Here, the path of fault current to towards ground and ground becomes as reference voltage level:

$$Vax = Vbx = Vcx = Vxg = 0 \tag{2.8}$$

4.1.2 Line-to-Line Fault

To the figure 19, it is easily understandable that, the first two lines i.e. Ifa and Ifb are contacted with each other has made such type of fault known as Line-to-Line Fault whereas the line current Ifc has remained as un-fault.

$$Vix = Vjx = 0 \qquad (2.9)$$

Here the faulted lines have become the path to return the fault current as:

$$Ifc = 0 \qquad (2.10)$$

$$Ifb + Ifa = 0 \qquad (2.11)$$

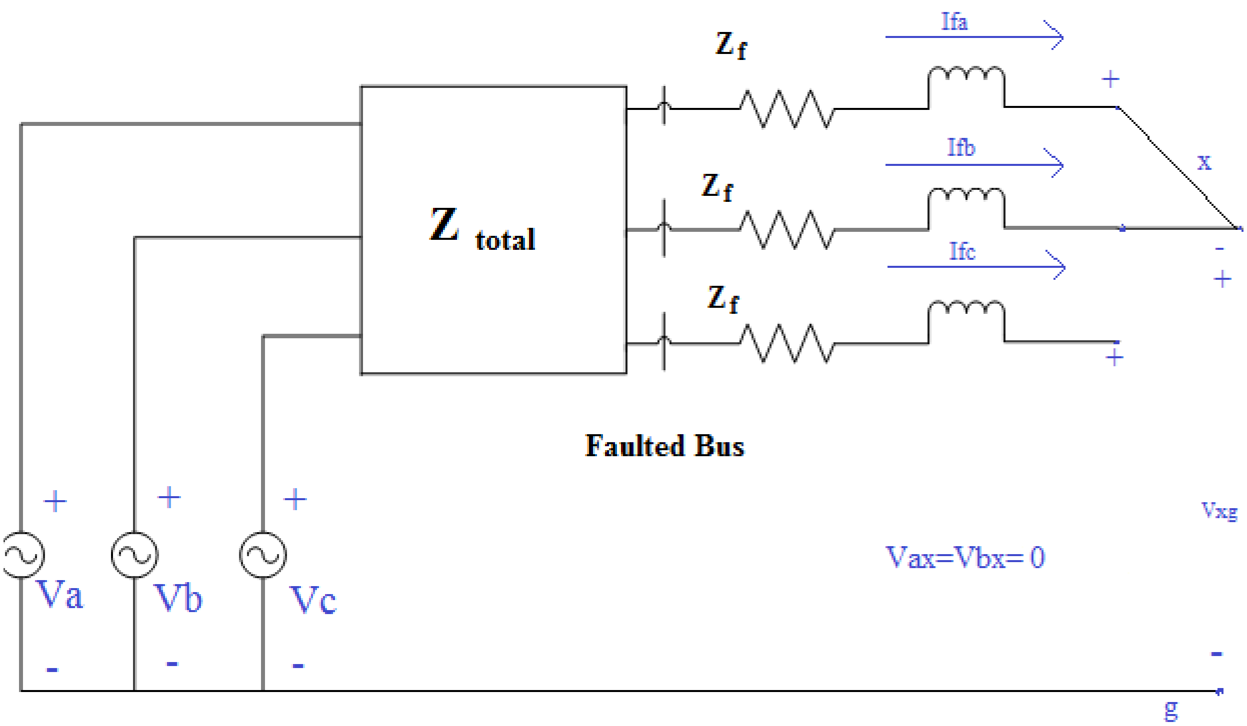


Figure 19: Thevenin Equivalent of line-to-line fault

4.1.3 Two-Line-to-Ground Fault

When any two line out of three phase line get into contact with ground is identified as Two-Line-to-Ground Fault as demonstrated by figure 20. Line a and b are considered to as the fault line and remaining line c assumed to be not affected by any fault thus the equation of the voltage is:

$$Vix = Vjx = Vxg = 0 \qquad (2.12)$$

Here, fault current goes through the ground path. Therefore,

$$Ifc = 0 \qquad (2.13)$$

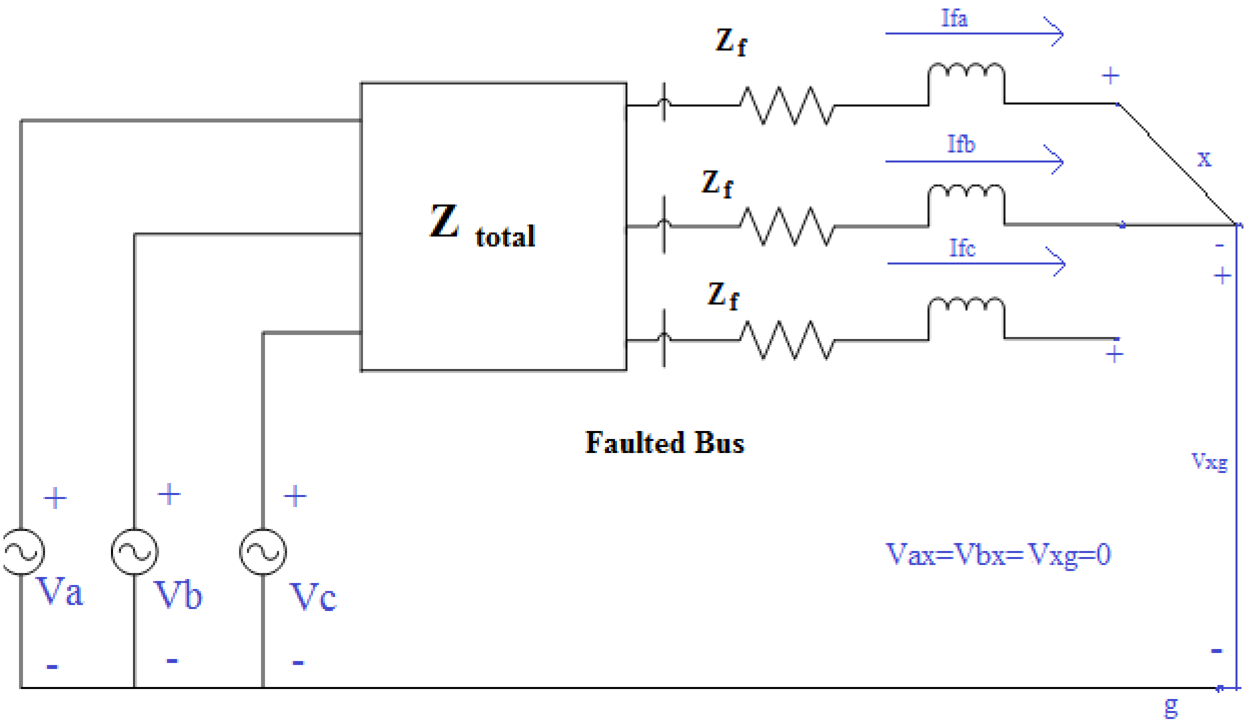


Figure 20: Thevenin Equivalent of a two-line-to-ground fault

4.1.4 Single-Phase-to-Ground Fault

According to the figure 21, phase a has a connection with ground makes as an example of Single-Phase-to-Ground fault. It is assumed that, the unaffected phase are "a" and "b" respectively and phase c is considered to be as fault line. Therefore, the voltage relation is going to become as:

$$Vkx = Vxg = 0 \tag{2.14}$$

Here, line k has become the path of fault current coming and returning as well. So that,

$$Ifa = 0 \tag{2.15}$$

$$Ifb = 0 \tag{2.16}$$

The above-mentioned equations are equally being applicable to line-to-line and line-to-ground fault at the time of missing phase. In symmetrical system, equations are followed by every case irrespective to types of missing line. Therefore, we can conclude that, the approach of analyzing this sort of fault is very important through these equations.

We can summarize the equations starting from 2.6 to 2.16 are as follows:

• Ground line is used to flow the return current act as the energy for additional source regarding the ground fault.

• Return current enters to system fault line in the context of line-to-line fault.

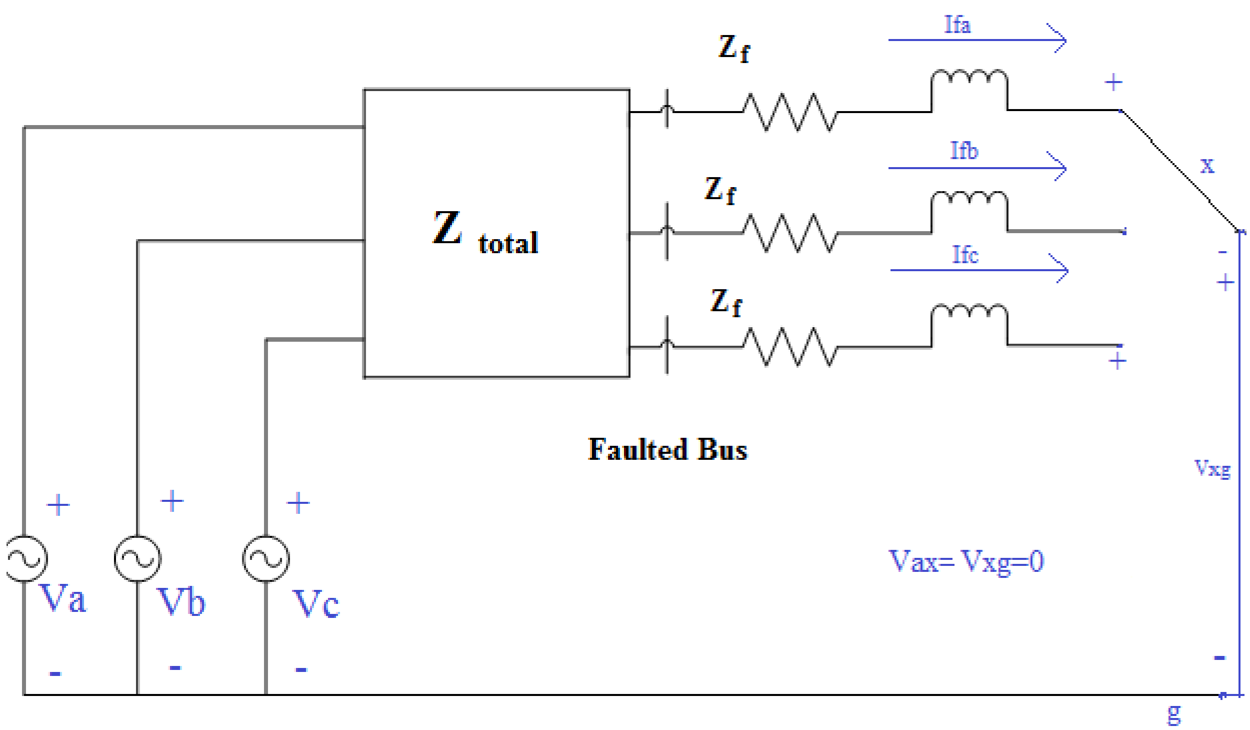


Figure 21: Thevenin Equivalent of single-line-to-ground fault

4.1.5 Influence of faults [22]

The consumer always wants a constant and stable power for their loads. However, it is very difficult to maintain the power stability for the system because fault can be happen at any time without having the sufficient protection system to the entire system. When, any short circuit fault is taken place to the circuit, the fault current is also increasing which make the system more venerable. Consequently, the loads could be affected seriously by this excessive current and can be the reason of permanent damage of the power supply. Therefore, it is needed to ensure that, proper protection system is applied or not.

4.2 Fundamentals of Protection

To the last topic, it is briefly discussed that, what types of fault can affect the load or user through analytical concept. In this topic, the fundamental of the protection system is discussed in briefly.

The main objective of designing the power system is generating and then delivering the power for the users load. In this context, it is very important to ensure the reliability of power in cost effective way. Two things may happen for the fault. First of all, high fault current can damage the load and secondly, it may also affect the generating stations for high current. Therefore, there have to an immediate action to detect the fault in the circuit and clear the fault thereafter. Another thing is needed to be considered is that, the protection system has to be designed in such manner that could minimize the damage as much as possible.

The protection system has a responsibility to isolate the fault part of the circuit. The response time of the de-energizing the circuit breakers of the load should be fast enough in minimizing the destruction of load. In EHV system, the equipments are very expensive and their destruction can confront us high economic loss. Besides, the damage of these high voltage equipment results in blackout the large area of the consumer side. Therefore, it is vital issue to make an accurate and perfect protection system for EHV transmission system having quick response time.

4.2.1 Qualities required of protection

The effectiveness of the any protection system brings some important terms to be discussed with are as follows [22]:

- Selectivity - The detection and clearing the fault is essential part.

- Stability - It is important to limit the protection system within venerable zone of system.

- Speed of operation - The longer flow of fault current is very dangerous for the system. As long as the fault current flows to the system, the possibility of damaging the system becomes higher. So, there has to be fault clearance protection system with very short time in minimizing the destruction as much as possible.

- Reliability - The appropriate protection system should not be activated during un-faulted condition. Otherwise, power breakdown time results in unproductive protection system.

4.2.2 Traditional Protection Principles [22]

- **Overcurrent protection**

This kind of protection system is very common to the network like distribution and this is known to be the most simple protection system serves as a fuse protected any domestic network/circuit. Mostly, the reason why these kinds of fault are taken place is the short circuit for low resistance fault in the circuit. As a result, there is a possibility of high current flow in the network. In this context, the protection system for the fault has to have the option to calibrate the duration of required time to clear the fault. Besides, it has to have the probation of energizing the closest relay even some times needs to active the backup relay when the closest one does not able to active in time.

- **Differential protection**

These types of protection system are considered to be an expensive protection system. Actually, this protection system is used for very limited and specific equipment or devices like transformer, generator etc. Protection system gets the input from both sides of the devices to compare the current difference. If any difference is found, the output of the protection system triggers the specific relay to disconnect the load from the network so as to safe the expensive power equipment devices. In this regard, any fault of the protection system may the reason of flowing high/transient current over the protected zone. On the other hand, the impedance difference of any boundary can certainly locate the source of fault zone. This is also known as a complex protection system because it needs good communication link among various zone of the network which ultimately refers the knowledge of topologies used in power system.

- **Distance protection**

It works on the principle of measuring the impedance between two location as relay location and fault location. Here, impedance value is directly proportional to the distance of mentioned location. This protection system is known to be the most traditionally used protection system ever use as protection system.

Out of so many advantages, the most salient and cardinal one is its quick speed of operation. As a result, protection system engineer always do prefer this protection system when it is required to protect the extra high voltage in transmission line.

Analyzing the transducers output information regarding voltage and current, it is possible to resolute the location of fault zone.

The relay is the responsible for the fault and the fault is within the location of protected line is considered provided that, the impedance value is not more than prescribed value.

The reason why this protection system is not preferable as mentioned below:

- It is not possible to protect the line with 100% safety.
- The frequency of the power is a critical issue of this protection system.

4.2.3 Transients Based Protection[22]

All the protection schemes traditionally being used as mentioned to the previous discussion has a very common ground i.e. analysis of power frequency based on their sampling data. The time when any fault occurs in the transmission line, power network undergo with some high frequency signal as identified as noise in the system and it is happened to be for very short duration of time results in unstable condition of the power however; come to a condition of steady state as because of the step change due to fault current.

There are some important things to be noted on this protection system discussion. First of all, the relays which are used for the protection system is not sufficient or unable to detect or respond to high frequency signal. As a result, the fault detection system has to have enough or certain capabilities to filter the unwanted signals of the network so that the appropriate fault signal can be detected. Therefore, it is very important to design the filter system as a justified system for network protection activities. Secondly, there is a requirement of analyzing the signal for at least one full cycle of 50Hz (as user power frequency). In regard of the protection system, this time period of 50Hz signal is considered to be very slow and insufficient for high frequency fault detection analysis. Hence, this requirement further adds the design complexity of relay and increases the manufacturing price. Lastly, the very common phenomenon in generators as electro-mechanical oscillation could result in unnecessary fault signal even may generate the trip signal from the protection system has to be taken into account precisely. In addition, the alarm can also be started for the false trip signal as a consequence of power swing.

When there is a fault created in the transmission line, the transient current is generated in a form of DC component ranging from zero to several hundred kHz. The bandwidth of this transient current implies its consequences and mostly it is depended on transmission line's electrical parameter like R, L, and C. In facts, these components are postulated as connected in series and parallel combination in transmission line. Therefore, when any fault is taken place, the fault current travels the entire transmission line as long as the length of this line goes to. It is apparent that, the fault undergo with many reflection and refraction when propagating from its origin to different path of transmission line ultimately absorbed in bus bars. By the time the fault current is generated, the voltage of the particular section becomes very high enough causes transient voltage change which is in fact far greater than the actual transmitted voltage as being transmitted from substations or power generation units.

Therefore, the transmission lines faults are to be depended on various types of fault condition. On the other hand, the protection technology has also been developed in dealing this sort of high frequency signal detection requirements. Nowadays, computer technology is used for this purpose and is widely known as Transient Based Protection (TBP) scheme.

The traditional protection schemes are therefore be replaced by this sophisticated computer based technology due to the following reasons:

1. The time of response of this scheme is very fast comparing to traditional system.
2. The protection system is not sensitive to ordinary phenomenon like power swing.
3. Useful in protection of whole system.

4.3 Designing Over Current Protection Model (OCPM)

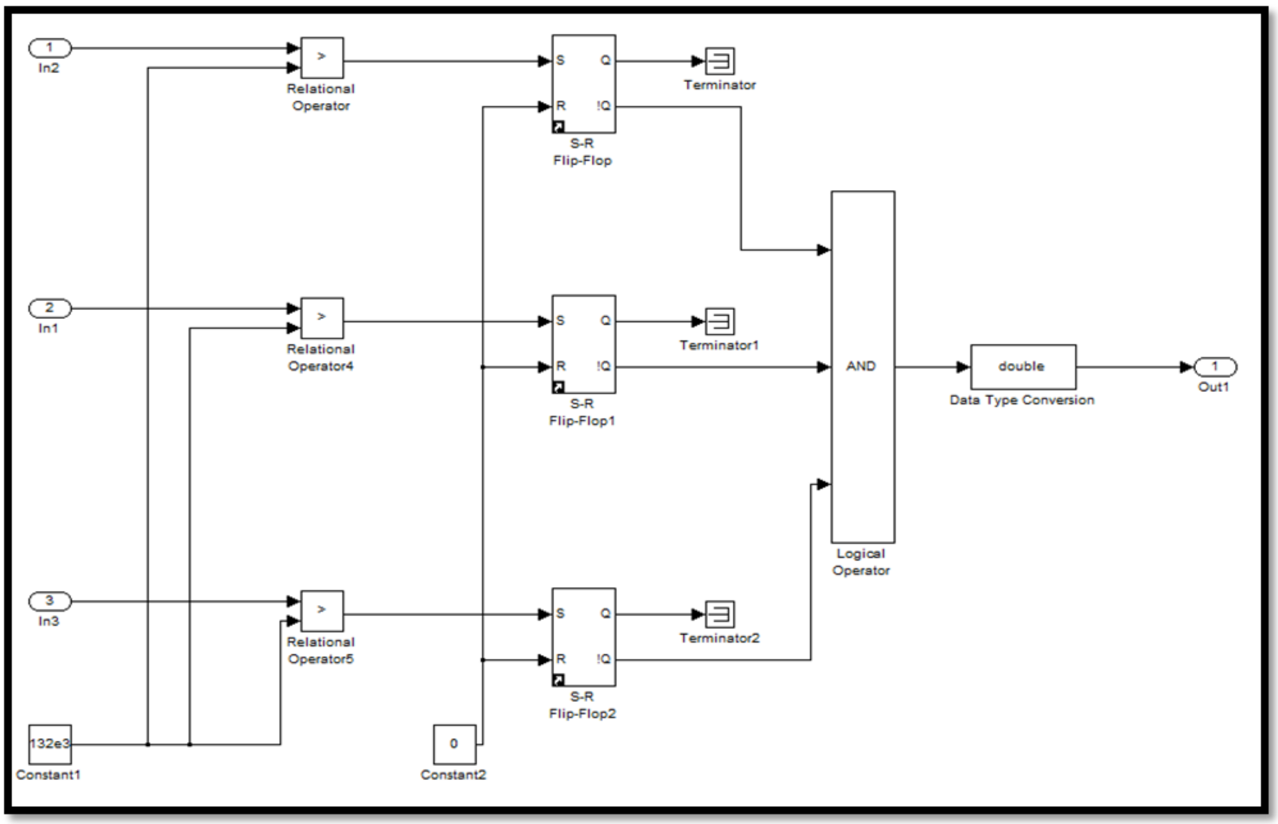


Figure 22: Over Current Protection Circuit.

In the figure 22, we can see the simulink model of over current protection circuit. Basically, we have used few logical operations in order to compare the input current and a constant reference current. If we look into the left side of the above figure, we see the three input has taken from three different phase of power generation side. These three inputs have been compared with a constant reference unit of 132KV through a relational operator. Whenever, any of these three inputs has a greater input than our reference level, the relational operator provides the output for the RS flip-flop circuit. Indeed, we are interested to have a positive signal to our AND gate to any of its three input so that, the output of the AND gate provides the signal for the circuit breakers. As we are operating the circuit breakers as closed operation, this breaker becomes open when it gets a signal to its control unit. In the picture, we have terminated the Q output because; it is not required for our logical operation. Only that what, we are looking for is, the Qbar output.

Three Phase Fault Circuit Testing and Result:

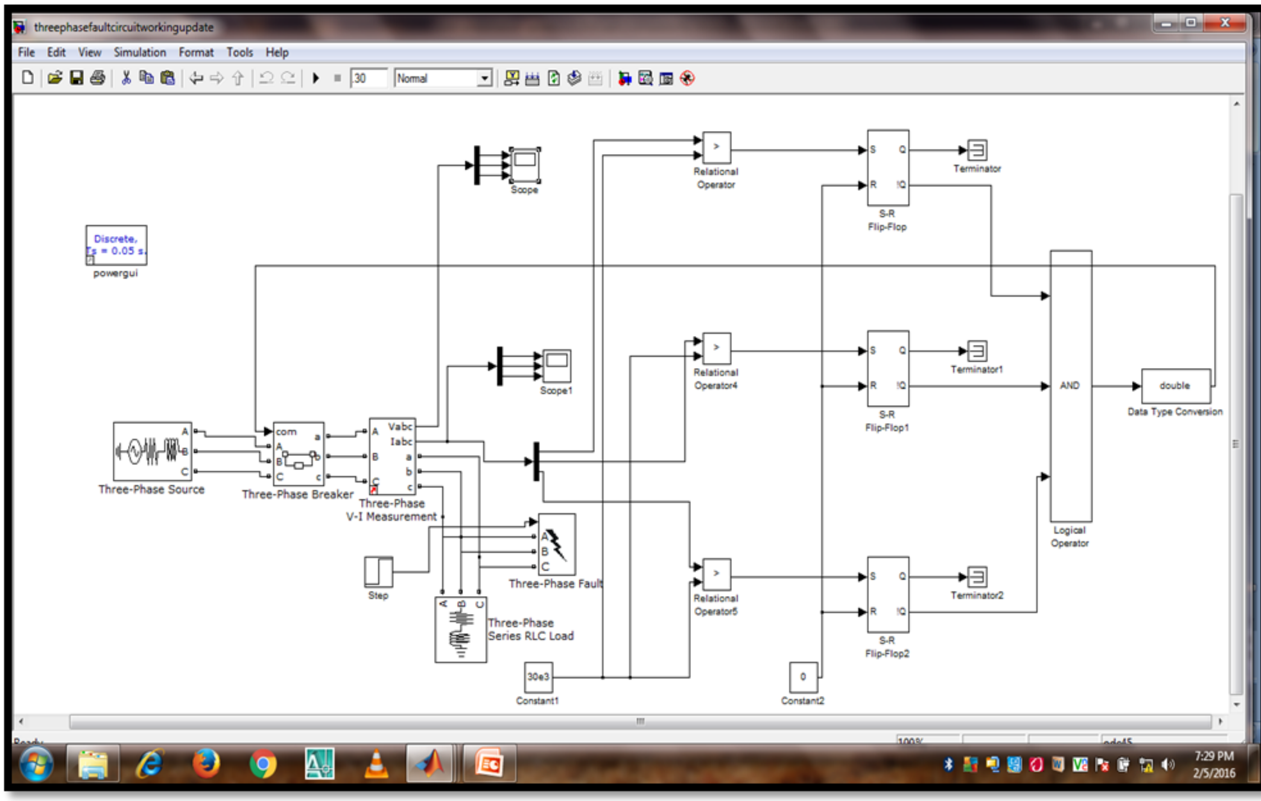


Figure 23: Testing and Evaluation of over current protection relay

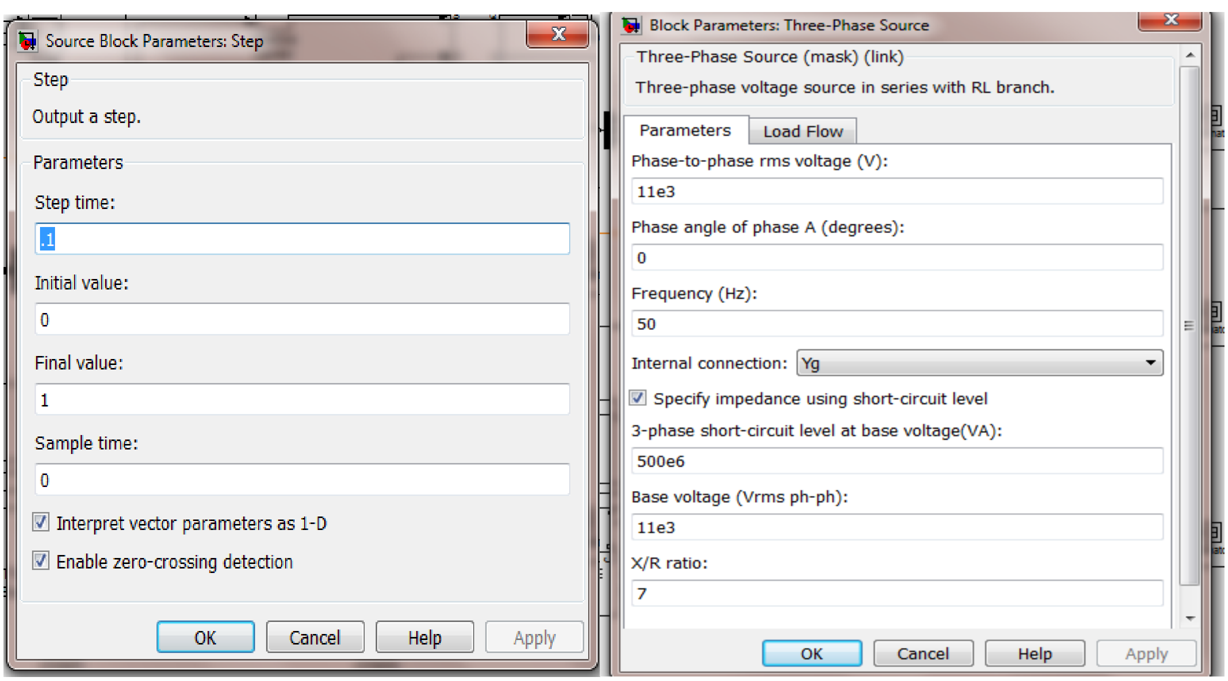


Figure 24: Step input and power generation parameters

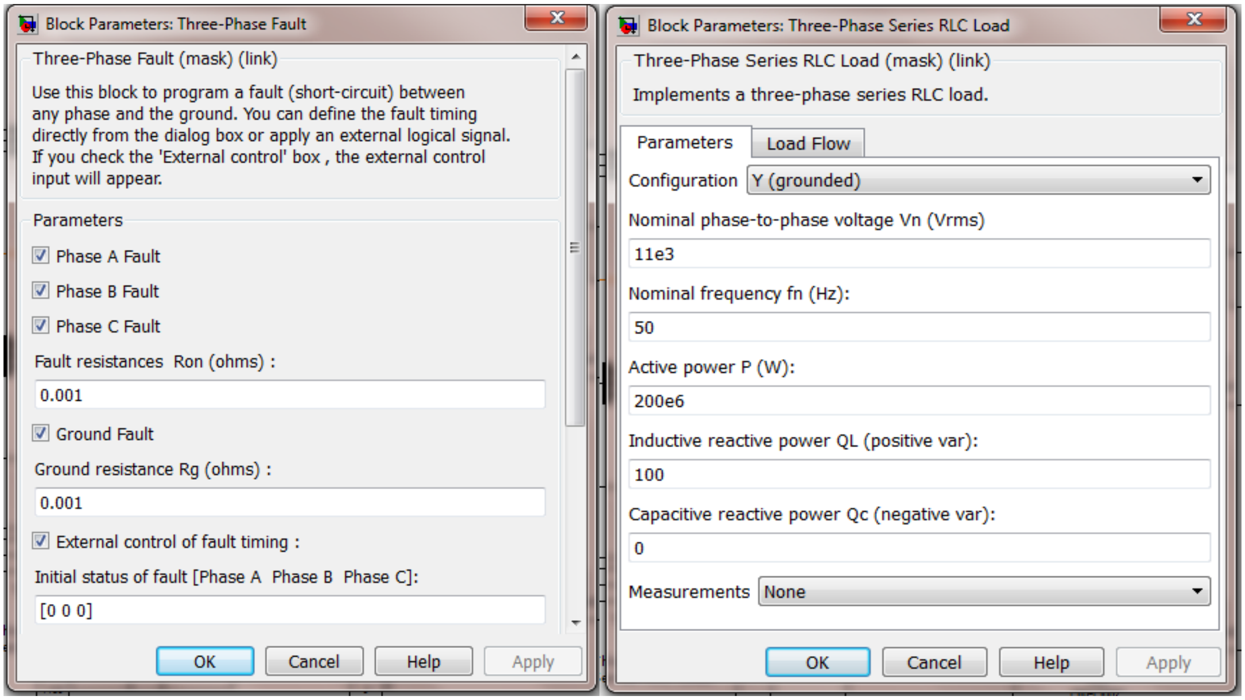


Figure 25: Three phase fault and Series RLC parameters

Result and Discussion:

In the figure 24 and 25 above, all the parameters and setting has been shown. To the test circuit, we just additionally added these four new important simulink blocks. They are: Three phase power source, step input, RLC series circuit (used as load) and the most important part known as three phase fault circuit. The step input pulse is used to provide the initialization for three phase fault circuit. Step time of step input is assumed to be 0.1 second which means, the will be a fault created in three phase fault circuit and this fault will be create a voltage increase in the load end eventually been compared by our reference voltage of 11kv. Whenever, the fault current crosses the reference level of our circuit the output will provide a positive signal for circuit breakers. Here, the cirucuit breaker of the connecting load has kept always in close contact. However, this contact would become open and there will be no signal after 0.1 sec. as shown the following pictures.

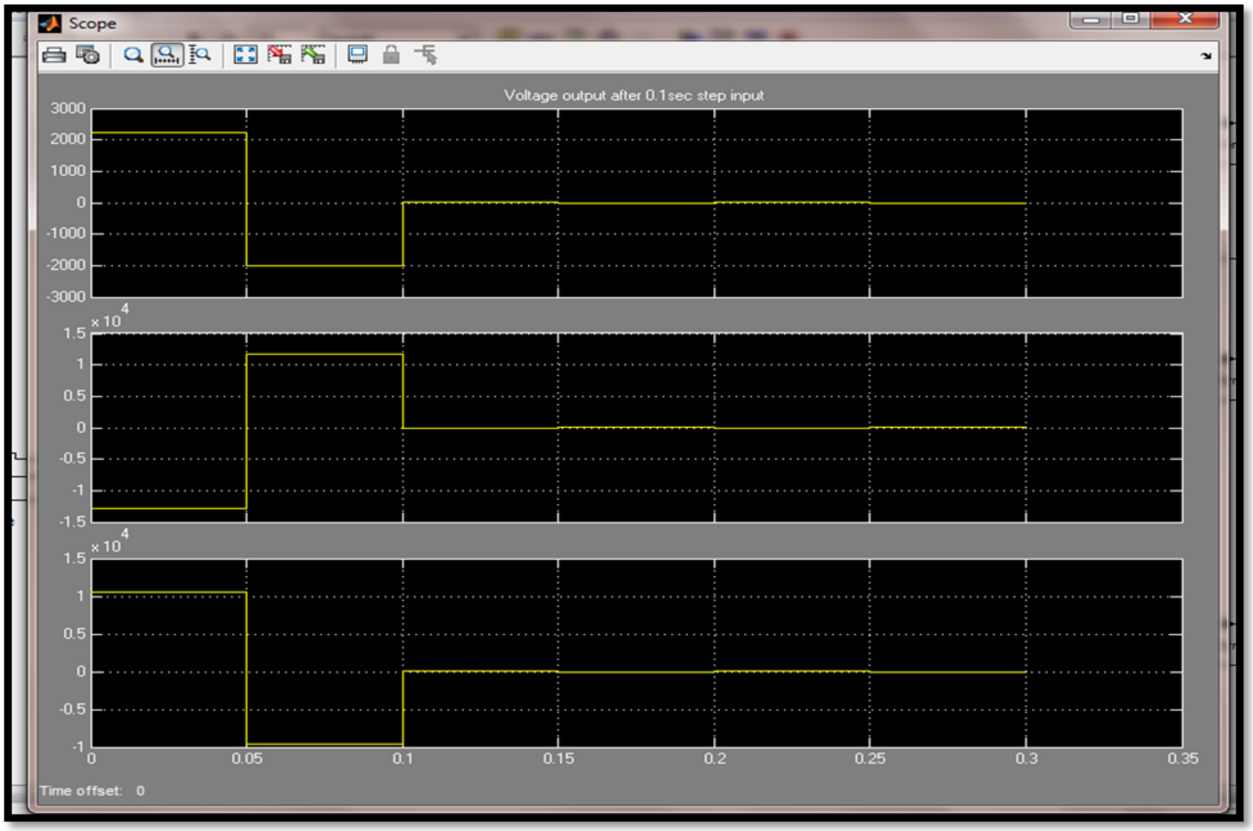


Figure 26: Voltage Output of over current protection relay

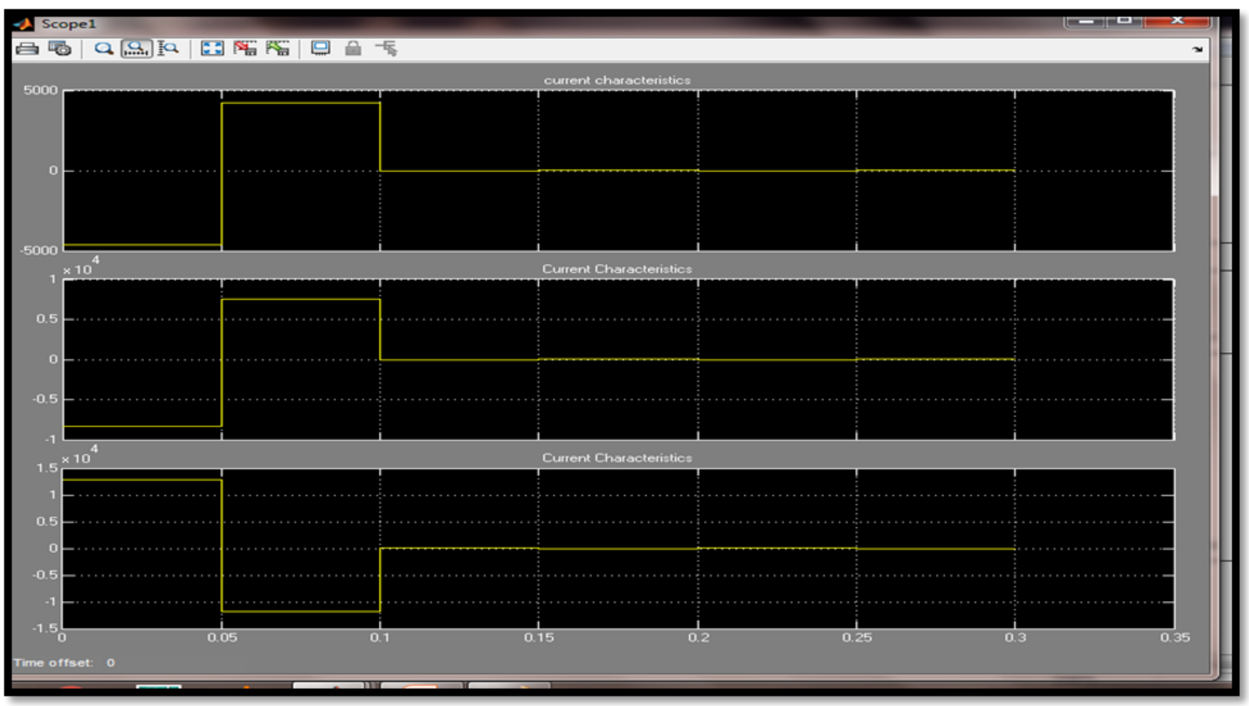


Figure 27: Current Output of over current protection relay

4.4 Designing Differential Logic Operation (DLO)

The differential logic operation works based on the theory of difference between primary and secondary current. If there is any differential current or leakage current generates between the primary and secondary side of the X-former, the differential current will provide the positive signal to its output. In this case, we have taken signals from both three terminals of primary and secondary side of the transformer as discrete values. Since, the secondary current of the transformer becomes less according to the theory of X-former; we have used three gain blocks in order to make a same current for both side of the transformer. Now, if a fault or leakage current happens for the consequences of the three phase fault which we would use for the test circuit, the fault current will be compared by relational operator having a constant reference current shown in the above figure. To the followings, the truth table of table 2 of the S-R flip flop is shown. Initially, we have kept the value of "S" is constant "1". So, we shall only pay attention to the first two logic of the truth table. Here, the relational operator will provide the "0" to its output which eventually be considered as "R" input. So, when S=1, R=0; we get Q=1. And, as we known, "a Boolean operator that gives the value one if and only if all the operands are one, and otherwise has a value of zero" for AND gate. Therefore, we get "1" to the output of the AND gate. Hence, this signal will be operating as triggering signal for circuit breakers where we want to make the breaker "open contact" from its closing contact.

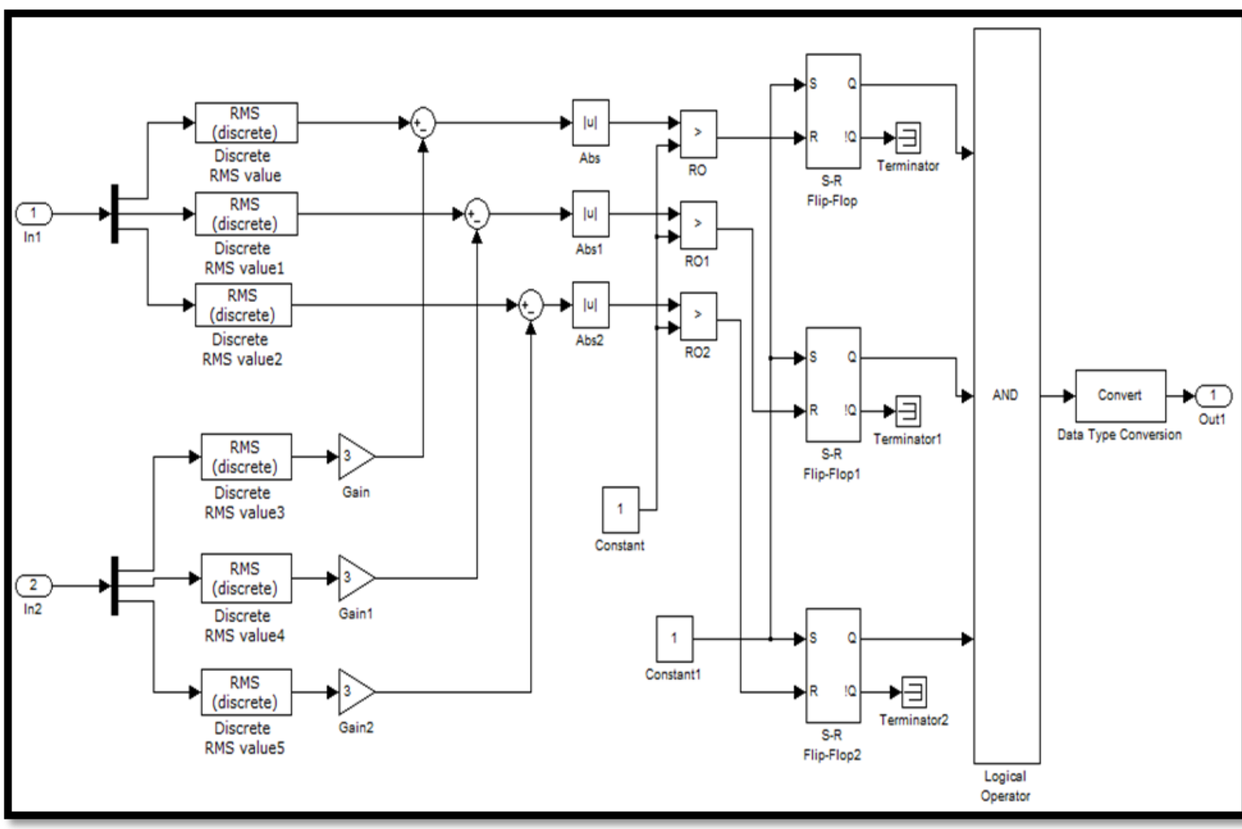
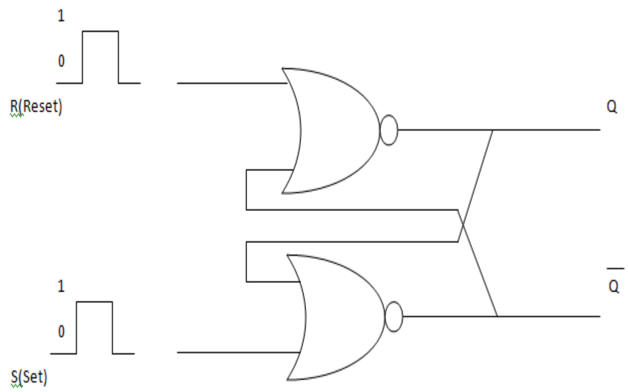


Figure 28: Differential Relay Circuit using simulink.



S	R	Q	Q'	
1	0	1	0	
0	0	1	0	After S=1; R=0;
0	1	0	1	
0	0	0	1	After S=0;R=1;
1	1	0	0	

Table 2: Truth Table of SR Flip-Flop

Differential Relay Testing and Result:

The basic objective of our designed differential relay is to detect the leakage current or any sudden increase of current to the primary or even in the secondary side of the substation transformers. Substation transformers are main key element of electrical substations. Therefore, the protection system of the substation should be adequate because the purchasing cost of these big transformers is very high comparing other elements.

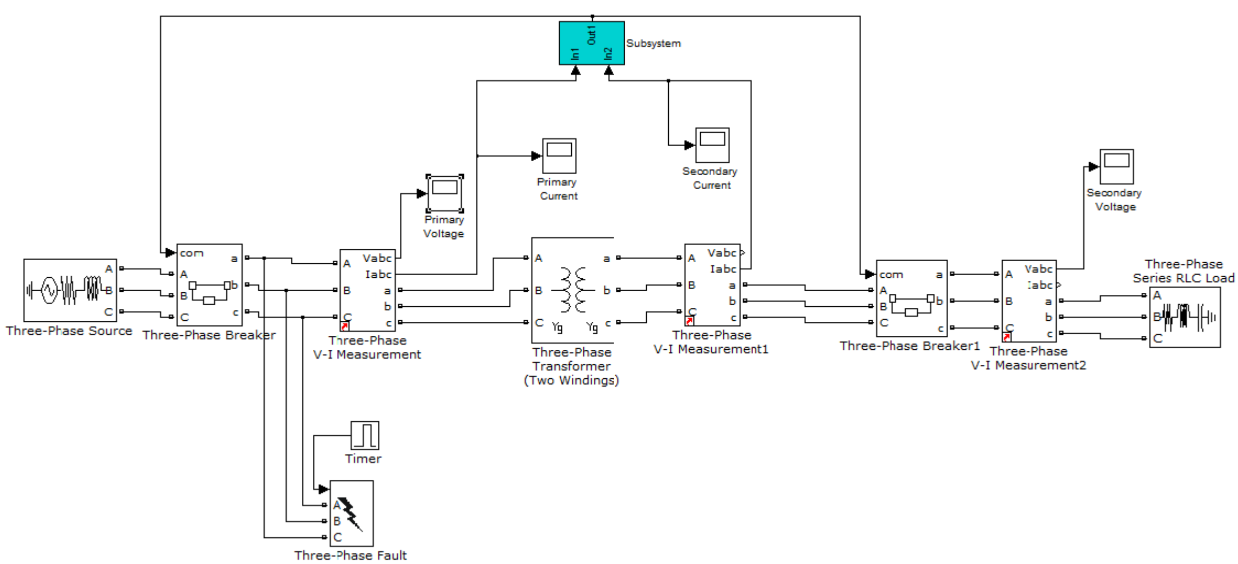


Figure 29: Three phase fault in primary side of the transformer.

To the above figure 29, the differential relay protection system has been shown for primary fault generation and its result. In fact, we are intended to see whether the output of the circuit breaker placed in the primary side of the transformer provides the output voltage or not. In this case, we have used a timer to initialization time of three phase fault. In the following figure, we see that during the timer time period of .01sec. there is no voltage found to the output of the circuit breakers located in primary side of the transformer which means, the fault circuit is operating as per our expectations. The required all other parameters are shown after the voltage wave form.

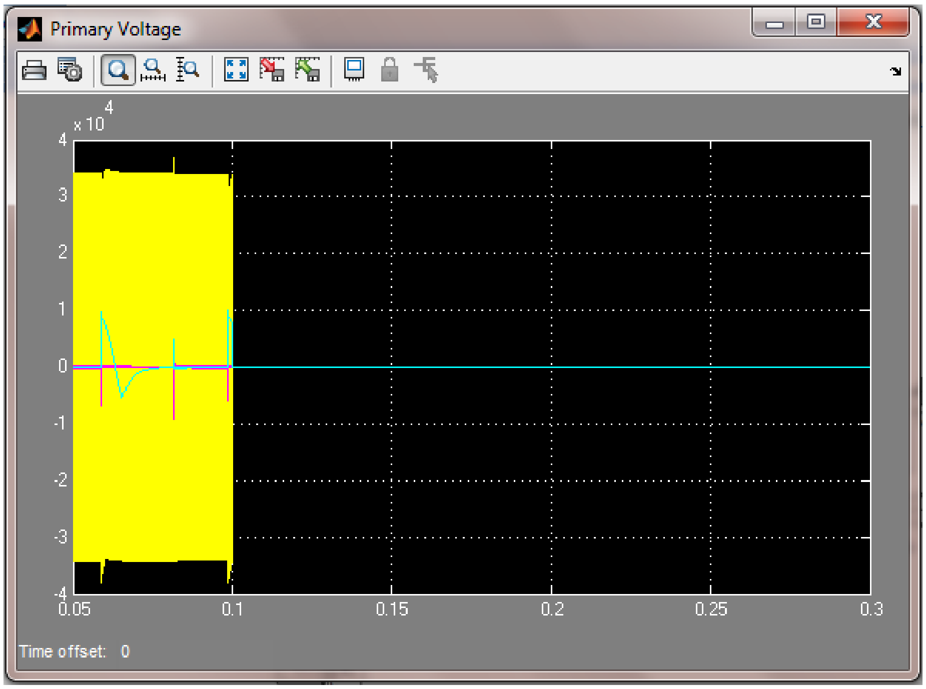


Figure 30: Primary voltage while step in is .01 - .02sec.

At the same method, we also did check the result of the fault circuit when the fault creates to the secondary side of the transformer. In this case, we are looking for the output voltage of the secondary sided circuit breakers. The V-I measurements block is nothing but a requirements of taking the signal through Scope in simulink. After simulation this circuit, we have found the same expected result what we did find for the primary side of the substation is shown in figure 30. All other simulink parameters would remain same for this simulation.

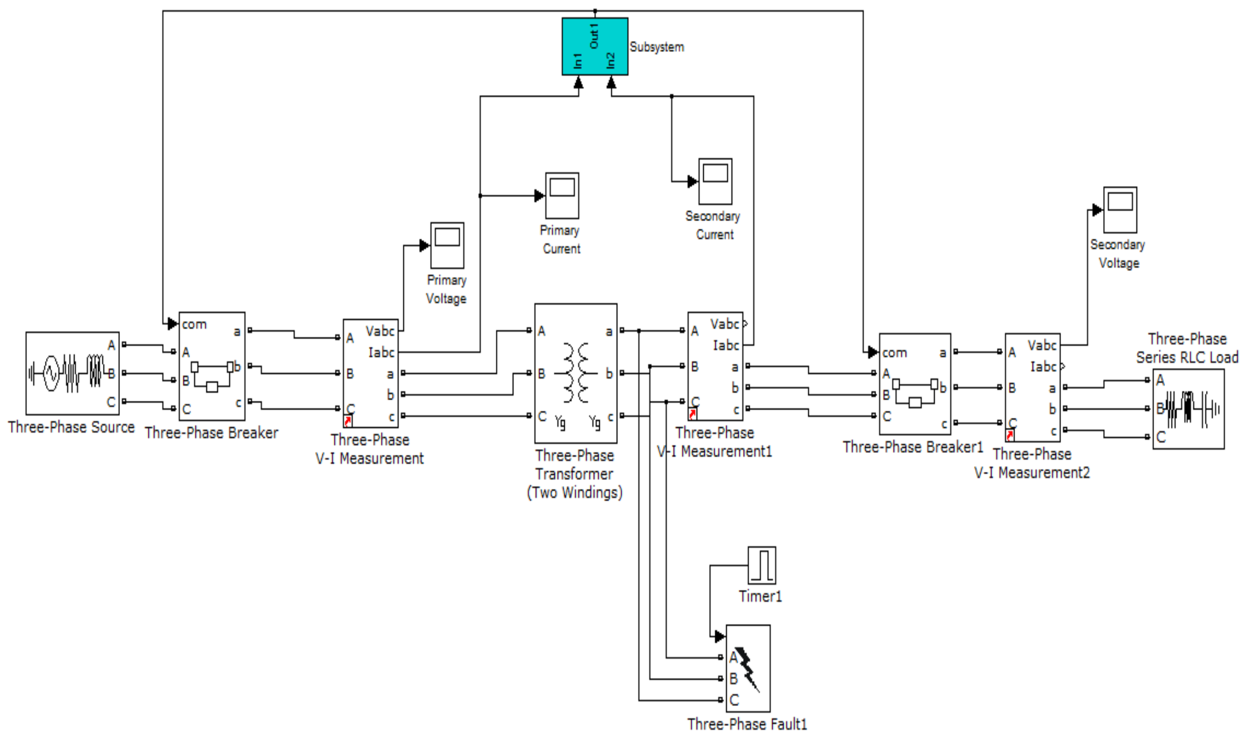


Figure 31: Three phase fault in secondary side

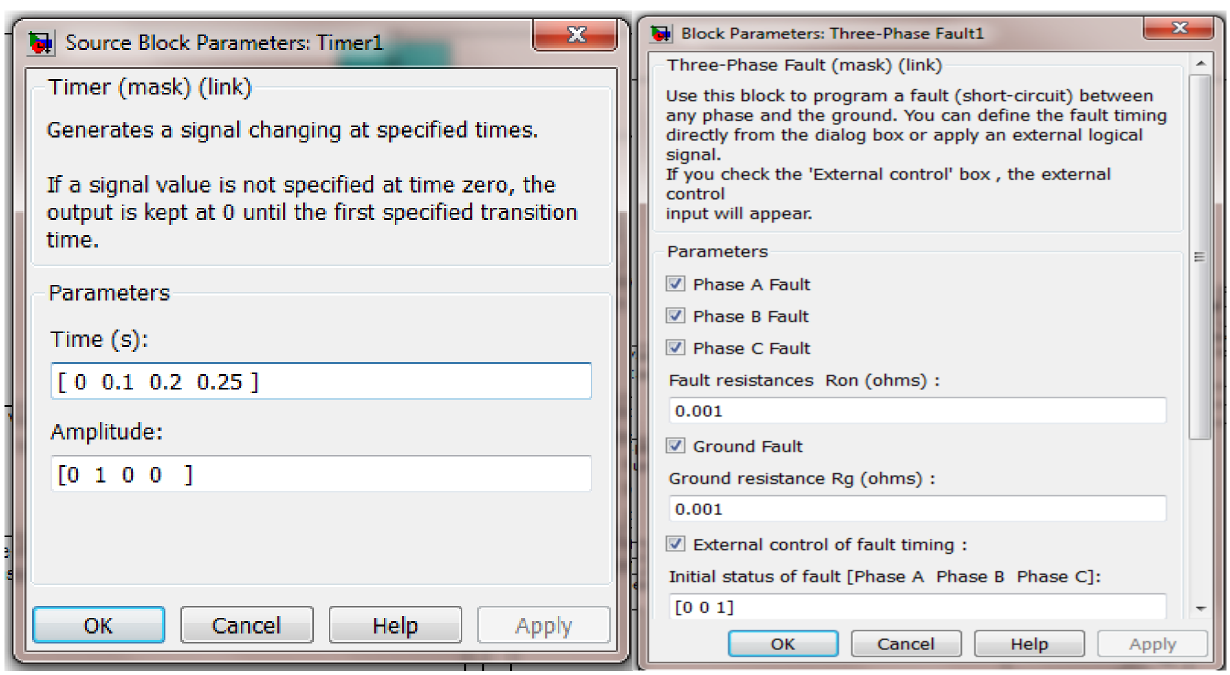


Figure 32: Step input and three phase fault parameter setting.

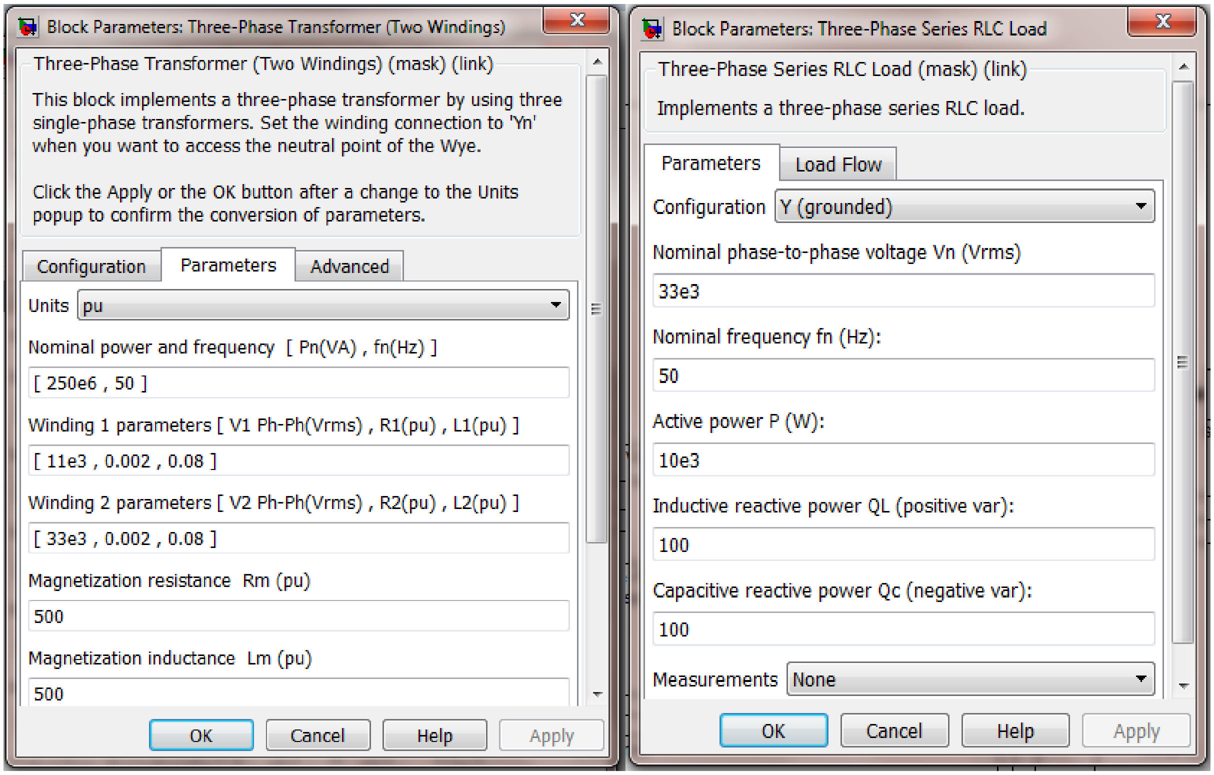


Figure 33: Three phase transformer and RLC series load parameter settings.

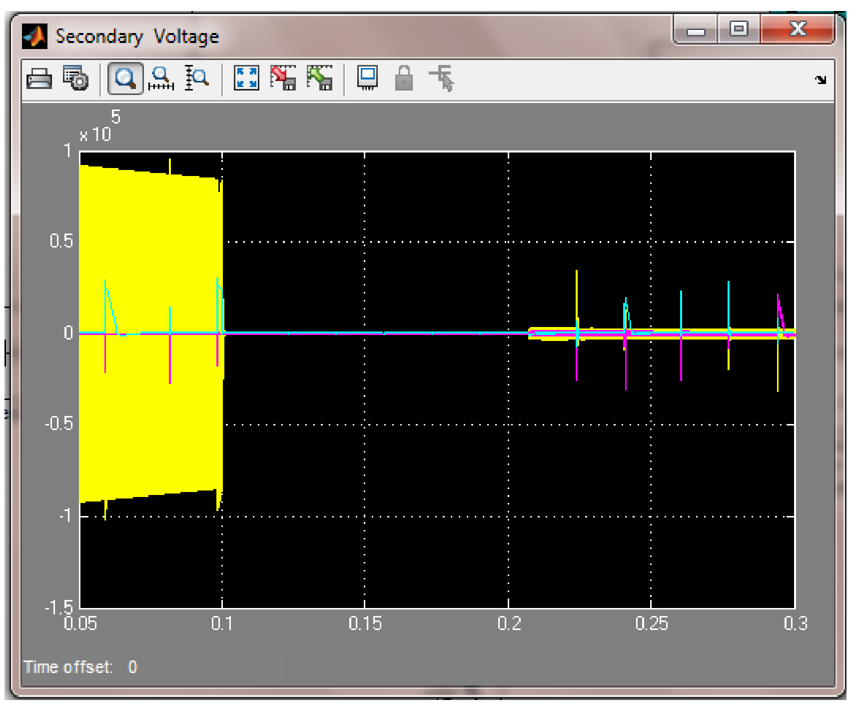


Figure 34: Secondary voltage while step in is .01 - .02sec.

4.5 Designing Emergency Power Backup (EPB)

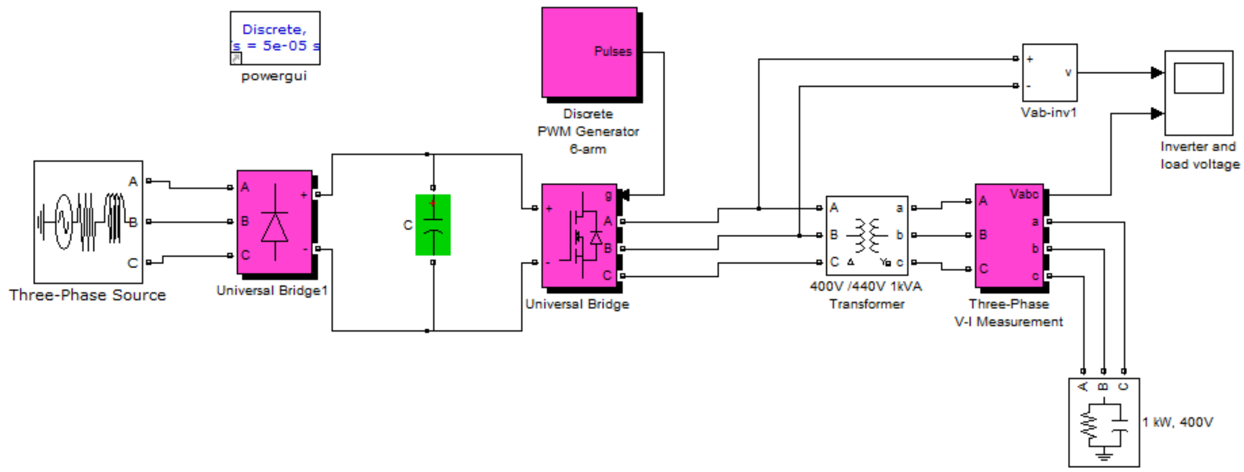


Figure 35: Emmergency power backup.

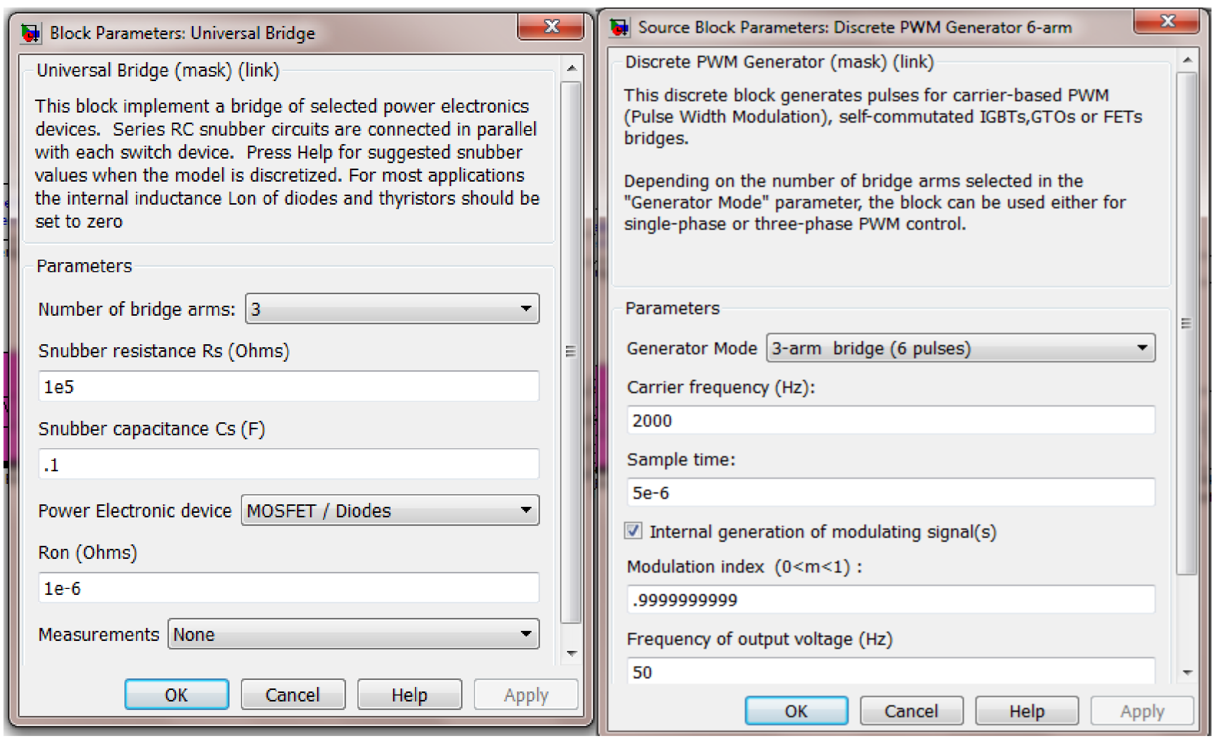


Figure 36: Parameter settings of universal bridge and Discrete PWM Generator 6-arm

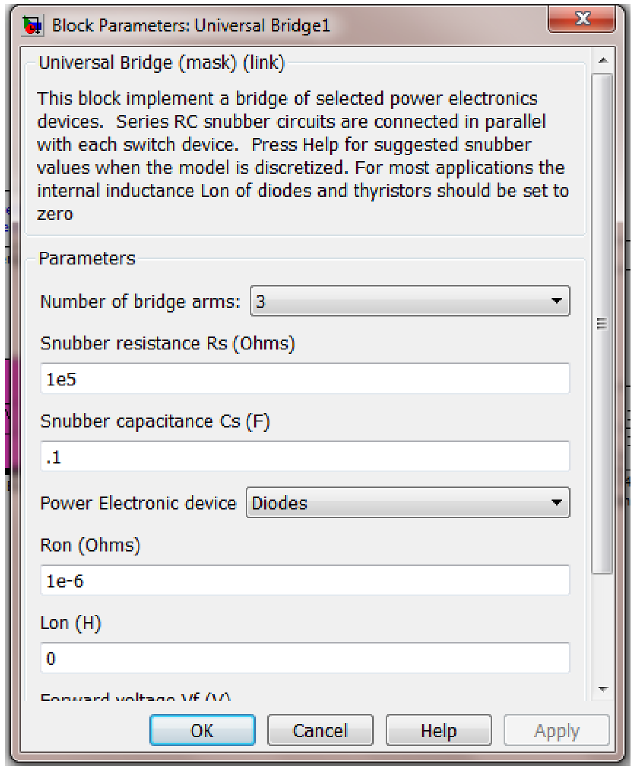


Figure 37: Parameter settings of Universal bridge

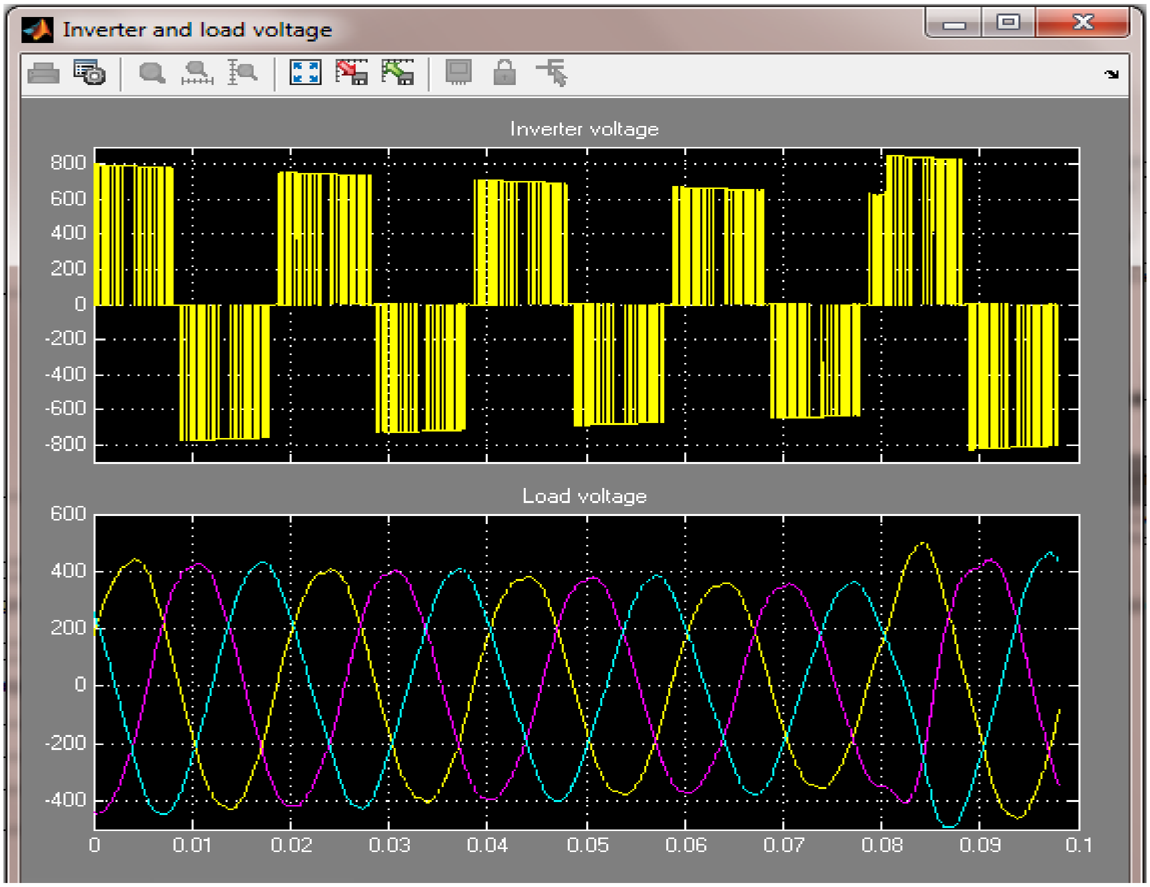


Figure 38: Inverter output and load voltage

4.6 Automatic fault generation circuit (AFGC)

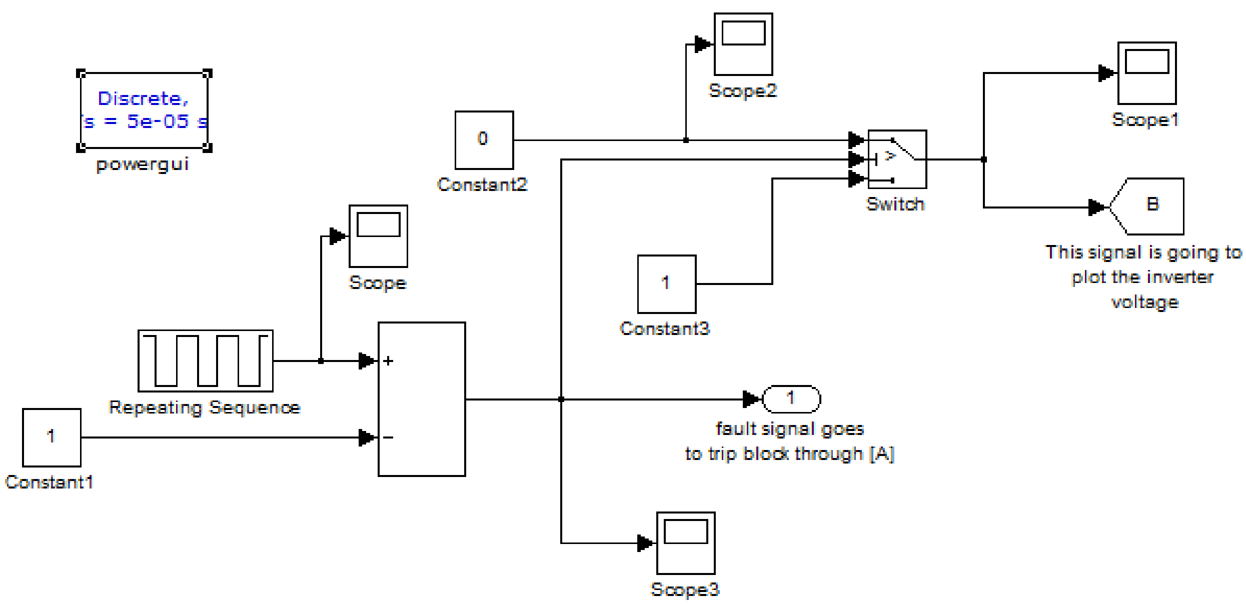


Figure 39: Automatic Fault Generation Circuit using simulink block.

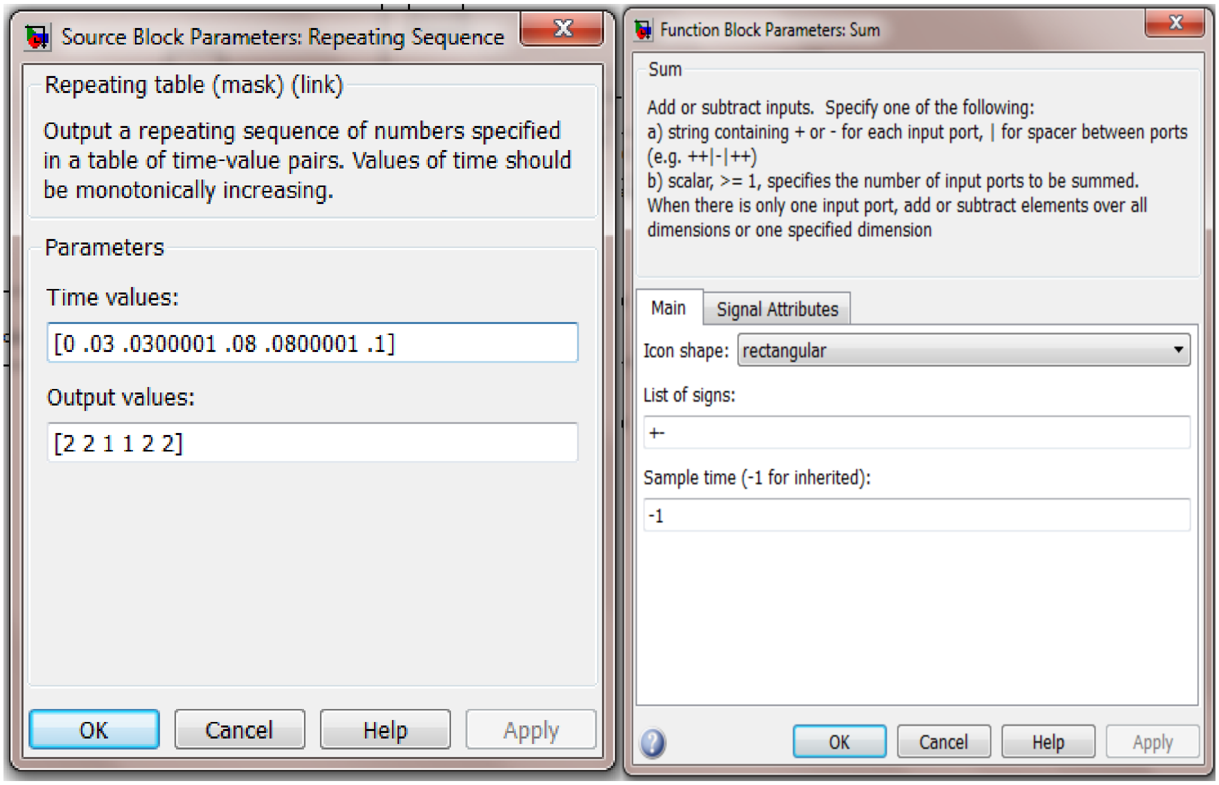


Figure 40: Parameter setting of repeating sequence and sum block

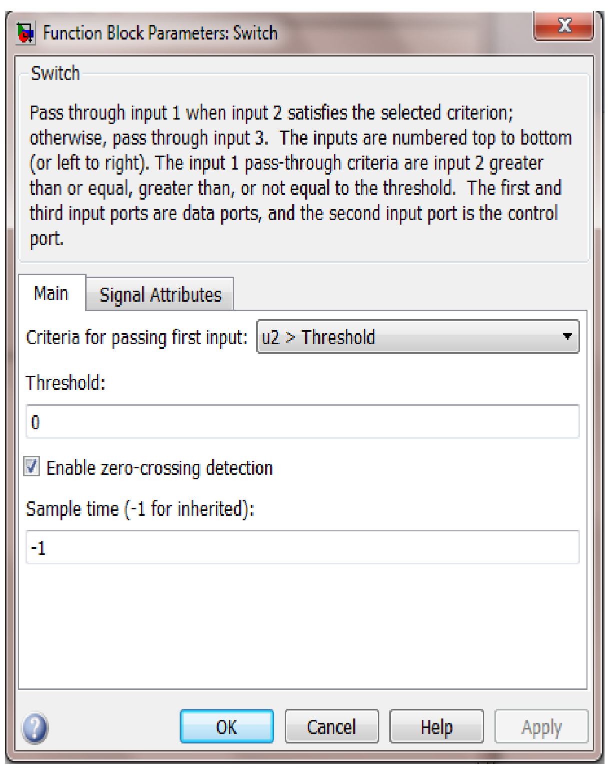


Figure 41: Parameter of switch block

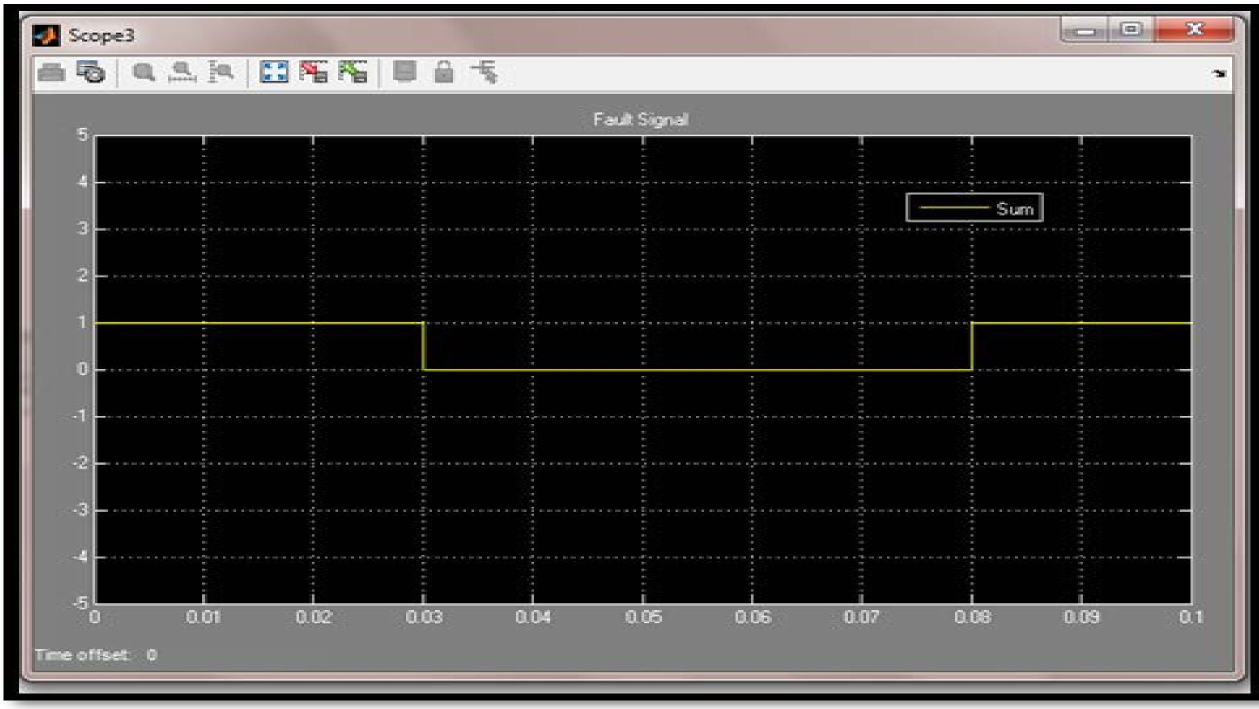


Figure 42: Generated Fault Signal: 0.03-0.08Sec.

4.7 Fault Detection and Inverter Triggering Ckt./By-Pass System

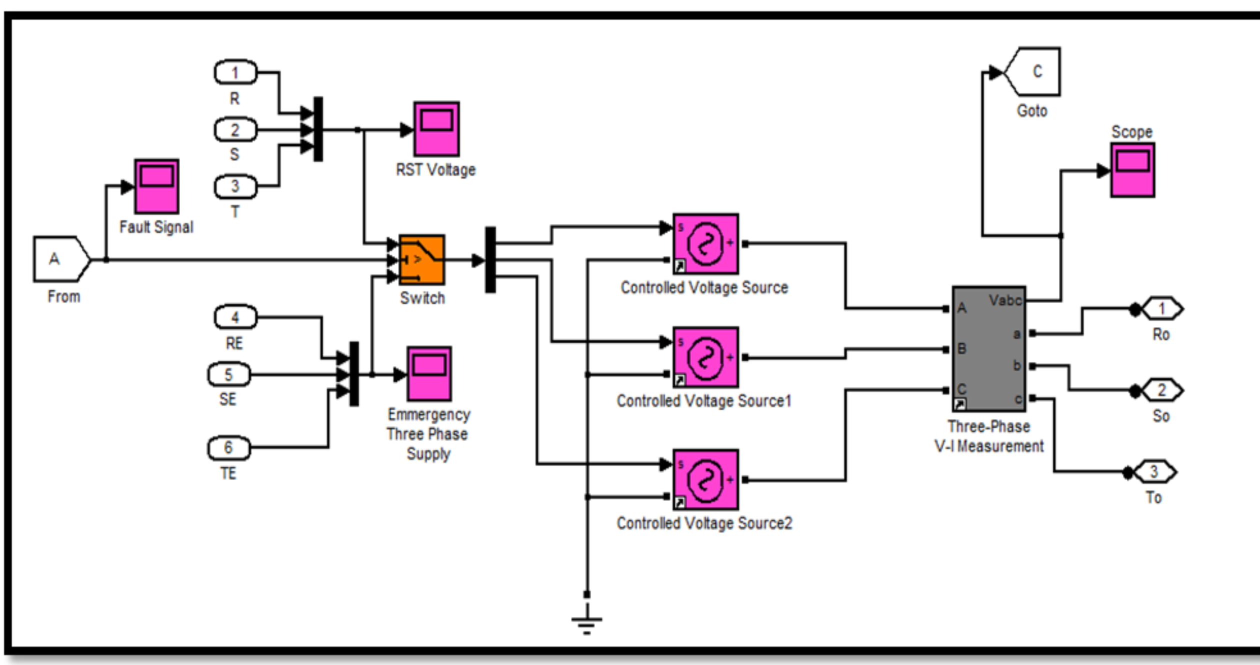


Figure 43: Simulink block of three phase by-pass system

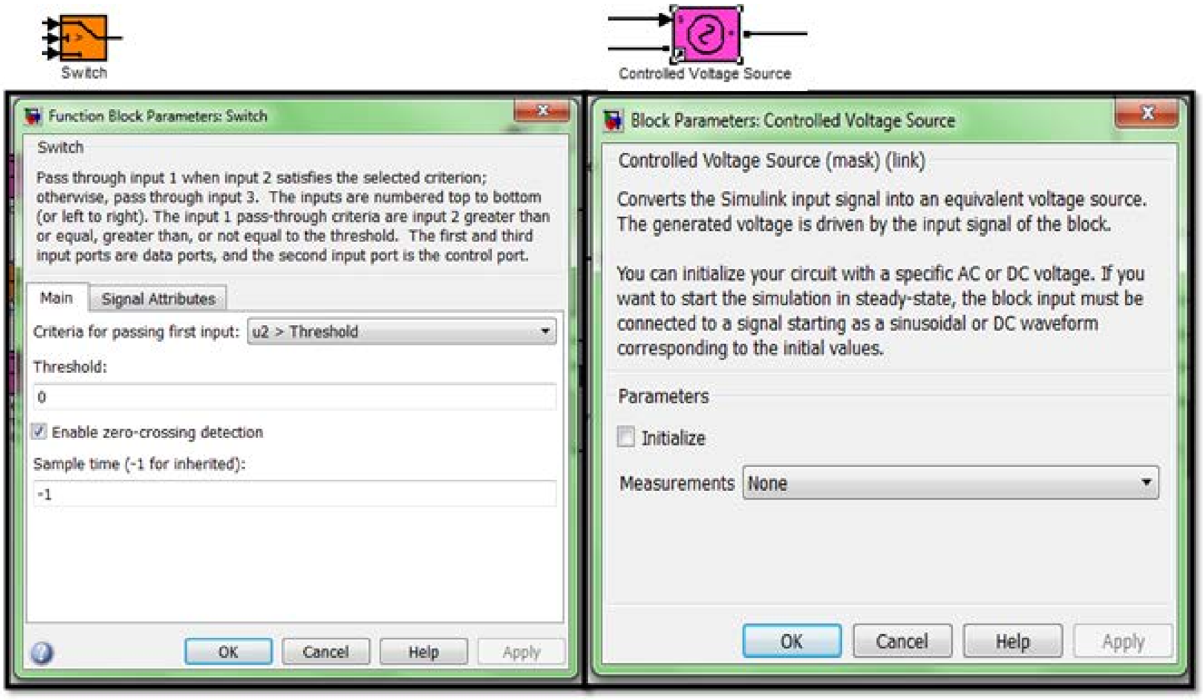


Figure 44: Parameter of Emergency Switching circuit/By-pass system

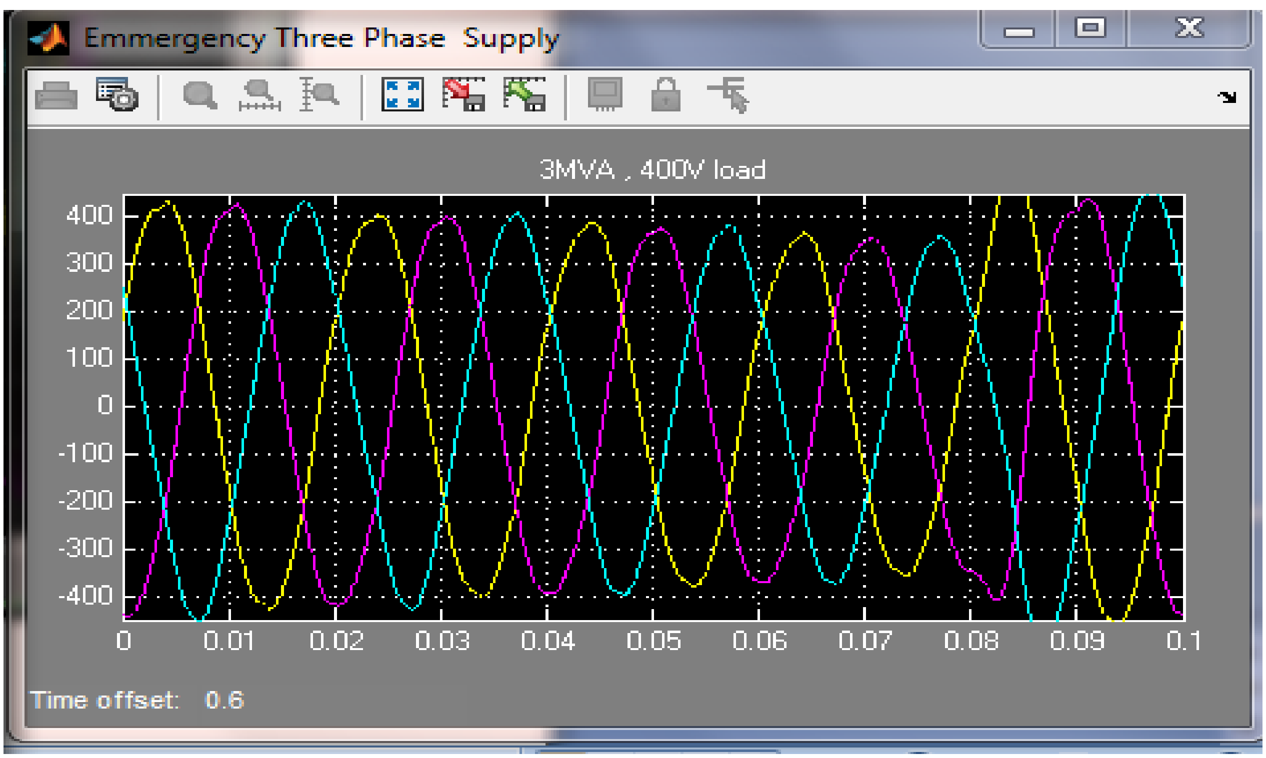


Figure 45: Inverter Output Voltage

Three Phases RST voltage is compared with Thresh-Hold/Fault Signal:

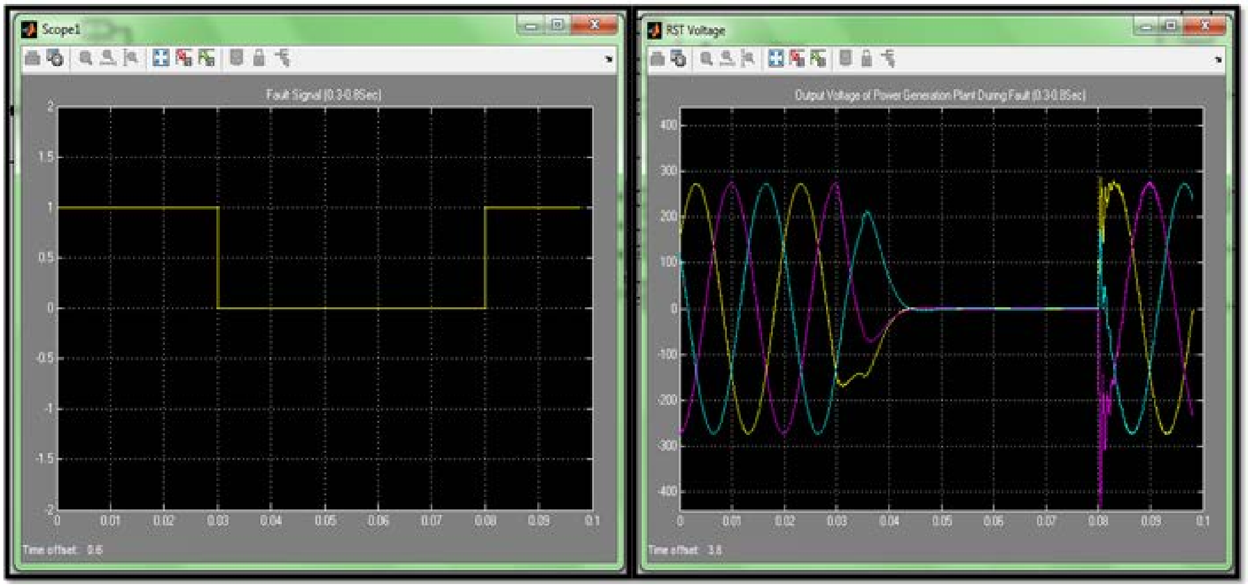


Figure 46: When the fault signal becomes “0”, the output of the power plant goes to zero “0”.

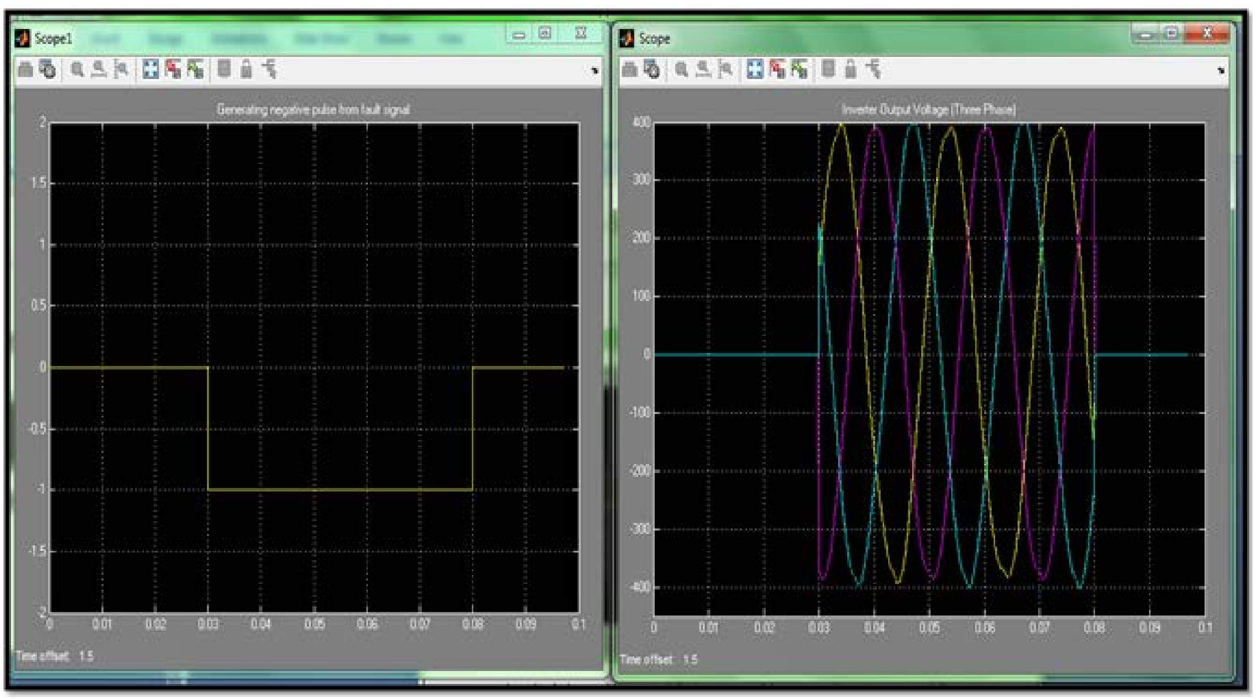


Figure 47: Inverter output during fault

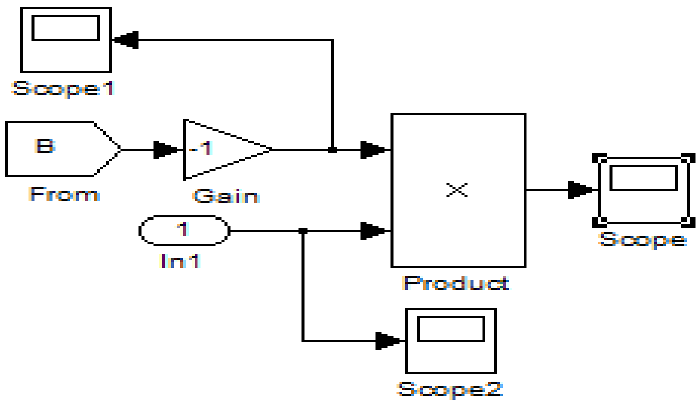


Figure 48: Inverter Plotting Circuit

4.8 Designing WiMAX Receiver and Transmitter circuit (WRTC)

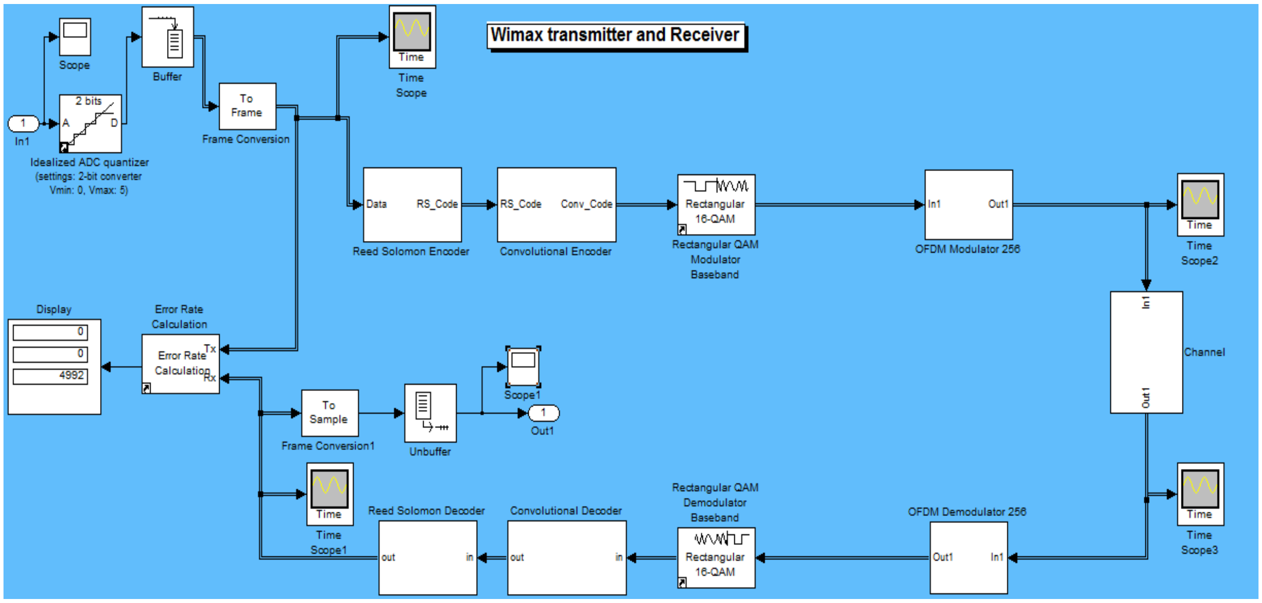


Figure 49: Simulink based WiMAX transceiver

In figure 49, the complete WiMAX transmitter and receiver circuit is shown using simulink block set. The details of this communication system are presented in chapter 03. However, here we shall discuss about how all these simulink block can be made with necessary parameter settings. Instead of using the randomizer as a data source to be transferred through this transceiver system, we have used ideal ADC to converter the fault signal into its digital form. Thereafter, we have sent the signal through buffer and frame conversion into fed the signal into Reed Solomon Encoder. The reason of using Buffer and Frame conversion is mentioned in the appendix. The Reed Solomon Encoder in consisted by the following simulink block as discussed in chapter 03. All the parameters are shown to the consecutive figures.

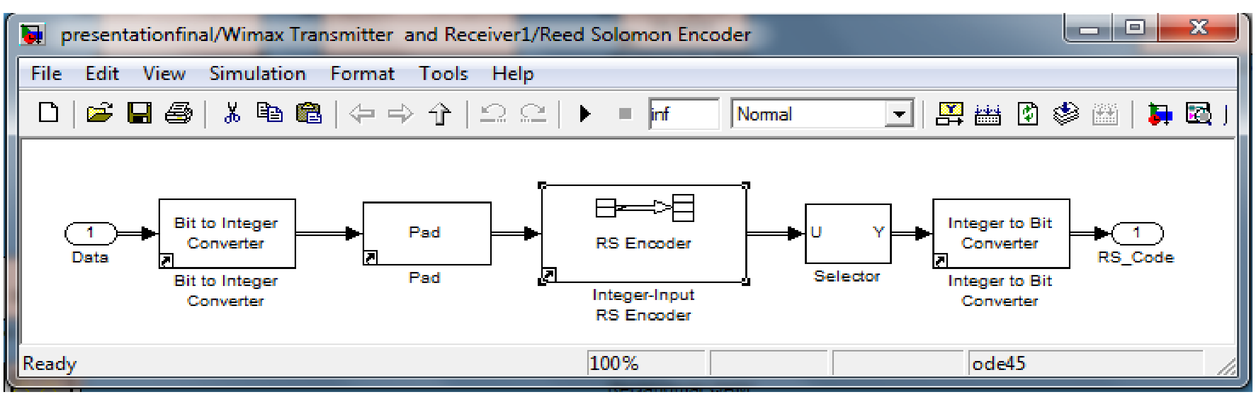


Figure 50: Simulink block of Reed Solomon Encoder

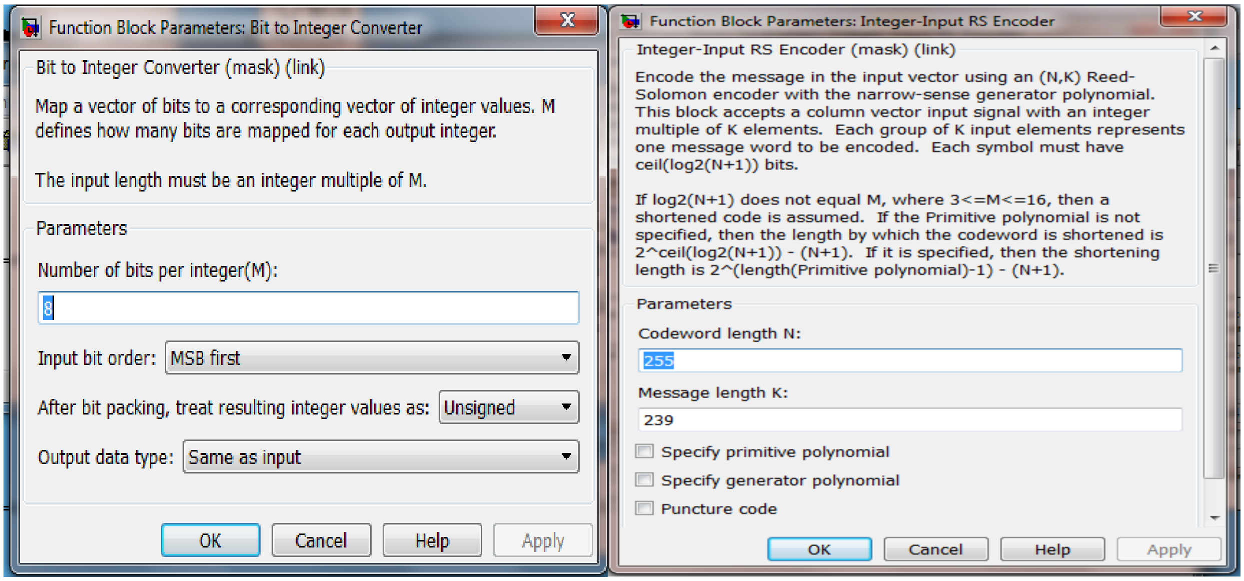


Figure 51: Parameter settings of Bit to Integer converter and RS-Encoder

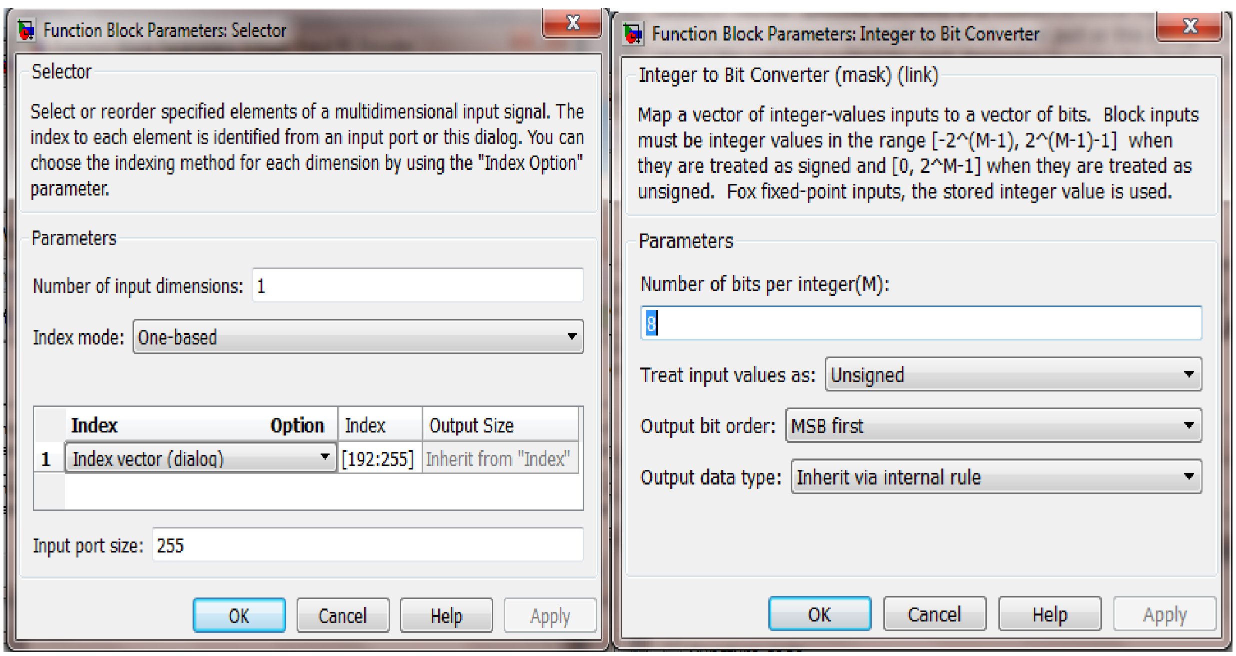


Figure 52: Parameter settings of Selector and Integer to Bit Converter

Convolutional Encoder:

In matlab simulink block, there is a block set available for making the Convolutional Encoder for communication system. We can directly use this simulink block for our desire system. Necessary parameters of this Convolutional Encoder is shown in figure 54.

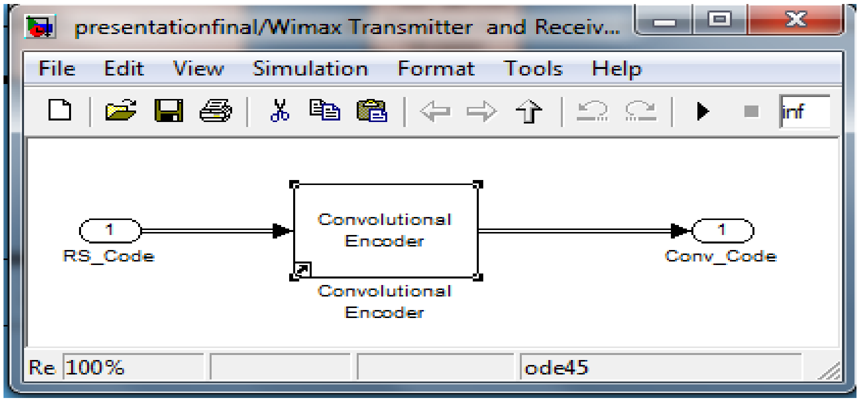


Figure 53: Simulink block of Convolutional Encoder

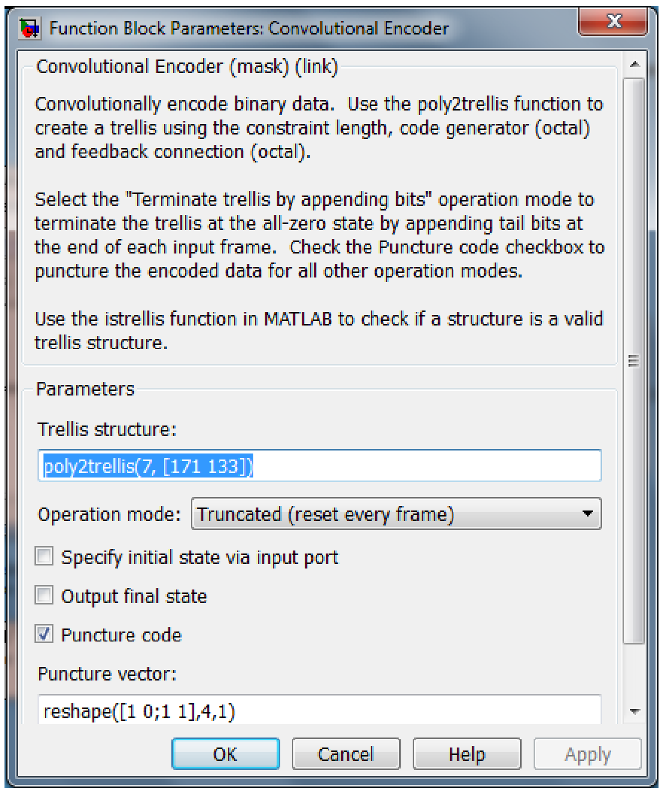


Figure 54: Parameter settings of Convolutional Encoder

Rectangular QAM Baseband Modulator:

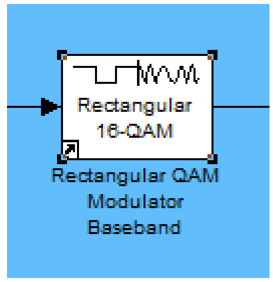


Figure 55: Simulink block of Rectangular QAM Modulator Baseband

To the same fashion, Simulink block of Ractangular QAM Modulator for Baseband is available in simulink block set. We just needed to drag and drop this icon to our design. The Rectangular QAM Modulator Baseband block modulates using M-ary quadrature amplitude modulation with a constellation on a rectangular lattice. The output is a baseband representation of the modulated signal. The parameter setting is presented in figure 56.

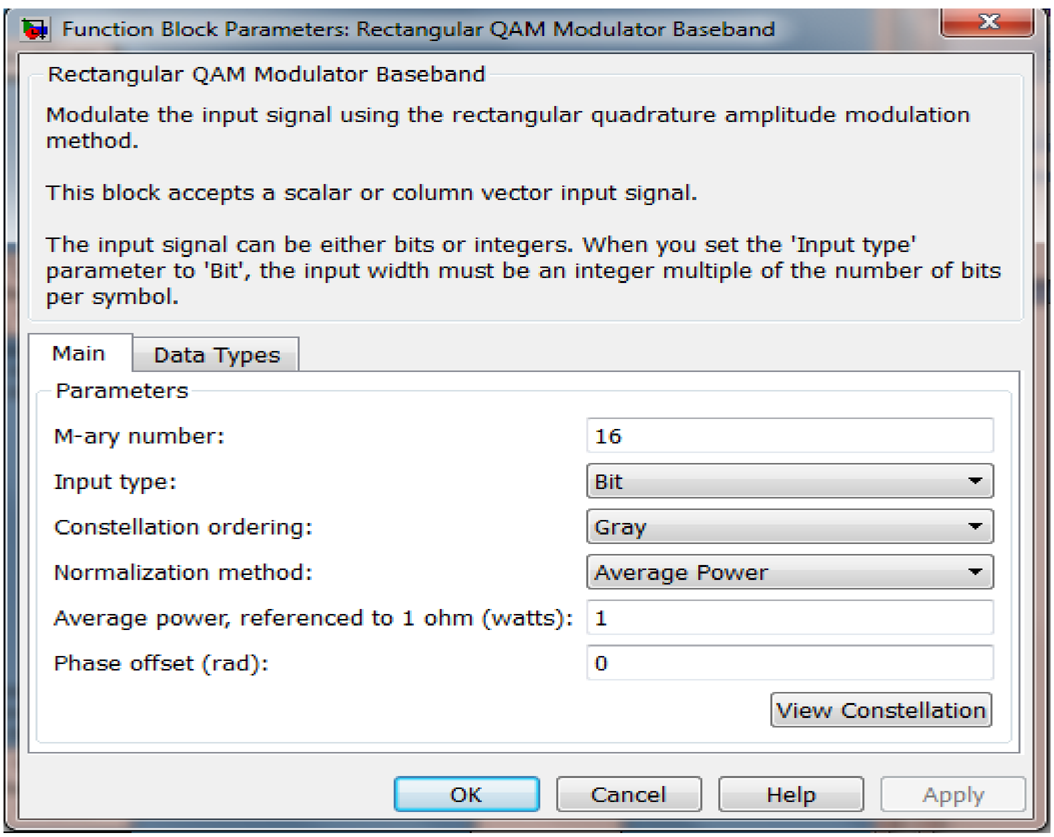


Figure 56: Parameter settings of Rectangular QAM Modulator Baseband

OFDM Transmitter:

Here in figure 57, we have generated the Training and pilot sub carriers using constant block here we have used complex function to generate complex training and pilot signal. We have use complex function because of after modulation our data transform into complex form. The main purpose of training to generate guard band we have create a complex null vector. The main purpose to use guard band to prevent inter symbol interference (ISI). Then we have used a “matrix” concatenation as an assembler. It is used to create an OFDM symbol and put the Sub carrier into that sequentially. Here we have set the matrix concatenation into vertical catenation format as our data in OFDM symbol is in vertical form. The symbol is look like following figure after assembling.

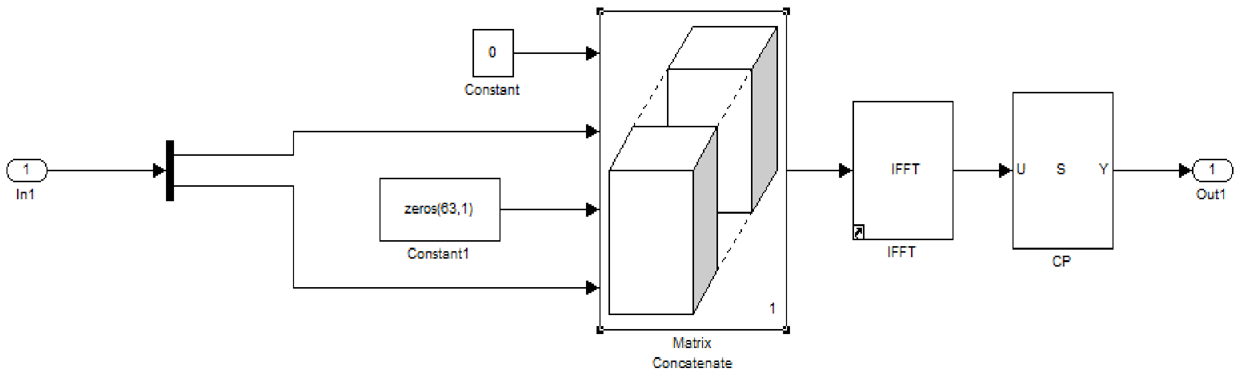


Figure 57: Simulink block of OFDM Transmitter

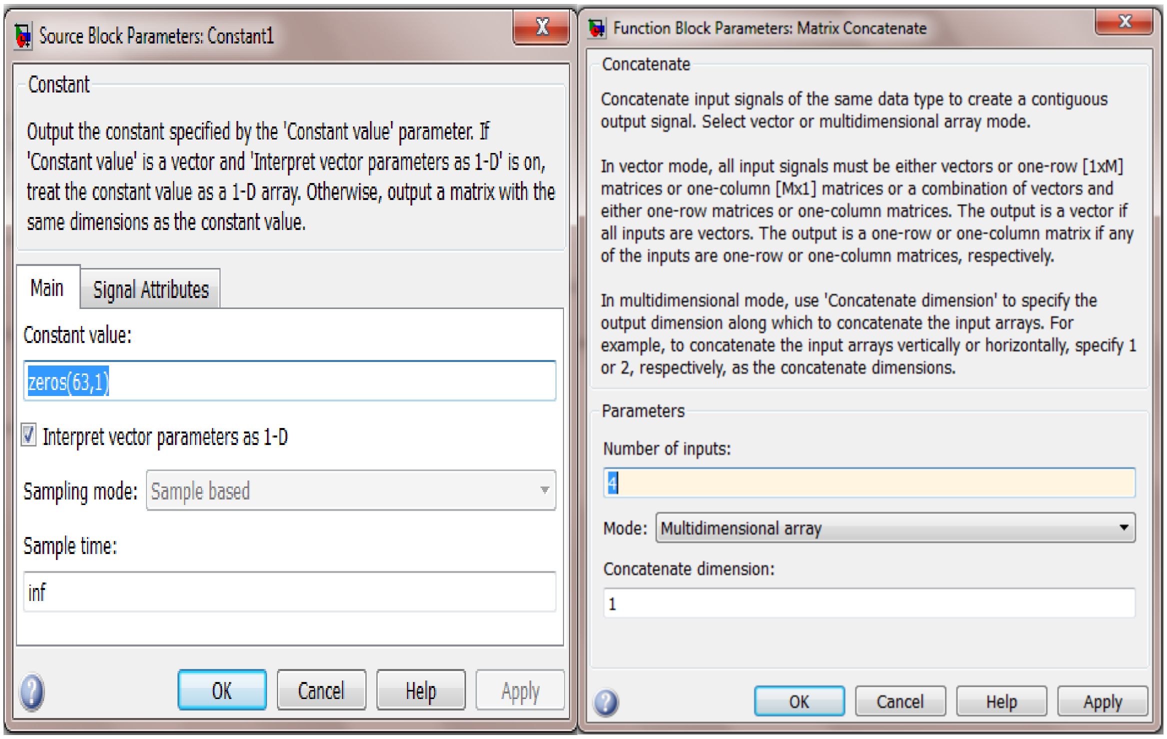


Figure 58: Parameter of constant block and Matrix Concatenate

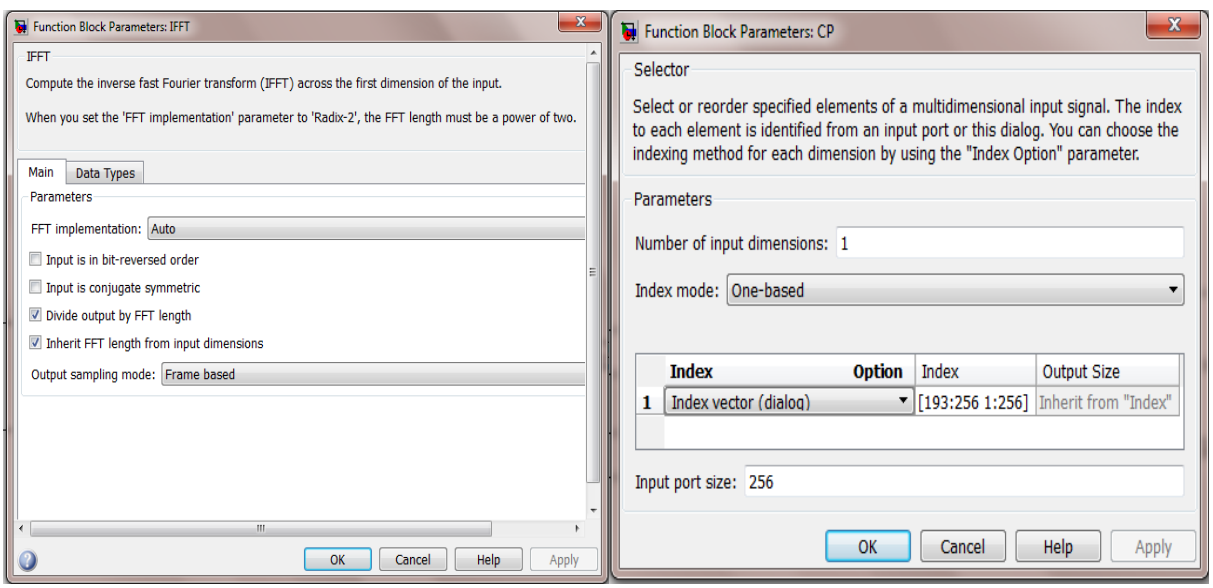


Figure 59: Parameter settings fo IFFT and CP block.

Channel:

The AWGN Channel block adds white Gaussian noise to a real or complex input signal. When the input signal is real, this block adds real Gaussian noise and produces a real output signal. When the input signal is complex, this block adds complex Gaussian noise and produces a complex output signal. This block inherits its sample time from the input signal.

This block accepts a scalar-valued, vector, or matrix input signal with a data type of type single or double. The output signal inherits port data types from the signals that drive the block.

Signal Processing and Input Dimensions

This block can process multichannel signals. When we set the Input Processing parameter to Columns as channels (frame based), the block accepts an M-by-N input signal. M specifies the number of samples per channel and N specifies the number of channels. Both M and N can be equal to 1. The block adds frames of length-M Gaussian noise to each of the N channels, using a distinct random distribution per channel.

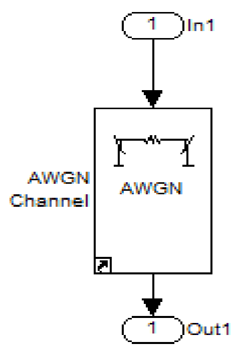


Figure 60: Simulink block of AWGN

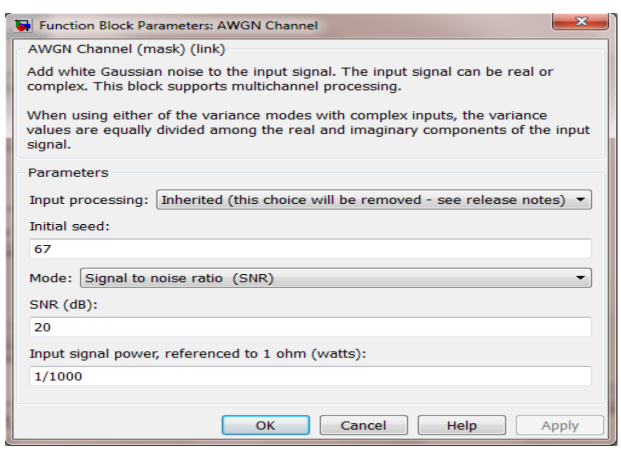


Figure 61: Parameter settings of AWGN Channel

OFDM Demodulator:

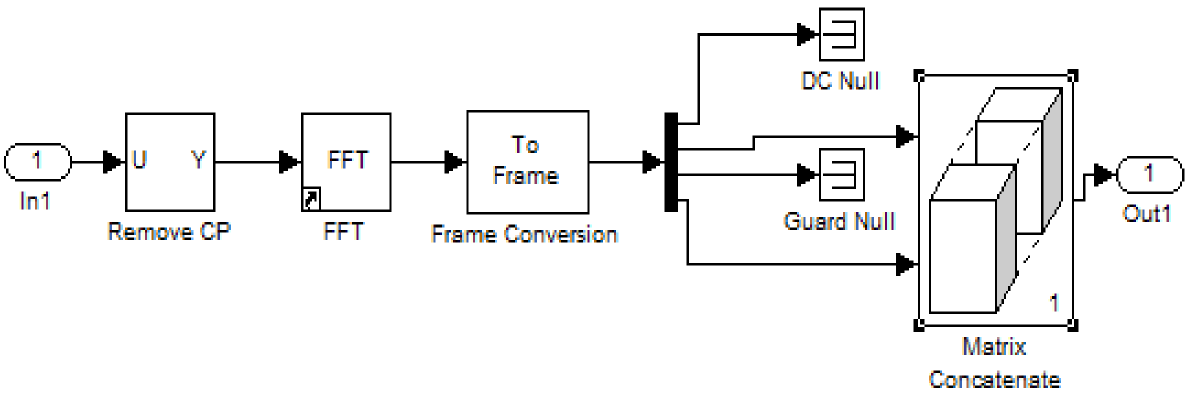


Figure 62: Simulink block of OFDM Demodulator

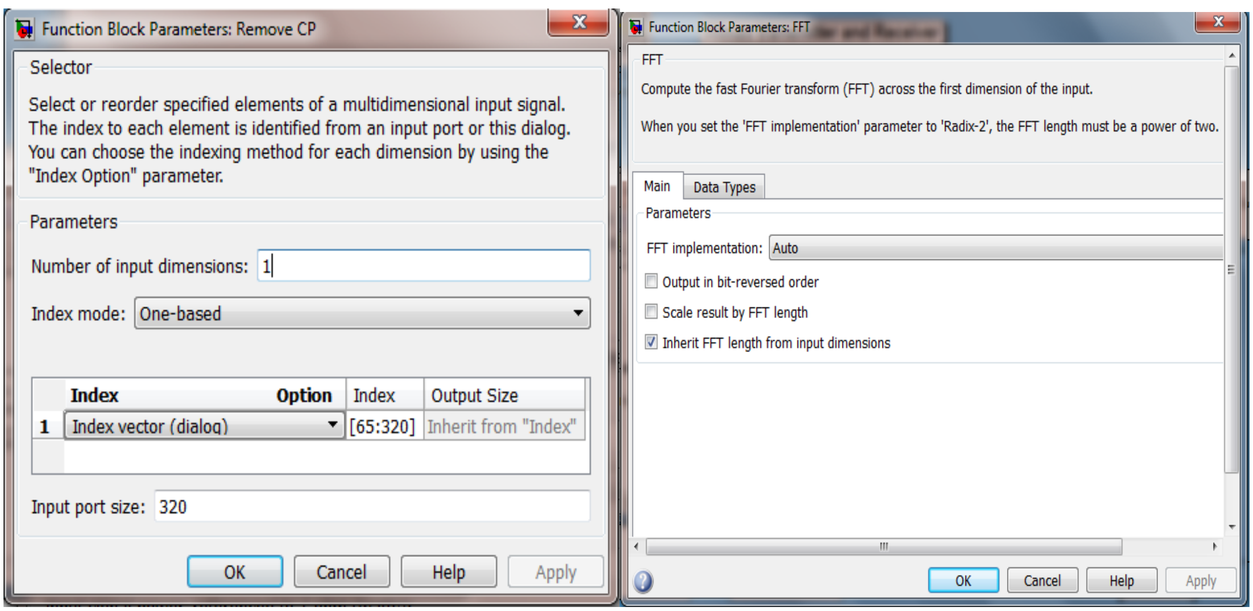


Figure 63: Parameter settings of Remove CP and FFT

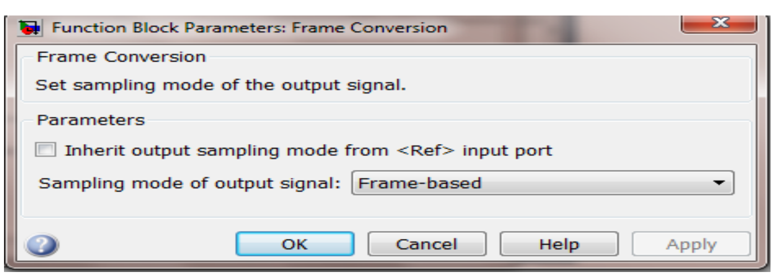


Figure 64: Parameter settings fo Frame Conversion

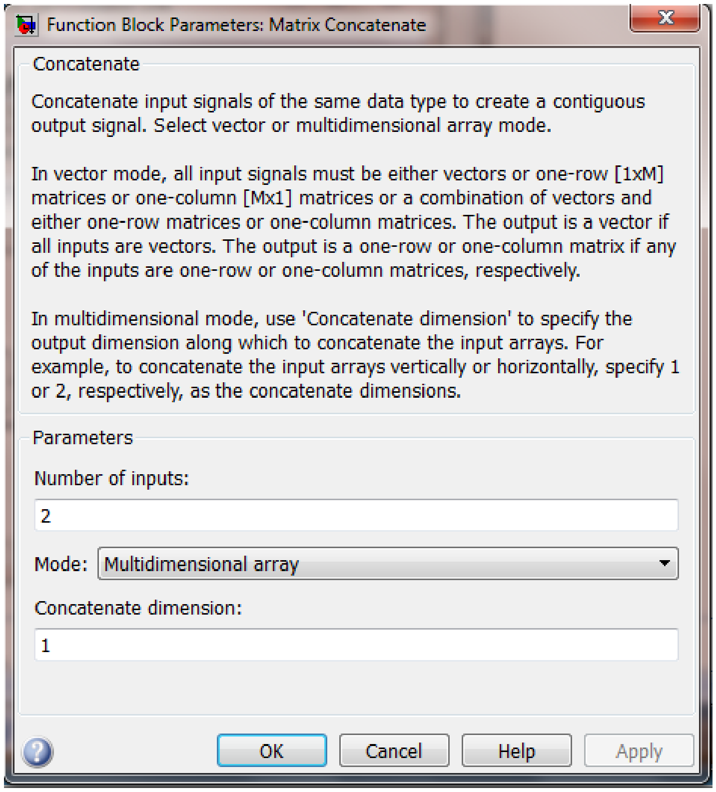


Figure 65: Parameter settings of Matrix Concatenate

Rectangular QAM Demodulator Baseband:

The Rectangular QAM Demodulator Baseband block demodulates a signal that was modulated using quadrature amplitude modulation with a constellation on a rectangular lattice. The signal constellation has M points, where M is the M-ary number parameter. M must have the form 2K for some positive integer K. The block scales the signal constellation based on how you set the Normalization method parameter.

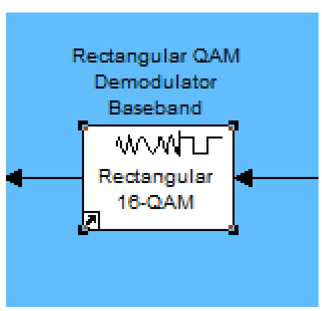


Figure 66: Simulink block of Rectangular QAM Demodulator Baseband

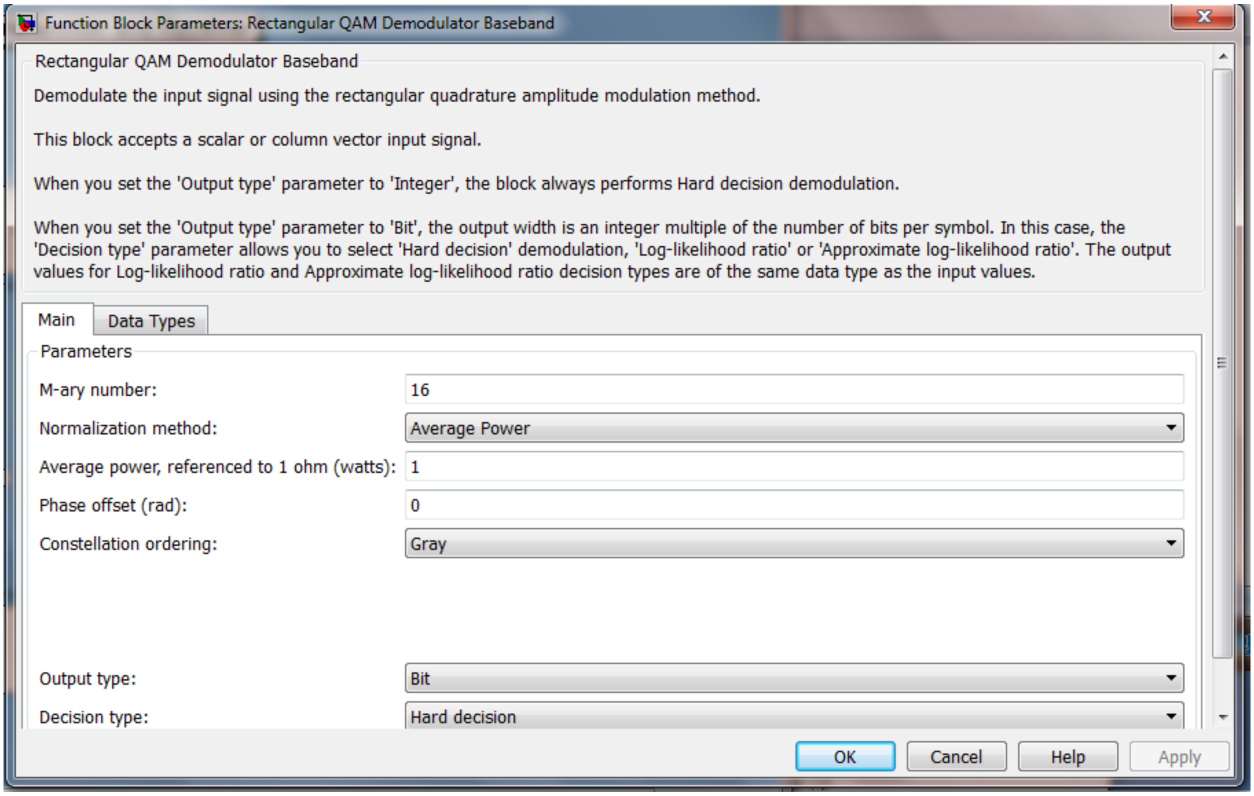


Figure 66: Parameter settings of Rectangular QAM Demodulator Baseband

Viterbi Decoder/ Convolutional Decoder:

The Viterbi Decoder block decodes input symbols to produce binary output symbols. This block can process several symbols at a time for faster performance.

This block can output sequences that vary in length during simulation. For more information about sequences that vary in length, or variable-size signals.

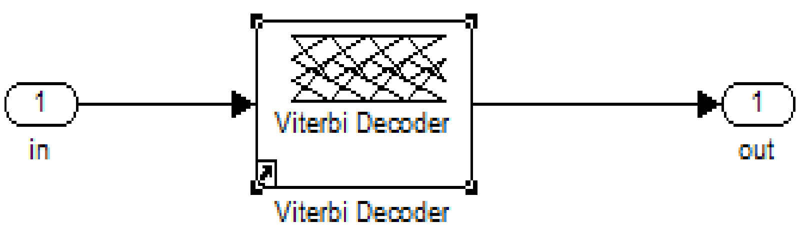


Figure 67: Simulink block of Viterbi Decoder

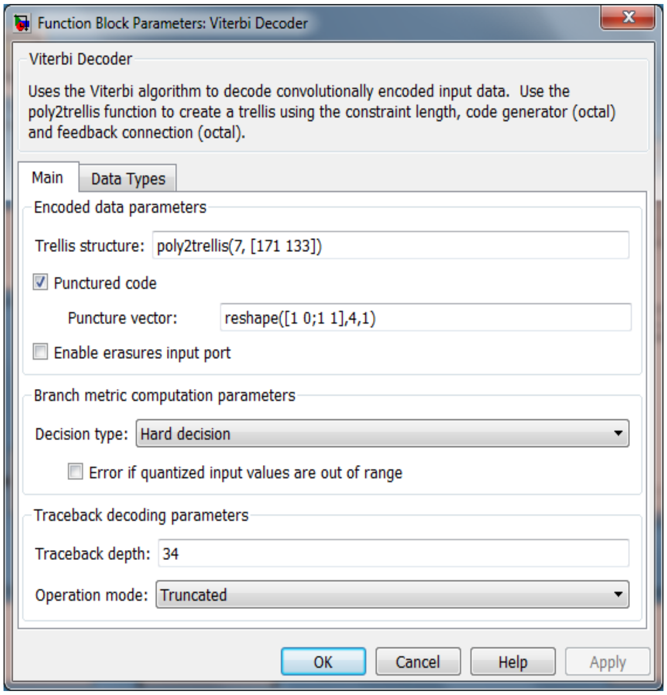


Figure 68: Parameter settings of Viterbi Decoder

Reed Solomon Decoder:

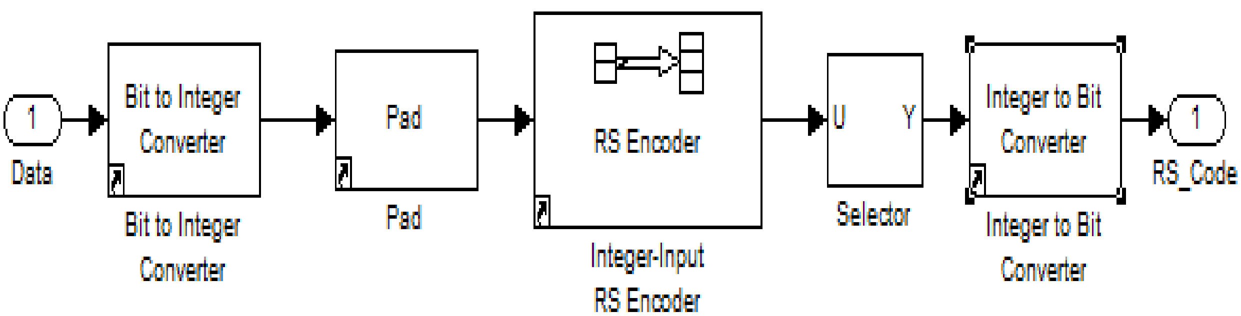


Figure 69: Simulink block of Reed Solomon Decoder

Error Rate Calculation and Display:

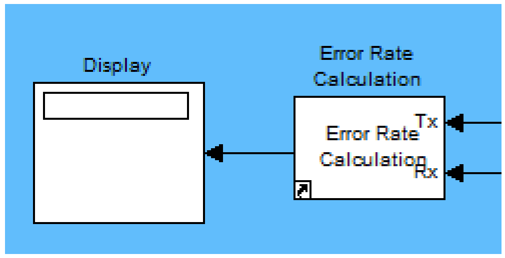


Figure 70: Simulink block of Error Rate Calculation and Display

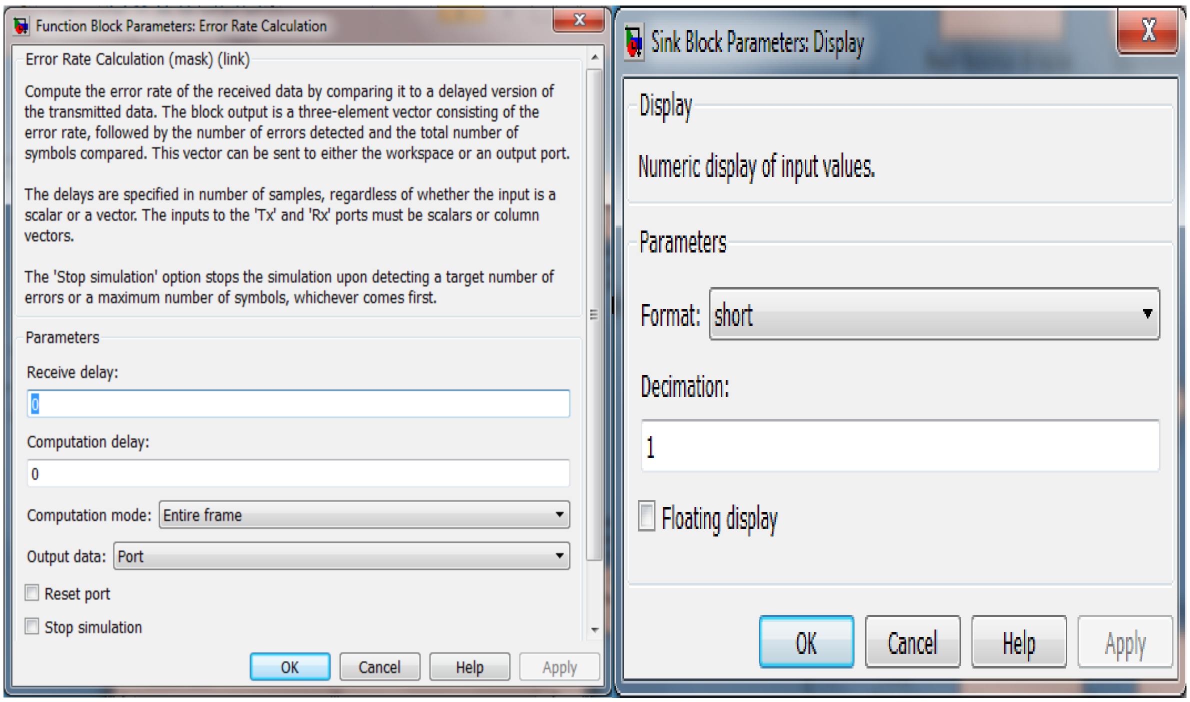


Figure 71: Parameter settings of Rate Calculation and Display

IDEAL ADC:

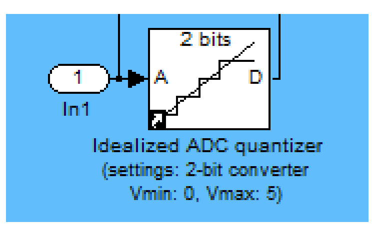


Figure72: Simulink block of Idealized ADC quantizer

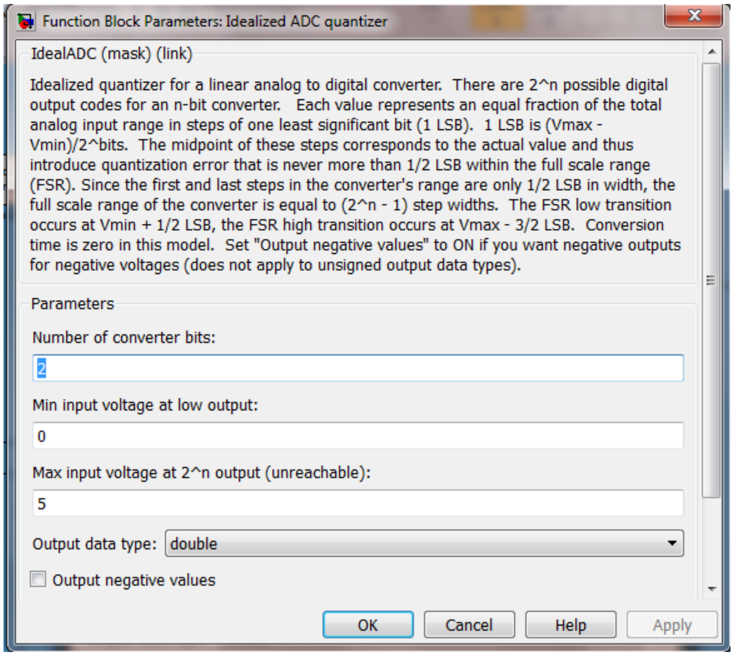


Figure 73: Parameter settings of Idealized ADC quantizer

Frame Conversion, Buffer and Unbuffer:

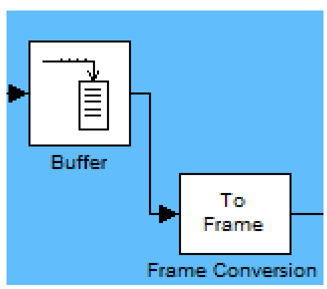


Figure 74: Simulink block of Buffer and Frame Conversion

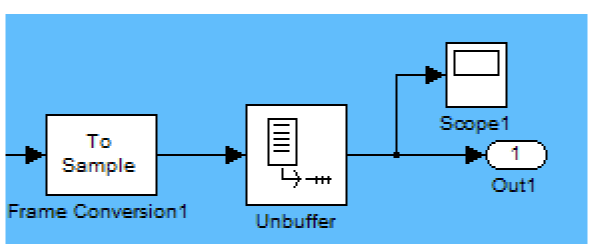


Figure 75: Simulink Block of Frame Conversion and Unbuffer

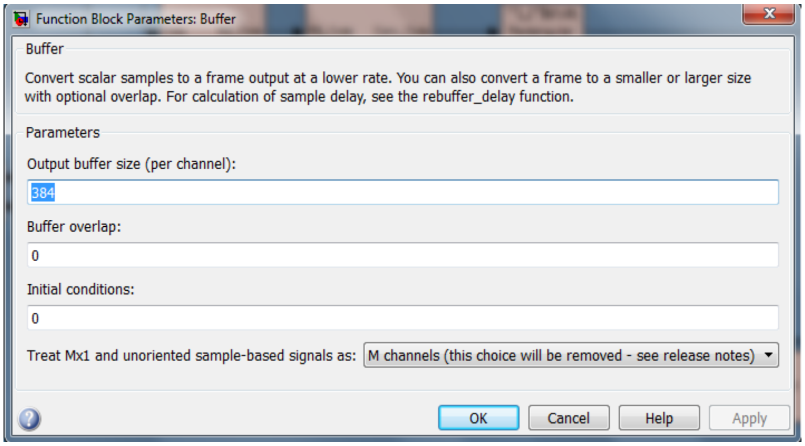


Figure 76: Parameter settings of Buffer

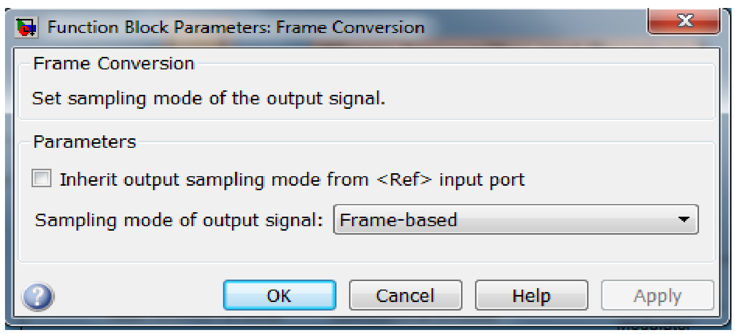


Figure 77: Parameter settings of Frame Conversion

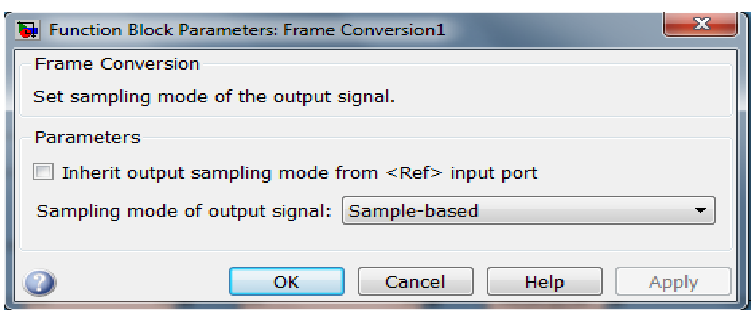


Figure 78: Parameter settings of Frame Conversion (Sample-Based)

Chapter 05
Result and Discussion

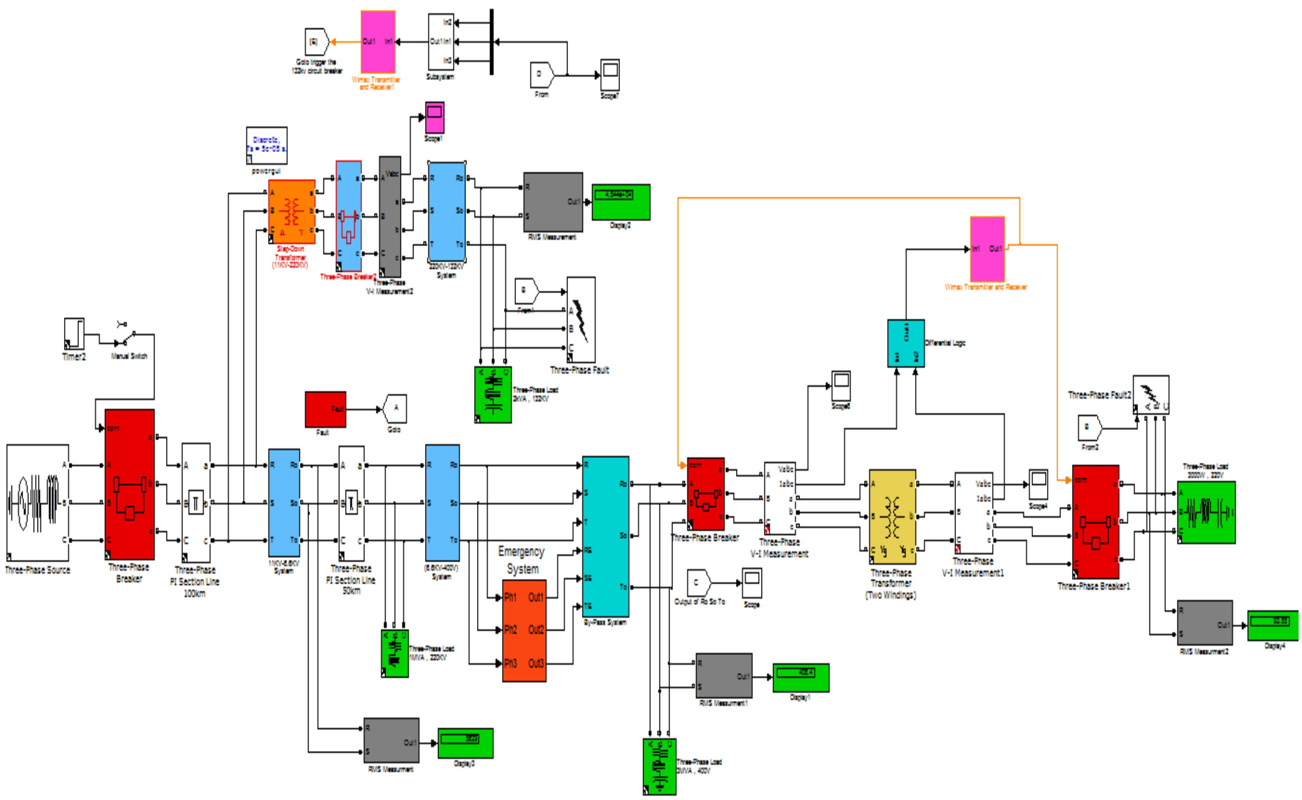


Figure 79: The WiMAX implementation of fault signal transmission using Matlab simulink.

To the above figure 79, the conceptual simulation diagram of WiMAX transmitter and receiver is presented in transmission of fault signal and its detection for the discretisation of load from generation unit. In this section, the analysis of fault signal generation and its impact on load side will be discussed. Moreover, the delay time for this wireless transmission is evaluated in the context of smart grid communication.

5.1 Differential Fault Current Transmission

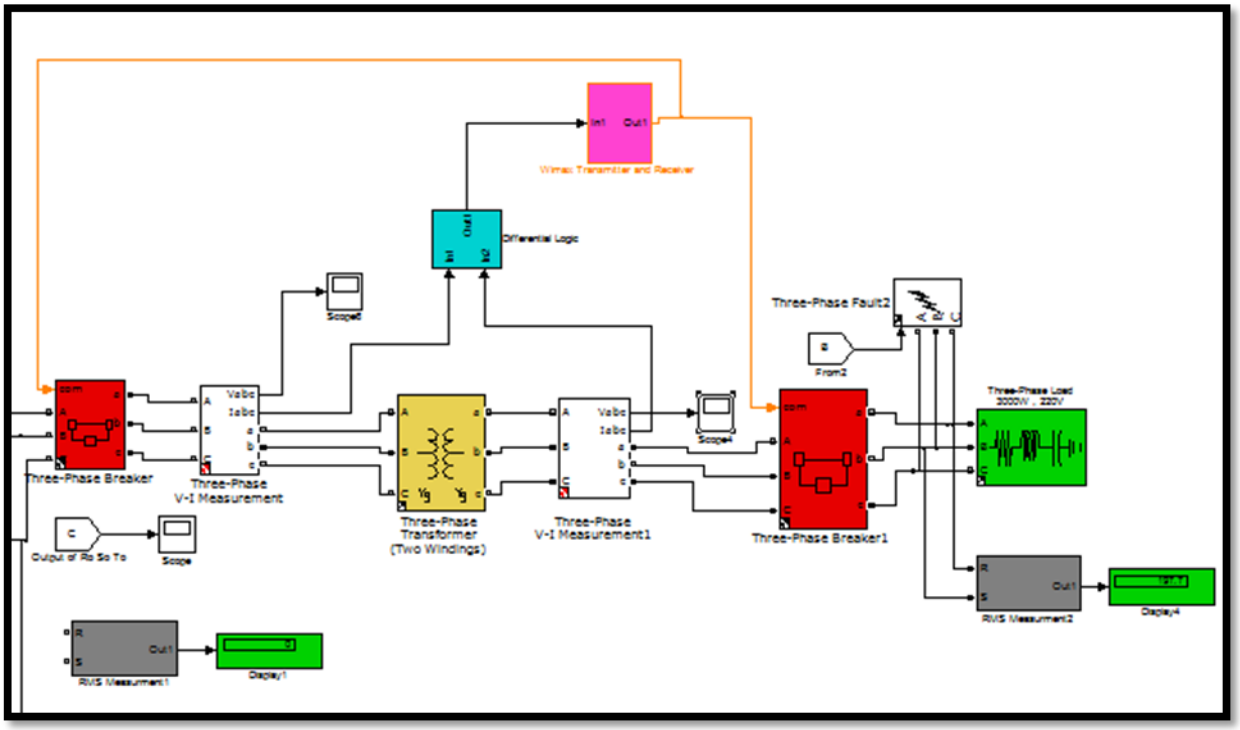


Figure 80: Differential fault current transmission

Here, the fault signal generated from 0.03-0.08sec. The generated fault signal in fact, makes a difference in differential logic circuit which ultimately goes to breaker circuit to make that open. During this fault signal, the load current goes to zero because of the breaker becomes open having the fault signal through Wi-Max transmitter and receiver system.

As our generated fault signal duration is .03-.08 second and it is a continuous pulse, it will have an impact to the load accordingly. Therefore, if we look into the following figure, we see that the fault signal makes the load detached from the generation unit thus it goes to zero.

In fact, the first signal of the following figure 81 shows the fault signal pulse, the second waveform shows the load voltage of 440volt power output before the inverter and the last waveform shows the performance of the inverter. In this case, the inverter provides the output for only .03sec to .08sec while the fault signal flows through the system.

To the second waveform, the load voltage does not go to the zero level immediately when the fault signal strikes the breakers. It takes about 0.02second to make the output completely zero stage.

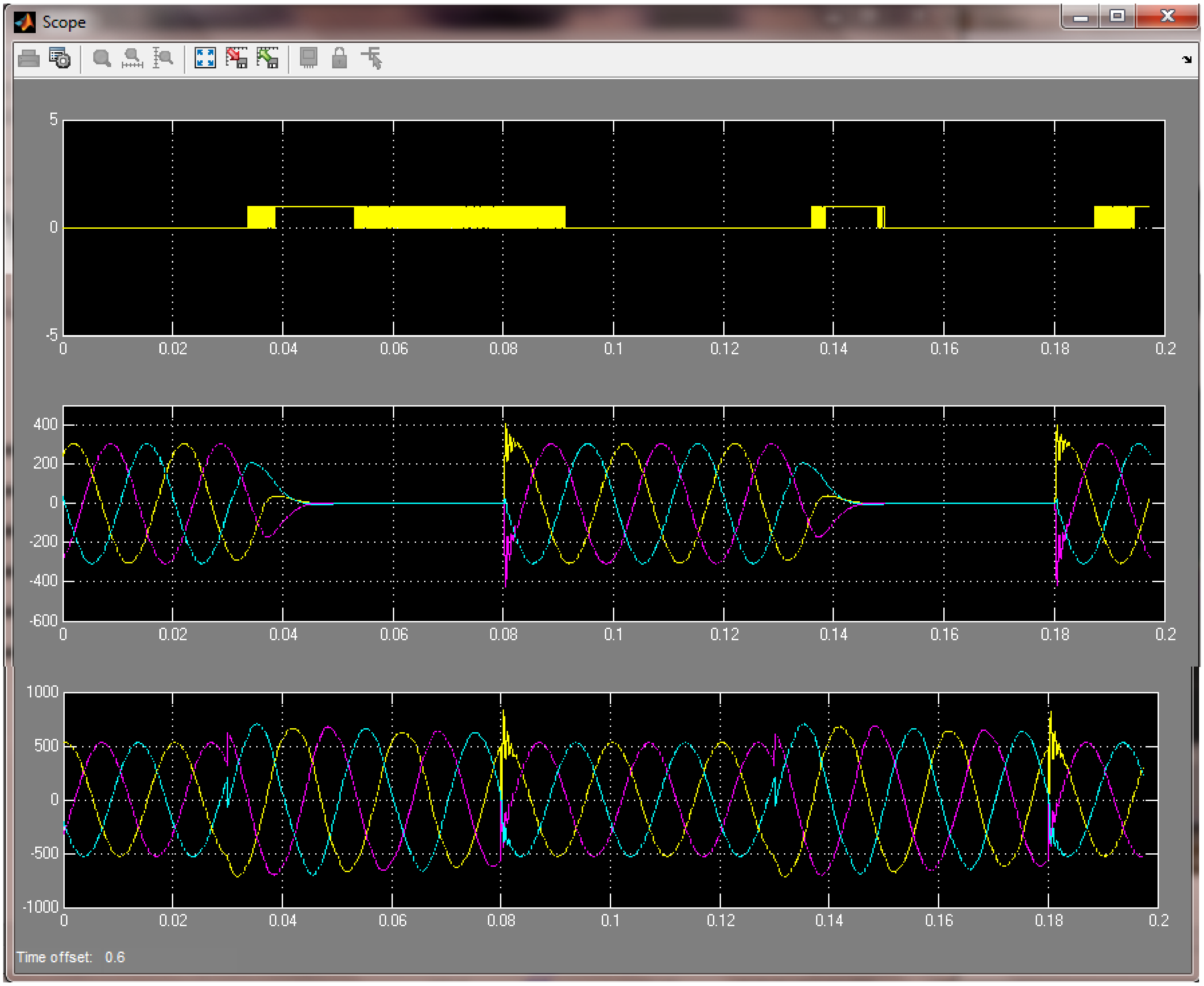


Figure 81: Output of 440V supplied load current

5.2 Three Phase Fault Current Transmission:

The fault time is set for 0.03sec to 0.08sec. Due to simulator drawback, the waveform has become distorted while simulation of the project. It is however, the output of the load current becomes zero when the fault circuit creates the fault current thus justifies the fault signal transmission through Wi-Max transmitter and receiver circuit. Figure 82 shows the load voltage becomes zero when the fault signals appear.

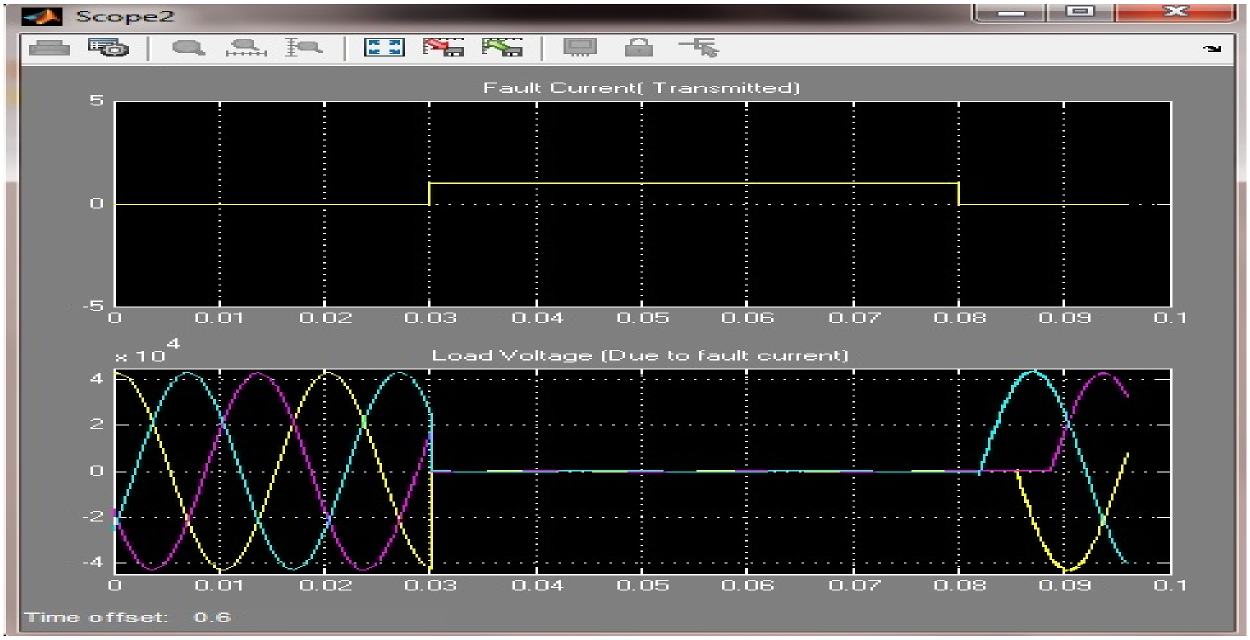


Figure 82: The load output of 132kv while the fault pulse duration is 0.05 sec

5.3 Differential Fault Current Analysis:

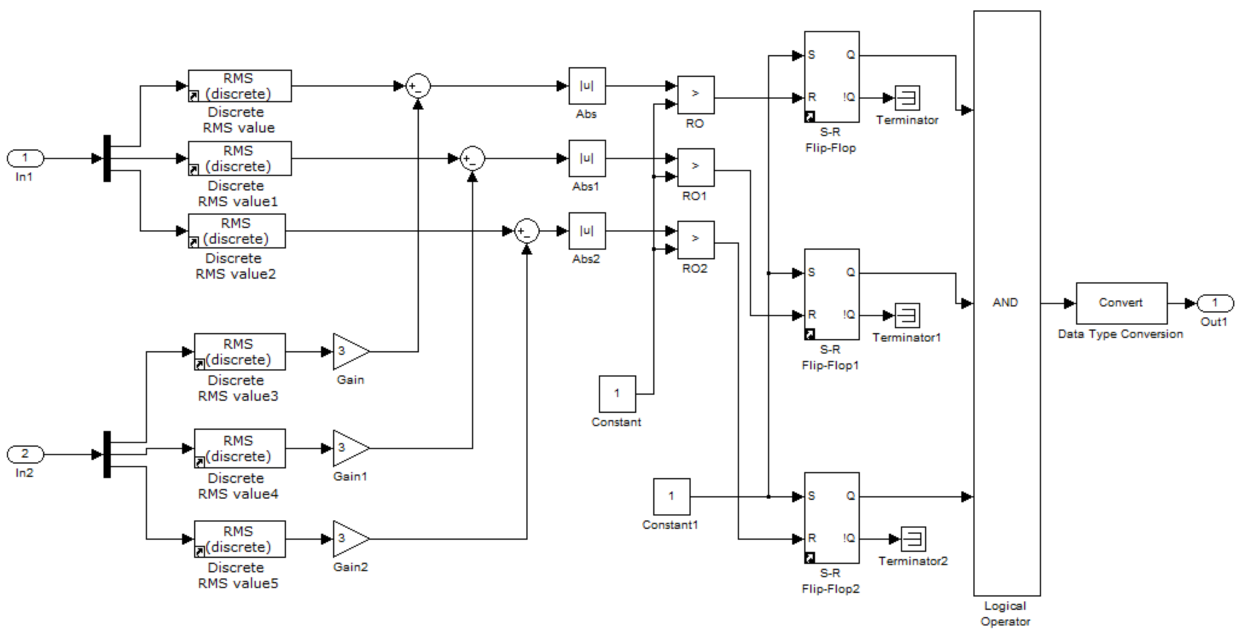


Figure 83: Differential fault current generation circuit

The main moto of this circuit is to compare the current between primary and secondary of the substation transformers of electrical smart gird. In this case, the smart grid has to has a probation to detect the fault current at the first moment when it flows through the network and detect to detach the load for their safety issue. Therefore, we had to increase the gain of the secondary so that this would become equal to the primary side current of the transformer. Thereafter, the three phase fault circuit of simulink block is triggered to generate the fault current to the load. This additional fault current makes an imbalance of the primary and secondary side current eventually be compared by the differential circuit so that its impact could create a pulse for the circuit breakers of the load for disconnecting them as soon as possible.

To the following figure 85, we see that, the current variation is happen between the primary and secondary side of the transformer. If we look closely, we have found that, the primary current is $1X10^5$ in amplitude and secondary side current is $5X10^4$. So, current variation has been taken place due to fault generation during 0.03-0.08sec. which we have created by simulink fault circuit as shown figure 90 below:

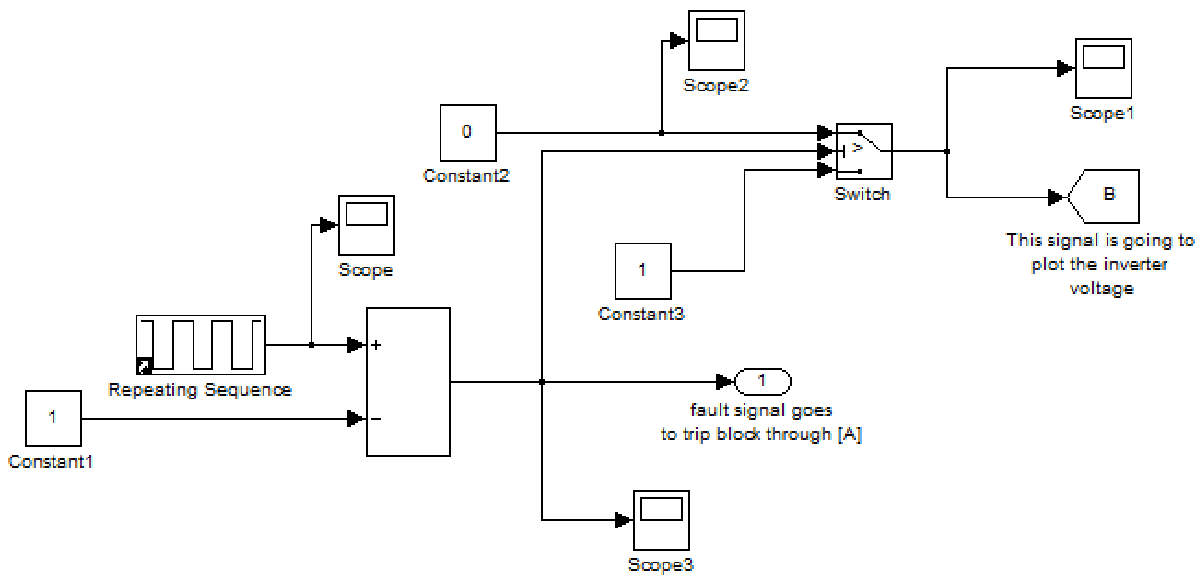


Figure 84: The fault signal generation circuit in simulink block

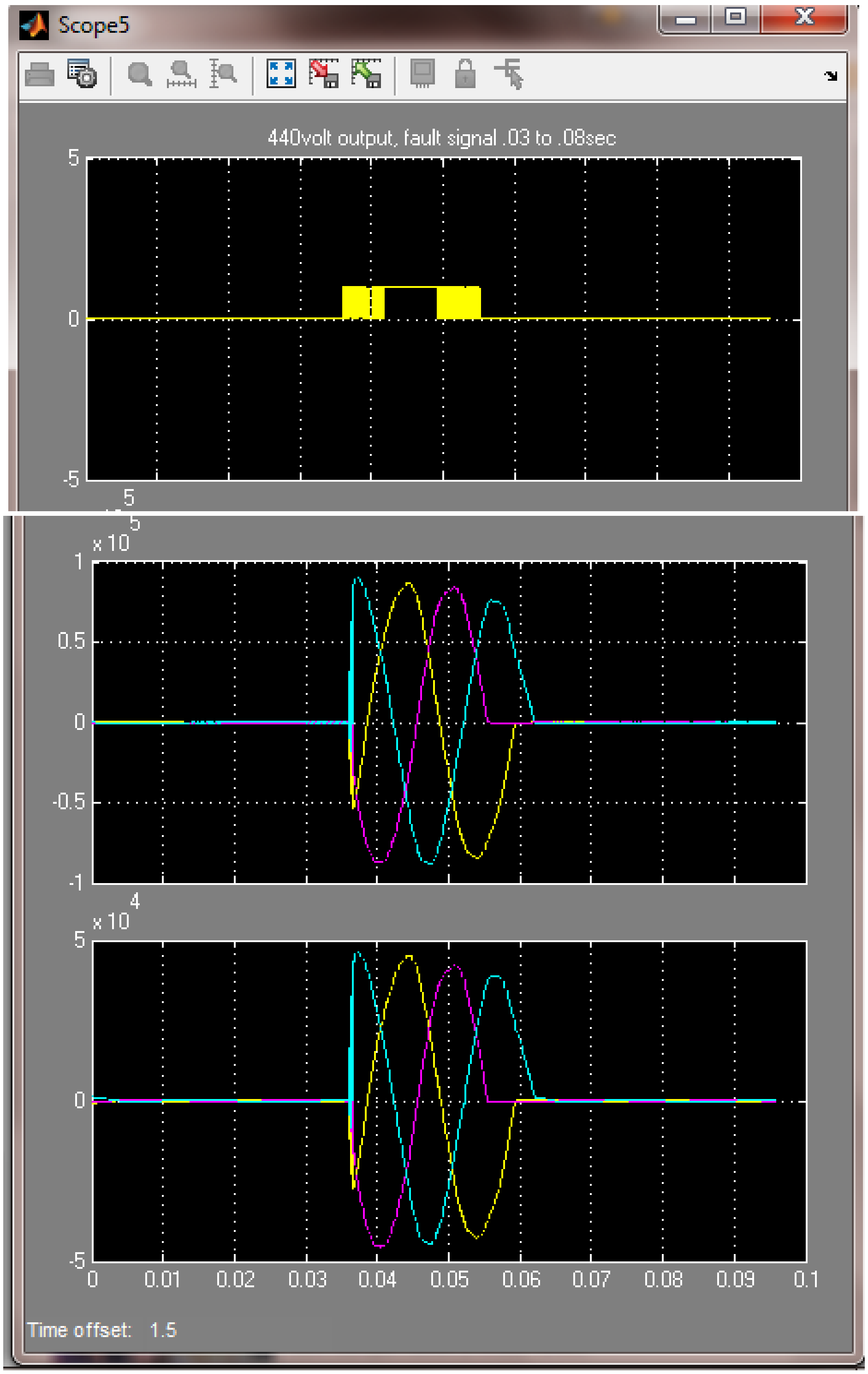


Figure 85: Differential Fault Current results in trip current for breakers.

5.4 Three phase fault current analysis:

The fault time is set for 0.03sec to 0.08sec. Due to simulator drawback, the waveform has become distorted while simulation of the project. It is however, the output of the load current becomes zero when the fault circuit creates the fault current thus justifies the fault signal transmission through Wi-Max transmitter and receiver circuit. To the following figure 86, we can see the part of three phase fault circuit in cyan colored block. This block has three input and one output. In fact, these three input takes the three phase current from three phase voltage output of 132KV substation transformer. As the transformer's secondary winding makes the balance of equal power both in primary and secondary considering voltage and current relation of transformer, we were needed to use gain block at the beginning of the three phase fault circuit so as to use a certain amount of current to be used as a reference current of the three phase fault circuit.

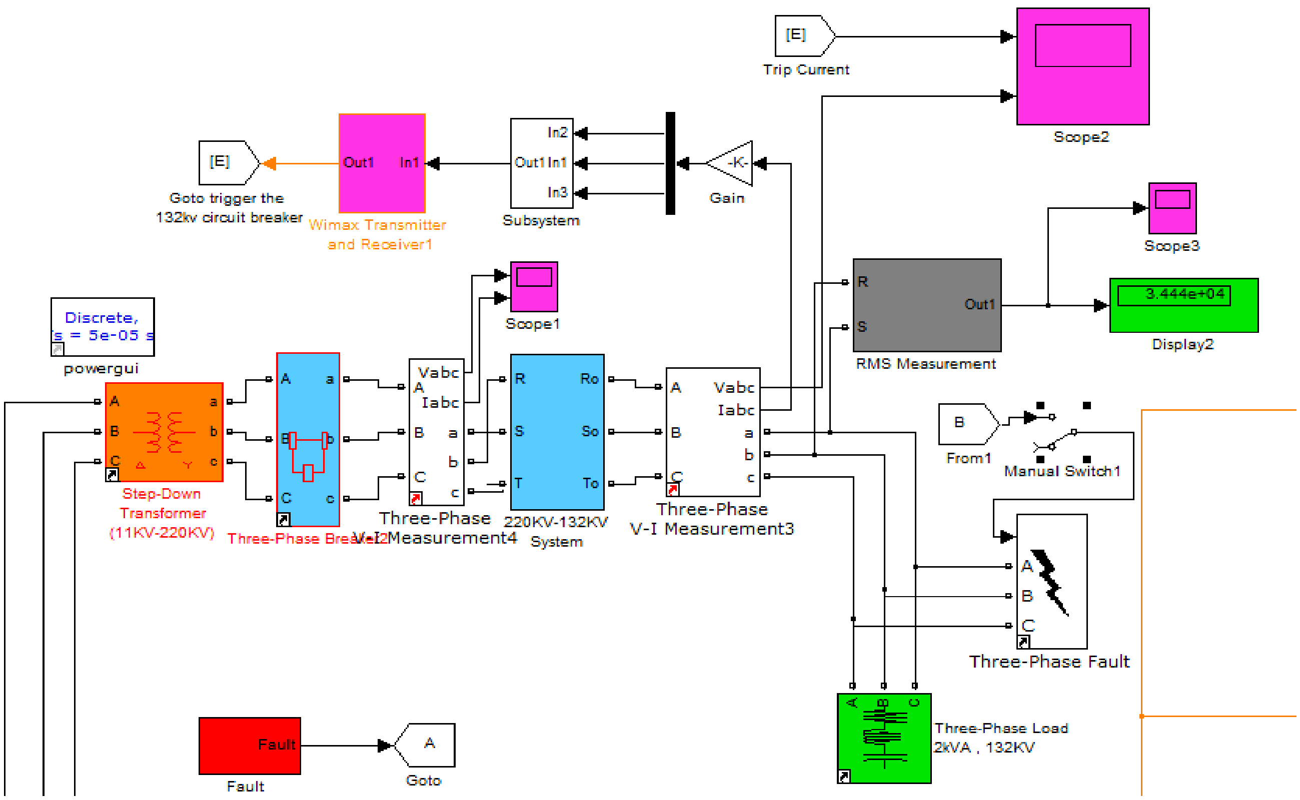


Figure 86: Fault signal creation when the reference voltage overshoots.

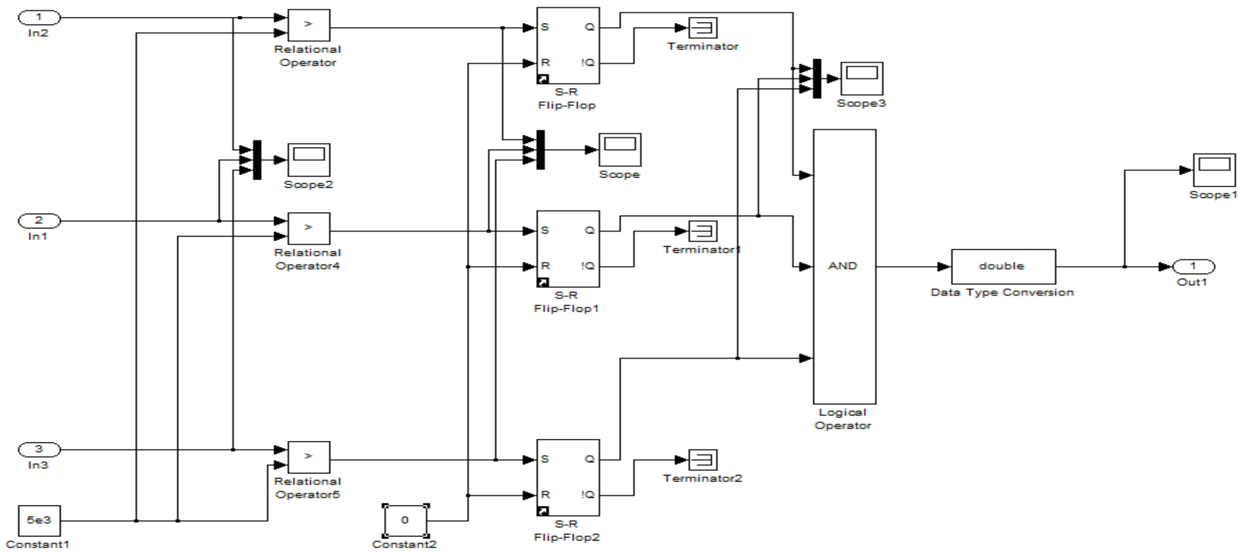
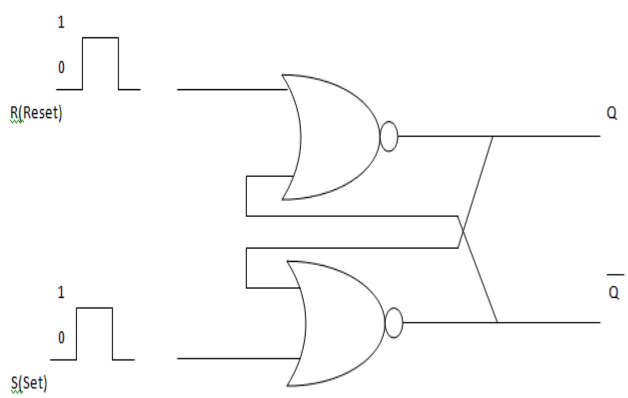


Figure 87: Three phase fault current generation.

In the figure 87, we see that the reference constant current has been assumed to be 5000amp. i.e. when the supplied current's reference level cross over this 5000amps due to the fault signal generation only when we trigger the three phase fault, its output provides a positive signal pulse to its output eventually goes to the circuit breakers of load circuit through WiMAX communication system.



S	R	Q	Q'	
1	0	1	0	
0	0	1	0	After S=1; R=0;
0	1	0	1	
0	0	0	1	After S=0;R=1;
1	1	0	0	

Table 3: Truth Table of SR Flip-Flop

Here, we have used the fault generator with a manual switch to see how the trigger pulse put its impact on the load voltage. According to SR flip flop, when s=1 and R=0; we have Q =1. The high pulse is then transmitted through WiMAX transmitter and received by WiMAX receiver.

The following waveform in figure 88 shows the fault signal is zero and the load has no effect in figure 89 due to fault circuit. This load will only be disconnected when the fault signal generation is taken place.

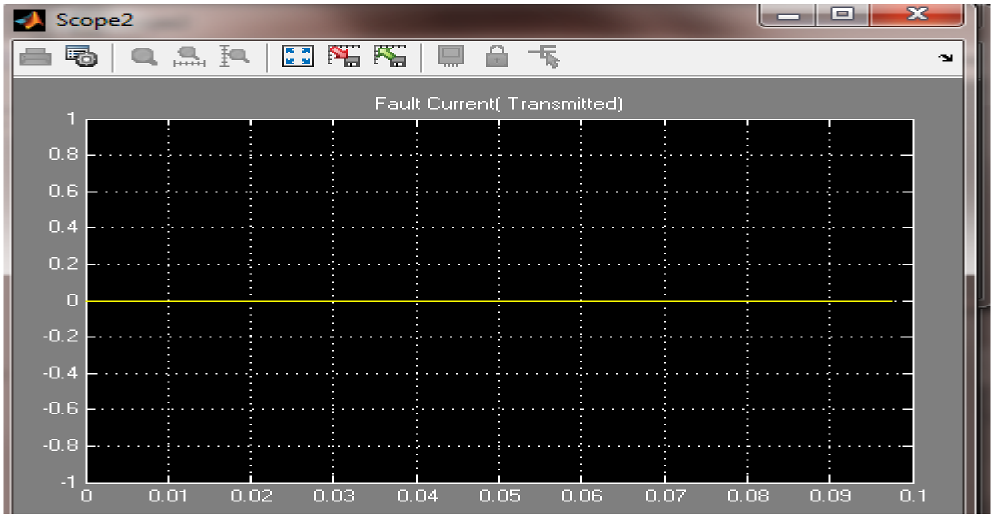


Figure 88: Fault signal is zero when Manual s/w is off.

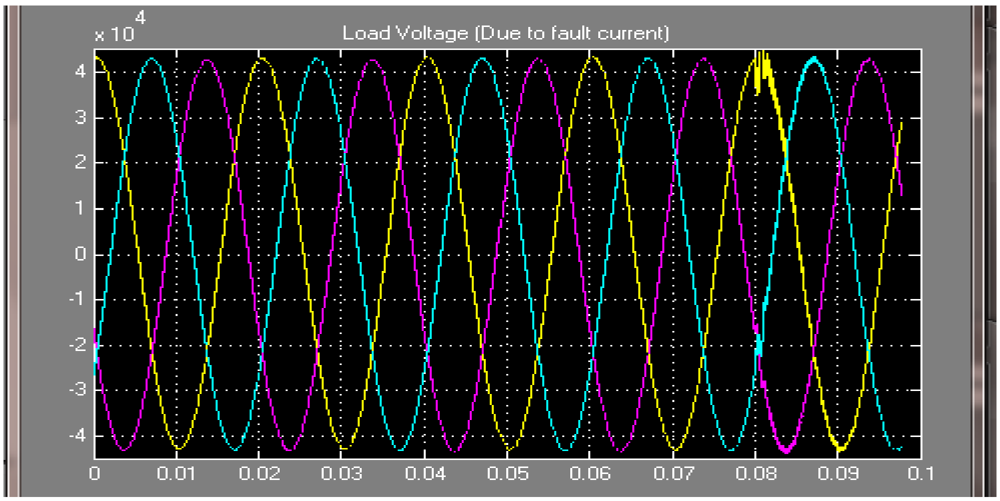


Figure 89: Output load voltage without fault for 132KV

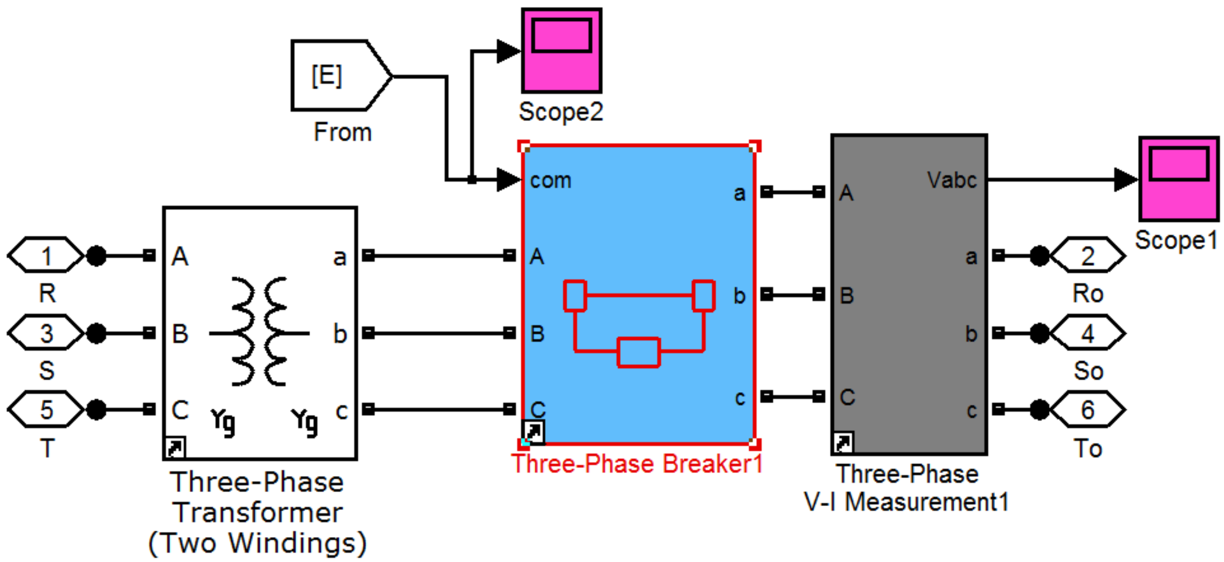


Figure 90: The trigger pulse is sent to trip open the breaker through "E".

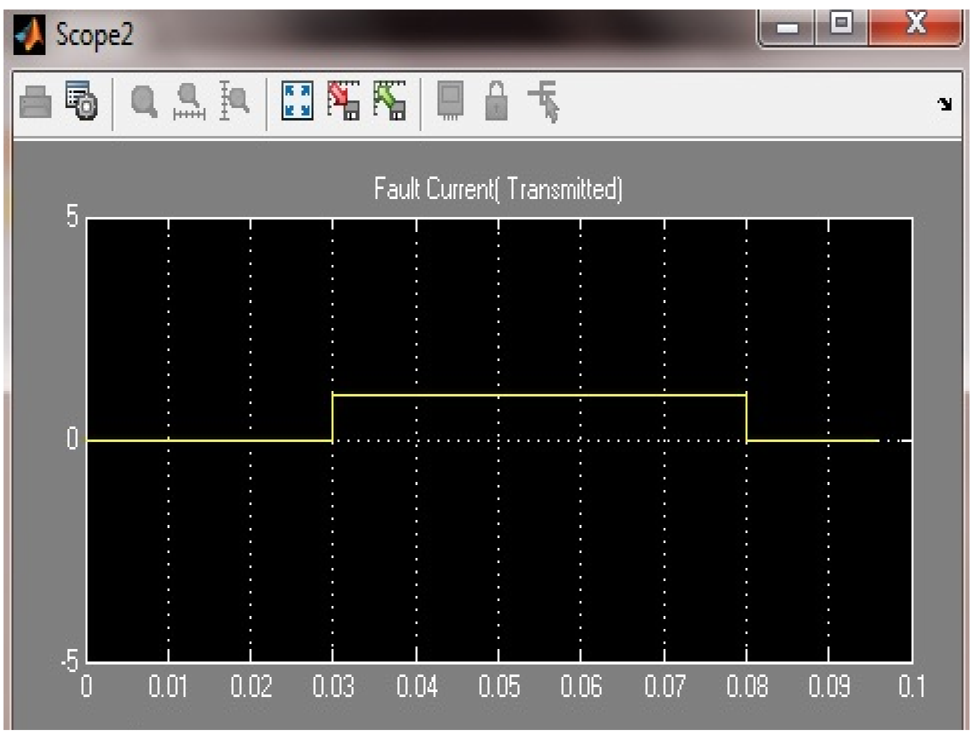


Figure 91: The trip current generation from three phase fault circuit manual s/w in trigged on.

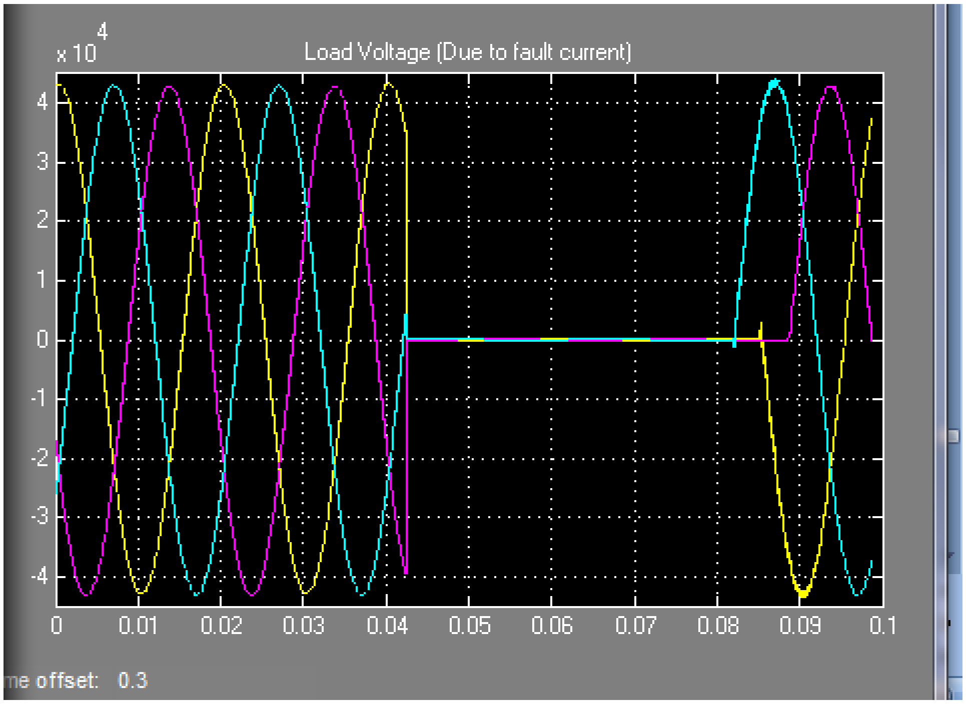


Figure 92: The load output of 132KV while the fault pulse duration is 0.05 sec

As we know that, the fault signal what we have generated by simulink block has a duration of positive signal for 0.05 sec. So, when we trigger this pulse to our simulink block of three phase fault, it provides the fault signal to the load for the same amount of duration. As a result, the picture shows that, the resultant fault signal makes the load voltage zero for the same time duration. However, it is conspicuous that, the load voltage is supposed to zero immediately after the fault signal generation. But, this case, the fault signal shows to the scope after about 0.03sec as because of the drawback of simulink software.

5.5 Time Delay of three phase fault current transmission and reception:

After generation of fault signal in the system, we have used WiMAX transceiver to transmit the fault to one of the remote circuit breaker so that the breaker becomes open for load protection. In this regard, we have made an ideal WiMAX transceiver using matlab simulink block. We have assumed that the antenna of this transmitter and receiver works without any distortion of the noise. It is however, we have used AWGN as a channel of the transmitter and receiver.

To the following figure 93, we see that, the fault signal which has been created to the output of the differential circuit is directly fed into the WiMAX transmitter with A/D converter as this WiMAX transmitter can only deal the digital signal.

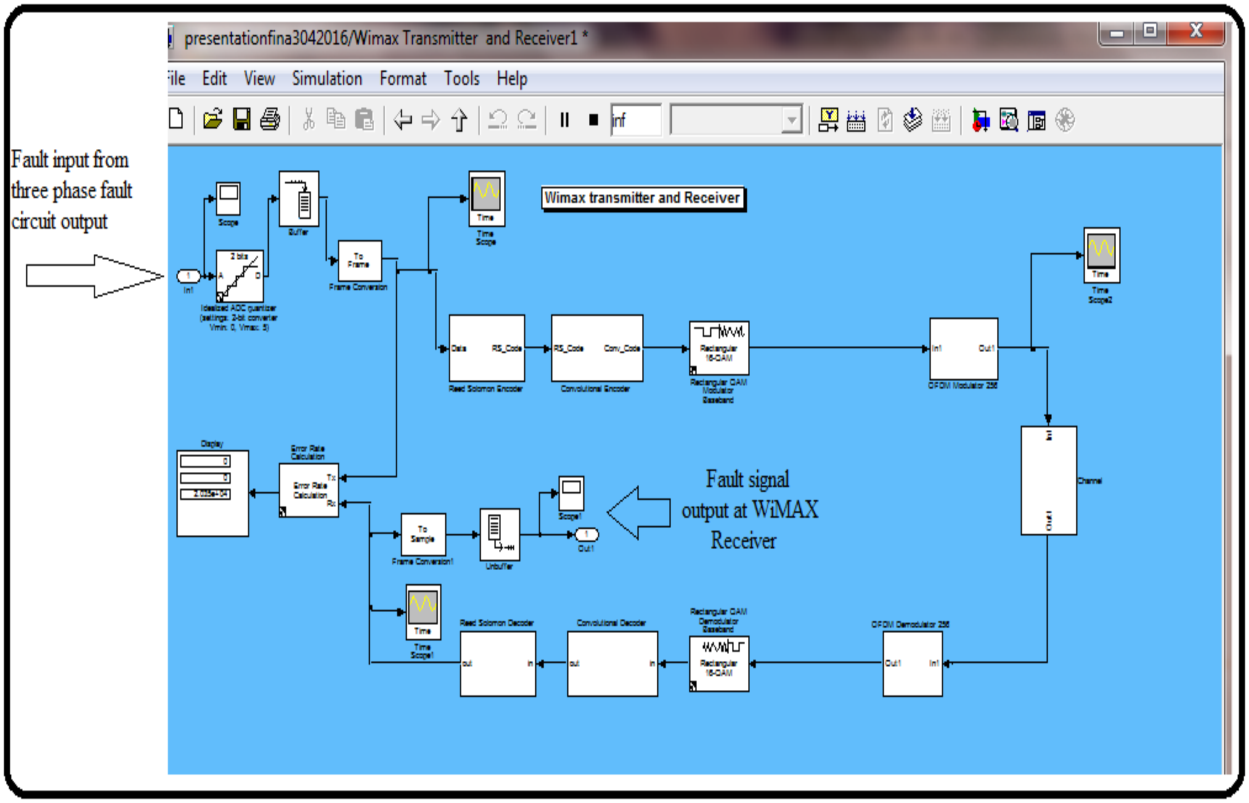


Figure 93: Three phase fault signal transmission and reception through WiMAX technology.

We have found that, there is time delay happen from the input and output terminal of the WiMAX transceiver as the whole transmission and reception comes under few steps of data encoding, modulation, decoding, demodulation etc and which duration is 0.02sec as shown in figure 94 and figure 95. The reason of using buffer and bit to frame and frame to bit converter is found to be in the appendix.

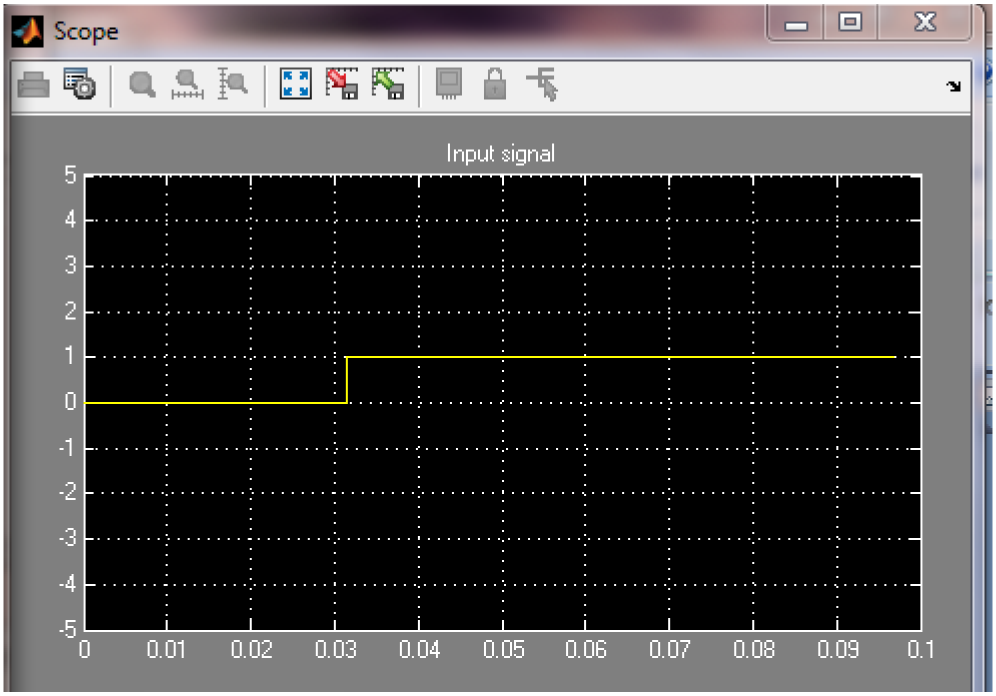


Figure 94: Input fault signal in WiMAX Transmitter.

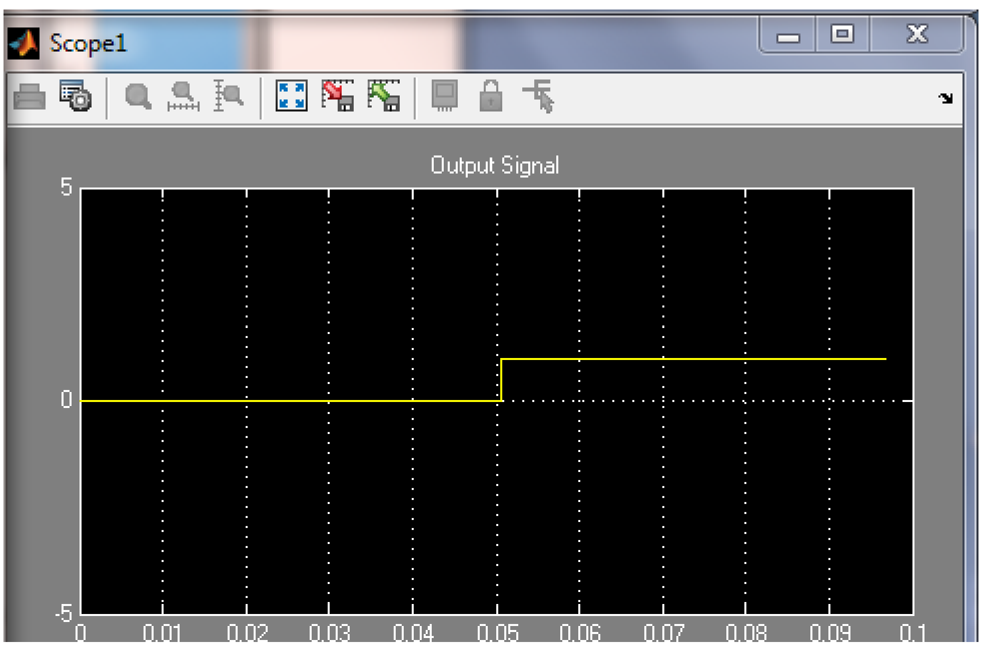


Figure 95: Output fault signal at WiMAX receiver.

5.6 Time delay for differential fault current transmission:

To the same fashion, we have found the time delay of about 0.01sec. when transmitting the fault signal generated from differential fault current generation circuit. But, this case, the delay time is found to be less than the time duration required for three phase fault signal transmission as shown by the following figure 96 and figure 97.

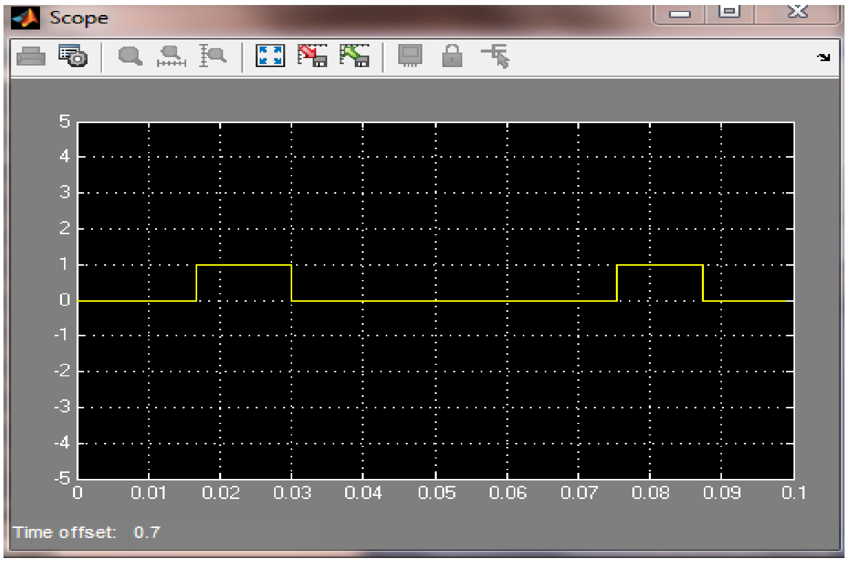


Figure 96: Input signal of WiMAX transmitter for differential fault current

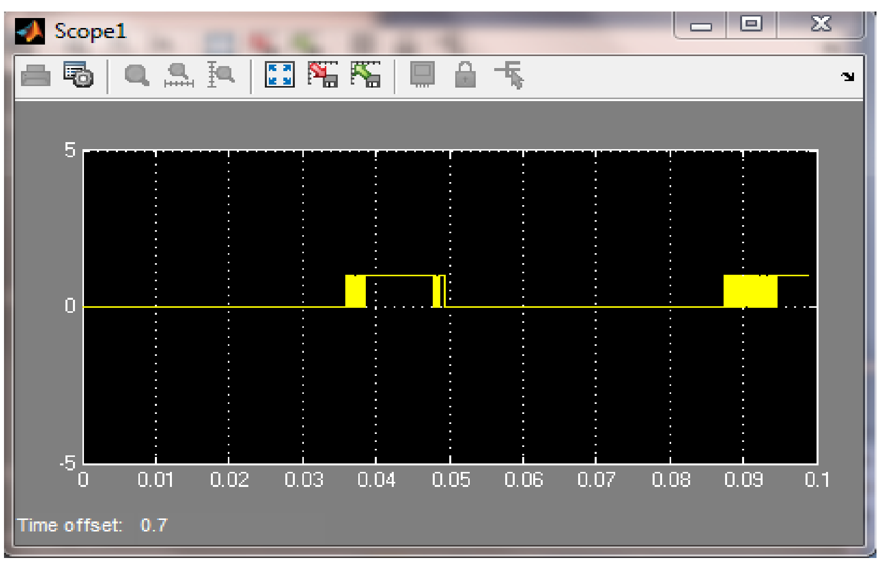


Figure 97: Received Signal of WiMAX receiver end for differential fault current

5.7 RMS Voltage Analysis:

The RMS voltage of the out 132KV and 440V transmission of smart grid system is shown to the consecutive figure when there are no fault current flows in the system and when there is a fault current flow in the system. Since, our generated fault signal affects to our load current at the duration of 0.03 – 0.08sec., we see that the waveform has sharply goes to the bottom end to that duration both 132KV and 440v output.

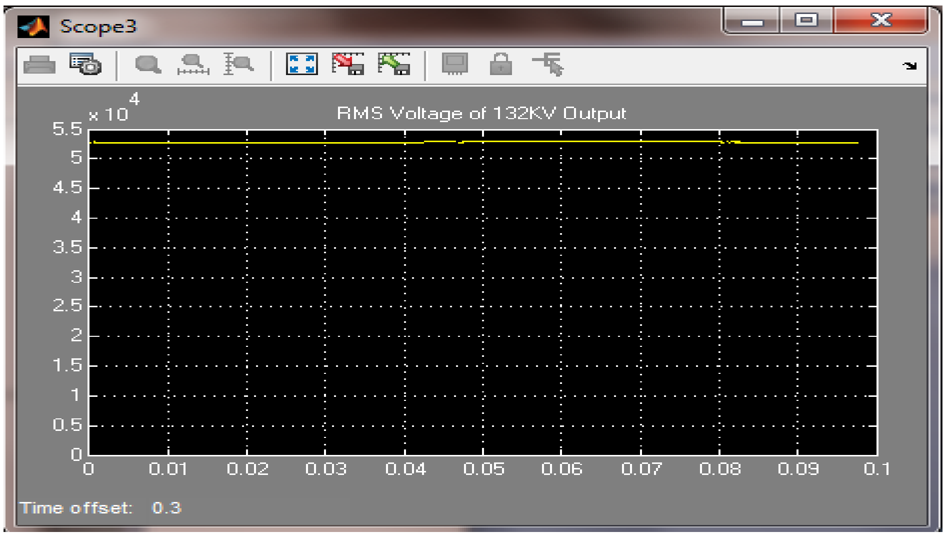


Figure 98: RMS Voltage of 132KV output (without fault)

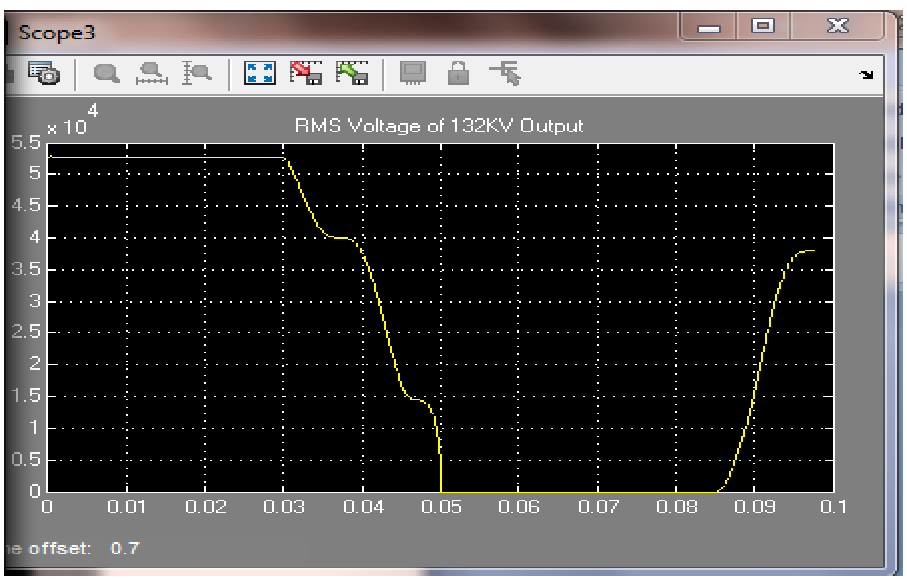


Figure 99: RMS Voltage of 132KV output (Fault siganl: 0.03-0.08sec.)

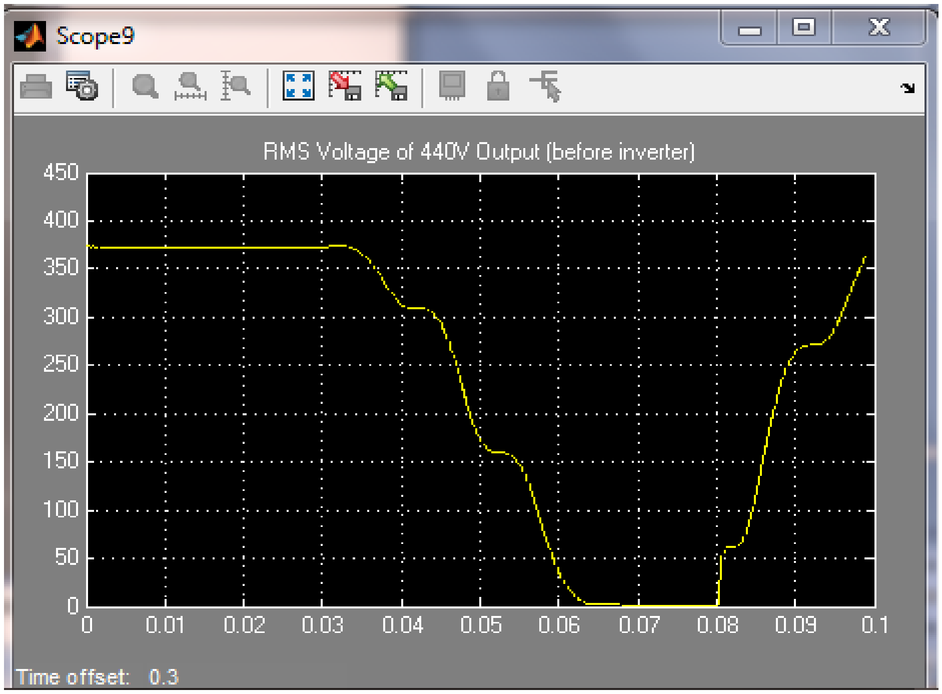


Figure 100: RMS Voltage of 440 output (before inverter)

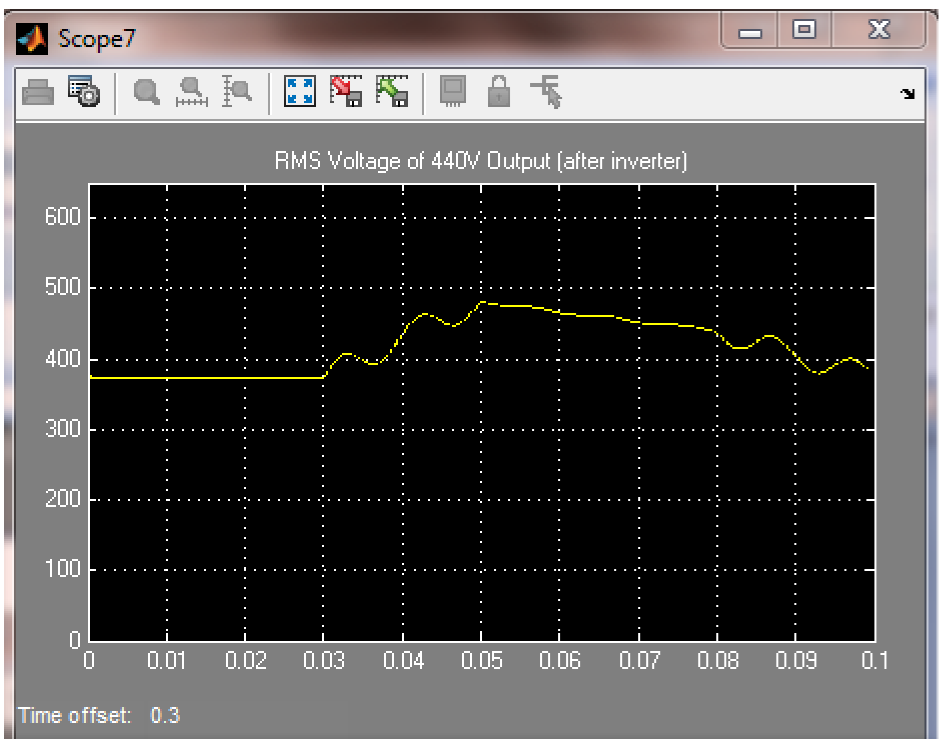


Figure 101: RMS Voltage of 440V output (after inverter)

Chapter 06
Conclusion and Future Work

Our main objective of this work was to create a simulink block to justify the performance of designed smart grid load protection and power back up model in the context of consumer load. In this case, we used WiMAX simulink transceiver as a medium of fault signal communication so as to disconnect the load from generation for safety matters.

Our designed over current protection model and differential current protection model have successfully shown that, they are able to identify the fault current while automatic fault generation current pulse triggers the three phase fault in the duration of 0.03-0.08sec. In this regard, the findings shows that both over current protection and differential protection model generates a positive pulse which has been considered as a trigger pulse for the circuit breakers made the load to be disconnected through faster wireless communication system as WiMAX.

We have assumed that, the WiMAX communication system is an ideal case and have found no changes of the signal from its input and output wave form but a less time delay during transmission and reception process. It was found that, it takes 0.02sec. and 0.01sec. time delay respectively when the trigger pulse of circuit breakers transmit and receive through WiMAX transceiver.

During our fault generation, the smart grid has to provide the continuous power to load so that consumer can get power without any interruption thus protect the loads. Therefore, we did evaluate the response time of inverter that how much time it takes to provide the electricity to the consumer load. It was found that, there was no significant time delay has taken place when providing the backup power from inverter to consumer load while generating the fault current in to smart grid load.

Moreover, when using this automatic power back up, we have measured the RMS voltage of the inverter output at 440v load end along with 440v output before inverter to see the performance of our designed simulink inverter. We have found that, the RMS voltage of the 440v load output starts going to zero from 0.03sec and again start increasing from 0.08sec as because of the fault signal duration is 0.03-0.08sec. Similarly, our have found almost steady RMS voltage at the duration of fault signal of 0.03-0.08sec when taking the output after the inverter.

In future, there is vast area to be investigated of this simulation based project as the effect on load current during fault in different capacity transformers used in substations. Moreover, exploration of delay time minimization technique for fault signal communication along with more accurate and stable RMS voltage generation for consumer load has to done to improve the overall performance of this innovative smart grid concept.

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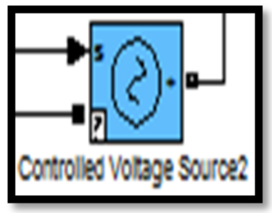
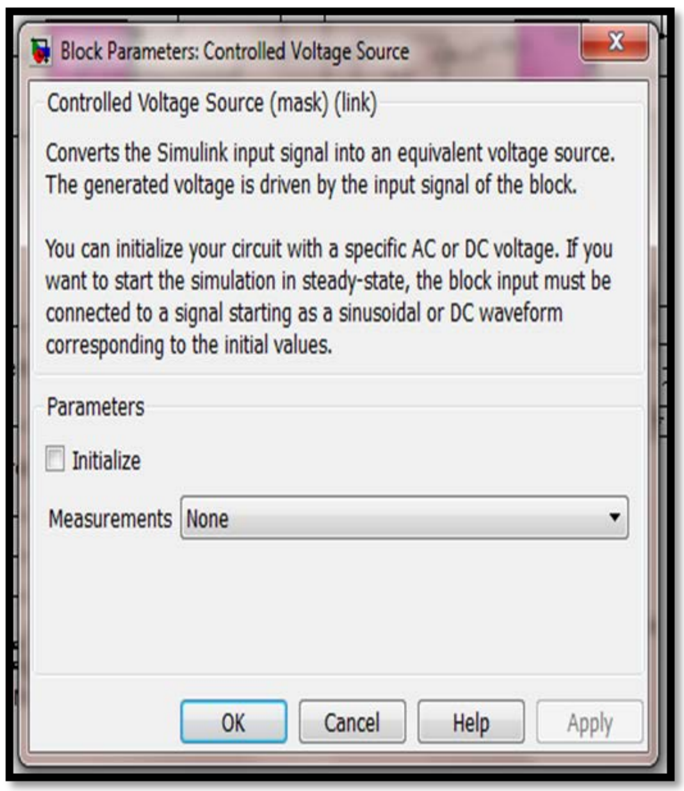
Appendix

Important Blocks For Instant Power Back-Up:

The Controlled Voltage Source block converts the Simulink input signal into an equivalent voltage source. The generated voltage is driven by the input signal of the block.

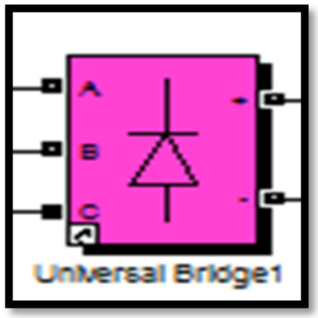
You can initialize the Controlled Voltage Source block with a specific AC or DC voltage. If you want to start the simulation in steady state, the Simulink input must be connected to a signal starting as a sinusoidal or DC waveform corresponding to the initial values.

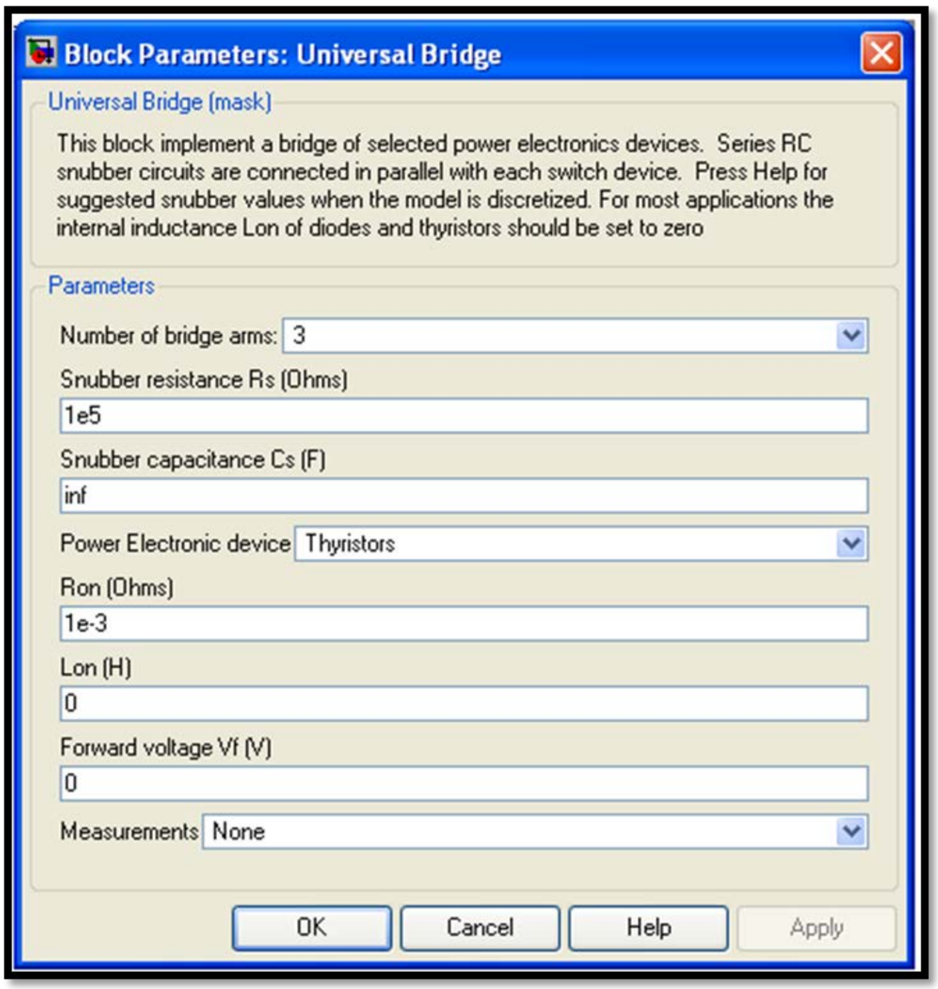




Universal Bridge

The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box.

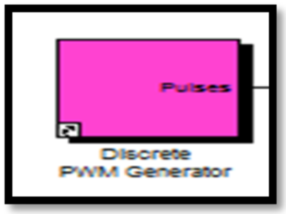


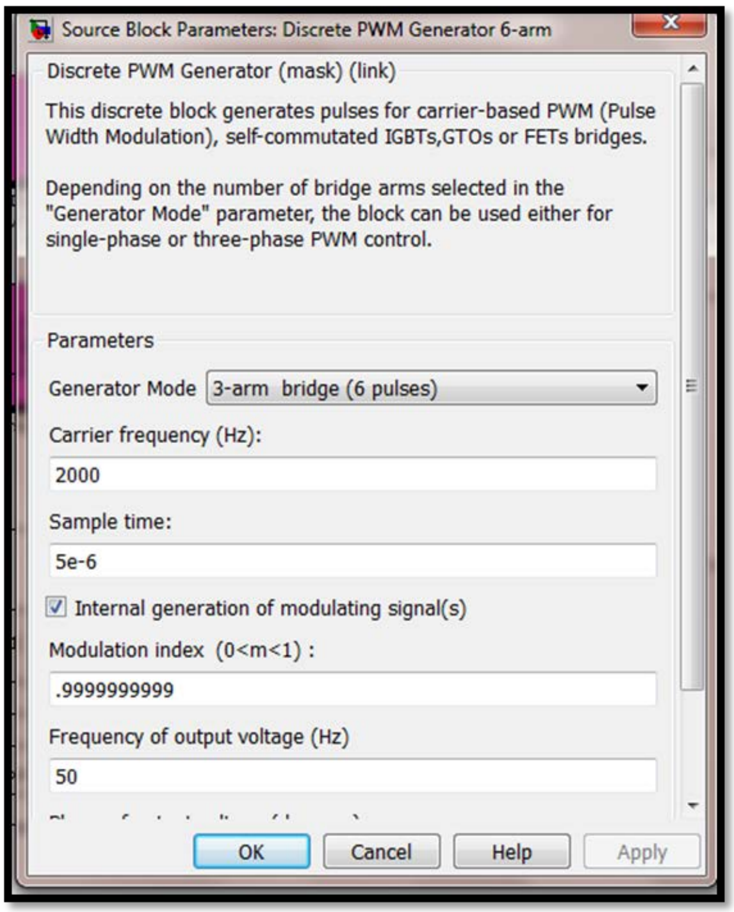


Discrete PWM Generator

- 3-arm bridge: Six pulses. Pulses 1,3 and 5 are respectively for the upper switches of the first, second and third arm.
- Pulses 2,4 and 6 are for the lower switches.

For double 3-arm bridges: Twelve pulses. The first six pulses (pulses 1 to 6) must be sent to the first 3-arm bridge and the last six (pulses 7 to 12) to the second 3-arm bridge.



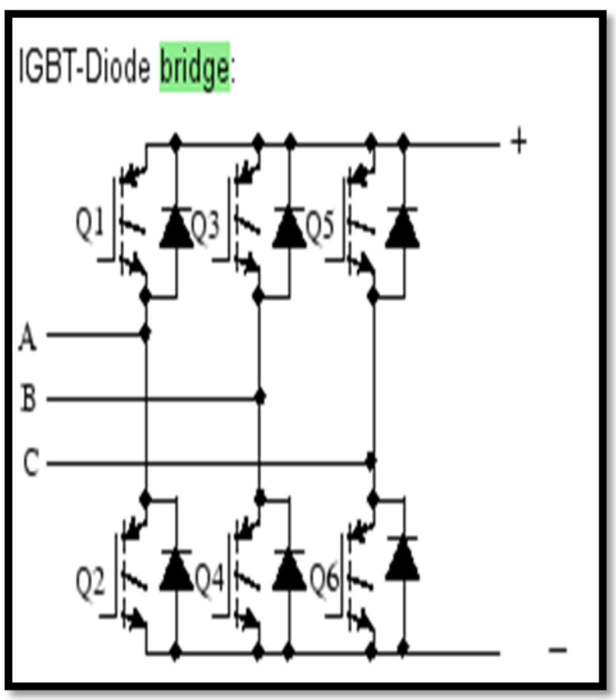


Determining the Carrier Frequency[15]

- The PWM switching frequency has to be much higher than what would affect the load (the device that uses the power), which is to say that the resultant waveform perceived by the load must be as smooth as possible.
- Typically switching has to be done several times a minute in an electric stove, 120 Hz in a lamp dimmer, from few kilohertz (kHz) to tens of kHz for a motor drive and well into the tens or hundreds of kHz in audio amplifiers and computer power supplies.
- The main advantage of PWM is that power loss in the switching devices is very low. When a switch is off there is practically no current, and when it is on and power is being transferred to the load, there is almost no voltage drop across the switch. Power loss, being the product of voltage and current, is thus in both cases close to zero. PWM also works well with digital controls, which, because of their on/off nature, can easily set the needed duty cycle.

Universal Bridge:

- The Universal Bridge block implements a universal three-phase power converter that consists of up to six power switches as shown below connected in a bridge configuration. The type of power switch and converter configuration are selectable from the dialog box.



- The Universal Bridge block allows simulation of converters using both naturally commutated (or line-commutated) power electronic devices (diodes or thyristors) and forced-commutated devices (GTO, IGBT, MOSFET).
- The Universal Bridge block is the basic block for building two-level voltage-sourced converters (VSC).
- The device numbering is different if the power electronic devices are naturally commutated or forced-commutated. For a naturally commutated three-phase converter (diode and thyristor), numbering follows the natural order of commutation: