Graduate School of Fundamental Science and Engineering

Computer and Communication Engineering

Waseda University

Master's Thesis

TITLE
The study of ICN based routing scheme for Power System Communication in Smart Grid

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2017 January,30

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1 Acknowledgement

I am pleasure to express my great thanks to my academic supervisor Prof. Takuro Sato for his kindly support since I joined Waseda University as a Research Student and a graduate student in his laboratory at the University sup as well as a regular master's student for the three years in Japan.

Also I would like to extend my thanks to all other Professor who have been cooperating with us throughout our studies. We appreciated their efforts to help us becoming more theoretically and practically academically oriented student for the future success of the world. Secondly I would like to extend my special appreciation and thanks to Prof. My thank giving are extended to Professor Nakazato for his great efforts to organize the ICN seminar for the students.

In addition I would like to thank my sponsors JICA-Japan for their great support to offer the scholarship opportunities for our country and other African Nations under the ABE Initiatives for African Business. We promise that we will utilize the skill and knowledge we gained from Japan for the development of our countries and Japan.

Lastly I would like to give my special thanks to my lab mates for their kindly support and love to fulfil the success of this research.

Finally I would like to thank my wife and children for her close support and courage during the preparations of this research.

2 Abstract

Information processing and controlling in the power system is a major concern of the Power supply Utilities during the generation and transmission of electrical power to the consumers. This is not only the matter of only providing communication to the human operators running the system but also the information has to be processed and controlled from the equipment's connected to power system. In order to maintain a reliable communication as well as data processing in power system, more efficient and well organized communication protocols are required. Poor communication or routing of data in power system networks is greatly caused by the protocols used as well as limited bandwidth due to traffic on communication networks.

Most of the substation today have been modernized and are governed by the IEC 61850 as a standard protocol for the substation automations and Smart Grid. IEC 61850 consists of ten parts with various functions to perform various tasks such as processing signal from the intelligent electronic devices (IED). These equipment's have to be controlled in such a way that there will a be proper flow of electrical power to the demand side as well as providing safety measure to the power equipment's installed in the power stations. The power stations are technically known as Substations and are responsible in monitoring and controlling the power flow before it reaches the consumers. Substations are always equipped with protective gears, monitoring equipment's such as supervisor computer systems to process the data from the consumers and other equipment's located in the remote areas. It accomplish this under the control of the Substation Automation Control Communication Protocols.

IEC61850 and DNP3 are the frequently used protocols to provide substation automation. The two protocols are based on the TCP/IP and UDP. The purpose of IEC 61850 was to sustain information exchange and automation between the devices in a substation. Due to the expansion of the power system network more devices were connected to the power system, and this forced the IEC 61850 to interface with other protocols so as to combine all the functions for the substation automation as well as data processing from sensors and smart meters. This indicates that in the future the IEC61850 will have to be standardized and becoming a global communication protocol for the power grid communication as other communication protocols. Currently the IEC 61850 is operating on TCP/IP and Ethernet link layer two (2). This method has been reported to be inefficient for some of the substation automation functions such as protection functions. The main aim of this research is to apply the ICN skills to test the performance of IEC61850 functionalities on place of its TCP/IP layer as well as proposing a routing scheme based on publish/subscribe and NDN to perform message forwarding in the power system communication networks. This approach will require the system to operate under the two schemes of message forwarding for publish/subscribe and NDN (named data networking)

The system will work in such a way that when the fault occurs within the substation the protective devices located in that location will respond to the fault signal. In this case, the named message will be published to the network where other devices located in the same zone will subscribe to respond to the request, failure to respond within the specified time the request will be sent to the other active devices located within the power system network to act in accordance. This is one of the requirement of ICN that the important information should be shared at the network by the other devices. This is a special consideration for machine to machine communication. Since the power system is becoming a complex system, more protection functions will be needed, which means more Intelligence devices will have to be installed in the power system. This will bring more costs due to the fact that the new technologies

will implement more automated devices based on internet of things to operate on the internet.

In this research we have also proposed the power system routing architecture equipped with various control functions which will be shared by the other devices located on the network. This will help to minimize the number of IEDs and the cost to implement more protective equipment's in power system communication. To evaluate the performance of the proposed architecture, two scenario for ICN and TCP/IP were simulated. The results were compared. The ICN communication protocol was observed to be suitable for the power system communication.

3 Contents

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5 List of Symbols

- IED-Intelligent Electronic Device
- IEC-International Electro technical Commission
- ICN-Information Centric Network
- TCP-Transport Control Protocol
- EMS-Energy Management Systems
- SAS-Substation Automation System
- QoS-Quality of Service
- IEEE- Institute of Electrical and Electronics Engineers
- GOOSE- Generic Object Oriented Substation Events
- G- Generator
- B-Breaker
- T-Transformer
- S- Ethernet switch
- HMI-Human machine interface
- WAN-Wide Area Network
- IP- Internet Protocol

Problem Statement

The control and protection functions for the current power system communication protocol IEC 61850 are currently operating at the Ethernet Link layer to provide protection for the substation devices. This has been contributing to inappropriate operation of the substation protection systems when faults occur within the power system.

Main Objectives

The main objective of this research is to improve the performance of the power protection system as well as proposing the ICN based routing architecture to be implemented in Smart Grid systems.

Specific Objectives

- Study the Existing power system communication protocol architecture to identify the gapes to be developed.
- Propose the ICN based power system communication protocol architecture
- Simulate and test the performance of the current communication protocol IEC 61850 for both TCP/IP and ICN as new approach to solve the problem

6 Introduction

Information processing and controlling in the power system is a major concern of the Power supply Utilities during the generation and transmission of electrical power to the consumers. This is not only the matter of only providing communication to the human operators running the system but also the information has to be processed and controlled from the equipment's connected to power system. In order to maintain a reliable communication as well as data processing in power system, a more efficient and well organized communication protocol is required. Poor communication or routing of data in power system networks is greatly caused the protocol used as limited bandwidth due to traffic on communication networks.

Most of the substation today have been modernized and are governed by the IEC 61850 as a standard protocol for the substation automation. IEC 61850 consists of ten parts with various functions to perform the tasks such as processing signal from the intelligent electronic devices (IED) [1]. These equipment's have to be controlled in such a way that there will a be proper flow of electrical to the demand side as well as providing safety measure to the power equipment's installed in the power stations. These power stations are technically known as Substations which are responsible in monitoring and control of power flow before it reaches the consumers.

Substations are always equipped with protective gears, monitoring equipment's such as supervisor computer systems to process the data from the consumers and other equipment's located in the remote areas. It accomplish this under the control of the Substation Automation Communication Protocols. IEC61850 and DNP3 are the frequently used protocols to provide substation automation. The two protocols are based on the TCP/IP and UDP. The purpose of IEC 61850 was to sustain information exchange and automation between the devices in a substation. Due to the expansion of the power system network more devices were connected to the power system, and this forced the IEC 61850 to be used other protocols that it combine all the functions for the substation automation as well as data processing from sensors and smart meters. This indicates that in the future the IEC61850 will have to be standardized and becoming a global communication protocol for the power grid communication as other communication protocols. Although IEC 61850 is still an efficient protocol in power system communication, it has to be reviewed for some more developments especially in it communication layers. Recently it has been based on its dependency on TCP/IP communication protocol some of its functions have to develop to run on the new existing protocol such as ICN. The protocols are installed in Substations Servers and IED devices so as to communicate with the field devices such as sensors located in other substations to collect information such as breaker failure, billing information. It is not only doing so but also it provides coordination's among the equipment's running under different protocols.

The IEC 61850 provides coordination of the equipment's located in the same substation or other substations. The communication among devices in the substation is based on IP addressing. The devices communicate in a Public /Subscribe manner through the data link layer which would affect the communication process when there is much traffic along the communication path. The power system is becoming a complex network which means more traffic will be generated along the communication path as the protocol have to attend various request sent to it, which means any fault signal to be occurred in this period will not be attended. This will in turn result into more disasters to the substation equipment's such as transformer burning, breakers failure as well as other equipment's connected to the faulted area.

More devices with different characteristics will be connected to the power system which means an efficient protocol will be needed not only to provide communication to the substation equipment's but also other equipment's running outside the substation. IEC 61850 will soon be replaced by the so called Information Centric Networking (ICN).

The main aim of this research is to apply the ICN skills to test the performance of IEC61850 functionalities on place of its TCP/IP layer as well as proposing a routing scheme based on publish/subscribe and NDN to perform message forwarding in the power system communication networks. This approach will require the system to operate under the two schemes of message forwarding for publish/subscribe and NDN (named data networking)

The system will work in such a way that when the fault occurs within the substation and protective devices located in that location are in operative the named message will be published at to the network where other devices located in the same zone will subscribe to respond to the request, failure to do so within the specified time the request will be sent to the other active devices located within the network. This fulfil the requirement of ICN that the main target is to find the valid data/popular content. Since the power system is becoming a complex system, more protection functions will be needed, which means more Intelligence devices will be needed to be installed in power system. This will bring more costs as we are about to implement new technologies based on internet of things more devices will be automated to operate in the internet. In this research we have proposed the power system routing architecture equipped with various control functions which will be shared by the other devices located on the network. This will help to minimize the number of IEDs and the cost to implement more protective equipment's in power systems. This Research will be organized as follows. In section 7 we give out the review of various literatures related to this research. The other related works are given in section 9. In section 20 we will introduce our ICN based routing scheme architecture to be implemented in power system communication. In section 5 we will introduce the methods used to analyze and simulate the performance of IEC 61850 protocol based on TCP/IP and ICN communication protocols so as to test the performance of its protection control functions. Our results discussion will be shown on section 6 and conclude our work in section 24.

7 Literature Review

7.1 Power System Communication Networks

Generation, transmission and Distribution system is a complex network system comprises of various types of loads with different characteristics. In designing and planning of the power transmission and distribution lines some special economic and technical considerations should be observed by collecting the reliable data during the feasibility study as well as during the designing stage in which various power system parameters are to be identified and analyzed so as to come out with a reliable, efficient and economical power system which will be beneficial to both the supply utilities and consumers of electrical energy. The power system consists of power system equipment's such as Generators, Transformers, Reactors, Capacitors ,protection equipment's, Transmission and distribution lines in which the parameters such as inductive reactance, conductor resistance and temperature are to be properly controlled to optimize the economy and power quality for the power supply utilities and consumers connected to that power system.

In some developed countries the power systems consists of larger consumers of electrical power such as Heavy Industries and small industries with inductive loads such as electric motors and fluorescent lamps which lacks suitable monitoring devices to maintain the power at reasonable quality and improved economy by controlling the running cost as well as controlling the abnormal power consumption to the consumers having the loads having the characteristics affecting the Power System Performance. It has been observed that some of the connected loads have been contributing in increasing the running costs of the power utilities, raising electrical bills to the consumers as well as affecting voltage stability to the power consumers and voltage regulation for the Generating Units and Transformers. For such conditions the power supply utilities should control the apparent power as caused by the active (resistive loads) and reactive loads (inductive loads) connected to the power system distribution networks.

As the some of the existing power system networks lacks the suitable intelligent control systems to control and identify the loads operating above the power system limits such as voltage output, voltage drop as caused by transmission parameters such as conductor's resistance due to length of the conductors, inductive reactance which contributes to the lower power factor to the power system. The lower the power factor the higher the current to be drawn from the Generators which means the power generation utilities should increase the transmission capacity by installing more power plants, Improving the cooling systems due to higher heat dissipation as caused by higher due to poor power factor loads. By identifying and controlling these parameters, the power system control station should have a liable and intelligent systems where the control constraints can be set to identify the characteristics of various loads to the consumers. To accomplish these requirements, this reports gives the concepts which can be used as an initial approach to optimize the economic and power system quality by introducing the concepts in which AMPL as an optimization program can be used to identify the number and types of loads connected to the power system as well as setting out the limits in which the power generating units should supply power at reasonable cost to the consumers at lower operating and running costs to increase the profit to the utility companies as well as improving the life standard to the consumers.

8 Smart Grid Systems

8.1 Smart Grid

Power transmission and distribution is among main components where efficiency is one of the important factors to be considered so as to bring the societies and other economic sectors sufficient energy for their daily needs. Recently there have been a rapidly growing of energy demands due to the increased energy marked from industrial and domestic consumers of electricity. The need to improve the power system has also been influenced by various loads connected to the power system as well as the complex infrastructures of Transmission, distribution system and distributed loads. As the power system is currently operating close to its limits, great efforts are being done so as to minimize the use of unclean power plants such as coal, diesel and nuclear power plants so as to meet the requirements for the sustainable and clean energy.

However minimization of some of the unclean power plants is not the only solution, more steps are to be taken so as to plan and design the new power system architecture, reliable communication systems supported with an intelligent communication protocols which will monitor and control the power flow as well as the behaviors of the power consumption consumers connected to the power grid. This existing problems have been recently started improved especially in some developed countries through the use of Smart Grid Systems. This was proposed to replace the existing power communication systems so as suite the requirement for both consumers and the power utilities. The Smart Grid provides a two way communication between the power Utilities and the Consumer connected to the power System as well as allowing distributed loads such various type's power plants, electrical vehicles to be controlled and monitored from a centralized station. As the system will involve more traffic in power system networks, the Smart Grid is to be supported with efficient and reliable communication protocols which will coordinate the interconnection among different vendors connected to the Smart Grid. A common standardized and efficient protocol is needed to control the bidirectional power flow between the consumers and power utilities.

As we approaching the 5the fifth generation where the new where new technologies will exit due to the inversion of Internet of things where various power consumption equipment's will be automated and digitized so as to transmit data as well as retrieving data from the utilities more traffic is estimated to flow in power system communication networks. For this case special knowledge is needed to process these data for evaluation concerning the usage and the quality of the power supplied. The existing Smart Grid System have been governed by some proposed communication protocols although some of these protocols are not updated to meet the requirement of the existing changes due to traffic load in communication networks. Some of these protocols such as IEC61850 and NDP3 were designed to provide Substation Automation as well as performing Meter data collection. Some of these protocols were developed to meet the need of the Smart Grid, although its function were bound for the specific application in power systems. IEC and NDP3 were designed purposely for the substation automation control.

The Protocols are based on TCP/IP communication protocol which is about to be replaced by the new existing technologies such as Information Centric Networking which has recently proved to be efficient in data processing as well as having some promising capabilities to improve the performance of the existing internet architecture. The ICN allows the data to be processed by names regardless its location. The data is stored in caching within the network for the future use whenever it will be needed in the other location, as compared to TCP/IP communication protocol which needs to pass through various stages in data searching from the main data server. Due to the recently increase in traffic in the existing Smart Grid Systems, the current communication protocols based on TCP/IP will become inefficient for data processing. A number of research papers have been published proposing the implementation ICN in power grid communications, where some have reported the future weaknesses the existing communication protocols.

Some Smart Grid architectures have been proposed to fulfil the existing requirements by considering various factors which were not initially considered during the design processes. The Smart grid will help to provide power in real time in a reliable manner so as to bring benefits for both customers as well the suppliers in a profitable way. A well designed and selected communication system will efficiently minimize the problems disturbances caused by the power outage in real time. This is a promising great improvements having a reliable power system which can control a large number of components regardless of the type of technology used in them. The implementation of Smart Grid have accelerated the use of sensor network to transmit a large number of data from the automated equipment's to the control center so as to reduce the number of cabling work as it was used before. Having Fig 1. Shows the architecture of the Smart Grid System. The advancements of censor networks have attracted the utilities and other vendors in power system to embed some of the control functions in some equipment's which provides an interface to access wireless communication signals from the control center. Through that invention it is now possible to manage the power consumption through the energy management systems EMS for the domestic and Industrial consumers. Some of these functions will be embedded in Home control equipment's such as lamp, switches, air-conditioning systems, refrigerators, music instruments, health management equipment's, industrial equipment's such as electric motors, power sources such as generators, solar panels, wind turbines, temperature sensing equipment's as well as weather monitoring equipment's. This is a justification that in the future the power system will be a more complex power and communication system which needs more improvements to meet the future needs.

A Smart Grid System consists of a Control Center (Server) where the Smart Grid Communication control functions (Protocols) are installed. The Server communicates will all the devices referenced to it. The sensors collects data from their sites (Industrial sites, Solar Power, Wind and Consumer and transmit the data to the control center for more processing and control. These data could comprise of billing information, temperature level, the quantity of electricity generated from power plants as shown in fig

Introduction to IEC 61850 Communication Architecture

The IEC 61850 is a substation standard protocol for substation which integrates various automation functions such as control, measurement and protection as well as perfuming monitoring of other functions for other protocols which communicate with it. IEC 61850 comprises of various applications which are very useful in substations to provide high speed communication between the protective devices such as IEDs located within the substation or to the remote substation.

The success of any Power System or Smart Grid Systems depends on the quality of the communication system employed on these systems. Most of the activities within the power system are controlled and managed at the Substation. Therefore in order for the Substation Automation Systems (SAS) to work properly in the organized way, a well-organized power system communication protocol is required to overcome the existing challenges due to the emerging new technologies. The major activities provided by the IEC 61850 monitoring the substation automation activities such as protection of substation equipment's such as Transformers, Generators, Transmission and Distribution Lines, Data processing from the Smart Meters and Sensor data.

The protocol provides greater interoperability since it allows other vendors to refer their equipment's design in order to be communicated to the power system .Although IEC 61850 has solved some of the major problems concerning communication in power system , there are some problems relating to communication topologies which has also being addressed by

8.2 IEC 61850 Communication Architecture

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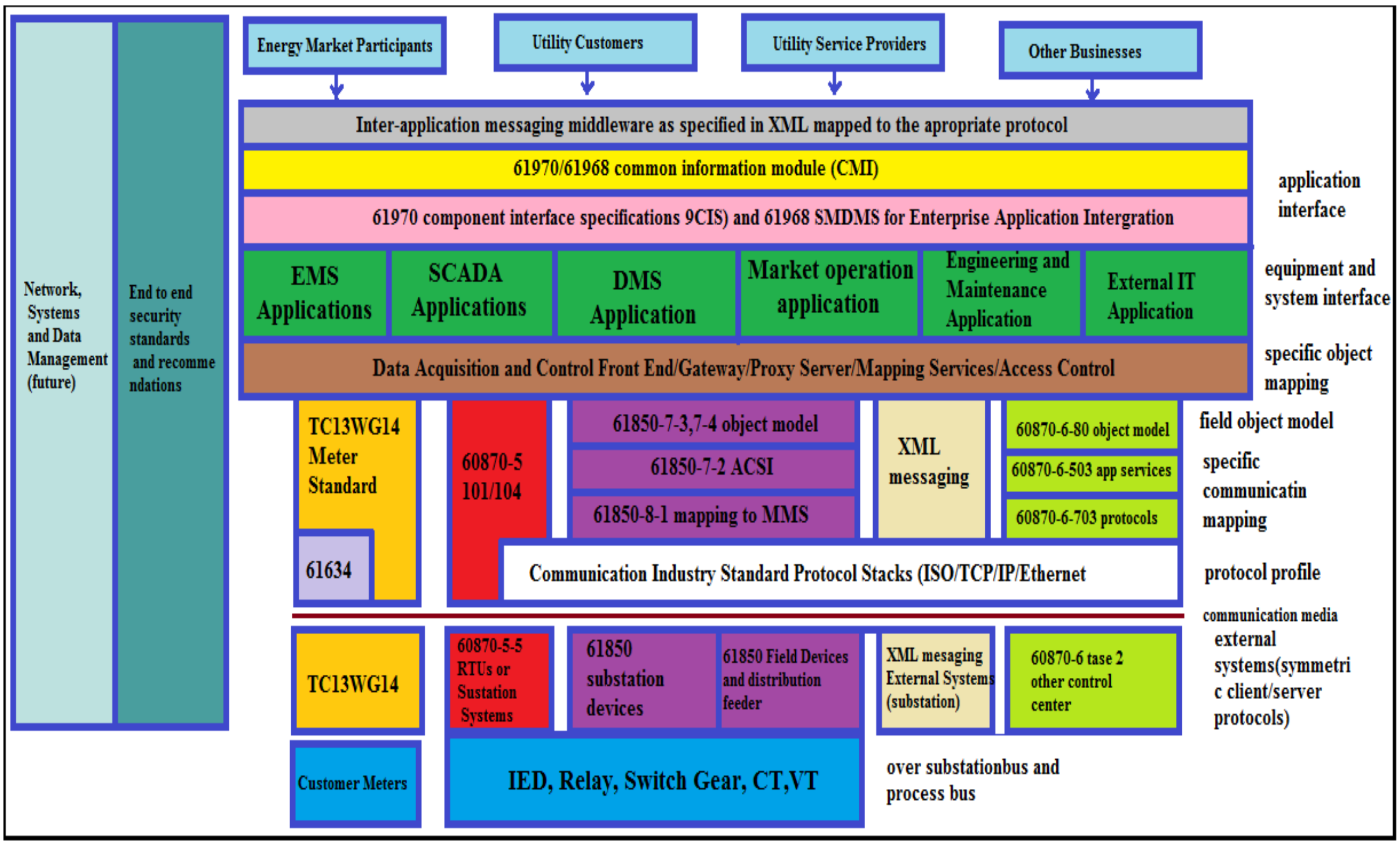

Figure 1. IEC 61850 Protocol communication Architecture

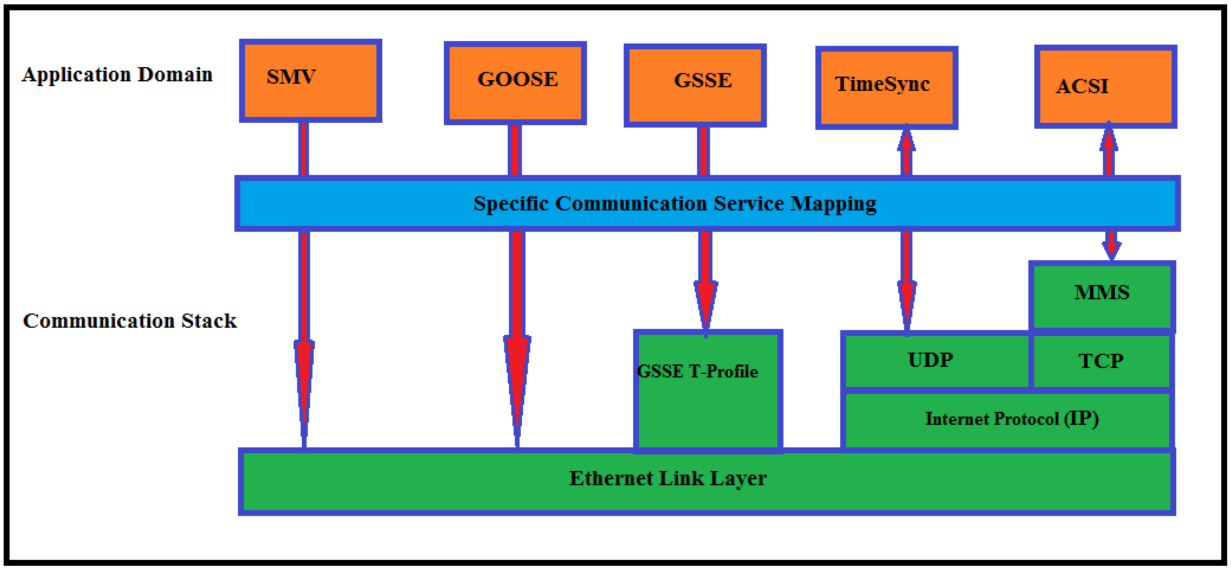

Figure2. IEC 61850 Communication Architecture

The IEC 61850 comprises of five communication profiles namely as:

Architecture description

- ACSI (Abstract Communication Service Interface): This provides communication access between the clients and servers
- GOOSE (Generic Object Oriented Substation Event): Provides the high speed data transmission and exchange between the protection devices on the bus.
- SMV (Sampled Measured Value-Multicast profile:
- GSSE (Generic Substation Status Event): Provides a rapid status exchange at different substation levels
- Time Synchronization(SNTP):

8.3 Naming in IEC 61850

THE component names are hierarchically named in IEC 61850. The names follow the hierarchical order from the physical component where the primary data and secondary data are to be identified. The hierarchical arrangement of the names in IEC 61850 gives the access to control the devices through the URLs. The figure () shows how hierarchical arrangement of names in IEC 61850.

Naming in IEC 61850 always starts with a physical device, which is usually connected to the network and it is identified by its network address. A single physical device can sometimes work as a gateway or proxy so that other devices can be aggregated to it as in data concentrator. The logical device can also contain other logical nodes that contain the data representing the power system functions. Within the logical nodes, more data elements can be specified, such as the type and functions of the data for the particular task can be accessed in the logical nodes. There are various logical nodes within the power system especially in substation. For example a circuit breaker in power system can be represented as XCBR[], within the circuit breaker XCBR various data and functions of the breaker can be retrieved as data such as Pos for position whether it is ON or OFF, some functions such as Blkopn [] means breaker open command.

9 Other related works on the same area.

9.1 GOOSE messaging in IEC 61850

In order to get high performance the GOOSE message is usually transmitted to the Ethernet data frame. For the delivery of the GOOSE messages the IP address is not employed, instead a multicast address is used and it has to be delivered to all the devices connected to the Local Area Network. One feature of the Multicast address is that the messages are to be delivered to all devices although the message was intended to be delivered to the few devices. For this case using a Multicast address to deliver messages to devices would cause more traffic especially when all devices will be transmitting at the same time.

To minimize the traffic, the concept of Virtual LAN (VLAN) has been proposed to solve the existing traffic problem in Ethernet. It was also observed that the use of TCP/IP cannot be suitable method to rout the GOOSE message between the IDEs communicating on the station bus since TCP/IP contributes to the loss of data packet as it is in the process of being transmitted to it destination. Despite the fact that TCP/IP helps to maintain packet loss by providing a packet loss retransmission mechanism, but it was observed to be very slow about 100ms to provide a real time communication among the substation devices.

To meet the reliability criteria, the GOOSE protocol automatically repeats the message several times without being asked. As such, if the first GOOSE message gets lost (corrupted), there is a very high probability that the next message or the next or the next will be properly received. The transmission of GOOSE message is accomplished by monitoring the change of state such as a status of a circuit breaker. To realize the continuation of the link operation, each time a **Keep-alive** message is transmitted among the devices so as to identify if there is a link failure. The GOOSE message header contains the following information:

- Control functions (user stings) and the name of the GOOSE. The number of times the GOOSE message changed •

- The frequency of the GOOSE message
- The change in configuration frequency of the GOOSE.
- A Test flag
- The size of the GOOSE message including other data elements in a GOOSE Message. This makes up 330 (2400BITS). This would take 24 microseconds to reach the destination when it is modulated on the 100Mb Ethernet LAN.

9.2 Virtual Area Networks-VLAN and Quality of Service (QoS)

VLAN is among the method proposed to reduce traffic for the IDEs communication. VLAN can create multiple Ethernet switches by performing network segmentation. The VLAN comprises the group of pots selected to perform such a specific task and is originated from the same broadcast domain as designated by the Ethernet switch so as to form a multiple LAN from the same Ethernet switch. VLAN provides security as well as separation of traffic in GOOSE communication.

Another technique which was used to ensure the minimum traffic was to implement the Ethernet switches that provides quality of service (QoS) as stated in IEEE 802.1Q Standard which allows the prioritization of messages especially if there is more traffic along the transmission media. This is important so that the critical data can be transmitted first. Therefore the Ethernet net switches to be used should be able to differentiate different types of traffic by allowing the prioritized first so as to improve the overall performance for message delivery.

9.3 Network Topologies

Various network topologies were discussed, since these are the backbones for efficient success of the GOOSE messages. It was reported that the star topology is not suitable for the GOOSE communication since it provides a single point of failure and a loss of communication. Full and partial mesh topology were also proposed but it was recommended to identify the points of failure before the loss of communication occurs as well as adding more expenses by implementing more cabling work and was observed to be the most cost effective solution. The Rapid Spanning Tree Protocol was observed to be the most promising solution to minimize failure on GOOSE communication due to its designed mechanism as well as it algorithm which was implemented to detect the broken path in an Ethernet network so that it can automatically reconfigure to the current network topology. This provides loop free for the ring topology as detecting the component failure. It accomplish this by sending messages to the nodes within the network to find the broken parts so as to perform network reconfiguration.

Figure 3 shows a Station Bus-Ring Topology to give an efficient routing of data from the sensors. The station bus consist of three sections named as Bay 1, Bay 2 and Bay 3. Bay 1- Bay3 connect the external devices to be controlled through the feeders. The IEDs are provided in each bay. They collect and process the data from the sensors such as current transformers, voltage transformers, metering units and other connect devices as per the specific requirements. The bus-ring topology helps to minimize the problem of single point failure. Any of the IDEs in Bay 1 to Bay 3 can send a GOOSE message to other IDEs through multicasting addressing. This is done in a publish/subscribe fashion.

During the abnormal conditions in of the the three Bays, the IDE should send the GOOSE message to the other IDEs in case it fails to clear the fault occurred in its Bay. Each IED located in each Bay can control a number of devices within the substation such as Circuit Breakers, Auto-reclosing Circuit Breaker especially for Power Transmission control, Transformers and other substation equipment's. Normally the Substations can control several power transmission and distribution ZONES. The IDEs are responsible in monitoring the proper operation of the power system equipment's and Transmission/Distribution lines feeding the customers. Any fault to be occurred within a particular zone, the IDEs should detect the fault and clear the fault within a set time before the situations becomes more critical and damage the power system equipment's as well bringing loss to the customers connected to the power system. In case it happens the IEDs failed to clear the fault due the Breaker failure, the IED should send the GOOSE message to the other IDEs located within the same fault area so that they can isolate the other health parts of the power system which could have been affected by the faulty. The figure shows how various zones can be protected by the IEDs and how the IDEs communicate during the abnormal conditions such as faults such as overvoltage, overcurrent, under voltage, Generator synchronization failure, load shedding and any other situations that require serious monitoring to avoid loss of property.

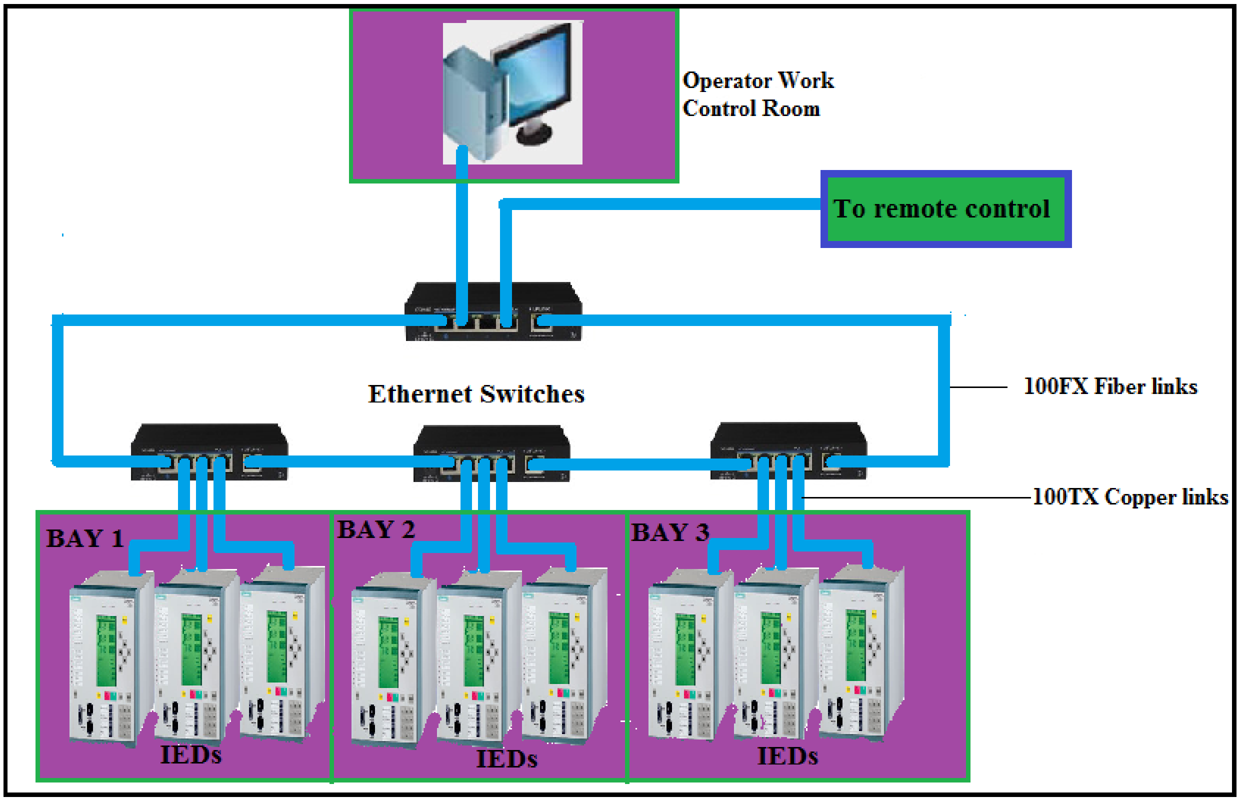

Fig. 3 The IEC 61850 Station Bus-Ring Topology

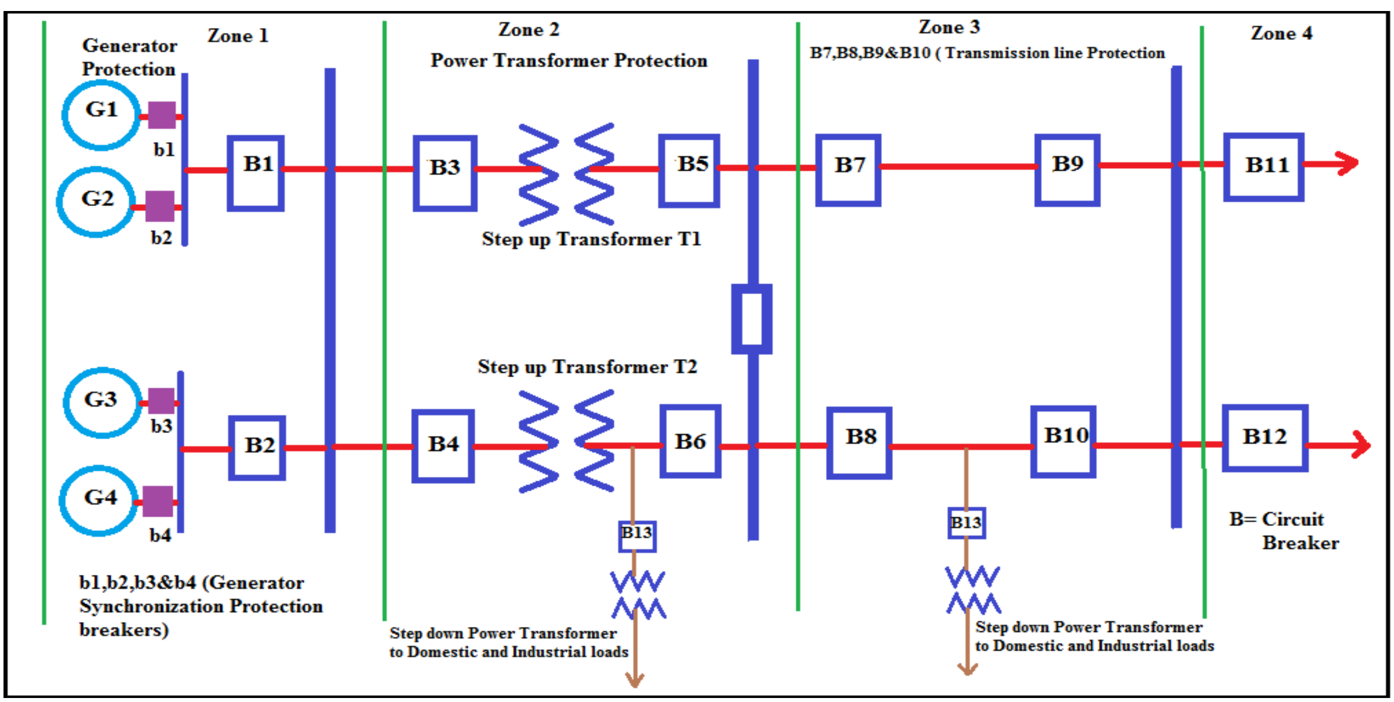

Figure4 Substation Architecture.

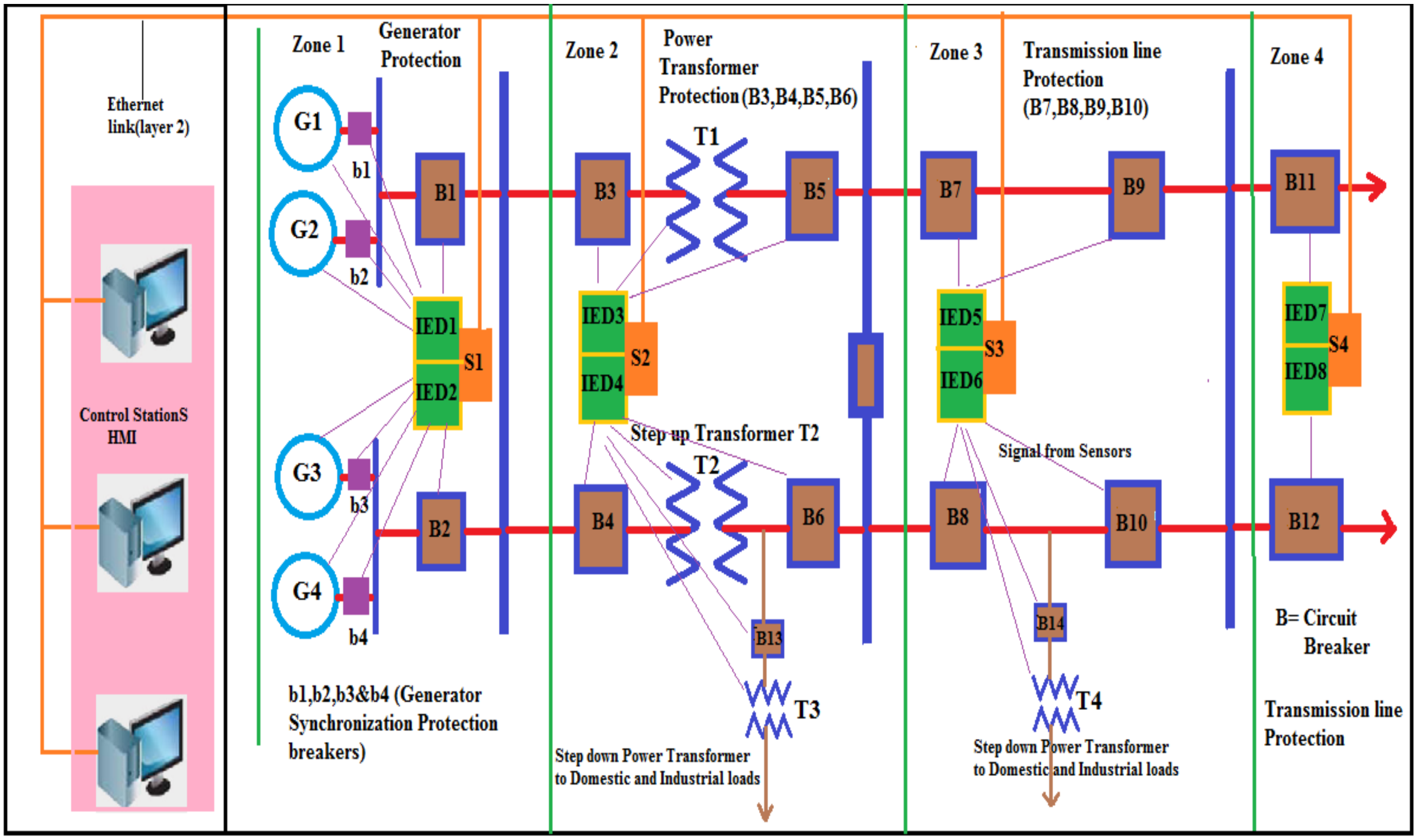

Figure5. IDEs GOOSE communication in Substation

From the figure above[http://circuitglobe.com/protection-zone-in-power-system.html]

- G1-G4: Generators
- BI-B12: Circuit Breakers for Generator Protection
- B7,B8,B9&b10: Breakers for Transmission Line Protection
- B3,B4,B5&B6: Circuit Breakers for power Transformer and Bus- bar Protection
- TI&T2: Power Step up Transformers
- T3&T4:Step down Power Transformers: Supply power to the Customers
- HM1: Human Machine Interface: Collects, Processing and control all the facilities connected to the power system
- SI-S4: High Speed Ethernet Switches
- b1-b4: Generator Synchronization Control Breakers
- IED1-IED8: Intelligent Electronic Devices- Collects and processing the data from the Breakers, Generators, Transformers and Transmission Lines for controlling purposes.

9.4 Substation Circuit Description:

The figure above represents a simplified model for the Power Communication Networks as used in Substations. The model represents various facilities to be monitored within the substation as well as outside the substations. Some of the facilities such as breakers, power transformers, IEDs and measuring instruments are located within the substation where other devices such as breakers and sensors are located to the remote areas and these are responsible in protecting the transmission lines, distribution power transformers feeding power to the consumers. The diagram above describe briefly how the various information are collected form the power system facilities located in transmission/distribution lines as well as power transformer and generators. The IEC 61850 as a communication protocol to facilitate the communication among the power system devices and the control station so as to gather various important information such as faults report, operating conditions for the power system devices such as transformers, generators, transmission lines and metering data from the customers.

For the power supply Utilities to operate profitably and economically, more efforts should be directed to utilization of the available resources used in power production so as to operate efficiently to provide a reliable services to the customers. In such a case more information such as power generated by various power plants, transmission line losses, operating condition of the power system devices are the important tools in the design of an efficient, reliable and economic power system with a two way communication. A well-organized power system will depend much on the planned feasibility study during the design process as well as the quality of the communication protocol used.

Most of the power system communication networks today are supported by the IEC 61850 protocol which is now currently employed in Smart Grid Systems which will integrate a number of devices to be connected to the Power Grid. Therefore more information are to be collected form these new devices, this means the more the power system is expanded the more the quality of the communication protocol is to be improved. For such a case most of the substations will involve a number of devices to be controlled and protected. That means more Intelligent Electronic Devices (IEDs) will be needed, and more cabling work will be needed in the substation. This will make a substation to be a very complex system involving a number of devices.

Most of the IEDs in the substation are communicated through the Ethernet link layer through GOOSE messaging using a multicast addressing which almost involves traffic along the communication media especially when all the devices will communicate at the same time. GOOSE messaging is always employed by the IDEs to communicate in case when either one of the IEDs fail to clear the fault originated from the transmission lines or any of the power system equipment which needs sensitive caring. There are various parameter to be monitored at the substation. But here we shall concentrate on the power system protection and generators synchronization.

10 Application of ICT in Power System Protection

ICT (Information and Communication Technology)

The diagram above represent a simplified power substations comprised of various power system facilities such as Power Transformers (T), Transmission line (L) and Circuit Breakers (B), Ethernet switches (S) and Intelligent Electronic Devices IEDs. The substation receives power from the Generators G1, G2, G3 and G4. The generated is transmitted through the transmission lines (L) via the breakers (B) to the consumers. The breakers are located at various section so as to provide protection at the particular sensitive section. To simplify the control as well as maintenance work the power system to be controlled from the substation is divided into zones named as Zone 1 consists of breakers B1, B2, b1, b2, b3and b4, Generator G1 to G4. All the devices in this zone are controlled by IED1. Any abnormal situation which will occurs within this zone will be detected by the IDEs unless otherwise the control is routed to the IED for more control in case when IED1 fails to clear the fault. Zone 2 consists of Breakers B3-B6, Power Transformers TI, T2 and T3, Breaker 13, IED3-IED4 and switch S2 where IDE2 and IED 3 are responsible in controlling the devices in this section, S2 control and gather the data from the IEDs located located in this Zone to be transmitted to the control station, it is also act as a media for data transmission during the IEDs communication for GOOSE messaging. The breakers B3-B6 and B13 protect the power transformers TI, T2 and T3 from excessive currents due to overload or short circuit currents. T1 and T2 step up voltage to a suitable level for transmission where T13 step down the voltage to a suitable level ready for distribution to the customers. Zone 3 consist of Breakers B7-B10 and B14 for transmission line protection and distribution transformer T4 respectively. The data from these devices are collected with the IED5 and IED6 via the Ethernet switch S3 to the control station for monitoring. The last zone consists of Breakers b11 and B12 controlled by IED7 and IED 8 via Ethernet switch to the Control station.

10.1 Application of ICT in power system in data collection, controlling and monitoring

For the power system to operate in a well-organized manner, the use of ICT is of great importance in the power system. IEC61850 communication protocol provides various functions such as substation automations. Performing automation activities such as fault detection within the power system, Generator control, Demand and Response control. In this Research we shall concentrate of few areas where ICT can be very useful, which is power system protection. This is important since the existing protection system are not capable of monitoring of various invisible parameters within the power system**.**

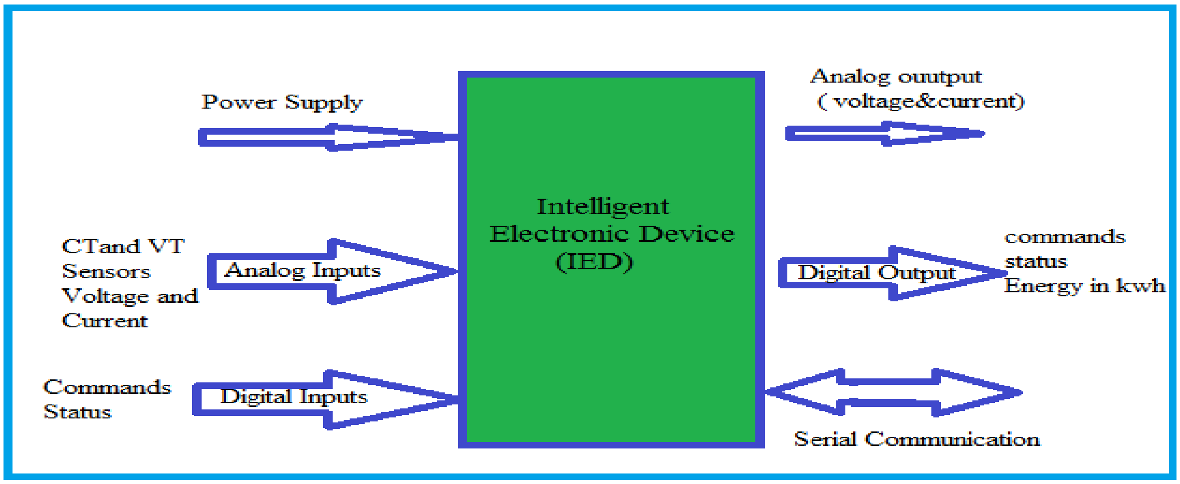

Fig6. Intelligent Electronic Devices, process the input signals from the substation devices to give out a control signal.

11 How IDEs protect the power system against abnormal conditions.

Figure 6 shows how IED accept and process the various data signal from the substation devices such as Current Transformers (CT), Voltage Transformers, Sensors and Command signals from other devices requesting a particular service within the IED. The current and Voltage Transformers are known as Instrument Transformers as they step down the voltage or current from the higher level into the lower level so that values can be read and processed by measuring instruments and other transducers. CT and VT are grouped according to their voltage and current levels and their turn's ratio which specify the value of the output voltage or current to be given out when the CT is connected to across the conductor carrying the current. From the diagram () the CT or VT are connected to the high voltage side for VT and High current side for CT. These are usually fitted across the transmission lines feeders supplying power to the consumers. When the fault occurs to the transmission lines a large magnitude of current will pass through the feeder conductor where the Current Transformer or voltage transformer is connected. The VC and CT will sense the voltage and current levels to produce a lower voltage for VT and lower current for CT proportional to the magnitude of current passed through their secondary side. The lower values of voltage and current are then processed at the transducers such as IEDs programmed in such a way t they can respond by sending the control signal to clear the fault at its specific location once they a fault is reported.

12 IEDs GOOSE messaging in Power System Protection

To understand how the IDEs detect faults signal from the power system devices, we start by observing the figure (). It has been assumed that a short circuit fault occurred on the Transmission line Feeder F1 between Breakers B7 and B9 at Zone 3.In that case a larger magnitude of current will pass along feeder 1 which will in turn circulate to the other parts of the power system. If this fault will not be cleared immediately, the current will circulate to the Transformers as well as other devices connected to the power system and this will result into damage to the power system devices such as transformers, Generators, breakers , transmission lines, Industrial and domestic equipment's. When this condition occurs a current sensor for the breaker B7 should be the first one to detect the fault and send the command signal to the IED5 so that the Breaker B7 can be opened so as to separate the fault part against the health part. When it happens the Breaker B7 failed to open then the IED5 send the GOOSE message (multicast message to the other IDEs through the Ethernet link through the switch S3 so that the other IEDs would respond to the request and clear the fault by disconnecting all the parts which could have been affected by the fault. In this case the Breakers B5, b3 and B8 should be next devices to be disconnected by their respective IDEs such as IDE 6 and IED 3. This will do the same procedures I case the fault occurred from the other locations, that the closest parts to the fault area should be given the first priority to be disconnected, unless otherwise they fail again the in that case the whole transmission line is to be shut down.

From this discussion it has been observed how ICT has been applied to coordinate power system devices to communicate together and share their various information. Some of the power system equipment's operate under the same criteria that they can share some of their functions. Most of the IEDs within the power system are falling in this group. Most of them are located within the substations where internal communication is provided for the IDEs installed in the substation. For the external communication between substation and substation some IEDs communicate through the serial line interface for teleprotection.In style the IEDs can communicate through GOOSE messaging with the other external IDEs. What if the power system becomes more complex due to the integration of more devices to be controlled, this more IEDs will be needed to compensate for the added ones. This will incur more expenses to the power supplier's vendors. This will involve more cabling work and system will become more complex that it will bring even more challenges in case of performing maintenance and service work.

The power system is currently expanding and the Smart Grid is getting popularity to replace the existing power system. A well-organized and designed power system communication architecture is required so as to provide interoperability among the devices to be connected to the power system to communicate with the other devices in the outside world. Here is where the power system communication protocol IEC 61850 comes into its place. This is the current communication protocol standardized to be used in Substation to coordinate communication among the power system devices as well as providing an access to interface other communication protocols manufactured by other vendors to make their devices communicate on the power system communication networks.

Although the existing communication protocol is performing well, still it has to face some future challenges such as facing the existing technology as implemented in some of the facilities connected to the power system, the Smart Grid technology is now becoming popular that it will involve more distributed energy resources, Home Energy Management System (HMS). The protocol is still employing the TCP/IP as a communication protocol for some of its applications. The aim of this research is apply the concept of ICN (Information Centric Networking) into the power system communication protocol especially IEC 61850 so as improve the performance of some of its communication layers such as TCP/IP layer as well as the link layer 2 where GOOSE messaging is operating.

Not only that but also the naming scheme for the communication protocol IEC 61850 supports the requirements for ICN naming scheme. As stated before that the IEDs are usually communicating through the link layer 2 through Multicasting (publish/ subscribe) in case there is a failure somewhere within the power system. Although this method has been seen to be an effective way for the IDEs to communicate, but some time the situation goes wrong and the communication cannot be done in real time due to the traffic which would have been caused by simultaneously operation of the IEDs along the communication link. This may cause a catastrophic within the power system a s the communication will not be done in real time which is a very important feature needed by the protection devices such as breakers.

Some Researchers have recommended the devices to communicate through the network layer to employ a TCP/IP protocol, but this would still bring more challenges for the protection system due to packet drop when the message fails to reach the destination. The only solution for this to apply the ICN concept on place of TCP/IP so that the IEDs can communicate through the Network (WAN) where more access for the other devices control and monitoring will be possible. In this research we specialize on the Substation Automation as a part of Smart Grid systems currently.

13 Introduction to ICN routing scheme for the power system communication

In order to identify the requirements for the ICN based routing scheme for the power system communication it is important to identify the working principle of the current power system communication protocol so as to know the gaps in which ICN knowledge can be applied. Not only that but also we have to identify the areas in the power system where the ICN .knowledge can be used to develop the power system communication networks. Before we Identify areas in which we apply the ICN knowledge to improve the power system communication, the architecture for each ICN and IEC 61850 will be briefly discussed as well as identifying the differences, Routing scheme and naming will also be briefly discussed.

The main aim of this research is to propose the implementation of the GOOSE messaging as used in IEDs communication through Ethernet link layer 2 into network layer in WAN under the ICN as the new Internet protocol. IDEs communicate with the other IDEs through publish and subscribe fashion at the station bus. An Ethernet LAN is used to provide communication for protective relay at the station bus. Logical I/O devices have replaced the traditional hard wiring so as provide an efficient exchange of information between the IDEs. The information being transmitted includes I/O devices, status for various protective systems. The processing speed of the information can range from 1-2ms in IEC 61850.

IEC 61850 Communication Architecture

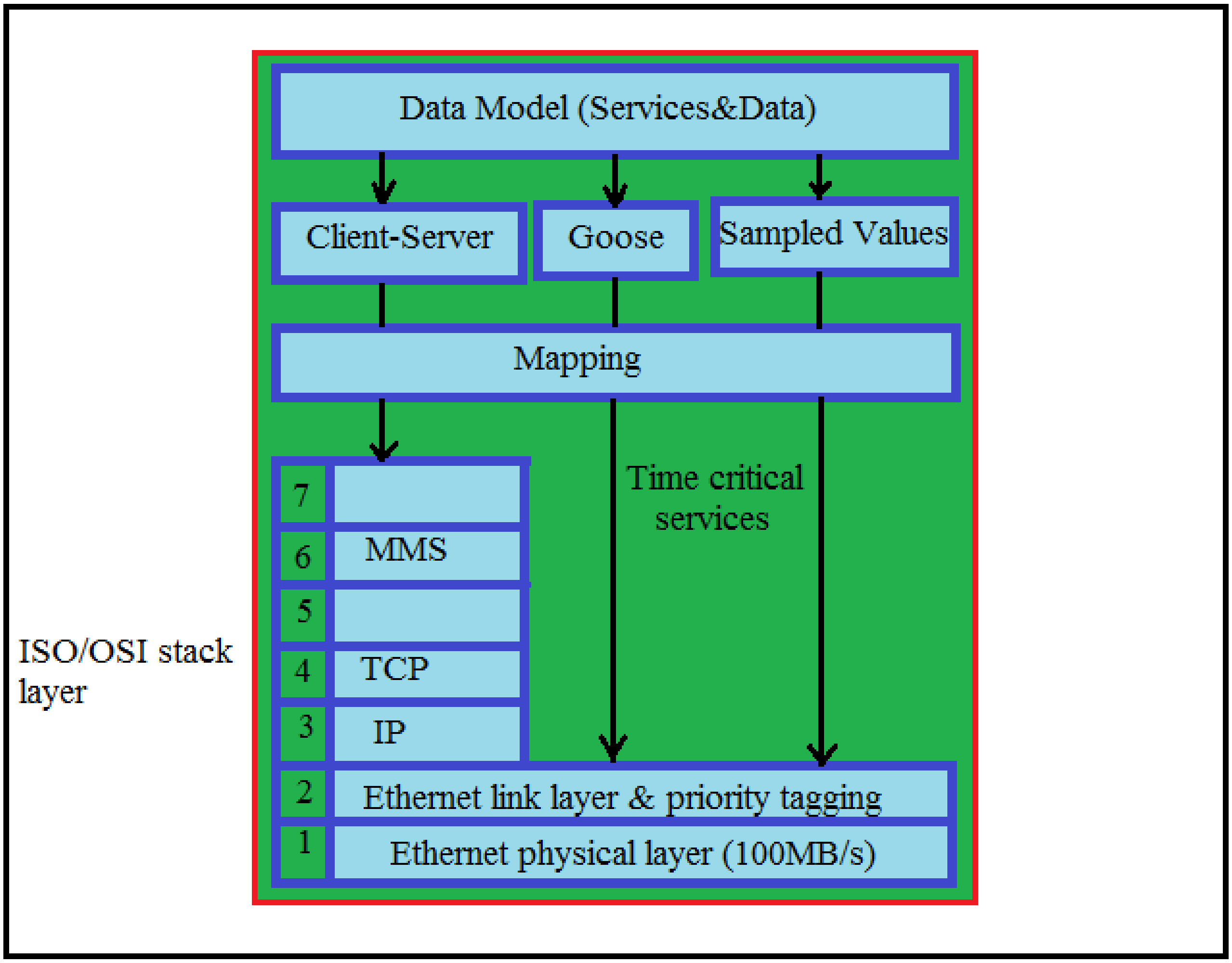

Figure 7. IEC 61850 Communication Protocol Architecture

13.1 IEC 61850 Architecture Description

Data Model: The data model is an application independent defined in IEC 61850.The data model consists of various applications functions. These application functions are divided into parts which can communicate with each other. These are the functions belonging to a particular logical node. A logical node represents the physical device in which some of it functional parts may be grouped logically to form a logical nodes

The functions of data model are

- Reading the value of an attributed data
- Writing the values for configuration data
- Controlling and monitoring switching devices
- Reporting the events in case of value changes
- Keep track of the local storage of timestamped events and historical data
- To read the data model
- Performing file transfer for configuration and recording of historical data

GOOSE: GOOSE means generic object oriented substaton events. This is used by the IEDs to speed up the transmission of time critical information such as status changes. IEDs use the GOOSE messaging to communicate among themselves when there is a critical situation within the power system which need to be solved.

Sampled value (SV): This process and synchronize the stream of sampled values for current and voltage.

The communication stack and mapping: IEC 61850 uses the selected mainstream technology which is TCP/IP mapped to MMS Manufacturing message specifications application which define various specification so that the devices can communicate with the IEC 61850.

14 Routing in IEC 61850

IEC 61850 use the IP routing to communicate with the substation devices for the client-server services and a multicast IP routing to provide a real-time communication between the substation devices such as IDEs. This address is used in GOOGE messaging, a communication between the Intelligent electronic devices on the Ethernet link layer 2. The method was designed for intersubstation communication. But when it comes to the external communication among the substations, that all IEDs are connected to the Ethernet link layer much traffic will be generated due to simultaneously communication among the devices.

15 Communication Networks for Intelligent Electronic Devices

15.1 Horizontal and Vertical Communication for IDEs in Substation

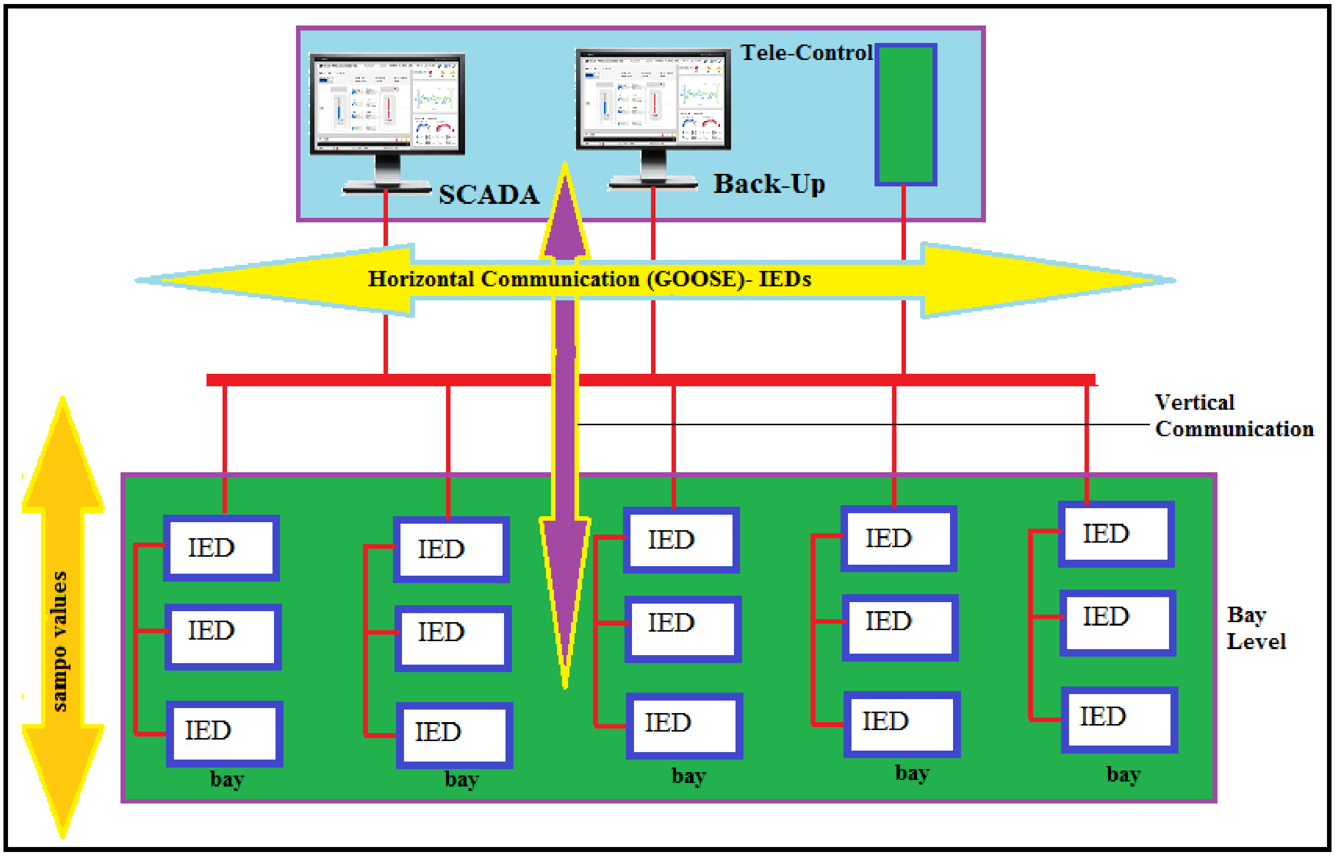

Figure 9. Horizontal and vertical routing of information (data) from the bay level to the IEDs and Scada.

The figure shows a vertical and horizontal routing of information from the substation devices to the IDEs and SCADA Systems. In the horizontal communication the IEDs communicate through the Ethernet link layer 2. This is known as GOOSE messaging where the IDEs exchange information by sharing their control functions in case an abnormal condition occurs within the substation. This type of communication has been reported to contribute a lot of traffic along the communication media and some time may affect the performance of the protection systems.

16 Introduction to Information Centric Networking (ICN)

Information –centric network is the promising communication protocol which is currently replacing the existing TCP/IP internet protocol. ICN is emphasizing the access of information regardless of it location. It accomplish this through the use of a well-organized database which allow various communication networks to share and deriver important information to the internet uses. ICN use different approaches in routing and naming of the content compared the existing TCP/IP communication protocol in which information are bound at particular location. Due to its characteristics, ICN has opened a lot opportunities I developing various systems as well as solving various communication problems which initially were not solved by the TCP/IP communication Protocol. Nowadays the ICN concept can be applied into various fields in the engineering sector to solve critical problems facing the societies. In this research we will study the application of ICN in power system communication.

17 Naming in ICN

It is important to know various information concerning the content available from the internet. To fulfil such kind of requirements, naming, routing and addressing are the important parameters to be addressed. The delivery of the contents in the current TCP/IP were based on host-centric which means the one looking for the information must know the IP address so that he/she can know where to retrieve or send the data/information. For this case a path is to be established first between the two parts before the communication starts. ICN allows content retrieval and request to occur based on the names .ICN uses various naming schemes to address the information on the communication networks.

18 ICN Naming Schemes

18.1 Flat Naming

Flat names are derived from various set of bits in order to identify various objects. In this case the content Identifiers are needed in order to use the flat names. To come out with the required content identifiers, the flat names uses various mapping techniques s such as using a cryptographic hash function in which the selected keys will be passed to produce the content Identifiers. One feature of the flat name is that there is no any relationship between the identifiers of the contents and the location where they have been stored. Self-certification has been guaranteed in flat names. In order for the nodes to verify the validity of the keys used in the content a cryptographic hash keys of the form P: l are used where P represents the publisher content key and L represents the label chosen by the publisher. Flat names cannot be aggregated for that case forwarding and routing table are to be used.

19 Hierarchical Naming

Hierarchical names are frequently used in ICN. One feature of these names is that they usually reflects to the content they present. These names are derived from the string name components to come out with the unique identifiers to be given to the content. The hierarchical names gives the user an access to search the content in different styles that he/she can create the name of the desired data without having any knowledge concerning the information he/she is going to look for. In this case partial names can be used to retrieve a particular content by just using any few words from the content to retrieve the whole document. Hierarchical names follows the hierarchical order of the name components. The structure of the Hierarchical Naming Scheme can be presented as: **/br.uff/video/intro.avi/<timestamp>/<chunk#>**

From the naming structure above, br.uff/video/intro.avi represents the user or application supplied name, where the other part <timestamp>/<chunk#> represents versioning and segmentation, this means a user should specify the version of the video to be watched. But since there could be various segments within one video version, the he/she has to specify which segment is to be watched. For example the first user request for the content br ./uff/video/intro.avi/1/1, this means a used requested version 1 and segment 1 of the video. When another request is sent for the same video, then the previous requested chunk will be used as a reference for other who will request the same video, but, this time the chunk for the second request will be looked as br.uff/video/intro.avi/1/2. This means the user requested the same video but he/she was interested with the second segment of the video. One of the disadvantage of this names is that they do not allow persistence, since any change of the name components, will force the other parts to be changed, this could be due to the ownership changes.

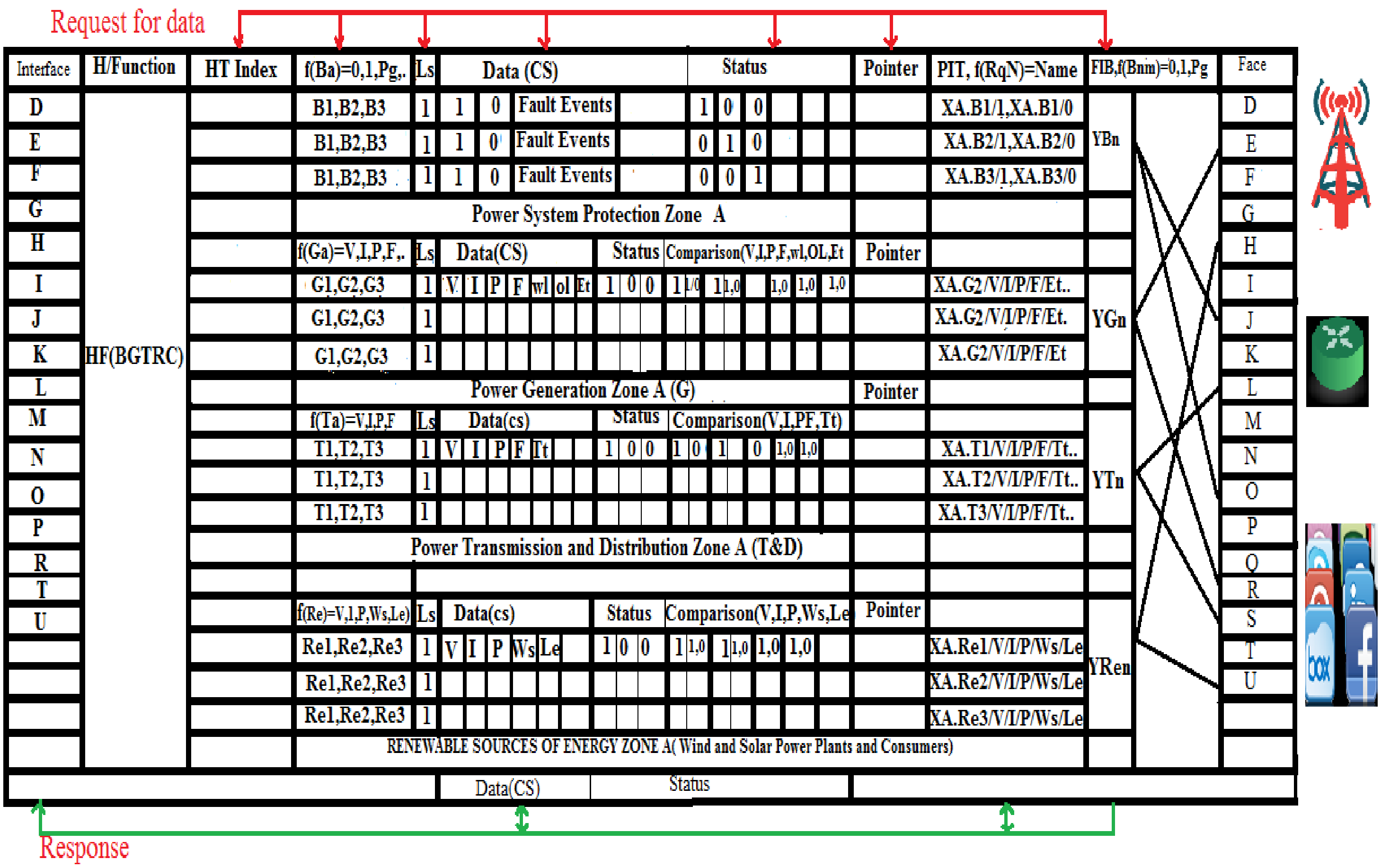

Figure 10. A functional Architecture for a proposed Power System Communication Network Architecture

Figure 10 is a proposed functional architecture for power system communication network. The architecture is proposed to be implemented in a network router to coordinate communication between the power system devices. The network router consists of various interfaces shown in first column and the last column. H (BGTRC) represents a hash function. This has been implemented in order to simplify the routing of various requests to the location where the information have been stored. For simplicity we have considered various functions of the power system devices such as Breakers (B1-B3), Generators (G1-G3), Transformers (T1-T3) and Renewable Energy Sources (Re). Each of these devices are governed by their particular processing function such as f (Bn) = (0, 1), this represents a breakers function at Protection Zone A. This process the breaker positions so as to give out the OFF (0) or ON (1) operations to control the breaker positions. The protection Zone consists of Content store (CS) with logical data 0 and 1. These are the data to be passed to the breaker function so as to return the value of either 0 or 1 to the caller function from the breakers so as to switch OFF or ON the breakers when the abnormal conditions occurs within the power system. The content store contains the periodical messaging to indicate the status of other Breakers sharing the same function with any of the breakers in a particular Zone. The pointers have been implemented in order locate the position of the next breaker to operate in case the other on failed operate in a proper time. The pending Interest table keeps track of the various requests sent to the networks by the other breakers. The FIB has been implemented to forward the requests to other to other face where the other active breakers can be available. Breakers B1, B2 and B3 operate within the same zone, but they share their function with other breakers located in the other protection zones close to them or sharing the same power system networks.

The protection Zone A from figure 10 operate as follows. When the faults arises from any of the B1-B3 located to the same zone, let say the message came from Breaker 1 (B1) then the message request should be of the form XYA.B1/0 is to be sent to any of the available face, where X is the name of the substation the breaker is belonged, Y is the common key to be used by the breakers B1-B3, A is the name of the zone where the fault occurs, B1 is the name of the breaker which sent the request and 0 is the data requested by the breaker B1. The request will be processed by the Hash Function H (BGTRC) so as to route the request to the location where the other functions to perform the requested task are stored. Before the data is sent back to the requested breaker, The processor should check the status of the breakers indicated by 0 and 1 to make sure they active as well as checking the condition of the link capacity (Ls) before it assign the data to the requested breaker. When all conditions are met then the processor should assign the data to breaker 2 (B2) function through the help of pointers. The data will be returned to where the breaker 2 (B2) is installed. Under this condition the breaker B2 will disconnect the fault part within the reasonable time before the whole system is affected by the faulty. In case B2 fails to operate the request should be directed by pointers towards Breaker B3 that means the data will be assigned to the Breaker 3 (B3) so as to disconnect the faulty part. When there is no any active data for B1-B3, then the request should be directed to the other faces where other breakers sharing the same power network are connected. The requests will be direct with the help of FIB (forward information base) The same procedures will be done even in case of failure in breakers 2 or 3

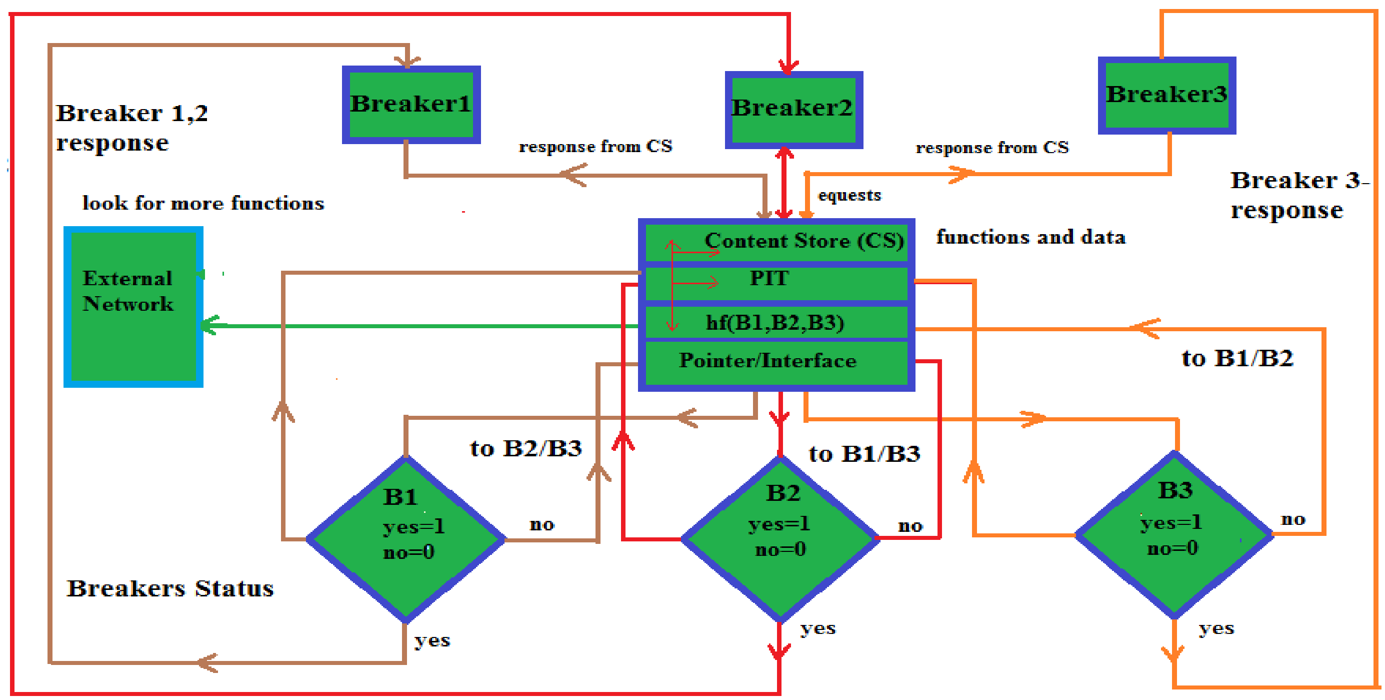

Figure 11. Data flow chart for Breaker GOOSE messaging on the Power System Network

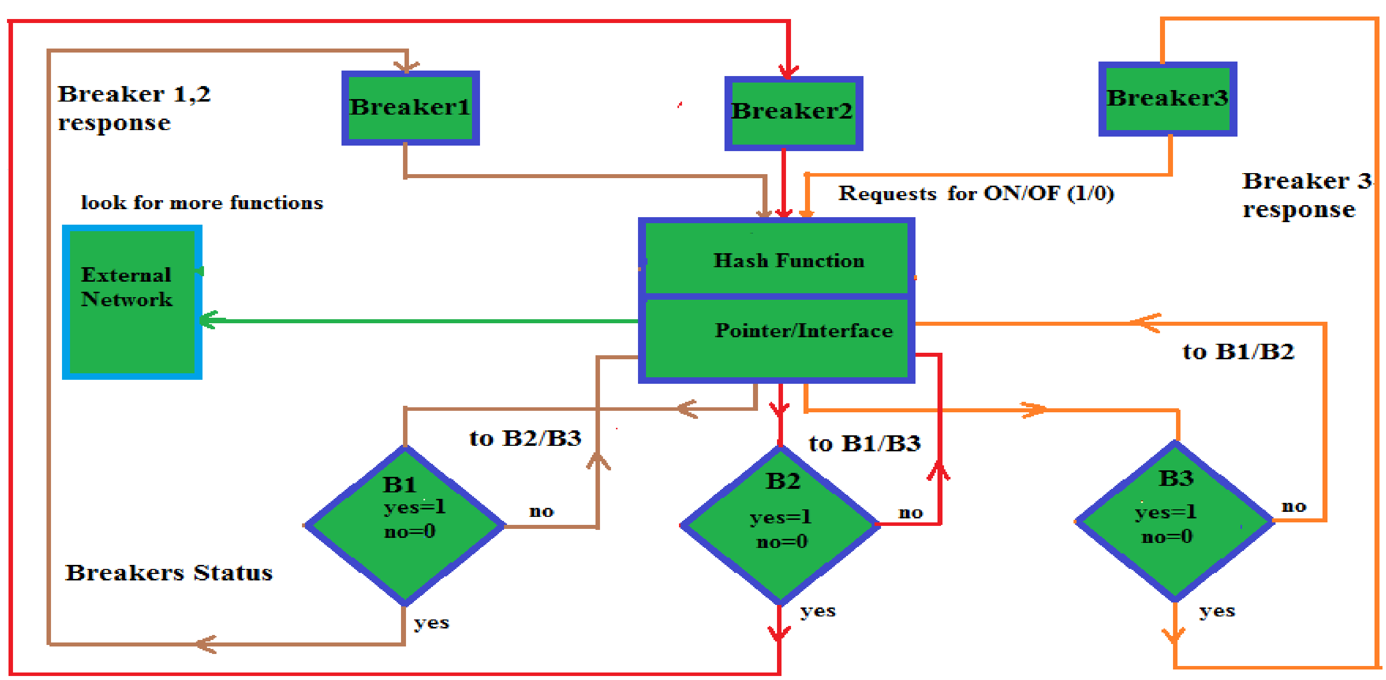

Figure 12. Hash function implementation

From figure 11, the command signal can be initiated by any of the breakers B1, B2 or B3. Assuming breaker 1 initiate the fault signal to the router requests to access the functions for breaker B2 or B3. In the first case the content store will be checked to find if the requested function is existing in the content store. If the function exist then the response will be given to the breaker B1 to disconnect it from the power system. In case both B1 and B2 sends the requests at the same time, then the found data will be assigned to both breakers, there the on function will be used to switch off two breakers at the same time. If the data will not obtained from the content store, the request will be kept pending in the PIT, then the status of the breakers will be checked as shown in the decision box in the diagram to see which breaker is active breaker to perform the switching operation, every breaker reports its status and output to the PIT so as make the data to be accessed by the other requesters. This is the GOOSE messaging on the network layer developed from Ethernet link layer 2 GOOSE messaging. If there were no any data for B1, B2 and B3, then the request will be forwarded to the external Network.

20.1 Message Naming

The message naming is based on hierarchical, for example when breaker 1 sends the request to the content router to access the functions for the other breaker, its message naming will be looked as XYA.B1/O. This will mean the breaker B1 send the request to the network to notify the other breakers that it failed to clear the fault. For this case the other breakers should take the control on behalf of breakers B1. Therefore the response from the network will not directed to the breaker B1 if its data was not available from the net. Therefore the data will be routed to the other active breakers, let say Breaker 2 (B2).In this case the response to the breaker 2 will be looked as XYA.B2 (B1)/0 (if the incoming interfaces were the same) otherwise the naming could be written as XYA.MB2(NB1)/0. This means the fault signal was originated from the Breaker 1 (B1) at face N when B1 failed to clear the fault, for that case the response came from the breaker 2 (B2) via face M. Putting the messages in this format will help the operators of the power station to identify where the problem occurred and that they should perform maintenance to the breaker 1. If the data was obtained directly from the content routers to Breaker B2 then the messaging will be looked like this: XYA.RB2 (B1)/0 here R means default router means breaker 2 got the response directly from the cached data in the router. The pending interest table should keep track of all the requests directed into various location to search for more information in case they are not available from the cache. When it happens two or more breakers request the same function, then only request will be forwarded to find the data and distribute it to the other requesters. In this case the pending interest table will be populated with the requests of the form XYA.MB2/NB1/0this means the same data was requested by breakers B1 at face N and B2 at face M.

20.2 Zone Generation Station

ICT plays a great role in providing machine to machine communication in power system networks. The introduction of Smart Grid systems will involve a number of devices connected to the power system. Currently the power system is based on semi-automatic system where human participation is of great importance in some of the oldest system. However the power system is becoming a complex system with a number of devices which require sensitive and accurate control of the intelligent systems. The major areas which require accurate control in the power system are such as protection and monitoring of the substation equipment's such as generators, transformers, domestic and industrial facilities to ensure they are operating under safe conditions. In this research we have proposed a partial machine to machine communication, where the power system devices communicate on the network and share their information such as generated voltage range, current, power , frequency, water level(for hydro power stations), engine temperature, phase sequence, generator synchronization. Our idea is to transfer some of the substation control function from the substation automation control equipment's into the networks where the functions can be shared by the devices located in the other areas within the power systems. Here we give a basic approach tom show how ICN can help to minimize the existing g control problem in the power system communication networks. As most of the control system in power systems such as SCADA systems are based on semi automation systems where human operator is involved in controlling the power system devices such as Generator Synchronization, Load Shedding, Transformer tape changing in distribution transformers in case of under voltage. However there are some intermittent disturbances used to occur in the power system networks such as over voltage due to suddenly decrease of load, instability of the generating units due short circuit faults. Some of these conditions are very critical that they cannot be monitored by the human operator alone. Therefore we have proposed an ICN concept for the machines control functions on the network as shown in figure 10. Each generating unit sends its data equivalent to its Power, Voltage, Current, Frequency, and Engine Temperature in form of an array of various classes of data. The data are then compared with the reference set of bit at the comparison stage. The function f (Gn) = V, I, P, F, Collects the data from the generators and publish them on the network cache where they have to be compared with the standard values so as to maintain a proper flow of power within the power system. Any variation of the function parameter will be detected and cleared by the on network control systems based on ICN. ICN provides he environment that the information available on the network can be utilized effectively to provide control for the power system devices in complex systems. Situations such as overvoltage will be published on the network where it will be detected by the standardized functions so as to be regulated to a reasonable value to bring safe operating condition of the power system. The system in figure 10 will follow the same procedures even in case of Transformers control.

20.3 A proposed ICN based Demand and Supply balance system for the Smart Grid Systems

Figure 11, represents a demand and supply balance system to be implemented in smart grid systems. The system is based on ICN concept. The system consists of two parts where the first part consists of Generating Units and the second part consists of transmission and distribution systems. The network routers Rt acts as edge routers, they implements the hash functions which help to locate the place to store the information. From the generation stations the data for the voltage, current, power and frequency are collected in the form array [V, I, P] by the function F (Gn) to the power plants Ps1-Pss. The collected data are then routed to the control station Y1 where they will be gathered and stored and part of it being submitted to the main control station. In the second part the distribution and transmission substations will gather the data from the customers due to their consumptions. The data for the voltage, current, power consumption will be collected at the control station Y2 and directed to the main station. At this stage the information gathered from the Generation stations and Distribution station will reflect the power consumption rate of the customers against the power generated. This will simplify the controllability of the power system devices connected to the power system to maintain the power flow stable as well as improving the QoS to the customers as well as protecting the power system equipment's .In this proposed architecture it is easy to monitor the behavior of customers by controlling their power consumption rates.

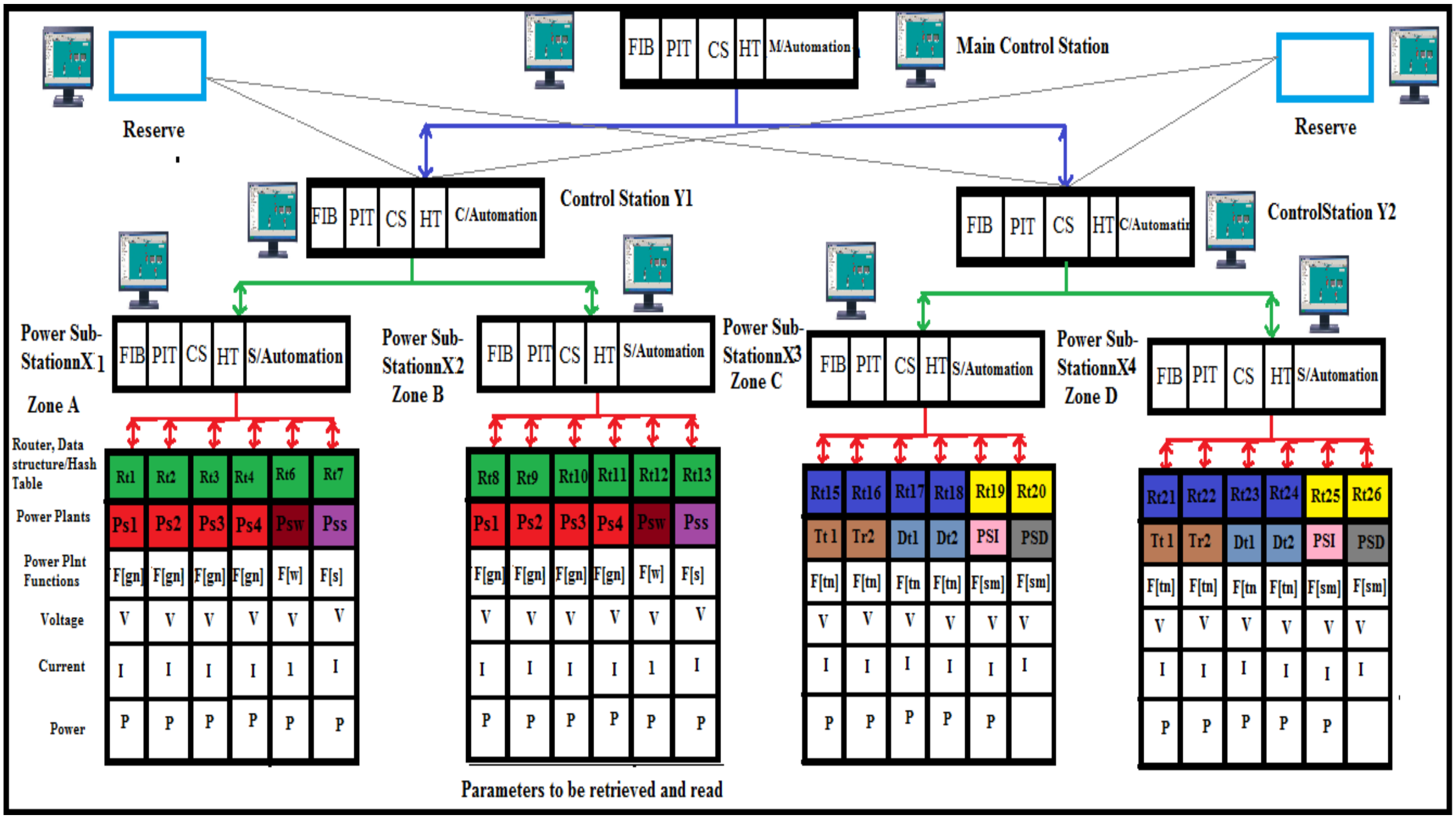

Figure13. A basic demand and supply balance system to be implemented in Smart Grid systems

21 Analysis of IEC 61850 substation communication protocol based on TCP/IP and ICN.

In this section we will introduce a brief analysis of the communication protocol used in the substation Automation so as to compare its performance under two protocols, TCP/IP and ICN.The IEC 61850 consists of the 7 layers which support the communication within the power system. The IEC 61850 uses the Ethernet link layer 2 to provide communication for the substation protection devices such as IEDs. IEDs are control devices used to process the data from the sensors such as current transformers, voltage transformers and other sampled values such as voltage and current. Most of the IEDs communicate within the substation to share their important information concerning their functions. They accomplish this through GOOSE messaging based on Publish /Subscribe on the Ethernet layer 2.

Currently the power system is expanding and the system is now becoming complex. The use of GOOSE messaging on the Ethernet link layer 2 has been contributing to a lot of traffic within the power system communication networks. Most of the protection systems require the real time communication so that they can operate in a safe condition. However the communication is limited within the substation, where the communication to the outside world is provided using a serial line communication which will in future not be implemented. Some Researchers have been recommending the use of GOOSE communication on the layer 3 network layer using TCP/I P layer, but this would still bring more challenges as TCP/IP will soon be phased out. However TCP/IP contributes to the packet loss, a characteristic which is not suitable for the protection system requires a real time communication. In this Research we have proposed the use of ICN layer on place of TCP/layer as used in the IEC 61850 communication protocol. To accomplish this we have proposed power substation model shown below which will be used in the simulation procedures.

22 Methods and Procedures used to simulate the proposed model

- To performance of the proposed system was tested for both ICN and TCP/IP communication protocols.
- We proposed a substation communication model consists of 3 zones to be protected by IEDs
- Our aim was to make the IEDs to communicate on the WAN through the network layer using ICN as a new protocol to provide a reliable communication
- Both of the IEDs share their information and functions cached in the routers.
- Most of the IEDs share the control functions to provide protection in various zones as shown in the figure.
- Each IEDs located in the substation has access request the functions of the other IEDs shared on the network routers through caches.

22.1 Model Functional Description

- The model below represents a substation communication system
- The model was developed from the current IEC 61850 where the IEDs communicate through the Ethernet link layer through publish/subscribe approach
- In this architecture we developed an idea that the IEDs from each substation A, B and C can communicate by sharing their information through router A, B and C
- The distributed hash table approach has been applied, the distributed hash table are applied at the end nodes at routers A, B and C.
- The distributed Hash table use a special function which accept the keys to locate where the information are stored.
- The IEDs communicate with the Breakers B1 to B3

- When the fault occurs from the Transmission Lines, let say the Transmission lines protected by Breaker B1. In this case Breaker B1 should send the fault signal to the IED1 as shown in the figure below. IED1 should respond by sending the control signal to open breaker 1 so as to clear the fault from the transmission line.
- In case Breaker BI fails to open the IDE 1 should send the GOOSE message to the network router A where the control functions for the other IEDs have been cached. The hash table located at the edge routers A, B and C will help to locate the information for the other IDEs which can perform the same function to clear the fault. This will be done hierarchically that IDE1 will send the request to IED2, and IED3 within the same zone, when it fails then it should go to another network or zone.
- Under this operating conditions, all the IEDs will have an access to communicate with minimum traffic since the contents are directly available routers caches

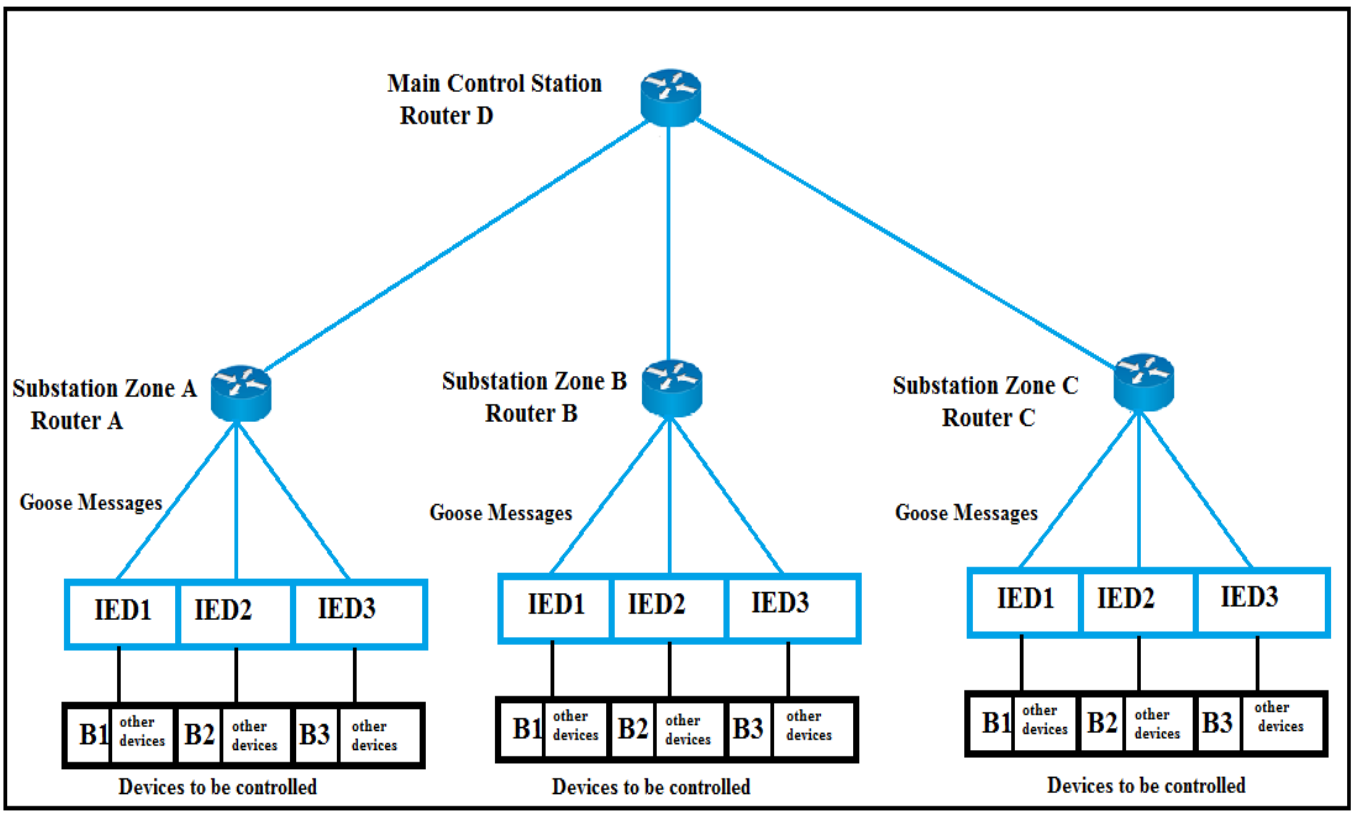

Figure14. A proposed Substation Zone Protection for IEDs Communication

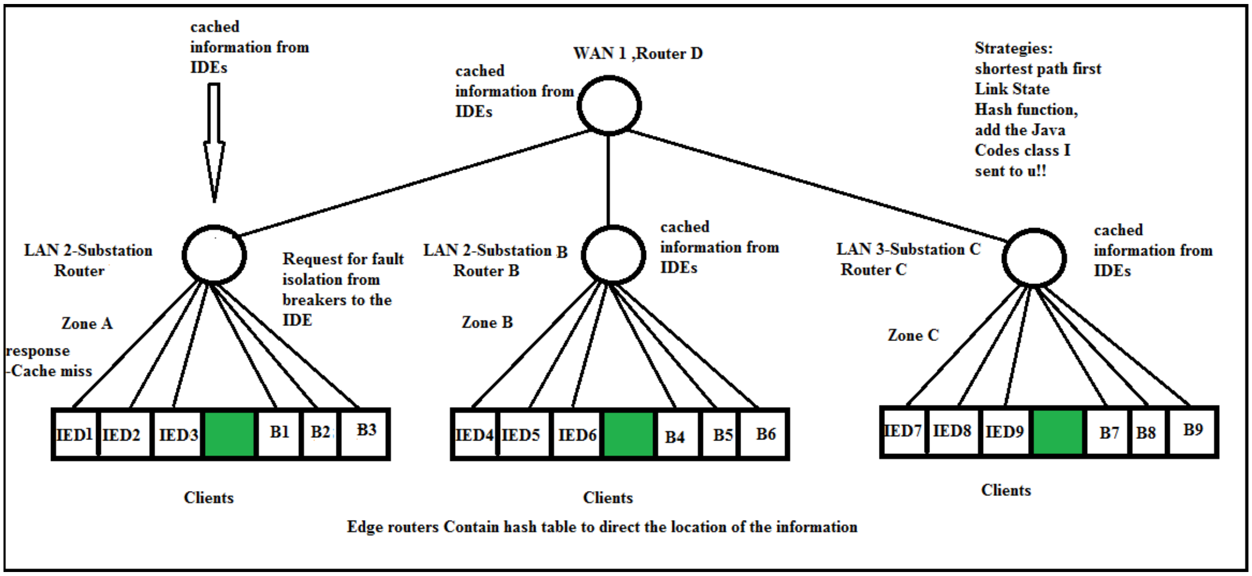

Fig 15. Communication between IEDs and Breakers through the network layer.

Simulation Tools and Methods used

ICARUS: This is a free software available on line which has the capability of evaluating the caching performance in Information Centric Networking. The software is based on Python. ICARUS has various features which have been missing from other simulators. The software is scalable that caching evaluation can be done with a minimum time as well as extensible since it can be adapted easily with the new designs. The workflow for ICARUS is shown in the table below.

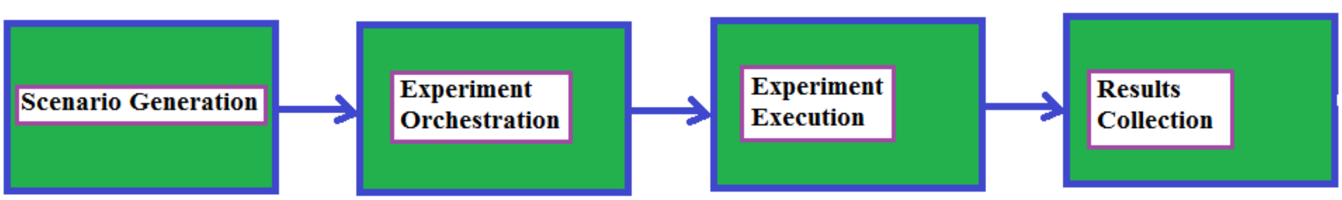

Fig 16. ICARUS Workflow

Scenario Generation: The section is responsible in setup of topologies to be used in the simulation as well as supporting random event generator.

Experiment Orchestration: This read the configuration file from the user so as to know the range of parameters to be simulated such as (cache policies, cache size) so as to combine all the experiments to run in parallel.

Experiment Execution: This is responsible with the execution of the experiment. Here the simulation engine is given a network topology and the event generator where the events will be read from the generator. The event read from the generator will be sent to relevant handler. The data collector will measure the metrics specified by the user when the experiment is over and return the result to the engine and aggregator.

Results Collection: at the end of the experiment the results are aggregated so that the user can plot the results.

Engine: This instantiate a caching and routing strategy for the experiment where all the events will be sent After being read from a request schedule. At the end of the experiment all the events will be received at the engine.

Strategy: Decide the contents to be routed and cached it implements the logic according to which requests and contents are routed and cached in the Network.

Icarus supports the following strategies:

Leave Copy Everywhere (LCE): In this strategy a copy of the content is replicated at every router after it has been delivered to the user.

Leave Copy Down (LCD) LCD: in this strategy, a copy of the content is replicated one level down the cache or towards the user when there is a cache hit.

Least Frequently Used (LFU): The LFU replacement policy maintain a counter associated each item.

Hash Routing: This implements off-path caching strategies. In this scheme edge nodes receive a content request so that they can compute a hash function to map the content identifiers to a specific catching node.

Simulation Procedures:

- In this simulation the edge routers were used to hold the hash tables
- The content request requests were generated randomly as the input keys from the IEDs as shown in the figure below. (minimum packet size for the GOOSE message =300bits)
- Since each request generated was required to check the status of the other IDEs to indicate their presence at the content store, we generated a random bits of 0 and 1, to represent the status of the IEDs on the network.
- In this process for every request sent from the IEDs to the content store CS, the random numbers 0, 1 were also generated to represents the status of the other IEDs.
- The experiment was performed for both ICN based has routing using Edge nodes with hash table and TCP/IP without caching.
- In this experiment we measured Latency and Link load to evaluate the performance of the system.
- The simulation results are given in the graph in fig.
- The main aim was to compare the Latency between the ICN hash routing and TCP/IP. Latency helped us to know the response time so that we can compare with the actual response time for the IEDs.

23 Results and Discussion

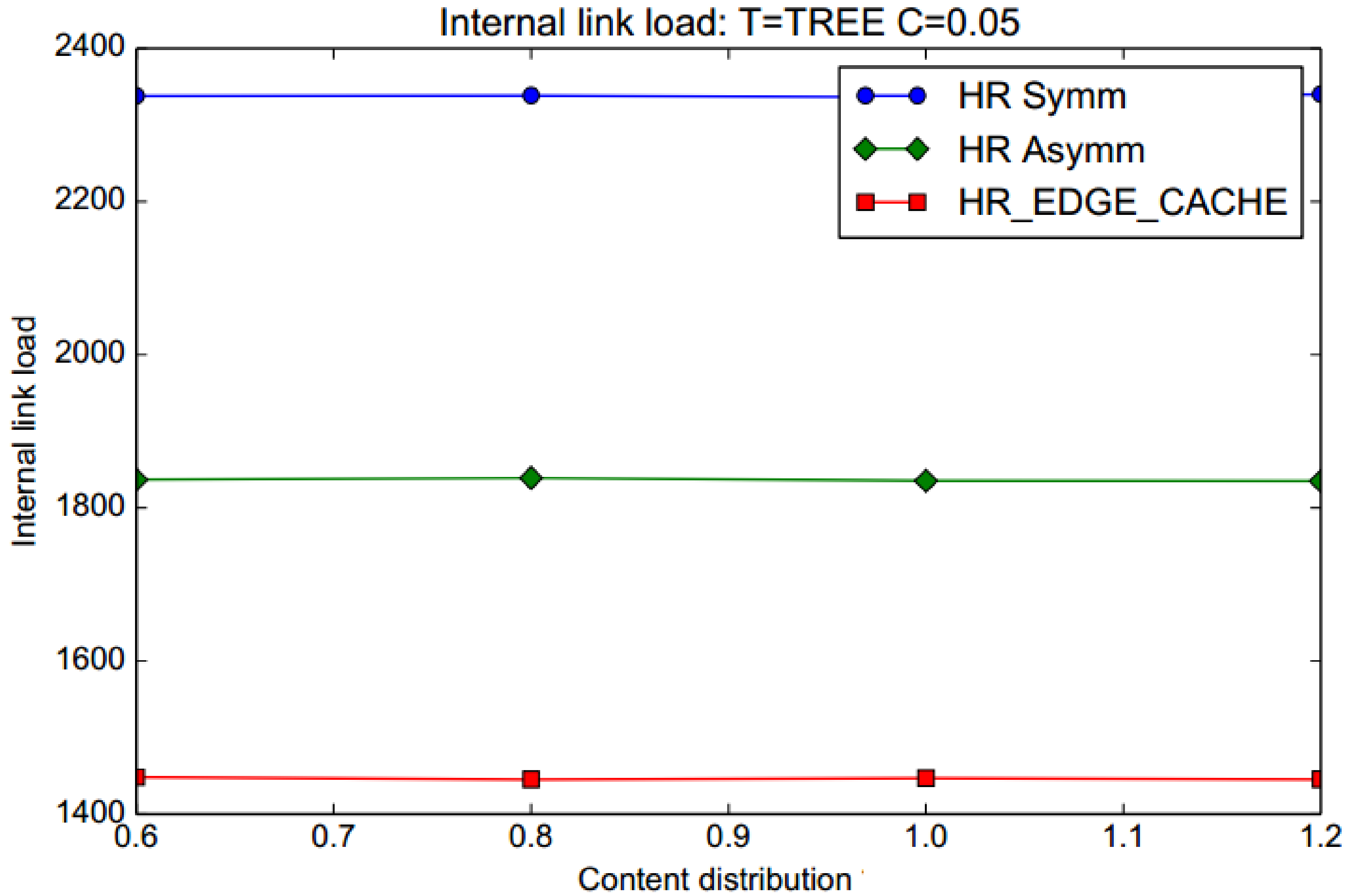

Fig 17. Combined Routing Scheme for Hash routing Edge, Symmetrical and Asymmetrical Hash Routing

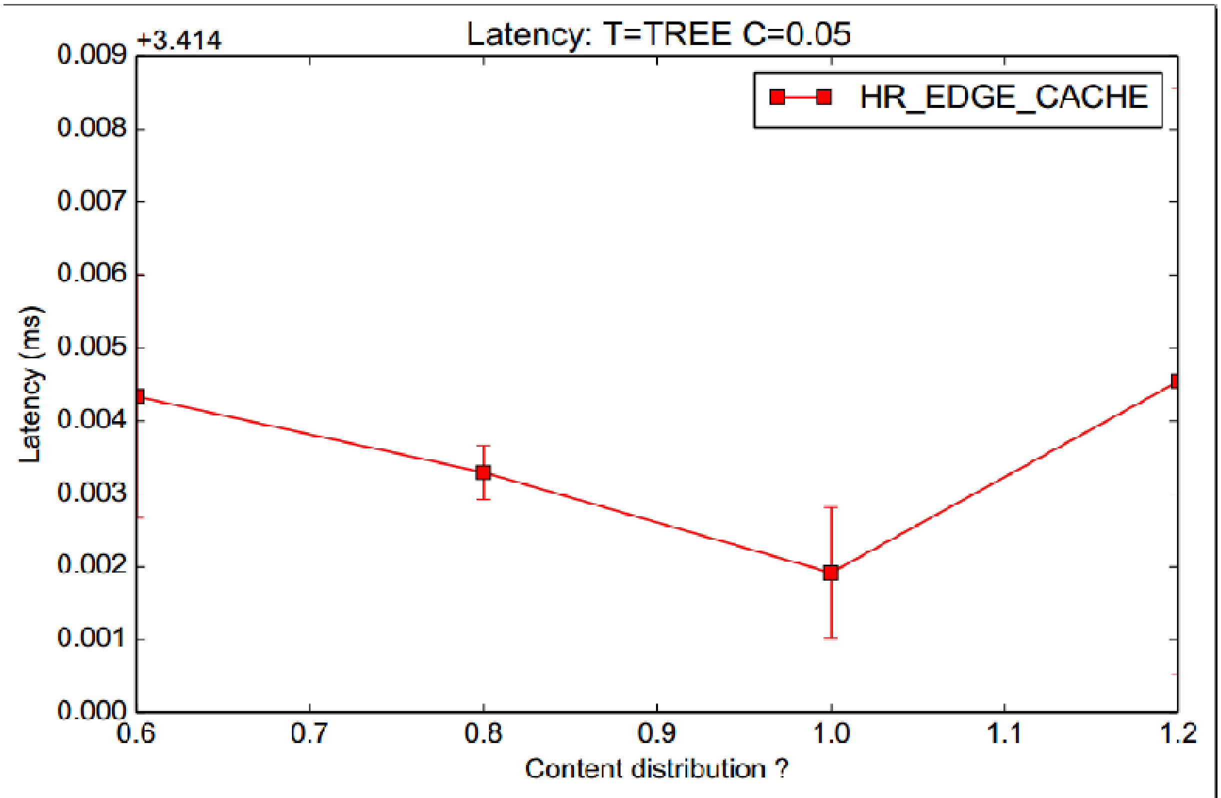

Fig 18. Response time for IEDs when the ICN protocol was used as a communication media

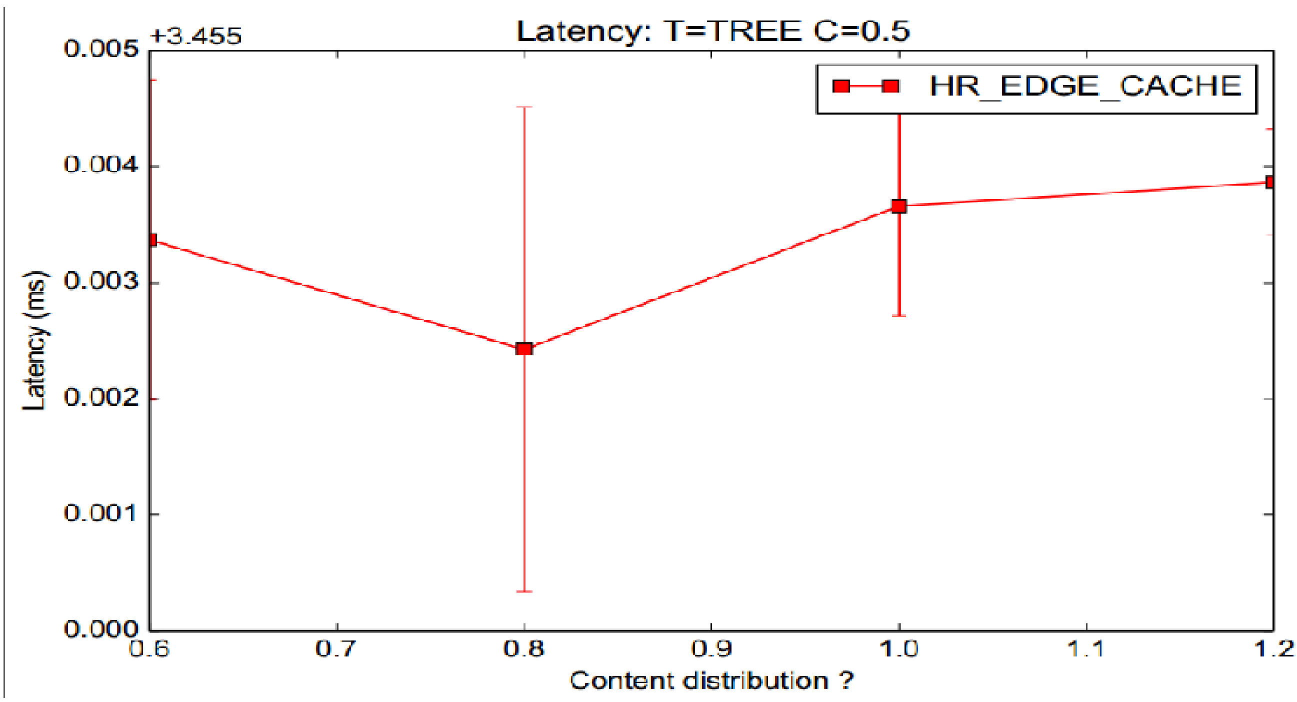

Fig 19. Response time for IEDs when the TCP/IP protocol was used as a communication media

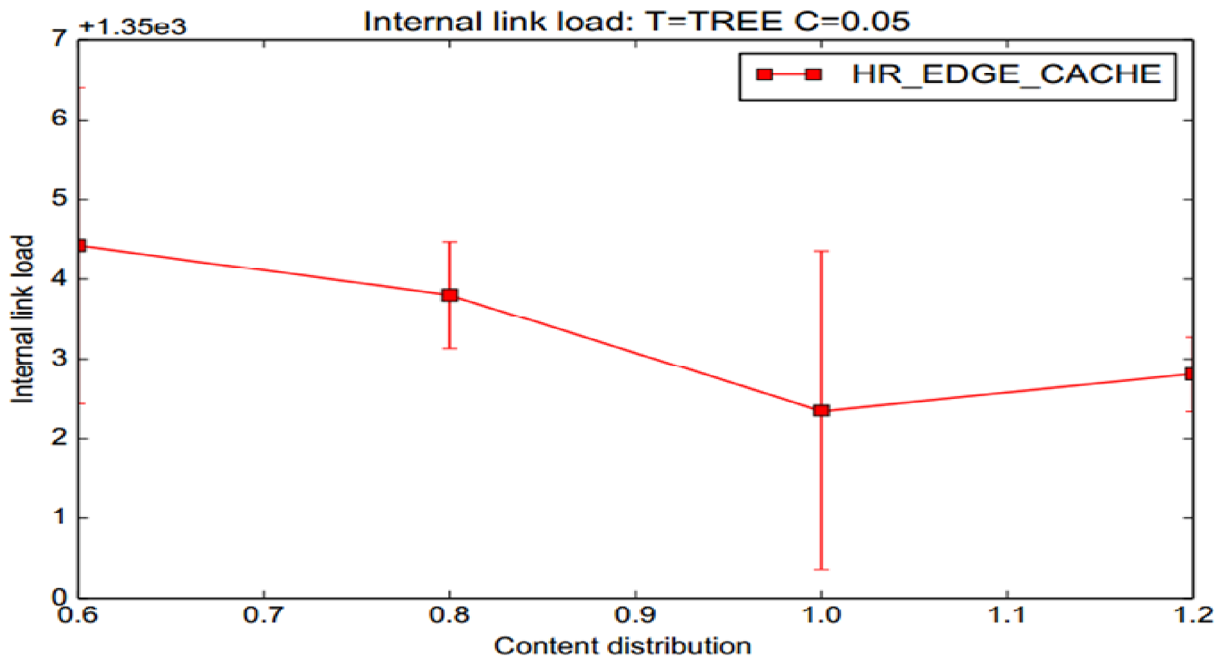

Figure 20. Link load when the TCP/IP protocol was used as a communication media

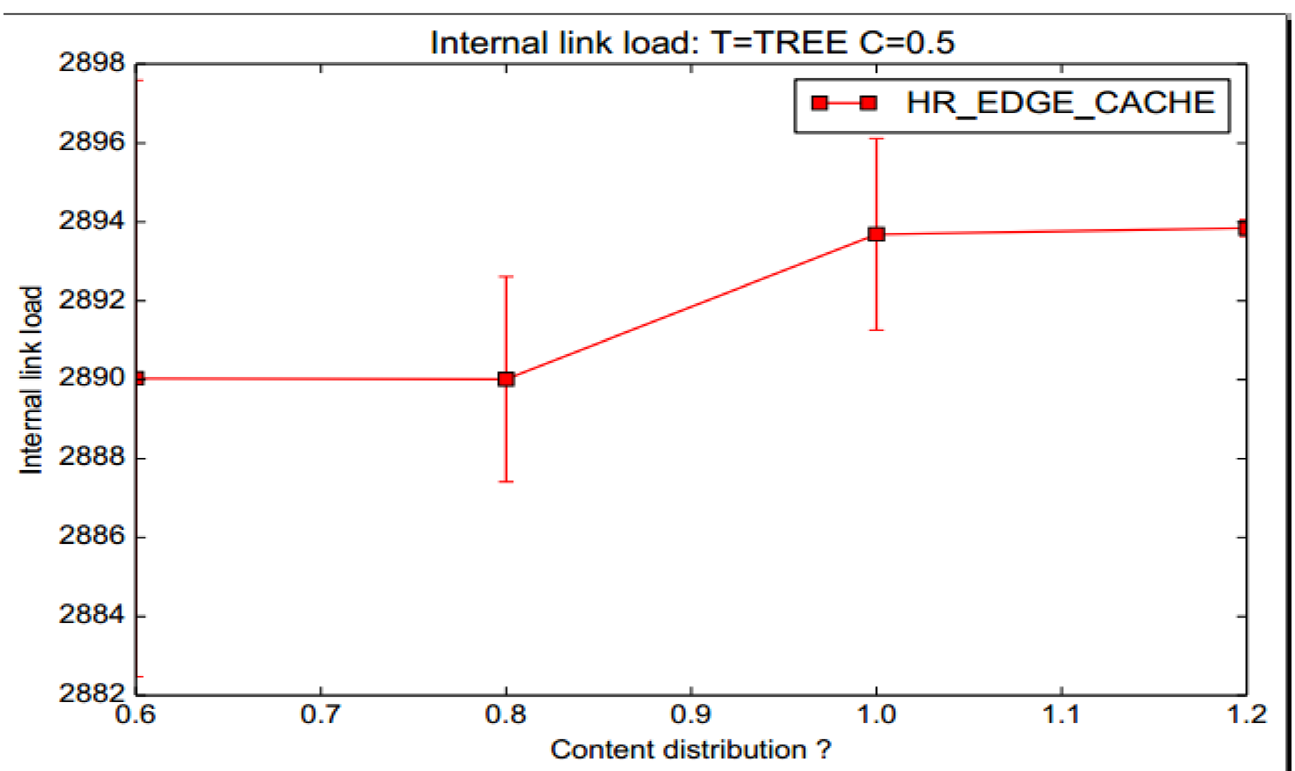

Fig 21. Internal link load when ICN protocol was used as a communication media

24 Conclusion

From figure 16 and 17. The response time seems to be more stable when ICN was used as a communication protocol as compared to the TCP/IP 1n figure 19. The response time in TCP/IP initially dropped to 0.002s where the content distribution was 0.8, and again raised to its normal value constantly at 0.004 where the content distribution is 1, while in case of ICN in figure 18 the response time dropped to 0.002s where at this time the content distribution was 1, then it keeps the same behavior in content distribution. This concludes that the response time in ICN communication protocol is more improved and it would perform better when it will be implemented as a communication protocol in power system or substation automation. In case of the link load the ICN was found to perform better as compared to TCP/IP protocol. Figure 21, is the combination of three routing scheme for edge hash routing, symmetrical and asymmetrical routing. The Edge hash routing was observed to perform better than the other two schemes in terms of link load utilization as shown in figure 20

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