# Design of a Quality of Service Framework for Micro Grid Communication Network based on IEC 61850 Standard

by

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# Abbreviations

| | |
|---|---|
| CBWFQ | Class Based Weighted Fair Queueing |
| DER | Distributed Energy Resources |
| DG | Distributed Generation |
| DS | Distributed Storage |
| ESS | Energy Storage System |
| GOOSE | Generic Object Oriented Substitution Event |
| GSSE | Generic Substation System Event |
| H2H | Human to Human |
| ICT | Information Communication Technology |
| IED | Integrated Electronic Device |
| LAN | Local Area Network |
| LC | Local Controller |
| LN | Logical Node |
| M2M | Machine to Machine |
| MAC | Media Access Control |
| MAS | Multi-agent System |
| MCN | Micro grid Communication Network |
| MGCC | Micro grid Central Controller |
| MMS | Manufacturing Message Specification |
| MPLS | Multi-Protocol Label Switching |
| NAN | Neighborhood Area Network |
| NED | Network Description |
| OO | Object Oriented |
| OSI | Open System Interconnect |
| PC | Point of Connection |
| PCC | Point of Common Coupling |
| QoS | Quality of Service |
| SGCN | Smart Grid Communication Network |
| SMV | Sample Measured Value |

| | |
|---|---|
| SV | Sampled Value |
| TCP/IP | Transmission Control Protocol/Internet Protocol |
| VLAN | Virtual Local Area Network |
| W/RED | weighted Random Early Detection |

# Definition of Common Terms

- Multi Agent System (MAS) is a distributed intelligence system which is formed by two or more intelligent agents that must have social ability and therefore must be capable of communicating with each other, (Nguyen & Flueck, n.d.) (Yang, et al., 2004).
- Measured values - analogue data objects measured from the process or calculated in the functions such as current, voltage power etc. and is produced locally and cannot be changed remotely (IEC, 2009).
- Metered Values – analogue data objects representing quantities measured over time e.g. energy, and produced locally and cannot be changed remotely (IEC, 2009).
- Intelligent Electronic Device (IED) is one that can process, send or receive data and/or can be controlled by an external source e.g. electronic multifunction meters, digital relays, controllers (IEC, 2003).
- Logical Node (LN) is the smallest part of a function that exchanges data and represents the function within a physical device; it performs some operations for that function, (IEC, 2003).

# Abstract

The micro-grid is a conceptual solution proposed as a better way to harness the potential of renewable energy generation and integration by offering a plug-and-play interface for various types of renewable generation resources and loads. One of the major challenges associated with micro-grids is the design and implementation of a suitable control and communication architecture. With a large penetration of micro-grids in a power distribution system, a dedicated communication network infrastructure is needed to coordinate their control actions under various system operating conditions. The information flow in a micro grid communication network has different Quality of Service (QoS) requirements in terms of packet loss rate, throughput, and latency. The changing nature of the micro grid also makes it a requirement to have Quality of service framework to ensure that the protection, control and operations requirements of the micro-grid are met without compromising the power network functionality and integrity. An appropriate communication network framework will ensure that micro-grid operation by enabling timely and reliable delivery of control and protection data.

The research maps the information for monitoring, control and protection of the micro-grid according to substation automation standard IEC 61850. Based on this, a multi agent micro-grid communication network is designed. The study further classifies various micro-grid QoS requirements into QoS classes from which a QoS framework is proposed. The QoS framework is evaluated through the use of OMNET object oriented simulator.

The results show that latency can be reduced and reliability increased for the data flow with a higher priority by use of an appropriate QoS mechanism.

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# Dedication

*To Ano,*

*Always.*

# Chapter 1 - Introduction

## Introduction

The proliferation of renewable energies is changing the way electricity is generated and distributed. Traditionally the model has been one of centralized generation with distribution networks spanning huge geographical areas to deliver electricity to consumers. However, the use of renewable energies is rendering the old model of electricity generation and distribution obsolete. The shift is towards distributed generation which takes advantage of renewable energies and other technologies to shift the generation from large scale plants to small scale decentralized systems at household, community, municipal or national level. Distributed generation is the concept of having many different generation points that are not/connected to the grid and allows energy generation to happen even at a small level in communities and be integrated into the main grid.

In the traditional model of the electricity grid, control and monitoring of the generation and distribution grid is simple, the data and traffic monitored is lean, and communication is provided through known channels and protocols. However, the introduction of micro grids and distributed generation has led to a rethink on the communication and control infrastructure of the electricity network. The new distributed model introduces many players into the generation and distribution equation who are different from traditional players as there is a requirement for two-way communication and two-way power flow in the grid. The monitoring and control of the many players in the network results in more complex requirements leading to the concept of "smart distribution grids/smart grids".

A smart grid is a self-aware intelligent system that integrates the behaviors of various actors at various system levels to allow for intelligent generation, monitoring and consumption power over various platforms and systems. The use of devices, services and software which allow bidirectional flow of information and data allows the optimization of smart grid. This enables electricity demand to be adjusted to accommodate instantaneous local (household) generation (for instance PV systems, small wind turbines, micro-turbines and storage capacities available on the grid).

The traditional electricity grid relies on communication networks to transmit control information from one point to another. The communication network in a traditional electricity grid normally covers the generation points, transmission and distribution networks in a hierarchical manner. The introduction of distributed generation and micro grids introduces some complexity which requires new communication models and designs to enable the full integration of such systems. Renewable energy based micro grids bring even more complexity because of the intermittent and varying nature of their generation capacities. This means that control systems must have almost real time responses if grid stability is to be maintained.

Safdar et al (n.d.) define a micro grid as a modern small scale electrical power grid infrastructure for better efficiency, reliability and integration of renewable energy sources which is characterized by two-way flow of power for the electric network and information for the communication network. Weber et al. (2014), also define a micro grid as an interconnection of energy storage devices, distributed energy resources (DERs), and loads within defined boundaries that act as a single controllable entity. These definitions cover the essential characteristics of the micro grid, which are:

- Distributed Energy Resources/generators (DERs)
- Energy Storage Devices
- Small scale power system
- Micro grid loads – household, commercial, industrial etc.
- Control and communication strategies –micro grids are on the vicinity of smart grid systems and should facilitate adaptive control strategies.
- Single controllable entity - a micro grid should allow to be treated as a controlled aggregated load within the power system
- Two-way flow of electricity and information

While so much research has focused on communications systems design and implementation in smart grid, there has been very little focus on micro grids communication. In most instances, the control of micro grids has not relied on communication networks, however the need to integrate with smart grids makes the design and implementation of communication networks within micro grids a necessity. Parhizi, et al. (2015), argues that the role of communication in the micro grid is to provide a means to exchange data and monitor various elements for control and protection purposes. Figure 1 shows the communication layer as part of a smart grid functional layers.

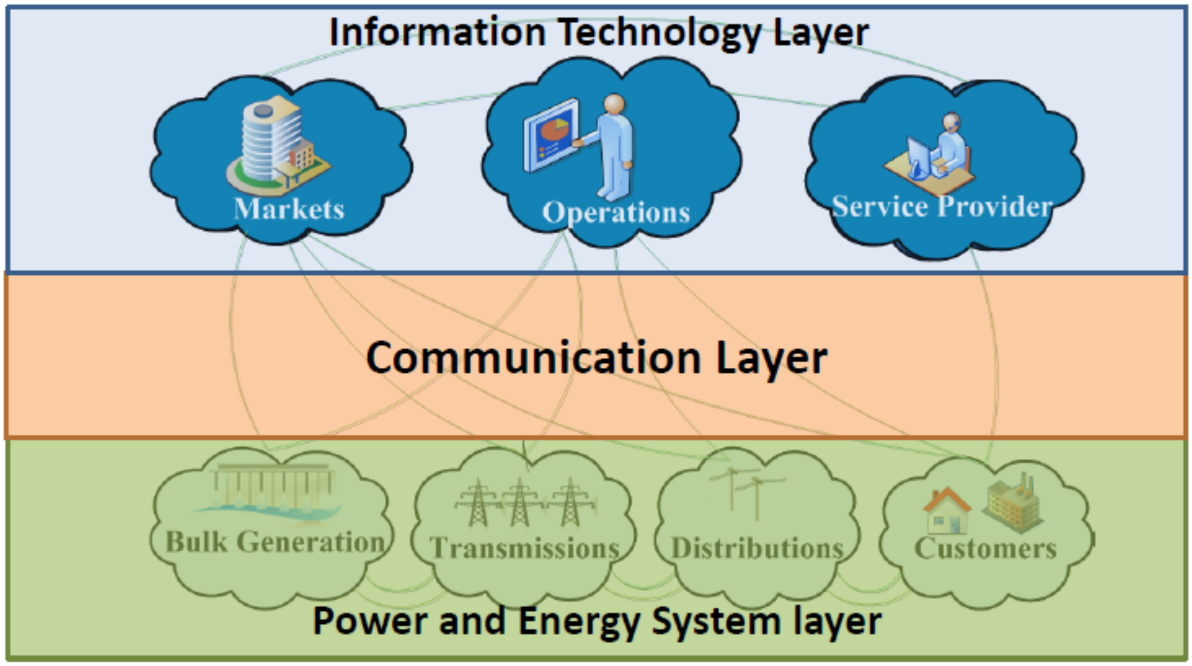


Figure 1-1: Smart grid layers. Source: (Ban, et al., 2012)

The introduction of communication network in power network comes with various design and research challenges that need to be overcome in order to enable the smooth transition of electricity grids into smart grids. Some of the major communications requirements in a smart grid are:

- Security – ensuring that there is end-end security in the communication network and no unintended access to data;
- Reliability – ensuring that the communication network delivers the required services; and
- Quality of Service (QoS) – a guarantee by the network to provide certain performance in terms of bandwidth, reliability, delay and jitter etc.

## Problem Statement

Conventional telecommunications networks are optimized to provide best effort service. This means that the network does not offer any guarantees in terms of reliability, latency or bandwidth that can be offered to any service or application. Therefore, conventional networks are not suited for providing quality of service guarantees to smart grid traffic. While there have been great strides in developing methods of offering QoS guarantees to multimedia applications such as voice over IP (VoIP), media streaming and web browsing, this is not true of power network applications. In multimedia, similar packets are grouped into traffic classes which are then treated according to the priority requirements of the associated traffic. This allows different types of traffic to be given the necessary priority and resources to be allocated accordingly. However, such QoS frameworks cannot be used in smart grid because of the different application characteristics and traffic patterns. In a smart micro grid, information exchange is mainly among a large number of sensors and actors without or with very limited human intervention (machine to machine communication). Machine to machine communication is autonomous in nature and triggered either by time or events. On the other hand, the coexistence of protection, control, monitoring and reporting traffic in the same network poses the additional challenge of how to implement adaptive QoS differentiation in the smart grid communication network. Smart grid communication networks need to support a wide range of traffic sources with significantly varying QoS requirements. It is important to acquire detailed knowledge about the potential applications and characterize their traffic requirements in order to properly assess the available communication technologies, architectures and protocols. Strict QoS mechanisms are required to efficiently handle the reporting, monitoring, control and protection traffic with different QoS requirements in the same network.

In smart grid sessions, the session durations are generally brief and involve only a handful of message exchanges. However, most of the applications require highly reliable message delivery within a strict delay bound. Hence their performance has to be measured in objective terms against a set of predefined QoS attributes (e.g. delay, jitter and packet loss). While currently there is a broad definition of bandwidth requirements, latency and packet loss expectations for various smart grid applications, these are broad and fail to take consideration of the changing nature of the grid. The heterogeneous nature of the communication network also makes it difficult to come up with a QoS framework that can be supported by the various network types.

The increased penetration of DERs into the power domain necessitates reliable and QoS aware communication in order to safely and efficiently manage the grid, (Demir, et al., 2015). Design of a QoS framework for micro grid communication requires a different approach beginning with an understanding and listing of all utility applications and their priority and latency requirements, (Budka, et al., 2010). The big dilemma is how to have QoS management for a large set of applications with different latency, availability and reliability requirements where such can actually change depending on the events occurring in the grid at any point in time.

## Research Objectives

This main objective of this research was the design of a QoS framework broker for the smart micro grid communication network. The main objective was achieved through the following sub objectives:

- Design of a small scale micro grid power system
- Mapping a communication network to the micro grid power network based on IEC 61850;
- Reviewing of micro grid communication applications and characterizing their communication needs according to the grid state and events;
- Defining QoS metrics and requirements for different micro grid applications into QoS classes;
- Designing the communication network QoS framework based on the metrics and other important parameter such as probability of occurrence, severity of impact etc.;
- Mapping the QoS framework on a communication network to assess the performance of the proposed QoS framework using OMNET++ simulation;

## Research Methods

- Literature review was the basis of much of the work towards the first, second and third sub objectives.
- The fourth sub objective was realized through the use of the IEC 61850 standard and previous research in communication networks;
- The final objective to test and evaluate the objective was based on simulation of the micro grid communication network using OMNET++ an open source simulator.

## Research Limitations and Bounds

- The research on QoS framework shall be limited to within a micro grid as defined in this paper up to the point of common coupling with the main grid. The operations, control and interactions with any entity outside the micro grid and its impact are not considered.
- The assumption is that all communication is over an Internet Protocol (IP) network
- Where possible the work shall borrow from others' previous works and researches up to the level indicated in the main report

- The micro grid shall be assumed to have a mix of various Distributed Energy Resources (renewable and now-renewable), Loads and Energy Storage Systems.

## Knowledge Addition

Currently there is no universally designed QoS framework for micro grid communications that can be used in the design and testing of network/ routing protocols. This paper seeks to establish such a framework for a smart micro grid. While there are general requirements on latency, bandwidth and network availability, these fail to consider the other important factors such as the changing nature of the micro grid and the impact of these changes on the QoS framework. The study is expected to provide a framework that will work as the basis for all future work in investigating the performance of network protocols or design of such for similar smart micro grids.

## Organization of the Study

Chapter 1 has presented the introduction, problem statement, research methods, significance and limitations of the study. Chapter 2 presents a review of relevant literatures and provides a reference to related studies of importance to the current study. Chapter two goes into detail on micro grids, communication in micro grids and narrows down on QoS issues in micro grids. A background to relevant standards for micro grid communication is also given. The IEC 61850 standard is reviewed in detail as it provides the core standards for the development of the proposed model. Lastly the chapter gives an overview of OMNET++ open source simulator. Chapter 3 presents the research methodology and procedures used in gathering data for the study. The research finding and discussion of results is presented in Chapter 4. Chapter 5 gives a conclusion on the research and the finding, and concludes by giving recommendation for future studies.

# Chapter 2 - Literature Review

## Introduction

The chapter provides relevant literature on issues that are relevant to the study. The chapter is divided into four major parts. The first part covers the communication standards with emphasis on IEC 61850. The second part reviews literature on micro grids. The third section covers micro grid communication including why communication is required in smart grid, different communication technologies and architectures. The fourth section covers QoS in detail. A detailed background on QoS is provided, QoS mechanisms and why QoS is required in MCN. In each section, relevant previous studies are reviewed.

## Standards

Different standards have been put forward for smart grids and DERs. Figure 2.1 below shows the different smart grid standards. Of interest to this study are IEEE1547 and IEC 61850.

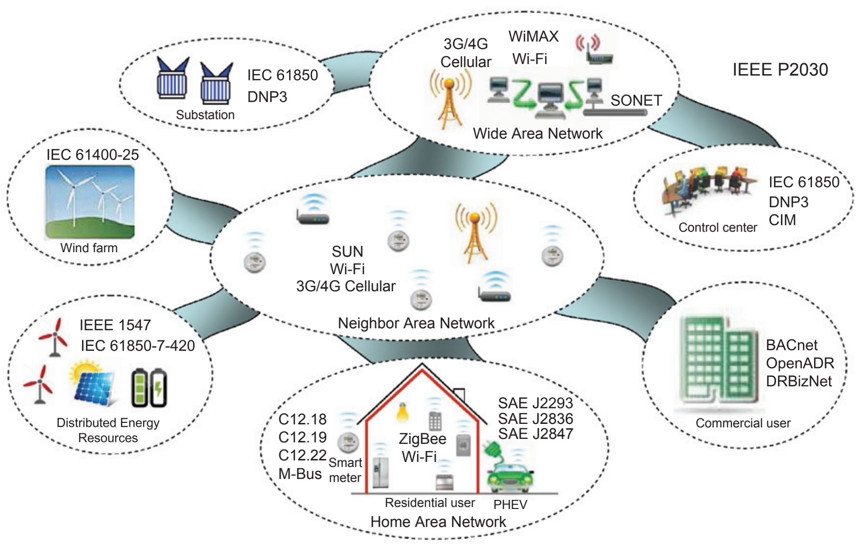


**Figure 5.2 Representative SG standards.**

**Figure 2-1: Smart Grid Standards (Source: Obaidat et.al., 2013.)**

### IEC1547

IEEE 1547 are a series of standards for interconnecting DERs with electrical power systems. The standard provides the minimum functional technical requirements universally needed to help ensure a technically sound interconnection, (Basso & Deblasio, 2004). The standard covers key considerations in designing the micro grid power systems. Major issues addressed by the standard include:

- Point of Common Coupling design;
- Micro grid components and sizing;
- Protection and control schemes;
- Power functionality requirements.

### IEC 61850

Is an international standard for substation automation aimed at reducing the diversity and complexity of utility automated solutions. It enables the integration of all protection, control, measurement and monitoring functions by one common protocol (ABB, 2011). It is a 10-part standard that covers various aspects of substation automation and of late has been extended to cover DERs modelling. It uses object oriented (OO) data models that describe the process to be implemented and controlled rather that how it is to be implemented. The IEC 61850 -7-420 defines data models for micro grid use.

#### Performance Classes and Message Types

IEC 61850 defines two groups of performance classes for substation automation as:

1. Control and Protection applications as shown in Table 2.1

**Table 2-1: Performance classes for control and protection data**

| Data Type | Class | Transmission time (ms) defined by trip time | Resolution (Bits) Amplitude | Rate (Samples/s) Frequency |
|---|---|---|---|---|
| Voltage | P1 | 10 | 13 | 480 |
| Current | | | 13 | |
| Voltage | P2 | 3 | 16 | 960 |
| Current | | | 16 | |
| Voltage | P3 | 3 | 16 | 1920 |
| Current | | | 18 | |

2. Metering and Power Quality applications as shown in Table 2.2

**Table 2-2: Perfomance Classes for Metering and Power Quality Application**

| Data Type | Class | Accuracy classes and harmonics | Resolution (Bits) Amplitude | Rate (Samples/s) Frequency |
|---|---|---|---|---|
| Voltage | M1 | Class 0.5 | 12 | 1500 |
| Current | | Class 0.2<br>Up to 5th harmonic | 14 | |
| Voltage | M2 | Class 0.2 | 14 | 4000 |
| Current | | Class 0.1<br>Up to 13th harmonic | 16 | |
| Voltage | M3 | Class 0.1 | 16 | 12000 |
| Current | | Up to 40th harmonic | 18 | |

The IEC 61850 also identifies seven types of messages to be exchanged in a power system as shown in Table 2.3:

**Table 2-3: IEC Message Types and Latency Requirements**

| Type | Message | Performance Class | Requirements (Transmission Time) |
|---|---|---|---|
| 1A | Fast Messages (Trip) | P1 | 10ms |
| | | P2/P3 | 3ms |
| 1B | Fast Messages (Other) | P1 | 100ms |
| | | P2/P3 | 20ms |
| 2 | Medium Speed | | 100ms |
| 3 | Low Speed | | 500ms |
| 4 | Raw Data | P1 | 10ms |
| | | P2/P3 | 3ms |
| 5 | File Transfer | | ≥1000ms |
| 6 | Time Synchronization | | (Accuracy) |
| 7 | Command Messages (Access Control) | | |

### IEC 61850 protocols and mapping

IEC defines three types of protocols for DER communication as:

1. MMS (Manufacturing Message Specification) designed for sending substation status information for monitoring;
2. GOOSE (Generic Object Oriented Substation Event)/GSSE (Generic Substation Event) designed for sending critical data such as control signals and warnings; GOOSE is a fast connectionless[1] communication service used for the transfer of time critical data where high speed and security are achieved by the repetition of messages a number of times (Yoo, et al., 2011). GOOSE is a multicast service that allow simultaneous delivery of the same substation event message to multiple IEDs, and GOOSE messages can serve different applications with different performance requirements (Hou & Dolezilek, 2010).
3. SMV (sampled Measured Value) - used for measured values from sensors.
4. The IEC 61850 model provides a mapping of the important communication messages to the TCP/IP model as shown in Figure 2.2:

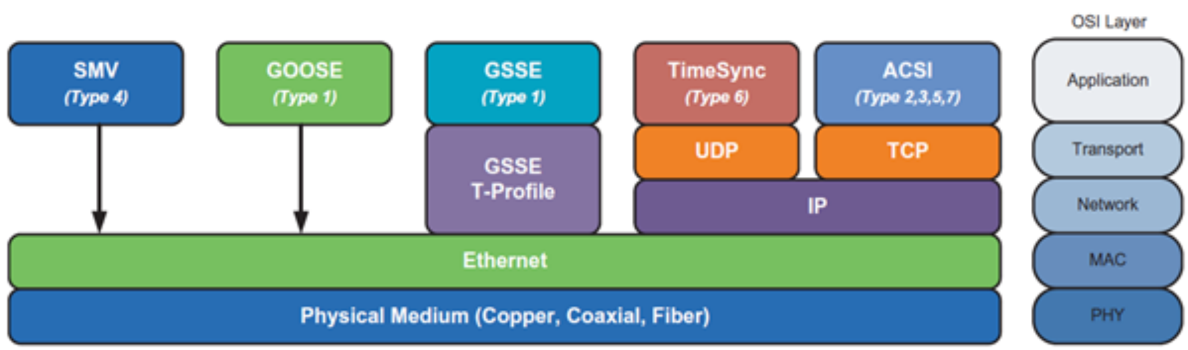


**Figure 2-2:IEC 61850 Communication Stack. (Short & Dawood, 2014)**

The time critical GOOSE and SV protocols were mapped directly to the Ethernet layer, thereby bypassing the network and transport layer. As such, GOOSE messages are not routable through a Wide Area Network as they can only be exchanged within a single VLAN (Hou, et al., 2014).

[1] The protocol does not seek to establish and end-to-end link from sender to recipient before data is transmitted.

*Performance Classes*

Based on the different message types to be transmitted for power system automation, IEC came up with 7 performance classes as shown in Table 2.4.

**Table 2-4: IEC 61850 Transfer Time Classes**

| Transfer Time Class | Transfer Time [ms] | Application examples |
|---|---|---|
| TT0 | >1000 | Files, events, log contents |
| TT1 | 1000 | Events, alarms |
| TT2 | 500 | Operator commands |
| TT3 | 100 | Slow automatic interaction |
| TT4 | 20 | Fast automatic interaction |
| TT5 | 10 | Releases, Status Changes |
| TT6 | 3 | Trips, Blocking |

The IEC 61850 series of standards provide the basic building block for the QoS specifications of DER/micro grid communication. Any design of the communication system, subsequent protocols and systems should aim towards fulfilling these requirements.

**Previous Studies**

(Islam & Lee, 2016)designed a micro grid power and communication network using the multi agent approach and the IEC 61850 standards. In their design, they defined the following agents in a micro grid power system:

- Grid Interface Agent – for monitoring grid voltage, phase angle and frequency and is also responsible for islanding or reconnecting a micro grid from/to main grid;
- Main Feeder/Sub-Feeder Agent for maintaining the information about the switch at the feeder point and allows the synchronization of upper and lower levels;
- Load Agent is responsible for monitoring and controlling of the load;
- Storage Unit Agent for monitoring the energy level and status information of a storage unit;
- DER Agent for monitoring and controlling the power levels, voltage, frequency and connection and disconnection of different DERs;

- Micro grid Control Centre (MGCC) Agent which monitors, controls and schedules micro sources and loads by providing reference voltage, frequency and reactive power set points for the DERs (including storage);
- Breaker Agent which perform function such as monitoring of switch status, agent isolation (switching on/off) based on information from control agent;
- Measurement Agent continuously measures and sends measured voltage and current samples to respective control and protection agents; and
- Protection and Control (P&C) Agent which represents Load Agent, Storage Unit Agent, Main Feeder/Sub-Feeder Agent, Grid Interface Agent.

Each protection point of a micro grid is made up of IEDs responsible for monitoring, controlling and protection of the various agents. Based on this understanding, Islam and Lee (2016) further modelled each protection point as having three agents: Measurement, Protection and Control and Breaker agent. They defined IED agents within each protection point as local agents and those at a different point as remote agents. All the IEDs act as data sources and local agents exchange data locally and exchange information with remote agents via the share communication network. In designing the communication network, they used the MAS approach. They proposed a list of extensible information for micro grid communication by identifying the different objects within the network.

**Table 2-5: Extensible Information in Micro grid (Islam & Lee, 2016)**

| Information Type | Source Node | Receiving Node | IEC 61850 Services | ASU Size in Bytes | Sample /sec |
|---|---|---|---|---|---|
| Status Value | Breaker agent | Control agent and MGCC | Unbuffered Reporting | 16 | 20 |
| MG Operating Mode | MGCC | DER agent | GOOSE | 16 | Random |
| DER/Relay operation Set Point | MGCC | DER agent/P&C agent | Buffered reporting | 64 | 16 |

| | | | | | |
|---|---|---|---|---|---|
| Generated or absorbed Power | P&C agent | MGCC | Buffered reporting | 32 | 16 |
| Synchronous Message | P&C agent | P&C agent | GOOSE | 32 | Random |
| Breaker Control | P&C agent /MGCC | Breaker agent | GOOSE | 32 | Random |
| Current rating and type of DER unit | DER agent | MGCC | Buffered reporting | 32 | 16 |
| Current and Voltage Sample | Measurement agent | P&C agent | Sampled measured value | 52 | 960 |
| File Transfer | P&C agent | MGCC | File transfer | 1000 | |

(Ustum, et al., 2011) evaluated the need for a centralized micro grid management system for control and monitoring of micro grid components, the communication strategy and standardization which are required therein based on the IEC 61850 standard and its extension for DERs, IEC 61850-7-420.

## Micro grids

The electricity generation, transmission and distribution model is gradually changing due to the high proliferation of distributed generation (DG). In the traditional model of the electricity supply chain, energy generation is normally done at centralized high capacity generation plants and is then transmitted over long distances to distribution centers and for final dispatch to consumption centers. The hierarchy is clear with each level of the power grid distinct in form and function from the other levels. However, there is a current shift in the power generation landscape with the introduction of low voltage generators which are connected to the distribution level of the electricity network. This has been brought about by the increase in deployment of Distributed

Energy Resources (DERs) which include renewable resources, diesel generators and in some cases even heat systems.

The introduction of the DERs means that the flow of electricity no longer follows the traditional hierarchical model, as there is now bidirectional flow of electricity at the distribution level. These changes and the need for the electricity network to evolve in line with technology and other changes in sectors such as ICT has resulted in the introduction of the smart grid concept. The concept of the smart grid is one that continues to develop and most of its aspects are under research. Jain and Mandloi (2012), define smart grid technology as a collection of existing and emerging technologies working together. The smart grid encompasses both old and new technologies and concepts that interwork to provide an intelligent, interactive, self-aware electric grid systems which allows for the bi-directional flow of electricity and information.

According to the Worldwide Smart Grid initiative, the future of electrical networks must be flexible, accessible, reliable and economic. This calls for the integration of various technologies and systems to provide the required intelligence and functionalities. These systems are interlinked through communication networks.

There is no commonly agreed definition of a smart grid. Different authors define the smart grid differently but there are common aspects which can be summarized as the combination of power networks and ICT systems to allow bidirectional/multidirectional flow and management of power and data. Figure 2.4 shows a reference model of a smart grid, showing the electricity supply chain from bulk generation, transmission, distribution and consumption. DERs are normally deployed at the distribution level of the smart grid and in this case, has been represented as part of a micro grid.

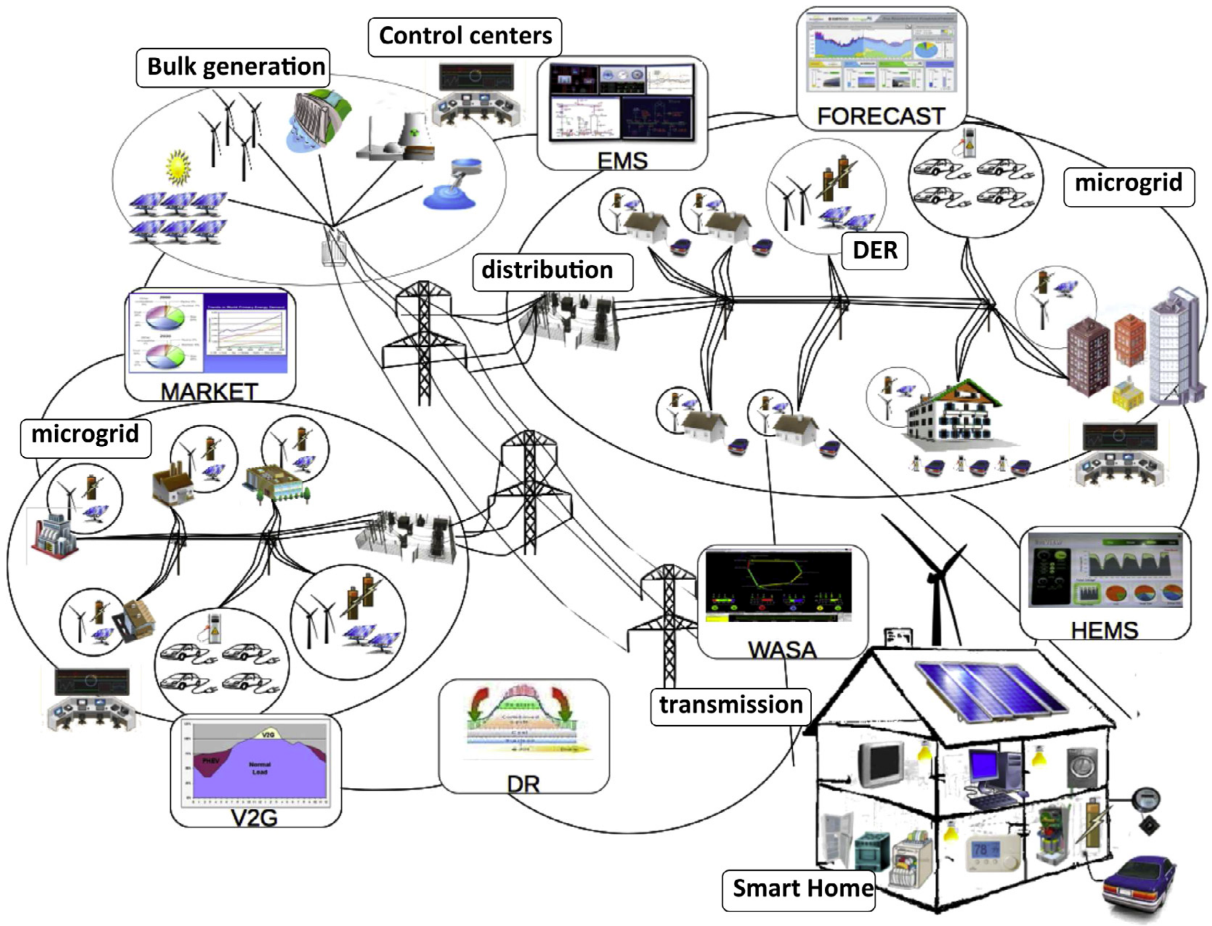


**Figure 2-3: Reference model of a smart grid: Source Ancillotti et.al., 2013**

The micro grid is the basic building block of a smart grid (Siemens, 2011), made up of integrated systems combining DERs, advanced control systems, load management, energy storage and communication infrastructure with capability to work in both grid connected and/or islanded mode to optimize energy usage (Jain & Mandloi, 2012). (Biagi & Favlo, n.d.) have defined a smart micro grid as a small low voltage grid, connected to the main medium voltage (MV) grid, using a single point of connection (point of common coupling, PCC) equipped with suitable ICT for making it smart. Mahmoud (2017) also defines micro grids as local grids comprising different technologies, such as power electronic converters, distributed generation (DG) units, energy storage systems (ESSs) and telecommunication systems that cannot only operate connected to the traditional centralized grid (macrogrids) but can also operate autonomously in islanded mode.

From the many definitions one can define the major components of a micro grid, which are:

- Distributed Energy Resources/generators (DERs)
- Energy Storage Devices

- Local loads – household, commercial, industrial etc.
- ICT systems for control, protection and monitoring
- Single controllable entity - a micro grid should allow to be treated as a controlled aggregated load/source within the power system
- Two-way flow of electricity and information

Figure 2.5 shows a schematic of a generic micro grid power system with a number of DERs and loads. The micro grid in Figure 2.5 is able to offer redundancy and security to its circuits and can allow and one of the sub circuits to be isolated without affecting the operation of the whole system. This is achieved through use of a control system and circuit breakers (CB).

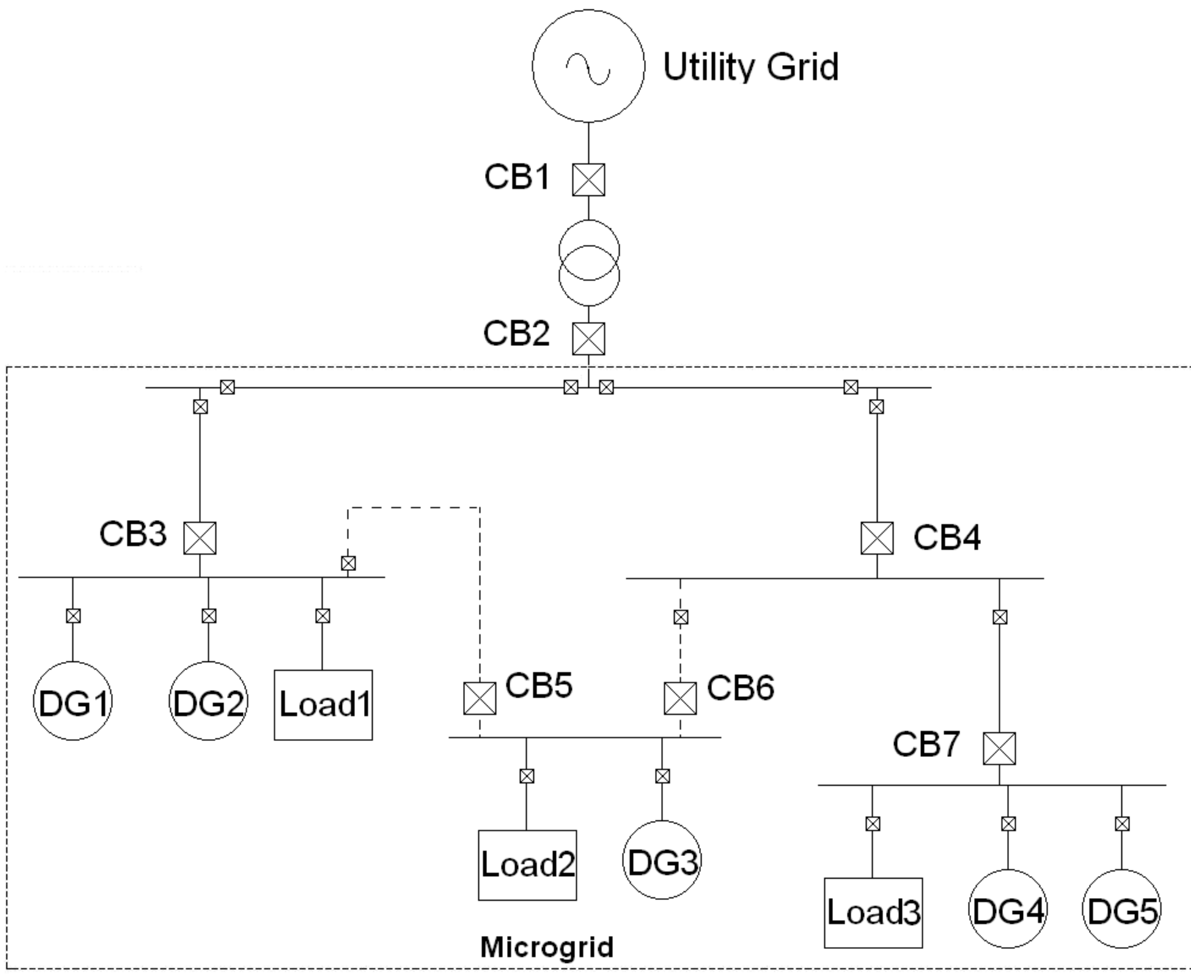


**Figure 2-4:Sample Micro grid: Source (Ustun, et al., 2012)**

(Kolja, et al., 2013) posits that since a micro grid contains most of the smart grid use cases in small, then arguments advanced in smart grid communication are equally applicable to micro grid. The vision of the future grid is one comprised of a number of interconnected micro grids in which every user is responsible for the generation and storage of the energy that is consumed and for sharing the energy with neighbors. In this system DERs must have power electronic interfaces (PEIs) and control systems to ensure flexibility to operate as a single aggregated system maintaining the power quality and energy output (Marian, et al., 2013).

Micro grids offer a lot of advantages which include:

- The ability to work in both grid connected/islanded mode making it possible to maintain supply to critical loads when the main grid is unstable;
- Ability to connect and integrate DERs including renewable energy sources;
- Increased reliability;
- Reduced carbon emissions;
- Long term reduction in energy cost
- Diversity of energy sources; and
- Reduction of energy poverty

On the other hand, there are drawbacks presented by micro grids:

- Increased complexity of control in islanded and transition mode;
- Security concerns with integration of ICT networks;
- Lack of one global standard for their design and implementation;
- Transient nature of generated power.

### Dynamic Nature of Micro grid

According to (Ustum, et al., 2011), the changes in the micro grid structure can be because of a new load/DER, islanding, faults or reconfiguration for maintenance. This on one hand is desirable as it offers flexibility to the operation but on the other hand is undesirable as it increases control complexity. They further explain that when such changes occur, this also changes the control and protection strategies assigned, and the communication network should allow the micro grid to respond to such changes without disrupting service.

Communication systems integration is required for the implementation of reliable, safe, secure, sustainable and cost effective micro grid control architecture (Weber, et al., 2014). According to (Safdar, et al., n.d.), the initial concept of smart grid was to design bidirectional communication infrastructure to support intelligent mechanisms such as real time monitoring, protective relaying and to satisfy consumers need of power. They further argue that because a micro grid constitutes a segment of the smart gris, it inherits some of its characteristics.

The role of communication in the micro grid is to provide a means to exchange data and monitor various elements for control and protection purposes (Parhizi, et al., 2015). The communication network also enable sending of control signals to micro grid components in a centrally controlled system.

## Micro grid Communication

A highly reliable communication network is a requirement to allow for fast recovery and automatic control of the micro grid to counter the fragile and transient nature of the micro grid. The communication system should be able to allow for quick isolation of faults, switch loads to reliable power sources, and collect key data of the faulty section to reduce downtime after a severe fault (Li et.al (2016)). The data collection requirements of a micro grid are as summarized in Figure 2.6.

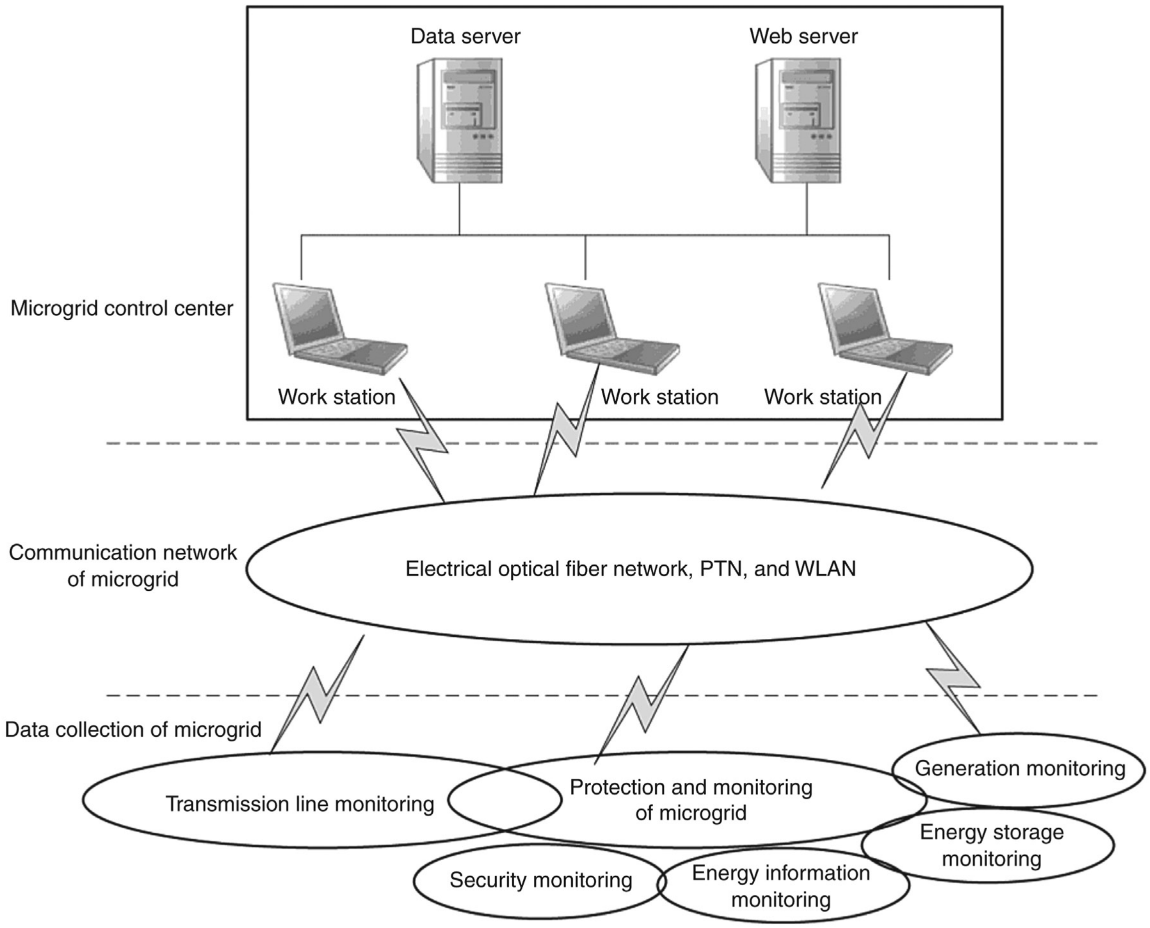


Figure 2-5: Architecture of the micro grid monitoring communication network (Source Li.et.al., 2016)

The smart grid concept defines different types of communication networks for the generation, transmission, distribution and consumption power system layers as shown in the diagram below. Figure 2.7 shows a layered model of the smart grid with the power system layer and the communication layer. Of interest to this study is the Neighborhood Area Network (NAN) where micro grids and DERs are defined.

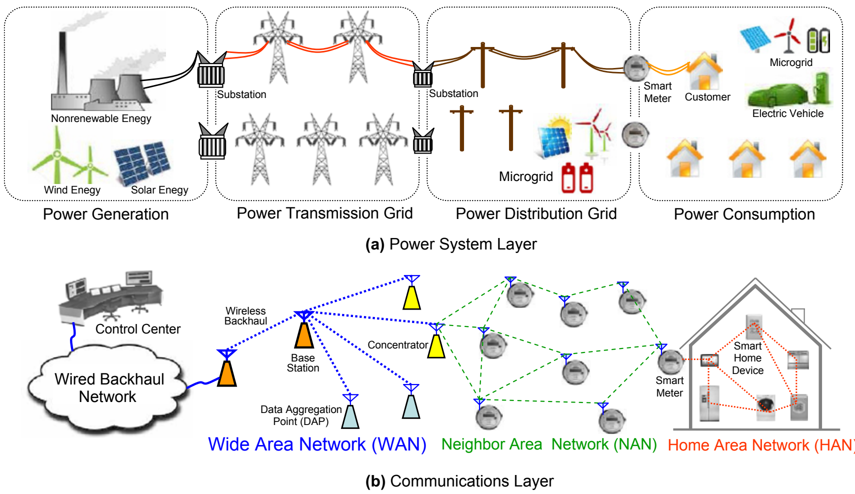


**Figure 2-6: Layered architecture of smartgrid (Source: Obaidat et. al., 2013)**

## Micro grid Communication Structure

Li et. al., 2016 have divided the micro grid communication system into three functional hierarchical layers as:

- local control layer[2]- which consists of the data collection devices which are directly connected to measured objects. The layer is responsible for transferring measured data and receiving orders from the central control layer;
- central control layer[3] - which is responsible for giving control orders to the local control layer based on the measured node information received from local control layer. The layer

[2] Some of its functions include:

- collection of micro grid data,
- local protection and control of equipment,
- high-precision and quick collection of measured data of feeders,
- protection of feeders against failure,
- monitoring of inverters for grid connection of DGs,
- maximum power point tracking,
- grid dispatch mode,

[3] Its functions include:

- dynamic power disturbance control
- central fault protection
- central differentiated protection of the micro grid
- control of transition between grid-connected mode and islanded mode
- quick dynamic stability control following a grid disturbance
- support of quick communication protocol of IEC 61850 process layer

also receives instructions from higher layers for dispatch to lower layers. The layer functionality requires high quality data transmission capability; and

(IEEE, 2011) has defined three control methods for the micro grid as: centralized control, distributed control and autonomous control[4]. The primary challenge in networked control design for a micro grid system is to build a distributed control system that can endure packet losses, delays, and partially decoded packets that affect system stability, Mahmoud (2017). Communication links have to fulfil connectivity requirements defined with quality of service parameters depending on the challenges of the data transport (Kolja, et al., 2013).

## Communication Technologies for Micro grid

Different communication technologies provide different characteristics in terms of important communication performance parameters such as latency, reliability, jitter and security and cost. (Sahin, et al., 2013) did a survey of various technologies for the different smart grid applications and concluded that there is no one-size fits all solution. (Kim & Lim, 2012) proposed a communication infrastructure based on the wireless sensor networks (WSN) for geographically islanded micro-grids. (Islam & Lee, 2016) experimentally evaluated the performance of wifi, wimax and an integrated network with fiber and wimax. They concluded that the integrated network design with fiber and wimax is the best model for meeting the communication requirements in a cost-effective manner. (Levensque & Maier, 2012) proposed a converged fiber-wireless (FiWi) broadband access network based on low cost Ethernet passive optical network (EPON) and wireless mesh networks as the best communication technology for achieving low cost effective and reliable smart grid communication in the NAN. Overall, a hybrid network of fiber

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- clock synchronization

[4] (IEEE, 2011)micro grid control strategies:

- Centralised control- provide the command to the entire system in what is effectively a master-slave configuration between the central system and distributed devices
- Distributed control- independent controls communicating with one another. Uses intelligent devices that are strategically located to detect conditions and initiate the required actions.
- Autonomous control- independent controls without communication with other devices.

and some wireless technology has been empirically proven to offer the communication requirements of a smart grid.

### Micro grid Communication Requirements

Micro grid communication is machine to machine (M2M) communication in that it is made up of various electronic devices exchanging information among themselves. This differs from human to machine (H2M) or human-to-human (H2H) communication in terms of the traffic pattern, the delay and latency requirements. (Vardakas, et al., n.d.) argue that M2M traffic has different characteristics compared to H2H traffic, and has mainly sporadic transmissions, triggered by events or time for data collection and monitoring. Smart grid sessions are generally brief with small data packets exchanged, however, most of the applications require highly reliable message delivery within a strict delay bound (Khan & Khan, 2013).

(Safdar, et al., n.d.) defined two major micro grid communication requirements as delivering the data within the limits of packet loss and latency. These two parameters specify the amount of resources to be dedicated to micro grid applications.

Micro grid communication is expected to happen over public shared networks. While the provision of dedicated point-to-point networks would provide the best QoS this is both costly and impractical. The major drawback with current networks is that they are not designed with QoS in mind, but rather are best effort services. This means that there is no guarantee to deliver micro grid data within specified levels unless special mechanisms are put in place to allow for this.

The traffic in a micro grid is also different from conventional traffic. (Gao, et al., n.d.) define smart grid NAN, downlink traffic as unicast and multicast, and uplink traffic as converge cast. This means that hosts send information to everyone in the network and listen to all incoming messages and decide if they are the intended recipients.

## QoS

### Introduction

Quality of Service (QoS) is a guarantee by the communication network to provide certain performance in terms of bandwidth, reliability, delay, jitter and security, (Saputro, et al., 2012). QoS mechanisms offers the network a capability to provide better service to selected traffic/applications while ensuring that other network flows do not fail (Cisco, 2012). Generally, communication networks have limited bandwidth for transmission of all traffic and when there is too much traffic this can result in a loss of important traffic as packets are dropped. The concept of QoS is anchored on the idea that traffic characteristics such as transmission rates, error rates etc. can be measured, improved to some extent and guaranteed in advance ( (Tech Target, 2008)Tech Target, 2017).

Such guarantees requires a detailed understanding of the different QoS parameters that should be fulfilled. (Kolja, et al., 2013) defined five important QoS parameters for any communication system:

- Delay or Latency - Time taken by a packet to reach the receiving endpoint after being transmitted from the sending point. It is a sum of propagation, processing, transmission and queuing delays on the path across the network;
- Delay variation (jitter)- difference in the end-to-end delay of packets;
- Throughput or rate- user bandwidth or bit rate measure between an ingress and an egress point;
- Packet loss; and
- Availability- fraction of time that network connectivity is available between an ingress point and a specified egress point.

## QoS Mechanisms

QoS can be provided by either raising the priority of a flow or limiting the priority of another flow (Cisco, 2012). This can be achieved through various mechanisms. (Ganz, et al., 2004) explores the QoS mechanisms in detail and classified QoS mechanisms into two major subgroups as follows:

**Table 2-6: QoS Mechanisms**

| Broad Category | Sub-Mechanisms |
|---|---|
| Traffic handling mechanism | 1. Classification<br>2. Channel Access<br>3. Packet Scheduling<br>4. Traffic Policing/monitoring |

| | |
|---|---|
| Bandwidth management mechanisms- manage network resources through coordination and configuration of network devices. | 1. Resource reservation<br>2. Admission control |

These mechanisms are not independent or exclusive of each other. Most of the times a combination of various strategies from the two broad groups are used together to achieve the required QoS. The first step with any of the mechanism in achieving QoS is traffic classification. The classification mechanism identifies and separates different traffic flows or groups of flows (aggregate flows or classes) (Ganz, et al., 2004) . This enables the unique identification of any traffic to be handled differently.

## QoS Requirements in Micro grids

The micro grid has different types of traffic with different QoS requirements. This calls for a solution that takes into account all these different dynamics. To derive the QoS requirement, it is important to describe the probabilistic dynamics of the power system to evaluate the impact of different QoS specification on the smart grid system and to derive the QoS requirements from the corresponding impact (Gungör, et al., n.d.). The micro grid communication infrastructure should adopt suitable mechanisms to enforce different QoS guarantees on network flows depending on the application constraints (Ancllotti, et al., 2013).

(Yuan, et al., 2010) classified power distribution network traffic into two categories as:

- Operational data which is periodic measurements of device condition and power quality; and
- Emergency data which is triggered by any detected failure in the system.

They further explain that while operational data should ideally be transmitted reliably all the time, to prevent possible catastrophic events, emergency data should be given priority to preempt any operational data waiting for service. The idea is reinforced by (Hou, et al., 2014) who also argue that control messages are the highest priority and the control action is considered successful only if all the controlled devices perform the specified actions within a certain time limit, for example, a system may blackout due to a breaker not turning off timely.

IETF has proposed many service models and mechanisms to meet the demand for QoS in communication networks such as Integrates Service(IntServ), Differentiated Services (DiffServ), Multi-protocol label switching (MPLS)and traffic engineering (Hunt, 2002). These mechanisms work at the transport and the network layer of the OSI communication model. The major shortcoming with these models when it comes to micro grid traffic is that they are designed for multimedia and VoIP services which normally do not require hard QoS guarantees. In power networks, failure by the communication network to deliver messages timeously can be catastrophic. Managing a diverse set of application priority and latency requirements for a smart grid network will require a different QoS design approach, which should begin with identification of all utility applications and their priority and latency requirements (Budka, et al., 2010).

TCP is normally used in industrial automation systems and would appear to be a suitable mechanism for micro grid traffic, however, in micro grid applications, message payloads are less than 1000 bytes, making TCP's additional overhead an unacceptably large protocol overhead (Demir, et al., 2015). They further argue that the low bandwidth usage also makes conventional bandwidth based traffic engineering an overprovision, so new mechanisms tailor made for MCN are required.

Micro grid traffic is made up of specific messages as specified by IEC 61850. The QoS requirements can be derived from these specifications to enable design of suitable QoS mechanisms. GOOSE messages are used for control and protection and therefore require the highest priority. Of note is that the IEC 61850 model maps the GOOSE and SMV messages to the Ethernet layer of the communication stack which means the suitable QoS mechanisms have to operate at physical and data link layer. The physical aspects have already been covered in various studies on communication technologies.

This means classification mechanisms, admission control, and queue scheduling mechanisms are the most suitable for QoS frameworks suited for MCN (Gao, et al., n.d.). With careful admission control at the edge of the network, it is possible to build a network QoS system with reasonably strong QoS guarantees (Foster & Roy, 2000).

## Previous Studies

- (Gungör, et al., 2013) provided a mapping for various smart grid services and their bandwidth, latency and availability requirements.

- (Yong-Hee, 2011) examines the challenges that arises in defining QoS requirements in the smart grid communications system and explores potential solutions for implementing them.
- (Li & Zhang, 2010) explore the problems of "How to define the QoS requirements in the context of the Smart Grid?" and "How to ensure the QoS requirements of home appliances in smart grid networks?". The study focus on two parameters namely delay and outage probability. They approach the design by considering the probabilistic dynamics of the power system and evaluating the impact of different QoS specifications on system performance to derive the corresponding QoS requirement.
- (Aurrecoechea, et al., 2008) examine state of the art in the development of QoS architectures for multimedia applications. They argue that meeting QoS guarantees in distributed systems is fundamentally an end-to-end issue i.e. from application to application.
- (Yang, et al., 2004) proposed an end-to-end QoS framework for multimedia which uses admission control and end-to-end bandwidth reservation to improve on IntServ and DiffServ.
- (Gao, et al., n.d.) designed a QoS framework for NAN SGCN. They validated their model using OMNET++ for simulation of the wireless network.
- (Levensque & Maier, 2012) proposed a multidimensional token bucket algorithm for adaptive admission control in smart grid networks and it addresses latency (such that high priority packets are processed first to reduce latency) and reliability ( by dropping packets from hosts that send packets when the queue is full.

  They also came up with a formula to calculate the minimum bandwidth required so that all applications can pass through a node in their allowed time.

$$Buf = \sum_{i=1}^{n} r_i P_i$$

$$B_i = \frac{\sum_{j=1}^{i} r_j P_j}{D_i - \sum_{j=1}^{i} r_j T_0}$$

$$B_Q = Max(B_i)$$

where:

$r_i$ is the arrival rate of the i[th] application;

$P_i$ is the packet length of the i[th] application;

$n$ is the number of applications

$B_i$ is the required bandwidth for all packets of the i[th] application;

$D_i$ is the allowed delay for the i[th] application;

$T_0$ is the inter-packet overhead;

Buf is the required buffer size for the queue;

$B_Q$ is the minimum required bandwidth for each queue.

- Other studies carried on QoS specifications include:
    - EU FP7 Open Node
    - US DoE NASPInet
    - IEC 61850-5 QoS Classes

Information on QoS classes from the various studies and surveys is not consistent and is not complete as it is dependent on the selected use cases and scopes of the projects.

## Simulation

In the network research area, it is very costly to deploy complete test beds containing multiple networked computers, routers and data links to validate and verify a certain network protocol or specific network algorithms (Pan, 2008). On the other hand, the smart grid and micro grid research area is fairly new and evolving such that real testbeds are few. As such, most of the research and design in this area is achieved through use of simulators. Simulators save time and money as they model objects or activities to investigate their possible performance in real life.

(Pan, 2008) argues that if a system can be modeled then one can modify the features of the model and analyze the corresponding results. Therefore, various scenarios can be tested without the added complexity of a real-life model. However, simulators can only estimate the real situation as it is not possible to capture all real-life variables into a model.

In smart micro grid research, various softwares have been used to model both the power network and the communication network. It should be noted however that power system dynamics and communication network behavior are different and as such there is no single simulator that can simulate the two systems simultaneously. As such researchers have either:

- Simulated the systems independently and then using findings from power simulations as input for communication network simulation and vice versa; or
- Made use of APIs (Application Program Interfaces) which is software code that allows two software programs to communicate with each other – to co-simulation the power and communication networks.

Each approach has its own advantages and disadvantages. The first approach is fairly simple but might not be able to provide the same level of real life co-dependencies between the systems.
The second approach provides a close approximation to real life situation but presents a higher level of technical complexities.

**Network Simulators**

Network simulation can be used to design, analyze, simulate and verify the performance of different network protocols and configurations (Katkarand & Ghorpade, 2016). Minimally, a network simulator should enable representation of a network topology, defining scenarios, specify nodes on the network, links between the nodes and the traffic between the nodes (Pan, 2008).
Network simulators have been used for a long time and the technology is mature. The type of simulator one uses depends on a number of factors. Broadly simulators can be classified based on:

- Source - Commercial or open source.
    - Commercial applications are generally more polished with detailed support services and are offered to end users for a fee. The most popular commercial network simulator is Riverbed (previously OPNET[5]).
    - Open Source network simulators – these are offered for free to end users and are usually developed and maintained by enthusiasts. The major advantage is that the code is offered free of charge and gives the end users the ability to customize the software as required. The major drawback is that documentation and support might not be very extensive, readily available or clearly documented. Some of the most popular Open Source simulators are NS2, NS3 and OMNET++.

[5] https://www.riverbed.com/gb/products/steelcentral/opnet.html?redirect=opnet

- Complexity – network simulators offer different levels of complexity. The complexity refers to the networking scenarios, customization, visualization etc. that can be offered by the network PAN.

In academic research, open source network simulators are the most popular. For this study, OMNET++ was used for simulations.

### OMNeT++

OMNET (Objective Modular Network Test bed in C++) is an open source object oriented modular discrete event network simulator which provides both command line and graphical user interfaces. OMNET consists of simple modules and compound modules. Simple modules are the basic elements in the module hierarchy, they cannot be divided any further. Its most frequent task is sending and receiving messages. Messages are sent via output gate which link to input gates of other modules. Gates are the input and output interfaces of modules, they can be linked with connections. Connections can be assigned properties (such as propagation, delay, data rate and bit error rate). Compound module consist of simple modules or other compound and simple modules

OMNET++ runs on all popular operating systems including Windows, OSX, Linux and Unix making it a universal platform. OMNET has been reviewed as having a short to medium learning period. OMNET produces predictions at a low level which makes it accurate (but slow) to generate results and it does not only support deterministic modelling, but also handles continuous and discrete stochastic variables that give randomness to models (Xian & Hung, n.d.).

### Previous Studies

- (Kemal, 2014), used OMNET++ to analyze the timing requirements for data aggregation and control in smart grids.
- (Kounev, et al., 2014) used OMNeT++ and Adevs for co-simulation of micro grid power network and a smart grid communication network.

- (Levensque & Maier, 2012)The paper outline co-simulation of communication and power network for smart grid and using OMNET++ and Open DSS

## Conclusions

QoS in communication networks for micro grid control, protection and monitoring requires a hierarchical look at various issues. The IEC 61850 standard covers substation automation and has been further extended to cover DERs. As such an understanding of this specification is important in designing a MCN. Communication networks generally offer best effort services and as such, there is need to put in place mechanisms that enable effective and efficient delivery of different messages in a micro grid. This calls for an understanding of the different traffic types within a micro grid and the traffic patterns. The mechanisms for ensuring Qos in a communication network can then be implemented if one understands the requirements fully.

The cost of setting up a test micro grid or a test communication network makes it necessary to have simulators, which are software that mimic the operation of a system. This enables both cost saving and quick evaluation of ideas.

# Chapter 3 - Research Methodology

## Introduction

This section looks at the research methodology taken in undertaken in designing the QoS framework for micro grid communication network. Generally, communication networks have limited bandwidth resources for delivering messages between systems and as such by default employ best effort service which means that there is no explicit guarantee or commitment to meet the communication requirements of the application. On the other hand, micro grid communication networks are critical to the operation of the control, protection and monitoring of the micro grid, which requires specific guarantees in terms of latency and reliability. In order to ensure that the communication network delivers the within the micro grid allowed timelines and reliability requirements, there is need for a QoS framework which can be used to guaranteed the QoS required. As such this study sought to design a QoS framework for a micro grid communication network within the confines of IEC 61850.
This chapter is divided into sections as follows:

## Research Objectives

The main research objective was "To design a QoS framework for a micro grid communication network guided by IEC 61850 standard". This main objective was realized through sub objectives as:

- Design of a small scale micro grid power system;
- Mapping a communication network to the micro grid power network based on IEC 61850;
- Reviewing of micro grid communication applications and characterizing their communication needs according to the grid state and events;
- Defining QoS metrics and requirements for different micro grid applications into QoS classes;
- Designing the communication network QoS framework based on the metrics and other important parameter such as probability of occurrence, severity of impact etc.;
- Mapping the QoS framework on a communication network to assess the performance of the proposed QoS framework using OMNET++ simulation;

## Research Design

The research design process followed the process shown in Figure 3.1.

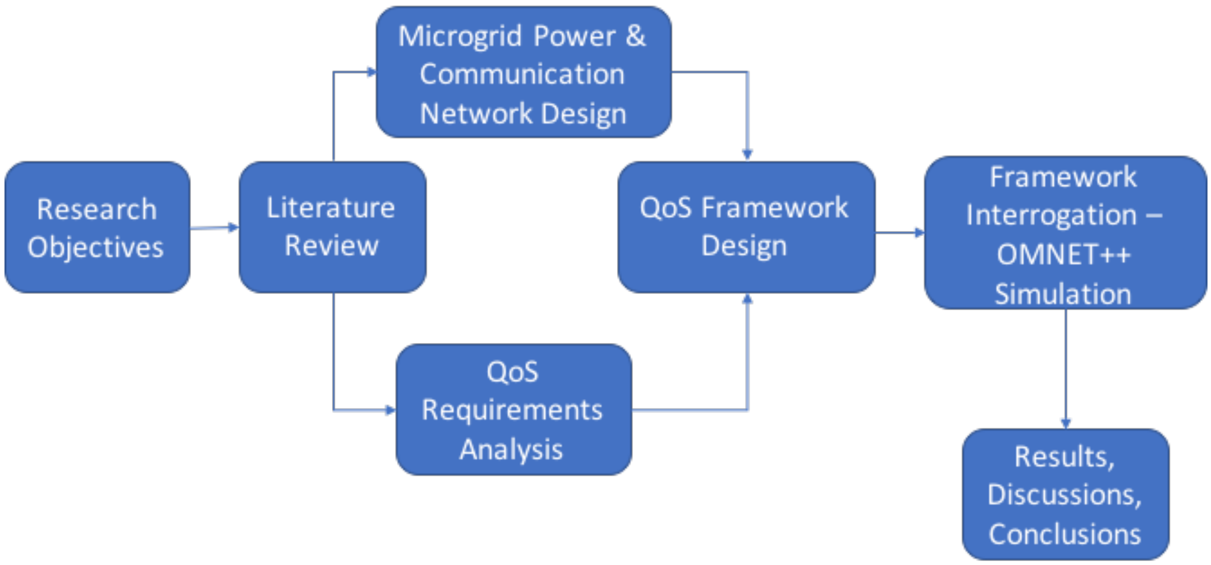



**Figure 3-1: Research process overview**

This section will provide detailed mechanisms of the methodology and theoretical frameworks used to fulfill the individual sub objectives.

### Micro grid Power Network Design

The design of the micro grid power network was based on the IEC 61850 standard and the multi agent system (MAS) approach. The approach views a micro grid as multi agent system made up of different intelligent agents actively exchanging information among each other to achieve certain specific performance goals. Islam and Lee (2016) used a similar approach in designing a micro grid and the corresponding communication network for their evaluation of different communication technologies in micro grid communication.

In this research, a similar approach was used and the micro grid was modelled along the sample micro grid architecture as given by (Ustun, et al., 2011). A micro grid power system was design as shown in Figure 3.2 based on theoretical framework that was analyzed. The micro grid has:

1. An MGCC
2. 1 PCC
3. 4 DERs

4. 1 ESS

5. 5 Loads

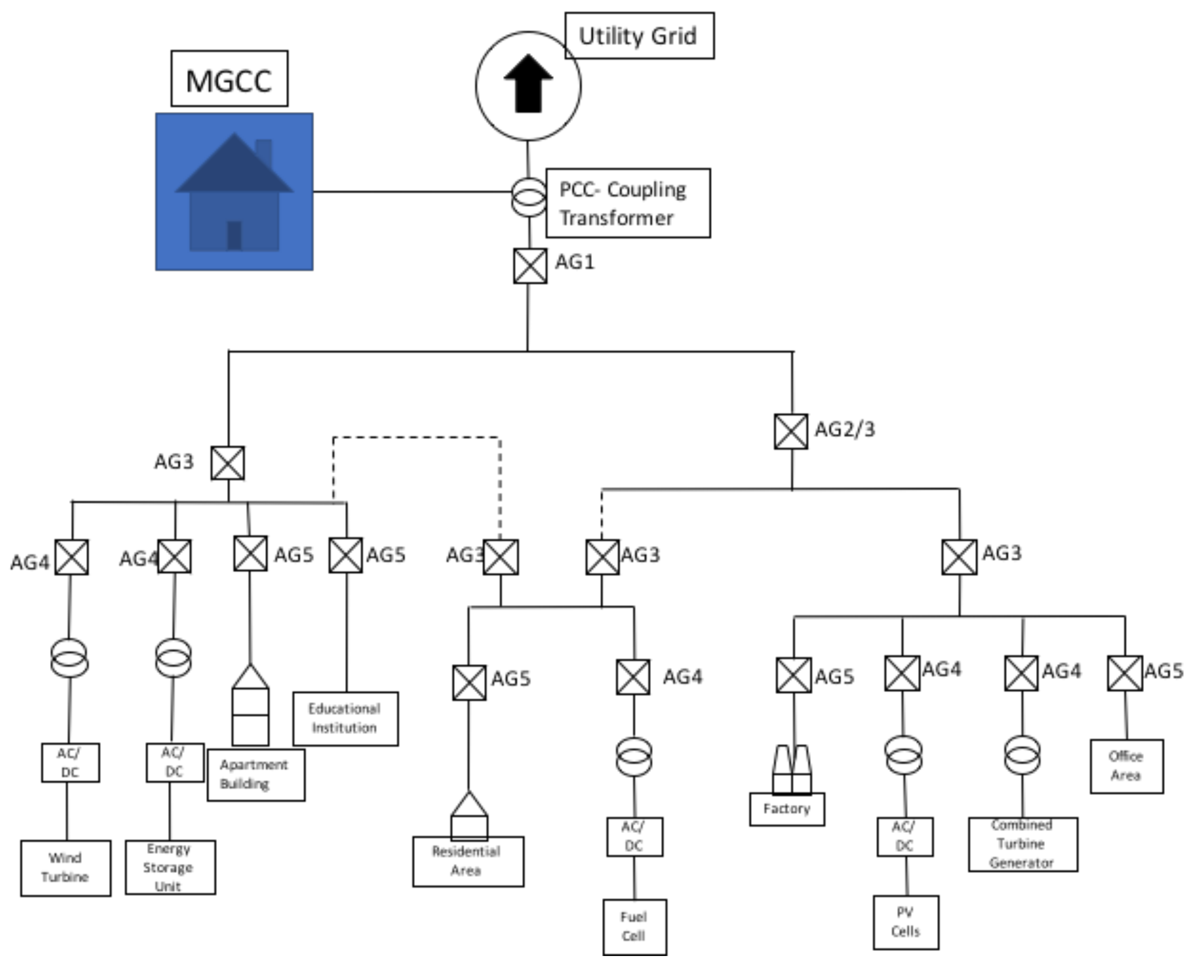



**Figure 3-2:Micro grid Power Network**

The different agents illustrated in the micro grid are:

1. AG1 -Grid Interface Agent;
2. AG2/3 - Main Feeder/Sub-Feeder Agent
3. AG4 – DER Agent/Storage Unit Agent
4. AG5 – Load Agent;
5. MCGG -Micro grid Control Centre (MGCC) Agent
6. Breaker Agent;
7. Measurement Agent; and
8. Protection and Control (P&C) Agent

## Micro grid Communication Network

Design of a micro grids communication network was based on the micro grid power network Figure 3.2. A fiber based communication network was proposed for both the linking of local agents and of remote agents.

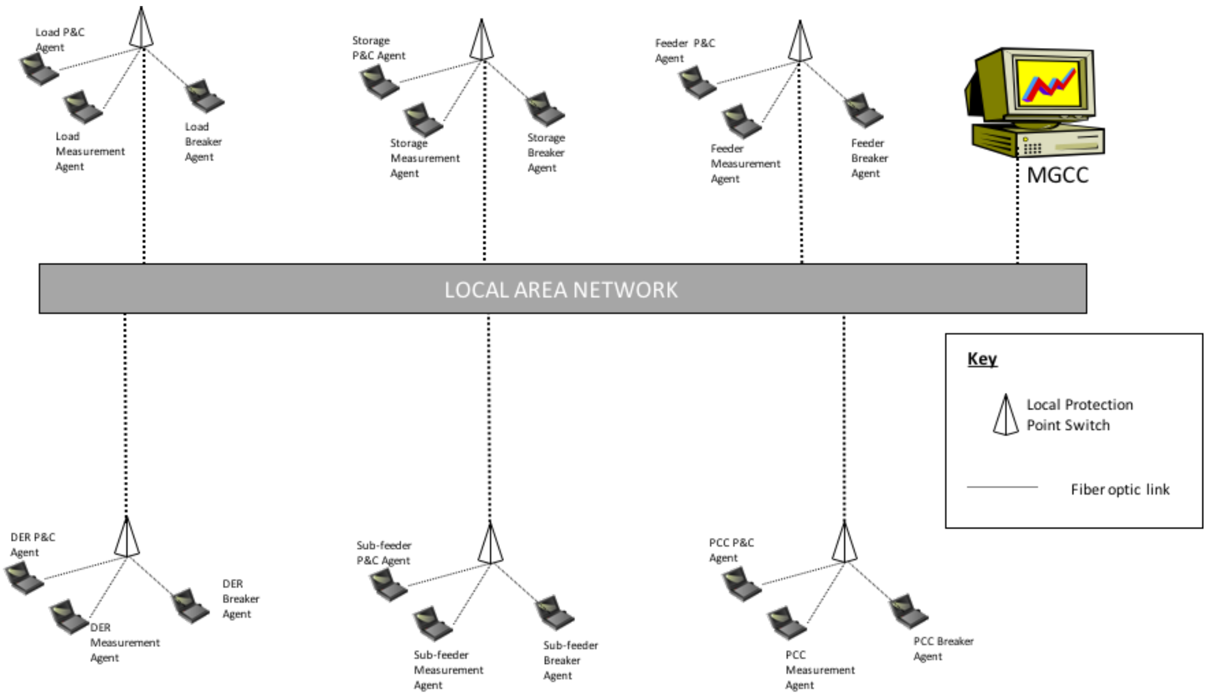



**Figure 3-3:MCN Schematic**

Local agents exchange data locally through the local hub and use the LAN for communicating with the remote agents. In this study only the LAN traffic was analyzed. Data exchanged between local hubs is considered irrelevant to the public communication networks as it remains local and therefore will not affect the QoS of the LAN.

The messages to be transmitted among the agents are as modeled by Islam and Lee (2016) as extensible micro grid information. Based on this table, the data for most of the interactions in the grid can be calculated as shown in Table 3.1.

**Table 3-1: Micro grid Extensible Information and Bandwidth Requirements**

| Information Type | Source Node | Receiving Node | IEC 61850 Services | ASU Size in Bytes | Sample /sec | Latency | Traffic (kbps) |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Status Value | Breaker agent | Control agent and MGCC | Unbuffered Reporting | 16 | 20 | 10-100ms | 0.320 |
| MG Operating Mode | MGCC | DER agent | GOOSE | 16 | Random | 20-100ms | |
| DER/Relay operation Set Point | MGCC | DER agent/P&C agent | Buffered reporting | 64 | 16 | 500-2000 | 1.024 |
| Generated or absorbed Power | P&C agent | MGCC | Buffered reporting | 32 | 16 | 500-2000 | 0.512 |
| Synchronous Message | P&C agent | P&C agent | GOOSE | 32 | Random | Accuracy | |
| Breaker Control | P&C agent /MGCC | Breaker agent | GOOSE | 32 | Random | ≤10ms | |
| Current rating and type of DER unit | DER agent | MGCC | Buffered reporting | 32 | 16 | 500-2000 | 0.512 |
| Current and Voltage Sample | Measurement agent | P&C agent | Sampled measured value | 52 | 960 | ≤10ms | 50 |
| File Transfer | P&C agent | MGCC | File transfer | 1000 | | Best effort | |

As per IEC 61850 standard, the measurement, control and protection message use GOOSE and SMV message types and as such the network is a layer 2 VLAN. All the logical modes are therefore modeled in one VLAN with no routed messages.

## QoS Requirements

The QoS specifications for micro grids communication are as stipulated by IEC 61850.

**Table 3-2: IEC Message Types**

| Type | Message | Performance Class | Requirements (Transmission Time) |
|---|---|---|---|
| 1A | Fast Messages (Trip) | P1 | 10ms |
| | | P2/P3 | 3ms |
| 1B | Fast Messages (Other) | P1 | 100ms |
| | | P2/P3 | 20ms |
| 2 | Medium Speed | | 100ms |
| 3 | Low Speed | | 500ms |
| 4 | Raw Data | P1 | 10ms |
| | | P2/P3 | 3ms |
| 5 | File Transfer | | ≥1000ms |
| 6 | Time Synchronization | | (Accuracy) |
| 7 | Command Messages (Access Control) | | |

**Table 3-3: IEC 61850 Transfer Time Classes**

| **Transfer Time Class** | **Transfer Time [ms]** | **Application examples** |
|---|---|---|
| TT0 | >1000 | Files, events, log contents |
| TT1 | 1000 | Events, alarms |
| TT2 | 500 | Operator commands |
| TT3 | 100 | Slow automatic interaction |
| TT4 | 20 | Fast automatic interaction |
| TT5 | 10 | Releases, Status Changes |
| TT6 | 3 | Trips, Blocking |

The IEC 61850 time classes were used for data classes. not been adopted as it specifies too many classes. This would mean increasing the number of bits required to specify the class in the underlying Ethernet frame to 4 bits in order to accommodate any other service classes. As such four priority service classes were defined as:

- Very high priority
- High priority
- Medium priority; and
- Low priority.

The priorities are an indication of the order in which the messages are to be sent when queued. This is not an indication of the latency requirements. Some messages can have low priority but require low latency.

### Framework Design

The framework design is based on the key finding from the literature review. The key issues to design are:

- Use of the IEC 61850 for communication mapping. This means the network design is at data link layer (layer 2 of OSI reference model). Layer 2 enables the exchange of data between two agents within the same network. The QoS mechanisms used have to comply with the layer at which they are used. The VLAN specification allows for classification of traffic into 8 different classes using the class of service field on the Ethernet head. In this case, the classes derived from the design were mapped to different classes in the Ethernet header. The classes were chosen to be able to reflect the priority of each message class
- There are three different types of messages that can exchanged within the micro grids. However, using the type of service as the class determinant is not adequate as the same message type can be used for services with different QoS requirements. For example GOOSE can be used for control messages such as TRIP which require are very high priority messages or for another type of application which requires very low latency but has a lower priority because it is not service affecting. Therefore, the packet/flow classification mechanism has to be able to distinguish the priority of such messages and offer the critical control message higher priority.
- The data exchanged between agents is very lean, as such aggressive mechanisms such as bandwidth reservation are not necessary.
- Network layer and transport layer mechanisms are also not applicable.

- Use of multicast and Unicast messages and converge cast means that there is a lot of traffic to each agent which is then discarded because it is not meant for the specific agent.

The following broad QoS mechanisms have been proposed:

- A classification mechanism
- Queueing Scheduling mechanism

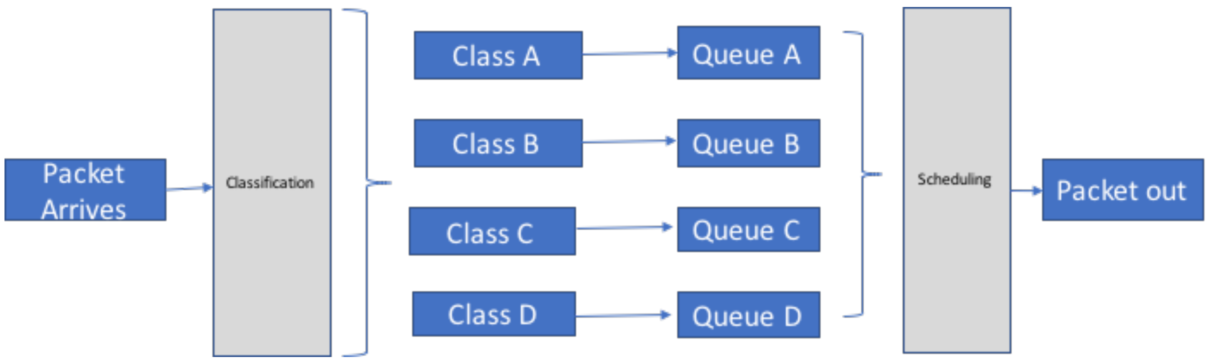



**Figure 3-4: Proposed QoS Framework Mechanism**

**Classification mechanism**

Classification mechanism works in the network to allow nodes and agents to intelligently identify incoming packets/flow and tag them appropriately according to their QoS requirements. This enables the network elements to identify the network that must be given different priority levels. Classification mechanisms can be simple or hierarchical and can base on various factors such as user, traffic type, receiving node etc.

A simple classification mechanism just uses one identification factor to appropriately place a packet/flow in an appropriate class. A hierarchical method goes through various iterations to identify the correct priority class for a packet/flow. While such a mechanism would help to ensure more detailed and precise classification, there is risk increased overheads and processing power. This could undo the benefits to be gained and as such to strike a balance between overhead and functionality, a simple.

In the micro grid, flow/packet can be classified by:

- Sending node (host) – load, DER, MGCC, PCC etc.
- Message type – GOOSE, SMV or MMS or file transfer
- Agent Type – measurement agent, protection and control agent, MGCC or breaker agent

Use of receiving agent is not possible since the messages are multicast and will be received by every node in the network segment. In this case, the message type was used as the classification mechanism as follows:

**Table 3-4: Proposed message priority levels**

| **Message Type** | **Priority Level** |
|---|---|
| GOOSE | Very High |
| SMV | High |
| MMS | Medium |
| Other | Best Effort |

### Queueing/Scheduling Mechanism

A packet scheduling mechanism helps in determining the next packet to be transmitted in a transmission queue or network. In the micro grid communication network, the use of Ethernet and multicast messages means all the agents that use the network have to have a mechanism of determining which particular agent can send a message. Scheduling mechanisms can be flat or hierarchical.

Class Based Weighted Fair Queueing (CBWFQ) with Weighted Random Early Detection (WRED) was used in this study. CBWFQ is a mechanism that is based on the concept of WFQ. It used some algorithms based on input to allocate a weight to each class of traffic. Each packet/flow class is then allocated resources corresponding to its weight.

The WRED is a congestion control mechanism that monitors the queues at each transmission point and decide of packets should be dropped from the queue. The algorithm tries and manages a situation where all new packets/flows are dropped when the transmission queue has transactions above its handling capacity. As such the algorithm uses a mechanism to drop off low priority packets from the queue so that high priority packets can be admitted into the queue.

WRED in this case would serve a double purpose of policing compliance to the QoS requirements and ensuring that the high priority flows can always be admitted into the network.

## Simulation

The simulation was carried out using the OMNeT++ object-oriented modular discrete event network simulation framework which provides infrastructure and tools for writing simulations, Omnet, 2017. OMNeT++ framework makes use of modules which are like bricks/blocks and can be combined to give different results. Different modules can be reused, to achieve different setup and results. Figure 3.4 shows the hierarchical structure of OMNeT++.

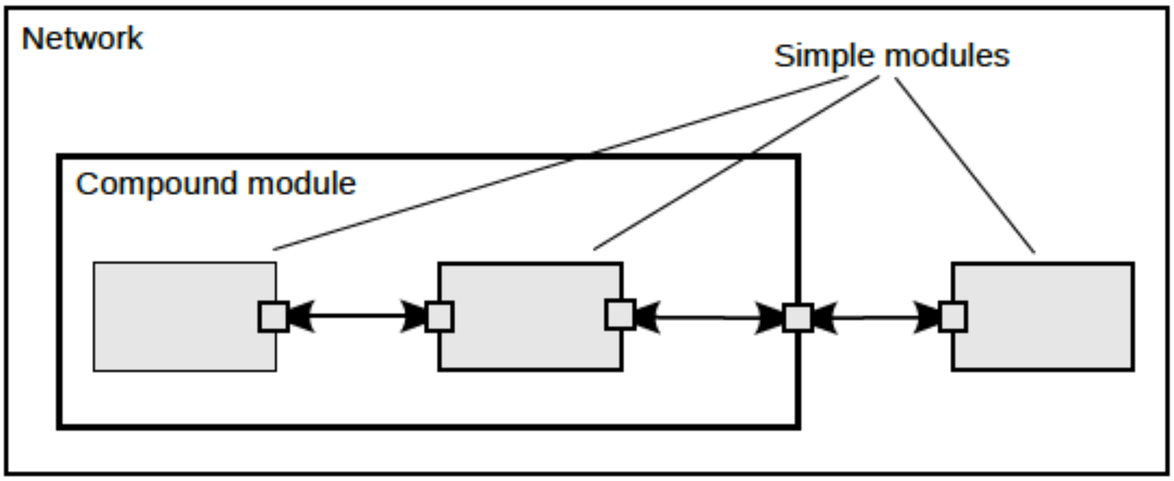



**Figure 3-5: OMNeT++ Structure**

Module hierarchy is as follows:

- Simple modules make the basic building blocks of any network;
- Compound modules are made a combination of simple modules but have no active behavior associated with them; and
- A Network is made up of simple and compound modules and is a self-contained simulation model.

Modules at each level can be customized through use of various parameters built into the system to achieve different topologies and behaviors. The modules are linked together by connections (channels) and exchange messages via input and output gates. These characteristics enable the OMNeT++ framework to be used for simulating communication networks as the modules can be customized to model different communication nodes. The channels can be customized in to mimic communication network channels with parameters such as delay, bit error rate etc.

An OMNeT framework is modelled by use of various system files that work together to provide required behavior. The major component of an OMNeT++ models are:

- NED language topology descriptions (.ned) : - these are files written in the NED (NEtwork Description) language which are used to describe the modules/submodules and entities that make up a network and how they are interconnected.
- Message Files (.msg) which define message types and are used to set the runtime parameters of the model
- Source and header files (.h/.cc)
- Configuration files (.ini) which contain settings for controlling execution of the simulation.

The OMNeT++ framework is based on C++ and as such also uses objects oriented concepts such as inheritance, polymorphism etc. This implies that once a module is designed, one can reuse it in a different scenario with little or no modification by reusing the required components and maybe introducing extra required properties.

Output from the simulation process can be written into output files as vector or scalar type data.

**MCN Modeling**

The micogrid communication network was modelled based on the OMNeT++ Hierarchical structure. The network was modelled such that at each protection point, the local agents are connected through to each other through a switch. Local messages are only exchanged through this switch and not broadcast into the main network. The switch at each protection point is then connected to the main switch through fiber.

As specified in IEC 61850 the communication is from each agent is multicast/unicast. In this case, the traffic was modelled as unicast such that each agent send a message to the main switch, which then sends it to all other nodes and only the intended nodes act on the message, the rest drop the message.

The network was designed in two part, one which uses best effort and one with QoS framework applied. The OMNeT++ implementation was made from various modules which were comnibed into a network as shown in the figures below.

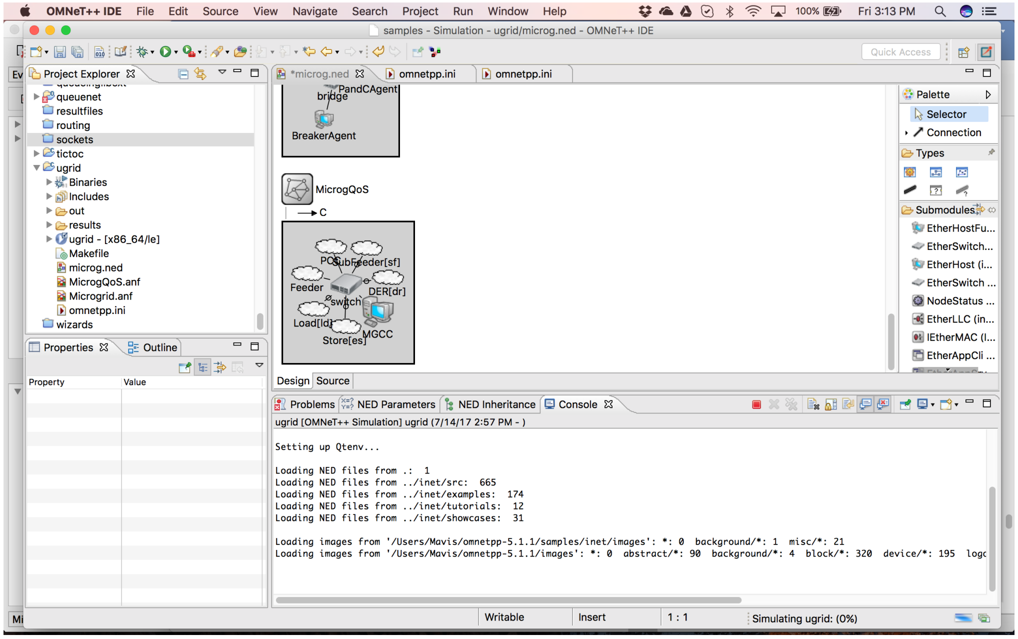


Figure 3-6:OMNeT++ Network Setup

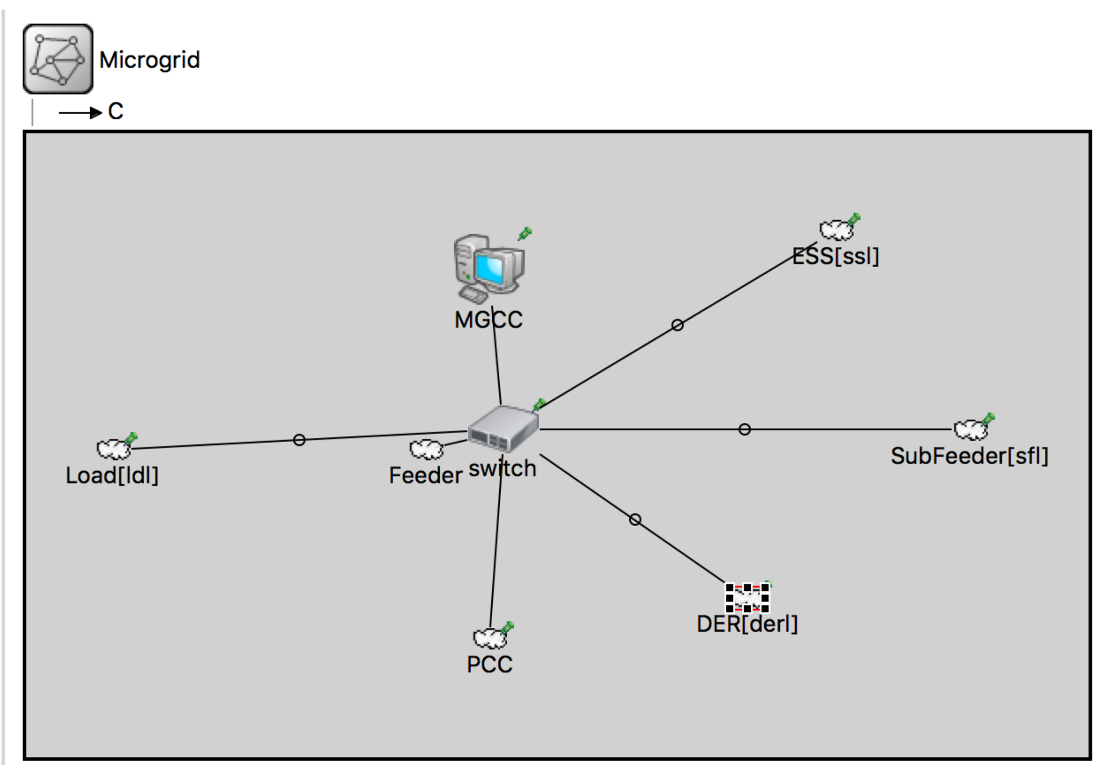



Figure 3-7: Microgrid Setup Screen

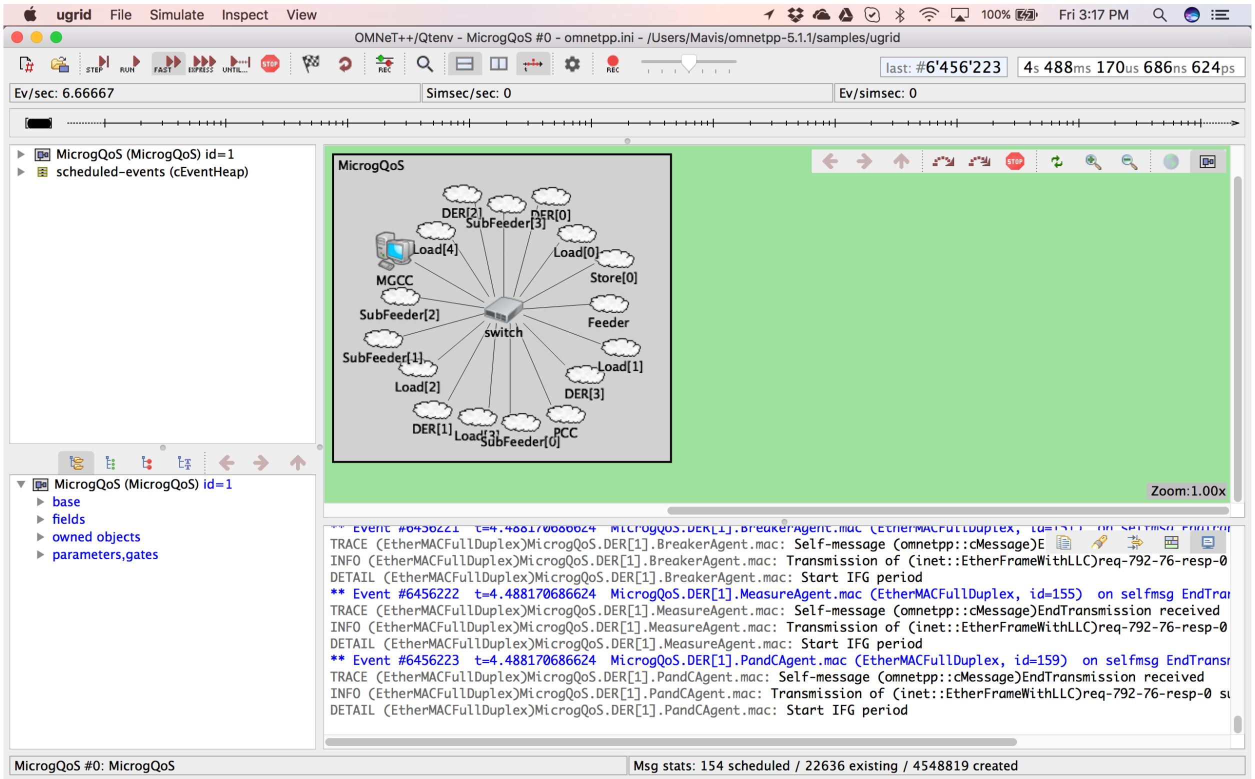
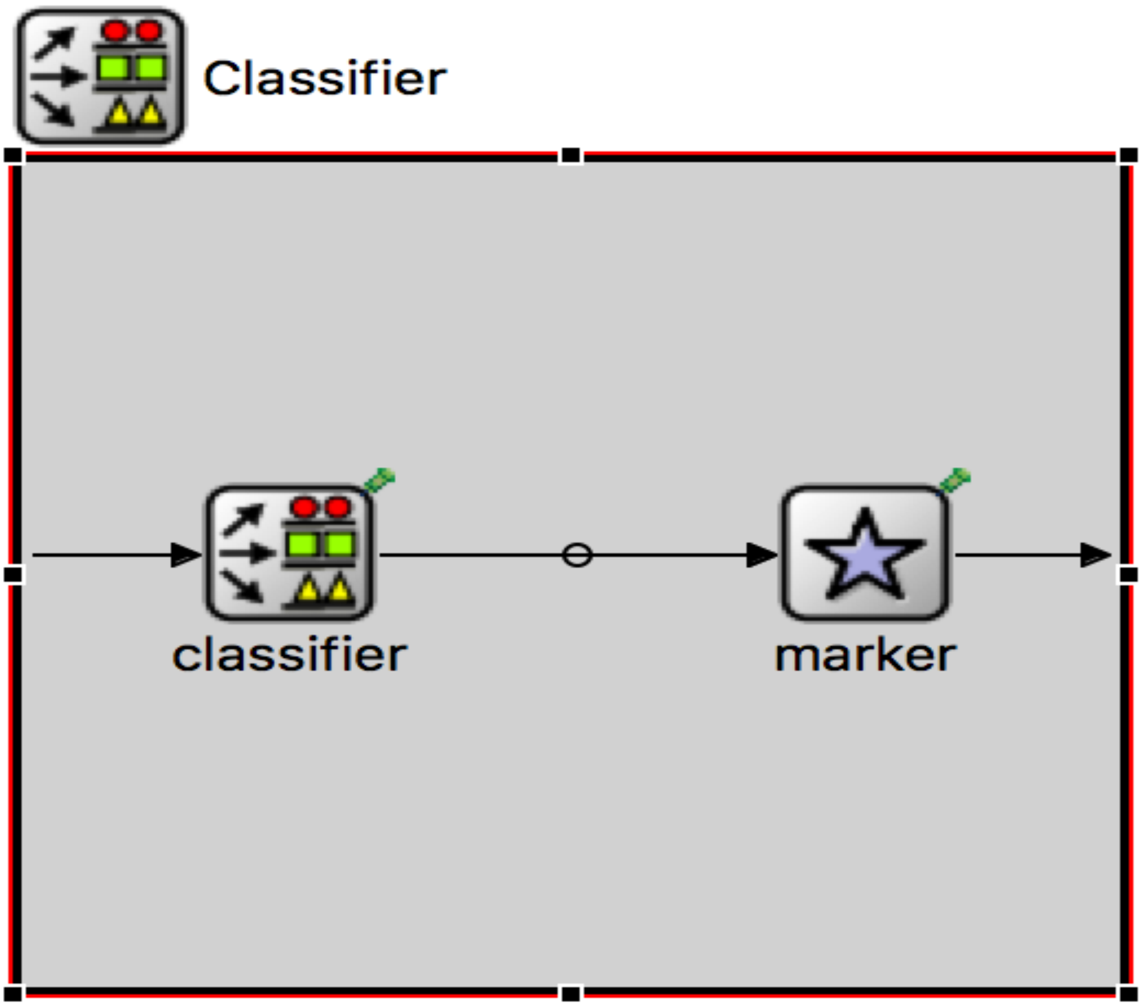


Figure 3-8: Runtime Simulation Screen




**3-9: QoS Framework Packet Classifier**

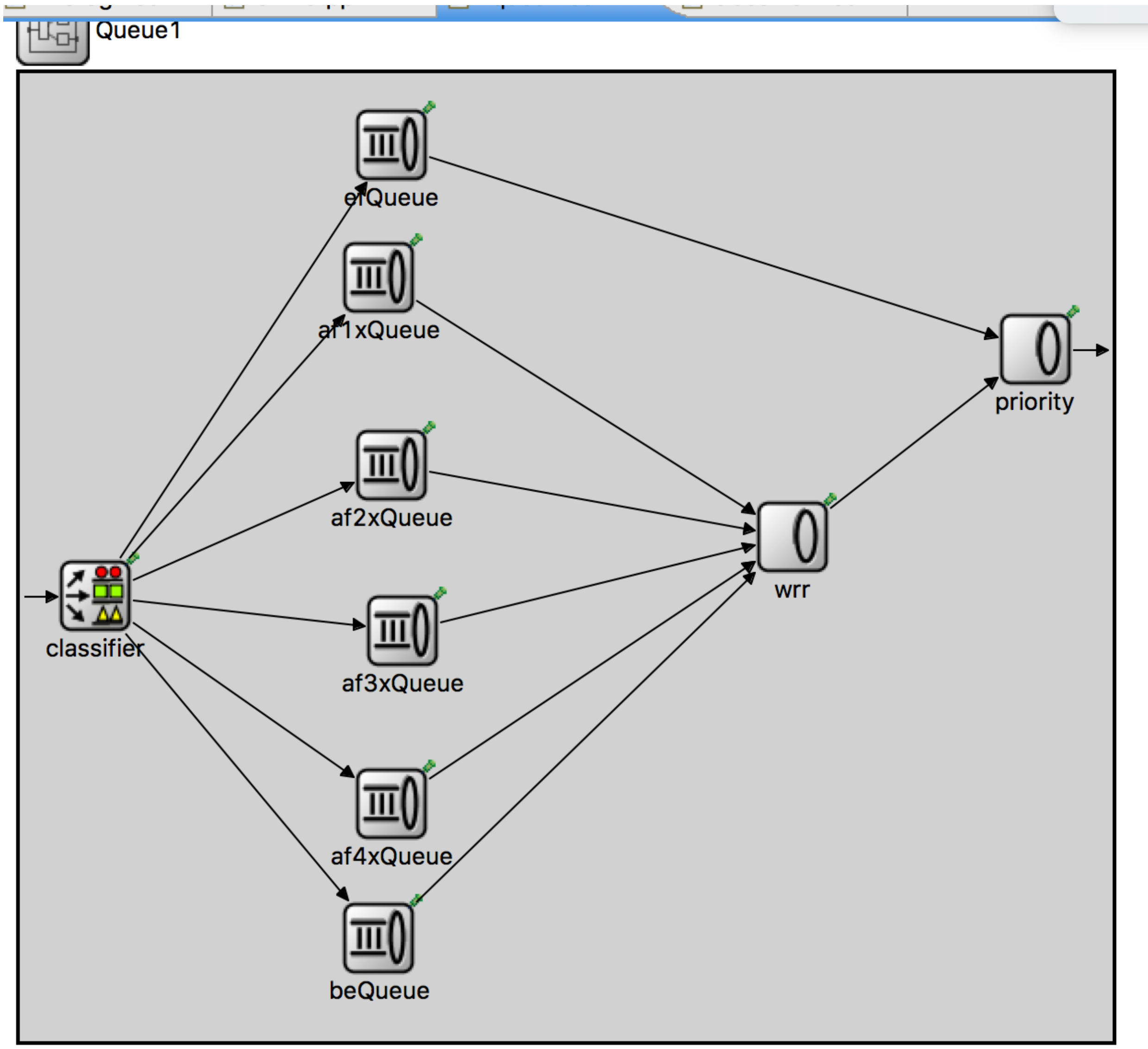



**Figure 3-10: QoS Framework Queueing SetUpFigure**

# Chapter 4 - Research Findings

## Introduction

The results obtained from the simulation were captured as various graphs. However, the analysis of most of the files involved too many variables making it difficult to plot graphs.

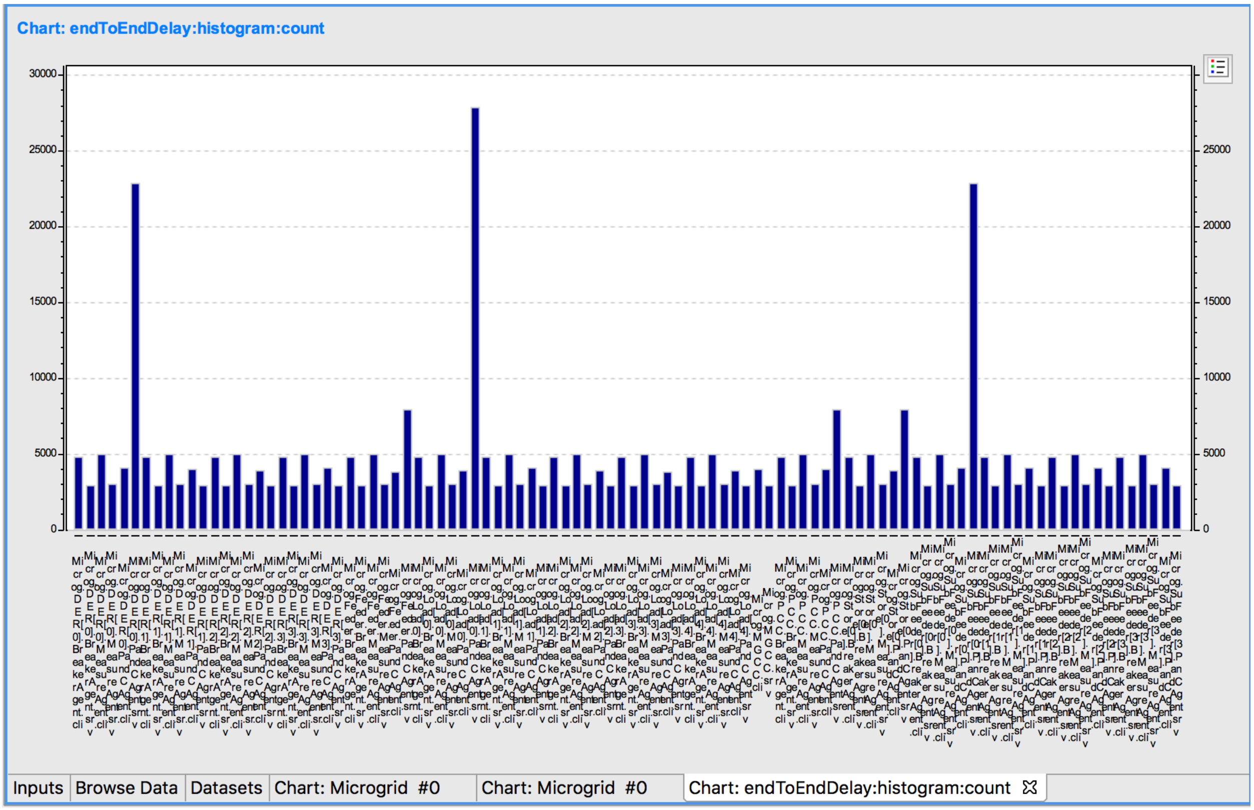



**Figure 4-1: Per component end-to-end delay count**

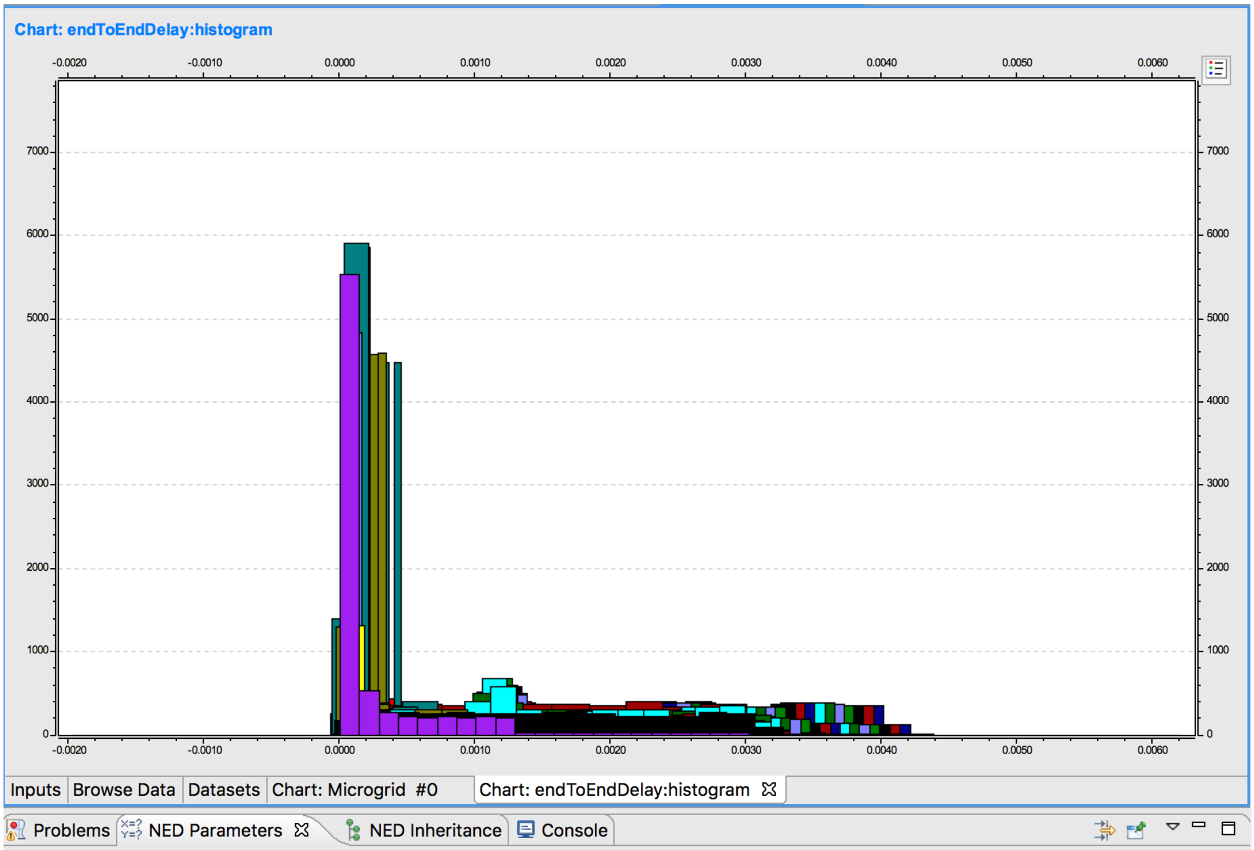



**Figure 4-2: Overall end-to-end delay for Microgrid**

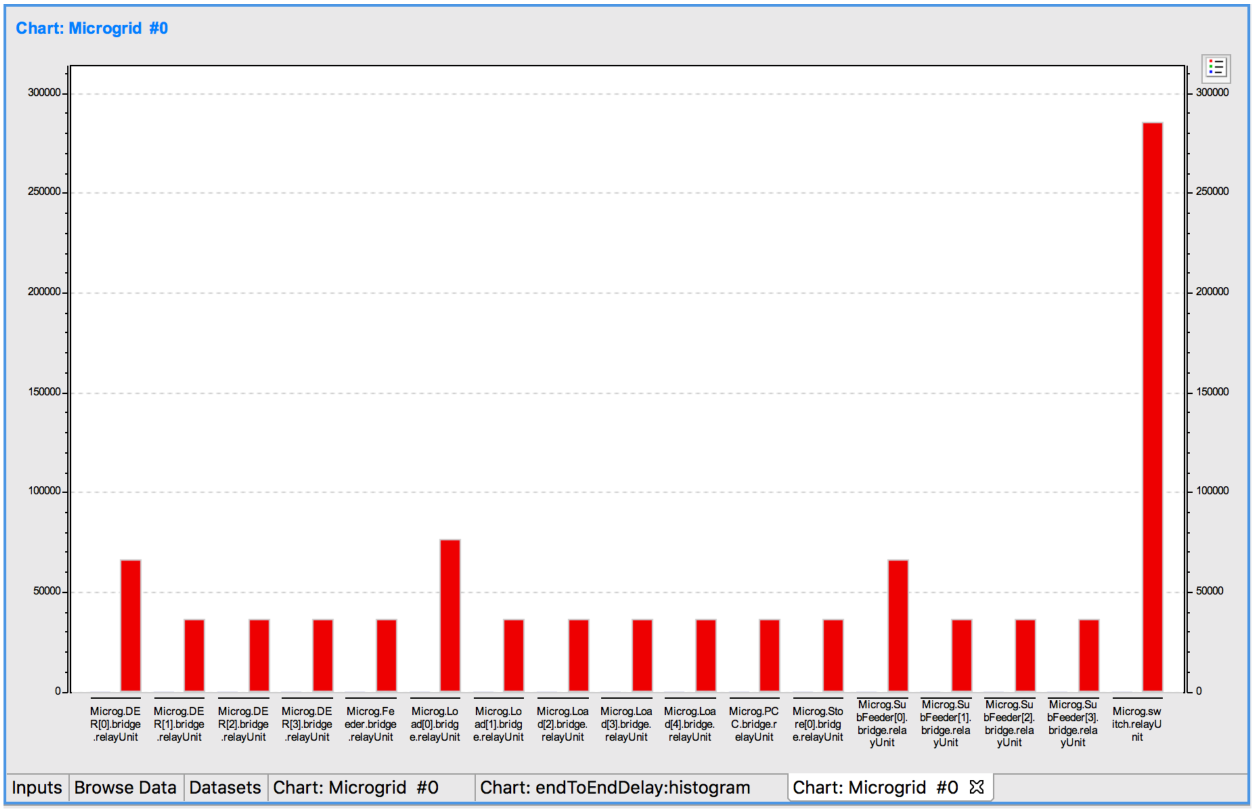



**Figure 4-3: Relay Utilization in the various component**

The switch relay unit is the only unit with high utilization. All the other units show low utilization level.

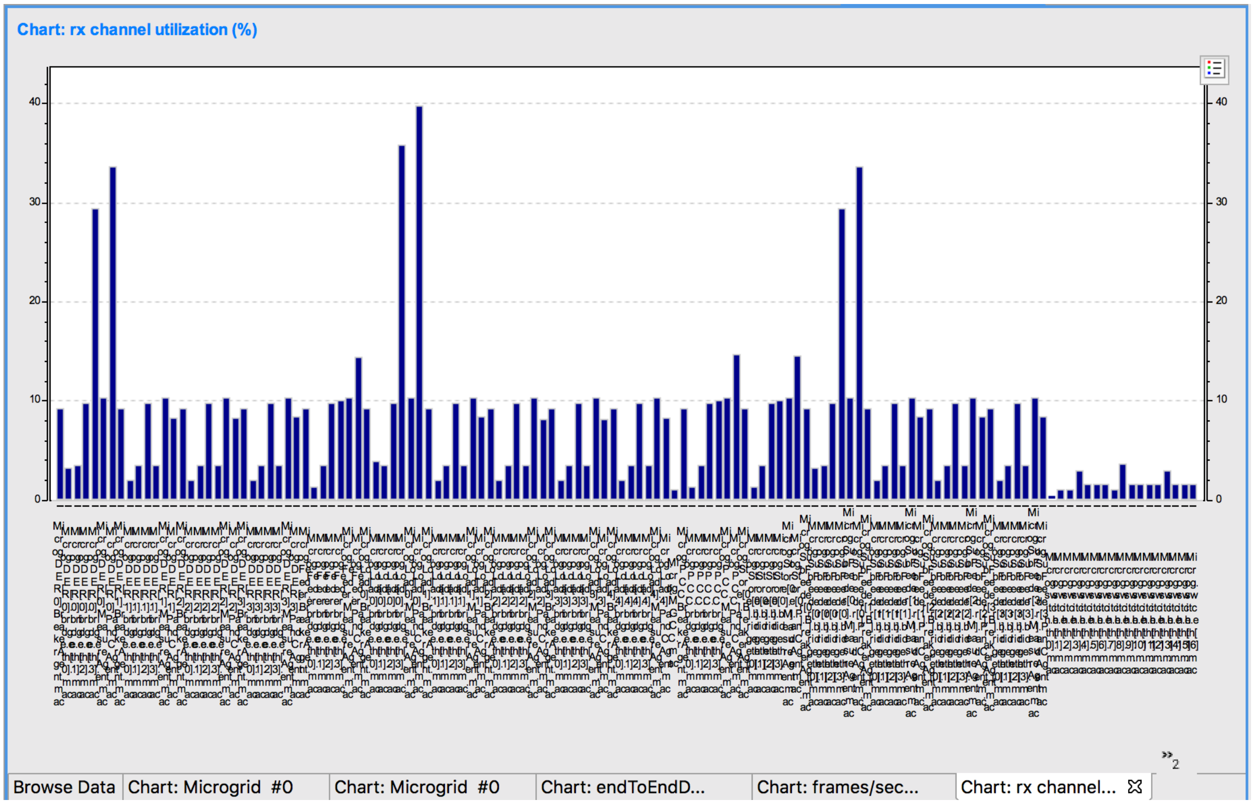



**Figure 4-4: Channel utilisation per module**

Only the switch has high channel utilization. All other components are low utilization.

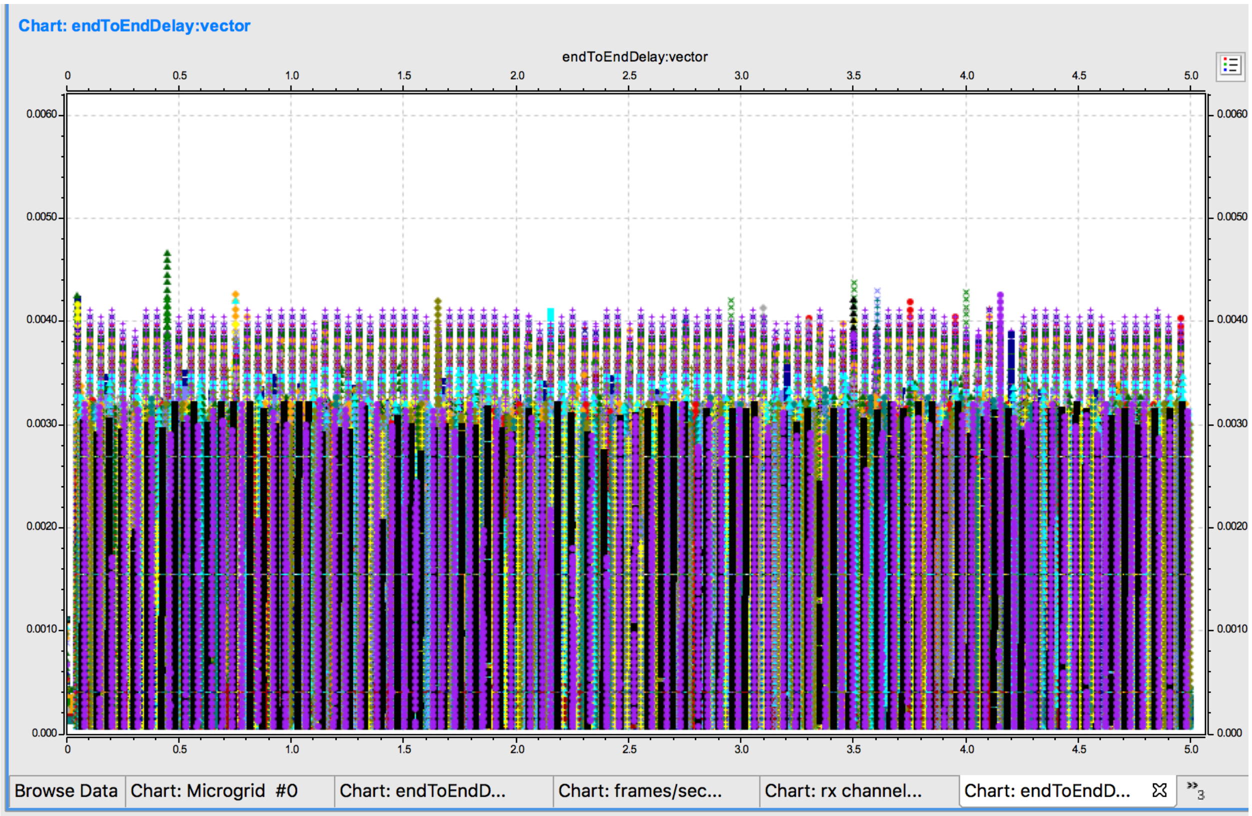



**Figure 4-5: End to end delay with QoS and without**

The end to end delay with Qos is generally lower throughout all components compared to the scenario without.

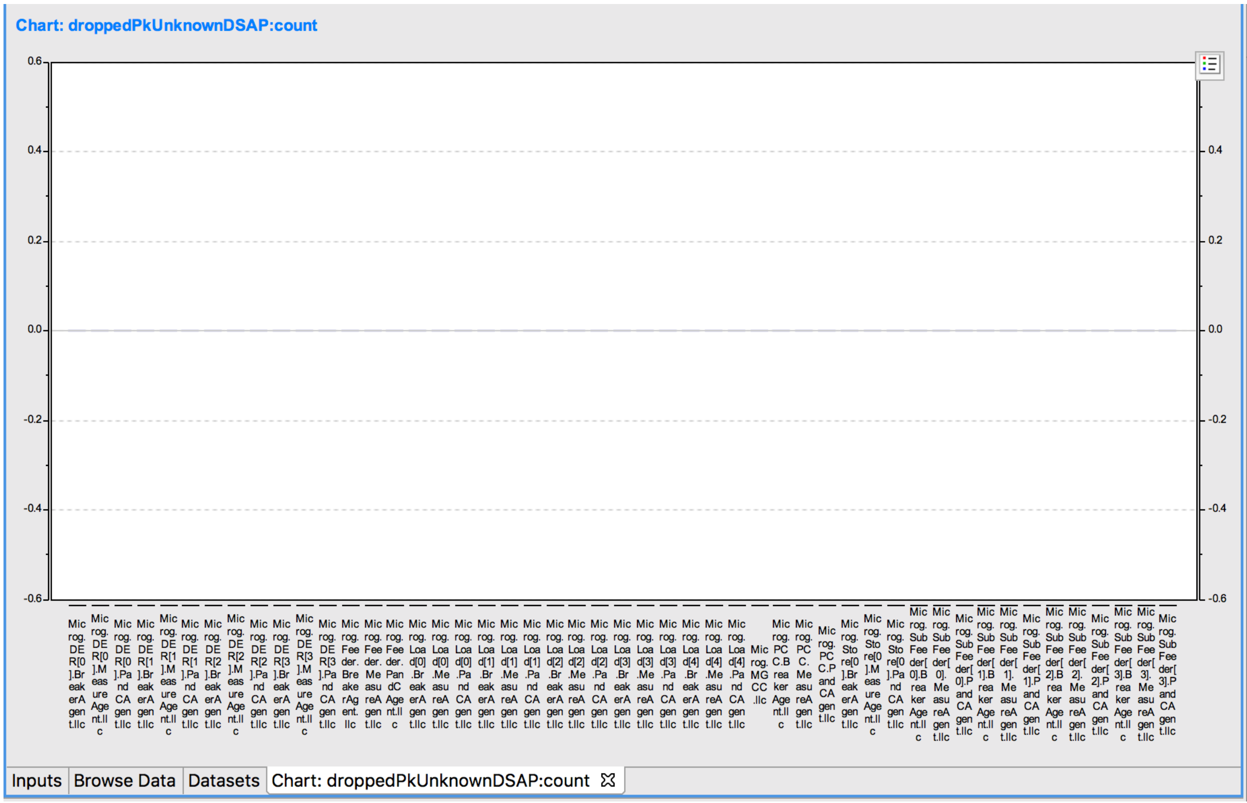



**Figure 4-6: Dropped packet count across the modules**

The graph shows that no packets were dropped across all modules with the configured QoS module.

# Chapter 5 - Conclusions

## Introduction

Integration of renewable energies has been one of the issues hampering their wide scale deployment. The introduction of micro grids, has one of its major aims being the smooth integration of renewable into small scale power network without disruption to the operation of the main grid. The micro grid is also viewed as the building block for smart grids: which are an integration of power networks and ICTs. As grids evolve from passive to smart grids, communication networks have been identified as key enablers to allow the connection of the power infrastructure to different agents and nodes to allow for intelligent control, monitoring and operation. However, in order to offer the required service to grid networks of the future, communication network have to be designed to offer the quality of service in line with the power network operation. A major challenge with communication networks is that they offer best effort service without any guarantees on service offered. On the other hand, power networks have stringent timing and message exchange requirements – implying ordinarily communication networks cannot offer the required services. QoS in communication networks seeks to offer guarantees on level of service that will be offered to application and agents in a network regardless of the network conditions.

The research sought to design a QoS framework for micro grid communication networks as per IEC 61850 recommendation. The research was motivated by the need to provide a common framework which can be used to ensure that micro grid traffic can be given the required priority to enable protection, control and monitoring of the power system. The problem was tackled through various sub objectives.

A critical review of existing literature on micro grid was carried out. The major areas reviewed were:

- Relevant standards and their implications;
- Micro grid power networks and their modelling;
- Micro grid communication network and their modelling;
- QoS and why it is critical to micro grid communication;

The methodology employed was based on similar previous studies carried out. Even through literature review failed to find a similar study in designing a QoS framework for a micro grid communication network, there are many related studies such as research on micro grid communication latency, evaluation of different communication technologies and architectures, and use of different mechanisms to address delay. The major drawback with such studies is that they fail to provide an end-to-end solution which can be used across heterogenous networks.

Based on the findings, a QoS framework was designed with two major mechanisms – classification and scheduling. While it is possible to use advanced mechanisms for designing QoS frameworks, the IEC message stack mapping, maps vital micro grid communication messages to the Ethernet layer which renders most QoS mechanisms ineffective as only layer 2 applicable mechanisms can be used.

## Conclusions

The QoS of a micro grid can be improved by a QoS mechanism even one as simple as a classification and scheduling mechanism. The micro grid communication network traffic is different from most communication traffic which is H2M or H2H in that it is mainly an exchange of data among devices. The size of data exchanged is also very small which means any mechanisms to enhance service should avoid additional overhead.

while the micro grid is the basic building block of a smart grid, there are vast differences in terms of the network structure and scope. This implies some of the arguments advance to the micro grid framework from the smart grid framework might need to be empirically tested in a micro grid testbed to prove their applicability.

While use of simulators gives an indication of real world operation of a theory, they are a long way off from the real situation. As such there is need for in investing in testbed to advance research in this area.

## Recommendations:

- QoS in communication networks for power networks remains an important research area into the foreseeable future. There is need to study the impact of developments in other area such as internet of things (IoT) on service quality in such networks;

- It is recommended that future research build on this research with co-simulation of the power and the communication network. More precise simulation of all components involved would save to further verify the operation of the framework.

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