East West University

INTERNSHIP REPORT

ON

POWER LINE COMMUNICATION SYSTEM FOR SMART METERING NETWORKS

SUPERVISED BY:

SARWAR JAHAN

ASSISTANT PROFESSOR

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

EAST WEST UNIVERSITY

SUBMITTED BY:

MAIMANAH BINTE JAHANGIR

ID: 2019-1-55-027

MAJOR IN ETE

DEPARTMENT OF ELECTRONICS & COMMUNICATION ENGINEERING

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AN INTERNSHIP REPORT PRESENTED TO THE FACULTY OF ECE IN PARTIAL FULFILLMENT

OF THE REQUIREMENT FOR THE DEGREE OF B.SC. IN ETE

DATE OF SUBMISSION:

18th JANUARY 2023

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Approval

The intern report titled "Power Line Communication System for Smart Metering Networks" submitted by Maimanah Binte Jahangir (ID: 2019-1-55-027) to the Department of Electronics and Communications Engineering, East West University, Dhaka, Bangladesh has been accepted as satisfactory for the partial fulfilment of the requirements for the degree of Bachelor of Science in Electronic and Telecommunication Engineering and approved as to its style and contents.

Approved By

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Supervisor

Sarwar Jahan
Assistant Professor
Department of ECE
East West University
Dhaka, Bangladesh

LETTER OF TRANSMITTAL

18th January, 2023.

Sarwar Jahan

Assistant Professor

Department of Electronics & Communication Engineering

East West University

Subject: Submission of the Internship Report.

Dear Sir,

It is a privilege and joy for me to introduce you the Internship report on "Power Line Communication System for Smart Metering Networks." As an essential of finishing the B.Sc. program. It has been made during the Internship time frame at DPDC in view of my useful gaining and the data gathered from my manager, associates, staffs and sites.

The purpose of this research is to illustrate the PLC network system used in smart metering system. Working for such a reputable company in the power field and preparingthis report was both a pleasure and a challenge, and it has really improved my expertise and abilities.

So, please accept my sincere gratitude for your kind assistance, supervision, and direction in the effective preparation of this report. I'm hoping you'll take this report under consideration and help me out. I will be glad to give any explanation on any significant matter.

Sincerely yours,

Maimanah Binte Jahangir

ID: 2019-1-55-027

Major in ETE

Department of Electronics & Communication Engineering

East West University

ACKNOWLEDGEMENTS

It gives me great pleasure to thank my supervisors, Sarwar Jahan, Assistant Professor, Department of Electronics and Communications Engineering, East West University, and my reputable trainer, Engr. Mohammad Emdadul Haque, Manager, ICT Development Circle, Dhaka Power Distribution Company Limited, for their exceptional supervision, priceless suggestions, and proper guidance. I am very grateful to them. The internship report would not have been possible without their gracious assistance and participation.

I am also grateful to my esteemed instructors from the East West University (EWU) Department of Electronics and Communications Engineering (ECE) and well-wishers for their insightful suggestions throughout the journey.

Finally, I would want to thank my parents for their unwavering encouragement and motivation to complete the task.

Abstract

Power line communications (PLC) are estimated using a number of technical research papers and up-to-date journals. The purpose of this study is to pinpoint crucial power line communications components for indoor and outdoor applications as well as the usage of consumer communication during the global commercial development of numerous potential services. Considerations include potential services, bandwidth, service area, quality, dependability, and pricing. The generation side of the power grid has seen major change recently, with a rise in the usage of energy sources (renewable), which are less centralized and have more variable availability than traditional ones. Similar to how electric vehicle uptake would significantly alter consumption habits. Because of these changing circumstances, the power grid's assets need to be better monitored and controlled, and smart metering is essential to achieving these goals. Power line communications (PLC) has emerged as a practical alternative in many situations, despite the fact that there are other communication technologies available for smart metering applications. Additionally, it offers a private communication network to the distribution system operator (DSO) and seamlessly integrates sensing and communication functions. This paper provides a brief explanation of PLC in the context of smart meters and the necessity of power line communication.

Keywords: smart metering; smart grid; PLC; broadband (BB); narrowband (NB); ultra-narrowband (UNB); strategy; deployment; distribution grid; Advanced Metering Infrastructure (AMI).

LIST OF ABBREVIATIONS

DPDC Dhaka Power Distribution Company Limited

ICT Information & Communication Technology

DSO Distribution System Operator

PLC Power Line Communication

AMR Automatic Meter Reading

AMI Advanced Metering Infrastructure

DSM Demand Side Management

PWM Pulse Width Modulation

DSL Digital Subscriber Line

IoT Internet of Things

RF Mesh Radio Frequency Mesh

NB Narrowband

UNB Ultra-Narrowband

HDR High Data Rate

LDR Low Data Rate

BB Broadband

EMI Electromagnetic Interference

LV Low Voltage

MV Medium Voltage

NOCS Network Operation & Customer Service

Table of Contents

Chapter 1: Introduction

1.1 Introduction

Systems for transmitting data on a power line are known as power line communication or Power line carrier (PLC), often referred to as power line digital subscriber line (PDSL), mains communication, power line telecom (PLT), power line networking (PLN), or broadband over power lines (BPL). Low voltages are utilized inside buildings, medium voltages are used for distribution, and high voltages are used for transmission. At each stage, power line communications can be used. Some PLC technologies can bridge across two levels, although most are limited to one set of wires (such as premises wiring) but some can cross between two levels (for example, both the distribution network and premises wiring). Typically (for example, both the distribution network and premises wiring). Typically, the transformer stops the signal from spreading, allowing for the use of several PLC systems. Spanned to create really big networks. Power networks can generally be divided into three major categories: use of dc current supplies in industrial settings, such as the automotive industry; sinusoidal supply used for home or electrical distribution networks, and pulse width modulated (PWM) networks utilized in the great majority of converter and other electrical equipment applications actuators.

The widespread usage of power-line communication (PLC) technology across sinusoidal and continuous electrical networks ensures data rates of up to a few hundred megabits per second. These PLC modems cannot function on PWM networks that naturally exhibit high spectrum occupancy. As a result, this course offers a general overview of PLC technology and its operational constraints inside a PWM network. New PLC modems designed specifically for the PWM network are created on the basis of a thorough research of the inverter spectrum. These modems' capacity is assessed in terms of data rate and transmission dependability. Between the actuator and the converter, this technique does not require any additional cables, which might be helpful in terms of cost and overall size.

1.2 Background

Initially, the main purpose of the first application incorporating data transmissions via power lines was to safeguard certain power distribution system components in the event of breakdowns. (In actuality, one of the main purposes of power line communications continues to be power line protection.) Power plants, substations, and distribution centers must quickly transmit information in this situation to reduce any negative impacts. The robustness of the power lines and their ready connectivity and availability make this technique an optimal solution. This method is the best one because it uses 2 lines, which are ready to join and are readily available. The development of widespread electrical power supply coincided with the introduction of narrowband power line communications. The first carrier frequency systems for telemetry started operating on high-tension lines about 1922, and they are still in use today. These systems run in the frequency range of 15 to 500 kHz. Baby alarms are among the consumer goods that have been around since at least 1940. Power line communications have historically been primarily driven by the desire to perform load control in the future. The downside of the present ripple control technologies is that several megawatts are needed for information transfer. To make remote meter reading easier has been a second significant driving force. A meter reader only manages an average information rate of roughly 1 bit/s, according to an English research. In the 1970s, the Tokyo Electric Power Co. conducted trials that resulted in several hundred units operating successfully in both directions. Given that data transmission over power lines has existed for a while, one might wonder why it has recently gained so much attention, especially given that the data rate needed for protection and telemetering is only a few kb/sec, which is much lower than the Mb/sec data required for multimedia applications. The tremendous growth of the Internet and the enormous advancements in VLSI (Very Large Integrated Circuits) and DSP (Digital Signal Processing) technology from the mid to late 1990s are all factors that contributed to the response. Then the telecom sector was liberalized, first in the US and then in Europe and Asia. Due to all of these developments, power line communications are now a widely used technology.

1.3 Objective of the Study

In this internship study, power line communication was a focus. Through this study, we want to demonstrate the significance of power line communication in smart metering. How Smart Metering was made simple through Power Line Communication. Additionally, we covered its purposes, benefits, and necessary elements. Finally, we have discussed our internship program experience with DPDC.

1.4 Significance of the Study

In this study, we've covered everything from the power line communication architecture to itsimplementation, requirements, costs, restrictions, difficulties, categories, and components in smart meters. This research, in our opinion, will be crucial to future efforts including smart meters and power line communication.

Chapter-2: Background and Literature Review

2.1 Smart Meter

2.1.1 Essentiality of Smart Meters

Smart Metering Concept:

A smart meter is a digital electricity meter that measures the electricity entering and leaving your home and transmits the data to the utility typically every 30 minutes. A meter reader doesn't have to go to the meter after a smart meter is installed. Utility and Meter can communicate with each other in both directions. The smart meter is an electrometer that measures electricity consumption by time repetition.

Smart metering is an application that enables a distribution system operator (DSO) to remotely read the energy consumption of its customers, also known as automatic meter reading (AMR); obtain information on power quality; detect energy theft, also known as meter tampering; and perform some operations on the meter, such as connection/disconnection and meter programming.

Bidirectional communication links to the meters are necessary for smart metering. Advanced metering infrastructure (AMI), the name of the communication network used for this purpose, is the part of the Smart Grid on which more implementation efforts are now being concentrated. Demand side management (DSM) or distribution automation, which are the systems used to remotely regulate transformer substations.

Why Smart Meter is needed?

1. Meter data reading on demand or on schedule at set intervals.
2. Reconnecting and disconnecting remotely
3. Detection, notification, and reporting of alarms and events.
4. Discovery of meter manipulation and theft.
5. Load Limiting / Load Control
6. Pre-paid / Net-metering
7. Energy auditing and accounting.
8. Upgrading of remote firmware.

2.1.2 Why Smart Meter is Essential?

1. Online Vending from anywhere
2. Customer can view meter status from home
3. Utility can update meter firmware and new tariff immediately
4. Scheduled / on-demand Meter data reading at configurable intervals
5. Remote Disconnection / Reconnection
6. Meter temper event immediately displayed on prepaid software
7. Automatic meter monitoring system and hence system loss may be reduced
8. Monitoring the transformer to protect overload
9. Immediate Load management possible
10. Smart meter is essential to go to smart grid

2.1.3 Smart Meter Design

Electricity meters are being replaced by smart meters because they are more capable, dependable, and precise than conventional electric meters. Smart meters monitor energy use, automatically replenish prepaid electricity credits, and inform users of the energy usage of their household or commercial equipment.

The components of the smart meter system include metering apparatus that is attached to the electrical circuit and measures overall electric usage. It functions as a lightweight communications gateway and contains a software-based application for managing gathered data. The gateway offers real-time data from a database through a mobile user interface. Each meter typically contains a number of communications technologies that can be chosen according to data rates, range, data type, and protocols.

In order for utilities and consumers to more accurately estimate their base and peak loads, enable demand-side management, and provide quick automatic outage detection and restoration, communications and data exchange help to quantify demand behaviors. The average lifespan of smart meters is 20 years. Figure 01 depicts the smart metering system's architecture.

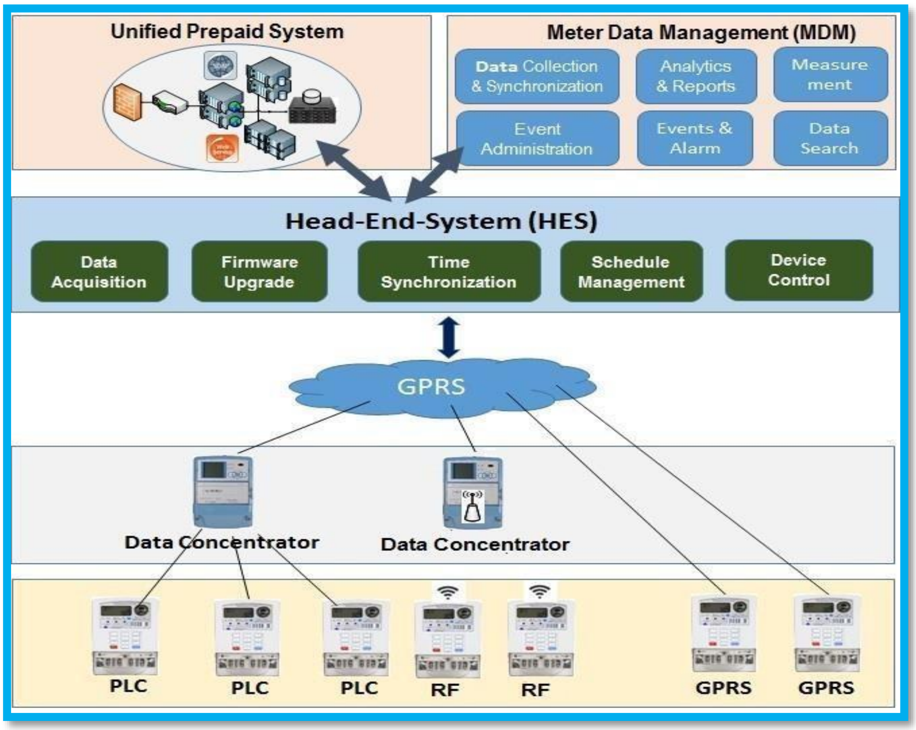

Figure-1: Architecture of Smart Metering System

Smart Electricity Meter Design

The system is adaptable and scalable due to the integration of a smart electricity meter into a 32-bit microprocessor on a shared peripheral and memory interface bus. The scheduling and resource managing capabilities of smart meters are optimized. This design facilitates resource sharing, inter process communication, and scheduling policies. The meter architecture controls measurements and billings, assigns task priorities, synchronizes concurrent activities, and offers interrupt handlers.as shown in Fig 2.

Figure-2: Software architecture of a conventional meter, showing communications with other meter components

The two major parts of a smart power meter are processing and communications. The communication component controls information sharing and internal communications between the meter and the user. The processing component transforms the voltage and current of a load into a digital form representation using an analog-to-digital converter and saves the information in an internal memory.

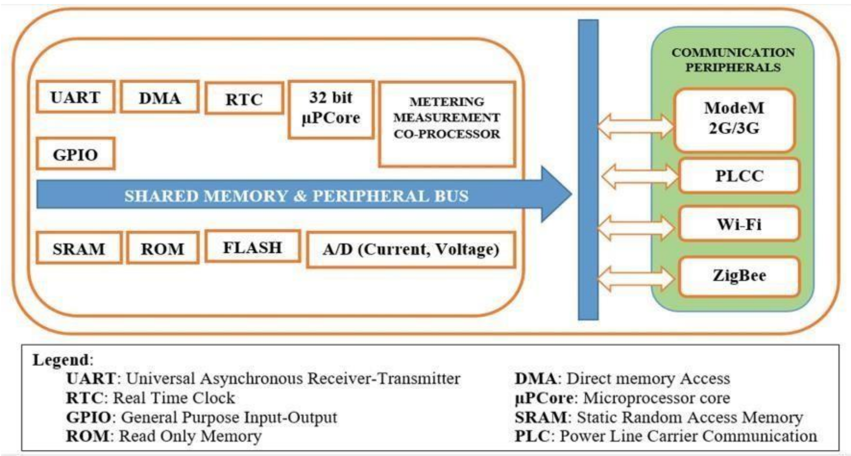

Figure-3: Smart meter architecture

These data are used to load a form representation into a digital format and store information in the device's internal memory. The power usage and outage occurrences are recorded using these data. Star, tree, and mesh topologies are the most often utilized in smart electricity meter communications. The hardware architecture of a silicon-and-chip-based smart power meter is depicted in Figure 3. Its primary parts are an analog-to-digital converter, a metering measuring co-processor, a shared memory and peripheral bus, and common peripherals.

Control and Management System

This is made up of a push button and microcontroller. The push button is used to simulate the load while the microcontroller is designed to handle management and control. They are described below:

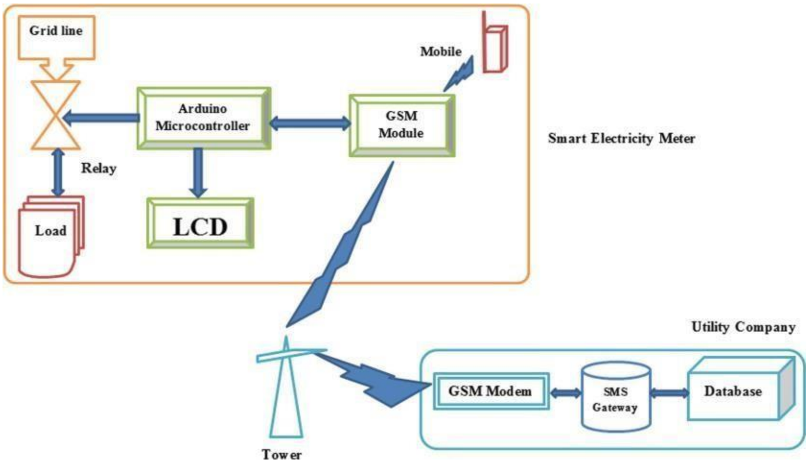

Figure-4: System block diagram of a smart electricity meter showing all the parts of the metering system.

The circuit architecture has a programmed microcontroller, as shown in Figure 4, which manages the overall system activities. The required output is produced by reading the input signal, which is read as a current, and using the installed software. The output action switches on or off certain appliances as well as connects or disconnects loads from the grid. Additionally, it gives the GSM module instructions to notify the user whenever there is a system issue, when the power is running low, or once any quantity of electricity has been recharged. This microcontroller can exchange data with the LCD and GSM module.

Display System

The output device for the smart metering system's display of the electrical energy balance in a 16X2 LCD. The microcontroller's remaining power balance can be received by this system and displayed. Additionally, it can respond to all microcontroller signals and carry out the necessary display operations.

Communication System

Both wired and wireless methods are used in the communication system. In addition to the internal connection among the meters' components, the interface between the SIM900A GSMmodule and the Arduino microcontroller serves as the foundation for external communication. Between the user and the smart meter circuit, the GSM module serves as a link. It gets the utility company's powering message and sends it to the microcontroller. Additionally, it receives the signals from the microcontroller and sends them through a wireless channel to the user. This GSM module enables the meter's owner, referred to as "theuser," to receive information from the meter as an SMS. A token created by the utility database on the server will be transmitted to the GMS module on the client side via a MODEM and phone line.

Database System

The utility business is the owner of the database system. It maintains a status of valid tokens so that used tokens cannot be recycled. Additionally, whenever a customer purchases electricity, it produces random token numbers and sends them to the GSM module at the client's residence via the SMS gateway of the network operator business.

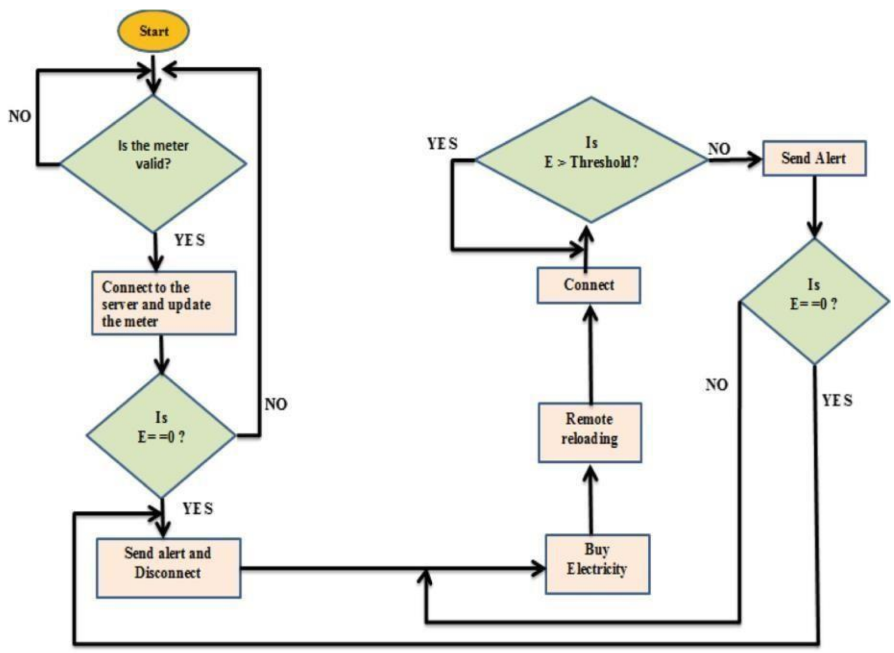

Figure-5: System flowchart showing the information flow during communication from the different parts of the meter.

Every time a meter is connected for the first time, the system, as depicted on the flowchart in Figure 5, checks to see if it is legitimate before allowing it to be used for subsequent actions. When the meter is attached, the system periodically checks the electricity level to see if it equals zero or not, and when it does, it notifies the user or home owner by sending a text message to their phone. The technology disconnects the meter and delivers an alert message when the electricity balance is zero. When a user purchases electricity, the meter is already reconnected and has entered a tracking mode that alerts the user whenever the electricity level hits a threshold or zero.

2.1.4 Communication Network for smart Metering

The key to smart metering is communication. Let’s take a quick look at the development of the various communication technologies used in smart meters and the numerous varieties that are currently available. These are separated into wired and wireless technologies by the transmission medium used to classify them. The first two “conventional” alternatives for advanced metering systems that were most widely used are:

1. Power Line Communications or PLC (Wired)

2. Radio Frequency Mesh or RF Mesh (Wireless)

Power Line Communication (PLC)

PLC uses power-line installations that are already in place for communication purposes. This has the advantage of exploiting existing infrastructure that is widely used without the need to install special cables. The PLC technology is the most widely used smart metering option because it is simple to integrate PLC modules into meters.

Radio Frequency Mesh (RF Mesh)

This technology, which differs from PLC is that it permits wireless connection, is essential to Automatic Meter Reading (AMR). The major purpose of this is to assess power use and gather information from energy consumers. Similar to PLC, it calls for modules to be mounted on the meters.

2.1.5 Smart Meter Tariff Calculation

The meter contains the tariff scheme. The mechanism sends the energy token (money) across the internet encrypted. According to the tariff rate, the smart meter subtracts money from the meter based on consumption. According to plan, HES gathers energy data from meters and sends it to MDM. Consumed unit money is deducted by the MDM from customer deposits. The applicable tariff rate is used as the foundation for the calculation.

2.1.6 Advanced Metering Infrastructure (AMI)

AMI refers to the entire measurement and collection system, which includes meters at the customer's location, communication networks between the customer and a service provider, like an electric, gas, or water utility, and data reception and management systems that provide the information to the service provider.

The Smart Meters send the gathered data over widely used fixed networks like Power Line Communications (PLC), Fixed Radio Frequency (RF), and open networks (such as landline, cellular, and paging), which is then combined by a concentrator and sent to the utility before being sent to a Meter Data Management System for data archiving, analysis, and billing. With over 100 million NB-PLC devices installed to date, studies demonstrate that Narrowband PLC is best suited for AMI.

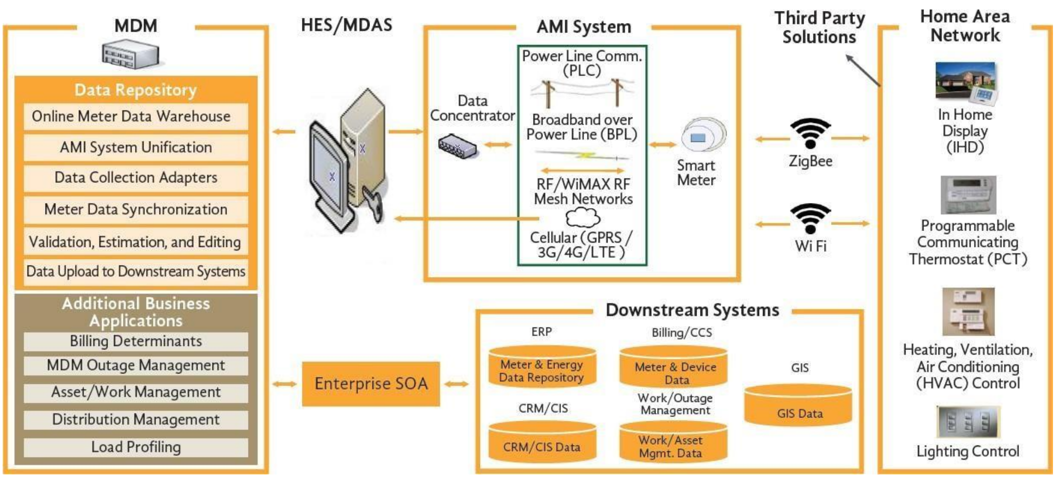

Figure-6: AMI Infrastructure for Smart Meter

AMI systems are receiving billions of dollars from utilities. Unlike wireless, the PLC option for data transmission leverages the existing power connections, which eliminates the need for new infrastructure. Many utilities have traditionally preferred power line carrier systems because it enables them to reliably transport data across a controlled infrastructure. Since public cellular has a small footprint, no deployment costs, and a low monthly rate, utilities may also use it as the backhaul for the AMI data. However, they might not always be able to cover the full customer base of a utility completely.

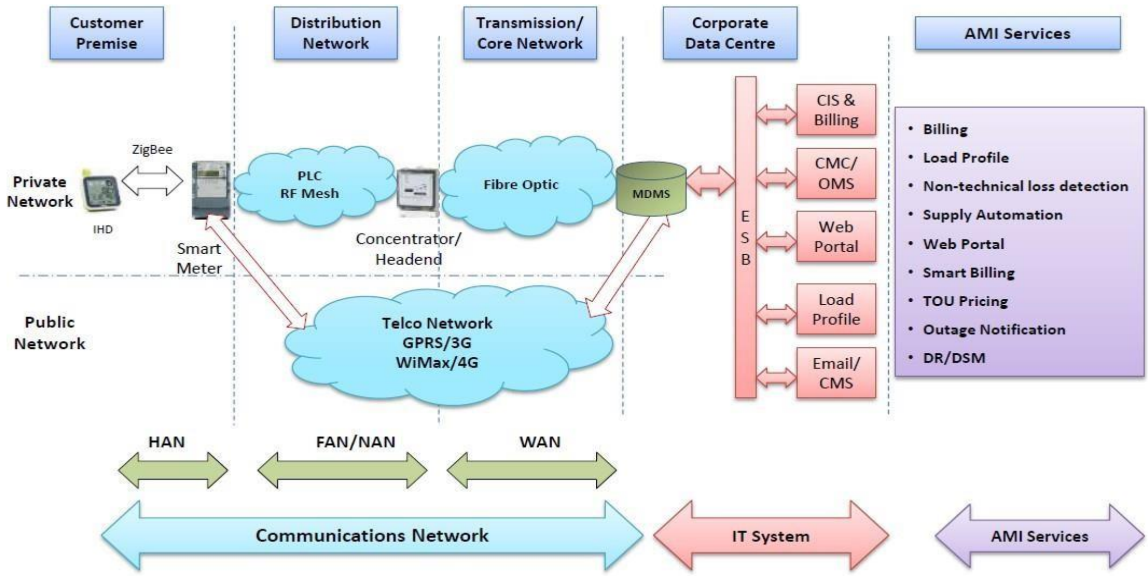

Figure-7: AMI System Architecture

This problem can also be resolved by using wireless networks, RF solutions, or PLC for data transmission. Communication with customers will be difficult for rural utilities or utilities in tough places (such as hilly terrains) that are underserved by wireless. Additionally, interference from Bluetooth devices, cordless phones, concrete objects, slopes, and even trees has caused wireless and RF solutions to degrade data speeds. PLC has no requirement for line-of-sight for data transfer and can communicate with any location connected via the power line.

PLC-based AMI have a history of being more effective at avoiding network congestion during emergencies. The need for redundancy in the communication route is another frequently noted necessity. Due to the widespread use of power lines, setting up a redundant channel is now more practical.

Chapter 3: PLC System

Overview of PLC System

Power Line Communication (PLC) carries data on a conductor that is also used parallelly for AC electric power transmission or electric power distribution to consumers. Other names for it include mains communication, power-line telecommunications, power-line networking, and power-line digital subscriber line (PDSL) (PLN). The initial purpose of power lines was to transfer electricity at frequencies between 50 and 60 hertz (Hz). The first purpose of data transmissions across power lines was to safeguard certain power distribution system components from breakdowns. The fastest method of exchanging information between power plants, substations, and distribution centers was through power line communication. The rationale took into account the fact that electricity transmission towers are among the most durable constructions ever made. As a result, this 13ynchroni network might be used to send protective messages with reliability. Additionally, a lot of isolated areas were not connected to telephone networks. Thus, it was decided that using existing power lines for signaling and information exchange for telemetering and power system protection was the best option. The system architecture of a PLC system is shown in **Figure 8.**

3.1 Classification of PLC technologies

The biggest distinguishing characteristic of the various PLC technologies is the bandwidth used. As will be demonstrated later in this paper, electromagnetic compatibility (EMC) laws actually classify PLC technology using this criterion. Three PLC technologies are distinguished by the helpful categorization:

Ultra Narrow Band (UNB): Refers to systems that transmit data at bit rates of about 100 bits per second and use frequencies below 3 kHz, which produce wide operational ranges. Existing systems, which use proprietary technology, have been applied to smart metering applications for many years.

Narrowband (NB): Refers to systems operating in frequencies up to 500 kHz. Two distinct technologies can be identified within this category:

- Low Data Rate (LDR): Single carrier modulation-based systems are limited to a few kbit/s of data transmission. They have historically been utilized in smart metering and home automation applications. These groups include the X10 standards and the IEC 61334-5, which uses frequency shift keying (FSK) and Spread-FSK modulations.

- High Data Rate (HDR): Systems that use multicarrier modulations and can reach hundreds of kbit/s are known as HDR systems. They have recently been invented, and they appear to be the most affordable option for smart metering applications. The most popular ones were first created by business coalitions like PRIME (Powerline Intelligent Metering Evolution) Alliance and G3-PLC Alliance, and they were later standardized by the ITU (International Telecommunications Union) as ITU-T Rec. G.9904 (ITU-T Rec. G.9904, 2012) and ITU-T Rec. G.9903 (ITU-T Rec. G.9903, 2017), respectively.

Broadband (BB): This category, often known as BPL (Broadband Power Line), includes a wide range of devices that operate in the frequency range 5 between 1.6 MHz and 250 MHz. The majority of them are based on multicarrier modulations, and the most recent versions feature multiple-input multiple-output (MIMO) technology, such as the IEEE 1901 (IEEE P1901, 2010), ITU-T G.hn (ITU-T Rec. G9960, 2015), ITU-T Rec. G.9961, 2015), and the HomePlug AV2 (ITU-T Rec. G.9963, 2011). (Homeplug, 2005). High bit-rate applications like local area networking in small workplaces and households are ideal for this technology. They serve as the telecommunications backbone for the Smart Grid, connecting the SS utilizing MV lines (Lampe et al., 2016), but a recent proposal also suggests employing them for the last mile of smart grid.

Frequency Band	Technology Name	Frequency Range	Transmission Distance	Physical Layer Speed	International Standard
Narrowband	G3-PLC	< 148.5 kHz(EU) < 490 kHz(FCC)	Long	< 280 kbps[1]	ITU-T G.9901 ITU-T G.9903 IEEE 1901.2
	Prime			< 1.0 Mbps[2]	ITU-T G.9901 ITU-T G.9904 IEEE 1901.2
Mid-band	HPLC	0.7 – 12 MHz	Middle	150 kbps to 10 Mbps[3]	IEEE 1901.1
Broadband	HD-PLC	1.8 – 100 MHz*	Middle to Short*	62.5 Mbps to 1.0 Gbps[4]	IEEE 1901 ITU-T G.9905
	HomePlug	1.8 – 50 MHz	Short	200 Mbps to 1.3 Gbps[5]	IEEE 1901
	G.hn	2.0 – 200 MHz		300 Mbps to 2.0 Gbps[6]	ITU-T G.9960 ITU-T G.9961 ITU-T G.9962 ITU-T G.9963 ITU-T G.9964

*Selectable

Figure-8: Types of PLC Systems

For the last mile of smart metering networks, NB-PLC is currently by far the most popular PLC technology. So from now on, our focus will be on researching this technology, accordingly.

3.2 Framework of PLC System

The system model of an NB-PLC-based smart metering network is shown in Fig. 8. The following elements make it up. A management hub where energy usage data is reported and smart meters are managed. It's interesting to note that data obtained from smart meters can also be applied to other tasks like managing transformer load, managing power grid tomography, managing power quality and outages, and integrating with the DSO GIS. The SS connects the management center to it via utilizing a backbone network.

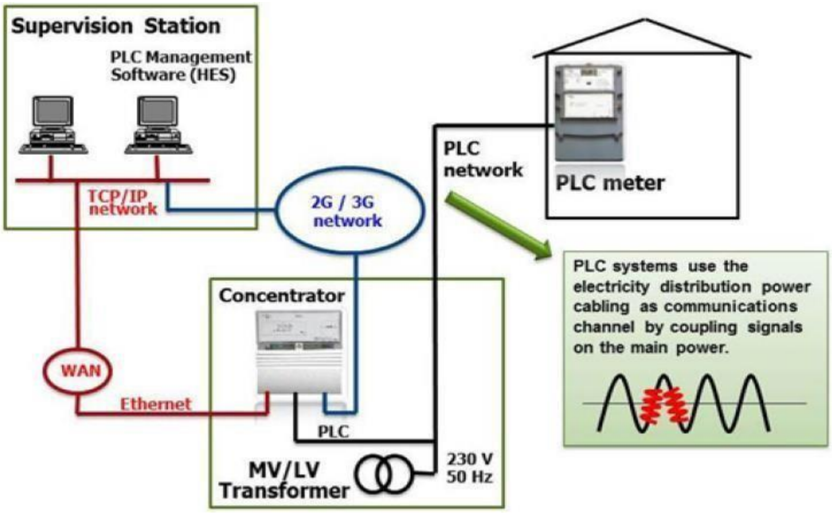

Figure-9: Architecture of PLC System

The last mile of the network links the data concentrator to the smart meters (DC). Depending on how many clients are connected to the MV/LV transformer, the latter may be situated in two separate locations. When there are several customers, the DC is typically located on the LV side of the transformer.

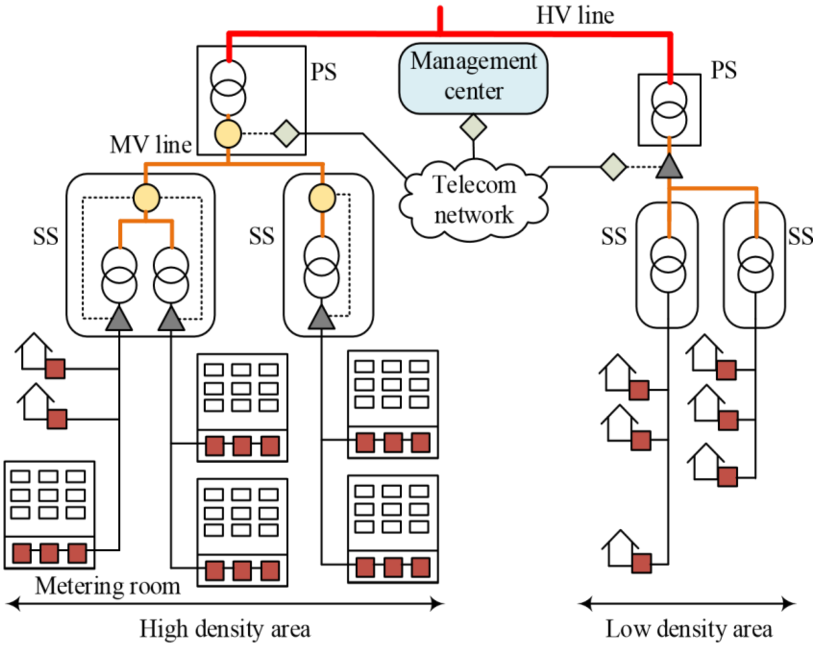

Figure-10: Simplified scheme of a smart metering network

Due to the fact that many NB-PLC solutions cannot be connected via transformers, the position of the DC is a crucial consideration when choosing the one to be used. This is the situation with systems that operate in the frequency band below 95 kHz, as it will be explored in more detail later in this chapter. Even though BB-PLC is used in the backbone network in these cases, the connection between the BBPLC device and the NB-PLC device is typically made using an Ethernet link, avoiding the transformer as shown in Fig. 10

An important aspect related to NB-PLC-based systems is the signal injection method. At the customer side, single-phase is generally the only possibility, since homes are usually fed with using a single phase. At the transformer side, while three-phase injection is possible, single-phase injection is currently the most widespread one, i.e. NB-PLC systems do not currently explore the MIMO nature of the network. This contrast to the BB-PLC case, where the latest standardized systems do all include MIMO techniques.

3.2.1 Electromagnetic compatibility (EMC Regulation)

EMC laws, which are designed to ensure compatibility with other communication systems, place restrictions on the frequency spectrum and signal intensity injected by PLC systems. By minimizing both the conducted and radiated emissions, this is accomplished. Common mode (CM) currents, commonly referred to as antenna currents, are what cause radiation emissions. CM currents also emerge because of the asymmetries in the network even while PLC signals are applied in a differential manner between two conductors, creating differential mode currents. Contrary to differential mode currents, which flow in the opposite direction, CM currents do not. Therefore, whereas the former radiates electric fields that have a tendency to cancel, the latter’s generated fields have a tendency to increase, leading to significant transmitted electromagnetic interference (EMI). When the length of the radiating structure is similar to the wavelength of the conducted signal, the amount of the radiated EMI caused by the CM becomes significant. This calls for cable lengths more than 600 m for frequencies lower than 500 kHz. Radiated emissions are therefore a significant issue exclusively for BBPLC and are not covered by NB-PLC laws.

3.3 How PLC System Works

Since it was not created with data transmission in mind, the power line carrier presents a challenging environment. The main problems are varying impedance, a lot of noise, and significant degrees of frequency dependent attenuation. With a network of lines this intricate, the amplitude and phase response is subject to significant frequency variations. Furthermore, the network topology would change if devices were added or removed from the network, therefore the channel transfer function itself is time-varying. Home devices often act as noise sources, affecting the signal to noise ration of receivers.

Signal propagation does not occur between the transmitter and receiver over a line-of-sight path, just like it does on a wireless channel. As a result, additional echoes need to be taken into account. There are several propagation channels between the transmitter and the receiver, which causes this echoing to happen. Due to the different impedance mismatches in the electric network, signal reflection frequently happens. A specific weighting factor would be assigned to each multi-path to take the reflection and transmission losses into consideration.

Higher frequencies have been found to result in greater channel attenuation. Since the channel's signal-to-noise ratio (SNR) over the transmission bandwidth is frequency dependent, it can be said to be random and time variable. Figure 11 displays the characteristics of the power line channel.

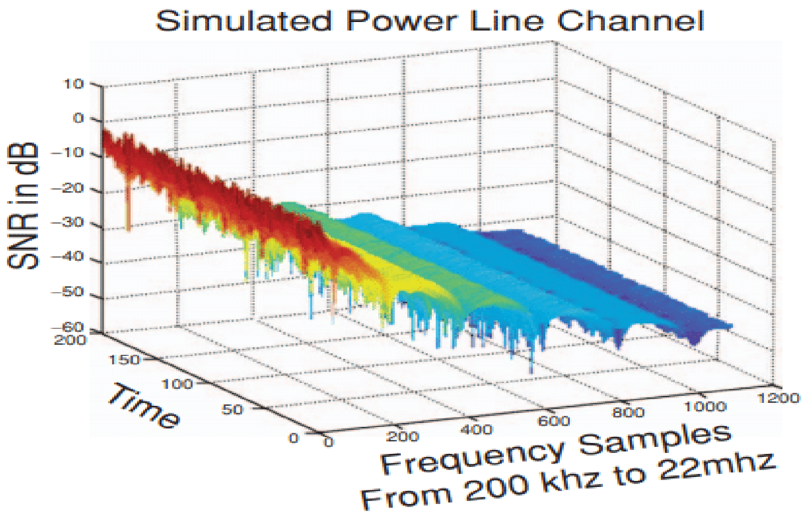

Figure-11: Power Line Channel Characteristics

Data transmission is significantly hampered by noise in power lines. Brush motors, fluorescent and halogen lamps, switching power supply, and dimmer switches are common sources of noise. Impulsive or frequency-selective noise can exist in power lines. Four groups of noise in power lines can be classified as:

1. Colored Noise: Low power spectral density with a frequency-dependent decline. It is thought to be the accumulation of all low power noise sources and could vary over time.

2. Narrowband Background Noise: mostly as a result of broadcast stations' amplitude modulated sinusoidal broadcasts in the medium and short wave regions.

3. Impulse Noise: Noise that often repeats at multiples of 50/60 Hz and is synchronous with the generator's real supply frequency. It has a brief duration and a frequency-dependent power spectral density. It is caused from power supplies.

4. Asynchronous Impulse Noise: This kind of noise is the worst for transmitting data. It can last anywhere between a few microseconds to milliseconds. Such impulse noise may have a power spectral density up to 50 dB above the spectrum of ambient noise. As a result, it has the ability to erase blocks of data symbols during intense data transmission at specific frequencies. Switching transients in the system network are to blame.

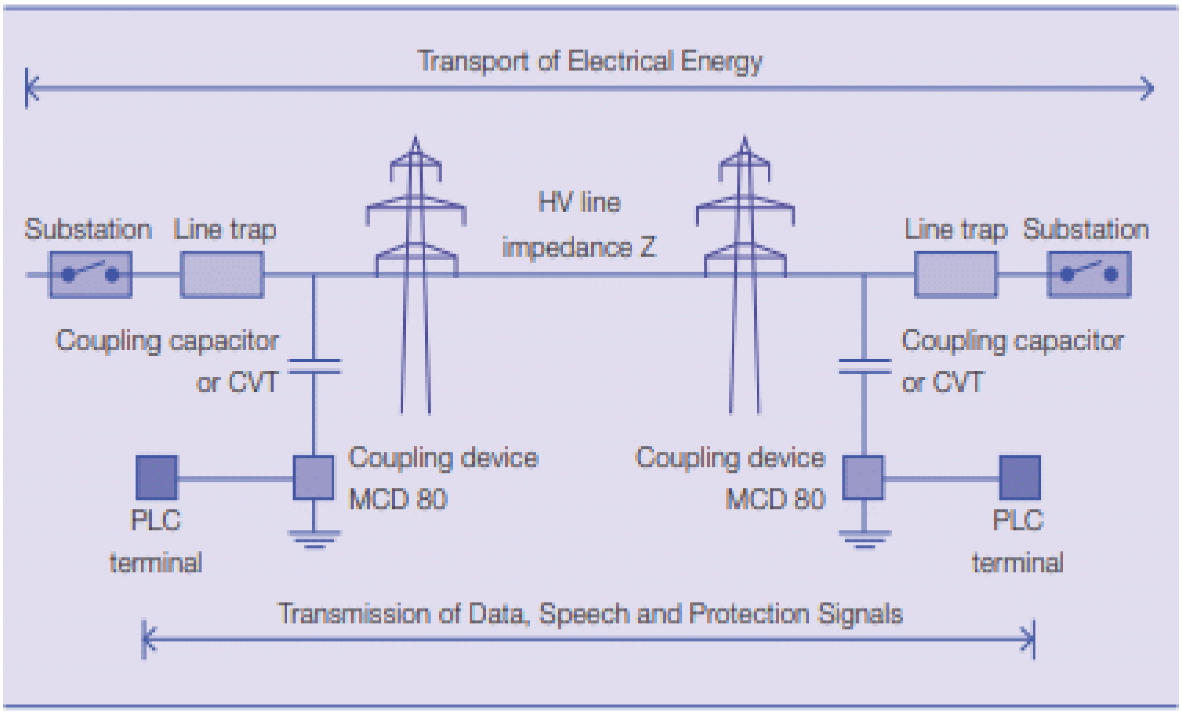

Figure-12: PLC System overview

For PLC, modulation techniques including orthogonal frequency division multiplexing (OFDM), code—division multiple access (CDMA), and frequency shift keying (FSK) are suitable. FS is regarded as an effective solution for low cost, low data rate applications such power line protection and telemetering. The capability of FSK for data rates over a few kilobytes per second is substantially hampered by frequency selective fading, as experienced by the power line channel. It would require extensive error control coding. It would restrict the data rate attained when combined with FSK's poor spectral efficiency.

The CDMA method can be a good choice for data rates under 1 Mbps. At the transmitter, a spreading code is used to distribute each user's signal. Using the same code, the receiver de-spreads the message. CDMA offers resistance to narrowband interference and other types of noise. However, in order to effectively combat interference from other users, the processing gain must be substantial.

The symbol duration is so short when sending via power lines at high data speeds that delayed versions of one signal are smeared over a lot of other symbols. The inter-symbol interference necessitates the use of sophisticated equalization algorithms, which complicates the detection procedure beyond that, though, OFDM is the PLC technology of choice for large data applications. Through a serial-to-parallel converter, serial data is sent. It divides the data into various parallelchannels with different modulators. There is a distinct carrier frequency for each modulators each modulator has a different carrier frequency and carries a small portion of the original datarate. By doing this, the symbol length is increased to outpace the longest delay path. This largelyresolves the inter-symbol interference issue. Additionally, OFDM stays away from frequenciesthat are deeply faded. All parallel modulators must meet a minimal signal-to-noise ratio threshold in order to operate; otherwise, they are turned off. Using adaptive bit loading technology, high signal-to-noise ratio modulators can transport more bits.

A resource sharing technique is employed for the medium access control of numerous users to the network transmission capacity. Contention-based protocols are not appropriate since they may result in collisions. For resource sharing, arbitration protocols like Polling, Aloha, and Carrier Sense Multiple Access (CSMA) are utilized. When the channel is empty, CSMA/CA monitors the signal level to determine when to broadcast tiny data packets to prevent collisions and retransmissions.

3.4 Modules for PLC System in Smart Metering

Electronic components account for the majority of costs because the transmission infrastructure is already in place. A communication system must have a transmitter and a receiver as a minimum. However, additional parts, such repeaters, filters, and wave-traps, are needed to ensure signal integrity. While the receiver reads the PLC signal, the transmitter is in charge of sending the signal into the power line. Both have similar configurations: the transmitter uses a frequency generator to modulate the signal, whereas the receiver uses a signal generator and an envelope detector to read the information. Both have an interface with the power line to prevent high voltages from entering sensitive parts of the circuitry. A standard PLC transmitter and receiver are depicted in a simplified manner in Figure 13.

The line filter is yet another significant element. Only the required PLC is bypassed by this filter, which is in charge of rejecting all undesirable frequencies from the power line (including the 50/60 Hz signal). For both transmitters and receivers, this serves as the primary point of contact with the power line. In this level, specialized decoupling capacitors are employed for straightforward applications. They enable a low impedance channel for the carrier frequencies while providing high impedance for the power frequency.

To prevent the communication signals to enter equipment through the power supply line and to allow signal sectionalization, a component called "wave-trap", or line-trap, is used. This component is made of different resonant circuits that provide high series impedance to the frequencies of the carriers, blocking all communication currents, while allowing power frequency to pass.

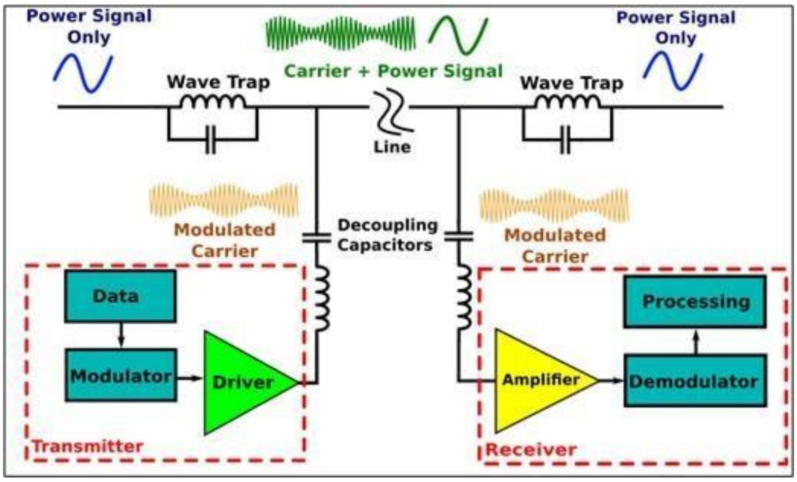

Figure-13: PLC basic components acting in a point-to-point communication. Decoupling capacitors provide interface and wave-traps provide line sectionalization.

Large propagation losses plague long PLC transmission. The repeater is thus among the most essential elements for long-distance applications. Basically, the repeater reads the required signal from the PLC line, rejects the power line frequency and undesired signals, and injects a signal that has been restored with improved amplitude and quality. The number of repeaters needed rises with frequency since propagation losses do as well. In order to transfer the signal via transformers that are designed for power frequencies (50/60 Hz), which can damage the transmitted signal, repeaters are also required.

3.5 Implementation of PLC for Smart Metering

As was already mentioned, the energy grid is a practical resource for the transportation of communication signals, particularly when they are used for services related to the electricity grid. PLC is a particularly alluring alternative in terms of availability and affordability due to the incorporation of the telecoms transport medium in the core of the energy assets. This section is divided into three subsections: the first introduces the concepts that will affect the choice and architecture of PLC deployments; the second introduces the electricity grid description and key elements in relation to PLC systems; and the third focuses specifically on NB PLC system deployments.

3.5.1 Grid Description

The generation plants, transmission lines, substations, and distribution system make up the four basic components of the electricity system. Different parts of the world have different types of electricity grids. Grids vary depending on the particular nation under consideration, and even their individual components vary according to the infrastructure's age. Depending on the particular purpose and network section it is addressed to, the Smart Grid takes on several instantiations. PLC is utilized in the access segment of the energy grid since it is a telecommunications access technology for the objectives of the Smart Grid in dispersed grids. The third part focuses primarily on NB PLC system deployments. The first two subsections discuss the ideas that will affect the choice and architecture of PLC deployments.

This is in reference to the grid's MV and LV segments. The grid's MV and LV segments are the ones closest to the PoS. The MV segment is the section of the grid that connects the HV grid to the so-called SSs, often known as transformer centers because they house MV to LV transformers. MV can be classified as overhead or underground depending on the cable layout; this categorization is significant for both the expense and difficulty of grid construction as well as the usability and effectiveness of PLC communications. Overhead power lines typically present a bus topology with mechanical switches in parts of the grid, whereas underground power lines configure a point-to-point network (where the "points" are the SSs) which is more important. Impedance of the power lines is different in both types of networks, propagation is typically favored in overhead scenarios, access to the cables is of a different nature, and signal couplers need to be installed differently. The portion of the grid closest to the PoS is known as the LV segment. The LV segment has two primary characteristics: the first is its capillarity and heterogeneity because it needs to be everywhere with the least amount of investment; to comprehend the diversity of this scenario, it is important to take into account the variety of configurations and the number of different components installed over time; the second is its susceptibility to the customer premises because loads (customers and their appliances) are connected there. This circumstance implies that impedances change in different parts of the grid, and that noises appear and disappear during the day and the season without any clear and traceable origin. As a consequence this variability of the physical transmission media leads to different telecommunication subnetworks ("subnetworks" are each one of the PLC networks associated to each specific SS) which may be considered unique in their characteristics and performance.

Despite the preceding description, it might be challenging to make generalizations about the nature and structure of the energy grid because these features are frequently the result of the historical development of socio-economic conditions in the various locations. To determine whether and how PLC will be used for communications, it is necessary to take into account the following factors:

• **MV segment:** Voltage levels must be taken into account while designing MV PLC systems. When designing the couplers that must transfer telecommunication signals from the transmitters to the receivers via the MV grid, the absolute value of the voltage level is a crucial consideration.

• **LV segment:** Distances, amount of PoS, and its density in LV grid. Since these three parameters are not independent variables, they are presented collectively. PLC might not be a desirable technology if the distance between transmitters and receivers is too great (in terms of attenuation) for a particular implementation of a technology, if the density of the PoS is too low to discourage repetition of the PLC signals, or if the number of PoS per subnetwork is insufficient to permit a sufficient economic return on investment. In a scenario where PLC turns outs to be a viable and adequate technology for any of the MV and/or LV segments (this is the case according to the deployment status of PLC systems for Smart Metering networks, due to economic reasons, e.g. once PLC systems have been technically proven on field at a massive scale, these aspects mentioned are the ones that need to be solved by the technology and the implementation of the PLC devices. There are still a lot of issues with the system design and the operational system level that need to be resolved. These additional factors aim to fill the gap between technology and the devices themselves, and their grid deployment ensures that the PLC network operates in a way that makes it capable of meeting the demands of smart metering and smart grid.

3.5.2.1 MV Grid

MV topologies can be classified in three groups:

• **Radial topology**: Radial lines are used to connect the secondary substations with the primary substations and the secondary substations with each other. These MV lines, sometimes known as “feeders,” may be used to connect to just one SS or a number of them. All SSs are under the overall control of radial systems. When these radial topologies become more complicated, they take on a tree-like form. In comparison to other structures, radial topologies are simpler, less expensive, and easier to operate and maintain.

• **Ring topology:** Ring topology is a fault-tolerant topology that overcomes the drawback of radial topology in the event that one component of the MV line is disconnected, causing an interruption in the supply of power (outage) to the other connected substations. An upgraded version of the radial topology that connects to other MV lines to provide redundancy is called a ring topology.

The grid is always run radially, regardless of the physical layout, but in the event of a feeder failure, other parts are moved to reposition the grid so that out-of-order lines are often restored.

• **Networked topology:** Primary and secondary substations are connected by a number of MV lines in a networked architecture. As a result, there are many reconfiguration alternatives to get around faults, and in the event of a problem, there may be other ways to redirect electricity.

3.5.2.2 LV Grid

LV grids have topologies that are more complicated and heterogeneous than MV grids. There are several reasons for this, including the geographic service area's extension and specifics, the PoS (loads), country- and utility-specific operational rules, etc. When one or more MV to LV transformers are located at the same location, an SS often offers electricity supply to several LV lines. The standard LV architecture is radial and develops branches that are connected to the extended feeders. In LV networks, there are instances of networked grids as well as ring or dual fed systems. LV lines are typically shorter than MV lines, and depending on the service area, they have varying features.

3.5.3 Grid Aspects with Influence in PLC Systems Design

The various facets and traits of the grid place restrictions on how PLC systems may be created and used to the fullest extent of their capabilities. The most crucial factors to take into account while picking one or more PLC technologies for a Smart Grid roll-out are covered in the following sections.

3.5.3.1 Communications Architecture: MV versus LV

Choosing which PLC technology combination to utilize in each segment of the grid while taking into account the limitations of the current MV and LV grid topology is crucial to developing the most suitable architecture for the services to be offered. There is no definitive answer to this because the final configuration will depend on the amount of bandwidth required for the services to be offered, the infrastructure of the electricity grid that is currently in place, the availability of suitable technology and vendors, and the utility's preferences. A BB PLC (also known as Broadband Power Line (BPL)) solution could be installed in both MV and LV segments if we simply take the high bandwidth demand into account; on the other hand, if merely metering restrictions are taken into account, only a completely NB PLC solution may be used in both segments. Combinations BB solutions in the MV segment and NB solutions for the LV segment can be discovered as a combination of both approaches this mixed approach can also be used in utility areas in conjunction with the other two approaches in other regions. UNB PLC is still an option as an extreme solution for very specific and particular grids.

3.5.3.2 Communication Characteristics of the Segments of the Grid

The selection of any architecture is always to be considered related to the physical aspects of the grid, which impose conditions and affect performance of the PLC technologies on top of them. The power lines' propagation characteristics in each section are the first significant effect to take into account (MV and LV). To determine how to best promote PLC signal propagation, factors such as cable design and disposition (overhead lines favor propagation) and the isolation of the segment from the PoS (disturbing noisy loads are mostly connected to the LV, and do not influence the MV segment) must be taken into account (maximizing desired signal and minimizing existing noise).

The interfaces between the MV and LV grid, or the transformers at the SSs, have a second significant effect. If the PLC system is to be used in both the MV and LV segment, the impact of these transformers at the interfaces must be taken into account. It is well known that UNB PLC systems can pass through the MV to LV transformer at SSs. Thus, this signal might emerge at the PoS with just a simple PLC signal injection in the feeders at the primary substations. In BB PLC systems, which normally operate in the frequency range of 2 MHz to 30 MHz, and inconsistently in NB PLC systems, this is simply not possible. The latter is a high-impact issue because it is impossible to predict in advance whether the PLC signal will be coupled from the primary to the secondary winding of the transformers without any external coupler. If a clear and universal rule cannot be established, this can be a major deployment problem. Therefore, the bandwidth will be shared among all systems (with the limitations and conditions of the MAC layer and the attenuation conditions of the different parts of the grid), lowering the available maximum throughput, if we only use one technology without using the natural segmentation of the grid (MV and LV).

PLC Signal Repetition in the Grid

The maximum distance that may be covered, whether in an MV or LV grid, is determined by the signal to noise ratio in the various communication lines. If the chosen PLC system is fixed and the grid conditions—distance and/or noise—cannot be changed, the difficulty that this limitation may impose is the impossibility to communicate the two distant points. This challenge can only be overcome if PLC signal repetition is possible. If the distance is shorter than the reach needed by the adjacent communication points—either two SSs in MV or the SS and a meter in the LV—this limitation may impose. Depending on the type of grid (mainly overhead or underground), the possibilities to connect devices to the grid to perform this repetition are different. If the repetition is to happen on the overhead grid, cable access might be easy if the repetition is needed in an underground grid, the devices can only be placed in points where access to the grid exists.

PLC Performance Assessment

The limitations of PLC communications networks make them particularly unique. Once the architecture has been decided upon, the network configuration becomes the key limitation. Network planning can be managed in many telecommunications systems by choosing where network equipment will be installed. The service points and locations where PLC signals must spread in the energy grid are fixed, but more importantly, the grid's characteristics are (cable types, specificities, etc.) are typically unknown or just partially known, making it impossible to forecast PLC behavior. Ex-post performance assessment is therefore necessary if ex-ante planning is severely constrained in order to determine whether the outcomes obtained are in line with the needs and whether any grid modification or network adjustment is necessary.

There are numerous techniques and best practices, making it simple to evaluate the performance of point-to-point connectivity. For shared media technologies, and particularly for ones that are NB (control traffic occupies a large portion of the available bandwidth), this is quite different.

NB PLC Systems for LV Grid Communications

NB PLC is the PLC technology that is most frequently used for smart metering. NB PLC is the most popular option for smart metering, including both meter reading and real-time nature applications like remote connection-disconnection of meters and remote firmware upgrade capabilities to guarantee that new features can be introduced to the field over the existing infrastructure, even though some tests and pilots have been conducted using BB PLC technologies and even real deployments with UNB PLC technologies exist.

For commercial Internet access and for simple local area network (LAN) connectivity, BB PLC systems have been installed across power grids. In cases where no other technological solutions were economically feasible due to the extremely low density and dispersed nature of the area, UNB PLC systems have been utilized as a last resort.

There isn't much information on the outcomes of NB PLC large-scale installations in the literature, as can be checked in. The majority of information on installations is based on the technical details provided by manufacturers (for both proprietary and non-proprietary systems), but sadly, marketing frequently distorts this information. On the academic side, research has traditionally been focused on the basic aspects of the underlying technology in the devices (modulation, coding) and systems (channel modelling, noise models, medium access control strategies).

It is necessary to have prior knowledge of a number of specific grid elements in order to deploy PLC for smart meters in the best possible way. These factors will influence how the PLC system behaves, and different grid factors and PLC parameters or functionalities should be adjusted based on their influence to enhance the performance of the entire set. The following sections provide more information on this.

Low Level System Aspects

Aspects of low level systems are connected to the fundamental physical layer of PLC technology. One of these crucial elements is modulation, which will be chosen based on the grid's constraints and the physical conditions at the time (mainly distance and noise). Modern multicarrier modulation systems based on OFDM typically offer a variety of modulation options in an effort to make the most of cutting-edge electronics while still providing the highest throughputs possible in secure communication channels. However, the use of high throughput (and poor noise immunity) modulations is not always advantageous due to grid conditions.

Despite the fact that PLC systems typically act in an adaptive manner to choose the most practical modulation for any given channel conditions, the feature does not come without a price: it burdens channels with control packet overhead to manage link conditions that might lower the useful throughput. Smart Metering systems often adhere to the polling technique, which involves taking meter readings one at a time, rather than establishing long-term contacts with a meter.

This fact, combined with the fact that in open and interoperable systems, peers needing to adapt the modulation scheme may be making less-than-optimal choices based on the assumption that their peer has some sensitivity characteristics that are not true (for example, PHY Robustness Management (PRM) is a feature that in PRIME systems allows to adjust modulation scheme robustness and power of the individual links in an end-to-end connectivity; this feature would need to precisely know the sensitivity of the peers to perform properly, as the assumptions and, subsequently, PRM messages may lead to build unstable subnetwork topologies), the possibility of establishing a fixed a modulation scheme is attractive to decrease system complexity. In addition to what was stated above, the information in is very helpful in helping you comprehend that the PLC communications layer is only one component of the system. Commonly, DLMS/COSEM-like application layers are used in smart metering systems. These systems function by having a concentrator, which is typically located at the SS, perform a polling routine to collect all of the meter readings. The overhead described is such that the performance decrease produced from physical layer throughput to application layer meter readings can be calculated with a factor in excess of 200.

As a result, and using the highest throughputs for PRIME modulation using various modulation methods as a reference, a factor of 6 is not significant for the total throughput performance. On the other hand, PLC communication channels in the LV electricity grid are harsh and have a rapidly changing nature which may result in unavailability in channels operating with Signal-to-Noise ratios (SNR) that are close to the electronics' physical limits.

The situation is exactly the same as in radio communications, where links are built to support an instant fading of a specific amount because statistics show that such a situation would arise. Studies on the nature of PLC channels that are modelled in terms of noise exist, but there aren't any that quantify the fades or the statistics that go with them because it would probably take more work to look at a representative sample of LV grid segments on the utility side of the grid in various parts of the world.

In the absence of such research, a field deployment should make a conservative choice of the lowest risk modulation. In PRIME PLC systems, this would be DBPSK with Forward Error Correction (FEC), which delivers 20 kbps throughput at the physical layer, as this modulation scheme should be accompanied by an error correction mechanism. The use of DBPSK modulation with FEC generated application layer availability of about 90%, according to the PRIME examples examined in. Other minor factors also demand consideration. The PRIME system must modify these possibilities while choosing from the available choices. Similar configurable parameters are offered by other comparable systems.

High Level System Aspects

One fundamental characteristic of PLC systems in LV grid for Smart Metering purposes is that node locations are basically fixed. Typically, PLC signal injection takes place at SSs, in the secondary winding of MV to LV transformers. In Smart Metering systems, service must be delivered at the locations where smart meters are installed. Since the meters are linked to the locations where electricity service is provided and the customer chooses those locations, there is no practical method to change the position of either the SSs or the meters. This circumstance compared to other technologies whose end service points are fixed, it is not that dissimilar. The major distinction, however, is based on two factors: the quantity of end points and the extreme difficulty of accessing intermediate grid sites, where network nodes may also be installed to design the required network to meet specified quality targets.

Although LV grids are not uniformly distributed, it is fairly common to encounter subterranean LV connections that have little to no access. Of course, there are LV grids that heavily rely on Both LV cables are installed on walls or hanging from poles, where access to the cables may be simpler. In the various utility service areas, both cable deployment architectures can be seen, with a tendency to be underground in urban areas and overhead in suburban and rural areas. In any case, the situation implies that traditional telecommunications planning is practically impossible when dealing with a Smart Metering deployment because the electricity distribution company cannot control this circumstance. As a result, system communications must rely on the current nodes on the grid, which are actually the service destination nodes. The majority of contemporary NB PLC systems have previously attempted to address the aforementioned scenario from the perspective of network node functionality, with varying degrees of success. The solution to this problem is to define a “node repetition” functionality that makes use of the capillarity and large number of network nodes to build a packet transport structure that enables any packet to reach any destination with the aid of the nodes in the grid. For example, the PRIME system refers to this repetition functionality as “switching” and bases this layer 2 capability on the ability of every node in the network to act as a “switch” to repeat a packet. The success of the layer 2 (e.g., PRIME) or layer 3 (e.g., G3, with 6LoWPAN protocols capable of defining the repetition solution is based in a combination of physical layer available throughput, together with the smart definition of the algorithms and packets structures to make repetition functionality subject to an agile implementation, capable of fulfilling close to the real-time objectives of technologies needed for Smart Metering systems as part of the bigger Smart Grid concept.

3.6 Issues in PLC

3.6.1. The Powerline Channel as Transmission Medium

First of all, the power line carrier, which presents a difficult environment for data transmission, was not created with that purpose in mind. The main problems are varying impedance, a lot of noise that isn't white in color, and significant degrees of frequency-dependent attenuation.

3.6.1.2. Varying Channel Model

The communication channel must first be modeled and appropriately analysed for effective communication. Any two outlets in a home can be connected by a channel that performs the transfer function of a highly intricate line network.

Typically, power line networks are constructed from a range of conductor types that are connected essentially at random and terminate in loads with various impedances. The frequency-dependent amplitude and phase responses can vary significantly over such a transmission medium. Over some frequencies, the signal might be barely audible when it reaches the receiver, but over others, it might be completely undetectable. Even worse, the network topology changes when devices connected to the network are plugged in or turned off, which makes the channel transfer function itself time variable. As a result, the signal to noise ratio (SNR) over the transmission bandwidth may be defined as random and time variable.

3.6.1.3. High Dependence of Transmitter and Receiver Location

There may be a significant impact on transmission error rates depending on where the transmitter or receiver is located (in this case, the power outlet). For instance, a receiver near a source of noise would have a lower signal to noise ratio (SNR) than a receiver farther away from the source of noise. Home devices that are connected to the network may be the noise producers.

3.6.1.4. Reflection, Multi-path Fading and Attenuation

Similar to a wireless channel, there is no line-of-sight propagation of the signal between the transmitter and the receiver. As a result, additional echoes need to be taken into account. There are several propagation channels between the transmitter and the receiver, which causes this echoing to happen. Reflection of the signal often occurs due to the various impedance mismatches in the electric network.

A specific weighting factor would be assigned to each multi-path to take the reflection and transmission losses into consideration. One may suppose that all reflection and transmission parameters in a power line channel are less than one. Since extra multi-paths are typically too weak to be significant, the number of dominant multi-paths to be taken into account (N) is frequently no more than five or six. This is due to the fact that a path's weighting factor would be smaller the more transitions and reflections it experiences. Channel measurements have shown that the attenuation of the channel rises with frequency.

3.6.2. Layers, Access Methods and Protocols

The Physical Layer and the Medium Access Control (MAC) Layer are the two fundamental layers that make up power line communication. While the MAC protocol describes a resource sharing strategy, or the access of numerous users to the network transmission capacity based on a defined resource sharing protocol, the Physical Layer defines the modulation techniques to transfer data over the power lines. Strong modulation methods like Frequency Shift Keying (FSK), Code-Division Multiple Access (CDMA), and Orthogonal Frequency Division Multiplexing are required for communication at the PLC Physical Layer (OFDM).

FSK is seen as a suitable option for low-cost, low-data-rate applications including telemetering and power line protection. The CDMA method can be a good option for data rates under 1Mbps.Beyond that, though, OFDM is the PLC technology of choice for large data applications. There are typically two types of access strategies for MAC.

3.6.2.1. Fixed Access

Regardless of whether a user needs to transmit data at that moment, it allots each user a fixed or predetermined channel capacity. Such plans are not appropriate for bursty traffic, such the data transmission offered by PLC.

3.6.2.2. Dynamic Access

These protocols can be divided into two groups: arbitration protocols, which are collision-free, and contention-based protocols, which are collision-prone. Since collisions could happen and data could need to be retransmitted, contention protocols might not be able to ensure a quality of service (QoS), especially for time-sensitive applications. Arbitration-based protocols are better equipped to ensure a specific QoS. Contention-based protocols, however, might actually offer better data rates in applications with lax QoS requirements (e.g., Internet applications). This is due to the fact that they have substantially lower overhead than arbitration methods (polling, reservation, token passing). The MAC Layer protocols for PLC have been extensively investigated.

3.6.2.3. Polling

The primary station queries the secondary station to see whether it has any data to send in this primary/secondary access mode. Heavy traffic can be handled using arbitration-based polling, and QoS assurances are present.

3.6.2.4. Aloha

It is a random access protocol in which a user accesses a channel as soon as it has data to send.

3.6.2.5. Token passing schemes

For PLC, CSMA with overload detection has been suggested. The contention-based access technique known as CSMA requires each station to listen to the line before transferring any data. CSMA is effective for various low-duty-cycle bursty terminals (like Internet browsing) and moderate to medium traffic volumes.

3.6.2.6. Carrier Sense Multiple Access (CSMA)

It has been suggested that PLCs use CSMA with overload detection. Each station listens to the line before transferring data while using the contention-based access mechanism known as CSMA. For many low-duty-cycle bursty terminals (like Internet browsing), CSMA is effective when there is mild to moderate traffic.

i. Collision Detection (CSMA/CD) senses the channel for a collision after transmitting. When it senses a collision, it waits a random amount of time before retransmitting again. But on power lines the wide variation of the received signal and noise levels make collision detection difficult and unreliable.

ii. Collision Avoidance (CSMA/CA) As in the CSMA/CD method, each device listens to the signal level to determine when the channel is idle. Unlike CSMA/CD, it then waits for a random amount of time before trying to send a packet. Packet size is kept small due to the PLC's hostile channel characteristics. Though this means more overhead, overall data rate is improved since it means less retransmission**.**

3.7 Applications of PLC System

Between electrical substations, power line communication is mostly utilized for telephony and tele monitoring. It is also frequently employed in advanced metering infrastructure, micro-inverters, and the smart grid. In order to remotely operate appliances and lighting in homes without installing additional cabling, medium frequency PLC is employed. More people will adapt to and use the technology as it develops and is exposed to bigger audiences.

Traffic light control, industrial irrigation control, machine-to-machine applications like vending machines, telemetry applications like offshore oil rigs, transportation applications like electronics in automobiles and trains, and many other uses are possible for it.

The utilization of BPL, which now exists in all smart homes and smart rooms, creates exciting new possibilities for the future. Many of the appliances in these homes, or even hotel rooms, are turned on and off automatically. Wider use is still rare, though. Several nations that tried to deploy Access BPL on a bigger scale were unsuccessful. Failure is attributed to the BPL's incompatibility with mobile devices, limited reach, and low bandwidth, use of standard broadband, routers, and modems.

The cost-effective installation, the ability to provide extensive coverage by utilizing the current electrical distribution network, the expanding use of smart grids, and the high penetration of Broadband over Power Line communication are the main factors propelling the growth of the Power Line Communication market.

These are the sectors where power line communication system can be used:

1. Transmission and distribution network

2. Home control and automation

3. Entertainment

4. Telecommunication

5. Security systems

6. Automatic meter reading

7. Telemetry

8. Telephony

9. Protective relaying

3.8 Advantages and Disadvantages of PLC

3.8.1 Advantages

• **Low Implementation Cost:** PLC eliminates the need for new cable installation, which greatly lowers deployment costs.

• **Large Reach:** PLC can facilitate communication with difficult-to-reach nodes where the RF wireless signal experiences significant attenuation, such as in underground structures or buildings with obstructions and metal walls, or simply anywhere the wireless signal is undesirable due to EMI problems, such as in places like hospitals.

• **Lower Running Cost:** Cost: When compared to other technologies now in use, such as RF wireless or visible light communication (VLC) systems, PLC offers a cost-effective alternative.

• **Indoor High Speed:** A lot of recent research has focused on the integration of PLC and VLC technologies, which has led to the development of a new generation of high-speed indoor communications for a variety of applications.

• Relatively long technology lifecycle (vs GPRS)

• Good option for new residential colonies and newly electrified villages with new electrical network designed and built for PLC applications.

• Communications possible in difficult environments such as underground installations, metal-shielded cases, etc.

• Broadband PLC (BPL) can provide consumers with both telephone and internet connections.

These advantages lead to more implementations of PLC networks in various industries. But with advantages there also comes some disadvantages.

3.8.2 Disadvantages

It also has some disadvantages such as:

• Low transmission speed.

• Sensitivity to disturbance,

• Nonlinear distortion and Cross-modulation between channels,

• Large size

• The high price of capacitors and inductors used in the PLC system.

• Due to these disadvantages, PLC is still not preferred in some applications.

• Requires good quality power cables with crimped joints (in Bangladesh mostly Aluminium wires are have twisted joints which are not good for PLC)

• Requires filters to clean the communication signal (from noise)

• Communication not possible in case of power outage

• Requires trained manpower for O&M.

3.9 Further Scope

We will undoubtedly be able to develop more applications for the idea with more research in the field of digital signal transmission through power lines. The most significant use of this idea, however, would be Internet Access via Power Lines. Digital transmission across power lines might give us this access through any of the billions of power sockets around the planet in the modern world, where having access to information while moving has become important for surviving in a society that moves at a breakneck speed**.**

We would be able to access the internet from any place that has power supply thanks to this. For ready-to-use "Plug and Play" Internet connection, the device to be used to access the internet might be simply plugged into the power socket. We will need to change the hardware for the power lines as a result because we will now need to install routers at transformer sections. In addition, these power lines will need to be connected to the servers. If this technology is to be used on a commercial level, protocols and standards must be created for it.

The installation of Wi-Fi Hot Spots in locations adjacent to transformers may also make it possible for people to access the internet. Thus, with careful work in this area, it's possible that we'll be able to access information on the internet in entirely new ways, rendering Cable and DSL technologies completely obsolete as the ubiquitous power lines themselves act as our access point to the Internet, the world's largest repository of knowledge.

3.10 Limitations of PLC System

There are a few issues with this concept that would need to be resolved before its commercial application, despite the fact that the prospects for its implementation and use appear promising.

1) Radio interference is the main issue with digital data transfer via power lines. The power lines may operate as antennas and radiate a lot of radio energy because they are typically exposed, unshielded, and untwisted. The other radio signals being transmitted at the same time would be severely interfered with as a result. The operation in reverse would interfere with the transfer of data since it would interfere with the signals sent via the power lines.

2) The power line cable is fundamentally unsuitable for transmitting the frequencies used by BPL, unlike any other broadband medium (copper twisted pair, fiber coaxial cable). When trying to send a signal across a medium like coaxial cable, power lines, or copper twisted pair, higher frequencies are attenuated more than lower frequencies are.

Electrical power is intended to be transported by power lines. Radio signals were not intended for them to carry. They do this horribly, losing a large portion of the signal due to losses. When data must be transferred via the many transformers, a significant issue will arise. Due to its large inductance, transformers function as low-pass filters, letting only low-frequency components pass through while blocking higher-frequency signals. As a result, we will need to use more repeaters in the communication channel.

3) The final issue would be the same as with any new technologies: the lack of any established procedures. An organization like IEEE would need to develop a set of guidelines or standards for digital data transmission via power lines in order for the technology to succeed and be widely used.

This would enable different equipment manufacturing businesses to create equipment that complies with the standard recognized by all nations and the service providers to transmit and receive data according to a predetermined protocol.

Chapter 4: Methodology

The study's objective is carried out using an exploratory research design, which entails reading research articles on power line communication systems for smart metering networks and reviewing the literature. Our supervisor provided us with the topic for the study. The subject was thoroughly discussed before assigning in order to write a well-structured internship report.

We first quickly evaluated what is known about the power line communication system for smart metering networks in order to grasp what it is all about. In the reference section a numberof papers that are pertinent to the problem have been highlighted, provides up the conceptual foundation. Secondly, a synthesized review of past publications has been finished.

From the practical deskwork, primary data was derived. Additionally, our supervisor at DPDC assisted us in getting information directly from the company. Lastly, related summaries required diagrams, comparative studies and technical aspects of the Power Line Communication System for Smart Metering Network has been presented in a concise manner.

Chapter 5: Discussion

5.1 Smart Meters:

5.1.1 The Smart Meter

An electrometer that measures electricity use over time is a smart meter. The advantage of these meters is that they communicate with and receive commands from the main hub or command center. The smart meter has a two-way communication feature.

5.1.2 Characteristics of Smart Meters:

1. The utility has the ability to remotely turn off all smart meters.

2. The meter cover must be opened in order to change any plugs.

3. A timestamp is added to the recording in the meter.

4. Send the command center an immediate notification of any essential events.

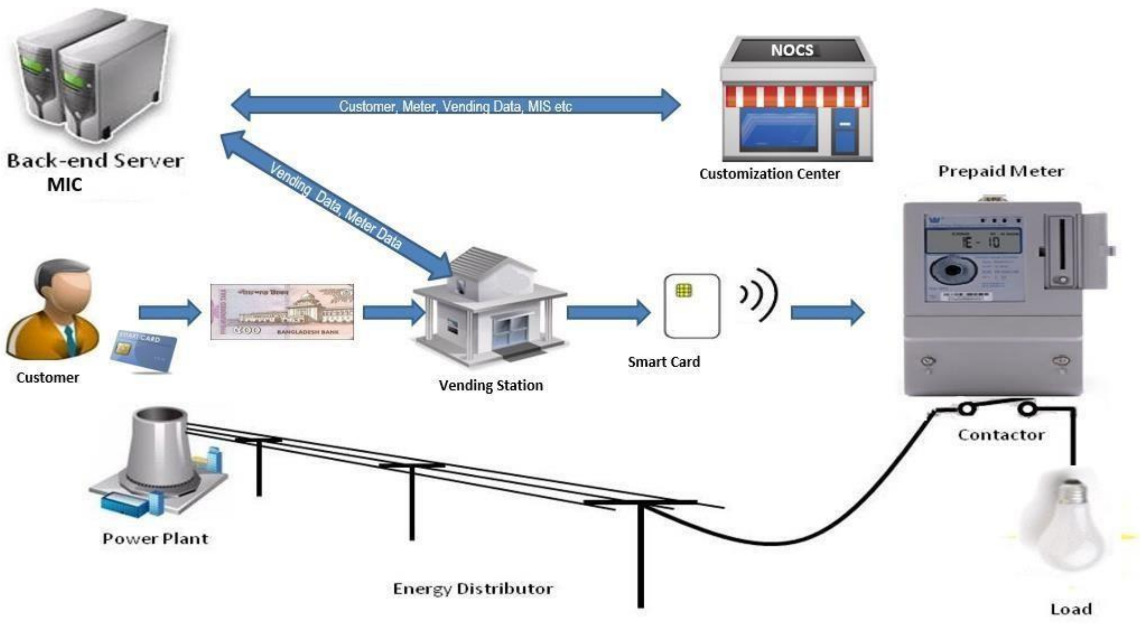

Figure-14: Smart Metering Features

Benefits to Utility:

1. Commercial Benefits:

- Increased Billing Efficiency due to Automated Meter Reading
- Efficiency Remote Disconnection which increases the effectiveness of collection
- Strengthening Data Analytics increases the success rate of tamper detection
- Reducing Ad-hoc readings leads to conserve time & resource
- Real-Time Energy Audit reduction in revenue billing cycle time and quicker detection of dead meters

2. Operational Benefits:

- DT Meters on same Covering prompts recognize the Asset Utilization.
- Evacuation of Manual Disconnection or Reconnection
- Quicker Blackout Location
- Constant Power Quality Observation

3. Consumer Benefits:

- Less Blackouts
- Error Free Bills due to no Manual Intervention
- Option to choose – Prepayment
- Better usage visibility through Mobile app
- Enablement for Renewable Integration
- Incentive for maintaining PF>0.85

5.2 Challenges of Smart Metering

Numerous design difficulties are raised by the use of smart meters. Clarifying characteristics is one of the first challenges because smart meters for utility and residential use fall under distinct feature sets with little overlap. The user community's description of the criteria can lower the cost of the smart meter by utilizing the best hardware and software. A list of some of the qualities that may have an impact on the design's cost and modularity is provided below:

a. Communication Protocol: To prevent proprietary protocols from making their way into Smart Meters, it is crucial that specific communication protocols be standardized or required by a centralized agency.

b. Communication Security: As remote control functionalities are implemented and critical revenue data is communicated, communication security in an AMI/Smart Grid context will become a top priority. It is crucial to specify which specific IEC 62351 standards must be implemented into the meter firmware in order for it to work with AMI and MDM systems.

c. Interoperability: It should be assured that the control instructions and other data formats used in smart meters are compatible with the current AMI infrastructure.

d. Meter Data:. Different measuring parameters are needed for different consumers (utilities, industry, and homes). It is essential to standardize parameter needs across customer categories.

e. Communication ports: Since Ethernet and optical Ethernet will be used for the Smart meters instead of the Serial connection and USB, The ports' specifications will aid in improving the case's design and upgradeability.

f. Communication: Smart meters provide a wide range of connection options, including wireless (Zigbee, WiFi, LowPowerRF) and power line. It would be ideal to identify this choice as allowing for specialized research, analysis, and application.

g. Power Quality Requirements:. Higher order harmonic distortions, Sag, Swell, Outages, Dips, Transients Recording, and Recording Duration will all need to be described, along with the types of power quality tests that must be taken across various consumer groups. The cost of the smart meter will be reduced if these criteria are well defined since they will affect how digital signal processors and high-speed memory are used to execute the power quality measuring capabilities.

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h. Time 41ynchronization: Designing the internal interfaces and selecting the right devices for these features requires a specification of the synchronization technique for RTC time based on GPS, IRIG-B, or from the network.

i. I/O expansion capability:. Definition of the several types of I/O capabilities, including analog inputs and outputs, solid-state vs electro-mechanical relays, and the number of inputs and outputs. This will establish if the I/O can fit in the smart meter or whether a different extension box has to be equipped with the required connections to the meter.

5.3 Challenges of PLC System for Smart Metering

The information flow of the Energy Internet will increase rapidly with the availability of numerous distributed generating units and numerous large-scale sensors. In light of this, power line carrier communication will be a crucial technological component of the Energy Internet access network, particularly in isolated mountainous regions and other industrial settings with complicated infrastructure. Power line carrier communication can deliver quick, flexible, and affordable network coverage. New services present further communication issues for power line carriers against the backdrop of Energy Internet. Currently, “local area networks” like smart homes employ high-speed and low-voltage broadband power line carrier communication primarily. Due to numerous narrowband disturbances, the frequency band used for high-speed broadband power line carrier communication is mostly centered in the range of 3 to 30 MHz. The capacity of power line carrier communication is highly connected to spectrum utilization and bandwidth. The bandwidth of power line carrier communication faces enormous hurdles as a result of the Energy Internet’s access to large sensors, power distribution terminals, and other equipment. In terms of the Energy Internet’s security and dependability, power line carrier communication likewise confronts enormous difficulties. One way it manifests itself is in dependability. Communication breakdowns have a direct impact on the power grid’s ability to handle energy production, transmission, consumption, and storage in a collaborative real-time manner. On the other side, it manifests in the communication’s security. The Energy Internet’s openness and sharing aspects raise the possibility of harmful assaults. Similar to Internet assaults, it may result in communication breakdowns, user and system data leaks, direct attacks on the power grid, tampering with power grid data, and compromising the power grid’s ability to function safely. Research on the application of forward error coding and adaptive modulation and demodulationto power line carrier communication can improve the reliability of communication and the efficiency of bandwidth spectrum utilization. Using advanced information technology (ant colony algorithm, genetic algorithm, adaptive control theory, etc.)

can improve the networkingcapabilities of the power line carrier communication system. It is one of the directions to solvethe problems caused by the large-scale equipment access brought by the energy Internet. The progress of semiconductor technology can improve the baseband processing speed of power line carrier communication. The transmission delay of power line carrier communication will significantly improve with the enhancement of modulation, coding rate, and RF performance. Last but not least, the reliability protection mechanism and security encryption technique of the physical layer and application layer data of power line carrier communication will undoubtedly become significant study topics in the communication technology of the Energy Internet access network.

5.4 Experience as an Intern at DPDC:

At the end of May 2022, some of us students from East West University participated in DPDC's 3-month internship program.

DPDC at a glance:

Name of the Company: Dhaka Power Distribution Company Limited (DPDC) Administrative Ministry: Power Division, Ministry of Power, Energy & Mineral Resources

Registered Office: Biddut Bhaban, 1 Abdul Gani Road, Dhaka-1000

Head Office: Biddut Bhaban, 1 Abdul Gani Road, Dhaka-1000

Incorporation: 25 October, 2005

Commercial Operation: 1 July, 2008

Authorized Capital: Tk. 10,000 crore

Total area covered: 350 sq. km

Total electricity line: 5,371 Km

Total Number of Substation: 58 Nos Max.

Demand (June 2018): 1479.40 MW

Distribution Transformer: 18,986 Nos

Annual Load Growth: 7.10%

Import of Energy (FY 2017-2018): Mkwh 8,819

Sale of Energy (FY 2017-2018): Mkwh 8,165 Sales

Revenue (FY 2017-2018): MTk. 46,218.24

System Loss: 7.41%

Payment to the National Exchequer: MTk. 7,671

Number of Customers: 11,95,829 Nos (As on 30.06.18)

Human Resources (As per set-up): 5,734.

The following topics are highlighted during the internship program:

(a) Introduction of electricity supply, gradual formation of PDB, REB, DESA, DESCO and DPDC by the Government under the Power Sector Reforms 1

(b) Power supply system at DPDC.

(c) Network Operations and Customer Service (NOCS) activities at DPDC.

(d) Activities of supporting offices of NOCS (eg: HR, Finance, ICT, Audit, Planning, Development, Metering, System Protection, Grid, Tariff and Energy Audit).

(e) Activities of Training and Development Department of DPDC.

(f) Inspection of 132/33 KD GIS Substation and 33/11 KV Substation.

(g) Inspection of SCADA System, Workshop, Meter Testing Lab, Central Warehouse, Medical Center of DPDC.

(h) Meter Installation

(i) PLC Networking

Unified prepaid metering project particular:

Name of Works	Design, Manufacture, Supply, Installation, Testing & Commissioning of Software, Hardware, Meter & Networking of Pre-Paid e-Metering System on Turn-key Basis
Sponsoring Ministry	Ministry of Power, Energy & Mineral Resources (Power Division)
Executing Agency	Bangladesh Power Development Board (BPDB)
Financing	Utilities own revenue Fund
Date of Turn-key Contract	14-Jul-2011
Name of Turn-key Contractor	Consortium of Ideal Enterprise, Hexing Electrical Co. Ltd. China & Bangladesh Internet Press Ltd. Bangladesh.
Cost of the Project	Total: BDT 42,65,50,662.40
Project Completion time	9 Months (July 14, 2011 to April 13, 2012)
Project Area	(1) BPDB – Tangail (2) DPDC – Dhaka (3) DESCO – Dhaka (4) REB – Savar (5) WZPDCO - Khulna

Meter Installation and PLC networking to communicate:

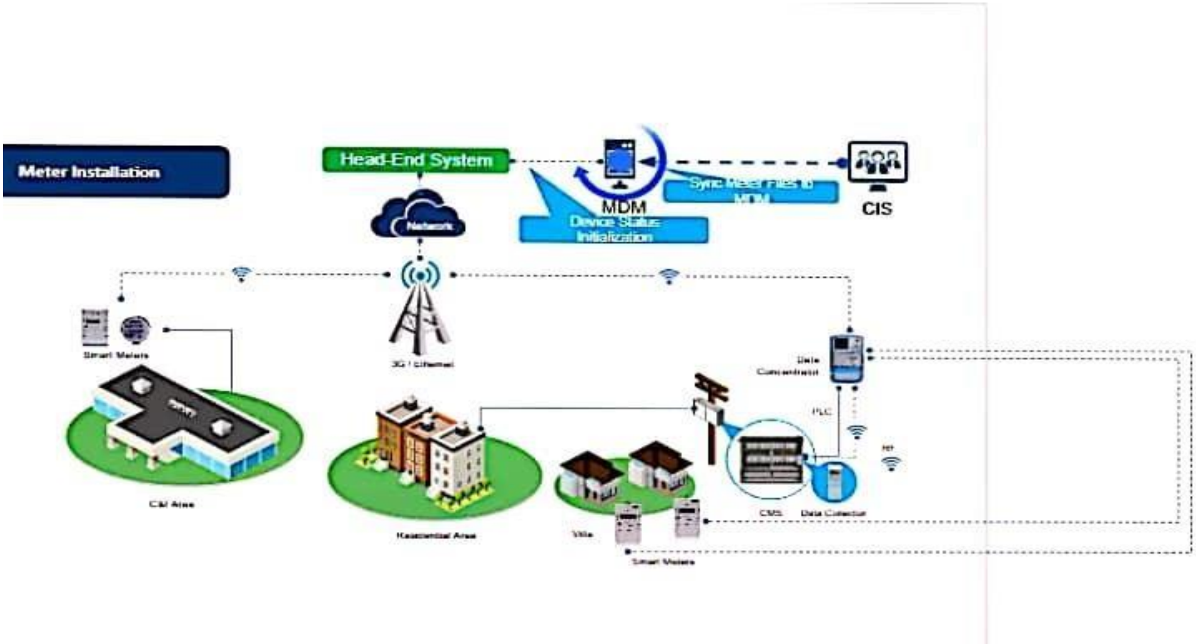

Fig:15 Meter Installation

Datas of the customers collected using PLC network:

Meter _no	02110004876
Customer_ no	22686805
Name	MR.M.A Akanda
Sanctioned_load(KW)	2
Tarrif	LT-A
NOCS	Mutail
Month End Reading(KWH)	4594.3100
Month End Balance(TK)	259.65
Consumed Unit(KWH)	156.87
Monthly Amount Of Mone Spent(TK)	782.52
MD(KW)	0.7310
MD 0ccurring Time	2022-12-14 13:30:00
Address	1304-Dhania

5.4.1 Visiting Sites:

SCADA (Supervisory Control and Data Acquisition):

Fig 16: SCADA Visit

Dhanmondi Sub-Station:

Figure-17: Dhanmondi Substation (1)

Figure-18: Dhanmondi Substation (2)

Grid Sub-Station (Shahjahanpur):

Figure-19: Grid Sub-station Visit

NOCS (Network Operation & Customer Service) Narinda:

Figure-20: Visit to NOCS Office Narinda

DPDC Library:

Figure-21: Visit to DPDC Library

HR, Finance, ICT Division, 132/33 KV GIS:

Figure-23: Several DPDC Office Visit

Along with all the site visits we are given several lectures on DPDC. We had to take part in three assessment tests on the lectures given by our honorable SE Sir. Our certificates are awarded based on these assessment tests.

5.5 Ongoing Projects of DPDC:

(a) Detailed description of self-financed projects

Projects completed in the financial year 2021-2022:

01. Project Name: Design, Manufacture, Supply, Installation, Testing & Commissioning of Smart Pre-Payment Meter at NOCS Kamrangirchar on Turnkey Basis.

Ongoing Projects:

01. Project Name: Design, Manufacture, Supply, Repair, Service, Installation, Testing and Commissioning of Mohammadi 132/33 KV Grid Substation on Turnkey Basis.

02. Project Name: Design, Manufacture, Supply, Installation, Testing & Commissioning of Smart Pre-Payment Meter at NOCS Banglabazar with 03 Years Maintenance Support Service on Turnkey Basis.

(b) Projects included in the Annual Development Program (ADP): Projects completed in FY 2021-2022:

01. Project Name: Construction of New 132/33 KV & 33/11 KV Substation under DPDC.

Ongoing Projects:

01. Project Name: Pre-payment Metering Project for 06 NOCS under DPDC.

02. Project Name: Expansion and Strengthening of Power Distribution System in DPDC Areas.

03. Project Name: Power Distribution System Development Project in DPDC Areas.

04. Name of the Project: Installation of eight lakh and fifty thousand smart pre-payment meters in the area under DPDC.

05. Project Name: Underground substation construction project at Karwanbazar, Dhaka under DPDC.

06. Project Name: Construction and Rehabilitation of Substations, Installation of Capacitor Banks in Power System and Introduction of Smart Grid System in DPDC Areas.

Chapter 6: Conclusion and Future Works

6.1 Conclusion

This paper has covered the strategic aspects of PLC systems applications over the electricity grid for the purpose of Smart Metering. The history, strong aspects and the constraints of PLC systems have been shown, in order to understand how PLC may fit in the Smart Metering networks. The paper rationale is the need to further evolve these PLC systems, their design and their architecture on field, to make them capable of offering the functionality and performance needed for the Smart Grid.

The system decisions to make PLC systems adapt to each Smart Metering scenario have been elaborated in Chapter 2-3. The first aspect that needs to be considered is the communications architecture to be developed in the MV and the LV grid segments, where the throughput requirements are an important factor to be taken into consideration, together with the isolation level of the PLC systems used in the connection points of MV and LV segments, i.e., the SSs. Once the architecture has been decided, the PLC signal injection at the SSs, and the capabilities of the PLC system chosen will condition the performance results obtained. To conclude the chapter, and being the NB PLC systems the most prevalent ones for Smart Metering networks, specific low level aspects recommendations are provided on the MAC layer, being packet size, FEC strategies and automatic retransmission the most important ones**.**

Chapter 3 includes the deployment guidelines for NB PLC systems. These guidelines are to be applied in both the SSs (injection of PLC signal from the masters of the system) and at the different points of the LV grid if signal repetition due to low SNR is needed. Signal injection strategy is heavily affected by the multi-transformer scenario described in the chapter, and by the nature of the signal injection (single- or three-phase). These guidelines will manage to obtain the performance results needed.

This paper also includes our experience as an intern at DPDC. We also discussed about smart metering at DPDC, ongoing projects on DPDC etc.

The paper ends with the challenges that PLC systems face in their evolution to fit the needs of Smart Grid networks. On one side, the need to further optimize existing PLC system is highlighted. On the other, the interaction between PLC systems and the grid is shown as a factor that needs to be used both to improve PLC systems performance, and to obtain a better knowledge of the grid itself. As a final idea, the combination of PLC and non-PLC technologies is suggested as a possibility to pave the way towards Smart Grids.

6.2 Future Scope

Nowadays experts investing not only in the actual communication technology, but also in the analytics. Combined with the knowledge they've gained through the acquisition of a meters company, the data scientists have been very creative in how scientists leverage the data from smart meters to create new value. For instance, the prospect of developing a cost-effective PMU (phasor measurement unit), is something that would have proved challenging in the past, but is now something that we are considering. And it's not necessarily just infrastructure that they're investing in—it's the entire solution for the customer. Certainly, companies have next generation R&D in the works where they are looking at ways to reduce the cost of substation communication equipment. They are also integrating some of the grid monitoring solutions with PLC so that they can provide enhanced fault detection with smart grid sensors on the medium-voltage side of the distribution grid. In addition, much of the development is happening at the head end and system as they are trying to take advantage of the data grid companies collecting to provide a broader range of solutions.

As our main concern for electrical utilities is to decrease the power consumption peak and shift it to the low load hours. A communication system linking consumers and electric utilities is likely to prove particularly helpful in areas such as metering and the lowering of peak loading. The PLC network as seen in this study simplifies and reduces living expenditure as technology advances. We must continue to search for a better solution hence the best solution one that fits with the variety of business scenarios. While studying technical possibilities we will have to build up those business scenarios as they are for commercial purposes. We look forward for patronizing from the appropriate authority for our new vision Digital Bangladesh.

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