Study of Application of Power Line Carrier (PLC) in Automated Meter Reading (AMR) and Evaluating Non-Technical Loss

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The thesis titled **"Study of Application of Power Line Carrier (PLC) in Automated Meter Reading (AMR) and Evaluating Non-Technical Loss"** submitted by Tasfin Mohaimeen Haq, Roll No.: 040506111P, Session: April, 2005, Department of Electrical and Electronic Engineering (EEE), BANGLADESH UNIVERSITY OF ENGINEERING AND TECHNOLOGY (BUET), has been accepted as satisfactory in partial fulfillment of the requirement for the degree of MASTER OF SCIENCE IN ELECTRICAL AND ELECTRONIC ENGINEERING (M.Sc in EEE) on March 28, 2015.

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ABSTRACT

In the modern world the usage of Power Line Carrier (PLC) is spreading as it is very cheap, simple, easy to deployment and uses the existing power supply line and infrastructure. However, in Bangladesh PLC is used only by the power transmission authorities to maintain their own communication system, Supervisory Control and Data Acquisition (SCADA) and Load Dispatching. This tradition can be changed by PLCs versatile applications in conventional residential building, home automation, commercial application and in several exploitable on-line condition monitoring of electrical appliance. This can be achieved at lower cost as extra networking systems are not needed. PLC can also be utilized in Multimedia Signal Distribution, Broadband over Power Lines (BPL), Internet Phone, Internet Service and Telecommunication. The devices like PLC modem, PLC Base/ Master Station, PLC Repeater and Gateway can replace the traditional networking equipments. As it uses the existing power transmission line and infrastructure, it can be implemented quickly and easily in everywhere in the country.

In this research work, the development of Power Line Carrier (PLC) is concentrated in Automated Meter Reading (AMR) Systems and Evaluating Non-Technical Loss (NTL) i.e Detection of Illegal Electricity Usage. If an AMR system via PLC is set in a power delivery system, a detection system for illegal electricity usage may be easily added in the existing PLC network. In the detection system, a digital energy meter chip will be used to store the value of energy. The recorded energy will be compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal will be generated and this error signal will indicate the illegal electricity usage with specific identification. The proposed systems will provide quick and reliable meter reading collection with less error, few technical people's involvement and eliminates the need of physically reading the meters. The system will also save many hours of billing time as billing employees will not have to manually input meter readings. In recent days, illegal electricity usage has been a major problem in our country. Hence the utilization of PLC in automated and remote detection of illegal electricity usage can be a novel solution to detect the consumer involved with Illegal Electricity Usage specifically. It will also increase the revenue earning of power distribution authorities.

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List of Symbols

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n	Signaling Path	19
v	Arriving Signal Path	19
•$_v$	Delay Time	19
•$_v$	Complex Attenuation Factor	19
φ_v	Phase of the complex attenuation factor	19
$h(t)$	Impulse response of the channel	19
•(t)	Dirac pulse.	19
A, B, C and D	Frequency dependent coefficients	19
Z_{in}	Input impedance	20
Z_S	Serially connected impedance	20
Z_P	Parallel connection of load impedance	20
Z	Load impedance	20
Z_{eq}	Equivalent load impedance	20
T	The transmission matrix	21
•	Magnetic flux	25
L	Load	25
P	Real power	27
E	Consumed energy	27
t	Time	27
S	Apparent power	28
Urms	Root-mean square voltage	28
Irms	Root-mean square current	28
PF	Power factor	28
Q	Reactive power	28
E_{Loss}	Total Energy Losses	28
$E_{Delivered}$	Energy delivered	30
E_{Sold}	Energy recorded or sold	30
R	Resistance	30
X	Reactance	30
I	Current	30
V	Voltage	34

List of Abbreviations

Abbreviations	**Elaboration**
PLC	Power Line Carrier
AMR	Automated Meter Reading
NTL	Non Technical Loss
HV	High Voltage
CTP	Carrier Transmission Over Power Lines
kHz	Kilo Hertz
kM	Kilo Meter
AM	Amplitude Modulation
dBm	Decibel milli Watts
RCS	Ripple Carrier Signaling
MV	Medium Voltage
LV	Low Voltage
Hz	Hertz
ASK	Amplitude Shift Keying
FSK	Frequency Shift Keying
PSK	Phase Shift Keying
CEBus	Consumer Electronic Bus
EIA	Electronic Industries Alliance
LonWorks	Local Operation Networks
PHY	Physical Layer
RF	Radio Frequency
BPSK	Binary Phase Shift Keying
HF	High Frequency
ASICs	Application Specific Integrated Circuits
UPA	Universal Power Line Association
ITU	International Telecommunication Union's
Gbit/s	Giga bit per Second
IEEE	Institute of Electrical and Electronics Engineers
BPL	Broadband over Power Lines
Mbit/s	Mega bit per Second

AT&T Co.	American Telephone and Telegraph Corporation
GE	General Electric
AMI	Advanced Metering Infrastructure
US	United States
AMRA	Automatic Meter Reading Association
NARUC	National Association of Regulatory Utility Commissioners
LTUs	Line Tuning Units
LMU	Line Matching Unit
CCVT	Coupling Capacitor Voltage Transformer
K Ohm	kilo Ohm
OFDM	Orthogonal Frequency Division Multiplexing
FEC	Forward Error Correction
QPSK	Quadrature Phase Shift Keying
IFET	Inverse Fast Fourier Transform
ISI	Inter Symbol Interference
FFT	Fast Fourier Transform
AC	Alternating Current
DC	Direct Current
TL	Technical Losses
NTL	Non-Technical Losses
CT	Current Transformer
PT	Potential Transformer
IP	Phase Current
PLM	Power Line Carrier Modem
kHz	Kilo Hertz
SCADA	Supervisory Control and Data Acquisition
LCD	Liquid Crystal Display
HCS	Host Central Station
DCU	Data Concentrator Unit
MIU	Meter Interfacing Unit
LAN	Local Area Network
DESCO	Dhaka Electric Supply Company Limited

BPDB	Bangladesh Power Development Board
REB	Rural Electrification Board
DPDC	Dhaka Power Distribution Company Limited
WZPDCO	West Zone Power Distribution Company Limited
PGCB	Power Grid Company of Bangladesh Limited
BERC	Bangladesh Energy Regulatory Commission

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTION

Using electric power lines as signal transmission medium, is possible as every building or home is already equipped with the power line and connected to the power grid. The Power Line Carrier (PLC) systems use the existing AC (Alternating Current) electrical wiring as the network medium to provide high speed network access points. In most cases, implementing a PLC network using the existing AC electrical wiring is easier than other networking systems and relatively inexpensive as well [1], [2]. Automated Meter Reading (AMR) is one of the most important applications of Power Line Carrier (PLC). If a PLC based AMR is set in a power delivery system, a detection system for Non-Technical Loss (NTL) as well as illegal electricity usage can be easily deployed [3].

This chapter serves as an introduction to the chapters that follow. The background, objectives and organization of the thesis have been discussed in this chapter.

1.2 BACKGROUND

The idea of utilizing power lines to carry signals is a very old invention. In 1838, the first remote electricity supply metering was proposed to check the voltage levels of batteries in an unmanned site of the London-Liverpool telegraph system. In 1897, the first PLC patent on power line signaling electricity meter was proposed in Great Britain [1]. In 1905, the remote reading of electricity meters using an additional signaling wire was patented in the USA. In 1913, the first products of electromechanical meter repeaters were launched commercially.

In 1920, the carrier frequency transmission of voice signal over high voltage (HV) power lines was deployed. The carrier transmission over power lines (CTP) was important for the management and monitoring tasks and also at the beginning of electrification the full-coverage of telephone network was not available. The frequencies used for CTP were between 15−500 kHz. Under favorable circumstances, it was possible to bridge the distance of 900 k.m between transmitter and receiver with the transmission power of 10 W (40 dBm). Firstly, only Amplitude Modulation (AM) was applied as it was simple and optimal for voice transmission [1]. Later, the telemetering and the telecontrolling systems were also implemented.

In 1927, the use of thermionic valves for metering was patented. From 1930 onwards, the ripple carrier signaling (RCS) system was applied in the Medium Voltage (MV) and Low Voltage (LV) networks where its main functions were the load distribution. It also made possible the avoidance of extreme load peaks and made the load curve smooth. MV and LV networks have large number of branches, so these were poor medium compared to the HV overhead lines. As RCS worked in the low frequency range (approximately 125−3000 Hz), the transmission power had to be according to the peak load of the network. Hence, the transmission power was large, in practice it is around 0.1−0.5 % of the maximum apparent power. Here, the applied carrier frequencies enabled the information to flow over transformers between MV and LV networks with less attenuation. Also, the data rates were low and the data transmission was unidirectional as it is from the power supply company to the consumers end. To transmit information through electrical networks, RCS was used with the Amplitude Shift Keying (ASK- a type of amplitude modulation that assigns bit values to discrete amplitude levels) as well as the Frequency Shift Keying (FSK- a type of frequency modulation that assigns bit values to discrete frequency levels) methods [1], [2].

In 1936, the indirectly heated cathode valve was introduced. In 1947, the invention of transistor reduced the size of all electrical and electronic devices. The invention of integrated circuits in 1958-59 by Robert Noyce from Fairchild Semiconductor and Jack Kilby from Texas Instruments and later the invention of microprocessor in 1971 by Ted Hoff at Intel launched the development of low cost integrated circuits for power line carrier communications. Also by the late 1980s and the early 1990s, sophisticated error control coding techniques and their implementation into low cost microcontrollers within the hardware of PLC modems were proposed.

The development of modulation methods and the use of higher frequencies in the carrier signal enabled higher data transmission rates and decreased the required transmission power. Also bidirectional data transmission was introduced and the benefits of using power lines for data transmission indoors were implemented along with the introduction of Internet. Several technologies concerned with PLC such as X10, MELKO™, LonWorks, CEBus, INSTEON and HomePlug® were used during the last few decades.

The X10 standard was developed by Pico Electronics in 1975. X10 is an international and open industry standard for communication of electronic devices used for home automation. It mainly uses LV power lines for signaling and control. In this system, the digital data is encoded to a 120 kHz carrier and is transmitted as bursts during zero crossings of AC voltage network [8]. Here, every single bit is transmitted at each zero crossing. Hence, data rates of 100 bps and 120 bps can be obtained in 50 Hz and 60 Hz electric networks respectively.

The next generation devices were based on more effective modulation methods and those provided higher data transfer rates and these were designed for load management in medium and low voltage distribution networks. Here, the transmit power was decreased and it supported bi-directional data transfer. The decrease in transmit power was achieved by increasing the carrier signal's frequency and using more sophisticated electronic devices. In 1984 the Enermet MELKO™ system was published which utilized the Phase Shift Keying (PSK- a type of angle modulation in which the phase of the carrier is discretely varied) modulation technique and frequency band between 3025−4825 Hz for data transmission. Here, in MV and LV distribution networks the data transmission rate of 50 bps was possible which were between a substation and measurement or control units. As the frequency band was low and the carrier signal could pass through the distribution transformers, bidirectional data transmission was possible by MELKO™. However, its main applications were remote meter reading and load management.

The members of the Electronic Industries Alliance (EIA) realized the necessity of standards that provides more capability than the X10. Hence, in 1992, they released the consumer electronic bus (CEBus) standard which was also known as EIA-600. CEBus provides protocols to communicate through power lines, twisted pairs, coaxial cables, infrared, RF, and fibre optics. It used spread spectrum modulation technique on power lines within the frequency band of 100−400 kHz. CEBus was a packet-oriented, connectionless and peer-to-peer network which was intended to transmit commands and data. It was mainly suitable for indoor applications.

In 1990, the Local Operation Networks (LonWorks) platform was created by Echelon. It is a flexible, robust and expandable standard based on control networking platform. Here, the physical layer (PHY) signaling can be implemented over twisted pair, power line, fibre optics and radio frequency (RF). The LonWorks provides information based control systems in contrast to the previous command based control systems. The LonWorks PLC technology have data transmission rate of either 3.6 or 5.4 kbps depending on the frequency. Some applications of LonWorks technology are lighting control, energy management, security and home automation systems. The Universal Powerline Bus was introduced in 1999 by PCS Powerline Systems. It is a protocol for communication among the devices used for home automation which uses power line wiring for signaling and control.

In 2001, SmartLabs Inc. introduced a home automation networking technology called INSTEON. It was developed for domestic control and sensing applications and was based on the X10 standard. INSTEON technology is a dual band mesh topology which enables devices to be networked together using power lines or radio frequency. Thereby it is less susceptible to the noise interferences compared other single band networks. Here, PLC uses the frequency of 131.65 kHz and binary phase shift keying (BPSK) modulation technique. The INSTEON technology includes error detection and correction systems. It is compatible with X10 and offers an instantaneous data rate of about 12.9 kbps and a continuous data rate of 2.8 kbps. INSTEON protocol devices are also peers in which each device can transmit, receive and repeat messages without any additional network devices or software. The main applications of INSTEON are control systems, home sensors, energy savings and access control. Further, in 2001, a promising PLC technology called HomePlug was specified for various power line communications specifications that support networking over existing home electrical wiring [6].

In the recent decade, the working frequency bands have been extended from kilohertz to megahertz. On the other hand, the development of advanced processor, digital signal processing schemes and algorithm techniques have made it possible to apply more sophisticated modulation and error control methods in the line carrier systems. Both the extended frequency bands and advanced technologies have enabled higher data transmission rates over power lines. However, radio amateurs protested against using this high frequency (HF) band as they also use such frequency bands and also the outdated regulations have slowed down the use of megahertz frequencies in PLC. In recent days, the electricity network covers almost all households through electricity transmission and distribution networks. Hence, the suitable carrier communication techniques have been intensively investigated. Power line channel characteristics have also been widely researched and the study being extended up to 30 MHz and several application-specific integrated circuits (ASICs) have been developed. In addition to PLC, there are two alternatives, wireless technologies or additional cablings [7].

Universal Power Line Association (UPA) was founded in 2004 to integrate PLC and the telecommunication systems. It also defines world-wide standards for PLC and adopting all type of applications for speedy world-wide deployment of PLC networks. Besides, between the year 2003 and 2006, a project named Real-time Energy Management via Power lines and Internet was funded by the European Commission. In 2008, the International Telecommunication Union's (ITU) Telecommunication Standardization Division (ITU-T) recommended

G.hn/G.9960 which is a home network technology standard for high-speed networking over power lines, phone lines and coaxial cables with data rates up to 1 Gbit/s.

Further, in 2008, a standard named IEEE 1675 was developed by Institute of Electrical and Electronics Engineers (IEEE) standards association for broadband over power lines [27]. It provided electric utility authorities or companies a standard for safely installing the required hardware for internet access capabilities over power lines. Subsequently, in 2009, the IEEE P1775 standard concerned with electromagnetic compatibility requirements, testing and measurement methods for powerline communication equipment is being completed by IEEE. Afterward, in 2011, the IEEE 1901 standard is published for high speed (up to 500 Mbit/s) communication devices via electric power lines, hence called broadband over power lines (BPL). The standard uses transmission frequencies below 100 MHz and it is usable by all classes of communication devices including internet access services within a building for local area networks, smart energy applications, transportation platforms (vehicle) and other data distribution applications less than 100m between devices. It includes a mandatory coexistence inter system protocol which prevents interference between different BPL implementations operated within close proximity [5]. Moreover, in September 2011, the standards association of the IEEE published a standard named IEEE 2030 which recognizes the interactive nature of the interconnection with the grid and all of its parts and realizes the significance of the integration of power, communications and information technologies into the smart grid (a modernized electrical grid that uses analogue or digital information and communications technology) with interoperability of energy technology and information technology operation with the electric power system, end-use applications and loads [4]. Then, in 2013, IEEE standard association published a standard called IEEE 1905 which defines a network enabler for home networking with support of both wireless and wire-line technologies. For IEEE 1905, the consumer certification program named nVoy was announced in June 2013 and consumer level products were expected by year end 2013 but are delayed till 2014.

On the other hand, the Automated Meter Reading (AMR) system was firstly tested by AT&T Corporation (American Telephone and Telegraph Corporation) in cooperation with a group of electric utilities in the USA in 1968. It was a successful experiment and after this AT&T offered to provide AMR service which was based on telephone communication link. However, from economical point of view, this project was non profitable. In 1972, the General Electric (GE)'s corporate research center in association with its meter department started a research and development attempt for a remote meter reading system. Meanwhile, in 1977, at Rockwell International a utility communication division had been introduced to develop distribution carrier communication systems. Later in 1984, General Electric achieved a license from Rockwell International to commercialize their project of distribution line carrier product designs and technology for AMR.

From 1985, the modern era of AMR started as several full-scale projects of AMR were implemented. Very firstly, the introduction of AMR technology was made by Hackensack Water Corporation and Equitable Gas Corporation into their water and gas measurements systems respectively. Following that, in 1986, the radio based AMR system was installed by Minnegasco for 450,000 customers. Further, in 1987, Philadelphia Electric Co. had installed thousands of distribution line carrier AMR units with the meters which were previously not accessible.

The primary implementation of the automation of meter reading was for reducing labor costs and obtaining data that was difficult to obtain. Because of technical advance in solid-state electronics, microprocessor components and communication sphere, a modern AMR system can provide more useful information which are beneficial for distribution authorities and also enables others additional services which is known as Smart Integrated Metering System. However, the basic idea of remote electricity measurement is common for both AMR and Smart Integrated Metering Systems [28]. Originally AMR devices just collected meter readings electronically and matched them with accounts. As technology has advanced, additional data could then be captured, stored and transmitted to the main computer and often the metering devices could be controlled remotely. This can include events alarms such as tamper, leak detection, low battery or reverse flow. Many AMR devices can also capture interval data and log meter events. The logged data can be used to collect or control the time of use or rate of use and that data can be used for energy or water usage profiling, time of use billing, demand forecasting, demand response, rate of flow recording, leak detection, flow monitoring, water and energy conservation enforcement, remote shutoff, etc. Advanced Metering Infrastructure (AMI) represents the networking technology of fixed network meter systems that go beyond AMR into remote utility management. The meters in an AMI system are often referred to as Smart Meters, since they often can use the collected data based on programmed logic [28], [29].

In 2003, in Europe, the Northern Europe became the hot spot of Advanced Metering when Sweden announced the decision to acquire monthly readings of all electricity meters by 2009. Soon activities spread to the other Nordic countries like Finland, Denmark and Norway. In 2004, the Essential Service Commission of Victoria, Australia has brought corrections to the electricity customer metering code to implement an order in the installation of interval electronic meters for Victorian electricity customers. According to the paper entitled "Mandatory Rollout of Interval Meters for Electricity Customers" for all small businesses and residences, the meters have to be installed by 2013, starting from the year 2006. It forecasts that, within seven years from the beginning of the replacing, up to one million large and other customers will have up graded meters. However, by mid July 2013, the first Smart Meter in home displays was being made available to Victorian consumers. At the beginning of 2014, over 2.5 million meters installed at homes and small businesses across the state.

The United States (US) energy policy act of 2005 asked the electric utility regulators to consider time-based rate schedule and enable the electric consumer to manage the energy use and cost through advance metering and communication technology. Besides, in November 2005, the Meridian Energy in New Zealand introduced the usage of smart meters in the Central Hawkes Bay area for over 1000 households. The communication link was based on radio and mobile technologies. It was expected to install over 6,300 smart meters by late 2006 as part of the initiated experiment. In Italy, the world's largest smart meter deployment was undertaken by Enel SpA for more than 30 million customers. Between 2000 and 2005, Enel SpA deployed smart meters to its entire customer base. These meters are fully electronic and smart, with integrated bi-directional communications, advanced power measurement and management capabilities with solid-state design.

The Commonwealth issued a joint communiqué at the council of Australian Governments meeting in Canberra in February 2006, committing all governments to the progressive rollout of smart metering technology from 2007. In September 2006, the Netherlands government conducted a cost benefit analysis of AMR for their country and proposed that all residential customers will get a smart meter by the year 2013, starting from 2008. Since then, two utilities named Continuon and Oxxio have been undertaking some pilot projects for the implementation of AMR. The smart meters register electricity and communicate through PLC.

In February 2007, the Automatic Meter Reading Association (AMRA) endorses the National Association of Regulatory Utility Commissioners (NARUC) resolution to eliminate regulatory barriers to the broad implementation of Advanced Metering Infrastructure (AMI). The resolution passed acknowledged the role of AMI in dynamic cost savings in revenue protection, outage management and its benefits to the consumers. In June 2007, the Norwegian energy authority declared that it would recommend new legislation for requiring smart meters to take effect in 2013. Also in 2007, the Republic of Ireland pledged to introduce smart meters in every home within a five year period. In December 2007, the smart metering was included in the national meter substitution plan of Spain for end users with an aim of remote energy management with a deadline for the completion of the plan by 31st December, 2018. The Ontario Energy Board in Ontario, Canada set a target of deploying smart meters to 800,000 homes and small businesses by the end of 2007, which was surpassed, and throughout the province by the end of 2010.

In July 2008, from government of Australia the Advanced Metering Infrastructure was mandated and being planned in Victoria for deployment of 2.6 million meters over a four year period. Also in 2008, Austin Energy of Texas, United States began deploying approximately 260,000 residential smart meters. According to the report from VaasaETT of October 2008, an energy think tank in Helsinki, Finland found that smart meters are saving energy by around 10%. At the end of 2008, the installed base of smart meters in Europe was about 39 million units, according to the analyst firm Berg Insight.

In 2009, Florida Power and Light in United States began installing smart meters in the Miami-Dade area for residential customers and it's expected to be completed by 2013. In October 2009, the U.S. Department of Energy awarded $200 million grant for the deployment of Centerpoint Energy's smart meter network in Texas. In December 2009, the United Kingdom's Department of Energy announced its intention to have smart meters in all homes by 2020. Here, the principal media of communication in the Home Area Network is ZigBee Smart Energy. ZigBee is a specification for a suite of high level communication protocols used to create personal area networks built from small, low power digital radios.

In January 2010, it was estimated to install 170,000 domestic smart meters in United Kingdom and in October 2010, First Utility became the first energy supplier to offer smart meters to all new and existing customers across the U.K. A smart metering pilot project named Linky was conducted by Electricité Réseau Distribution, France involving 300,000 clients supplied by 7,000 low-voltage transformers. The experimentation phase started in March 2010. A key determining factor will be the interoperability of the equipment of various suppliers. The general deployment phase will start in 2016 and continue through 2020.

In January 2011, the American Council for an Energy-Efficient Economy reviewed more than 36 different residential smart metering and feedback systems internationally. Their conclusion was "To realize potential feedback induced savings, advanced meters must be used in conjunction with in home displays and well designed programmes that successfully inform, engage, empower and motivate people." In United States, Texas based CPS Energy has launched a pilot program with 40,000 smart meters deployed in the summer of 2011. CPS plans to complete the installation of smart meters (electricity and gas) for all customers by the end of 2016.

The United Kingdom rollout is considered to be the largest program involving more than 27 million homes to replace meters for both gas and electricity. The rollout officially started in 2012 but some energy suppliers started installing smart meters in people's homes before this. Besides, in spring 2012, Baltimore Gas and Electric of Maryland, United States began installing or upgrading approximately two million electric and gas meters in every home and small business in their service area. This process will take about three years to complete. These smart meters help customers to manage their energy budgeting, tracking and save money. By July 2013, the first Smart Meter in home displays was made available to Victorian consumers of Australia. At the beginning of 2014 Smart Meter in home displays were spreading rapidly. By the end of 2014, in United Kingdom the full rollout with the data communications for domestic customers are almost completed. Most households will have smart meters installed by their energy providing company/authority between 2015 and 2020, although some energy companies are starting to install smart meters already.

1.3 OBJECTIVE OF THE WORK

(i) The research of this thesis provides a development of Power Line Carrier (PLC) in Automated Meter Reading (AMR) Systems and Evaluating Non-Technical Loss (Detection of Illegal Electricity Usage).

(ii) In recent days illegal electricity usage has been a major problem in our country. The utilization of PLC in Automated and Remote Detection of Illegal Electricity Usage can be a novel solution in this respect. If an AMR system via PLC is set in a power delivery system, a detection system for illegal electricity usage may be easily added in the existing PLC network. In the detection system, a digital energy meter chip will be used to store the value of energy. The recorded energy will be compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal will be generated and this error signal will indicate the illegal electricity usage. The AMR system also provides quick and reliable meter reading collection with less error, few technical people's involvement and completely eliminates the necessity of physically reading the meters. The system will save many hours of billing time as employees will not have to manually input meter readings and will also increase the revenue earning of power distribution authorities.

(iii) In Bangladesh, the power distribution authorities/companies introduced (as pilot project to determine the feasibility) remote metering technology for meter reading collection but they are transmitting the reading via GSM technology. For using GSM system, it has been necessary to involve a third party GSM service provider and a dependency on them is creating operational chaos and scope of vague and illegal activities. On the other hand, using GSM technology, the consumer involved with Illegal Electricity Usage cannot be detected specifically. Also the Pre paid meter system cannot prevent the electricity theft made by bypassing the energy meter. However the above mentioned problems could be overcome by using PLC based AMR system.

(iv) Generally, the power distribution authorities/companies of this country is charging the bill of non-technical loss among all the users under a electric feeder by using the consumption data found from the energy meter connected with the supply end of the specific feeder. Due to inability of detecting the consumers involved with Illegal Electricity Usage specifically, the innocent consumers are getting frustrated because of extra bill and the practices of Illegal Electricity Usage are getting increased.

(v) In practical fields, in the case of bulk load consumers (some of whose monthly electricity bill ranges from several lacs to crores of taka) a critical problem is noticed that, it has been necessary to monitor and record the electricity consumption data physically from meter dial at least for three/four times per week to prevent the Illegal Electricity Usage. It is not an easy task and there is a big scope of error with less reliability in peak/off peak readings along with the determination of turnover of meter reading dial. However, the proposed PLC based AMR system could solve these problems accurately.

1.4 THESIS ORGANIZATION

This thesis has been structured into five chapters.

Chapter 1 introduces the research area and presents the critical review, objectives and scope of the research work with thesis organization described in this thesis.

In chapter 2, the theory of PLC based AMR is discussed. If an Automatic Meter Reading system via Power line Carrier is set in a power delivery system, a detection system for illegal electricity usage may be easily added in the existing PLC network.

In chapter 3, the methodology of the research work is discussed. In the detection system of PLC based AMR, a second digitally energy meter chip is used and the value of energy is stored. The recorded energy is compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal is generated and transmitted via PLC network. This means that there is an illegal usage in the network and hence the Non-Technical Loss can be determined specifically.

The Results of the implementation of the proposed model are discussed with its conclusive remarks in chapter 4.

Then the summary of the achievements made in the present work and suggestions for future work is concluded in the fifth chapter.

CHAPTER TWO

PLC BASED AMR AND NTL

2.1 INTRODUCTION

Power Line Carrier (PLC) network uses the existing Alternating Current (AC) power line for signal transmission. Among the versatile applications of the PLC, the Automated Meter Reading (AMR) is considered as one of the most important applications of Power Line Carrier (PLC). In a PLC based AMR system, a detection system for Non-Technical Loss (NTL) as well as illegal electricity usage can be easily deployed [3].

2.2 PLC BASED AMR

In every part of electricity generation, transmission and distribution, the energy meters play a role of information source of the energy consumption. The technical advancement in the sector of electronics and communication are replacing early day’s electromechanical induction energy meter because of their insufficient accuracy in metering and management. Hence, different type of metering system, such as the Automated Meter Reading (AMR) got introduced which can give the real time measurements of the consumed energy. The AMR system is also able to provide other various services which are useful for the electric utility planning and operation; such as distribution network management, power quality monitoring, fault and outage reporting, load management, protection against the electricity theft. To detect illegal electricity usage, in the detection system of a PLC based AMR, a secondary digital energy meter chip is used and the value of energy is stored. The recorded energy is compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal is generated and transmitted via PLC network. This indicates that there is an illegal usage of electricity in the network. Hence, the Non-Technical Loss (NTL) can be easily determined [3], [31].

2.2.1 Power Line Carrier (PLC)

Power Line Carrier (PLC) is a method of transmitting information using the electrical power distribution network as a channel. This technology provides the transmission of information data through the same cable that supplies electrical power. This idea of transmitting information and data through electric cable; bridges the electrical, electronic and communication networks.

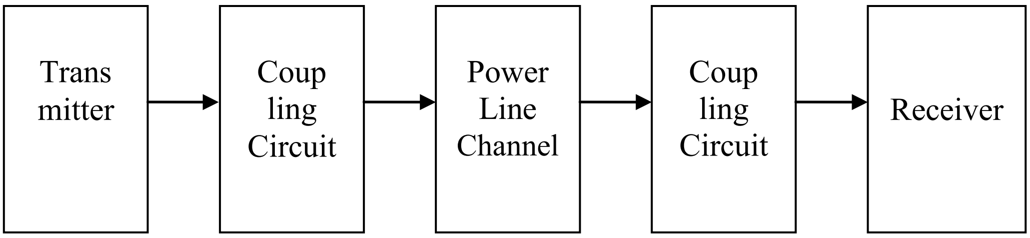


Figure 2.1: A Typical PLC Network

In PLC, generally the same electric cables used for power delivery are also used for signal and data communication [1]. Here, the powering and signaling circuits are separated by a high-pass filter, called a coupling interface. The coupling interface makes it possible to connect different circuits with different voltage levels. As the power line is made for transmission of power at 50/60 Hz and mostly at 400 Hz, the use of this medium to transmit data (especially at high frequencies) presents some technically challenging problems. It is also one of the most electrically contaminated environments, which makes it very hostile for transmission of data signals. The channel is characterized by high noise levels and uncertain (or varying) levels of impedance and attenuation [25]. In addition, the line has limited bandwidth in comparison to cable or fiber-optic links [12]. Power line networks are usually made of a variety of conductor types and cross sections joined almost at random. Therefore, a variety of characteristic impedances are encountered in the network. This also imposes difficulties in designing the filters for the carrier communication networks. So many factors will affect the reliability of a PLC channel. However, the goal is to obtain a signal level in the remote terminal which is above the sensitivity of the receiver and with a signal-to-noise ratio (SNR) well above the minimum, so that the receiver can be able to make a correct decision based on the transmitted information [2]. The PLC channel will be reliable if both of these requirements are fulfilled.

2.2.1.1 Power Line Carrier (PLC) Equipments

A power line carrier system includes three basic components: the transmission line which provides a channel for the transmission of carrier; the tuning, blocking and coupling equipments which provide the connection to the high voltage transmission line and the transmitters, receivers and relays [10].

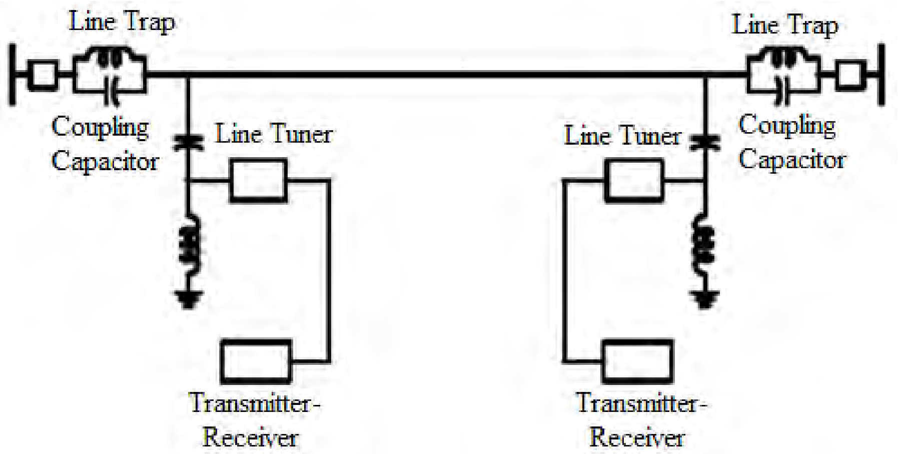


Figure 2.2: Basic Elements of a PLC System

• **Line Trap Unit:** Line traps block the flow of carrier signal to transmission line sections. Line traps are parallel inductance (L) and capacitance (C) circuits where variable inductances and capacitances are selected to resonate at a specific frequency, thus blocking the carrier frequency. It is also called as Wave Trap [1].

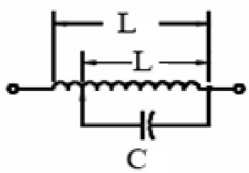


Figure 2.3: Equivalent Circuit Diagrams of Line Traps

Line trap unit is placed between bus-bar and coupling capacitor of the line. It possesses low impedance usually less than 0.1 for power frequency (50 Hz) and high impedance to carrier frequency. Thus it prevents the high frequency carrier signal from entering the transmission line.

• **Line Tuning Units:** Line tuning units (LTUs) or line tuners are used to tune the carrier frequency and provide impedance matching between the power line and the transmitter/receiver. The LTU includes an impedance matching transformer, a series-resonant L-C circuit tuned to the carrier frequency and also a protective device i.e. isolation transformer with lightning arrester and earth switch [1].

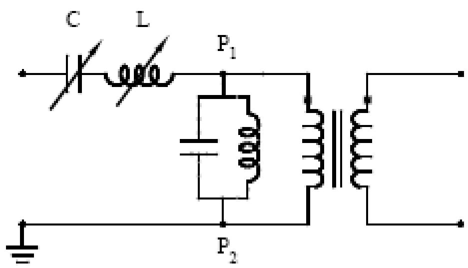


Figure 2.4: Equivalent Circuit diagrams of Line Tuning Units (LTUs)

• **Lightning Arrester:** The lightning arrester protects the wave traps against high voltage surges caused by atmospheric effects or by any switching operations. The nominal discharge current of this lightning arrester is selected to suit with the substation lightning arrester which is behind the wave trap. The tuning elements are rated at least 20 to 30% more than the maximum residual voltage of the lightning arrester at maximum discharge current.

• **Drainage Coil:** The drainage coil has a pondered iron core which serves to ground the power frequency. The coarse voltage arrester consists of air gap which spark about at 2 K.V and protect the matching unit from the line surges.

• **Earth Switch:** The earth switch provides a temporary direct earthing of the coupling capacitor during the maintenance or commissioning.

• **Line Matching Unit:** Line Matching Unit (LMU) is a composite unit which consist drainage coil, isolation transformer with lightning arrester on both of its sides, a tuning device and an earth switch.

• **Coupling Network:** The biggest technical challenge in a power line carrier is to couple the low voltage and high frequency carrier set to the high voltage and low frequency power line. The carrier signal is injected on the power line through the coupling network. Inductive coupling (phase to ground) method is an optimal choice because of its convenience, efficiency, less attenuation, less noise, low cost and no physical connection to the high voltage network makes it safer to install. In this method, the carrier terminals with line tuner, coupling capacitor and all other necessary equipments are connected between one phase conductor and ground [19].

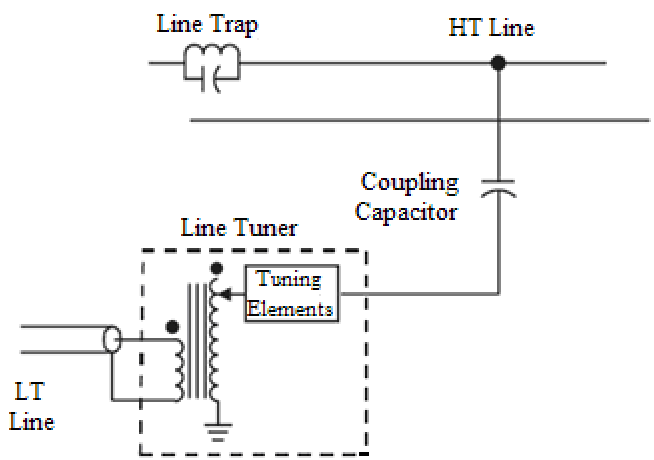


Figure 2.5: Phase to Ground Coupling

• **Coupling Capacitor Voltage Transformer (CCVT):** CCVT is a transformer used in power systems to step down extra high voltage signals and provide a low voltage signal. Transformers are also used as coupling devices as they provide isolation between the power and carrier circuitry. CCVT in combination with wave traps are used for filtering high frequency carrier signals from power frequency. The coupling capacitor is operated with a line tuner to form a resonant circuit or a band-pass or high-pass filter at carrier frequencies.

Generally there aren't many transformers between the source and destination of the power line carrier signal. There may be very few sub-stations but all the transformers aren't between the signal paths. However, only the sub-stations and the transformer would be a problem for the signal transmission. A data bypass system (consists band pass filter circuit and isolators) could be installed to get the data around the transformers. Since the frequency difference is so great, the system should contain amplifiers to boost the signal and amplifiers would also be needed along the power line at intervals to boost the signal.

2.2.1.2 Channel Model of Power line Carrier (PLC)

The channel can be any physical transmission medium such as coaxial cable, twisted pair, optical fibre, air or water. In PLC network, the power distribution line works as the channel. Since the distribution line network is not designed for communication; attenuations, reflections, noises and multi-path propagation may occur [23]. Also the channel parameters vary with time, load, frequency etc. A channel model is required to simulate every communication channel [18]. The power-line channel is considered as a multi-path propagation media and it is necessary to acquire the parameters of the channel [13], [15], [17]. The transmitted signal arrives in the receiver via the 'n' signaling path. On path 'v' the arriving signal is delayed by the time '$\bullet_v$' and attenuated by the complex attenuation factor '$\bullet_v$':

$$\bullet_v = |\bullet| \cdot e^{j\varphi_v} \qquad (2.1)$$

where, 'φ_v' is the phase of the complex attenuation factor. The impulse response of the channel '$h(t)$' can be written as a sum of the delayed and attenuated Dirac pulses:

$$h(t) = \sum_{v=1}^{N} |\bullet_v| \cdot e^{j\phi_v} . \delta(t - \tau_v) \qquad (2.2)$$

where, '$\bullet(t)$' is the Dirac pulse.

The relation between input voltage (V_1) and current (I_1) and output voltage (V_2) and current (I_2) of a two-port network can be described as:

$$\begin{pmatrix} V_1 \\ I_1 \end{pmatrix} = \begin{pmatrix} A & B \\ C & D \end{pmatrix} \cdot \begin{pmatrix} V_2 \\ I_2 \end{pmatrix} \qquad (2.3)$$

where A, B, C and D are frequency dependent coefficients [14].

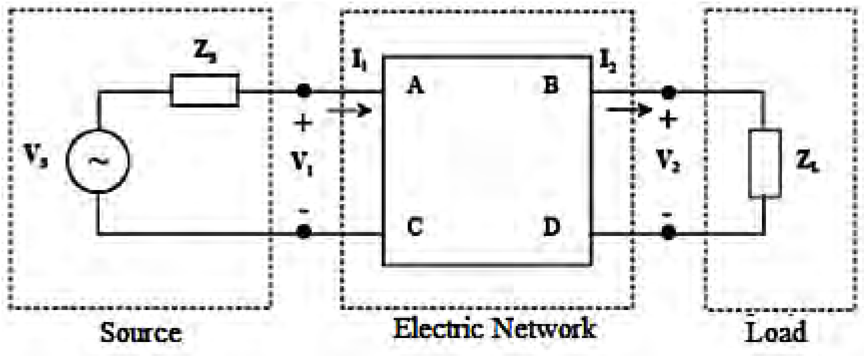


Figure 2.6: Two-Port Network Connected to a Voltage Source and Load

The frequency dependent input impedance 'Z_{in}' of the two-port network can be calculated by equation:

$$Z_{in} = \frac{AZ_L + B}{CZ_L + D} \tag{2.2}$$

Respectively, the amplitude and phase at a certain signal frequency is given by equation:

$$H = \frac{V_2}{V_S} = \frac{Z_L}{AZ_L + B + CZ_L Z_S + DZ_S} \tag{2.4}$$

The coefficients of the transmission matrix are dependent on the type of the load. The transmission matrix for the transmission line is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} \cosh(\gamma L) & Z_0 \sinh(\gamma L) \\ \frac{1}{Z_0}\sinh(\gamma L) & \cosh(\gamma L) \end{bmatrix} \tag{2.5}$$

The transmission matrix for the serially connected impedance 'Z_S' is given by:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & Z_S \\ 0 & 1 \end{bmatrix} \tag{2.6}$$

and the transmission matrix for the parallel connection of load impedance 'Z_P' is:

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 1/Z_P & 1 \end{bmatrix} \tag{2.7}$$

The branch cable terminated by the load impedance 'Z' can be considered to be equivalent load impedance 'Z_{eq}' :

$$\mathbf{Z}_{eq} = \mathbf{Z}_0 \frac{\mathbf{Z} + \mathbf{Z}_0 \tanh(\gamma L)}{\mathbf{Z}_0 + \mathbf{Z} \tanh(\gamma L)} \quad (2.8)$$

The channel from a source to a load may consist of several network sections having different cabling, branch cables and loads connected in parallel. Each section can be described with a single transmission matrix. The sections are serially connected. The transmission matrix 'T' from the source to the load can be formed applying the rule:

$$\mathbf{T} = \prod_{i=1}^{n} \mathbf{T}_i \quad (2.9)$$

where 'n' represents number of network sections.

In the power distribution line, the impedance is highly varying with frequency and ranges between few Ohm and k-ohm. At some specific frequencies, the network behaves like a parallel resonant circuit. However, in most other frequency ranges the network shows inductive or capacitive behaviors. Characteristic impedance of a powerline cable is typically in the range of 90 Ohm [15], [26]. The net impedance is not only influenced by characteristic impedance but also by network topology and the nature of connected loads which may have highly varying impedances as well. Statistical analysis of some achieved measurements has shown that, the mean value of the impedance is between 100 and 150 Ohm. However, below 2 MHz, this mean value tends to drop between 30 and 100 Ohm [11], [22].

2.2.1.3 PLC Transmitter and Receiver System

A transmission system has to convert the information data in a suitable form before it is injected in the communication channel. There are several multiplex and modulation schemes which are investigated to be applied in the PLC transmission systems. However, OFDM (Orthogonal Frequency Division Multiplexing - The multiplexing technique where the data is divided into several numbers of closely spaced parallel orthogonal sub-carriers to carry data and each sub-carrier is modulated with modulation scheme) is found as the best for the application in PLC based transmission systems because of its excellent bandwidth efficiency with higher data rates [20]. As OFDM based transmission system uses a number of sub-carriers distributed in a frequency spectrum, each sub-carrier has a transmission capacity and it is possible to make a group of the sub-carriers to build up transmission channels with a higher capacity [21].

The Figures 2.7 and 2.8 illustrate the conversion process that takes place at the transmitter and receiver. FEC (Forward Error Correction - It is a method of obtaining error control in data transmission in which the transmitter sends redundant data and the receiver can recognize only the portion of data that contains no apparent errors) redundantly encodes the input data to compensate the harsh channel characteristics. The encoded data is mapped onto a set of tones by QPSK (Quadrature Phase Shift Keying - It encodes two bits per symbol and has four phases while using the same bandwidth.) technique, which assigns subcarriers to it. OFDM modulation is generated using an IFFT (Inverse Fast Fourier Transform- the discrete inverse fast Fourier transform of a variable) processor which converts signals of the frequency domain to the time domain and produces an OFDM symbol. ISI (Inter Symbol Interference - It is a form of distortion of a signal in which one symbol interferes with subsequent symbols) is a major complication caused by multipath propagation. This is handled through time domain processing. If a copy of the signal arrives a significant fraction of one OFDM symbol time late, symbol error can occur [16].

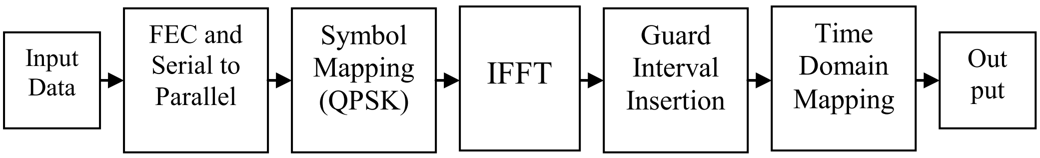


Figure 2.7: PLC System Transmitter Model

These multipath distortion effects can be almost completely removed by adding a guard time (cyclic prefix) to the OFDM symbol. The prefix is essentially a copy of the last few microseconds of the symbol. The cyclic prefix absorbs any multipath interference that occurs when time-delayed reflections of the original symbol arrive at the receiver [24]. By ensuring that the cyclic prefix is as long as the longest possible delay variation, the integrity of the OFDM symbol is preserved. At the receiver, the reverse process takes place and the cyclic prefix is removed. An FFT (Fast Fourier Transform - It is an algorithm to compute the discrete Fourier transform and its inverse. As the Fourier transforms converts time to frequency and vice versa; an FFT rapidly computes such transformations) is applied on each symbol, converting it from the time domain to the frequency domain.

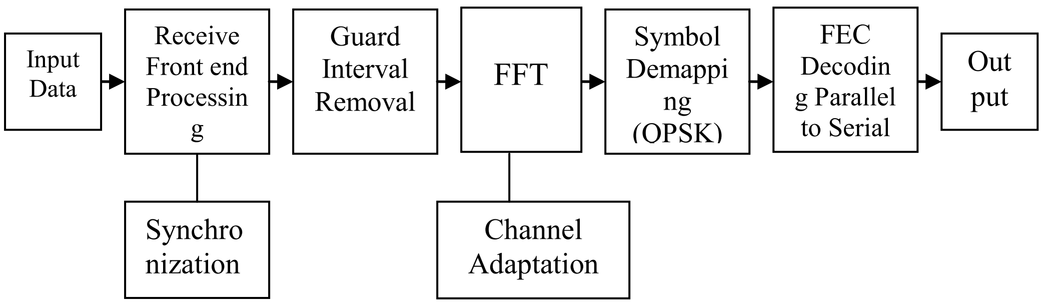


Figure 2.8: PLC System Receiver Model

OFDM provides resistance to deep, narrow fades by using many carriers. The loss of a few tones can be compensated for with FEC coding which redundantly encodes data across all active tones. If some of the tones are not received due to noise or other effects, the remaining carriers can be used to recover the original signal. Automatic channel adaptation allows the system to respond to current conditions on the power line.

The PLC transmission and receiving system consists PLC Modem (It is connected to the power line by coupling method and make the information data suitable for transmission), PLC Base/Master Station (It realizes the connection between the backbone communications network and the powerline transmission medium and controls the operation of a PLC access network) and Repeater (It provides signal forwarding between the network segments). The Transmitter modulates and injects the signal into the powerline. However, the impedance of the powerline attenuates the signal and any noise in the medium tends to interfere with the signal. The receiver at the opposite end demodulates the signals and retrieves the data.

2.2.2 Automated Meter Reading (AMR)

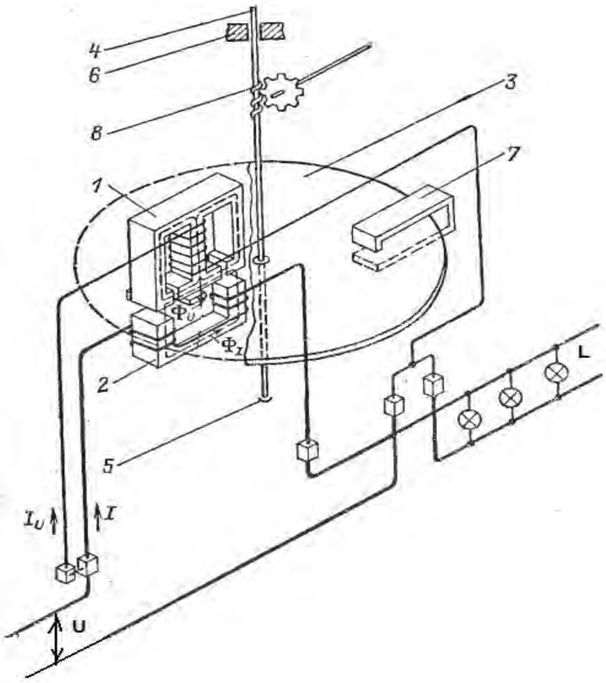
AMR (Automated Meter Reading) is a technology that gives utilities the ability to obtain meter-reading values remotely without having to physically visit and manually read the customer's electric meter. The reading of electric energy meter can be transmitted through the PLC (Power Line Carrier) protocol [3]. To understand about the working principle of AMR systems firstly it is necessary to have an idea about the Energy Meters and the recording process of energy consumption.

2.2.2.1 Energy Meter Development

Throughout the processes of electricity generation and delivery; energy meters play a significant role as an information source about the end-users' energy consumption. The most common type of energy meters is a kilowatt-hour meter, which measures the amount of electrical energy supplied to residents or industrial plants. On the basis of these consumption data, the electric utilities submit electricity bills for the customers. At present, technically developed countries have refused to Electromechanical Induction Meters because of the inaccuracy in measurements. However, the modern electricity meters are based on the principle of continuous measurements of the instantaneous voltage and current.

2.2.2.1.1 Electromechanical Induction Meters

An electromechanical induction combines the instantaneous values of voltage and current. Its operation is based on counting the revolutions of an aluminum disc which rotates with a speed proportional to the power and the number of revolutions is proportional to the energy consumed. These are also known as Analog Meters.



Here,

1 = Potential electromagnet;

2 = Current electromagnet;

3 = Aluminum disk;

4 = Shaft;

5 = Top bearing;

6 = Lower bearing;

7 = Permanent magnet;

8 = Worm gear;

L = Load.

Figure 2.9: Design of a Single-Phase Electromechanical Induction Meter

In Figure 2.9, the electromagnet 1 is connected in a parallel with the load L, hence the magnetic flux $\bullet_U$ is proportional to the voltage of the network. The other electromagnet 2 is in cascade connection with the load and its magnetic flux $\bullet_I$ is proportional to the current. As a result, there are eddy currents in the disc and a force acts upon the disc which is proportion to the instantaneous values of current and voltage. The rotation of the disc is made by electromagnetic forces generated by the interaction of magnetic fluxes and eddy currents of the two electromagnets. When power consumption stops, the disc will stop by the retarding action of a permanent magnet 7 operating on the aluminum disk.

The aluminum disc drives a register by a worm gear 8. The register is a series of dials which can record the amount of the consumed energy. Each dial has a single digit, which can be seen through the faceplate of the meter or it can be a pointer type, where each pointer indicates a digit. Figure 2.10 demonstrates these two types of meters.

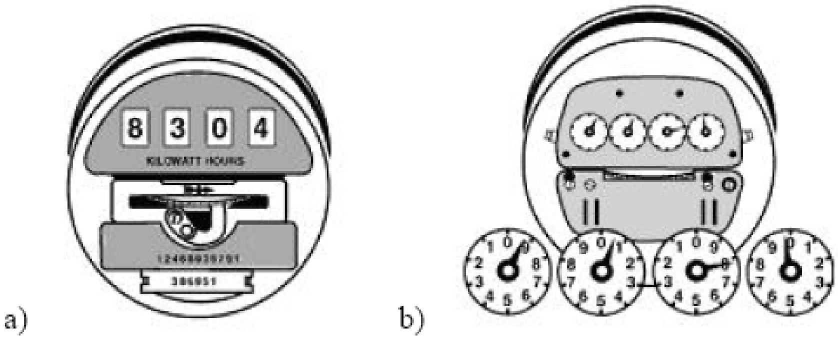


Figure 2.10: Design of Electro-Mechanical Meters

a) Digital Type, b) Pointer Type

The existence of various mechanical parts in this type induction meter sometime might provide inaccurate data because of the following reasons:

- appearance of any magnetic particles in the air gap of permanent magnet;
- presence of oil or dirt in the bearing and thus increase in friction;
- vibration on the all internal parts;
- impact of the external magnetic fields which may add or subtract value of normal magnetic flux;
- the magnetization of the permanent magnet can be changed due to overloads and short circuits;

The amount of energy consumed is read manually from this meter indicator and faceplate either by the customer or by a representative of the power distribution authority. Hence, this system of meter data reading requires a physically periodic visit and also technical checkup of the device.

2.2.2.1.2 Solid State Meters

Solid state meters are more advanced and developed compared to electromechanical meters. These meters do not consist any mechanical parts and the power measurement is made by the electronic circuits. That is why a solid state meter is very often called as electronic meter. Moreover, solid state meters can register some other parameters such as maximum demand, power factor and reactive power etc.

The operating principle of the electronic meter is based on the output of current and voltage transformers and its conversion to digital value by an analog-signal transformer. A microcontroller processes this value and shows it on a liquid-crystal display. A solid state meter can reserve the measured data in built in memory. Because of the absence of any mechanical parts, the reliability and accuracy of these meters are higher level compared to the induction meters.

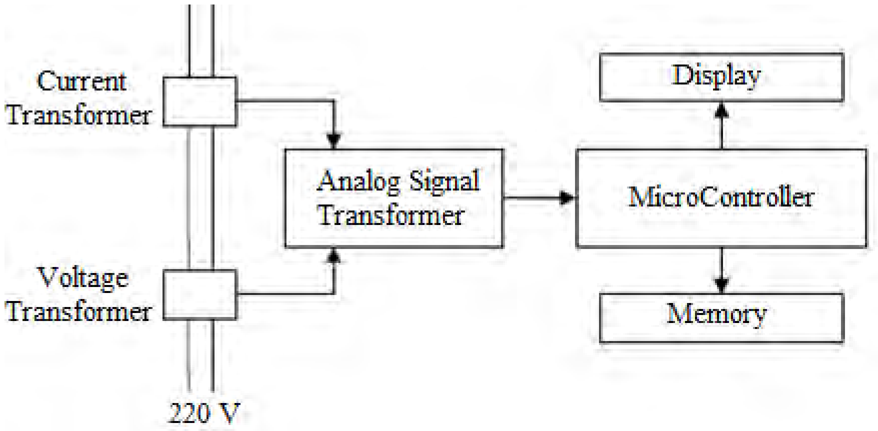


Figure 2.11: Construction of the Solid State Meter

Because of their ability to record data and have electronic interface, these types of meters are widely used as a part of automated meter reading system. As the solid state meters can operate in various frequency ranges, these can be used in both AC and DC power system.

2.2.2.2 Measurements in Energy Meters

The Consumed energy can be calculated by integrating real power with respect to time and it is illustrated in Equation (2.10):

$$E = P*t, \qquad (2.10)$$

where,

P = real power, W;

E = consumed energy, Wh;

t = time, during which the energy was consumed, h.

The apparent power can be calculated as a product of rms voltage and rms current (Eq. 2.11):

$$S = Urms*Irms \tag{2.11}$$

where,

S = apparent power, VA;

Urms = root-mean square voltage, V;

I rms= root-mean square current, A.

Then, the power factor of the load can be expressed as a ratio of consumed (real) power to apparent power (Eq. 2.12):

PF = P/S, 0 • PF • 1 (2.12)

where,

PF = power factor;

P = real power, W;

S = apparent power, VA.

Apparent power can also be calculated as it is shown in Equation (2.13) :

$$S = \sqrt{\mathrm{P2} + \mathrm{Q2}} \tag{2.13}$$

where,

S = apparent power, VA;

P = real/ active power, W;

Q = reactive power, VAr.

2.2.2.3 Arrangement of the AMR System

The AMR system starts at the meter by some means of translating readings from rotating meter dials, or cyclometer style meter dials, into digital form is necessary in order to send digital metering data from the customer site to a central point. The meter used in an AMR system is almost the same ordinary meter used for manual reading but the difference with conventional energy meter is that there some extra devices are added to generate pulses relating to the amount of consumption monitored or generates an electronic, digital code that translates to the actual reading on the meter dials [3].

Three main components of AMR system are:

1. Meter interface module: It consists of power supply, meter sensors, controlling electronics and communication interface which allow the data to be transmitted from the remote device to a central location or device.

2. Communications systems: It is used for the transmission or telemetry of data and to control signals send between the meter interface units and the central host.

3. Central host module: It includes modems, receivers, data concentrators, controllers, host upload links, and host computer.

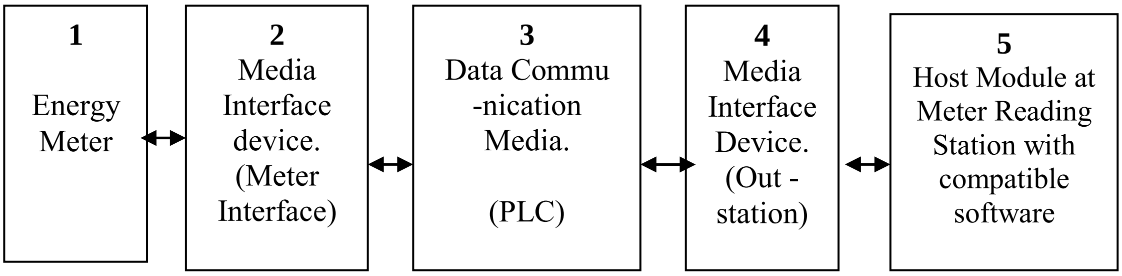


Figure 2.12: Functional Block Diagram of AMR Components

2.2.3 Non-Technical Loss (Detection of Illegal Electricity Usage)

Power or Energy losses occur at all levels in the entire electricity system, from generation, through transmission and distribution to the consumer and the meter. Normally at the distribution level majority of avoidable losses occur. All electrical power system operates with some accepted degree of losses. Losses incurred in electrical power systems can be classified into two categories:

Technical losses (TL) and Non-technical losses (NTL). So the total loss can be expressed as:

$$\text{Total Energy Losses } (E_{\text{Loss}}) = \text{NTL} + \text{TL} \qquad (2.14)$$

According to theory, the electrical energy generated should be equal to the energy consumed. However, in real practice, the situation is different because the losses occur as an integral result of energy transmission and distribution. These energy losses can be expressed as the following equation.

$$E_{\text{Loss}} = E_{\text{Delivered}} - E_{\text{Sold}} \qquad (2.15)$$

Where,

E_{Loss} is the amount of total energy lost,
$E_{\text{Delivered}}$ represents the amount of energy delivered, and
E_{Sold} represents the amount of energy recorded or sold.

Technical losses (TL) are the naturally occurring losses (generally caused by actions internal to the power system) and mainly caused by power dissipation in electrical system components such as transmission lines, power transformers, measurement systems, etc. The most common technical loss is the power dissipated in transmission lines and transformers due to their internal resistance (R) or reactance (X). Two major sources of technical losses are: (i) load losses consisting of the I^2R and I^2X loss components in the series impedances of the system elements and (ii) no-load losses which are independent of the actual load served by the power system. The majority of the no-load losses are caused by the transformer core losses.

Non-Technical Losses (NTL) refer to the losses that occur independently of technical losses in power systems. NTLs are caused by the actions external to the power system and also by the loads and conditions that technical losses computations fail to take into account. NTLs are related to the customer management process and it can include a number of means of consciously defrauding the utility concerned. More specifically, NTLs mainly relate to power theft. NTLs generally include the following activities:

1) Tampering the energy meters so that meters record lower consumption rate;
2) Stealing power by bypassing the meter or otherwise making illegal connections;
3) Arranging false readings by bribing the meter readers;
4) Arranging billing irregularities with the help of internal concerned employees by making lower bills, adjusting the decimal point position on bills or just ignoring unpaid bills.

By default, the amount of electrical energy generated should equal the amount of energy registered as consumed. However because of the Technical losses (TL) and Non-technical Losses (NTL), by combining the equations 2.14 and 2.15,

$$NTL = E_{Delivered} - E_{Sold} - TL \tag{2.16}$$

2.2.3.1 Electricity Theft: The Major Component of Non-Technical Loss

The theft of electricity is a criminal offence and power utilities are losing billions of moneys in this account [3]. The use of electricity is considered illegal if:

• Electrical energy is consumed without legal agreement between the electricity provider authority and consumers.

• The consumer does not comply with the agreement clauses for the consumed energy entirely or partially and not measuring the actual energy consumed and intentionally creating error to the energy measuring device (Watt-hour Energy Meter).

A) Factors That Influence Illegal Consumers:

Factors that influence consumers to steal electricity depend upon various parameters that fall into multiple categories like social, political, economic, literacy, law and enforcement of law, managerial, infrastructural, and economical. Of these factors, mainly socio-economic factors influence people in stealing electricity.

B) Methods of Electricity Theft:

There are mainly two categories for methods of electricity theft: 1) directly connecting an unregistered load to a power line, and 2) tampering the registered load's meter in order to reduce the amount of the bill. Once the meter is tampered (breaking its seal), there are many things that can be done to the meter to make it slow or stop it. Below is a list of various common methods of electricity theft:

1. Connection of supply without a meter,
2. Bypassing the meter with a cable,
3. Interfering with the meter to slow or stop,
4. Interfering with the timing control.

The connection without meter or bypassing the meter are easily identified during routine inspection of the power line, clearing the line faults, making power line's right-of-way or easement and also other consumers/peoples frequently complain to power supply authorities about such illegal connections.

However it is much critical and challenging to identify the incident and method of electricity theft related with the meter and tampering the meter by any means. Sometime meter readers, line inspectors/line technicians/concerned officials also fail to identify the meter tampering incidents. So, it is much necessary to have adequate knowledge about common meter tampering processes and introducing Automatic Meter Reading systems to overcome the human labor, limitations and time expenses in identifying the meter tampering. If an Automatic Meter

Reading system via Power line Carrier is set in a power delivery system, a detection system for illegal electricity usage or the non-technical loss may be easily deployed.

C) Electricity Theft by Tampering Energy Meters:

An Electric Energy Meter is used to measure the amount of electrical energy consumed by a household, business organization, industry etc. These energy meters are most commonly calibrated in billing units, the kilowatt hour. Periodic readings (according billing cycles) of the meters provides energy used during a period. There are two types of energy meter such as 1) Analog meter and 2) Digital meter. The ways to tamper both of the types are:

D) Different Types of Tampering in Analog Meter:

The analog meters are operated by counting the revolutions of an aluminium disc which is made to provide revolutions proportional to the consumed energy. Here, CT (Current Transformer) measures the phase current (IP) and PT (Potential Transformer) measures the phase voltage and hence the energy consumption is calculated. The meter itself also consumes a small amount of power (typically around 2 watts for its operation). The block diagram of an analog meter is provided in the Figure 2. In normal condition, current flowing through the phase (IP) should be equal to current returning through the neutral (IN).

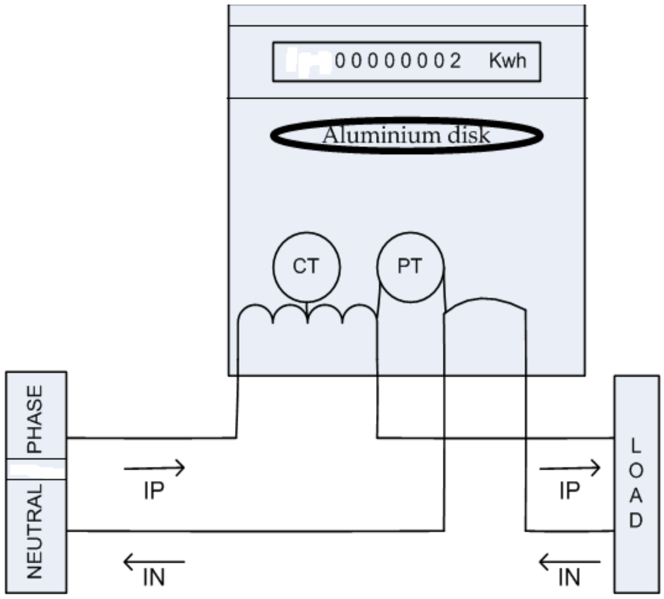


Figure 2.13: An Analog Electric Energy Meter

There are various ways to tamper an analog energy meter. The most common ways are:

1) Shorting the Phase Current Coil: If the current coil is shorted by the consumer then the phase current goes through the short and reading of current coil becomes zero, I=0. It is known that P=VI. As I=0, the power P=0.

2) Reversing the Direction of Current Flow: If the connection of load and supply is swapped, the current flows in reverse direction to the actual current at normal condition. It is experimentally observed that the meter does not respond to reversing the current direction and it acts as there is no load connected to the energy meter. Therefore, it does not show any energy consumption in the display.

3) Disconnecting the Neutral Line: A very common method of tampering analog meter is disconnecting the neutral line of both power supply neutral and load neutral side. In this condition, the meter cannot detect any voltage difference between the supply line and neutral line. As here V=0, power will also be zero by according to P=VI formula. So, no energy consumption will be shown by the meter.

4) Using the mechanical objects: A consumer can use some mechanical objects to prevent the revolution of a meter, so that disk speed is reduced and the recorded energy is also reduced.

5) Using a fixed magnet: A consumer can use a fixed magnet to change the electromagnetic field of the current coils. Here, the recorded energy is proportional to electromagnetic field as the aluminium disk is revolving by the magnetic flux produced inside the device due to the current flow. If a magnet is kept in the path of this flux, the magnet interferes with the flow of flux. So, the produced flux cannot help the aluminium disk to rotate. In this case, the disk is stopped or revolves slower producing less number of revolutions than that it should give. Therefore, the real energy consumption is not shown in the meter.

E) Tampering in the Digital Meters: Digital energy meters are more developed than the analog energy meters. These meters do not have mechanical parts, rotating disk and power measurement is realized by means of electronic circuits. This is why digital meters are also called as electronic meters. The operating principle of the electronic meter is based on a transformation of analog signals metered by current and voltage transformers into a pulse sequence; this action takes place in an analog-signal transformer. A pulse frequency is proportional to the energy consumed. A microcontroller processes this information and gives it on a liquid-crystal display. These meters have an opportunity to conserve the measured data in a built-in memory and have more protective options than the analog meters. A schematic diagram of a digital meter is shown in Figure 3. It measures both IP and IN. IP is measured by taking the voltage of a shunt resistor connected in series with the line and later converting it to current in the microprocessor unit. Here, IN is measured by the CT. At normal condition, IP and IN are equal. This value and the phase voltage value found from the PT is provided to the microprocessor unit which is located inside the meter to calculate the amount of energy consumed and then the value is shown in LCD (Liquid Crystal Display). Because of their ability of an automated and remote meter reading, these kinds of meters are widely used as a part of the automatic meter reading system.

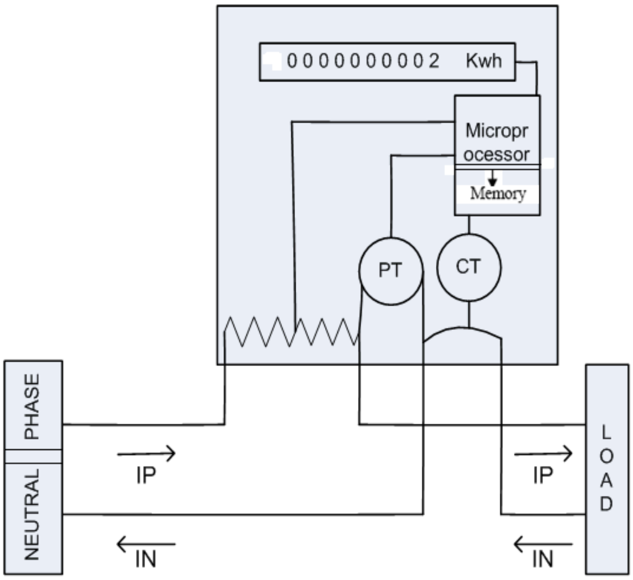


Figure 2.14: A Digital Energy Meter

The digital meter is able to protect the tampering methods like reversing the current direction, using magnet and shorting phase current coil. Unlike analog meter it measures both IP and IN which are compared in the microprocessor unit. If the microprocessor unit can find that these values are different, then the digital meter detect the possible pilferage. However, it is experimentally found that the digital meter is not able to detect the pilferage if the neutral is deliberately disconnected to tamper the meter.

2.3 NON-TECHNICAL LOSS DETECTOR IN ENERGY METERS

To obtain Non-Technical Loss as well as electricity theft in the meter, it is necessary to translate the readings provided from rotating meter dials into digital form in order to send a digital metering data from the consumer end to the central point.

The Automated Meter Reading (AMR) system starts at the meter end. Generally, the meter used in the AMR system is the same ordinary meter used for manual reading but its difference with the conventional energy meter is the addition of devices to generate pulses related to the amount of consumption monitored, or generate an electronic, digital code translated from the actual reading of the meter dials. One such technique to convert electromechanical movement into digital signal using optical reflector sensor along with frequency to voltage converter transducer is shown in Figure 2.15. Appendix 2.1 provides more details. Here, the disk speed of the kilowatt-hour meter is counted and the obtained data is counted as energy value of the kilowatt-hour meter.

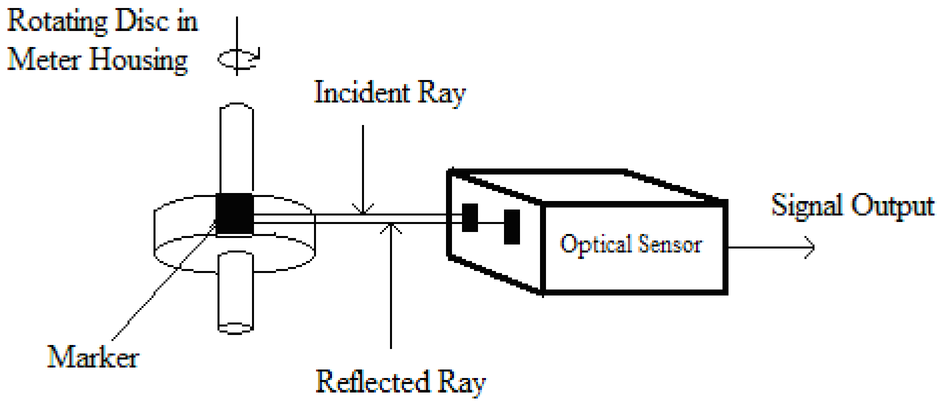


Figure 2.15: Electromechanical Movement to Digital Signal Conversion

On the other hand, the digital or electronic meters have the digital value of reading because of its construction and it can also store the reading data in its memory module. In the digital energy meter system, the recorded energy can be received in the digital form directly using the communication port of the meter. So, there is no need for an optical reflector system in digital meters [9].

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In a PLC based AMR, the detection of Non-Technical Loss (NTL) as well as illegal electricity usage can be easily determined. In the detection system, a second digitally energy meter chip is used and the value of energy is stored. The recorded energy is compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal is generated and transmitted through PLC network. This error signal indicates the presence of NTL in the system.

3.2 THE AMR SYSTEM TO COLLECT DATA

The Automatic Meter Reading (AMR) System is a host driven, multi-level network system which consist a Host Central Station (HCS), Data Concentrator Units (DCU) and Meter Interfacing Units (MIU). Appendix 1-5 provides more details. Each HCS can work independently; can also be integrated with an information management system through software interface. By some additional hardware and software support, the HCS can work as a workstation in an existing Local Area Network (LAN) and several HCS can be connected together to form a network.

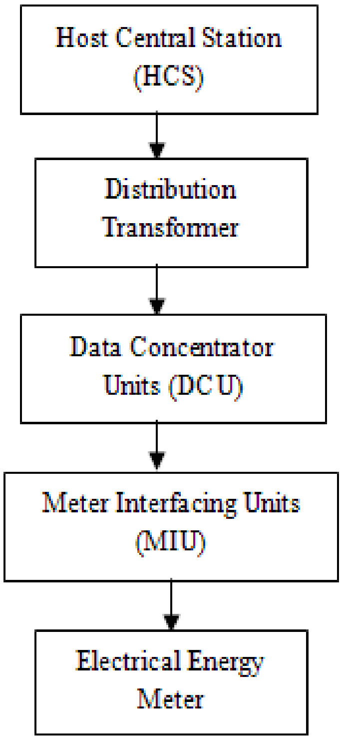


Figure 3.1: Block Diagram of PLC based AMR system

All the MIUs and meters connected to the DCU and it is a sub-system of the HCS. This sub-system monitors and collects meter readings from all the meters connected to it through the power line carrier (PLC) and communicates with the HCS. The components involved for communication via PLC are [30]:

1. Power Line Carrier Unit, which provides signal transmission and reception.
2. A Coupler used for "clamping" around a live wire for injecting the communication signals into the power line.
3. PLC Modem (PLM)

The monitoring system functions for automated remote meter reading and data acquisition system. PLC transmissions are synchronized to the zero crossing point of the AC power line. It should be transmitted as close to the zero crossing point i.e. within 200 µs. Square wave with a max Delay of 100 µs from the zero crossing point and the maximum delay between signal envelope input and 120 KHz output bursts is 50 µs [28]. So, it should be arranged that the output is within 50 µs. A Binary 1 is represented by a 1 ms burst of 120 KHz the zero crossing point and a Binary 0 by the absence of 120 KHz. Therefore only the 1 ms "envelope" needs to be applied to their inputs. Also, these 1 millisecond bursts should actually be transmitted three times to coincide with the zero crossing points of all three phases in a three phase distribution system [8], [9]. The mains voltage zero-crossings offer a reliable time reference while the symbol rate is reduced. There are two options in order to increase the data rate. On one hand, modulation level can be increased and on the other hand, several low symbol rate parallel streams can be transmitted [3].

The main communication device of the PLC system is a Power Line Modem (PLM), which transmits and receives data over the power line. Both the MIU and the DCU contain a PLM device. The binary data stream is keyed onto a carrier signal by the Frequency Shift Keying (FSK) technique. The central frequency is shifted +0.3 KHz to represent 1 or 0 of the binary data stream. Then the signal is coupled onto the power line by the PLM. At the receiving end, an identical PLM will detect the signal and convert it back to a binary data stream. Time Division Multiplex communication mode is essential for the two-way communication between DCU and MIU by the PLMs that are operating in a half duplex, two-way mode.

In AMR systems, the transmission speed is not an important fact whereas the reliability is very important. Generally the data rate of the PLC channel is set around 600 bps, to ensure communication over a longer distance with a reduced level of transmission error. Every MIU is also equipped with embedded repeaters to enhance the communication with DCU. With the sensitive signal detection and sophisticated digital filtering, the PLC communication is made highly immune to the electrical noises and interferences. The MIU is an intelligent device, which can collect, process, and record power consumption data from the electric meter. It senses and collects the pulse output of the meter and converts it to a digital format which is suitable for data processing. Thus it is possible to monitor the electrical load. The MIU also saves the data collected in a memory and all data are protected against power failure. Data stored in the MIU are transmitted to the DCU via the power line through the Power Line Modems (PLM). The Host Central Station (HCS) is the central control centre of the whole system, where all the functions of the system are controlled and monitored. The HCS sends instructions and information requests to the Data Concentrator Units (DCU) by calling their addresses and the DCU will respond accordingly. The address codes of the DCUs are stored in the HCS. With sufficient mass storage all DCUs can be covered by the HCS and in case of any failures in of the MIUs, the DCU can also send report to the HCS. The HCS equipped with necessary software, convert all the data received into a text file compatible with the existing Meter Reading Management System, and store it in any suitable memory device or Hard Disk [3], [31].

3.3 DETECTION AND CONTROL SYSTEM

The system is shown in Figure 3.2 for one distribution transformer network and it needs to be repeated for every distribution network. Here, the Automated Meter Reading (AMR) system is used via PLC to detect the NTL. In every network, there should be Data Concentrator Unit embedded with host PLC Modem Unit and a PLC modem for every consumer. In the Figure 3.2 the PLC modems which are connected directly with the energy metes are denoted as PLC1A, PLC2A,…….,PLCNA and these modems are used for the AMR. These units can communicate with each other and send the recorded data of the kilowatt-hour meters to the Data Concentrator Unit. To detect illegal usage of electrical energy, another PLC modem and an energy meter chip are added to an existing AMR system for every consumer. In Figure 3.2, another set of PLC modems denoted by PLC1B, PLC2B,…......,PLCNB and energy meter chips are shown in the detector units. Here, the detector units and energy meters are placed at a suitable point between main distribution lines and consumer's connection line.

As the connection point is usually in the air and at distant place from consumer premises it is not easy to access by the consumer however it's controlling by the power supply authorities is easy. Here, the PLC signalling frequency bands, signalling levels, and procedures are restricted between 03-95 k.Hz for the electricity suppliers and 95-148.5 k.Hz are restricted for the consumer use [1].

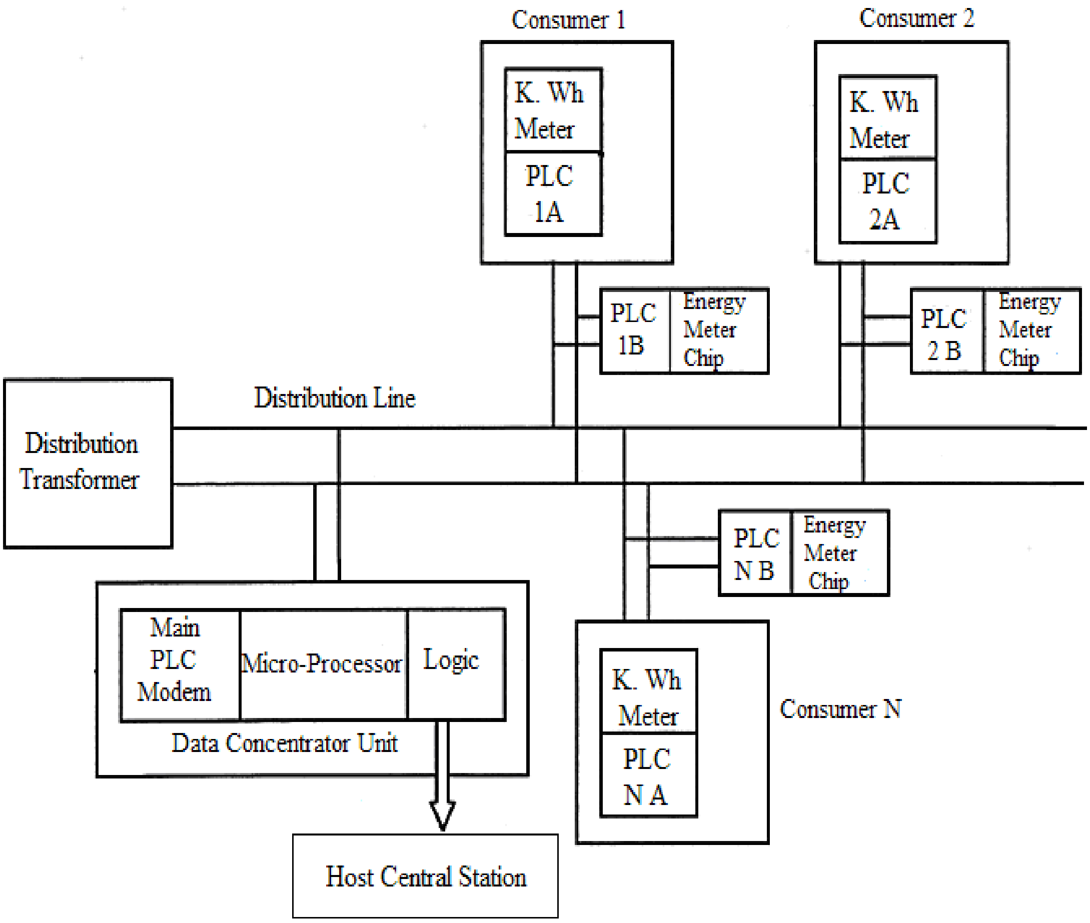


Figure 3.2: Detection System of Illegal Electricity Usage

For every consumer the recorded data of kilowatt-hour meters are sent to the Data Concentrator Unit via PLC system. On the other hand, the energy meter chips located at the connection points read the energy in kilowatt-hours and also sends the data to the Data Concentrator Unit. Therefore, the Data Concentrator Unit has two recorded energy; one from the AMR via PLC and the other from the PLC modem equipped with energy meter chips. Then, these two recorded energy data are compared in the logic circuit of Data Concentrator Unit and if any difference is found between the two readings, an error signal is generated. This indicates the illegal usage of electricity in the network with specific consumer identification. After that, the error signal and the consumer address are combined and forwarded to the Host Central Station. In the case of illegal usage, a contactor may be added in the system at consumer locations to automatically turn off the energy supply [3].

The flow chart of the above mentioned detection and control criteria could be expressed as Figure 3.3.

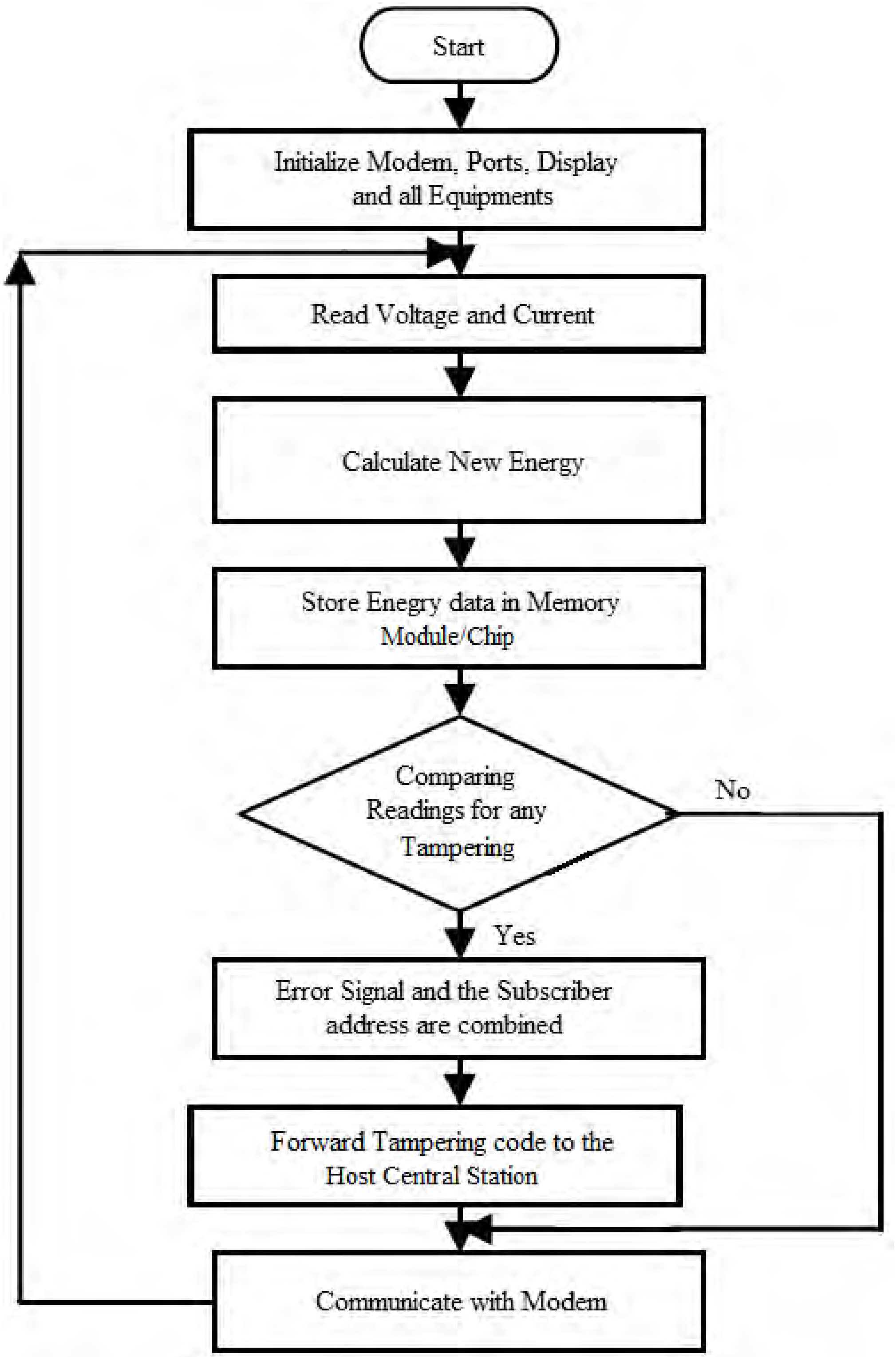


Figure 3.3: Flow chart of illegal electricity usage Detection system

CHAPTER 4

ANALYSIS AND DISCUSSION

4.1 INTRODUCTION

The System Loss (Technical and Non-Technical Loss) data of the power distribution authorities and companies of whole Bangladesh are collected and analysed the economic efficiency of the proposed system with cost estimation. On the other hand, both the manual and automated meter reading of a consumer of Dhaka Electric Supply Company Ltd. (DESCO) is collected for calculating the difference of two readings and hence discussed the necessity of implementation of PLC based AMR for the detection of NTL.

4.2 SIMULATION OF THE PLC BASED AMR SYSTEM

The system simulation of the detection system of illegal electricity usage is shown in Figure 4.1. It contains a Data Concentrator Unit, an energy meter chip with PLC modem, an electromechanical kilowatt-hour meter with PLC modem equipped with optical reflector sensor system. The energy value of the electromechanical kilowatt-hour meter is converted into digital form by using optical reflector sensor. Here, the disk speed of the kilowatt-hour meter is counted by sensor and this data is sent to PLC modem as energy value of the kilowatt-hour meter. In simulation process, in the same power line a legal load is connected beyond the electromechanical kilowatt-hour meter and an illegal load is connected to the power line before the kilowatt-hour meter by switch ‘S’. Here, two readings are compared with each other to determine any error and the Data Concentrator Unit reads two recorded data coming from the PLC units. If the switch ‘S’ is closed, the illegal load gets connected to the system and the two recorded energy values become different which indicates an error. This indicates the illegal electricity usage with specific identification of consumer involved with electricity theft.

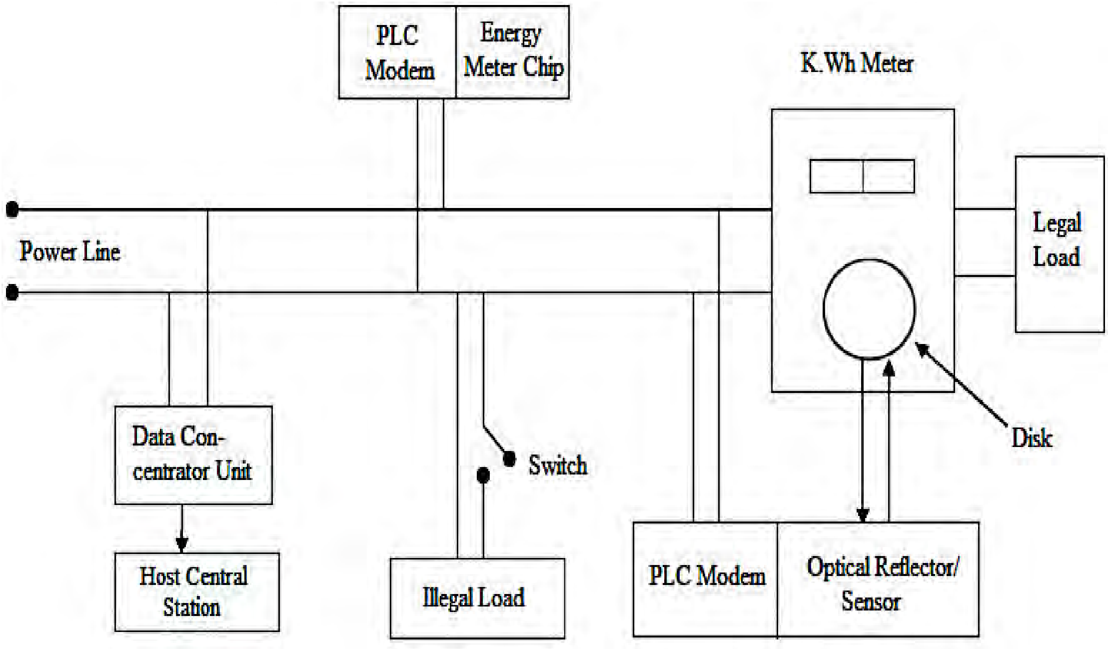


Figure 4.1: System Simulation of the Detection System of Illegal Electricity Usage

4.3 POWER SYSTEM LOSS (TL AND NTL) IN BANGLADESH

In power distribution and transmission System Loss (Technical Loss and Non-Technical Loss) is a key performance indicator. To achieve desirable performance of the power system, there is no alternative to bring down the system loss to an acceptable limit. Table 4.1 provides the distribution loss and the total transmission and distribution loss of the power distribution authorities and companies of whole Bangladesh from the year 1999 to 2014.

Table 4.1: Power Losses Trends in Bangladesh, 1999-2014

Fiscal year (F.Y)	BPDB	REB	DPDC	DESCO	WZPDCO	Overall Distribution Loss	Overall Transmi-ssion and Distribu-tion Loss
2013-14	11.89%	13.72%	8.99%	8.43%	10.97%	11.96%	14.13%
2012-13	11.95%	13.89%	9.07%	8.44%	11.38%	12.03%	14.36%
2011-12	12.15%	13.99%	9.87%	8.52%	11.66%	12.26%	14.61%
2010-11	13.06%	14.13%	11.95%	8.79%	11.67%	12.75%	14.73%
2009-10	13.11%	14.81%	13.38%	8.86%	11.73%	13.49%	15.73%
2008-09	13.58%	13.97%	18.25%	9.79%	12.22%	14.33%	16.85%
2007-08	14.39%	14.73%	18.44%	10.91%	13.04%	15.56%	18.45%
2006-07	16.58%	12.38%	20.44%	13.44%	14.72%	16.26%	20.25%
2005-06	19.06%	12.98%	20.13%	16.20%	16.21%	16.53%	21.25%
2004-05	20.00%	13.78%	21.94%	16.64%	19.04%	17.83%	22.79%
2003-04	21.33%	15.60%	25.62%	19.24%	22.72%	20.04%	24.49%
2002-03	22.35%	17.33%	27.97%	21.06%	Not Established	21.64%	25.69%
2001-02	24.50%	16.61%	29.71%	26.66%	Not Established	23.92%	27.97%
2000-01	26.11%	18.08%	27.77%	29.86%	Not Established	25.34%	28.43%
1999-00	27.73%	16.24%	26.88%	32.47%	Not Established	26.09%	31.60%

The power system loss of Table 4.1 is depicted graphically in Figure 4.2

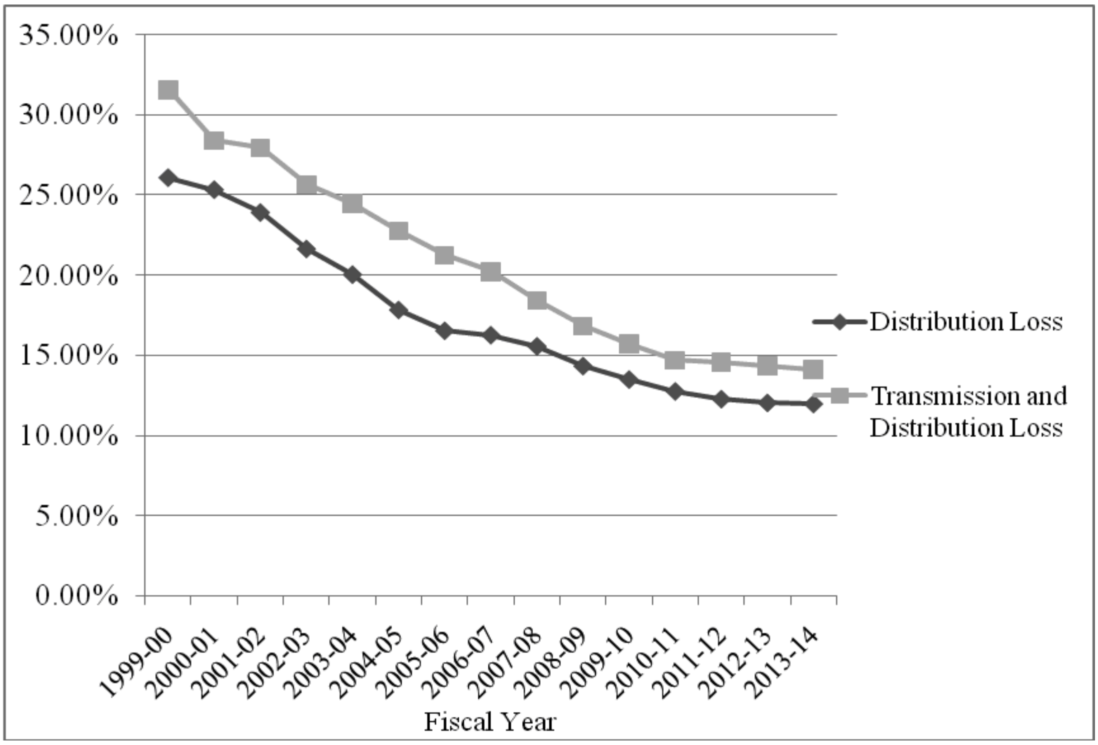


Figure 4.2: Power Losses in Bangladesh, 1999-2014

Various initiatives like continuous monitoring of the performance of the utilities, reforms and target oriented measures along with remote metering and Pre-paid Metering systems are underway to reduce the system loss. However, the introduction of the proposed PLC based AMR illegal electricity detection system would reduce the power loss significantly with the specific identification of consumers involved with power theft.

4.4 ANALYSIS AND COMPARISON BETWEEN COLLECTED AMR AND MANUAL METER READING

Both the manual and automated meter reading of an electricity consumer of Dhaka Electric Supply Company Ltd. (DESCO) is collected for analysis and make a comparison between the automated meter reading and the conventional manual reading by a human. It should be mentioned that, DESCO is running an experimental project regarding GSM based AMR for checking and testing the feasibility, accuracy and economy of AMR over conventional meter reading system.

The collected both readings and their differences are provided in the Table 4.2 and 4.3

Table 4.2: Manual and Automated Meter Reading of an electricity consumer

Reading Date	Manual Meter Reading	Reading Difference	Automated Meter Reading	Reading Difference
27-02-2015	107904.48	-	42795.51	-
28-02-2015	108097.82	193.34	42994.87	199.36
01-03-2015	108299.63	201.81	43204.77	209.90
02-03-2015	108496.67	197.04	43408.95	204.18
03-03-2015	108695.83	199.16	43616.04	207.09
04-03-2015	108901.60	205.77	42829.25	213.21
05-03-2015	109104.53	202.93	43038.32	209.07
06-03-2015	109310.72	206.19	43252.30	213.98
07-03-2015	109518.43	207.71	43467.41	215.11
08-03-2015	109723.77	205.34	43680.47	213.06
09-03-2015	109927.56	203.79	43891.39	210.92
10-03-2015	110135.62	208.06	44107.25	215.86
11-03-2015	110342.16	206.54	44321.42	214.17
12-03-2015	110552.19	210.03	44539.21	217.79
13-03-2015	110761.53	209.34	44756.20	216.99

Table 4.3: Reading difference between Manual and Automated Meter Reading

Reading Date	Manual Meter Reading Difference	Automated Meter Reading Difference	Difference between Manual and Automated Meter Reading
28-02-2015	193.34	199.36	6.02
01-03-2015	201.81	209.90	8.09
02-03-2015	197.04	204.18	7.14
03-03-2015	199.16	207.09	7.93
04-03-2015	205.77	213.21	7.44
05-03-2015	202.93	209.07	6.14
06-03-2015	206.19	213.98	7.79
07-03-2015	207.71	215.11	7.40
08-03-2015	205.34	213.06	7.72
09-03-2015	203.79	210.92	7.13
10-03-2015	208.06	215.86	7.80
11-03-2015	206.54	214.17	7.63
12-03-2015	210.03	217.79	7.76
13-03-2015	209.34	216.99	7.65

From Table 4.2 and 4.3, it is noticed that there is always a reading difference between manual and Automated Meter Reading. Here, in every case the automated meter reading is higher than the manual reading which indicates AMR's accuracy and its capability of identification of technical and non technical losses.

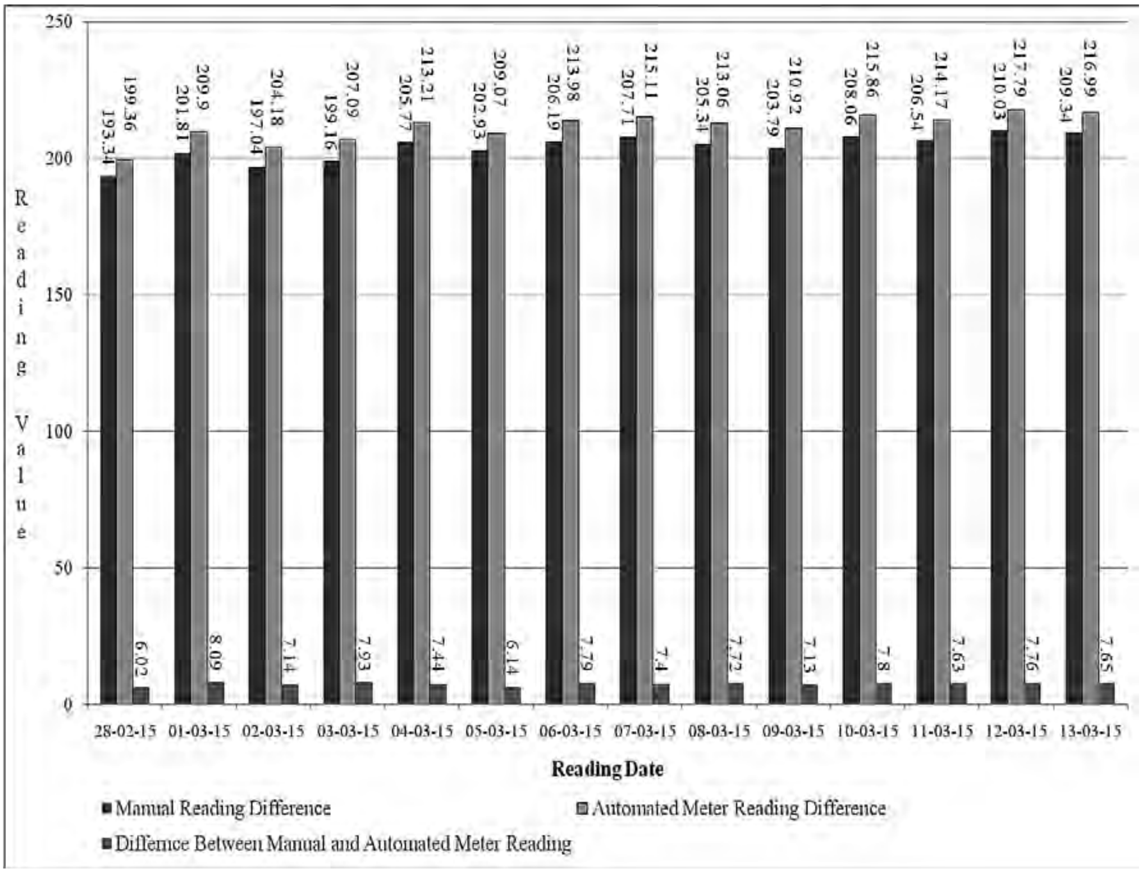


Figure 4.3: Difference between Manual and Automated Meter Reading

4.5 CALCULATION OF THE NON-TECHNICAL LOSS

According t o t he t heories de scried e arlier, f rom e quation (2.14); (2 .15) a nd (2.16) the Non-Technical Loss (NTL) for a s elected power system network can be eva luated. On t he ot her ha nd, a ccording the de scribed PLC b ased AMR system, the difference between two recorded energy data is generating an error with the specific location of energy theft i.e. the amount of NTL is also found specifically.

4.6 ANALYSIS OF ECONOMIC EFFICIENCY OF THE PROPOSED SYSTEM

The pr esent power Generation Capacity (Installed Capacity) pr ovided by al l sectors of whole Bangladesh is 10,648 MW. However, according to the study made on t he da ily power g eneration statistics, the ave rage generated and distributed pow er c ould be c onsidered a s 6,000 M W (Approx.). T his po wer i s transmitted t hrough the national pow er grid by P ower G rid C ompany of

Bangladesh Limited (PGCB) and then distributed among the consumers by the five distribution authorities or companies, which are namely Bangladesh Power Development Board (BPDB), Rural Electrification Board (REB), Dhaka Power Distribution Company Limited (DPDC), Dhaka Electric Supply Company Limited (DESCO) and West Zone Power Distribution Company Limited (WZPDCO).

The percentages of power distribution by the five authorities or companies are: REB- 40%, BPDB- 23%, DPDC- 20%, DESCO- 11% and WZPDCO- 6%. The overall power consumption is 51% in domestic, 34% in industrial, 9% in commercial, 4% in agricultural and rest 2% in other miscellaneous type. However, according to the number of consumers 83% is domestic, 12% is commercial, 2% is industrial, agricultural is 2% and rest 1% is of other categories. Considering the latest power tariff plan of the country and the data provided in Table 4.1, the power loss in terms of Watt and money is depicted in the Table 4.4 for the fiscal year 2013-2014.

Table 4.4: Power losses in terms of MW and Moneys (Fiscal Year 2013-2014)

Power Utility Authority/ Company Names	Energy Imported/ Purchased (in Million KWhr)	Energy Sold (in Million KWhr)	Energy Sold (in Million Taka)	Overall Distribution Loss (in %)	Overall Distribution Loss (in Million KWhr)	Distribution Loss (in Million Taka)
BPDB	9597.00	8455.94	49122.00	11.89%	1141.06	6628.61
REB	17461.59	15065.86	91238.58	13.72%	2395.73	14508.50
DPDC	7404.56	6793.83	45518.69	8.99%	610.73	4091.89
DESCO	4064.19	3722.23	24431.03	8.43%	341.96	2244.47
WZPDCO	2394.77	2131.83	12692.92	10.97%	262.94	1565.55
Total	40922.11	36169.69	223003.22	11.96%	4752.42	29039.02

Source: Annual Report, Monthly Operational Data, Management Information System Data, Financial Report, Bangladesh Economic Review Report.

The total number of consumers under the five power supply utility authority/ company with the number of substations, feeders and distribution transformers are depicted in the Table 4.5 at a glance.

Table 4.5: Bangladesh Power System Utility's Attributes (Up-to Year 2014)

Power Utility Authority/ Company Names	Number of Consumers/ Energy Meters	Number of Distribution Transformers (11/0.4 KV)	Number of Feeders (11 KV) (Approx.)	Number of Substations (33/11 KV)
BPDB	29,01,235	15,030	918	153
REB	1,06,81,964	67,500	2,552	638
DPDC	9,22,325	11,125	405	43
DESCO	6,41,933	5,672	283	29
WZPDCO	7,90,080	5,457	315	63
Total	1,59,37,537	1,04,784	4,473	926

Source: Annual Report, Monthly Operational Data, Management Information System Data.

4.6.1 Cost Estimation for the Equipments of Proposed PLC Based AMR System

The power supply distribution system involving the proposed PLC based AMR system needs two PLC modems, one MIU, one energy meter chip for every energy meter/consumer. At least one Data Concentrator Unit is needed for every distribution transformer and a Host Central Station for each supply feeder or substation. However control and monitoring system equipped with necessary software, server, client, local area network connection, storage device is also necessary for each or several 33/11 KV substations as preferred by the utility provider. The schematic architecture of the above mentioned system is shown in Figure 4.4.

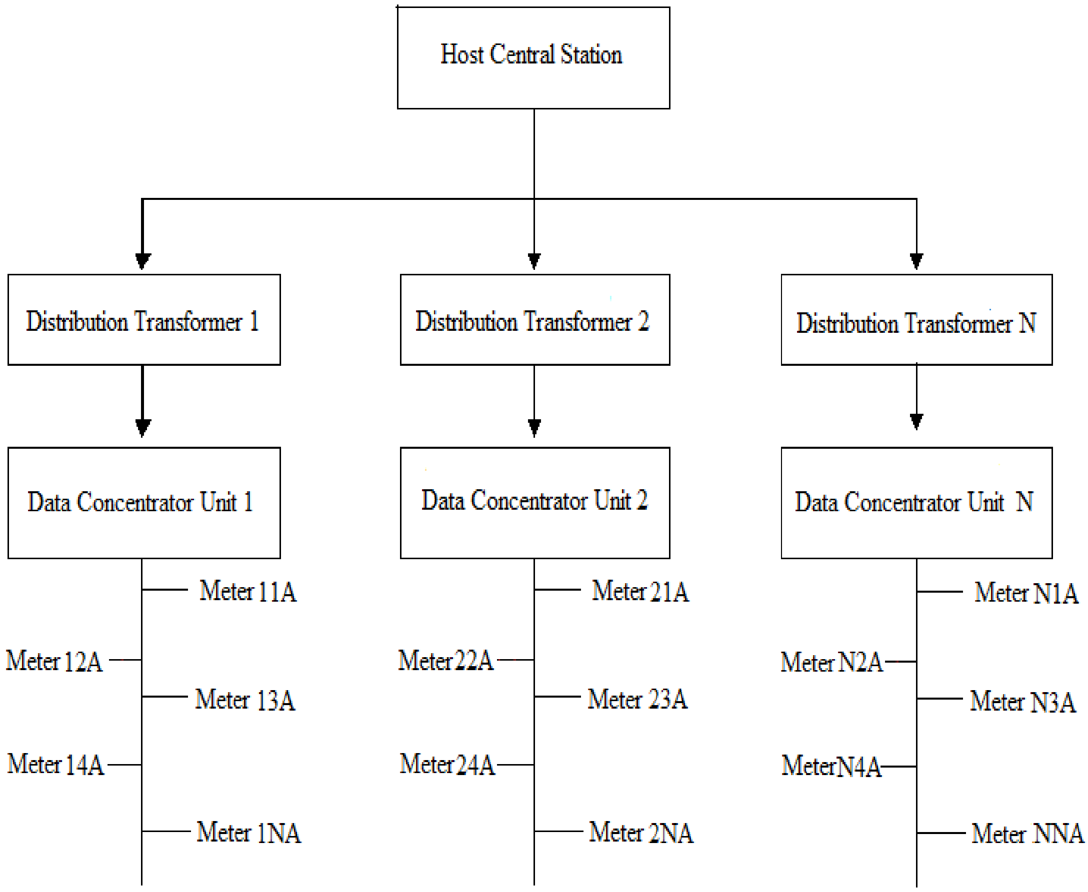


Figure 4.4: Schematic Architecture of Distribution System with the Proposed PLC based AMR

The estimated cost of the necessary equipments for the proposed system for the consumers mentioned in the Table 4.5 is calculated as below. The equipments and their respective prices have been collected according the Appendix A 2.1. [Considering the Exchange rate of USDollar to Bangladeshi Taka on 25th March'2015 as 01 USD = 77.80 BDT. Information Source: Bangladesh Bank]

- Cost of a PLC Modem = 50 US Dollar ie. 3890 BDT
- Cost of a MIU = 45 US Dollar ie. 3501 BDT
- Cost of an Energy Meter Chip = 25 US Dollar ie. 1945 BDT
- Cost of a Data Concentrator Unit = 100 US Dollar ie. 7780 BDT
- Cost of a Host Central Station = 700 Us Dollar ie. 54460 BDT

The estimated number of the necessary equipments for the consumers mentioned in the Table 4.5 is shown in the Table 4.6.

Table 4.6: Necessary Number of Equipments

Power Utility Authority/ Company Names	Necessary Number of PLC Modems	Necessary Number of MIU	Necessary Number of Energy Meter Chip	Nece -ssary Number of DCU	Nece -ssary Num -ber of HCS
BPDB	58,02,470	29,01,235	29,01,235	15,030	153
REB	2,13,63,928	1,06,81,964	1,06,81,964	67,500	638
DPDC	18,44,650	9,22,325	9,22,325	11,125	43
DESCO	12,83,866	6,41,933	6,41,933	5,672	29
WZPDCO	15,80,160	7,90,080	7,90,080	5,457	63
Total	3,18,75,074	1,59,37,537	1,59,37,537	1,04,784	926

Considering the necessary number of equipments of Table 4.6, the cost of necessary equipments is calculated in the Table 4.7.

Table 4.7: Cost of Necessary Equipments (in Bangladeshi Taka)

Power Utility Authority/ Company Names	Cost of Necessary PLC Modems	Cost of Necessary MIU	Cost of Necessary Energy Meter Chip	Cost of Nece ssary DCU	Cost of Nece -ssary HCS
BPDB	22571608300	10157223735	5642902075	116933400	8332380
REB	83105679920	37397555964	20776419980	525150000	34745480
DPDC	7175688500	3229059825	1793922125	86552500	2341780
DESCO	4994238740	2247407433	1248559685	44128160	1579340
WZPDCO	6146822400	2766070080	1536705600	42455460	3430980
Total	123994037860	55797317037	30998509465	815219520	50429960

= 2, 11,65,55,13,842 BDT

In Table 4.1, the total distribution of all the power supply utility is shown in terms of money and from Table 4.7, the cost of necessary equipments for the implementation of the proposed system is found. The total process of the implementation can not be done in one year or within a short period. Like other developed countries those are implementing the remote or prepaid meter system; the proposed system of PLC based AMR system should take around eight years. So, considering the time period, the implementation cost could be adjusted by the loss of money caused by the distribution loss ie. the non technical loss. After the total implementation process, the benefit of saving thousand millions of taka could be achieved by the power utility authorities/companies with cost effectiveness. Also the intension of Illegal Electricity Usage must be decreased significantly.

4.7 DISCUSSION

The detector system of theft of electrical energy as well as the NTL is a combination of some equipments and a control system of several remote stations from a master control station. This system includes PLC modems, energy meters, control logics and system software. The PLC modems acts as host and target modem for two way communications to and from the host station and the remote targets. Here, the energy meters consists metering chips and some circuit elements; the control and logic units to compare and generate the error signal in the case of illegal electricity usage. The system software should have an assembler program for the micro controller and the operating software for the overall system management. The operating software must be designed for the information of every consumer in every sub network with consumer identification number, billing address etc.

The proposed system refers an AMR system via PLC with a detection system for illegal electricity usage where a digital energy meter chip will be used to store the value of energy and the recorded energy will be compared with the value at the main kilo Watt-hour meter. In the case of the difference between two recorded energy data, an error signal will be generated and this error signal will indicate the illegal electricity usage with specific identification.

This system also provides quick and reliable meter reading collection with less error and peak/off peak data, few technical people's involvement and completely eliminates the need of physically reading the meters which will save many hours of billing time. This will also eliminate the dependency on a third party GSM service provider which is creating operational chaos and scope of vague and illegal activities. The ability of detecting the consumers involved with Illegal Electricity Usage specifically, the innocent consumers will get rid of extra bill and the intension of Illegal Electricity Usage must be decreased significantly. It will also increase the revenue earning of power distribution authorities or companies.

CHAPTER 5

CONCLUSION

5.1 CONCLUSION

In recent days illegal electricity usage has been a major problem in several countries throughout the world. The theft of electricity is a criminal offence and power utilities are losing billions of moneys in this account. If an AMR system via PLC is set in a power delivery system, a detection system for illegal electricity usage as well as the NTL may be easily added in the existing PLC network. Also, the AMR systems will provide quick and reliable meter reading collection with less error, few technical people's involvement, completely eliminates the need for physically reading the meters and saves many hours of billing time as employees don't not have to manually input meter readings. It will also increase the revenue earning of power distribution authorities. This research describes the specific detection and evaluation of Non-Technical Loss (Illegal Electricity Usage) using the PLC based AMR system and proposes a possible solution for this problem.

5.2 SUGGESTIONS FOR FUTURE WORK

In Bangladesh PLC system is only used for day to day routine works and system operation by the power transmission/distribution companies to maintain their own communication system. This function includes Telecommunication, Tele-protection, Data-transmission, Supervisory Control and Data Acquisition (SCADA), Economic Load Dispatching etc. The frequency band of the existing PLC system is 100 KHz to 500 KHz and its speech band is 4 KHz. However this tradition could be changed by further research concreted with the implementation of PLC based AMR to detect Illegal Electricity Usage and to Evaluating Non-Technical Loss in power sector of Bangladesh.

On the other hand, the development of AMR can be also concreted in load modeling, low voltage network fault indication, low voltage network outage management, power quantity monitoring, customer services, customer's on/off-peak time billing, distribution network management etc.

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APPENDIX-A

A 1.1 PLC MODEM DETAILS

The power line modem (PLC Modem) is a dedicated device for transferring data over low voltage power line. Using the extensive power line cable network in a region that is distributed by a single transformer, one can use a multiple PLC Modem to form a data network among the various data terminals. Thus, a data communication network infrastructure can be formed among all the data terminals. The unit can be used in centralized electric meter reading, remote monitoring of electrical equipment, building automation and security control, stage lighting and street lighting control applications, information displays and it can also play a role in the final leg of Internet connection in special circumstances.

The power line modem uses the power line cable as communication medium. It is convenient as it eliminates the need to lay additional cables. The modem at the transmission end modulates the signal from data terminal through RS-232 interface onto the carrier signal in the power line. At the receiving end, the modem recovers the data from the power line carrier signal by demodulation and sends the data to data terminals through RS-232 interface.

Figure A 1.1: A PLC Modem with RS-232 Interface

A 1.1.1 Main Features of the PLC Modem

- PLC Modem can be used for broadcasting in a one-to-many manner without the need to worry about handshaking.
- PLC Modem can be either master or slave, depending on the pin definition of RS-232. There is no prior classification of master-slave role for the modem.
- A PLC Modem acting as master can be designed to work in a 3-phase manner
- Operating Environment:
  Power : 85-275VAC, 50/60 Hz +/- 5%
  Temperature : -10 °C ~ +50 °C
  Relative Humidity : • 95%, Non-Condensation

- Cost of a PLC Modem = 50 US Dollar

A 1.1.2 Pin Diagram of the PLC Modem

This PLC Modem can transfer data over the power cable at the low voltage end of the power transformer of a 3-phase/ 4-wire distribution network. A pair of the PLC Modem 201/3 connected on the same phase and neutral line of the power network can provide bi-directional data communication at a baud rate up to 1200 bps.

- Single Phase Type

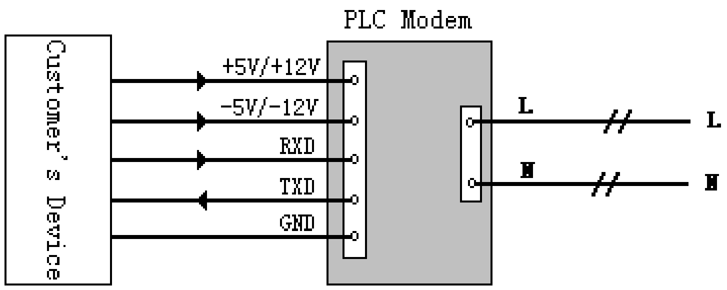

Figure A 1.2: Pin Diagram of a Single Phase Type PLC Modem

• Three Phase Type

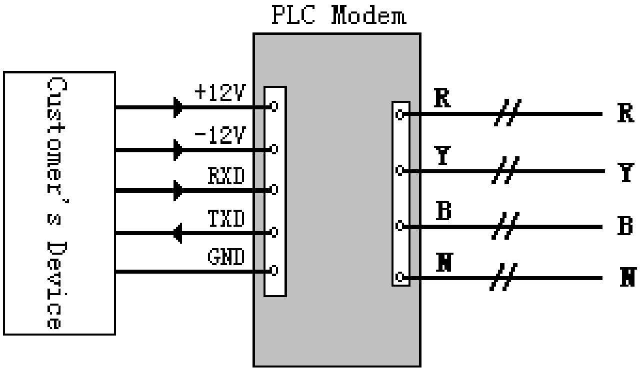

Figure A 1.3: Pin Diagram of a Three Phase Type PLC Modem

A 1.1.3 Application Diagram of PLC Modem

This PLC Modem is capable of transferring data over the power cable at the low voltage end of the power transformer of a 3-phase/ 4-wire distribution network. A pair of Embedded PLC Modems connected on the power line can provide low speed bi-directional data communication at a baud rate of 300/600 bps. It is built in a small form factor that can be easily integrated into and become part of the user's power line data communication system.

The m odules pr ovide bi -directional ha lf-duplex data c ommunication ove r t he mains of any voltage up to 250v a . c., and for frequency of 50 o r 60 H z. Data communication of t he modules i s t ransparent to us er's da ta t erminals a nd protocol independent; as a result, multiple units can be connected to the mains without a ffecting t he ope ration of t he ot hers. T he us e of D SSS modulation technique ensures high noise immunity and reliable data communication. There is no ha ssle of building interface circuits. Interface to us er's data devices is a simple data-in and data-out serial link. It has a built-in on boa rd AC coupling circuit, which allows direct and simple connection to the mains.

Applications of the Power Line Modem include status monitoring, control and data c ommunication of de vices c onnected on t he pow er l ine, s uch Home Automation, Lighting C ontrol, H VAC c ontrol, L ow S peed D ata N etworks, Automatic Meter Reading, Signs and Information Display, Fire and Security Alarm and so on.

- In Single Phase Application

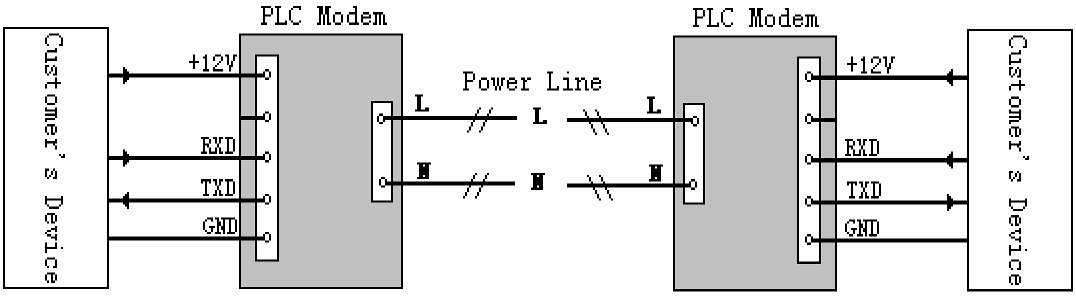

Figure A 1.4: Application Diagram of a Single Phase Type PLC Modem

- In Three Phase Application

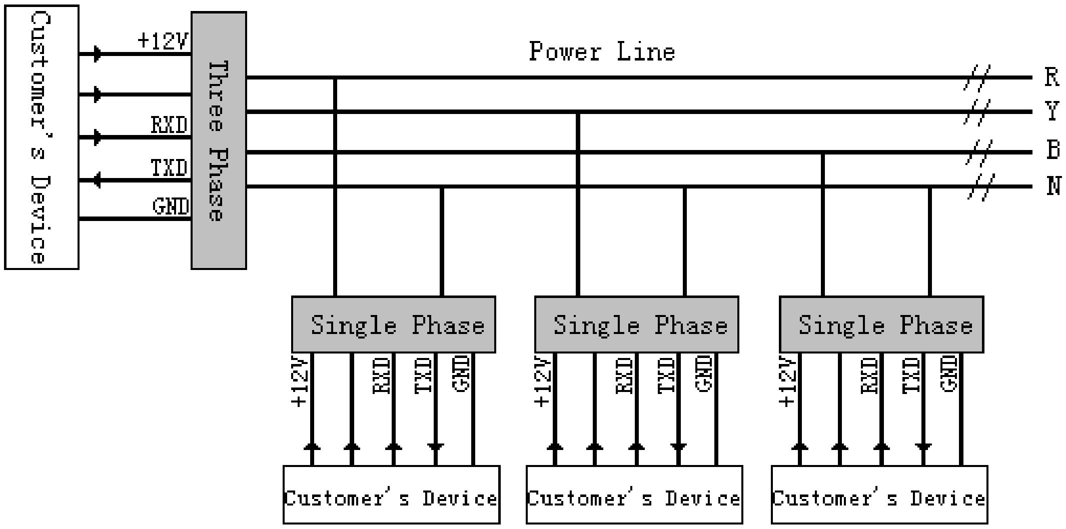

Figure A 1.5: Application Diagram of a Three Phase Type PLC Modem

A 2.1 METER INTERFACING UNIT (MIU)

This MIU has Two-way Data Communication by Power Line Carrier. It is compatible with Electricity Meters and all MIUs can be used in the same Data Concentrator Unit (DCU). Reliable Back-up Battery to ensure proper recording of meter consumption at the time of power failure. Applicable to different types of Electricity and Flow Meters

- Cost of a MIU = 45 US Dollar

A 2.1.1 Main Features of the MIU

- Support all functions (data reading, time-triggered operation and management) of the AMR System
- Fit for different models and makes of electronic and mechanical electric meters
- Especially suitable for the situations where meters are installed dispersedly
- Compatible with MIU via Power line carrier communication
- Provide special indication (e.g. Arrearage Indication)
- Every Meter Interface Unit (MIU) has the relay capability
- Metering initialization means: handheld computer and power line compatibly
- Metering initialization contents: meter constant, window value and MIU address (8 decimal digits)
- High quality AC/DC scheme with high resistance to disturbances
- Storage of data into nonvolatile RAM which does not need power supply to maintain memory
- Two types: Internal and External configurations

Optical Meter Reading acquisition system based on Frequency-to-Voltage converter transducer including Optical Probe with serial port RS 232 data interfacing system is applied for meter communication, such as data reading, parameterization, in production line, on-site service and more. Its Optical communication adapter accord to IEC62056-21 (former IEC1107) between electricity meters with optical interface and reading devices with Serial interface (e.g RS 232). This unit monitors the meter and translates the mechanical display to digital values. The digital values are transmitted to a data concentrator via PLC Modem.

Figure A 2.1: Optical Meter Reader Attached With
Electro-Mechanical Energy Meter

The optical meter reader is small low cost optical reader that is mounted on the front of the dial of electro-mechanical energy meter where as in the case of digital energy meter it is connected directly with the communication port.

Figure A 2.2: Optical Probe With RS- 232 Port
Data Interfacing System

Figure A 2.3: Optical Meter Reader Attached With
Digital Energy Meter

A 3.1 ENERGY METER CHIP

Energy Meter Chip is used to store the value of energy. It stores the energy in kilowatt-hours and sends the data to the Data Concentrator Unit. This is actually a memory chip build with Non-Volatile Memory units such as Electrically Erasable Programmable Read-Only Memory (EEPROM) with Micro-Processor Unit. It has RS-232 communication port with which it can collect meter energy data from PLC Modem and also send it to the DCU. It performs various logical tasks as required.

- Cost of an Energy Meter Chip = 25 US Dollar

Figure A 3.1: Energy Meter Memory Chip Unit

A 4.1 DATA CONCENTRATOR UNIT (DCU)

The Data Concentrator sits on the loop of secondary of the distribution transformer. Collects meter readings from all the meters via PLC based Modem System at predefined intervals. The DCU and all the meters connected to it can be considered as a sub-system of the HCS. The sub-system is set up with a DCU monitoring the low voltage power zone downstream of a Distribution Transformer.

Figure A 2.1: A Data Concentrator Unit (DCU)

- Cost of a Data Concentrator Unit = 100 US Dollar

A 4.1.1 Main Features of the DCU

- Use of PLC for Remote Meter Reading and Data Management. Support all functions (data reading, time-triggered operation and management) of the AMR system
- Able to transmit data to higher level hosts station through RS-232 standard communication facilities and channels.
- Standard RS-232 interface which facilitates site debugging and data checking Communicate with lower level Meter Interface Unit (MIU) using power line

- Able to issue broadcast commands simultaneously through all 3 phases of R, Y and B.
- All commands have clock-adjusting function
- Absolute industrial grade PC and modem warrant against failure under harsh operating conditions
- Large capacity solid-state disk to store all types of data. This will help to reduce the frequency of connections to host station and increase the efficiency of each connection. This is especially imperative in practical application where an extensive automatic metering network is deployed. The host station may not be able to communicate frequently with every Data Concentrator Unit (DCU). This requires each DCU to store large amount of data to reduce the load of the host station.
- Three-phase power supply ensures the system to operate well even when any 2 phases are cut off
- Check the voltage levels of 3 phases automatically. The time and duration of all blackouts and disruptions of any phases is logged. It is able to perform self-diagnosis and monitor the working conditions of MIU. It is able to record and report any abnormalities to the higher level host station
- Alternative of metallic and plastic casing, both of which can be lead-fused. Fire resistance and electric insulation of the casing measure up the national standards

A 5.1 HOST CENTRAL STATION (HCS)

The Host Central Station (HCS) centrally controls and monitors all the functions of the system like a computer host server system. The HCS sends instructions and information requests to the Data Concentrator Units (DCU) by calling their addresses and the DCU will respond accordingly on the basis of multiplexing system. The address codes of the DCUs are stored in the HCS. All DCUs can be covered by the HCS and in case of any failures in of the MIUs, the DCU send report to the HCS. The HCS convert all the data received into a text file compatible with the existing Meter Reading Management System, and store it in any suitable memory device or Hard Disk. In actual fact the maximum number of DCUs can be connected to a HCS is about 1000 as it will be limited by the required response time and efficiency of data management. In case of failures in self-diagnostics or any abnormal behavior of the MIUs, the DCU can also make requests to report by dialing to the HCS. The HCS will convert the data received into a text file compatible with the corporation's existing Meter Reading Management System, and store it in the Hard Disk Drive. File transfer between the HCS and the Corporation's MIS system can be done through standard input/output ports, such as RS-232.

Each HCS work independently. By some additional hardware and software support, the HCS can work as a workstation in an existing Local Area Network (LAN) and it can become a member of the entire system or several HCS can be connected together to form a network. The system software has an assembler program for the micro controller and the operating software for the overall system management. The operating software is designed for the information of every consumer in every sub network with consumer identification number, billing address etc.

- Cost of a Host Central Station = 700 Us Dollar

A 5.1.1 Minimum Hardware Requirement of HCS

- PC with Pentium IV and above, Memory 1 GB, Hard disk 500 Gb, 15" SVGA display at a resolution of 600 x 800
- Modem: ITU-T V.34 and above
- Printer: Any
- UPS: 1 kVA and above

A 5.1.2 Software Requirement of HCS

The application software is prepared as required which operates on Windows Server 2000/NT/2003 platform.

- Host Central station software support host station to Data Concentrator Unit (DCU) and other workstation

- Centralized management and remote setting by DCU
- Automatic classification and storage of data, providing data interface for user
- Generation and printing of various reports
- Prompt online help makes the operating system easy.