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

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Abstract

In the modern world the usage of Power Line Carrier (PLC) is spreading as it is cheap, simple, easy to deployment. Using the existing power transmission line and infrastructure this can be achieved at lower cost in every where of the country especially in remote rural areas as the extra networking system and equipments are not needed. This paper provides a development of Power Line Carrier (PLC) in Automated Meter Reading (AMR) Systems and Evaluating Non-Technical Loss (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. The AMR Systems can also provide quick and reliable meter reading collection with less error, few technical people's involvement and completely eliminates the need for physically reading the meters. In recent days illegal electricity usage has been a major problem in some of the countries. The utilization of PLC in Remote Detection of Illegal Electricity Usage can be a novel solution in this respect. It will also increase the revenue earning of power distribution authorities.

Keywords - *Automated Meter Reading (AMR), Electric Energy Meter, Illegal Electricity Usage, Non-Technical Loss (NTL), Power Line Carrier (PLC)*

1. Introduction

Using electric power lines as signal transmission medium, is possible as every building and 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, building a PLC network using the existing AC electrical wiring is easier than other networking systems and relatively inexpensive as well. 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 as well as illegal electricity usage can be easily deployed.

2. Background and Analysis

Power Line Carrier (PLC) is a method of transmitting information using the electrical power distribution network as a channel. This technology provides the flow of information through the same cable that supplies electrical power. This novel idea of transmitting information bridges the electrical and communication network. In PLC, generally the same electric cables used for power delivery are also applied in communication [1]. 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 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. In addition, the line offers limited bandwidth in comparison to cable or fiber-optic links. 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 power line carrier (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.

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. 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 [4].

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.

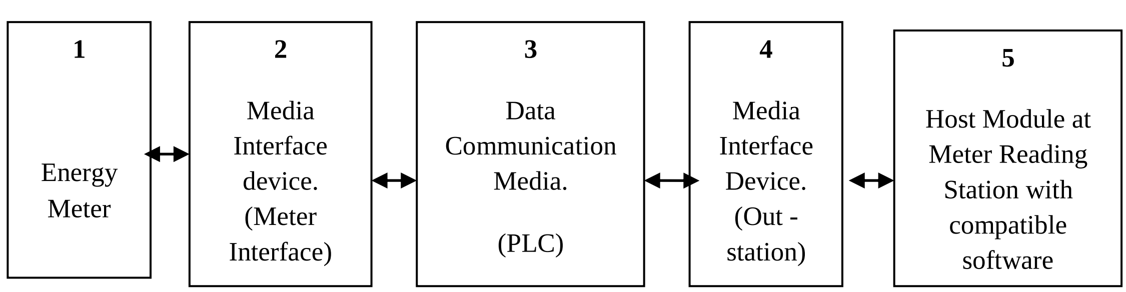

Figure 1: Functional Block Diagram of AMR components

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:

$$\text{Total Energy Losses } (E_{Loss}) = NTL + TL \qquad (1)$$

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.

$$E_{Loss} = E_{Delivered} - E_{Sold} \qquad (2)$$

Where,
E_{Loss} is the amount of total energy lost,
$E_{Delivered}$ 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 equation 1 and 2, we get

$$NTL = E_{Delivered} - E_{Sold} - TL \qquad (3)$$

3. 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. 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 Fig. 2. In normal condition, current flowing through the phase (IP) should be equal to current returning through the neutral (IN).

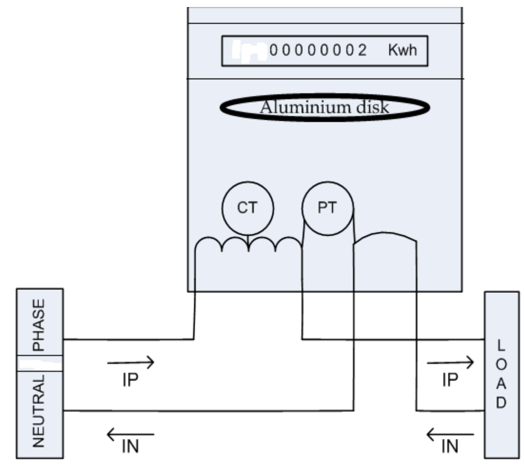

Figure 2: An Analog Electric Energy Meter

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. We know 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 subscriber 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 subscriber 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 meters 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 Fig. 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.

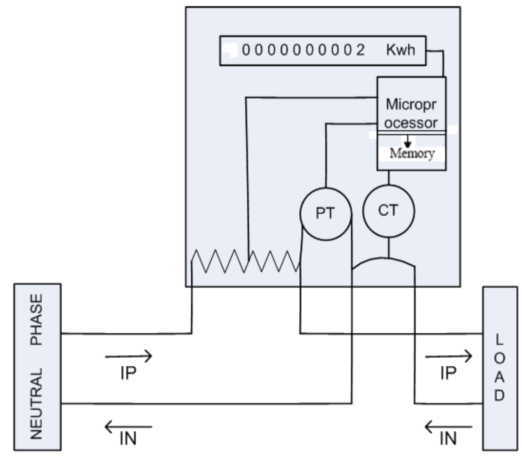

Figure 3: A Digital Energy Meter

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.

4. Detection and Evaluation of Non-Technical Loss

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 is shown in Fig. 4. Here, the disk speed of the kilowatt-hour meter is counted

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and the obtained data is counted as energy value of the kilowatt-hour meter.

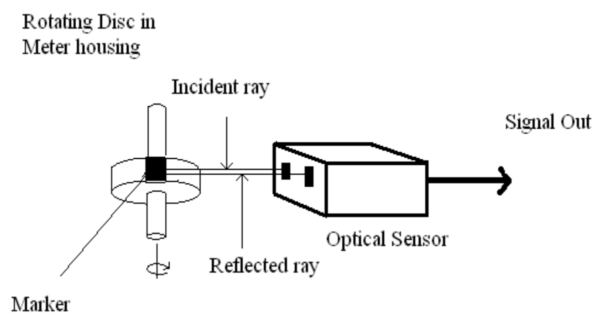

Figure 4: Electromechanical movement to digital signal conversion

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 port of the meter. So, there is no need for an optical reflector system in digital meters.

A) The Automated Meter Reading (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). 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 function as a workstation in an existing Local Area Network (LAN) and it can becomes a member of the entire system or several HCS can be connected together to form a network.

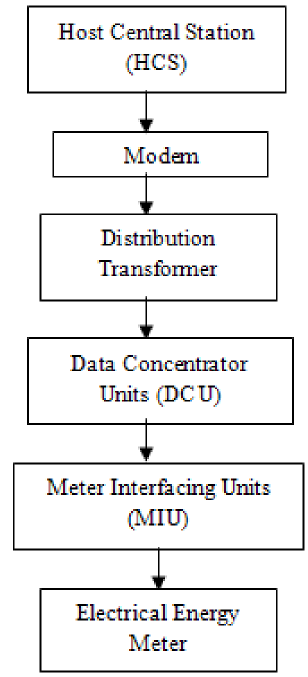

Figure 5: Block Diagram of PLC based AMR system

The DCU, all the MIUs and meters connected to 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 here for communication via PLC are [5]:

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 has the functions of automated-remote meter-reading and data acquisition. 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. So, it should be arranged that outputs to the 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.

There are two choices for signal coupling to the power line: 1) Differential or Line -to- Neutral mode, in which the line to neutral pair is used to inject the signal and 2) Common or Line-to-Earth mode which uses the ground wire as the second terminal. This second method has less attenuation and less noise (neutral line is the return for all the noise present in the power line), but may have potential dangers and is not always allowed by the safety regulation agencies. For these reasons, it is efficient to use the first coupling method for PLC based AMR system. There are several multiplex and modulation schemes which are investigated to be applied in the PLC transmission systems and multi-carrier modulations are found suitable when dealing with frequency selectivity and narrowband interferences. OFDM (Orthogonal Frequency Division Multiplexing) is the most efficient modulation technique for the application in the PLC based AMR transmission systems with higher data rates, because of its excellent bandwidth efficiency. OFDM provides a data transmission over a number of sub-carriers which makes possible deviation from critical frequencies used by other communication systems. An OFDM based transmission system uses a number of sub-carriers distributed in a frequency spectrum [7]. If we focus on the modulation issues, the synchronization procedures are the most critical points that affect the complexity and cost of the equipment. In this situation, it is mandatory to use the implicit time reference that the power line network offers. The mains voltage zero-crossings offer a reliable time reference while the symbol rate is reduced. We have two options in order to increase the data rate. On one hand, we can increase the modulation level and, on the other hand, we can transmit several low symbol rate parallel streams [3].

The communication device of the PLC communication system is a Power Line Modem (PLM), which transmits and receives data over the power line. Both the MIU and the DCU contain the 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. Two-way communication between DCU and MIU by the PLMs operating in a Half Duplex, two-way, Time Division Multiplex communication mode is essential to establish a proper communication channel.

In AMR systems, the transmission speed is not an important fact but 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 transmission error. Every MIU is also equipped with repeaters to enhance 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 built-in Power Line Modems (PLM).The Host Central Station (HCS) is the central control center 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 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 [6].

B) Detection and Control System:

The system shown in Fig. 6 has one distribution transformer network and it needs to be repeated for every distribution network. Here, it is used with automated meter reading (AMR) system. In the network with AMR system, there should be host PLC unit and a PLC modem for every subscriber. In the Fig. 6 the host PLC unit and PLC modems are denoted as PLC1A, PLC2A, ……. ,PLCNA and are used for the AMR. These units communicate with each other and send the recorded data in kilowatt-hour meters to the PLC unit. To detect illegal usage of electrical energy, a PLC modem and an energy meter chip are added to an existing AMR system for every subscriber. In Fig. 6, PLC1B, PLC2B, …..,PLCNB and energy meter chips are belonged to the detector. Here, the detector PLC's and energy meters are placed at the connection point between main distribution lines and subscriber's line.

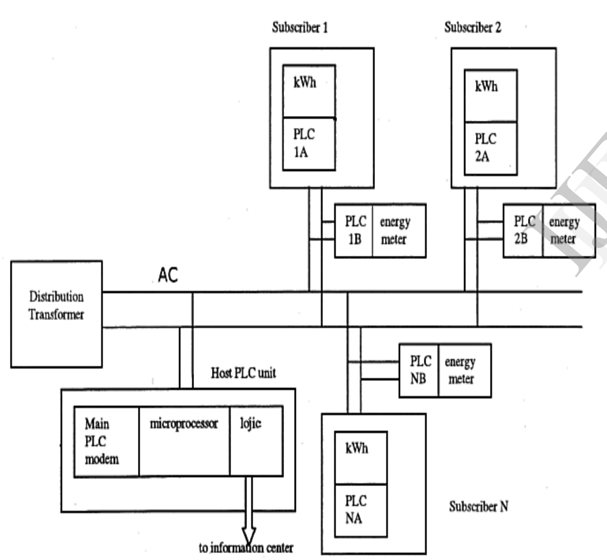

Figure 6: Detection system of illegal electricity usage

As the connection point is usually in the air or at underground it is not suitable to access however it's controlling is easy. Here, the PLC signaling frequency bands, signaling levels, and procedures are restricted between 3–95 kHz for the electricity suppliers and 95–148.5 kHz are restricted for the consumer use.

For every subscriber the recorded data of kilowatt-hour meters are sent to the host PLC modem via PLC. On the other hand, the Energy meter chips located at the connection points read the energy in kilowatt-hours and also send the data to the host PLC unit. Therefore, this detector system has two recorded energy data in host PLC unit; one from the AMR via PLC and the other, which is provided from the PLC modem at the connection points. Then, these two recorded energy data are compared in the host PLC and if any difference is found between the two readings, an error signal is generated. This indicates that there is illegal usage of electricity in the network. After that, the error signal and the subscriber address are combined and forwarded to the central control unit. In the case of illegal usage, a contactor may be added in the system at subscriber locations to automatically turn off the energy supply.

5. Discussion

This detector system of theft of electrical energy as well as the non-technical loss is combination of some equipments and a procedure of controlling 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 modems 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 Illegal electricity usage. The system software has 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 subscriber in every sub network with subscriber identification number, billing address etc.

The Results and the variations in the relations between distance, frequency, length, and bit-error probability are shown in Figures 7 and 8.

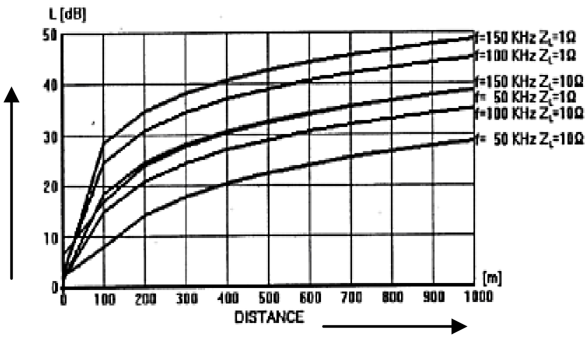

Figure 7: Effects of distance between the source-receiver on the loss for various frequency load combinations

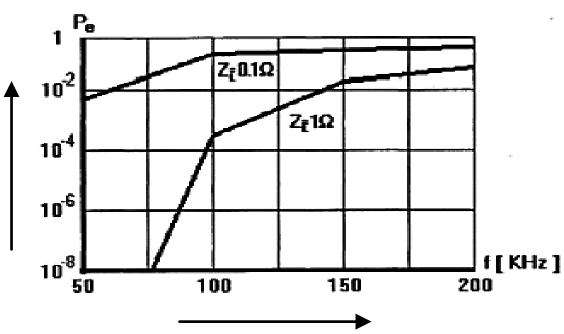

Figure 8: Variations in Bit-error probability with the frequency and load impedance for a 1000-m line

6. Calculation of the Non-Technical Loss

According to the theories descried earlier, from equation (1); (2) and (3) we can get the Non-Technical Loss (NTL) for a selected power system network. On the other hand the value of energy theft i.e. the NTL is also found from the described PLC based AMR system. Logically both the values of NTL should be same. However by comparing both the values of NTL we can verify the accuracy of the described system as well.

7. 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 (hence determining 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 detection and evaluation of Non-Technical Loss (Illegal Electricity Usage) using the PLC based AMR system and proposes a possible solution for this problem.

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