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Power line carrier technologies: a review

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Abstract. This paper gives an elaborate insight into the Power Line Carrier (PLC) communication technology in the power system. It explores the various characteristics, properties, and advancement of the power line carrier system and individual analysis of its components. These components, however, are in concerning power line carrier communications over high voltage lines majorly used in transmission stations. Power Line Carrier (PLC) components, including wave traps, coupling capacitors, line matching units, were highlighted. The paper discussed the operation principle of the Power Line Carrier (PLC) system together with their functionalities and how it makes transmission of information and power possible. It gives us the step by step functionalities of the different parts and how they make the information dispersion possible. A communication strategy was deployed for the effective transmission of data and information over the power line channel. Challenges were considered, solutions, and future directions for the advancements in the power line carrier system were also provided.

Keywords: Power line carrier, transmission line, Smart grid, home automation, internet Access

1. Introduction

Power line carrier (PLC) in communications describes the procedural stages involved for the transmission and receiving of data and information using high-voltage power lines as the channel or transmission path [1] [2]. However, this is achieved by superimposing high- frequency carrier signals on power lines at the nominal voltage level. PLC evolution has also been quite impactful in the distribution sector, making communications between household users and distribution substations possible with smart metering and other data acquisition features [3][4]. In this age of information technology, communication or rather the dispersion of information has become a significant necessity in virtually all sectors of life from the industrial sector to power, medicine, commercial and residential at large [5][6]. With evolutions in communication modes, other alternatives to PLC are also being studied for effective communication between substations in transmissions and end-users in the distribution sector[7-8]. The main focus of this review article is to explore the power line carrier communication technologies, applications, challenges, and solutions. Power line communication system block diagram presented in figure 1

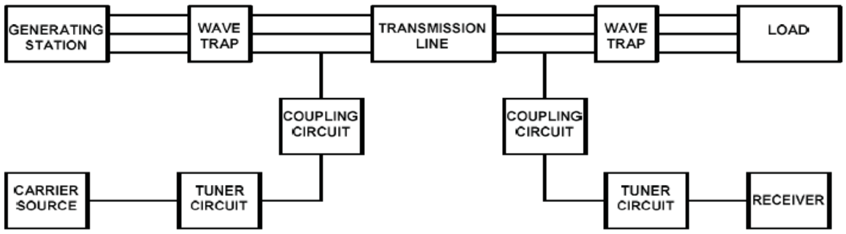

Figure 1. PLC Block diagram

2. Review of related works

Several works have been done in PLCC, some of the works are highlighted below:
Tong et al. [9] investigated the power transmission that gives ways of improving the method and means of communication on the conventional power line. The performance of PLC when transmission lines transfer of radio-frequency signals depends on the electric wiring of the power distribution system with environmental influences on power transmission lines also been considered. Berger et al. [10] studied Power Line Communications for Smart Grid applications proposing that though there are wireline and wireless communications in the power system, the PLC still does more functions in the modern power grid. By providing natural better data communication to the simple electricity wire, with no need to depend on telecommunication companies. The authors identify the use of power line communications in the smart grid. The communication scenarios highlighted in this paper are: High-voltage lines which have voltages in the range from 110kV to 380kV comprises of long overhead lines without branches. This high voltage lines connecting the primary transformer substations were also connected to the Medium-Voltage lines with the voltage range from 10kV to 30kV. The secondary transformer connects the Low-voltage lines which range from 110 V to 400V to the medium voltage lines.

In [11], the author provided an overview of the various technologies of the PLC and their configurations that are in the market considering their applications in various sectors. The focus was on the challenges that the PLC system might encounter in a few years to come, considering the distributed generation that will be using Electric vehicles, which can cause noise in the PLC frequency. Dushyant et al. [12] studied the power line communication application as a possible solution to frequency regulation in an intelligent microgrid with a frequency controller and diesel generator that operates in constant power mode. The PLC was used in regulating the frequency whenever there was a need to communicate information to the diesel generator from the control center. Vivek et al. [13] investigated the power transmission line issues, and the modeling approaches. Considering PLC as a new technology that still needs improvement in some vital aspects. The author studied the PLC over low –voltage power networks as the part gaining the researcher's attention both in the narrowband and the broadband area of applications with the communication medium of PLC modem.

Kuzlu, et al [14] considered wired communication technique using a cable, which can be categorized into power line carrier communication and fiber optics techniques. The fiber optics techniques offer a connection at a high-speed level. The PLC technologies can be cost-effective, more so Home plug with a data rate of up to 10 Mbps can be used. More so, a Home plug with a data rate of up to 10 Mbps can be used. They may not be suitable for many applications in the smart grid because of noises and interferences issues.

Zhilenkov et al [15] proposed the use of PLC technology for homes using IoT systems. Though RFID (Radio Frequency Identification), was initially used in IoT. It could be changed to PLC since radio frequency range in the urban areas are overloaded already, the network will no longer have extra load thereby transmitting data to a large number of devices already connected to the power network, on the same line.

3. Working Principle of the Power Line Carrier System

A power line carrier (PLC) system is operated by the superimposition of a high-frequency communication signal in the range of 1.6 Mega-Hertz to 30 Mega-Hertz upon the low- frequency power signals[16] [17] The useful information is retrieved from the filtering process, and the power signals are prevented from entering the communication systems to damage them. The structure of a power line communication system is given in Figure 2 [18].

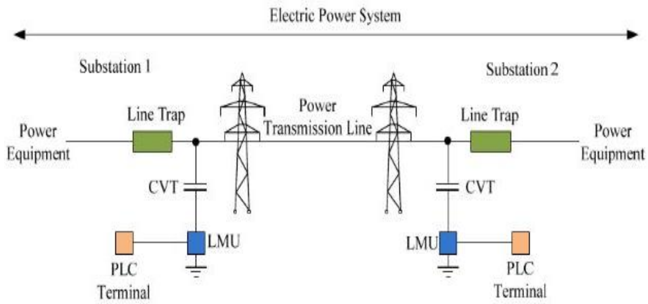

Figure 2. Schematic of Power Line Carrier [18]

The communication signals are prevented from entering the substation equipment. This critical filtering process is carried out by the coupling capacitor and the line trap unit. The coupling capacitor is connected to the PLC system, so it filters out the low-frequency power signals and allows the high - frequency communication signals to pass through the capacitor reactance of the capacitor is given in equation 1.

$$Xc \ \frac{1}{2\pi \times f \times C} \ (\Omega) \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where X_C = Capacitive reactance, C = Capacitor capacitance, f = frequency. The frequency and capacitive reactance are inversely proportional. Consider a 5000pF capacitor for a low power frequency of 50Hz and a high communication frequency of 30MHz. The capacitor offers a high reactance of 636.619 kilo-ohms to the 50Hz power frequency, whereas it offers a 1-ohm resistance for the very high communication frequency. Conversely, the line/wave trap unit is the low pass filter for the substation equipment as it allows only the low-frequency power signals into the substation equipment and blocks the high-frequency communication signals from the power equipment. The wave trap inductive reactance is given in equation 2.

$$X_L = 2\pi \times f \times L \ (\Omega) \ \ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where X_L = inductive reactance, f = frequency, L = wave trap inductance. The wave trap offers a high impedance of 1.885 mega-ohms to the high-frequency communication signals but offers a very low impedance of 3 ohms for the low-frequency power signals.

A typical power line carrier communication system includes the following elements, which are the transmission line, Line trap, coupling capacitor tuning unit and blocking element, and relay system, Transmitter and Receiver, Protection, and earthing Battery. Some of these elements are highlighted below.

3.1 Line Traps: The line trap shown in Figure 3, also known as a wave trap, is a very highly inductive element with a capacitor in parallel to it. It is a high pass filter that chokes any high-frequency communication signals.

Figure 3. Line/Wave Trap [19]

3.2 *Line Tuning/Matching Units*: This unit is an aggregate of the tuning devices, earth switch, drain coil, and an isolation transformer with a lightning arrestor on its two sides.
3.3. *Coupling Capacitors:* This is a filtering component for the PLC terminal. It couples the high-frequency communication signals with low-frequency power signals on the power line.
3.4. *Drain Coil:* As the name implies, the drain coil is an inductive component that provides a very high impedance path to the ground for high-frequency communication components.
3.5. *Hybrids and Filters:* This is the interconnection of two or more transmitters on the same channel or path without any distortion or destructive superposition, that is: Interference.
3.6. *Master Oscillator and Amplifier:* The oscillator in the PLCC is used for generating high -frequency signals that are fed into the amplifier to compensate for any loss in the transmission.

4. Applications of Power Line Carriers

The application of PLC can be found to be extremely basic or can be quite challenging, considering the line characteristics and specifications used. Some of which are highlighted below,

4.1 Industrial Automation and Telecommunication Services

PLC networks can be applied to provide power services like remote billing, demand management, and meter reading. It also gives value-added services like e-business opportunities automation and remote control. Internet service and traditional telephony are telecommunication services offered by PLC for transmission of data, voice, or fax electronically. Current PLC networks can achieve speeds of 200Mbps[20].

4.2 Solutions for Electricity Suppliers

Power line carrier can serve as a solution to electricity suppliers in different ways. They can be used for fraud detection, system protection, and fault detection. In detecting fraud, the energy been supplied to the consumer can be compared to the power received from the transformer. Form this comparison, losses are determined, and fraud can be detected. In protecting the system, the communication link is capable of transferring control signals that will be used in protecting the system. In identifying a fault, the combined energy between the PLC communication systems can be used. Preventive maintenance can be done to improve the operation of the grid [21].

4.3. Carrier Protection Relaying of Transmission Line

The relay can release an inter trip command to protect the carrier; there are thee methods of doing this. They are the differential comparison method, distance protection relay, and the phase comparison method.[22].

4.4. Smart Grid Applications

The application of an existing power line infrastructure is an alternative to the creation of modern communication links in substations at medium voltage level because the traditional grids are not provided with communication capabilities. Also, PLC is used for fault location, detection, and isolation in a medium voltage network. Additional applications of PLC for medium voltage networks are the measurement of oil transformer temperature, analysis of the voltage on the secondary winding of the transformer, power quality measurement, and fault survey. [23].

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4.5. Broadband Internet Access

Broadband internet access in PLC makes it possible for customers to access the internet via the present electrical structure. A primary advantage of the use of a PLC network is the means to reuse the existing power wired network to offer communication abilities. With an increase in the deployment of PLCs, they are now being implemented as an in-home smart grid and various other applications[24]. Multiple input multiple-output (MIMO) signal processing is recently being considered for use in broadband power line communications (PLC). Despite being a well-established ingredient to many wireless systems. Though some issues need to be solved before adapting multiple-antenna transmission in an electric power system, which is wired[25], therefore, an automated distribution is set up in which a power line carrier is used as a communication link[26].

4.6. Automatic meter reading

PLC technology is also applied to meter reading; data are automatically collected from energy meter is and sent to the central control room for billing and analysis. This saves regular trips helps billing not to be estimated, but based on real consumption.[20]

4.7. Home networking and Internet Access:

Several computers can be connected in a home and building by using the existing network, hence there is no need to install new wire or cable for the connections; this reduces installation cost and time by using the available low voltage power network for the home networking.

PLC is also used for Home Automation for controlling light and home appliances remotely, such as drapes and curtains[27].

5. Types, Challenges, and Solutions

5.1 Types

Power line carrier is majorly categorized into Narrowband PLC and Broadband PLC[28]. Narrowband Power Line carrier (NB-PLC) is a High-data-rate network that is now prominent in smart grid communications in the low-voltage grid [29][30]. In the smart grid and data distribution, broadband is applied to distances that are not more than 100m; hence suitably uses higher frequencies for indoor communication[31]. Comparison between Narrowband PLC and Broadband PLC is shown in table 1

Table 1. Comparison between Narrowband PLC and Broadband PLC

	Narrowband PLC	**Broadband PLC**
Bit rates	Up to 200kbps	Over 1Mbps
Frequency Band	Up to 500kHz	Over2MHz
Applications	Building automation, Renewable Energy, Street light, Advance Metering, Electric Vehicle Smart grid	Internet Gaming Audio

5.2. Challenges

In the existing electricity network, there are several challenges in the power transmission line infrastructure. One of the problems that are faced by the power line carrier is that the electrical power lines are usually very noisy due to the high amount of energy that they transmit. The signal strength and the operating frequency is also another challenge in power line carrier [32][33]. It has also been noticed that with the deployment of power line carriers, there has been a significant interference with the present radio communication environment. For example, in developed countries like Canada that have radio service providers that operate with a range of 2-80MHz, there will be an interference that will be caused by the power line carriers.

Bad weather can also pose a challenge to the power line carrier as they had adverse effects on the system, some of the impacts of harmful weather include the following;

a Inability to propagate on the conductor in situations where massive frost forms on the carrier line
b When it is raining, the effect of contaminants is increased
c Noise can also be introduced in lousy weather
d Poor compatibility with users of the radio spectrum
e Signal attenuation
f Security issues with the integration of internet services
g Poor coordination between the telecom and power providers
h Low voltage transformers allow electricity through it at small losses and low frequencies but not higher rates.

5.3 Solutions

From the above most of the challenges are caused by an emission, so the proposed solution is incorporating an emission limit for the line carriers, especially for the broadband power line carrier in certain countries like the US, regulations have been put in place to integrate the emission limits [34]. Prohibition of specific frequency bands can also be a solution to the interferences caused by power line carriers, including groups used for an aeronautical service, public safety, and national defense[35]; this will serve as a safety measure. Some other criteria include Filtering, frequency avoidance Power reduction, and Controllable shut-down features.

6. Opportunities and Way Forward

Power line carrier (PLC) involves sending, controlling, and receiving data and or information over existing power cables. It is, therefore, essential to reuse the power lines for communication purposes [36]. The electrical distribution sector has always constituted a regularized wiring system but was never built with the intent of the communication. The area of opportunities involving applications and use of PLC can be seen in such applications as automatic metering systems, programmable controllers, and real-time demand and supply management[37]. Bandwidth increment of the PLC would grossly prepare for the much-needed capacity envisioned by 2023. Expanding the available bandwidth by over five times introduces broadcast interference concerns.

7. Conclusion

The power line carrier system is an effective means of transmitting information via power lines for utilization in power stations. However, the reservations made by the channel being the power line in terms of bandwidth is low. And with the advancements of networking and information technology and other communications modes, there is a need for development in the power line carrier system to enable the transfer of a large amount of information at a specified bit rate possible. The traditional power line carrier system for control and communication purposes is still widely revered in power systems despite other advancements in communication modes; it remains highly reliable in issuing control commands to power systems equipment.

Conflict of Interest: The authors declare at this moments that there is no conflict of interest.

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