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Power Line Connections for a Smart Grid Implementation and Application

Khawla Mohsan Guma [1*], Salim Abdallah El Hussain[2]
College of Technical Sciences, Derna Libya

[*]*Corresponding author: khawlaali81@yahoo.com*

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Abstract:
Power line communication, through the use of electricity infrastructure for data transmission, is witnessing the renaissance of the smart grid context that includes the goals of the smart grid with the integration of intermittent renewable energy sources into a chain of electricity supplies, in addition to securing reliable electricity delivery, and the use of existing electrical infrastructure in a higher In this paper, we reviews power line communications (PLCs) according to the context of the smart grid, as the specifications G3-PLC, PRIME, HomePlug Green PHY, and HomePlug AV2 are discussed.

Keywords: Application, Analysis, Power Line, Smart Grid

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Introduction:
Electricity generation in huge power stations is transmitted through high-voltage transmission lines interconnected in electrical grid systems at the present time, but there are no cost-effective control systems on the lines,[1] and due to the lack of effective transmissions, it is possible to affect the potential power outages passively on high voltage transmission lines on other networks. In view of these reasons, it may necessitate the establishment of a new network that is emerging,[2] but it will be used in the network communication system so that it is more understandable. The traditional network includes energy centers connected to long transmission lines and has a connection structure that could cause power outages,[3] in addition to the presence of other connected countries, and this is done through power outages. Smart grids play an important role for many, especially since the technological revolution has its own entity since the invention of the Internet, as governments all over the world pump huge sums of money into research,[4] development and publishing through (SG) or the smart grid, with multiple goals. Smart grids also have a special ability to reduce carbon dioxide emissions by integrating renewable and distributed energy resources, energy storage,[5] and hybrid electric vehicles that run on electricity. Real-time monitoring of power plants, distribution and transmission networks, and it is possible to increase the efficiency of use of primary power plants and electricity transmission infrastructure, and to deploy dynamic pricing and demand response strategies.[6]
Given the importance of smart grid systems that improve the reliability of electrical power systems, provide more power quality, reduce time delays, control resistance to attacks, etc., there are a variety of candidate technologies available for optical fibers, wireless communications and power lines. Power (PLC) to devices Smart Grid Communication Infrastructure. However,[7] it is important that this connection be achieved by the most effective means.

The field of telecommunications includes a long list of complementary and sometimes competing specifications and standards for wireless and wireline communications that can be used in smart grid deployments. Industry adoption and large-scale customer rollouts are still in their infancy. That is, communications through the existing electrical infrastructure, [8] which has its interrelated role to provide the natural upgrade from simple electrical connectors to hybrid, bi-directional electricity and data communication solutions.

The idea of using power lines for communication purposes also existed at the beginning of the last century, but the obvious advantage is the availability of electrical infrastructure on a large scale, as deployment costs are theoretically limited to connecting modems to the current electrical network, and it is possible to combine power line technologies in PLC to narrow the scope (NB-PLC), [9] often operating below 500 kHz, and Wide Band PLC (BB-PLC), usually operating at frequencies above 1.8 MHz, are discussed in succession starting with the following with an introduction to PLC scenarios, followed by aspects of channel, noise, and electromagnetic compatibility (EMC). EMC).

By shedding light on the complementary reading available for free on the most modern PLC and the development in another source of relevant PLC values, which the researcher summarized in the following points:

Table 1: Domain and actor in the smart grid conceptual model

	Domain	Actors in the domain
1.	Distribution	Distribution comes from electricity distributors to customers, and electricity can also be stored and generated.
2.	Transmission	Bulk electricity travels over long distances, allowing electricity to be stored and generated.
3.	Bulk generation	Electricity generators exist in large quantities, and it is possible to store and distribute energy as well, in addition to the bulk electricity carriers over the long period of time
4.	Operations	It is associated with the management of electricity traffic.
5.	Service providers	Organizations provide services to customers in addition to electrical utilities.
6.	Markets	Electricity market participants and operators

2.0literature review

2.1The role of power line communications in grid and cross grid smart grid

The study clarifies its candidacy for Power Line Communications (PLC) for network applications, in addition to providing an overview of Power Line Communications (PLC), which witnessed an evolutionary movement, and perhaps the technological intervention in the region had a positive role with Power Line Communications (PLC), and the treatment of smart grid applications as a case of Sensor networks and network control problems with extracting literature related to the same topic, and the analysis of the main scenario with the PLC application was related to the modeling of the network planning component, in addition to the engineering modeling arranged by fading models, and the unique information delivery systems while using the PLC.

2.2 Applications of the new power line communication model for smart grids

Explain here the requirements of the new network system architecture that is irresistible in the near future, as well as the system capable of providing remote controls to develop more efficient, more convenient and reliable systems, while smart networks that will transmit data and their communications infrastructure with job control The task, examining the control requirements and communication structures of electrical networks, discussing the power line communication (PLC) systems for the smart grid system, and creating a new (PLC) model to simulate the smart grid communication systems through MATLAB.

3.0 Communication overview

National and international organizations are now mapping out SG roadmaps for brevity, so that other people can orient themselves around the work of the US National Institute of Standards and Technology (NIST). [10] With the structuring of the different domains of the smart grid, NIST standards and technology have been devised as a domain-based conceptual model, each domain includes actors working through domain boundaries with the help of communication, domains and actors are redefined, domains are interconnected, and common practices are defined To differentiate between power line communication scenarios according to power line operating voltages, and to define voltage-based differentiation with the NIST conceptual model.

(HV) Any high voltage lines that are used with voltages in the range from 110 kV to 380 kV, for power transmission internationally and consist of long overhead lines with few or no branches, which makes them positive and acceptable evidence with less attenuation per line length as It is the case with its medium and low voltage counterparts, however,[10,11] if high-voltage, time-varying arcing and corona noise with noise power fluctuations on the order of a series of tens of decibels and practical applications, the coupling costs of communication signals inside and outside these lines as a problem, moreover there is fierce competition between Optical fiber links, and some cases in which these links may be cut with the ground conductor of the high-voltage system, in addition to reporting many successful experiences using high-voltage lines.[8,11]

Medium Voltage (MV) Lines, with voltages ranging from 10kV to 30kV, connected to high voltage lines via primary transformer substations, medium voltage lines are used to distribute power between cities, towns and larger industrial customers, it can be realized as overhead or underground lines, In addition,[9,10] it bites a low level of branches and communicates directly with smart electronic devices (IEDs), the most prominent examples of which are (reclosing devices, capacitor banks, interrupters, and phase measurement units), which requires monitoring improvised explosive electrical circuits with relatively low data rates, It is possible for NB-PLC to provide economically competitive communication solutions for these tasks, moreover, studies and experiences related to MVs can be found.

As for the low voltage (LV) lines, with voltages in the range from 110 volts to 400 volts, they are connected to the low voltage lines through the sub-secondary transformers, and it is possible for a communication signal to pass on the MV line through the transformer for the LV line, and perhaps the severe attenuation comes in the range of 55 dB for 75 decibels. Hence a special coupling device (inductive, capacitive) or a PLC repeater is often required if one wants to set up a communications path with high data rate,[12,13] leading to low voltage lines directly or over street tanks of buildings and end customers, and it is noted that the regional topology varies A large, and a common example is the United States of America, where a smaller secondary transformer on a utility pole may serve one house or a small number of houses, however it is common in Europe to provide up to one hundred households from a substation of one secondary transformer, moreover Despite the large differences in building types, it can be classified as multi-apartment buildings with antagonistic buildings, multi-apartment buildings with common meter room, single-family houses, high-rise buildings, and the effect of their different electrical wiring structure on signal attenuation and interference between Neighboring PLC networks.[14]

In most cases, the electrical network enters the customer's premises through a home access point (HAP) followed by an electric meter (M) and a distribution panel (fuse box), and often the individual refers to the PLC systems that work to reach the point as access systems, and access to the Internet is provided through Broadband over the electric grid, also known as broadband over the power line (BPL), and at the end of 2008 for less than 1% of the world's Access customers with 65% using DSL and cable used,[14,15] BPL is on the rise especially in Rural areas and in developing countries with poorly developed fixed line telephone and coaxial cable infrastructure.

Apart from public access to the Internet, automatic meter reading (AMR) systems are frequently used with ultra-wideband power line communications (UNB-PLC) technologies such as Turtle and TWACS to access and control energy meters within private homes. UNB-PLC for communication over long distances with the signal passing through the LV/MV converters. However, the disadvantages represent low data rates in the range of 0.001 bits / s and 60 bits / s for Turtle and TWACS, respectively. There are limitations on unidirectional communications, with UNB-PLC technologies because they are among the most prominent in AMR With areas of distribution automation.

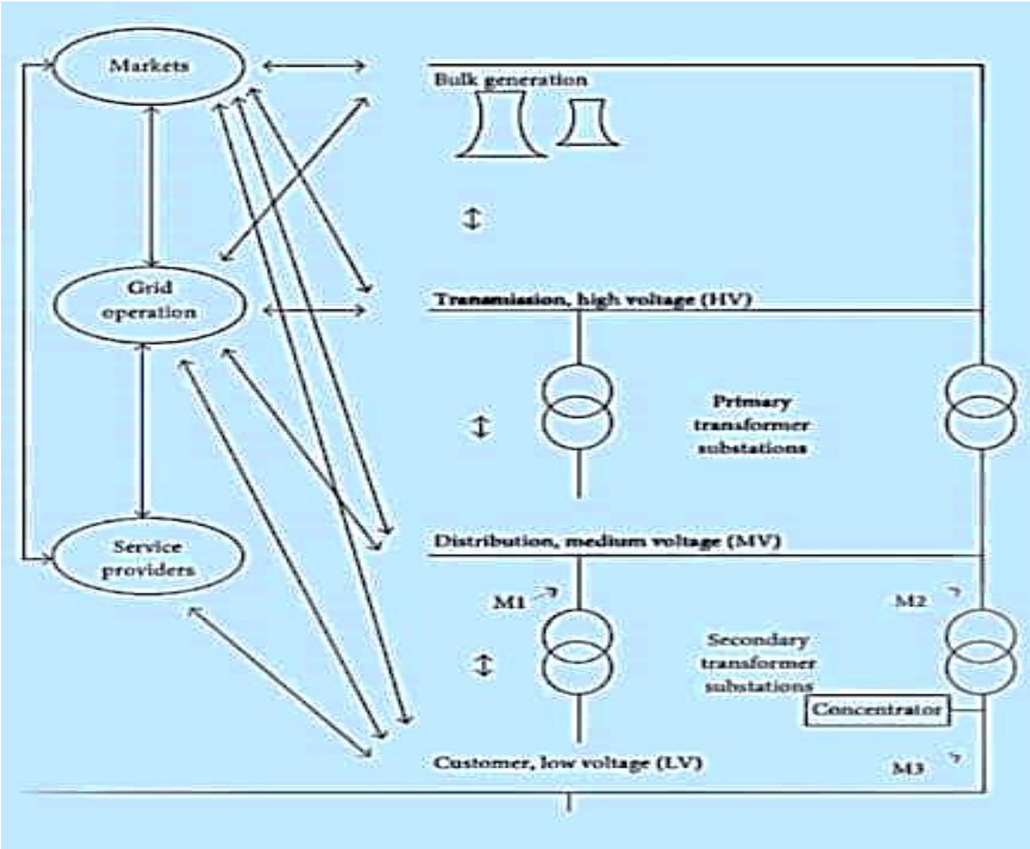

Figure 1: The areas of the smart grid and its electrical and communications connections.

The following figure shows the distribution panel. Low voltage lines connect to different power sockets in each room. The lines can also work for electric vehicle service equipment (EVSE).

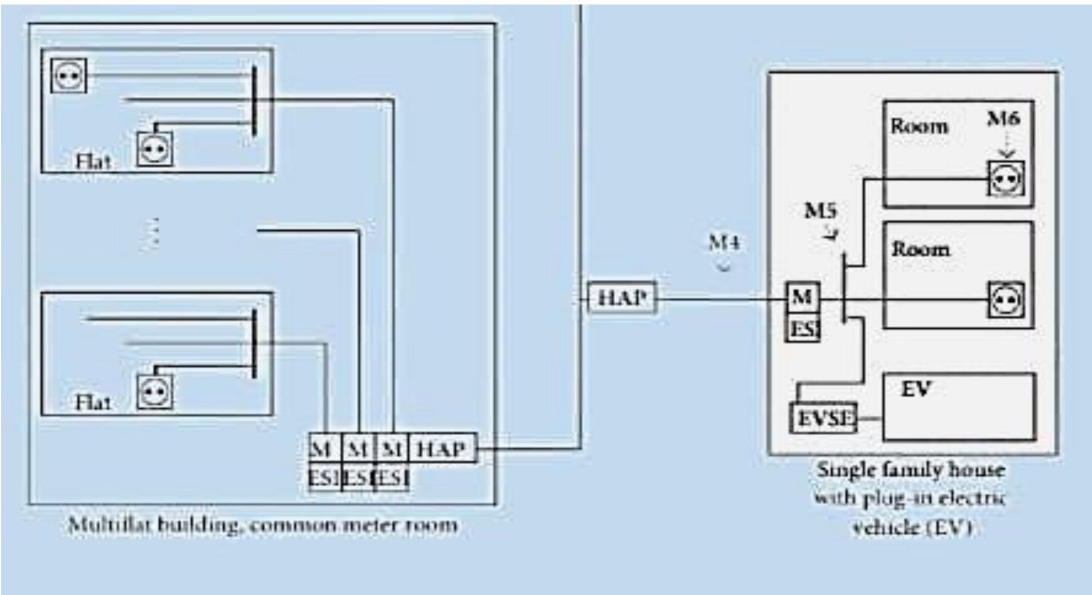

Figure 2: Smart Grid domains and their electrical and communication interconnections.

In view of the many upcoming deployments of the smart grid, there are many higher demands on the communication infrastructure, e.g., support for demand response, distributed generation, and demand side tool applications. [1,15] It is believed that these applications could be, among others, supported by the advanced measurement infrastructure (AMI) associated with the PLC, and a wide range of materials are available related to the requirements and architectures of AMI, and the project of the European meter was OPEN, and it was dealing with the increasing requirements of AMI, so the present paper tries By offering solutions for UNB-PLC applications on the sidelines in favor of the most recent PLC (NB-PLC) technologies, such as the development of Power Line Linked Intelligent Measurement (PRIME) and G3-PLC.[17] Bidirectional NB-PLC data rates are within 100 kbit/s, partially maintaining the advantage of communication over long ranges and through switches.
As for the applications demonstrated by the high data rate of the reliable home area network (HAN), broadband power line communication technologies are becoming more and more attractive, Field proven BB-PLC technologies provide data rates of more than 200 Mbit/s, which makes it easier to meet the needs of users Household including high-definition television (HDTV), SG services emanating from the home include precise control of smart appliances, the ability to remotely manage electrical appliances, and display consumption data, often causing consumer awareness to change consumption habits to sequentially save energy between 10 % and 20%.

3.1 Business relationship related to the power line communication system
PLC is one of the many communication technologies that can realize SG. PLC provides communication and control capabilities through the use of existing power line network. The use of PLC for SG shows that the price is valid, safe and reliable, as it is implemented by adding a carrier signal to the rectifier power cable, and the PLC can be distinguished by the operating voltages of the power lines. High-voltage (HV) lines with voltages in the range of 110 kV to 380 kV are used for nationwide power transmission (Wide Area Network - WAN) [2,5] through overhead lines, medium voltage lines (MV) with a voltage in the range of 10 kilovolts to 30 kilovolts and it is connected to the high voltage lines through a substation of the primary transformer and is used to distribute power in cities and major industrial areas such as (Neighborhood Area Network - NAN). LV lines having voltages in the range of 110V to 400V interconnected to the MV lines by a secondary transformer substation, with the applied (Home Area) Network (HAN) by the LV lines, where the MV lines are redundantly coupled to the PLC to establish rectified communication High data transmission is associated with reduced strain attenuation and with low voltage lines, one of the main advantages of a PLC is complete control of the physical surroundings.[18] PLC technology can be divided into two parts; Broadband PLC and Narrowband PLC.

3.2PLC is divided into two parts (Broadband and Narrowband):

1. Broadband Power Line Communications (BPLC) operates in the high frequency range of 1.8-250MHz and has data rates of hundreds of megabits per second, and is used to provide broadband Internet access.

2. Narrow Band Power Line Communications (NBPLC) These lines operate in the low frequency range from 3 kHz to 500 kHz, and it enhances and supports internal and external communications with low and medium voltage power lines, especially as it is capable of data rates of up to 500 kbps. One, it is considered safer, more reliable and cost effective and is more preferred for home automation and smart metering.

PLCs also work by imposing a modulated vector, orthogonal division multiplexing (OFDM) signal on the wiring system, [19] due to the fact that the current power line system is made only for transmitting AC power at frequencies of 50 or 60 Hz, which results in the power lines having the capacity Support for higher frequencies.

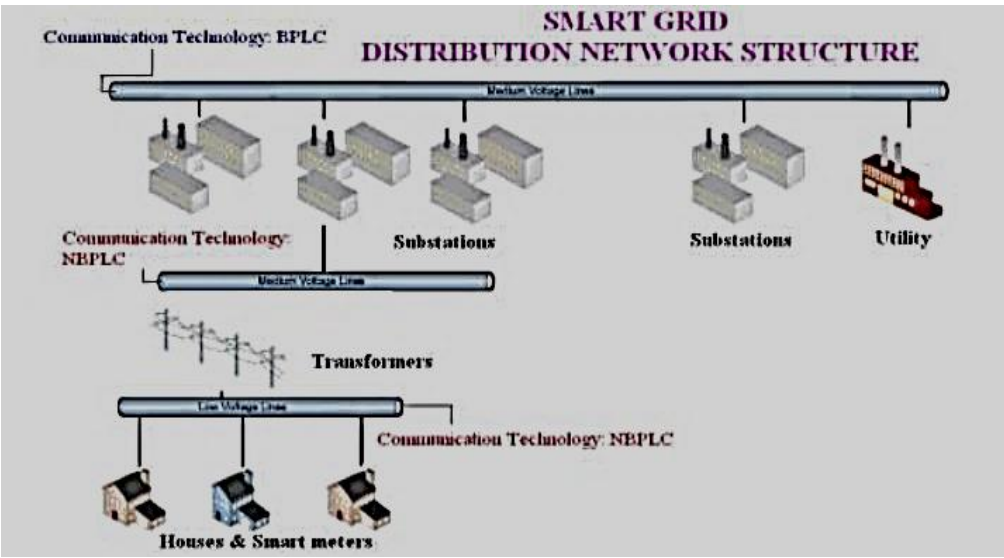

Figure 3: Smart Grid Distribution Network with PLC

The above image shows the current situation provided by the PLC from the advantages granted to SG applications, in addition to the updates that are made to meet the challenges and continuous changes, which are considered among the basic requirements for considering the PLC model suitable for work.

3.2.1 Advantages of PLC in smart grid

PLC provides several advantages for smart grid applications, the most prominent of which are:
1.It covers a wide area due to the existing power line infrastructure, providing mobility for SG applications.
2.It is cheap because there is no need for additional cables
3.PLC systems are flexible so that they can cover long range communications
4.PLC systems provide stable communication for SG applications
5.The installation of PLC control is easy for internal implementations.

3.2.2 PLC frontiers for smart grid

The design of electric lines is related to power transmission. Similarly, some difficulties were noted in data transmission through power lines, although PLC offers effective and direct solutions to reach the cost of the SG application, and it was to confirm the challenges that require consideration of SG applications, including some potential concerns.

$$y_n = \begin{cases} r_n & |r_n| \leq Tc \\ Tc^{e^{J\,avg\langle r_n \rangle}} & |r_n| > Tc \end{cases} \qquad n = 0,1 \ldots \ldots, N-1,$$

where Tc is the cut-off threshold.

3.3 Turbo Equalizer

It represents the projected process to solve the attenuation in the channel, which is defined by the (Turbo Equalizer) method. This method is the turbo equalizer that works through the following:

- First: Noise / (PLC) is intended for the transmission of electricity, which is not considered suitable for transmitting data. Rather, the noise generated by electrical devices on the network affects the (PLC) system.
- Second: The varying resistance/ causes the devices connected through the power grid to vary.
- Third: channel attenuation
- Fourth: Its lack of a PLC allows it to operate interoperable with several types of devices
- Fifth: electromagnetic interference.

4.0 METHODOLOGY

The methodology chosen for this research is action research. It was chosen because the design allows precise research questions to be formed more clearly during the research investigation, according to some findings, called “progressive illumination” (Saunders, et al., 2019). The nature of this type of research can be seen in the form of an illustrative representation shown in Figure 3 below, where the influences include the philosophical reflections of interpretation as the basis for the systematic analysis, using a qualitative inductive approach to the secondary data.

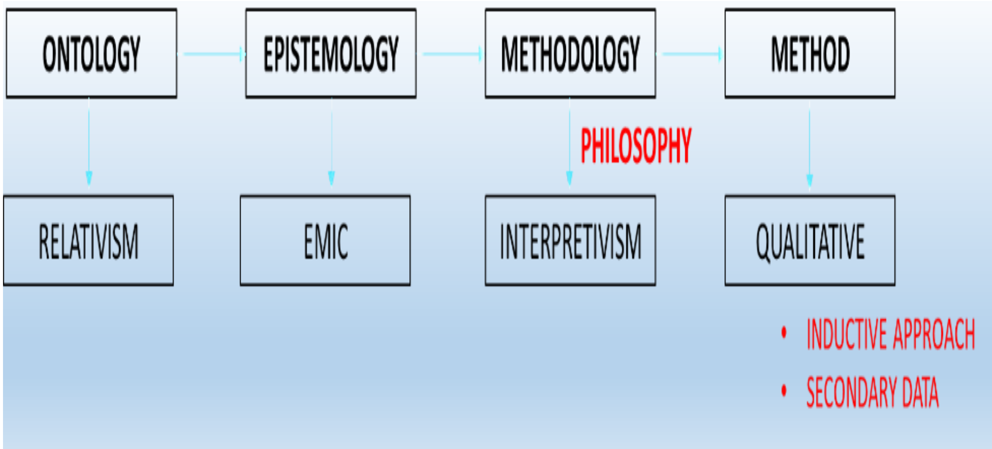

Figure 4: Diagram showing the background of a qualitative research approach

The primary step of action research methodology is to pose a hypothesis or research question, which is then doubted upon and challenged through knowledge and data collection. Therefore, there is a considerable amount of critical thought process on the types of educated guesses that might occur upon deciding what the next steps of the research should be and what types of sequential actions would best benefit the research's purposes.

4.1Methods of Data Collection

The data collection method is based on the strategic suggestions of action research following the process of defining a challenge, gathering data relevant to the challenge, reflecting on the data gathered, and choosing the directions of the next steps of the research (Norton, 2019). The approach is different from the one typically used for a research paper that fills a literature gap. The process involves taking actions after data collection and reflection and looking for learning opportunities in the author’s organization. Ultimately, applying the action research approach, while attempting to resolve an issue in existing organizations, specific knowledge is gained, and the understanding of the topic under concern is improved. The data collection for this project covers some of the options under action research methodology using the outcomes of other studies that have been previously carried out on the topic.

4.2 Action Research Contribution

This action research project will test the theory that power lines are a valuable application for smart grid systems, as the primary goal of the smart grid is to provide real-time monitoring, control, and development functionality to improve and develop electricity transmission efficiency, and by using PLC for SG, there have been many applications that are suitable for the surrounding environment without Influencing the stability of the electrical network and ensuring the PLC supply to users. The research will improve the understanding of how PLC works for SG and explain why the improvement may be traditional business model adopted by companies.

5.0 Findings

5.1Progress of the Research

The research project was implemented in five stages, from conceptualization and initiation to the stage of analyzing power lines, and thus the realization of application objectives through the smart grid in the telecommunications sector. Through this stage, the project met the critical characteristics of action research that addresses an important and complex issue with multiple causes and required procedures. There is no doubt that the problem of power line connections in the smart grid is one of the main concerns in the whole earth, as it is complex because it consists of many interrelated variables, and it is possible to meet multiple reasons that are separated by time and place and appear on the lines of contemporary issues that require action with something.

The second phase of the project consisted of the definition and planning of action research. Following the action research approach, this phase respected a well-defined structure to ensure all parts were linked together and feeding one another.

The third phase involved executing the planned tasks and controlling their effects, becoming the research methodology's heart. Three main actions were undertaken during this phase: the first one was the control of the progress, the second one was the collection of data, which became the evidence of the research, and the third was the production of periodic reports.

The fourth phase involved the performance and control, which was translated into the reflection part of the action research methodology. It involved reflecting upon the different activities, and secondary sources studied, creating a continual interaction between these two activities that ultimately helped the solution emerging on the surface based on the data collected. During the reflection process, the main questions regarded the outcome's expectations, the actual results attained, their justification, and **finally,** the next research step's identification. The last phase consisted of wrapping up the research after recycling some actions undertaken within the previous phases.

5.2 Action Research Cycle

The project follows the action-reflection mechanism that is characteristic of action research, which uses "a combination of cognitive mechanisms" and "procedural mechanisms" (Bradbury, 2015). This mechanism is repeated to suggest after data gathering and reflection on the findings, the most promising technologies and the most appropriate business model to achieve the research stated aim. Consequently, action research is developed through a series of spiral steps that repeat this type of process, as shown in Figure 4.

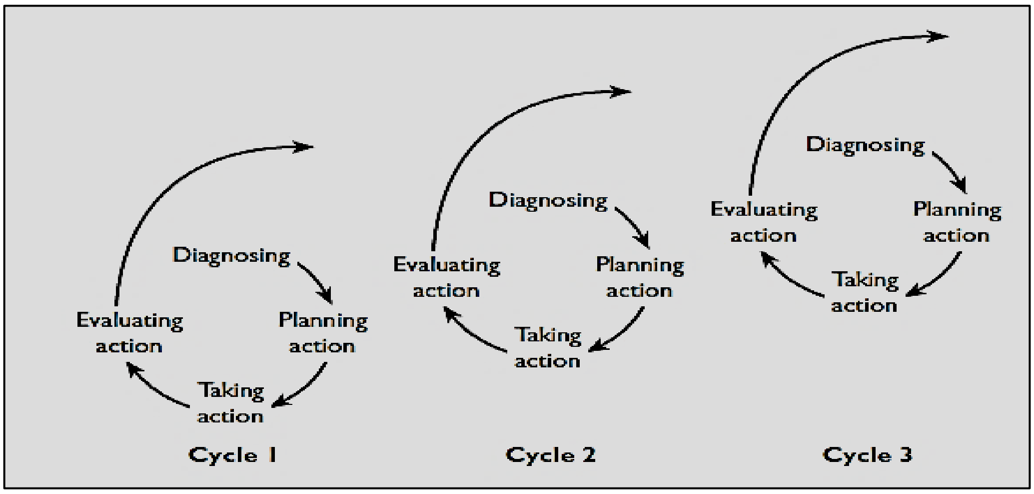

Figure 5: series of spiral steps that repeat

During the diagnostic step, the evaluation of the independent variable of the research is performed. In particular, as detailed in the following paragraphs, an evaluation of the best possible advanced SYSTEM MODE technologies is performed as a precursor to the cycle planning step where dependent variables (technology maturity level and costs) are compared. The action step is strictly related to the results of the comparison of the dependent variables and allows to propose a solution to the author's problem. After evaluating the action taken and the proposed solution, the Action Research cycle can be considered completed. At the same time, the completion of the first cycle corresponds to the beginning of the subsequent cycle and through repetition and reflection on the data collected, the research arrives at its validity and qualitative learning outcomes and draws cognitive conclusions (Coghlan, 2005).

Given the time available for completion of this project, only the first cycle of action research results are reported, along with suggested steps and procedures for the subsequent cycle (Cycle 2). The ultimate goal is to find ways to sustainable solve the intermittent issues of PLC sources. In the following paragraphs, a description of the different steps of this first research cycle is provided.

5.3 Diagnosing

The following paragraphs describe the PLC system model. The most promising advances used in conjunction modify the input data through encoder or (convolutional encoder), and make use of the data from previous studies.

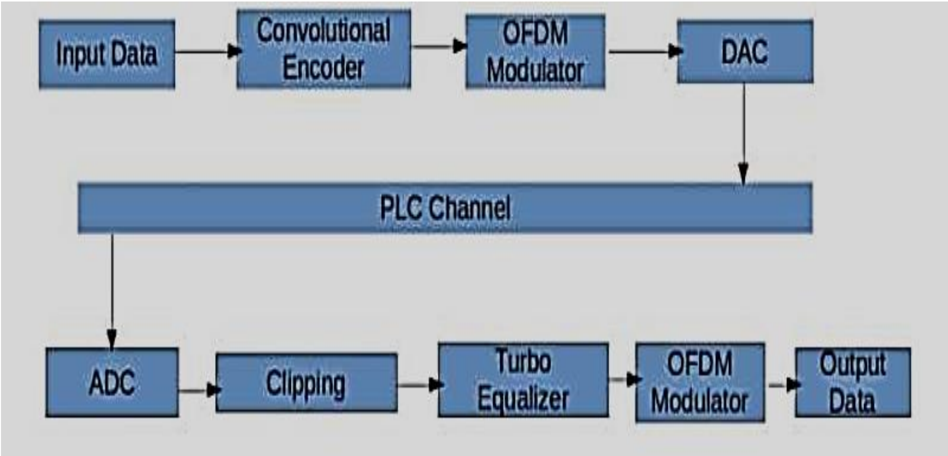

Figure 6: PLC System Mode

The above model shows the PLC working system in detail, as the input data is modified through the channel or convolutional encoding, which is directly limited by the channel fading effect, and the signal then passes through the OFDM modulator, and the indication signal is superimposed with the OFDM signal, where it has been modified to increase the frequency The signal that will be transmitted on the power line, and since the power lines have the ability to transmit analog signals only, it is possible to convert the OFDM signal as it is considered a digital signal to an analog signal through the digital ranger to analog and is sent over the power lines, and the received signal is converted to noise and attenuation This distortion and attenuation of the channel is reduced by cutting and equalizing blocks, after which the future signal is demodulated and the original data is restored.

In order to ensure the interoperability of SG, a role is played by IP support, which improves the performance of PLC technology, and requires consideration of the converged network architecture with integration with Ethernet-based networks so that this convergence is achieved through a common layer, data link or financial layer that enables communication Interface, the use of integration with the Ethernet network Relying on the use of the TCP / IP protocol to form a converged network to reduce attenuation, G3-PLC based on the G3 alliance converged way was born.

5.3.1. PLC-BASED SG APPLICATIONS

The main goal of the smart grid is to provide (monitoring and control) as a function in real time to improve the efficiency of electricity transmission, and the PLC of SG is used for many applications dealings with applications and it has been divided into the following subsections:

First: Advanced Metering Infrastructure / so that the programmable logic control (PLC) system allows as a two-way communication that can be used to exchange information between customer devices and AMI control systems.

Second: Management (DSM), which is the demand side / and is one of the applications of (DSM), i.e., demand response, where DR responds to the requirements of various energy requests, and DR helps to reduce peak demand and enables consumers to monitor energy consumption, and the DR controls peak and energy conditions that increase Energy system efficiency by relying on a real-time pricing scheme.

3th: Home environment / The home energy management system (HEMS) provides advantages to the network, and one of the most famous examples of this is reliability, and reducing peak demand due to continuous monitoring and reporting of the energy requirements of the network.

4th: Fault detection / It is possible to use high voltage (HV) lines to remotely detect faults such as insulators with short circuits and cable explosions, and prevent losses such as traffic and signal errors by detecting faults remotely through PLC.

5.3.2. Application Layer Interoperability

Although conflicts persisted between stakeholders promoting different technologies of NB-PLC and BB-PLC, it was clear that IP support would become critical to ensuring smart grid interoperability, and in this regard the Home Plug-promoted alliance and the Home Grid forum associated with In partnership with wireless stakeholders, specifically the Wi-Fi Alliance and ZigBee Alliance, the Smart Energy Profile Interoperability Consortium was formed with the purpose of "developing joint documentation and testing processes to certify SEP 2 interoperability", with the Smart Energy Profile 2, and creating layer developments associated with smart energy within the ZigBee Alliance. It conforms to the IEC's Common Information Model (CIM), maintains link-layer neutrality, describes the use of XML, and follows a representative state transfer architecture. For hypertext transfer (HTTP). A test of the widely adopted base-blocks, it can be utilized for interoperability between devices of different home area network.

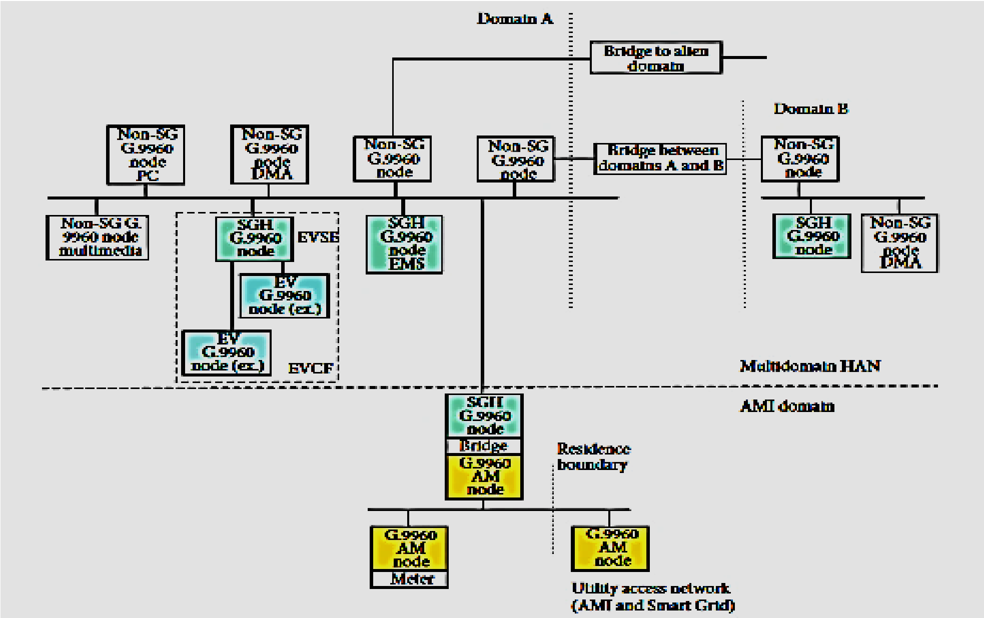

Figure7: Smart Grid HAN implementation based on G.9960

The bridging of OSI Layer 3 as suggested in the following image, and given the interoperability of the upper layer, the last foundation of the Intelligent Power Profile Interoperability Federation, is a promising step forward that will allow users and operators to deploy a multitude of wired and wireless technologies with the ability to Seamless interoperability at the application layer that is essential for widespread acceptance in the smart grid.

6.Conclusions

Despite facing strong telecommunications competitors, it is likely that Power Line Communications (PLCs) will fulfill different communication tasks in upcoming smart grid deployments in terms of providing PLCs for the natural upgrade from simple electrical connectors to hybrid and bi-directional electrical communications as solutions. Electricity and data communications. One of the main advantages of (PLCs) is complete control over the physical medium without relying on third-party providers such as telecommunications companies and cellular operators. NIST PAP15, it is important for the PLC industry as a whole when defending the region against competing wired and wireless choices, which is related to broadband BB-PLCs. Perhaps the coexisting standards here are ITU-T G.hn and IEEE P1901 with Home Plug AV2 specifications. Currently expanded as the most promising standards, while the standardization of narrowband PLC (NB-PLC) and IEEE P1901. 2 and ITU-T G.hnem as they are still ongoing.
The PLC is seen as a solution to achieve the smart grid, and it is easy to construct because it is used in the existing infrastructure of power lines. PLC for many ongoing research projects in applications, solutions and analysis.

Cases where NB-PLC and BB-PLC systems operate on the same physical medium may become more frequent with increasing penetration of PLC systems, however it is necessary to coexist between the two as a straight forward because they use different frequency bands, and in general it is possible to establish interconnections between NB standards Various -PLC and BB-PLC coexisting amid OSI Layer 3 bridges.

Highlighting upper layer interoperability, the latest foundation of the Smart Energy Profile Interoperability Consortium, is a promising step forward to allow users and operators to deploy a multitude of wireless and wired technologies with seamless interoperability at the application layer that is essential to widespread acceptance of the smart grid.

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