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STUDY OF THE MOST IMPORTANT FACTORS AFFECTING ON EFFICIENCY OF POWER LINE COMMUNICATION SYSTEMS

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Abstract: Due to the increasing demand for communications services, particularly the application of broadband multimedia services, it has become necessary to search for easy, low cost and reliable communications with information security. Communications via power lines PLC have become an attractive environment for communications services because of the power grid covering large areas of the world. This research will discusses the most important factors affecting the efficiency of PLC systems, and will focus more on distance between modems and change in load within the network. A set of modems has been connected to the local area network LAN, performing the tests at different distances, then switching the load and observing changes in system efficiency. The practical results have shown that the long distance had a negative effect, also the change in load has a significant negative impact on the rate of transfer of information and efficiency, as described later in the practical section. Therefore requires further practical research and full knowledge of other challenges that currently limit their widespread commercially PLC application.

Keywords: *Power Line Communication (PLC), Power Line Network (PLN), Quadrature Amplitude Modulation (QAM), Orthogonal Frequency Division Multiplexing (OFDM), Local Area Network (LAN).*

دراسة اهم العوامل التي تؤثّر على كفاءة أنظمة الإتصالات عبر خطوط الكهرباء

الخلاصة: نظرا لزيادة الطلب على خدمات الاتصالات، ولا سيما تطبيق خدمات الوسائط المتعددة عريضة النطاق، أصبح من الضروري البحث عن اتصالات سهلة ومنخفضة التكلفة وموثوق بها مع أمن المعلومات. أصبحت الاتصالات عبر خطوط الطاقة PLC بيئة جذابة لخدمات الاتصالات بسبب وجود شبكة الطاقة التي تغطي مناطق واسعة من العالم. يناقش هذا البحث أهم العوامل التي تؤثر على كفاءة أنظمة PLC ، وسيكون التركيز اكثر على المسافة بين المودمات والتبدل في الحمل داخل الشبكة. تم توصيل مجموعة من أجهزة المودم بشبكة المنطقة المحلية LAN ، لإجراء الاختبارات على مسافات مختلفة ، ثم تبديل الحمل وملاحظة التغييرات في كفاءة النظام. وقد أظهرت النتائج العملية أن للمسافة الطويلة تأثير سلبي ، كما أن للتغير في الحمل تأثير سلبي كبير على معدل نقل المعلومات والكفاءة ، كما هو موضح فيما بعد في القسم العملي. لذلك يتطلب مزيدًا من البحث العملي والمعرفة الكاملة بالتحديات الأخرى التي تحد حاليًا من تطبيق PLC التجاري على نطاق واسع.

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1. Introduction

Due to the great development of communications systems and the increasing need for multimedia services and broadband applications, it is necessary to find new ways of communication easy of install, economical, confident and able to meet the needs of consumers. One of the mediums of communications capable of achieving above requirements is power line communications (PLC).

The basic concept of PLC is to provide high-speed Internet access for homes, offices, businesses and other facilities. In PLC systems, the existing alternating current (AC) power lines serve as a transmission medium by which voice or data is transmitted to one or more receivers. It is used the same wire used in power transmission for data transfer alongside the transfer of electrical energy. That used of broadband services over power lines (BPL) is to provide broadband Internet access through power distribution networks. This means access to high-speed Internet through computers once the modem is connected to any power outlet in a building equipped with BPL[1].

Power networks face some challenges when used to transfer of data because their design is originally for power transmission only. Previous studies have shown this challenges associated with data transfer through the infrastructure of these networks.

Due to the less of research and practical experience related to this type of communication services and the different topology of the power lines from one region to another it became necessary to conduct more studies, in order to study that possibility commercially applied in the coming years. Hopes that this research will contribute in increasing the knowledge and practical experience in PLC.

The aim of this paper is study of the most important factors affecting on efficiency of PLC systems.

The paper is arranged as following: In section 2 background for PLC technology is described. Structures and characteristics of electrical power networks and coupling circuits will be discussed in section 3. Factors affecting, and modulation technique in PLC discussed in section 4. Description of Practical part will be in section 5. Finally, Analysis of the results and conclusions are given in Sections 6 and 7 respectively.

2. Background of PLC Technology

PLC is a type of communication systems which uses medium voltage (MV) and low voltage (LV) in the electrical distribution network as a medium of communications to perform the transfer and exchange of data. It is provide a competitive and cost effective alternative to internet access and Local Area Network (LAN) applications.

There are many difficulties facing the spread of PLC, most important factors affecting for efficiency of PLC systems are attenuation, interference, reflection, distortion and noise. Using of power line network for access to global communications networks has attracted considerable attention and has become a mature topic of researches [2].

There are many high-speed and multimedia applications, often preferred the effective and reliable communications. power facilities can provide PLC to customers, this can bring a major breakthrough in communication systems. Power lines were not originally designed for use in communications, it designed to transmit power at a frequency of 50 or 60 Hz not for several MHz or GHz. Therefore the characteristics of transmission power lines differ from cable characteristics originally designed for communications such as twisted pairs, coaxial cables and fiber optics.

PLC has advantages and disadvantages like any communication system, its advantages are:-

Easy to install, no need to install new wires, share Internet connection, move computers and other home appliances to anywhere else you need, solve coverage problems caused by walls, securely encrypt for data, low cost, do not need antennas, and high speed with long distances compared to the cables of Local Area Network (LAN).

The disadvantages of PLC are:-

Interference, attenuation, reflection, noise, power loss as well as legal restrictions on frequency band that limit data transfer.

PLC operates by inject and extract of the modulator carrier signal over PL wires. PL is the physical medium for communication systems, as in "Fig. 1 a" which shows the general arrangement of BPL operating in PLC systems. It consists of an injector that provides the main data signal, repeater serves to enhances the signal, and the extractor that extracts the data and pass it through the power transformer to the users. "Fig. 1" (b) shows used of PL for communications and its applications for automatic meter reading (AMR) in power network.

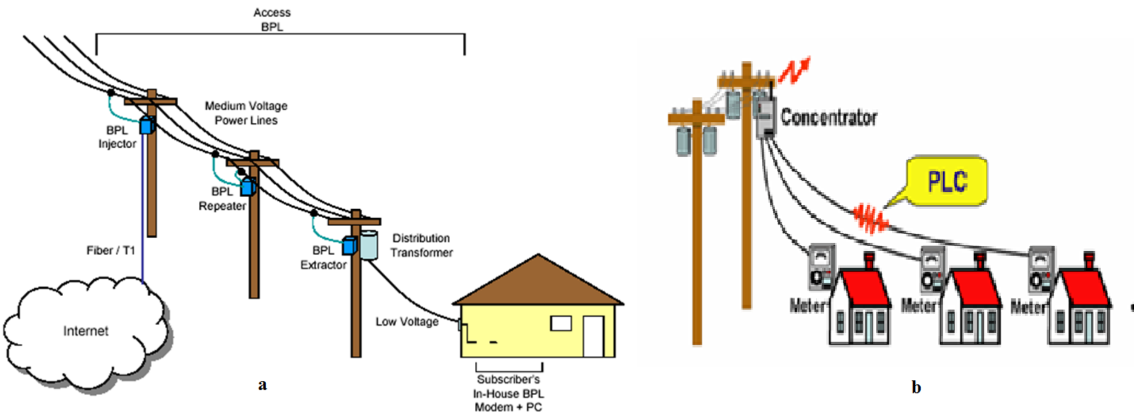

Figure. 1 (a) shows general arrangement of BPL system and (b) shows PLC used (AMR)[3].

3. Electrical Power Supply Networks

The power lines were not originally designed for communications and until recently they were used for low-speed services such as telemetry and the management of power supply facilities. This limited scope of power line functions has changed at presently because of the large demand for communication high-speed broadband multimedia services [4].

The use of power lines as a medium of transfer data in a residential area allows high-speed communications to reach any place where AC outlet is exist. It's easier than establish a new wires, secure, relatively inexpensive and reliable more than wireless systems [5].

3.1 Levels of Electrical Power Supply Networks

There are three levels of networks used to transmit and distribute electricity, in addition for internal voltage networks (I.V), which complementary of (LV), these levels are:-

1 - High voltage networks (H.V)

2 - Medium Voltage networks (M.V)

3 - Low-Voltage networks(L.V)

1 - H.V networks:- These networks ranges between 100 and 500 kV. They are generally used to connect a power station with large supply or connect large customers. It is also used to exchange energy between different countries, which is not suitable for data transfer because interference at high frequencies constitutes an obstacle to reliable communication, in addition to energy loss, corona discharge can generate impulses that interfere with wireless communication, when using low and medium bandwidth.

2 - M.V networks:- These networks range between 10 and 30 kV. They are used for transmission and distribution electric power in large areas such as large cities, industrial or commercial cities . For communications, medium networks are the backbone of data transfer via power lines.

3 - L.V networks: is the last part of the power distribution networks, ranging from 100 to 400 volts for the final consumer. It's similar to the medium voltage lines and consist of copper or aluminum. PLC use low-voltage power networks to provide home or office internet services. "Fig. 2" shows a simplified structure of three levels of power networks.

4 - Internal voltage networks (I.V): - They are systems of distribution of indoor power supply and are the complementary part of low voltage networks because it is the last part of an electrical system that delivers electricity to consumers. PL not fully exploited broadband applications in the home / office environment due to the noise and characteristics hostile to the deployment of high-frequency signals [6].

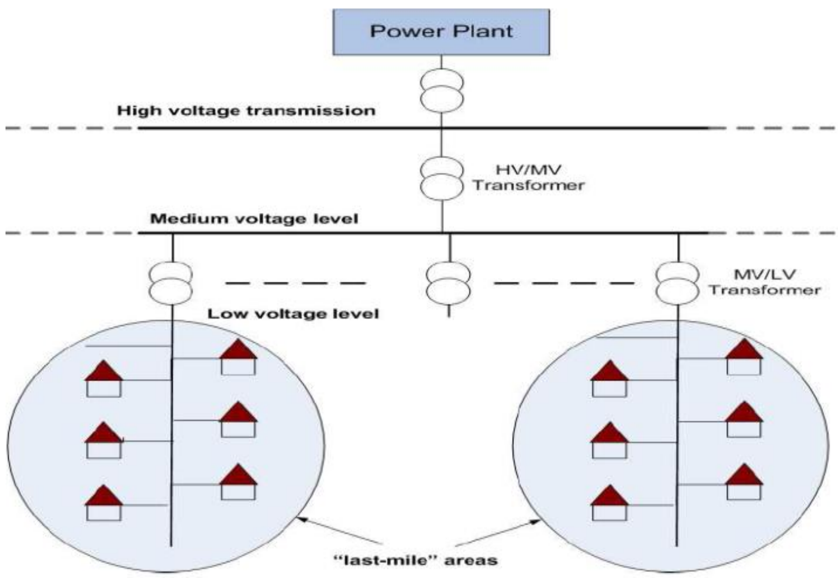

Figure. 2 shows a simplified structure of an electric power supply networks [4].

3.2. Properties of Electric Power Networks

PL are primarily designed to transmit electrical signals at 50 or 60 Hz, not for communications and do not take into account the use of these networks for data transmission. To use these networks for communications there are factors affect on PL require their knowledge (induction, capacitance and resistance) as well as the natural resistance of wires.

1- Inductance (L) :- PL network distributes electrical power to various devices connected to the network. Each these devices have inductance (L) and capacitance (C) depending on the current flowing through its circuits. Where an electric current (I) drives the magnetic flux (φ), the induction (L) can be defined by Eq. (1)

$$L = \frac{\theta}{I} \qquad (1)$$

In AC circuits, when the voltage (V) , the frequency (f) and an electric current (I) drives the magnetic flux (φ), it can define the induction (L) by "(2)" [4].

$$L = \frac{V}{j2\pi f I} \qquad (2)$$

2 - Capacitance (C):- It's represents a measure of the amount of electrical energy stored between two adjacent conductors surfaces with an opposite charge. It can be expressed in AC circuits in "(3)".

$$C = \frac{I}{j2\pi f v} \qquad (3)$$

3 - Impedance (Z):- The complete opposition current flow in AC circuits is measured by impedance. The impedance of the cable consists of three components, they are resistance (R), capacitance (C) and inductance (L). The impedance can be expressed in a complex form by "(4)".

$$Z = R + j2\pi f L + \frac{1}{j2\pi f c} \qquad (4)$$

In PLC systems, the maximum signal is received when the impedance of all components (transmitter, power line, receiver) are identical.

3.3 Coupling Circuits in PLC

One of the most important components in modems for PLC systems is the coupling circuit, it considered a simple unit compared to the difficult characteristics of the PLC channel, for design a perfect coupling circuit, must select the suitable components and must understand their operation[7]. Coupling circuits must be carefully designed to provide the specified signal transmission with the suitable bandwidth and safety level required [8], must optimum matching between the two systems Power system and communication system.

In power system the frequencies are very low and the power is very high, in communication systems the frequencies are very high and the power is very low. To design PLC systems and provide an interface between the power system and communication system, coupling circuits must be clearly understood. Providing the isolation required between power lines and PLC system can be achieved by inductive or capacitive coupling. Inductive coupling avoids the physical connection of the network, its safer and easier than coupling capacitance. Coupling of capacitance achieves the high frequency filtering required for communications, using devices easy of design and small in size. In practical coupling circuits often apply a combine of both types [8].

3.3.1 Coupling Circuit Components

The components of the coupling circuit are:

1 - Coupling capacitors: These are widely used in PLC, more commonly, more develop and higher-order. Coupling capacitors carry the communication current and filtering the power voltage, therefore need to be high-voltage capacitors [7],[8]. The properties of the coupling capacitors are highly dependent on the load[8].

2 - Coupling of transformers: The primary function of coupling transformers is to provide isolation and impedance adaptation, pass the signal of high frequency communication, and it must be designed as such. The power wave has very low frequency and high voltage level, power waveform is usually filtered firstly by (low pass filter) before entering the coupling transformer[8].

3 -Blocking inductors: These be designed for the power frequency in order to prevent the saturation, and for the power current in order to prevent the voltage drops. The air-core inductors are which be very suited to this application.

For PL coupling circuits, have to trying to avoid using resistors, as a pure resistor, due to a loss of power for communications signal or for the power waveform[8].

To design of coupling circuit, which allows transmitting and receiving high frequency signal and prevent the low frequency the 50 - 60 Hz, must be coupling circuit is composed of a broadband 1:1 transformer and capacitors, combination of which acts as (LC) a high-pass filter as shown in "Fig. 3" , in the secondary stage of the transformer, there are five switching diodes to fixed the output voltage into the coupling circuit, thereby protecting the sensitive measuring equipment. If there is a voltage rise larger than 2.1V via the output, diodes D1, D3, D4 will turn on and fixing the output voltage. Conversely, if the voltage rise is less than –2.1V, diodes D2, D3, D5 will turn on and fixing the output voltage[8].

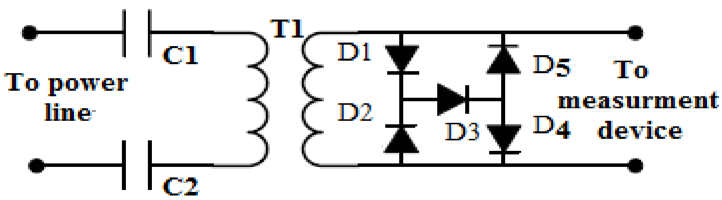

Figure. 3 shows a coupling circuit of the broadband communication modem for PLC[8]

4. Factors Affecting the Efficiency of PLC Systems

Designing of PL originally to transmit and distribute power at low frequency, not for communications, there are factors affecting the efficiency of PLC system when use PL for communication such as distance between modems, switching load, type of wires, and number of modems. Most important parameters which depended to factors above effecting the Efficiency of PLC Systems are : Attenuation, interference, reflections, distortions and noise.

4.1. Attenuation

The most important factors affecting the efficiency of PLC systems is the distance, where increasing the distance leads to increase in signal attenuation, and increasing the number of branches causes increase in signal attenuation. "Fig. 4" shows the relationship between transmitted power (P) and distance (d) in several cases, better, average and worse, where the X-axis is represent the distance and the Y-axis represent the power, the blue curve represent the best attenuation (less attenuation) while the green curve represent the worst attenuation (high attenuation) and the red intermittent curve represent the average attenuation. As shown in the "Fig. 4" and "Table 1" the transmitted power decreases when the distance is increase, which lead to increase in an attenuation.

The receiving signal power is given by "(5)" and "(6)", where S is the receiving signal power of distance (d).

$$s = P * 10^{-0.004*d} \quad \text{watt} \quad \text{at best} \quad (d) \qquad (5)$$

$$s = P * 10^{-0.010*d} \quad \text{watt} \quad \text{at wrost} \quad (d) \qquad (6)$$

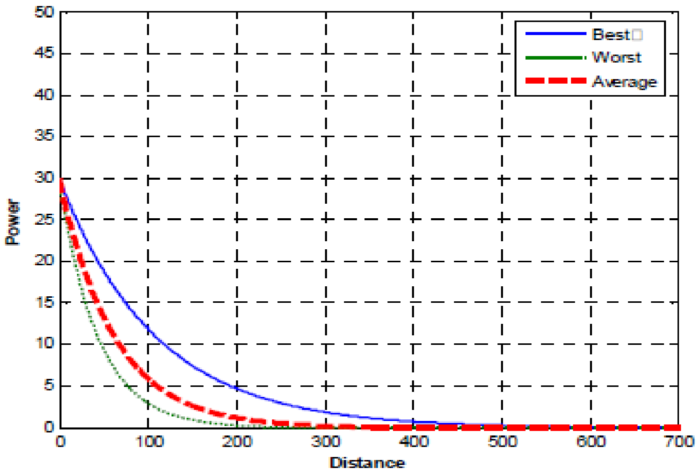

Figure. 4 shows the relationship between transmitted power and distance

Table (1) illustrates the relationship between power and distance through PLC

Distance between modems	Power in best channel case	Distance between modems	Power in worst channel case
50 m	20 w	50 m	10 w
100 m	13 w	100 m	3 w
200 m	5 w	200 m	0.5 w
300 m	2 w	300 m	0.2 w
400 m	1 w	400 m	0 w

4.2 Interference and Reflection

Interference is one of the main issues facing use of PLC technology, is often the result of interference of radio emissions. In order to avoid interference between PLC and radio transmission, common regulations have been developed.

Reflection is also the factors that increase attenuation and decrease efficiency. Due to number of branches and the distance which vary from place to place within the network and are connected in a complex manner, which may cause reflections at different frequencies due to impedance mismatch.

4.3. Distortions

In addition to the factors above, such as attenuation, interference and reflection, which often result in weak signal, or lead to distortions of signal, these distortions affect the shape of the transmitted signal, these factors lead to disturbances in the communication systems and have a negative effect on the efficiency of PLC systems.

4.4. Noise

In order to use power lines in PLC systems, with high-speed and reliable, it's necessary study and understand the different interference scenarios in the electric network. Power line noises can be classified into 5 categories as follows[4]:-

1 - Colored background noise: This noise is mainly caused by the sum of all low power noise sources and which may be occur at varying times, for minutes or even hours [7].

2 - Narrowband background noise: This type of noise is mainly due to the spectral repetition of low-frequency, high-power disturbances produced by non-linear power supply components [9]. This type of noise also originates from amplitude modulation signals emitted by radio broadcasting [5].

3 - Periodic impulsive noise synchronous to the mains frequency: The main reason for this noise is the switching in rectifier diodes for direct current (DC) equipment that connected to the electrical network.

4 - Periodic impulsive noise asynchronous to the mains frequency:- This periodic noise is caused by a power supply switching or result from multiples of the horizontal scan frequency of the 15.734 kHz TV receiver [10].

5 - Asynchronous impulsive noise: The main cause of this noise is transient transitions that occur in different parts of the electrical grid. And have a random behavior and can be shown as a bursts, it have a large negative impact on high-speed applications using PLC systems.

"Fig. 5" shows scenario of noise in the PLC channel, where the transmitted signal x(t) passes through a PLC channel expressed by a channel transfer function H(f). After that, different types of noise are added to x(t) before arriving at the receiver.

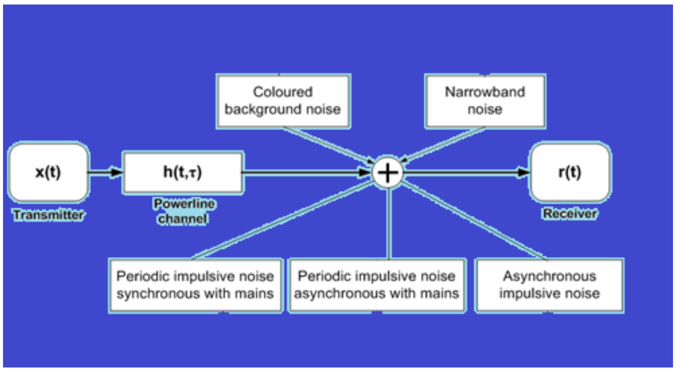

Figure. 5 scenario of noise in the power line channel[4]

4.5. Modulation Techniques for PLC Systems

There are various modulation techniques are suitable for broadband applications, including using (PLC), these methods are orthogonal frequency division multiplexing (OFDM), spread spectrum modulation (SSM), discrete multi-tone modulation (DMT), single carrier modulation(SCM), quadrature amplitude modulation (QAM) and other.

OFDM technique is one of the most important techniques was applied in broadband communications, and is the leading candidate in PLC, due to its good specifications, it increases the speed of data transfer. Given the challenges suffer PLC, which reduce the efficiency, such as attenuation, interference, noise, reflections, OFDM technique offers a natural solution for PLC, as it can mitigate most of impairments above.

One of the main benefits of using this modulation in PLC systems and other systems is its ability to convert broadband channel to narrow-band sub-channels[4]. Available bandwidth is divided into very many narrow bands, sending data in parallel and multi-carrier instead of sending data in series on single carrier, without interference.

The mathematical relationship between the carrier frequencies, shows the orthogonal signals mathematically as shown in "(7)".[11]

$$\int_0^T sin\frac{2\pi kt}{T}\sin\frac{-2\pi lt}{T}dt = 0, \quad k \neq 1 \tag{7}$$

"Fig. 6" depicts OFDM with the placement of carrier centers on orthogonal frequencies. The orthogonality is shown through the peak of each signal coinciding with the trough of other signals and spaced by 1 / T.

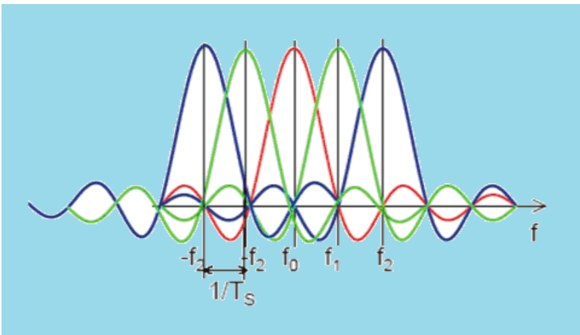

Figure. 6 OFDM = Orthogonal FDM

Discrete Fourier Transform (DFT) and Inverse Discrete Fourier Transform (IDFT) are the keys element of process in OFDM operation. This can be implemented in practice using the FFT algorithm in a very efficient. "Fig. 7" shows block diagram of OFDM system including transmitter, receiver and channel.

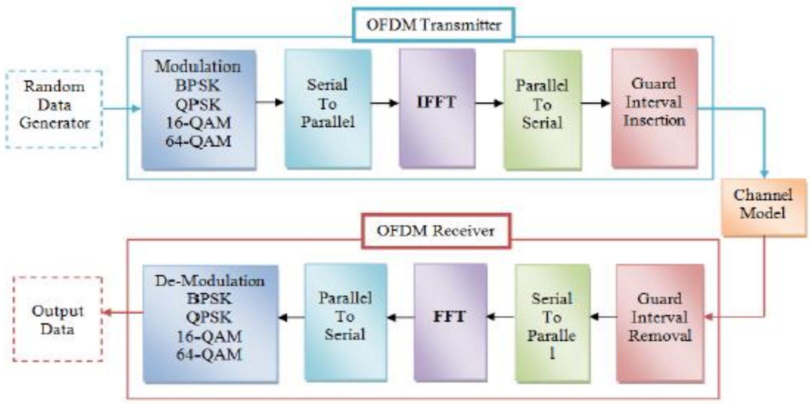

Figure. 7 Block diagram of OFDM modulation system[12]

5. Description of the Practical Part

For a practical test of modems used in this paper, a pair of wire at100 meters length was used in first time, 200 m in the second time, 300 the third time and at 400 meters in the fourth time, and diameter of wire is (1) mm.

Three sockets are connected to the power line, are socket (1) at the beginning, socket (3) at end of distance and socket (2) at the mid-distance, and the length of distance was between (50 to 200) meters from each socket. There are three modems, namely the near modem (N.M), the far modem (F.M) and the mid modem (M.M), the first modem is connected to socket No.(1) at beginning of distance and the second modem is connected to socket No.(3) at end of distance, and distance between them from (100 to 400) meters, this distance different each case of test. As shows in "Table 2" and "Fig. 8".

"Fig. 8" shows computers connected to each modem connected to the power line. The load or third modem (M.M) was placed and connected to socket (2) in mid distance between the two modems (N.M) and (F.M), at distance between two modems (N.M) and (F.M) are (50 to 200) m . "Fig. 9" shows image of the external shape for one of symmetrical modems used in this paper, but because of the materials and method of manufacturing it can not be completely symmetrical.

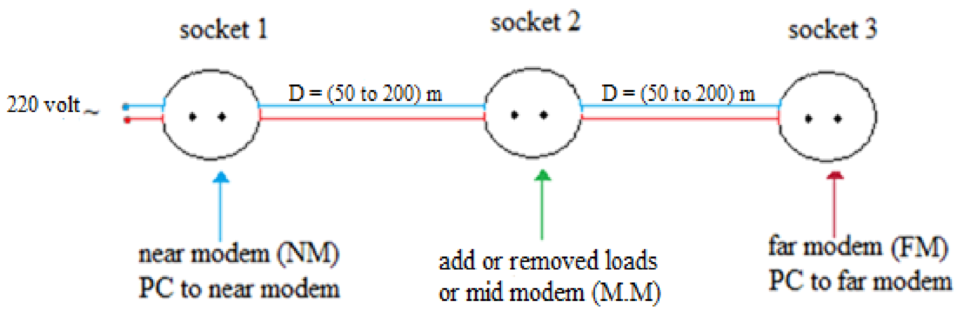

Figure. 8 illustrates a diagram of the practical part of connecting modems

Figure. 9 DLAN modem 200 AV mini Starter Kit

Table (2) illustrates the relationship between data transfer rate and distance through PLC with different distances and the application of peer to peer.

Distance between modems (Length of wire) at d = 1mm	The data transfer rate Without actual transfer
100 m	(138 → 198) Mbps
200 m	(112 → 156) Mbps
300 m	(72 → 128) Mbps
400 m	(62 → 98) Mbps

6. Analysis and Presentation of the Results

When the tested and the distance between the two modems is 200 m The results showed that the rate of data transfer for the near modem is clear after operation of the modems for a short period and reached 112 Mega bit per second (Mbps) at start operation with the load (1) and then start in semi-linear increase until it reaches at 151 Mbps and then settled at 151 as shown in "Fig. 10". Then start the rapid change when added or removed the load (2) as the data transfer rate dropped rapidly and reached from (151 to 5) Mbps. After a short period of time the transfer rate is began to increased at rapid, and reached from (5 to 112) Mbps. The change in data transfer continued with switching in load by oscillating from the 18th minute to the 50th minute until transfer rate reached 76 Mbps with semi-stability.

"Fig. 10" shows the relationship between the data transfer rate and the switched load to (N.M). The results demonstrated in the figure were recorded in practically by connecting the computers to the network through the modems as shown in "Fig. 13" and "Fig. 14" ,and continued for a period of 50 minutes.

Matlab was used to draw graphs of figures (10,11,12) that are related to the results of this research. Where the X-axis is represent the time that measured by minutes and the Y-axis which represent the data transfer rate and measured by Mbps.

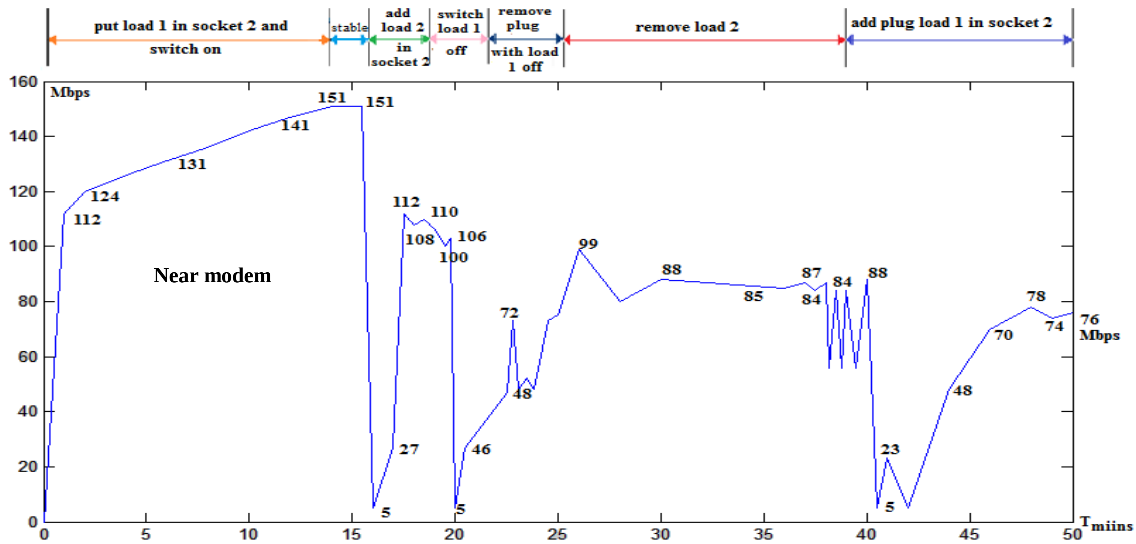

Figure. 10 shows the relationship between the data transfer rate and switched in load.

While in the far modem (F.M) the data transfer rate appeared clearly at same time and conditions of test in (N.M) but reached 116 Mbps at start operation with the load 1 and then began to increase semi-linearly until it reached 156 Mbps and settled at 156 Mbps. Then the change began when added or removed the load 2 as in (N.M), where the data transfer rate decreased from 156 to 114 Mbps. After a short period of time, the transfer rate began to increase from (114 to 136) Mbps. The change in data transfer continued with the switch in load at 136 Mbps with semi-stability.

Then the rapid change began when switching loads (1 and 2) as the data transfer rate dropped rapidly and reached from (136 to 5) Mbps almost in the 20th minute . After that, the data transfer rate began to increase from 5 to 76 Mbps at the 23rd minute . The change between (76 to 116) Mbps continued with swing at switch in load until it reached 102 Mbps in the 50th minute , and semi-stable at test end. "Fig. 11" shows the relation between the data transfer rate and switching in load for 50 minutes to (F.M) Which shows the negative impact of switching load on the of data transfer rate and that leads to the decrease efficiency of power line communications systems.

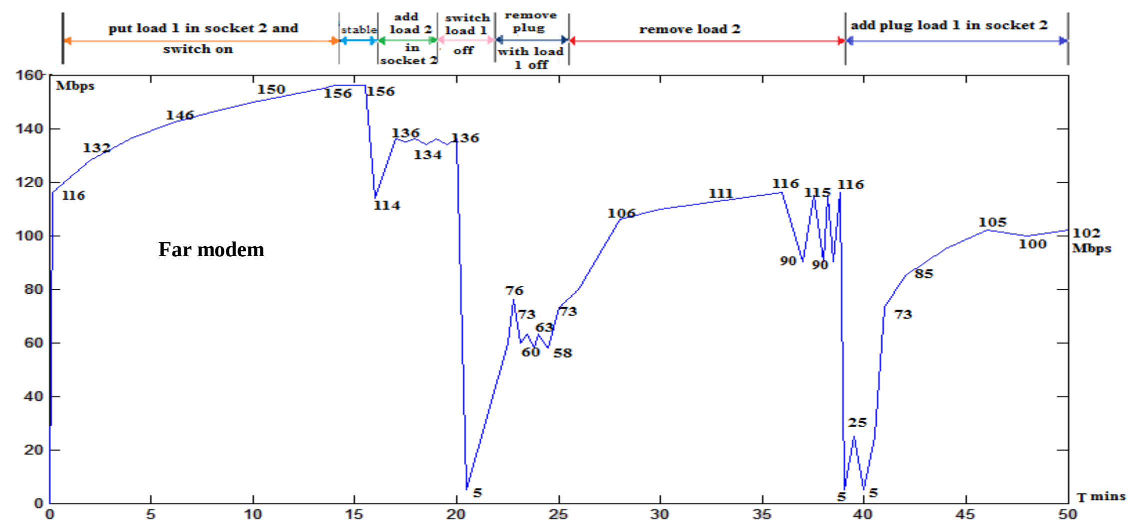

Figure. 11 shows the relationship between the data transfer rate and switched in load.

"Fig. 12" shows the collect of Figs (10) and (11) in one form and the testing process performed on both the modems (N.M) and the (F.M) and the changes in load, and the observation of asymmetry in the modems when transfer data despite their similarity in form and manufacturing as shown in "Fig. 9" which illustrates the image for modems. Where the near modem started at 112 Mbps and ended at 76 Mbps, while the far modem began with 116 Mbps and ended with 102 Mbps and semi-stable also.

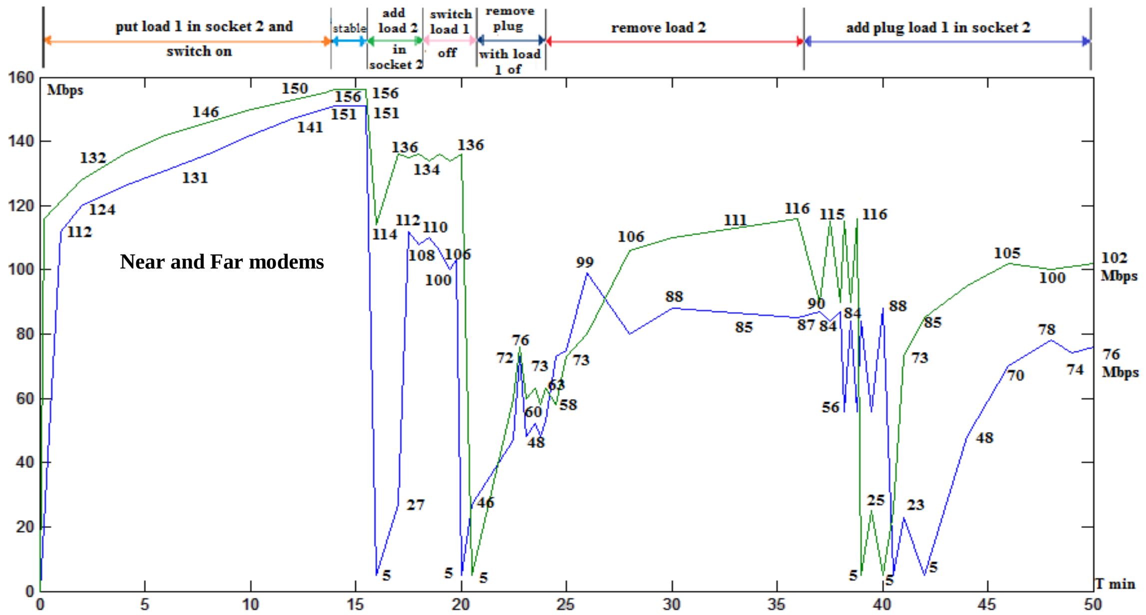

Figure. 12 shows the collect of Figs (12) and (13)

Table 3. Shows the data transfer rate for a network of 3 computers with two types of un rolled wires with 3 PLC communication modems connected as a computer network.

Length of wire and its type	Diameter of Wire	Mini transfer rate at start of test (Mbps)	Max transfer rate at end of test (Mbps)
100 m good type	1 m.m	156	196
100 m bad type	1 m.m	150	192
200 m good type	1 m.m	88	137
200 m bad type	1 m.m	76	133

The practical results obtained as shown in "Table 3" show that there is a difference in the data transfer rate with the presence of load. When using a good-manufactured wire the data transfer was higher than use of a bad-manufacturing wire. That mean increase in efficiency when use good wire.

By comparing "Tables 2,3" when length of wire between the two modems a 100 m , data transfer rate in peer-to-peer applications was higher than that of a computer network application, reaching 198 Mbps in peer-to-peer as shown in "Table 2", while in network reached up to 196 Mbps for a good wire, and reached to 192 Mbps for a bad wire as shown in "Table 3".

While using a 200 meter wire between modems, data transfer rate was higher in peer-to-peer applications also, reaching 156 Mbps as shown in "Table 2". With regard to "Table 3", when using a network of computers, the highest transfer rate at distance 200 m between two modems is 137 Mbps for good wire and up to 133 Mbps for bad wire.

"Fig. 13" and "Fig. 15" illustrate data transfer rate in PLC. Where "Fig. 13" shows peer-to-peer communication where up to 171 Mbps, while "Fig. 15" shows a network of computers with a transfer rate up to 133 Mbps in modem 2 and 141 Mbps in modem 3. This indicates that increasing the number of modems reduces data transfer rate, at modems are designed to transfer up to 200 Mbps. "Fig. 14". image illustrates method connect 3 computers with 3 modems used in PLC.

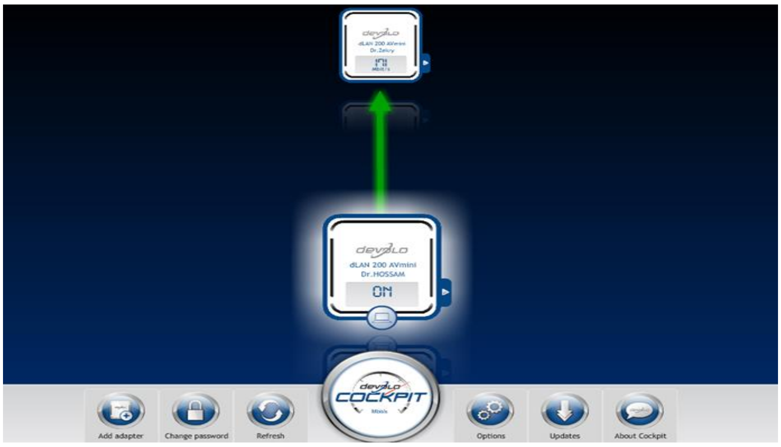

Figure 13. Data transfer when bottom modem is sender and top modem is receiver

Figure 14. Connect 3 computers with 3 modems used in PLC

Figure 15. Data transfer when bottom modem is sender and top modems are receivers

7. Conclusions

This paper discussed the most important factors affecting the efficiency of communication systems via power lines, they are distance and switch in load, type of wiring and the number of modems used.

Two modems used in the first test and three modems were used in the second test. Through practical testing of these devices by connecting them to the power line through a network of computers. The results showed that the data transfer rate decreased with increasing distance due to increased attenuation, and that the relationship between them was inverse, and when compared with previous published research, it was identical with that of researches. And that the impact of switching load within the network on data transfer rate is negative impact and lead to un-stable of the system.

These technique can be used to transfer and exchange information between two or more sides. PLC has proved highly efficient although the large challenges experienced by power lines, can be application this technique instead of normal LANs or complementary for existing networks, after further practical testing to verify other factors affecting the data transfer rate and the efficiency of the communication system such as number of nodes in the network, the number of branches in one node and noise.

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