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Research Article

The Use of Data Transmission Technique Via Power Line Communication

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Abstract—**The smart grid requires the use of communication methods. One of these communication methods is power line communication (PLC). In this study, TMDSPLCKITV4 evaluation boards are programmed with the G3-PLC standard and operated as transmitter and receiver in low voltage distribution grid. Then, the distances between the transceiver points, the load characteristics were changed and the received signal strength indication, signal noise ratio, bit error rate and package error rate values for each modulation type of the G3-PLC standard were measured in real time. According to these measured values, the success of the PLC has been demonstrated. In general, it is observed that the number of erroneous data bits increases in each modulation type under pulsed variable load. Robust mod and binary phase shift keying modulation types appear to be the most successful modulation types with the least number of erroneous data bits when all experimental conditions are considered.**

Index Terms—**Smart grid, power line communication, modulation, TMDSPLCKITV4, G3-PLC**

I. Introduction

THERE IS an estimation that worldwide electrical energy consumption will increase by 60% in 2030 to approximately 37000 TWh [1]. The need to meet the energy demand increase should be managed in an environmentally friendly manner when the concepts of carbon emissions and fossil fuel use are considered. Naturally, this situation will significantly increase the dependence on renewable energy sources. But the problem is that today's electricity grids are not designed to meet the growing energy demand or to support electricity generation from renewable energy sources. For this reason, the need for updating the existing electricity grid arises. Updating the existing grid reveals the concept of a "Smart Grid". The smart grid introduces new load groups to the system, such as grid-integrated electric vehicles. This technology holds promise for both the smart grid and reducing the environmental impact of vehicles [2]. In addition, it is also possible to see different power electronics switching elements and converters in smart grids. DC-AC Inverters that can be managed with different control techniques are examples of this situation [3].

The smart grid generally consists of a communication technology that will provide data communication between two points in electricity generation, transmission and distribution systems. With this structure, the smart grid provides a two-way energy flow and communication signal transmission in power systems, thus revealing a large-scale control and communication infrastructure [4]. The use of communication technologies in applications such as smart grids and the Internet of Things has led to the development of next-generation technologies such as 6G [5, 6]. However, it is more important to effectively utilize the communication technologies that are already accepted. Currently, communication technologies for the smart network are divided into two main groups as wired and wireless communication methods [7]. All communication methods inherently have some advantages and disadvantages, but communication methods used for smart grids are expected to have essential features such as high data transmission rate, low signal degradation, high flexibility and coverage, sustainability, low cost, strong encryption, compatibility with hybrid communication operations [8]. PLC provides communication using existing power grid lines. Therefore, it provides technical, economic benefits and wide usage area.

Considering all these situations, PLC has been an active research area for smart grid implementations that has been effectiveness for years [9]. PLC stands out for smart grid implementations with its benefits such as wide coverage, flexible and long-distance communication, low cost, ease of installation, stable operation in fixed grid conditions [10]. On the other hand, the PLC signal can be negatively impacted by electromagnetic interference resulting from high frequency switching in the distribution grid. Additionally, changes in impedance within the communication channel used for data transmission can lead to attenuation of the PLC signal. PLC can be used at the medium voltage level of the electrical grid for operations such as fault monitoring, breaker status monitoring, transformer parameters acquisition and distributed generation monitoring [11]. Besides this, PLC can be used for remote detection of broken insulators, fuse locations, cable breakage and deflection tracking at high voltage levels [12]. PLC is suitable as communication technology in SCADA systems, which are known as remote monitoring and management systems. In addition, it is possible to monitor the real-time

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remote monitoring of the Sag event, known as the sudden voltage drop in the grid by examining the status of the PLC signal [13]. Smart grid operations, where the PLC communication method is used most widely and extensively, are located in the LV electricity distribution grid. The most preferred operation of the PLC method is AMR which the reading results of smart meters is obtained remotely [14].

In this paper, TI TMDSPLCKITV4 evaluation boards are programmed in Narrowband (NB) G3 -PLC standard and perform real time in LV distribution grid. Then, parameters such as distance, load, modulation type were changed in the laboratory and data transmission between two points was carried out with PLC technology under different conditions. It is seen that most of the studies in the PLC literature are simulations but this study produces real time real data for thanks to TMDSPLCKITV4. This study produces a pre-field output about the PLC usage suitability of the grid where PLC will be used by running evaluation cards in the LV grid in the laboratory. Another contribution is the most suitable PLC modulation type can be detected easily according to grid conditions like load and distance. In addition, evaluation cards software provides the opportunity to change the data package size used in the transceiver communication, the data package sending frequency and the total number of the data package to be sent, making a very important contribution to determining the data characteristics to be included in the communication before the field implementation and provides experiments in the laboratory.

II. The Theory Of Power Line Communication

PLC technology is defined as the realization of data communication between sending and receiving ends by a signal containing information while carrying out generation, transmission and distribution operations in the grid by using the existing electrical grid. The advantages of using PLC are listed as minimizing the need for a new installation, no coverage area problem and no need for antenna use. On the other hand, the disadvantages of using PLC can be listed as the fact that the power lines are not designed for communication purposes, the communication channel conditions are constantly changing, the number of switching in the grid is excessive, the signals carrying data are corrupted by exposure to interference.

For the use of the PLC method, three basic parameters must be considered; the impedance value of the PLC channel, the noise that the PLC channel will be exposed to in the grid and the signal attenuation that may occur during data transfer between sending and receiving ends. If the impedance value of the Tx / Rx circuit is the same as the channel impedance on which the data communication is provided, the parameters of the signal that will carry the data sending and receiving ends two points will be transmitted to the line in an optimum way. Noises in the power grid directly affect the frequency and amplitude values of the carrier signals that provide data communication between sending and receiving ends with the disruptive effect is created by them. Signal attenuation depends on the length of the power line where point to point data communication is provided and the number of cable splices on this line. Higher signal attenuations are observed in industrial areas than in rural and urban areas for PLC technology [15]. Impedance, noise and signal attenuation parameters are evaluated by measuring BER, PER, SNR and RSSI values for PLC technology. NB-PLC is one of the structures of PLC with its standards and modulation types [16]. NB-PLC is the most prominent structure of PLC communication types. G3-PLC and PRIME standards of NB-PLC technology are extensively studied and widely used standards. NB-PLC is known as a type of PLC used to get smart meter data remotely in the power grid. The organization named CENELEC in Europe has determined the frequency bands for NB-PLC level use [17]. The CENELEC standard uses the frequency range 3 kHz – 148.5 kHz. CENELEC has divided the operating frequency range into four sub-frequency bands to ensure efficient and trouble-free operation, considering the diversity of operations. One of these sub-bands is CENELEC A band that uses the 9 kHz – 95 kHz frequency range, is reserved only for distribution and generation service providers and is available for smart grid implementation, primarily AMR [18].

The data-carrying signal must be made suitable for the PLC channel where communication will be occurred to use PLC technology. In this way, the characteristic of one of the phase, amplitude or frequency parameters of the data-carrying signal must be transformed according to the regulatory signal, in other words, it must be modulated. Modulation types are basically phase shift keying (PSK), amplitude shift keying and frequency shift keying. The case of using more than one carrier for signal transmission in the PLC channel is expressed as multi-carrier modulation. The most well-known structure of multi-carrier modulation is the orthogonal frequency division multiplexing (OFDM) technique [19]. In the OFDM technique, the PLC channel increases efficiency by saving bandwidth when the subcarriers are positioned orthogonally for data transmission in the segmented frequency range [20]. In addition, OFDM is robust against interference in the NB-PLC channel. It shows low sensitivity to time matching errors. It is suitable for Fourier transform operations and is robust against fading caused by multipath propagation. On the other hand, OFDM is sensitive to frequency synchronization problems and phase noise. OFDM is known as the most widely used technique in NB-PLC types smart grid AMR implementations with this mentioned working structure, especially with PSK methods [21]. OFDM based PSK modulations are used as binary phase shift keying (BPSK), quartet phase shift keying (QPSK), octal phase shift keying (8PSK) according to the phase angles and bit values they use. It is possible to have an idea about the success of data communication with OFDM-based PSK modulations in NB-PLC level by performing BER analysis [22].

G3-PLC, PRIME and IEEE1901.2 structures are very common among NB-PLC communication technology standards. The frequency range of 35.938 kHz – 90.625 kHz in the CENELEC-A sub-band is used by OFDM-based G3-PLC. Besides the G3-PLC, another globally accepted standard is the PRIME standard. The PRIME contains 97 subcarriers while the G3-PLC contains 36 subcarriers [23]. Although PRIME maximum data rate can reach 128.6 kbps and its uncomplicated structure, it has been proven that the G3-PLC is more robust and powerful than the PRIME [24]. The G3-PLC standard consists of physical layer, data link layer, network layer and transport layer. In the physical layer (PHY), the OFDM technique process steps of the G3-PLC standard are included together with the process steps specific to G3-PLC. For this reason, PHY is the most important layer where the G3-PLC standard is defined and its execution structure is located. The media access control (MAC) sublayer, located as a lower layer in the data link layer, allows the transmission of MAC packets using the PLC channel through which communication is made [25, 26]. It provides verification control by notifying the upper layers that the transmission is positive or negative and enables the establishment of the network structure between communicating points by associating nodes.

III. Material, Method and Experimental Findings

All experiments were done in a laboratory environment as real time by TI TMDSPLCKITV4 evaluation boards which have been programmed with the OFDM based G3-PLC standard in the NB-PLC communication type CENELEC A band. Two evaluation board products, one for the Tx side and one for the Rx side, were used to evaluate the operating situations of PLC technology under different conditions in LV distribution grid.

G3-PLC standard was uploaded to the evaluation boards via “Code Skin” program. These boards work like gateways for transmitting and receiving data at Tx and Rx points on the PLC channel. In this way, by changing the load and distance conditions between Tx and Rx points, RSSI, SNR, BER, and PER values for each modulation type of the G3-PLC standard, including ROBO, BPSK, QPSK, 8PSK, were captured thanks to evaluation boards software and all experimental findings were obtained. “Intermediate Mode (IM)” of TMDSPLCKITV4 board was used for all experiments. IM program can show the RSSI, SNR, BER, PER values which are the communication quality basic parameters in the PLC channel, in real time and graphically according to the modulation type.

The setups in which all the experiments were executed in the laboratory environment are shown in Fig.1. In these images, evaluation boards positioned as Tx and Rx points which are responsible for performing data transmission are seen. Also power line connection scheme of TMDSPLCKITV4 can be seen.

All experiments were performed with the IM program. The regulated data unit parameters are aligned as follows; the data packet sending time interval is 1000 (the selected time parameter is multiplied by the value of 10 µs by the program, in this case, there is a time difference of 0.01 s between each data packet), the total number of data packets to be sent for each test is 1000 and the size of a data packet is 100 bytes. All graphs were obtained with updated data at 3-second intervals throughout the test period on the Rx side. In addition, the same cable cross-section was used in all experiments.

Experiment-1 was performed to measure the effect of signal attenuation in BPSK modulation type without load at 5m and 25m distances. The results of 5m distance no load condition is shown as Fig.2. It is seen that in Fig.3., the RSSI value indicating the received signal power is 116 dBµV with a distance of 5m between Tx and Rx in the no load condition in BPSK modulation type. Also, there is no bit error value. On the other hand, in Fig.3., the results are obtained when the distance is increased to 25m in the same modulation type and no-load condition. It is seen that in Fig.3. the RSSI value is measured as 113 dBµV at a distance of 25 m under the same test conditions. When compared with the experiment performed at 5m distance in Fig.2. there is a signal attenuation of 3 dBµV due to the increase in distance, but this signal attenuation did not cause any error bit.

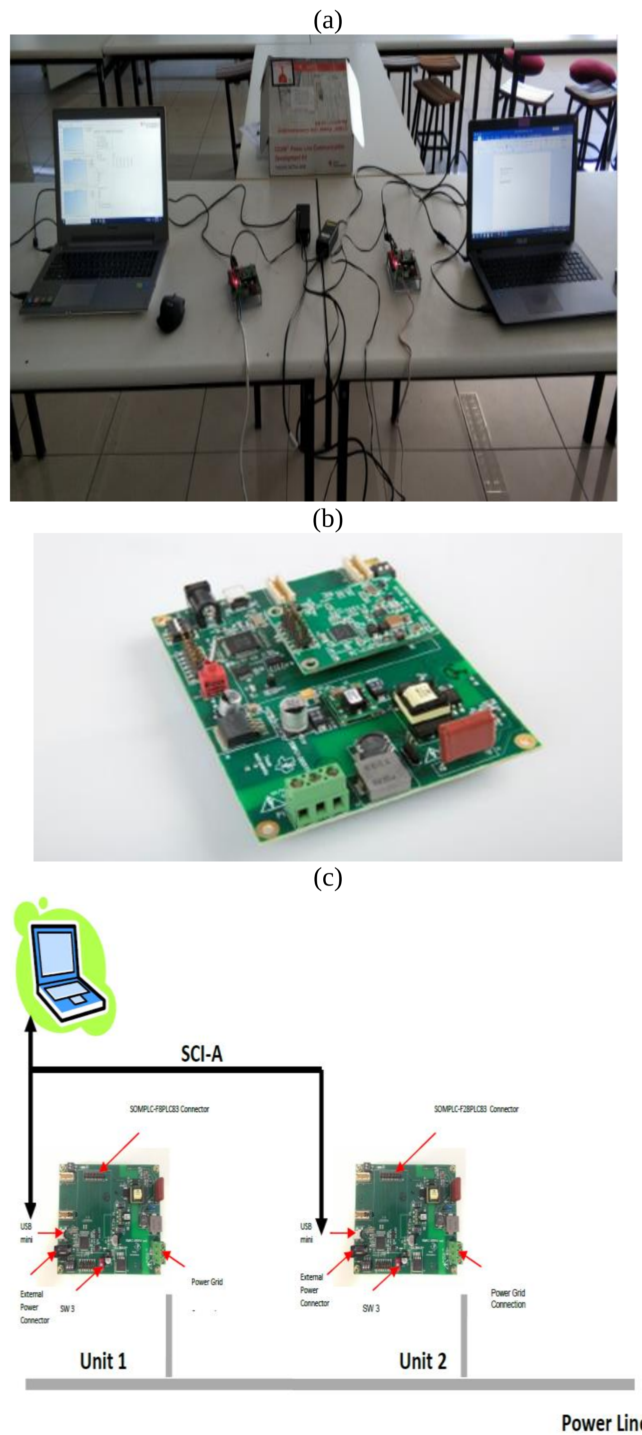

Fig.1. (a) Tx and Rx points in the experimental setup (b) TMDSPLCKITV4 (c) TMDSPLCKITV4 power line connection

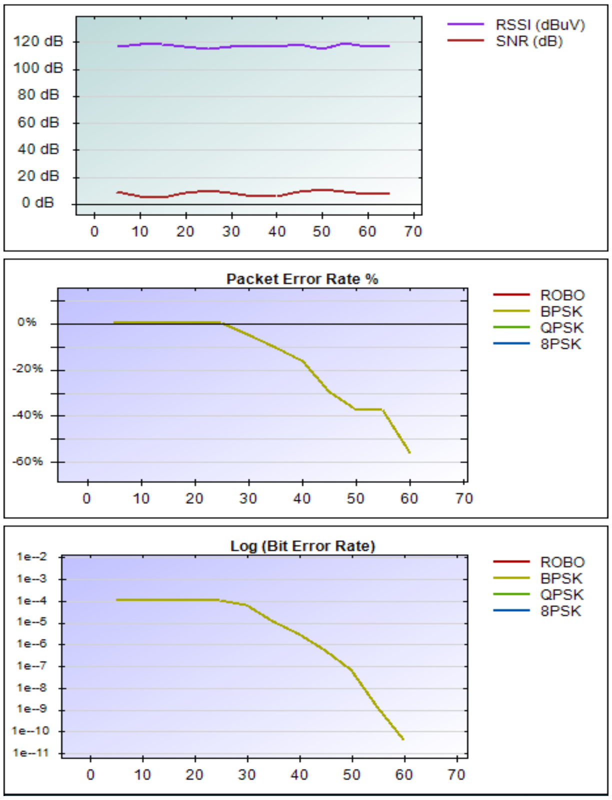

Fig.2. Experiment-1 no load, BPSK, 5m

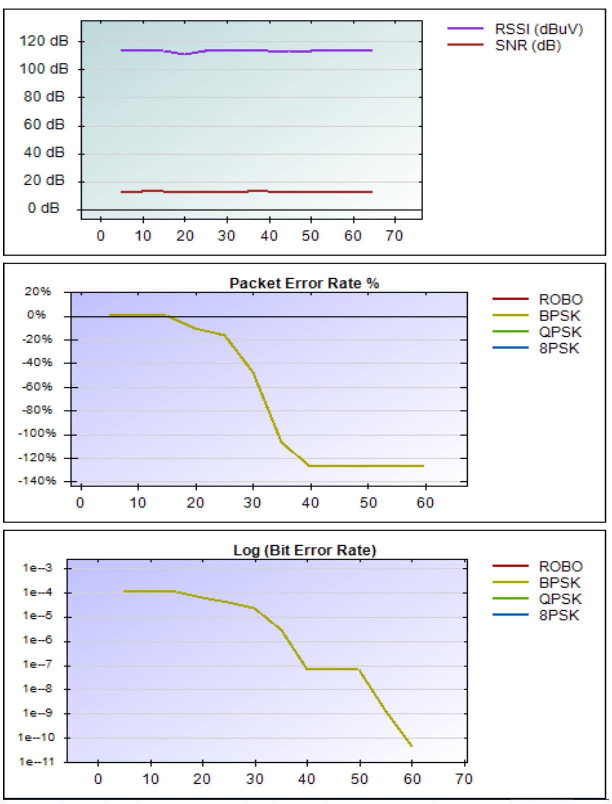

Fig.3. Experiment-1 no load, BPSK, 25m

25m distance between Tx-Rx and 3300W constant ohmic load conditions were used for Experiment-2. PLC tests were performed separately in the modulation types ROBO, BPSK, QPSK, 8PSK, respectively. The results of Experiment-2 are shown in Fig. 4., 5., 6., 7. and Table 1.

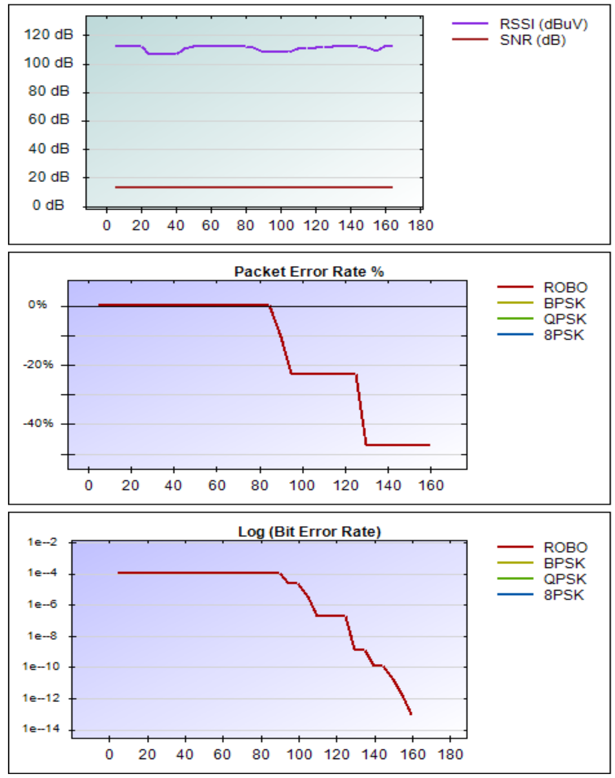

Fig.4. Experiment-2 3300W constant ohmic load, ROBO, 25m

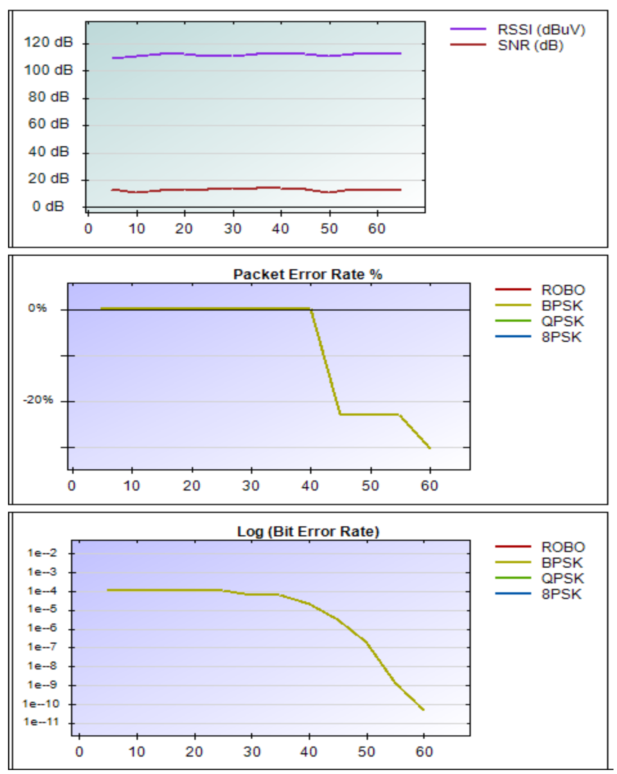

Fig.5. Experiment-2 3300W constant ohmic load, BPSK, 25m

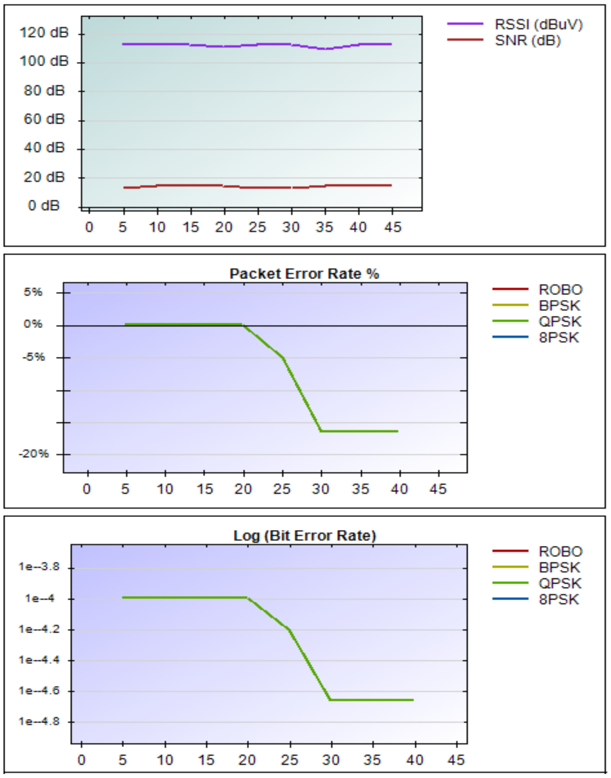

Fig.6. Experiment-2 3300W constant ohmic load, QPSK, 25m

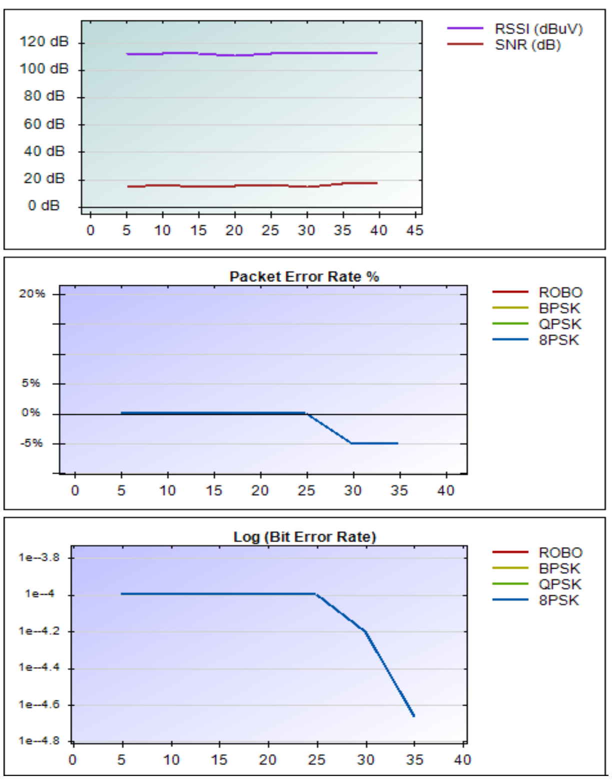

Fig.7. Experiment-2 3300W constant ohmic load, 8PSK, 25m

Experiment-3 was performed using a total load of 3300W including 1800W constant ohmic load and additional 1500W Pulsed Variable Load (PVL) at 5m distance between Tx-Rx. Pvl is a type of load with frequent changes in impedance and current values due to its characteristic feature. Since PVL directly affects the communication channel parameters with this structure, it determines the realization of data transmission with PLC. All tests were conducted with modulation types ROBO, BPSK, QPSK, 8PSK, respectively for Experiment-3. All results for Experiment-3 are shown in Figures 8, 9, 10, 11 and Table-2.

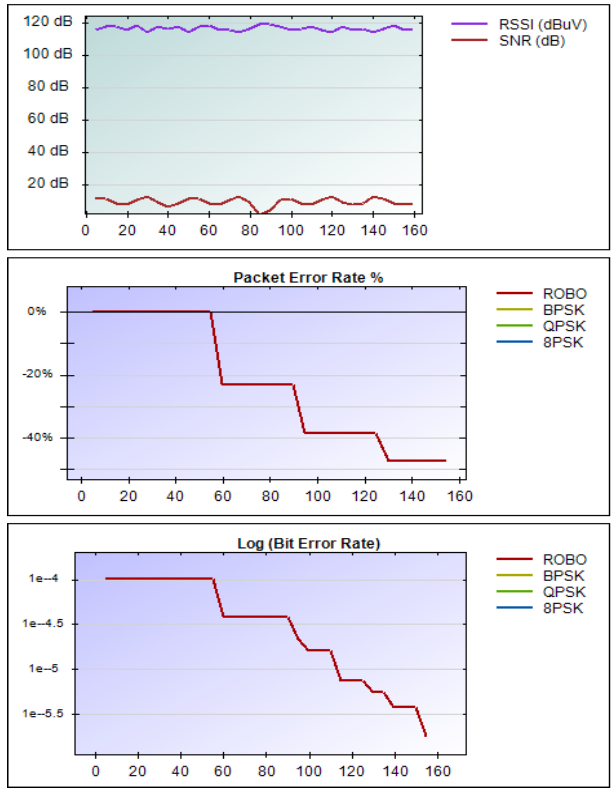

Fig.8. Experiment-3 1800W constant ohmic load, and 1500W PVL, ROBO, 5m

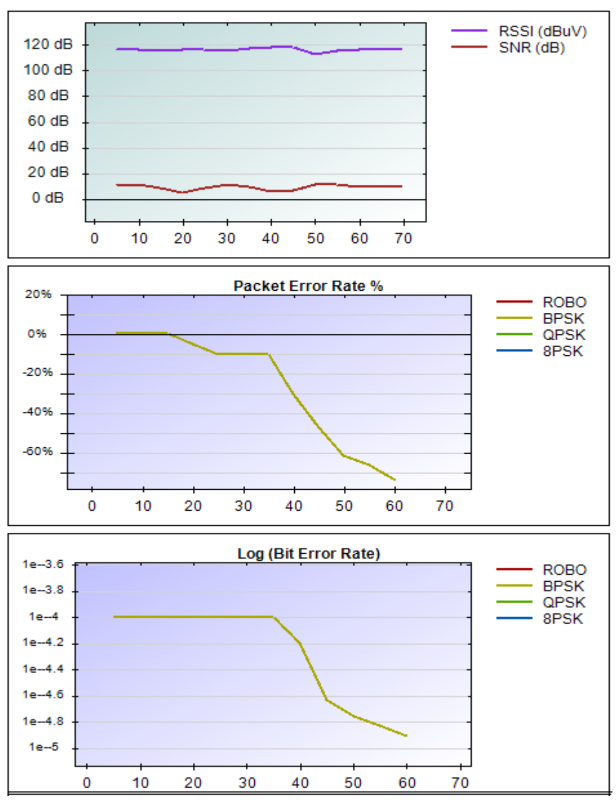

Fig.9. Experiment-3, 1800W constant ohmic load, 1500W PVL, BPSK, 5m

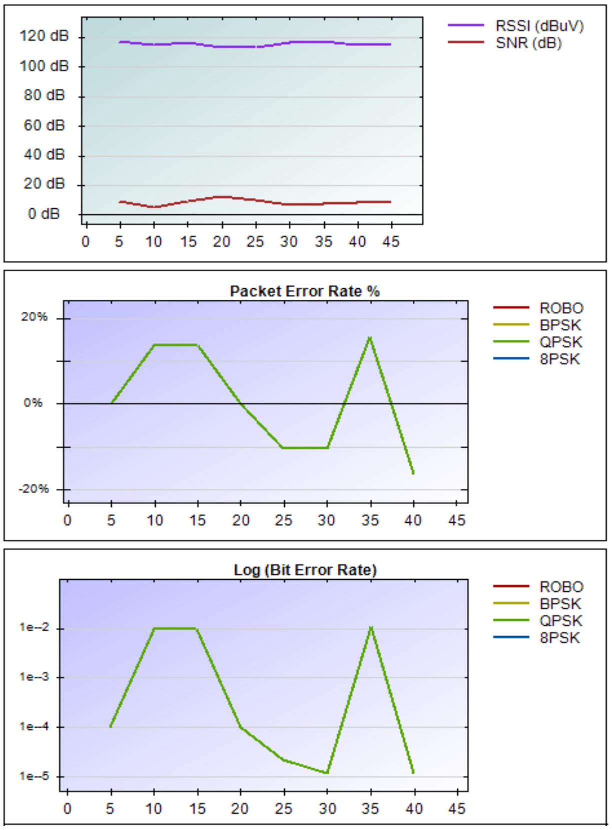

Fig.10. Experiment-3 1800W constant ohmic load, 1500W PVL, QPSK, 5m

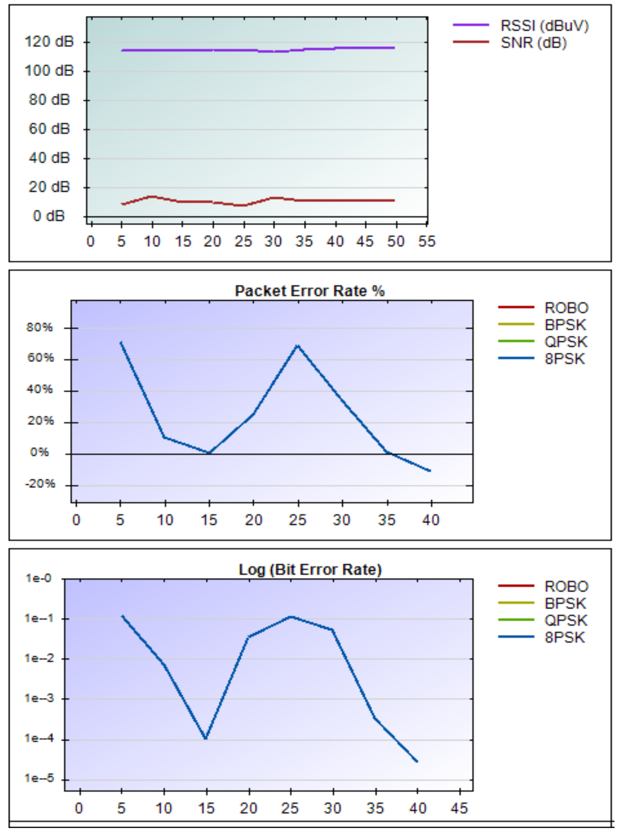

Fig. 11. Experiment-3 1800W constant ohmic load, 1500W PVL, 8PSK, 5m

TABLE I
RESULTS OF EXPERIMENT-2

Modulation Type	Distance	Load	BER	SNR(dB)
ROBO	25m	3300 Watt	1e-13	13
BPSK	25m	3300 Watt	1e-10	12
QPSK	25m	3300 Watt	1e-4.6	14
8PSK	25m	3300 Watt	1e-4.7	17

TABLE II
RESULTS OF EXPERIMENT-3

Modulation Type	Distance	Load	BER	SNR(dB)
ROBO	5m	1800 Watt+1500 Watt (PVL)	1e-5.7	7
BPSK	5m	1800 Watt+1500 Watt (PVL)	1e-4.9	9
QPSK	5m	1800 Watt+1500 Watt (PVL)	1e-2	8
8PSK	5m	1800 Watt+1500 Watt (PVL)	1e-1	11

IV. CONCLUSION

PLC signal attenuation was investigated with Experiment-1. The 3dBμV attenuation in the RSSI value because of the distance increase did not cause any bit errors. So the variation of the distance between Tx and Rx points does not significantly affect the signal attenuation. Experiment-2 was conducted with only constant load and it shows that all modulation types of G3-PLC are suitable for smart grid communication in stable grid conditions such as residential or rural AMR operations.

According to the results of Experiment-3 which has a 1500W pulsed variable load, SNR values decreased for all modulation types. Depending on this, the highest data bit errors and BER values were seen in PVL tests with low SNR values. Bad SNR values and high BER, PER values caused data bit errors and data packet errors, especially in the QPSK and 8PSK modulations. In PVL tests, although SNR values decreased in ROBO and BPSK modulations and BER values increased significantly compared to the results in only constant load conditions, no data bit error and data packet errors were not seen. Thus, it has been revealed that only ROBO and BPSK modulation types should be used for smart grid communication in unstable grid conditions.

Especially, Experiment-3 shows that sudden load changes in the grid, namely impedance changes, impose restrictions on the use of PLC and error bits that occur during data communication reduce PLC success. When we compare this situation with the signal attenuation problem in Experiment-1, it is possible to say that sudden impedance changes are a bigger problem for PLC than signal attenuation. As seen in the results mentioned above, the most resistant modulation type against impedance changes due to sudden load changes is ROBO. In addition, it should be noted that when using 8PSK and QPSK, there should be no sudden changes in the grid load status, otherwise bit errors may occur during data communication.

With this study, the modulation type that should be used according to the grid conditions is determined in the laboratory before the field installation. In addition, the data size of the smart grid implementation, data transmission frequency and the number of data packets are set and tested, allowing data communication regulation before field installation (For example, customizing AMR meter, load profile, short read out and long read data packets). Beside this as explained in section 3, the receiver and transmitter exchanged data packets with high data size and frequency at short intervals. Stress test conditions were created to clearly demonstrate the success status of the PLC, and the load effects were measured in real-time.

The smart grid and the internet of things are developing day by day and this development will accelerate in the near future. This means that the need for data communication between sending and receiving points will increase rapidly and new frequency bands will be required to meet this need. In this way, all existing communication methods that can be used in smart grid operations should be utilized with the highest efficiency. This study showed that PLC is a suitable and proven communication method so it should be more widespread.

REFERENCES

[1] Shlebik T., Fadel A., Mhereeg M., Shlebik M. 2017. The development of a simulation-based smart grid communication management system using MATLAB. International Conference on Green Energy Conversion Systems (GECS), Tunisia.

[2] Erdogan B., Tan A., Savrun M. M., Cuma M.U., Tumay M. 2023. Design and analysis of a high-efficiency resonant converter for EV battery charger. Balkan Journal of Electrical and Computer Engineering 12(1):198-205.

[3] Deniz E. 2021. Medium and large vector-based SVPWM technique for five-phase two-level inverter. European Journal of Technique 11(2):209-216.

[4] Kabalci Y. 2016. A survey on smart metering and smart grid communication. Renewable and Sustainable Energy Reviews: 302-318.

[5] Hamamreh J.M., Iqbal S. 2023. Precoded universal MIMO superposition transmission for achieving optimal coverage and high throughput in 6G and beyond networks. Balkan Journal of Electrical and Computer Engineering 11(1):25-34

[6] Mageed I.A. 2023. Cosistency axioms of choices for Ismael's entropy formalism (IEF) combined with information theoretic (IT) applications to advance 6G networks. European Journal of Technique 13(2):207-213

[7] Zhou X., Ma Y., Gao Z., Wang H. 2017. Summary of smart metering and smart grid communication. IEEE International Conference on Mechatronics and Automation (ICMA), 300-304. Japan.

[8] Yaqoob I., Hashem I.A.T., Mehmood Y., Gani A., Mokhtar S., Guizani S. 2017. Enabling communication technologies for smart cities. IEEE Communications Magazine 55(1):112-120.

[9] Lopez G., Matanza J., De La Vega D., Castro M., Arrinda A., Moreno J.I., Sendin A. 2019. The role of power line communications in the smart grid revisited: applications, challenges and research initiatives. IEEE Access 7: 117346-117368.

[10] Yigit M., Gungor V.C., Tuna G., Rangoussi M., Fadel E. 2014. Power line communication technologies for smart grid applications: A review of advances and challenges. Computer Networks 70: 366-383.

[11] Galli S., Scaglione A., Wang Z. 2011. For the grid and through the grid. The role of power line communications in the smart grid. Proceedings of the IEEE 99(6):998-1027.

[12] J.F., Silveira P.M., Martinez M.L.B., Perez R.C., Dallbello A.C. 2009. New approach to improve high-voltage transmission line reliability. IEEE Transactions on Power Delivery 24 (3): 1515-1520.

[13] Villiers W., Cloete J.H., Wedepohl L.M., Burger A. 2007. Real-time Sag monitoring system for high-voltage overhead transmission lines based on power-line carrier signal behavior. IEEE Transactions on Power Delivery 23(1):389-395.

[14] Usman A., Shami S.J. 2013. Evolution of communication technologies for smart grid applications. Renewable and Sustainable Energy Reviews 19:191-199.

[15] Cavdar I.H. and Karadeniz E. 2008. Measurements of impedance and attenuation at CENELEC bands for power line communications systems. Sensors 8(12):8027-8036

[16] Sharma K., Saini L.M. 2017. Power-line communications for smart grid: Progress, challenges, opportunities and status. Renewable and Sustainable Energy Reviews 67:704-751

[17] Berger L.T., Schwager A., Garzas J.J.E. 2013. Power line communications for smart grid applications. Journal of Electrical and Computer Engineering:1-16

[18] Masood B. and Baig S. 2016. Standardization and deployment scenario of next generation NB-PLC technologies. Renewable and Sustainable Energy Reviews 65:1033-1047.

[19] Gotz M., Rapp M., Dostert K. 2004. Power line channel characteristics and their effect on communication system design. IEEE Communications Magazine 42(4): 78-86.

[20] Omri A., Fernandez J. H., Pietro R. 2023. Subcarrier index modulation for OFDM based PLC systems. IEEE Symposium on Computers and Communications (ISCC). Tunisia, 649-655.

[21] Ndjiongue A.R., Ferreira H.C. 2019. Power line communications (PLC) technology: More than 20 years of intense research. Transactions on Emerging Telecommunications Technologies 30 (7): 1-20.

[22] Moaveninejad S., Kumar A., Scazzoli D., Piti A., Magarini M., Bregni S., Verticale G. 2017. BER evaluation of post-meter PLC services in CENELEC-C band. IEEE 9th Latin-American Conference on Communications (LATINCOM). Guatemala, 1-6.

[23] Sadowski Z. 2015. Comparison of PLC-PRIME and PLC-G3 protocols. International School on Nonsinusoidal Currents and Compensation (ISNCC). Poland, 1-6.

[24] Hoch M. 2011. Comparison of PLC G3 and PRIME. 2011 IEEE International Symposium on Power Line Communications and Its Applications. Italy, 165-169.

[25] Ngcobo T. and Ghayoor F. 2019. Study the topology effect on a G3-PLC based AMI network. Southern African Universities Power Engineering Conference/Robotics and Mechatronics/Pattern Recognition Association of South Africa (SAUPEC/RobMech/PRASA). South Africa, 629-633.

[26] Razazian K. and Bali M. C. 2023. Evaluating various machine learning techniques in selecting different modulations in G3-PLC protocol. IEEE International Symposium on Power Line Communications and its Applications (ISPLC). United Kingdom, 55-60.

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