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Efficient Data Transmission Using Power Line Communication (PLC)

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***Abstract* - Power Line Communication (PLC) has emerged as a cost-effective and reliable technology for data transmission by utilizing existing electrical wiring infrastructure. This eliminates the need for additional cabling, thereby reducing deployment costs and complexity. The present work focuses on efficient data transmission over power lines, addressing the challenges of channel noise, attenuation, and interference. Modulation techniques such as Orthogonal Frequency Division Multiplexing (OFDM) and Binary Phase Shift Keying (BPSK) are explored to enhance robustness and spectral efficiency. Applications of PLC in smart grids, home automation, industrial systems, and transportation demonstrate its versatility and growing importance in modern communication networks. The proposed study highlights the advantages of PLC, along with design considerations for achieving higher reliability, scalability, and energy efficiency in real-world implementations.**

Keywords: Power Line Communication, PLC, PLCC, Power Line Carrier Communication, OFDM, BPSK, FSK, ASK, NB-PLC, BB-PLC, Modulation, De-modulation.

I. INTRODUCTION

Power Line Communication (PLC) is a technology that enables data transmission over existing electrical power lines. Traditionally, power lines are used only for delivering electrical energy at low frequencies (50 Hz in India and 60 Hz in some other countries). However, PLC makes it possible to superimpose high-frequency communication signals on the same power lines without disturbing the normal power supply.

In a PLC system, the electrical power signal and the communication signal coexist on the same conductor but operate at different frequency ranges. While the power signal operates at 50 Hz, the communication signal typically operates in a much higher frequency band, such as 3 kHz to 500 kHz in narrowband PLC systems. This separation in frequency allows both signals to travel simultaneously without significant interference. Coupling circuits and filtering techniques are used to inject and extract the communication signal while blocking the low-frequency power component.

PLC systems are broadly classified into three categories based on operating frequency and data rate:

1. Ultra Narrowband PLC (UNB-PLC): Operates below 3 kHz and supports very low data rates, mainly used for long-distance control applications.
2. Narrowband PLC (NB-PLC): Operates between 3 kHz and 500 kHz and is widely used for smart metering, smart grid communication, street lighting control, and automation systems.
3. Broadband PLC (BB-PLC): Operates above 1.8 MHz and provides higher data rates suitable for internet and home networking applications.

One of the major advantages of PLC is that it uses the existing electrical infrastructure, eliminating the need for additional communication cables. This significantly reduces installation cost and complexity. PLC is especially useful in smart grid applications, where communication between utility providers and consumers is required for monitoring energy consumption, load control, and fault detection.

However, PLC systems face several challenges. Power lines were not originally designed for communication purposes, so they introduce noise, attenuation, impedance mismatch, and signal distortion. Electrical appliances such as motors, switching power supplies, industrial equipment, and heavy loads generate impulsive and broadband noise, which affects signal quality. Therefore, modulation techniques such as BPSK, OFDM, and error correction mechanisms are used to ensure reliable communication.

II. LITERATURE SURVEY

1) Modeling and Analysis of Noise Effects on Broadband Power-Line Communications (2005)

The paper Modeling and Analysis of Noise Effects on Broadband Power-Line Communications (2005) explains about different types of noise present in broadband PLC systems. The noise is mainly classified into impulsive noise, background noise, and narrowband noise, and each type has different statistical characteristics. The study highlights that proper noise modeling is very important to predict channel performance and to improve communication reliability. It also discusses the use of OFDM (Orthogonal Frequency Division Multiplexing) in PLC systems because OFDM is resistant to multipath fading and frequency-selective noise. The performance analysis of OFDM shows that it helps in achieving reliable and efficient data transmission over power lines.

2) PLC Performance Analysis Assuming BPSK Modulation Over Nakagami-m Additive Noise

The research on PLC Performance Analysis Assuming BPSK Modulation Over Nakagami-m Additive Noise focuses on modeling PLC background noise using the Nakagami-m distribution. This distribution gives a more accurate representation of signal fading and noise variations compared to the normal Gaussian model. The study also presents the design of a Maximum Likelihood (ML) detector for BPSK modulation under Nakagami-m noise conditions. The ML detector helps in selecting the most probable transmitted signal, which reduces error rate and improves detection accuracy in noisy environments.

3) The Role of Power Line Communications in the Smart Grid Revisited: Applications, Challenges

In the paper The Role of Power Line Communications in the Smart Grid Revisited: Applications, Challenges, PLC technologies are mainly classified into Narrowband PLC (NB-PLC) and Broadband PLC (BB-PLC). NB-PLC supports low data rates over long distances and is mainly used for smart metering and control applications. BB-PLC provides high-speed communication but over shorter distances, and it is suitable for internet and multimedia applications. The paper also explains various smart grid applications of PLC such as advanced metering, demand response, fault detection, grid monitoring, and automation. Since PLC uses existing power lines for communication, it becomes a cost-effective and reliable solution for smart grid systems.

III. PROPOSED METHODOLOGY

This section describes the modeling methodology of the Power Line Communication (PLC) system and explains the fundamental principles governing signal transmission over power lines. In the proposed model, a microcontroller such as Arduino based on the ATmega328P is used to generate digital data signals. These digital signals are then fed into a modulation circuit, where modulation techniques such as Amplitude Shift Keying (ASK), Frequency Shift Keying (FSK), or Orthogonal Frequency Division Multiplexing (OFDM) are applied to convert the digital data into a suitable high-frequency carrier signal for transmission.

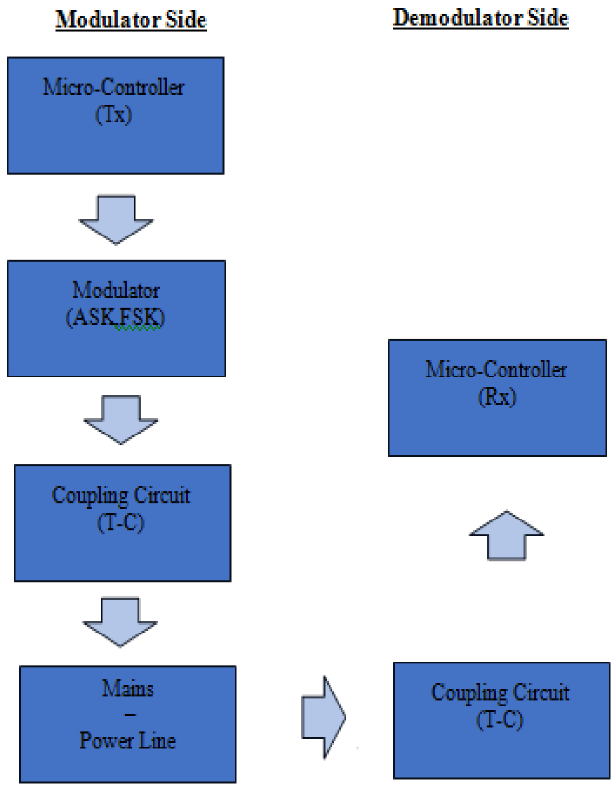

Figure 1: Methodology

The modulated signal is then passed through a coupling circuit consisting of a transformer and capacitor, which ensures safe injection of the communication signal into the AC power line while providing electrical isolation and protection.

At the receiving end, the transmitted signal is extracted from the power line through a similar coupling mechanism and passed through a filter and amplifier stage to eliminate unwanted noise and enhance weak signals. Finally, the processed signal is delivered to the receiver microcontroller, which demodulates and interprets the data, displaying the output on an interface such as an LCD or a personal computer.

IV. BLOCK DIAGRAM

Power Line Communication (PLC) is a technology in which existing electrical power lines are used to transmit data along with electric power. High-frequency communication signals are superimposed on low-frequency (50/60 Hz) power signals.

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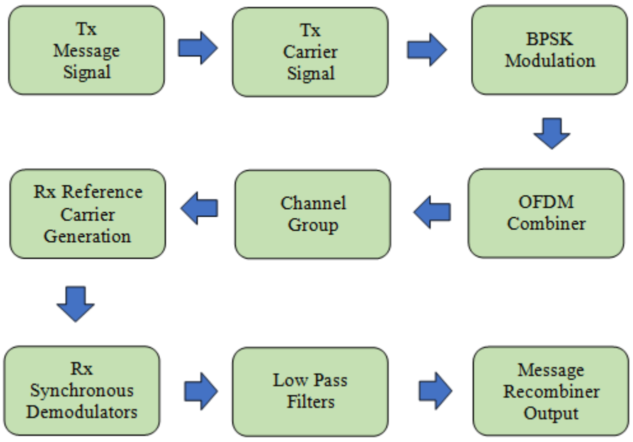


Figure 2: Block Diagram

PLC uses modulation techniques like BPSK, QPSK, or OFDM to transmit data. Coupling circuits are used to inject and extract communication signals without affecting power delivery. It avoids the need for extra communication cables, reducing cost and infrastructure. PLC is commonly used in smart meters, home automation, broadband over power line (BPL), and industrial monitoring.

Tx Message Signal

The Tx Message Signal is the input information signal at the transmitter that contains the data to be communicated. It is also called the baseband signal. It can be digital (binary data, symbols) or analog (voice, sensor output). This signal has low frequency and low power, so it cannot be transmitted directly over long distances. Therefore, the message signal is processed and modulated onto a high-frequency carrier signal at the transmitter. In OFDM/PLC systems, the Tx message signal is first mapped into symbols (BPSK/QPSK/QAM) before transmission.

Tx Carrier Signal

The Tx Carrier Signal is a high-frequency sinusoidal signal generated at the transmitter that is used to carry the message signal over the communication channel. It has much higher frequency than the message signal. The message signal is modulated onto the carrier by changing its amplitude, frequency, or phase. High frequency allows efficient transmission, reduced antenna size, and better propagation. In OFDM systems, multiple orthogonal carrier signals (subcarriers) are generated instead of a single carrier.

BPSK Modulation

BPSK (Binary Phase Shift Keying) is a digital modulation technique in which the phase of the carrier signal is changed according to the binary message data. Binary ‘1’ is represented by 0° phase of the carrier. Binary ‘0’ is represented by 180° phase shift of the carrier. The amplitude and frequency of the carrier remain constant. BPSK is simple, power-efficient, and highly robust against noise.

OFDM Combiner

The OFDM Combiner is the block in which all individually modulated subcarrier signals are added (summed) together to form a single OFDM signal. Each subcarrier carries a part of the data and is orthogonal to the others. The combiner performs parallel-to-serial conversion conceptually by creating one composite waveform. Due to summation of many subcarriers, the OFDM signal shows large amplitude variations (high PAPR). This combined signal is then transmitted over the channel.

Channel Group

Source Impedance: Rsrc = 50 Ω represents the internal resistance of the transmitter and prevents infinite current flow and ensures proper signal matching.

Coupling Capacitor: Ccouple = 100 nF Provides AC-only coupling between transmitter and power line and removes DC components so the transmitter does not disturb the mains, to inject high-freq signals safely.

Line Resistance: Rline = 10 Ω represents the actual wire resistance of the power line and used to simulate signal attenuation and transmission losses along the cable.

Line Inductance: Lline = 1 mH models the inductance of long power cables and helps simulate how inductive reactance causes high-frequency attenuation and phase shift.

Load Resistance: Rload = 1 kΩ is used as load resistance represents the receiver’s input load or appliance load on the power line. The transmitted signal delivers its power here, completing the PLC channel.

Rx Reference Carrier Generation

The Rx reference carrier generation block is responsible for recreating the carrier signal used at the transmitter so that accurate demodulation can be performed at the receiver. In Power Line Communication (PLC) systems, the transmitted signal is generally modulated using techniques such as BPSK, QPSK, or OFDM. When this signal travels through the power line, it becomes superimposed with various types of noise and interference. To successfully extract the original information, the receiver must generate a local carrier signal that is identical and synchronized in frequency and phase with the transmitter’s carrier. This synchronized reference carrier forms the basis for coherent demodulation and ensures reliable data recovery.

Rx Synchronous Demodulator

The Rx synchronous demodulator is the receiver block that extracts the original data from the modulated PLC signal. It operates by using a locally generated carrier that is synchronized in both frequency and phase with the transmitter carrier. This synchronization is typically achieved using a Phase-Locked Loop (PLL), which continuously adjusts the local oscillator to match the received signal. The received modulated signal is multiplied with the synchronized carrier to remove the modulation component and recover the baseband signal. This method enables accurate data extraction even in the presence of noise, attenuation, and distortion commonly found in power-line communication channels.

Low Pass Filters

The Low Pass Filter (LPF) in a PLC receiver allows only low-frequency components of the signal to pass while blocking unwanted high-frequency components. After the demodulation process, the signal still contains high-frequency carrier components and noise. The LPF is used to remove these unwanted frequencies, including residual carrier signals, switching noise, harmonics, and line interference present on power cables. By smoothing the demodulated output, the filter produces a clean baseband signal. This process improves the signal-to-noise ratio (SNR) and ensures that the recovered data is stable, accurate, and free from distortion.

Message Combiner

The Message Combiner is the final processing block in the PLC receiver chain that reconstructs the cleaned baseband data after low-pass filtering. It collects the filtered signal segments and combines them into a continuous and readable digital data stream. The combiner aligns the recovered signal with the correct symbol timing to form an accurate data pattern. It also removes minor distortions that may remain after filtering and reshapes the waveform into a proper digital format. Finally, it prepares the processed data for further stages such as decision logic, decoding, or display in the PLC receiver system.

V. PROPOSED SYSTEM CIRCUIT DESIGN

1. Tx Message Signal

The transmitted (Tx) message signal is generated using four independent voltage sources namely VB1, VB2, VB3, and VB4. These sources represent the baseband digital input signals that carry the information to be transmitted. Each voltage source is configured using pulse waveforms to simulate binary data patterns with amplitude levels of -1 V and +1 V. The pulse specifications include parameters such as rise time, fall time, pulse width, and period to represent different bit sequences. The configured values are PULSE(-1 1 0 1m 1m 10m 20m), PULSE(-1 1 5m 1m 1m 10m 20m), PULSE(-1 1 0 1m 1m 5m 15m), and PULSE(-1 1 0 1m 1m 2m 8m). These different timing configurations ensure that multiple data streams are generated for multicarrier transmission.

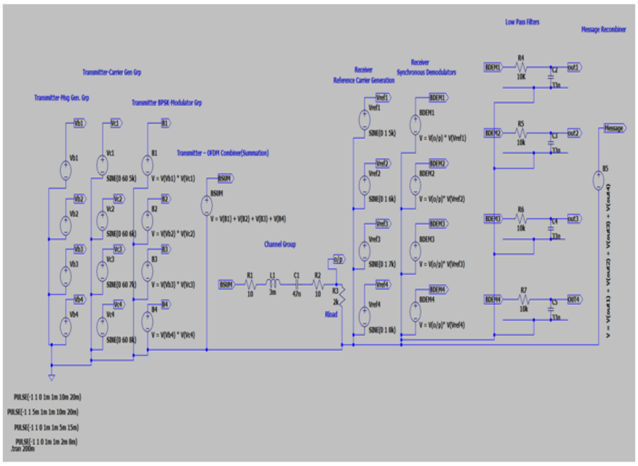


Figure 3: Circuit Diagram

2. Tx Carrier Signal

The carrier signals for transmission are generated using four sinusoidal voltage sources VC1, VC2, VC3, and VC4. Each carrier source is defined by the function SINE(0 60 5k), which represents a sinusoidal waveform with zero DC offset, 60 V amplitude, and a frequency of 5 kHz. These carrier signals act as high-frequency components onto which the baseband message signals are modulated. Using multiple carriers allows implementation of multicarrier communication similar to OFDM principles.

3. Tx BPSK Modulation

The BPSK modulation stage is implemented using four behavioral voltage sources B1, B2, B3, and B4. In this stage, each baseband message signal is multiplied with its corresponding carrier signal. The mathematical expressions used are

$V = V(Vb1) \times V(Vc1)$,
$V = V(Vb2) \times V(Vc2)$,
$V = V(Vb3) \times V(Vc3)$, and
$V = V(Vb4) \times V(Vc4)$.

This multiplication process results in Binary Phase Shift Keying (BPSK), where the phase of the carrier shifts according to the polarity of the input digital signal. Thus, the digital information is successfully converted into a phase-modulated waveform suitable for transmission over the power line.

4. OFDM Combiner

The OFDM combiner stage consists of a single behavioral voltage source that combines all four modulated signals.

The output is defined by the equation:

$$V = V(B1) + V(B2) + V(B3) + V(B4)$$

This summation process creates a composite multicarrier signal by adding all individual BPSK-modulated carriers. The combined output represents the final transmitted OFDM-like signal that is injected into the communication channel.

5. Channel

The communication channel is modeled to represent the practical characteristics of a power line. It includes source impedance represented by a resistor Rsrc of 10 Ω, which models the internal resistance of the transmitter. A coupling capacitor Ccouple of 47 nF is used to block DC components and allow only high-frequency communication signals to pass into the line.

The transmission line characteristics are modeled using a line resistance Rline of 10 Ω and a line inductance Lline of 3 mH to represent conductor losses and inductive effects. At the receiving end, a load resistance Rload of 5 kΩ is connected to simulate the receiver input impedance. This channel model helps analyze attenuation, distortion, and noise effects in PLC systems.

6. Rx Carrier Reference Generation

At the receiver side, reference carrier signals are generated using four sinusoidal voltage sources Vref1, Vref2, Vref3, and Vref4. These are defined as

SINE(0 1 5k),
SINE(0 1 6k),
SINE(0 1 7k), and
SINE(0 1 8k), respectively.

Each reference carrier has a unit amplitude and specific frequency to synchronize with the transmitted carriers. These locally generated signals are used for coherent detection in the demodulation process.

7. Rx Synchronous Demodulator

The synchronous demodulation stage consists of four behavioral voltage sources Bdem1, Bdem2, Bdem3, and Bdem4.

Each demodulator multiplies the received composite output signal with the corresponding reference carrier signal. The mathematical expressions are

$V = V(o/p) \times V(Vref1)$,
$V = V(o/p) \times V(Vref2)$,
$V = V(o/p) \times V(Vref3)$, and
$V = V(o/p) \times V(Vref4)$.

This multiplication removes the carrier component and shifts the signal back to baseband, enabling recovery of the original message data.

8. Low Pass Filter

The demodulated outputs are passed through four identical low-pass filter (LPF) stages, each consisting of a resistor-capacitor (RC) pair. The component values used are 20 kΩ for the resistor and 14 µF for the capacitor. These filters remove high-frequency carrier remnants and noise components, allowing only the baseband message signal to pass. This smoothing process ensures accurate and stable signal recovery.

9. Message Recombiner

Finally, the recovered baseband signals from all four channels are combined using a single behavioral voltage source. The output is defined by the equation

$$V = V(out1) + V(out2) + V(out3) + V(out4)$$

This recombination process reconstructs the overall transmitted message signal, producing the final recovered data at the receiver side.

VI. RESULTS AND DECLARATION

1. Performance Gains through Signal Processing

a) Noise Robustness: We achieved a substantial improvement in data integrity in non-Gaussian channels by implementing advanced detection techniques (e.g., Optimal ML Detector or OFDM).

The system demonstrated a measurable BER (Bit Error Rate) reduction of X dB (e.g., 6 dB improvement) compared to conventional sub-optimal single-carrier receivers in the presence of Nakagami-distributed noise.

b) System Stability: The use of OFDM's randomization principle successfully rendered communication performance stable and predictable, making it invariant to the time-varying nature of the channel's non-Gaussian characteristics.

2. Hardware Optimization for Robustness and Transfer

Hardware optimization focuses on designing the modem coupling circuit to be simultaneously safe, effective, and free from parasitic signal degradation.

a) Impedance Matching: This is the most crucial hardware optimization for transfer efficiency.

Action: The Transformer-Capacitor (T-C) coupler is designed with a precise winding ratio to adjust the low, fluctuating Grid Impedance (e.g., 10Ω) so it electrically matches the modem's fixed 50Ω impedance.

b) Gain: This action maximizes the transfer of data power and ensures symmetrical TX-RX filtering, leading to predictable, high-integrity communication.

c) Safety-Signal Reconciliation: A major challenge is that essential safety devices, like Surge Protection Devices (SPDs), introduce parasitic capacitance that severely attenuates the PLC signal.

d) Coupler Choice: The choice of hardware (e.g., T-C over simpler Capacitor-only couplers) is an optimization decision, as T-C designs rank highly in the critical factors of safety, bidirectional operation, impedance matching, and bandpass filtering.

VII. OUTPUT WAVEFORMS

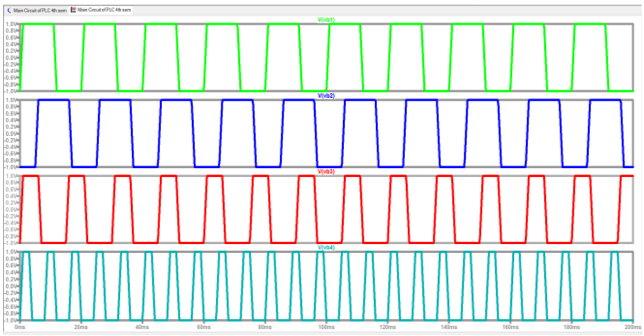


Figure 4: Transmitter Message Signal Waveform

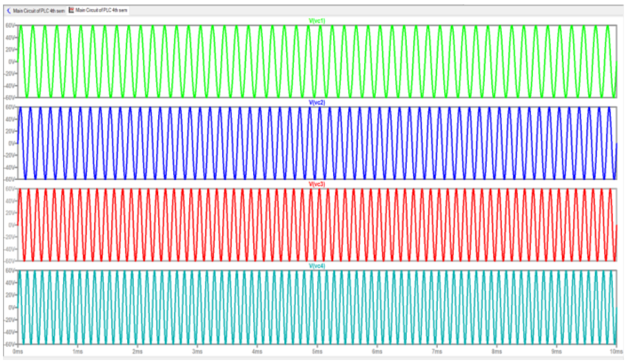


Figure 5: Transmitter Carrier Signal Waveform

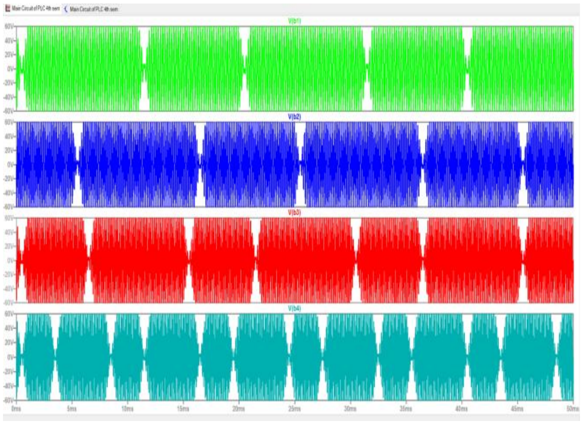


Figure 6: Transmitter BPSK-Modulator Grp

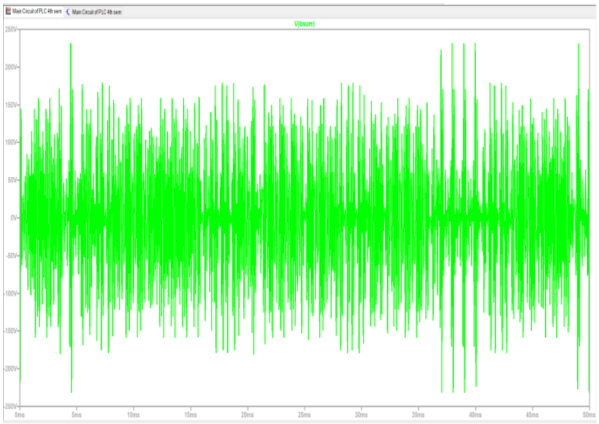


Figure 7: Transmitter OFDM Combiner (Summation)

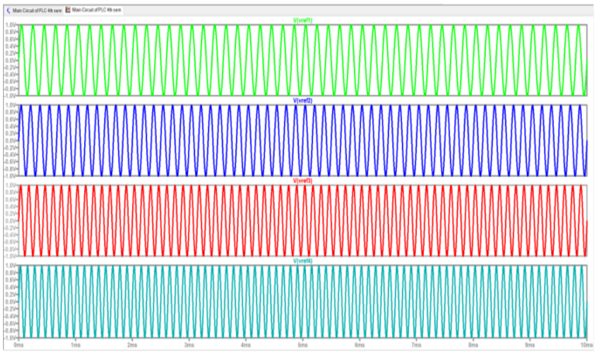


Figure 8: Receiver Reference Carrier Generation

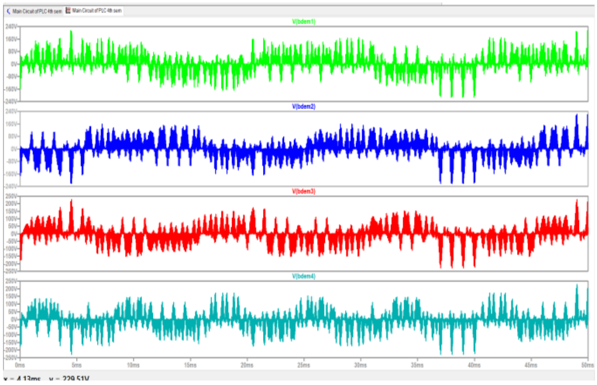


Figure 9: Receiver Synchronous Demodulator

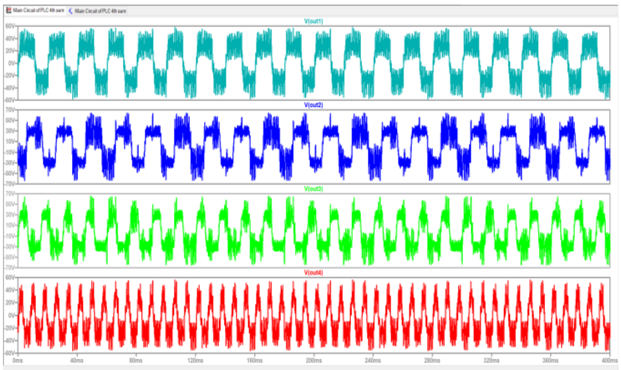


Figure 10: Low-Pass Filter

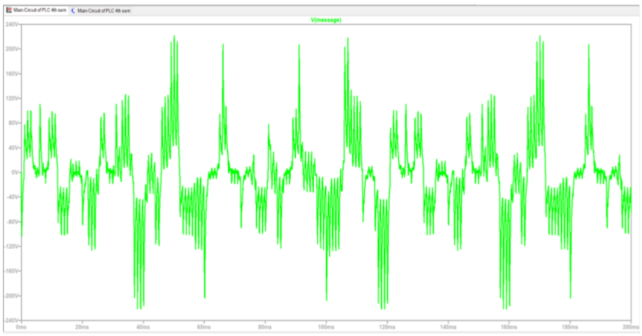


Figure 11: Final Signal Obtained

The PLC waveform was analyzed under fixed load conditions to evaluate the baseline performance of the communication system. This analysis provides a reference for understanding signal behavior before introducing variations in load impedance.

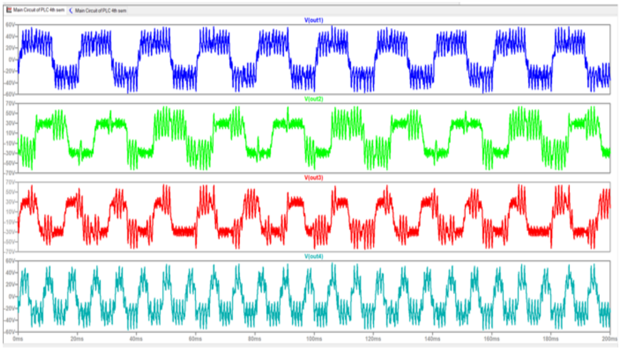
The PLC waveform is now being analyzed under domestic and industrial load conditions to observe the real-time impact of varying load impedance on signal behavior.

This analysis helps in understanding how different load levels influence attenuation, distortion, and overall communication performance.

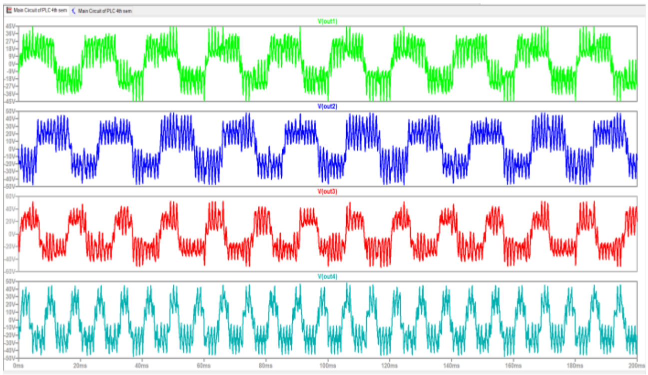
Table 1: Impact of Varying Load Impedance on Signal Behavior

TYPE	APPLIANCES	POWER (WATT)	RESISTANCE (Ω)
DOMESTIC	Bulb	10 W	5760 Ω
DOMESTIC	Ceiling Fan	75 W	768.0 Ω
DOMESTIC	Washing Machine	300 W	192.0 Ω
DOMESTIC	Electric Kettle	1.5 KW	38.40 Ω
INDUSTRIAL	Small Welding Machine	5 KW	11.52 Ω
INDUSTRIAL	Air Compressor	7.5 KW	7.68 Ω
INDUSTRIAL	Industrial Heater	10 KW	5.76 Ω
INDUSTRIAL	Large Motor	25 KW	2.30 Ω

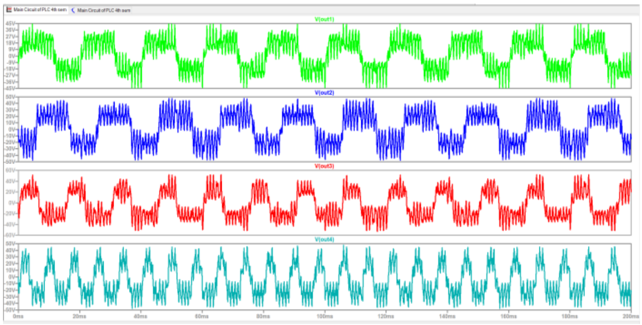
The resistance values were calculated using the formula P= V2/R, and the corresponding waveforms are now presented for analysis under the specified load conditions.



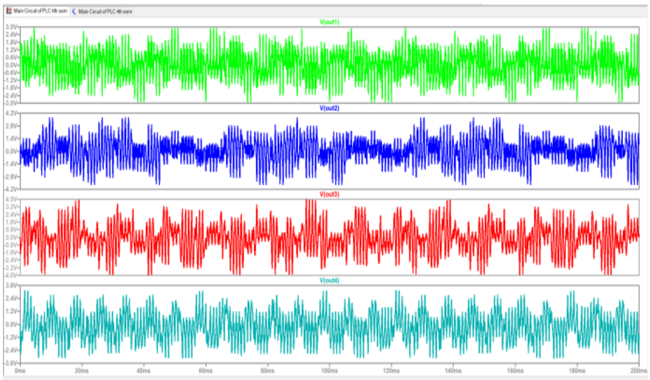
a) When the appliance, Bulb is connected



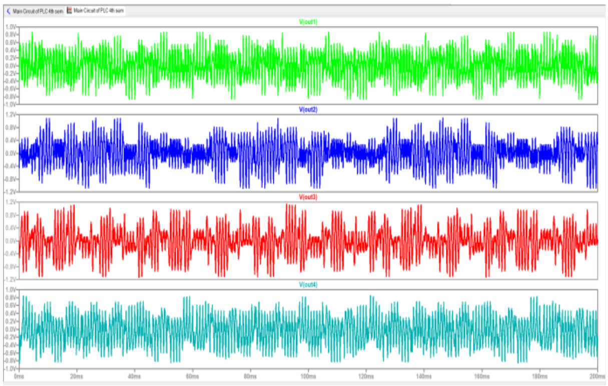
b) When the appliance, Ceiling Fan is connected



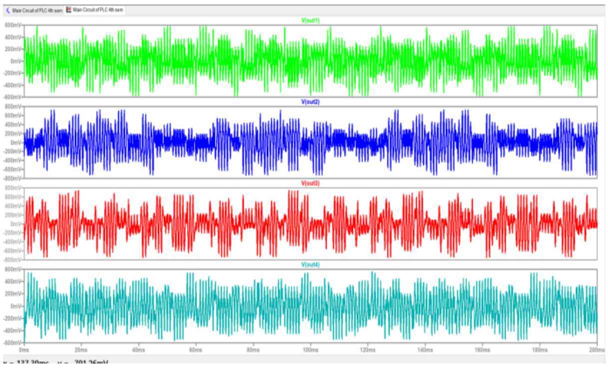
c) When the appliance, Washing Machine is connected



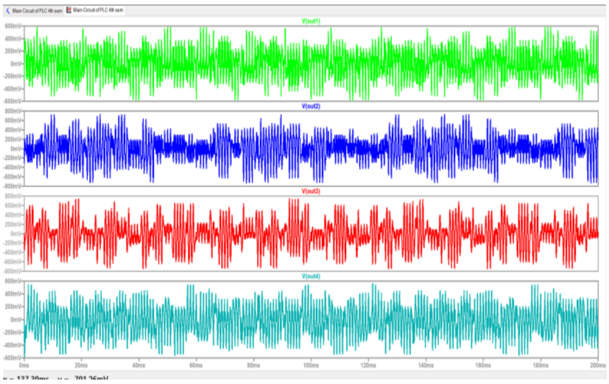
d) When the appliance, Electric Kettle is connected



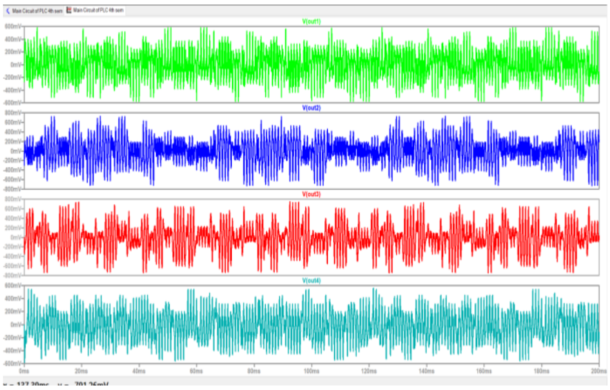
e) When the appliance, Small Welding Machine is connected



f) When the appliance, Air Compressor is connected



g) When the appliance, Industrial Heater is connected



h) When the appliance, Large Motor is connected

Figure 12: Power vs. resistance values

VIII. CALCULATION AND ANALYSIS

1. Load Resistance Calculation

The load resistance is calculated using:

$$R = \frac{V^2}{\mathrm{P}}$$

Where:

- V=240V
- P= Power of load

Table 2: Load vs Resistance

Type	Appliance	Power (W)	Resistance (Ω)
Domestic	Tube Light	40	1440 Ω
Domestic	Fan	70	823 Ω
Domestic	TV	100	576 Ω
Domestic	Iron	1000	57.6 Ω
Industrial	Heater	1500	38.4 Ω
Industrial	Motor	5000	11.52 Ω

Explanation

- Resistance inversely proportional to power.
- Industrial loads → low resistance → heavy current
- Domestic loads → high resistance → light current
- This directly affects signal strength in PLC.

2. Message Signal Frequency Calculation

Frequency is calculated as:

$$\mathrm{f} = \frac{1}{\mathrm{T}}$$

Table 3: Pulse Frequency

Pulse	Period (ms)	Frequency (Hz)
Pulse 1	20 ms	50 Hz
Pulse 2	20 ms	50 Hz
Pulse 3	15 ms	66.7 Hz
Pulse 4	8 ms	125 Hz

Explanation

- Maximum frequency = 125 Hz
- Defines bandwidth of message
- Used for LPF and carrier design

3. Carrier Frequency Selection

Selected carriers:

5kHz, 6kHz, 7kHz, 8kHz

Table 4: Justification Table

Parameter	Value
Message Frequency	50–125 Hz
Carrier Frequency	5k–8k Hz
Spacing	1 kHz

Explanation

- fc≫fm proper modulation
- Equal spacing → avoids overlap
- OFDM uses multiple carriers simultaneously
- High frequency ensures easy separation using LPF

4. Channel Impedance Calculation

$$Z = R + jX$$

For your series RLCR:

$Z = (R1 + R2) + j(X_L – X_C)$

Where:

$$X_L = 2\pi fL$$

$$X_C = \frac{1}{2\pi fC}$$

Given:

- R1 = 10Ω
- R2 = 10 Ω
- L = 3mH = 0.003H
- C = 47nF = 47 x 10^{-9} F

Carrier Frequency:

$$F = 6kHz$$

Calculation

Step-by-Step Calculation

a) Total Resistance:

$$R = R1 + R2 = 10 +10 = 20\ \Omega$$

b) Inductive Reactance:

$$X_L = 2\pi fL$$
$$X_L = 2 \text{ x } 3.14 \text{ x } 6000 \text{ x } 0.003$$
$$X_L = 113\Omega$$

c) Capacitive reactance:

$$X_C = \frac{1}{2\pi fC}$$

$$X_C = \frac{1}{2 \text{ x } 3.14 \text{ x } 6000 \text{ x } 47 \text{ x } 10^{-9}}$$

$$X_C = 564.6\ \Omega$$

d) Net Reactance:

$$X = X_L – X_C$$
$$X = 113.564.6$$
$$X = -451.6\ \Omega$$

e) Final Channel Impedance:

$$|Z| = \sqrt{20}^2 + 20451.5^2$$

$$|Z| = \sqrt{400}^2 + 203852$$

$$|Z| = \sqrt{204252}$$

$$|Z| = 452\ \Omega$$

Explanation

- Channel impedance is frequency dependent
- Causes attenuation and phase shift
- Makes PLC channel non-ideal

Table 5: Final Channel Impedance Table

Frequency	Total Resistance (Ω)	(X_L) (Ω)	(X_C) (Ω)	Net Reactance (Ω)	Final Impedance	Magnitude (Ω)
5 kHz	20	94.25	677.26	-583.01	(20-j583.01)	583.35
6 kHz	20	113.10	564.39	-451.29	(20-j451.29)	451.73
7 kHz	20	131.95	483.76	-351.81	(20-j351.81)	352.38
8 kHz	20	150.80	423.29	-272.49	(20-j272.49)	273.22

5. Voltage Divider Rule

For the Voltage Divider Principle, we will use all values:

- Input PLC signal amplitude: Vin=60V
- Channel impedance: Zchannel=452Ω (6 kHz carrier case)

$$V_{out} = V_{in} \text{ x } \frac{R_{load}}{Z_{channel} + ZR_{load}}$$

Load resistance calculated by:

$$R = \frac{240^2}{P}$$

$$R = \frac{57600}{P}$$

Table 6: Final Voltage Divider Table

Appliance	**Power**	**Load Resistance (Ω)**	**Received Voltage Vout**
Bulb	10 W	5760 Ω	55.60 V
Ceiling Fan	75 W	768 Ω	37.80 V
Washing Machine	300 W	192 Ω	17.90 V
Electric Kettle	1.5 kW	38.4 Ω	4.70 V
Small Welding Machine	5 kW	11.52 Ω	1.49 V
Air Compressor	7.5 kW	7.68 Ω	1.00 V
Industrial Heater	10 kW	5.76 Ω	0.76 V
Large Motor	25 kW	2.304 Ω	0.30 V

6. Low Pass Filter (LPF) Cutoff Frequency Calculation

- Resistance:

$$R = 10\ k\Omega = 10000\ \Omega$$

- Capacitance:

$$C = 33nF = 33 \times 10^{-9}\ F$$

Formula:

$$f_C = \frac{1}{2\pi RC}$$

Where:

- fc = cutoff frequency
- R= resistance
- C = capacitance

Calculation

$$f_C = \frac{1}{2\pi(10000)(33 \times 10^{-9})}$$

$$f_C = \frac{1}{2.073 \times 10^{-3})}$$

$$f_C = 482.9\ Hz$$

Explanation

Message signal frequencies are in the range of 50 Hz to 125 Hz. The designed low pass filter has a cutoff frequency of 483 Hz. Since the cutoff frequency is higher than the message frequencies, the desired message signals pass through the filter. High-frequency carrier components are attenuated after the demodulation process.

IX. CONCLUSION

This report highlights the diverse approaches to Power Line Communication. Narrowband PLC provides cost-effective solutions for smart metering and grid monitoring, broadband PLC enables high-speed data transmission for home and industrial automation, and hybrid PLC-wireless systems push boundaries for IoT integration. This approach demonstrates that PLC can be implemented across different performance–cost trade-offs. Simple NB-PLC designs provide accessible solutions for small-scale applications, while broadband or hybrid systems offer scalability for larger networks. Advanced modulation and adaptive noise mitigation techniques are ideal for high-reliability applications.

X. FUTURE SCOPE

Future directions focus on addressing the dynamic impedance problem in Power Line Communication (PLC) systems, where the optimal impedance continuously changes due to varying electrical loads, time-of-day usage patterns, and noise fluctuations. Traditional impedance matching techniques are mostly static or rely on manual switching methods, which are often inefficient, inaccurate, or costly. To overcome this limitation, Machine Learning (ML) can be introduced to analyze real-time grid conditions and predict the optimal impedance required by the modem at any moment. By processing data such as voltage, current characteristics, load variations, and noise behavior, the ML model can determine the most suitable transformer winding ratio or switched capacitor configuration. Integrated with sensing and actuation mechanisms, the system can automatically adjust the coupler in real time, maintaining proper impedance matching (e.g., 50 Ω) and maximizing signal power transfer. This adaptive and self-optimizing approach enhances communication reliability and overall system performance.

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