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Sustainable Grids: Smart Meter Solutions for Efficient Energy Measurement

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Abstract

In this study, an energy meter simulation is designed with MATLAB/Simulink and active-reactive power, power factor and energy consumption measurements are realized. The energy meter is crucial for producers and consumers to precisely measure the quantity of electrical energy produced or consumed. This paper aims to establish a three-phase system that simulates the energy meter and assesses its efficiency. The energy consumed under different loads has been measured to accomplish this goal. The study summarizes the simulation findings, encompassing tabular and graphical representations. Hence, the dependability and precision of the simulated energy meter model should be observed.

Keywords: "Smart Meter, Energy Measurement, Smart Grid."

1. Introduction

The energy sector must be digitized for the energy transition. All consumers and producers must communicate continuously for a safe and effective energy system. Smart meters can help with this[1]. Thanks to smart meters (SMs) used in smart grids (SG), consumers' energy consumption is measured by obtaining information from the end user's load devices and information can be presented to the system operator. Many sensors and control devices supported by special communication infrastructure are used in smart meters [2].

This technology, known as smart meter technology, is a device that monitors energy use in real-time in comparison to more conventional ways of measuring. In recent years, smart meters have made it possible to monitor energy use in an intelligent, efficient, and systematic manner. This has led to technological breakthroughs that have revolutionized the measuring business. There is tremendous potential for the growth of smart meters through measurement intelligence and analytics. Smart meters are currently being utilized worldwide in residential infrastructure and industrial applications. In order to measure the amount of electrical power that is consumed in each of the three phases, the three-phase energy smart meter (3PESM) modeling provides for the gathering of data in real-time, as well as analysis and control of energy consumption. The monitoring and management of electricity usage, the identification of locations with excessive energy consumption, and the development of strategies for energy efficiency are all made more accessible as a result of this. The capabilities of smart meters include sophisticated metering and computational hardware, software, calibration mechanisms, and communication capabilities. If smart meters are engineered to fulfill functions, store data, and transmit data adhering to specific standards, they can seamlessly integrate into the smart grid infrastructure. Implementing smart grids, smart meters, and smart metering presents a prospective solution to ensuring efficient power supply management and optimizing resource utilization. This objective could be attained by mitigating electricity demand [3].

Smart metering systems have evolved with the revolutionary development of existing power networks and are considered as a new generation power measurement system. Smart metering systems are generally referred to as the next-generation power

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metering system and are considered to be the revolutionary and evolutionary regime of existing power grids. With the integration of advanced computing and communication technologies, the smart meter (SM) is expected to greatly enhance the efficiency and reliability of renewable energy sources and future power systems, as well as distributed intelligence and demand response [4].

Hardware, software, and communication infrastructure are the components that compose smart meter systems. These components allow for the transmission of data remotely between energy consumption monitoring equipment and the central data system in smart grids. In smart grid networks, these systems play a significant role in facilitating remote data transmission and facilitate the measurement of energy consumption. They also support the measurement of energy consumption [5]. In addition, smart energy meters can be utilized per the directives provided by individual consumers to monitor and control various gadgets and appliances associated with the home [6]. Several aspects are of utmost significance in the realm of smart meters. These include the provision of customers with real-time access to consumption information and guaranteeing their involvement in the market, dynamic tariff applications, real-time demand tracking, and improved demand-side management [7]. The critical tasks of smart meters are the effective management of energy consumption through the use of data transmission methods, the protection against cyber attacks through the implementation of security measures, the prevention of power outages in advance, and the control of consumers' energy usage through the use of particular thresholds [8]. The next generation of smart meters will certainly aid society in accomplishing its future energy goals and improve the interaction between energy providers and consumers [9].

1.1. Literature Review

Research on smart meters designed using MATLAB/Simulink reveals several significant findings.

Emmanouil et al. (2018) developed an energy circuit model for single-phase electrical energy consumption measurement, minimizing errors through frequency measurement methods [10]. Ahmad et al. (2022) introduced a single-phase prepayment energy meter, employing Arduino Uno, relay, and GSM Shield Sim9000 to inform customers about energy usage and cut off power when necessary [11]. Azmi et al. (2018) simulated a three-phase energy consumption meter using MATLAB/Simulink, analyzing its performance across various load types and concluding high accuracy and efficiency [12]. Malathi and Sugasini (2022) proposed a three-phase energy meter model utilizing MATLAB/Simulink, incorporating IoT for real-time energy monitoring and usage restriction [13].

Tobias and Natalia Kryvinska examined the current state of smart meter technology and communication technologies utilized in smart meter systems [1]. Gouri R. Barai et al. investigated smart metering, smart grid technologies, and related standards [3]. Konark Sharma et al. explored smart meter technology's metrology ICs, harmonic effects, and security requirements [4]. Considering existing technologies and legislation, Francesco Benzi et al. proposed a local interface for smart meters [14].

Sarah Darby focused on smart metering's impact on demand and supplier-user interface enhancement [15]. Umayal Muthu et al. introduced a Smart Energy Meter for IoT-based energy management [16]. Rosado, J.; Cardoso, Filipe, Silva, and Marco developed an accurate energy meter measuring multiple parameters [17]. Jambi, J. Remang Ak et al. addressed security challenges in smart energy meters [18]. Liu, Yan, and Gu Yang investigated DC energy meters, presenting a highly accurate device for measuring DC voltage, current, and electrical energy [19].

Traditional meters often introduce errors in the energy billing process, such as human reading mistakes[20]. Since smart meters are information-gathering units, examining their reliability is paramount [21]. Energy meters are devices that calculate and display the power usage in the consumer's premises. Energy meters display each load's energy model to assist consumers become more conscious of energy waste [12].

The MATLAB/Simulink software facilitates the measurement of electrical parameters, encompassing current, voltage, active power, and power factor, across diverse load conditions within the system, obviating the need for hardware components [13]. To ensure the desired functionality of the meters, developing a simulation model for the meters and verifying its accuracy through experimentation is imperative. Various design and software tools, including MATLAB/Simulink, PSCAD, PSIM, and LabVIEW, are utilized for energy system simulations and control designs. Consequently, MATLAB/Simulink was chosen to model the three-phase energy meter in this investigation. This study presents an energy meter simulation model anticipated to be a valuable asset in critical domains such as enhancing energy systems' efficiency, reliability, and performance, reducing economic losses, and optimizing energy consumption. Measurements were conducted under diverse load conditions in the simulated model to assess the system's operational performance.

Table 1. Literature Review

Study	Topic	Hardware and Software Used
Emmanouil et al. (2018)	Single Phase Energy Meter	MATLAB/Simulink
Ahmad et al. (2022)	Energy Meter	Arduino
Azmi et al. (2018)	Energy Meter	MATLAB/Simulink
Malathi and Sugasini (2022)	Three phase energy meter	MATLAB/Simulink
Tobias and Natalia Kryvinska’s (2022)	Smart Meter Technology	SWOT-analysis
Jixuan Zheng et al. (2013)	Smart Meter Technology	Value Proposition
Gouri R. Barai et al. (2015)	Smart Meter Technology	Research
Konark Sharma et al. (2015)	Smart Meter Technology	Research
Francesco Benzi et al. (2011)	Local Interface For Smart Meters	Research
Sarah Darby (2010)	Smart Metering	Research
Umayal Muthu et al. (2023)	Smart Energy Meter	Embedded Controller
J. Rosado et al. (2023)	Energy Meter	Microcontroller
Jambi,J. Remang Ak et al.(2023)	Smart Meter Technology	Research
Liu, Yan, and Gu(2023)	DC Energy Meters	
Rajput et al. (2018)	Energy Meter	Arduino,GSM
Zhang, C. D. Xiao, Y. Xue, and X. L. Zhang (2014)	Energy Meter	MATLAB/Simulink
N. H. Azmi et al.(2018)	Energy Meter	MATLAB/Simulink
R. Malathi and K. Sugasini(2022)	Three Phase Energy Meter	MATLAB/Simulink

2. Materials and Methods

Meters that are equipped with smart technology are among the most essential elements of smart grids (SG). The grid is the electrical system that is responsible for the generation, transmission, distribution, and consumption of electricity.Smart meter is one of the most important devices used in smart grids (SG). Grid is the term used to describe the electrical system, which includes the generation of electricity, the transmission of electricity, the distribution of power, and the consumption of electricity. In conventional power grids, the movement of electrical energy occurs from a limited number of central generators to a large number of load centres. These load centres are the locations where consumers or electricity suppliers are located. [22]. The growth of traditional grids has led to the creation of smart grids (SG), which consist of an automated and distributed energy distribution network that enables electricity flow as well as information movement in both directions. A tabular representation of the comparison between the conventional grid and the smart grid (SG) is given in Table 2 [2].

Table 2. A comparison of the SG and the current grid [2]

Existing Grid	Smart Grid
Electro-mechanical	Digital
One way communication	Two way communication
Centralized production	Distributed production
Few sensors	Through-length sensor
Manually observing	Self-observance
Restoration by hand	Self-healing
Malfunctions and blackouts	Adaptable and islanding
Restricted Control	Prevalent Control
Few consumer options	Many consumer options

Smart meters give customers the advantage of controlling their energy consumption and lowering their electricity bills since they can forecast their bills based on the data they collect. From the service provider's view, the advantage is that they may price in real-time using the data gathered from smart meters. This enables companies to set maximum electricity consumption limits and encourage customers to lower their demand during high load times. n order to optimize power flows based on data received from demand participants, the system operator can remotely cut off or reconnect any customer’s electrical supply using the relevant mechanism. The comparison between a smart and a traditional energy meter is shown in Figure 1 [3].

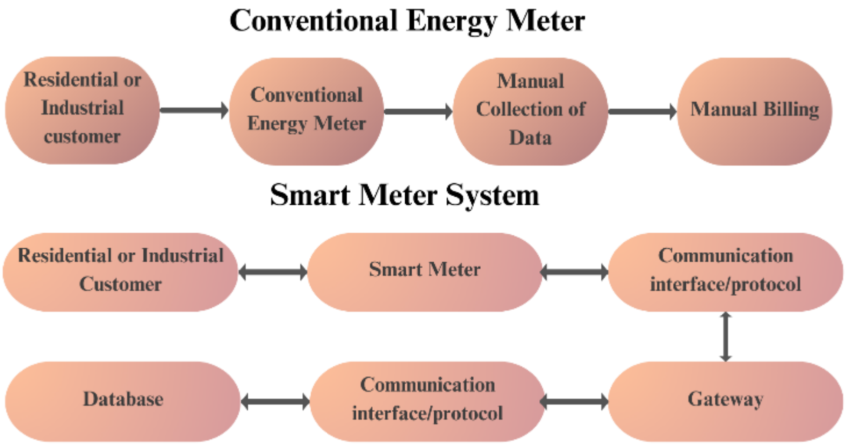

Fig. 1. Comparing the Architecture of Smart and Conventional Energy Meters [23]

Smart meter systems have a simple general operation and a variety of technologies and designs. Smart meters gather information from end users and send it across a local area network (LAN) to a data collector. Depending on the requirements of the data request, this transmission process may be carried out seldom, once a day or every 15 minutes. After that, the data is received and sent by the collector. Service center aggregation points use the Wide Area Network (WAN) to further analyze data.

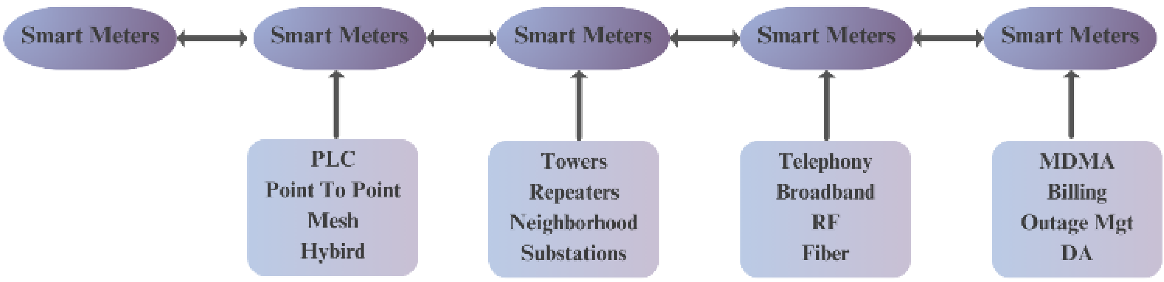

Fig. 2. The Fundamental Design of Smart Meter System Functions [2]

Power Line Carrier (PLC) and Radio Frequency (RF) are the two fundamental technologies used in smart meter system communication. Applications involving smart grids include a variety of benefits and drawbacks. Utilities will select the technology that will yield the greatest commercial return based on their features. A detailed evaluation and study of the business's present requirements and potential future benefits is necessary to make the best technological selection.

In modeling a three-phase energy meter, it is important to accurately measure current and voltage across multiple loads, including resistive (R), inductive (R-L), and capacitive (R-C) loads. Confirmation of the phase angle discrepancy of the load is an essential step. At this point, it is necessary to ensure that the power factor measurement measurements are accurate. The system may resume the modeling process to reevaluate the voltage and current levels if the criteria for phase angle difference is not satisfied. The power factor measurement is contingent on fulfilling the criterion for the phase angle difference. The number that represents the power factor provides information about the kind of load that is being employed by this system. Next, the methodology entails quantifying energy consumption by measuring utilized energy. A graphical format facilitates the visualization of energy consumption metrics for each load type. The energy meter model is elucidated in the flowchart depicted in Figure 3.

The energy meter model consists of three basic equations. Equation 1 represents Ohm's Law and provides the output current.

$$I = \frac{V}{R} \tag{1}$$

Here, R is the resistance of the connected load, I is the current and V is the voltage across the load. Equation 2 provides the active power for a three-phase energy meter.

$$P = \sqrt{3} I V \cos\theta \tag{2}$$

Here, P is the active power and cos θ is the power factor calculated using the formula. Equation 3 gives the computation for the energy consumption (E) of any load in a particular time interval.

$$E = \int_{t_0}^{t_1} v(t)\, i(t) dt \tag{3}$$

Here, the three-phase energy meter system's voltage supply is represented by v(t) and its load current by i(t).

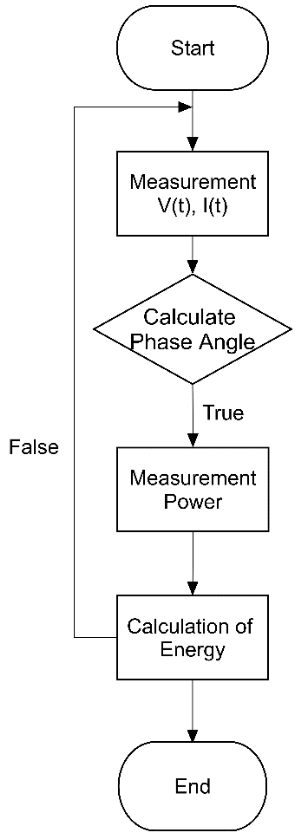

Fig. 3. Energy Meter Model Flowchart

2.1. System Design

The transmission of electrical energy in three-phase systems provides balanced load distribution, high efficiency, lower current and voltage fluctuations, and higher power capacity. The phase difference in three-phase electrical energy systems indicates the angular displacement between the sinusoidal waveforms of different phases. In an AC power source, three phases are 120° apart. "Three-phase energy meters" are used for energy measurement in these systems. The design of a three-phase energy meter involves the measurement of current and voltage, calculating power factors, determining active and reactive power, and, subsequently, estimating energy consumption. The power factor value in our developed system is derived by taking the cosine of the current and voltage waveforms' phase angle. These calculations are done after the current and voltage values have been measured. The active power value was determined by multiplying the RMS values of current, voltage, and power factor. The reactive power calculation involves multiplying the phase angle sine, voltage, and RMS current. Energy consumption is calculated based on active power measurements over a specific time interval.

The schematic diagram depicting the outlined three-phase energy meter is presented in Figure 4.

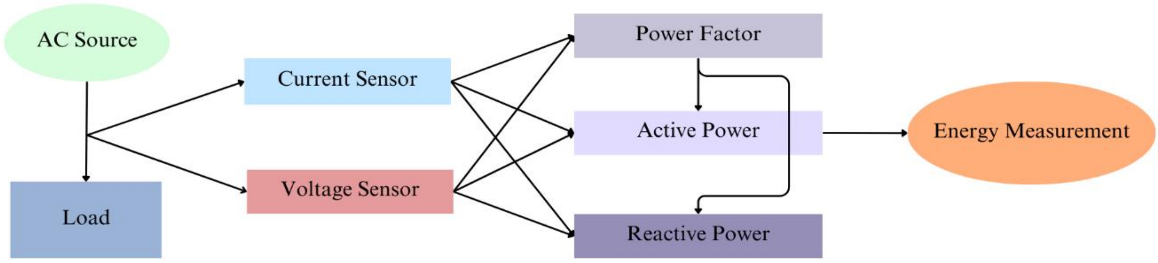

Fig. 4. Energy Meter Block Diagram

3. Simulation Model

The simulation of our three-phase energy meter model was carried out using the MATLAB/Simulink program. Several blocks are included in this model. The first is the load block, consisting of an ideal switch connected in series with the load. The ideal switch ensures the synchronous operation of all three phases. The simulation visualization of the system is shown in Figure 5.

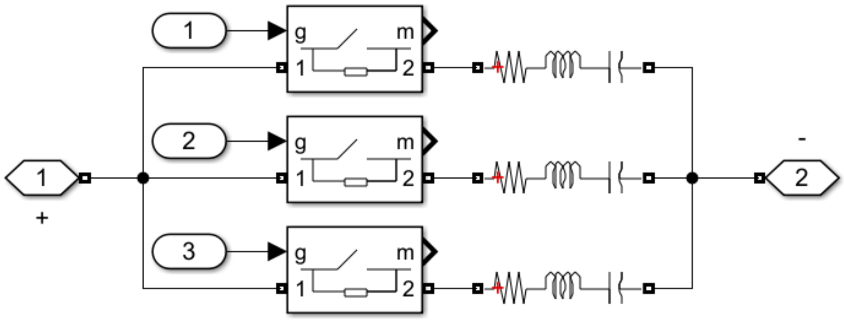

Fig. 5. Load Block

Another block is the power factor block. This is where the power factor computation from the voltage and current phase angle difference is performed. Figure 6 shows the simulation model.

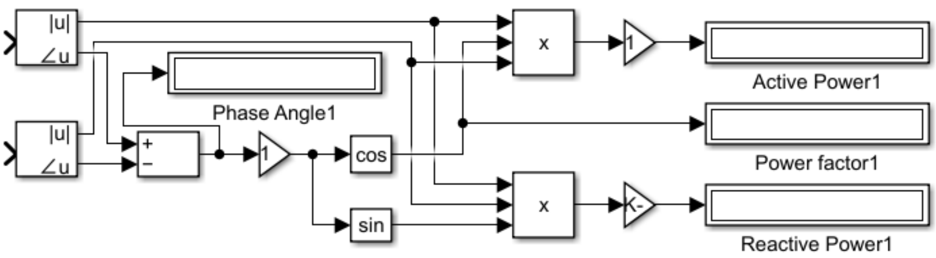

Fig. 6. Power Measurement Block

The Energy Metering block showing the energy consumption value in Kilowatts (kW) for different load types is shown in Figure 7.

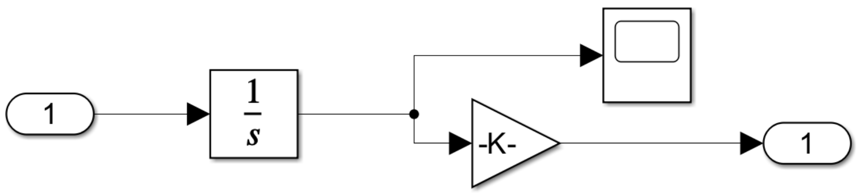

Fig. 7. Energy Measurement Block

The full simulation model of the three-phase energy meter is shown in Figure 8.

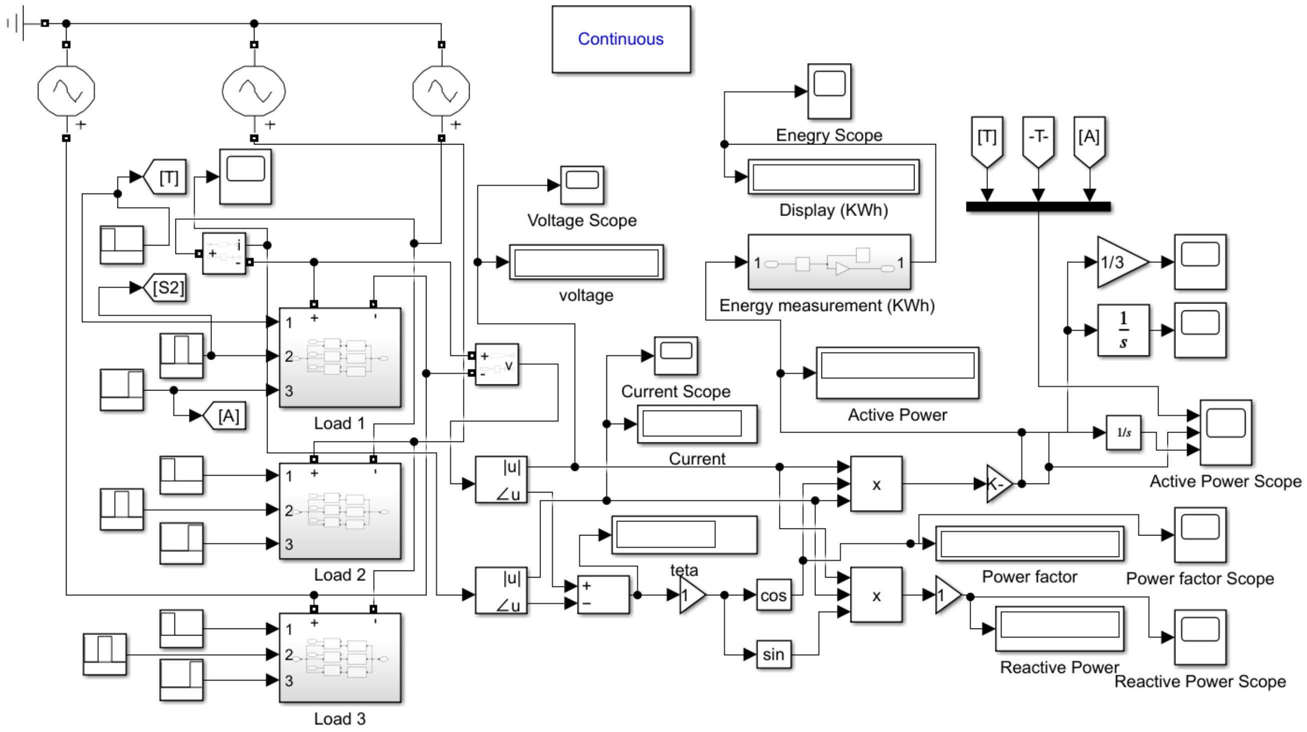

Fig. 8. Three-Phase Energy Meter Model

3.1. Simulation Model Results

In the simulation modeled to analyze the system's operating performance, measurements were performed under different loads, namely R, R-L, and R-C loads. The simulation results of the measured current and voltage values, power factor, active and reactive power, and energy consumption values for R load, R-L load, and R-C load are shown in graphs.

3.1.1. R Load

In the three-phase energy meter simulation model, measurements were conducted under resistive load conditions spanning from 100 ohms to 1000 ohms. The resulting measurement data is presented in Table 3.

Table 3. Results of Simulation with R Load

Resistance (Ω)	Voltage (V)	Current (A)	Power Factor	Active Power(W)
100	220	2.20	1	839.98
200	220	1.104	1	420.83
300	220	0.7377	1	281.11
400	220	0.5544	1	211.25
500	220	0.4444	1	169.33
600	220	0.371	1	141.38
700	220	0.3187	1	121.42
800	220	0.2794	1	106.45
900	220	0.2488	1	94.81
1000	220	0.22	1	85.49

As seen in Table 3, the voltage remains constant for varying resistance values, while the current and active power decrease with increasing resistance. These observations are corroborated by the principles of Ohm's Law (Equation 1) and the active power formula (Equation 2). Accordingly, the rise in resistance leads to a decline in current, dictated by Ohm's Law, consequently resulting in a reduction of active power, while voltage remains constant. Figure 9 illustrates the temporal profile of voltage measurements taken at a resistance of 100 ohms. Figure 10 depicts the temporal dynamics of current measurements recorded at a resistance of 100 ohms over time. Initially, both current and voltage values exhibited fluctuations until the 12th second. Subsequently, these fluctuations ceased entirely, leading to a period of stable current and voltage values.

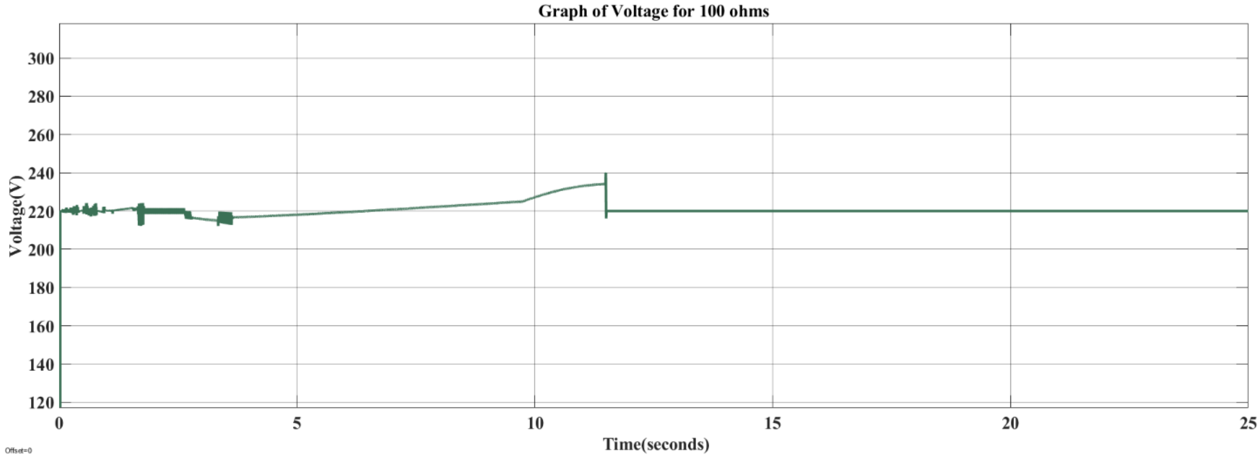

Fig. 9. Graph of Voltage for 100 ohms

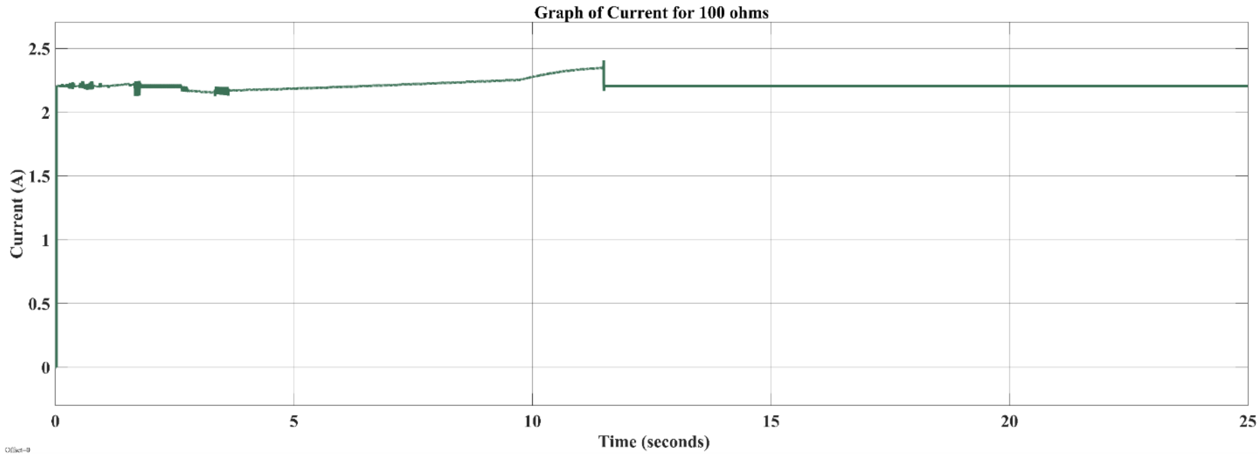

Fig. 10. Graph of Current for 100 ohms

The power factor graph depicted in Figure 11 remains consistent across all resistance values. A resistive load is characterized by a phase angle value of 0 degrees. The phase angle quantifies the temporal disparity between the voltage and current oscillations. Equation 1 states that the current changes linearly with the voltage in a resistive load. The voltage and current waves are synchronized in this scenario, meaning their phase angle is 0^o. The significance of a phase angle of 0^o in a resistive load is directly linked to the power factor. The power factor measures the proportion of reactive power (caused by the phase difference between voltage and current) to active power in a circuit. The power factor is a numerical value that ranges from -1 to 1. In a resistive circuit, the presence of reactive power is negligible or nonexistent due to the alignment of current and voltage in phase. Hence, the power factor is 1. A power factor 1 indicates that the circuit operates with high energy efficiency and does not require reactive power. A resistive load operating at a phase angle of 0^o achieves maximum energy efficiency by eliminating reactive power in the system. Low power factors in industrial applications and energy systems increase loads and losses.

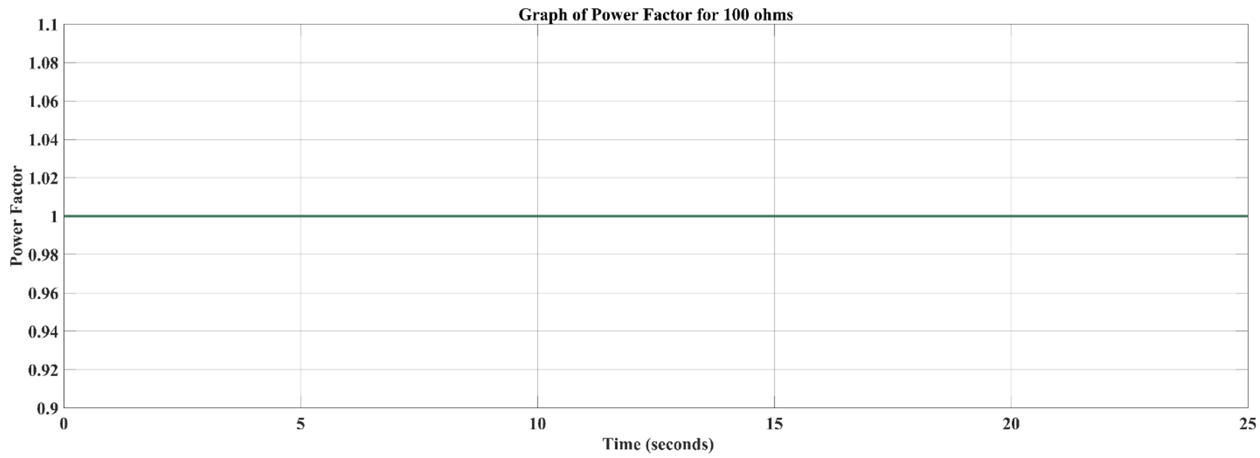

Fig. 11. Graph of Power Factor for 100 ohms

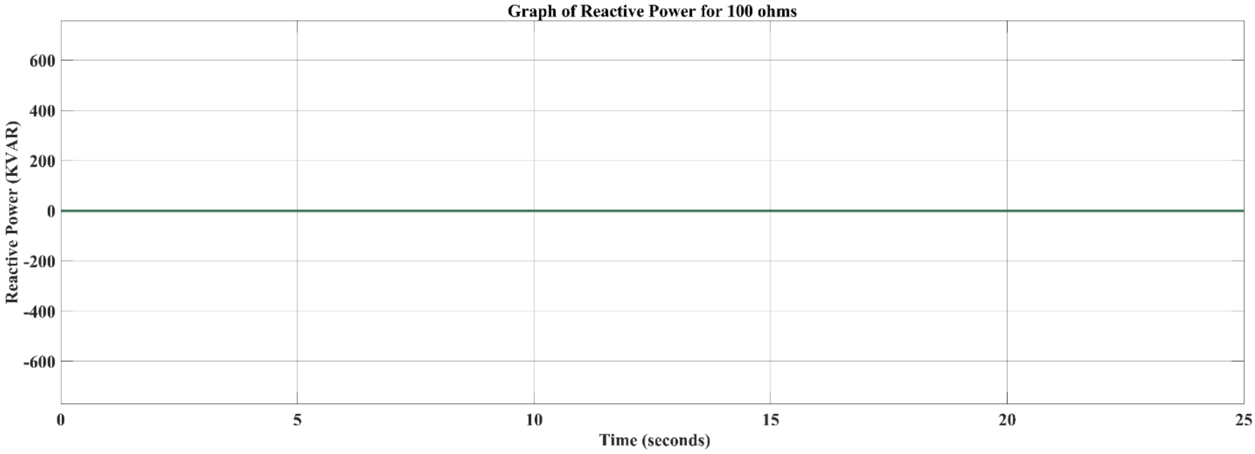

Fig. 12. Graph of Reactive Power for 100 ohms

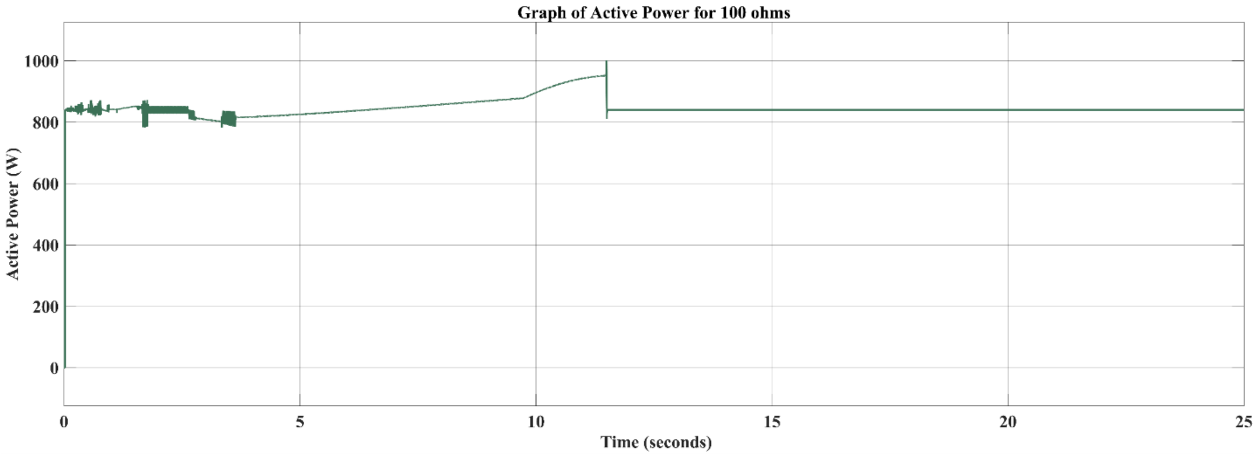

Fig. 13. Graph of Active Power for 100 ohms

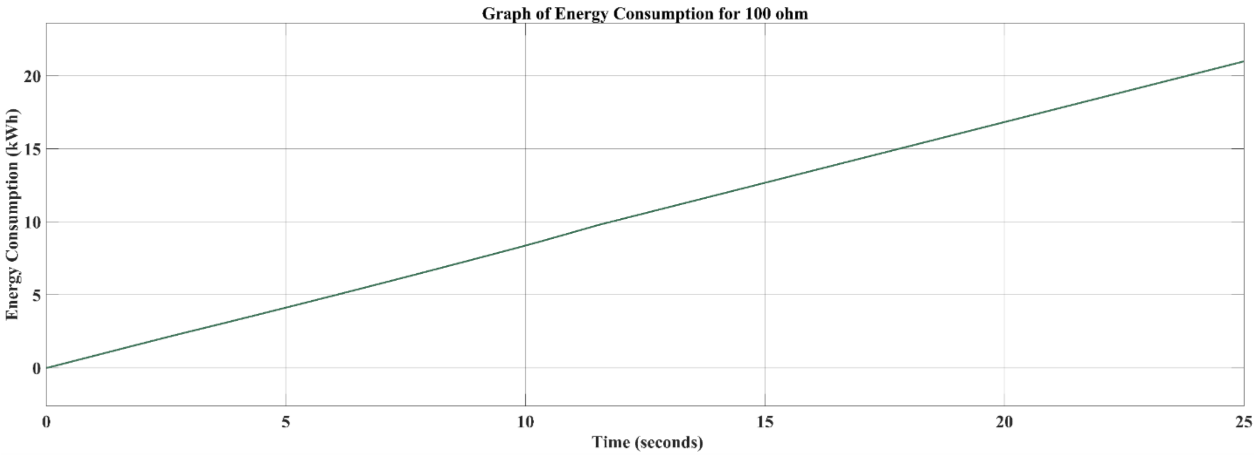

Fig. 14. Graph of Energy Consumption for 100 ohms

As shown in Figure 12, the reactive power graph for 100 ohms shows that the reactive power is 0. This is the model's expected reactive power value for a resistive load. Reactive power in a small range usually does not cause problems in power systems. However, suppose the power factor is low, and the system has a continuous high reactive power. In that case, it reduces efficiency, causes power losses, causes consumers to pay more, and can damage the equipment of power producers. Therefore, power factor management is essential in energy systems. Reactive power compensation systems can be used to improve the power factor. These systems optimize the power factor by balancing the reactive power, allowing energy systems to operate more efficiently.

Figure 13 is the measured active power curve for 100 ohms. It is seen that the active power has a fluctuation parallel to the current and voltage fluctuations in this graph.

When the energy consumed graph for 100 ohms shown in Figure 14 is analyzed, the observed energy curve is smooth and continuous.

3.1.2. R-L Load

In the three-phase energy meter simulation model, measurements under inductive load were performed for constant 100 ohms and varying inductance values. These measurements are given in Table 4. The voltage value is 220 V for all loads.

Table 4. Simulation Results under RL Load

R (Ω)	L (mH)	Current (A)	Power Factor	Active Power(W)
100	0.5	2.21	0.996	841.46
100	1	2.204	0.983	826.84
100	1.5	2.206	0.963	811.76
100	2	2.202	0.934	784.91
100	2.5	2.194	0.897	746.54

Table 4 shows a decline in current, power factor, and active power values as inductance increases. The phase difference between the oscillations of the voltage and current in inductive loads is the cause of this phenomena. The present electrical waveform mirrors the voltage waveform. As a result of this phase change, the current diminishes as the inductance increases. Figure 15 displays the voltage plot of the measurements obtained from the simulation model under RL load conditions, specifically with a resistance of 100 ohms and an inductance of 0.5 mH. Figure 16, on the other hand, shows the current plot.

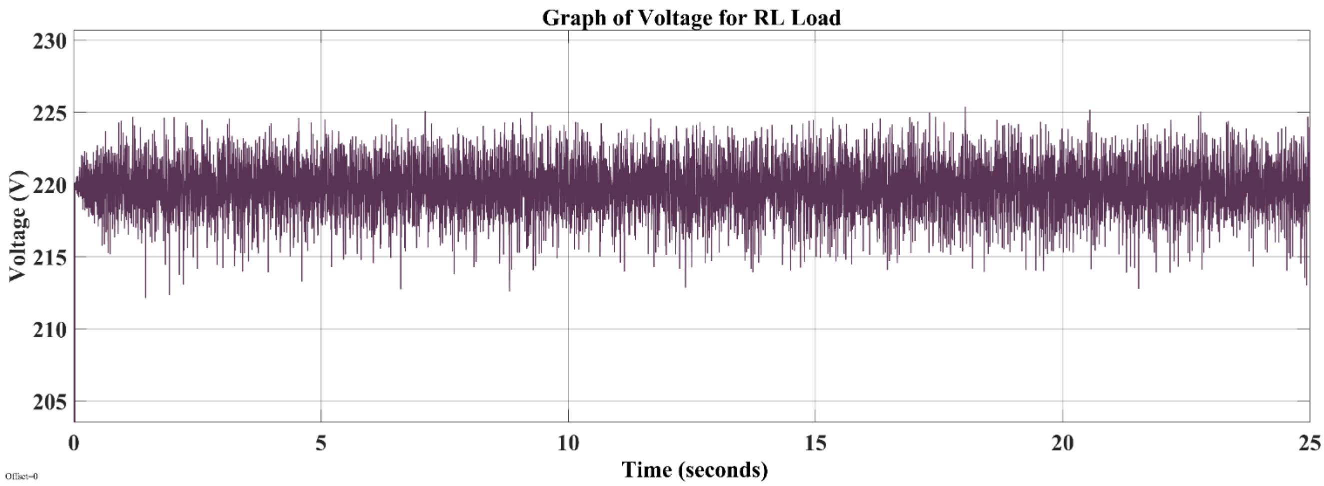

Fig. 15. Graph of Voltage for RL Load

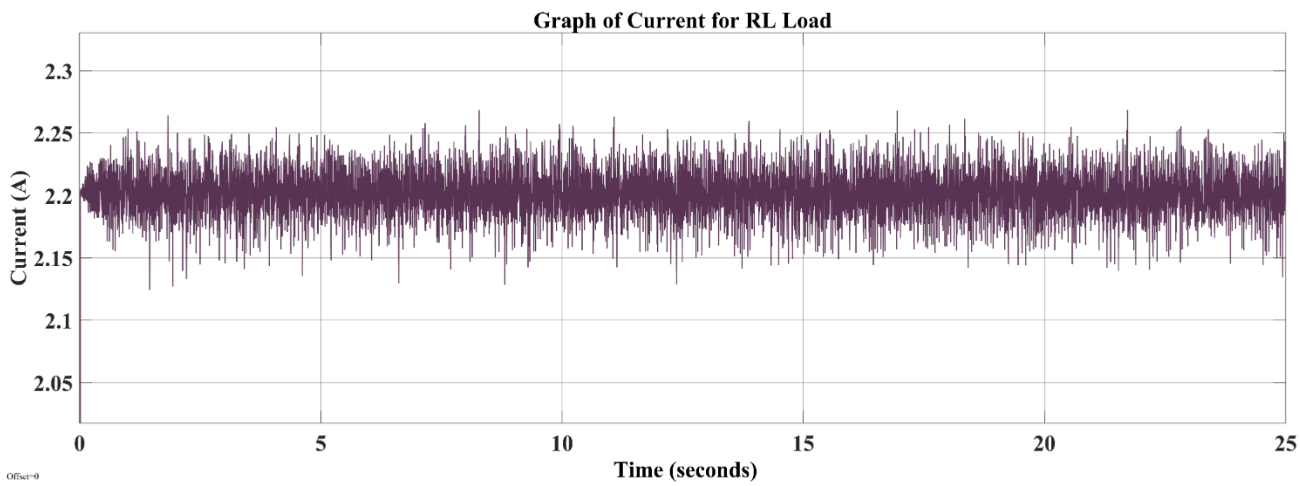

Fig. 16. Graph of Current for RL Load

Since the ratio of active power to reactive power is referred to as the power factor, an increase in reactive power causes a decrease in the power factor. As seen by the power factor graph in Figure 17, the power factor is less than 1 and occasionally fluctuates. It is possible to offset these effects using compensation systems that correct the power factor and increase the active power in inductive loads. These systems enable energy systems to operate more efficiently and reduce energy costs.

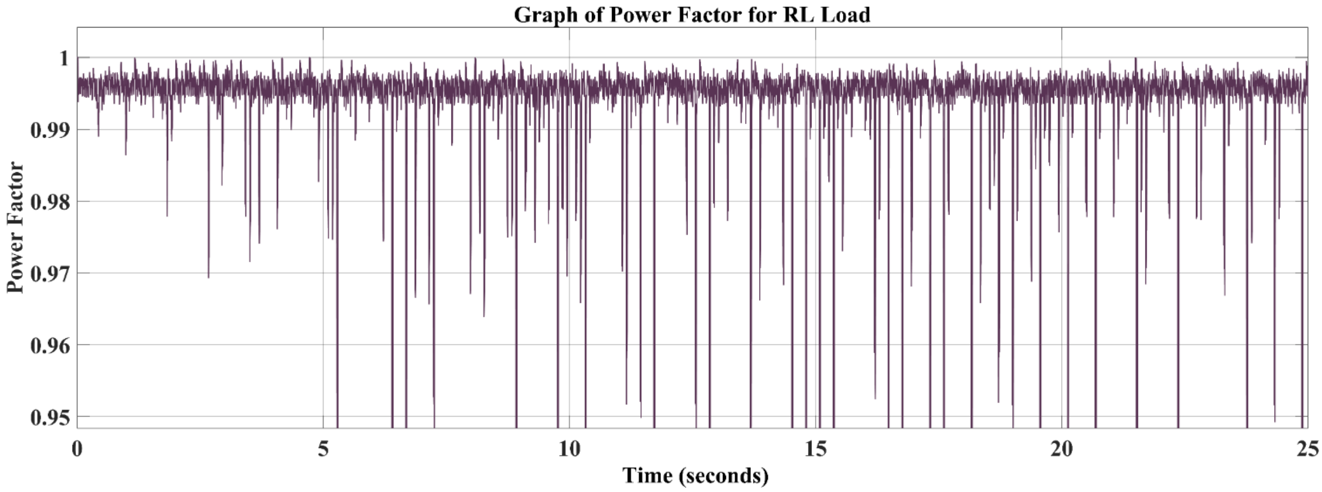

Fig. 17. Graph of Power Factor for RL Load

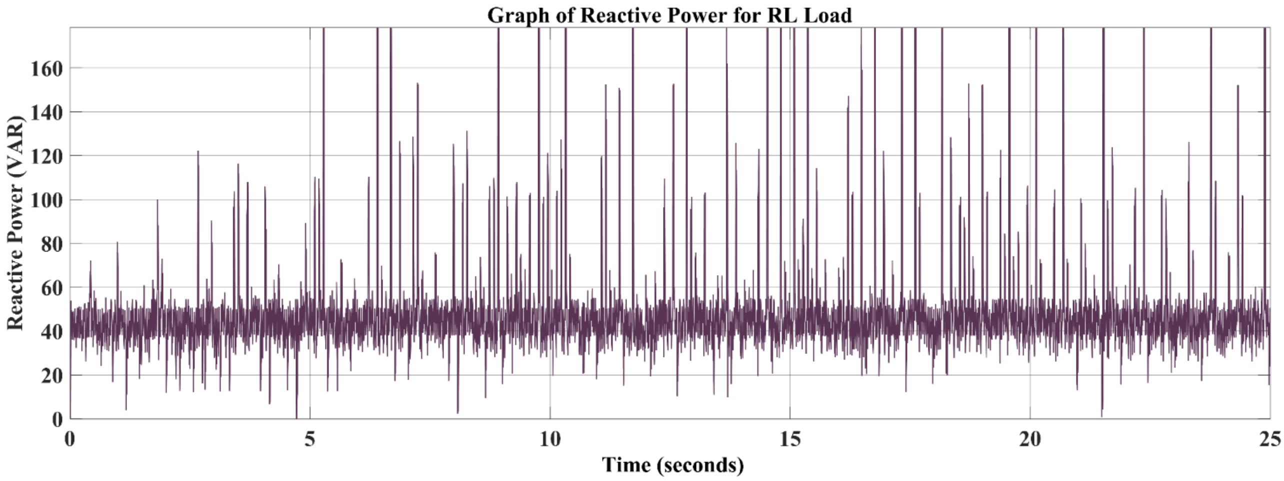

Fig. 18. Graph of Reactive Power for RL Load

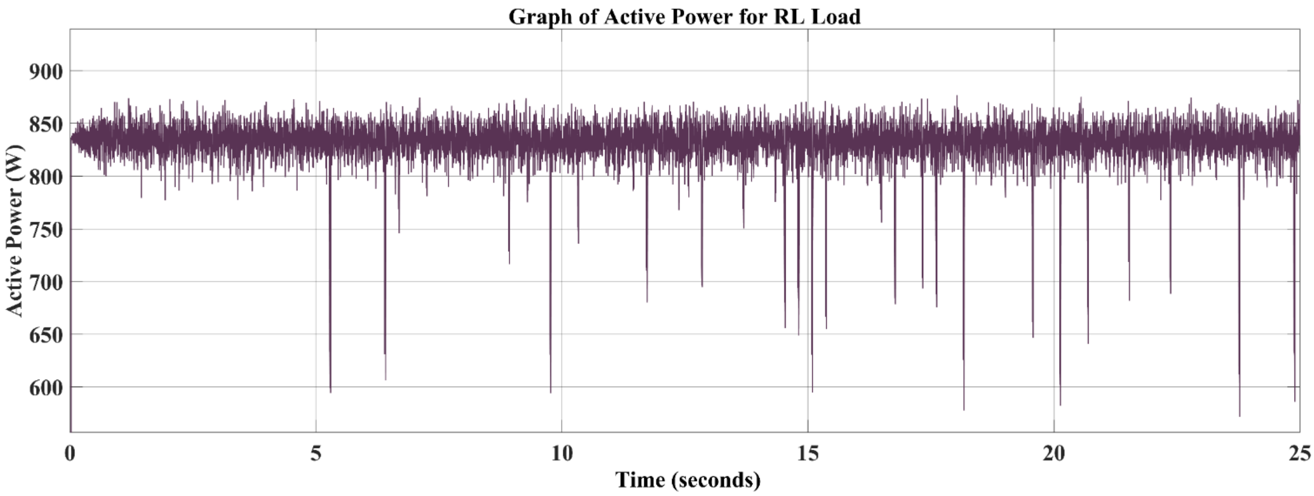

Fig. 19. Graph of Active Power for RL Load

Figure 18 shows the reactive power graph. In an inductive system, the phase angle will be greater than 0, and the reactive power will be positive since reactive power is computed by multiplying the sine of the current, voltage, and phase angle. There are positive swings in the graph and the reactive power value is greater than 0.

Figure 19 shows the graph representing the active power, while Figure 20 illustrates the energy consumption. Fluctuations are observed from time to time in the active power curve. The energy consumption values exhibit a continuous and smooth pattern.

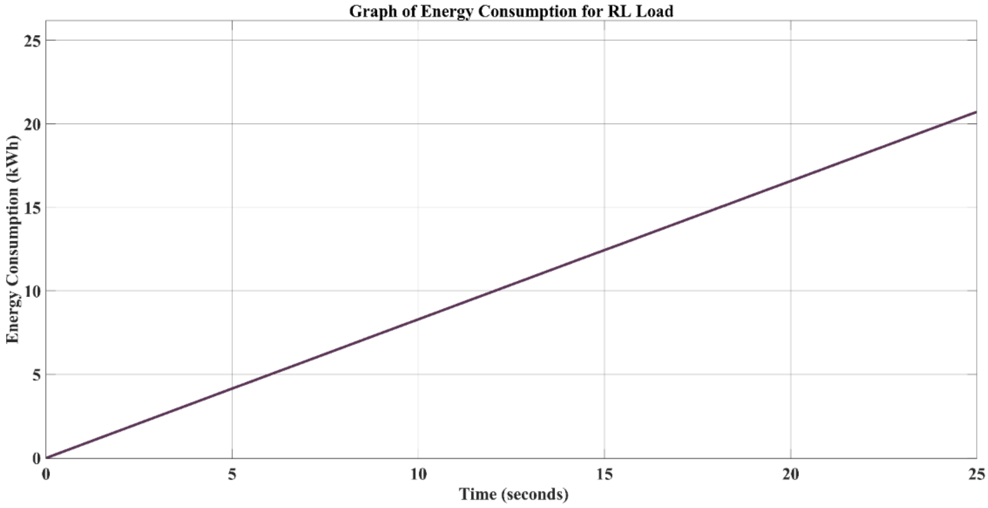

Fig. 20. Graph of Energy Consumption for RL Load

3.1.3. R-C Load

In the three-phase energy meter simulation model, measurements under inductive load are performed for constant 100 ohms and varying capacitance values. Capacitor values are selected by considering the stability conditions obtained from literature studies and simulation results. These measurements are given in Table 5. The voltage value is 220 V for all loads. According to the data presented in Table 5, the current and active power values show a positive correlation with increasing capacitance. The current waveform in capacitive loads occurs before the voltage waveform. Due to the energy stored in capacitors, capacitive loads result in delayed current and voltage alterations.

Table 5. Simulation Results under RC Load

R (Ω)	C (F)	Current (A)	Power Factor	Active Power(W)
100	0.09	2.063	0.986	722.872
100	0.11	2.127	0.998	778.80
100	0.15	2.239	0.997	865.01
100	0.192	2.222	0.999	852.35
100	0.2	2.213	0.999	845.96

Figure 21 shows the voltage graph of the measurements taken under an RC load with a resistance of 100 ohms and a capacitance of 0.11 F. Figure 22, on the other hand, shows the current graph.

Figure 23 shows the power factor, which exhibits continuous fluctuations ranging from -1 to 1. For capacitive loads, the current wave leading to the voltage wave results in a negative phase angle. It can be inferred that the power factor in this specific case will be positive because it is defined as the cosine of the phase angle. The variability in the graph is attributable to the condition of the load.

Figure 25 shows the graph representing the active power. The active power graph exhibits nonlinearity in the case of inductive and resistive load types. The reason for this is the energy storage and release properties of capacitors in capacitive loads. Capacitors utilized in capacitive loads accumulate energy during the highest points of voltage waves and release this energy when the voltage decreases. Fluctuations in the active power curve could stem from changes in the phase angle of the current and voltage waves. Fluctuations in active power can lead to corresponding fluctuations in actual energy consumption. Figure 26 shows the graph illustrating energy consumption.

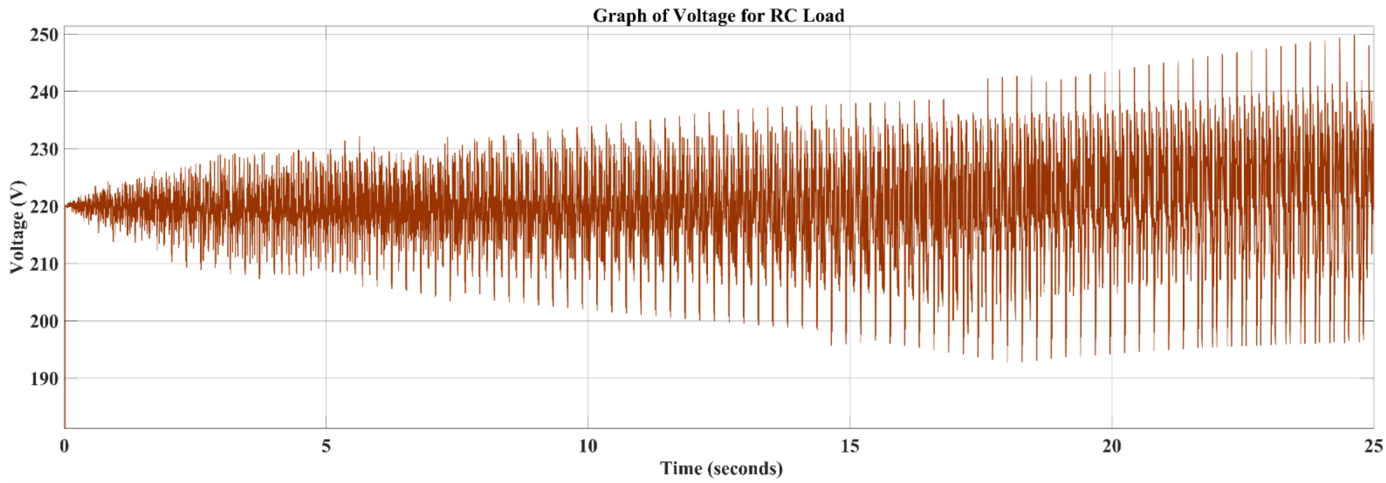

Fig. 21. Graph of Voltage for RC Load

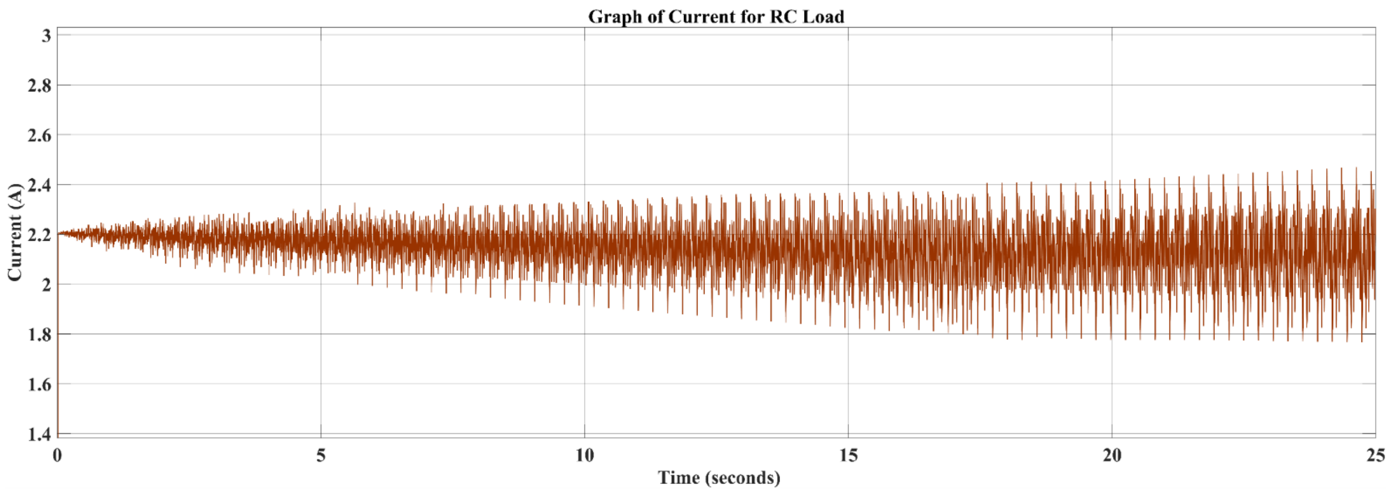

Fig. 22. Graph of Current for RC Load

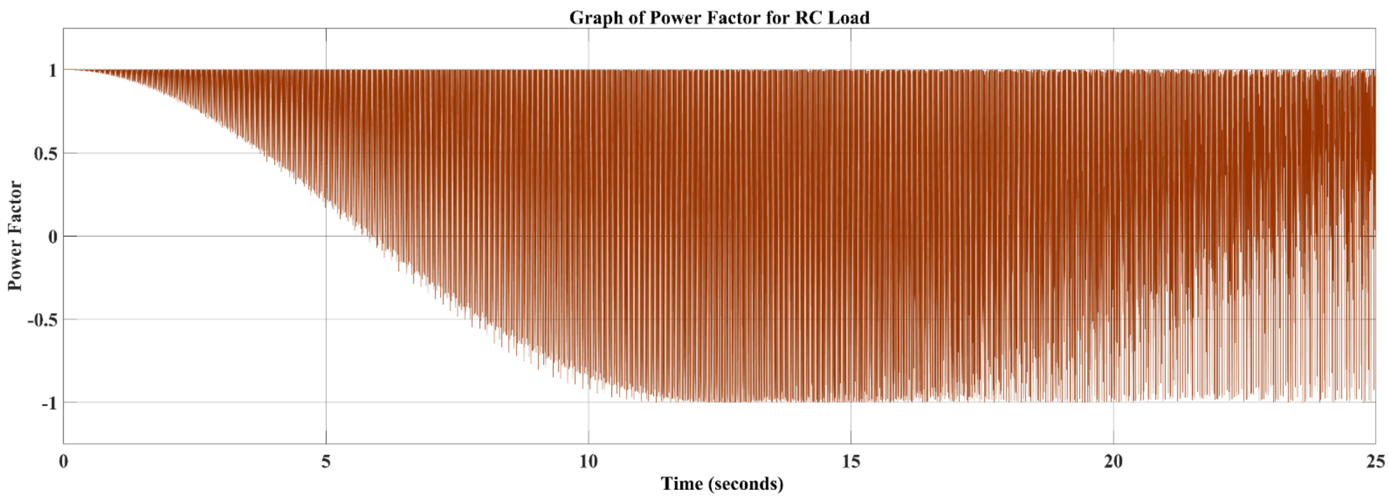

Fig. 23. Graph of Power Factor for RC Load

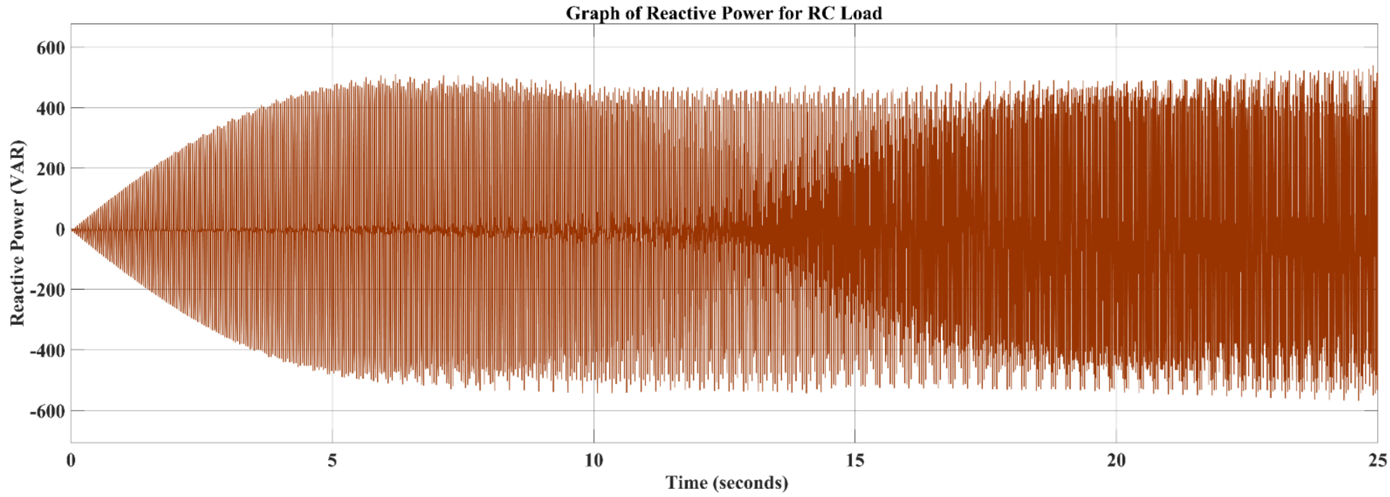

Fig. 24. Graph of Reactive Power for RC Load

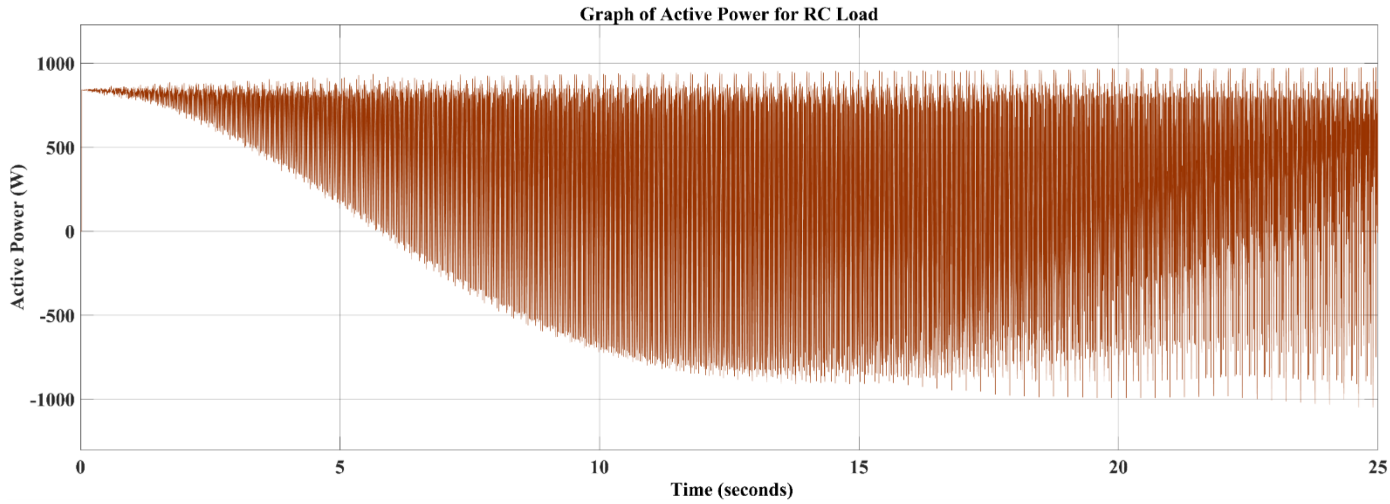

Fig. 25. Graph of Active Power for RC Load

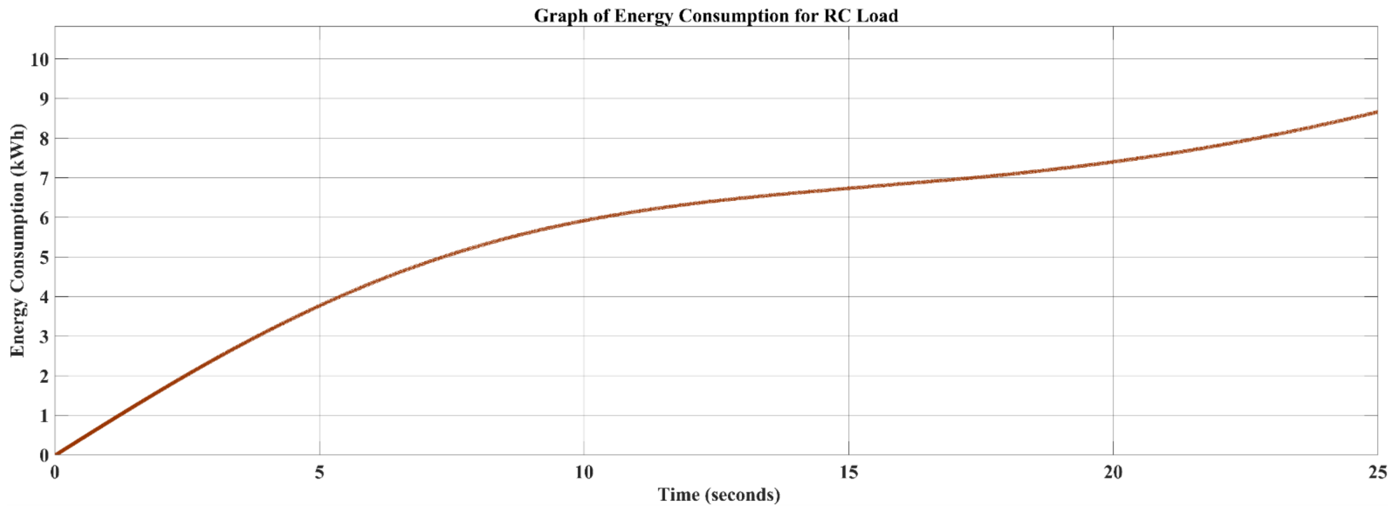

Fig. 26. Graph of Energy Consumption for RC Load

4. Conclusion

This study introduces a MATLAB/Simulink simulation model for three-phase energy meters. The model is validated by conducting energy consumption experiments under various load conditions. The results, comprising measurements obtained from the model, are meticulously presented in tabular and graphical formats. Furthermore, as a prospective avenue of research, integrating the proposed three-phase energy meter simulation model (3PESM) with smart building energy management systems is suggested. This integration can potentially enhance energy consumption efficiency in residential and commercial buildings. Such integration enables the monitoring and controlling smart building functions and facilitates the management of power-consuming devices. Moreover, leveraging the analytical capabilities of smart meter data, the integrated system can offer insights into the energy consumption and operational patterns of individual household appliances. This information can be utilized to implement energy-saving measures and optimize the energy supply-demand balance within the building infrastructure.

References

[1] M. Y. Erten and N. İnanç, "Machine Learning Based Short Term Load Estimation in Commercial Buildings," *International Scientific and Vocational Studies Journal*, Dec. 2021, doi: 10.47897/bilmes.1033438.

[2] Jixuan Zheng, D. W. Gao, and Li Lin, "Smart Meters in Smart Grid: An Overview," in *2013 IEEE Green Technologies Conference (GreenTech)*, Apr. 2013, doi: 10.1109/greentech.2013.17.

[3] G. R. Barai, S. Krishnan, and B. Venkatesh, "Smart metering and functionalities of smart meters in smart grid - A review," in *2015 IEEE Electrical Power and Energy Conference: Smarter Resilient Power Systems, EPEC 2015*, pp. 138–145, Jan. 2016, doi: 10.1109/EPEC.2015.7379940.

[4] K. Sharma and L. Mohan Saini, "Performance analysis of smart metering for smart grid: An overview," *Renewable and Sustainable Energy Reviews*, vol. 49, pp. 720–735, Sep. 2015, doi: 10.1016/j.rser.2015.04.170.

[5] G. Dileep, "A survey on smart grid technologies and applications," *Renewable Energy*, vol. 146, pp. 2589–2625, Feb. 2020, doi: 10.1016/j.renene.2019.08.092.

[6] Q. Sun *et al.*, "A Comprehensive Review of Smart Energy Meters in Intelligent Energy Networks," *IEEE Internet of Things Journal*, vol. 3, no. 4, pp. 464–479, Aug. 2016, doi: 10.1109/JIOT.2015.2512325.

[7] B. Karaman, S. Taşkin, and M. Tokay, "Gerçek Zamanlı Enerji İzleme ve Tüketici Farkındalığı için LabVIEW ™ Programı ile Otomatik Sayaç Okuma," *International journal of advances in engineering and pure sciences :*, vol. 33, no. 2, pp. 225–232, Mar. 2021, doi: 10.7240/jeps.759782.

[8] R. Bayindir, I. Colak, G. Fulli, and K. Demirtas, "Smart grid technologies and applications," *Renewable and Sustainable Energy Reviews*, vol. 66, pp. 499–516, Dec. 2016, doi: 10.1016/j.rser.2016.08.002.

[9] S. Jurado, À. Nebot, and F. Mugica, "The importance of robust and reliable energy prediction models: Next generation of smart meters," *in SIMULTECH 2020 - Proceedings of the 10th International Conference on Simulation and Modeling Methodologies, Technologies and Applications, SciTePress*, 2020, pp. 248–254. doi: 10.5220/0009885802480254.

[10] M. Emmanouil, N. Markoulakis, E. N. Antonidakis, and G. S. Stavrakakis, "A Simulink Circuit Model For Measurement Of Consumption Of Electric Energy Using Frequency Method," 2018. [Online]. Available: https://drive.google.com/file/d/0B0A8uTBvEiQRcGJlbGlO

[11] N. Ahmad, W. A. A. Q. I. Wan, and S. S. S, "Enhancement of Single-Phase Energy Meter in Residential Area Using GSM Shield Sim9000 for An Economics and Environment Assessment," *International journal of academic research in economics and management sciences*, vol. 11, no. 3, Aug. 2022, doi: 10.6007/ijarems/v11-i3/14535.

[12] N. H. Azmi, N. A. Mat Leh, and N. A. Kamaruzaman, "Modeling of energy meter using MATLAB/Simulink," in *2018 9th IEEE Control and System Graduate Research Colloquium, ICSGRC 2018 - Proceeding, Institute of Electrical and Electronics Engineers Inc.*, Jul. 2018, pp. 75–80. doi: 10.1109/ICSGRC.2018.8657635.

[13] R. Malathi and K. Sugasini, "International Journal of Research Publication and Reviews Modeling of Three Phase Energy Meter Using Matlab/Simulink," *International Journal of Research Publication and Reviews*, vol. 3, no. 6, pp. 4808–4815, 2022, [Online]. Available: www.ijrpr.com

[14] F. Benzi, N. Anglani, E. Bassi, and L. Frosini, "Electricity Smart Meters Interfacing the Households," *IEEE Transactions on Industrial Electronics*, vol. 58, no. 10, pp. 4487–4494, Oct. 2011, doi: 10.1109/tie.2011.2107713.

[15] S. Darby, "Smart metering: what potential for householder engagement?," *Building Research & Information*, vol. 38, no. 5, pp. 442–457, Oct. 2010, doi: 10.1080/09613218.2010.492660.

[16] V. Umayal Muthu, A. Shunmugalatha, K. Balamurugan, D. S. Aravind, and B. ShanmugaSundarapandi, “Design and Development of Autonomous Smart Energy Meter with Remote Management Control,” in *Proceedings of the 2023 2nd International Conference on Augmented Intelligence and Sustainable Systems, ICAISS 2023*, pp. 1782–1785, 2023, doi: 10.1109/ICAISS58487.2023.10250533.

[17] J. Rosado, F. Cardoso, and M. Silva, “A Low Cost and Highly Parameterizable Energy Meter,” in *International Conference on Electrical, Computer, Communications and Mechatronics Engineering, ICECCME 2023*, 2023, doi: 10.1109/ICECCME57830.2023.10252483.

[18] J. R. A. Jambi, W. K. Wong, F. H. Juwono, and F. Motalebi, “Smart Energy Meter Implementation: Security Challenges and Opportunities,” in *2023 International Conference on Digital Applications, Transformation and Economy, ICDATE 2023*, 2023, doi: 10.1109/ICDATE58146.2023.10248469.

[19] Y. Liu and Y. Gu, “A Metering Device for DC Energy Meters,” in *Proceedings of 2023 IEEE 16th International Conference on Electronic Measurement and Instruments, ICEMI 2023*, pp. 239–243, 2023, doi: 10.1109/ICEMI59194.2023.10270441.

[20] U. A. Rajput et al., “Modeling of Arduino-based Prepaid Energy Meter using GSM Technology,” 2018. [Online]. Available: www.ijacsa.thesai.org

[21] P. H. Zhang, C. D. Xiao, Y. Xue, and X. L. Zhang, “Modeling and simulation of smart meters based on matlab/simulink software,” in *Advanced Materials Research*, 2014, pp. 760–763. doi: 10.4028/www.scientific.net/AMR.846-847.760.

[22] X. Fang, S. Misra, G. Xue, and D. Yang, “Smart Grid — The New and Improved Power Grid: A Survey,” *IEEE Communications Surveys & Tutorials*, vol. 14, no. 4, pp. 944–980, 2012, doi: 10.1109/surv.2011.101911.00087.

[23] S. S. S. R. Depuru, L. Wang, V. Devabhaktuni, and N. Gudi, “Smart meters for power grid - Challenges, issues, advantages and status,” in *2011 IEEE/PES Power Systems Conference and Exposition, PSCE 2011*, 2011, doi: 10.1109/PSCE.2011.5772451.