

Development of a Smart Metering System for Efficient Energy Consumption

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Abstract

Smart energy concepts are based on the utilization of emerging integrated microprocessors and communication technologies for monitoring energy consumption. In the utilization of electricity, energy management is a core problem, especially for cost savings to the benefit of electricity customers. In modern electricity generation, transmission and consumption, energy management has occupied the center of attention for sustainable techno-economic motives. The present-day power sector has an immense role to play in the overall economic performance of the global community, thus, requiring the application of efficient and reliable metering systems for the measurement of energy consumption. The application of a smart metering system depends on the effectiveness of the embedded smart communication interface in the utility service provider system and the energy consumers' metering devices based on energy supply reliability and consumption security. Therefore, this study focuses on the design and development of an efficient smart energy meter using the advancements provided by the Internet of Things (IoT). The system was tested based on the collection of real-time data and subsequently analyzed for performance evaluation through a case study of household data collection.

Keywords: Smart Meter, Energy, Internet, Communication, Technology, Electricity Customer.

Introduction

In recent years, the electricity demand has increased in households with the use of different appliances. There is a need for consumers or people to track their daily power usage in houses. In Nigeria, the energy crisis is a major challenge in the country. Thus, the responsibility of humans to save, control and manage their energy consumption is a priority. The application of smart energy meters for energy management is continuously gaining ground in our modern socio-economic development. A smart energy meter is a device that accurately measures the amount of electricity that is consumed by any physical property powered electrically. It can be used to eliminate energy theft and to achieve remote monitoring and control due to its capability for a two-way communication system. Makanjuola *et al.* (2019) indicate that the primary objective of the smart meter is for the reduction of energy consumption. In an era where sustainable practices and resource conservation are paramount, the integration of smart metering systems stands as a beacon

of hope for efficient energy consumption. The conventional paradigm of energy usage, characterized by opacity and inefficiency, is swiftly being replaced by the dawn of intelligent metering technologies (Martins *et al.*, 2019). The application of a smart metering technology brought about the use of different technologies such as wireless communication and Information and Communication Technology (ICT).

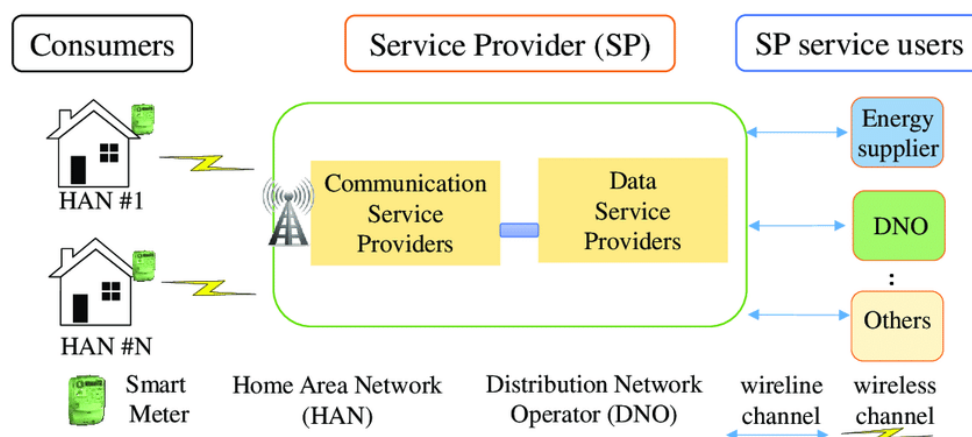


Figure 1: Smart metering architecture (Braeken et al. 2018)

The advent of smart metering systems heralds a transformative shift, empowering both consumers and utility providers with real-time insights and control over energy consumption patterns (Adetokun *et al.*, 2018). Smart metering systems represent the convergence of cutting-edge technologies, including IoT (Internet of Things), data analytics, and advanced metering infrastructure. Unlike traditional meters, which merely record cumulative energy usage at predetermined intervals, smart meters serve as dynamic gateways, facilitating bidirectional communication between consumers and utilities. Through seamless data transmission, these systems offer granular visibility into energy consumption patterns, empowering users to make informed decisions regarding their usage habits (Dahunsi *et al.*, 2021 and Ajenikoko *et al.*, 2015). This research work focuses on a Smart Metering data analysis for distributing the electricity smartly and efficiently to the consumers using a monitoring system of IoTs. Smart meter technology is considered an enabler of the energy transition and a driver of digitization and energy efficiency (Somefun *et al.*, 2019 and Dahunsi *et al.*, 2021).

Objective

This research focuses on the analysis of smart metering systems for efficient power consumption in various households. It develops a dynamic model for the operational unit of a smart metering system using electric circuit theory.

Problem Statement

One of the present problems in our electric energy sector is the issue of over-billing. Energy customers pay for more than they consume without their knowledge. An alternative to the smart meter is the prepaid meter but these meters do not provide information that can help the users make better decisions about their energy consumption. The prepaid meters have a poor Graphic User Interface (GUI) that is hard to interpret and does not have information saved that can be accessed. Two main groups can be distinguished in smart metering technologies such as wireless and wired. Wireless technologies usually entail less deployment costs and quicker installation than wired options. Additionally, they are more suitable for remote locations (Mudaliar & Sivakumar, 2020). However, wired alternatives for smart metering do not present interference problems from other network sensors that may occur in wireless technologies.

Literature Review

The advent of smart metering systems represents a watershed moment in the quest for energy utilization efficiency and sustainability. By harnessing the power of technology, data, and collaboration, these systems offer a pathway towards a more resilient, equitable, and environmentally conscious energy landscape. With the advent of smart meters, individuals will have the convenience of checking their electricity consumption information and paying their electricity bills directly from their smartphones, eliminating the need to physically visit an office or leave their homes. This technological advancement has greatly enhanced the accessibility and ease of managing electricity usage for consumers (Sivakumar *et al.*, 2021). The manual checks of energy metering and monitoring system performance are quite laborious, highly subjective, and unnecessarily time-consuming. Hence, there is a need for an efficient and cost-friendly energy management system; this serves as a motivation for this research to develop a smart metering system for efficient energy consumption through the Internet of Things (IoT) monitoring system.

At the heart of the smart metering ecosystem lies a smart technology that is measurable, achievable, relevant, and time-bound. This framework serves as the cornerstone for optimizing energy efficiency and fostering sustainable practices across residential, commercial, and industrial sectors. By harnessing the power of real-time data analytics, smart metering systems enable stakeholders to identify inefficiencies, mitigate wastage, and streamline operations proactively (Dahunsi *et al.*, 2021). The significance of smart metering extends beyond mere monitoring and billing; it encompasses a holistic approach to energy management that encompasses demand-side management, load forecasting, and grid optimization. Through advanced analytics and predictive algorithms, smart metering systems enable utilities to anticipate fluctuations in demand, identify potential bottlenecks, and deploy resources more efficiently. This proactive approach enhances grid reliability and resilience, reduces operational costs, and enhances the integration of renewable energy sources.

The study conducted by Sui et al. (2009) introduced a smart meter proprietary software program, based on an Advanced Metering Infrastructure (AMI) configuration and data collection system, which is situated in the data processing center at the base station of the smart meter. This software does three tasks: it receives data, decodes it, and stores it in a database for later analysis. Unusual data records occasionally may contain corrupted data as a result of abrupt stops or shutdowns brought on by lightning strikes or short circuits. This software does not take into account the previously described faulty data; it merely captures energy data. As a result, data on energy consumption becomes less precise, which has an impact on load profile analysis. This issue was resolved by Seoung-Hwan et al. (2011) using the Outage Management System (OMS), which locates outages and promptly restores them. Subsequently, many other researchers have worked on the improvement (Zanghi et al., 2024; Rind et al., 2023; Kumar et al., 2023; Aqeel et al., 2023).

Many other studies have been conducted concerning the design and development of smart metering systems using different computational algorithms. For example, Ahmed et al. (2017) developed a smart energy meter for Demand-side Energy Management (DEM) based on a novel real-time controller and scheduling technique. The computational technique of the Binary Tracking Search Algorithm (BBSA) was utilized in the framework for energy savings. In Haq et al. (2022), used a Reinforcement Learning Algorithm (RLA) for the development of a smart metering system for energy management. The purpose of the system development was to control appliances for energy management by applying the smart meter. The simulation results obtained in the study proved that an energy cost reduction from 6.23% and 11.54% can be achieved. In another study conducted by Rocha et al. (2021) for home energy management through the application of integrated Artificial Intelligence (AI) techniques using Elitist Non-dominated Sorting Genetic Algorithm II and Support Vector Regression (SVR) and K-means clustering. The new method was used for the effective implementation of demand-side energy management with the consideration of the instability in the price of electricity. The technique was able to make an appropriate forecast of electricity consumption for the next day. Therefore, this present study intends to develop a smart metering system based on the integration of modeling of the Internet of Things (IoT) platform, software application and circuitry mathematical modeling.

Scope of the Study

This research is limited to the analysis of smart metering systems using IoT technology through a case study conducted on the standard data obtained for three sets of households. The utilization of IoT technology provides energy users with accurate energy data, enhances energy efficiency, and enables users to make reliable decisions based on the information they have.

Methodology

Mathematical Equations for Energy Metering Device

The Root mean square (RMS) calculation, is the measured value of an AC signal. The rms of an AC signal equals the quantity in value of the required DC to produce an equivalent amount of power in the load. RMS is expressed mathematically as:

$$F_{rms} = \sqrt{\frac{1}{T} \int_0^T f^2(t) dt} \quad (1)$$

where; F_{rms} denotes the RMS value of the function $f(t)$ and T is the periodic time in seconds. The equation given below represents the RMS value of a time-sampling signal.

$$F_{rms} = \sqrt{\frac{1}{N} \sum_{n=1}^N f^2(n)} \quad (2)$$

where; F_{rms} denotes the RMS value of the sampling signal, N denotes the number of samples, and n denotes the N^{th} sample point of the signal. The computation for the instantaneous current is shown in Equations (3) and (4) respectively.

$$I(t) = \sqrt{2} I_{rms} \sin(\omega t) \quad (3)$$

$$I^2(t) = 2I_{rms}^2 \sin^2(\omega t) \quad (4)$$

where,

$I(t)$ is expressed as the instantaneous current, I_{rms} is the RMS current, ω is the angular frequency, and t denotes the time used.

Equation (4), square both sides and substituting the value of $1 - \cos^2(\omega t)$ for $\sin^2(\omega t)$ as explained in a trigonometry formula that states;

$$\sin^2(A) + \cos^2(A) = 1 \quad (5)$$

$$\cos^2(A) - \sin^2(A) = \cos(2A) \quad (6)$$

$$\sin^2(A) = \cos^2(A) - \cos(2A) \quad (7)$$

Since,

$$\cos^2(A) = 1 - \sin^2(A) \quad (8)$$

$$\sin^2(A) = 1 - \sin^2(A) - \cos(2A) \quad (9)$$

$$2\sin^2(A) = 1 - \cos(2A) \quad (10)$$

Therefore,

$$\sin^2(A) = \frac{1 - \cos(2A)}{2} \quad (11)$$

Recall, from Equation (4), we have; $I^2(t) = 2I_{rms}^2 \sin^2(\omega t)$

$$I^2(t) = 2I_{rms}^2 \frac{1 - \cos(2A)}{2} \quad (12)$$

$$I^2(t) = I_{rms}^2 (1 - \cos 2\omega t) \quad (13)$$

$$I^2(t) = I_{rms}^2 - I_{rms}^2 \cos 2\omega t \quad (14)$$

Root Mean Square Voltage

Based on the calculation of the RMS current. However, some energy measurement chips use the mean absolute value calculation to derive the RMS voltage. The mean absolute value is accurate when the signal has only the fundamental component. When the signal has harmonic components, the calculation is inaccurate. Therefore, the mean absolute value calculation can be as expressed in Equation (15):

$$V_{mav} = \frac{1}{T} \int_0^T |\sqrt{2}V_{rms} \sin(\omega t)| dt \quad (15)$$

V_{mav} is the mean absolute voltage, $\frac{1}{T}$ denotes the periodic time, and V_{rms} denotes the periodic time.

$$V_{mav} = \frac{1}{T} \left[\int_0^{T/2} \sqrt{2}V_{rms} \sin(\omega t) dt - \int_{T/2}^T \sqrt{2}V_{rms} \sin(\omega t) dt \right] \quad (16)$$

When the derivative with respect to $\omega = 2\pi f$, where $f = \frac{1}{T}$, $\omega = \frac{2\pi}{T}$, $\pi = \frac{\omega T}{2}$, $\pi = \frac{\omega T}{2}$ and $\theta = \omega t$ are considered, thus:

$$V_{mav} = \frac{\sqrt{2}V_{rms}}{2\pi} \quad (17)$$

V_{mav} is directly proportional to V_{rms}

Internet of Things (IoT) for Energy Monitoring System

In Figure 2, the development of the smart energy meter is shown. The system is designed with remotely controlled technology using a device that is based on centralized management, digital instrumentation and communication networks. The system is based on the browser and server mode structure which can be seen as an improvement from the client and server mode of internet technology. A three-layer structural scheme is used in browser and server mode. The user's interaction with the entire system is provided by the first-tier client. The Web page would contain an interactive feature that allows multiple users to send information to the backend via the Web page's application form, as well as make processing requests. The response process would start with the second-tier Web server, which dynamically generates a string of code that embeds the processing results and sends it to the client's browser. The monitoring system stems from the browser and electricity meters.



Figure 2: Developed smart meter system

Software Design and the Blynk Library

The design source code model would be the Arduino program which is based on C and C++ programming languages with three divisions such as initialization, assignment and command. The model deployed for the design of the software platform for the IoT Energy Monitoring System (EMS) in the smart meter is shown in Figure 3. The communication interface in this system is established through the Blynk IOT platform, which aims to provide users with information to promote awareness and knowledge of energy consumption and efficient usage. The Blynk platform is compatible with both IOS and Android devices, enabling wireless control of the ESP01 controller over the internet. The Blynk server facilitates communication between the user and the energy metering unit. Blynk is a widely used Internet of Things platform that enables the connection of various devices to the cloud, facilitates the development of control applications, and provides resource management capabilities. It supports the integration of more than 400 hardware models with the Blynk Cloud through the Blynk Library. Some of the compatible hardware models include Arduino, ESP8266, and ESP32. The Blynk ESP32 integration allows for seamless communication between the ESP32 microcontroller and the Blynk cloud platform, enabling the execution of programmed tasks and data transfer.

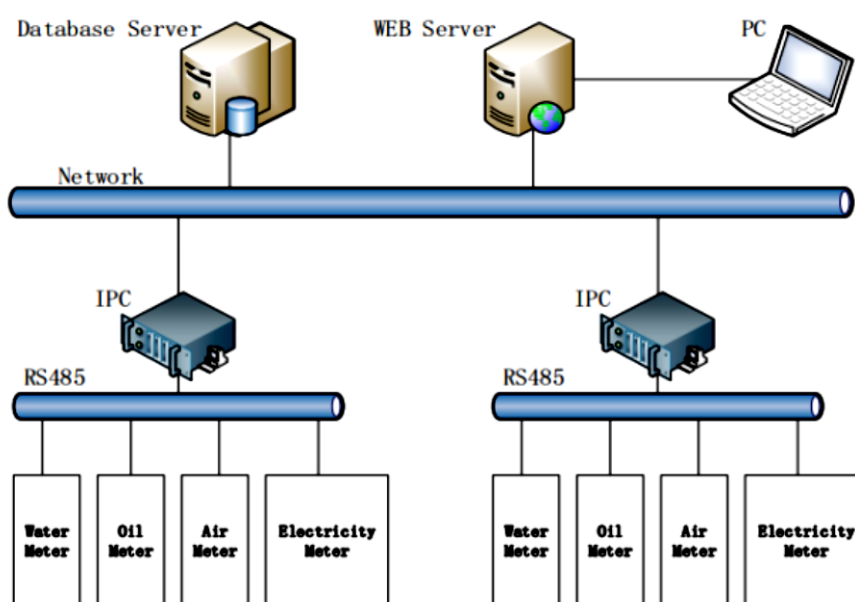


Figure 3: Model of IoTs Energy Monitoring System

Constructional Model of the Smart Metering System

The constructional operational model (Altomonte et al., 2021; Jaiswal & Thakre, 2022) of the developed smart energy meter shown in Figure 4 is composed of a standard energy measuring chip, microcontroller, LCD and GSM module as the basis for smart energy meter design. The design and development of the new smart energy meter involved the use of components like Arduino Uno board ATmega328P. These components operate as the

microcontroller unit to stabilize the energy meter. The microcontroller has 14 digital input and output pins that accommodate pulse width modulation (PWM) which comprises 6 pins, six analog inputs a 16MHz crystal oscillator and a USB connection, a power jack and ICSP header, and a reset button. Furthermore, the microcontroller board can be programmed to measure the active, reactive, energy, power current and voltage RMS, all in a single-phase system. The use of datasheet guides through a test circuit boosts the advantage of date readings as well as controls the distribution of SMS and calls in monitoring the household energy consumption rates and engaged energy billing.

This operation is aided by a microcontroller unit to attain proper communication of data and calibration. However, this operation is catalyzed by the introduction of the serial peripheral interface (SPI) bus, which enables the microcontroller to receive information from the energy chip and relay it to the consumers through LCD. The due process will enable the consumers to access and monitor their energy consumption by communicating the energy parameter GSM to the consumer. The device has a reset button linked to the microcontroller to enable a constant check of the information relayed to the consumers from the utility on a monitoring screen. The information relayed includes a time stamp processed by an in-built real-time clock located in the controlling unit, which relays up-to-date signals to keep records with every data. Furthermore, the energy parameters are transmitted via the SIM900 module as it communicates with the GSM and is sent to the end-user's phone as a display.

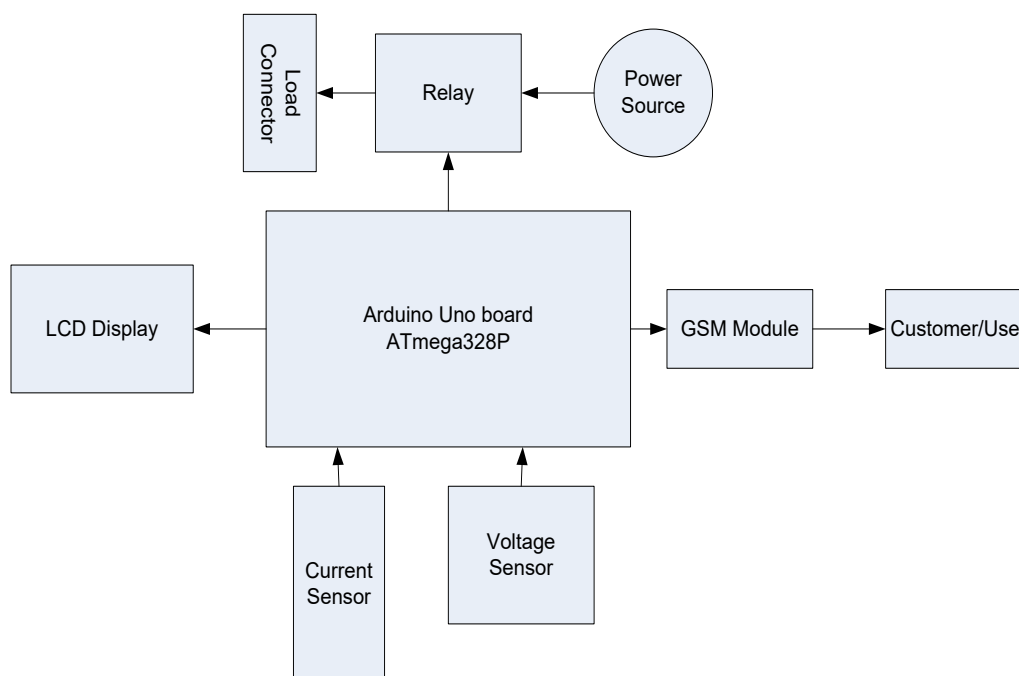


Figure 4: Constructional Model of the Smart Metering System

Results and Discussions

Real-time hourly power consumption data for the case study household and prices for the whole day from an electricity provider at IBEDC headquarters located in Ibadan, Oyo State was acquired. The time, price, cost, consumption, cumulative consumption, and cumulative cost are tabulated in an Excel sheet. The autocorrelation, price-cost correlation, price-consumption correlation, cost-consumption correlation, average deviation, standard deviation and coefficient of variation of price, cost and consumption are calculated. Every factor specified was tabulated for easy understanding. The data is arranged for the case study household and results are generated for consumption, price, cost and cumulative cost. Based on the systematically analyzed data, the results are drawn and evaluated as the performance metrics such as:

- i. The energy consumption result of the households is graphically displayed by showcasing the consumption (KWh) on the y-axis and time (24 hours) on the x-axis.
- ii. The price and cost graph of the households is graphically displayed by showcasing the price (monetary unit/KWh) and cost (monetary unit) on the y-axis and time (24 hours) on the x-axis.
- iii. The cumulative cost of the households is graphically displayed by considering the cumulative cost on the y-axis and time (24 hours) on the x-axis.

The three-performance metrics that would be considered are based on the energy consumption, price-cost and cumulative cost on a particular day of the household, which are interesting for some specific reasons. The data collected for the household are presented in Table 1.

Table 1: Datasheet of the case study household

Time	Price (Monetary Unit/KWh)	Cost (Monetary Unit)	Energy Consumption (KWh)	Cumulative Consumption	Cumulative Cost
1:00	238.48	531.744	2.23	2.23	531.7435
2:00	216.39	486.878	2.22	4.48	1018.621
3:00	207.75	452.895	2.38	6.66	1471.516
4:00	196.37	447.724	1.60	8.94	1919.239
5:00	203.07	452.846	1.91	11.17	2372.086
6:00	207.04	459.629	1.59	13.39	2831.715
7:00	199.54	474.905	1.46	15.77	3306.619
8:00	210.22	336.352	1.60	17.37	3642.972
9:00	215.77	412.121	1.91	19.28	4055.093
10:00	225.21	358.084	1.59	20.87	4413.176
11:00	217.71	317.857	1.46	22.33	4731.033
12:00	216.48	346.368	1.60	23.93	5077.401
13:00	203.25	359.753	1.77	25.70	5437.153

Table 1: Contd.

Time	Price (Monetary Unit/KWh)	Cost (Monetary Unit)	Energy Consumption (KWh)	Cumulative Consumption	Cumulative Cost
14:00	191.60	346.796	1.81	27.51	5783.949
15:00	181.02	302.304	1.67	29.18	6086.253
16:00	173.52	249.869	1.44	30.62	6336.122
17:00	170.25	316.665	1.86	32.48	6652.787
18:00	175.55	475.741	2.71	35.19	7128.527
19:00	206.86	562.659	2.72	37.91	7691.186
20:00	220.18	660.540	3.00	40.91	8351.726
21:00	227.51	445.919	1.96	42.87	8797.646
22:00	224.07	540.009	2.41	45.28	9337.655
23:00	217.36	376.033	1.73	47.01	9713.6874
24:00	211.89	457.683	2.16	49.17	10171.369

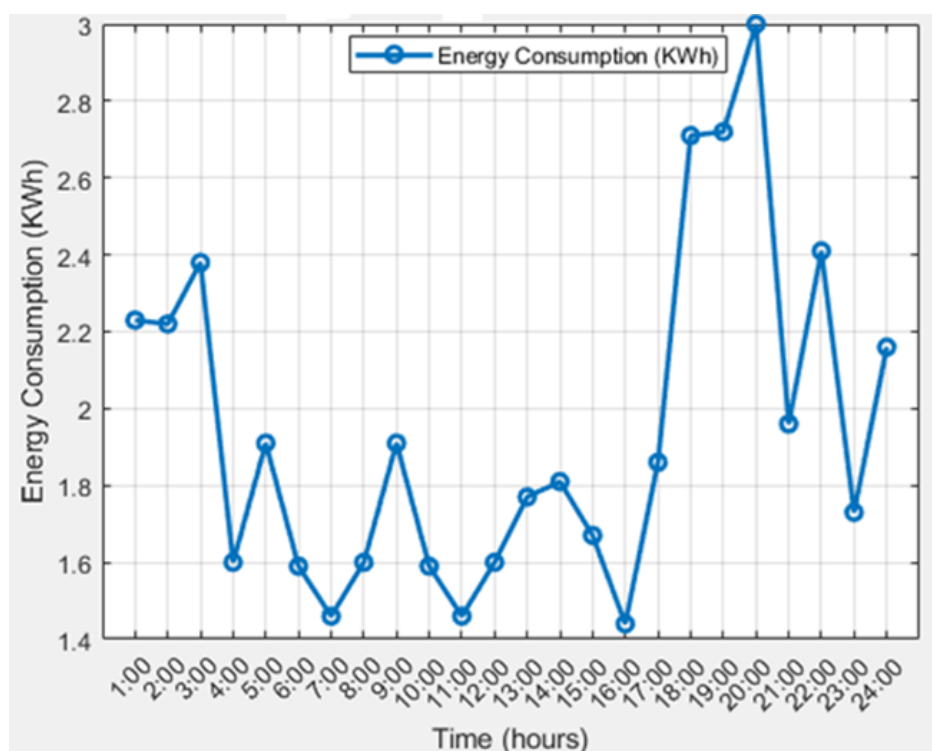


Figure 2: Energy consumption for household one over 24 Hours

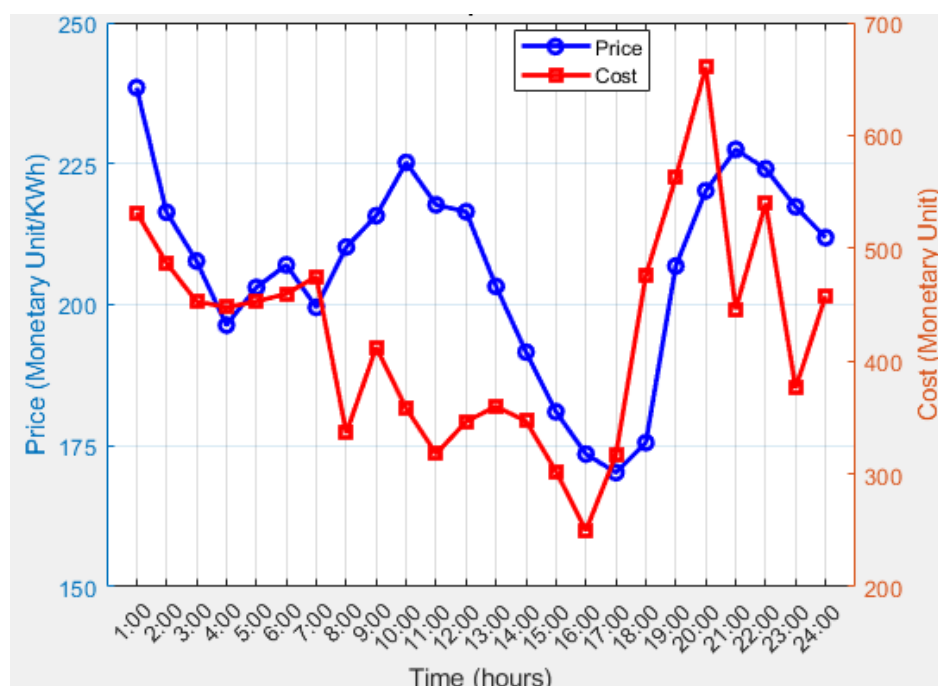


Figure 3: Price and cost consumption for household one over 24 Hours

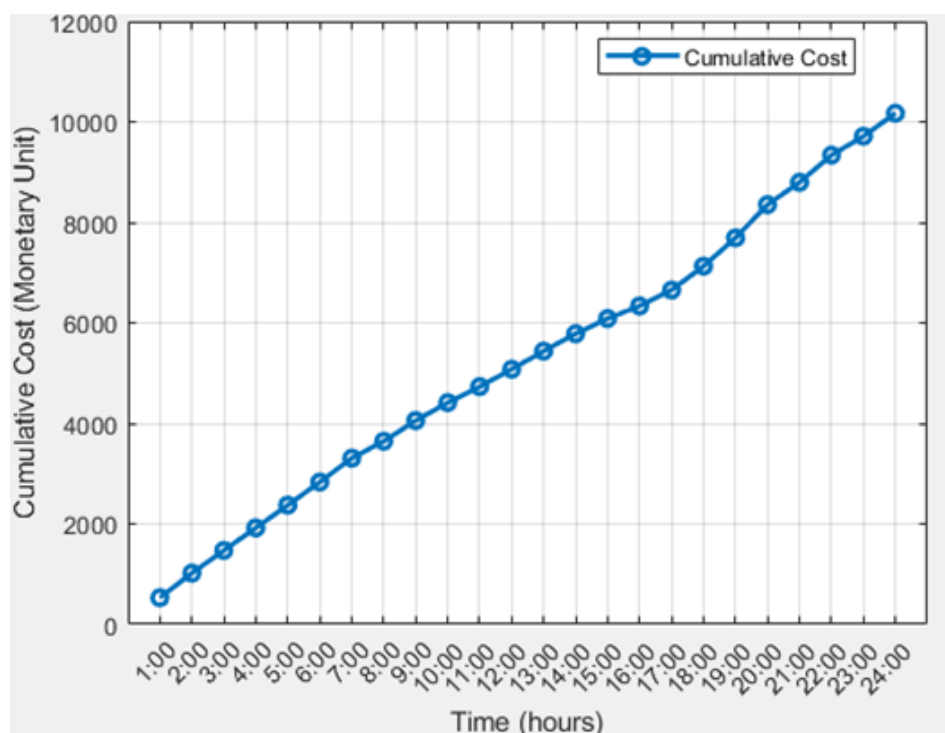


Figure 4: Cumulative cost for household one over 24 Hours

The energy consumption shown in Figure 2 regarding household one (1) declines from hour 1:00 to 3:00 and increases sharply from 4:00 to 20:00 at peak period hour before it finally

declines again at the hour 21:00 to 24:00. Figure 3 indicates the graphical representation of the household one (1) data set. This showcases the monetary price and cost of energy consumption. As the user is consuming much energy, the cost factor is high even though the price is low. At 20:00, the monetary cost increased to 660.540 with 220.18 units per kWh. When a consumer is engaged in subjecting the meter to many loads, the meter operates at a high kWh rate. During the low peak hours from 1:00 to 18:00, the cost of metering usage dropped concerning the unit price per kWh. Figure 4 shows the graphical representation of the cumulative cost. The result deduced that the cost linearly increased from 1:00 to 24:00 hours. The user should be smart enough to play a safer role in utilizing energy efficiently by avoiding spikes.

Conclusions and Recommendations

This research has explored the possible means to achieve an accurate process and effectiveness of a smart metering system for efficient energy consumption compared to a conventional metering system. With all the obtained data from the statistical analysis, the results imply that a close inspection is done from the obtained data and the achieved results justified that the usage of electricity by a household is high during the beginning of the day, middle of the day and low during the ending of the day. The results generated from the obtained data state the performance and analysis of the household for consumption, price-cost and cumulative cost. The experiment and simulation conducted also revealed that any fraudulent activity can be detected irrespective of when the system is tempered with at variable or fixed energy price. The patterns of graphical analysis suggest that the consumers serve a competitive nature. Several models were observed and a precise selection is done based on goodness of fit statistics. The statistical approach utilization can be effectively improved with the observation of distributed statistics while the unstable behaviour of users is noticed in the graphical analysis.

In this research work, the behavioural pattern of the data obtained was analyzed and interpreted based on the set of consumption data from the case study household. It can be concluded that effective measurement of electricity consumption can be performed by using Smart Meters. The major advantages of these models when compared to other models are determining complex nonlinear relationships between dependent and independent variables, assessing the flexibility and improving future forecasts using previous forecast errors can be achieved through the recommended computation intelligent methods. Therefore, the following important recommendations are suggested:

- Improvement in the communication system of the current smart system is necessary to be carried out in the future for dependability enhancement.
- Future study should also be directed towards investigation of the robustness of the security architecture of the smart metering system for data privacy protection.

- In addition, future work can also be directed towards the application of Artificial Neural Networks and machine learning algorithms with a stochastic model approach for data prediction through the application of the smart meter.

References

- Adetokun, B. B., Somefun, T. E., Adekitan, A. I., Aligbe, A., & Orimogunje, A. M. (2018). Development of an ANN-based estimated electricity billing system. In *2018 IEEE PES/IAS PowerAfrica* (pp. 96-101). IEEE.
- Ahmed, M. S., Mohamed, A., Khatib, T., Shareef, H., Homod, R. Z., & Abd Ali, J. (2017). Real time optimal schedule controller for home energy management system using new binary backtracking search algorithm. *Energy and Buildings*, 138, 215-227.
- Ajenikoko, A. G., & Adelusi, L. O. (2015). Impact of prepaid energy metering system on the electricity consumption in Ogbomoso South local government area of Oyo State. *Computer engineering and intelligent systems*, 6(5), 99-105.
- Altomonte, A., Arena, F., Riccio, M., & Irace, A. (2021). A New Three-Phase Smart Meter for Cloud Connection: Network Architecture and Performances. *Engineering Proceedings*, 10(1), 46.
- Aqeel, M., Shahab, H., Naeem, M., Shahbaz, M. S., Qaisar, F., & Shahzad, M. A. (2023). Intelligent Smart Energy Meter Reading System Using Global System for Mobile Communication. *Int. J. Intell. Syst. Appl*, 14(1), 35.
- Braeken, A., Kumar, P., & Martin, A. (2018). Efficient and privacy-preserving data aggregation and dynamic billing in smart grid metering networks. *Energies*, 11(8), 2085.
- Dahunsi, F. M., Olakunle, O. R., & Melodi, A. O. (2021). Evolution of electricity metering technologies in Nigeria. *Nigerian Journal of Technological Development*, 18(2), 152-165.
- Haq, E. U., Lyu, C., Xie, P., Yan, S., Ahmad, F., & Jia, Y. (2022). Implementation of home energy management system based on reinforcement learning. *Energy Reports*, 8, 560-566.
- Jaiswal, D. M., & Thakre, M. P. (2022). Modeling & designing of smart energy meter for smart grid applications. *Global Transitions Proceedings*, 3(1), 311-316.
- Kumar, G., Kumar, L., & Kumar, S. (2023). Multi-objective control-based home energy management system with smart energy meter. *Electrical Engineering*, 105(4), 2095-2105.
- Rind, Y. M., Raza, M. H., Zubair, M., Mehmood, M. Q., & Massoud, Y. (2023). Smart energy meters for smart grids, an internet of things perspective. *Energies*, 16(4), 1974.
- Makanjuola, N., Shoewu, O., Akinyemi, L., & Ogunsanya, O. (2019). Investigation on Smart Meters and Revenue Generated for a Year Using Eko Electricity Distribution Company of Nigeria as Case Study. *Data Research*, 3, 1-12.
- Martins, J. F., Pronto, A. G., Delgado-Gomes, V., & Sanduleac, M. (2019). Smart meters and advanced metering infrastructure. In *Pathways to a smarter power system* (pp. 89-114). Academic Press.
- Mudaliar, M. D., & Sivakumar, N. (2020). IoT based real time energy monitoring system using Raspberry Pi. *Internet of Things*, 12, 100292.
- Rocha, H. R., Honorato, I. H., Fiorotti, R., Celeste, W. C., Silvestre, L. J., & Silva, J. A. (2021). An Artificial Intelligence based scheduling algorithm for demand-side energy management in Smart Homes. *Applied Energy*, 282, 116145.
- Seoung-Hwan, C., S. H., Kang, S. J., Jung, N. J., & Yang, I. K. (2011). The design of outage management system utilizing meter information based on AMI (Advanced Metering Infrastructure) system. In *8th International Conference on Power Electronics-ECCE Asia* (pp. 2955-2961). IEEE.

- Sivakumar, V., Swathi, R., & Yuvaraj, V. (2021). An IoT-Based Energy Meter for Energy Level Monitoring, Predicting, and Optimization. In *Challenges and Opportunities for the Convergence of IoT, Big Data, and Cloud Computing* (pp. 48-65). IGI Global.
- Somefun, T. E., Awosope, C. O. A., & Chiagoro, A. (2019). Smart prepaid energy metering system to detect energy theft with facility for real time monitoring. *International Journal of Electrical and Computer Engineering*, 9(5), 4184.
- Sui, H., Wang, H., Lu, M. S., & Lee, W. J. (2009). An AMI system for the deregulated electricity markets. *IEEE Transactions on Industry Applications*, 45(6), 2104-2108.
- Zanghi, E., Brown Do Coutto Filho, M., & Stacchini de Souza, J. C. (2024). Collaborative smart energy metering system inspired by blockchain technology. *International Journal of Innovation Science*, 16(2), 227-243.