DEVELOPMENT OF AN ELECTRIC POWER OUTAGE MONITORING AND LOGGING SYSTEM

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Abstract
Recently, the Nigerian Electricity Regulatory Commission implemented the service reflective tariff to encourage investment, improved service delivery and competitiveness in the electricity distribution sector. This tariff system imposes a higher tariff on consumers in band allocations with longer duration electricity supply. However, the discrepancy between the duration of supplied electricity and the expected duration for the respective bands results in inaccurate billing, financial losses and a lack of trust. Additionally, unmetered electricity customers are usually billed based on an averaged estimated energy consumption including losses and is not reflective of the actual energy consumed. This work focuses on the development of a device for monitoring and logging electricity power consumption and outage duration. The system control is achieved using the Microchip ATmega328P microcontroller and relies on sensed inputs of voltage, current and power from the PZEM-004T module for its operation. The developed system provided accurate measurements of the electrical parameters and was tested for supplied electricity duration and outage over a period of three days. The results show that at the selected location belonging to the Band A category (> 20 hours/day supply), the daily electricity supplied were 4 hours, 57 minutes, 16 hours 13 minutes and 11 hours 39 minutes, respectively, much lower than the expected duration for the designated service band.

Keywords: *Outage monitoring, electricity meters, data logging, microcontroller*

Introduction

A Currently, Nigeria's electric power generation (approx. 5000 MW) severely lags its actual installed generation capacity (13000 MW) due to a prolonged neglect and poor investment in the power sector. Additionally, the inability to meet the installed generation capacity have been linked to a combined 60% losses from maintenance-related outages of generation units and pipeline vandalism leading to inadequate gas supply to power plants and a further loss estimated to be between 15%-20% of electricity generation occurring during transmission due to aging infrastructure (Daggash and Dowell, 2021). These factors have resulted in Nigeria's low energy consumption per capita, which is among the lowest in the world, and severe power cuts across the country with a significant negative economic impact (Dimnwobi et al., 2022; Lawal et al., 2020). Some of the factors that lead to outages in Nigeria include (i) load shedding due to insufficient generation capacity; (ii) insufficient investment in the power sector, poor maintenance practices and inadequate trained personnel; (iii) insufficient gas supply usually due to vandalism of pipelines and the resultant low generation capacity; (iv) transmission and distribution losses due to aging infrastructure and energy theft; and (v) environmental and climatic factors such as extreme weather events (Heavy rains, flooding, lightning strikes, and storms often damage power infrastructure) (Komolafe and Udofia, 2020; Babatunde et al., 2020; Daggash and Dowell, 2021).

In an effort to improve efficiency and attract the urgently needed investment in the power sector, the Nigerian government, while retaining the transmission assets, privatised electricity generation and distribution. Recently, the Nigerian Electricity Regulatory Commission (NERC) implemented a new tariff system aiming to encourage investments in the Nigerian energy sector and improve its financial viability. This policy appears to have been undermined by inadequate regulatory framework and has resulted in the exploitation of electricity consumers. The Multi-Year Tariff Order (MYTO) 2020 effective from September 2020, ensures that tariffs charged by the distribution companies are both cost (true cost of service) and service (incentive-based pricing) reflective. This means that electricity consumers are grouped into clusters based on their expected service levels and the tariffs charged by the distribution companies (DisCos) for each customer band is reflective of the quality of service, availability of power committed to such customers and the average response time to customer complaints (Ogba and Pila, 2020). Based on the daily duration of electricity supplied to customers, the Service Reflective Tariff (SRT) regime categorizes electricity customers into five (5) Service Bands with different tariffs: (i) Band A - a minimum of 20 hours supply daily; (ii) Band B - minimum of 16 hours supply daily but less than 20 hours daily; (iii) Band C - minimum of 12 hours supply daily but less than 16 hours daily; (iv) Band D - minimum of 8 hours supply daily but less than 16 hours daily; (v) Band E - minimum of 4 hours supply daily but less than 8 hours daily. Due to inadequate monitoring by the regulators, customers are usually supplied electricity for durations lower than their respective band allocation but are charged at the rate of their assigned bands.

A key regulatory problem is the large number of unmetered consumers, which by NERC's estimate is about 39.8% of registered electricity customers (11,058,939) in the second quarter of 2021(NERC, 2021), resulting in the prevalence of seemingly inaccurate estimated billing by the electricity distribution companies (DisCos). The NERCs second quarterly report for 2021 indicates that eleven (11) DisCos installed a total of 315,717 prepaid meters in the second quarter of 2021, but could not close the metering gap as about 4.4 million customers remain unmetered (NERC, 2021).The large number of unmetered electricity consumers in Nigeria motivates the electricity distribution companies to use estimated billing. Computed estimated bills are usually not accurate and can sometimes be exploitative especially in situations where there is no evidence on the part of the consumer to dispute the estimated values (Soyemi et al, 2021).

Since the current tariff structure in Nigeria, which consists of bands A-E, depends on the duration of electricity supplied, electricity bills even for the metered customers may not reflect the quality of electricity supplied. Consequently, there is a need for a user-centered energy metering device that can be used to dispute the inaccurate billing system and instil a level of trust in the system. This study therefore presents the development of a device for electricity outage monitoring and logging.

Electricity monitoring systems play a crucial role in modern power distribution networks, providing valuable insights into power quality, consumption patterns, and outage events (Dahunsi et al., 2021). Among the various aspects of electricity monitoring, outage duration estimation and logging have received significant attention due to their impact on network reliability, maintenance planning, and in this work, for validating the tariff class of consumers. Outage duration estimation refers to the process of accurately determining the duration of power outages experienced by consumers. Accurate estimation and logging of outage durations are essential for power utilities to assess the reliability of their networks, identify critical areas prone to frequent outages, and plan maintenance activities effectively (Macmillan et al., 2023; Salman et al., 2023).

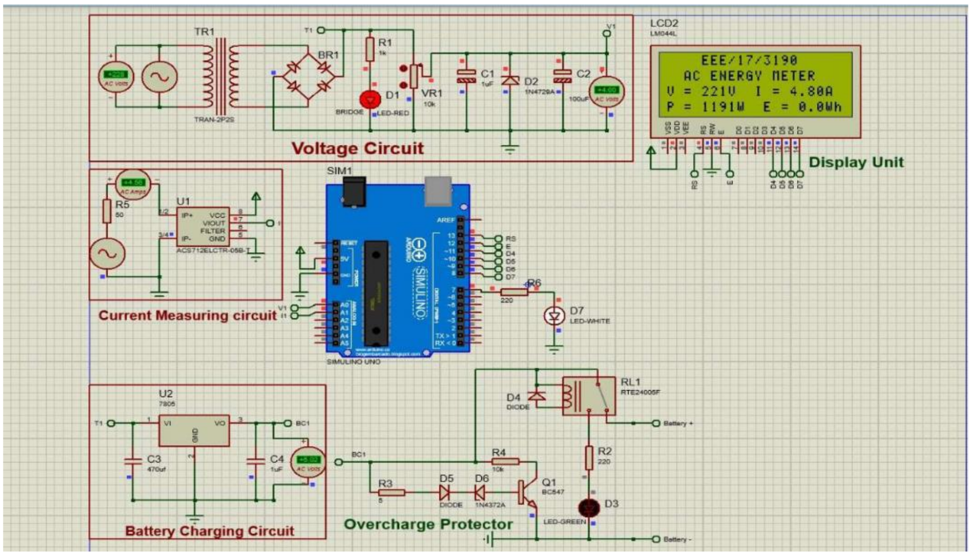


Figure 1: Simulation of the device in Proteus software application

Zhao et al. (2019) developed an internet of things (IoT)-based system for a real-time monitoring of power system parameters. The developed system was based on an FPGA-embedded controller due its high speed and reliability both of which are important requirements in power systems monitoring. Ali and Alrikabi (2022) developed an electricity monitoring system that is also based on the internet of things. The developed system uses the PZEM-004T sensor for measuring electrical parameters, ESP32 microcontroller and a Rhaspberry Pi configured as a server to transfer the measured electrical parameters of current, voltage and power to a database through the internet. The study focused on analysing consumption patterns and improving power supply management. In Vinogradov et al. (2019), a system for monitoring the number and duration of power outages on electrical power networks was developed. The proposed system consisted of sensors that were installed at the consumer terminals of the electrical transmission lines and at the low voltage buses of a transformer substation. The system proposed to provide a network-based power quality and reliability monitoring. Bayat et al. (2021) developed a complimentary technique for power outage detection that relied on the status of residential internet connections. The proposed method achieved an accuracy of 90% when compared with data from power utility companies. Also, Ferrand and Vela (2023) developed an algorithm for outage detection and localization in power distribution systems by pinging proximal internet connections. Kabir et al. (2023) developed a methodology for estimating power outages based on data about the electrical power network and environmental and weather conditions. The proposed methodology is a probabilistic approach to outage prediction. Most of these systems focus on electrical power network monitoring and in some cases were developed to predict outages from remotely acquired parameters. However, in this work, the developed device is user-centered and is expected to provide logged data of energy consumption, electricity supply duration and electricity outage duration at the consumer premises.

Materials and Methods

The system design involves the following key objectives: (1) design an electricity monitoring and logging system; (2) collect and compute the daily duration of electric power supplied; and (3) compare the supplied duration with the service band allocation of the user. The device operates by logging time stamped measurements of electrical parameters like the voltage and current at any given point in time. It is powered by both the mains supply and a back-up battery in order to ensure a continuous operation. The system logs data at intervals of 10 seconds and obtains the outage duration from the difference in time between the intervals of non-zero measurements of voltages and currents. These intervals of between successive non-zero measurements are accumulated and saved on a memory card.

The developed system incorporates both hardware design and software simulations. The software aspects involved circuit simulations in Proteus Software (Wu and He, 2012) of the electronic sub-circuits such as the battery charging circuit, current measuring circuit, voltage measuring circuit and overcharge protection circuit (see Figure 1). Additionally, the KiCad software, a tool used for printed circuit board (PCB) design, was used for PCB design and circuit transfer onto a physical board. The developed system uses the Microchip ATmega328P microcontroller to monitor sensor data, perform operations on the acquired data and control the overall system. The microcontroller performs such operations as reading the energy consumption data from the sensors, calculating the outage duration and logging the processed data. The interactions between the microcontroller and the connected circuits are performed in software within the Arduino Integrated Development Environment (IDE).

Figure 2 shows the block diagram of the developed system. A major component in the design is the PZEM-004T energy sensor (PZEM-004T-V3.0

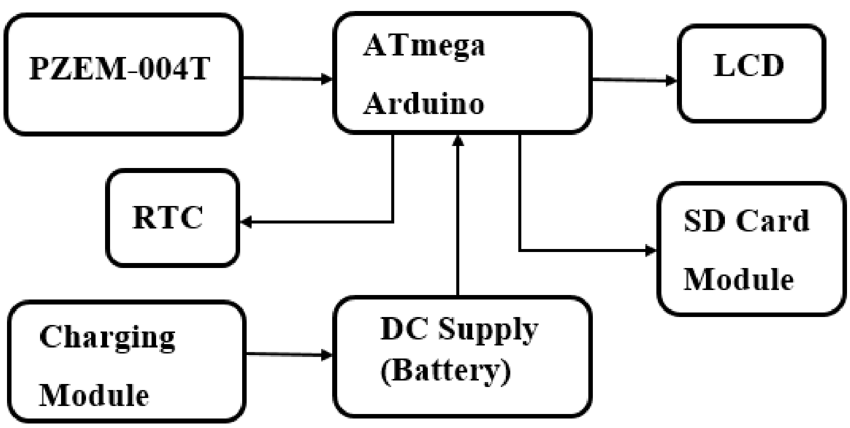


Figure 2: Block diagram showing the interconnection of the system sub-components

Datasheet), which is designed to measure electrical power, voltage, current and energy consumption. It has a built-in microcontroller and processing circuitry that allows for the computation of electrical parameters based on the measured voltage and current. Also, the PZEM-004T utilises non-invasive current transformers ensuring safety and ease of installation. In order to provide a timestamp for the measured parameters, ensure estimation of outage times and a precise scheduling of the data logging (intervals of 10s), the real time clock (RTC) was used. The RTC (DS1307) operates independent of the microcontroller ensuring uninterrupted timekeeping even win the absence of a power supply to the system. The microcontroller takes inputs from the PZEM-004T and the RTC saves the processed data on local SD card with a capacity of 2 GB and displays in real time on an LCD screen. The saved data on the SD card is in '.txt' format and each logged data includes time stamps indicating the date and time of the measurement.

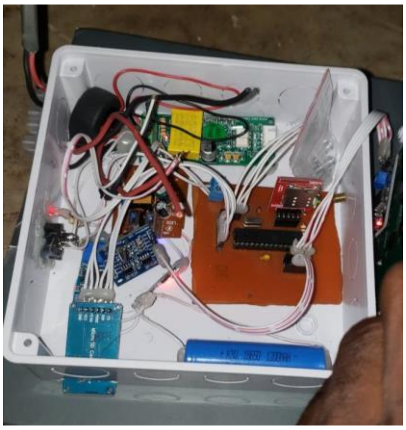
Table 1: The extracted data from the monitoring system illustrating the occurrence of an outage and the calculation of outage duration from logged data

Row Number	Date	Time (WAT)	Voltage (V)	Current (A)	Supply Duration	Outage Duration
1835	2024-1-11	23:0:32	226.60	0.05	5hour(s),1minute(s), 13second(s)	
1836	2024-1-11	23:0:42	224.60	0.05	5hour(s),1minute(s), 23second(s)	
1837	2024-1-11	23:0:53	NaN	NaN	5hour(s),1minute(s), 34second(s)	59 minutes, 51seconds
1838	2024-1-12	0:0:48	210.40	0.05	0hour(s),0minute(s), 0second(s)	
1839	2024-1-12	0:0:59	209.80	0.05	0hour(s),0minute(s), 11second(s)	

The system incorporates a power supply unit (PSU) that is connected to the main power source and produces a direct current (D.C) output of 5V. The PSU provides power to the various system components and is connected to the TP4056 charging module used to charge the back-up power source- a rechargeable battery (18650). Other hardware components used include jumper wires, switch and battery holder.

Results and Discussion

Figures 3(a) and 3(b) show the component assembly and the developed electricity monitoring system. The display shows measured voltage, current and power of 216.20 V, 0.06A and 4.00 W, respectively. In order to evaluate its performance, the monitoring system was installed at a selected location (Band A allocation) in Alagbaka, Akure, Ondo State, and operated continuously for three days. The system logs the timestamp, voltage, current, power and the duration of outage events and saves as a '.txt' file on the SD Card.



(a)

(b)

Figure 3. Electricity monitoring system (a) component assembly (b) complete system displaying measured parameters

The system records NaN (Not a Number) for measured voltage and current during an outage event. It is programmed to accumulate the supply duration and the outage duration. In Table 4.1 on row 1835, it shows accumulated supply duration of 5 hours, 1 minute, and 13 seconds. After a 10 second interval (row number 1836), the system collected and recorded additional data, extending the power supply duration to 5 hours, 1 minute, and 23 seconds. Similarly, the accumulated outage duration as shown in table 4.1 is 59 minutes and 51 seconds. The following row indicates that power was restored, and the system resumed logging the supply duration at a 10-second interval until another outage event occurred.

Additional results show that for the selected location, the daily power supply duration for January 12, 2024 to January 14, 2024 are respectively 4 hours, 57 minutes, 16 hours 13 minutes and 11 hours 39 minutes, respectively. These results clearly indicate that the electricity supplied is far lower than the expected minimum of 20 hours/day for the premium Band A customers.

Conclusion

This work has highlighted the disagreement in service provision by the Nigerian electricity distribution companies and the current cost and service reflective tariff system. This disparity leads to the electricity consumers paying high tariffs for services that were not provided. It has shown that by having a monitoring system, consumers can dispute electricity bills based on the electricity supply and outage duration information. Consequently, the work has demonstrated the design of an electricity monitoring system for outage duration and logging. The system was tested over a period of three days at a location in Alagbaka, Akure, Ondo State, categorised as belonging to Band A customers (>20 hours/day electricity duration). The results indicate that the daily power supply duration over the three day period are respectively 4 hours, 57 minutes, 16 hours 13 minutes and 11 hours 39 minutes, respectively, which is far lower than the expected electricity supply duration for Band A customers.

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