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An Edge Device for Monitor and Control of Electrical Appliances using Smart Power Line Communication

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***Abstract*—Smart control and monitoring have been critical in recent times due to the increase in cost and demand for electrical energy. In residential, commercial, and industrial sectors like building energy management, IoT farming, Smart Street Lighting, and Hospitals, Internet of Things (IoT) play a vital role in analyzing the consumption of individual loads. Available smart switches are restricted to changing the switch state (control) using a wireless channel. However, they fail to analyze the consumption of each electrical appliance. Signal propagation is more efficient in the case of low voltage networks by using Power line Communication (PLC). PLC is more convenient in analyzing the electrical consumption of individual loads as it does not require any additional wiring infrastructure. The paper proposes a smarter way of controlling and monitoring the consumption of individual appliances using PLC, IoT Sensors, and the Webserver. The design can be effectively implemented and yields appropriate results, as shown by the field experiments that were conducted and presented.**

***Index Terms*—Power Line Communication, Energy Management System, Internet of Things, Smart control, master device, slave device.**

I. Introduction

Technological advancements and shift of technology to a digital era enabled to begin new data-driven and the decision based techniques in building energy management system. In these times of rising energy prices, energy conservation is critical. In the current environment of rising prices, there is an urgent need to control and monitor the energy consumed in our daily lives. Monitoring consumption of an individual electrical appliance provides the data corresponding to the complete system. This data is needed to take decisions related to energy management and conservation. Monitor the consumption of individual load time to time is a good practice to omit local safety issues. On the other hand with out the knowledge of actual consumption of existing load possibility of upgrading the system by adding additional load is quite challenging task. This also leads to a reliability hazards to the existing electrical system. By monitoring power consumption at major loads users may observe how much power is utilised when, by who, and at what cost. The loads are monitored and controlled by creating a mobile-based Android app and web based Graphic User Interface (GUI) for the consumer. By offering an interactive graphical depiction, the user may get full control over the individual load and monitor the energy usage of each load periodically.

As the demand for electricity increases day by day, Consumers and utility companies focusses to develop the solutions for capturing power consumption information [1]. Peak demad at the grid was occured primarily at the night, where all the household electrical appliances like television, air conditioner, lights and fans are operated [2] - [5]. Automatic Meter Reading (AMR) is one solution to the problem. Power lines are one of the AMR system's communication mediums. AMR with power line carrier [6] is currently being employed in major cities. As the utility industry experiences structural changes, the metre must provide a broader variety of performance and usefulness [7]. The performance of industrial control is changed by the inclusion of advanced techniques in communication and programming platforms. The device should be built as a customizable product with low cost, robust and market viable solution [8]. Energy management Systems are classified as industrial, commercial, and residential. In [9], author examines the present state of EMS technology in manufacturing organisations, as well as common techniques to increasing energy efficiency. Substations are in accountable for providing safety, control, and monitoring tasks that enable reliable power transfer from generators to loads over a complicated network of transmission lines [10]. Using current measurement infrastructure, a non-intrusive method to transformer monitoring, assessment, and dynamic loading was proposed in [11].

In today's world, houses are getting more sophisticated. Instrumentation and automation technologies that have been making their way into our auto mobiles over the last decade are projected to spread into the home market in the near future [12]. On low-voltage (LV) distribution networks, Power Line Communications (PLC) have emerged as one of the prospective technologies for transferring data between end customers and power providers.

It is necessary to develop a completely new PLC system with variable information rate in order to provide communications services with varying priorities under the smart grids environment [13]. Currently, active distribution networks require capillary generation and storage at the Low Voltage (LV) level. Several smart energy devices now request the level of data sharing associated with distribution system operation and aggregated demand response. Nonetheless, due to complex field environments and security concerns, it is difficult to extend current information systems to end users. At the lowest voltage level, utilization networks lack the space and communication channels required to add additional remote devices to enable interoperation with power distribution systems.

The main contributions of this paper includes:

1) Develop a method and system to monitor and control load profiles of various electrical appliances and the consumption of each appliance is made available to both the users and the utility company through web and mobile applications.
2) Establishes a network consisting of the main switch designated as Master device located at host and all other switches designated as Slave devices connected to individual appliances.
3) Comprising a data storage unit at the Master device to store the sensed data with a sampling rate of 1 sec and further the data is transmitted through Wi-Fi to the indigenous cloud platform.
4) Provides information regarding power factor, tariff, low voltage, high current protection, and theft identification and also an intelligent control and monitoring mechanism through a mobile application such that users can have control over the consumption of individual appliances, users can also reduce the power bill by controlling the consumption.

The structure of this paper is as follows. Section II introduces the complete design of the system which includes hardware and software, Section III details the results of webserver and the findings of the examination, and the last Section offers conclusions.

II. Detailed Design of the System

The complete system to monitor and control consumption of individual appliances consists of three major segments namely hardware, software and the communication. Figure 1 shows the complete block diagram of the system where Master device, Slave device and the communication are labled. The system also comprises a hybrid combination of Wi-Fi and PLC to trasfer the signal/ data between Master to Cloud and Slave to Master respectively.

The detailed discussion on the individual blocks of software and hardware are presented in the following subsections.

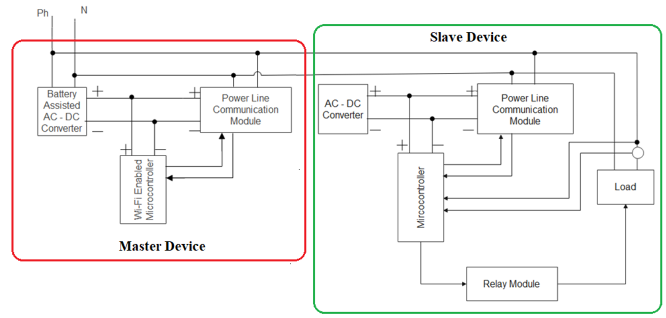

Fig. 1. Block diagram of complete system

A. Hardware

The system comprises two devices namely a Master Device and one or more Slave Devices. Master Device consists of a Wi - Fi enabled micro-controller and a Power Line Communication Module. This Master Device communicates with a user-friendly interface through a wireless medium via a mobile device. A microcontroller, a Power Line Communication Module, and a relay module comprise Slave Devices.

These Slave Devices are directly attached to the electrical appliances, sensing voltage, current, power, and power factor and sending the data to the Master Device via a Power Line Communication (PLC). User sends ON/ OFF signals from a mobile device which is connected to the master device via a wireless communication medium. Then the command signal sent by the user is transmitted by the master device using a Power Line Communication. At the other end the signal is received by the slave devices and accordingly the relay module connects the electrical appliance to the mains supply. At the instant of Switching ON of the electrical appliance slave device captures the data related to current, voltage, power and power factor of the appliance and transmits it to the master device using Power Line Communication.

In the final stage the master device receives the information from the slave devices and the information is communicated to the mobile device through a wireless medium for display and analysis purposes.

*1) **Master Device:*** At the initial phase input AC signal is converter to a 5 V DC using an AC- DC converter. The converted DC supply of 5 V is fed to Power Line Communication module, ZMPT101B AC Voltage Sensor, Node MCU, and the SD Card shield. Here Node MCU is the processing unit which will receive/ send both command and data signals from different slave devices to the web server. It also verify the internet connectivity to send the data to the web server if the internet is not available or poor signal the data received from the slave devices is stored temporarily in the local storage (SD Card). Voltage sensor in the device detect the AC voltage applied to various slave devices in parallel. Based on the voltage and current data received from the sensors computation of Power in KwH, bill, and the power factor are done in Node MCU using open source arduino programming IDE.

*2) **Slave Device**:* The DC 5 V obtained from the AC- DC converter is fed to ACS 712 current sensor, ATtiny 85 micro controller, and Power Line Communication module. Here the command signal from the master device is received through power line and the opto coupler based traic switch connects the load to the AC supply mains. Current sensor detects the consumption of load in amps and send to the ATtiny 85 micro controller. Then the micro controller push the data to master device for computation and storage using the same power lines as communication channel.

*3) **Power Line Communication Module**:* The system comprises of KQ330f power line communication module [14], [15], which uses single-carrier class modulation technique [16]. The module transmit the data via low voltage power line as the medium. The modulated signal frequency is of 50 kHz - 350 kHz. It is most prominent way of modulating a high frequency signal on low voltage power line such that it can be transmitted over a distance. By using this module the system effectively transmit the data without any interference, provide quality communication, reduces the cost of communication.

B. Software

The complete software system is devided into two parts (i) Control flow (ii) Data flow. Figure 2 presents the detailed control flow used to access individual appliances through a web server/mobile application. Data flow is used to monitor device performance in terms of voltage, current, power and power factor readings as shown in figure 3. Web application is built using django framework. A postgresql database is connected to the server. Different functions have been defined in order to retrieve and insert data into the database. An User Interface (UI) is designed using bootstrap framework, which makes it responsive across different devices. User can toggle the switches of the load, view the statistics, analyse previous data and download the statistics into a Comma-Separated Values (CSV) file.

Django is a Python web framework that promotes rapid development, clean, and pragmatic design. It takes much care about the security and hassle free web development. It's free and open source. Django provides a framework that has been engineered to "do the right things" to defend the website automatically, which helps developers avoid many common security blunders. Django also provides a secure approach to manage user accounts and passwords, avoiding mistakes like keeping session information in cookies (instead, cookies just carry a key, while the actual data is saved in the database) or directly storing passwords rather than a password hash.

III. Results

Figure 4 gives the hardware setup of the complete system, where the individual components are listed in table 1 as follows.

Figure 5 and 6 shows a sample view of the webserver and graphs of voltage, current and power. Power data will be send to the webserver automatically. The data on webserver can be exported in the csv extension using the button print statistics. So that it can be used for future analysis.

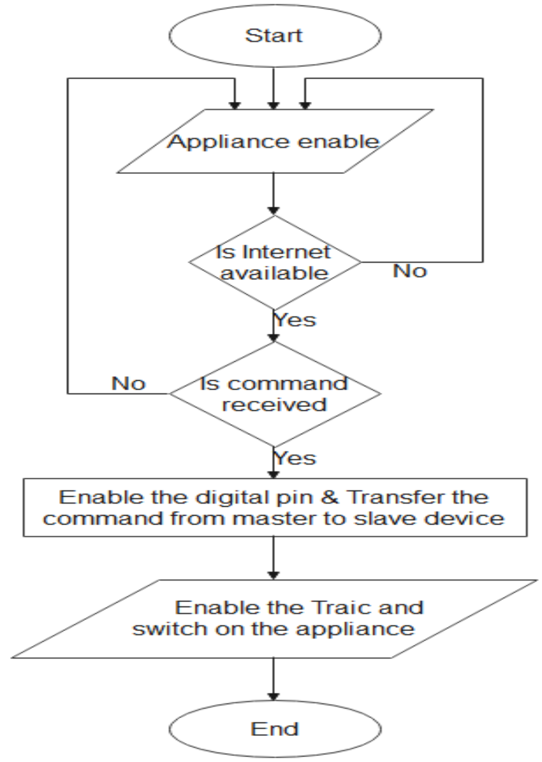

Fig. 2. Controlling of the appliance flow chart

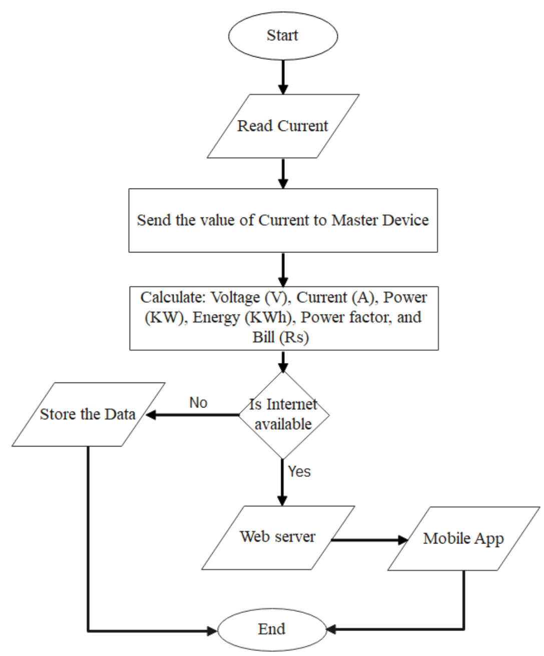

Fig. 3. Monitoring of the appliance flow chart

IV. Conclusion

This study proposes and develops an IoT-based edge device for smart power line communication monitoring and management of household appliances. The methodology is intended to create an easy-to-use monitoring and control system. The

TABLE I
DETAILED HARDWARE COMPONENTS

S. No	Name of the Equipment
1	Power Line Communication Module (KQ330F)
2	Voltage Sensor Module (ZMPT101B)
3	Current Sensor Module (ACS712)
4	Lamp Load (CFL)
5	AC - DC Converter Module (SO5V500)

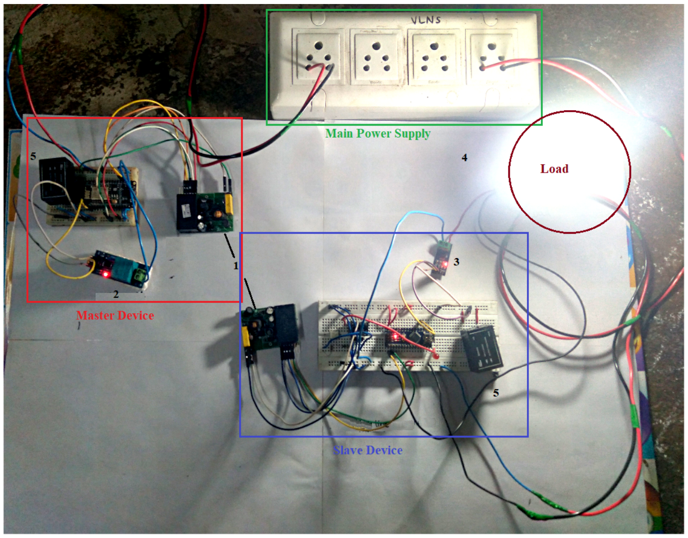

Fig. 4. Experimental Setup

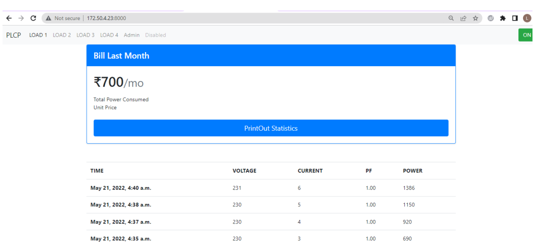

Fig. 5. sample view of a webserver

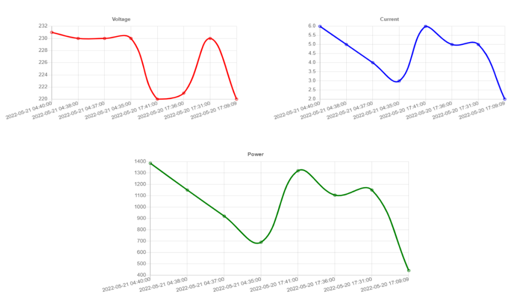

Fig. 6. various plots of the output data

proposed system was the most effective in measuring and monitoring current, voltage, and power usage. The data was displayed on a web server and a custom created mobile application using a hybrid technique of PLC and Wi-Fi module. The data was also monitored in real time and in the past, and it was saved in a cloud database. Customers will be able to see usage rates clearly in real time thanks to the monitoring system. The control system is designed to meet safety requirements, monitor individual or group appliances in the home, and raise awareness about power consumption. As a future work this can be extended to a substation level by upgrading the range of communication and increase the measuring range of individual sensors. The Analytics using some machine learning algorithms is also left for the future work.

REFERENCES

[1] Ahmed Helmy, M. Abdel-Rahman, Mohamed M. Mansour, “Examining Power Line Communication on Egypt’s Low Voltage Grid for AMR Network”, 2007, pp.1-2

[2] D. P. Rani, D. Suresh, P. R. Kapula, C. M. Akram,N. Hemalatha, and P. K. Soni, “IoT based smart solar energy monitoring systems,” In Materials Today: Proceedings, Elsevier, 2021.

[3] M. K. Hasan, M. M. Ahmed, A. H. Hashim, A. Razzaque,S. Islam, and B. Pandey, “A novel artificial intelligence based timing synchronization scheme for smart grid applications,” Wireless Personal Communications, vol. 23, pp. 1–8, 2020.

[4] M. K. Hasan, S. H. Yousoff, M. M. Ahmed, A. H. A. Hashim,A. F. Ismail, and S. Islam, “Phase offset analysis of asymmetric communications infrastructure in smart grid,” Elektronika irElektrotechnika, vol. 25, no. 2, pp. 67–71, 2019.

[5] A. Ponniran, E. Sulaiman, S. A. Jumaat, M. Ishak, M. A. Chulan, and S. Saiman,“A study on electric energy usage at the residential area,” In Engineering Conference, pp. 27-28, 2007.

[6] C Nunn, K Sullivan, “from theory to practice: the development implementation powernet-anadvanced power line carrier system for amr, dsm, da and non-utility applicationS”, IEE MatesConference, 1992,304-308

[7] Dr. A. Inan, E. Verhasselt, S. Vandecasteele, “SEMMS : a meter readout system with an open architecture and open standards communications, installed by the electricity utility interelectra”,1997

[8] Juan García, Francisco Rogelio Palomo, Antonio Luque, Member, IEEE, Carmen Aracil,José M. Quero, Member, IEEE, Daniel Carrión, Francisco Gámiz, Plácido Revilla, Juan Pérez-Tinao,Manuel Moreno,Pedro Robles, and Leopoldo G. Franquelo, Senior Member, IEEE “Reconfigurable Distributed Network ControlSystemfor Industrial Plant Automation” 6, DECEMBER 2004

[9] Jorge Arinez, Member, IEEE, and Stephan Biller, Member, IEEE,“Integration Requirements for Manufacturing-BasedEnergy Management Systems” IEEE PES Conference On Innovative Smart Grid Technologies, January 19-21, 2010

[10] M. Kezunovic, Fellow, IEEE “Substation Fault Analysis Requirements” 2010 IEEE

[11] A.P.Sakis Meliopoulos, George J.Cokkinides, Thomas J.Overbye “Component Monitoring and Dynamic Loading Visualization from Real Time Power Flow Model Data” 0-7695-2056-1/04, 2004 IEEE.

[12] Joao M. G. Figueiredo, Jose M. G. Sa da Costa, “A Two Level Hierarchical Control Strategy Applied to an Intelligent House” 0-7803-9030-X/05,2005 IEEE.

[13] Z. Ming-Yue, ”Transmission Characteristics of Low-Voltage Distribution Networks in China Under the Smart Grids Environment,” Power Delivery, IEEE Transactions on, vol. 26, pp. 173-180, 2011.

[14] Xiao Yong, Fang Ying, Zhang Jie, Dang SanLei, ” Research on characteristics of low voltage power line communication channel” in Power system protection and control, vol. 40, No. 4, pp. 20-25, October 2012.

[15] Yin, Q. U. N., and Zhang Jianbo. ”Design of Power Line Carrier Communication System based on FSK-KQ330 Module.” Electrotehnica, Electronica, Automatica Vol 62, No.3, 2014.

[16] J. Michael, Whitney Bruce, ”Evaluation of the potential for powe line carrier (PLC) to interfere with use of the nationwide Differential GPS network Silva”. IEEE Transactions on Power Delivery, Vol 17, No. 2, pp. 348-352, April 2002