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Smart Grid Communication Using Open Smart Grid Protocol

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Abstract

The smart grid transfers electricity from power utilities to the customers' end using full-duplex digital communication technology and helps us to control the home appliances and factory machines to save electricity while reducing costs and increasing reliability and transparency. So, in order to ensure the grid reliability, we need to monitor and control the smart meters by means of data transfer and command signals on the single power line without using any other communication media to improve the cost-effectiveness of the proposed study. This paper proposes a hardware implementation of a Power Line Communication (PLC) protocol named Open Smart Grid Protocol (OSGP). This protocol is based on the Open System Interconnection (OSI) model. The proposed system comprises monitoring and controlling server (Lap-top/Desktop), power line communication modem, two PIC18f4520 microcontrollers, one energy meter and power line as transmission media. This protocol is first implemented on a server in C-sharp by using the OSI model approach, and then on micro-controllers in order to control the energy meter. The power line communication modem is used to send and receive the data between the server and the energy meter. Finally, results are presented to validate the hardware implementation of the protocol.

Keywords

C-Sharp, Distribution System, Microcontroller, Modem, Protocol, Smart Meter, Smart Grid

1. Introduction

The smart grid is a modern energy grid that gathers information about the utilities and end-users using the information and communications technology in an automated fashion to improve the sustainability, efficiency, reliability, and economics of the energy distribution and production [1]. Almost as soon as the traditional power grids were unidirectional, where the power can only deliver from generating stations to the end-users, this system was working fine for the hundred years. However, modern society demands this system more efficient, reliable, resilience oriented, cost-effective and interoperable [2]. The future electrical power system is known as the "smart grid" [3], which is a long-term cost-effective solution for the industries. The smart grid has modernized the existing power generation, transmission, and distribution by using the two-way communication infrastructure [4]. The modern grid contains renewable energy sources, such as solar, biomass, and wind, which is environmentally friendly compared to the fossil fuels used for the conventional grid. These renewable energy sources are small and can be used as an islanded microgrid in order to improve the reliability through reducing the transmission losses.

The definition of the smart grid is not unique. As different stakeholders define this in different manners [5]: 1) the Ontario Smart Grid Forum has defined the smart grid as a modern energy grid which comprises electrical transducers, automated energy meters, power line communication modems, microcontrollers, and computers to improve the reliability, security, efficiency, scalability, and safety of the electrical power system. It allows the end-users to control their electricity use and respond to the electricity bill changes by adjusting their energy usage. The smart grid contains diverse energy resources and facilitates the electric vehicles charging system. By means of the smart grid, the energy generation, transmission and distribution are very economical for energy supplier companies, environment and for end-users [6]. 2) The US Department of Energy (DOE) has defined the smart grid as an automated and distributed two-way communication assisted power flow from the power plant to the customers by means of controlling the home appliances using data and commands signals on the same power line. This will be beneficial for both end-users and energy providers by delivering real-time information on the same line and enable the balance of supply and demand at the device level [7]. Due to the new technological improvement on distributed generation helped to create a new energy grid era the smart microgrid distribution network [8]. A microgrid is an is-landed electrical power distribution network mainly consisting of loads, diesel engine generators, solar panels, wind energy, transmission, and energy storage systems. The benefit of a microgrid is that it can dynamically respond to the changes in energy delivery by adjusting the supply and demand [9].

The smart grid enables fault detection, isolation and service restoration of the distribution network which is called self-healing of the network. This will increase the reliability of the energy supply. The next-generation grid allows bidirectional energy flow from energy suppliers to the end-users. It efficiently handles the distributed energy sources, such as solar, wind turbines, fuel cells, and battery storage systems. Due to the two-way communication on a single line along with commands and control signals, it helps to reduce the cost, enables load adjustment and increases the overall efficiency of the distribution system. The smart grid is now evolved to microgrid, and hence the renewable energy sources can easily be integrated with the distribution system without even using the battery storage elements or fossil fuels and increasing the sustainability of the grid network. For communication purposes in the modern smart grid, there are many other communication standards such as Lon talk protocol but the most popular and latest communication standard is Open Smart Grid Protocol. With the help of this communication protocol, we can reduce the demand during the peak period by disconnecting some low-priority loads at the consumer's end.

The communication infrastructure for the smart grid mainly relies on the bidirectional flow of power and control information on a single line from the power generation companies to the end-users and vice versa [10]. The communication between different devices in a smart grid is very important to efficiently utilize the available electric power. So, in order to ensure reliable and cost-effective communication for smart grid, researchers have presented different studies. In [11], the authors have described the use of the smart metering system for the home in two cities in Korea. This survey results demonstrated that if we have real-time feedback about the usage of electricity at home, then we can reduce the power consumption up to 10% during the winter season.

In order to reduce the generation and operation costs, the Optimal Power Flow (OPF) is a popular tool for power systems. The authors in [12] have presented an approach to address the load control problem in distribution systems. Their main aim was to reduce the overall cost of energy distribution firms. In [13], the authors have summarized the wired and wireless communication methods for smart metering. Accordingly, the power line communication is an ideal low-cost and low-bit-rate method for smart meters. In comparison with time-varying noise, they also presented an Orthogonal Frequency-Division Multiplexing (OFDM) scheme based on the PLC system. The authors of [14] have presented a smart metering scheme in order to optimize the energy usage of data centers. They have deployed many smart meters in data centers for real-time energy consumption information and presented a new architecture to integrate the conventional grid with the smart grid. According to this architecture, the data centers, energy supply companies, information and communication layer, and energy management systems can cooperate with each other to reduce energy consumption during peak hours and avoid energy outages.

Some researchers have presented their work on the customers' side load management by the power supply companies to enhance the efficiency of the smart grid. Demand-side management is the key to realize smart grid distribution systems. Because in order to integrate the energy supply companies, customers, electric cars and microgrid with the smart grid, the efficient demand-side management is mandatory. In [15], using game theory and in [16], using optimization and microeconomics, the demand-side management has been studied. The economic aspects are listed in [17]-[25] and the grid-related issues such as frequency and voltage control are presented in [26] [27] [28] [29].

In [19], the authors have presented how a customer can schedule his home appliances according to the pricing information as suggested by the power company. In [20], the particle swarm optimization method is used to reduce the cost in the presence of distributed energy resources. Reference [28] has developed another approach using both optimization and pricing method to control the customer loads within a DC microgrid for efficient grid operation. The demand response and grid constraints for AC networks are presented in [27]. The use of batteries for demand-side management is presented in [23]. Using game theory and auctions the pricing problem relates to demand-side management is described in [24]. In [30], the implementation of LonTalk protocol using the "C" programming language on MC68360 is presented by Echelon corporation for the purpose of communication between energy supply companies and end-users. Even though this protocol does not use a Real-Time Operating System (RTOS), it has its own scheduling and timing facilities. The existing study mainly focuses on different load management schemes, in which no standard protocol is defined for power security and reliability, and real-time integration of energy meter with the smart grid without any other communication media.

The aim of this paper is to develop a reliable end-to-end communication using the existing power line by sending control and command signals in order to integrate the energy meters with the smart grid. The OSI-based open smart grid communication protocol is implemented in C-Sharp and microcontroller PIC18f4520 and data is transferred on the existing power line by using a power line communication modem without any other media which is a cost-effective solution. In order to secure the data from being lost due to the same power line media, the OSI layers-based communication platform is used. This model is reliable for an end-to-end communication and data exchange between energy supply companies and customers' end.

The rest of the paper is organized as follows: Section 2 describes the OSGP frame-work; Section 3 introduces the system architecture and illustrates each component used in this work; Section 4 presents the results and discussions; and concluding remarks are given in Section 5.

2. OSGP Framework

Open Smart Grid Protocol is one of the most widely used protocols for smart meters and for other smart grid devices. It was originally developed by Echelon Corporation's power lines. It is very popular for automation in transportation, smart meters, industrial control, and buildings systems. We can use this protocol to efficiently deliver the command and control information for energy meters and other smart grid devices. The OSGP is based on the OSI protocol model to overcome the security issues of the smart grid. This Protocol provides services at all 7 layers of the OSI reference model as shown below: 1) Physical layer: At this layer, the data in the form of bits is delivered from the source to the destination by using a communication medium. 2) Link layer: It is responsible for framing, frame encoding, and error detection. 3) Network layer: It handles packet delivery. 4) Transport layer: This layer is responsible for end-to-end communication on the basis of network-layer addressing format. 5) Application layer: It is responsible for messages sending and receiving.

The OSGP is not only for smart meters at home, but also for other smart grid devices. The OSGP provides efficient and reliable networking services for any device connected to the low-voltage side. It also sends critical information about the present condition of the distribution line itself, which further reduces the operating costs. The reliability of OSGP-based systems is 99.6% to 100% which is because of the modern layered-based approach and careful monitoring of data on each layer.

The motivation why OSGP based framework can execute this kind of execution is the direct result of advanced hierarchical profile and the careful choice made in each layer of the framework, so as to focus on solving the final problem smart measurement and intelligent proficiency, practicality, reliability, flexibility, protection, two-way sensing and control grid. **Figure 1** shows the layer by layer protocol execution sequence. The functionality of each layer is as follows:

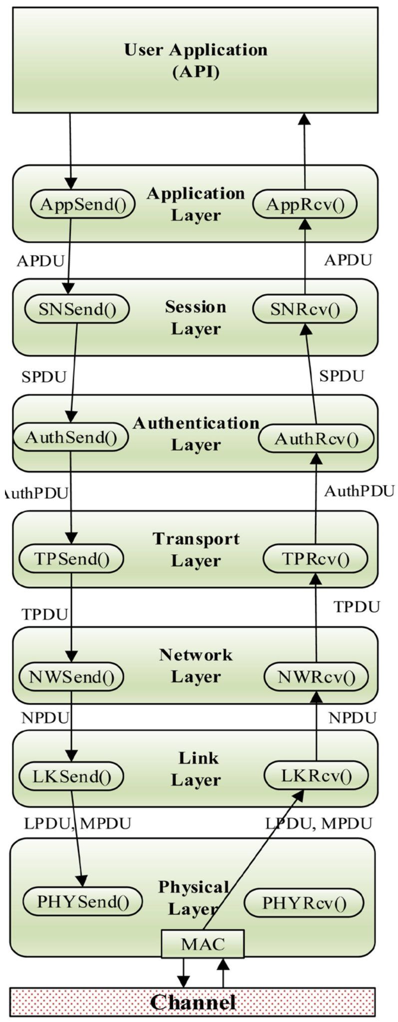

Figure 1. Protocol execution sequence.

Physical layer protocol and data encoding scheme are used in OSGP. Each encoding scheme is media dependent, here we are using the serial port modem with Frequency Shift Keying (FSK) modulation used for power line on zero-crossing and also collision detection algorithm implemented in modem for data collision and loss of data. Data link layer is used for simple connectionless service. This layer is limited to error correction with no recovery and frame encoding.

The network layer is the handler for delivery of the packet to destination without acknowledgment, connectionless and no reassembly of the message. The network layer is a topology based in OSGP like broadcast, unicast or multicast. The broadcast routing algorithm is used for sending information to all connected items, the unicast routing algorithm is used for specific node to node communication and a multicast routing algorithm is implemented for a specific group area is concerned to be communicated.

The important part of OSGP is the transport layer, the sub-layer of this handle's the transaction order of packets needs to send and detects duplicate packets in the unicast and multicast routing algorithm. This layer also authenticates the sender's identity which is optional.

The presentation/application layer is a form of inter-operability for OSGP nodes. The application layer provides all support for sending and receiving messages containing all network layer variables. The presentation layer provides information for the application header that how this packet will work on the presentation layer as well as the network layer.

3. System Architecture

The proposed system comprises of server-side (Laptop/Desktop), end-user side (Zone 1, Zone 2, Zone 3), power line communication modem, and communication media. **Figure 2** illustrates the logical diagram of the system. The purpose of this study is to provide a successful communication between the users and server on the power line by using power line communication protocol OSGP. At the server-side, the PC is first connected to the microcontroller PIC18f4520 with the help of serial interface, and then to the power line through a power line communication modem. This modem is connected to the power socket in order to use the power line for transmitting and receiving the data. At each user side, the data is received by the power line modem through the power line. The data is demodulated by the respective modem and transmitted to the microcontroller. **Figure 3** shows the physical connections of the system.

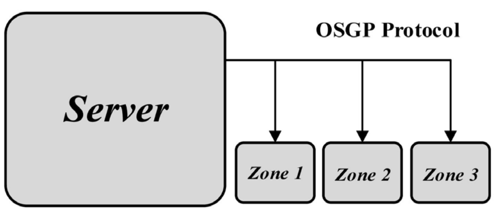

Figure 2. Logical diagram.

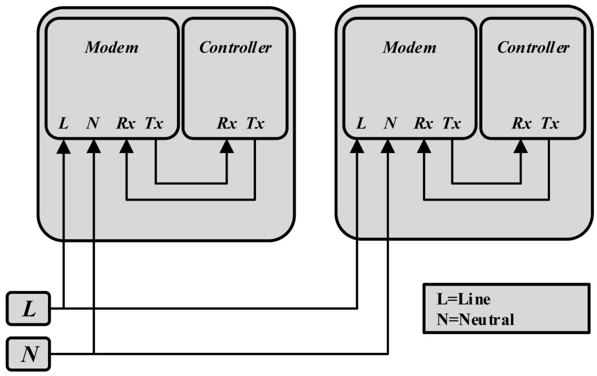

Figure 3. Diagram of the physical connections.

3.1. Overall System Model

Figure 4 shows the overall system block diagram used in this paper. The server is connected with a modem through serial interface max232 which is further connected with a power line. Another side is the user side which consists of microcontrollers and modems. Modems are connected with respective microcontrollers through the serial interface. The communication between the server and the end-user is taken place on the power line by OSGP.

3.2. System Description

Figure 5 displays the description of the components used in this study. We have used the PIC18f4520 microcontroller in order to receive the data from the power line through a power line communication modem. We have used an adapter (220v AC to 5v DC) in order to provide dc supply to microcontrollers and modems so that there is no separate dc supply in our system except main (AC). In order to communicate with the server, we have used max 232 circuits that are connected to the server first, and then to the modem which is further connected with the power line. We have implemented an open smart grid protocol in C-Sharp and MPLAB in order to transfer and receive the data and control signals on the power line.

3.3. Real-Time Implementation with Energy Meter

Figure 6 presents the real-time communication of energy meter with the server side by means of OSGP. The control and command signals from the server-side have been sent to energy meter for real-time feedback about the total load voltage, load current and load power at the customer side. The data and acknowledgment are successfully sent to the server-side from energy meter on the power line medium which validates the real-time implementation of OSGP.

4. Results and Discussions

We have developed a Graphical User Interface (GUI) in C-Sharp for user ease. There are two types of login on the basis of User Type, one is for user and the other one is for the admin to administrate the software with full rights to add/remove

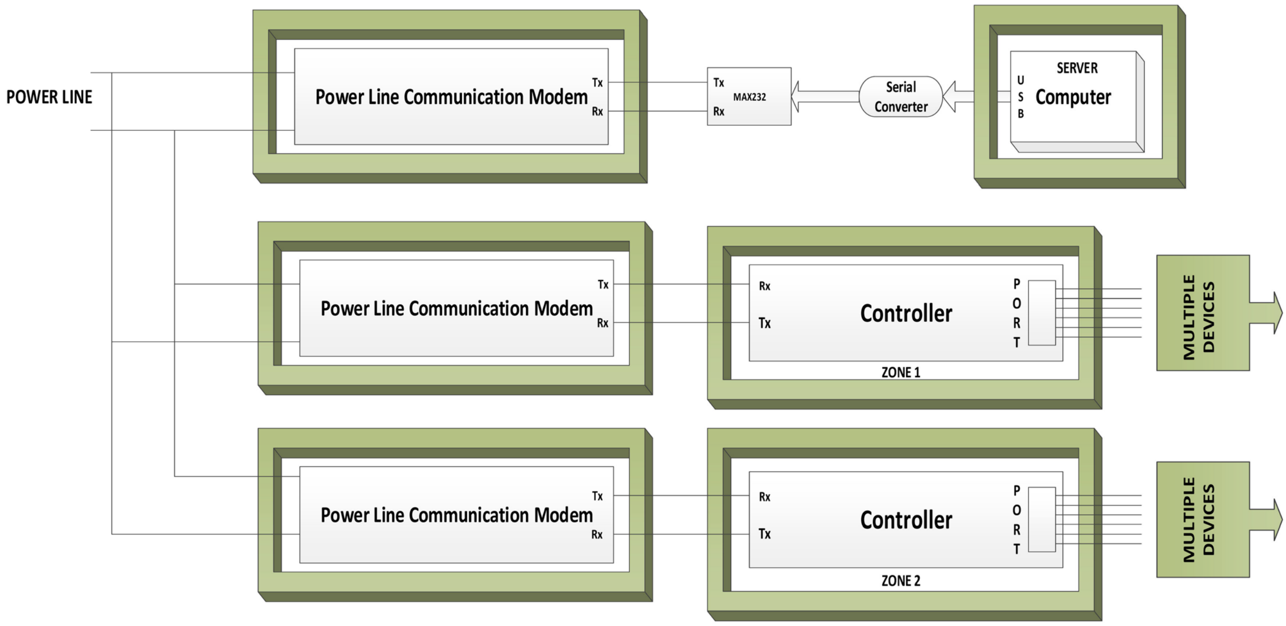

Figure 4. Overall system model.

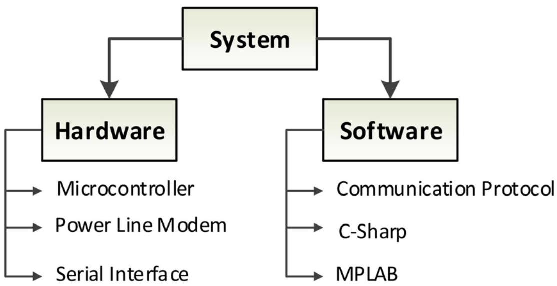

Figure 5. System description.

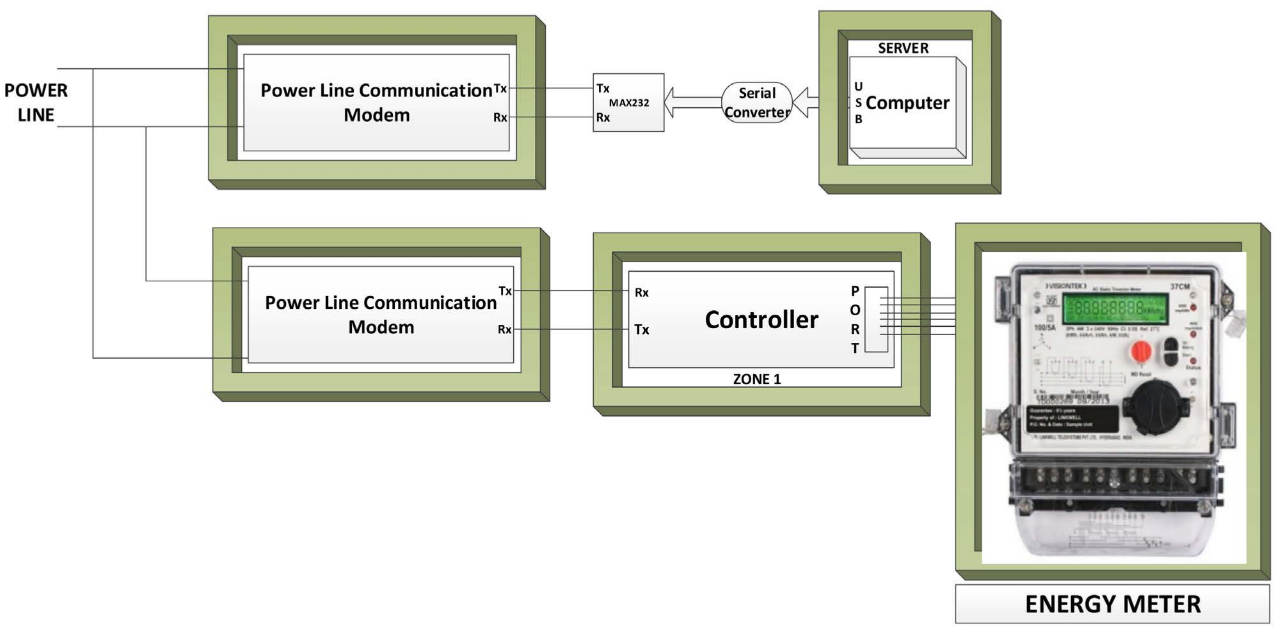

Figure 6. Real-time implementation.

user and to see any client's data. We used half-duplex serial port communication mode for data sharing and having a baud rate of 9600. The layers' wise message formation and delivery are as follows:

In Data Link Layer we start decoding the received packet. The first two bytes of the packet from the left side are identifier 0 × 1010 (start of the packet). The next two bytes are the size of the packet and again we repeat the size of the packet for identification. The next two bytes are the packet ID. The last byte of the packet should be 0 × 7F. 3rd and 2nd last bytes are the Cyclic Redundancy Check (CRC) of the packet to verify the packet. We calculated the CRC of the packet for error-detection in the received data. **Figure 7** shows the MAC Protocol Data Unit (MPDU) message format.

Figure 8 shows the Network Protocol Data Unit (NPDU) message format. First, two bytes of NPDU is a version of a packet named "ver". On the basis of the version, we can modify packet data. NPDU envelops a Packet Data Unit (PDU) format like Transport Packet Data Unit (TPDU), Standard Packet Data Unit (SPDU), Authentication/Acknowledge Packet Data Unit (Auth-PDU) or Application Packet Data Unit (APDU). Address format specifies address type that message is specific to you or as a broadcast message. This layer ensures the source-to-destination delivery on the basis of source and destination addresses. Two bytes of the address length show the size of the source and destination address.

Figure 9 shows the TPDU message format. "Auth: 1" bit shows that this is an acknowledgment of the last message according to transport number. "TPDU type" is of 15-bits which shows the type of the message whether it has data for APDU, authentication/acknowledge (ACKD), handshake, broadcast or multicast. The "Trans_no" field sends information about the acknowledgment of the packet.

Figure 10 indicates the APDU message format. The APDU consists of a header and application data field. The header is a single byte and the data section is dependent on message-id that is encapsulated in data. We sent data for load adjustment and received the adjusted load from the energy meter. The server requested clients for specific load status at customer end and after the successful reception of data from clients, the status of the load along with acknowledgment is shown in **Figure 11**.

1010	Size(2)	Size(2)	Msg-id	NPDU(2)	CRC(2)	0x7F

Figure 7. MPDU message format.

Ver(2)	PDU fmt(2)	Addrfmt(2)	Addr length	Address	TPDU

Figure 8. NPDU message format.

Auth:1 TPDU-type(2)	Trans_no(2)	APDU

Figure 9. TPDU message format.

Table 1 shows the load disconnection from the system during peak hours. Initially, the command signal is sent to the customer end for the calculation of total load connected to the system in terms of Voltage, Current Power and Frequency as depicted in **Figure 11**. During peak hours when it is mandatory, some low-priority loads are disconnected from the system in order to bring the stability in the grid. So, we sent a signal in the form of the packet on the same power line to disconnect the low-priority loads at the customer end. After disconnecting some loads from the system, an acknowledgment message has been received at the server side to confirm the reliable data transfer on the power grid which shows the security and reliability of this protocol.

After disconnecting some low-priority loads at the customer end, again the message is sent to inquire about the status of the priority load online at that time, as depicted in **Figure 12**. The frequency of the grid is 50 Hz, the total power of the priority load is 65 Watt, the Current is 380 mA and the Voltage is 213 V.

Type/header	Data

Figure 10. APDU message format.

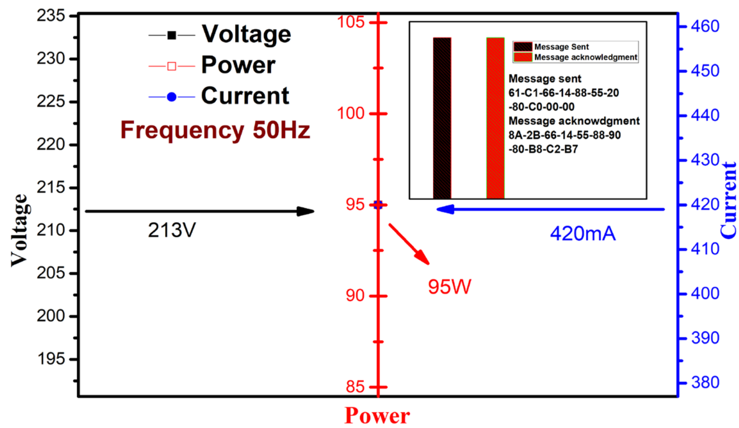

Figure 11. Load status.

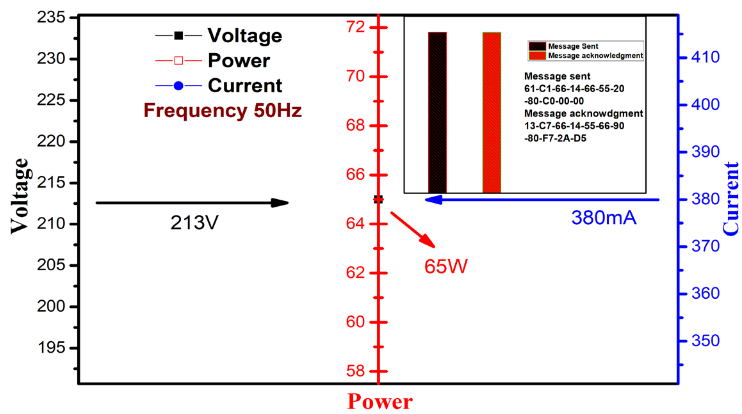

Figure 12. Load status after disconnecting load.

Table 1. Least priority load disconnection.

Message Sent	Acknowledgment Received	Output
61-C1-66-14-77-55-20-80-C0-00-00	9F-2F-66-14-55-77-90-80-C4-A1-D9	Least Priority Load Disconnected

5. Conclusion and Future Work

This paper proposed a hardware-based implementation of a power line communication protocol named OSGP. The purpose of this protocol is the communication of different smart grid devices on the power line without using any other medium. An OSI-based communication strategy is implemented in C-Sharp, Microcontroller and data is transferred from server to customer end and vice versa by using a power line communication modem. The successful delivery of data from source to destination is verified by sending the acknowledgment. Experimental results validate the effectiveness of this smart grid communication protocol.

In future work, we can extend the application of this protocol and can implement security encryption on data for safe transmission. We can use packet id for data type identification and packet version for data modification/up-gradation.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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