# Chapter - 5

# DESIGN AND IMPLEMENTATION OF WIRELESS MONITORING AND CONTROL OF SMART MICROGRID POWER SYSTEM USING PAN, LAN AND WAN

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# DESIGN AND IMPLEMENTATION OF WIRELESS MONITORING AND CONTROL OF SMART MICROGRID POWER SYSTEM USING PAN, LAN AND WAN

This chapter depicts design and implementation of prototype based on IEEE 802.15.1, IEEE 802.3 and IEEE 802.11 standards. The prototype is developed for PAN, HAN and WAN for IoT based real time monitoring and control of entire system. The chapter includes graphical representation of real time readings acquired for validation of the research work.

## 5.1. INTRODUCTION TO SMART MICROGRID POWER SYSTEM

Smart grid communication infrastructure is an integration of diverse communication standards and hierarchical network layers such as HAN, NAN and WAN. Home area network mainly comprises of various energy sources, electronics devices, sensor network and smart meters. All these devices and meters are integrated with each other for realization of smart home system. Smart home is beneficial to consumers in various functional and economical aspects such as optimization of energy usage, selling of extra energy, informed and dynamic billing cycle, remote monitoring and control of home appliances and fully safeguarded home automation system. Consumers can actively participate in the process of energy generation, consumption and billing. Electric vehicle and Plug in hybrid electric vehicle are also the parts of HAN.

Consumers can monitor their energy consumption statistics, take decisions based on priorities and prices, control their appliances and generate revenue by selling extra energy to energy service provider through renewable energy generation. Energy usage statistics is communicated to central home monitor and regulator which is a part of AMI and it further communicates this statistics to main grid through various intermediate networks for billing, fault diagnosis, control and management of generation, transmission and distribution of energy. This makes the process of generation and consumption of energy transparent and reliable. Smart microgrid is intended to expedite the usage of renewable energy sources. An intermittent and non dispatchable nature of renewable energy sources necessitates consistent monitoring and control. Home area network ranges for few hundreds of meters. Various communication standards such as Bluetooth, Zigbee, WLAN, Ethernet, Z-Wave, WiMAX etc. can be used for real time monitoring, control, operation and management of smart power system in home area network [63-70]. This chapter covers the description of prototypes using IEEE 802.15.1, IEEE 802.3 and IEEE 802.11 standards. An execution of Energy management system is realized using PAN, LAN and WAN.

## 5.2. DESIGN AND IMPLEMENTATION OF WIRELESS MONITORING AND CONTROL OF SMART MICROGRID POWER SYSTEM USING PERSONAL AREA NETWORK

The prototype is developed by considering DC microgrid. Three energy sources namely grid, solar and battery are considered for validation of hypothesis on Smart grid communication infrastructure. DC load is considered. User can remotely and wirelessly monitor and control the behavior of designed prototype in a personal area network [65]. Fig.5.1 shows the block diagram of developed prototype.

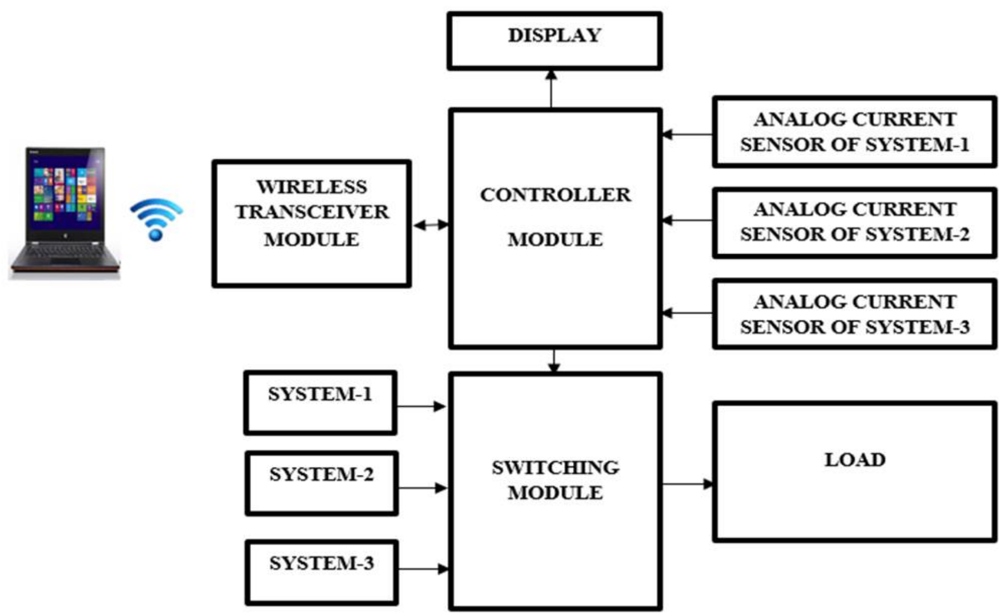


Fig.5.1. Block diagram of developed prototype

The above prototype is developed using IEEE 802.15.1 standard. A DC load is switched between three energy sources based on threshold value. A user can monitor and manage the value of the load current on serial monitor. The current is sensed by ACS 712 analog current sensor. The sensors work on the principle of Hall Effect.

According to Hall Effect principle, when a current carrying conductor is positioned in a magnetic field, a potential difference perpendicular to the path of magnetic field and current is generated. This sensor can sense both AC and DC currents. The sensitivity of this sensor is 66 mV/A. ACS 712 sensor used in this prototype can sense maximum 30 A current.

- ACS 712, 30 Amp Hall effect Sensor Output Voltage = analog Read (sensor Pin)*5.0/1023.0

At zero current, Sensor Output Voltage = 2.5 V

Sensitivity= 66 mv/A, (Sensitivity : Output voltage proportional to AC or DC currents )

Sensor Output Voltage = 66 mv/A*Current + 2.5 V

Current = (Sensor Output Voltage – 2.5)/ 66 mv/A

- Fig.5.2 shows the sensing and measurement characteristics of ACS-712.

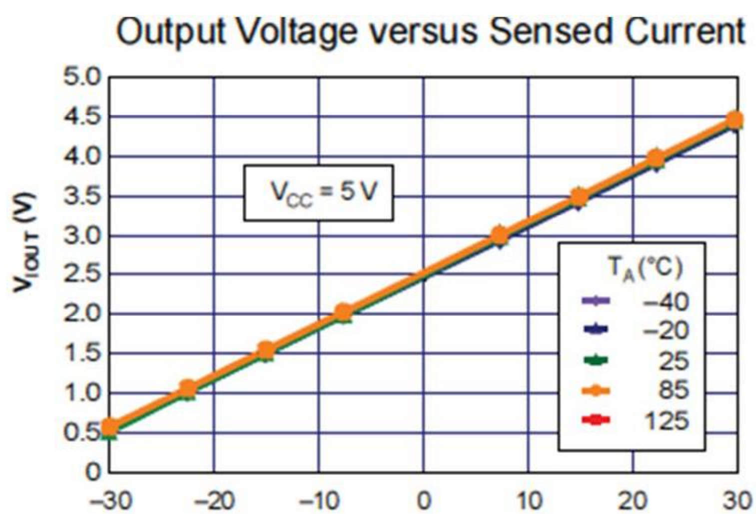


Fig.5.2. Sensing and measurement in ACS 712

The prototype is controlled using ATMEGA328P microcontroller. Three Single Pole Double Throw (SPDT) relays are controlled by microcontroller for load shifting. HC-05 module is used for communication with user terminal. It is a Bluetooth based serial port module with V2.0 + EDR up to 3 Mbps. The module functions in the frequency band of 2.4 GHz. The prototype is tested for various threshold values for different time of the day. Fig.5.3 shows the flow diagram of designed prototype. Table 5.1 shows the list of components used in the prototype.

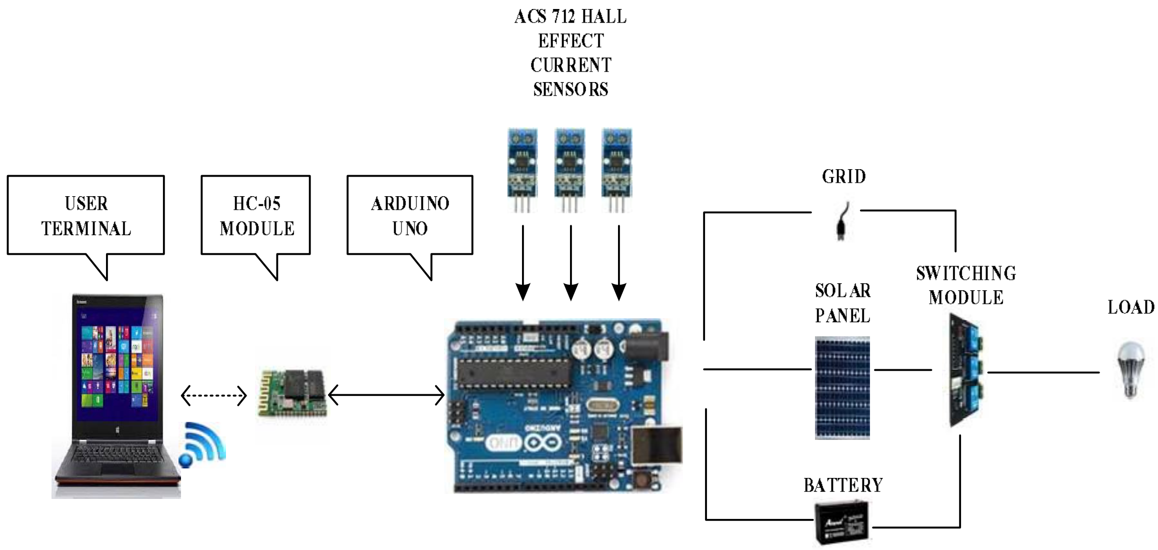


Fig.5.3. Flow diagram of designed prototype

Table 5.1. shows the brief technical specifications of various components used in above prototype.

| Sr No. | Device/ Module | Technical Specifications |
|---|---|---|
| 1. | Arduino Uno | Open Source Platform with Atmega328p Microcontroller |
| 2. | HC-05 Module based on IEEE 802.15.1 Protocol | Based on IEEE 802.15.1 Protocol, 2.4 GHz radio transceiver, Attuned with Bluetooth V2.0+EDR |
| 3. | ACS 712 Current Sensors | Hall effect current sensor, 30 Amp, Sensitivity-66 mV/A |
| 4. | LCD | 16*2 |
| 5. | Solar Panel | 40 W, Voc=20 V , Isc=1.5 A |
| 6. | Battery | 12 V, 1.3 AH, Lead acid |

Table 5.1. Technical specifications of various components used in the prototype

Fig.5.4. shows the circuit diagram of developed prototype.

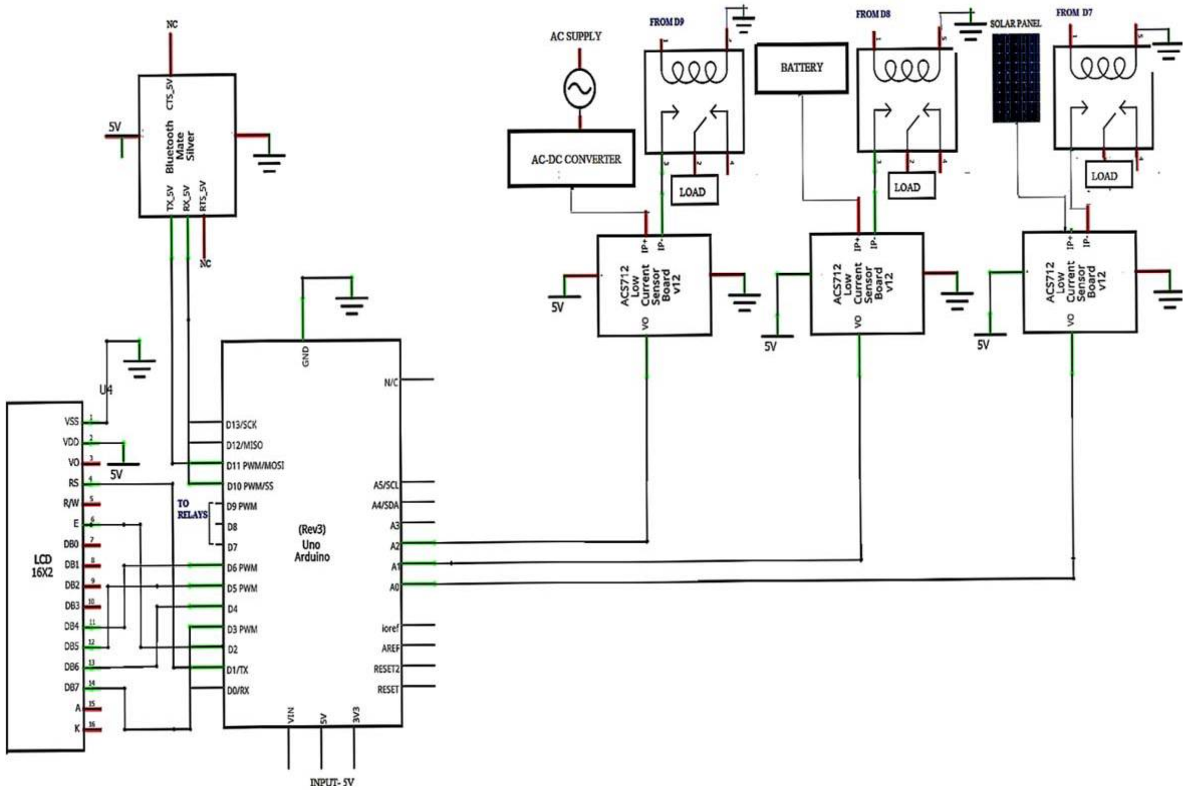


Fig.5.4. Circuit diagram of designed prototype

Arduino Uno is used for monitoring, sensing and controlling functions of prototype. ACS 712 sensors are used to sense DC current from all the three energy sources. Sensed currents are given to input pins of controller. Relay module is connected to the output pins of controller. Whenever the current goes below the threshold value, user can switch the load to a different energy source. HC-05 module is used for wireless monitoring as well as control of smart power system from remote terminal. The prototype functions successfully in the range of 30 meters using IEEE 802.15.1 standard. Fig.5.4 shows the circuit diagram of developed prototype. Figures 5.5 and 5.6 show the flowcharts of monitoring and control operations of developed prototype respectively. Fig.5.7 shows the snapshot of readings observed on user terminal.

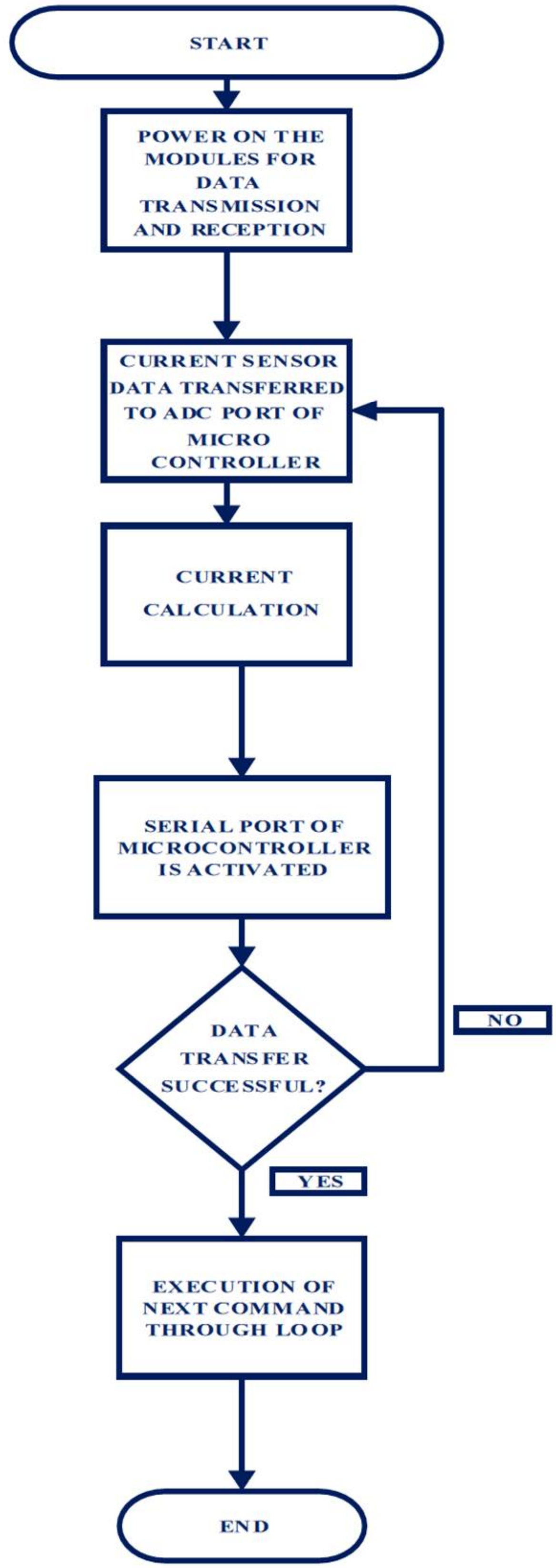


Fig.5.5. Flowchart of monitoring of prototype

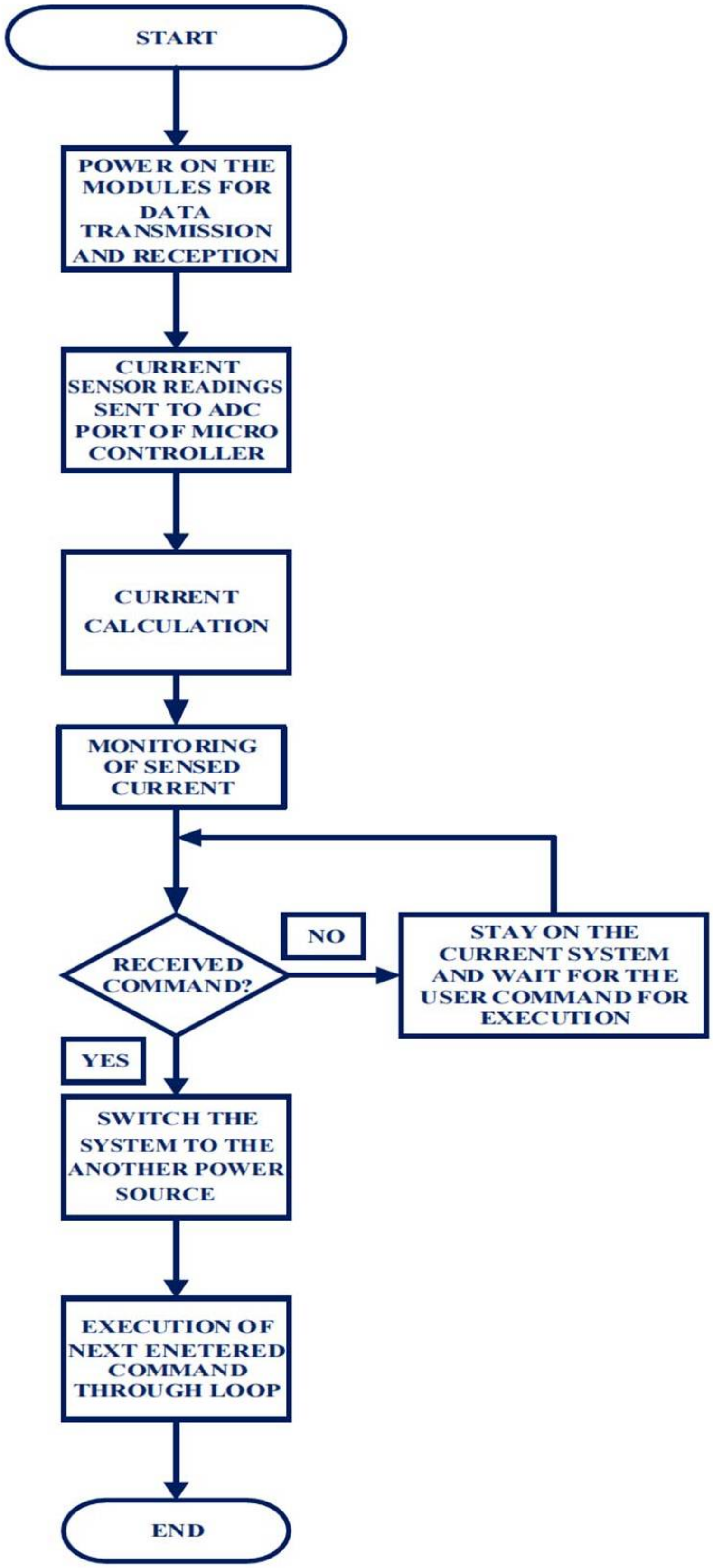


Fig.5.6. Flowchart of control of prototype


Fig.5.7. Snapshot of monitoring and control of developed prototype

Figure 5.7 shows the snapshot of real time data captured for monitoring and control of developed prototype. The current sensors provide measured current to Arduino which communicates with user terminal through HC-05 module working on IEEE 802.15.1 protocol. It is a Bluetooth serial port protocol module working on 2.4 GHz band with full duplex functionality. The HC-05 module communicates with inbuilt Bluetooth of the laptop. The readings illustrate the value of load current in Ampere when load is shifted on system 1. When the load current decreases below threshold value, user can switch to another source. For designed prototype, the threshold value is 250 mA. An Arduino Intelligent Development Environment facilitates the use of serial monitor for monitoring and control of Arduino from laptop's keyboard by predefined commands. Serial monitor is a separate window which communicates by means of serial communication. The results are viewed using Arduino serial monitor. Any other serial terminal such as CoolTerm or Tera term can also be used for serial monitoring.

The prototype can also be implemented for AC microgrid with few modifications. It can also be used for solar rooftop system. The design can be implemented using other communication standards for HAN.

### 5.3. DESIGN AND IMPLEMENTATION OF WIRELESS MONITORING AND CONTROL OF SMART MICROGRID POWER SYSTEM USING LOCAL AREA NETWORK AND WIDE AREA NETWORK

The developed prototype is intended for remote wireless management of smart power system in LAN [67]. The prototype is controlled using IEEE 802.3 and IEEE 802.11 standards. Three energy sources namely Grid, Solar and Battery are considered. A DC load is switched between three energy sources based on the value of threshold current. An HTML webpage is developed to wirelessly monitor and control the designed system from user terminal. An Ethernet shield W5100 is used for communication and control purposes. A GUI (Graphical User Interface) is designed for monitoring as well as control of developed prototype. The webpage is refreshed automatically every two seconds and the new data is fetched. The prototype is working successfully in the range of around 70 meters in a local area network. The designed prototype is tested using all three energy sources.

Fig.5.8 shows the block diagram of designed prototype. Fig.5.9 shows the flow diagram of designed prototype. Various components used in the prototype are listed in Table 5.2.

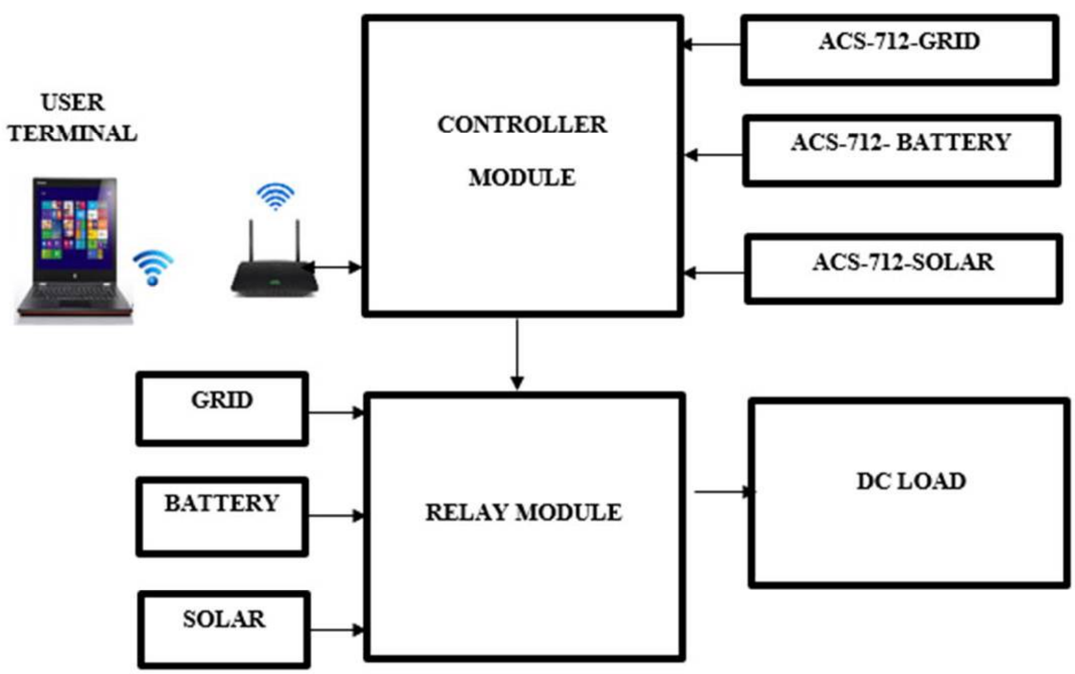


Fig.5.8. Block diagram of designed prototype

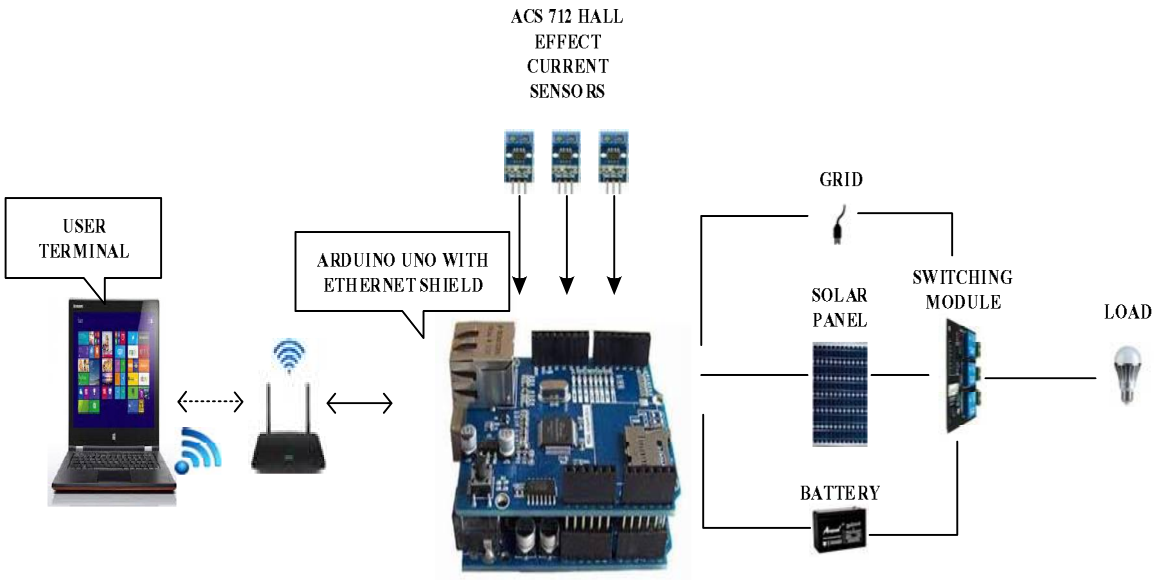


Fig.5.9. Flow diagram of designed prototype

Table 5.2. shows the technical features of various components used in above prototype.

| Sr No. | Device/ Module | Technical Specifications |
|---|---|---|
| 1. | Arduino Uno | Open Source Platform with Atmega328p Microcontroller |
| 2. | Ethernet shield | Based on IEEE 802.3 Protocol, W5100 Chip, SPI |
| 3. | ACS 712 Current Sensors | Hall effect current sensor, 30 Amp, Sensitivity-66 mV/A |
| 4. | Wireless Router | D-Link ADSL router with port forwarding, LAN & WAN Support, Supports IEEE 802.11 & IEEE 802.3 Protocols |
| 5. | Solar Panel | 40 W, Voc=20 V , Isc=1.5 A |
| 6. | Battery | 12 V, 1.3 AH, Lead acid |

Table 5.2. Various components used in the designed prototype

Arduino Uno is configured to work as a webserver using Ethernet shield. The combination of Arduino Uno and Ethernet shield enables user to observe the values of sensed current read by analog input pins on the web browser. W5100 Ethernet shield is used which is a stand-alone Ethernet controller and can be used with any microcontroller having SPI. An Ethernet shield is connected to LAN port of router to wirelessly communicate with user terminal. ACS 712-30A current sensors are used to sense the DC currents. The sensed current is given to the analog input pins of Arduino. The values of sensed current is visible on the webserver. Dynamic Host Control Protocol (DHCP) is used for the webserver. When the DHCP request is initiated, router automatically assigns IP addresses to the connected devices. This avoids IP conflicts. Arduino is programmed to work as a webserver and the user terminal functions as a client. The server serves the requested web page to client. A webserver is assigned an IP address 192.168.1.177. When a user opens a browser and requests for this IP address on a local network, Arduino webserver displays the Graphical User Interface. HTML buttons are used to control the relays for load switching. Whenever a user switches on a specific system, the webserver shows the value of current sensed by ACS-712. Output pins of ACS 712 are connected to input pins of Arduino and output pins of Arduino are connected to relay modules for load switching among three sources. The webpage will be reloaded every two seconds to get near real time data. The webpage can be accessed by all the devices connected in local area network. GET method is used to request the data from a specific resource. A query string is used in the URL entered in the browser. The designed prototype uses WPA-PSK algorithm and AES for secured wireless communication. Moreover, MAC filtering can be used for prevention of unauthorized access.

The developed prototype is working successfully in the range of around 70 meters. The IP address of local server is 192.168.1.177. Maximum 254 devices can be connected using DHCP within the local area network of a single router. The range can be extended using various network devices such as routers and switches. A serial terminal software CoolTerm is used to fetch and save the received data with time stamp to analyze the system behavior. Fig.5.10 shows the snapshot of developed prototype. Fig.5.11 and Fig.5.12 show the flow charts of monitoring and control of developed prototype. The snapshots of webpage readings are shown in Fig.5.13 and Fig.5.14. Serial monitor and data captured by CoolTerm software are presented in Fig.5.15 and Fig.5.16 respectively.

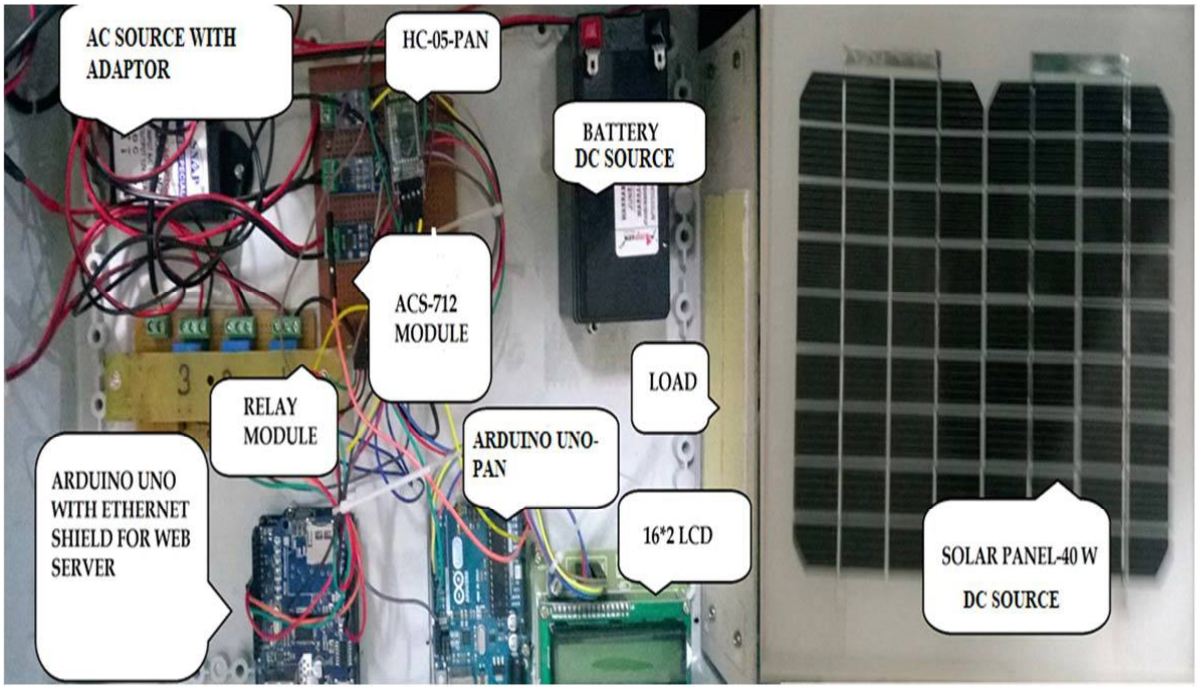


Fig.5.10. Snapshot of developed prototype

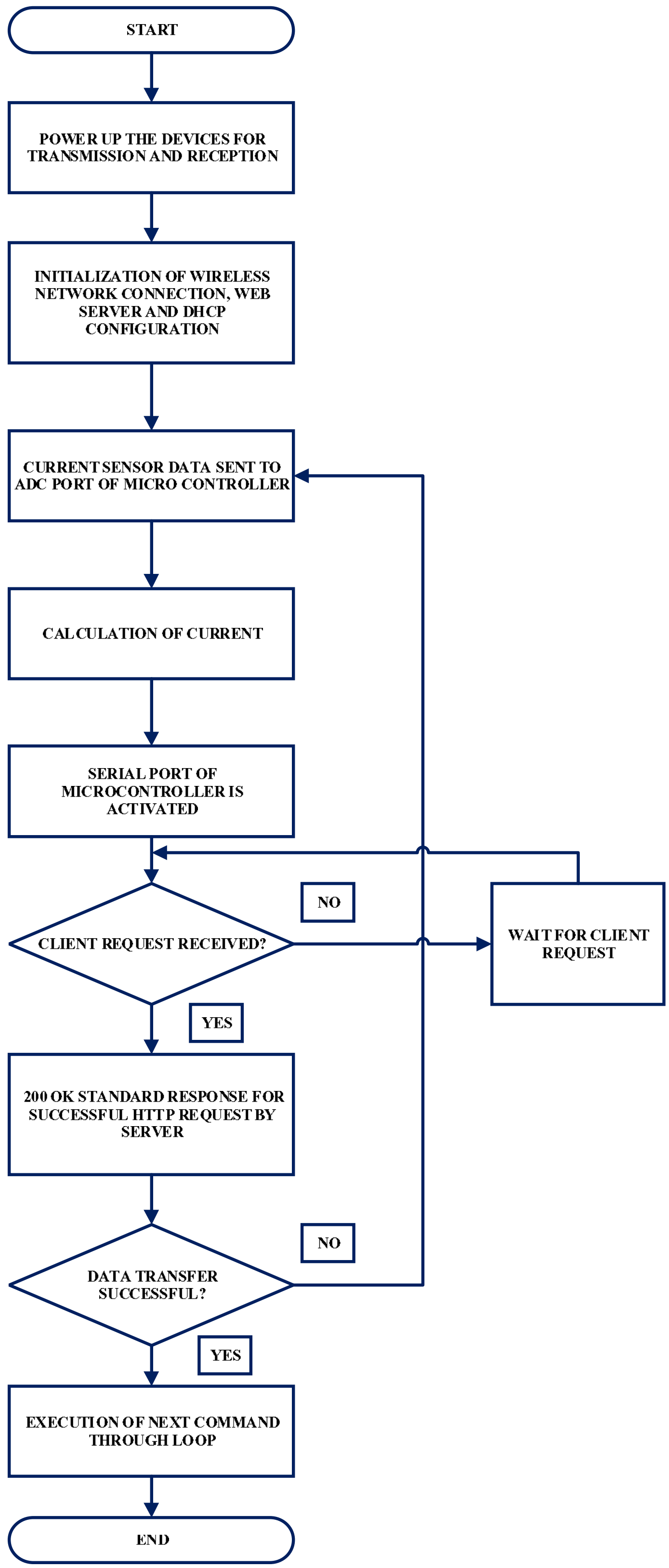


Fig.5.11. Flowchart of monitoring of prototype

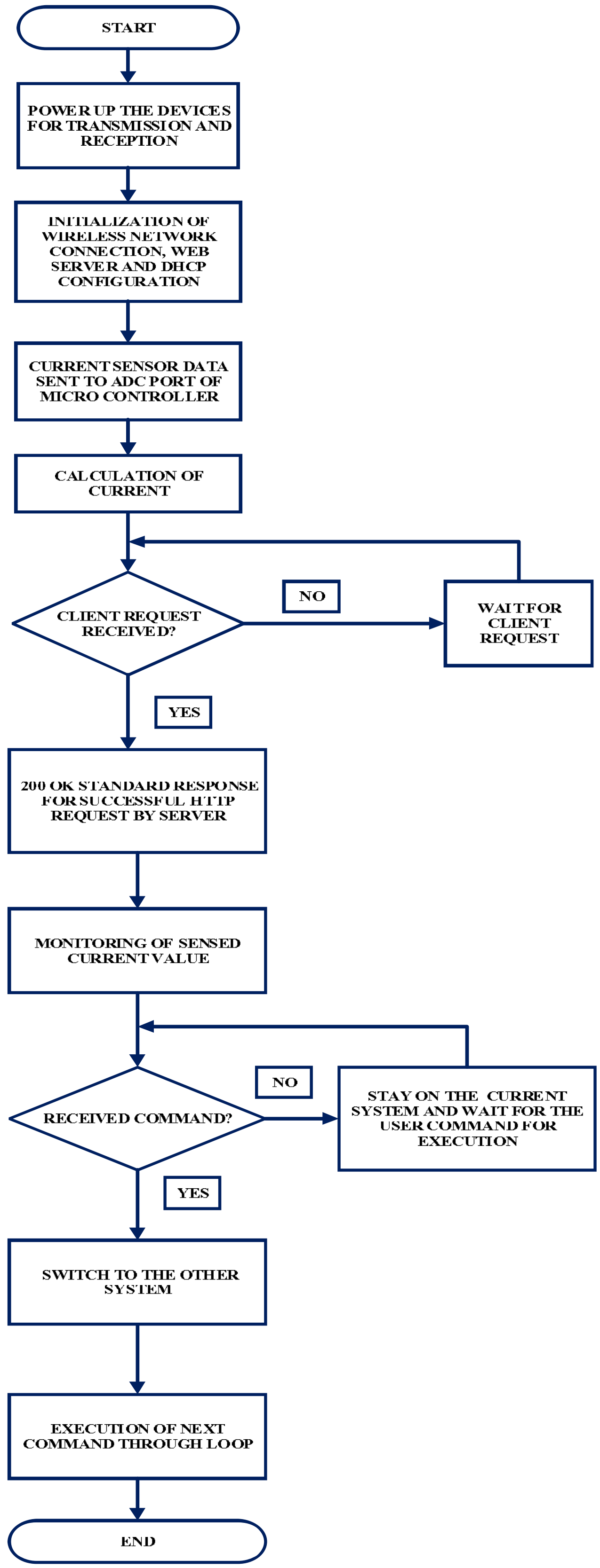


Fig.5.12. Flowchart of controlling of prototype

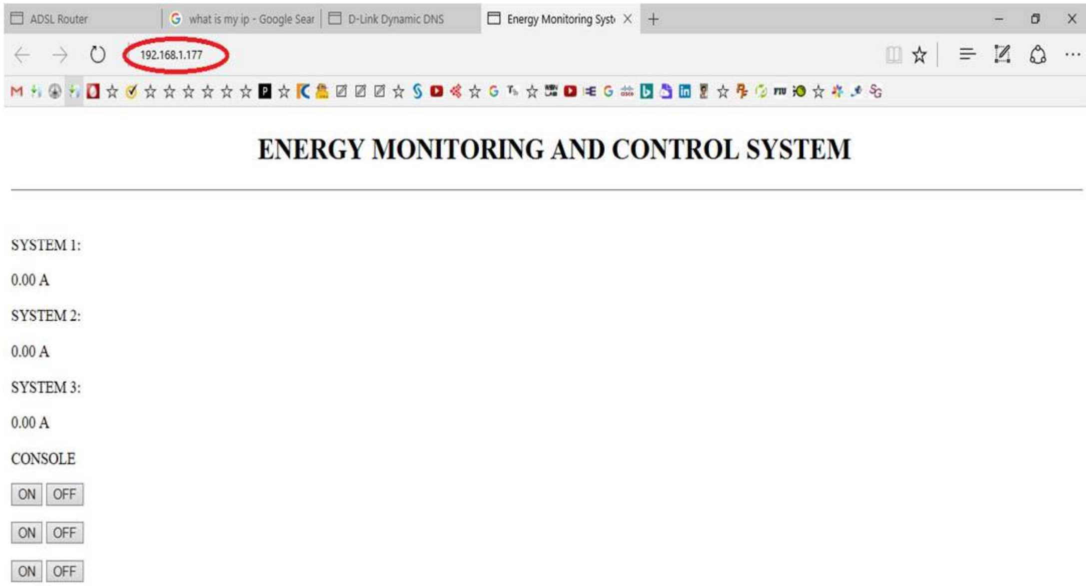


Fig.5.13. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage

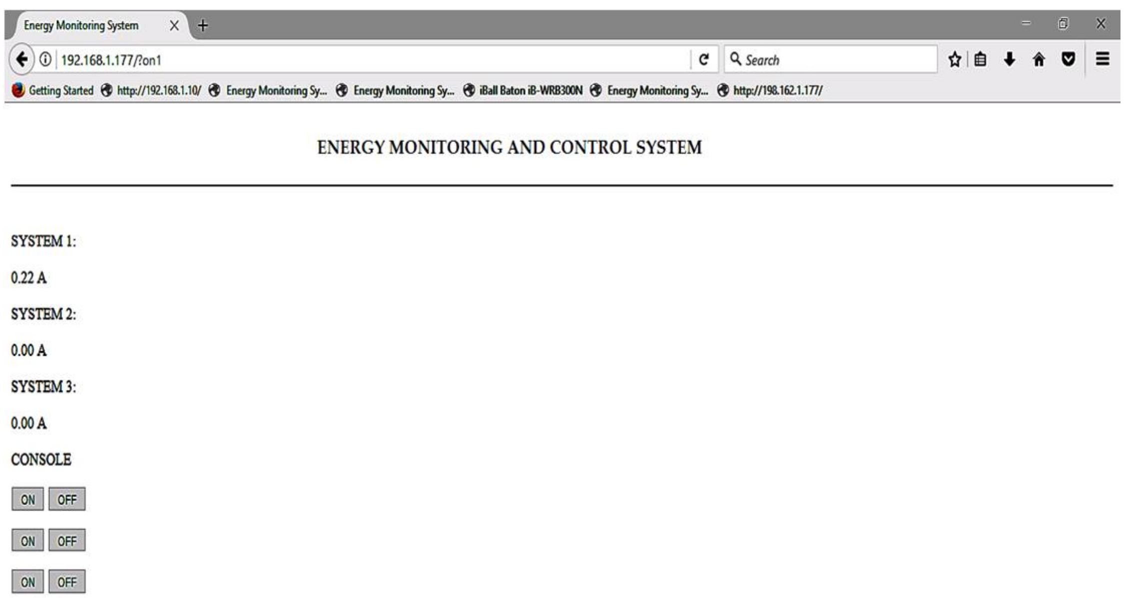


Fig.5.14. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage

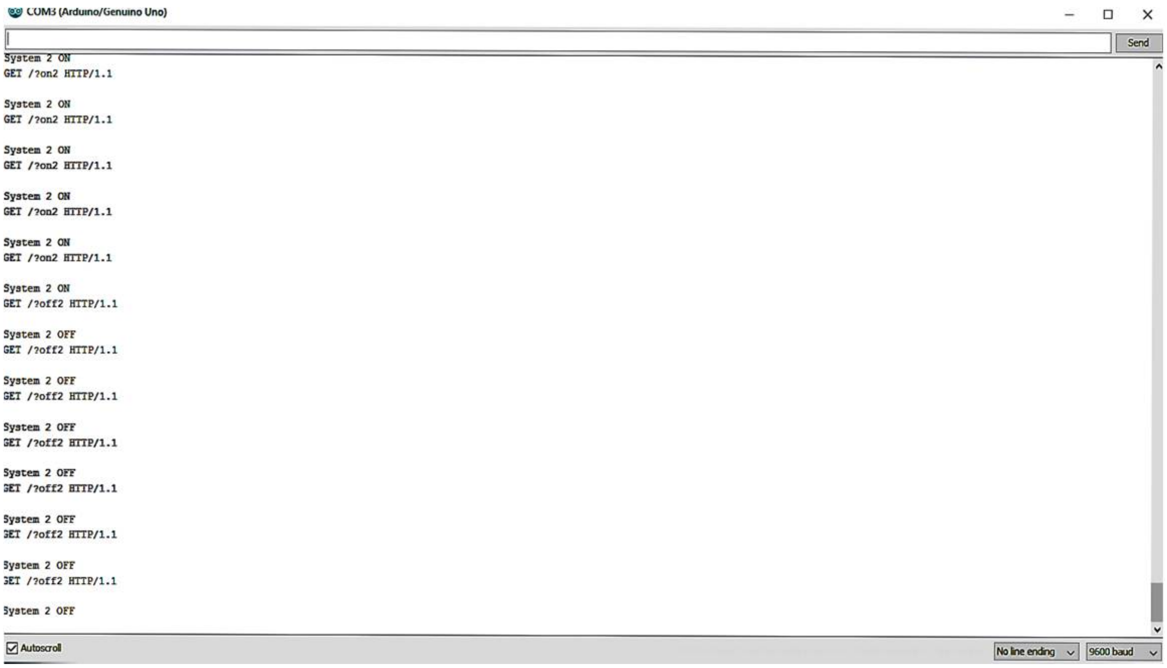


Fig.5.15. Snapshot of remote wireless monitoring and control of smart power system on Arduino serial monitor

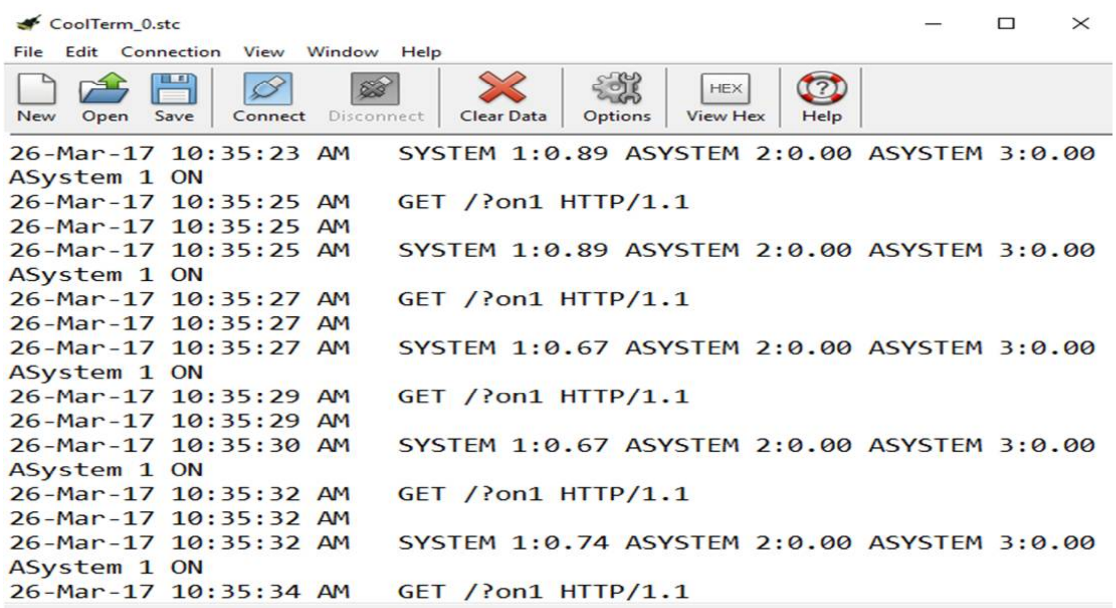


Fig.5.16. Snapshot of remote wireless monitoring and control of smart power system on serial terminal program

The prototype is tested using all three energy sources for various time intervals of the days. Graphical representations of real time readings are shown below. The prototype is developed for household energy management. The results include readings of household for two days between 9 AM to 4-30 PM as mentioned in the graphs.

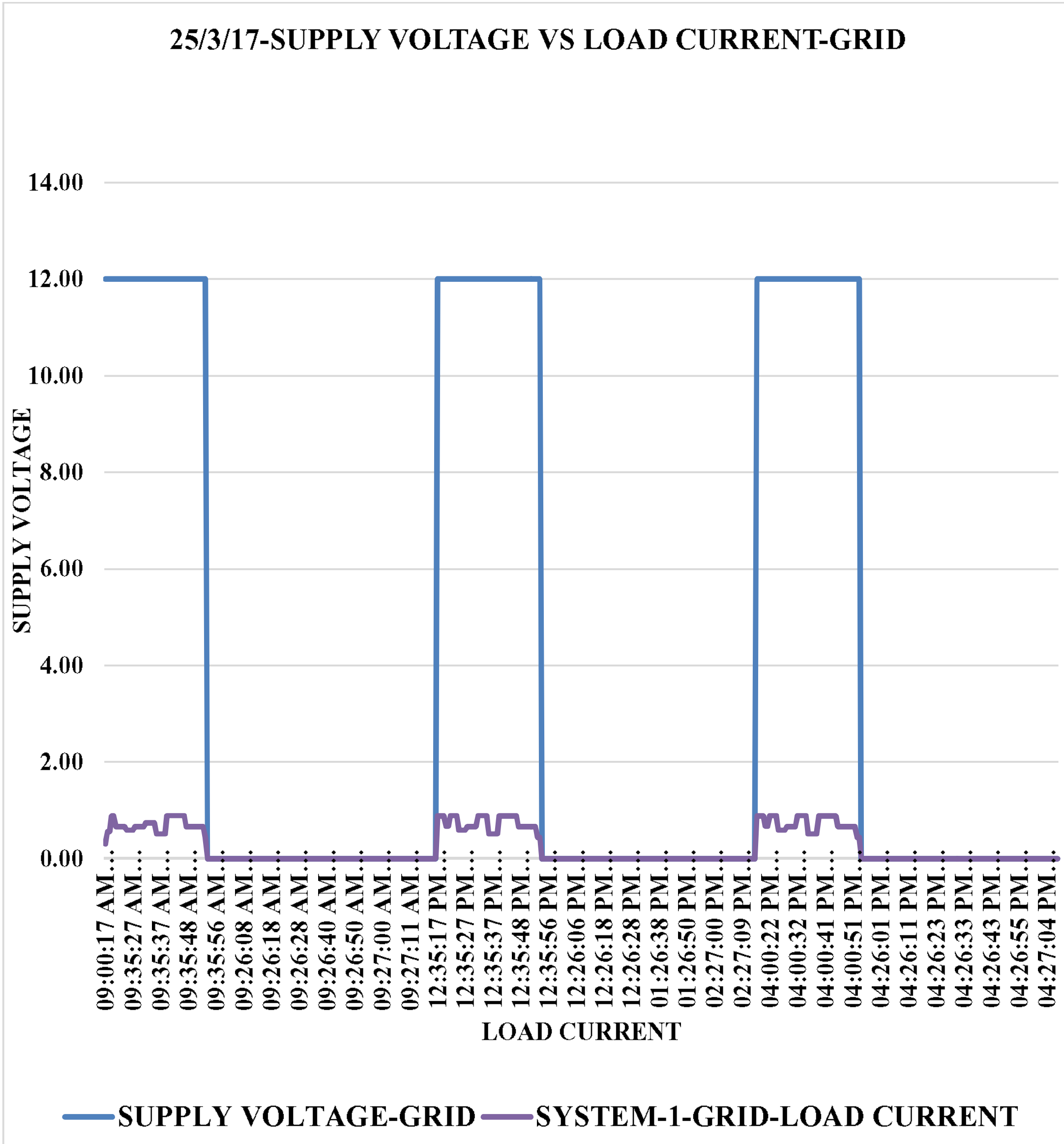

Fig.5.17. Graph of System-1

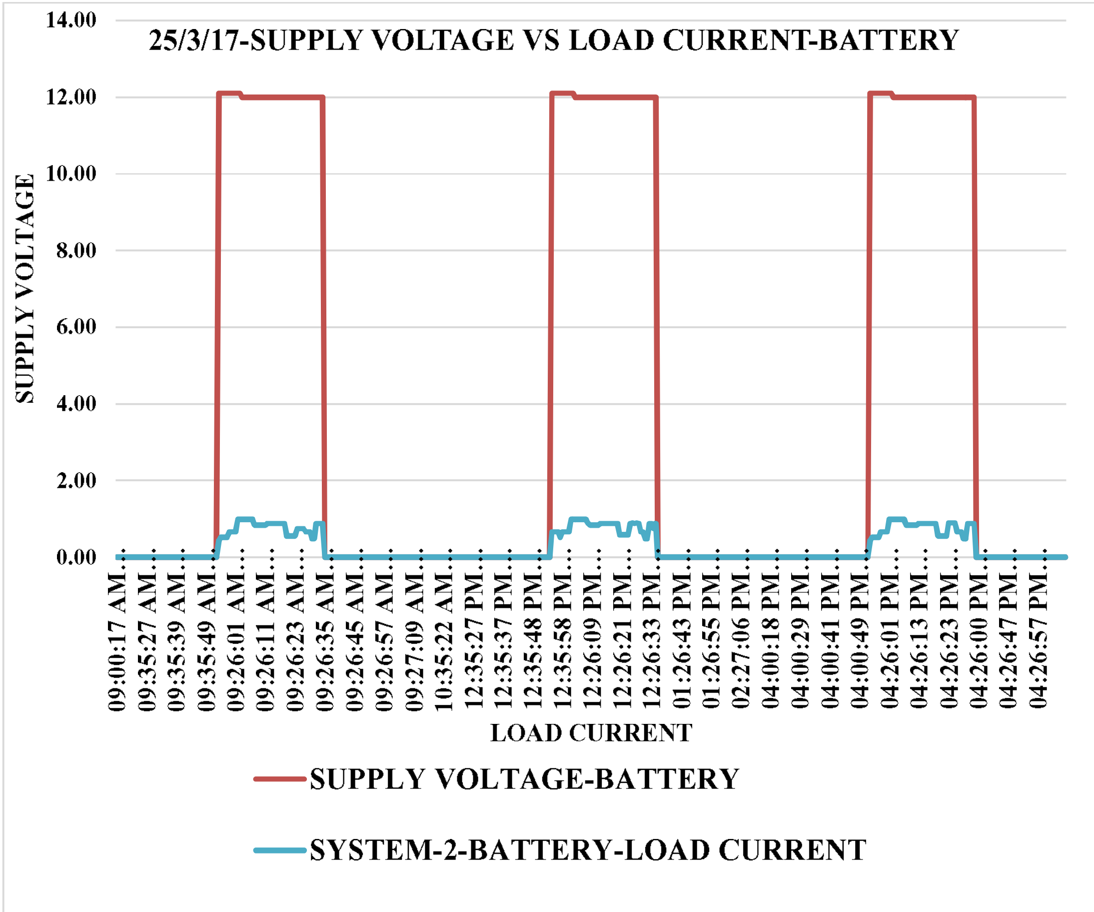


Fig.5.18. Graph of System-2

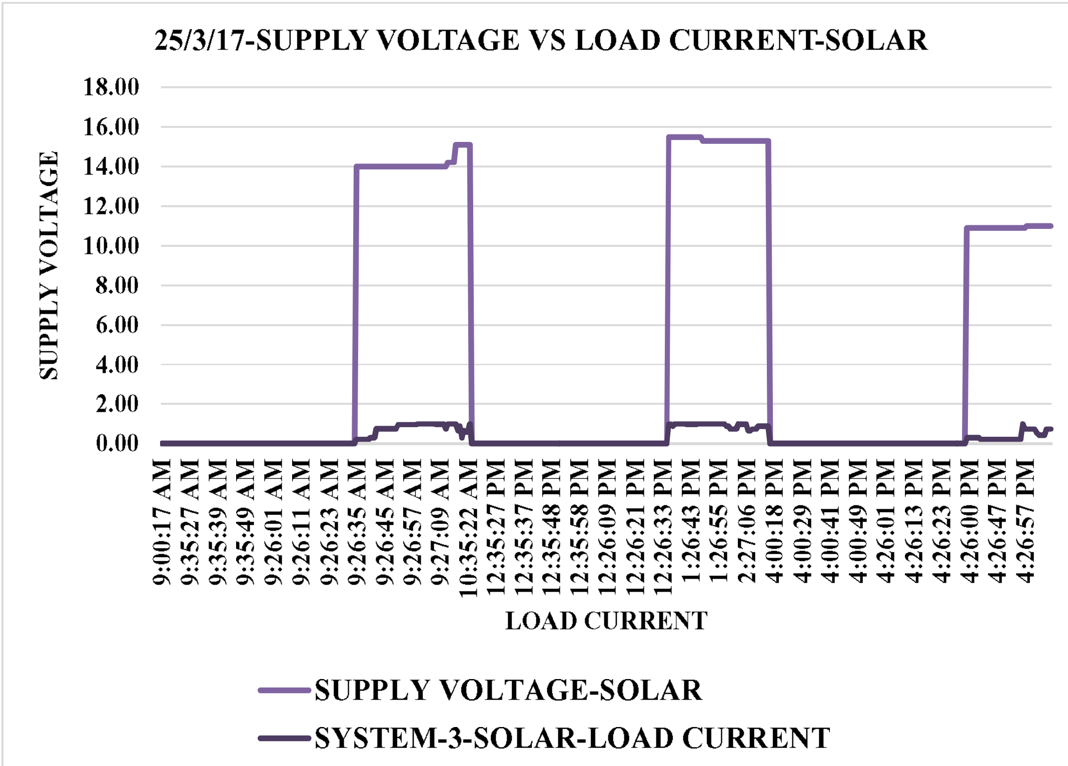


Fig.5.19. Graph of System-3

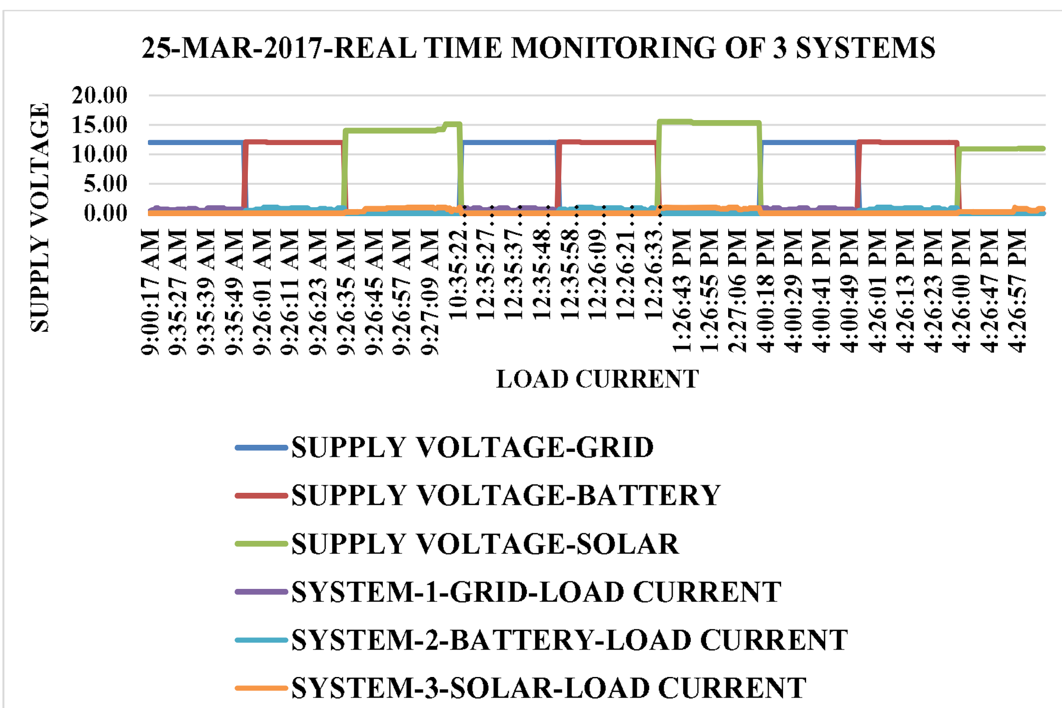


Fig.5.20. Graph of all three systems

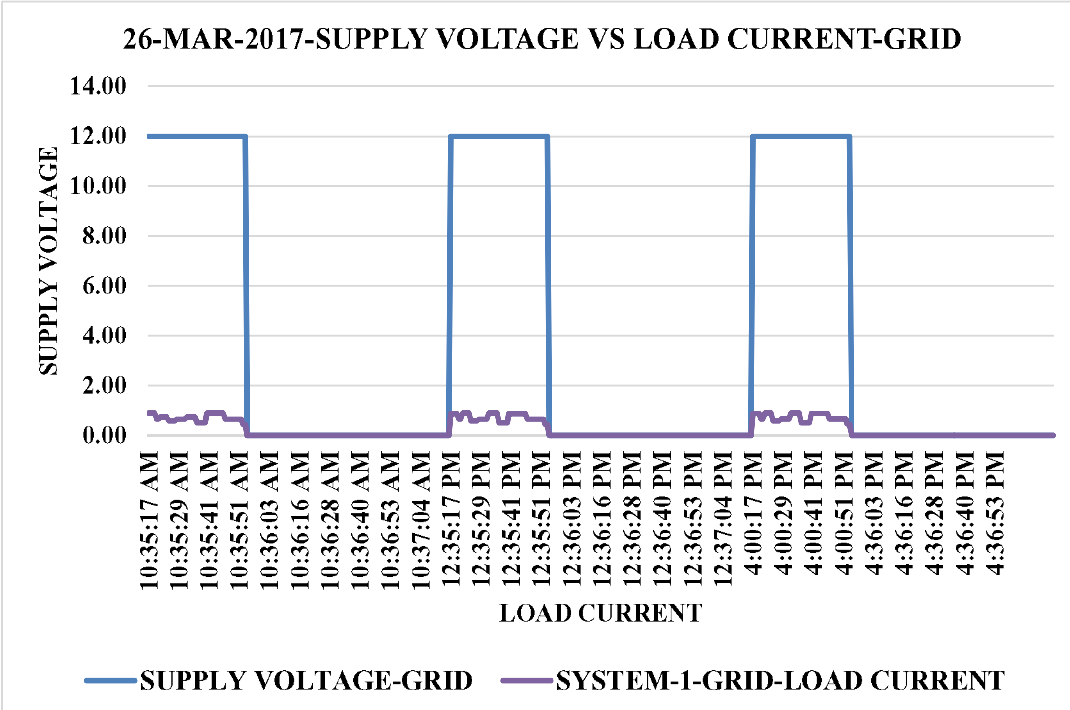


Fig.5.21. Graph of System-1

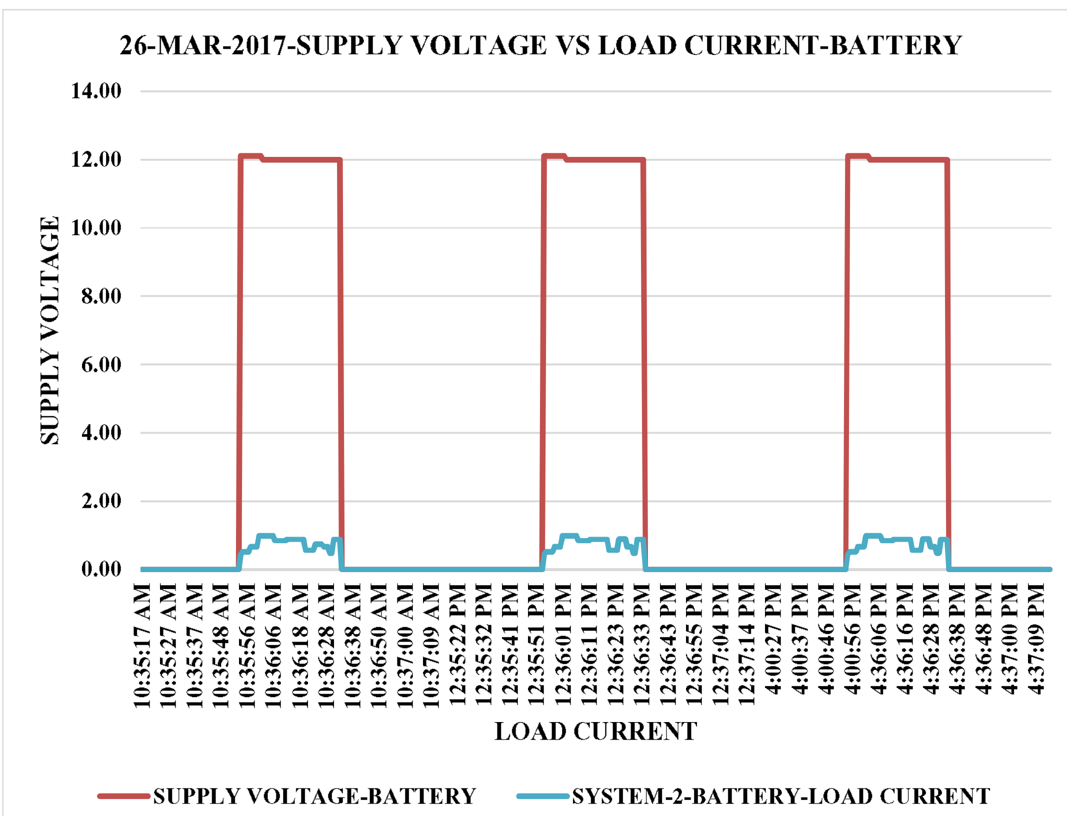


Fig.5.22. Graph of System-2

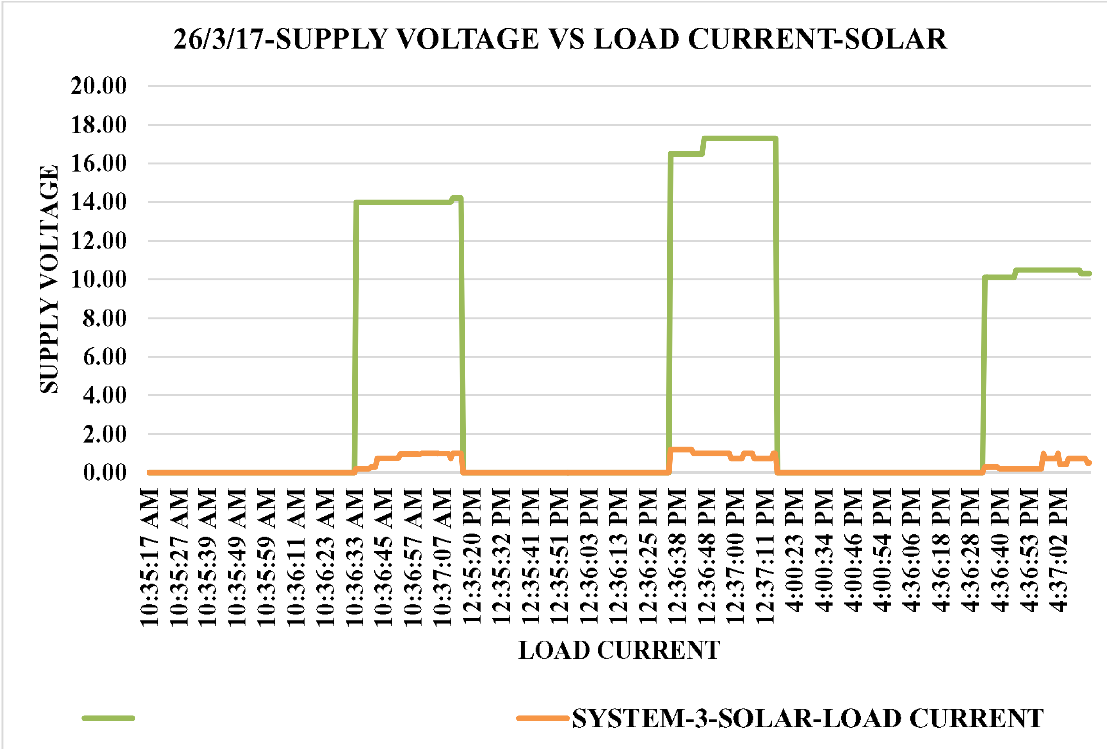


Fig.5.23. Graph of System-3

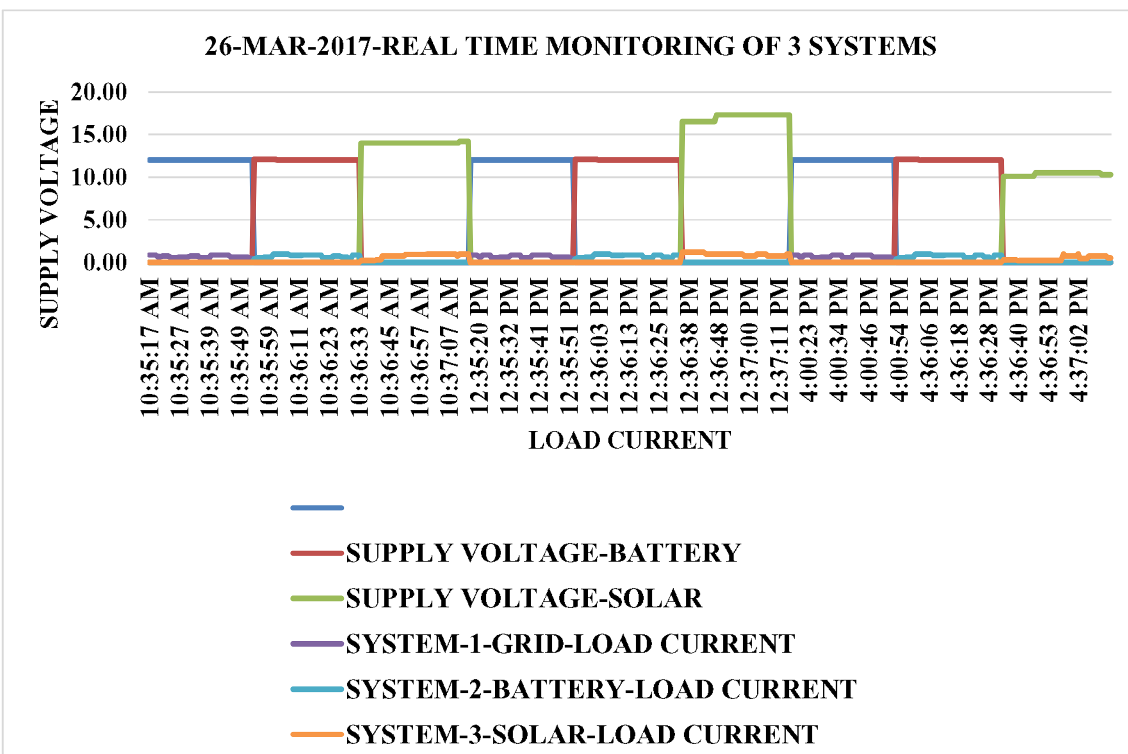


Fig.5.24. Graph of all three systems

The prototype has also been designed, implemented and tested for IoT solution by monitoring and control of smart energy system through WAN. The local IP address can be linked with Internet through port forwarding method. Port forwarding is a technique of forwarding web traffic/request to a specific internal or local IP address. A specific port listens to web traffic. A static IP address is required for this purpose. If the static IP address is not available then a dynamic IP address can be used for monitoring and control purpose. The developed prototype uses dynamic IP address with dynamic DNS service. The designed prototype is tested on web for IoT application. The address of the website developed for the designed system is **''smartenergy.dlinkddns.com''.**

When the prototype is functioning on the local network, the port can be forwarded for WAN application. The designed prototype is tested on the developed website. The snapshots of monitoring and control of prototype on Internet are shown below.

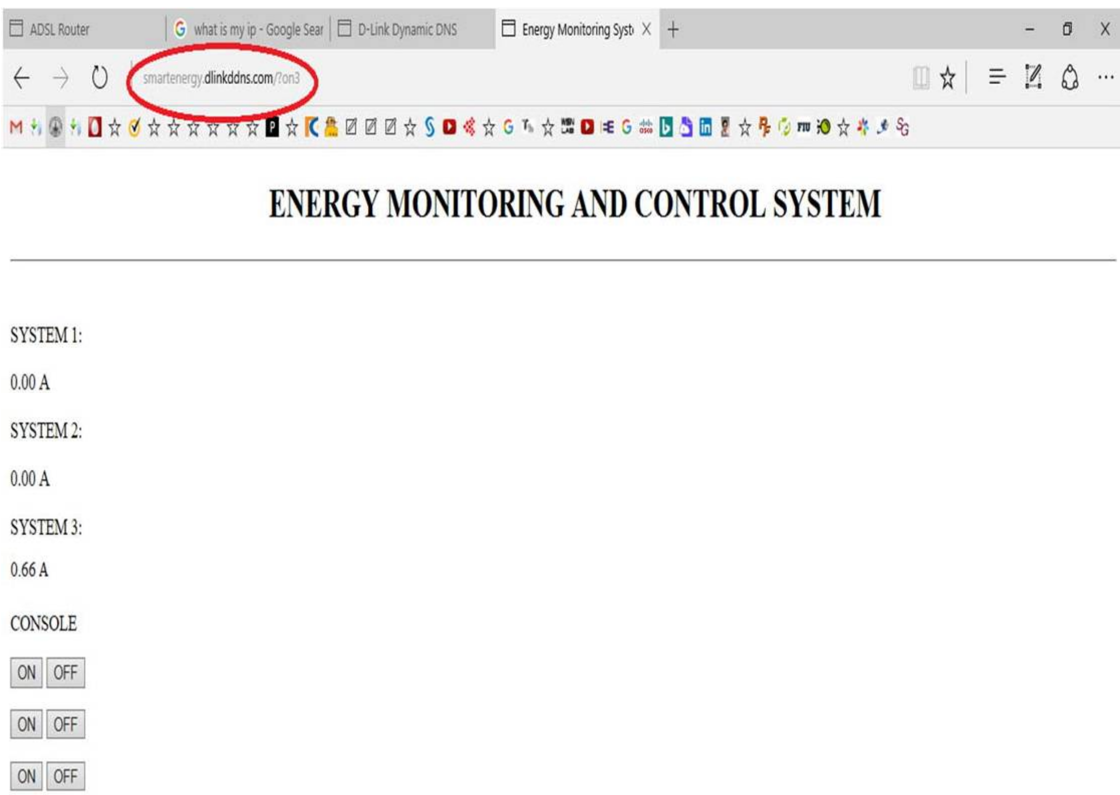


Fig.5.25. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage in Wide Area Network

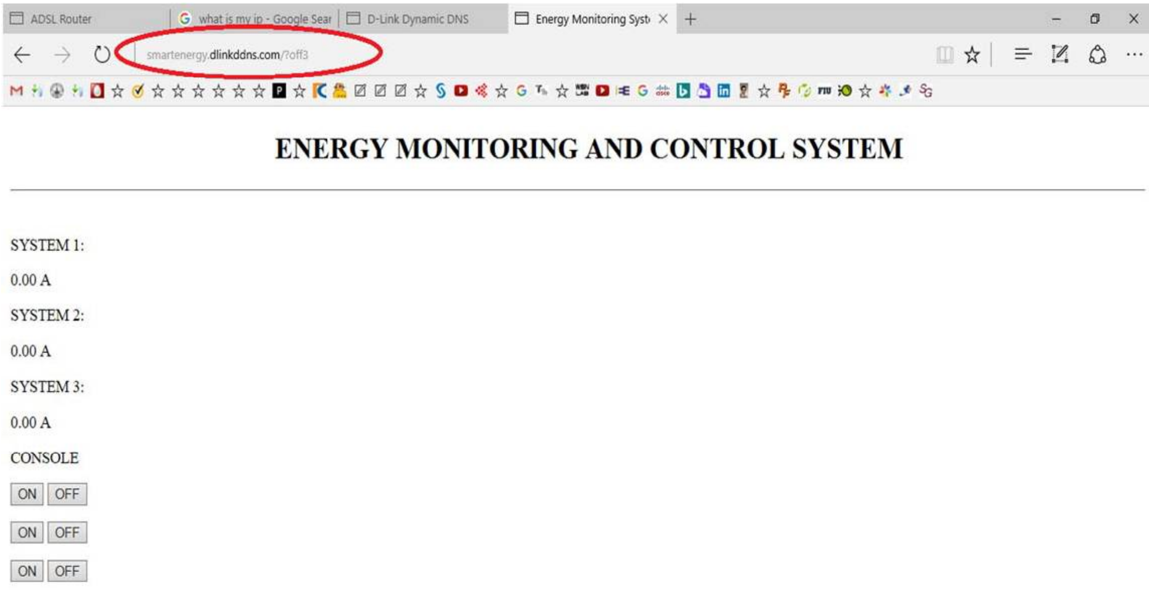


Fig.5.26. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage in Wide Area Network

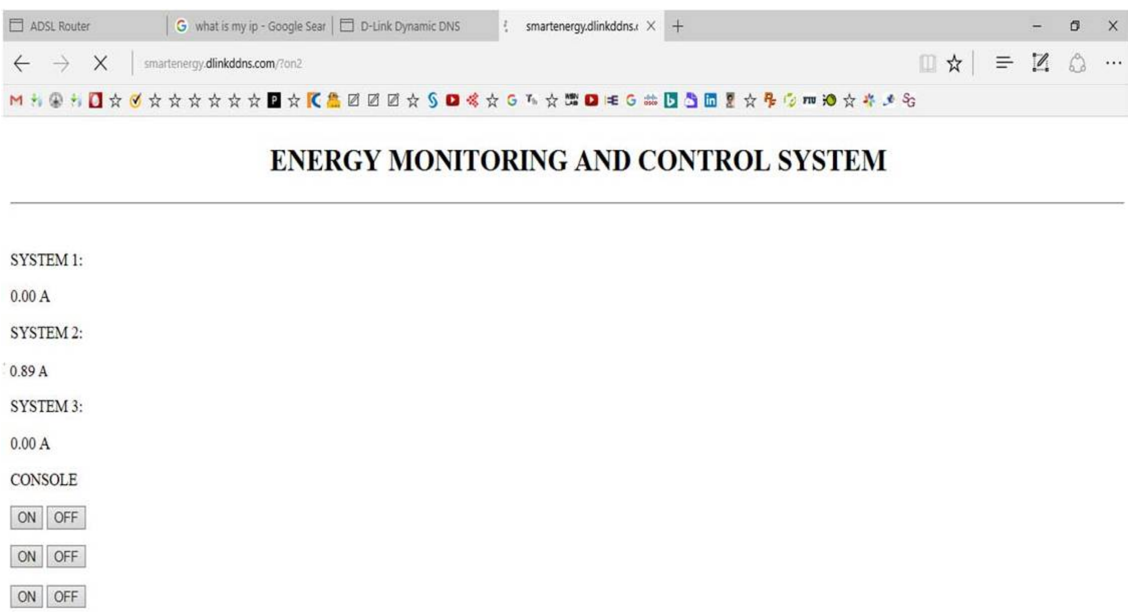


Fig.5.27. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage in Wide Area Network

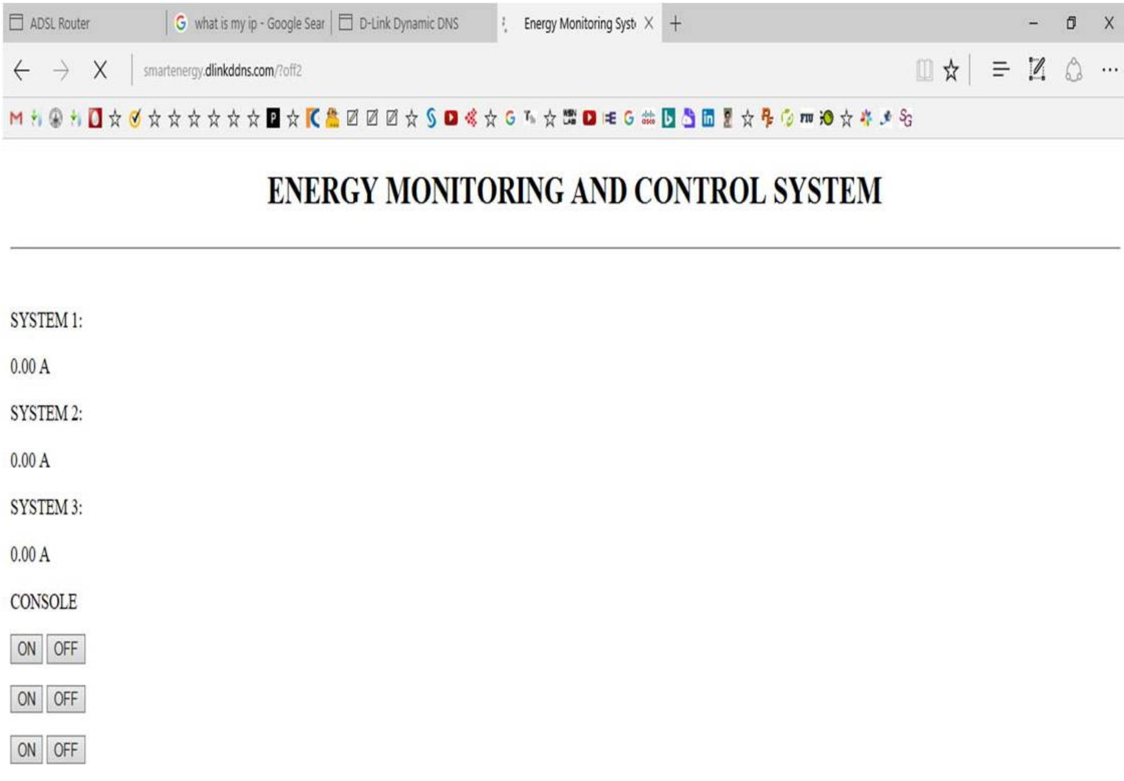


Fig.5.28. Snapshot of remote wireless monitoring and control of smart power system through HTML webpage in Wide Area Network

The prototype covers HAN, NAN/LAN & WAN for Smart grid communications with interoperable backbone network. The same can be upgraded and commercialized with some modifications but with the same communication protocols. The similar communication protocols and architecture can be applicable for AC/DC microgrid. Driven by developments and innovations in control, automation, computing and wireless communications technologies, future network deployments can be led by Ethernet. Interoperability between communication standards will result into simplified network design by avoiding the concealing of the boundaries between LANs, MANs, WANs and Industrial networks.

## CHAPTER SUMMARY

An experimental investigation of various hierarchical network layers of Smart grid communication infrastructure is implemented in this chapter. IoT is an integral component of Smart grid infrastructure. It facilitates web connectivity of various components of Smart grid network for real time operation and management. The prototypes are designed and verified to validate the conceptual aspects of Smart grid architecture. The prototypes are designed for Home area network using IEEE 802.15.1 and Wide area network using IEEE 802.3 and IEEE 802.11 standards. An integrated development environment (IDE) 1.6.11 is used as a source code editor and debugger. An HTML based webserver and GUI are developed for HAN and WAN. An independent web server works on an address **''192.168.1.177''**. The prototypes are verified using serial monitor as well as HTML based GUI. IDE serial monitor and CoolTerm softwares are used to monitor, capture and store the real time data. The real time data with time stamps is captured for graphical representation of acquired results. The GUI is developed using HTML-5. GUI is meant for remote wireless monitoring and control of designed prototype. A website for IoT exploration is developed and can be accessed on URL **''smartenergy.dlinkddns.com''.** The website is developed for dynamic IP using port forwarding method.