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Basic Home Automation Using Smart Sockets with Power Management

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Abstract: The power generated in today's time, is dominated using fossil fuels that may get exhausted within the coming decades. Monitoring and management of the energy consumption hold a prime standing due to the discrepancy between power demand and production. Power meters are a part of every household, which provides us with a measurement of the overall power consumed in units. The problem with them is that they do not provide us with the individual consumption of an electrical appliance leaving customers unsatisfied with the electricity bills. This paper presents the design and application of a smart power management system (SPMS) using a variety of sensors combined with an Arduino microcontroller. This will be replacing conventional home sockets with smart sockets, allowing us to cover the monitoring, control and safety aspects of any individual appliance in the house. This system is based on a newly evolving field worldwide, called the Internet of Things (IoT). The SPMS will be measuring the current, voltage, power factor and power consumed. Along with these measurements it can also control the power state of the device and help protect against overvoltage and overcurrent. This is basically a home automation system, in combination with smart power management, all controlled and monitored by our smartphones. The edge this device has over conventional energy monitoring systems is that it allows the user to have an exact idea of individual power consumption plus the billing on daily basis and take measures to reduce it.

Keywords: IoT, power management, sensors, energy conservation, smart-plug, Blynk, online monitoring, consumer application of sensors

1. Introduction

Energy, as we know, is a very scarce resource, and conserving it is the responsibility of every individual. Modern technologies are becoming an important aspect of our life, making things simpler and manageable along with keeping a low cost. There is a huge development towards creating everyday appliances energy efficient. These energy-efficient devices use reduced power, thus using lesser resources and are easier on the pocket. This paper focuses on measuring the energy consumption of an individual appliance and analyzing its efficiency. The user has an awareness of the entire working cycle of a device, in operation and in standby mode. Along with this the customer can tally the monthly billing by the electricity supplier with the measured usage of devices. Furthermore, allowing any errors to be eliminated from the supplier's side. An image illustrating the outline of the device configuration is shown is Figure 1.

The main goal of this project is to produce a working model, which can measure the voltage, current and power factor of an appliance using sensors. This information can be used to identify the real and reactive power usage of the device and indicate its efficiency and energy usage. Any electrical device is prone to failure, and in case of an

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overcurrent situation, it can be fatal. The SPMS tackles this issue by using a relay as a circuit breaker in case of any overcurrent or overvoltage. This project is a low-level smart home setup. Different devices connected all over the home can be controlled wirelessly, and their power consumption measured. The device to device (D2D) communication will be maintained through Wi-Fi internet module [1, 2]. This arrangement has the benefit of being in a small overall size, a form factor of a conventional socket, thus giving us the liberty of connecting selected household appliances in a home automation setup (See Figure 2). The cost of each device is kept to a minimum; thus, it is very cost-effective. It is highlighted in [3] that sophisticated home automation can increase the electricity cost by a significant margin. Thus, to keep the implementation cost to a minimum level is one of the prime objective.

The communication platform used for SPMS is Blynk [4, 5]. The choice of using Blynk was since it is much more convenient for a user to monitor from a smartphone GUI, than to use a website. A multiple of SPMSs can be connected in a network and can all be controlled from a single interface. This could very well be a step towards home automation. This setup could be upgraded for load distribution and management as presented in [6].

Performing a survey of the existing projects shows that there has been a lot of progress in smart power monitoring devices which all have the basic concept of measuring power and wirelessly transmitting it [7-10]. Performing a review on the existing literature, we can safely say that there are several methods of measuring power. A very common method utilized by numerous applications is only measuring the current and assuming the voltage used to be fixed at 230V.

A proposal presented by [11], uses a SEN-11005 split-core non-invasive current sensor for power measurement. This type of a current sensor can measure up to 60A giving an output of 1V. The same sensor can also be found in a project by [12]. A similar type of a split-core current sensor is the SCT-013- 030 which can measure a maximum of 30A. These sensors are basically a current transformer, which converts the high currents to a lower level, giving the output in terms of voltage levels which is used for the processing in the microcontroller.

Reviewing the existing methods for the connectivity, we find out that there are numerous ways to do so. The most common way of communicating with the device is by providing it internet connectivity. The project by [1] introduces the use of an ENC28J60 Ethernet module on their energy monitoring device. However, the most popular is the use of Wi-Fi to connect the device. For the Wi-Fi module, [13] proposed the use of a ZigBee Pro Series 2 Wi-Fi device. This is a very commonly used module, but only downside is its high cost. Another alternative to the Wi-Fi module is the ESP8266 ESP-01. This module was utilized in several existing projects and is easily the most popular choice. Projects by [14-16] all utilize this ESP8266 module. When compared to the ZigBee it is the fraction of the cost, with almost double the range. In [17], H.G. Rodney presents the design of wireless automatic meter reading system (WARMS). This implementation uses a GSM network for wireless transmission, by sending and receiving text messages to and from the device periodically [18, 19]. It has the same usage of voltage and current sensors which transmit power reading after a certain amount of time. The main disadvantage is that this application greatly relies on the network coverage of the area and the fact that there is no control over the power state of the device. Another project in [20], has designed a smart electrical power meter based on PIC24FJ128GA010 cotroller. For sending the data it utilizes an XBee PRO RF module which is based on Radio Frequency communication. However, it has also limited range of operation. Considering all these designs, this project aims to implement a new power management system which can monitor the electricity consumption of the devices continuously and can be controlled through mobile apps.

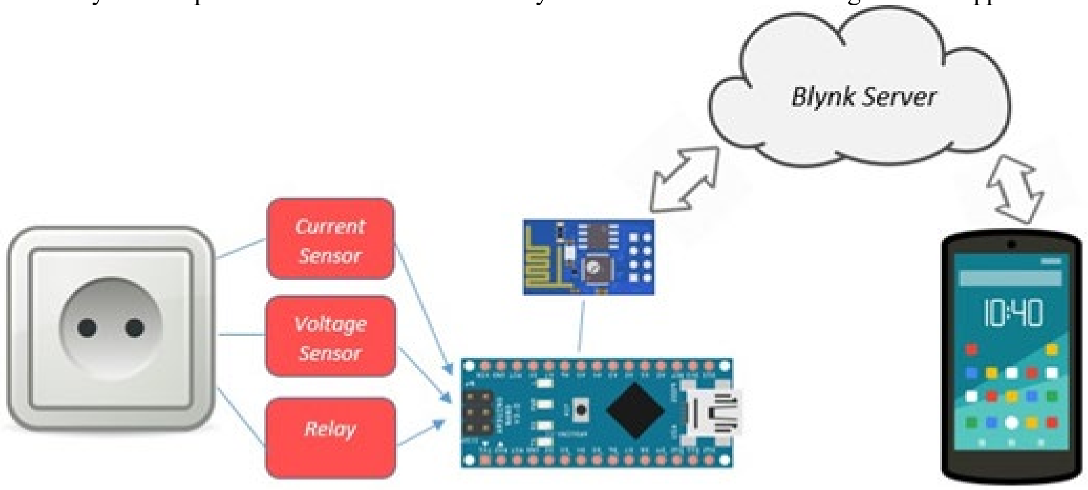

Fig. 1 - Overview of the setup

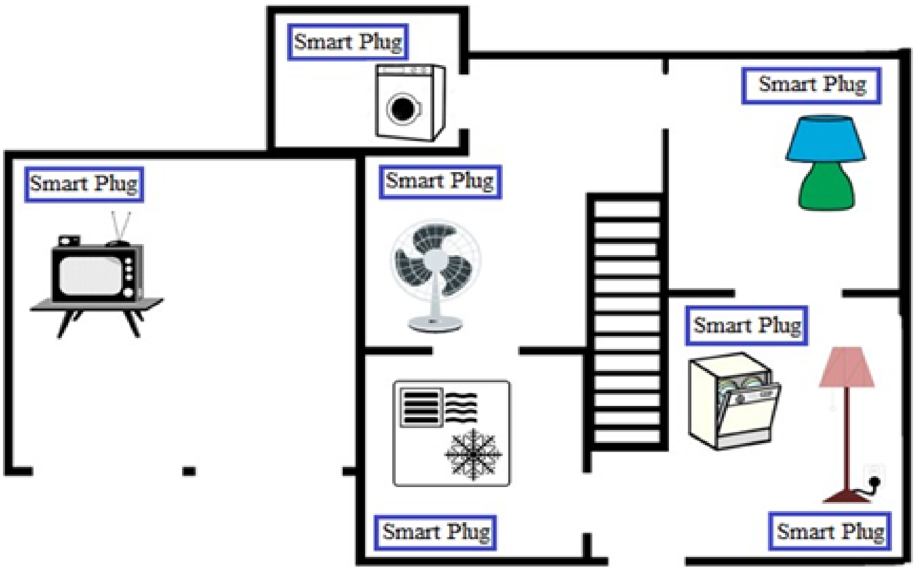

Fig. 2 - An example of the application of such a system

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2. Prototype Development

2.1 Hardware Components

Each hardware component was selected carefully, based on its size, functionality and cost. These components were commercially available and were selected from a wide variety of sensors. The smart power management system consists of three basic application of sensors: sensor signal processing, Internet of Things and online monitoring through mobile apps. A block diagram of the project is seen in Figure 3.

1) Arduino Microcontroller

The brain of the system is the Arduino Nano which is based on ATmega328P which has the same functionality as an Arduino Uno, but on a smaller overall size. The Nano has a 5V VCC output, which has a limit of 200mA. A separate 5V 700mA power supply was used to power the different modules used, along with the Nano itself [21].

2) ESP8266

Wireless connectivity was a requirement in the design of the SPMS for it to connect to Wi-Fi network, which falls under the category of online monitoring of the device representing an IoT. One of the most common and readily available modules, for this purpose is the ESP8266. The model used in this project is the ESP-01 from the ESP8266 series developed by Expressif. It is a very low cost Wi-Fi chip with 802.11 b/g/n connectivity which allows the Arduino to have full internet capability. The ESP8266-01 also includes a 32-bit microcontroller with a TCP/IP stack. It communicates with the Arduino through the serial pins D2 and D3 connected to RX and TX pins of the ESP. The ESP has been loaded with a custom firmware provided by Blynk which allows it to be connected to its server.

3) Current Sensor

For the current sensing application, an ACS712 module was used which is a sensor signal processing unit. The module used in this project can measure up to 30A using a Hall Effect sensor. It has a voltage resolution of 66mV/A which is suitable for high, as well as low current values. This is an invasive current sensor, which means that it requires to be set up in series with the circuit. The input of the current usage, as we know is a Sine wave. The hall effect sensor reproduces the Sine wave with a 2.5V DC offset, the raw output of the ACS712 current sensor can be seen in Figure 4.

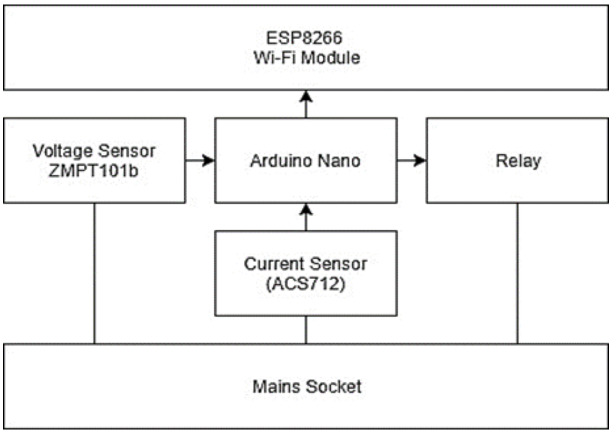


Fig. 3 - Block diagram of the basic layout

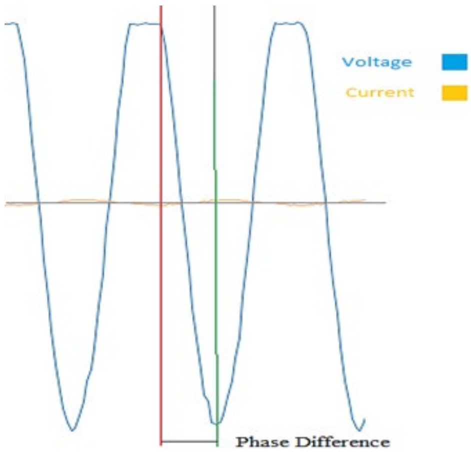


Fig. 4 - Graphical representation of the phase difference

The input signal is sampled at 10-bits. To measure the RMS current, we get the peak current by dividing the peak to peak value shown in (1).

$$\mathrm{I}_{\max} = I_{pp} / 2 \qquad (1)$$

After getting the peak current, we multiply it with 0.707 to get the RMS current as seen in (2).

$$\mathrm{I}_{rms} = I_{\max} / \sqrt{2} \qquad (2)$$

Each ACS712 has a scale factor, depending on its maximum current reading capability. The module we used was the 30A module, which had a scale factor of 66mV/A. After multiplying the scale factor with the initial RMS current, we receive the actual RMS current in the system using (3).

$$\mathrm{I}_{rms(actual)} = I_{rms} \times 66 \quad \text{mV/A} \qquad (3)$$

4) Voltage Sensor

The voltage sensor used in this project is based on ZMPT101b, working as a sensor signal processing unit. This consists of a voltage transformer that has a turns ratio that makes it suitable for the module to handle mains voltage. The voltage sensor, like the ACS712 has a sine wave with a DC offset at 2.5V. This module is rated for 350V and must be calibrated beforehand. Measuring of the voltage, calculating the power and power factor was done by using the already available library developed by Open Energy Monitor. This library includes all the algorithms needed to sample the voltage, and measure power factor using the peak to peak times of the current sine wave and voltage sine wave. The raw output of the ZMPT101b voltage sensor can be seen in Figure 4. The same principle used for measuring the current is utilized in measuring the voltage. The voltage measured is in RMS and the power is simply calculated by using (4).

$$P = V_{rms} * I_{rms(\text{actual})} \quad (4)$$

The power factor is a very important characteristic of a power system. It is the cosine of the phase difference in the voltage and current usage. The power factor can provide us the reactive power and the apparent power of a system since it is the ratio of true power to apparent power. The phase difference between the two inputs is calculated by using the zero crossings as seen in Fig. 4. The time of a zero crossing for a voltage signal and current signal is stored. The difference is a value in radians. The Cosine of this value gives us the power factor as seen in (5).

$$\text{Power factor} = Cos(\theta_v - \theta_i) \quad (5)$$

In the Arduino program, if the value of this power factor is negative, it signifies that it is lagging which means an inductive load is present, and if it is positive it is leading, signifying capacitive loads.

5) Relay

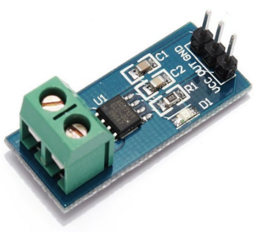
A relay is used for switching purposes, which works from the 5V output from the Arduino. This relay can handle 250V AC with up to 10A. It is connected in a NA (naturally open) configuration which means that if no signal is provided, the relay remains off.

The IC circuit board of current sensor, voltage sensor, Wifi module and relay is presented in Figure 5.

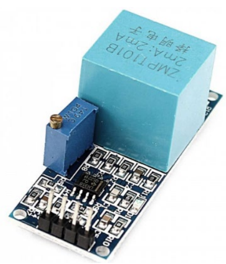
2.2 Software Components

All coding is done on the Arduino IDE. Since this project consists of several different modules, each had to be tested and programmed individually. The safety factors were included in the coding of the microcontroller. If the sensed current exceeds 10A and if the measured voltage is greater than 260V, the relay opens which disconnects the appliance from the mains. It is very important to keep the connected device to function safely and prevent surge usage of power. The user is notified of any such case immediately. The data collected from the sensors are sampled and processed, then it is sent to the cloud server. Any incoming requests from the cloud are also processed. A process flowchart of the program can be seen in Figure 6.

Blynk is an app designing platform supported by Android and iOS, which can control a microcontroller such as Raspberry Pi and Arduino wirelessly over the internet. The microcontroller can have an either of connection methods, Wi-Fi or Ethernet. The basic working principle of the Blynk application is based on IoT (internet of things). The Blynk application can be used for displaying values received from a microcontroller and send control commands to it. A very informative and easy to design UI is used for the control interface. An initial GUI of the Android application is shown in Figure 7.



(a)



(b)

(c) (d)

Fig. 5 - (a) Current sensor (ACS712); (b) Voltage sensor (ZMPT101b); (c) WiFi chip (ESP8266); (d) switching relay

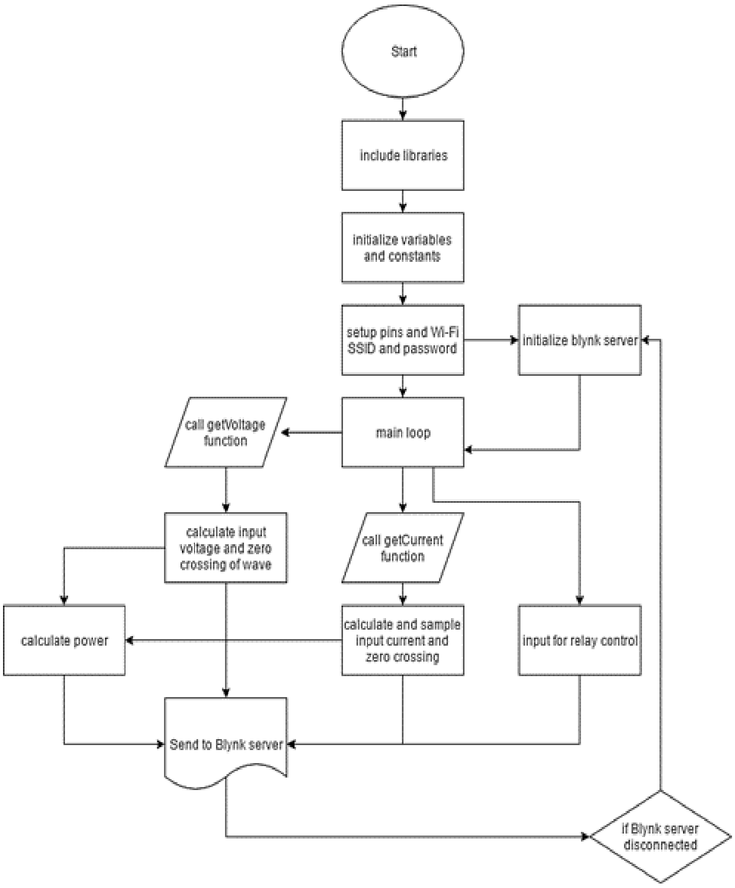


Fig. 6 - Flowchart showing the program process

2.3 Circuit schematics

A circuit diagram of the circuit was created as shown in Figure 8. The different components were connected by referring to their datasheets. The ACS712 current sensor and the relay were connected in series with the live mains 230V line. The line goes towards the outlet socket. Voltage sensor, however, was connected directly to the outlet, which means that if no device is connected there will be no readings. The ESP8266 Wi-Fi module was connected to the Tx and Rx pins of the Arduino and was powered by a separate 5V power supply with an AMS1117 3.3V regulator.

1) Calibration

Before using the current and the voltage sensors, we had to calibrate them initially. For this, a fixed resistive load (5W100RJ) of 100Ω was used. When connected to AC voltage of 230V, we should be using 2.3A of current, which was confirmed using a multimeter. The voltage sensor uses a potentiometer for calibration, however, for the current sensor, software modifications had to be made since it receives the raw sampled output. The test was confirmed using a 40W halogen bulb, which uses 0.186A at 228V, giving 42.41W.

2) Prototyping

Following the circuit diagram from Figure 8, a prototype was created. For testing purposes initially, the setup was made on a breadboard, and later a PCB. The SPMS, theoretically can handle up to 10A of current since it is the maximum rated current of the relay. The voltage sensor can handle up to 450V, which keeps the device always in safe working conditions.

In the breadboard prototype (See Figure 9), two power supplies were used, each able to provide 5V DC at 700mA One of them was used to power Arduino and the sensors, whereas the other to power the ESP8266 Wi-Fi module.

Following the successful test in the breadboard, a PCB module is built. That is placed in the socket housing as presented in Figure 10. The main power line is first connected to the PCB prototype and then active line is connected to the power socket. The supply neutral line is passing through the relay (see Figure 8), which gives control to the Arduino microcontroller to switch On/Of the appliance connected to the power socket.

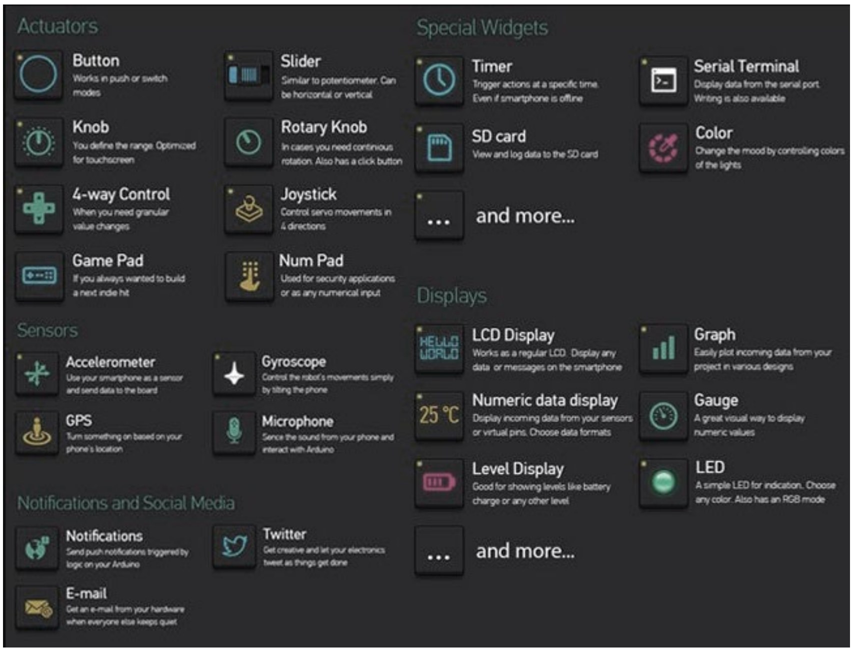


Fig. 7 -Widget options is Blynk

3 Results and Discussion

Several tests were conducted on various household appliances to measure their power. A setup in which a multiple of such devices can be connected in a network is a step towards a very modular home automation setup. Since this device is low cost and in a small overall size, along with providing us with the power consumption of an appliance it allows the user to switch it on or off wirelessly from anywhere in the world. Appliances such as lamps, fan, HVAC systems washing machines etc. can be connected safely.

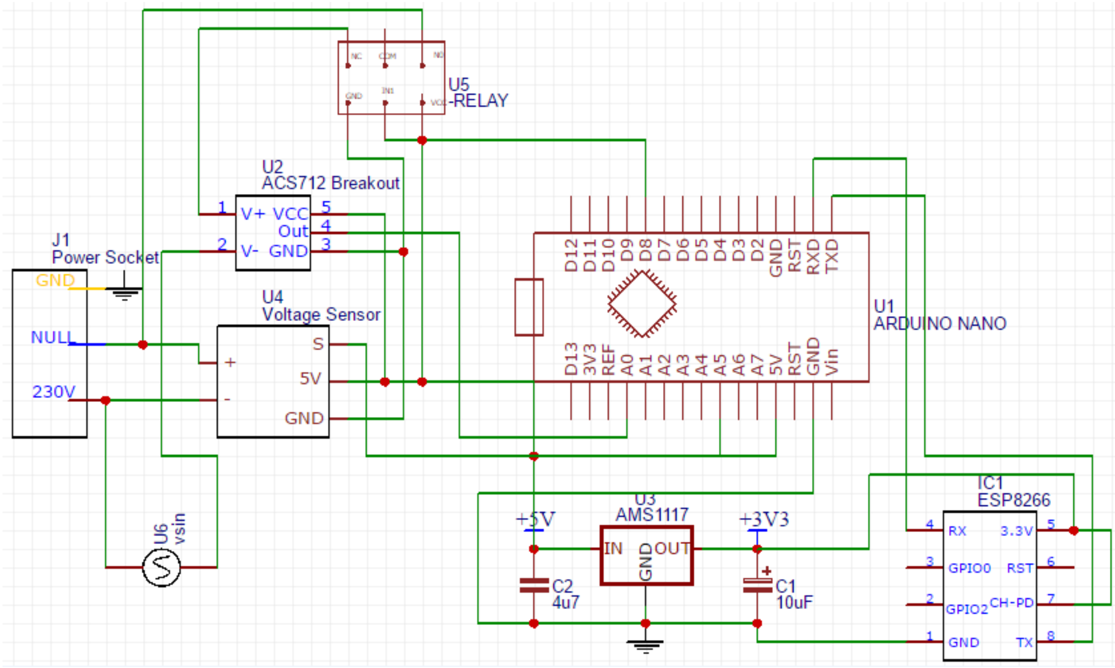


Fig. 8 - Project schematic

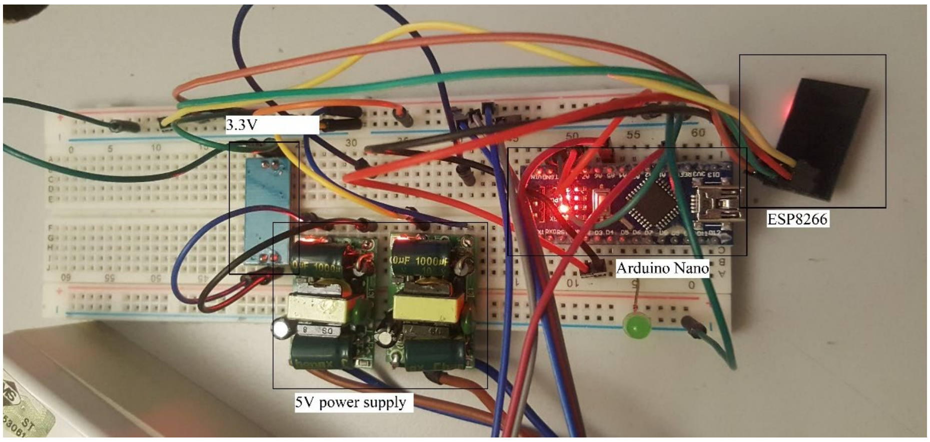


Fig. 9 - Prototype on breadboard

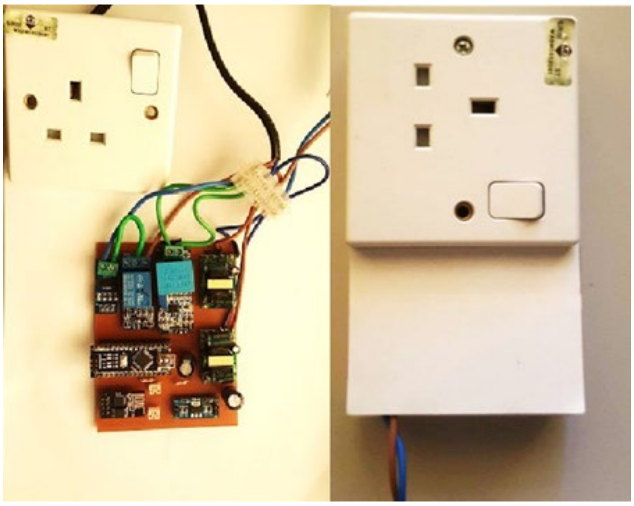


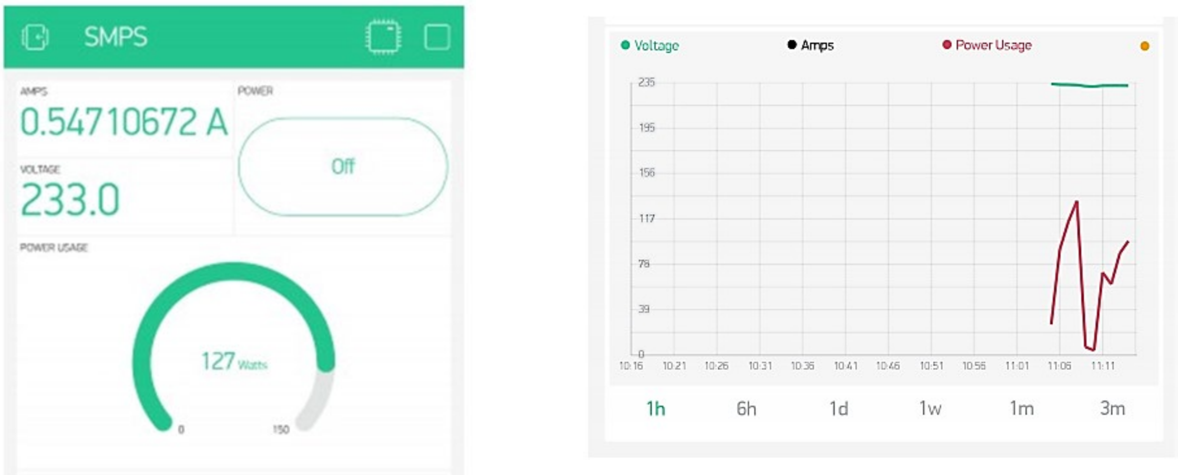
Fig. 10 - PCB and socket (left), Enclosed Socket housing (right)

Before the smart power management system could be used for measuring and controlling an appliance, some sensors had to be programmed and calibrated beforehand. Each appliance has a rated working power, which was used to compare with the actual results. The appliances were tested in their operating as well as standby modes, giving us an overall power usage cycles of a device.

Table 1 - Energy consumption of tested appliances

Appliances		Philips Incandescent Bulb	Soldering Iron	Panasonic 42″ LED TV	Xbox One S
Rated Power		40 W	30 W	120W	130W
Measured voltage (V)	Operating	228	231	233	231
	Standby	-	-	233	231
Measured Current (A)	Operating	0.186	0.134	0.547	0.594
	Standby	-	-	0.135	0.006
Measured Power (W)	Operating	42.41	30.88	127.45	138.88
	Standby	-	-	31.46	13.00

The test results are shown in Table 1. Four different household loads were tested namely Philips Incandescent Bulb, Soldering Iron, Panasonic 42" LED TV and Xbox One S. The rated power of these appliances are 40 W, 30 W, 120 W and 130W respectively. The measured data from the SMPS app is also tabulated in Table 1. It can be seen that the measured operating power for the appliances are 42.41 W, 30.88 W, 127.45 W and 138.88 W. Such measurement is very close to the actual rated power and thus validate the working accuracy of the developed prototype. Figure 11(a) shows the GUI of the Blynk application used to display the measurements. The application also provides us with the overall usage graphically, as seen in Fig. 11(b) which shows the usage of an Xbox. This shows us the power used when it is switched on, in gameplay mode and in standby mode. It is noticeable that the TV and the Xbox consume energy in standby mode. Thus it would be wiser to switch it off when not in use. Such data through mobile apps gives us the idea of how the energy consumption of every appliance varies and what steps to take to reduce usage and keep the appliance in safe working conditions.



(a) (b)

Fig. 11 - (a) Graphical User Interface (GUI) for power management system and (b) Test showing the power usage of Xbox One S

4 Conclusion

This project presents the design and working model of a standalone smart power management system which can monitor and control the usage and cycles of any individual device. This device can be used as a smart socket since it has a very small form factor, and if multiple of them are connected in a network, it can be used as a setup of home automation. Through this device, users can have an actual idea, how much energy is consumed by the individual appliances and thus can take appropriate measures to optimize energy consumption. Although the device fulfills its overall functionality, there is always room for improvement. The idea is to make the device to an even smaller scale by using components and modules of reduced size. In addition to that, complete setup for home automation is a good future prospect.

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