Household Power Optimisation and Monitoring System

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Chinhoyi University of Technology
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John Batani, Silence Dzambo and Israel Magodi
ICT & Electronics Department
Chinhoyi University of Technology,
P.Bag 7724 Chinhoyi, Zimbabwe

ABSTRACT

Like most of the developing countries, Zimbabwe continues to face critical electricity shortages. In this paper, the authors present a smart solution for reducing electricity usage in households while improving comfort levels for the dwellers. The authors developed a prototype to optimise electricity usage by domestic appliances. In attaining optimal power usage in households and remote manipulation of household appliances, the researchers utilized the design science research methodology. The proposed system reduced power usage and cost of electricity in households by at least 50 per cent. The results benefit the nation by reducing domestic electricity usage and thus reducing the overall electricity shortages which may affect the manufacturing and other sectors of the economy. Remote manipulation of, and communication with the devices by the user are achieved through the Bluetooth technology and the Global System for Mobile communication. When the user turns on a stove, the system automatically turns off the fridge to minimise power consumed. However, the performance of this system may be affected by the performance of the sensors used. The focus of this paper was to reduce the amount of electricity consumed by households, thus reducing the overall stress on the national power grid and increasing the available electricity for industrial use, leading to employment creation. The proposed system can help in the realization of the UN's SDGs through ensuring there is adequate electricity for industrial use, as espoused by SDG 9.

Keywords

Power optimization, Household power saving, Electricity saving, Electricity shortage, SDGs, IT4D, ICT4D.

1. INTRODUCTION

The importance of electricity in any economy cannot be underestimated [1,2], hence the need to efficiently use it. Zimbabwe currently has a shortage of electricity and since 2007 the nation has experienced load shedding due to inadequate generation of electricity by the national power utility company [3]. [4]has it that there is generally shortage of electricity globally, and Zimbabwe is no exception. According to [3] Zimbabwe will continue to have electricity shortages for upto 8 more years due to the incapacity to generate sufficient electricity. Several attempts, such as the use of energy savers, electricity importation and use of alternative, natural power sources such as gas and solar, have been made to ease pressure on the insufficient electricity in Zimbabwe. However, the problem of electricity shortage in Zimbabwe still persists, and there is a call to everyone to contribute towards solving the problem [3]. In light of this, the researchers developed a household power optimization and monitoring system for optimizing the usage of the inadequate electricity that is currently generated in the country while not inconveniencing the users.

Africa's electricity shortage is hugely characterised by continuing power cuts and a complete deficiency of electricity infrastructure [5]. This has resulted in negative effects to human and socioeconomic development across the continent [5]. According to [5], only an average of 40 per cent of Africans enjoy a consistent electricity supply; while only 69 per cent of the electrified homes really have electricity that works most or all of the time. 62 per cent of Zimbabwe's population has access to an electricity grid [5]. [5] claim that only 30 per cent of Zimbabweans have electricity that works reliably, 26 per cent have electricity that works half the time while 44 per cent have electricity that either works ocassionally or not at all. Zimbabwe Electricty Supply Authority (ZESA) is the sole producer, distributor and seller of electricity. [6] states that the electricity industry in Zimbabwe has operated as a controlled monolopoly for about five decades. [3] has it that they will reduce electricity generation from 750MW to 475MW due to reduced dam levels since most of the electricity in the country in hydro generated. Zimbabwe has had an 80 per cent urban electrification, 20 per cent rural electrification, and 41 per cent overall elecrification growth from 1980 to 2007 [7]. An unmatched increasing population and balooning number of electric appliances has created an electricity shortage in Zimbabwe, resulting in substantial load shedding [3]. This electricity shortage is despite several efforts that have been made to increase electricity supply and reduce electricity consumption in Zimbabwe, including power importation, use of energy savers and use of alternative energy sources such as solar and biogas [3]. All over the world, several IT based systems have been developed in an attempt to reduce excessive power demand, such as the Green Building in Italy [8]. In Zimbabwe, little has been done to optimise power usage through the use of ICTs [1]. In 2012 ZESA introduced pre-paid meters as to enable customers to manage their electricity bills and encourage them to use electricity wisely. Despite all these efforts, Zimbabwe still faces electricity shortage [3], hence the need to come up with a solution for optimisation

1.1 Problem Statement

There is generally a serious shortage of electricity in the whole world in general and Zimbabwe in particular [4]. Zimbabwe has a reliable electricity capacity of the order of 1 320 MW (Megawatts) against a demand of about 2 200 MW [9]. [10] concurs that Zimbabwe is facing critical electricity shortages due to inadequate electricity generation. Several efforts have been made in Zimbabwe to reduce electricity consumption and improve electricity supply. Such efforts include the use of energy savers, electricity importation and use of alternative, natural power sources such as gas and solar. However, Zimbabwe continues to face electricity shortages as evidenced by massive power cuts and load shedding [3]. This has affected both domestic and industrial consumers; hence the need to come up with a solution that optimises electricity usage in Zimbabwe.

1.2 Research Objectives

1. To design an automated system that optimises electricity usage in households.
2. To design an android application that enables remote manipulation and monitoring of plugged on household electric appliances.

1.3 Significance of the Study

This study seeks to come up with a solution for optimising electricity usage in households; hence reducing the load on the national grid. Reducing electricity consumed by households reduces the national demand for electricity and may save the country foreign currency in reducing electricity imports. Moreover, if domestic electricity consumption is reduced, it increases the amount of electricity available for industrial use, which in turn may improve employment creation. According to [11], every single occupation in the manufacturing sector generates more than two million occupations in other sectors, hence it is important to ensure that the manufacturing sector is sufficiently powered. In addition to power usage optimisation, the study also seeks to reduce electricity bills for household consumers

2. RELATED WORKS

Power optimization refers to reducing the amount of power consumed by devices (such as home appliances, while preserving their functionality) through designing automation tools that minimise power wastage [12]. A well designed monitoring system should be capable of maintaining preset environmental conditions in the building [13]. Various solutions for energy saving in households using smart technology have been proposed and developed. Most approaches in literature for energy saving in households focus on lowering the power consumed by heating, ventilation and air conditioning (HVAC) appliances, such as the household heating systems

[14], air-conditioning [15] or both of them [16]. [17] further identified lighting and home appliances as two more areas to be incorporated in energy management features to minimize the domestic energy waste. Other power optimisation solutions indirectly attend to lowering the power consumed by such (HVAC) devices by providing improved monitoring and controlling options for the devices, which will in turn result in power consumption being lowered [18]. The majority of such solutions employ a wide range of sensors for measuring humidity and temperature, the data from which are processed by fuzzy controllers [14].

[8] designed an automated power management system called the GreenBuilding. This system used sensors to intelligently monitor power usage and automatically control the behaviour of devices in a building. The system provides a dashboard through which a user can view power consumption statistics by each appliance [8]. The Arduino platform was used in designing the network of sensors. Although GreenBuilding allows the user to view reports based of power consumptions, it does not send notifications/alerts to the user through the phone pertaining electric appliance consumption or status notifications. Moreover, once GreenBuilding is installed, it does not allow users to create their own modes based on their own priority preferences on appliances.

The Smart Grid is another power optimisation solution which is an amalgamation of communication and electric infrastructure through IT in the current electrical networks to boost efficiency [19]**.** This system can control daily used household devices according to user defined tariff rates for each particular device, thus reducing electricity costs to the consumer and reducing pressure on the grid [20].

[21] designed a simple system for remotely controlling and monitoring lights, using the Global System for Mobile Communication for long range communication and Bluetooth technology for short range communication. The system sought to reduce electricity consumed by household devices through the use of infrared sensor. Apart from reducing electricity usage, the system also notified users of any irregular situations (like high temperatures and intrusions) through Short Messaging System or Bluetooth technology. Upon receiving a notification on a mobile phone the user initiates appropriate action which will be implemented by the system [21]. The use of Bluetooth for communication reduces costs since communication via Bluetooth is not charged. However, the system is inefficient in circumstances that require high real-time data transfer. It also does not operate in various modes once it is started off, leaving the user with little room to make some options on the usage level of the system. Moreover, the

system does not prioritise electricity usage on different household appliances based on the available power.

[22] developed a Smart Power Saving System in smart homes for controlling appliances with the aim of saving power. The system comprises two modules namely fingerprint electronic door-locking and electricity saving. It uses GSM for interaction between the microcontroller and the phone. A user scans their fingerprint on the door-lock and if it matches, the electricity saving module will be turned on. The electricity saving sub-unit controls household electric devices in the home in response to the relative conditions from different sensors installed in the room. Fan and lights are switched on/off in response to the temperature and light intensity inside the home [22]. However, the module had a narrow scope in terms of monitoring and controlling electricity usage. This is evidenced by the system's target on small household appliances specifically fan and lights whilst larger appliances with higher consumption were excluded such as stoves and fridges. The biometric module in the system added unnecessary costs as far as the power saving was concerned. The biometric module was more into security than power saving.

Artificial Intelligent-based systems have also been proposed for power usage optimization. These learn about the behavior of an inhabitant in a smart house to self-adjust the system so that it can be independent and easy to personalize [23]. Of late, several of such Artificial Intelligent methods for recognizing user activities using supervised learning in a smart home have been published [24]. The main disadvantage of such systems though is that they need prior labeled data for training the algorithms. Manually representing human behavior data in line with event sensor readings takes a lot of time and is monotonous and makes the system less scalable [25]. Furthermore, it is highly impractical in reality that all further inhabitant activities will be similar with training data, thus making such systems more suitable only for the homes for which they were designed [26]. [6] implemented a home automation system using Arduino and Android, but their focus was more on smart homes and the comfort associated with them rather than power saving.

3. METHODOLOGY

The design science research methodology (Improvement Research) was adopted for this research. The approach focuses on creation, invention or design of some new artifacts, while deriving or obtaining suggestions to solving the problem from current knowledge or theory base for the problem domain [27]. Figure 1 shows the architecture of the proposed system.

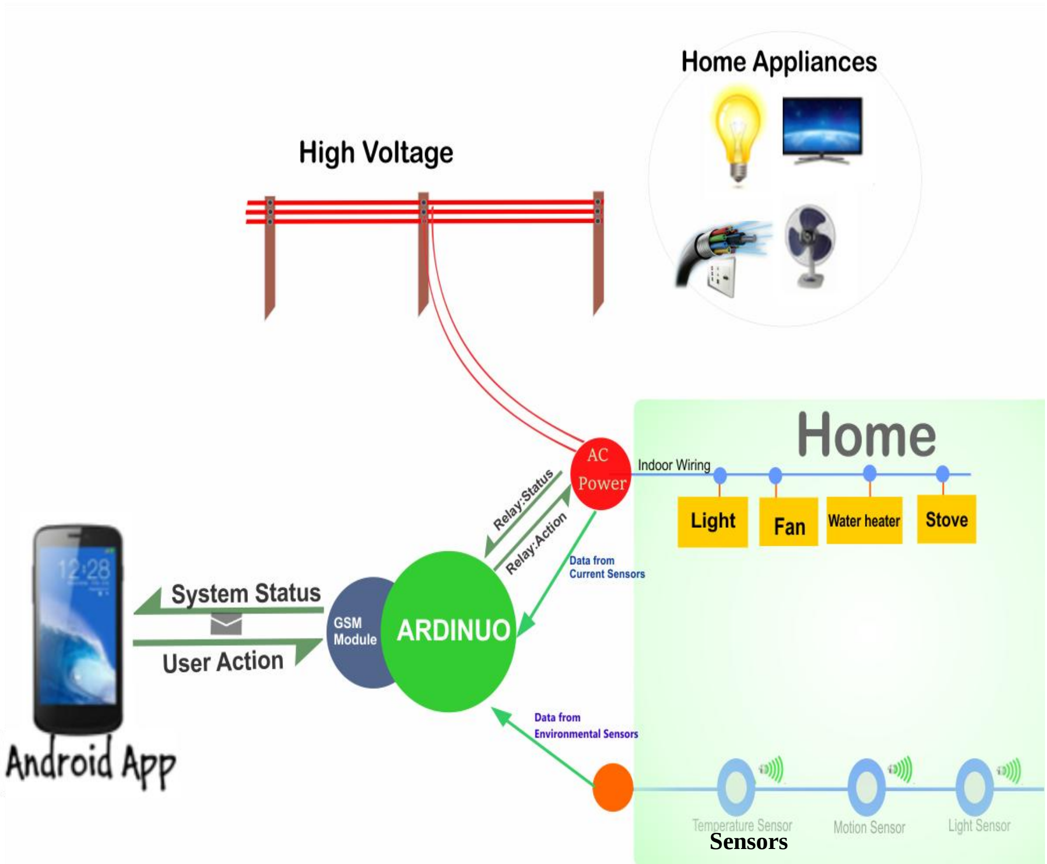

Figure 1. System Architecture

Current sensors are connected to AC power source to which home appliances are connected. The current sensors communicate with Arduino which in turn is interfaced with the GSM module. A user can interact with the system through an Android application. For example, if an appliance is turned on, say a fan, a current sensor will send information to the Arduino which will communicate with the GSM module, and a user will be notified either via SMS or Bluetooth in the form of a system status. A user can also turn on or off appliances remotely via an Android application through the GSM module, Arduino and a relay action will be sent to the AC power source. This means a user can turn on or off any appliance in the home from anywhere. When power is restored after a power cut, the user will be automatically notified and shown all appliances that will be on at that time so that the user can decide which ones to turn off, thus eliminating unnecessary power wastages. Temperature, motion and light sensors will provide values to the Arduino, and depending on the rules set and values read it will send appropriate relay actions to the power source. The system also generates graphical electricity consumption reports, showing which appliances consumed how much electricity per given period.

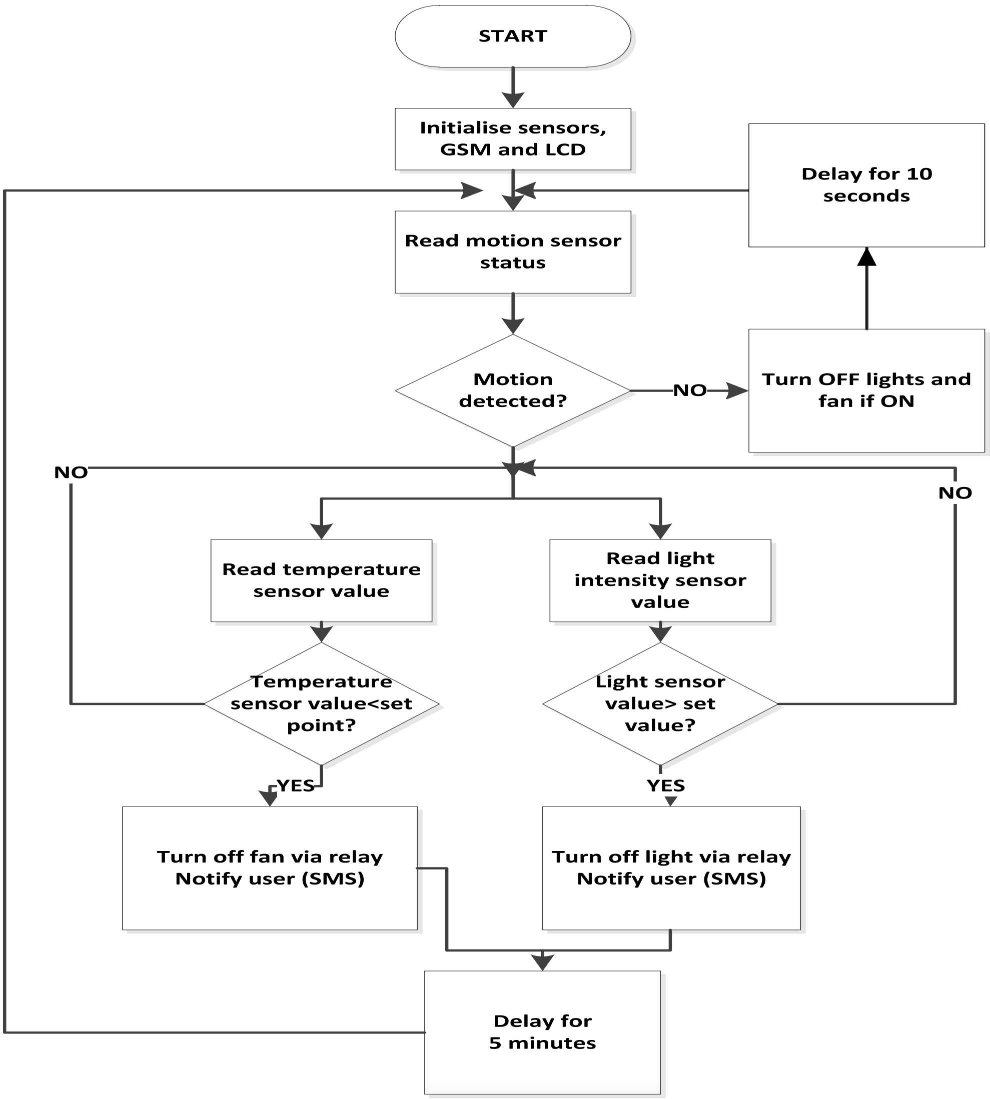

Figure 2. System Flow Chart

The motion sensor is used to check whether there is anyone in the house. If there is no one yet lights and/ or fan is on, the system will automatically turn them off. The assumption is someone might have forgotten to switch them off before leaving the room. The system will check again whether there is anyone in the room after ten seconds. This ten seconds delay can be set to another value as determined by the user in line with their requirements. If motion is detected, the system checks whether there is enough light intensity and heat as determined by the user. If light intensity is too low, lights will automatically be turned on. Conversely, if light intensity is too high, lights will be automatically turned off. The fan will also be turned on if temperature is higher than a user set value and will be turned off if temperature rises to a maximum desirable value. When 5 minutes have elapsed, the system will check again whether there is anyone in the room by reading a motion sensor status. This iterates as long as the system is up and running.

The Algorithm

START

Let:

MaxTemp be the maximum room temperature before fan automatically turns on

MinTemp be the minimum room temperature before fan automatically t urns off

MaxLight be the maximum room light intensity before lights automatically turn off

MinLight be the minimum light intensity before lights automatically turn on

Note: User sets custom values to MaxTemp, MinTemp, MaxLight and MinLight according to their preferences.

Steps:

I. Initialise sensors, GSM and LCD
II. Read motion sensor status
    a. If motion is detected
        i. Read temperature sensor value
            1. If temperature sensor value < MinTemp Then
                a. Turn off fan and notify user on mobile phone
                b. Delay for 5 minutes and ***goto*** to step I
            2. Else if temperature sensor value> MaxTemp Then
                a. Turn on fan and notify user
            3. Else delay for 6 seconds and ***goto*** step II.a.i.
            4. End if
        ii. Read light intensity sensor value
            1. If light intensity > MaxLight Then
                a. Turn off lights
            2. Else if light intensity < MinLight Then
                a. Turn on lights and notify user

3. Else delay for 6 seconds and ***goto*** step I.a.ii.

b. Else
   i. Delay for 5 minutes
   ii. Goto step II

   End If

III. If stove is turned ON Then
   a. If fridge is ON Then
      i. Automatically turn OFF fridge and notify user
      ii. End If
   b. End If

IV. If user turns stove OFF Then
   a. If fridge is OFF Then
      i. Automatically turn ON the fridge and notify user
      ii. End If
   b. End If

The system was implemented using the Java Programming language, which was used to link the user interface and the SQLite database. In addition to Java code, XML was used to create the interfaces for the android application. Eclipse Indigo IDE was used to implement the application. The Android SDK and ADT were also used. The researchers created, compiled, debugged and deployed the android application from the Eclipse IDE using the android ADT. The Android SDK was integrated into the Eclipse IDE to help create and test the system during different iterations of the application. SQLite was used for the database.

The following hardware components are required in the development of the prototype and testing of the prototype: Arduino UNO (R3), GSM Module with an unlocked SIM card, 4 Channel 5 volt Relay, Connecting wires, Bread board, 16x2 LCD, Power supply, An Android mobile phone for hosting the user application, Sensors (PIR motion sensor, ACS712 current sensor, LM35 temperature sensor and LDR light intensity sensor), and Resistors. Android Studio, Arduino Development Tool, Eclipse IDE and Proteus must also be installed on the development computer.

4. RESULTS

The system was evaluated in terms of its ability to optimise power usage by domestic appliances. While a prototype was developed and tested using a fan, light bulb, stove and water heater as the household appliances, its effectiveness in terms of power consumption optimisation was measured for the light bulb only. The researchers calculated light bulb power consumption over 24 hours for best and worst cases. The researchers then ran a 24 hours long experiment using the same light bulb on a prototype of the proposed system. The results of these experiments are shown in Table 1. The results indicate a significant drop in power usage when using the system being proposed herein. Monthly figures are derived from the average daily figures obtained from the experiments. The light bulb used was a 230V, 100W bulb which consumes 0.1 kW per hour.

Table 1. Power Consumption Comparison for a light bulb before and after installation of the system

		Before Installation		**After Installation**
		Worst Case	Best Case	Optimal Case
Appliance: light bulb	Average hourly consumption (kW)	0.1	0.1	0.1
	Maximum total consumption time (Hours)	24	18	12
	Maximum total consumption (kW)	2.4	1.8	1.2

The worst case scenario is when an appliance remains on for the whole day and night. Given that the bulb used consumed 0.1kW per hour, if left on for 24 hours it will consume 2.4kW. This worst case scenario is only possible if no power optimisation system is implemented. In this experiment, the researchers defined the best case as the case when consumption time is at least 12 hours but less than 24 hours per day. Taking the lower bound of 12 and upper bound of 24 hours per day and calculating the average of the two, it gives 18 hours as the best case scenario's hours when the light will be on per day. The assumption is that the user will be turning the lights on and off when necessary. For 18 hours at a consumption of 0.1 kW per hour, the light bulb will consume 1.8kW per day. The optimal case is was when the power optimisation system was used. Under this case, lights were only on for 12 hours per day, when it was dark, and hence consumed 1.2kW.

Table 2. Comparisons of Power Consumption Costs

		Before Installation		After Installation
		Worst Case	Best Case	Optimal Case
Appliance: light bulb	Average hourly consumption (kW)	0.1	0.1	0.1
	Maximum total consumption time (Hours)	24	18	12
	Maximum total consumption (kW)	2.4	1.8	1.2
	Cost per kW per hour (US$)	0.09	0.09	0.09
	Estimated total cost per day (US $)	0.216	0.162	0.108
	Estimated total cost per month (US $)	6.48	4.86	3.24

The researchers used Equation 1 for calculating electricity cost savings as a percentage:

$$ECSP = \frac{(ECBI - ECAI)*100}{ECBI} \quad \ldots \ldots \; \textit{Equation 1}$$

Where

ECSP = Electricity Cost Savings as a percentage,

ECBI = Electricity Cost Before Installation of the system,

ECAI = Electricity Cost After Installation of the system

Cost savings were calculated for both the worst and best case scenarios using Equation 1. For the worst case scenario:

$$ECSP = \frac{(ECBI - ECAI) * 100}{ECBI}$$

$$= \frac{\$(6.48 - 3.24) * 100}{\$6.48}$$

$$\therefore \boldsymbol{ECSP = 50\%}$$

For the best case scenario:

$$ECSP = \frac{(ECBI - ECAI) * 100}{ECBI}$$

$$= \frac{\$(4.86 - 3.24) * 100}{\$4.86}$$

$$\therefore \boldsymbol{ECSP = 33\,{}^{1}\!/_{3}\,\%}$$

Cost of electricity is directly proportional to usage, hence reducing electricity consumption results in reduced cost of electricity to domestic electricity consumers. In terms of percentages, reduction in cost is equal to reduction in the amount of power consumed. The results indicate that implementing the household power optimisation and monitoring system resulted in cost saving of 33.3 per cent and 50 per cent for the best and worst case scenarios respectively. Consequently, it means the amount of power consumed was reduced by the same margins. The system resulted in optimal power usage and thus reduced demand for electricity. Apart from power usage optimisation, the system improves comfort levels for users as they remotely monitor and control their household devices. The ability of users to monitor and control household electric devices from a distance is also useful for people living with disabilities as they can control and monitor appliances in the home without having to physically move around to power switches which are usually mounted on different points on the walls of houses.

A number of authors who have been engaged in making smart homes systems concentrated more on improving the comfort for inhabitants than electricity saving. [28], [29] and [30] have focused more on automation with little inclination towards power saving, hence they did not state how much could be saved by implementing their systems. While some of the systems resulted in electricity savings the researchers did not quantify the electricity savings; thus providing no comparison basis. [14] claim that their system reduced electricity consumption by domestic heating but did not state by how much.

5. CONCLUSIONS

The Household Power Optimisation and Monitoring System proposed herein focused mainly on reducing the amount of electricity consumed by households and hence reducing stress on the national power grid. The results of the system indicate that the system can reduce power consumption in households by up to 50 per cent. This 50 per cent reduction in electricity consumed translates to 50 per cent savings in electricity costs to households. It is important to save electricity since electrical power is scarce in developing countries like Zimbabwe [11]. Saving electricity in households increases the amount of electricity available for industrial use, which in turn increases employment creation. [11] claims that every single occupation in the manufacturing sector generates more than two million occupations in other sectors of the economy, hence it is imperative to make sure that there is enough electricity for the manufacturing industry. The system also has other benefits of convenience and comfort since users can remotely manipulate appliances on their phones. This feature makes this system an inclusive solution as it also helps people living with disabilities to manipulate appliances on their own without having to move around to different power switch points around the home to power on or off appliances. However, the system could be improved by incorporating voice commands to control appliances. It could also be improved by adding a functionality of predicting future consumption of an appliance based on past and present consumption patterns. The system is designed on the assumptions that supply of electricity is always less than demand; the users are not using the available electricity optimally and all policies pertaining electrical usage are held constant. The performance of this system depends on the performance of the sensors. Moreover, remote manipulation of electric gadgets will depend on the availability of network, hence remote manipulation and monitoring may not work if there is no network coverage, unless the user is within the Bluetooth range. The focus of the study is to optimise power usage in households only.

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