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Dynamic Load Sharing at Domestic Level Using the Internet of Things

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Abstract: At domestic level, the load management plays a vital role as the consumer line gets overloaded due to the various load categories. The fully loaded line consumes more energy units, which increases the electricity bill of the consumer. To circumvent the issue of load unbalancing, an automated load management system is developed that shifts the load from one line to another. The proposed system is developed by making use of current and potential sensing transformers and Arduino Mega board. Moreover, the proposed system also provides an internet of things (IoT) based monitoring facility to the user. The sensed information from the system is uploaded to the web server by the help of Wireless Fidelity (Wi-Fi) from where the user can access this information at any time through appropriate applications. Based on the monitoring data, the user can take necessary decisions regarding the switching off unnecessary load. Both simulation and hardware results demonstrate the effectiveness of the proposed system.

Keywords: Electricity bills, IoT, load management, microcontroller, tariff, Wi-Fi

1. Introduction

The swift surge in the load demands throughout the day contributes to an unbalanced load state. Owing to the different categories of load, there exits voltage unbalancing that can cause serious damage to the equipment and load [1, 2]. Unbalancing of load on a domestic level is a common problem that leads the lines to overload by experiencing an extremely high voltage which is often disastrous for the appliances. To overwhelm the unbalancing of load issues, traditionally two schemes are generally used i.e., load transfer and power compensation [2]. The power compensation is done by the use of reactive power compensation devices but at the expense of increasing the power factor and high cost of the system [3]. In this connection, the most efficient technique is to dynamically change a few load currents from heavily loaded lines to comparatively lightly loaded lines [4-6].

In a country like Pakistan, consumer bills are calculated using a tariff and according to that tariff, there are different slabs for rate per unit. The users have multiple energy meters connected to their houses and can face a surge in their electricity bill due to the increase in tariff on a loaded meter. The fully loaded energy meter consumes more units while burning only a few units on the others. At peak hours, this situation becomes even worse as the per-unit rate of the electricity is charged at higher prices. Therefore, immediate energy saving is required which can be achieved by load scheduling which is a part of load management. Based on load scheduling decisions, the change in meter supply can be done. Initially, the change in meter supply was performed manually which results in temporary power loss [7].

At present, the switching of load from one-meter supply to the other is made with the aid of automated control and modern-day communication technologies. Accordingly, a microcontroller-based load sharing system is introduced in

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[8]. The system uses numerous transformers that operated in a parallel configuration to circumvent the overloading. But the system is not cost-effective. In [9], another control technique based on voltage source inverters is implemented in micro-grids but the reliability of the technique is questionable as it requires the information of impedance. Moreover, it is worthy to mention that the aforesaid techniques only cater to control operation and need human effort to perform their functions.

Later, in [10], a dual load system is designed and implemented using a PIC16F877A microcontroller that is capable of supply $500W$ load. The system shifts the load efficiently when the microcontroller senses overload on the system. However, the system has few shortcomings in terms of high-power load and long duration monitoring. The current work targets the automatic balancing and shifting of heavy loads such as air conditioners (AC) and acquaints the IoT based service for the users so that they are capable of easily monitor the automated system anywhere at any time by using the webserver. The load can be shifted by using a matrix of relays which will feed the loads with all the three lines. This shifting is done automatically by using a monitoring system and the microcontroller on the Arduino board. The proposed system will also make sure that the number of units or energy consumed on each line will be the same at the end of the month.

2. Domestic Load Classification

The domestic load is classified into three different categories: basic load e.g. household appliances such as lights, fans, etc., impulsive load, and static load e.g. AC. The impulsive load includes the washing machine, hair drier, water pump, iron, etc. which is used for a short duration. The nominal load of a house is around $6KW$ which varies according to demand. The system is designed for maximum demand $20KW$ for three different lines with the individual maximum demand of $6KW$ a single line [11]. The load classification of a typical house is enumerated in Table 1.

Table 1 - Domestic Load Classification

Load Type	Items	Wattages (W)	Winter Months			Summer Months		
			Hrs./Day	Days/Week	WH/Day	Hrs./Day	Days/Week	WH/Day
Basic Load	Lights	260	10	7	2600	6	7	1540
	Fan	480	0	0	0	20	7	9600
	Router	5	24	7	2600	24	7	48
	TV	50	2	6	100	2	6	100
	Fridge	150	24	7	3600	24	7	3600
	Misc. load	50	5	7	250	5	7	250
Burst Load	Oven	500	0.1	3	500	0.1	3	50
	Iron	1000	0.25	4	250	0.25	4	250
	Washer	320	0.5	3	160	0.5	3	160
	Other appliance's	150	0.25	7	38	0.25	7	38
Static Load	AC's	3600	0	0	0	24	6	18000
Total		6565W	7168WH/Day			33656WH/Day		

3. System Modeling

The generic block diagram of the complete system is portrayed in Figure 1. The system consists of multiple stages i.e., power supply, load monitoring, control, and the switching unit. The next subsequent sections will briefly discuss each stage.

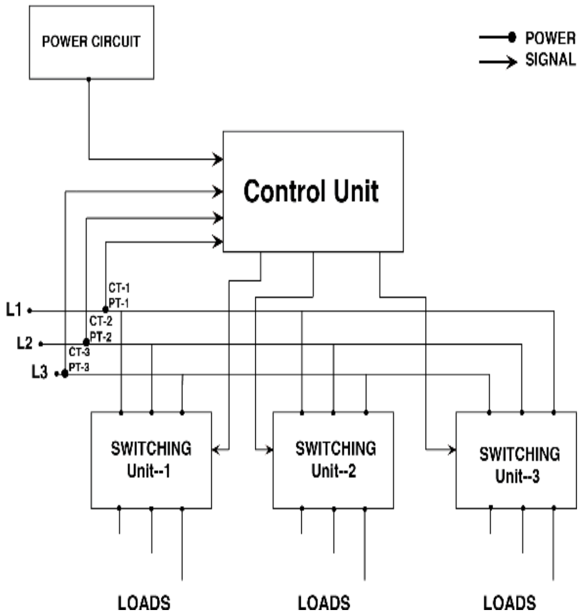

Fig. 1 - Block diagram of a complete system model

3.1 Power Circuit

The power circuit consists of a 12V step-down transformer that converts an electrical 220V AC signal to12V. Afterward, a bridge rectifier is used to transform the AC signal into pulsating DC. To remove the pulses from DC signal a 470μF capacitor is also employed in the circuit design. In the next step, a voltage regulator LM7805 is connected in series with the filtering capacitor that makes the constant 5V DC signal [12]. Figure 2 displays the circuit diagram of 5V the DC supply.

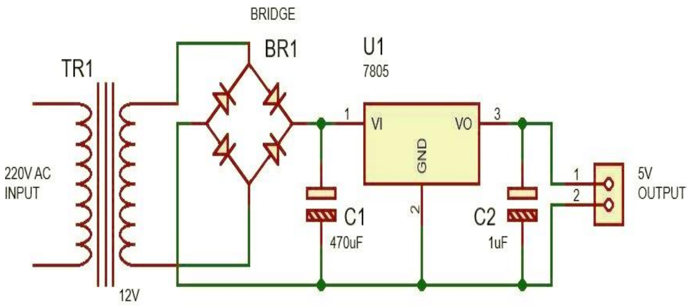

Fig. 2 - Power supply unit

3.2 Load Monitoring

This part consists of the measuring Current Transformers (CTs) and Potential Transformers (PTs) connected on the main incoming lines. The current sensors ACS712 are connected to the load side for monitoring the heavy loads. ACS712 sensor is a type of Hall Effect sensor that is used for the current measurements. It’s a different rated version such as 8A, 20A, and 30A can be used according to the type and current rating of the load.

The analog signals ranging $0 - 5V$ from both the measuring CTs and PTs are fed to the Analog to Digital Converter (ADC) pins of the microcontroller. By measuring the voltage and current values, the controller will calculate the load and the units consumed on each line. Based on the calculation, the controller will share the loads on each line. The complete flow chart for the monitoring of load is demonstrated in Figure 3. It is pertinent to mention here that the output signals from CTs and PTs are not directly applied to the microcontroller because they only accept the voltage signal in the range of $0 - 5V$. Hence, a voltage divider circuit is used to ensure the desired voltage range from the sensing CTs and PTs.

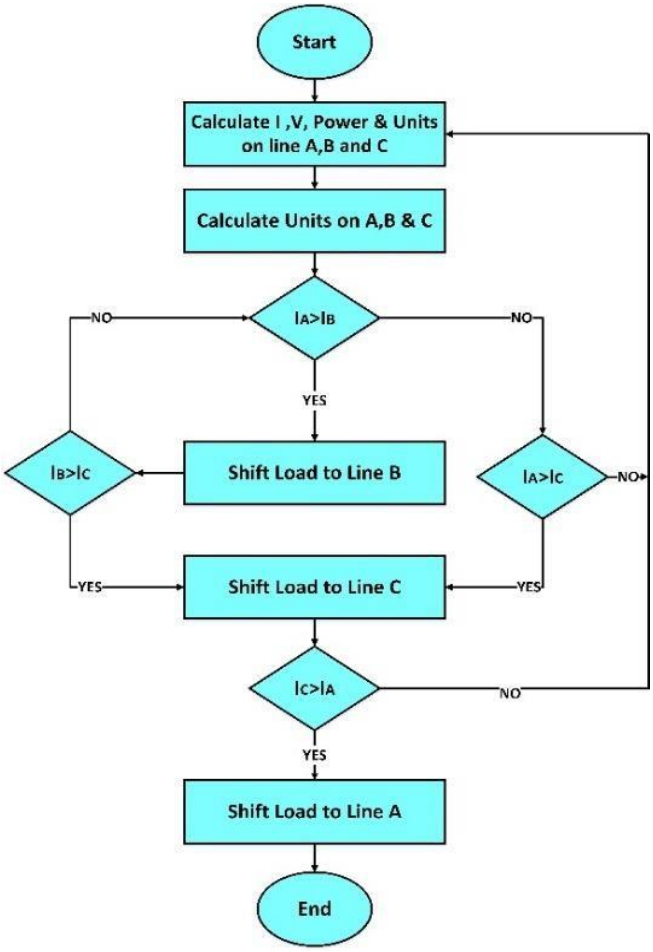

Fig. 3 - Flow chart of load monitoring

3.3 Control Unit

The control unit consists of Arduino mega 2560 microcontroller that analyzes the load and power on each incoming line. Moreover, the controller also measures the current consumption of the load with the help of CTs and PTs. The Arduino tries to balance the load on each line by sending switching signals to the relay unit, which will shift the load on different lines. According to the algorithm, the load on each line will be calculated separately and if the load increases than the threshold value then the controller finds the less loaded line. On finding the less loaded line, the controller shifts the high power consuming electrical appliances to that line. It is pertinent to state here that all the lines are not perfectly balanced. The algorithm of the controller is formulated in such a manner that the power consumed by all lines should be equal for the complete day.

3.4 Switching Unit

For switching purposes, a relay-based switching unit is employed in the design. Here, Single Pole Double Through (SPDT) relays are used. Relays are arranged in the cascaded configuration in such a way that any type of load can be fed to any line. There is a number of relays controlling all three lines to the load separately. Each relay controls a single load or group of smaller loads connected to the same relay. However, for a static load, there will be a separate relay. This is because the static load cannot be shifted frequently since it can disturb the other line.

Figure 4 exhibits the block diagram of the switching unit. For feeding the load with three different lines 2 relays in the cascade configuration are used. For RELAY-1, line 1 is connected at the normally open (NO) terminal and line 2 is connected with the normally closed (NC) terminal. The output of the RELAY-1 is input to the NO terminal of RELAY-2, and line 3 is connected to the NC terminal of the RELAY-2. For three different conditions, the relays feed the load with one line at a time. The relay operating conditions are listed in Table 2.

- Condition 1

For load on line 1, the RELAY-1 is given the active high signal, which will energize its coil, and the RELAY-2 is also fed with the active high signal. Both relays are at the NO terminals and line 1 (L1) is connected to the load.

- Condition 2

For load on line 2, the RELAY-1 is given the low signal while RELAY-2 is provided with the active high signal. In this way, RELAY-1 is at NC terminal and RELAY-2 is at NO terminal and the load is connected with line 2 (L2).

- Condition 3

For load on line 3, only the RELAY-2 condition is important. The RELAY-2 is given with the low signal, which means RELAY-2 is at NC terminal and the load is connected to line 3 (L3).

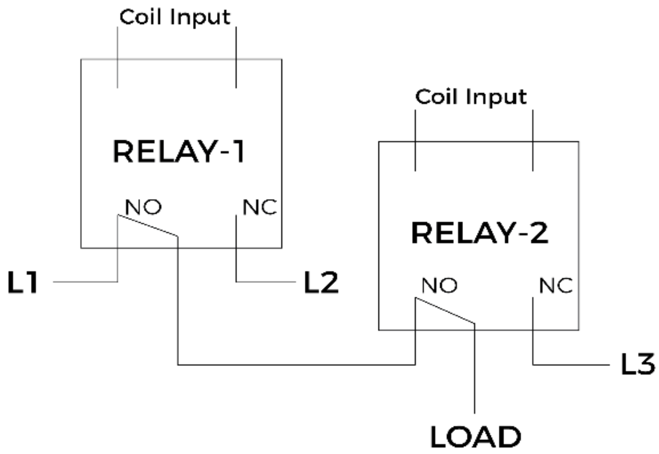

Fig. 4 - Relays functional block diagram

Table 2 - Operating conditions of relays

Lines	RELAY-1		RELAY-2	
	NO	NC	NO	NC
L1	1	0	1	0
L2	0	1	1	0
L3	0	1	0	1

4. Simulation Results and Discussions

The proposed circuit diagrams are simulated using Proteus® software. For the balancing of two lines, the circuit diagram is illustrated in Figure 5. The current sensing modules ACS712 are connected in series with the load lines through which the current will pass. To energize the sensors, 5V battery is used. The output analog signal from the sensor is connected to Analog to Digital Converter (ADC) of the microcontroller. In the beginning, the microcontroller sends the signal to the relays, which cause the unbalance of the system, and then the unbalanced system is balanced by dividing equal load to both the lines. The load unbalances is formed by shifting more load on line B as compared to the line A. After the system gets unbalanced and the current on line B is increasing in comparison to line A then the microcontroller balances the load by sending signals to relays and shifting the load while balancing them on each line equally. Figure 5 shows the circuit diagram after the load gets balanced while ammeter results are recorded in Table 3.

For simulations, initially we fixed the line C for the static load and the microcontroller only monitors lines A and

B. In an event, where the load on lines A and B are unbalanced then with the help of an algorithm, the microcontroller tries to balance the load again. It will not shift any load to line C. Figure 6 demonstrate the 3 lines balanced load circuit. For verification, the ammeter results are shown on the LCD interfaced with Arduino. It is noticeable through the simulation results that the current on line C is not equal to the load currents of lines A and B. This difference is about 8% and it is acceptable. The ammeter results before and after the load balancing are also recorded in Table 4.

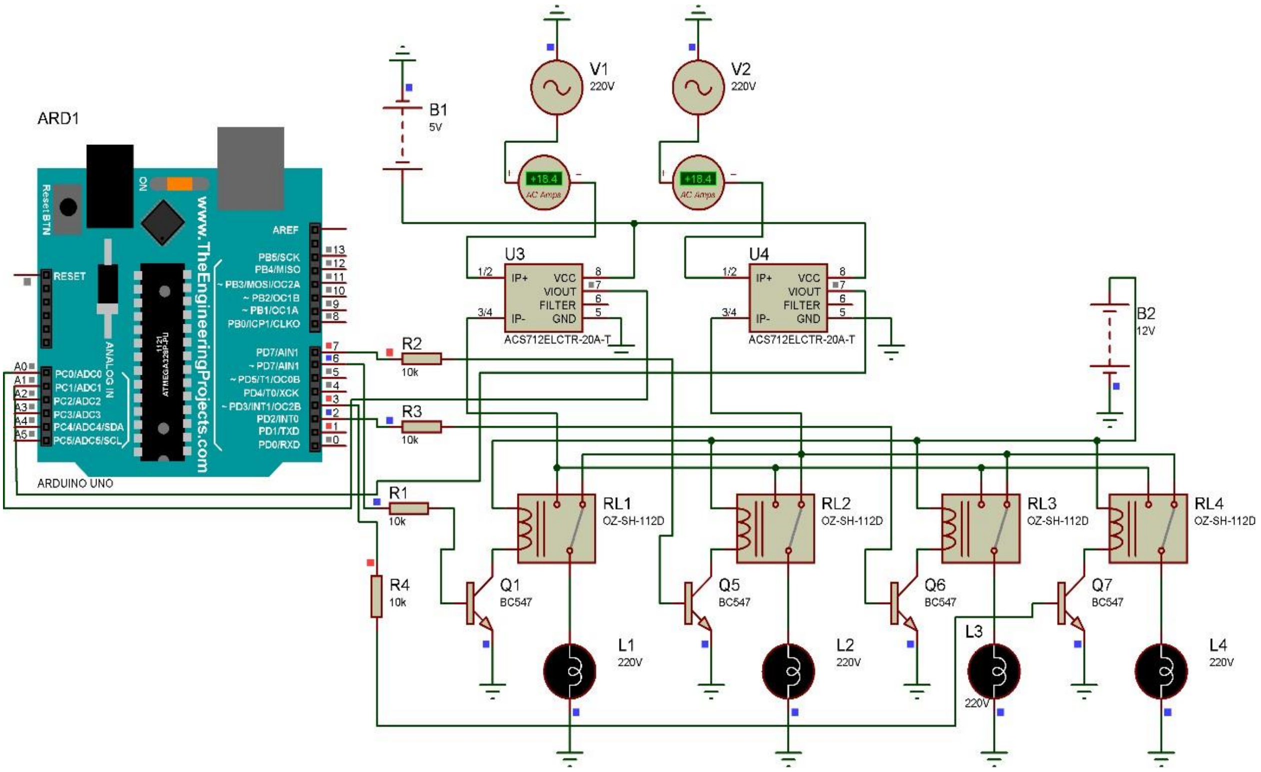

Fig. 5 - Circuit diagram with 2 lines balanced load

Table 3 - Ammeter results

Current	**Line A (A)**	**Line B (A)**
Before balancing	9.07	27.2
After Balancing	18.4	18.4

Table 4 - Ammeter results

Current	**Line A (A)**	**Line B (A)**	**Line C (A)**
Before balancing	15.91	0.34	7.31
After Balancing	7.97	7.97	7.30

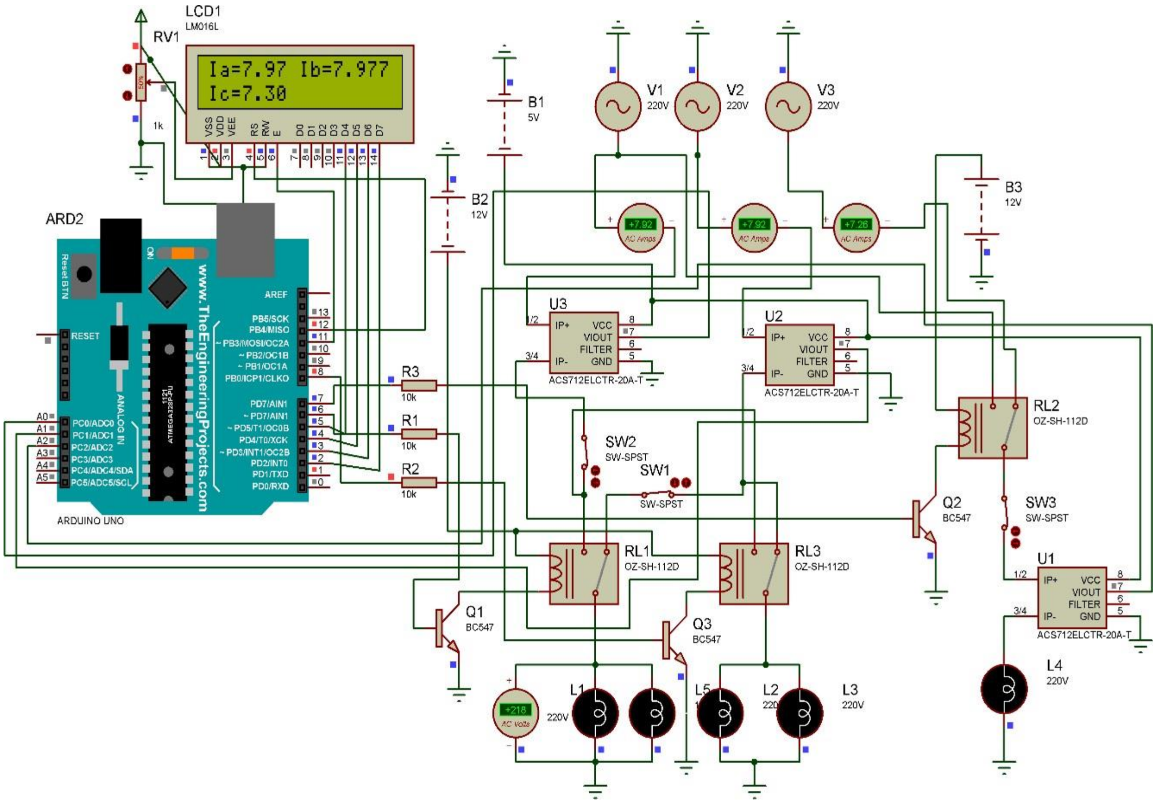

Fig. 6 - Circuit diagram with 3 lines balanced load

5. IoT Based Monitoring

For monitoring, Wi-Fi-based communication is used to send data on the ThingSpeak web server [13]. It is a free web server that enables the user to create different channels, which can be shared with multiple users or multiple devices using a unique code. Users can add different field charts in the channel that plots the incoming data values with respect to time. This monitoring system will allow users to monitor their power consumption and units consumed this can help them reduce their power consumption when needed [14]. Figure 7 shows the Field charts of the currents and power consumption on each line. Initially, the IoT part of hardware was tested by sending a constant 20*A* current on line A. The current data is sent to the webserver that is shown in Field 1 chart. Afterward, a load of four bulbs around 200*W* was connected. Before switching to the load graph, the current reaches to 0*A* which is shown through a down spike in Field 1 chart. After the successful switching, a linear graph of increasing current is observed. Similarly, the Field 2 and 3 charts present the current patterns for lines B and C respectively. These values are received from the Wi-Fi module on to the web server and the user can access the ThingSpeak application using his/her mobile device. The Field 4 chart shows power consumption of around 200*W* which goes on increasing with respect to time and will increase as the appliances increases.

6. Hardware Setup

The prototype of the proposed system is developed using the appropriate components and it is also tested for the load of 200*W*. For prototype, 30*A* / 1*V* CTs and 100*mA* / 220 /12*V* PTs have used for current and voltage sensing respectively. Since the total current of the load for this work is confined to 8*A*, the relays 10*A* are suitable enough for the shifting of such load. For Wi-Fi communication, WEMOS D1 mini is used as it takes calculated data from the Arduino Mega, which is the main controller and then sends the data to the Wi-Fi using the local wireless network available. Figure 8 illustrates the designed prototype with the test load of bulbs of power rating around 200*W* each. The shifting of the load from one line to another line was tested and it is noticeable that the prototype automatically balanced the loads on each line.

7. Conclusion

This paper gives the solution to the common problem of an unbalanced load on different lines that ultimately increase the electricity bills. The proposed solution is simulated in Proteus® software. Over and above, a cost-effective hardware prototype is also conceived and tested in this work. It is noticeable from the hardware-based numerical results that the conceived prototype efficiently performs the load analysis as well as shift the load from the fully loaded line to lightly loaded line. Furthermore, smart monitoring is also done by the prototype with the aid of IoT based wireless communication. The future work includes the conceiving of a similar prototype that can perform load monitoring and balance in smart grids. Furthermore, this work can also be done for more than three lines.

Fig. 7 - Current and power field chart

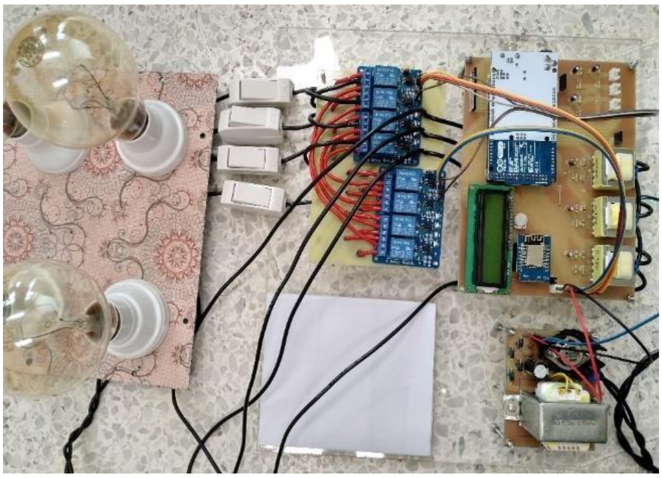

Fig. 8 - Prototype design with the test load

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