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IoT Based Energy Management System for Optimal Energy Consumption in Residential Facilities

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Abstract: Rapid advancements in technology have moved the world towards cloud computations and the Internet of Things (IoT) in virtually all walks of life. The implementation of these technologies in the power sector is inevitable and it is only matter of time that smart grids become a necessity. The optimal utilization of electrical energy is a prime objective of the smart grid because of two main reasons. First, it addresses the problem of CO_2 emission from the burning of fossil fuels and secondly, it has the potential to improve load factor through demand side response within the smart grid. In this paper, an IoT based energy management system has been developed which schedules home appliances during peak load hours to minimize demand charges and reduce overall electricity bill. This paper discusses the infrastructure and hardware to develop an efficient energy management system keeping the user's convenience intact. The paper also highlights a comparison of energy consumption of a conventional home and the smart home.

Keywords: Internet of things, smart grid, HEMS, automation, smart home.

I. INTRODUCTION

In recent years, technology has become an integral part of everyday life and has greatly influenced the life of the common man in mind-blowing ways. The incorporation of Internet-of-things is a phenomenal concept that integrates devices and objects in a holistic way and enables them to interact intelligently with each other without human intervention. This state-of-the-art technology has great potential to shift the existing grid to smart grid, which is a modern-day requirement. One of the major areas where the smart grid has the capacity to make a difference is IoT- based home energy management system. A significant portion of the home appliances consists of schedulable loads and their usage can be optimized. Refer to Fig. 1.

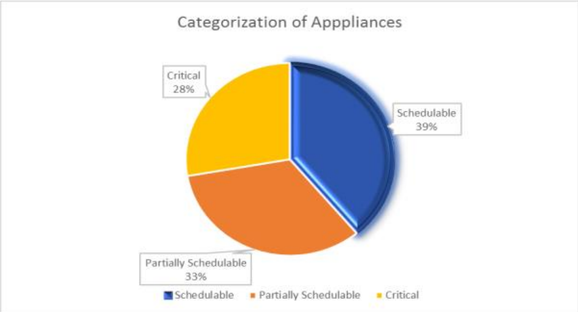

Fig. 1: Portion of schedulable appliances in a conventional household

Therefore, we need to optimize the energy consumption at residential facilities. This paper discusses a technique to maximize the load factor during peak load hours, and reduce demand charges thus, the overall electricity bill.

II. BACKGROUND

In developing countries like Pakistan, the electricity shortfall is a chronic issue. This problem increases during peak load hours when the demand increases beyond the scheduled amount as depicted in Fig. 2. This increase in energy consumption negatively affects load factor. Load factor is an indication of electricity consumption characteristic over specific time-period. As a penalty, supply company charges an additional amount on per unit consumption during peak hours which is called demand charges or peak load charges. It is the ratio of average to peak load demand over a specific time. Mathematically, it can be expressed at Eq. (1).

$$\text{Load Factor} = \frac{\text{Average Load}}{\text{Peak Load over a specific time}} \quad (1)$$

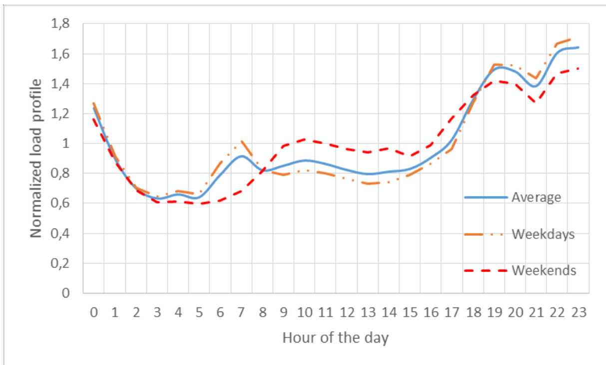

Fig. 2: Normalized load profile over a day

Ideally the ratio should be unity, reflecting a balance between demand and supply. But during peak, the load factor falls below unity as the load increases.

III. PROBLEM STATEMENT

The drastic increase in electricity consumption in evening causes congestion on supply side and the user must pay demand charges for the increased demand. The supply company has fixed the additional charges on per unit consumption of electricity. According to K-Electric, for a 5KW and above residential sanctioned load, the off peak per unit price is Rs 16.33 per KWh and the on-peak per unit price is Rs 22.55 per KWh. That means an additional 6.22 rupees per unit must be paid by the consumer. Fig. 3 represents the additional demand that rises during peak time, which, if shifted to off peak hours can reduce electricity bill as well as improve load factor.

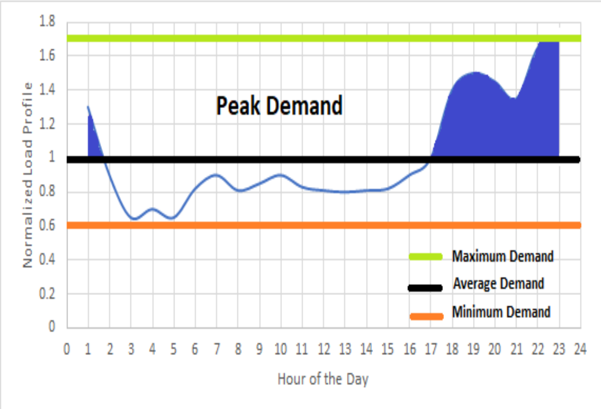

Fig. 3: Increased demand during evening

The peak load occurs in summer as well as in winter season as seen in Fig. 4 but the rise in demand is significantly larger during the summers. During summers, the peak load hours are marked from 6:00 pm to 10:00 pm, that makes four hours. So, if a load of 5 KW operates during that time, the total cost would be higher than the same usage during off peak hours. The electricity bill can be calculated using Eq. (2). Putting above data in Eq. (2), the total electricity bill for this can be calculated.

$$\text{Total price} = \text{Unit price}*(\text{hours}*\text{power}/1000) \qquad (2)$$

To achieve that shifting of load to off peak hours, this paper discusses a system that does not require user's education. Rather it provides a technological edge that is based on a software come hardware embedded system. The proposed solution enables the user to schedule their appliances according to their comfort without disturbing the load factor, thus enabling peak load reduction. and shift the load that disturbs the load factor.

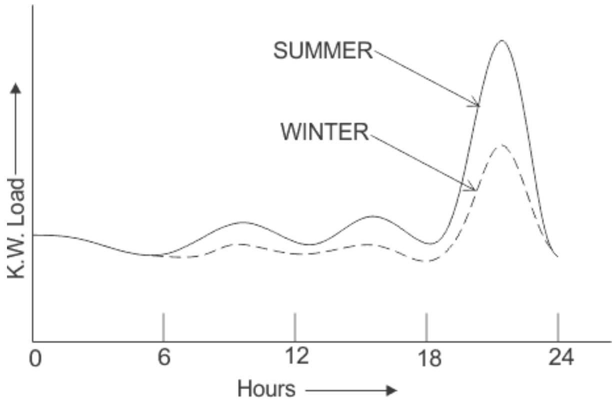

Fig. 4: Comparison of energy utilization during summer and winter seasons

IV. PROPOSED ARCHITECTURE

A. Classification of load

The objective of proposed technique is to ensure smart utility of energy particularly during peak hours. First the residential electrical appliances are identified. The architecture is pictorially explained in Fig. 5. The list includes lightening, fans, HVAC system, refrigerator, television, electric iron, washing machine, laptop and mobile chargers, UPS battery charger, fire alarm system and surveillance. To implement our designed home energy management system, we have classified the electrical appliances of a conventional home into three categories which are:

1. Critical loads
2. Partially schedulable loads
3. Schedulable loads

For a detailed view of the classification, refer to the table 1. We have classified loads based on their flexibility of scheduling and time of operation. According to this categorization, we can automate our schedulable and partially schedulable appliances to be operated other than the peak hours, thus minimizing our tariff and hence reducing the electricity bills.

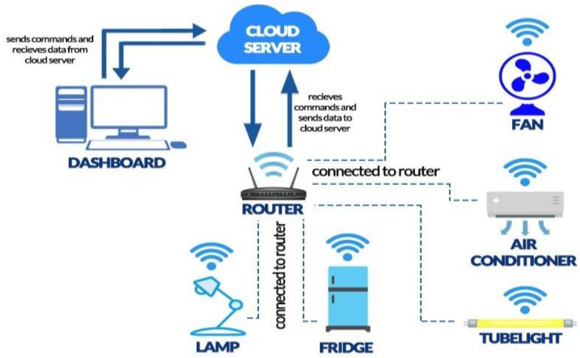

Fig. 5: HEMS architecture

	Appliance	Category	Power rating (Watt)	Working hours
(i)	Lights	P	60	6pm – 12pm
(ii)	Fan	C	75	24 hrs.
(iii)	Heater	C	3000	7pm - 5am
(iv)	AC	C	1000	7pm - 5am
(v)	TV	S	100	8pm - 11pm
(vi)	Iron	S	1100	5pm - 7pm
(vii)	Washing machine	S	3500	3pm - 6pm
(viii)	Charger	P	5	7pm - 11pm
(ix)	Security system	C	15	24 hrs.
(x)	UPS charger	S	160	8pm - 10pm
(xi)	Refrigerator	C	180	24 hrs.
(xii)	Printer	S	40	7pm - 9pm
(xiii)	Oven	P	2400	9pm - 11pm
(xiv)	Dish washer	S	1800	8am - 10pm
(xv)	Coffee maker	P	800	8am - 10am
(xvi)	Toaster	P	1200	8am - 10am
(xvii)	Vacuum cleaner	S	1400	10am- 12pm
(xviii)	Hair dryer	P	1500	2pm - 4pm

Table 1: P = partially schedulable; S = fully schedulable; C = critical (not schedulable)

B. Hardware details

The goal of the developed system is to disable the shiftable appliances during peak hours and schedule them at another time of the day. The detail of hardware is discussed in detail below.

i. NODEMCU

NodeMCU is an open-source development board based on ESP8266 -12E Wi-Fi module. With this we can program the ESP8266 Wi-Fi module using the LUA programming language or Arduino IDE.

ii. SPDT RELAY MODULE SRD-05VDC-SL-C)

The SRD-05VDC-SL-C relay has three high voltage terminals (NC, C, and NO) which connect to the device to be controlled.

iii. AC 220V TO 5V DC CONVERTER MODULE

AC 220V to 5V DC converter module is required because NodeMCU operates on 5V DC but we are receiving 220V AC from the main supply, thus we need to step 220V down to 5V and convert AC signal into DC.

iv. WI-FI MODULE

NodeMCU is connected to a Wi-Fi connection and is assigned an IP by the router. But this IP is dynamic, therefore, we make it static explicitly, so that it remains the same until the device is decommissioned or the network is changed.

v. GUI

A user-friendly graphical user interface is developed to schedule appliances. Users can plan the next day activities and the system automatically schedules the appliances as per user's preference.

V. METHODOLOGY

The developed system enables or disables the appliance as per user's comfort. Fig. 6 explains the flow diagram for HEMS. The appliances were connected to NodeMCU with a relay module in between them. NodeMCU has already been allotted an IP address by the Wi-fi router and when the user schedules the appliances, based on his preference, our system automatically sets operations and disable schedulable appliances for peak load hours.

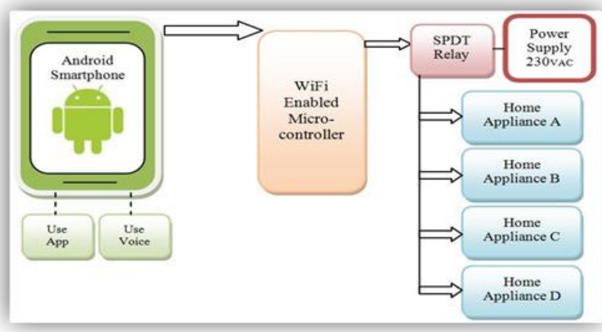

Fig. 6: Flow diagram of HEMS

By pressing buttons on the dashboard, a command is sent to the NodeMCU, which has been coded using Arduino IDE to receive commands from the dashboard and to transmit HIGH or LOW logic to the relay of selected appliance as per the user's requirement. Since we used the normally open configuration of relay module, therefore when it receives a HIGH signal, the 120-240V switch closes and allows current to flow from the C terminal to the NO terminal and thus the respective appliance turns on. Similarly, LOW signal deactivates the relay and stops the current, thereby switching off the desired appliance (Fig. 7). In addition to this, a record of switching of appliances is also maintained by logging the data into a Google spreadsheet along with the switching date and time.

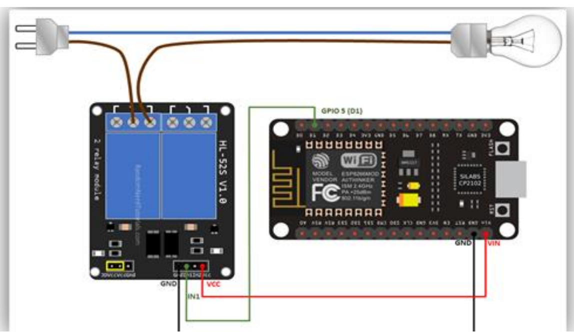

Fig. 7: Hardware connections

VI. RESULTS

Fig. 8a represents the energy consumption of a house before scheduling and Fig. 8b represents the energy consumption distribution after scheduling the appliances. The graphs are formulated based on synthesized arbitrary data of a conventional house. A significant change in terms of cost can be attained by implementing this technique.

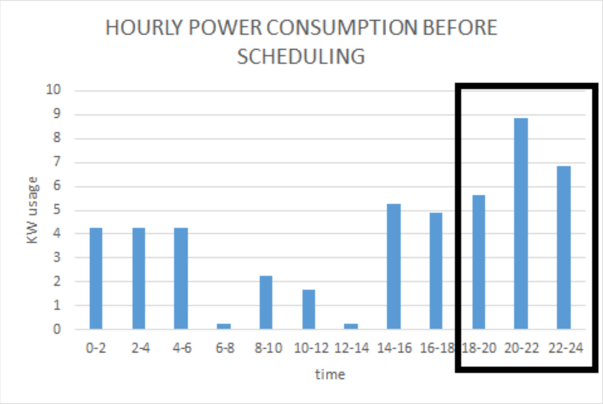

Fig. 8a: Hourly power consumption before scheduling

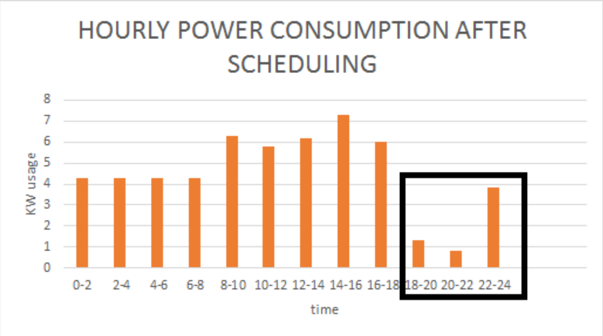

Fig. 8b: Hourly power consumption after scheduling

The above results show that the load from peak hours can be shifted to off peak hours by scheduling without causing discomfort to user.

V. CONCLUSION

The Internet of Things is the new standard that permits the communication between electronic devices and sensors using the internet to facilitate our lives and reduce energy consumption. With the advent of IoT and the recent developments towards smart grids, we reap various benefits such as expenditure reduction, saving time and energy, and the smartness of grid equipment. The technology behind smart grids helps utility companies to reduce power surges and outages by providing self-healing solutions i.e., the ability to reconfigure itself in case of a blackout. This, coupled with devices like our IoT-based Home Energy Management System, provides full visibility (real-time usage) and pervasive control over the assets and services.

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