AN IoT BASED SMART HOME APPLIANCES SCHEDULING MANAGEMENT SYSTEM

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Abstract*: This paper proposes a smart home appliance scheduling management (HASM) system based on demand response. An IoT based HASM system is developed to provide an efficient electricity consumption scheme to residential consumers for scheduling their appliances in a cost-effective way and smartly throughout a day. This smart load scheduler takes residential electricity users' preferences to shift the appliances with deferrable characteristics at cost effective periods considering the user is aware of dynamic tariff information. The user interaction to the scheduling of loads provides maximum comfort level as well as saving of total electricity bill, and the effective utilization of demand response strategies to reduce peak hour electricity consumption. The results of this development indicate a reduction of daily energy consumption confirming the consumer comfort.*

1. INTRODUCTION

The demand of electricity is increasing day by day with our standard of living. The production of electricity cannot keep the pace with the ever-increasing demand of electricity. As fossil fuels' demand increases, they are becoming scares and are responsible for emission of various greenhouse gases. Researchers investigate new research areas such as integration of renewable energy, discovering new energy sources and energy saving programs by encouraging customers through demand side management (DSM) and demand response (DR) programs in order to meet the ever-increasing energy demand. Utilities participate in DSM programs to improve power system stability where end users participate in DR programs to minimize their electricity bills [1,2].

The DR program is defined as variations in electricity usage of end-use customers from their regular consumption patterns in accordance with variations in electricity price. DR-based load shifting is helpful in reducing the electricity cost of end users, at the cost of user comfort. Similarly, the utility-based direct load control technique improves power system stability [1], while disturbing user comfort. Thus, both cost reduction and comfort maximization cannot be achieved at the same time. Previous research highlighted that the use of DR is essential to improve home energy management system (HEMS) in the domestic sector [2]. For efficient HEMS system with DR, a variety of consumer electronic devices must be controlled using the internet and the home network for remote management so as to reduce peak demand that may lead to reduce risk of outages at transmission and distribution networks [3-5]. The operation of the home appliances schedule was proposed according to the ever-changing real time prices and the tariff rate-based DR program [6,7]. The dynamic pricing is a method of DSM, which could be a very important factor for including electricity consumers to reduce their energy consumption. This strategy also provides opportunities to customers to reduce their monthly electricity bill. The peak load reduction is considered an immediate outcome of using variable electricity prices. A number of dynamic pricing strategies, such as Real time pricing (RTP), Time of use (TOU) pricing, Critical peak pricing (CPP), Critical peak rebate (CPR) and so on [8,9].

The most popular one for the residential electricity user and the electricity distributor is TOU pricing [10]. In the country like Bangladesh, the electricity distributor companies do not practice with such pricing techniques. As the demand for electricity rises, the price increases, and as it decreases, so does the price. So, using the various appliances with high power rating increases the peak hour electricity demand as well as electricity bill. Shifting these appliances at the non-peak hour helps to reduce both the problems but it affects the user's comfort. Achieving the reduction in peak hour electricity demand as well as electricity bill with maximum user comfort level became one of the major challenges in the scheduling of the appliances.

In this proposed development the standard TOU pricing system is considered [10]. The proposed IoT based smart load scheduler takes residential electricity users' preferences to shift the appliances with deferrable characteristics at cost effective periods considering the user is aware of dynamic tariff information. The user interaction to the scheduling of loads provides maximum comfort level as well as saving of total electricity bill, and the effective utilization of demand response strategies to reduce peak hour electricity consumption. It is more flexible, compatible and adjustable to any home applications.

The rest of this paper is organized as follows. In Section 2, we introduce the system overview of our proposed system. Section 3 covers the procedure of system design and mobile application development for HASM. In Section 4, the description of operational flow, the IoT based implementation in mobile app and the implementation of DR program with TOU pricing information are presented. In Section 5, the results of DR analysis are illustrated and discussed. Finally, we conclude this paper in conclusion section.

2. SYSTEM OVERVIEW

The proposed HASM system basically consists of a mobile application, communication device, appliance scheduling operation controller and the appliances that are needed to be scheduled. The block diagram of the HASM system is illustrated in *figure 1*. The system is designed in such a way that a user can set his household appliances to a certain period of time at Off-Peak hours using the home appliances scheduling mobile application. The mobile app is connected to a database where all the user preferences are stored. The controller consists of Arduino, relay board and nodeMCU ESP8266. The nodeMCU ESP8266 allows the controller to be connected to internet through a communication device such as router so that it can receive the scheduling information from database and operates accordingly [9]. Appliances to be scheduled have the following characteristics: 1) high power rating, 2) user interaction no longer required during their operations, 3) can be operated at any time throughout a day and 4) does not affect the user comfort.

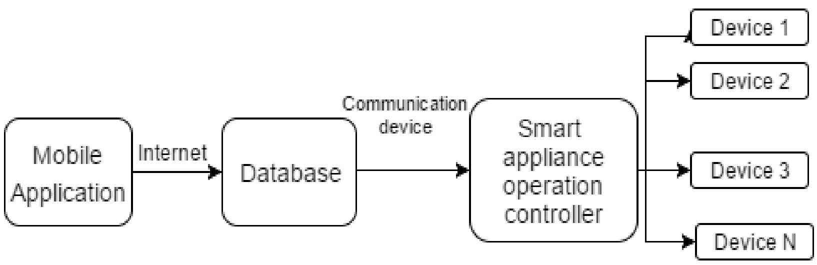

Fig. 1. System Overview of HASM System

3. DESCRIPTION OF DESIGN

This section describes the designing of the HASM System, which can be divided into two parts such as system design and HASM Mobile app development.

3.1. HASM system design

The system design of the HASM system involves using a microcontroller and interfacing the system with appliances or loads through relays as the block diagram is shown in *figure 2.* The smart appliance scheduling operation control overview is also found in *figure 2*. The commands to the microcontroller are given through a nodeMCU module. The description of hardware used in this development are given below.

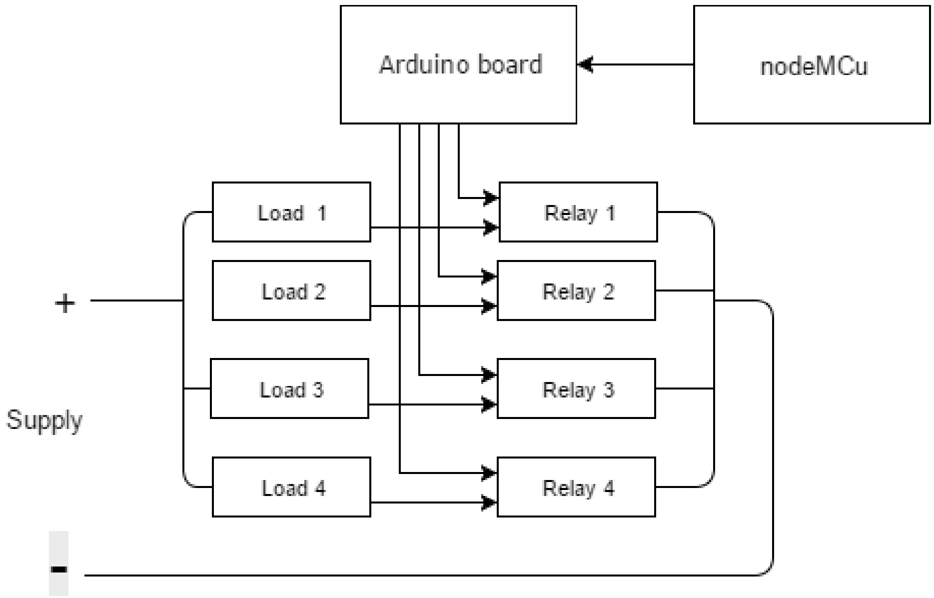

Fig. 2. Block Diagram of the Appliance Operation Controller

3.1.1. Arduino Board

Arduino shown in *figure 3* is an important component of the smart controller. It is connected to the nodeMCU and relay board. Arduino takes inputs through nodeMCU and operates the relay switches. The switching operations of HASM system are performed by Arduino [11].

3.1.2. Relay

The relays are used to accomplish switching opearation of the load connected to the controller as in *figure 3*. It is an electromechanical switch that turns from its normally closed position to its normally open position when the coil of the relay is excited by a voltage.

3.1.3. NodeMCU ESP8266 Wi-Fi Module

NodeMCU ESP8266 Wi-Fi module plays a vital role in this developed system. An ESP8266 Module receives commands from mobile application wirelessly through the internet (see in *figure 3*). According to the commands the home appliances are scheduled based on the proposed control algorithm.

3.1.4. Circuit Diagram of HASM

The HASM controller is designed to perform the load scheduling automatically. It includes a power supply unit, a controller, relays, Wi-Fi module and driving part as shown in *figures 2* and *3*. All parts including smart controller are powered by the power supply unit so that it can operate independently. A DC current supply is required to the digital parts such as a microprocessor. The driving part is connected inside the electric load of the home through the relay circuit. *Figure 4* shows the pin connections of the HASM controller.

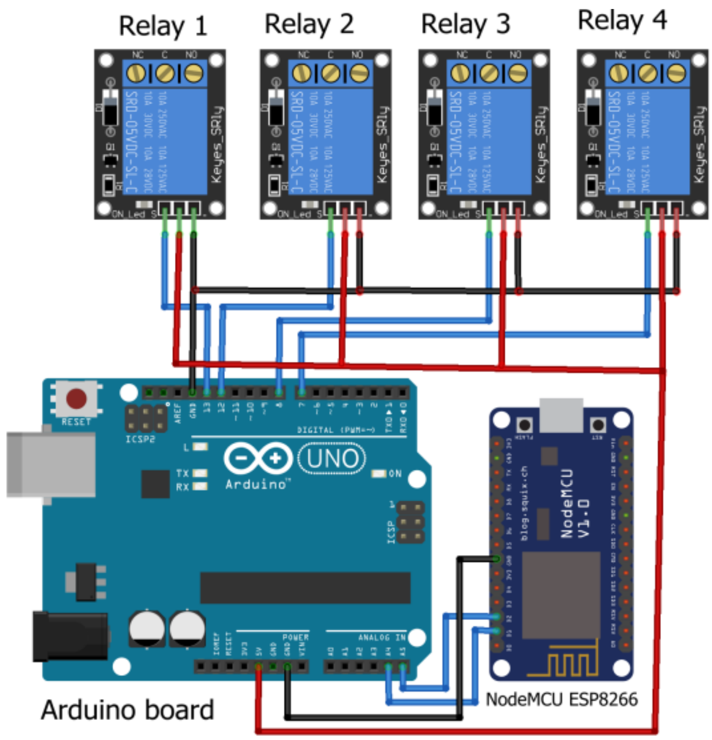

Fig. 3. Pin connections of HASM Controller

3.2. HASM mobile application development

The major part of this system is the appliance scheduler application, which is developed using Android studio. Android Studio is the official Integrated Development Environment (IDE) for Android application (app) development, based on IntelliJ IDEA [9,12]. The application designed has the options to schedule the household appliances and set their duration of operation of the particular appliance. This application acts as user interface (UI) of the Home energy management system. *Figure 4* shows the layout of HASM system in mobile app. User has provision to make a preferable schedule by using the HASM mobile app by giving a starting time, off time and the duration of operation for particular appliances. The app is designed in such a way that it sends the 'duration' information given by user only when the mobile operating system time matches with the 'starting time' of any particular appliances in the HASM app. The database receives the information and holds it till the 'off time' matches with the system time.

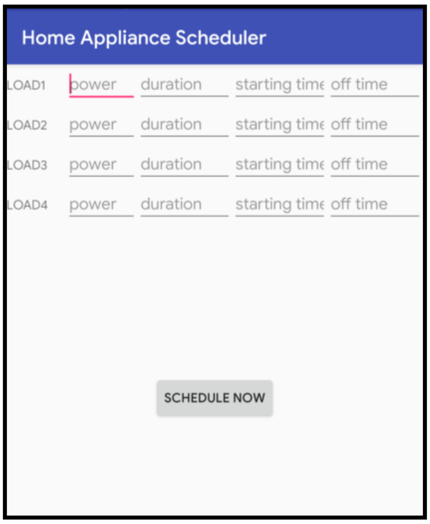

Fig. 4. HASM App Layout

4. SYSTEM OPERATION AND IMPLEMENTATION

The working flowchart for the overall HASM system is shown in *figure 5* where the input is taken by the mobile app. The app checks the operating system time (T.sys). The app sends the duration information to the database when T.sys matches with the start time (T.start) set by user. The nodeMCU continuously checks the database for appliances operation information. When information arrives at database the nodeMCU sends the information to Arduino. Arduino process the information and turn on the appropriate relay till the duration value exceeds.

In the proposed system, for DR program, TOU pricing information is used as presented in Table 1. The demand periods are considered according to daily load profile of residential house in Bangladesh. The typical daily load profile for a residential household is used in this implementation as depicted in *figure 6* [13]. A total day is divided in four demand periods to matches with the pricing technique provided where varying TOU rates according to the demand is considered. During the evenings, on weekends and on holidays the demand is low where the loads are powered as a baseload from sources like large hydroelectric stations and nuclear generators. As daytime begins, more people turn on their lights and appliances, and businesses ramp up their operations for the workday. The demand becomes high that to be scheduled smartly by using this proposed system.

Table 1. TOU pricing information

Periods	Demand Load	Pricing Information ($/kW)
7 AM – 10 AM	On-Peak	0.132
10 AM – 5 PM	Mid-Peak	0.094
5 PM – 11 PM	On-Peak	0.132
11 PM – 7 AM	Off-Peak	0.065

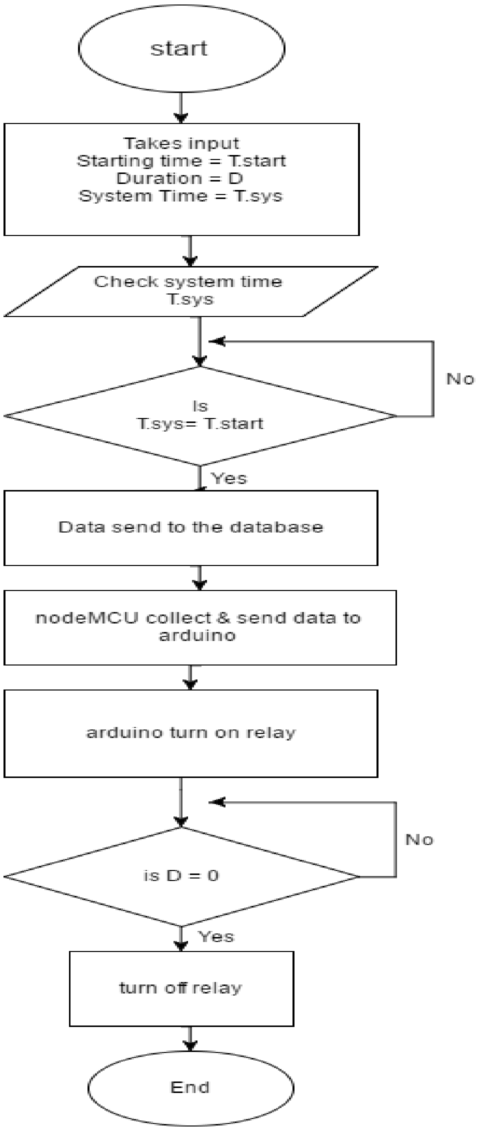

Fig. 5. Flowchart of HASM algorithm

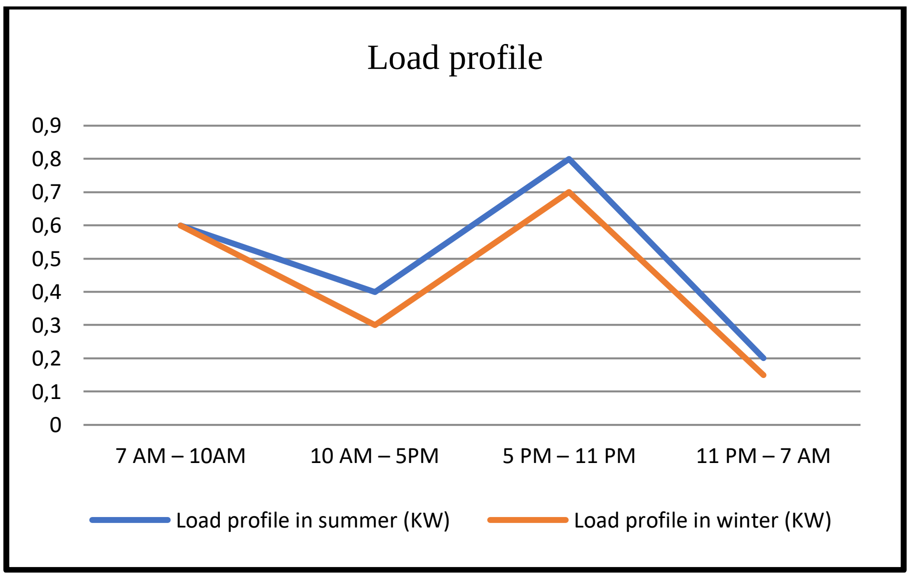

Fig. 6. Typical daily load profile

5. RESULTS AND DISCUSSIONS

The results of the proposed development are given in this section that includes the results of data transfer from the HASM app to database, DR analysis and the results obtained from scheduling appliances at low tariff periods by using HASM system.

5.1. Data transfer

The Data consists of duration information of scheduled appliances are transferred to the database through internet. The HASM app and HASM controller are connected to internet. From *figure 7* it can be seen that a user scheduled multiple appliances at 1:30 (GST) (Off-Peak period). When mobile system operating time matches with the starting time 1:30 (GST) the HASM mobile application send a signal to the database. Database receives the information as shown in *figure 8*. This information is then sent through nodeMCU Wi-Fi module connected to the Arduino board and processed into control signal to turn on the relay connected to the appliances and turn off the relay when the time duration exceeds for scheduling operation of that particular appliance.

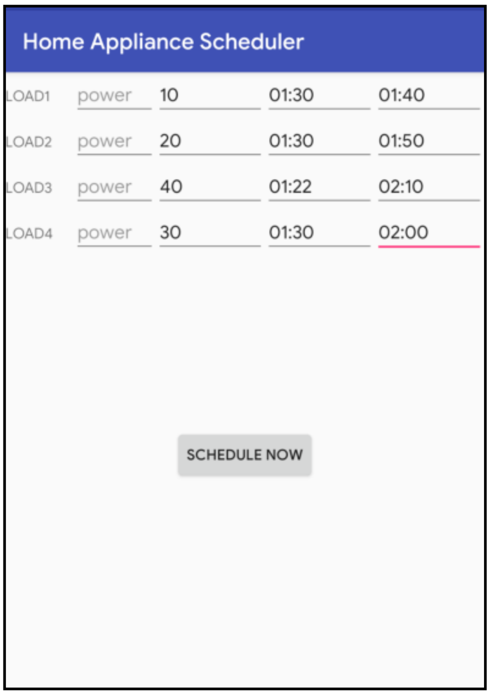

Fig. 7. Home appliances scheduling

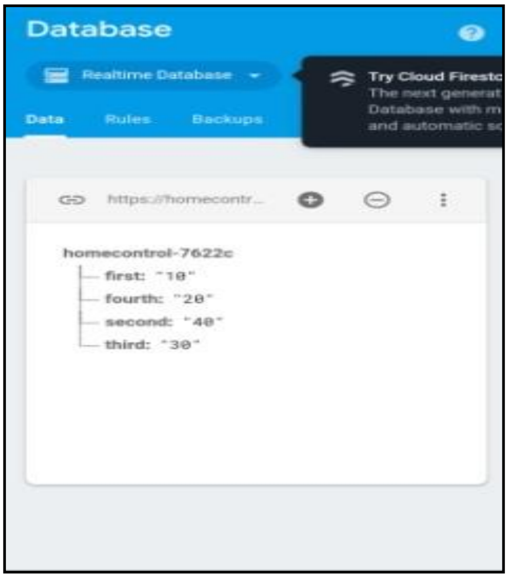

Fig. 8. Database with the duration information

5.2. DR Analysis

The DR analysis consists of typical and scheduled load profile verses TOU pricing system of Table 1 which is applied to develop the algorithm for the shifting of appliances. Table 2 shows typical electricity usage pattern of household appliances of high-power ratings. The data are obtained from a survey on electricity usage pattern of household appliances on 40 dwellings. Based on the proposed algorithm the typical load pattern is shifted from On-Peak to Off-Peak or somewhat Mid-Peak to Off-Peak and load distribution among the periods is accomplished accordingly. The scheduling is configured maintaining consumer comfort and balanced distribution. Table 3 shows usage pattern of appliances after scheduling the deferrable appliances at the Off-Peak period based on demand response.

Table 2. A typical usage pattern of household appliances

Appliances	**Periods**			
	7 AM – 10AM	10 AM – 5PM	5 PM – 11 PM	11 PM – 7 AM
	On-Peak	Mid-Peak	On-Peak	Off-Peak
Water Pump 750 W	-	-	(2 hr) 1500 Whr	-
Iron 1200 W	(1 hr) 1200 Whr	-	-	-
Washing Machine 800 W	(2 hr) 1600 Whr	-	-	-
Fridge 180 W	(2.5 hr) 450 Whr	(5.8 hr) 1044 Whr	(5 hr) 900 Whr	(6.6 hr) 1188 Whr
TV	(1 hr)	(3 hr)	(4 hr)	-

90 W	90 Whr	270 Whr	360 Whr	
Desktop PC 200W	(1 hr) 200 Whr	-	(3 hr) 600 Whr	-
Oven 1000W	(15 min) 250 Whr	-	-	-
Lights (8x 22W) 176W	88 Whr	50 Whr	1056 Whr	50 Whr
Total	3.88 kWhr	1.36 kWhr	4.42 kWhr	1.24 kWhr

Table 3. A scheduled usage pattern of appliances

Appliances	**Periods**			
	7 AM – 10AM	10 AM – 5PM	5 PM – 11 PM	11 PM – 7 AM
	On-Peak	Mid-Peak	On-Peak	Off-Peak
Water Pump 750W				(2 hr) 1500 Whr
Iron 1200 W	(1 hr) 1200 Whr			
Washing Machine 800 W		(2 hr) 1600 Whr		
Fridge 180 W	(2.5 hr) 450 Whr	(5.8 hr) 1044 Whr	(5 hr) 900 Whr	(6.6 hr) 1188 Whr
TV 90 W	(1 hr) 90 Whr	(3 hr) 270 Whr	(4 hr) 360 Whr	
Desktop PC 200W	(1 hr) 200 Whr		(3 hr) 600 Whr	
Oven 1000W	(15 min) 250 Whr			
Lights (8x 22W) 176W	88 Whr	50 Whr	1056 Whr	50 Whr
Total	2.3 kWhr	2.96 kWhr	2.92 kWhr	2.74 kWhr

Scheduling of deferrable appliances at Off-Peak period reduces the On-Peak electricity demand which can be seen from the load profile comparison in *figure 9*.

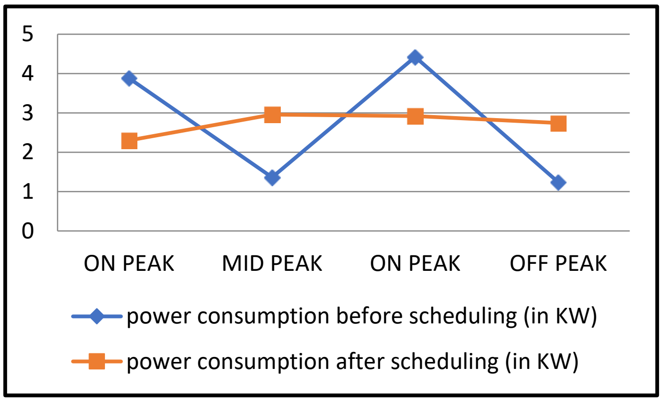

Fig. 9. Load comparison profile per period

As the electricity consumption is shifted, the electricity usage bill according to the periods reduces significantly as illustrated in *figure 10*. When the deferrable appliances are shifted from their typical using periods to the off-peak period significant reduction in electricity usage bill can be observed in *figure 11*. The shifting of appliances reduces the demand of electricity at the On-Peak period significantly as the analysis presented in *figure 12*. Thus, it is shown that the proposed HAMS system has a good home appliances management capability smartly with efficient utilization of energy and significant reduction of electricity bills.

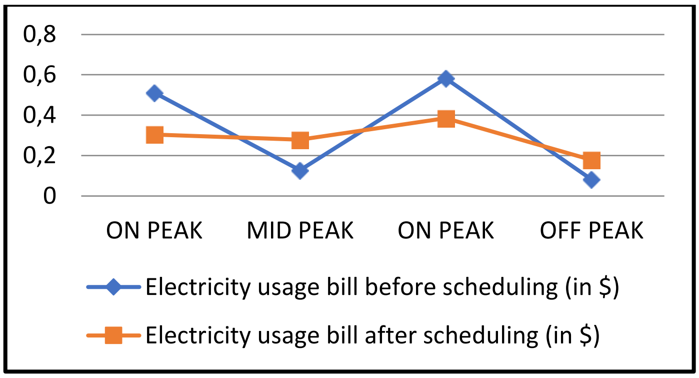

Fig. 10. Electricity usage bill comparison per period

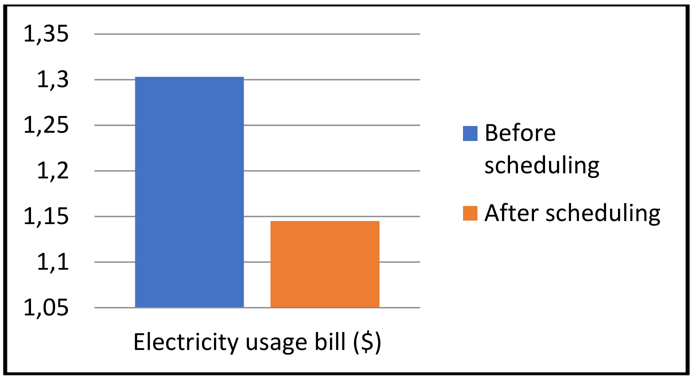

Fig. 11. Total electricity usage bill comparison for a day

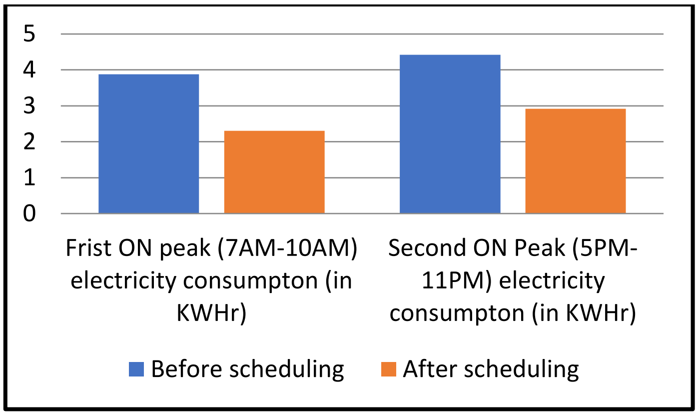

Fig. 12. Peak-hour electricity demand reduction

6. CONCLUSION

A smart home appliance scheduling management system based on IoT for residential household appliances is proposed in this paper. Dynamic pricing system TOU is discussed and used from Bangladesh perspective for obtaining DR analysis. The proposed HASM system is implemented in mobile app based IoT control platform that operates by receiving a user's input through the home appliance scheduling application and schedules the appliances at the preferred time. The scheduling operation and demand response analysis results show that this developed system is capable to reduce On-Peak period electricity demand and electricity usage bill. It is a very convenient and economical solution for home energy management keeping the household user comfort level high. This system can be modified to manage loads with larger ratings.

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