Smart Home Appliances Scheduling to Manage Energy Usage

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***Abstract*—It is imperative to manage household appliances in a cost-effective way to realize efficient energy utilization, reduce spending on electricity bills and increase grid reliability. This study presents a Home energy management system (HEMS) scheduling analysis. The scheduling plan avoids the electricity wastages which arise majorly due resident's negligence on appliances control. The home appliances employed in the research work are classified in terms of their operating periods. The energy consumption was evaluated using a Fixed Pricing (FP) data. The appliances scheduling plan was developed using Microsoft.net framework with C# Programming language whereas the front end showing the scheduled operating periods for the appliances was developed using Telerik UI framework for Windows forms. Simulation results of the scheduling plan show energy consumption in homes can be planned, monitored and controlled to avoid energy wastage and minimize energy expenditure.**

Keywords— demand side management; home energy management system; smart home appliances; scheduling

I. Introduction

Residential consumers' engagement and active participation is paramount for the successful implementation of the smart grid vision. Residential energy users are expected to be more involved in the planning, implementation, monitoring of energy usage. Current and future residential infrastructure is expected to require less home energy use in order to boost energy savings and grid reliability [1]. One of the initiatives of the Smart Grid (SG) electricity market operation is the introduction of Demand Side Management (DSM) programs whereby consumers' loads can be managed in a smart way [2-3]. Some of these DSM programs are realized through Home energy management systems (HEMS) which allows consumers to enjoy price savings, avoid energy wastages and most importantly, utilities operating at reduced peak demands [4]

The amount of energy consumed in residential sectors [5-6] in recent times is a serious concern to both utility providers and consumers. The United State Energy Information Administration (EIA) report [7] for 2015 stated that about 1,404,096 million kWh of electricity was sold to residential consumers in 2015, the value amounts to about 37.4% of the total electricity sales to the four major sectors (residential, commercial, industrial and transport) considered. Furthermore, according to [8], about 30% of global total energy consumption is currently being consumed within the home. This accounts for the high demand of electricity at the household level. However, in developing nations like South Africa whereby electricity cost about 15 or 20% of the income in a typical household [9]. The need to reduce the energy consumption is highly imperative for utility providers to meet energy demand and more importantly, for residents to benefit from less spending on electricity bills.

One of the methods to achieve low expenditure on electricity bills without compromising electricity needs in the home is via home energy management systems (HEMS) schemes. HEMS schemes allow consumers to monitor, control and efficiently manage various household appliances energy consumption in response to Demand Response (DR). By effectively scheduling major household appliances, residents can spend less on electricity bills [10].

Several appliances scheduling strategies have been proposed in various literatures. Several algorithms that involve residential appliances scheduling has been proposed using various linear programming and particle swarming optimization techniques [11-12]. The authors in [13] proposed smart home electrical appliances scheduling whereby the household do not only depend on the supply from utility providers but also have a rooftop photovoltaic (PV) to supplement the home energy demand. Mixed integer linear programming (MILP) modelling was used in scheduling the energy consumption of various appliances in a SH whereby the SH uses various forms of energy sources [14]. Smart home appliances scheduling operation that involves shifting of domestic loads with real time pricing to maximize energy savings was proposed in [15].

Energy consumption pattern of home appliances vary depending on properties such as operating periods, power rating and the specific duties of the appliances. However, some appliances exhibit similar patterns and hence can be grouped together. In this study, electricity consumption of the typical home appliances was managed by scheduling the operating hours of the appliances daily. A fixed pricing data obtained from [16] was used for the analysis evaluation. The scheduling model was developed using Microsoft.net framework with C# programming language. The front end showing the scheduled operating period for the appliances was developed using Telerik UI framework for Windows forms. The study shows that the scheduling and programming plans makes life easier for the smart home and it reduces the electricity consumption pattern which arises majorly due to some appliances being left switched on due to negligence of the home residents as well as the time taken to individually switch off the active appliances. For example, a resident sleeping off at night forgetting to switch off the television and other gadgets will result in wasting energy for several hours over the course of the night.

The rest of the work is organized as follows. Section II presents the description of the scheduling model while the methodology employed for the scheduling as well as the energy consumption parameter used for the SH are presented in Section III. Results and discussions are found in Section IV and the conclusion in Section V.

II. Description of the Scheduling Model

The tasks performed by the smart home appliances and gadgets can be programmed and scheduled to start at a specific time frame and get switched off at a specific time frame. Example of such smart home analogy whereby appliances can be programmed to start performing their task is analyzed below. Consider a typical smart home that contains a geyser (water heater), interior lightings, electric stove, television, pressing iron, washing machine, refrigerator and coffee maker. Assuming the SH residents typically wakes up at 5am. The home appliances can be programmed and scheduled to get turned on and off daily as follows; the geyser can be programmed to get switched on at 5am to get the water to the right temperature for bath and get switched off at 6am. The interior lightings also get switched on at 5am and get switched off at 7am when the day is bright enough. The coffee maker and television can be programmed to start working at 7am simultaneously for the residents to hear the morning news, watch weather forecast and road traffic report before they set out for their workplaces. Also, when the residents come back from work, the scheduling can be made to suit needed satisfaction.

III. Methodology

As shown in Fig. 1, the study refers to a SH whereby the appliances in the SH are classified into group *i* and group *j* depending on the number of times they are scheduled to perform their task daily.

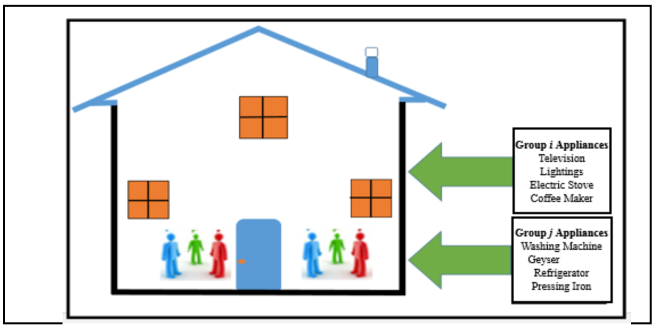

Figure 1 : Illustration of the Smart Home

Group *i* appliances are the appliances that are scheduled to be used once daily and they include television, interior lightings, electric stove and coffee maker while group *j* appliances are the appliances that are being scheduled to be used more than once in a day and they include the washing machine, geyser, refrigerator and pressing iron. Hence group *i* appliances have one operating period θ, while group *j* appliances have two operating periods. The expression of the two groups are shown in (1) and (2) as:

$$i = \{i_a, i_b, i_c, i_d\} \quad (1)$$

$$j = \{j_a, j_b, j_c, j_d\} \quad (2)$$

Tables I and II show the details of the group *i* and group *j* appliances parameters respectively.

TABLE I
GROUP *I* APPLIANCES PARAMETERS

Appliances	**Appliances code**	***P* (*k*W)**	T_s	T_f	θ ***(hrs)***
Television	i_a	0.6	7:00am	9:00am	2
Interior lightings	i_b	0.5	5:00am	7:00am	2
Electric stove	i_c	1.0	8:00am	9:00am	1
Coffee maker	i_d	0.8	7:00am	9:00am	2

θ is defined as the operating period of each appliances and it is the difference between the finishing time, T_f and the starting time, T_s of each appliance as defined in (3) as:

$$\theta = T_f - T_s \quad (3)$$

TABLE II
GROUP *J* APPLIANCES PARAMETERS

Appliances	**App code**	***P* (*k*W)**	T_s	T_f	T_s'	T_f'
Washing machine	j_a	0.9	8:00am	9:00am	10:00pm	11:00pm
Geyser	j_b	1.0	5:00am	6:00am	5:00pm	6:00pm
Refrigerator	j_c	1.1	1:00am	6:00am	7:00pm	10:00pm
Pressing iron	j_d	1	7:00am	8:00am	9:00pm	10:00pm

Ç is the Energy consumed by each appliance are defined as:

$$Ç = n \times P \times \theta \quad \forall\, n, P > 0 \;\; and \;\; \theta \geq 0 \quad (4)$$

Where *P* denotes the power rating of the appliances and n denotes the number of appliance(s) being used at a period θ.

The total energy consumed by group *i* and group *j* appliances for all operating periods are defined in (5) and (6) respectively.

$$\varsigma_{i\theta} = \varsigma_{ia\theta} + \varsigma_{ib\theta} + ...\varsigma_{iz\theta} = \sum_{iz} \varsigma_{iz,\theta}, \quad \theta \in \mathrm{H} \qquad (5)$$

$$\varsigma_{j\theta} = \sum \varsigma_{ja\theta} + \sum \varsigma_{jb\theta} + ...\sum \varsigma_{jz\theta} = \sum_{jz} \varsigma_{jz\theta}, \quad \theta \in \mathrm{H} \qquad (6)$$

Where $1 \le z \le$ other appliances operating at operating period θ for $\theta \in \mathrm{H}$, $\mathrm{H} = \{0,1,2,3,.......24\}$. The summation of all the energy consumed by all the appliances scheduled to work in a day is stated as (7) below:

$$\varsigma_{ij} = (\varsigma_{iz,\theta-1} + \varsigma_{jz,\theta-1}) + (\varsigma_{iz\theta} + \varsigma_{jz,\theta}) \qquad \forall\, \theta \in \mathrm{H} \qquad (7)$$

IV. Results and Discussions

Daily energy usage profiling which involves fixed electricity billing system was employed. The data from [16] was used for the billing. The data stated that residents using a monthly consumption of 600 kWh/month or less is considered as Domestic Low Consumption (DLC) while residents that uses above 600kWh/month are considered as Domestic High Consumption (DHC). For DLC, energy charge rate is at 46.34c/kWh (VAT inclusive) while for DHC, the energy charge rate is 34.77c/ kWh with a daily service charge of R2.27 (R denotes the South African currency).

As stated earlier, the SH appliances scheduling plan application was developed using Microsoft.net framework with C# Programming language. The front end showing the scheduled operating periods for the appliances was developed using Telerik UI framework for Windows forms. The application was installed and operated on a PC with an Intel Core i5-3340, 3.10 GHz CPU and 8.00 GB of RAM. The Telerik UI for Windows software is a freeware that demonstrates achievable scenarios. Fig. 2 depicts the backend code controlling the group *i* appliances. Validation checks on each input box ensures that the resident has inputted a value.

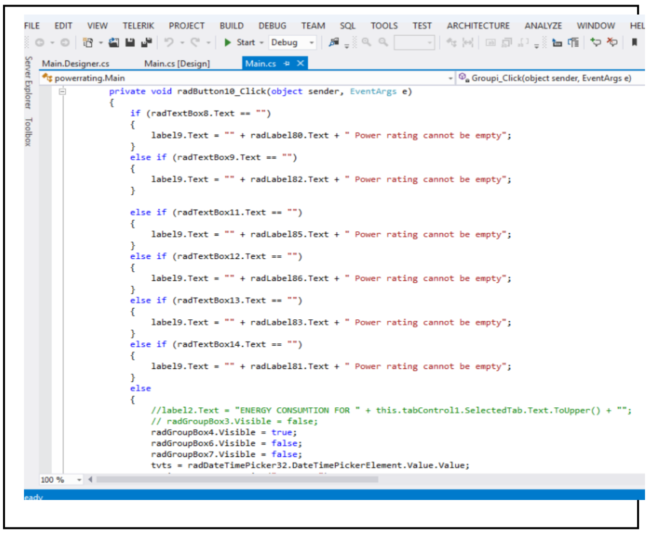

Figure 2 : Screenshot of the backend code for group *j* appliances

Similarly, for group *j* appliances, the back-end code is presented in Fig. 3 as shown below.

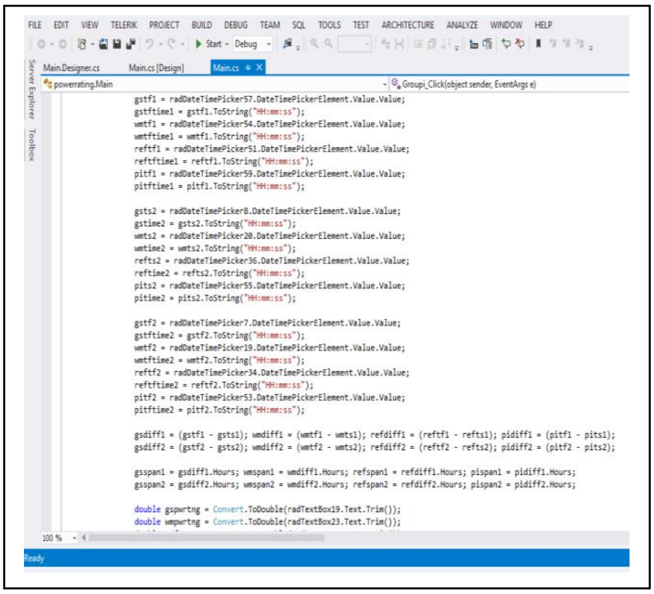

Figure 3 : Screenshot of the backend code for group *j* appliances

Fig. 4 shows the simulation result of all the group *i* appliances as they are scheduled to operate with their operating periods as indicated in table I.

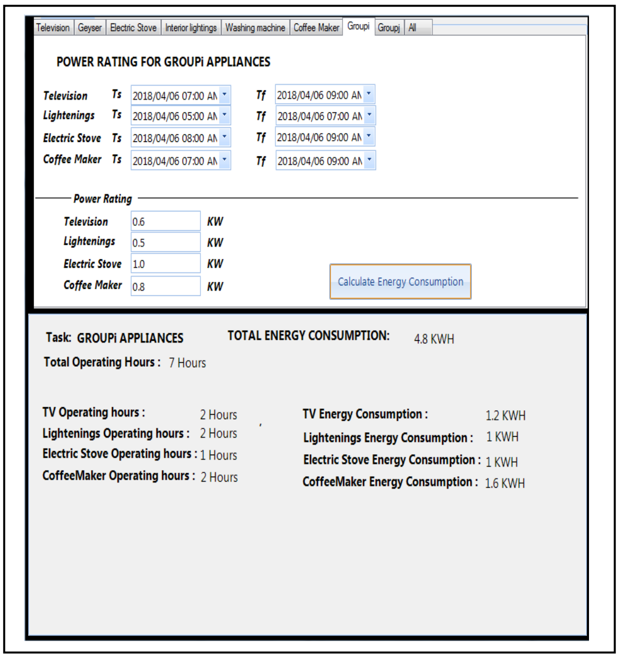

Figure 4 : Group *i* appliances simulation tab

Furthermore, the graphical presentation of the daily energy consumption result of group *i* appliances is presented in Fig. 5. The total energy usage for group *i* appliances is between the early hours of 5:00 am till 9:00 am and all the group *i* appliances are switched off afterwards.

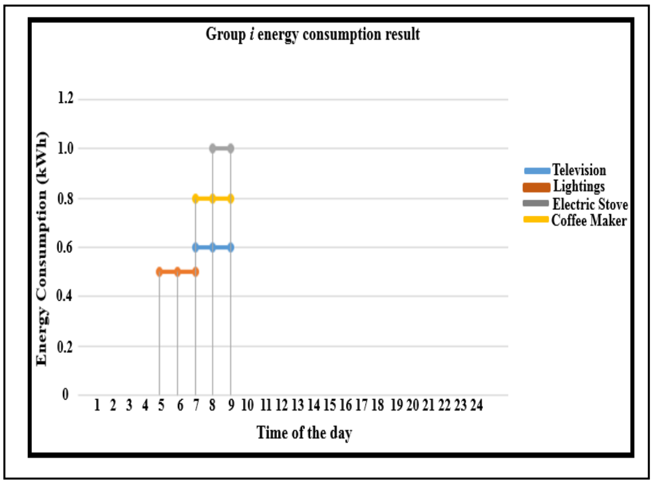

Figure 5 : Group *i* appliances energy consumption result

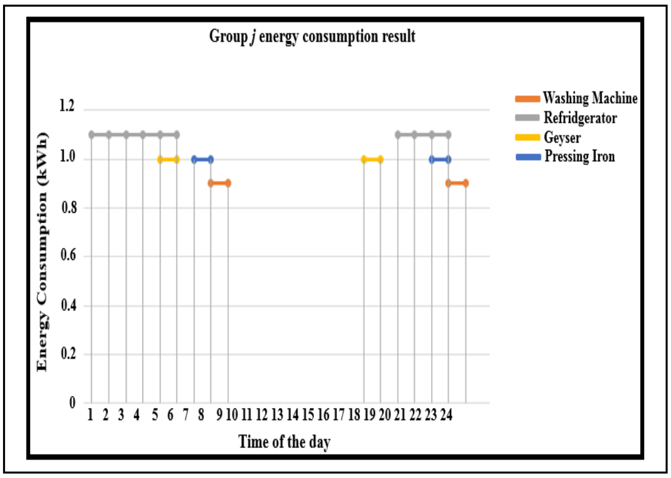

Figure 7 : Group *j* appliances energy consumption result.

As indicated in Fig. 4, the daily total energy consumption of all group *i* appliances as shown in Fig. 4 is 4.8kWh. The simulation result of all the group *j* appliances as they are scheduled to operate with the operating periods as indicated in table I is presented in Fig. 6. The daily total energy consumption of all the group *j* appliances as shown in Fig. 6 is 14.6kWh.

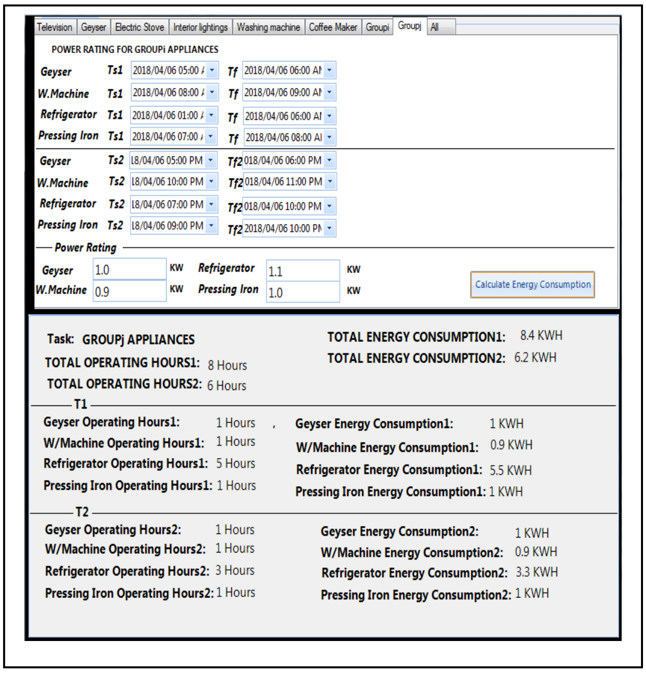

Figure 6 : Group *j* appliances simulation tab

Similarly, Fig. 7 depicts the graphical presentation of the daily energy consumption result of group *j* appliances. As shown in Fig. 7, the group *j* appliances are switched off between 10:00am until 7:00pm.

The simulation result for all the appliances is shown in Fig. 8. The total daily energy consumption for all the appliances using (7) is 19.4kWh and the total energy consumption is approximately 582kWh monthly.

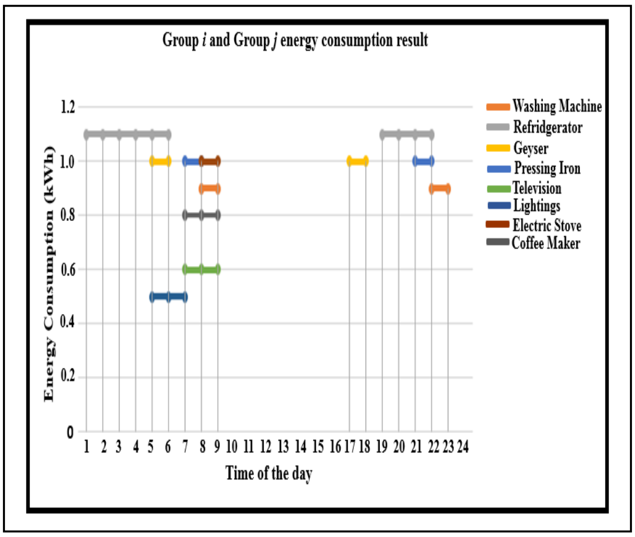

Figure 8 : Group *i* and group *j* appliances result

The result implies that the SH will be well suited to the DLC, whereby resident that uses a monthly consumption of 600kWh/month or less are charged at a rate of 46.34c/kWh. These appliances scheduling scheme avoids energy wastages and makes it possible for the residents to spend less on energy.

V. Conclusion

It is necessary to monitor household appliances operating periods in a cost-effective way to avoid energy wastage and high utility bill. A smart home scheduling scheme was analyzed and developed using Microsoft.net framework with

C# Programming language. The front end showing the scheduled operating periods for the appliances was developed using Telerik UI framework for Windows forms. The scheduling plan involves household appliances that are grouped into classes, depending on daily operating period(s). The scheduling scheme was analyzed using a data from the Western Cape electricity billing system, South Africa. The result shows that daily energy consumption can be planned, monitored and controlled to avoid energy wastage.

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