SMART RESIDENTIAL HOUSE SAVING ENERGY SYSTEM

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Abstract: *The special design process of an efficient residential house energy saving energy system is presented in this work. The main objectives are to achieve major energy cost reductions, providing safe house and reliable service. Thus, the essentials tool of the system will focus on providing useful information for the user by continuous monitoring and recording of the consumption behaviour of the operating appliances, also will raise early alarms in case of fault detection by high temperature monitoring. The outcomes of monitoring and analyzing the real power demand of group of typical house appliances is then used as a case-study for proposing further tools such as consumption forecast, tariff comparing and scheduling tools. Rule based system was designed for efficient and reliable operation control of house energy system with distributed energy source and storage units. Lab-View software package is used for implementation of most of the proposed algorithms which have been tested by variation of possible operating conditions. The results have shown that 22.75% energy savings can be achieved by applying the proposed tools and control strategies on typical home appliances. Modification of the system is recommended to include wide range of consumer's types such as industrial and commercial sectors and to include more than one type of distributed energy sources.*

Keywords: ENERGY SAVING, SMART HOUSE, ENERGY MANAGEMENT SYSTEM, LAB-VIEW

1-Introduction: Recent developments in information and communication technology such as intelligent meter technology, intelligent smart electrical appliances and intelligent storage systems, has led to the establishment of the smart home concept, and aid in building the energy management system infrastructure (Dounis&Caraiscos,2009). Energy Management Systems (EMS) technology such as home or building energy management system which is recognized as the most important element in the smart grid appear in response to the continuous requirement of high reliability and demand of increasing safety measures for the traditional power grid to meet customer satisfaction. Smart houses are expected to help power companies by dynamically adjusting power consumption in response to grid conditions, allowing for lower peak power costs as well as energy and maintenance costs. These savings help to reduce capital investment and the purchase of excess electricity from additional generators at peak time. The company's strategies to reduce the amount of fuel consumed to produce electricity are the pricing rates and demand response strategies (Li, 2013). Intelligent demand-side electricity use has a significant role in improving energy consumption by home users, and also effects on their daily behaviors and activities. The smart meter receives signals such as the maximum level of power allowed in a specified period or real-time price signals (Yoon et al., 2014). The flow of information between suppliers of electricity and consumers helps the energy management system play a role in demand response strategies. Where the demand response allows the consumer to reduce or convert their use of electricity during peak time in response to changes in prices by controlling the electrical devices manually or automatically, especially for the appliances of cooling, heating, air conditioners and water heaters, which considered the most used electrical appliances for electricity (Augean, et al, 2015). Real-time optimization and scheduling schemes for power storage systems and household electrical appliances are planned by the end-users. The object of the scheduling scheme of the home Energy Management System (EMS) is to manage the power consumption of the appliances during the peak and off-peak periods, to reduce consumption costs and to improve energy use (Shariatzadeha, et al, 2015).

2-Data collection: Dataset of house appliances operating conditions and power demand are to be available for the purpose of system testing and evaluating, for the purpose of saving time, effort and financial cost. When generating a log-file, two rules must be followed: The first rule is avoiding any appliances data with missing fragments. The second rule is selecting what local users are familiar with and avoid device duplicating. Table-1 shows the nine selected appliances for the present work house and figure-1 shows the suggested layout of the proposed house with appliances locations in addition to solar cells system with their storage batteries. When selecting development environment for the software, the followed rule was to search for a powerful programming software but user friendly at the same time, it is required to be able to communicate with external devices, able to send and receive data from the home system components. The Lab-View software package was selected for implementation of the system tools and functions.

3-Monitoring: Monitoring of house appliances will start form major part of the intended design objectives. Suitable monitoring tools are selected in this work for implementation. Their design criteria focus on automating instantaneous monitoring or saving data for later usage such as later analysis and comparisons for various appliances and delivering useful information quickly without effort even for beginner energy manager or ordinary user quite simply because it is going to be user every day partner. Figure-2 shows screen shot which represents the first system stage that the user will encounter when operating the software.

4-Individual consumptions: This feature is important and need to be included in any professional Energy Managing System (EMS). Although it could be difficult to be applied on all types and kinds of appliances in the house but at least it should be there for the important and heavy loads, those loads which need to be identified causing and driving the peak power demand and also it is important to identify cyclic loads whose operation could be delayed. In present work will simulate the case-study house which has nine major appliances, which are included in the individual loads power demand profile scheme. A small window of the registered devices list is included in the left side of the main window and shown in figure-3. Moving between the different items can be achieved easily using mouse clicks or moving by arrows in the key boards. One scheme of monitoring which is implemented in the main screen of the proposed system is the twenty-four-hour period of individual power consumption information. When an item name is selected, it will be highlighted and its load power demand profile will be updated automatically on the chart, which is shown to the right side of the list and on the upper side of the system main window. The chart will provide twenty-four-hour period of individual power consumption information. Continuous monitoring requires instantaneous updating with any change in the absorbed power values. The user will then have the freedom to select any device he is interested in showing its load pattern. Following, some recordings examples are included for some loads to understand the general operating pattern and the power demand. The operating pattern of the fridge, kettle and freezer are illustrated in Error! Reference Source not found as shown in figures, 4, 5, and 6. The lines in the plot connect the data points and the data points were recorded at five minutes intervals. The figures show the active power consumed by the appliances. The operating patterns display the cyclic nature of the appliances and their energy demand. Another scheme of monitoring is suggested which is based on keeping record of each device cumulative consumption over a period of one day for example depending on the tariff type and details as shown in figure-7, which illustrates the system idea based on using the traditional total dayly cumulative consumption meter.

5-Total power demand profile consumptions: Another scheme is similar to the individual loads power demand profiles monitoring scheme but it is monitoring the total home consumptions instead. The consumption sum is calculated on a minute by minute basis. A chart is continually monitoring and showing a period of twenty-four hours of the home load profile. The total consumption reading data for each minute represents the summation of all appliances consumption data, the summation was performed internally by the system and the total consumption is plotted with the time on the x-axis as shown in figure-8. This figure shows the home uses approximately 250 W/h during low power demand times and this rise and reaches approximately 2 kWh during peak power demand times. This is approximately eight times as much power required during the low power demand time. A similar power profile exists for different days, the minimum and maximum values will vary slightly but still in the same ranges.

6-Alarming systems: The previous section focuses on monitoring of home appliances to achieve one major design objective of providing home owner with important management advices and information. Another major design objective of present work proposed system is to provide alarming services. These services can be categorized in two main groups; first group design criteria focuses on alarming of high temperature detection and this is mainly for supporting safety measures in addition to achieving power savings, the second group design criteria focus on alarming regard detecting of any high or up-normal power consumption and although this is mainly for achieving power savings purpose and bill payments reducing but could also be used for supporting safety measures as well. It is important for the proposed system to have the ability of raising alarms to warn house owners of dangerous situations.

6-1 High temperatures alarms: Unlike power consumption data, real operating temperature from the REFIT electrical load measurements data set was not recorded. Hazard scenarios are essential for testing of the proposed management system ability for providing alarm if required and thus hazard scenarios need also to be simulated and stored on the system for testing purposes. Figure-9 shows an example of this approach block diagram connections. Here, the alarm monitor will turn color to red if temperature found to reach any value between 24.5-25 degrees. Of course, these values and threshold constants can be altered easily by the system programmer. Figure-10 shows the front panel of present work proposed house.

6-2 High power consumption alarm:

High power consumption may occur in the system during daily operations and having early alarm raise when such increase occur will be an advantage over traditional homes with no monitoring facilities. The alarm will help mainly in reducing bills, aiding safety measures of home owners, and increasing expected life of some part of the home system. High power consumption may occur due to faulty conditions, some of these faults may not be detected by home protection systems such as current leakage in high resistance. Figures- 10 shows the front panel of present work proposed alarm and the monitoring meter, *Грешка! Източникът на препратката не е намерен.* Figure-10 shows an example where the consumed power is less than the preset threshold, while figure-11 show the same example when the consumed power exceeds the preset threshold. Alert is raised for the high consumption by converting its color from green to red.

7- Consumption forecast tools: The consumption forecast tool work on raising an alert to inform of possible high consumption. The tool is designed to involve current month usage and previous month consumption as well in its estimations. Figures-12-15 show the structure for the front screen of the designed consumption forecast tool and an example for the forecasting tool outcome. Figure -15 shows an example for the forecasting tool outcome, the selected block was 300kWh, the previous month used data was set to 500 kWh for testing and the calculated forecast is expected to exceed the allowance. Figure-16 shows a one day home consumption with peak time tariff, while table-2 shows the total cost reduction before and after dishwasher scheduling strategy. Figures-17 and 18 Illustrate the savings after applying scheduling on freezer and Scheduling savings calculations for freezer, respectively. Finally the Summary of estimated reduction percentage is shown in table-3.

8- Analyses and Discussion of Results: Extra reductions in bills for some tariff types can be achieved if some measures are considered at the time of the application, example of this application of the peak time tariff or the real-time tariff when combined with a well-designed scheduling strategy. To build the wanted scheduling strategy, some rules should be defined, starting by rules for appliances classification into two groups, namely; essential and nonessential load. Essential loads include loads where operation automatic control may negatively affects the user comfort, such as TV, PC or router. On the other hand, turning off or rescheduling some loads will not have big impact on the user regular life activity, these will be defined as the nonessential loads such as the dishwasher or the washing machine. For illustration example of the proposed scheduling tool, figure-***16*** shows a plot of a typical total home consumption for one day with details of the peak time tariff on the same figure. The plot found to be containing five major consumption spikes. The first three will be treated with by the shoulder rate and the last two will be paid by the peak rate. These spikes will effectively contribute to a large payment share of the expected bill. Information from the installed individual power meters will be passed on to the scheduling strategy in order to identify the source of these spikes. Error! Reference source not found, shows that the Dishwasher is responsible for the rest four of these spikes, the first two was during the shoulder rate period and due to the dishwasher usage, that starts at around 8:50am and finish at around 10:00am. The second usage of the dishwasher was encountered at a longer interval which starts at 6:00pm and continues until 7:40pm; the main point here to be noticed is that this usage was at the peak rate period. The scheduling tool function may be utilized regard the power spikes which was generated by the dishwasher as shown in tables-4. This device can be considered as a non-essential device since shifting its operation time will have no effect on the user. Error! Reference source not found, figure-19 is an example of this set power consumption. A simple control strategy is proposed for this set which is based on the master-slave principle. The TV will be the master device, the control strategy will be based on turning off the whole set if the master device was not in use and turning it on will signal the on-control order to the whole set of slave devices as shown in tables 5 and 6. Figures-20 and 21 show the already monitored freezer power consumptions profile (i.e. before and after suggested modification). Its cyclic operation is governed by two temperature limits; the total time for each cycle can be estimated to be in the range of two to two and half hours divided almost in half between the on-time and off-time. Similar cyclic operation behavior is also noticed in fridge power consumptions profile. The strategy algorithm can be built on the principle of controlling the on-times and off-times according to the rate of that period. Flowchart shown in figure-22 represent summary of this proposed strategy steps. The idea is to keep fixed cycle time, monitoring the time will be used to identify the rate different periods and then selecting Ton1 for operating- time in the off-peak period, Ton2 for the shoulder peak period or Ton3 for the peak period. The following equations of 1,2 and 3 may be used to summarize the proposed algorithm.

$$\text{Time delay} = T_{on}+T_{off} \quad (1)$$

$$Ton_1 = 1.5*T_{on2} \quad (2)$$

$$Ton_1 = 3*T_{on3} \quad (3)$$

Although, following the previous strategy algorithm will serve achieving the scheduling purpose, but there are few aspects regard the safe operation of the device which if neglected may have serious negative consequences on the man life especially regard using of these vital appliances i.e. fridge and freezer. Healthy and food conserving safety serious issues may be encountered if operating of this equipment was determined and controlled by time constrains only. The low temperature limit in the shoulder time T_{low2}, will be little bit higher than T_{low1}, and the low temperature limit in the peak time T_{low3}, will be higher than both T_{low1} and Tlow2. The general rule will be to ensure that $T_{low3}>T_{low2} >T_{low1}$. Low temperature limits must be selected in a manner that ensure early turn off and thus means more power savings to avoid device long operation intervals in high rate periods. Flowchart shown in figure represent summary of this proposed strategy steps. For illustration, figure-17 shows an example of calculations for applying the peak tariff rate structure for day, month, year and ten years durations. The calculation is performed for normal operation without scheduling case and also on the scheduled operation of the device. Further increasing in the savings percentage may be achieved by further decrement in the shoulder and peak on times. For energy storing, a slight increase in the off-peak on-time duration may be suggested. Figure-18 shows a comparison between the previous example of time parameters set and a new set of time parameters and the increase in the savings percentage. Summary of estimated reduction percentage is included in year's durations. The calculation is performed for normal operation without scheduling case and also on the scheduled operation of the device. Further increasing in the savings percentage may be achieved by further decrement in the shoulder and peak on times. For energy storing, a slight increase in the off-peak on-time duration may be suggested. Summary of estimated reduction percentage is included in table-3.

9-Conclusions:

The functionality of the proposed design system is demonstrated by modeling and simulation of various scenarios for reducing bill payments; appliances operation controlling strategies are investigated. For some of the appliances, such as the fridge and kettle, application of storage-based strategy can achieve 12.7% cost reduction. For the washing machine and the dishwasher, a peak clipping based strategy by operating time shifting can achieve 22.4% cost reduction. For the TV set and the PC set, a master and slave principle is selected. For the TV set, 44.4% consumption reduction can be achieved. The router controlling strategy is based on monitoring the presence of the home owner and calculating the expected reduction requires a study of his daily behavior. Applying suggested strategies can achieve total cost reduction of 22.75%.

Table 1: *List of appliances used in present work case-study*

Number	Registered devices
1	Fridge
2	Freezer
3	Microwave
4	TV
5	Kettle
6	Dishwasher
7	Washing machine
8	Computer
9	Router

References:

Dounis, A.I., Caraiscos, C., "Advanced control systems engineering for energy and comfort management in a building environment- A review", Renewable and Sustainable Energy Reviews 13 (2009) 1246-1261.

Elma, F., Selamogullari, U. S.,"A new home energy management algorithm with voltage control in smart home environment" Energy 91 (2015) 720-731.

Francisco, D., Moya, C., Juan, C., Lopez, A., Luiz, C. P., da, S., "Model For Smart Building Electrical Loads Scheduling" 978-1-5090-2320-2/16/$31.00 ©2016 IEEE

Li, Y., "Design of A Key Establishment Protocol for Smart Home Energy Management System"2013 Fifth International Conference on Computational Intelligence, Communication Systems and Networks. 5-7 June 2013, Madrid, Spain, DOI: 10.1109/CICSYN.2013.42.

Murray, D.; Stankovic, L.; Stankovic, V., " An electrical load measurements dataset of United Kingdom households from a two-year longitudinal study" Scientific Data; London Vol. 4, (Jan 2017): 160122

Ozkan, H. A."Appliances based control for power management systems" Energy 114(2016)693-707.

Shariatzadeha, F., Mandalb, P., Srivastavac, A. K., " Demand response for sustainable energy systems: A review, application and implementation strategy" Renewable and Sustainable Energy Reviews 45 (2015) 343–350.

Yoon, J. H., ladick, R. B., Novoselac, A., "Demand response for residential buildings based on dynamic price of electricity" energy and building 80 (2014) 531-541.

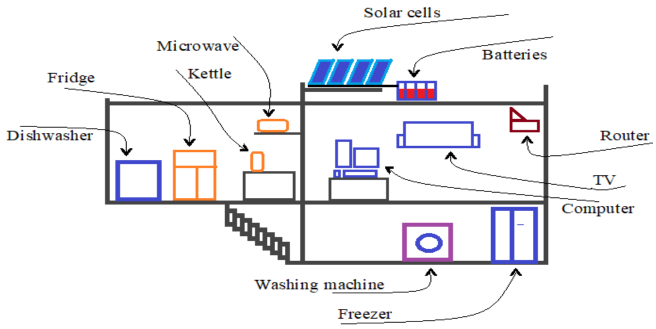

Figure 1: *Layout of proposed case-study house*

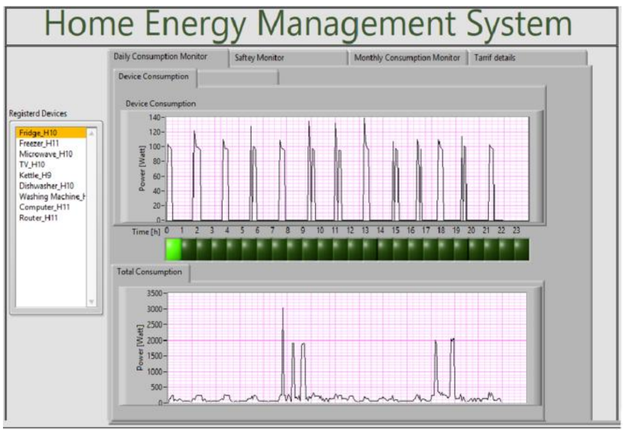

Figure 2: Desk top screen shot

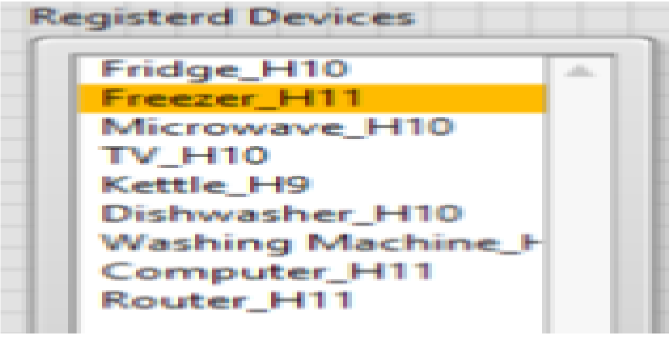

Figure 3: *Registered devices list*

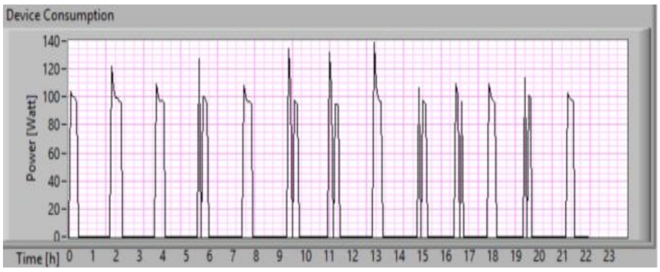

Figure 4: Example of the fridge consumption

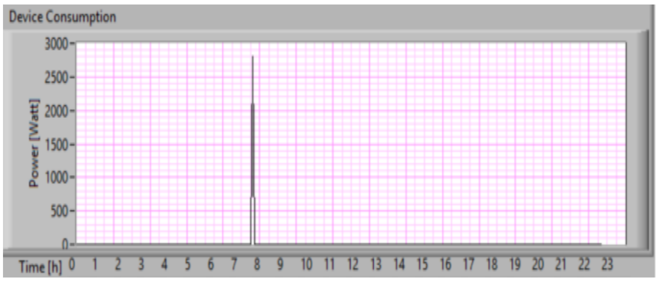

Figure 5: *Example of the kettle consumption*

Figure-7*: Cumulative consumption meter panel*

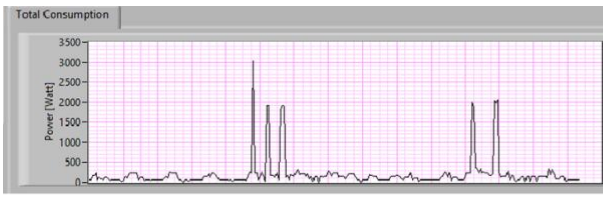

Figure-8: *Example 1 of total consumption for a day*

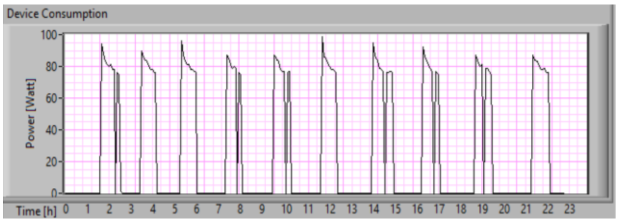

Figure 6*:* *Example of the freezer consumption*

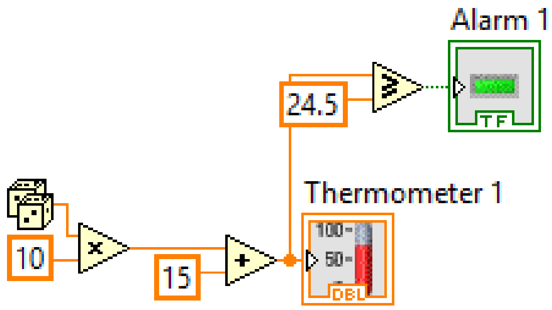

Figure-9: *first approach block diagram connections*

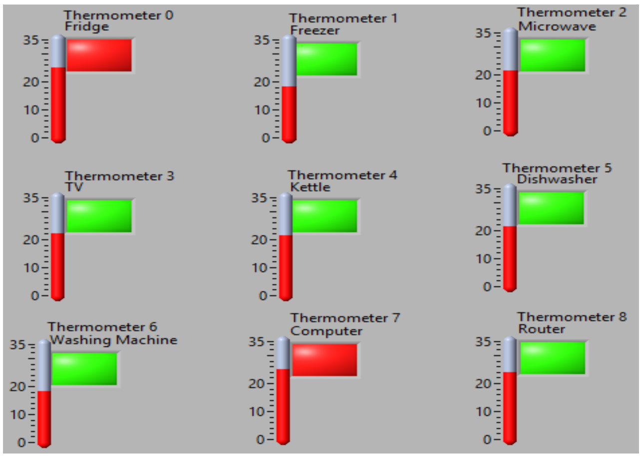

Figure -10: *Alarm system front panel*

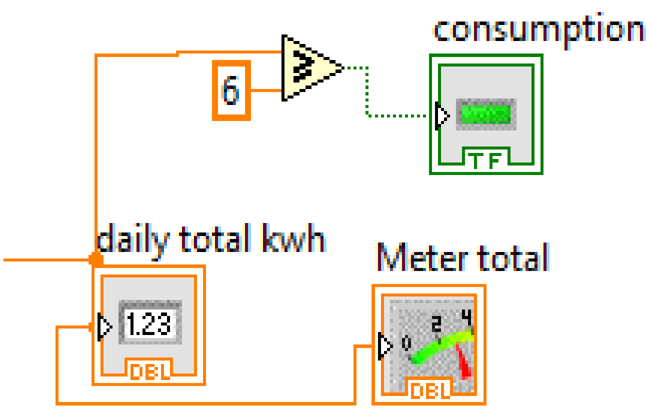

Figure 11: *High power consumption alarm Block diagram connections*

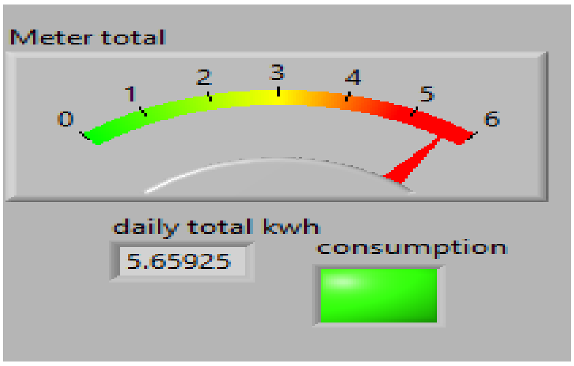

Figure 12: *Monitoring meter with proposed alarm*

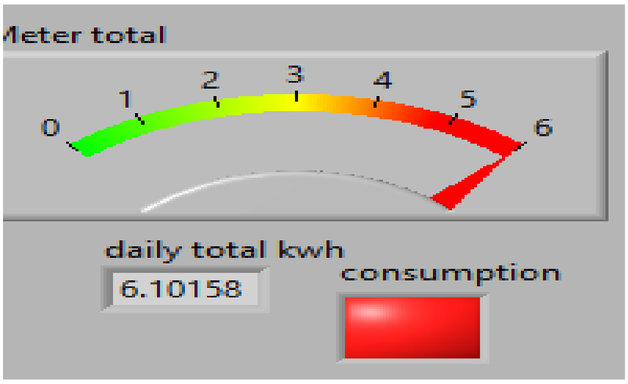

Figure 13: *Raised alert for high consumption*

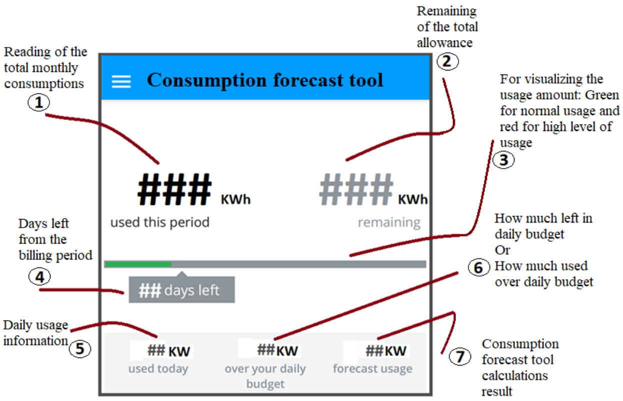

Figure 14: *Consumption forecast tool front screen structure*

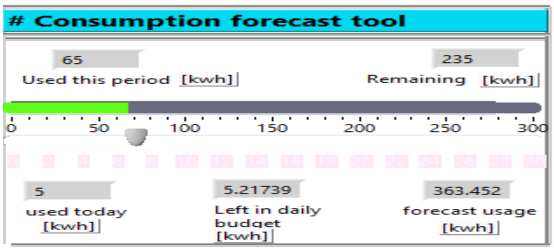

Figure 15: *Forecast if normal usage and previous month consumption was 500 kWh*

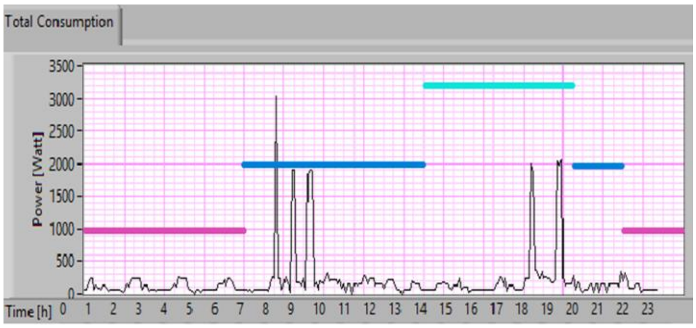

Figure -16: *One day home consumption with peak time tariff*

Table 2: *Total cost reduction before and after dishwasher scheduling strategy*

Total appliances operating cos with Time of day tariff	before Appling Dishwashe scheduling strategy	1.01 $
	after Appling Dishwashe scheduling strategy	0.91 $
		Reduction Percentage 9.9%

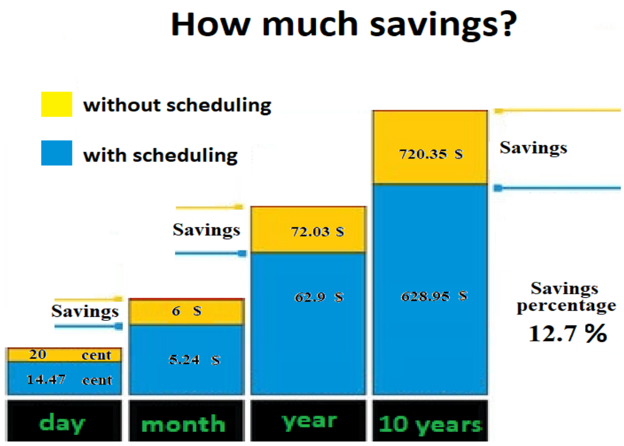

Figure-17: *Savings after applying scheduling on freezer*

Time parameter set		Total costs over 10 years	Savings percentage
T_{on1}=90 minutes T_{on2}=40 minutes T_{on3}=20 minutes	Without scheduling	720.34 $	12.7%
	With scheduling	628.95 $	
T_{on1}=100 minutes T_{on2}=35 minutes T_{on3}=15 minutes	Without scheduling	720.34 $	14.3%
	With scheduling	617.44 $	

Figure-18: *Scheduling savings calculations for freezer*

Table-3: *Summary of estimated reduction percentage*

Appliance	before	after	Reduction percentage estimation
Freezer	0.2001 $	0.1747 $	12.7%
Dishwasher	0.42 $	0.33$	22.4%
TV set	0.27 $	0.15 $	44.4%

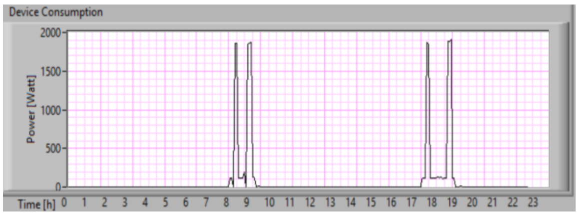

Figure-19: *Example of the dishwasher consumption*

Table 4: *Dishwasher operating cost reduction before And after dishwasher scheduling strategy*

Dishwasher operating cost with Time of day tariff	before Appling Dishwasher scheduling strategy	0.42 $
	after Appling Dishwasher scheduling strategy	0.33 $
		Reduction Percentage 21.4%

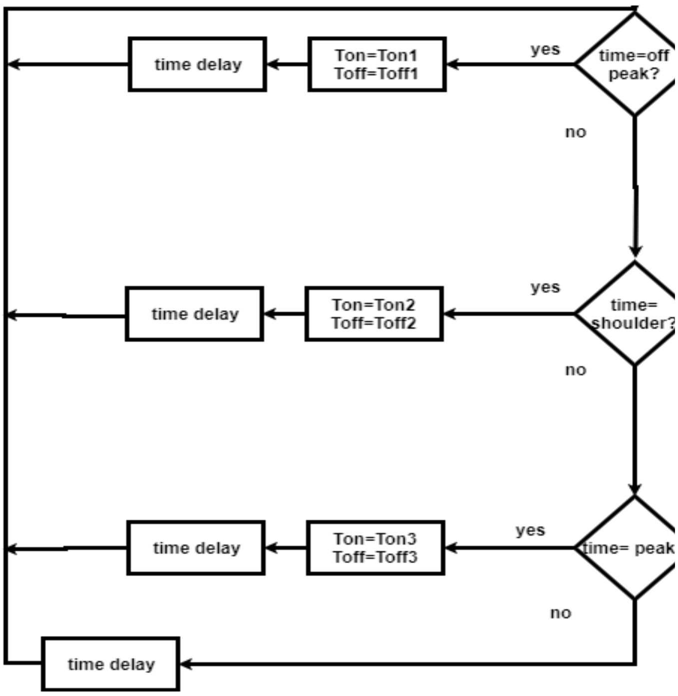

Figure 22: *Time constraint-based algorithm*

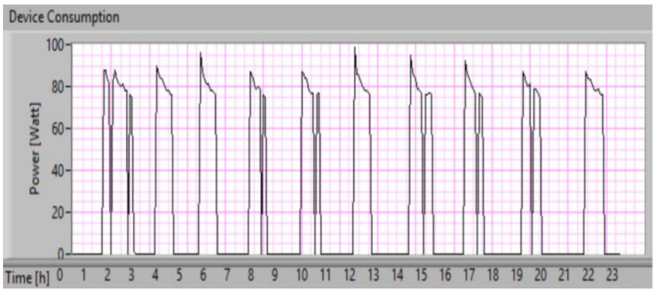

Figure-20: *Freezer power profile before suggested modification*

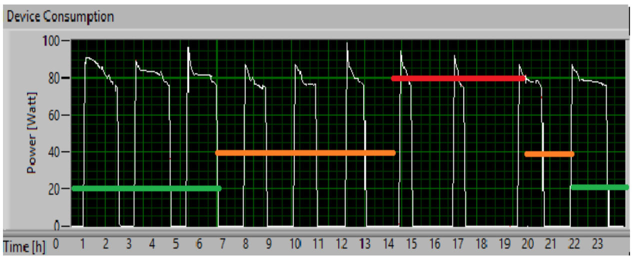

Figure-21*: Freezer power profile after with energy storage*

Table-5*: TV control strategy consumption results*

TV operating kWh	before control strategy	1.322 kWh
	after control strategy	0.722 kWh
		Reduction Percentage 45.3 %

Table 6: *TV control strategy cost results*

TV operating kWh	before control strategy	0.27 $
	after control strategy	0.15 $
		Reduction Percentage 44.4 %