Peak Shaving Energy Management System for Smart House

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Abstract - **This paper introduces a peak shaving energy management system that reduces peak demand of the power usage, shifts usage to off-peak hours and lowers total energy consumption. Constraints such as due time of a process, limit of electrical energy consumption and use of preferable resources are taken into account. The proposed system takes into consideration the rated power and the usage time of the house applications and adapt them to the available power with the help of sensor networks using smart monitoring and controlling algorithms. The proposed system enables the use of the renewable energy and uses Yahoo weather forecast from the Internet to make tuning for the controlling algorithms. The used sensor network includes motion detection sensor to turn off the unnecessary devices when there is no need for it. It is proved that implementation of the proposed strategy would improve energy management by proper choice and timing of resource usage in smart houses.**

Keywords – **Smart House, Energy Shaving, Energy Management, Energy Scheduling, Sensor Network, House Automation.**

INTRODUCTION

A Smart house can be briefly described as a house that is supplemented with technology in order to increase the range of services provided to its inhabitants by reacting in an intelligent way. The technology can be diverse but generally will have two main components: a set of sensors and a networking layer linking those sensors with some computing facilities. Typical sensors are carbon monoxide sensors, heat sensors, motion sensors used for burglary alarms and sensors detecting if a window or a door has been opened. All these sensors send out signals and some of them can also receive signals so that for example, the cooker can be turned off automatically [1]. An obvious way to turn off a device would be with a timer but usually this can be a very rigid mechanism. A more useful and flexible use of the device demands the intelligent analysis of several factors in order to decide if the turning off of a cooker is meaningful given a context [1]. Smart house technology started for more than a decade to introduce the concept of device and equipment networking in house. Smart house contains internal network and intelligent control on different house's services [2].

The internal network can be built via wire or wireless communication techniques between sensors and house applications. The intelligent control means the entire house is managed or monitored by a computer. Smart house is the integration of technology and services through house networking for a better quality of living. Integrating the house services (Fig. 1 [3]) allows them to communicate with one another through the house controller, thereby enabling single button to control the various house systems according to preprogrammed scenarios or operating modes. Smart houses have the potential to improve house comfort, convenience, security and energy management. Moreover it can be used for elder people and those with disabilities, providing safe and secure environments. A smart house is a good choice for people caring about security, health, energy saving and convenience. The benefits of smart technology at house could be apparent to everyone if this potential is fulfilled. This is when the system will be able to protect habitant's privacy and having low cost. The disadvantage is that elder are more reluctant to try new things or change their way of thinking about the risk of the losing privacy due to their feeling of being monitored all the time [4].

Fig. 1 Smart house integrated network [3]

1.1 Energy Demands

World human population increases today more than 80 millions of individuals per year, therefore, the energy needs increase more and more. A building is both a place of power consumption and potentially a place of decentralized power production using resources like wind, solar, geothermal, etc. The resort to renewable power resources comes up in houses knowing that they represent 47% of the global power consumption. Design of a control system which allows the exploitation of different energy resources, while managing globally the power needs and the production capacity of a house, is an upcoming issue [5].

The role of a smart house system dedicated to power management is to adapt the power consumption to the available power resources, and vice versa, taking into account inhabitant comfort criteria. It has to reach a compromise between the priorities of the inhabitant in terms of comfort and in terms of cost while satisfying technological constraints of devices. Such methods for controlling electricity consumption are part of demand response, which relies on varying price of electricity to reduce peak demand. Reduced peak demand lowers electricity bills and benefits utilities by reducing complexity of grid stability, occurrences of equipment failures, brownouts, and blackouts [6].

1.2 Energy Management

The main function of the smart house power management system is to reduce peak demand of the power usage through shift the overload usage from on-peak hours (4 PM until 8 PM in the summer and 5 AM until 8 AM during the winter in west Florida). On-peak or peak load are terms used in energy demand management describing a period in which electrical power is expected to be provided for a sustained period at a significantly higher than average supply level. Peak demand fluctuations may occur on daily, monthly, seasonal and yearly cycles [7].

For an electric utility company, the actual point of peak demand is a single half hour or hourly period which represents the highest point of customer consumption of electricity. Off-peak hours (10 PM to 6 AM all days, 6 AM to 10 PM Sunday and holidays) are considered to be the opposite to on-peak hours when power demand is usually low. [7].

Considering peak shaving procedure (Fig. 2) will lower total energy consumption, reduce the cost of the power from the national grid through the use of renewable resources and through the shift of high power devices to the night where the power cost is lower and actively manage other usage to respond to solar, wind, and other renewable resources.

One of the major benefits of smart house are their ability to incorporate energy management features through lighting, air conditioning and house appliances [4].

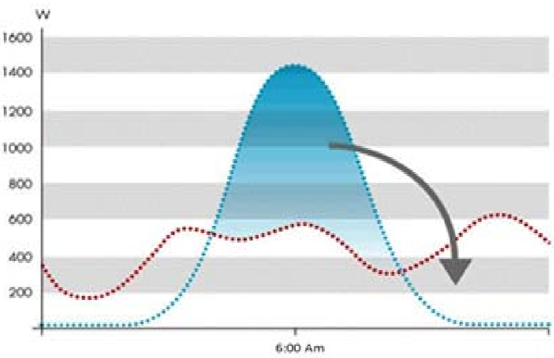

Fig. 2 Peak shaving procedure

A. Lighting

The lights in a smart house can be turned on and off automatically based on occupancy sensor. When a person enters a room in the day time, the system will open the drapes instead of turning on the lights, but at night it would make sure the lights came on and they turned off when no one is in the room hence waste of energy can be preserved [4].

B. Air Conditioning

An appropriate placement of temperature sensors and the use of heating and cooling timers can reduce the energy used and hence saving money and also the house can set to turn off air conditionings when no one is in the room [4].

C. House Applications

Smart houses can even go further in energy management by keeping track of the energy usage of each and every appliance in the house. The smart house controllers could schedule the operation of heavy power consuming appliances (such as dishwashers and electric water heaters) to take maximum advantage of off peak electric rates [4].

1.3 Electricity Resources

Electricity is split into two different resources: low cost, and expensive electricity, because of daily changes of electricity prices in certain countries. Electrical energy is cheaper by night because of the smaller demand at that time of a day. The expensive tariff is chosen to last from 8 AM till 10 PM, while the low-cost lasts from 10 PM till 8 AM. There are two parameters that describe the resources of electricity: the maximal reserved power, and the limit power [8]. The maximal reserved (allocated) power is the maximal amount of electric power that can be provided to a household. The limit power is defined by a user and it is the amount of electricity defined as the maximal power that can be drawn from the grid. That amount should never be reached in the normal working conditions. For example, if the maximal reserved power is 6kW and the limit power is defined as 3kW, the smart house will try to work at every time instant with only 3kW. Default limit power will be exceeded only if not using it would threaten the performances of the processes (short duty time). As user's actions cannot be interfered by a designed algorithm, this occurs in the case when the user initiates too many processes with too strict deadlines for the execution. In that particular case, crossing the limit power is inevitable. However, it is not possible to withdraw more power than the maximal reserved power [8].

1.4 Household Energy Use

In order to start saving money on energy bills and understand house energy consumption, one have to know where the best place to start. The pie chart in Fig. 3 shows the percentage of energy consumed in regards to energy bills in the typical American household. The majority of the consumed power in the house is dedicated to heating and cooling. This is followed by water heating and then lighting [9].

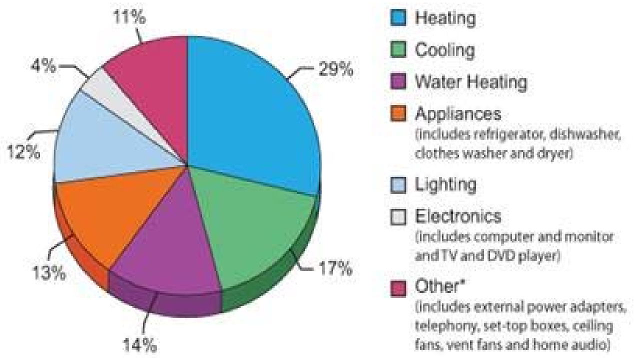

Fig. 3 PI chart of energy consumed in the typical American household

1.5 Demand Response [10]

In electricity grids, demand response is similar to dynamic demand mechanisms to manage customer consumption of electricity in response to supply conditions, for example, having electricity customers reduce their consumption at critical times or in response to market prices. The difference is that demand response mechanisms respond to explicit requests to shut off, whereas dynamic demand devices passively shut off when stress in the grid is sensed.

Demand response can involve actually curtailing power used or by starting on site generation which may or may not be connected in parallel with the grid. This is a quite different concept from energy efficiency, which means using less power to perform the same tasks, on a continuous basis or whenever that task is performed. At the same time, demand response is a component of smart energy demand, which also includes energy efficiency, house and building energy management, distributed renewable resources, and electric vehicle charging.

Current demand response schemes are implemented with large and small commercial as well as residential customers, often through the use of dedicated control systems to shed loads in response to a request by a utility or market price conditions. Services (lights, machines, air conditioning) are reduced according to a preplanned load prioritization scheme during the critical time frames. An alternative to load shedding is on-site generation of electricity to supplement the power grid. Under conditions of tight electricity supply, demand response can significantly decrease the peak price and, in general, electricity price volatility. Demand response is generally used to refer to mechanisms used to encourage consumers to reduce demand, thereby reducing the peak demand for electricity. Since electrical generation and transmission systems are generally sized to correspond to peak demand (plus margin for forecasting error and unforeseen events), lowering peak demand reduces overall plant and capital cost requirements.

Depending on the configuration of generation capacity, however, demand response may also be used to increase demand (load) at times of high production and low demand. Some systems may thereby encourage energy storage to arbitrage between periods of low and high demand (or low and high prices). There are three types of demand response: emergency demand response, economic demand response and ancillary services demand response. Emergency demand response is employed to avoid involuntary service interruptions during times of supply scarcity. Economic demand response is employed to allow electricity customers to curtail their consumption when the productive or convenience of consuming that electricity is worth less to them than paying for the electricity. Ancillary services demand response consists of a number of specialty services that are needed to ensure the secure operation of the transmission grid and which have traditionally been provided by generators [10].

1.6 House Network [11]

A house energy management network focuses on appliance energy use and load management by providing scheduled ON/OFF and tracking of appliance power. In this way, each appliance is monitored and the costs associated with electricity use are recorded to a centralized node. This information is available to the house owner through the use of a handheld monitor, cell phone (or iPhone clones) or house PC as part of a demand side management function. The network monitors appliance efficiency and provides status reports on all appliances linked within the network. It would also make this available to outside agencies that are part of the network, such as an energy management service provider. On the demand response side of the equation, the network receives input from the energy management service provider, the utilities, or the grid sensing unit assigned to the network. The grid sensor gives the network a preemptive command should the grid experience a rolling blackout or if there is an imbalance in the grid. The sensor notifies the node, based on prearranged settings, that takes whatever action is needed to turn off appliances for whatever predetermined time. In a scheduled blackout, the node will receive that notification from the utility or energy management service provider [11].

1.7 Peak Shaving Procedure

One of the most common applications of energy management is peak shaving. In these applications, the power absorbed by the installation is constantly monitored, making it possible to automatically adapt the power consumption to the required levels. The system records the profile of the power absorption on a daily basis and from that data it can make forecasts of power peaks that may occur. Based on the forecasts, the system will cut-off specific loads by priority set by the user in order to maintain the peak load under a certain preset level. When the power level decreases, the system will gradually reinstates the loads that were suspended. The main benefit of a peak shaving system is that peak power levels are maintained within the limits agreed with the power supplier, thus avoiding extra costs and power system overloads.

PROPOSED SYSTEM

2.1 Peak Shaving Energy Management System Layout

The smart house peak shaving energy management system, shown in Fig. 4, consists of a wired network that connects the house applications to a personal computer via

USB port using K8055 interface board [12] with a custom relay and sensing electronic boards that controls driving AC power to the house applications. A dedicated control and scheduling programs were designed and implemented to handle all the tasks.

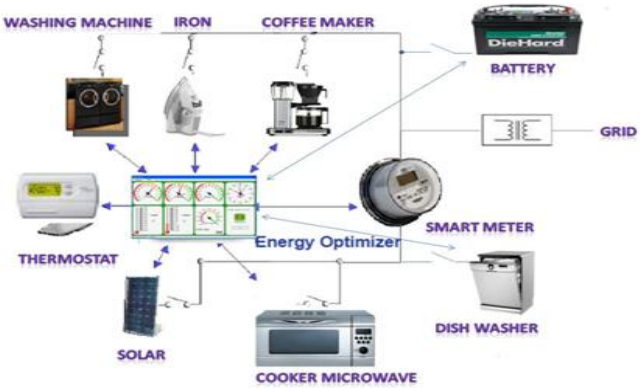

Fig. 4 Smart house peak shaving energy management system layout

2.2 House Applications

Five house applications were chosen in this research in addition to the electrical storage device (acid battery). The applications power rating and their predefined operation priority during 24 hours is show in Table (1).

2.3 Application Statuses

In this paper, each application can have one of four statuses which is “on, off, hold and pause”. When the application is inactive which is turned off by the user or finished its job, the application is in its off state, the on status indicates that the application is currently active. The hold status indicate that the application is requested to operate but its currently inactive because its priority is low and there is no enough power for it to operate. The pause status indicates that the application is turned off by the user and he can resume it when he wants, taken in to consideration its remaining operation time when paused.

Table (1) House Applications Ratings and Priorities

Application	Power Rating (watts)	Application Operation Priority During 24 Hours (*) Indicates the application will work in its predefined scheduled time and if there is availability of power)						
		6 am 9 am	9 am 12pm	12 pm 3 pm	3 pm 6 pm	6 pm 9 pm	9 pm 12 am	12 am 6 am
Iron	1000	1	*	5	*	5	*	2
Coffee maker	2300	2	*	4	*	3	*	*
Cooker microwave	2100	3	*	1	*	1	*	*
Dish washer	1500	4	*	2	2	2	*	*
Washing machine	1000	5	*	3	1	4	*	*
Battery	100	6	*	6	*	6	*	1

2.4 Sensor Network

The smart house energy management network uses the LM35 precision integrated-circuit temperature sensors which are distributed all over the house to sense the temperature inside the house rooms. Also, the system is connected to the Internet Yahoo forecast servers to have online updates for the weather.

2.5 Interfacing Card

The K8055 interface board, shown in Fig. 5, is used to make the interface between the management PC (which has all the sensing and control algorithms) and the house applications using a simple relay card. The K8055 has 5 digital input channels and 8 digital output channels. Also, there are two analogue inputs, two analogue voltage output and two pulse width modulation outputs with 8 bit resolution. The number of inputs/outputs can be further expanded by connecting more (up to maximum of four) cards to the pc’s USB connectors [12].

Fig. 5 The K8055 interface board

2.6 Power Management Requirements

There are two power resources used in this paper, the grid power and the battery power, giving the residential the ability to use either the grid power only or the grid power with the battery power or the battery power only.

The total power consumption of the applications must not exceed the total available power (Eq. 1), otherwise the application will enter the hold state until an enough power will available or the application priority will be changed to a higher level by the user.

$$\text{Total Available Power} \geq \sum \text{Total On Applications Power Consumption} \quad (1)$$

The proposed system will make sure that Eq. 1 will be always true.

2.7 Peak Shaving Power Management Algorithm

The power management algorithm depends on the application priority according to its use time as shown in Table (1). The algorithm calculate the requested applications power and if their total power is below or equal to the power limit, all the applications will be activated and if their total power is above the power limit, the algorithm sorts the applications according to its priority in a descending way. However, if the total power consumption of the requested applications exceeds the available power limit, the algorithm makes a comparison between the applications and temporary holds the lower priorities applications until the total power consumption is equal to or below the available power limit. When the first stage of the algorithm is finished, the algorithm then searches for a temporary hold applications that the residual power enough to operate it. The result of the algorithm is sent to the device manager which is responsible for activation or deactivation of the application. The hold application will operate as soon as there is an enough power for it. All applications are assumed to be preemptive. Preemptive is the act of temporarily interrupting a task being carried out by a system, without requiring its cooperation, and with the intention of resuming the task at a later time. The algorithm makes sure that the maximum number of requested applications is activated and the largest part of the available power is used. Fig. 6 shows the flowchart of the algorithm.

The code of the power management is listed below:

```
public int[,] Schedular(int[,] device_list)  {
int total_power = 0;
device_list = sort(device_list);// descending sorting to the devices priorities
for (int i = 0; i < 6; i++)
if (devicE[device_list[i, 0]].status != "Pause")
total_power += device_list[i, 2];
if (total_power <= Power)
return device_list;
for (int i = 0; i < 6; i++)     {
if ((device_list[i, 2] != 0) && (devicE[device_list[i, 0]].status != "pause"))   {
devicE[device_list[i, 0]].command = "wait";// wait the device
devicE[device_list[i, 0]].status = "HOLD";
total_power -= device_list[i, 2];  }
if (total_power <= Power)
break;    }
// search for device with enough power less or equal to the residual power
for (int j = 5; j >= 0; j--)   {
if (devicE[device_list[j, 0]].command == "wait")   {
total_power += device_list[j, 2];
if (total_power > Power)   {
total_power -= device_list[j, 2];
devicE[device_list[j, 0]].command = "OFF"; }
else   {
devicE[device_list[j, 0]].command = "ON";
devicE[device_list[j, 0]].status = "ON";  }  }  }
return device_list;     }
```

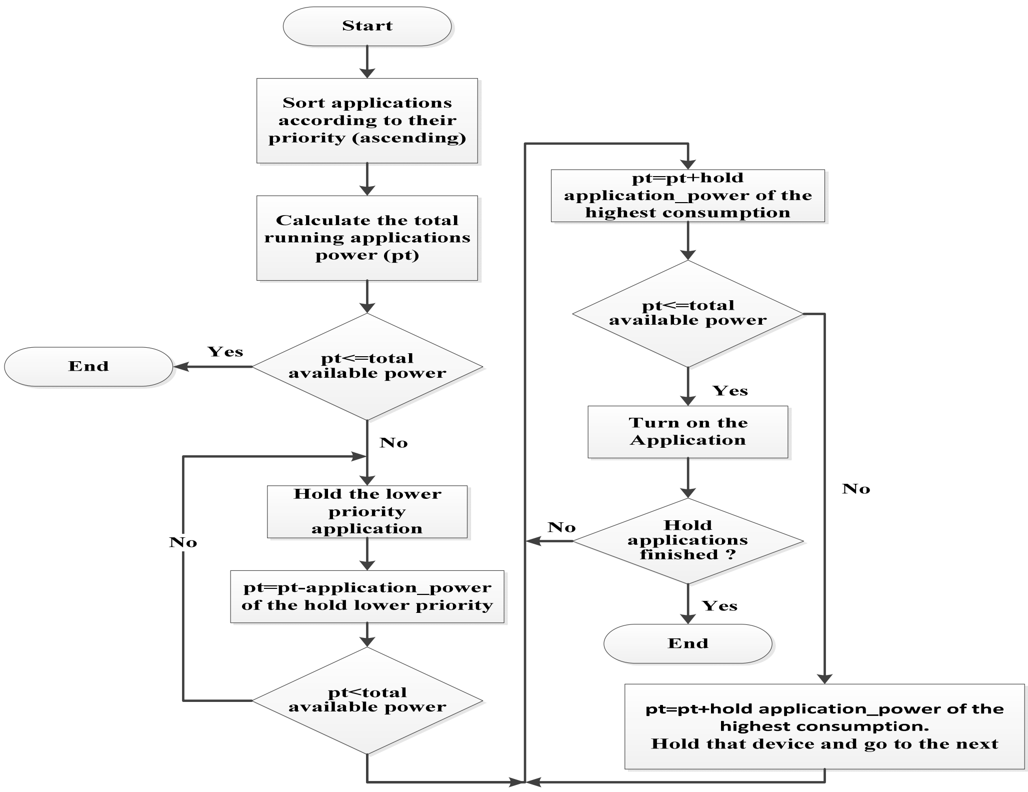

Fig. 6 Flowchart of the peak shaving power management algorithm

2.9 Applications Starting and Finishing Time Algorithm

The application starting time of each application cannot be earlier than the given starting time as shown below:

If starting time (hour: minute) = current time
Then start the application
Else do nothing
End if

$$\sum_{applications} \text{Application (i, t)} = 1$$

Application (i,t) is 1 if application i starts at time t,
0 otherwise

Each application can't finish be until its working time has finished.

If working time = 0
Then turn off the application

2.10 Applications Working Time Algorithm

The application working time determines the period (in seconds) that the application must operate, each application can't end operation until its working time equals to zero as shown below:

$$\sum_{applications} \text{working time} = 0$$

If working time = 0
Then turn off the application
Else decrement the timer by one second
End if

The code to read and calculate the working time (in seconds) is listed below:

```
public void workingtime(int j)    {
TextBox[] box = new TextBox[6] { tiron, tcoffee, tcooker, tdish, twashing,
tbattery };
string[] words;  int t = 0;
words = box[j].Text.Split(':');
int www = words.Length;
if (www <= 3)
{ int[] we = new int[www];
for (int ii = 0; ii < www; ii++)
{       try         {
we[ii] = Convert.ToInt32(words[ii]);   }
catch (FormatException)    {
yy.AppendText("\r do not enter any character \r");  goto lab;} }
int weight = 3600;
for (int ii = 0; ii < www; ii++) {t = t+(weight  we[ii]);
weight = weight / 60;  }
devicE[j].time1=devicE[j].time = t;
yy.AppendText("\r " + devicE[j].nickname + " time was
changed\r"); }   else
yy.AppendText("\rinvalid input use H:M:S \r");
lab:   yy.AppendText(" ");  }
```

2.11 Smart House Power Management Graphical User Interface

The graphical user interface of the peak shaving power management system consists of four panels, each one of them supports system control and/or monitoring.

A. System Monitor Panel

The system monitor panel provides basic information for the user about how much watts the house consumes, consumed current, total cost for the consumed power, watt/hour power consumption, current time and date, current battery charging percentage and the indoor/outdoor temperature using lm35 sensors and form Internet Yahoo Weather RSS Feed, Fig. 7 shows the system monitor panel.

B. Applications Configuration Panel

The application configuration panel enables the user to control the house applications, switch the application to on or off using the RUN/STOP button, pause and resume them using the PAUSE/RESUME button and this property works for the running applications only and if the user clicks it to pause a stopped application, operation will be canceled and the system will provide a notification that notifies the user that the device is currently stopped, Fig. 8 shows the flowchart of this property.

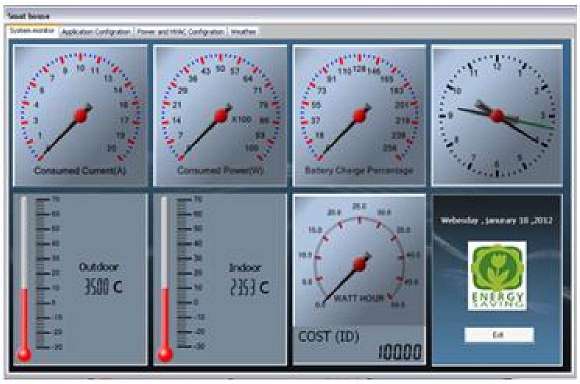

Fig. 7 System monitor panel

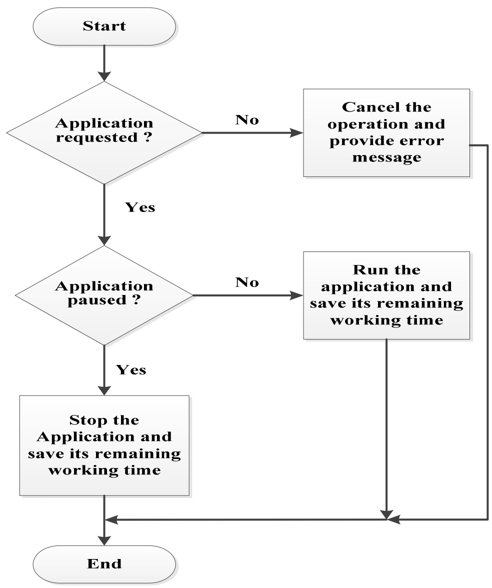

Fig. 8 Flowchart of pause/resume property

The user can enforce an application to run if it is in the hold state by changing its priority to zero, which is the highest priority, using RUN-IT/STOP button. This can be provided for the applications in the hold state only and can be used once at a time. Fig. 9 shows the flowchart of this property. The applications can start automatically by setting its starting time, each application can take its own starting time from the user, starting time takes the format (hour: minute). In addition to the starting time, the application must run for a specific time period, each application can take its own working time of the format (hours : minutes : seconds), if no time period was given, the application runs on the last given working time and if started for the first time the applications run on their default predefined start time. The configuration panel (shown in Fig. 10) provides the current progress, remaining operation time (in seconds) and the starting time for each application. The application status is also provided. Finally, for the application power, the user can choose the application power or use the default power.

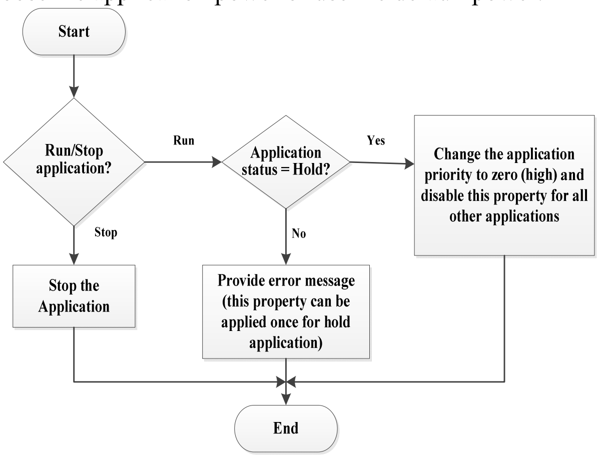

Fig. 9 Flowchart of force/stop property

Fig.10 Application configuration panel

C. Power and Air Conditioning Configuration Panel

The panel enables the user to choose how much watts will be drawn form the grid and the price of the electricity. The battery options also included in this panel with three options: (1) “Don’t use the battery” option, which is automatically activated when the battery charging percentage is dropped below 20%. (2) “Add it to the power” option, which adds the battery power to the grid (it chooses an applications to operate on the battery power while the other applications operate using the grid power, the two power sources are independent). (3) “Use battery instead of grid power” option, in this case, the used power from the grid will be zero. The supplied power to the house will depend on the battery power only. Also, from this panel, several settings can take place for the high voltage air condition configuration, for the maximum and minimum temperature configuration, and for the starting and working time adjustment.

The user can choose the scheduling algorithm. The user can use priority and least power or priority and least time or least time or least power. The priority scheduling deals with the application according to its importance to the user, the least time deals with the application according to its working time so that a maximum number of application can accomplish its job within a minimal time period. The power scheduling deals with the applications according to its power consumption to achieve power saving by shifting these applications to the night which has a low power consumption and low electricity price.

The implemented system makes notifications to provide messages for any activity or error that is caused by the user in order to make the system more interactive. Fig. 11 shows power and air conditioning configuration panel.

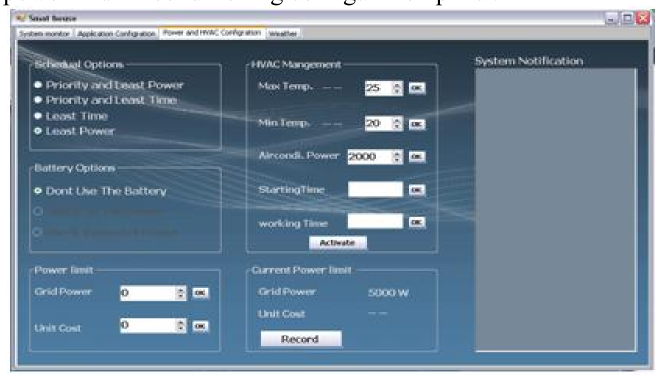

Fig.11 Power and air conditioning configuration panel

The button “Record” (in the power panel) provides a real time graph to show the consumption of the power and the needed power in order to activate all the requested applications. The graph provides a record for one day only. The user can clear the record and start a new one. Fig. 12 shows online power consumption recorder output.

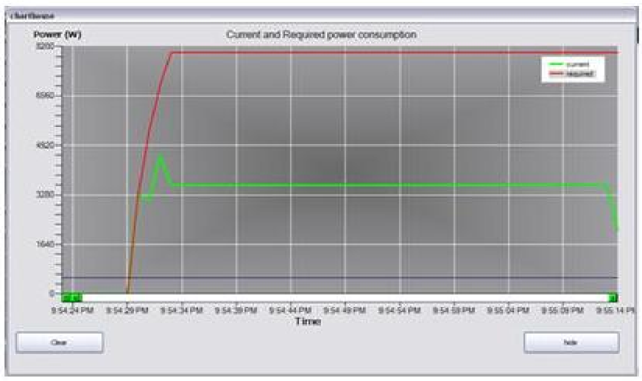

Fig.12 Online power consumption recorder output

D. Weather Panel

Weather is the state of the atmosphere, to the degree that it is hot or cold, wet or dry, calm or stormy, wind speed, visibility, barometer, sunrise and sunset, clear or cloudy. Weather refers, generally, to day-to-day temperature and precipitation activity, whereas climate is the term for the average atmospheric conditions over longer periods of time. When used without qualification, "weather" is understood to be the weather of Earth. In this paper, weather forecast is taken from Internet Yahoo weather forecast. The user can select his city to see its weather. This panel is useful for managing renewable energy resources (solar and/or wind). Fig. 13 shows the weather panel.

Fig. 13 Weather panel

RESULTS AND DISCUSSION

- The algorithm has been implemented successfully for five house applications with one air conditioning and storage battery using Visual C# language. Although the predefined priorities of the applications are static, the algorithm can ensure a high level of conformance and energy saving. Providing of the extra controls like pause and resume, enforcing to run, adjusting starting time, working time, remaining time, application power and air conditioning management makes the system more flexible for residual conformance.
- Energy management reduces the load on the national grid or the local generators in the rural areas.
- The setting of the starting time enables the user to do a work even when there is no one at house, thus the resident can enter the starting time for each application and go to his work and when he comes back to his house, he will find that the required tasks was finished.
- One of the system fates in the implemented system is that there is no actual feedback about the status of current electricity condition, its frequency, its voltage. Also, there no feedback about the applications actual power consumption and condition, is it gammed?, is it disconnected from the network? or is there any failure on the grid or in the network?.
- Another minor glitch is that the algorithm performs two searches, the first is to shutdown the low priority applications when there is no enough power, and the second is to search for a low priority application that the residual power is enough to operate it.
- The smart house energy management affects the resident behavior, thus the resident could feel gradually that his daily life at the house is getting better.

SUGGESTIONS FOR FUTURE WORK

- Design a system that includes a feedback about the grid electricity and applications conditions in order to take into account their effects in the overall system performance.
- Include the light control on the energy management system for the indoor and the out door.
- Build a smart algorithm that adapts itself according to the resident behavior so that the application priority fits what the resident needs or study the behavior of the application usage time for the house and build the algorithm according to it.
- Use smart and modern house applications that have low energy consumption.

ACKNOWLEDGMENT

I wish to acknowledge Mr. Ali Hameed M. Hamza for his efforts in completing this project.

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