Smart Home Energy Management

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Multi-Agent Systems

***Abstract*—In recent years, agent-based technology has become a powerful tool for various applications. One among them is the *smart grid* in which *multi-agent systems (MAS)* play a major role. The smart grid consists of controls, parts, computers, power lines, and new technologies and equipment working together to make electrical grid respond to the quickly changing electricity demand. Energy savings and user comfort are the two major design considerations for the smart home energy management system. In MAS based smart home energy management systems, every home appliance acts as an autonomous agent and the agents communicate in such a way to reduce overall power consumption in the smart home. In this paper, Multi-agent based smart home energy management systems were evaluated.**

Keywords—Multi-Agent Systems; Smart Grid; Consumer Electronics.

I. INTRODUCTION

Global warming has been the biggest threat to the earth from the past few decades. Increase in the electricity consumption increases the CO_2 emission which is one of the main reasons for global warming [1]. Major home appliances account for about one-fifth of electricity consumption in the United States. As a result, it is important to reduce the power consumption by home appliances in order to control global warming. Other factors such as the economy, health, and safety will also depend on efficient delivery of electricity [2]. However, home appliances are an important part of any household. Therefore, smart strategies are needed to control the power usage by home appliances.

It is evident that different home appliances such as refrigerators, microwaves etc. consume different levels of power and create demand differently. The cost per unit is also more during peak times which is a concern for the customers [3]. For some households, using energy outside peak times may be an effective way to reduce energy costs. Due to the dynamic electricity pricing, the traditional building control strategies are no longer sufficient to reduce electricity consumption. A smarter, more efficient, and intelligent energy management system is therefore required.

Smart grids will play an important role in the near future delivering electricity ranging from industrial, commercial to residential zones in an efficient and reliable manner. Smart grids use a variety of appliances such as smart digital meters, renewable energy resources, automated feeder switches, and batteries to store excess energy. These technologies are already in existence in other areas such as manufacturing and telecommunications and are being adapted to smart grid operation [4]. Smart Grid enables two-way digital communications between utilities (supply) and common house hold devices (demand). Figure 1 shows the architecture of a smart grid.

Smart homes which use the concept of Smart Grid [5] has been introduced to reduce energy consumption during peak times and shift the load to off-peak times. Smart homes comprise multiple interactive autonomous agents which monitor power demand and supply in a household. Agents in a smart home communicate with each other in such a way to offload some of the power usages to off-peak times of the day.

A Multi-Agent System (MAS) is a computerized system composed of multiple interacting intelligent autonomous agents. Smart Grid literature shows a way to implement Smart

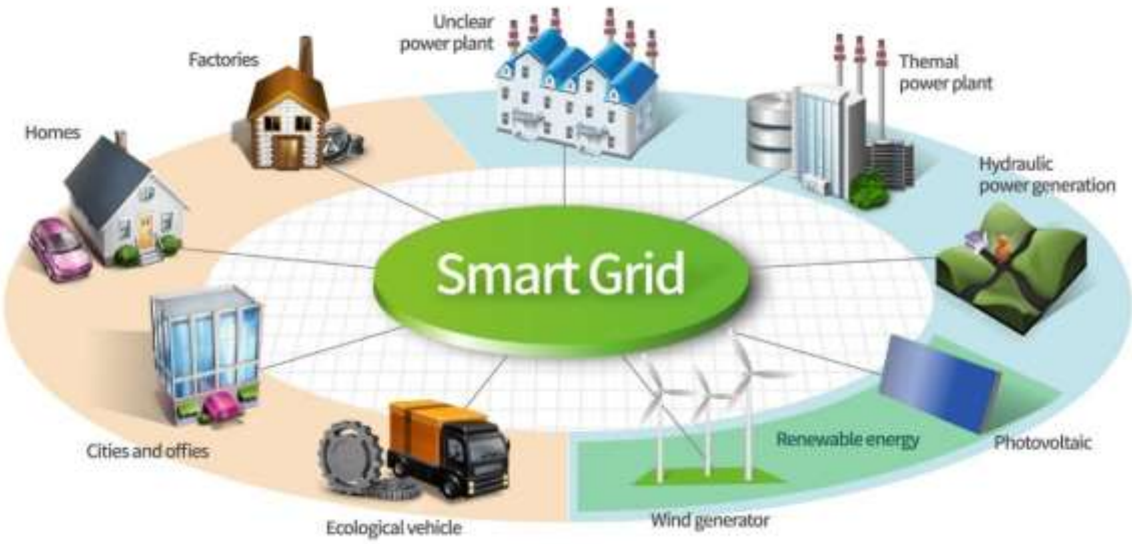

Fig. 1. A Smart Grid

Home energy management System using agent-based technology [6]. Multi agent systems consist of agents and their environments. An agent refers to either a software or hardware. Agents communicate, coordinate and negotiate with each other. In this study, Multi-Agent systems' approach was used to Smart Grid application.

II. Related Work

A lot of research is currently being perceived to reduce the energy consumption in households. The existing approaches reduce electricity by directly controlling the devices used by the consumers (i.e. automatically switching off high load devices such as air conditioners based on occupancy), or forces customers to follow certain practices that prevent peak time use of electricity.

ZigBee home network systems in [7] use a sensor network-based smart light control system for smart home energy management. Zigbee was also used to build an active sensor network-based home control system to efficiently manage home control tasks and devices [8]. In this study, they have extended the smart light control to other home appliances as well. The *home automation/energy management system (HAEMS)* [9] sends optimal control actions to the thermal smart devices based on the information it receives about the task operating status, usage requests, and network signals. The system uses multi objective mixed integer nonlinear programming model to generate the control actions. The objectives that were considered during optimization were operational cost, user's convenience rate, and thermal comfort level. Systems like *POEM: power-efficient occupancy-based energy management system* [10] control *Heating Ventilation and Air-Conditioning (HVAC)* systems based on occupancy levels. POEM uses *OPTNet*: wireless network of cameras and *BONet*: wireless sensor network of PIR sensors. The output from both OPTNet and BONet is used to estimate the actual occupancy. However, the transmission errors in the camera were not addressed and there was a considerable amount of delay to ramp up the HVAC system. Other systems also use cameras, motion and audio sensors, and RFID to analyze human behavior on a daily basis and optimize the home energy management.

III. Proposed System

References [11], [12] implements distributed Multi-agent based smart home energy management system. This paper demonstrates and simulates a simplified model of MAS based architecture for optimal energy usage.

The important module in MAS based architecture is "*Home Energy Management System (HEMS)"* module. HEMS is a computer-aided software tool, which observes the home power generation and storage capacity and sells it to Main Grid if possible. In addition, HEMS monitors the electricity transmission and optimizes the electricity demand based on customer needs.

Home Energy Management System (HEMS) is further classified into *Supply side Management* and *Demand side Management* modules. Supply-side management module takes care of charging and discharging of power in storage and communication with the main grid when storage power is not sufficient. Renewable energy sources like solar power, wind power along with main grid comes under Supply-side management system. Functionalities of Supply-side Management module includes start-up, shutdown and recovery decisions of power plants based on various constraints like the weather. The supply-side management module is more adaptive to add or remove power generators.

Moving towards the smart energy management will require changes not only in the way energy is supplied, but in the way it is used, and thereby reducing the amount of energy required to deliver various goods or services is essential. One of the most essential factors to be considered to deliver various goods or services is to reduce the amount of energy required. If we want to shift towards smart energy management, we will have to bring changes to the way energy is used and is being supplied. Demand side management is another important module in HEMS. The main objective of Demand side Management module is to reduce electricity demands during

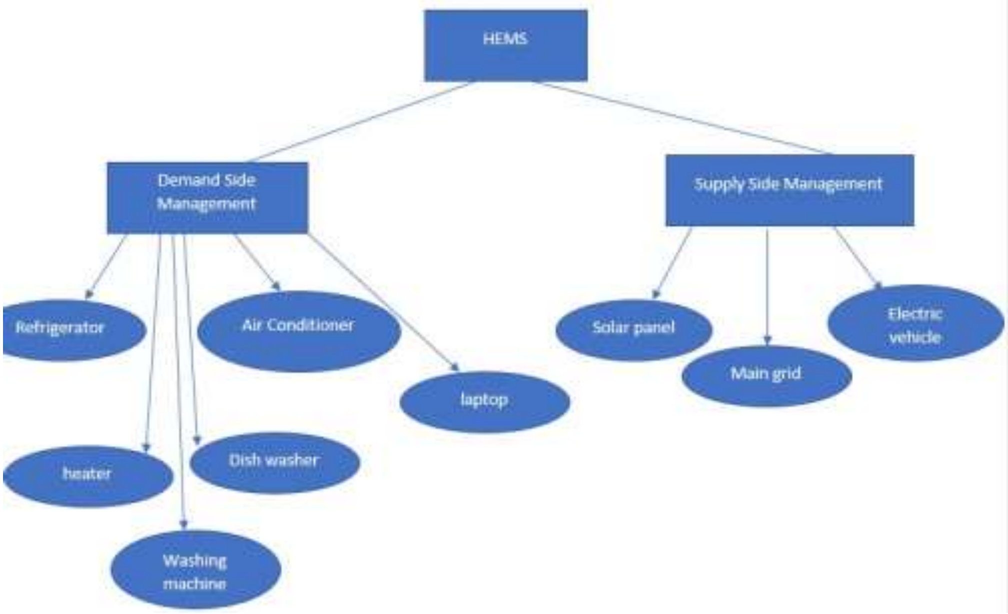

Fig. 2. MAS based smart home energy management system architecture.

TABLE I

HOME APPLIANCES AND THEIR POWER CONSUMPTION PER HOUR (IN WATTS) AND HOURS USED PER DAY

Appliance	Consumption(Watts per hour)	Hours used per day
Hair dryer	1500	0.16
Dish Washer	1800	1
Clothes Washer	1000	0.5
Clothes dryer	5000	0.5
Refrigerator	180	24
Vacuum cleaner	1400	0.16
Air conditioner	3500	3
Desktop Computer	100	6
Oven	2400	1
22 inch LED-backlit TV	30	5
Microwave	1200	0.5
Water Heater	4000	3
Ironer	1100	0.25
Incandescent Light Bulb	60	5
Toaster	1200	0.20
Fan	75	3
Laptop	60	6

peak hours and to shift the load to off peak hours. In other words, Demand side management module helps consumers to save cost per unit by reducing electricity consumptions during peak hours. Figure 2 depicts the proposed distributed Multi-Agent based control architecture for smart home energy management system.

IV. SIMULATIONS AND RESULTS

The model demonstrates how to reduce electricity usage during peak hours thereby reducing electricity usage cost. In MAS based smart home energy management system each home appliance acts as an autonomous agent. An Agent could be either software or hardware to control energy management system. HEMS initiates both Demand-side Management and Supply-side Management Agents with its capacities and priority values. Agents communicate their power consumption in watts, priority set by the user, schedule time and time taken to complete the task with each other. Agents communication plays a crucial role in reducing overall power consumption in the smart home energy management system.

Data

1) Table I provides various home appliances, power specifications and average time in hours the home appliances are used per day in any household.
2) This simulation model assumes peak hours are from 8:00 A.M to 9:00.P.M.
3) In addition, Electricity usage cost per unit (KWH) during peak hours is 0.12$ and 0.08$ during off-peak hours respectively.
4) Priority values are manually set up by the user via user interface.
5) Renewable energy resources like solar panels set up and

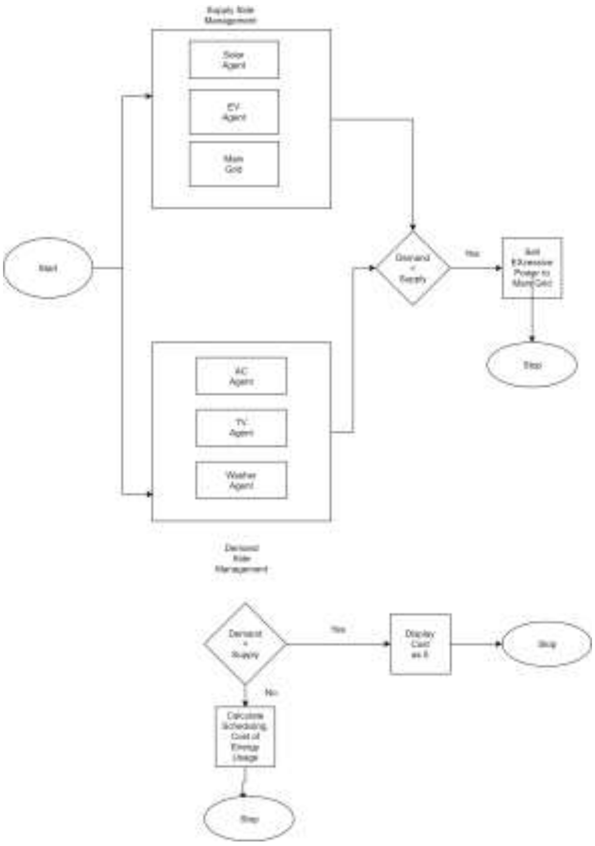

Fig. 3. Steps involved in scheduling and cost estimation in supply-side management module

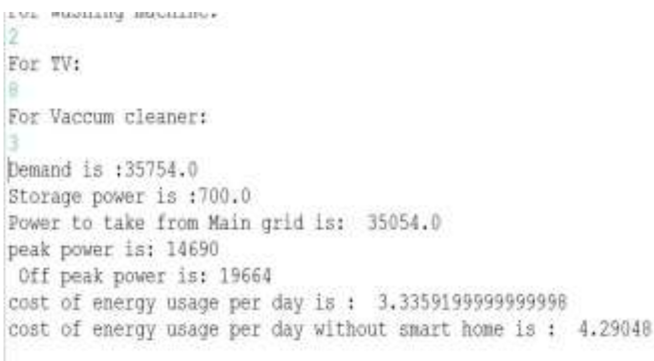

Fig. 4. When electricity demand greater than electricity supply.

TABLE II
EXPLANATION OF OUTPUT FIELDS

Output field	Explanation
Demand is	Total power required by the home appliances
Storage power is	Total power generated in smart grid
Power to take from the main grid	Demand-storage power
Peak power is	Power consumed during peak hours
Off-peak power is	Power consumed during off-peak hours
Cost of energy usage(With smart home)	Total electricity cost per unit
Cost of energy Usage(without a smart home)	Total electricity cost per unit without smart grid

installation costs are not considered in this simulation.

Figure 3 shows the flow chart behind the simulation program. Electricity supply is adjusted based on electricity demand in the smart grid. The algorithm tries to offload the appliances demand to off-peak hours based on their priority.

V. RESULTS AND DISCUSSION

Various simulations were run with demand greater than supply, demand equal to supply and demand less than supply. Figure 4 depicts the simulation results when demand was greater than supply which is the main component of Smart Home Energy Management System. Table II provides details of output fields and their explanations.

A. *Cost Analysis*

Figure 5 represents cost saved per annum on y-axis and number of smart home appliances on X-Axis. From the figure we can clearly see that cost saved per annum is directly correlated to number of home appliances keeping renewable storage power constant.

Figure 6 shows cost saved per annum on Y-axis and storage power on x-axis. From the figure we can conclude that as the storage power increases cost saved per annum also increases.

B. *Agent Communication*

Agents negotiate with each other in order to get a required schedule. Agents with the highest priority are scheduled immediately and agents with the lowest priority are scheduled later or during off-peak hours. Agent communication plays an important role to minimize the energy usage during peak hours and maintains user comfort. Agents might miscommunicate about their power usage or priority or time required to finish a task.

Various simulations are performed on different types of agent's miscommunication protocols. For example, if a dishwasher agent miscommunicates its priority value, then the agent gets an immediate schedule which might be scheduled during peak hours. On an average, a dishwasher takes 1 hour to complete the task and the average power consumption is 1800 watts per hour.

Cost of energy usage if dishwasher agent schedules during peak hours:

Cost1 = (1800/1000)*0.12 = $0.216 per day (78.84 per annum)

Cost of energy usage if dishwasher agent schedules during off-peak hours (if there is no miscommunication):

Cost2 = (1800/1000)*0.08 = $0.144 per day (52.56 per annum)

There is an extra charge of 26.28$ because of dishwasher

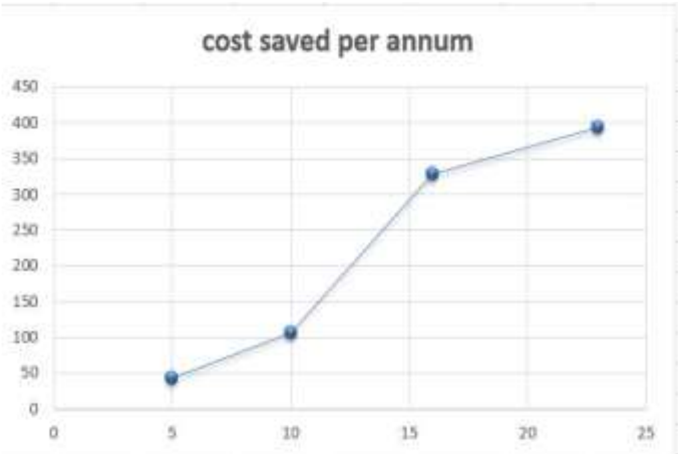

Fig. 5. Cost saved per annum when the number of appliances increases

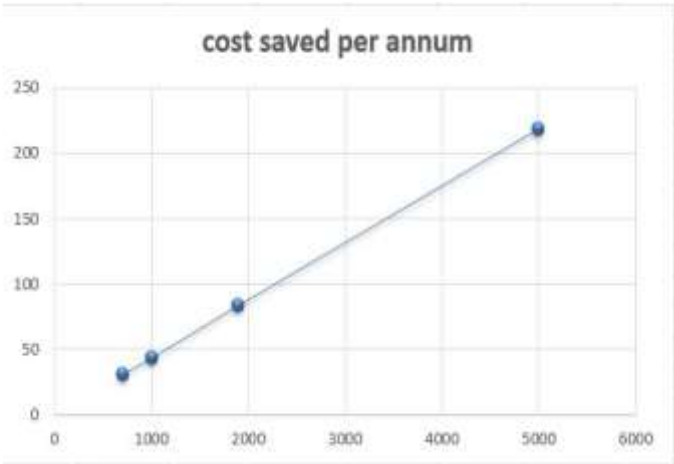

Fig. 6. Cost saved per annum when storage power is increased.

agent miscommunication. Another example: If the heater or air conditioner miscommunicates about its priority value and bids the lowest priority value. Then heater tasks are scheduled during off-peak hours which might cause discomfort to the user. If an agent miscommunicates its power consumption or time to finish its task, then the agent might run into another agent's schedule which might put an extra load on the Main grid.

VI. FUTURE WORK

In the current scope, simple MAS based energy management system is presented and evaluated to reduce the cost of energy usage during peak time. All the calculations are based on reduction of cost for energy consumption. The user comfort level for scheduling the tasks at different timings has not been considered in the calculations. Hence, the future work for this project can be performed by extending this work is to consider user comfort and also various parameters which affects user comfort.

VII. CONCLUSIONS

In this paper Multi-Agent based (MAS) architecture for smart home energy management has been proposed and evaluated. Also, developed a dynamic price model and a home energy management system model. Various simulations are performed with and without smart home energy management system and costs are calculated respectively. From the simulation results, an average 50% of energy cost is saved per annum.

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