Intelligent Multi-Agent System for Smart Home Energy Management

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***Abstract* - Smart grid literature shows a potential way to implement smart grid using Multi-Agent System (MAS) which is a distributed computational intelligence technique that comprises of multiple interactive intelligent agents in an environment. This paper presents an application of MAS technique for improving the efficiency and optimizing the energy usage of smart homes. The smart appliances in a smart home are modeled as agents and optimization algorithms are used in decision making of the agents. These agents work together to reduce energy consumption while striking a balance between consumers comfort, energy cost and peak energy saving in the distribution grid. Such a way, a Home Energy Management System (HEMS) was designed and developed using MAS. This research enables smart homes to communicate, interact and negotiate with energy sources and devices in smart homes that achieve maximum overall energy efficiency and minimum electricity bill. Simulation studies carried out on the developed MAS have shown that it has the potential to provide the optimum solutions. How MAS communication influences on decision making of the agents and getting the optimum solution is also demonstrated in this paper.**

***Index Terms* -- Smart grid, Smart home, Multi-agent system, Demand side management, Supply side management, Optimization, Electricity bill**

I. INTRODUCTION

In the current society, electricity is one of the most important forms of energy. As electricity is generated from burning fossil fuels, increase in consumption of electricity is one of the leading factors for global warming and tremendous climate changes. These problems can be minimized by decreasing the amount of electricity consumed, and it can be done by optimizing the electricity consumption.

Generation, transmission, and distribution are three main sectors of the power industry. Production of electricity is a process that is often used to cater electricity for industrial, commercial, residential and rural customers. Generators such as gas turbine, steam turbine, diesel engine and nuclear power plants all operate on magnets with copper wire, and motion equals to electric current. Electricity produced via different types of generators was known to be the same irrespective of the source of energy. Generation of power is often done at power stations. Typically, power plants contain generators located at the center [1]. Electric power transmission is a process where electrical power is transferred in bulk form from generation to distribution. It normally goes through substations where transform of high voltage to low voltage or the reverse do happen. In such cases, different voltage levels can be observed at different substations. When transmission lines are interconnected, it becomes transmission networks [2]. At the final stage, electricity is delivered to end users. This is done via power distribution system network which carries electricity from high voltage transmission system to end consumers. Such distribution process is all encompassed to ensure electricity are delivered to all consumers [3]. All this structure makes up the electric power grid.

This project is about the interaction between automatic energy management of a smart home and a smart grid to achieve smart power distribution that brings high efficiency and sustainability to the system. The project sets out to realistic design and development of ICT (Information & Communications Technology)-enabled collaborative technical and commercial architecture for smart homes in Singapore. Smart homes are one type of fundamental units of smart grid which is a modernized electrical grid that leads to much efficient and reliable distribution of electricity. This would help creating a more productive environment for the use of electricity [4]-[6].

Multi-agent system is a computational intelligent technique which shows its potential to implement smart grid [7]-[18]. This technique comprises of multiple interactive intelligent agents in an environment. An agent is a software or hardware entity that can respond to changes in an environment.

Implementation of multi-agent system for energy management of smart homes allows consumers to check the amount of energy used through electronic meters or smart meters, and able to solve problems when it occurred. The monitoring and controlling functions are known as SCADA (Supervisory Control and Data Acquisition) with optimizing function referred as "advanced applications" would help to ensure the network is not overloaded due to over usage of electrical appliances.

The remaining paper is organized as follows: Section II presents background information about this project. Section III explains the proposed control architecture for smart homes. Section IV describes the proposed MAS architecture for smart home energy management. Section V provides simulation results and discussion. Finally, the paper is concluded in the section VI.

II. BACKGROUND INFORMATION

Energy Management System (EMS) is a computer-aided system or software tool used to monitor, control and optimize functionalities of electricity generation, transmission and distribution. Supervisory Control And Data Acquisition (SCADA) is the system used to monitor and control, the optimization function is often known as "advanced applications".

Supply Side Management (SSM) also known as Generator Scheduling is a function of EMS. It schedules power production from various generation units over a time spectrum while considering the constraints of the generators and systems. Objective functions of SSM include costs associated with energy productions, start-up, and shut-down decisions and lastly predicted profits which in turn results in large-scale nonlinear optimization problems.

Modern distributed power systems consist of multiple distributed generators, thus increasing the number of generators units. Due to the increased number of generator units, the SSM problem would also grow and hence the time needed to compute the issues will be excessive. In this case, due to the modern restructured environment, improvement in SSM problems solution would result in significant changes to the system. Therefore, it plays an important role in the EMS [19, 20].

A perfect balance should be achieved in the aspect of a safe and efficient electricity grid. Schweppe et al. mentioned the reasons for why the demand for electricity should be made more adaptive to supply conditions [21]. It was renowned that with lower demand, it would result in cheaper production and longer term contracts thus resulting in a more effectual grid at lower prices.

Demand-Side Management (DSM) is another important function of EMS. It is used to reduce electricity consumptions and promotes electricity efficiency for the end-users. Other than increasing electricity demands during peak hours, consumers are benefitted through cheaper cost for using electricity during the off-peak hours. In other words, DSM helps consumers to save cost and using electricity more efficiently.

The existing approaches to reduce electricity demand have been limited to either directly controlling the devices used by the consumers (i.e., automatically switching off high load devices such as air conditioners at peak times), or to providing customers with tariffs that prevent peak time use of electricity. Thus with the disposition of smart meters, it is possible to make immediate calculation on the amount of electricity consumption, providing every home, every commercial and industrial consumer with the capability to spontaneously reduce load in response to signals from the grid.

The key to Artificial Intelligence (AI) [22] challenge in demand-side management would be the designing of automation technologies for heterogeneous devices where it learns to adjust energy consumption against real-time price signals when challenged with uncertainty in predictions of future demand and supply.

III. PROPOSED CONTROL ARCHITECTURE

Fig.1 depicts the overall picture of the proposed multi-agent system. Home Energy Management System (HEMS) was further divided into two major parts based on functionalities. These are Demand Side Management (DSM) and Supply Side Management (SSM).

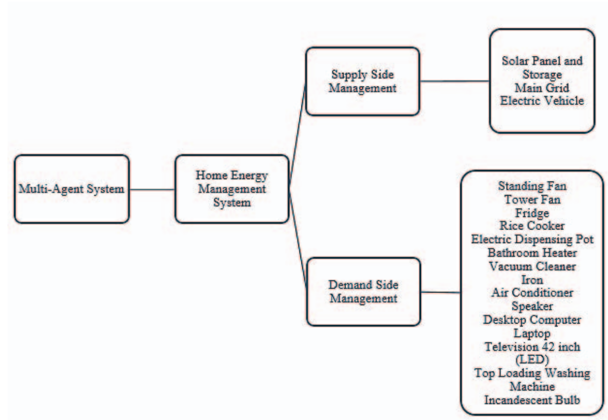

Figure 1. Proposed multi-agent system

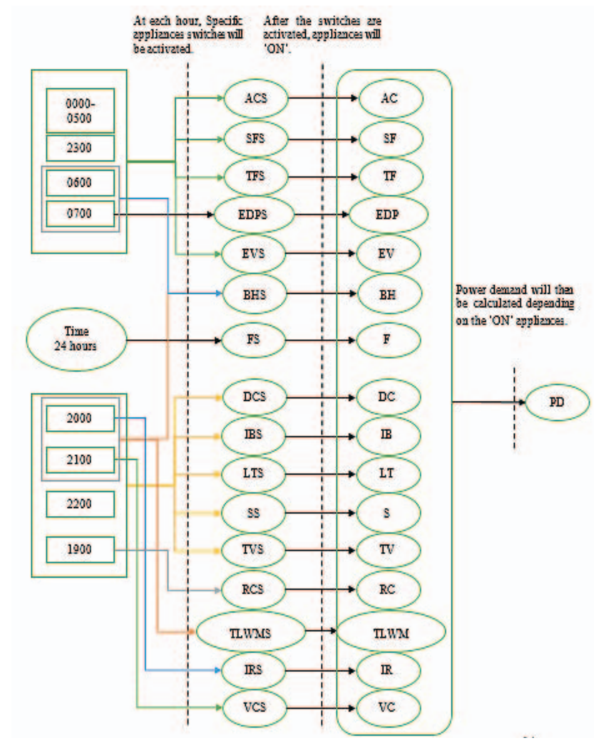

Figure 2. Proposed demand side management architecture

Fig.2 shows the flowchart that was designed to facilitate appliances for different hours or period of the day. The DSM controls appliances in terms of priorities via level of importance, limitation of power consumption on each hour or day and limitation of costs per day. For example, priority of fridge would be the highest as it cannot be turned off due to preserving of foods and other miscellaneous product.

Fig.3 shows the flowchart of the algorithm behind smart home energy management system. The idea was handling the usage of excessive power when there is more power or handling the shortage of power when there is insufficient power. It shows the way of adequately using power with conditions on the amount that solar panel can yield and the demand

SSM helps to optimize energy usage across main power grid (MG), electric vehicle (EV), solar panel and energy storage. For example, if the storage has enough energy to provide the power demand of the household, it would use the energy from the Storage instead of buying from the main grid.

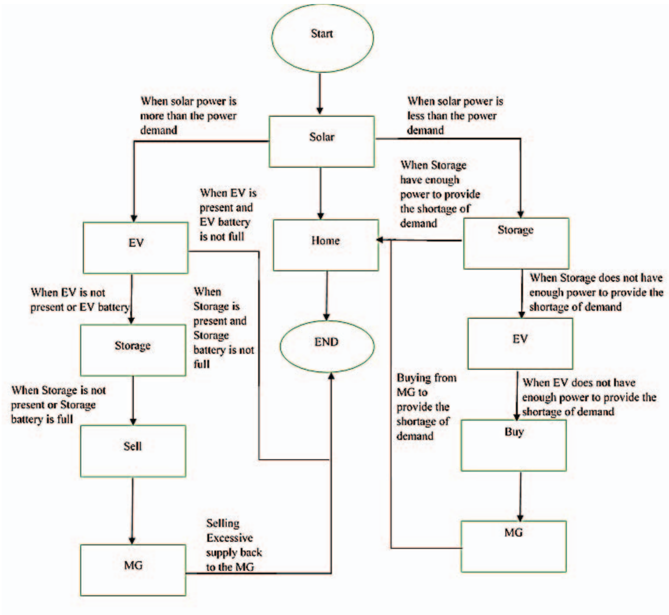

Figure 3. Flowchart for supply side management (SSM)

IV. PROPOSED MULTI-AGENT SYSTEM

Table I provides the major agents in the multi-agent system. SSM agent manages power flow from the electrical supply systems. DSM agent manages the power flow to the home appliances. HEMS agent manages the SSM agent and DSM agent.

TABLE I. MAJOR AGENTS IN THE MULTI-AGENT SYSTEM

Management Agents	
Home Energy Management System	HEMSAgent
Demand Side Management	DSMAgent
Supply Side Management	SSMAgent
Electrical Supply System Agents	
Solar Panel and Storage	PVSystemAgent
Main Grid	MGAgent
Electric Vehicle	EVAgent
Home Appliance Agents	
Standing Fan	SFAgent
Tower Fan	TFAgent
Fridge	FAgent
Rice Cooker	RCAgent
Electric Dispensing Pot	EDPAgent
Bathroom Heater	BHAgent
Vacuum Cleaner	VCAgent
Ironer	IRAgent
Air Condition	ACAgent
Speaker	SAgent
Desktop Computer	DCAgent
Laptop	LTAgent
Television 42 inch LED	TVAgent
Top Loading Washing Machine	TLWMAgent
Incandescent Bulb	IBAgent

The above hierarchical system allows smart appliances and agents to have a designated communication. The decision marking of agents have been implemented with optimization algorithm. The hierarchical system would also help to control or manage overall smart home management easy so that it has flexibility upgrade the system if it is necessary.

When agents are launched and initiated, it executes the threads to start its capacities, load requirements, and bids for obtaining data from the database.

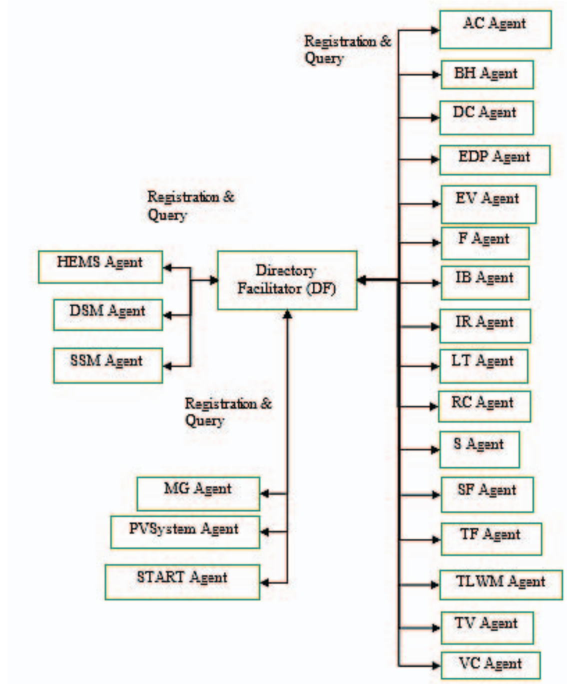

Figure 4. Registration and query of agents

After all agents are initialised, as shown in Fig.4, each agent would register with Directory Facilitator (DF). Agents would then query the DF for agents and its services in the networks with certain search constraints which usually types of services or agents names. DF would respond with a list of agents and its physical addresses that matches with the search constraints.

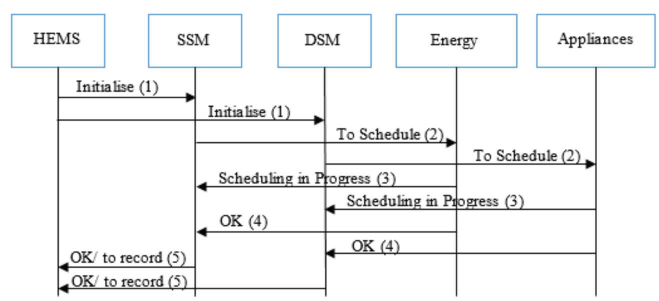

Figure 5. Interaction of agents

As shown in Fig.5, energy and appliances block diagram are represented in Table I. It shows the communication between the agents in Fig.4. The HEMS agent will initialise SSM agent and DSM agent. SSM agent would then request from energy agents, and DSM agent would request from appliances agents for the schedules.

V. SIMULATION AND RESULTS

As shown in Fig.6, it shows the communication between the smart appliances by sending information like “REQUEST”, “INFORM” and “CONFIRM”. The communication was implemented as per Fig.2.

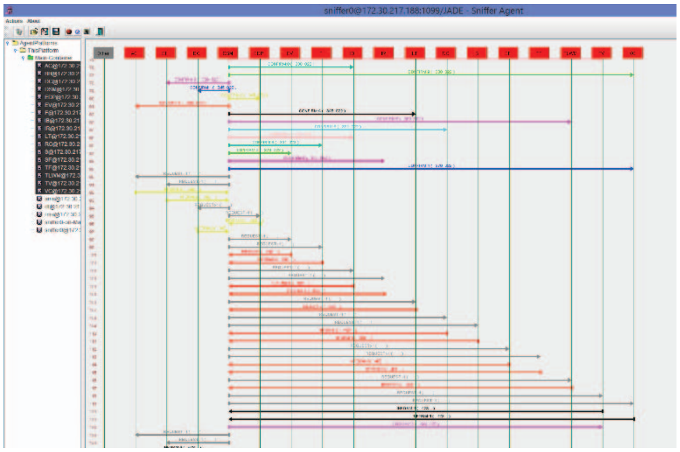

Figure 6. Communication between appliances and DSM agent

Fig.7 shows how Supply Side Management (SSM) agent manages and communicates with the power supplies. The communication was implemented as per Fig.3.

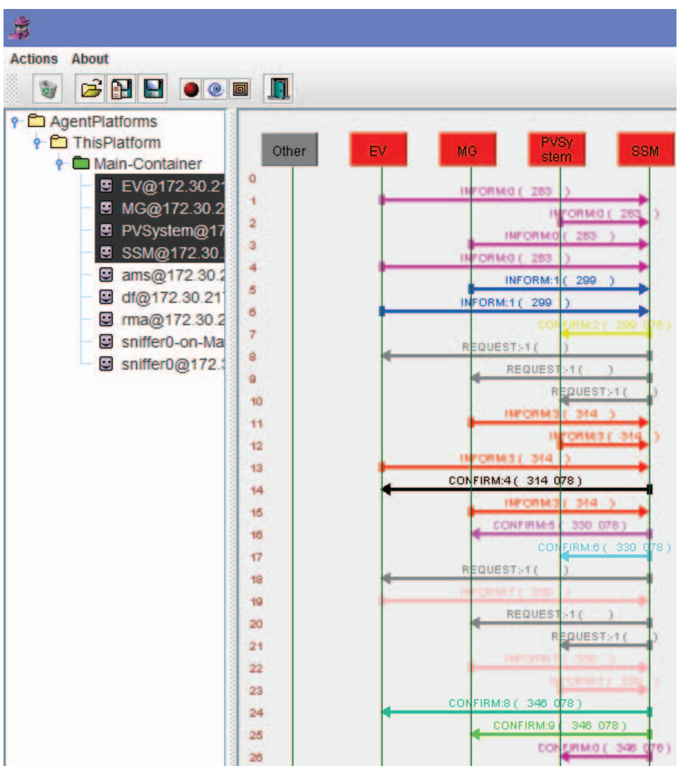

Figure 7. Communication between power supplies and SSM agent

As shown in Fig.8, it shows the communication among the home energy management system agent, supply side management agent and demand side management agent. The communication was implemented as per Fig.5.

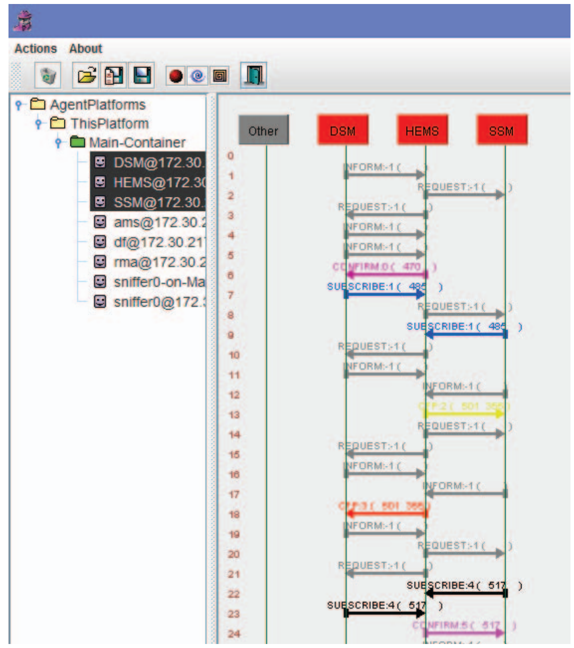

Figure 8. Communication between SSM agent and DSM agent in HEMS

Fig.9 show the overall communication of the multi-agent system for this project. It shows the types of information sent during the communication and the procedure of the process. The communication structure was implemented based on Fig.1.

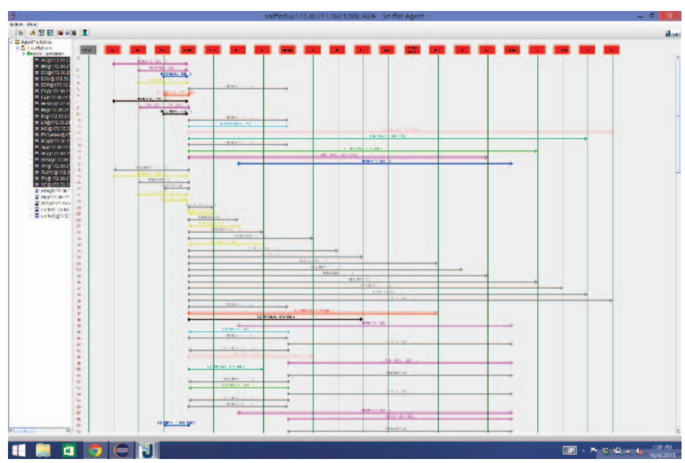

Figure 9. Communication in the overall multi-agent system

Multi-agent system simulation studies show the creation and registration process of the agents for this project. It had also established a type of communication between agents. The communications involve ACL message that allows the message to set performatives like “REQUEST”, ”SUBSCRIBE”, ”CONFIRM” and “INFORM” as information will be sent base on the type of request.

Fig.10 shows the simulation study was carried out on the DSM agent to understand the amount of power demand (PD) for each hour in a day. With the power data, it enables the estimation of electricity cost over the stipulated time frame.

TABLE II. DESCRIPTION OF SSM SIMULATION

Name	Description
Power Distribution	
Demand	Demand Power From Appliances/HDB
Supply	Supply Power From Main Grid
Storage Status	
Storage	Current Storage capacity
Full Storage	Full Storage capacity
Storage charge	Power charging of Storage
Storage discharge	Power discharging of Storage
Electrical Vehicle(EV) Status	
EV	Current EV capacity
Full EV	Full EV capacity
EVC	Power charging of EV
EVD	Power discharging of EV
Power Redistribution	
Insufficient power	(Demand Power – Supply Power)
Excessive power	(Supply Power – Demand Power)
Main Grid Power	When there is still insufficient power, Main grid will supply
Power Balance After Simulation	
After Storage	After Simulation, Storage current capacity
After EV	After Simulation, EV current capacity
After Excessive power	After Simulation, Excessive power value
After Insufficient power	After Simulation, Insufficient power value

Demand Side Management (DSM) simulations show the amount of power that the energy demands when appliances are switched 'ON' at different hours.

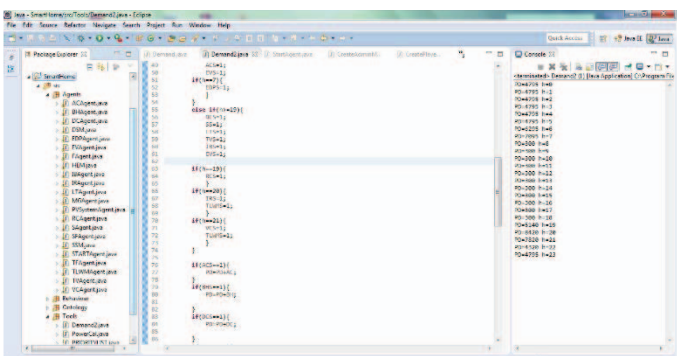

Figure 10. Implementation of DSM in JADE

Table II shows the descriptions of the name in the simulations. The following case studies show the results in different circumstances.

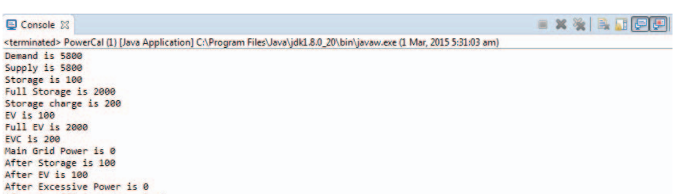

Figure 11. Simulation studies: when supply equals demand

Fig.11 shows a SSM simulation studies when power supply equates to power demand. From Fig.3, the total amount of power yielded would be supplied straight to home. This was done as shown in the simulation where demand (5800W) and supply (5800W) were equal as Fig.11.

Supply Side Management (SSM) simulation study shows when power supplied equals to demand. From the simulation, the total amount of power yielded would be directly supplied to the home demand without excessive or insufficient power.

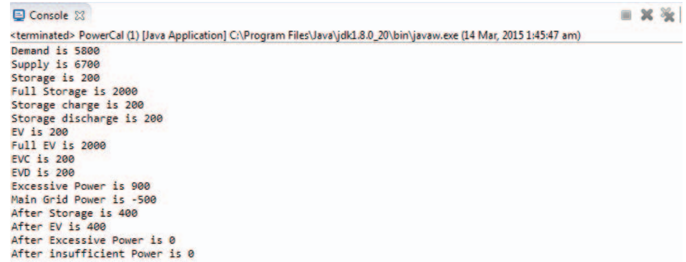

Figure 12. Simulation studies: when supply more than demand

From Fig.12, the simulations studies shows the total amount of power yielded were entirely supplied to the home with excessive power. With the excessive power, the power was directed to the EV with charging limitations. When EV is fully charged/ disconnected, all excess power was directed to the storage system for with charging limitations. After which if there is still excessive power available, then it would be sold to the main power grid.

Figure 13. Simulation studies: when supply less than demand

From Fig.13, the simulations shows the total amount of power yielded was entirely supplied to the home with the shortage. The shortage of power was then taken primarily from the storage system with discharging limitations. When the storage system is thoroughly drained/disconnected, extra power would be retrieved from the EV with discharging limitations.

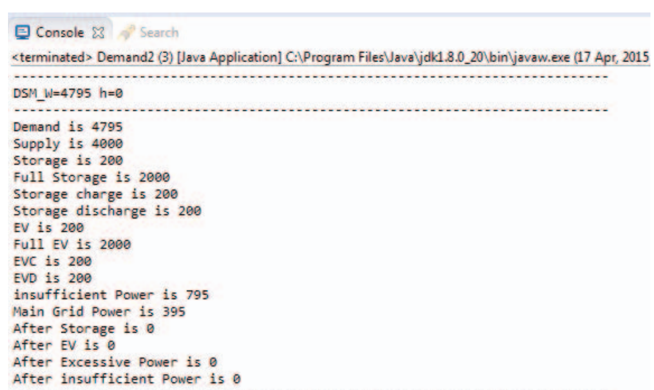

Figure 14. Simulation studies: Combination of SSM and DSM

Fig.14 shows the simulation studies of combined supply and demand side management. The structure of this algorithm is shown in Fig.2 and Fig.3. The combination of supply and demand side management will help to update and computerised the needed power for this project.

After doing the simulation studies, the multi-agent system developed has shown that it was able to provide optimum solution based on the algorithms that are used when the multi-agent system was designed. It has also shown that the multi-agent system communication has a big influence on the decision making of the agents.

VI. Conclusion

In this paper, the development of a smart home model was designed and developed using multi-agent system to have high comfort level, power efficiency and energy cost of saving of a household. A general concept of smart home energy management was developed using multi-agent system which enables smart homes to communicate, interact and negotiate with energy sources and devices in the smart home that achieves maximum overall energy efficiency and minimum electricity bill.

From the smart grid point of view, this research provides a decentralized control and management system for electrical power system which is the main characteristic of smart grid. The HEMS software would help to build a smart grid for the smart nations by providing decentralized optimization tools and two-way communication channel for the smart grid entities. Further enhancement of smart grid technique would benefit the entire power grid due to the capabilities of increasing reliability of supplies for the grid and software advancement. It would also decrease the overloading of the thermal generators in the grid with the help of renewable energy. Decentralized intelligent agents would help to increase the efficiency of communication, local and decentralized decision makings thus further enhancing the grid efficiency. Ultimately, it provides a fault tolerance and reliable control and management system.

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