SMART HOME MODEL BASED ON AN INTERACT IVE DSM DEVICES WITHIN A MICRO ELECTRICITY MARKET

P. Tzscheutschler, and W. El-Baz
Institute of Energy Economics and Application Technology, Technical University of Munich, Munich, Germany

ABSTRACT

The ongoing increase in the integration of renewable energy resources and domestic micro co-generation requires different operation and management strategies and flexible demand side management (DSM) to cope with the fluctuating resources.

A smart home model will be presented in this contribution where the supply and demand side devices interact within a micro electricity market to minimize the energy consumption and cost. The benefits and methodology of the model integration with the community and larger scale electricity markets will be explained, as well as, the applications of such model in future cities and possible model developments.

Keywords: Demands-side management, Energy Management System, Smart Home, Micro Market, Micro Cogeneration

INTRODUCTION

Demand Side Management (DSM) represents one of the many driving agents to a better integration of renewable energy resources and domestic micro co-generation. Through the DSM, several benefits can be witnessed, it can assist in shaving the peak load, increasing the electricity autonomy, improving energy efficiency and minimizing CO_2 emissions as well. Consumers are encouraged to shift their load to maintain a specific consumption pattern based on financial incentives. The load shifting can be managed manually by the consumer or through an Energy Management System (EMS). The EMS is the system connected to all the devices to communicate the information so that the device load can be shifted. Such an EMS is usually a part of what is called a 'Smart Home'.

Smart Home Concepts

Smart home concepts have been discussed by several researchers from different perspectives. In the 80s, the American Association of House Builders has seen the smart home as a home where space is being used effectively (Harper, 2003). Yet, along with the technological development, smart homes have been visualized to be functioning along with robots which do all the required home tasks. Also, due to the progress of the information and communication technology (ICT), further concepts have been developed leading to focusing on improving the household appliances' interactions with the user and having them all connected to the internet for a better user experience.

Another important concept of smart home is concerned with empowering elders or people with disabilities, especially after the noticeable increase in life expectancy due to medical advancements. The aim behind the design of this house is to improve the quality of life of those people and to enable them to choose their life style through increasing their independence and preventing occurring emergencies (Demiris & Hensel, 2008)

Definitely, the concepts, technologies, and developments of smart home could be endless. However, most of these concepts are focusing on providing the residents with more leisure time, increasing quality of life or simply to raise user comfort at the residence. But, from the perspective of the common user, smart home is always seen as a home where all the expensive devices are used. Thus, smart home concepts have been always targeting a certain sect of people. Usually, the more functions the devices can provide, the more it gets expensive except if the main function of such devices is to save money. This would enable the smart devices to be even more economical than the conventional devices over time.

Energy Management Systems

An Energy Management Systems (EMS) is one of the products that could be categorized under the section of saving money devices in a smart home. Generally, the need of an EMS to save energy, enabling renewable energies and micro co-generation is important under the current energy availability situation worldwide. Primary energy scarcity is increasing over time, several shutdowns for nuclear power plants have occurred, in addition to the increase in the user demand. All of these reasons are leading to an ongoing increase in the electricity bill and consequently, a growing burden affecting the home residents.

Common EMS are more concerned with deploying several sensors all over the house to maintain an appropriate temperature, light brightness and to monitor users' actions. They are collecting a massive amount of data about a behavior which is at the end of the day exposed to considerable doubts. Also, they are usually designed to be fitted along with specific household appliances. All these reasons didn't only lead to increasing the system cost, but also it increased the complexity of these systems installations.

Thus, an EMS should be a system that address all sects of the community and could be applied to smart homes and conventional homes. It should have a simple system that would enable it to be compatible with all kinds of household appliances. Throughout this concept, EMS would be more widely distributed and used leading to a distinguished net savings of energy and economic costs for the society.

Objective of the Paper

The main objective of this paper is to present the concept of a micro market structure within a Smart Home. Within this micro market, supply side and demand side devices interact based on the market disseminated information for the sake of reducing energy costs and consumption.

Thus, through this paper the micro market model concept will be explained, including the market players and communication signals. In addition to that, a brief will be presented about the state of the art of the current large scale electricity markets and the possibility of communication between the micro market and larger scale markets of electricity. Furthermore, an insight about the benefits and the possibility of having multiple smart homes communicating within a micro grid. Finally, a conclusion and an outlook will be presented about the further development possibilities in such smart home model.

ELECTRICITY MAKRETS STATE OF THE ART

On the level of a smart home, there were no proposals presented about creating a micro market between the supply side and demand side household devices, yet there were several proposals about electricity market mechanisms from the level of the micro grid and on. Although those market mechanisms have been designed for a higher level markets, they still contribute to the same goals of the smart home micro market. The goals behind these markets can be summarized in the following:

- Increasing energy efficiency
- Coping with the increasing renewable resources
- Reducing energy costs to the consumer

Automated Electronic Markets

Although in (Santos, Pinto, & Morais, 2012)(Block, Neumann, & Weinhardt, 2008) (Deindl, Block, Vahidov, & Neumann, 2008) each author has presented his own market mechanism, they all shared the same vision of the automated markets, where the electronic bidding agents of the micro markets i.e., market players, are continuously bidding for each time slot of the day. Also, the market supervisor is an electronic agent as well and it works on supervising the current contracts being done on the system.

The benefits behind the automated electronic markets are numerous, however to list a few would be:

- Allowing micro markets to be easily integrated and interacting with upper level markets
- Enabling bidding at any time of the day, if allowed, through the electronic bidding agents
- Enable integration of combined heat and power generation into market

Multi-Level Markets

At the moment electricity markets are already growing to regional and continental level to allow better integration of renewable energies, where the excess of energy is being sold from one place to another. Along this growth of energy markets, developments of the approaches of electricity automated market and electronic agents are being done. Several ideas have been formulated that would enable market levels integration, including micro markets. This integration shall allow not only the large players to participate in the market, but also the small players.

Thus in the paper of Santos (Santos et al., 2012) a simulation was done using the Multi-Agent Simulator of Competitive Electricity Markets (MASCEM) to show up the possibility of integration of the Continental Electricity Market, Regional Electricity Market and Micro Electricity Market. The three markets were made to be coordinating all together the energy needs and supplies.

In such a model, market negotiations processes aren’t applicable to all markets levels, so according to the market level rules, the negotiations processes are chosen.

MICRO MARKET DESCRIPTION

Overview

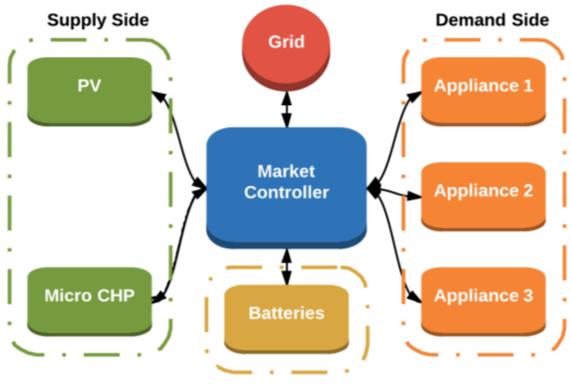

Figure 1: Smart Home Model

The micro market created within the smart home is like any common market. Figure 1 shows out the basic structure of such market. As shown, it contains a supply side that can include the internal generating devices of the smart home such the photovoltaic (PV), or a micro CHP. Also, it includes a demand side devices which includes all the possible devices that can shift their load (i.e., DSM devices) such as the washing machine, dishwasher, dryer or even the electrical vehicle. In addition to that, supply/demand side devices can be included, which sometimes purchase energy out of the market for the sake of storage and then sells it back at a later time to the market beneficiaries. Then, it comes the market controller which represents the main block that disseminates information and supervise the whole sale and purchase processes. Also, it is the one responsible for declaring the cost of energy for each hour of the day. Finally, it comes the grid which allows the import and export of any surplus or deficiency in energy

Grid Tariffs

Grid tariffs play a very important role in demand side management. If a constant tariff is presented throughout the whole day, then there will be no interest by the consumer to shift the load. Thus, grid tariffs in several countries are opting to having a Time-Of-Use tariff (TOU) or Quasi Real-Time Pricing (RTP). In this case the electricity prices are received one day a head, and the house residents pay a different price for each hour of the day (Gottwalt, Ketter, Block, Collins, & Weinhardt, 2011).

Through this TOU tariff, load shifting can be managed and the model can decide about the time of the load operation.

Market Signal

The main signal of communication in the micro market is the cost per kilowatt hour. It represents the time series of the future electricity prices. Devices act like viewers to the electricity market, and they should never be receiving a signal of operation from the electricity market. Based on the cost signal being viewed, the demand side devices start to choose the optimum time of operation within the time range allowed by the user. The devices have only to send a schedule to the market including the duration of operation, the load and the starting time. Based on this signal, the electricity market update the costs shown to the other devices. Thus, the devices know automatically through the cost signal that another device has already made a purchase in this time slot. The batteries also arrange their purchase orders based on the electricity market cost signal. It always purchases whenever the costs are low, which often means that the smart home is feeding energy into the grid. Thus, the battery uses the spread of the cost signal between different time steps to charge for a low piece and discharge for a higher price. Losses and consumption of lifetime have to be taken into account.

It should be clarified that the market cost signal is not the TOU tariff issued by the grid but rather a signal formulated based on the available supplies from the PV and the CHP, the national feed-in tariffs, electrical loads, and the grid tariff. All these inputs are sent automatically into the market controller to generate an energy cost signal for each time step.

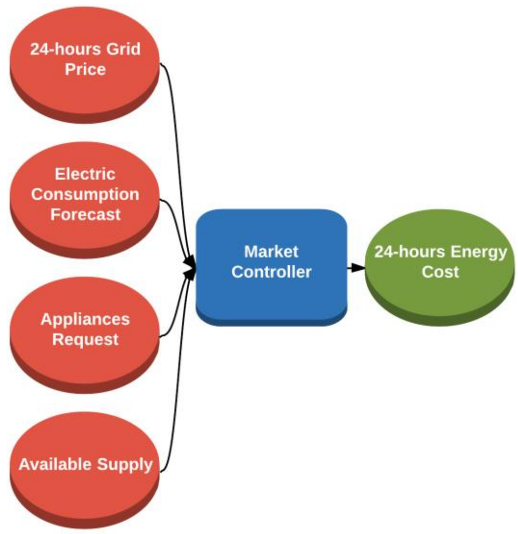

Figure 2: Market controller inputs and outputs

The signal generated by the market controller is a time-series for 24 hours, and so electrical load, PV supply and CHP supply shall be forecasted to provide an accurate cost calculation to the household appliances. More details about the possible operation strategies of the supply side devices will be followed in the upcoming sections.

The benefits behind using this market signal can be summarized by the following:

- It allows the devices to take its decision independently which would facilitate devices integration into the system
- It combines information about the electrical load, available supplies, battery status, and grid tariff in one piece of information
- It enables the system to maintain a faster communication due to small amount of data being transferred
- Manufacturers of appliances easily can integrate this scheme into their products as only the rules of the market have to be fulfilled.

DEVICES MODELS

Devices Classification

Figure 1 has shown already the basic classification of the devices as supply, demand, and supply/demand side devices. Yet, devices have a deeper classification based on its interaction with the electricity market. For the supply side, it includes the devices which have the ability to modulate such as CHP, and devices that can't modulate and should be always operating such as the PV. Also, demand/supply side system (i.e., energy storage), can be included in the smart home. Then, it comes the demand side devices which have been divided into two main categories, fully controllable and semi-controllable. The fully controllable devices are the devices which work without any user interference such as the freezer. It should be always maintaining its temperature and at the same time interacting with the market. But the semi-controllable devices are the devices which operated based on a user input such as washing machine, dish washer, tumble dryer and car charger. It should be noticed that the car charger is classified among the operationally interruptible devices as it stops charging, if the market price got high and then continues charging at a later time. All remaining devices are considered uninterruptible, because once they operate they should complete their cycle.

Demand Side Devices

Figure 3 shows out the basic inputs and outputs for a semi-controllable uninterruptible device such as the washing machine. The user has to define the earliest starting time and the latest time by which the device should end the task. Within this period, the device searches for the cheapest hours of operation by analyzing the incoming market signal and feeds back to the market an order of purchase at the specific hours of operation.

Having the device always reviewing the market signal, allows the device to change its time of purchase based on the updates coming out of the market signal at any time before the start.

Figure 3: Inputs and outputs of a household appliance

Semi-controllable interruptible devices get the same inputs represented in figure 3, yet they have the ability of dividing their operating hours over multiple hours based on the market signal provided. This is due to their ability to interrupt their operation and resume it later. Thus, such devices always feed back to the market multiple operation starting times and duration based on their own market signal analysis.

Fully controllable devices on the other side have the ability to store energy or use thermal inertia such as the freezer, the refrigerator or even the air conditioner. Such devices are always in continuous operation and communication with the market. Based on the market signal, these devices can arrange their energy storage capacity. For example, if a cooling device found out that the current market signal cost is much cheaper than the upcoming hours, it may decrease the temperature by two or more degrees Celsius to stop operation and energy consumption during the upcoming expensive hours and consequently decrease the overall operation costs. Through this technique, the average required temperature by the user will be maintained most of the time, while the operation costs will be minimized. It would be worth mentioning that such temperature fluctuation due to the use of thermal storage along with the market signal fluctuation might not be suitable for certain devices such as the refrigerator. In such case, stored food might be exposed to damage due to temperature fluctuations, yet there would be no effect on the food in the freezer due to its relatively low temperatures.

Supply Side Devices

Non-modulating devices (e.g., PV) aren't viewing the market status at all, as they will be either selling all their energy to the market or to the grid. Thus as per figure 4, they only feed in information about their availability, amount of energy that could be fed and its cost per kWh to the market. The cost proposed to the internal market is always equal to the grid feed-in tariff, as the supply device will always have the option either to supply the household appliances or the grid. The supply devices aren't allowed to sell to the market at a price higher than the grid feed-in tariff as these devices aren't looking for profit but rather the overall decrease of the energy consumption bill.

For the non-modulating devices a 24-hours ahead forecast must be available about their supply and their costs to be fed to the market controller, so that it can calculate and produce the new market clearing price for each hour and make it present to all the devices who are interested in the purchase. The forecast provided can be updated throughout the whole day so that the household appliance can take better and more accurate decision.

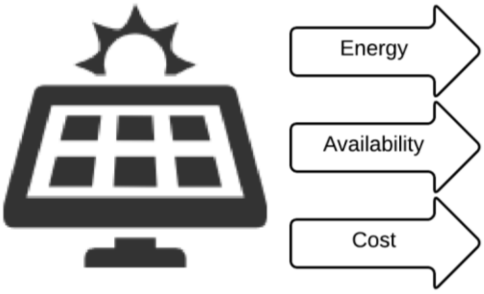

Figure 4: Non-modulating supply side devices

Modulating devices such as micro CHP systems can operate in different modes along with the market. Two basic modes of operation could be applied for micro CHPs, either an 'active control' or a 'passive control'. The active control is the control through which the micro CHP's operatipon is optimized to minimize the costs between the required electrical load and the heat load based on the heat and electricity demand forecast provided. Based on this optimization output, a 24-hour prediction is provided to the market controller to create the market clearing price. In the 'passive control', the micro CHP receives no forecast about the heat or electricity demand but it rather acts based on the current status of the system. In another words, it satisfies the heat demand based on a heat led CHP controller and it increases the temperature of the heat storage whenever the current cost of energy shown by the market signal reaches a certain level. Thus, it helps in clearing cost peaks and maintaining an appropriate cost level.

There are definitely several other possible control methods that could be applied to the micro CHP. The micro market model is already compatible with current control schemes and allows also further degrees of freedom in control for the micro CHP within the smart home.

DEVICES INTERACTIONS

Interactions of the devices within the market might vary from a system to a system based on the device operation nature, input signals and loads. Figure 7 shows out the basic variation of market signal versus the grid price all over a 24-hour timespan. It should be noticed that from hour 0 till hour 6 the market signal cost is simply the grid cost, but then at hour 7 the battery discharges energy to decrease the cost. Then at hour 8, the effect of the PV energy generation leading to significant decrease in the costs to go negative in hour 9 and 10 (i.e., PV was feeding-in energy to the grid). At hour 10, the tumble dryer operated to make use of the PV energy and its operation led to increase in the energy cost seen by the washing machine and batteries. From hour 16 till 19, it can be noticed that the batteries were discharging their energy leading to decrease in the overall costs seen by the other devices.

It is worth mentioning that it could be possible that two devices send a purchase signal at exactly the same time to the market about the same purchase. In this case, the market gives the priority of purchase to the highest load and then renews the market signal based on the purchase order given.

COMMUNITY INTEGRATION

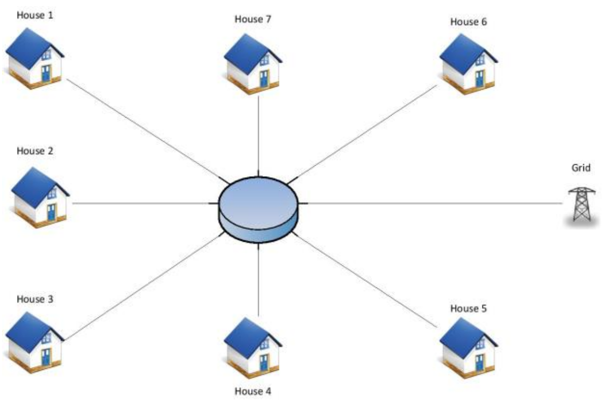

Figure 5: Community integration

Several researchers have discussed the possibility of integrating smart home systems within the community grid. The goals behind integration are decreasing operational costs of the smart home a more leveled demand and support of grid stability. Most of the approaches are heading to the optimal scheduling algorithms of the smart homes within the micro grid. Thus, all the houses had to be transmitting information about their storages, supply side devices and their consumption to the micro grid controller.

The approach presented in this contribution of the micro market within the smart home could be extended to the micro grid. Thus, there will be also a market between all the micro grid smart homes where all the smart homes compete on the available amount of energy to minimize their own costs. The market rules and architecture will vary from that market rules and architecture within the smart home. For example,

in this market, the market players won't be allowed to withdraw their bids in comparison to the micro market within the smart home, in another words, it will be a typical auction market based on a double sided bidding. Thus, this market will have a uniform market clearing price (MCP). Such uniform MCP is set based on the available bids in a way that it could be sometimes higher than the price offered by the supplier, and so the supplier will be able to make an even higher profit, or it could be lower than the price offered by the consumer, and so the consumer will be able sometimes as well to save more money. Such thing will lead to a higher profit for both the consumer and the supplier all over the days of the month. Furthermore, since the grid is into the competition, the supplier minimum price will be the feed-in tariff, and the consumer highest price would be the grid real-time price. Thus, the market always guarantee no losses, but possible wins (i.e., savings).
For example, figure 5 shows out a possible conceptual connection for a micro grid of the smart homes. Supposing the grid price at this moment is 26 Euro cents per kWh and feed in tariff of the PV is 19 Euro cents per kWh, while the MCP of the market at this hour is 21 Euro cents per kWh. If house 1 has an extra available supply of PV, house 1 can sell it to the market under an MCP which is higher than the feed-in tariff of the PV. Also, house 6 will be able to buy energy from the micro grid at a price which is lower than the grid price of this hour. Thus, both houses will be able to decrease their operation costs and increase their electricity autonomy as well.

Micro Market Integration

The micro market could be a part of the multi-level market clarified earlier. In this way, the continental market will be connected to the regional markets down to the micro grid market and micro market within the smart home. In all or some of these market levels the bidding will be done by an electronic agents. Thus, the smart home residents i.e., the small market players, will be able to enroll in the market without even knowing and deciding. Such thing will enable the smart home residents to purchase energy at a competitive price and without even exerting any additional efforts.

Figure 6: Micro market integration

On the other hand, through evaluating the sale and purchase requests or bids created by the smart home micro markets, upper level markets shown in figure 6 can have a better evaluation about the electrical load demands. Thus, energy suppliers within the regional market will be able to have a more accurate forecasting and allocate the resources in a more efficient way that would increase their profitability and satisfy the customers as well. In addition to that, linking the overall system along with the continental markets will enable a better use of the renewable energy resources all over continents.

Furthermore, smart home micro market model can also enable creation of a heat market within the home that can be integrated with the upper level combined heat and power markets.

CONCLUSION

The core of this contribution is the design of the EMS. The EMS system was created in a way that enables a micro market within the smart home. This micro market includes customers such as the household smart demand side devices, and suppliers such as the PV and micro CHP. Also, it includes devices which act as customers or suppliers such as the batteries. The micro market controller doesn't send an operation order to any device, but it just acts as cost monitor which can be accessed by all the devices. Based on the cost shown in this monitor, the devices can take the appropriate decision.

The benefits of such

- Decision independency for the devices (i.e., decentralized control)
- Less communication data transfer
- Easy integration of a smart home micro market into multi-level markets
- High potentials of savings once applied in a residential compound, as the EMS will enable the smart home to sell and buy energy to and from the micro grid

Outlook

To improve the efficiency of this smart home, model can be updated to enable identifying the source of energy consumed by the demand side devices so that the self-use tariff of the micro CHP could be used,

Moreover, the integration of this kind of smart homes needs to be further investigated and simulated to evaluate the real potentials of having a micro market within the micro grid. Also, to show out the variation of devices decision of different homes based on the micro grid market price.

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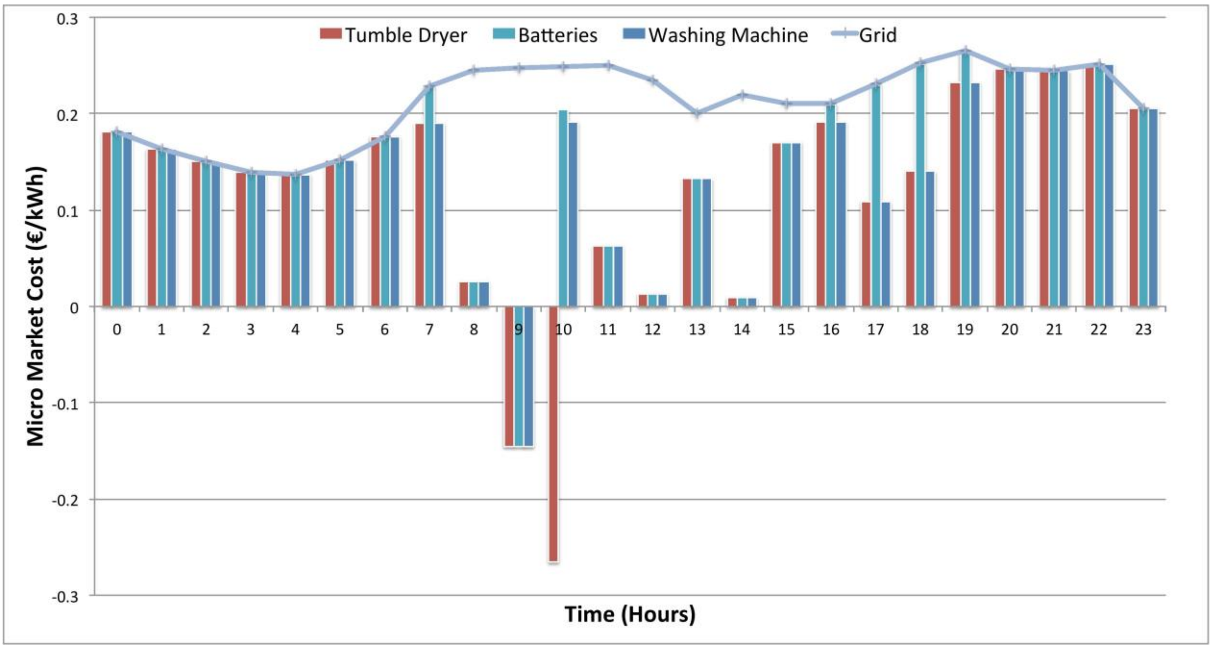

Figure 7: Cost Variation for multiple devices over time