Home Energy Management System based on Power Line Communication

Young-Sung Son, Topi Pulkkinen, Kyeong-Deok Moon and Chaekyu Kim

**Abstract — ***This paper describes a home energy management system (HEMS) based on power line communication. Smart metering and power line communication can provide detailed information of energy consumption patterns and intelligent controlling to appliances at home. We propose a HEMS that can provide easy-to-access information on home energy consumption in real time, intelligent planning for controlling appliances, and optimization of power consumption at home. The HEMS consists of three modules: an advanced power control planning engine, a device control module, and a power resource management server. Our prototype system reduces the cost of power consumption by about 10%*[1].

Index Terms — Power Management, Power Saving, Load Management, Home Network.

I. INTRODUCTION

Recent advances in electronic circuit chipset and device management technologies can enhance the efficiency of energy consumption devices in the commercial market [1].However, the current energy crisis has exacerbated the need for more optimized energy management. Users endeavor to use less power and save money, especially with regard to peak demand rates. To address this situation, we think that a home network, context management and Internet technology can be combined to enhance total energy management [6, 7]. The combination of a smart meter and power line communication could provide remote access, facilitate planning, and save the energy consumption of home appliances, such as an air-conditioner or radiator [2, 3, 5]. It could also be used to manage the peak energy consumption of all devices. In this paper, we propose a home energy management system that combines a home network and the Internet.

II. ENERGY USAGE REQUIREMENTS IN KOREA

Energy management is becoming increasingly an important issue in Korea. Because there is a lot of energy consuming industries like ship-building and semiconductor manufacturing, maintaining the average loads in the power grid is very important. This is also a reason why normal households, with increasing amount of electrical appliances, should be in the scope of energy management. The statistical data presented in Table 1 show that energy management is important especially in huge cities like Seoul.

TABLE I
STATISTICS TABLE OF POWER CONSUMPTION (SEOUL, 2005)

Seoul	unit	2005	%	Jan	Feb	Mar	Apr	May	Jun
Total	Mwh	40,523,744	100	3,532,194	3,408,048	3,204,767	3,149,886	2,977,756	3,314,667
Home	Mwh	11,600,996	29	1,025,561	1,009,389	924,987	943,949	886,447	984,001
Common	Mwh	2,677,881	7	22,6035	215,132	214,497	210,856	193,876	218,998
Service	Mwh	23,639,864	58	2,047,049	1,961,256	1,845,680	1,777,220	1,699,366	1,949,029
Industry	Mwh	2,605,008	6	233,549	222,271	219,608	217,861	198,067	212,639
Agriculture	Mwh	20,144	0	2,091	2,185	1,868	1,643	1,423	1,514
Mining	Mwh	7,671	0	746	497	748	667	611	605
Manufacturer	Mwh	2,577,188	6	230,712	219,589	216,987	215,551	196,033	210,519
Seoul	unit			Jul	Aug	Sep	Oct	Nov	Dec
Total	Mwh			3,632,608	3,979,611	3,569,706	3,092,913	3,116,691	3,544,897
Home	Mwh			968,588	1,100,187	971,113	909,114	929,910	997,750
Common	Mwh			245,165	252,670	240,795	201,764	212,352	245,741
Service	Mwh			2,197,105	2,402,629	2,132,356	1,784,567	1,771,243	2,072,364
Industry	Mwh			221,750	224,125	225,442	197,468	203,186	229,042
Agriculture	Mwh			1,470	1,624	1,589	1,356	1,427	1,954
Mining	Mwh			502	540	506	684	778	786
Manufacturer	Mwh			219,778	221,961	223,347	195,428	200,981	226,302

Currently the electricity in Korea is distributed by just only a power company. This company is monitored by the government so even though it is a profitable business, the government wants to limit energy consumption at least in cases where energy is not utilized in manufacturing industry.

As normal houses are only "wasting" energy they should be the first to limit their consumption. However, a survey shows that the amount of appliances at home is increasing (e.g. TVs and air conditioners). Also new devices like kimchi refrigerators will be more popular [4].

A. Cost saving theme

At the moment KPX does not provide exact billing information to its customers, so HEMS type of system is not supported. However, the situation should be changing with the Smart Grid technology. Smart Grid is a system that can integrate environmental friendly energy sources into conventional power grid. Other important feature is the city-level load balancing, using different power plants based on the current power consumption.

To be able to balance loads, Smart Grid requires online power consumption information from the houses. In return, the smart grid provides house-level functions in form of the smart meter. Smart meter should provide up-to-date

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information to the user, so monitoring energy consumption in the house is possible online. Therefore it is very likely that the customer can track the energy costs in the future as well.

B. Energy saving theme

Statistical data presented in the following tables show that currently the users do not care about how much an appliance is consuming. In Table 2, the appliances' energy consumption (kWh) is presented on the left side. It can be seen that in many cases, especially in case of an air conditioner, the energy consumption is not regarded as a problem. This means that the user understands the inefficiency of the appliance but is still using it.

In Table 3, the amount of days an appliance is used in a year is presented. As it can be seen, the consumption of the device is not a factor when deciding if the device is used or not [4].

TABLE II
YEARLY CONSUMPTION OF DIFFERENT APPLIANCES WITH DIFFERENT POWER CONSUMPTIONS (3500 HOUSES)

kWh	Electronic fan	Air conditioner	Humidifier	Electric blanket	Electric heater
100 below	34,751	349,532	43,731	97,722	199,139
101 – 150	35,760	396,792	47,465	98,283	208,568
151 – 200	35,264	433,944	50,146	105,094	216,240
201 – 250	35,670	457,032	53,874	103,230	212,440
251 – 350	36,462	467,830	52,767	104,152	216,177
351 upper	38,003	492,279	55,628	109,045	218,640

TABLE III
THE AVERAGE NUMBER OF USAGE DAYS PER APPLIANCE IN A YEAR (500 HOUSE)

kWh	Electronic fan	Air conditioner	Humidifier	Electric blanket	Electric heater
100 below	99	53	98	98	85
101 - 150	98	53	94	94	88
151 - 200	95	56	93	96	101
201 – 250	98	67	98	111	98
251 – 350	98	64	98	114	94
351 upper	102	65	99	124	104

III. POWER MANAGEMENT SERVICE MODEL

This service model is based on the service provider's position in the business hierarchy. The basis for the models is the current market share in the Korean energy markets and the business models used for home network companies.

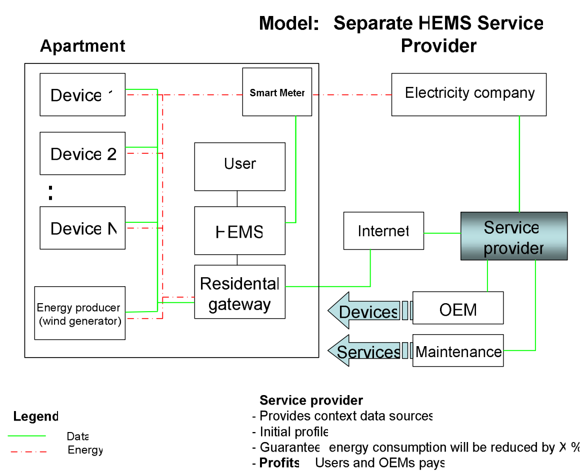

Fig. 1. The separated model :Service provider and electricity company

In the model presented in Fig.1, the energy management service and the electricity company are separated. The model also concentrates on data transmission between the systems, which are shown on the green lines. The electricity company provides the billing information to the service company, who uses it to reduce electricity costs for the user by a certain amount per year. Smart meter provides data for statistical control of the devices. The service company makes profit by selling the service to the user and also by making contracts with maintenance companies and OEM companies. Without contracts the service provider might not support their devices or maintenance service. The electricity company, who is owned by the government, would not get any straight profit in this model. The benefits for the electricity company would be the expected load balancing in the power grid, the possibility to introduce green energy via smart grid and smaller investments in the network capacity. This business model is very straightforward and provides clear profiting methods for the different parties.

IV. STRUCTURE AND COMPONENTS OF THE HOME ENERGYMANAGEMENT SYSTEM

Fig. 2gives a schematic overview of our home energy management system (HEMS). For providing the alternative energy sources, smart houses would be equipped with a solar power generator and a windmill power generator. Also intelligent appliances are controlled by power line communication, and a smart meter. Every 15 minutes the smart meter would provide reports on power consumption through an energy service portal (ESP)via a broadband Internet connection and that information would be available online through a Web interface. The HEMS relies on the power consumption history to control appliances.

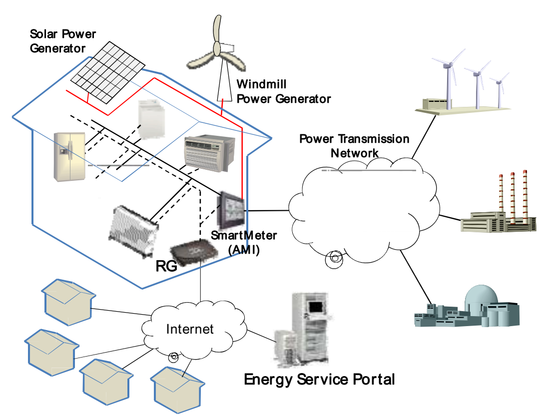

Fig. 2. Schematic overview of the HEMS

Our home network model is based on three basic network entities: (1) Devices, (2) Networks and (3) Services. Each of them contains some information or working concepts, which restrict interaction between other entities or enable functionality between them. These three basic entities can be further defined is as follows:

1. Device: Device is an entity that can contain services or functions. These services and functions can be accessed

both locally and remotely. If a service is located in the device, the device can also activate other device's services/functions. Each device should have at least one network. The basic operation of a device is to be controlled or monitored.

2. Network: Network has own specific properties such as Address, QoS and some configuration information. Network represents a path from device to device.
3. Service: Service is a process that contains the service logic. The service logic executes different device functions and services, and monitors their states. Service logic handles the relationship with the device and the network, as well as the relationship between the devices it interacts with.

Fig.3 describes an example home network configuration model with the above mentioned entities. It illustrates a home network example with basic entities of *devices(1), networks(2) and services(3)*. The *devices(1)* in the example area residential gateway(RG), a light, an air conditioner, a temperature sensor and two routers, one for the LAN and one for the WLAN accordingly. Also the network interface cards are part of the device group. The *networks(2)* in the example are LAN, WLAN and WAN and the *services(3)* are the Lightning service, the Cooling service and the Measuring service.

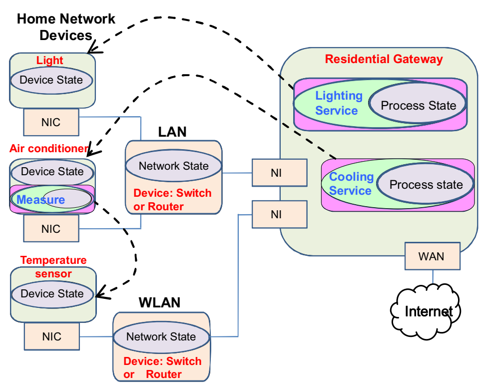

Fig. 3. Home network configuration

The deployment of the functions can be spread over different devices depending on the business model. Some user functions can also change owner in this case, e.g. if a service company operates in a turnkey basis (provides devices, services and management) the user does not need many functions. In this type of outsourced model, the planning can be mostly reside on the operator server, but some minimum planning is required to be on the apartment level, because of the feedback from online monitoring.

Fig. 4 illustrates the software structure of the HEMS. It has three parts: an advanced power control planning engine(APCPE), a device control module (DCM), and a resource management server (RMS). The APCPE and the DCM run in a RG. The RMS is operated by a local power supply company. It is designed for the efficient management of numerous home devices related to energy consumption, the home network configuration, and the service provider's management policy.

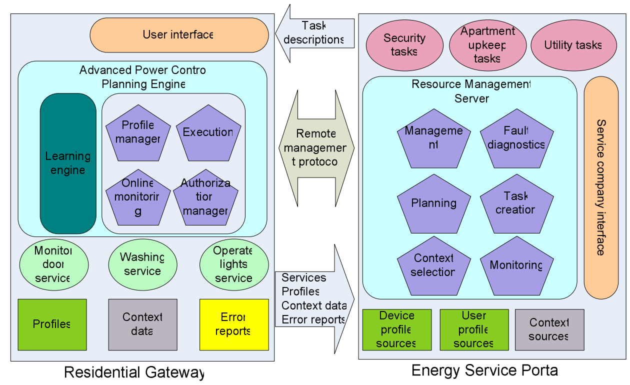

Fig. 4. The software structure of the HEMS

The DCM in a RG configures and controls all devices (such as an air-conditioner, boiler, and lighting) with power line communication (PLC) technology. The APCPE formulates an optimized control plan and collects detailed information about the status of devices and the cost policy information from the RMS. The APCPE and the RMS manage all the information pertaining to a customer's power consumption pattern. Whenever a change is detected at home, the APCPE orders a new plan that covers any change of device or network.

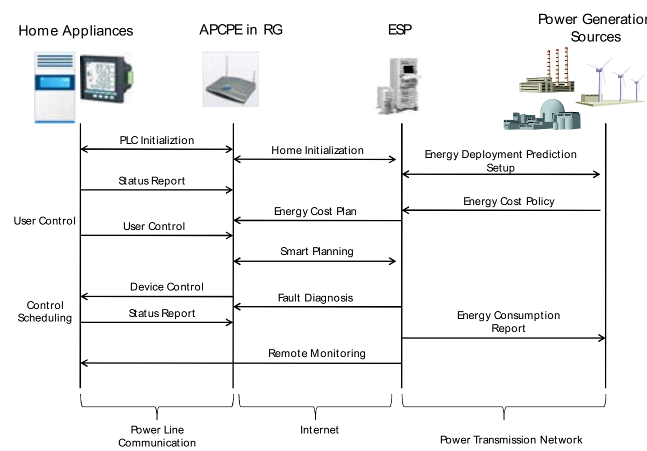

Fig. 5. Flowchart of our energy management system

For energy management, we considered three major concepts in HEMS.

The first major concept is related to smart planning. The HEMS is based on real-time price-responsive load management concepts. In particular, the APCPE understands the cost policy and the shift controlling appliances in peak load periods. For this work, the APCPE uses all kinds of relevant information (including weather forecasts) to control appliances, such as solar panel or windmill power generators.

The second major concept is related to plausible controlling. To prevent a peak load overflow, we prepare two control policies for intelligent device control and group management. The plausible appliance control is a control method customized for specific devices. Although unique control programs are embedded in each device, device experts can define some efficient knowledge about the energy consumption rate of a device through an external examination. The HEMS then controls the device with an optimized device control algorithm.

The third major concept is related to group management—specifically the overall management of a group of devices. In electric load management, the peak consumption management is crucial. Through group management, for example, the EMS can successively switch off the outer fan of an air-conditioner for 10 to 15 minutes without having to notify the customer.

V. KEYFUNCTIONALITIES OF ENERGY MANAGEMENT

Energy management consists of a group of functions that facilitate remote monitoring, controlling, planning and repairing of operations and provide information on the status of installed devices and the network. The HEMS has the following four functions:

- auto-configuration: auto-configuration is the most important function for customers of home network services because many homes have a wrong configuration.
- easy monitoring: comfort and easy access to real-time information on energy consumption help the user pay attention to energy saving.
- remote controlling: online access to a customer’s usage pattern and device status enables appliances to be controlled remotely.
- smart planning: automatic peak load management provides smart planning for reducing energy consumption.

A. *Auto-Configuration*

When device plug-in, automatic device discovery (PnP mechanisms) using (1) PLC (power-line communication) (2) WLAN or (3) existing home automation bus is the key technology to enable easy installation.

Installing a new device requires the software (services and interfaces) and firmware (hardware control), which are updated automatically using either the centralized service provider database or the OEM’s own software distribution servers. The hierarchical architecture of home network ensures the correct operation of the devices.

The user can add a LED system to the kitchen to increase light intensity while maintaining average level of consumption. When a new light is added to the power-line and turned on, HEMS detects it by its load current in the power-line. Because the newly added device doesn’t share any information (it is a non-intelligent device), the HEMS enables only basic on-off functionality for it. After the new device is detected, the user configures its location. With this information, HEMS recognizes the device as a kitchen light. If the user would not provide the information, the system would ask if there is a new device installed at all.

B. *Energy Saving Appliance Control*

A house has two basic heating systems: a gas boiler, which circulates the warm water in radiators and electrical heat-pump. In addition to these, some rooms are equipped with electrical radiators. The user can apply general energy saving, which would include both gas and electricity, or just save one of the energy types. Because electricity is more expensive then gas, the user wants to save more electricity, but still wants the minimal affordable carbon footprint.

The house heaters are optimized based on many factors:

1. The available heater’s energy efficiency
2. Timetable: different rooms need to be heated in different times of the day
3. The renewable energy available in the power grid / estimated renewable energy
4. The time that is available for heat transportation inside the house
5. The passages that will be available for heat transportation
6. Other services related to heating (water heating, sauna, floor heating, drying clothes etc.)
7. Weather forecast
8. Sensors (outside temperature, inside temperature, draft from room to room, open doors/windows)
9. Power company’s pricing policy

The user sets the general temperature level and also wants his bedroom to be a bit chiller during the night, because it is easier for the user to sleep that way. In the morning time, the bedroom should be as warm as the rest of the house, so waking up is more comfortable.

Sensors in the house detect the general movement pattern of the heated air, adjusting the heaters to work accordingly. Because the heat pump is most energy effective heater, it is utilized as much as possible. However, when the outside temperature is too cold the heat pump gets quite inefficient and shouldn’t be used. Gas boiler, on the other hand is the only way to heat the house as much as is needed, especially, when the outside temperature gets too low. In energy saving mode electrical radiators should be used when renewable energy is available in the power grid, even though it is more expensive. Also in the morning, the gas boiler has to be utilized, so there is warm water available in the shower.

C. *Cost Saving Appliance Control*

A house has renewable energy sources (wind generator and solar panels), and new washing machine with different service modes for drying the clothes. In addition, the house has a normal cloth dryer, which is generally a big waste of energy. The user enables HEMS to control the non-ubiquitous dryer through an on/off PLC-module, which is placed between the power outlet and the dryer. The house owner uses cost-saving theme and leaves it to HEMS to decide when to wash his clothes and how to dry them.

In the up most timeline it is Monday and HEMS knows that the clothes need to be ready just next week, so there is plenty of time to schedule the washing. However, the weather forecast shows there is 50% chance of rain in the whole week.

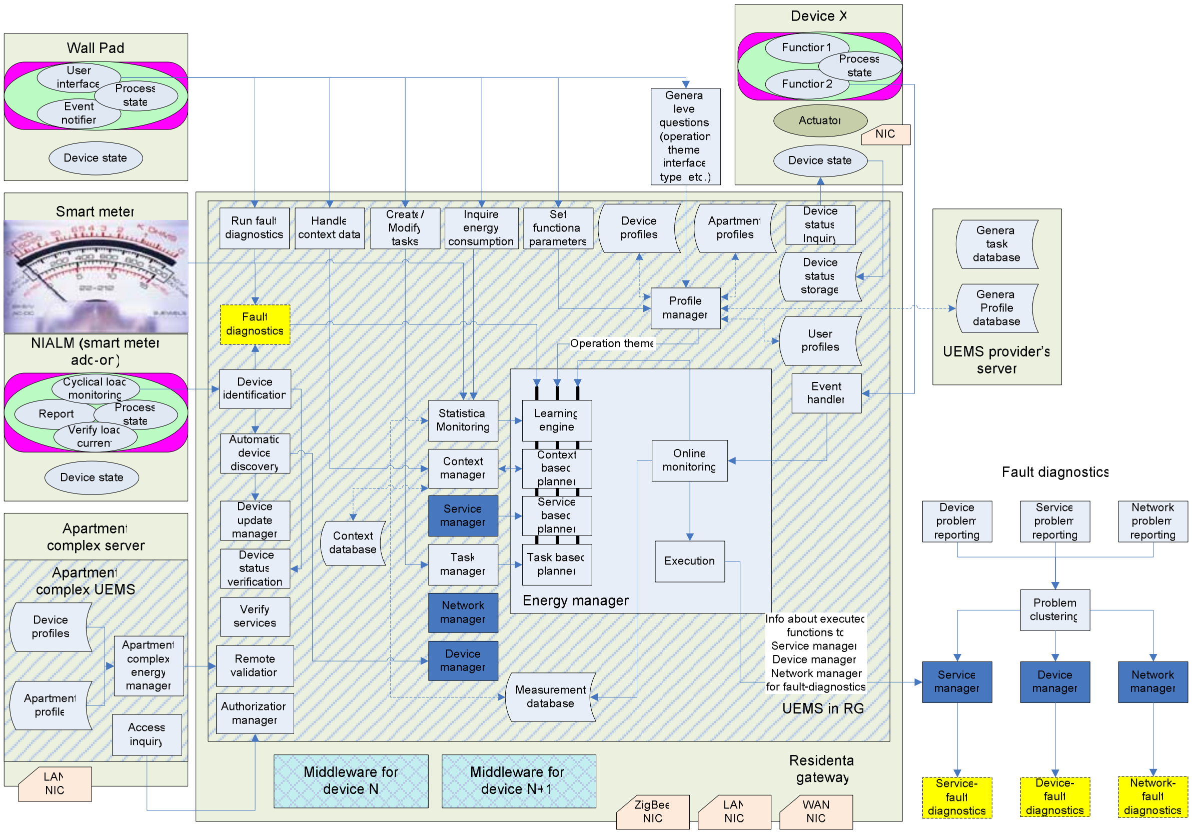

Fig. 6. HEMS functions and some supporting devices

Luckily, it is also windy so wind generator produces electricity. Knowing the average energy consumption in the house, HEMS schedules the washing in Thursday evening. If the wind generator has produced enough electricity for both washing machine and the dryer, the service will be free for the user.

Unfortunately, on Wednesday HEMS notices that this is not true, because the user wants to have dishes done as well. HEMS schedules the cloth washing on Friday, leaving a good margin before the deadline. However, the wind generator does not produce enough energy for even washing machine, so the washing is scheduled on early Saturday night, when the electricity is quite cheap. Because the weather forecast says its still 30% possibility to rain on Sunday, high tumble mode is used by the washing machine to dry the clothes. The HEMS ask the user to put the clothes in the dryer before going to sleep. The dryer, which uses a lot of energy, is set to run only half of its normal operation time. This is enough because the clothes were properly dried by the washing machine. The clothes are ready on Sunday morning.

D. Detecting Energy Consumption Abnormalities

If the user has approved apartment complex (AC) level monitoring and control, the AC energy manager will receive statistical data from user's HEMS or smart meter. When AC energy manager detects abnormalities in one apartment, remote fault diagnostic can verify and solve possible problems. AC energy manager accesses the apartment's HEMS and checks devices' operating modes and status. Then it can help to identify problems caused by faulty devices (e.g. gas leak, broken electronic device etc.) or incorrect usage problems (e.g. parameterization problems, incorrect context data, etc.).

Apartment smart meter sends periodically data to apartment complex HEMS. If the data varies a lot from the data in other apartments, the AC HEMS makes a remote inquiry to match the apartment energy profile with the apartment profile and device profile. The AC HEMS level of control over apartment appliances can be set in the remote validation function at the fault diagnostic process.

IV. EVALUATION RESULTS

In order to verify the feasibility of our proposed system, we've implemented a prototype with an embedded linux RG and a PLC-home network. RG consists of embedded chipset, flash 32MB, SDRAM 64MB, Ethernet and 2 serial ports. Our PLC chipset uses following phy-layer as a frequency band with 50~400kHz, multi-carrier modulation and 128 sub channels.

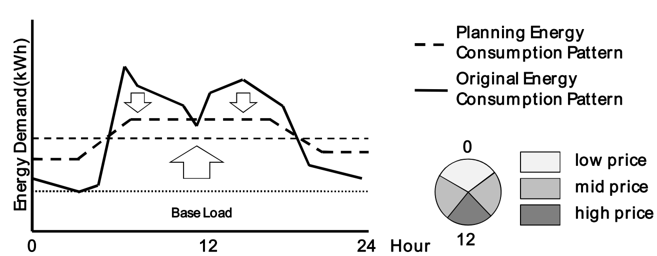

Fig. 7. Comparison of HEMS effect

In our prototype system, we had evaluated energy management to three homes with an air-conditioner. Our system show total cost reduction of the power consumption of about 10%. Cost saving smart planning makes an effect to increase the base load and plausible controlling decrease the peak load of power. Even if we consider weather information, it can grow intense degree 2~3% to cost saving.

APPENDIX :ELECTRICITY CONSUMPTION REDUCTION MODEL

Energy retrenchment efficiency is a sum of many different factors, which are related to policies, consumers' so sio-economic circumstances and new energy saving devices' supply and features.

Example factors are:

- Investment- and operational expanses
- Product lifetime
- Price of the energy
- Taxes
- Subsidies from government
- Availability of information
- Consumer's personal motivation
- Supply and marketing of the devices
- Government regulations

Because there are so many factors it is difficult to examine the energy saving choices as whole. One method is to use Reduce-model, which examines energy saving devices' market penetration. Reduce model is statistical model, which is based on the observation that new device market penetration follows S-function. S-function is the consequence of slow launch of a product, increase in the market segment and finally market saturation. Market penetration S-function is related to Fisher and Pry substitution model, which is presented in (1).

$$\partial P / \partial t = S \cdot P(t) - (1 - P(t)) \;, \quad (1)$$
$$P(t_0) = P_o$$

where P penetration level, t is time and S is calibration coefficient. There are different ways to present the calibrartion coefficient, but in Reduce-model it is presented as in (2).

$$S = \alpha \cdot IRR \;, \qquad (2)$$

where α describes the consumer behaviour and IRR is internal rate of return of the device. The IRR can be calculated from the equation (3).

$$\sum_{t=1}^{lt} \frac{CashIn}{(1+IRR)^t} - CashOut \;, \quad (3)$$

Where *Cash Out* means the difference between buying energy saving product rather than other model, *Cash In* is the benefit from the usage of the device and lt is the lifetime of the product.

The consumer behaviour term (alpha) describes the motivation to purchase energy saving product rather than other device. Motivation is optimal at level α=1, in which case the device is bought based on the economical feasibility. Some fields in the industry follow the optimal behaviour, but in the home environment the economical feasibility thinking is little bit lower. Many studies have found the alpha to be around 0,7.

V. CONCLUSION

This paper describes the home energy management system and its implementations using power line communication. For supporting energy management services, HEMS monitors smart meter and make a plan to control the appliances related to energy remotely from internet providing auto-configuation, remote monitoring, energy management, flausible controlling. Especially, planning makes to shift device controlling on peak price time and to smooth power demand work load. Finally, HEMS can deliver clear benefits about resource utilization, energy conservation and cost reduction to users.

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BIOGRAPHIES

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