DEMAND SIDE MANAGEMENT IN PRIVATE HOMES BY USING LONWORKS®

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Abstract - *This paper presents a system to distribute power consumption in private homes uniformly over time as well as to reduce total power consumption to meet the interests of the energy producers. We proclaim autonomous and intelligent domestic appliances that communicate with each other. Every electrical device is supported by a built-in LonWorks-Node that incorporates distributed algorithms. The main objectives are the to provide logical relations between the devices, and to coordinate the energy consumption policy. All this happens in an autonomous, distributed way without any interaction with the user. The paper elaborates four different algorithms and indicates strategies to save energy in global dimensions*

1 INTRODUCTION

Demand Side Management (DSM) is a method to coordinate the activities of energy consumers and energy providers and is very much in the interest of energy producers. DSM seeks to avoid peaks of energy consumption [1] in order to achieve an approximately constant energy consumption that meets the characteristics of power stations. The typical pattern of energy consumption in a household stands in contrast to this; a lot of energy is consumed in the morning and at noon and almost none at night.

There are already simple DSM-solutions with programmable timers for washing machines etc., but they cannot be used for more complex problems and they must be programmed by the user. Other solutions (used at mountain huts where energy consumer and producer are the same person) offer a lock for certain devices when another device is running to avoid power peaks. These solutions are, however, difficult to control and often quite expensive when used for a larger number of appliances.

The objective is to smooth energy consumption by using intelligent domestic appliances that communicate with each other. The most important feature of an interconnected home is its multifunctionality [2]. A home network can be used to increase comfort as well as safety and security. DSM is a further application and reason for using home networks. Alternative energy sources, reservoirs, and sinks like solar panels, heatpumps, hot water tanks, transparent insulation [3], intelligent lighting systems [4] and air conditioners can also be coordinated by the DSM system. This DSM System is not limited to private households. It can be also used in large business facilities, machine halls and wherever electrical appliances are in use.

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Some criteria have to be considered:

- Invisibility: The net must not require new wires, cables, displays and switches. It has to communicate over power-line [5], must represent a plug'n'play[1] system with autoconfiguring mechanisms and work autonomously without any interaction with the user. A DSM-supported vacuum cleaner looks and works like an old one, but after plugging it in it automatically connects to the software framework of the energy management system.

- Safety: When the DSM-net breaks down it must at least offer the functionality of a non-interconnected home. Furthermore, a defective appliance or an intruder should not be able to paralyze or influence the communication between the members of the energy system.

- Profitability: It is only a question of time until private households have to pay power-peaks like the industry. New standards, energy taxes and adaptive rates will be a further inducement for a DSM-System.

The objective of this project is to offer a software model and to implement a DSM-System as a part of "green engineering" [6] to develop new strategies to save energy.

The chosen home-network for the control system was LonWorks [7]. This system offers an architecture of distributed intelligence and all kinds of communication-media like twisted-pair, fiberoptics, power-line, radio,..etc.

2 SOFTWARE STRUCTURE OF A DSM-HOUSE

A domestic appliance for an energy saving system has to have certain properties. This includes the possibility of an economy-mode, a sleep-mode to finish its work later and other modes to fit the device into the actual electrical state of the system. Furthermore it is necessary to control the device from another point in the home net and to get information about it such as current and future power consumption and general future behavior. Also new strategies for switching on and shutting down a device in an energy-saving manner are required. All these features have to be controlled and therefore every electrical device in the household (shaver, washing machine, TV,...) is supported by a built-in LonWorks-Node that includes 3 software layers (Figure 1):

- Energy-Management (EM), the user side layer
- Case Management (CM), the middle layer
- Power Management (Short Term- and Long Term-PM), the device side layer

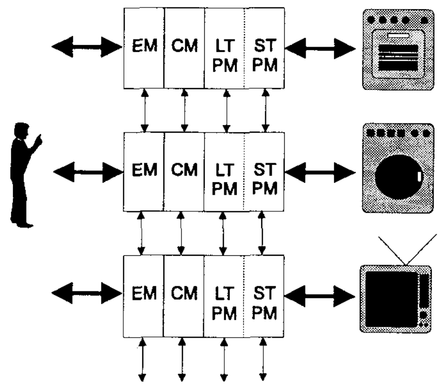

Figure 1: Software Layers

2.1 Energy Management

EM tries to save energy by reducing and correcting excessive demands by the user like 27°C room temperature and hints for optimizing the lighting (Figure 2). This supposes an easy-to-use user interface.

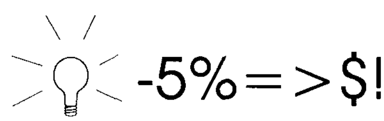

Figure 2: EM - Energy Management

EM analyzes the circumstances why someone wants to turn on the light owing to architectural reasons, personal preferences, the weather and other things. This requires a large number of sensors and a distributed database system. EM represents an expert system for energy-tuning. It suggests to change the light bulbs in the often frequented rooms to neon tubes which save energy, produce less heat and thus relieve the air conditioner [8]. Furthermore the best position for a new floor lamp can be calculated considering personal preferences.

2.2 Case Management

CM deals with logical relations and connections between the devices (Figure 3). For example it makes no sense to project slides while the light is on and presence-sensors control the lighting. These connections

[1] Plug'n'play means installation of the device without manual configuration

depend on the person who is living in and with this system.

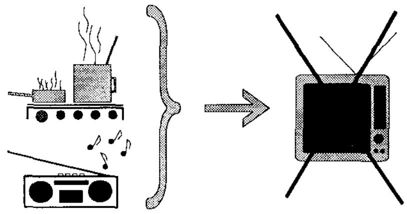

Figure 3: CM - Case Management

It might make sense for someone to inhibit the TV Set during cooking, but would be not acceptable for someone else. The system has to identify the person's lifestyle and to adapt itself to singles, grandmothers, double-income-no-kids and to other types. Even more so, the system has to be a mixture between a system analyzer and a sociologist. A simple adjustment of the system by a symbolic programming language is also conceivable.

2.3 Power Management

PM represents the classical Demand Side Management; it smoothes power consumption. The refrigerator turns itself off for 20 minutes when the stove is turned on, the washing machine runs in economy-mode if the total power consumption exceeds a certain value and the dishwasher activates itself at night, when power is cheap. Power Management is split into two parts, the Short-Term PM and the Long-Term PM.

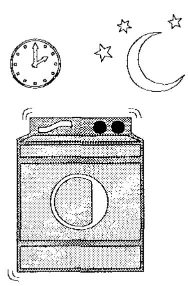

Figure 4: Long-Term-Pówer-Management

- The Long-Term PM (LT-PM) coordinates the devices (Figure 4) with a kind of time-table, where the appliances can register their demands. A scheduler tells the device when it may do its work depending on the price of power and other entries in the table. A table entry may include a current profile and a point of time when the device wants to have its work finished. A washer, for instance, predicts its power consumption for heating the water, washing, and spin drying and tells that it wants to finish by 8:30 am.

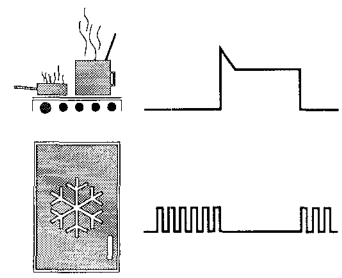

Figure 5: Short-Term-Power-Management

- The Short-Term PM (ST-PM) does not care about time, it decides for the moment (Figure 5). Appliances that have the possibility to change their source of energy or their energy consumption might do so if it is necessary. A simple example is that the dishwasher changes into economy-mode when the overall current consumption exceeds a preset value of amperes. The difference to ordinary DSM-Systems is that the future behavior needs not to be known because the system reacts on actual changes that are predicted by the devices (the automatic curtain predicts, for instance, 1 ampere current consumption before it gets into action due to the sun). Real current peaks are not only detected, they are avoided. The predicted energy consumption may exceed the desired maximum current, but after the DSM-System has reached its equilibrium the devices put their now balanced forecasts into action.

PM does not save energy because economy-modes may need less power, but they take longer and in terms of energy it makes no difference if the washer runs at night or not. The difference is that energy costs less at night and the consumption profile is smoothened which will also be a financial advantage in future

The different layers of one device filter and coordinate the user's commands and the device's wishes by communicating with corresponding layers of different devices and with its own upper and lower layers.

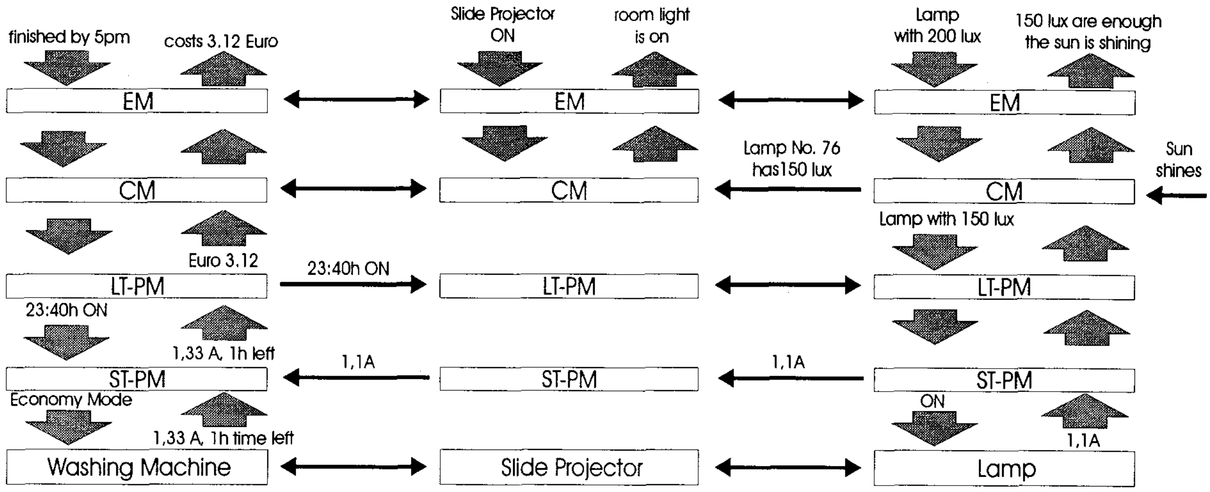

Figure 6: Communication between the layers

Figure 6 shows a small part of a possible interaction between the layers of three appliances. A washing machine, a slide projector and a lamp are to be switched on. The washer enters economy-mode because of the total current consumption, the slide projector knows that it would not be able to produce a picture because of the burning light and the light reduces its intensity because of the shining sun. Clearly the more sensors and the more information is available the better the system works

Let us focus on one of the layers:

3 SHORT-TERM POWERMANAGEMENT (ST-PM)

If, in case of a too high (predicted) peak load, some appliances have the possibility to switch to another electric circuit, to switch off or to enter another mode, it must be guaranteed that not all devices economize their operation but only as many as necessary. Therefore, the appliances must act one after another while communicating with each other. Let us have a look on three different strategies and compare them:

a.) Centralized ST-PM

One ST-PM node (P) collects the predicted data (pred) and organizes all devices (D) by sending out control data (ctrl) (Figure 7). The required algorithm is quite complex and powerful. The optimum can always be found.

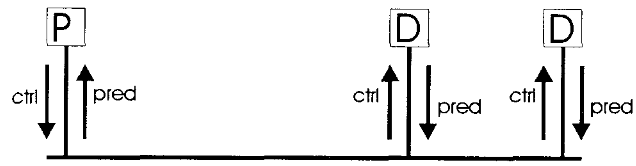

Figure 7: ST-PM Method a.)

It is obvious that remote control of the devices is a potential security gap and the functionality collapses when the PM node breaks.

b.) Decentralized ST-PM

Every device has a ST-PM node of its own (Figure 8) that collects all predictions of all appliances and joins them to an overall prediction. In case of a too high energy consumption prediction the PM nodes will influence their particular devices to decrease consumption.

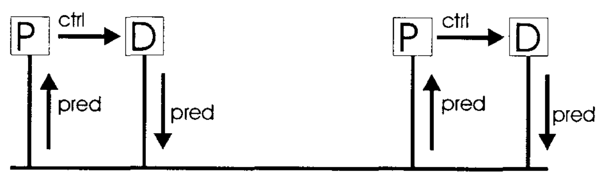

Figure 8: ST-PM Method b.)

Every device can offer different possibilities for a lower consumption and the PM node chooses the best one. A PM node can only control one device and cannot influence any other device which increases safety but decreases the flexibility of the system. If a device decides to change its mode it adds this wish into a queue and waits until it is its turn. All nodes have identical queues that are permanently checked for consistence.

c.) Decentralized and redundant ST-PM

This mechanism is a mixture between approaches a) and b). Every device has a PM node that can control its device and every other device in the system (Figure 9). The proper function of every node is monitored by the rest of the nodes.

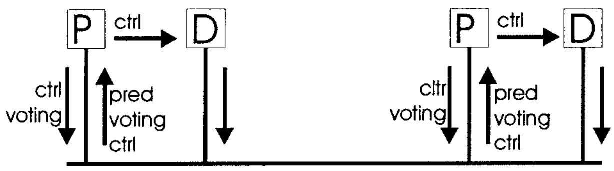

Figure 9: ST-PM Method c.)

Every node calculates an optimum configuration for all the devices and marks its solution with a system-wide valid key. This key assesses the future current and the amount of the changes. This mark is broadcast over the net and received by every other node. Every node calculates a different solution and the best will be taken. After the winner node is found it sends its changes to the devices which adopt accordingly. The algorithms on the nodes are ideally different ones and include random mechanisms. This provides fault tolerance because at least one correct node can control the whole system if all other nodes cannot solve the problem. Another advantage is that the system can easily be connected to a powerful computer which calculates faster, better solutions.

It is no problem if a node marks itself wrong, because all other nodes check the mark after the broadcast control data.

The common quality of all three strategies is their position in the layer model. They are located directly at the device and their received commands (ON, OFF,...etc.) are already filtered and cleaned of all meaningless and absurd instructions, they have an ideal timing and they are not exaggerated. This is done by the upper layers and the ST-PM only takes care of the changes of the connected machine or appliance. The ST-PM layer communicates with the ST-PMs of other devices.

4 REACHED OBJECTIVES AND ASPECTS FOR THE FUTURE

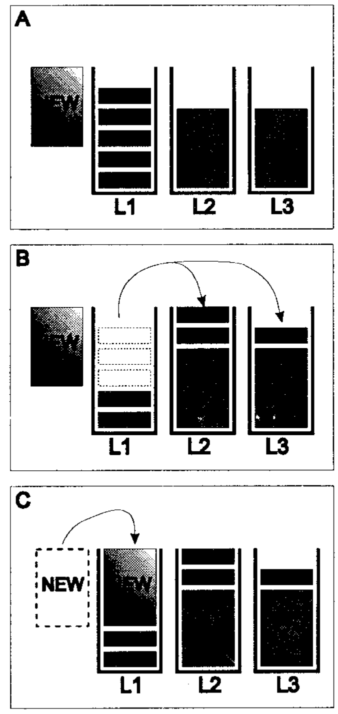

Figure 10: Arbitration of devices

The HomeNetConfigurationTool-Project[2] [9] at the Technical University of Vienna includes a model of a private home interconnected with LonWorks. This model was extended by adding simulation nodes which simulate the behavior of a TV Set, a washing machine and so on. These simulation nodes can be controlled remotely as well as manually (open the door of the refrigerator, turn on the microwave,...etc.). Their interface to the rest of the Home Net consists of a network variable[3] that represents the remote control functions as an input and another one that offers the needed prediction as an output. Some of the devices are supported by a ST-PM node, others are not, in order to test how the system deals with non-intelligent appliances which do not send out a prognosis of their power consumption.

The chosen strategy for the ST-PM is Strategy b.) - the decentralized ST-PM - which prefers safety to flexibility.

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[2] granted by FWF Austria, P-10699 ÖMA

[3] Network Variables are a LonWorks communication objects that are based on layer-7-services

A classical problem for this system with limited possibilities is to arrange devices in a self-ordering way. The PM-node can only influence its own device and not other ones. A simple example is the case of three limited electric circuits (L1, L2, L3) and devices which can change the circuit but cannot be switched off or switched into economy mode to relieve the circuit. Fig. 10 shows how a new device which announces its predicted load is fitted into the circuits. Three other devices have to change their circuit to make place for the new one which is a simple task for a centralized ST-PM node because it can control all devices. But the three autonomous ST-PM nodes do not see any advantage in changing their circuit as long as there are no self ordering algorithms used (like „always fill up one circuit first" or other rules to increase the statistical probability to find a free circuit).

Strategy c) - the decentralized and redundant strategy - would also find a solution but would be more complex.

The actual realization corresponds to a self-ordering strategy b.) (decentralized ST-PM) because of safety reasons. The queues are administered by network variables and are of stochastic order to ensure a statistical deviation: The devices should take their chances to influence the system in turns. Every node has its own queue and every incoming queue entry is checked for plausibility. After a new broadcast prognosis the other devices react on it.

Figure 11 shows the reactions of two devices (D1 and D2) after a third appliance (D3) has predicted that it will immediately switch on. This prediction includes the current, needed by the device in future (at t1). The devices have the possibility to change into sleep-mode or save-mode, where the consume less power. Device D2 realizes that the common power consumption is too high and changes into sleep-mode (t2). After this, the overall power consumption allows device D1 to switch from save-mode to on-mode (t3).

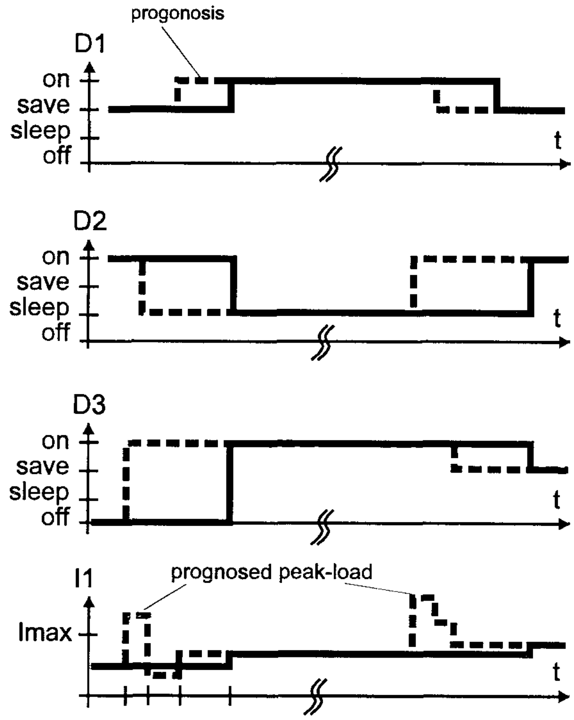

Figure 11: reactions of the power management system after a new prognosis

The reactions are random-ordered, and the situation would look different, if device D1 had been faster than D2. As seen at the bottom of the figure, the current-peaks occur only as an information on the network. The real, physical current stays smooth and changes after the system has reached its equilibrium (t4). After a certain time device D3 leaves sleep-mode (for instance D3 is a refrigerator and its internal temperature is rising) and again the other members of the net have to react.

The current objective is to add the behavior of typical users to the simulation and to increase the number of devices and sensors. The development of new strategies and algorithms will be done on simulation environments where multiple households consisting of more than 500 devices and several users can be simulated. The results from these simulations will help to find new strategies to minimize overall energy consumption. In consequence, new power plants can be prevented and existing ones optimized.

Another future objective is to implement all four layers of the model to offer full functionality and an easy-to-operate user-interface. This work finds its continuation in a new project together with STEWEAG, an austrian utility company, where the results of this work will be used build up a network that supports the customers of STEWEAG to save energy. This network offers a lot of possibilities for a new sort of service provided by the utilities.

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