Implementation of User-Oriented Smart Services into an Innovative DC Low Voltage Net

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Abstract. In this paper a concept of smart services implemented in an innovative DC net (direct current) is described. It shows how various components with different DC-energy-level-demands and user-based requirements can be connected interoperable. Thus smart services can be defined in that technical environment. The implemented system is able to remember the residents' individual preferences to provide a comfortable living situation.

Keywords: DC voltage · Services · Smart home · Interoperability

1 Introduction

In terms of smart homes and cyber-physical systems it is a general effort to provide house systems with more intelligence to achieve an enhanced usability. At the same time, in terms of scarcity of natural resources and increasing environmental awareness, energy and cost efficiency is indispensable for a profitable operation.

Today's households' demand for electricity is fulfilled either via the public energy network or internal measures. The most widespread system for generating own electricity are photo-voltaic (PV) systems. But in 2012, less than one percent of the German households supplied themselves with self-generated electricity on the basis of a PV system. [1] A PV system produces power with DC voltage. This is normally converted into AC voltage before it is fed into the home network. But many household appliances operate with DC voltage. Therefore, a rectifier is installed in the power supplies of the appliances. Both the inverter and the rectifier lead to conversion losses. [2]

In this paper a model room with an innovative DC net is presented. This DC net is supplying the electric and electronic devices in a residential unit directly with DC voltage. The necessary adaptation of the appliances is described. Based on these appliances a smart services environment is defined. The services build a platform for an interoperable connection between these appliances and, at the same time, serve as a gateway for individual user intervention.

The paper gives an overview about the projects main ideas and the project partners' contributions.

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2 Relationship to Cloud-Based Solutions

In this paper, the preliminary results of a project are presented, which is igniting subsequent projects. Therefore it represents a fundamental conceptual basis. The actual prototypical model room includes a central local control. A following project will dissolve this restriction by shifting significant portions of the control into a cloud. Firstly this offers the user ubiquitous access to the system. Furthermore, by outsourcing of information the system would be less affected. It would handle only the information it needs at that moment. An expensive performance improvement of the components would not be necessary, yet strong functionality would be guaranteed.

3 Related Literature

Currently there are various ideas for services in a smart home, but most of them are based on an AC net with AC appliances. The differences in the approaches of provided services are resulting from their intentions. For example, one of the greatest German energy companies, RWE, is including into the definition of services the opening and closing from windows, blinds and heating as well as the lighting and consumer electronics. The target of these services is to provide home safety, by increasing the protection from burglary and fire, as well as to maximize comfort and convenience. [3]

Regarding the implementation of DC networks in buildings, many studies and approaches already exist, like the project "Stroomversnelling" from the Netherlands. The aim is to implement a DC system, with only one AC socket connection, within three steps. [4] There are more similar conceptions like in [5] and [6], but nearly all of them are only focusing on the implementation of a DC net, without a smart interconnection of the appliances. This situation is unsatisfactory, especially when, simultaneously, the number of devices in households is permanently increasing.

The problem is also mentioned by the Energy Information Agency (EIA). According to their studies, consumer electronics and small appliances are the fastest growing sectors of residential electricity use. Twenty years ago, in 1993, this category played no role in their investigations. But eight years later, they already counted more than ten devices in that category. Last year, some members of the IEEE listed all small appliances and consumer electronics devices in their houses. They counted to more than fifty. [7] This is an important argument to perform research how the small appliances and consumer electronics should be integrated in a smart home.

4 Research Contribution and Innovation

Based on these observations, the project EGNIAS was launched. The project team decided to combine a DC approach for the technical energy network with the ideas of the smart home, to let DC appliances interact with each other.

For defining the services, a technical base has been created. The system was built as a model room with an inside dimension of approximately 140x90x50 cm (WxDxH). The room is divided into an entrance area, a working area, a dining area, a lounge area and a reading area. The model has been populated with furniture built by the universities faculty of wood design.

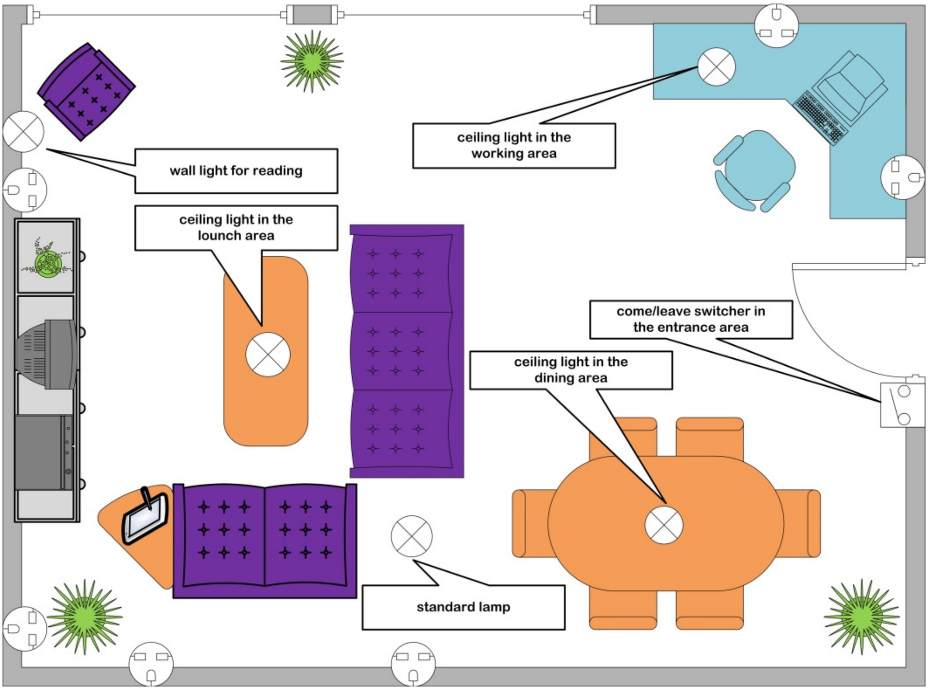

Fig. 1. The model room

Technically, the room controller is implemented with a PLC (Programmable Logic Controller). It is connected by an IO-unit with the model apartment. The power outlets are controlled by a digital output terminal; the lamps are connected to a dimmer with an analog output terminal. The feedbacks of the achieved luminosities come from light sensors, which are connected to the analog inputs of the PLC. The control button next to the door in the entrance area is connected with the system by a KNX-communication terminal.

The central PLC is responsible for the room observation and control as well as the residential unit's energetic supervision. This includes determining the energetic subscription and usage sizes which allows the determination of user-dependent power efficiencies, as well as the monitoring of the energy storage. Thus, power supply reliability can be achieved, combined with the possibility for an ex-post review of the power storage characteristic.

The model room was equipped with a DC voltage based power supply system. Therefore, a PV element and an energy storage have been connected to the room. With the PLC based room controller various components (sensors, actuators, power supply, operator controls ...) are interoperable connected via various transmission media (KNX, radio, etc.).

The challenge was set by configuring reasonable and suitable services for the inhabitants based on the DC low voltage appliances. The highest power supply voltage into the pattern room can maximum achieve 24 volt. The project team decided, according to the statement of the Energy Information Agency (EIA), to install in a first step only consumer electronics like a television, a radio, a personal computer, a tablet and a telephone as well as a standard lamp, three ceiling lights and one wall light. Including all of these components, a set of services should be designed.

The plugs from a number of these appliances have been changed, so that the appliances can be connected to the newly designed power supply system, requesting the suitable voltage level.

With these appliances, individualized settings for well-being should be created. Special attention is given to the creation of an intelligent interface between the deterministic system behavior and the complexity of human perception. (The same brightness can be perceived differently in various situations.) Furthermore, external influences, like sunlight, have to be taken into consideration for the models.

In these appliance settings, services have been defined. A service is defined as a process to influence physical environmental parameters selectively. Input variables of these processes are the actual values of the environmental parameters and planned activities of the users. The resulting values of the output parameters are derived from the planned activities (of the selected services).

Special attention was given to the matching of the provided services with the user's needs. They should provide an appropriate room climate. This concept has been implemented so far, that different room regions are differently illuminated and that the combination of services is restricted to reduce possible distractions. For example during the meal service the TV is turned off, so that the people are not distracted and the communication is encouraged at the table. A service is therefore not responsible for the control of one appliance. It provides a combination of control commands for a multitude of devices.

Because the environment is perceived differently by each person, the user can change the room situation as desired, and customize the services individually. Appliances can be turned on or off and the light intensity can by adjusted. These individual settings for the services can be stored for later replaying after a service change.

The built-in brightness sensors are considering the effects of external light sources as well. This guarantees that external influences are taken into account when controlling the illumination.

Overall, the system architecture includes three layers: the hardware layer, the abstract layer and the user-oriented layer.

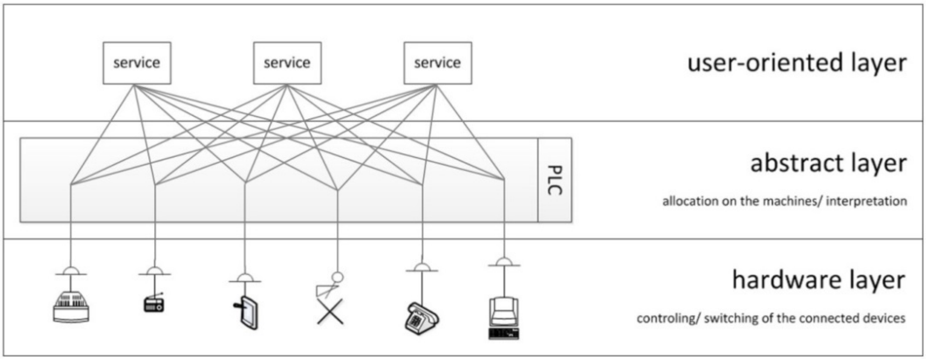

Fig. 2. The systems layer-based architecture

The user-oriented layer is the interface to the user. It provides the user's access to the system. In particular a tablet computer interface offers different views to the system, according to differing demands of several user groups. There are technically-skilled users, who want a detailed access, and technical-agnostic users who want a very simple and easy-to-use interface.

The hardware layer is the technical foundation. It is the layer, where the DC net is physically implemented and the appliances are connected and switched.

Between these two layers, there is an abstract layer. This layer serves as the translator between the other two layers. Here are the connection points established. It does not only interface with the two other layers. In this layer, all information and signals of the whole system are collected. The service processes, which were introduced earlier in this paper, are running here. This layer makes the system smart.

5 Discussion of Results and Critical View

It has been shown that different components with different DC-energy-level-demands and user-based requirements can be connected interoperable. In particular the appliances power slots are designed in a new and innovative way, so the appliances are directly provided with DC voltage. This makes the use of AC and DC converters unnecessary. It allows increasing the energy efficiency of the overall system.

The system is able to remember the resident's individual preferences of a feel-good atmosphere. The room is able to react on its environmental variables, for example the intensity of the solar radiation.

Because the appliances landscape is not yet very flexible, the implementation of services has to be classified as a static implementation. Each device has to be manually integrated into the system. This does not reflect the dynamics a user likes to have in his apartment. In fact, during the day he connects various appliances to the power supply and removes them again. This is not represented in the actual model.

6 Conclusions and Further Work

Within the built model it is shown how different voltage levels are provided to different consumers in a DC network. Using their specifically designed plugs the appliances get access to the relevant voltage level from the energy net, so no converter has to be used at this point. That increases the energy efficiency of the system significantly and user-side mistakes are prevented in advance.

In the next step, this interface should be made more intelligent, so that the appliances can tell the system what kind of devices they are (and what energy they need). Technically, this should be implemented by a NFC tag (near field communication) that is attached to the power plug of the appliance and behind the socket of the power outlet. By plugging the plug into the socket a data exchange connection is built like the universal plug&play method. So the information is exchanged, which voltage level must be provided to the appliances and how the devices may be integrated into the already existing services. This should be visualized for the user on his tablet-based user interface. If new room usage options are resulting from the enhanced appliances (like plugging in a media server), the definition of new high-level services will be possible. Technical alternative to the NFC technology may be a Bluetooth based technology.

In the basic model, the user accesses directly to the PLC program via the tablet's user interface or the control buttons in the room. The evolution plan of the project envisions the changing of this interface. Appropriate control variables should no longer be stored in the memory module of the PLC, but in a cloud. If the user wants to use a new service, the PLC gets a signal to download corresponding parameters from the cloud to be able to control the appliances. Thus, a continuous exchange of information is not necessary, limiting the information exchange. To manage his housing unit, the user does no longer need to be within the house. He only needs to be able to connect to the cloud and can control his home environment via a remote interface.

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