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Demand side management through home area network systems

Grzegorz Bazydło*, Szymon Wermiński

University of Zielona Góra, Institute of Electrical Engineering, ul. prof. Z. Szafrana 2, 65-516 Zielona Góra, Poland

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ABSTRACT

The increasing demand for power in the Electrical Power System (EPS) causes a significant increase of power in the daily load curve as well as transmission line overload. The large variability in energy consumption in the EPS combined with unpredictable weather events can lead to a situation in which, to save the stability of the EPS, power limits must be introduced or even industrial customers in a given area have to be disconnected, which causes financial losses. Nowadays, a Transmission System Operator (TSO) is looking for additional solutions to reduce peak power, because existing approaches (mainly building new intervention power units or tariff programs) are not satisfactory due to the high cost of services in combination with an insufficient power reduction effect. The paper presents an approach to reduce peak loads with the use of Home Area Network (HAN) systems installed at residential units. The algorithm of the HAN system, executed by the HAN controller, is modeled using Unified Modeling Language (UML). Then using model transformation techniques, the UML model is translated into Verilog description, and is finally implemented in the Field Programmable Gate Array (FPGA). The advantages of the proposed approach are that with only a small loss of residential user comfort, there is a gain in energy reduction for a relatively small cost, an effective and convenient design of the HAN algorithm, and the flexible maintenance of HAN systems. The latter gain is possible thanks to using modern FPGAs, which allow for dynamic reconfiguration of the HAN controller. It means that a HAN algorithm of a selected user can be exchanged without power interruption of other residential users. A practical example illustrating the proposed approach and a calculation of the potential gains from its implementation are also presented.

1. Introduction

Due to the increasing standard of living and rapid technological advances there is a greatly increased demand for electricity. The nature of electricity users depends on the time of year, the type of day (working or weekend) and ad hoc responses to the current weather. Consequently, the power demand curve in the EPS forms valleys and peaks (Fig. 1). These problems are the cause of financial losses in the EPS or transmission line overload, therefore the aim is to equalize the power curve [5]. Issues associated with controlling the DR of residential units are widely described in the literature [42,11,77,33,65,32,25,56,46,28]. Table 1 gives abbreviations used in this paper.

1.1. Energy consumption structure

The residential sector constitutes a very large part of the energy consumption at an estimated 30% of global electricity demand, with a very significant impact on peak demand [29]. Considering the results of analyses of the energy consumption structure in Poland (the daily load curve in EPS in Fig. 1, and the structure of the load in Fig. 2), it can be seen that global trends are confirmed – a significant share in evening peak power is taken by residential users (G11 tariff) and to a lesser extent by companies (C11 tariff). In the case of the Polish EPS, peak hours occur almost every day throughout the year.

This leads to the conclusion that the effective reduction of peak load power in the evening peak load period can be carried out thanks to a commitment to reduction by residential users (households). Such action, because of the considerable power dissipation intervention (a large number of energy consumers participating in the reduction program) must be stimulated, for example, through tariffs or technically aggregated, which may create legitimate concerns as to the effectiveness of the service.

1.2. Existing Polish DR services

To make a proposal more realistic and enable estimation costs, the proposed solution is related to the conditions of the Polish EPS, but may also be applicable in power systems in other countries.

Given the above, the TSO, responsible for the stability of the EPS,

* Corresponding author.
E-mail addresses: g.bazydlo@iee.uz.zgora.pl (G. Bazydło), s.werminski@iee.uz.zgora.pl (S. Wermiński).

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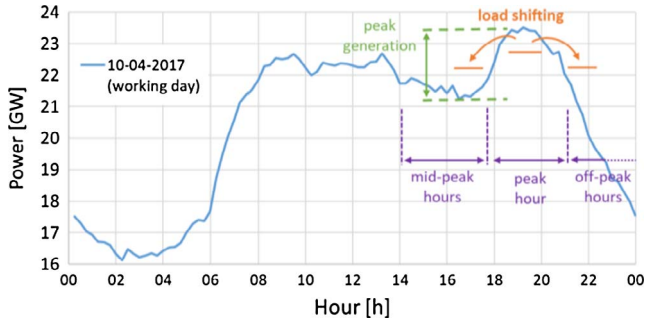

Fig. 1. An exemplary daily load curve in Polish EPS on a working day.
Source: www.pse.pl.

Table 1
Abbreviations used in the paper.

Air Conditioning	AC
Concurrent Finite State Machine	CFSM
Demand Side Management	DSM
Demand Response	DR
Direct Load Control	DLC
Electrical Power System	EPS
Energy Management System	EMS
Field Programmable Gate Array	FPGA
Finite State Machine	FSM
Hardware Description Language	HDL
Heating Ventilating Air Conditioning	HVAC
Home Area Network	HAN
Model-Driven Development	MDD
Systems Modeling Language	SysML
Transmission System Operator	TSO
Unified Modeling Language	UML
Very High Speed Integrated Circuits Hardware Description Language	VHDL

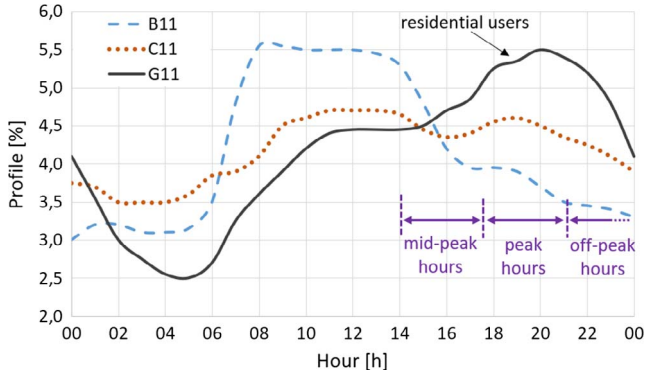

Fig. 2. Electricity consumption profile – single-zone tariff.
Source: www.pse.pl.

launched commercial DSM service elements in the form of several reduction packages. Within each package, the TSO is entitled to a maximum of 15 four-hour reductions in a period of 24 months' service in the respective months of the offered package reduction. The TSO request may involve no more than one reduction during a day and not more than 3 weeks' reduction. The program is aimed at bidders (aggregators or industrial customers) who have a power reduction exceeding 10 MW [55] and the execution of the service is billed based on the volume of energy that as a result of the service has not been downloaded from the power system. The offered price reduction for services reaches the average value of 360 EUR/MWh [53]. The desired (target) amount of power reduction to be achieved through similar services is estimated approximately at 1 GW, which is about 4% of the peak load on the Polish EPS. The main disadvantage of this solution is the significant cost of power reduction service intervention (approximately 360 EUR/MWh) and a not foreseeable enough amount of reduced energy. Moreover, such actions often ended in the failure to meet the expectations of the TSO and payment of fines by users. Currently, the Polish TSO is planning to develop a communication network whereby power reduction can be more effective and predictable [55].

1.3. Price-based and incentive-base DR programs

The price-based and incentive-based programs are aimed at encouraging domestic customers to consume more energy overnight and during the weekends, when the energy price is usually cheaper than during the daytime.

In the case of intentional user prompts for load shifts, the demand-response is related to price-based programs such as Time of Use, where the price of electricity varies during the day within two or three static price zones. With these programs, and under pressure from high energy bills at peak hours the user is forced to modify his energy profile, which does not always achieve the desired effect of reducing peak loads [39], but may cause an increase in charges for energy bills and as a consequence the abandonment of such a tariff program [32,14]. Price-based programs like Real Time Pricing or Critical Peak Pricing [70,76], in practice can only be done by leveraging an automatic management system, for example DLC [59].

1.4. Contribution of the paper

Considering the above, the most effective method of peak hour reduction is an automatic management system implementation at residential units. An important aspect in the DLC systems is the possibility of convenient algorithm change, depending on residential user lifestyle and expectations. This makes the system more user-friendly and impacts on the number of willing participants (increasing the reduction potential). The major contributions of the paper are summarized as follows:

- increase in the ease of use of the HAN system through the flexible and convenient maintenance of HAN systems using modern FPGA devices with a dynamic reconfiguration feature (making it possible to exchange part of the algorithm without interruption of other residential user working devices),
- minimizing user discomfort using current measurement sensors for less invasive control of loads (the HAN system can delay switching off a home appliance until the device completes its work),
- relatively low costs of implementing the HAN-based power reduction service compared with incentive-based programs or the construction of new generating power plants,
- use of standardized graphical specification language and model transformation techniques for effective and convenient design of the load reduction algorithm implemented in the HAN controller,
- hardware verification of the designed HAN controller.

1.5. Structure of the paper

The remainder of this paper is structured as follows. Section 2 provides a quick review of related works. Section 3 deals with the main idea of the proposed approach. A case study of the presented technique is shown in Section 4. Section 5 discusses the benefits of using HAN systems in respect of Polish circumstances and restrictions. Finally, Section 6 is devoted to concluding remarks.

2. Related works

2.1. Load reduction using DLC systems

To meet the expectations of the TSO for reducing peak loads it is necessary to obtain the consent of the residential user to install DLC systems in the household, e.g., Home Automation System [7], Home