Digital Audio Broadcasting (DAB)-based demand-side management for Buildings, Virtual Power Plants and Prosumers

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Abstract

The main objective of this paper is to present a new and cost-effective ICT tool that can lead to efficient energy management in buildings and optimal operation of electricity networks with increased share of Renewable Energy Sources (RES). The new ICT infrastructure is based on the Digital Audio Broadcasting (DAB) standard and its interoperability with smart metering technology, Intelligent Transportation Systems (ITS) and Building Automation Systems (BAS). The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs), and the development of proper DAB interfaces and gateways to building automation systems, in order to enable DAB-based switching of electric loads and implementation of the functionalities for smart metering systems and building automation. The first, necessary step towards the realization of the new technology is the development of a DAB communication protocol.

1. Introduction

The trends of increasing urbanization, increasing number of electric appliances and the expected penetration of heat pumps and electric-vehicles (EVs) lead to the conclusion that the electricity demand in urban areas in Europe will rise in the near future. On the other hand, all European Union (EU) countries have the commitment to increase the share or Renewable Energy Sources (RES), which however are fluctuating and uncertain. Therefore, in many EU countries, the laws allow premium access to the grid for RES. Consequently, weather-dependent RES, such as PV-plants and wind-farms, operate at their maximum possible outputs whenever technically possible and therefore do not follow the variation of energy consumption. In high RES penetration cases and especially whenever local grids (e.g. microgrids) or isolated energy networks (e.g. islands) are considered, the above operational principles and trends include the risk of reduced reliability of power supply to the consumers [1-9]. Hence, a holistic approach is required that will enable at the same time increased RES participation into the energy mixture, grid stability and consumers satisfaction by replicable, cost-effective and advanced technological tools.

Positive trends towards this approach are:

(a) The need of energy efficiency improvement in buildings, which leads to the adoption of Building Automation Systems (BAS) at demand side,

(b) The Smart Grid trend, which will enable a comprehensive interoperable energy management,

(c) Smart meters, which are installed in more and more households to enable time-dynamic electricity tariffs and

(d) The Green Mobility and especially the electro-mobility trend, which turns vehicles into an active part of the grid with storage options.

To address these issues, the authors rely on a new technology in the ICT sector: digital audio broadcasting (DAB) [10-12]. DAB is seen as the replacement for the outdated FM radio broadcasting in many European countries. It is well established and allows transmitting arbitrary data alongside audio programs and is especially suited to address small electric loads for demand response. This technological approach is so far unique and enables new, innovative business models. Due to the cost effectiveness of this technology and the already existing infrastructure, small electric loads can be utilized for demand response which otherwise could not be integrated economically.

The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV units) in order to enable DAB-based switching of electric loads and Distributed Generators (DGs). As a second step, to have the manufacturers of the devices integrate a receiver already in the factory. This integration can involve also several DAB services, from which the user picks one using displays and controls on the devices. Another advantage of the DAB-energy data related concept is the possibility to develop secure interfaces and systems that will enable and enhance the implementation of the functionalities for smart metering systems recommended by the EC (Recommendation 2012/148/EU). For example, a BAS/DAB gateway, that will enable the control of a pool of loads through only one DAB energy data receiver. The functionalities for smart metering systems that will be enabled by the new interfaces will be user-friendly and support implementation of Demand Response (DR) schemes by special user groups, such as elderly persons, disabled persons, etc, with special focus on smart homes.

2. Main aspects of the DAB standard

The nature of DAB as a uni-directional communication standard naturally ensures the protection of users' privacy rights and data protection. There are no further regulatory constraints concerning the frequencies used for the DAB broadcast, as the data is sent within a multiplex with an already existing broadcasting license. Regarding DAB standard and its availability in Europe, in many countries regular service is provided while in the rest, DAB is in the phase of final trials or implementation, as shown in Fig. 1.

DAB is mostly transmitted in Band III (174-240 MHz) and can transport arbitrary digital data in parallel to the live audio stream. The protocol [10] is based on several layers, the lowest ones containing error-correction coding and an orthogonal frequency-division multiplexing (OFDM) modulation. On the higher levels, data can be transported in the fast information data channel (FIDC), which is done already for traffic data and emergency warning system data or it can be transported in the main service channel (MSC). On the broadcasting operator's side, multiplexing is done to combine several audio and data streams into a single data stream. On the receiver side, several commercial DAB baseband receivers are available offering DAB reception on a single IC. DAB receivers exist that combine DAB, FM-radio (including RDS decoding) and WLAN on a single chip. Stand-alone DAB processors can further directly connect to digital displays and device's control keys. Signal decoding can be done on-chip and output through the serial peripheral interface (SPI) or universal asynchronous receiver transmitter (UART) standard. The bitrate of a multiplex can vary, but a typical value for the UK is 1,184 kbit/s.).

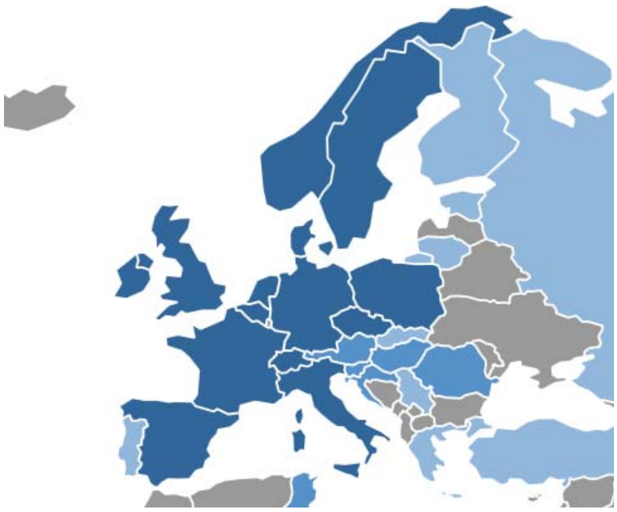

Fig. 1. DAB broadcasting countries: (i) dark blue color: full-scale roll-out with close to 80-100% coverage of private households in the coming years, (ii) blue color: coverage of up to 50% and expectations to switch to DAB in the coming years, (iii) light blue color: trials and services or have plans to switch [12].

3. DAB in the context of energy supply system relevant data

The main goal of using DAB for energy data transmission is to adjust various existing Demand Response (DR) schemes on the Digital Audio Broadcasting (DAB) standard and its secure interoperability with smart meter technology (which can act as a back-channel of the information flow), Building Automation Systems and Intelligent Transportation System technologies. The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV systems and other RES) in order to enable DAB-based switching of electric loads and DERs, and as a second step, to have the manufacturers of the loads integrate a receiver already in the factory. This integration can involve also several DAB services, from which the user picks one using displays and controls on the devices. The electric loads (e.g. heat pumps) are grouped into subsets-clusters. Each subset is treated and addressed as a single unit using the DAB standard, thus representing and demonstrating a virtual power plant that consists of a pool of a large scale of small electric loads or prosumer's. Using this technology, a trade-off is made between the ideal, individual control of each load and the communication and infrastructure costs, which are kept as low as possible, enabling even small loads for demand response and therefore increasing the total available load for demand response. By furthermore equipping the loads with voltage and frequency metering electronics, the devices can contribute to grid stability as well, since they will act properly when local voltage or frequency variations occur. These local voltage and frequency measurements can furthermore ensure optimal security against cyber-crime by decoupling grid stability intelligence of the switchable loads and the information technology infrastructure. The advantages of using unidirectional DAB signalling are the following:

- ✓ DAB is one of the cheapest technologies as it exploits synergies with radio programs, has very cheap and established infrastructure costs as well as inexpensive receiver technology, and this maximizes the total load which can be exploited for demand response. A large city can be connected with a single antenna; for example, compare GSM with 1000 antennas for Berlin vs. 1 antenna for DAB vs. 1 million routers/home WLAN installations for WLAN connectivity.
- ✓ It is the most promising technology for applying emergency grid stability actions, since it reaches simultaneously to a great number of appliances with minimum time delays.
- ✓ It has very good reliability; it has emergency battery supply in the case of a blackout which is much more robust than other technologies.
- ✓ It can be easily integrated into existing devices/appliances. Therefore, a much larger market can be addressed.
- ✓ It is future proof (compared to FM radio, even though both systems may exist in parallel for some time).
- ✓ It can be combined with local voltage/frequency measurements to obtain a technology with very high protection with respect to cyber-security issues.
- ✓ There are no privacy/data protection issues.
- ✓ There is reception in buildings and outside.

- ✓ It is one of the few demand response technologies that can be easily attached to special loads, like pumps used in agriculture, etc.
- ✓ In a final solution, the DAB receivers are integrated into the appliances by the manufacturer already, bearing also a “DR-enabling label” in analogy to the “EU energy label” for devices which support this feature.
- ✓ In a final solution, standardization efforts (starting during the project) will lead to the development of one (1) protected DAB communication protocol for DR schemes.

As the DAB standard is already available in most parts of Europe, in 2015 uGreen AG has conducted the first feasibility study, demonstrating a DAB controlled switching of an electric load under laboratory conditions for the first time. Therefore, broadcasting electricity grid relevant data to various electric loads in a large scale urban environment using the DAB standard can be applied. The long-term ambition is to provide this service alongside the DAB signal in Europe and any location where DAB or similar standards are available.

4. DAB protocol extension for transmission of energy data and DR schemes

The first, necessary step towards the realization of the new technology is the development of a DAB communication protocol that will enable the functionalities of the smart buildings and of the smart electricity grids. The potential of smallest household loads for demand response, prosumers and PV plants is enormous and of the order of billions in Europe. The requirements of such a protocol (DAB+) are:

- ➢ The protocol extension should integrate into existing software from the transmitter side as multimedia objects. Reception and decoding should be possible using currently available digital broadcast receiver integrated circuits.
- ➢ The transmitted data is placed as encrypted data within the DAB data stream.
- ➢ The protocol is modular and new features can be added at a later time.
- ➢ The protocol has to support very low datarates (one DAB capacity unit, corresponding to approximately 1 kbit/s) and high reliability. This excludes for example any ascii based encoding such as XML.
- ➢ There is the possibility to transmit conditions and parameters.
- ➢ Despite a flexible and extendible structure, the protocol is always unambiguous and no freedom for interpretation by the receiver side exists.
- ➢ The data sent is intended to be read by electrical loads (or machines in general). It should be possible to distinguish between different classes of loads, but it is not intended to address individual loads only.
- ➢ There is the possibility to address loads only in a specific region or only for a specific timeframe.
- ➢ The system as a whole is robust to transmission errors in any case (even if no data is received at all).
- ➢ There is a way to guarantee that received data is free of errors.

The overall structure is as follows: The protocol itself is structured into data packages which are considered to be transmitted instantaneously. Each data package contains zero or several ”and-condition” fields, one or more parameter fields and zero or several ”or-condition” fields. Only if the receiving device meets all conditions of the “and-condition” fields and at least one condition of the ”or-condition” fields, it will regard the parameter fields. If a condition field is not known to a receiving device, it is considered as not fulfilled. If no “or-condition” fields are present, it will be interpreted as a valid condition. Newer data packages overwrite settings or data of older data packages if they are contradictory. It is legitimate that a package is not received due to data losses during transmission. A parameter field can contain data such as a price signal for example or a command code to lead to a behavioural change of the receiving device. If the field is unknown to the receiving device, it is disregarded.

And-Conditions: Each condition field consists of a key and a value pair which have to be defined in a table. These comprise, for example:

1. Location: Two lines of longitude and two lines of latitude which describe an area the receiving device has to be contained in.
2. Time-frame: A starting time and ending time which has to be fitted. After the ending time, parameters are set back to default values.
3. Device class: A classification number of a device.

Parameters: Each parameter field is supposed to carry parameters or, more general: arbitrary data. Each Parameter field is separated into a key and a value field. Possible parameter fields are, for example:

1. Price: a price value.
2. Temperature: a reference temperature value.
3. Command: a command byte leading to some action of the receiving device.

Or-Conditions: These conditions are defined in the same way as the and-conditions, the difference is only in their interpretation. It is sufficient that a single or-condition is valid for the parameter fields to be regarded by the receiver, while all the contained and-conditions have to be met.

Full protocol: The full protocol contains a header with version and length infor-mation and cryptographically relevant bit. It uses 128 or 256 bit AES encryption and an additional 1 byte CRC. The and-conditions, parameters and or-conditions are aligned in this seemingly unlogical order to minimize the amount of necessary separation characters.

A main concern of the application of the DAB+ protocol to the electricity grid devices is the back-channel information flow from the loads, prosumers and PV installation to the DSOs or energy providers. This should be achieved through the smart metering infrastructure and is possible, since DAB+ receivers are supposed to be installed to smart meters as well. Thus, the smart meter will send data back to the DSOs and energy providers on-demand, i.e. only when it receives the DAB signal to do so, e.g. after an emergency request for reducing the output power of a PV installation or for switching on or off or dimming loads, or when it receives a signal for DSM policy application, etc. This way, data transfer congestion is avoided and an immediate feedback, of which PV installations or loads responded, is available. The adjustment of the DAB receivers even to existing smart meters is possible, since DAB extension boards and interfaces to other protocols (MODBUS, etc) are already available [1], such as the ones shown in Fig. 2 [11].

Fig. 2. A DAB+ DIN-rail controller

5. Example of DAB usage for domestic load switching

We report on a first proof of concept of the technology, using a precursor protocol version. The proof of concept was done with the help of SwissMedia-Cast AG in Switzerland. During this proof of concept, data was transmitted in northern Switzerland for several weeks and processed by specially developed electric receivers which were attached to different electric loads. Control data was transmitted and received successfully. In Fig. 3, the results of the operation of a refrigerator with an attached DAB+ receiver and a wireless thermostat are presented. However, it is obvious that the operation curve of a heat-pump or an air-conditioning unit would be similar with Fig. 3.

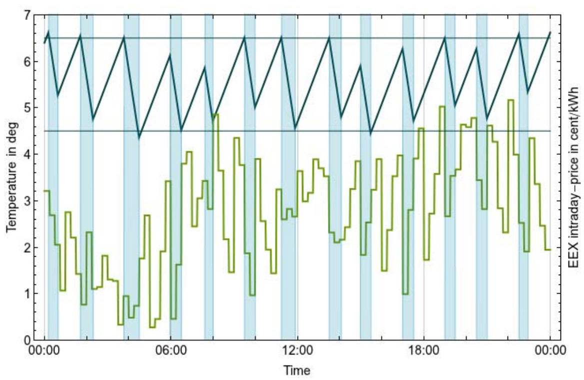

Fig. 3. Operation of a refrigerator with attached DAB+ receiver. The right-hand side prices are Phelix intra-day trading prices, 20 Aug. 2014 (data: epexspot.com) but could also be any arbitrary price signal.

The green line is the energy-charging prices, which are transmitted through the DAB+ protocol. The blue line is the inner-temperature variation of the device. The down-hill slopes correspond obviously to the operation phase of the cooling system, whereas the up-hill slopes correspond to the idle phase of the cooling system. The command for the starting or the stop of the cooling system comes from the thermostat and the DAB+ receiver, which is programmed to take into consideration not only the inner-temperature upper and lower limits (here 6,5 ºC and 4,5 ºC respectively), but also the cost-effective operation according to the price line. So, it is obvious that the down-hill slopes of the temperature appear almost concurrently with local minima of the energy prices.

6. Conclusions

The main objective of this paper is to present a new technology for the efficient energy management of electricity loads in buildings and cities in the framework of the smart grids trend. The new technology is based on the Digital Audio Broadcasting (DAB) standard and its interoperability with smart metering technology, that optimally utilize the Distributed Energy Resources (DER) penetration and energy price signals. DAB is a powerful and highly reliable technology and its integration with smart grid can enable secure contribution of distributed load in the power grid. The main idea involves the attachment of a DAB receiver to electric devices (from small household appliances up to EVs and PV plants) and the development of proper DAB interfaces and gateways to building automation systems, in order to enable DAB-based switching of electric loads and enable the implementation of the functionalities for smart metering systems. In this paper, the DAB+ protocol is described, enabling high cyber-physical security and support of virtual power plants that include a large scale of small electric loads (household appliances) and small DER units that are addressed using the DAB standard. The new technology can be easily compatible with building automation networks and technologies for smart city applications, which also include smart energy meters operation and with the Intelligent Transportation Systems (ITS) technology that is developed rapidly and it concerns Grid To Electric-Vehicles communication tools (G2EV).

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