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Application of Hierarchical and Distributed Cognitive Architecture Management for the Smart Grid

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ABSTRACT

Moving from the current power grid to the Smart Grid (SG) requires decentralizing management. This should be done by distributing intelligence over the entire grid, thereby, the intermittent production of renewable energy, customer consumption and electricity storage in electrical vehicles (EVs) could be managed in real time. In this paper, the Hierarchical and Distributed Cognitive Radio Architecture Management (HDCRAM), initially proposed to manage Cognitive Radio systems, is proposed for the management of the SG. This architecture can both be applied to the whole SG and to any sub-part (distribution network, production network, microgrid). In this paper we focus on the distribution network and the hierarchical position of each element is identified. As an example, HDCRAM is used for smart home management and multi-agent based modeling shows benefits of such an architecture. In the simulated scenario, without any management the peak power consumption is 5500 W and the hierarchical and distributed management allows to reduce it to 900 W. This diminution allows to reduce the pressure on the grid and can decrease the risk of failure.

1. Introduction

The European Technology Platform (ETP) Smart Grids was set up in 2005 to create a joint vision of European networks for 2020 and onwards [1]. According to the European Commission, the definition of the Smart Grid is as follows [2].

Definition 1. A Smart Grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.

A more explicit definition is given by the *Energy Independence and Security Act of 2007* [3].

Definition 2. The term "Smart Grid" refers to a modernization of the electricity delivery system so that it monitors, protects, and automatically optimizes the operation of its interconnected elements, from the central and distributed generator through the high-voltage transmission network and the distribution system, to industrial users and building automation systems, to energy storage installations, and to end-use consumers and their thermostats, electric vehicles, appliances, and other household devices.

This latter definition (Definition 2) incorporates the distribution and transmission networks that are major agents in the Smart Grid. Moreover, it includes many different actors that will participate in the Smart Grid such as electric vehicles, thermostats, etc. Six categories of communications have been identified by the Department of Energy (DOE): Advanced Metering Infrastructure (AMI), Demand Response or Demand Side Management (DR or DSM), Wide Area Situational Awareness (WASA), Distributed Energy Resources and Storage (DERS), Electric Transportation or Electric

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Vehicles (ET or EV) and Distribution Grid Management (DGM) [4]. Management of such a complex network is of great importance and this is the purpose of this paper. The electrical grid will become a smart system. Introducing smartness is all about increasing communications between local entities in order to coordinate all the elements of the global system.

Indeed, it is mandatory to refer to communications when we talk about the Smart Grid. The data volume exchanged by the different actors is such that it would be impossible to transport the data without a reliable and distributed communication system. Cognitive radio [5,6] could be an efficient way to transport the data without overloading the frequency spectrum [7]. It has been envisaged to use different frequency bands for cognitive communications for the Smart grid [8], for example, free TV bands [9,10], in [11], authors consider the use of cognitive communications over unlicensed band for home communications and over licensed band for communications over longer distances. In [12] the smart grid is viewed as a huge Wireless Sensors Network (WSN) in which all the elements of the smart grid communicate using cognitive radio. These papers are applying Cognitive Radio to the Smart Grid from the SG communication point of view. In this paper, the application of CR is done through the application of a Cognitive Radio Manager to the Smart Grid. The Smart Grid management architecture affects the complexity of the management of cognitive radio equipments, as a consequence, the design of the architecture must take into account the communication system.

In order to fulfill the communication requirements of the SG, we propose to use a Cognitive Radio Management Architecture that was initially proposed during the first CROWNCOM conference in 2006 [13]. This architecture, named HDCRAM for Hierarchical and Distributed Cognitive Radio Architecture Management, was successfully demonstrated in several Cognitive Radio (CR) scenarios such as the Dynamic Spectrum Access (DSA) [14,15][1].

We believe that the current centralized management of power system, is not suitable anymore for several reasons such as the increasing consumption, the introduction of distributed renewable energy (distributed geographically and in time), the customers involvement, the huge amount of data to handle, etc. We believe that, in the case of the management of such a big and complex system as the SG, the management should be distributed among all actors of this system and HDCRAM could be a management solution. This is what we would like to highlight in this paper.

Some hierarchical and distributed architectures have already been proposed for the Smart Grid. In [16], coordinators receive information from consumer or from the lower level coordinators and broadcast to all agent the same data which are used to make decisions. In [17], the architecture has three levels and decision can be done at the microgid level, at the feeder level or at the substation level. In these articles hierarchical architectures are only used for demand-side management and for management pricing. In [18], a detailed hierarchical and distributed architecture is proposed for microgrid management but this architecture hasn't been applied over a larger part of the grid as we do in this paper.

In summary, in this paper :

- A hierarchical architecture (coming from Cognitive Radio domain) is proposed for the distribution network and is used to manage consumption, intermittent production, storage and grid monitoring;
- The hierarchical position of each element of the grid (e.g. Smart Meters, Phasor Measurement Units (PMUs) or EV aggregator) is clearly identified in this paper.
- This architecture is finally implemented for Smart Home management .

This architecture can also be mapped on any of the sub parts of the SG. Moreover, HDCRAM is composed by two independent paths, one for the cognitive management and the other for the (re)configuration management, that differentiates it from existing solutions.

This paper is organized as follows: Section 2 describes the basics of HDCRAM, while Section 3 proposes the deployment of HDCRAM for the SG (illustrated by two clear schemes). In this section, the metrics used for both the cognitive information and the reconfiguration orders are also described for some elements of the networks. Section 4 gives a concrete example of application of HDCRAM for Smart home management and its simulation results otained through using JADE (Java Agent DEvelopment Framework). Conclusions are drawn in Section 5.

2. Hierarchical and Distributed Cognitive Radio Architecture Management (HDCRAM)

This section presents an architecture designed at first for Cognitive Radio purposes[19]. Its name is Hierarchical and Distributed Cognitive Radio Architecture Management, in short: HDCRAM. The HDCRAM architecture is depicted in Fig. 1. The cognitive cycle (see Fig. 2) shows that a Cognitive Radio equipment or system has three main activities: a sensing activity, an intelligent activity (decision making) and a reconfiguration activity (adaptation). In HDCRAM, those activities are distinguished. The two other characteristics that are also well separated in HDCRAM, are the management architecture (level 1, 2 and 3) and the radio transceiver chain (at operator's level). Hence HDCRAM is all that has to be added to transform a non-intelligent legacy system to a smart system, whatever the system is: radio, grid, city, car, etc.

As it can be seen in Fig. 1, this architecture comprises two managing sub-parts [20]:

- A cognitive part featuring Cognitive Radio Management Units (CRMu): a CRMu exchanges information from the lower level to the upper level only. This entity has intelligent capabilities, and can make decisions and alert the upper-level CRMu;
- A reconfiguration part featuring Reconfiguration Management Units (ReMu): a ReMu exchanges information from the upper to the lower level only. This entity receives reconfiguration orders from the upper level and transmits them to the lower level ReMu.

[1] A demonstration is also available on the internet : https://youtu.be/0-MIpPwgG4E