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ScienceDirect

Procedia Computer Science 112 (2017) 167–176

Procedia Computer Science

www.elsevier.com/locate/procedia

International Conference on Knowledge Based and Intelligent Information and Engineering Systems, KES2017, 6-8 September 2017, Marseille, France

Microgrid Components Clustering in a Digital Ecosystem Cooperative Framework

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Abstract

A MicroGrid (*MG*) is a distributed power system consisting of a number of heterogeneous components having direct/indirect impacts on each other. In order to provide an appropriate collaboration (from several perspectives) between components, we propose a "Digital Ecosystem Cooperative Framework" called *DECF*. In this paper, we present the clustering algorithm of *DECF* designed to build Alliances by gathering all the DE heterogeneous components having similar needs and preferences. Conducted simulations showed that the proposed algorithms yield significant results.

Keywords: Clustering; Digital Ecosystems; Microgrids; Cyber-Physical Systems; Information Processing

1. Introduction

A MicroGrid (*MG*) is a smaller version of the traditional power grid [10] which consists of a number of heterogeneous components (power generation, electrical loads, and storage systems) all within a controlled network. An *MG* can enhance the power reliability thanks to the local power generation and its ability to be islanded from the main grid. Thus, blackouts and power disturbances are significantly minimized. Since an *MG* is composed of a number of heterogeneous components, each having a direct/indirect impact on the other components and consequently on the entire environment, there is a need of establishing a dedicated internal *MG* cooperation addressing the components' heterogeneity and the problem of power exchange from different perspectives: technical [16], ecological [7] and economical [14]. In addition, the power exchange problem becomes more tricky with the rapidly growing population, the increasing energy demand, and the growing number of electrical equipment to be integrated into the *MG*. However, and to the best of our knowledge, none of the current approaches [16,20,13,12,7,14] seems to keep the pace since they don't consider the aforementioned perspectives at the same time nor allow end-users to fine-tune the importance of each one of them.

To address these issues, we propose *DECF*, a 'Digital Ecosystem Cooperative Framework' designed for optimizing the *MG* power exchange. *DECF* contains two main components: 1) the **Alliances Builder** provides an appropriate clustering algorithm aiming at gathering all the heterogeneous components having similar needs and preferences, and

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Peer-review under responsibility of KES International
10.1016/j.procs.2017.08.010

2) the **Seller2Buyer Matcher** is applied inside each cluster and between clusters, targeting a better collaboration inside the *MG*. In this paper, we detail the **Alliances Builder** of *DECF* and show how it meets the *MG* constraints.

The rest of the paper is organized as follows. Section 2 provides details about existing power exchange optimization techniques and their drawbacks. In Section 3, an overview of our *MG* information layers is given, before detailing and illustrating in Section 4 the clustering algorithm. In Section 5, the experiments conducted to validate our approach and the main results obtained are presented. Section 6 concludes the paper and draws several future directions.

2. Related work

Many approaches have been proposed in the literature to solve the optimization problem of the power exchange. They can be categorized into two main groups: game-theory based[16,12] and agent-based[1,7,11].

2.1. Game-theory approaches

In[16], the main goal was to develop an *MG* power exchange model which incorporates several energy sources (considered as Microgrids), allowing them to reduce the power load on the main grid and to minimize the transmission power losses over the distribution lines. In[12], the authors developed an approach that enables to determine the optimal operation of a solar-powered *MG* with respect to the consumers demands. The adopted scenario is a multiple sellers/buyers scenario, consisting of a village generating enough power and able to satisfy the demands (homes needs). The objective of the proposed approach is to make the village be at least cost-neutral in power while improving the revenue of the producers by comparing the uniform and discriminatory bidding. In[17], the authors developed a non-cooperative model within which the Plug-in Hybrid Electric Vehicles (PHEV) can decide on the amount of energy they want to sell to the main grid. In addition, the authors proposed a scheme for determining the trading price of the power exchanged between the PHEVs and the main grid.

2.2. Agent-based approaches

The literature is rich with examples of agent-based *MGs* optimization applications[1,7,11]. In most of these approaches[11], the *MG* is designed as a distributed power network comprising various distributed agents (generators, storage and loads, etc.) that are operated in interconnected or islanded mode. To do so, JADE framework is commonly adopted for agents' modeling. In[7], the authors developed a multi-agent system that aims to minimize *MG*'s photovoltaic (PV) operating costs and the toxic pollutants emissions while maximizing the output of the energy sources. In[1], a decentralized control architecture for *MG* was presented, aiming at maximizing the use of renewable energy sources and minimizing the use of conventional generators. The proposed control architecture contains different types of agents (such as PV agent, Fuel cell agent, etc.), where each represents a major component in the *MG*.

2.3. Discussion

None of the existing approaches can solve all the requirements presented previously. First, all of the existing approaches do not cope with ALL of the three objective aspects of an *MG*: technical, economical, and ecological aspects. Second, agent-based approaches[1,7,11] showed an efficiency in modeling all types of components, each represented by an agent, while game-theory approaches[16,12,17] failed in doing that by targeting solely the optimization of one type of *MG* components. Third, end-user requirements were almost absent in the existing approaches, with the exception of[7]. All that lead us to develop a new cooperative model, based on a solid information model, taking into account the various aspects of an *MG* while allowing the user to assign each aspect with an appropriate importance.

3. *MG* Information Layers

Beware that the *MG* can be perceived as a cyber-physical system, we designed our *MG* information model as a 5C architecture (Connection, Conversion, Cyber, Cognition and Configuration), complemented with additional modules specific to the needs in the *MG*. Our information modeling relies on three layers briefly described in what follows.

- Field Layer (FL): Via this layer, the data collector gathers all data exchanged between *MG* components via a low-level communication environment[19] relying on standardized protocols (e.g., BACnet[9] , Modbus[15] , etc.). Once gathered, those data are stored in a low-level data repository and pushed up to the next layers.
- Knowledge Layer (KL): In order to resolve the interoperability issues and open up the possibility to model the new trends in today's energy systems (i.e., prosumers, electric vehicle, etc.), it is essential to capture and understand the semantics of exchanged data to ensure a seamless communication between the *MG* components. Through this layer, the semantic middle-ware insures the semantic translation of the collected data using our ontology-based information model called *OntoMG*[18]. Furthermore, the reasoner is responsible of processing information and using it to infer additional value thanks to many rules and constraints defined in this layer.