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Agent Based Simulation Model of Virtual Power Plants for greener Manufacturing

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Abstract

Green energy supply can play an important role for manufacturing companies. To achieve this, companies can support their energy supply with renewable energies (RE). For designing and planning a Virtual Power Plant, the PREmdeK simulation can be used. Realized with the AnyLogic© software, PREmdeK 3.0 simulates combinations of RE sources, energy storages and consumers as a multiagent system (MAS). In this MAS, every member of the local energy system is represented by an agent. The agents negotiate to reach a balanced energy state. The negotiation is based on operating data (energy production and/or demand) and sustainability criteria. The simulation is set up in a generic way, able to reflect changes in the constellation of the energy system. New agents can easily be implemented into the generic MAS through inheritance. In this paper, the implementation of this MAS to handle energy balancing of local energy system including sector coupling is presented.

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Keywords: Green Factory; Multiagent System; Virtual Power Plant; AnyLogic Simulation

1. Introduction

The energy revolution is driven by several reasons, such as the finite nature of fossil energy, the dependence of energy imports on other countries, and the increase of greenhouse gases (GHG) emissions. Until 2050, Germany plans to increase the electrical RE to at least 80% and decrease the emission of GHG by 80% [1]. It is intended to reach this goal by advancing large projects, wind parks and solar parks, but in addition by implementing decentral power systems for small and middle-sized manufacturers (SME). SMEs are a central part of economies worldwide, comprising 99% of enterprises, providing about 60% of employment and being responsible for at least 13% of total energy consumption [2]. Environmental awareness in German SMEs is already an important factor, one in four German SMEs has implemented sustainability measures with energy saving aspects and CO2-emission reduction as driving factors [3]. An interesting option to improve sustainability indicator and decreasing energy costs is the installation and use of a Virtual Power Plant (VPP). A disadvantage of this option is the complex design of the best fitting solution for a local, company owned energy system.

The technical and legal feasibility to install and operate one or more RE producers has been verified, the question of the optimal RE system fitting the SMEs' energy demand and profile has to be decided [4]: Does it consist of one producer or of different ones? In which combination and of which size? To what extent is the energy demand satisfied by the RE? How is an overproduction handled? Is it suitable to store it, or can it be injected into the grid? Under which conditions?

To support decision maker in SMEs to design a suitable VPP, the PREmdeK simulation has been developed at the University of Applied Science Emden / Leer [5]. In German, the word PREmdeK stands for "prognostics and realization of the energy supply through decentral energy plants". The PREmdeK simulation helps to design a VPP that is able to

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cover a specified energy demand, e.g. of certain consumers like production companies. It visualizes and simulates different scenarios through the representation of above mentioned energy producers and consumers. The current PREmdeK version (3.0) allows for the user to quickly design and combine different scenarios for comparison. To achieve realistic results, consumers' historic load profiles and local weather data are used for the calculations.

The distributed nature of this problem makes it perfect for the MAS paradigm, according to the definition of Wooldridge and Jennings [6]. In the case of the PREmdeK 3.0 simulation, an agent represents an element of the local energy system, such as a consumer, RE producer/prosumer or an energy grid. The agent is situated in the simulation environment and is capable to act autonomously for balancing its energy. In most cases, this task cannot be completed by an agent alone. Rather, the agent needs to cooperate with other agents to achieve its objective and the objective of balancing the entire energy system.

This paper presents the architecture and communication concept of a self-organizing and generic multiagent system. The simple architecture with its generic design allows an easy integration of new agents into the system with all its interoperability functions. For this reason, different basic agent types and a suitable communication phase for the energy exchange are defined.

To create the PREmdeK 3.0 Simulation, a multi method simulation platform called AnyLogic© was used [7]. It supports agent-based simulations, system dynamics, and process-centric (discrete event) modeling [8]. Various studies have already compared AnyLogic© to other agent platforms [9–11]. The Java based program supports the concept of inheritance, which is a key factor for our MAS realization. Additionally, the flexibility through the agent based and state chart based modeling led to the decision of using AnyLogic©.

After discussing related work in section 2, the theoretical background of the PREmdeK Project, the AnyLogic© Software, and the MAS with its IEEE standard on Foundation for Intelligent Physical Agents (FIPA©) related realization shall be explained. Section 3 contains the theoretical background of the PREmdeK project, the simulation software and the FIPA© reference architecture. Section 4 covers the concept of the PREmdeK MAS with its architecture, agent design and negotiation approach and the simulation itself. Finally, section 5 presents the conclusion and gives an outlook on further potentials of the PREmdeK simulation.

2. Related Work

Typically, many applications of MASs have been devoted to the management and operation of micro or smart grids. The focus can lie on the optimization of energy distribution [12], the design of an MAS for an easy implementation of VPP [13] or the energy resource scheduling of an islanded power system with distributed energy resources (DER) [14]. The MAS paradigm is mainly used to represent the autonomic members of a grid and achieve the best method to balance the energy. In our case, the focus lies on finding the best design for a local energy system. An energy balancing behavior is needed, but getting a balanced energy system is not mainly achieved through management or operation, but through changing the composition until the intended balancing level can be achieved.

For operation and coordination of DER in grids, the contract net protocol (CNP) is often used. The paper "Multi-agent coordination for DER in MicroGrid"[15] uses it to establish a communication and coordination structure for a scalable system. In "An Intelligent Multiagent System for Autonomous Microgrid Operation"[16] the CNP was used in a modified way to implement the function of announcing a new task, bidding, and awarding a contract. Both use the CNP for the same reason we do: to select the most suitable service provider for a task among several possible service providers.

The PREmdeK 3.0 simulation model approaches the topic from another direction, not designing a MAS for a local energy system, but designing a local energy system with the help of MAS and the focus on specific user scenarios.

3. Theoretical Background

Before discussing the implementation of the MAS architecture, the Negotiation Phase (NP) or the simulation, focus will be put on the project PREmdeK itself, the AnyLogic© software and the specifications from which this MAS is based off.

3.1. The Project PREmdeK

The current version of the PREmdeK Simulation is 3.0. Its predecessors, version 1.0 and 2.0 (see Figure 1), are implemented in AnyLogic© and follow the same energy concept: a simulation for prognostics and realization of the energy supply through decentral energy plants. PREmdeK balances local energy production with energy demands of (industrial consumers) in intervals of 15 minutes for up to a year time frame. The PREmdeK 1.0 simulation started off as a monolithic simulation with a hybrid power plant, grid connection and one main consumer as static and centralized control architecture. The simulation was not scalable and hardcoded without generic setup which made it difficult to change or expand the simulation. The following version – PREmdeK 2.0 – allowed access to databases that include historic weather data and load files. In PREmdeK 3.0, the simulation is implemented as generic MAS.

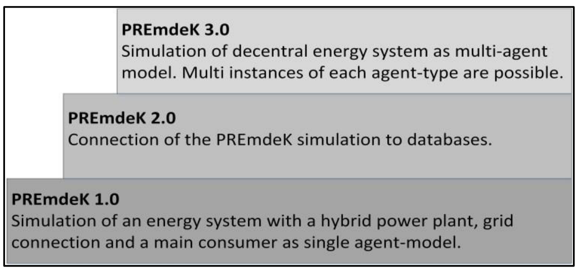

Fig. 1. The evolution of the PREmdeK Simulation