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Kurzfassung

der von Stefan Dähling, M. Sc. vorgelegten Dissertation

„Cloud-based Multi-Agent Systems for Flexibility Management in Future Distribution Grids“

Motivation, Goal and Task of the Dissertation

Electrical distribution grids are undergoing a tremendous transformation process. More and more renewable energy sources are installed and the power demand increases due to the coupling with different sectors such as mobility and heating. These changes require a different operation of the grid. In the past, distribution grids had only the task to deliver power to the end consumer. Moving the power generation to the distribution level leads to a bidirectional power flow. As a result, voltage violations are more likely to occur. New concepts addressing the arising challenges of balancing power generation and consumption are required.

A key concept to address the mentioned challenges is the exploitation of flexibility. Flexibility is made available by shifting the operation of a power producer or consumer in time. In addition to active power flexibility, many components in the distribution level are connected to the grid via a converter enabling a flexible reactive power behavior as well. Besides the functionality, a flexibility management concept has to be scalable and fault-tolerant. This dissertation aims at developing and assessing a flexibility management concept for grid services in the distribution level. Moreover, a modular deployment system enabling scalability and fault-tolerance is developed. In particular the work aims at satisfying the following requirements:

1. Voltage control: Flexibility is used for local voltage control in the distribution grid.
2. Transmission system support: Additional flexibility which is not used for local voltage control is offered to the transmission system.
3. Scalability and fault-tolerance: The concept is highly scalable and it tolerates faults of single flexibility providers and parts of the ICT system.
4. Modularity: The management concept can be rolled out step-wise enabling a smooth transition from the current status. Moreover, it is self-configuring and highly automated.

Major Scientific Contributions

The four requirements are considered in a three step approach. These steps also depict the major scientific contributions of this dissertation.

In a first step, the requirements 1 and 2 are addressed by a multi-agent based flexibility management concept, called SwarmGrid-X. In SwarmGrid-X each power producer and consumer is represented by one agent. Producer and consumer agents constantly negotiate the amount of power that is produced and consumed, aiming at balancing production and consumption as locally as possible. Multiple voltage levels are integrated in the concept by means of a holonic architecture. Also the transmission system is represented by one agent which participates in

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the negotiation process to drive the entire distribution grid towards a desired behavior. Several scenarios representing possible developments of future distribution grids are simulated. Results indicate that SwarmGrid-X is capable of using flexibility for the purpose of voltage control. Specifically shifting electric vehicle charging processes and the use of reactive power during times of high PV power generation turn out to be key flexibility sources that are successfully exploited by SwarmGrid-X. Also the support of the transmission system by means of a specific set-point for the reactive power exchange at the point of common coupling is demonstrated.

The second step deals with the implementation and deployment of the concept targeting the requirements 3 and 4. While multi-agent systems (MAS) generally enable high scalability and fault-tolerance, a poor implementation might destroy these features. In fact a literature review reveals that popular multi-agent platforms (MAP), such as JADE, are not well suited for large-scale MASs comprising thousands of agents or even more. That is why a novel MAP based on cloud computing techniques is developed as part of this dissertation: cloneMAP. It utilizes a microservice architecture which enables horizontal scalability and fault-tolerance of platform components. Also on agent level fault-tolerance mechanisms are implemented. A performance comparison with JADE based on different benchmarks reveals a massively improved scalability of agent messaging and platform components. Fault-tolerance is demonstrated successfully as well.

In a third and last step SwarmGrid-X is implemented using cloneMAP. The resulting software is executed as a real system and coupled with a scalable software-in-the-loop simulation methodology to simulate the distribution grid. An assessment shows that the functionality of SwarmGrid-X is not affected by the integration with cloneMAP and that the performance is sufficient for the purpose of flexibility management.

Major Publications

- S. Dähling, S. Kolen, and A. Monti. "Swarm-based automation of electrical power distribution and transmission system support". In: IET Cyber-Physical Systems: Theory & Application, 3.4 (2018), DOI: 10.1049/iet-cps.2018.5001
- S. Dähling, L. Razik, and A. Monti. "Enabling scalable and fault-tolerant multi-agent systems by utilizing cloud-native computing". In: Autonomous Agents and Multi-Agent Systems, 35, 10 (2021), DOI: 10.1007/s10458-020-09489-0
- S. Happ, S. Dähling, and A. Monti. "Scalable assessment method for agent-based control in cyber-physical distribution grids". In: IET Cyber-Physical Systems: Theory & Application, 5.3 (2020), DOI: 10.1049/iet-cps.2019.0096

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