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Blockchain-based orchestration of distributed assets in electrical power systems

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Abstract

For historical reasons, power systems are designed, controlled and operated centrally. A coordination of the rising number of increasingly heterogeneous, small-scale and citizen- or company-owned assets is not possible with this approach, especially not in the distribution system. The goal of the PhD project presented in this extended abstract is to find out how well distributed approaches perform in orchestrating distributed assets in future power systems from a holistic point of view in comparison to centralized approaches. The research questions are defined and the planned methodology of the project is presented. The most promising use cases in this context are identified, the concept of a decentralized virtual power plant is proposed as a new use case for providing flexibility with small-scale assets and the first ideas for an evaluation framework are presented. Next steps in the project are refining the evaluation framework and evolving the yet existing lab setups. Once these are completed, simulation models can be developed and the main research questions can be answered in detail.

Keywords: Decentralized power supply, Distributed ledger technology, Blockchain, Cellular concept, Renewable energies

Introduction

Our society depends on a reliable power supply. Therefore, the electrical power system (EPS) is traditionally planned and operated hierarchically and centrally. However, this does not reflect the increasingly decentralized and volatile energy landscape. The rising number of highly heterogeneous actors in the EPS results in an increased total complexity of the system. Many of the newly installed distributed assets generating renewable electricity are owned by citizens or small companies and are thus not controlled centrally.

A bottom-up approach like the cellular concept (Benz et al., 2015) is able to face the increasing complexity in the system. According to the cellular concept, locally limited areas consisting of electrical producers, consumers and storages form an energy cell. Many of these cells form a larger cell, in which the individual cells organize themselves and balancing is done at the lowest possible level. In this context many recent studies and publications attribute a high potential to peer-to-peer (P2P) approaches based on distributed ledger technologies (DLTs) (BDEW Bundesverband der Energie und Wasserwirtschaft e.V., 2017; Dütsch & Steinecke, 2017; Merz, 2016). Therefore, we investigate if and how an orchestration of assets in the EPS is possible according to the cellular concept and based on DLTs, such as blockchains (Nakamoto, 2008). This extended abstract presents the current stage of my according PhD project including the definition of the research question, related work, the proposed methodology, first results and a conclusion.

Research question

Assuming the hypothesis that a distributed approach is desired in order to (self-) coordinate distributed assets in the EPS for political or philosophical reasons or owner preferences, the central research question (RQ) of this research project is: *(How) can distributed assets in a future EPS empowered by renewable energies and storages be orchestrated in a distributed way* and in particular *how well perform blockchain-based approaches in this context in comparison to centralized approaches*? In order to answer this question the central research question is split into the following subquestions.

- **RQ1:** Which are the use cases of interest?
- **RQ2:** Which metrics are of importance in order to quantify how well blockchain-based approaches suit the selected use cases? How are these metrics formally defined and quantified?
- **RQ3:** Can the use cases with their quality of service requirements be realized with blockchain-based approaches? If yes, which possible different blockchains designs are most suitable and how do the different designs influence the determined metrics?
- **RQ4:** How well perform and how large is the extra effort of blockchain-based approaches in comparison to a centralized approach for the selected use cases from a holistic point of view? Which type of blockchain is most suitable?

As shown in Fig. 1, the final subquestion builds upon the previous RQs and aims for a comprehensive answer of the central research question given at the beginning of this section. The costs of disintermediation in the identified use cases in RQ1 are evaluated in a quantitative way applying the metrics defined in RQ2 and considering the results from RQ3.

Related work

The earliest and probably best-known blockchain-based local energy market (LEM) project is *The Brooklyn Microgrid* (Mengelkamp et al., 2018a). This pilot was followed by research projects like the *LAMP* project (Mengelkamp et al., 2018b). The new project

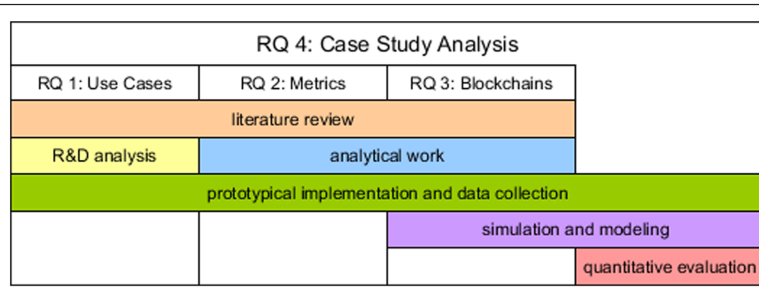

Fig. 1 Overview of RQs and proposed methodology

Pebbles aims for an integration of grid friendliness in LEMs (Allgäuer Überlandwerk GmbH, 2018). The *Enerchain* project tackles large-scale electricity trading in Europe (Merz, 2016). The *Energy Web Foundation* aims at accelerating blockchain technology across the energy sector. Therefore, they build upon *Ethereum* and develop a downward compatible blockchain suitable for energy related applications (Energy Web Foundation, 2018). The Token *NRGcoin* (Mihaylov et al., 2014) enables decentralized electricity trading as well but in addition allows for demand response. Equally, *Power Ledger* (Power Ledger, 2018) provides a decentralized platform for P2P electricity trading.

In terms of evaluation metrics considering blockchain technology a good starting point is offered in (Wüst & Gervais, 2017). Furthermore, a performance analysis for private blockchains is presented in (Pongnumkul et al., 2017) and first benchmarks considering private blockchains are described in (Dinh et al., 2018). They conclude that there is still a big performance gap between blockchains and current databases.

This PhD-project bases upon preliminary research concerning simulation of and algorithms for an efficient and decentralized provision of ancillary services by conventional virtual power plants (VPPs) with a central information technology (IT) infrastructure (Schlund & German, 2017; Schlund et al., 2017; Schlund et al., 2018a). The project intends to analyze existing and think of new use cases, to develop an unbiased evaluation framework for such use cases, to identify the most suitable blockchain designs and to quantify the extra effort of a blockchain-based approach in comparison to centralized approaches for the most promising use cases. Therefore, it complements and fits in well in the overall picture.

Proposed methodology

The general idea of the PhD-project is to simulate the use cases of interest with different blockchain networks in order to evaluate them according to a defined evaluation framework and to use prototypical implementations for the validation of the simulation models. Therefore, the proposed methodology consists of a theoretical and an empirical part. The theoretical part includes literature reviews, an analysis of current research developments and analytical work. In the quantitative part, prototypical implementations and experimental test runs are used for data collection and extensive simulation and modeling is used for studying the use cases. In order to mind both IT and EPS layer probably hybrid simulation including discrete and continuous simulation will be used. An overview of the proposed methods for answering the RQs is visualized in Fig. 1.

First results

In this section RQ1 is partially answered and first ideas considering RQ2 are summarized.

RQ1: Identification of the use cases of interest

Considering RQ1, use cases of interest have been identified as visualized in Fig. 2. The use cases are clustered into three subgroups presented successively in the following.

The first subgroup is P2P electricity trading. A central trusted third party (TTP) contradicts the idea of P2P trading and obviously storing state is necessary for being able to trade. In addition, a trading partner might be unknown and therefore possibly untrusted. This is the area in which most research and development is done at the

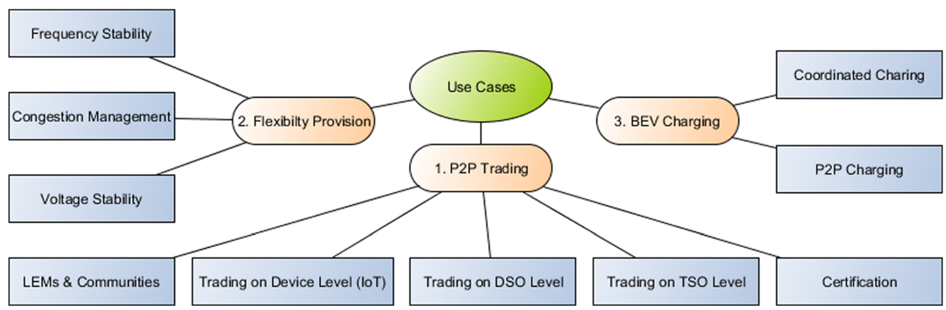

Fig. 2 Identified use cases in RQ 1

moment and in which recent studies see a high potential, mainly because local trade is currently not possible due to the complexity in current electricity trading processes. Specifying, the use cases of interest are electricity trading on different levels, each with different requirements. The most investigated use case at the moment is LEMs (or communities), in which P2P trading (or sharing) is facilitated between end consumers or producers in a locally limited area. The same concept is also applicable on other levels, from device level up to distribution system operator (DSO) or transmission system operator (TSO) level. Besides trading the electricity, trading of certificates of origin or CO_2 emissions is also possible. This is mainly motivated by the properties of blockchains considering transparency and immutability.

The second subgroup is the provision of flexibility as an ancillary service for the EPS. In comparison to the market-based approaches summarized under P2P electricity trading, this approach faces the need for flexibility in the EPS in a more straightforward way. So far, such flexibility is either provided by central power plants, which will become less in numbers in future, or by centrally controlled VPPs. A new blockchain-based approach for such services is a decentralized virtual power plant (DVPP), which is a self-organized VPP and thus without the need for a central operator. This way there are no costs for an always-online TTP and the participants can profit from the full economic benefit. The DVPP has thus the potential of organizing and mobilizing small-scale distributed flexibility sources, which are not part of a VPP and do not have access to a flexibility market so far. In analogy to a VPP, possible applications are frequency or voltage stability or congestion management. Such a DVPP is currently implemented in our lab and a pre-stage of is published in (Schlund et al., 2018b).

The last identified subgroup is battery electric vehicle (BEV) charging. This is chosen as it is expected that the share of BEVs will increase drastically in the next years and because uncoordinated charging might cause problems in distribution grids. A TTP is undesirable as there are many different charging station operators and energy providers involved. As of today, problems already exists considering the interoperability between different providers.

RQ2: First ideas for an evaluation framework

So far, two different classes of metrics have been identified: quantitative metrics, which can be derived by means of the simulations and qualitative metrics, which only play a secondary role in the PhD project. The main metrics for the quantitative evaluation of the suitability of the bockchain-based approaches are:

- the **general performance** from the point of view of the EPS
- the **investment and operational expenses** from the point of view of the IT system
- the **scalability**
- the **level of decentralization**

In total, the cost of disintermediation is valuated by restraints in performance, additional holistic costs and limitations in scalability. In addition to the quantitative evaluation, the subordinate qualitative metrics are the security of the EPS, data integrity, transparency and privacy. These are the first ideas considering the evaluation framework. However, the metrics need to be formally defined to be able to quantify and evaluate them at a later stage of the PhD-project. This formal definition is the next step in the PhD-project.

Conclusion and outlook

This extended abstract describes the current stage of my PhD-project. The aim is to provide a foundation for deciding how to orchestrate distributed assets in a future electrical power system empowered by renewable energies and storages under the hypothesis that a central control is not desirable. Specifically, the main research question is to investigate how large the necessary extra effort of distributed approaches based on blockchain technology is compared to a centralized approach from a holistic point of view. An overview of the related work is given and this project is placed in the research landscape. Planned and partly already applied methodologies are literature reviews, lab setups and hybrid simulation.

The use cases of interest are identified as different P2P electricity markets, distributed flexibility provision, BEV charging and its coordination. With a DVPP, a concept for self-organized distributed flexibility provision is proposed. However, the DVPP implementation still needs to be formally described, refined and analyzed more in detail. Besides that, a second lab setup of a peer-to-peer electricity market with a focus on grid-friendly operation is currently in work. First ideas for an evaluation framework are provided here, its formal definition is still pending. Considering blockchain design, permissioned blockchains or hierarchical hybrid public and consortial proof-of-authority multi-chains seem promising at the current stage of the project. Next steps are investigating analytical relationships between blockchain designs and the quantitative evaluation metrics and building simulation models, which will be used in the last step to extensively answer the central research question.

Abbreviations

BEV: Battery electric vehicle; DLT: Distributed ledger technology; DSO: Distribution system operator; DVPP: Decentralized virtual power plant; EPS: Electrical power system; LEM: Local energy market; P2P: Peer-to-peer; RQ: Research question; TSO: Transmission system operator; TTP: Trusted third party; VPP: Virtual power plant

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Author's contributions

This is a single-authorship paper. All work was done by the author. The author has written, read and approved the final manuscript.

Competing interests

The author declares that he has no competing interests.

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