Local Energy Supply from Campus to Community – A Taxonomy of Microgrids

BACHELORARBEIT

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1 Introduction

Climate change, its causes, and its consequences have been an ongoing issue for the last decades. One of the greatest challenges mankind is currently facing is the mitigation of the climate change. According to the Intergovernmental Panel on Climate Change (IPCC), a global warming of over 1.5 degrees Celsius must be prevented to avoid serious irreversible consequences for humans and the nature (Masson-Delmotte et al., 2018).

However, based on the latest reports of the IPCC, the situation has deteriorated to such an extent that the beforementioned critical level of 1.5 degrees Celsius is expected to be reached in the year of 2030 already (Masson-Delmotte et al., 2021).

The global warming is mainly caused by the emissions of human consumptions and the increased concentration of greenhouse gases (GHG) in the earth's atmosphere. To provide a measure of the maximum amount of GHGs tolerated, in order not to miss the 1.5 degrees Celsius target, the Mercator Research Institute on Global Commons and Climate Change (2021) has calculated the carbon dioxide (CO_2) budget. That currently adds up to approximately 330 billion tons of carbon dioxide equivalent (CO_{2eq}). With the current emission of GHGs exceeding 45 billion tons of CO_{2eq} per year, this would result in exhausting the budget in less than eight years (Breitkopf, 2021).

If the distribution of emissions per sector is considered, it becomes clear that the energy sector contributes significantly to the global emissions. This is due to the predominant combustion of fossil primary energy sources for the generation of energy (Climatewatch, 2018). Thus, a sudden transition to renewable energies is urgently necessary.

Due to their properties, renewable energy sources (RES) are mostly located in a distributed manner, which is why the energy supply with predominantly RESs is described as decentralized energy supply (Badeda et al., 2015). One way of integrating distributed energy resources (DER) and enabling decentralized energy supply are microgrids (MG), which are small electricity grids that directly transport energy, generated by DERs over short distances to the loads.

As MGs are not a new invention, a number of scientific papers are already available. However, this literature often includes very theoretical and specific descriptions of individual design elements and functions. For instance, Vergara et al. (2018) only focus on the properties and possibilities of the design of the energy management systems, while Tan et al. (2013) exclusively examine the technologies of different storage systems.

Most of the existing classifications are limited to a small subset of the relevant aspects (e.g., (Zhu et al., 2020)) and only a few cover a wider range of subjects (e.g., (Shahbazitabar et al., 2021)). However, the link between theory and practice is often missing and evokes a gap between these areas, which hinders the classification from finding application in practice.

Although previous research has identified applications areas for MGs that are mainly selected from their location, no research has been conducted on application-specific design elements.

Thus, there is a lack of research that groups and organizes MGs based on certain empirical patterns in the design elements. Such archetypes help practitioners and researchers to identify the relevant components and functions for specific application areas.

To bridge these research gaps, this thesis aims at answering the following research questions (RQ):

RQ1: *What are conceptually grounded and empirically validated design elements of domain specific Microgrids?*

RQ2: *Which microgrid archetypes can be empirically identified across divers application domains?*

First, chapter 2 introduces the fundamentals of electrical energy supply. For this purpose, an overview of the status quo of energy supply is given, followed by a demonstration of the required changes and the role of MGs in this process. In order to answer the first RQ and to provide a structured overview of all relevant design elements, a detailed taxonomy development according to Nickerson et al. (2013), described in chapter 3, is conducted. Therefore, in the fourth chapter, theoretical concepts are elaborated on and empirically validated with real-world microgrids in several iterations. Once all the conditions for a qualitative taxonomy are met, it is presented in the fifth chapter and exemplified with real objects. In order to subsequently answer the second RQ and identify archetypes based on the design elements provided by the taxonomy, a k-means cluster analysis is conducted in chapter 6. In the seventh chapter a critical discussion of the approach and the results is presented. Furthermore, the implications for the research and practice of this thesis are elaborated on. Based on the results of the discussion, the limitations of this paper are pointed out in the eighth chapter in order to give an impulse for further relevant research directions. Finally, the conclusion of this work is drawn in chapter 9.

9 Conclusion

With the aim of bridging the research gaps and providing a structured overview of all relevant design elements of microgrids in all application areas, the first research question was formulated:

What are conceptually grounded and empirically validated design elements of domain specific Microgrids?

In order to answer this question, an iterative taxonomy development procedure was applied, involving a total of four iterations. In the first iteration, 16 high-quality scientific papers were examined to derive all relevant theoretical concepts of MGs. In the subsequent three iterations, a total of 42 real-world MGs were examined with the aim of revising and adapting the theoretical concepts. Since all ending conditions have been fulfilled after these four iterations, the process is completed and results in a taxonomy that is structured into the four superordinate layers Physical, Communication, Intelligence, and Business Model, which altogether contain a total of 19 dimensions and 52 characteristics. These are characterized by their completeness, as no further dimensions and characteristics could be identified. Thus, researchers and practitioners are provided with a detailed overview of all relevant design elements of MGs.

Furthermore, the shares of the applied characteristics demonstrate which components and functions are predominantly integrated in the current state of development of MGs. The very high percentage of MGs that use renewable energy sources is particularly striking and indicates the suitability of MGs for integrating RESs. Additionally, a majority of these MGs use at least one energy storage technology to be able to efficiently use the energy generated by the RESs.

The relatively small share of intelligent functions within the objects considered underlines the wideness of the gap between theory and practice. This work reveals this phenomenon and thus provides initial approaches for bridging it, while further research still is required to develop possibilities for aligning the two areas.

A major limitation of this work is the low availability of information on real-world MGs, which risks missing relevant aspects. However, by contacting companies, it was possible to obtain sufficient information for a robust classification.

Furthermore, some aspects exist that are not directly design elements, but do have an influence. Such aspects could not be considered in this taxonomy and can be considered objects for further research.

However, a comprehensive taxonomy of all relevant design elements of MGs has been created, providing a useful tool for decision making by researchers and practitioners.

Subsequently, based on the results of the taxonomy, the second research question could be answered:

Which microgrid archetypes can be empirically identified across divers application domains?

To answer this question, the results of the taxonomy were used to carry out a cluster analysis that identifies certain patterns in the combinations of characteristics among the MGs and thus different groups of MGs. This analysis resulted in five archetypes that provide researchers with an overview of the different application areas of MGs.

What is more is that the archetypes enable the developers of MGs to identify the necessary project-specific characteristics.

The relatively small number of the considered MGs bears the risk of neglecting a more precise subdivision of the clusters. However, it was still possible to define a clear and unambiguous classification into the clusters.

In conclusion, answering the research questions led to a comprehensive taxonomy, which was subsequently used to identify five archetypes of MGs. These results provide both researchers and practitioners with a decision-support tool and form the basis for further relevant research directions.