PERFORMANCE INDICES OF PARTIALLY SELF-SUSTAINING DIRECT CURRENT COMMUNITIES IN THE GIVEN REGULATORY FRAMEWORK

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ABSTRACT

Due to the increase in decentralized energy generation, distribution grids are currently facing a transition in terms of local energy communities based on the concept of a prosumer market. European regulation allows business models which focus on energy self-consumption, provided that grid stability and customer rights are not violated. This paper presents six indicators that can be applied for the assessment of different low-voltage grid topologies.

INTRODUCTION

Since the share of electric vehicles, home battery applications and electronic devices is generally boosted, more and more DC-based devices are penetrating the future electric grid. Concurrently, higher numbers of distributed generators are installed, altering the relevancy of resilient, decentralized energy communities which can partially or fully supply their own energy consumption. Decentral located generators like photovoltaic (PV) systems produce unidirectional flows of electrons with 12 to 24 V DC. FEN Research Campus focuses on DC technology and takes a closer look at a possible integration of DC distribution in geographically local energy communities (LECs).

The European Distribution System Operators for Smart Grids (EDSO) support consumers' active participation in electricity markets like it is proposed in the Clean Energy Package: the emerging energy communities can serve as one important tool for the necessary energy transition since the generated renewable energy can be exploited to a greater extent and new services in the small-scale energy sector arise [1].

Unbundling of System Operation and Provision of Energy Services

Besides new business models in the energy market such as flat rate energy contracts for home battery owners, regulation also has to change towards an economic and technical perspective with the smarter electric grid.

As soon as LECs are involved in grid activities, regulatory conditions that apply for distribution system operators (DSOs) should apply correspondingly to LECs. Since a system operator owns and maintains the local electric grid, he is only allowed to operate energy generation assets and trade energy in terms of an energy service provider as long as the number of connected customers does not exceed 100.000 (see German regulation in §7a EnWG). Therefore, typical LECs can do both, i.e. operate their own grid and provide energy services within and outside of their local grid, as long as the total limit of connected household or smaller industries is kept accordingly.

German History of Municipal Electric Utilities

Today, the ownership of local electric utilities can either be a private business, public business or a private-public partnership. In Germany, the history of privatization and re-municipalization of electric infrastructure and utilities dates far back to the time when Emil Rathenau acquired the Edison light bulb patent in 1881, followed by the foundation of *Deutsche Edison-Gesellschaft für angewandte Elektricität* in 1883, which triggered the first power supply of Berlin [2].

Defying the fact that infrastructure such as pavements lies in the responsibility of the municipalities, municipal utilities were privatized, especially in the 1980s and 1990s, due to necessary cost-intensive remediation [3]. Today, the major municipal businesses are settled with concession agreements that enable LECs to take over the tasks of electric energy generation and reliable distribution in a geographically and electrically (e.g. number of grid connection points and assets like transformers) defined area.

One predecessor version of a local energy community is sub-metered electricity supply for tenants in buildings equipped with PV modules that are owned by a third-party operator. According to German regulations (*Mieterstrom* §23b EEG), a maximum price cap of 90 %, in relation to the local base electrical supply, applies to the sub-metered electricity. The contractor or operator, on the other hand, cannot force the tenants of the building to enter the local energy supply contract since every consumer has the right to freely choose his energy service provider.

Similar conditions apply to LECs, which have a larger impact compared to the tenant electricity business model, and possibly include other energy generating sources and consumers that are connected to that local grid.

CURRENT REGULATION ON SELF-CONSUMERS & ENERGY COMMUNITIES

According to the white paper of the Council of European Energy Regulators (CEER) on renewable self-consumers and energy communities, LECs should only operate networks in the form of a DSO. This ensures that there is no negative impact on consumers and that network developments can be managed in an *efficient* way. Additionally, the authors point out the following key recommendations [4]:

1) Participation in local energy communities should be strictly voluntary
2) Shareholders should not lose their rights as customers
3) It must be possible to change the energy supplier

The recommended approach guarantees a non-discriminatory and efficient solution for grid operators and active consumers. Thus, the question might be under which circumstances can a LEC be more *efficient* than the conventional grid operation.

DEFINITION OF PERFOMANCE INDICES

This paper presents possible key performance indicators to address the efficiency aspect and enable a pre-assessment logic for LEC operation and planning.

Operational Efficiency

Typical performance indices to compare utilities with regard to their reliability of energy supply can be divided into two categories: frequency indices (System Average Interruption Frequency Index, SAIFI (1)) and duration indices (System Average Interruption Duration Index, SAIDI (2))[5]. Both serve to evaluate stability during active grid operation according to the following definitions:

i. $\text{SAIFI} = \frac{\textit{total number of interruptions}}{\textit{number of customers}}$

and

ii. $\text{SAIDI} = \frac{\textit{total duration of interruptions}}{\textit{number of customers}}$.

SAIFI quantifies the number of resilience irruptions. In relation to that, duration indices, like SAIDI, measure a utility's response time to those irruptions, thus reflecting the reliability domain [5].

Economic Efficiency

To assess the efficiency in an economic way, the total installation costs and the return on investment (ROI) (3) of the network operator or an asset contractor, respectively, are highly relevant. In well-established electrical infrastructures, DC can only be integrated as a parallel infrastructure to existing AC systems in the private building sector because some household devices, e.g. ovens, still need to be supplied with AC. Households with PV installations and storage, on the other hand, can save cost for a number of inverters. Hence, the total balance for extra investment and savings has to be compared for each AC or DC microgrid.

Another relevant value that is considered in this paper is the total average annual energy price per customer (AEPI) (4).

Technical Efficiency

Besides operation and cost efficiency, electrical efficiency (5) has to be evaluated as well. For example, due to the reduced amount of voltage conversions and the higher efficiency of each DC/DC conversion (η = 97.0%-99.5%) compared to AC/DC conversions (η = 82.1%-99.0%), energy as well as conversion material in each end-consumer device can be saved. Therefore, material and energy savings can help to quantify the solution efficiency.

System Efficiency for Interconnected Control Areas

In large systems, the difference between a net actual and scheduled interchange of an interconnected balancing area is referred to as *area control error* (ACE) (6). In order to prevent distortion, effects of frequency bias (FB) and meter error corrections need to be taken into account [6]:

$$ACE = \underbrace{(NI_A\text{-}NI_S)}_{\text{Tie Line Deviation}} - FB\cdot\underbrace{(F_A\text{-}F_S)}_{\text{Frequency Deviation}} - I_{ME}, \text{ where:}$$

– NIA: actual net interchange [MW],
– NIS: scheduled net interchange [MW],
– FB: balancing authority frequency bias [MW/Hz],
– FA: actual frequency [Hz],
– FS: scheduled frequency [Hz],
– IME: interchange metering error.

Assuming that the LEC is interconnected (joint European control area), the second part of the equation is negligible since frequency deviations in such small systems (microgrids) would not cause severe grid instabilities. In any case, a physical energy community that is realized in form of a DC microgrid does not affect the system frequency. Thus, the major indicator in AC and DC systems is given by the balancing tie line deviation which signifies a mismatch of the actual and scheduled net interchange between the LEC and neighboring control areas.

LOW-VOLTAGE GRID STRUCTURES

LECs can comprise one or multiple AC or DC microgrids. This paper focuses on LECs with a size comparable to subsets of a typical German distribution system. Therefore, two generic types of low-voltage grids are presented in order to distinguish between local energy communities in urban and rural areas.

In comparison to standard AC systems, DC grids that integrate a great number of power electronics can achieve higher degrees of intermeshing which, on the one hand, increases system and network reliability but, on the other hand, also sets higher requirements for advanced control mechanisms such as fault detection.
Other major differences between urban and rural distribution systems are:

- Total number of loads and generators
- Geographical distribution of loads and generators
- Degree of intermeshing (see Fig. 1 and Fig. 2)
- N-1 criterion mostly only in urban systems
- Rural often equipped with overhead lines instead of cables
- Larger distributed energy resources in rural areas

In this paper, the proposed AC grid topologies, taken from [7], are similarly applied to the DC local energy communities.

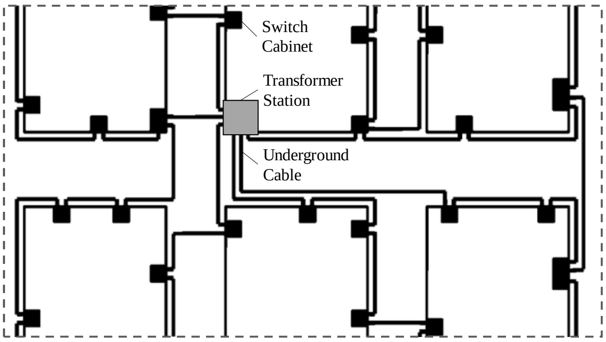

Figure 1: Generic LEC Topology in Urban Area [7]

The urban LEC (Grid A) reveals a rectangular cable routing with loop ring topologies distributed from a central MV/LV transformer station. In contrast to that, the rural LEC (Grid B) is in a star topology that is also known from rural medium-voltage grids [8].

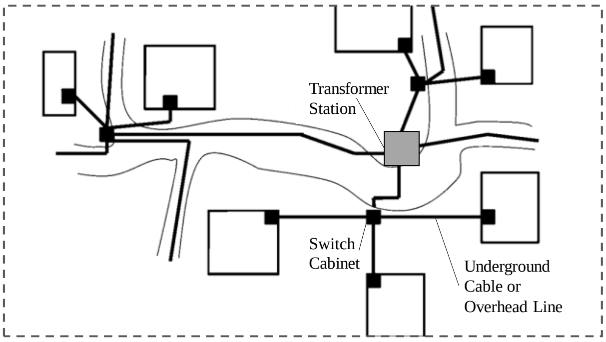

Figure 2: Generic LEC Topology in Rural Area [7]

ASSESSMENT OF EXAMPLE LOW-VOLTAGE GRIDS

The key performance indicators that have been evaluated in this paper are applied to the presented LEC topologies (see Fig. 3).

Grid A represents one part of the urban low-voltage grid and Grid B represents the rural one, respectively. Additionally, the example of an industrial LEC with back-up power supply from the grid is shown.

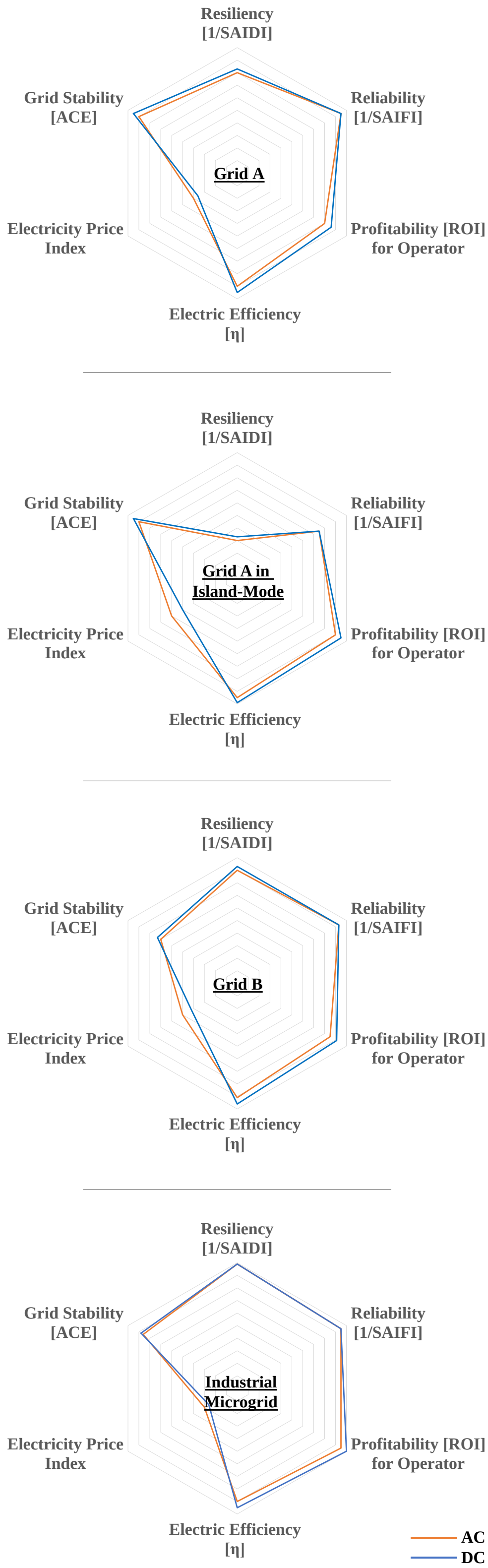

Figure 3:Evaluation of Efficiency Indicators for Different LEC Scenarios

Each spider chart shows how the performance and efficiency of the LEC scenarios are quantified based on the following assumptions:
The SAIDI, for instance, in an island rural LEC with no backup is higher than the one connected to the rest of the grid since re-supply cannot be guaranteed that quickly without an experienced and responsible system operator (*note that the chart shows the reciprocal value*). The electricity price per customer, on the other hand, is lower in the island grid, even if the power generation costs are higher because a major part of the electricity price consists of network charges.
According to that, the profitability of the island system is also assumed to be higher. The evaluation greatly depends on the composition of the stakeholders and the grid assets (existent energy resources, batteries and electric vehicles). The profitability in rural areas could be higher since the rental rates are generally lower and larger PV plants can be deployed and maintained at lower costs, for instance. This effect is mitigated to some extent by lower numbers of household and therefore 'smaller' energy communities in rural areas.
The electric efficiency depends on the actual size and type of application. Using the same components, the different scenarios only vary in AC and DC implementations since DC comes with superior inverter efficiencies.
The grid stability in the rural grid deviates from the urban LEC due to a more difficult prediction of generation and load when covering a larger area with fewer inhabitants. In high-density areas, however, the difference between base load and peak load is lower and thus the total prediction error is minimized compared to grid B.
The industrial microgrid is used as an additional LEC scenario due to the fact that electricity costs are of high importance in the energy-intensive sector. Also, more and more business solutions arise for industrial companies that invest in decentralized energy generation and storage in order to be more flexible and resilient. Generally, industries get lower electricity rates than households. Nevertheless, in addition to the general network charges, the electricity price for industrial loads also depends on the peak power demand that is consumed throughout a year. In a LEC, the peak power demand can be reduced, resulting in the lowest electricity price index among the presented LEC scenarios.

CONCLUSION AND OUTLOOK

On the basis of increasing numbers of decentral energy generation, home battery systems and electric vehicle deployment, local energy communities and microgrid projects are starting to penetrate the market and challenge traditional distribution systems.
This paper presents indicators that help to analyze the suitability of such approaches and shows one possibility to evaluate and compare different local systems from rural and urban to industrial sectors.
The presented results were obtained on the basis of the aforementioned assumptions that are oriented towards the current German energy landscape. In that way, this paper addresses the efficiency topic that is discussed in current European regulations regarding self-consumers and LECs.
Future research on already established and new LEC models can analyze efficiencies according to the mentioned six indicators SAIDI, SAIFI, ROI, η, the annual average electricity price per customer, and the area control error. As a result, efficient network planning for future electrical grids can be preserved.
Further topological analyses should be done for more detailed LEC scenarios which differentiate between renewable energy generator types, geographical allocation, size and number of generators as well as storages and loads in general.
In electric systems other than the typical German ones, the evaluation would differ significantly from the shown examples. Especially in systems with no existent grid or very critical resilience, LECs are the key solution for safe and efficient power supply in the future.

ACKNOWLEDGEMENT

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