The role and interaction of microgrids and centralized grids in developing modern power systems

Jonas Tjäder
Power Systems
STRI AB
Gothenburg, Sweden
jonas.tjader@stri.se

Susanne Ackeby
Power Systems
STRI AB
Gothenburg, Sweden
susanne.ackeby@stri.se

Caroline Bastholm
Solar Energy Research Center
Dalarna University
Borlänge, Sweden
caroline.bastholm@du.se

***Abstract*—An extension of microgrids is now underway, primarily to allow increased electrification in growing economies but also to meet the need to reduce global CO2 emissions and to provide ancillary services to centralized grids. Energy Access constitutes one of the fundamental building blocks for economic growth as well as social equity in the modern world. Access to sustainable energy is needed to achieve sustainable development. Through examination of several implemented cases from different parts of the world the following topics are considered: i) Analysis of the interaction between centralized grids and microgrids ii) Analysis of stakeholder decision parameters for electrification iii) Analysis of design differences and requirements for microgrids, depending on the intended purpose and the need of the end customer.**

It is determined that good planning, suitable requirements and clear regulations for microgrids (in relation to centralized grids) limits the risk of stranded assets and enables better business cases for the involved stakeholders.

Keywords*—*Energy Access, Microgrids, Rural Electrification

I. INTRODUCTION

The recent increased activities in the microgrid sector serves primarily to allow increased electrification in growing economies but also to remove some of the barriers against large-scale deployment of renewable electricity production (to reduce global CO2 emissions) and provide ancillary services to centralized grids. In 2015, 15% of the global population still lacked access to electricity [1]. Energy access constitutes one of the fundamental building blocks for economic growth as well as social equity in the modern world, and access to sustainable energy is needed to achieve sustainable development. To improve the lives of the 1.2 billion people with the lowest income and to reach the vast potential of rural electrification, the decade 2014-2024 has been declared by the UN General Assembly as the decade of Sustainable Energy for All [2].

This paper intends to act as an input document to the global discussion regarding the interaction between centralized grids and microgrids. The objective of the work has been to investigate the decision parameters when deciding between bottom-up and top-down solutions. Also, how the need of the end customer is reflected on the design of the microgrids has been analyzed. The objective has been met by sharing main findings from cases in different parts of the world. The paper is based on a coming discussion paper from ISGAN (International Smart Grid Action Network) Annex 6: Power T&D Systems [3]. ISGAN is a mechanism for international cooperation with a vision to "*accelerate progress on key aspects of smart grid policy, technology, and investment through voluntary participation by governments and their designees in specific projects and programs"*. ISGAN is an initiative within the Clean Energy Ministerial (CEM) and an Implementing Agreement within the International Energy Agency (IEA) [4].

II. THE ROLE OF CENTRALIZED GRIDS

The mission of the Transmission System Operator (TSO) in the power market is to transmit electrical power from the generation side to regional electricity distributors. The Distribution System Operator (DSO) is responsible for the final stage, i.e. delivering electric power to the customer. Due to the high cost of building the grid and the need of coordination within a transmission area, the market model built around the TSO/DSO has been a natural monopoly on the infrastructure side. In today´s power market, electricity is considered a commodity and most of it is centrally produced by large generation facilities. These are often owned by independent power producers and electricity is sold to retailers and some individual customers in a market. The utility then provide electricity to the retail customer [5]. The traditional model and the existing rules used by public utilities envision a particular regulatory or service model. However, this model is becoming increasingly strained due to the introduction of new entities to the grid, such as PV, net energy metering, batteries and microgrids [6]. One challenge for the traditional model is how to deal with these new entities. For countries with large scale hydro- and wind power, the most energy effective way can still be to produce in large scale and use a centralized grid to distribute the energy produced.

III. THE ROLE OF MICROGRIDS

Microgrids are defined by Cigré WG C6.22 as *"electricity distribution systems containing loads and distributed energy resources, (such as distributed generators, storage devices, or controllable loads) that can be operated in a controlled, coordinated way either while connected to the main power network or while islanded [7]"*. One important benefit with microgrids is that they are faster to build (weeks to months) whereas it can take several years before the centralized grid is extended. However, microgrids should not necessarily be considered as a competitor but rather as a complement to the centralized grid when it comes to solutions for electrification. IEA forecasts that 60% of future electrification needed to reach the goal of energy for all by 2030 will take place through microgrids and other small stand-alone systems (see figure 1) [2].

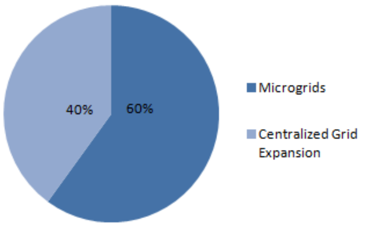

Fig. 1. Forecasted generation needed to reach universal access to energy for all by 2030, divided by grid-type [2].

Several approaches have been suggested for connecting microgrids and building the grid from "the bottom-up". The microgrid can then be considered a "cell" in a matrix of interconnected nodes such as Distributed Energy Resources (DER) and customer loads. In that context, control will be based on the interaction between the microgrid operator and the distribution utility and the system created will enable the microgrid to support the centralized grid, and vice-versa [6]. During a successful integration of a microgrid in a larger centralized grid, the microgrid can support with ancillary services (such as load shedding).

IV. CASE STUDIES

This chapter aims to present case studies on the interaction between the centralized grid and microgrids. Case studies include India, Canada, Uganda and Tanzania. Additional and elaboration of the case studies can be found in the ISGAN discussion paper on which this work is based.

A. India

India has the fourth-largest energy producing capacity in the world, with an installed capacity of 284 MW [8]. However, in 2010, 36% of the population (404 million people) still had no access to electricity [9]. Also, the centralized grid has had problems ensuring stability and adequate and consistent supplies to avoid major load shedding. One example of poor grid resiliency is the major black out in 2012, leaving 670 million people without electricity supply [10].

The goal in the 12th 5-year plan is to reach electricity access for all by the year of 2017 and therefore the government has initiated different programs to work with financing and funding [11]. The main driver for deployment of microgrids in India is to electrify the large part of the rural population that are either under-electrified or does not have access to power at all. In affect of this, India is one of the leading countries in the field of microgrids with over 100 deployed systems. The Government of India is also devoted to continued expansion of the centralized grid. However, there is an implicit understanding that some rural parts of the country are improbable to be reached by the centralized grid within foreseeable time and hence are suited for microgrids [12]. Most microgrids are being developed in communities located far from the grid. Therefore the potential interaction with the centralized grid has not been actualized yet. However, in cases where the microgrid will be operating in parallel with the grid, it can offer a higher reliability due to the frequent power outages of the centralized grid.

Currently the microgrids deployed in India are not connected to the centralized grid and are not considered "Smart". However, plans are to build a smart 15 MWpeak microgrid in the region of Tamil Nadu. This microgrid would have the possibility to be connected to the centralized grid as well as operated in Island mode. It also provides services such as load shedding and demand-response with the help of a 5MWh battery. The system would connect 29 000 customers and is planned to start early 2016 [13].

There is currently no consolidated policy in place for the sector of microgrids. There have been indications that there will be a Renewable Energy Act that would include all microgrids in a single framework. The lack of policy can give some degree of freedom for the actors in the field, but can make it hard to secure funding due to the unclear future [12]. Central Electricity Regulatory Commission (CERC) is critical to provide rules and regulations for development, funding, ownership and operation of such smart grid.

The main findings from this case are the following:

- In India, microgrids are built primarily to provide energy to all within a foreseeable future but also to increase the reliability by providing ancillary services to the centralized grid.
- The investor risk of grid expansion and stranded assets can be decreased if the issue of grid interconnection is given more attention. Regulators should provide legal framework to prevent risk of stranded assets due to central grid takeover.

B. Canada

Canada is a sparsely populated country where the whole population has access to electricity. Some communities receive electricity through microgrids due to being distanced from the centralized grid (although only a minor part of the total households with electricity access). This case example comes from northwest Ontario where 27 remote first nation communities are located. Out of these, 25 are not connected to the provincial electricity grid. Instead they are using diesel-based microgrids. Diesel generation costs are often three to ten times higher than the cost of the generation in the provincial grid [14]. Due to the drawbacks associated with diesel generation (and the fact that many of them are reaching the end of their lifetime [15]), three strategic options for energy supply for the remote communities have been assessed by Ontario Power Authority (OPA) in co-operation with the communities [16]:

1. Microgrids - using diesel generation (Status Quo)

2. Microgrids - using integrated solutions of renewable generation and the existing diesel solutions.
3. Transmission connection – connecting the communities that are considered economically feasible to the Independent Electricity System Operator (IESO) controlled provincial grid.

Constraints to load growth, cost and adverse environmental impact was used as the factors for evaluating the alternatives. Also the question of short-term but labor intensive jobs with building a transmission line compared to long-term jobs of maintaining a community microgrid was an aspect taken into consideration [15]. The financial study process of deciding if it is feasible to connect the remote communities to the provincial grid can be seen in Fig.2.

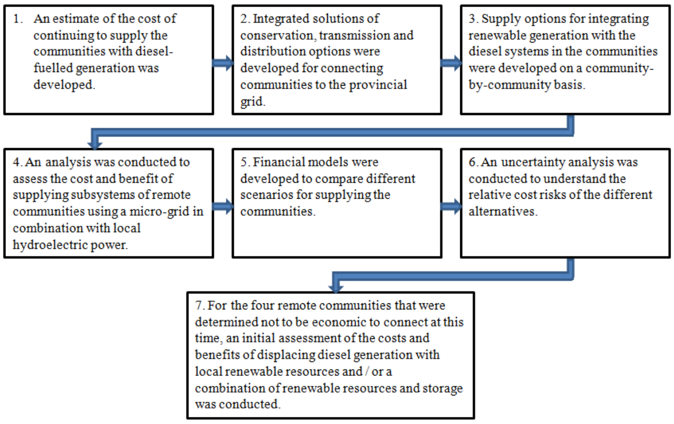

Fig.2. Study process for deciding feasibility of grid connection of remote communities [14].

Out of the 25 communities assessed, 21 were considered feasible to connect with the transmission line. For the communities considered feasible to connect to the centralized grid, the generation curves of locally available renewable resources, especially wind and solar, was found not to match well with the projected community demand, and would need to be coupled with diesel generation [14]. Therefore, the transmission line was considered a better alternative also from an environmental perspective [16]. Introducing storage as an alternative to handle the mismatch of the load and the generation curve of renewable resources was not included in the investigation of transmission connection compared to renewable-diesel microgrids. However, it was included in the assessment of the 4 communities found not economic to connect. IESO has conducted preliminary studies on how to provide electricity for the remaining communities in a sustainable and economic way. They have found that it is possible to reduce the cost of supply by using renewable generation combined with battery storage and diesel generation [14].

Already some attempts have been done in the field of remote diesel-renewable hybrid microgrids. A community whose diesel system was at max capacity and unable to connect any additional buildings in northern Ontario contracted Canadian Solar to install a 152 kW rooftop solar array in an elementary school to offset diesel consumption. Canadian Solar is considering expanding its off-grid microgrid project portfolio across Canada, and has identified more than 80 off-grid communities for potential microgrid solutions [17].

The main findings from this case are the following:

- With only one feeder line microgrid systems could also serve as increased reliability.
- Load growth, cost and environmental benefits where the three weighted factors when deciding between grid-connection and microgrids.
- Matching between load patterns and generation curves of locally available renewable resources is an important aspect when comparing solutions.

C. *Uganda*

Uganda is a country in sub-Saharan Africa with a population of 37.6 Million people and an electrification rate of 18.2 % [18]. The lead ministry for the development of the energy sector in Uganda is The Ministry of Energy and Mineral Development (MEMD). The network in Uganda is owned by the Government but operated by private companies. During the current 10-year planning period (2012-2022), the Government's strategy is to achieve a rural electrification access of 22% from the current level of 5% [19]. About 10% of the new connections are expected through microgrids.

The ambition to electrify the country as fast and cost-efficient as possible has lead to a governmental program to work with third parties, handled by the Rural Electrification Agency (REA). REA invests in extension of the national grid but also provides subsidies for the development of microgrids. To be allowed to generate and distribute power, licenses or Power Purchase Agreements are required, which are received from the Electricity Regulatory Authority (ERA). Small decentralized microgrids need an exemption of license.

The license or exemption of license enables the electricity utilities to obtain subsidies and leasing agreements with REA. The leasing agreement gives the right to operate a microgrid for a certain period of time. This is an insurance that the centralized grid will not take over the customers in this area as long as the agreement is valid. REA owns the microgrid, but the entrepreneur will get a leasing agreement to operate it.

The leasing system is a strategy for the government to attract investment in both centralized and decentralized power [20]. This also makes sure that the microgrid operator does not risk stranded assets since the microgrid plans are being developed together with REA.

Mostly private actors, but also NGOs are players in the rural electrification area in Uganda. Today most microgrids in Uganda are built to provide energy access in rural areas. They are mainly to support household demands like lighting loads and mobile phone charging, but some small industrial loads in the villages could also be supplied with electricity.

The main findings from this case are the following:

- Uganda has an established policy for co-operating with private companies to increase the number of connected customers, utilizing decentralized electrification.
- The fact that the authority that provides subsidies for the development of microgrids is also responsible for investing in extension of the national grid increases the possibility of long-term entrepreneur commitment and decreases the risk of stranded assets.

D. Tanzania

The ambitious vision of Tanzania's government is to have moved Tanzania from a low to a middle income economy by 2025 [21]. Electricity is regarded as one major factor in the social and economic development [22]. The national electricity access has increased from 13% in 2008 to 35% in 2014. In rural areas, the electricity access is 11% (in 2014) [23]. Tanzania's Power System Master Plan expects the national grid to supply 75% of the population by 2035 [24]. As most other sub-Saharan African countries (see case C: Uganda), a two track electrification strategy is promoted in Tanzania [25]. The centralized track focuses on extension of the national grid. In the decentralized track, distributed system solutions like microgrids are promoted for communities, villages and institutions like schools and hospitals.

Here, we are looking at the interaction between the centralized grid and microgrids at a micro level - from the system owner's and/or user's perspective. What options does a user have when the national grid enters the area where a microgrid is already in operation, and what are the advantages and disadvantages associated with different alternatives? The content in this case is based on yet unpublished work on a system near Mwanza in Tanzania [26-28].

Basically, the user has three main alternatives to consider when the national grid reaches the microgrid; to continue to use the microgrid as before, to shift to the national grid, or to convert the stand-alone microgrid into a grid connected microgrid. For grid connected microgrids, one can further consider using or not using batteries. If the user has the possibility to do a proper investigation of what the different available system solution alternatives would imply, access to uninterrupted electricity together with associated costs would certainly play important roles in the decision making.

In Tanzania, as in many other countries, there are interruptions in power supply from the national grid. In 2012, the average number of hours with blackouts was 54, declining from 71 hours in 2006 [29]. On average, 5.5 % of the annual sales in the country is lost due to power outages, and over 40% of enterprises identify electricity as a crucial factor for doing business [30]. In interviews, owners, operators and users of PV and PV-diesel systems have expressed their concerns regarding the power availability in the national grid. Although microgrids have their limitations in terms of power extraction, sometimes resulting in blackouts, they are often perceived as more reliable than the national grid.

When searching the optimum system configuration in terms of energy access and economic advantage, choosing between stand-alone operation of a microgrid, grid connection of a microgrid with or without batteries, and using the national grid only, a number of factors influence the results. In areas close to the national grid, it is generally speaking difficult to reach grid parity for PV and PV-hybrid solutions (i.e. that the cost of using a stand-alone system is the same or lower than the cost of using the national grid)[31]. Tanzania has in recent years lowered the connection fee to the national grid enabling for more people to connect, but also resulting in stand-alone systems being somewhat less competitive [22].

A system configuration offering high redundancy to power outages is to have a microgrid connected to the national grid. This is especially valid if intermittent energy sources (PV, wind) are combined in the microgrid with technologies which can be used upon demand (generators), and batteries can serve as immediate backup. The economic viability of different system configurations, enabling continuous access to power, however varies from system to system [30], [32]. It depends on what components the microgrid consist of, which of these can be used in a grid-connected system configuration and how reliable the national grid is.

In a situation, for example, where interruptions in the national power grid are rare, and the microgrid is equipped with a generator, it may be economically viable to not use any batteries. The cost of generator operation at times with blackouts in the central system does in this case not reach the costs of battery replacements. Generally speaking, using batteries is a good idea both from an economic perspective as well as a power access perspective if blackouts in the grid are frequently occurring. The power availability in the national grid obviously plays a major role in choice of system configuration. If PV is a part of the microgrid, it is often economically beneficial to keep the PV and use it within the microgrid, and buy only the remaining needed power from the national grid. To what extent though depends on whether the load curve matches the solar irradiation curve well or not.

The main findings from this case are the following:

- An unreliable centralized grid can sometimes lead to microgrids being considered as a superior solution, and access to both can increase the reliability of the electricity access.
- The viability of batteries in a microgrid is dependent on the reliability needed, frequency of grid outages as well as if there is access to dispatchable generators.

A summary of the main findings from the analyzed cases can be seen in Table 1.

TABLE I. COMPARISON OF MAIN FINDINGS FROM ANALYZED CASES

Case	Main Findings
India	• In India, microgrids are built primarily to provide energy to all within a foreseeable future but also to increase the sustainability by providing ancillary services to the centralized grid. • The investor risk of grid expansion and stranded assets can be avoided if the issue of grid interconnection is given more attention. Regulators should provide legal framework to prevent risk of stranded assets due to central grid takeover.
Canada	• With only one feeder line microgrid systems could also serve as increased reliability. • Load growth, cost and environmental benefits where the three weighted factors when deciding between grid-connection and microgrids. • Matching between load patterns and generation curves of locally available renewable resources is an important aspect when comparing solutions.
Uganda	• Uganda has an established policy for co-operating with private companies to increase the number of connected customers, utilizing decentralized electrification. • The fact that the authority that provides subsidies for the development of micro-grids is also responsible for investing in extension of the national grid increases the possibility of long-term entrepreneur commitment and decreases the risk of stranded assets.
Tanzania	• An unreliable centralized grid can sometimes lead to microgrids being considered as a superior solution, and access to both can increase the reliability of the electricity access. • The viability of batteries in a microgrid is dependent on the reliability needed, frequency of grid outages as well as if there is access to dispatchable generators.

V. ISSUES RELATED TO GRID INTEGRATION OF MICROGRIDS

Many countries are proceeding to expand the centralized grid and at the same time trying to reach many unserved costumers by microgrids. With this two-way approach, the two electrification solutions will certainly come to cross each other's paths, and there should be a distinctive plan on what to do when the two grids meet for this two-way approach to work. If no such policy or regulations exist, investors could be reluctant to invest in microgrids since it can result in stranded investments once the centralized grid is reaching the area of the microgrid [25]. There is a possibility for the centralized grid and microgrids to support each other in a way that is beneficial for all actors. However, there are still some issues arising in the situation of grid integration of microgrids, also due to the fact that the practical experience from interconnecting centralized grids and microgrids is limited.

Technical issues with integrating microgrids into distribution grids includes specific elements such as dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliability, power quality and protection. Also from the markets point-of-view, several questions remain: i) How can markets be formed where microgrids can help support the centralized grid? ii) What technical, policies and regulatory solutions are needed for this to become a reality? iii) What market barriers are still to be solved from a local and global perspective? iv) What regulatory support is needed for decentralized grids to thrive as a supporting entity to the grid?

VI. CONCLUSSIONS

An increasing number of microgrids will be seen in the future. Both for the purpose of reaching the UN goal of Sustainable Energy for All, but also for functioning as a cell of the centralized grid providing the possibilities of ancillary services like increase resilience, demand side management and facilitation of selling generated electricity. Depending on the hosting capacity of the centralized grid, microgrids can be seen as both a way to achieve end-of-the-line grid strengthening or as a way to avoid load shedding when strain is high on the centralized grid.

Governments providing clear regulation and co-operating with private companies to increase the number of connected customers using both microgrids and grid extension can be a very powerful tool for making sure that an optimal solution to electrification is reached. When evaluating the best alternative of electrifying a rural area, distance alone is not enough to determine if it is feasible to build a microgrid. Factors such as i) poor development of infrastructure, ii) challenging terrestrial conditions, iii) low density of rural population and iv) low income levels of communities also play an important role. In countries with a limited number of isolated communities, a case-to-case evaluation is beneficial. For the design of a microgrid without a connection to the central grid, considerations should be taken regarding when a potential connection will become a reality. If this could be seen in a reasonable time, the potential increase in energy demand should be considered when specifying the electrical requirements of the equipment.

With good planning and suitable requirements (i.e a connection to the centralized grid is technically feasible at a later stage) on new isolated microgrids, the risk of stranded assets if the centralized grid reaches the area will be limited. It will also increase the potential for the microgrid to become a long-term solution leading to better business cases for the involved stakeholders.

Building a strong relationship with the customer, as well as understanding the customer-need in a specific area should be in focus when designing the microgrid. Also, a sustainable revenue model to support investment funding as well as Operation and Maintenance (O&M) of such projects is important. The design will differ regarding the capacity, potential need of energy storage, type of production, the level of grid intelligence, the communication possibilities etc.

Even though the benefits are clear, microgrids can sometimes be considered to be inferior to a reliable centralized grid since power extraction can be limited. In other cases, where the centralized grid is unreliable, they can be preferred due to higher reliability. Even though there are still several issues to solve regarding the interaction between microgrids and centralized grids, it is clear that it is an area that will receive increased attention as the two methods of electrification come to cross paths.

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