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" Electricity Supply to Africa and Developing Economies …. Challenges and opportunities."

Enabling universal access to electricity in developing economies

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

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SUMMARY

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. A microgrid should not be seen as a competitor to the centralized grid but as a complement.

Through examination of several implemented cases from different parts of the world the following topics are considered:

- Analysis of the interaction between centralized grids and microgrids
- Analysis of stakeholder decision parameters for electrification
- 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.

The paper is based on the discussion paper *The role and interaction of microgrids and centralized grids in developing modern power systems – A case review* publiced by ISGAN (International Smart Grid Action Network) Annex 6: Power T&D Systems.

The discussion paper and further information about ISGAN is available at http://www.iea-isgan.org/.

KEYWORDS

Energy Access, Microgrids, Rural Electrification

INTRODUCTION

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* [1]*".*

In 2016, 16% of the global population still lacked access to electricity [2]. The 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.

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 worked carried out within ISGAN (International Smart Grid Action Network) Annex 6: Power T&D Systems published in [3] and [4].

ISGAN

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) and has to date 25 members: 24 countries from five continents and the European Union. ISGAN aims to improve the understanding of smart grid technologies, practices, and systems and to promote adoption of related enabling government policies. Further information can be found at the ISGAN website [5].

CASE STUDIES

Six case studies on the interaction between the centralized grid and microgrids are presented to share their learning and main findings. Case studies include Uganda, South Africa, Tanzania, India, Canada and the United States of America. Additional and elaboration of the case studies can be found in the ISGAN discussion paper on which this work is based.

I. Uganda

Uganda is a country in sub-Saharan Africa with a population of 39.0 Million people [6] where about 20% of the population has access to electricity [7]. 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 26% from the current level of about 10% [8] [9]. About 10% of the new connections are expected through microgrids.

The ambition to electrify the country as quickly and cost-efficiently 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 and in microgrids, and also provides subsidies for the connection of low-income customers to the 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 [10]. 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 or institutions (research centers) 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.

II. South Africa

South Africa is a country with a population of 54 million people. Electrification in South Africa 2014 reached 86% of the population [7] with a goal of 100% electrification by 2025. The Department of Energy has a goal for the centralized grid to connect 1 400 000 new users (of which 1 050 000 households will be in the rural areas) by March 2019 [11].

According to the South African TSO, Eskom, a distance of roughly 230 km and up is where the levelized cost of electricity in microgrids becomes competitive with grid extension [12]. Among other challenges for grid extension is the current low income levels of the rural communities, difficult terrestrial conditions and low density of rural population [13]. Roughly 7.6% of the new connections planned until March 2019 will be made through decentralized solutions.

In South Africa it is prohibited to produce or charge for energy without a license from the National Energy Regulator of South Africa (NERSA). No permission would be required to build a microgrid that is not synchronized to the main grid (completely stand-alone) and that does not charge for energy [12].

Roughly 11% of the population currently lives in areas that are out of reach of centralized grid electrification initiatives. Rural microgrids are considered the best way to electrify these households. Eskom has initiated “Smart Microgrid Pilots” throughout the country in order to provide energy access to these customers, and also to increase the resilience in the centralized grid. The microgrids are designed according to the demographic group where they will be located. This means that they consist of different generation capacities and fulfill different purposes. Smaller microgrids can be designed for low-income rural households with small loads and short payback times, while bigger consumers can be connected with more complex microgrids, serving as end-of-the-line grid strengthening [12].

Building on earlier experiences, Eskom places a lot of emphasis on customer/community engagement. This includes giving a clear picture of what will be delivered in terms of electricity, the balance between cost of system vs. the system output and how this impacts the return on investment of the system as well as maintenance costs etc. The importance of training local inhabitants to run and maintain the system, and to build skills within the community has also been identified.

III. Tanzania

The ambitious vision of Tanzania's government is to have moved Tanzania from a low to a middle income economy by 2025 [14]. Electricity is regarded as one major factor in the social and economic development [15]. The national electricity access has increased from 13% in 2008 to 35%[1] in 2014. In rural areas, the electricity access is 11%[2] (in 2014) [16]. As most other sub-Saharan African countries, a two track electrification strategy is promoted in Tanzania [17]. 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.

In this case, the interaction between the centralized grid and microgrids has been studied at a micro level - from the system owner's and/or user's perspective. What options would 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 perform 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. 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) [18]. 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 [15].

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 [19], [20]. 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, 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 in this case does not

[1,2] Including stand-alone solar PV-systems and mini-hydro grids

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.

IV. India

India has the fourth-largest energy producing capacity in the world, with an installed capacity of about 330 GW [21]. However, in 2014, about 20% of the population still had no access to electricity [7]. Also, the centralized grid has had problems ensuring stability and adequate and consistent supplies to avoid frequent load sheddings in parts of the country. One example of poor grid resiliency is the major black out in 2012, leaving 670 million people without electricity supply [22].

The goal in the 12th 5-year plan issued by the Planning Commission, Government of India was to reach electricity access for all by March 2017 and therefore the government had initiated different programs to work with financing and funding [23]. However as of end March 2017, there were about 4000 villages and several thousand small habitations still not electrified. The new goal of completion of village level electrification is 2019 which may be achieved. But there will be large number of households in electrified villages that still may not be connected, owing to both a poor financial situation, as well as unreliable supply in the rural areas. The main driver for deployment of microgrids in India is to electrify the large part of the rural populations that are either under-electrified, or do not have access to electricity at all. As a result of this, India is one of the leading countries in the field of microgrids. The Government of India is also committed to the continued expansion of the centralized grid. However, there is an implicit understanding that some rural parts of the country and many islands are improbable to be reached by the centralized grid within foreseeable time and hence are suited for microgrids [24]. 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, the microgrid 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, there are large ongoing plans like a smart 15 MWpeak microgrid (with plans for it to be connected to the centralized grid) in the region of Tamil Nadu which would supply 29 000 customers [25]. India Smart Grid Forum (ISGF) is also working with Indian Railways to build a demonstration Smart Microgrid at a Railway Station. If found to be commercially viable, a project like this could easily be replicated in large numbers.

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 [24]. Respective State Electricity Regulatory Commissions (SERCs) are expected to provide rules and regulations for development, funding, ownership and operation of such smart grids in each state.

V. Canada

Canada is a sparsely populated country where the whole population has access to electricity. Some communities receive electricity through microgrids due to being a significant distance from the centralized grid (although these communities are only a minor part of the total electrified households). 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 [26]. Due to the drawbacks associated with diesel generation (and the fact that many of them are reaching the end of their lifetime [28]), three strategic options for energy supply for the remote communities have been assessed by the Independent Electricity System Operator (formerly the Ontario Power Authority (OPA)) in co-operation with the communities [29]:

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 were used as the factors for evaluating the alternatives. In addition, local economic development opportunities through job creation were taken into consideration. Transmission line development provides short-term but labor intensive jobs, while community microgrid development and maintenance provides long-term jobs [28]. The financial study process of deciding if it is feasible to connect the remote communities to the provincial grid can be seen in Figure 1.

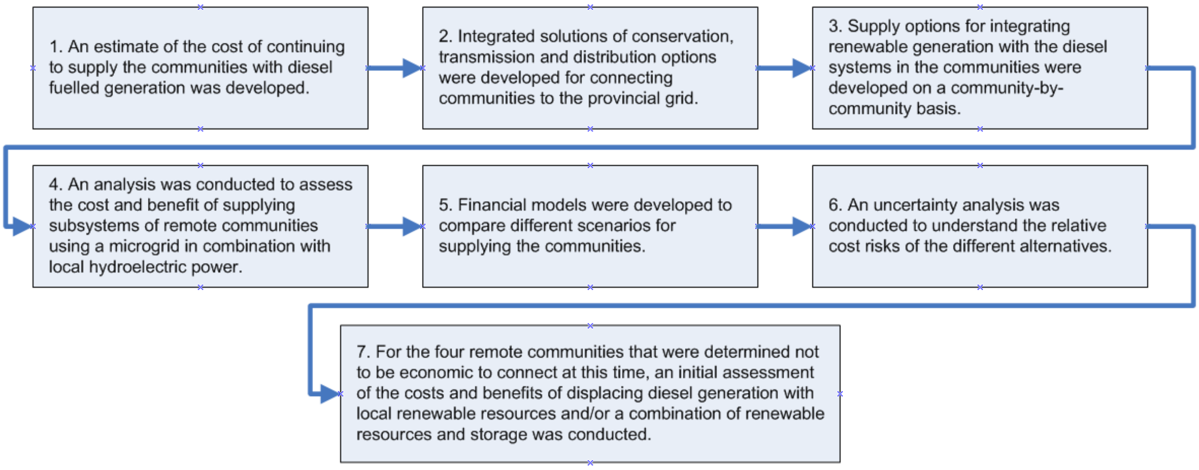

Figure 1 Study process for deciding feasibility of grid connection of remote communities [27].

Out of the 25 communities assessed, 21 were considered feasible to connect with a 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, were found not to match well with the projected community demand, and would need to be coupled with diesel generation [27]. Therefore, the transmission line was considered a better alternative also from an environmental perspective [29]. 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 [27].

The province of Ontario continues to work to support the implementation of renewable powered microgrids to support diesel reduction, where it is economical to do so, in its northern and remote First Nations communities. Some communities have moved forward with projects. For example, one community is installing solar and wind with an advanced microgrid controller. That project is expected to reduce the community's reliance on diesel by 50 %. Another community is proposing to develop, construct and operate a biomass fueled electric power and heat cogeneration plant, and wood pellet facility. This project would fully offset their diesel use (aside from the potential use of diesel generation for back-up power). That community is in discussions with the IESO to secure a Power Purchase Agreement for their cogeneration plant. A third community whose diesel system was at maximum capacity and unable to connect any additional buildings 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 [30].

VI. The United States

The United States of America is home to over 320 million people [31], with nearly universal access to electricity [7]. Despite widespread access to a reliable electricity supply, the market for microgrids in the US is growing more rapidly than studies had estimated [32]. Much of this growth is fuelled by electric utilities that are seeking ways to accommodate variable distributed generation, as well as military and commercial developers who are looking to achieve energy security, and to meet renewable energy deployment goals.

An evaluation of lessons learned by the Department of Energy [33] identified a number of research and development needs and challenges related to centralized grid and microgrid interactions. Some of the major takeaways include a need for greater cooperation between utilities and microgrid developers, and clear demonstrations of the value of a microgrid, from the perspective of the utility. While it was expressed that microgrids can help to counter intermittency and aid in the integration of renewable generation, it was unclear whether microgrids, in optimizing their performance for local benefit, had the potential to create or exacerbate instabilities in the local distribution system that they interconnect with. The overwhelming majority of microgrids developed in the US have been designed to operate in parallel with the utility during system operations, and to support critical loads while the microgrid is islanded and the utility network is unavailable.

The Performance Excellence in Electricity Renewal (PEER) rating system [34] measures the performance of sustainable power systems and was issued as a help for determining if a particular energy system design is well suited for a given application. A key attribute of the PEER system is its ability to account for the needs of all stakeholders involved in developing energy systems. The rating system provides 16 different categories wherein developers can earn credits (for higher ranking) related to customer contribution to a project.

Microgrids in the US have been designed to meet a number of specific customer needs. The NY Prize competition, hosted by the state of New York, funded 83 feasibility studies, each exploring a community's ability to meet its local needs using a microgrid. These studies can be accessed freely via the NY Prize website [35] and offer critical insights into design strategies for communities attempting to mitigate the effects of climate change, integrate renewable resources, and lower the costs associated with importing power from external geographic regions.

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

Table 1 Comparison of main findings from analyzed cases

Case	Main Findings
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 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.
South Africa	• Microgrids are seen as a mean to increase resilience and reliability in the centralized grid, but also as a means to reach out to households that are not feasible to electrify within a reasonable time through grid extension. • Meeting the needs of the specific customer affects the microgrid design. • The customer/community engagement, training and a clear message of what could be expected are important project success factors.
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.
India	• In India, microgrids are built primarily to provide energy to all within a foreseeable future but also to increase the sustainability by serving critical needs when there are load sheddings or power failures. It can also provide 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 utility 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.
The United States	• There is a need for greater cooperation between utilities and microgrid developers to meet the challenges related to centralized grid and microgrid interactions. • A robust framework is helpful for determining if a particular energy system design is well suited for a given application, considering all relevant constraints.

DISCUSSION

The introduction in the generation mix of a continuously increasing share of generation from renewable energy sources (RES), the geographical spread of generation when increasing the amount of distributed production, as well as changing patterns of demand from new types of loads, creates new challenges for electric power systems. New technology together with drastically decreasing cost of, for example PVs and storage, has made other energy supply solutions possible, compared to the use of a centralized grid to transmit electrical power from large scale energy resources to customers.

A centralized grid and a microgrid of course differ in many aspects, both having their advantages and challenges. The most energy effective way can still be to produce power on a large scale and use a centralized grid to distribute the energy produced, for example when it comes to integration of large scale hydro- and wind power. This is especially true in countries where the energy source is geographically far away from the consumers. A microgrid could, on the other hand, be a more economical solution when it comes to electrification of isolated communities. Another 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.

Microgrids should not 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 [36].

A microgrid can also be seen as a building block in creating a flexible electric grid. The microgrid can then be considered a "cell" in a matrix of interconnected nodes such as DER and customer loads. In this context, control is based on the interaction between the microgrid operator and the distribution utility; and the system created enables the microgrid to support the centralized grid, and vice-versa [37].

Researchers have theorized that the future grid will include grids of various capacities, nested in various hierarchies, and interconnected through standard interfaces, protocols, and interoperability standards. Nanogrids may exist on a household level, being integrated into microgrids on a community level. Microgrids can then network on a higher level, forming the grid at large. This concept of interconnected cells is illustrated in Figure 2.

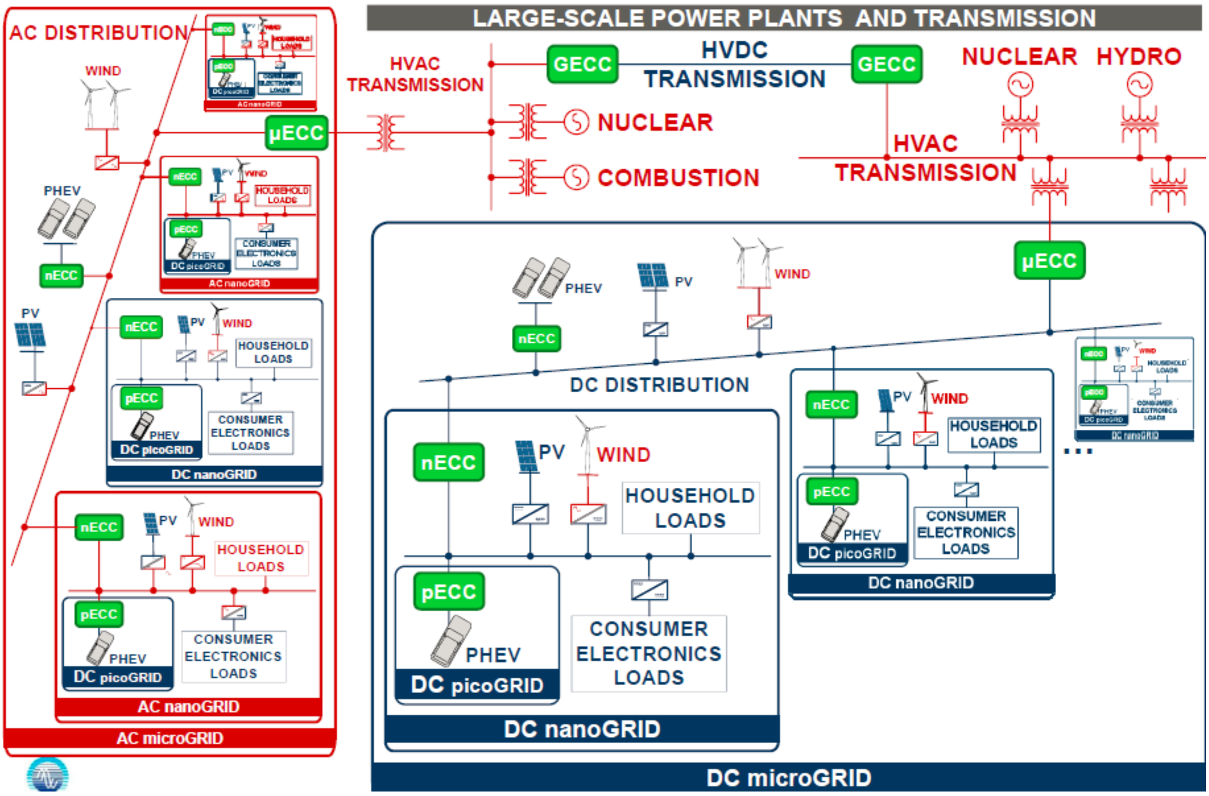

Figure 2 A future grid concept including grids of various capacities, nested in various hierarchies, and interconnected through Energy Control Centers (ECC) on each level: piko- (p), nano- (n), micro- (µ) and giga- (G). [38]

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, it is highly likely that the two electrification solutions will come to cross each other's paths, and there should be a distinctive plan on what to do when the two grids meet. 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 [17]. With coordinated planning there is instead a possibility for the centralized grid and microgrids to support each other in a way that is beneficial for all actors, such as by using the microgrid to provide customer back up service and distributing the electricity locally.

Substations have represented critical junctions in traditional power systems, allowing for the interconnection of various technologies, networks, and subsystems. Researchers have begun to explore the design of future power substations, with advanced capabilities, enabled by the use of power electronics technologies. These substations [39] can serve as the critical connecting point between the bottom-up development of microgrids, and the top-down modernization of centralized electric grids. Though this concept is still in the early stages of development, it does have the potential to address the uncertainty associated with the current two-way development approach.

There are still some issues arising in the situation of grid integration of microgrids, like dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliability, power quality and protection. Still the practical experience from interconnecting centralized grids and microgrids is rather limited.

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?

CONCLUSIONS

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.

In the challenge of increase the electrification access, a very powerful tool could be that the Governments provides clear regulation and co-operates with private companies to increase the number of connected customers using both microgrids and grid extension. 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.

With good planning and suitable requirements on new isolated microgrids (e.g. a connection to the centralized grid is technically feasible at a later stage), 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. A sustainable revenue model to support investment funding as well as Operation and Maintenance of such projects is crucial. Also the importance of customer/community engagement and of training local inhabitants to run and maintain the system, and to build skills within the community has been identified. 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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