ISGAN
international smart grid action network

ANNEX 6

The role and interaction of microgrids and centralized grids in developing modern power systems – A case review

Discussion Paper

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ISGAN Annex 6
Task 3

CLEAN ENERGY MINISTERIAL
Accelerating the Transition to Clean Energy Technologies

iea Energy Technology Network

About ISGAN Discussion Papers

ISGAN discussion papers are intended to serve the purpose of input documents to stimulate global discussions on smart grid thought leadership. Each paper is a statement by the author(s) regarding a specific smart grid related topic of international interest. These documents reflect work in progress in the further development of smart grids in the different regions of the world. Their aim is not to communicate a final outcome or to advise decision-makers, but rather to lay the ground work for further research and analysis.

Disclaimer

Abstract

A rapid expansion of the introduction of microgrids is underway universally, primarily to allow increased electrification in growing economies, but also to meet the need to reduce global CO_2 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. This paper serves as an input document to the global discussion on how to reach the UN goal of "Sustainable Energy for All", by sharing case study knowledge in the field. The following topics are considered through the examination of several implemented cases from different parts of the world:

- Analysis of the interaction between centralized grids and microgrids.
- Analysis of stakeholder decision parameters for electrification through extension of the central grid or microgrids; such as distance from grid, economic feasibility and environmental sustainability.
- Analysis of design differences and requirements for microgrids, based on intended purpose and the needs of the end customer.

It has been determined that good planning, appropriate requirements and clear regulations for microgrids limit the risk of stranded assets and enable better business cases for the involved stakeholders.

Executive Summary

This discussion paper intends to act as an input document to the global discussion regarding the interaction between centralized grids and microgrids. It aims at presenting main findings from several case studies as well as advise on preparation for future grid connection of microgrids.

The recent increased activity in the microgrid sector serves primarily to enable increased electrification in growing economies, but also to remove a number of the barriers that inhibit large-scale deployment of renewable electricity production (to reduce global CO2 emissions). Improvements in technology and decreasing prices of key components, (such as photovoltaics, energy storage and communication), has lead to increasing technical and economic feasibility of sustainable microgrids. An important benefit of microgrids is the build time frames of weeks to months, whereas it can take several years to extend the centralized grid. Microgrids can complement the centralized grid in supporting electrification solutions, whilst also providing ancillary services such as increased resilience, demand side management and facilitation of the sale of generated electricity.

To meet the challenges of achieving the goals of Sustainable Energy for All and integration of renewable energy, both the expansion of centralized grids and the development of decentralized microgrids are needed. The International Energy Agency (IEA) forecasts that 60% of future electrification needed to reach the goal of energy for all by 2030, will be enabled through microgrids and other small stand-alone systems.

Preparation for future grid connection of microgrids

Based on the knowledge drawn from the analyzed cases, a best practice can be formulated to guide preparations for the connection of microgrids to the centralized grid. Technical insights include preparing the microgrid for integration into the centralized grid in the planning stage. When the centralized grid expands into the area of the microgrid, it can then directly connect to the microgrid, with the microgrid operating as a cell to the centralized grid. To achieve this objective, the microgrid equipment needs to comply with the technical requirements of the centralized grid[1]. Technical requirements should be evaluated in detail for each case and the consequences of the interaction between the microgrid and the centralized grid should be analyzed. The roles of the microgrid owner, the centralized network operator, governmental actors and local stakeholders should be investigated to ensure the determination of interaction mechanisms and parameters.

[1] No such generic guidelines exist today and would probably vary for each country. However key considerations sho uld include cable dimensions to handle the new requirements, communication systems that can interact with the oper ation system of the centralized grid (i.e. demand response, peak shaving and voltage regulation), and converters that can handle the connection to the main grid.

Main findings from analyzing microgrid and centralized grid interaction in five countries

Cases	Electrification Rate	Main Findings
Malaysia	86%	• The Ministry of Rural and Regional Development and the TSO/DSOs should develop specifications together. There should also be clear legislation and regulations that establish a sense of ownership of the microgrids to avoid becoming stranded assets. This work has been started. • The poor condition of some microgrids creates perception and reputational risks and centralized solutions are considered to always be the best solution for electrification. • No or unclear legislation could lead to some independent microgrids operating without any interaction with the government. • Monetary support for O&M of microgrids could enable bigger repairs in cases of the breakdown of equipment. However, O&M requirements should also be factored into the business planning process.
South Africa	84%	• Microgrids can be a means to increase resilience and reliability in the centralized grid, but also serve as a way to reach out to households that are not feasible to electrify within a reasonable time through grid extension. • Meeting the needs of the specific targeted customers affects the microgrid design. • Since the national utility, Eskom is both the owner of the centralized grid and the microgrids, the risk of stranded microgrid assets is carried by the same entity. Since the owner of the centralized grid also owns the microgrid assets it is in their interest to keep utilizing the equipment. • The importance of customer/ community engagement, training and a clear message of what could be expected in terms of the nature of electricity delivered, costs etc. has been identified as a key element in project success.
Uganda	18.2%	• Uganda has an established policy for co-operation with private companies to increase the number of connected customers, utilizing rural 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. This can increase the willingness to invest in microgrids. • The electrification of villages can lead to an increased value, with villagers investing more in their houses as a consequence, even though electricity access is limited to certain hours of the day.
Canada	100%	• With only one feeder line from the centralized grid, the microgrid systems could also provide increased reliability. • The demonstrated case highlights some of the complexity when comparing the alternative of grid connection with microgrids, and which are the aspects that should be considered. In this case load growth, cost and environmental benefits where the three weighted factors • The possibility of future job creation is an important factor for community involvement. • In countries with 100% electrification, microgrids could still play an important role. • Moving from diesel generation to using renewable energy sources in combination with battery storage can save costs in a microgrid setting.
India	64%	• In India, microgrids are built primarily to provide energy to all within the foreseeable future, but also to increase sustainability 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 also provide a legal framework to mitigate the risk of future stranded assets due to central grid takeover or central grid competing against microgrids for the same customer base. • Lack of policies, revenue models and finance mechanisms are seen as a barrier to the development of microgrids.

Conclusions

The solution that should be chosen to electrify an area can be determined based on a set of different criteria such as distance; development of infrastructure; terrestrial conditions and density of population. Another set of criteria should be considered in the design of the microgrid. Building strong relationships with the customers, as well as understanding customer needs in a specific area should be a point of focus. Further, a sustainable revenue model to support investment funding, as well as Operation and Maintenance (O&M) expenditure of such projects, are important considerations when designing the microgrid. The design will differ depending on parameters such as capacity, potential need of energy storage, type of production, the level of grid intelligence, communication requirements etc.

It is possible for the centralized grid and microgrids to support each other in a way that is beneficial for all stakeholders. However, there are still a number of technical and policy related issues to be resolved with respect to grid and microgrid integration. Issue resolution is constrained partially due to the fact that the practical experience of interconnecting centralized grids and microgrids is limited. Technical issues related to the integration of microgrids into distribution grid include specific elements such as dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliability, power quality and protection.

Many countries are proceeding with the expansion of the centralized grid in parallel with the deployment of microgrids to reach unserved customers. Given this two-pronged approach, the two electrification solutions are likely to cross paths at some point, in most instances. Anticipating the likelihood of the two grids meeting well in advance of the event allows for appropriate and specific planning to accommodate a solution that best serves the interests of all impacted parties. In the absence of policies and/or regulations directing an integration framework, investors could be reluctant to invest in microgrids, as the potential of stranded investments exists once the centralized grid reaches the area of the microgrid. Clear regulation and adherence to relevant technical requirements will increase the potential for the microgrid to become a long-term solution, leading to an improved business case for all stakeholders.

The provision of clear regulation and active co-operate with private companies to increase the number of connected customers using both microgrids and grid extension, can be a very powerful Government tools in reaching an optimal solution to electrification requirements.

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Acronyms

CERC	Central Electricity Regulatory Commission
DER	Distributed Energy Resources
DSO	Distribution System Operator
ERA	Electricity Regulatory Authority
GC	Grid Interlinking Converters
HDI	Human Development Index
IEA	International Energy Association
IESO	Independent Electricity System Operator
IPP	Independent Power Producers
LED	Light Emitting Diode
LSM	Living Standard Measures
MEMD	Ministry of Energy and Mineral Development
NERSA	Nation Energy Regulator of South Africa
NGO	Non Governmental Organisations
O&M	Operation and Maintenance
OPA	Ontario Power Authority
PPA	Power Purchase Agreements
PV	Photovoltaics
RD NKRA	Rural Development National Key Result Area
REA	Rural Electrification Agency
TSO	Transmission System Operator
UN	United Nation

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1 Introduction

This discussion paper is part of Task 3 within the International Energy Agency (IEA) ISGAN Annex 6 which focuses on Power Transmission & Distribution. The main objective of this task is to identify the potential and feasibility of new technology, to prioritize the need for further developments and to make recommendations on how to stimulate the demonstration and deployment of promising technology options. Furthermore, necessary measures, practices and standards to manage risks and interoperability should be identified in order to ensure a faster, more efficient and more reliable deployment of new technology. Figure 1 positions this work in the ISGAN context.

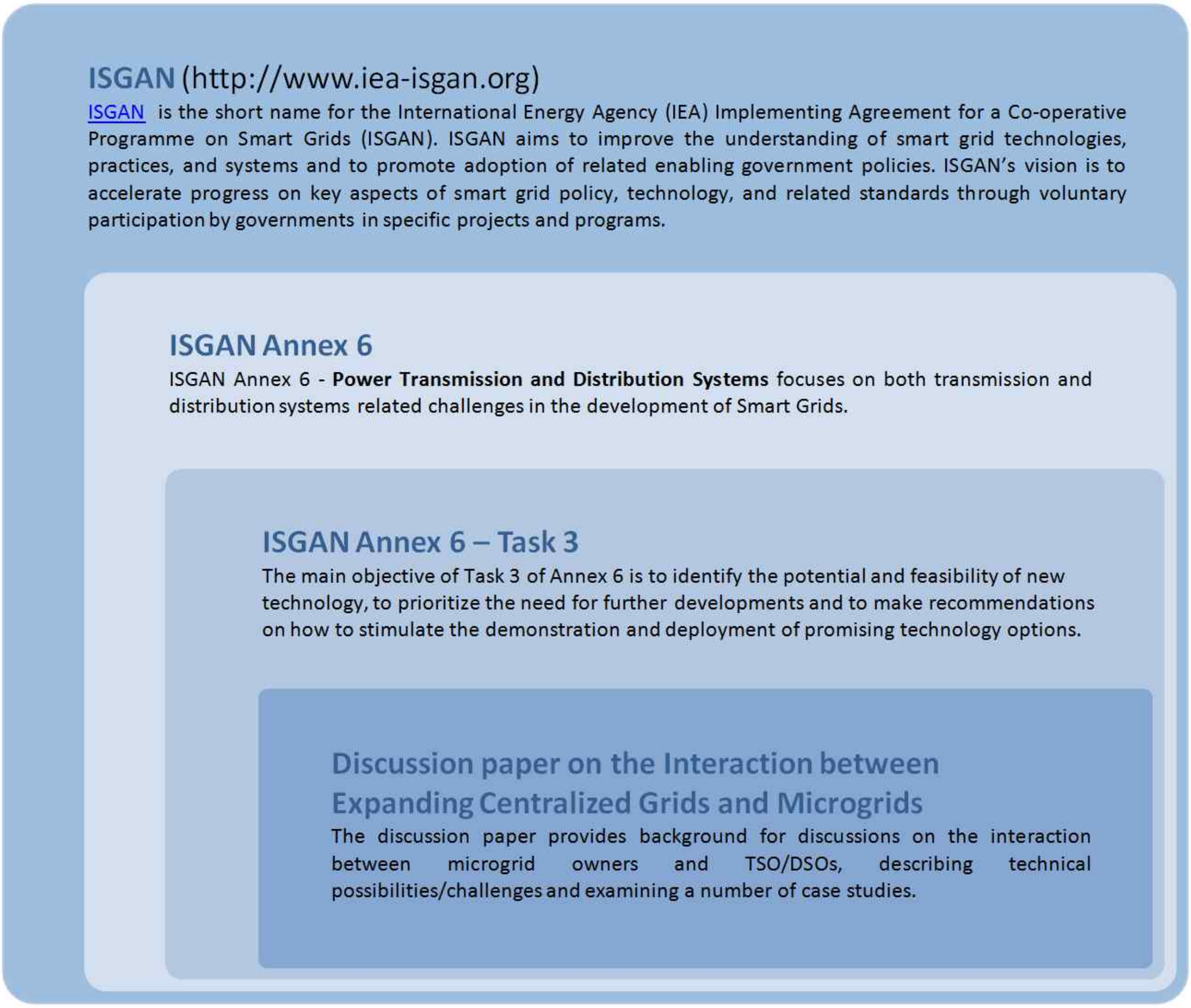

Figure 1- Position of Discussion paper in the ISGAN context

1.1 Objective of discussion paper

This paper intends to act as an input document to the global discussion regarding the interaction between centralized grid and microgrids. The paper also investigates the decision parameters when deciding between bottom-up and top-down solutions in the analyzed cases; and further considers the impact of end customer needs in the design of electrification programmes.

These objectives will be met by sharing knowledge and lessons learned from several cases in different parts of the world, and by bringing together experts from relevant fields to further the debate on the topic.

1.2 Background

The recent increased activity in the microgrid[2] sector serves primarily to enable increased electrification in growing economies, but also to remove a number of the barriers that inhibit large-scale deployment of renewable electricity production (to reduce global CO2 emissions); and to provide ancillary services (demand response, increased reliability etc.) to centralized grids.

In 2015, one person in five on the planet still lacked access to electricity. 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 across the globe 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 [1].

The history of electrification started with the construction of large isolated plants. However, the network built up by a larger transmission and distribution system provided utilities with several economic advantages that eventually became decisive [2]. This top-down approach to electrification (large power plants providing electricity to distributed loads) created large electrical systems. Due to the cost of establishing a larger transmission infrastructure for electricity, the Transmission System Operator (TSO) is usually a natural monopoly, and is subject to regulation.

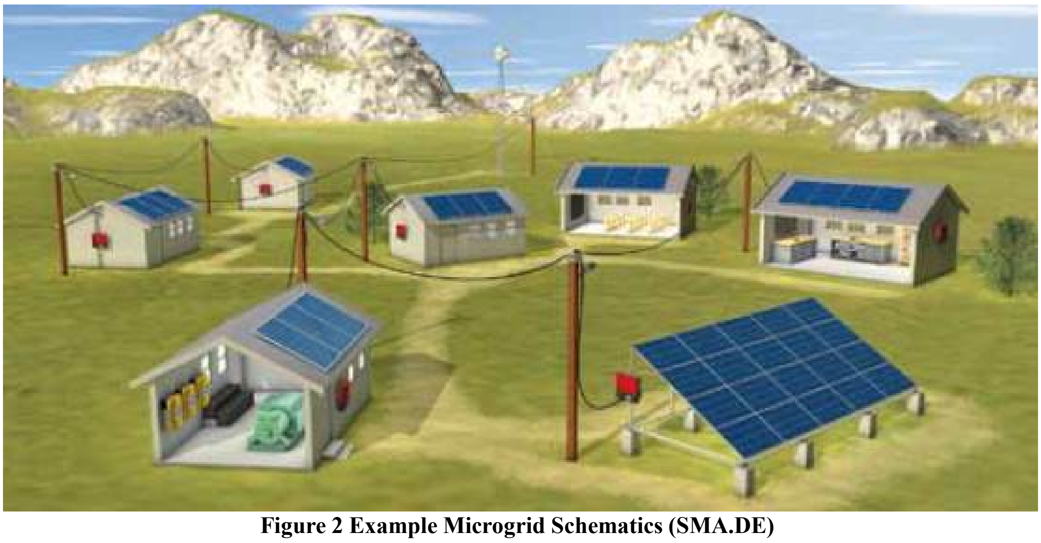

Figure 2 Example Microgrid Schematics (SMA.DE)

The technology driven price-drop on the generation side (photovoltaics, wind power plants, energy storage technologies etc.), in combination with new technologies for energy efficiency and load management on the consumer side, enables new sustainable alternatives to the top-down approach of electrification, regarding both technical solutions and new market possibilities.

[2] A group of interconnected loads and distributed energy resources within clearly defined electrical boundaries

These new technologies can potentially enable countries with low rates of electrification an alternative to the top-down approach, but is also recognized as a way to increase resilience and introduce more renewable energy into the power system.

The term “Decentralized Energy Systems” is used in this paper to describe bottom-up solutions ranging from solar home systems to microgrids. The focus of the paper is on microgrids and their interaction with the centralized grid as solar home systems do not always serve as a possible technological stepping stone to grid connection. The term “Centralized grid” is applied as a reference to the primary or national grid that is traditionally constructed as the “top-down” interconnected approach to electrification. The IEA believes that 60% of future electrification of rural households will take place through decentralized energy systems [3].

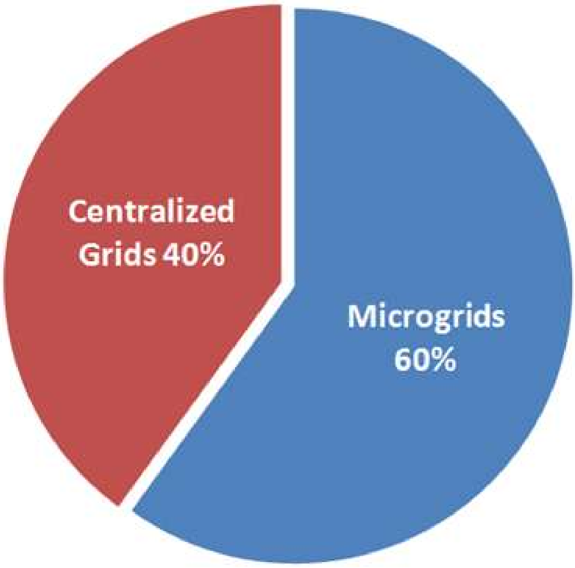

Figure 3 Additional connections needed to provide electricity to the 1.2 billion people who do not currently have access to electricity, divided by type of electrification [4]

This new paradigm of bottom-up solutions introduces the question of what happens when the centralized grid reaches the area of the microgrid; and how to ensure that the bottom-up solution is not seen as a competitor to the centralized grid, but as a contributing building block in the creation of an electric grid that is “smart”[3].

This paper investigates how the following related questions have been addressed in the cases examined:

- How will the microgrids and the centralized grid interact?
- What are the decision parameters for stakeholders when deciding between top-down and bottom-up electrification in unelectrified areas?

[3] In reality, the level of intelligence of a microgrid can differ vastly. How advanced a microgrid is required to be depends, for example, on the needs of the customers in the specific area.

- What are the design differences and requirements for microgrids, based on the intended purpose and the needs of the end customer?

The paper further collates major findings from cases that describe previous interactions of decentralized and centralized grids.

2 Technical Possibilities/Challenges

2.1 Energy Access and the role of electricity

The challenge of improving energy access for low-income households is substantial. Solutions such as providing lighting using solar panels and super-efficient LED lights do not lead to the enablement of direct income-generating activities in the same way as grid connection enables industrial and manufacturing loads. However, the provision of a very limited number of kWh can vastly improve the quality of life, and electrification is highly correlated with an improved Human Development Index (HDI) [4].

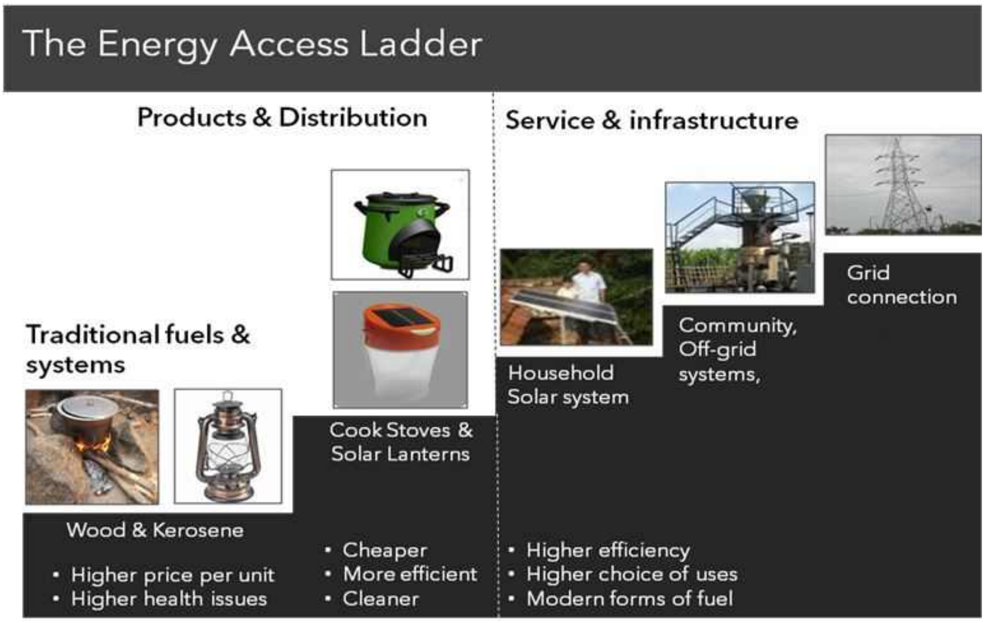

Figure 4 Energy Access Ladder, based on [5]

When ascending the energy access ladder (see Figure 4), low income households move from using traditional fuels like kerosene and wood towards the ultimate objective of universal access to electricity. Kerosene and wood are ineffective, expensive and can be hazardous to health. Given that a substantial portion of the household budget is spent on these forms of energy, little opportunity exists to improve the situation and climb the energy access ladder without external support [5]. The UN goal of Sustainable Energy for All translates into moving 1.2 billion people along the energy access ladder and providing them with sustainable electricity solutions. It should be noted that while the ladder of energy access provides some initial insight in ranking different electrification solutions, it does not consider important parameters such as availability of energy (time of day) and sustainability of the system. A connection to a centralized grid does not automatically lead to 100% access to energy and the sustainability is largely impacted by the source of the production.

Figure 5 Drums full of diesel stacked up at a diesel generator at Havelock Island, India [6]

Electricity supply to off-grid remote communities is often achieved by means of diesel fueled generators, which has associated health and environmental impacts on those communities (see Figure 5). In addition, many of these communities can only be accessed by winter roads once lakes freeze, making the supply of diesel logistically challenging, with the duration of periods of supply changing from year to year. In some cases communities have to fly diesel in and ration electricity to make up for shortfalls in the supply of fuel in the particular year. The economic burden on communities and public programs for supplying fuel can quickly exceed planned budgets and result in emergency measures being applied.

2.2 Expanding centralized grids: Top-Down Perspective

The mission of the TSO in the power market is to transmit electrical power from the generation side (power plants) 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 for coordination within a transmission area, the market model built around the TSO/DSOs has traditionally been a natural monopoly on the infrastructure side. Historically, the utility has been a vertically integrated monopoly, owning generation, transmission and distribution systems in a geographic area, and serving the end customers. 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 the market. The distribution utility then provides electricity to the retail customer [2]. 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 solar plants, net energy metering, batteries, behind-the-meter microgrids and so on [7]. How to deal with these new entities presents a significant challenge to the traditional model.

Despite the challenges and barriers, the concept of a centralized grid is unlikely to disappear. For countries with large scale hydro- and wind power, the most effective model is large scale production combined with the use of a centralized grid to distribute the energy produced. The IEA forecasts that 45% of households currently lacking a connection to the grid will still be electrified through extension of the centralized grid [3]. However, the question of best practice for the utility facing the new challenges and potentially game-changing technologies remains uncertain, and is likely to differ depending on the location and varying maturity of the power systems.

2.3 Decentralized Energy Systems – Microgrids: Bottom-Up Perspective

Microgrids are a type of decentralized energy system that transmit power from interconnected local Distributed Energy Resources (DER) over low or medium-voltage distribution networks, and can function in a manner that is completely isolated from the centralized grid (see Figure 2). They can be either AC or DC. There are many definitions of microgrids and no clear distinction between microgrids or other similar terms, such as minigrids or picogrids exists. 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"* [8].On the energy access ladder, isolated microgrids place themselves between the "Solar Home Systems" (which aims to provide electricity for basic usage such as lights and mobile phone charging) and centralized grid connection (which aims to provide unlimited access to electricity at all times). Hence, microgrids can in some cases also support industrial and commercial applications which can drastically reduce the payback time and increase the productivity of the community; in contrast to a more limited lighting system for households which have a longer payback time. A common practice is to build microgrids around an "anchor load" to ensure increased microgrid productivity and potentially shortened payback periods. This leads to a "critical" minimum load that enables economies of scale of microgrids.

A reliable centralized grid aims to provide high quality power for homes, industry, businesses and other services, placing them at the top of the energy access ladder. However, extending the centralized grid may not be technically or financially feasible for all rural areas. Further, as the costs of DER reach grid parity, some of the advantages with a centralized system, such as economic feasibility, are lost. A further reason for choosing a decentralized solution can be that in some instances the traditional base load generation does not respond fast enough to variations in generation from DER. The procured resources might also not be sufficiently flexible to address the emerging grid conditions [7].

With the high number of microgrids deployed, as well as the magnitude of research effort, one could assume that all microgrid related technical challenges would be resolved. However, specific elements such as dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliable power quality and protection can still cause some problems [9].

Most research in the field of microgrids focuses on the technical challenges. However, other challenges such as supportive policies, the regulatory framework and business structures for stakeholders have recently received more attention. In case study [10] a theory of vicious and virtuous cycles for microgrids is introduced as can be seen in Figure 6. According to this theory, the possibilities of cost recovery, how operation and maintenance is handled, as well as how customers use the microgrid, are all crucial factors for microgrid sustainability.

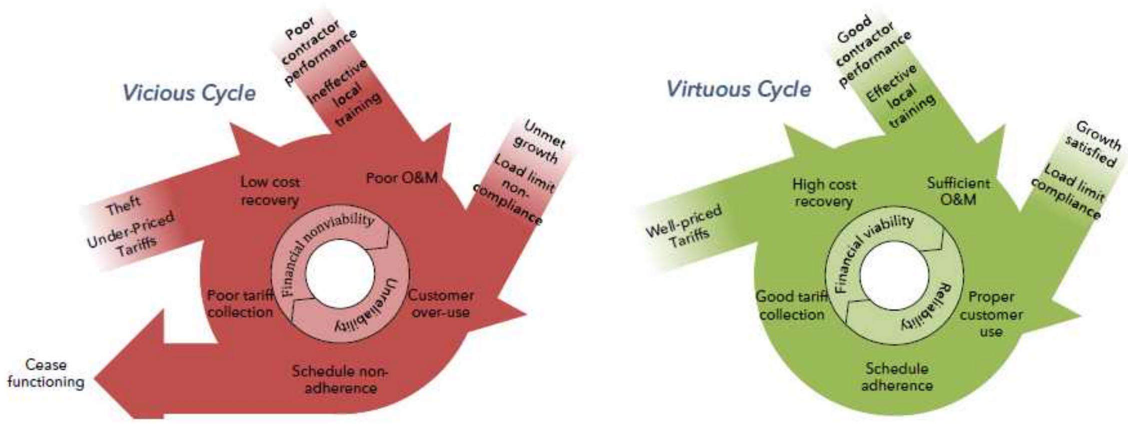

Figure 6 Vicious and virtuous cycle for microgrids [10]

For a household to connect to a microgrid, an upfront capital cost is required to be paid by the customer. This can be a barrier since many of the customers in rural areas are extremely poor. Different approaches have been suggested to address this issue, including subsidies and payment models that distribute the cost of connection over a longer timeline. The cost of electricity paid by the customer depends on a number of things, such as the levelized cost of electricity produced by the DER, the cost of distribution services and the profit for the distributed energy system owner / operator.

While this base formula remains for the cost of electricity, in wealthier industrialized countries the price or customer rate charged for electricity in off-grid locations can also be influenced through policies which subsidize costs to the average centralized grid rates.

Microgrids with diesel generators have been available for many years. However, due to the improvement in technology and the decreasing prices of technologies such as photovoltaics, energy storage and communication; it is becoming technically and economically feasible to build more economically viable and sustainable microgrids.

The level of intelligence of a microgrid can differ vastly. How advanced a microgrid is required to be largely depends on the need of the customers in the specific area and thus the level of services to be provided.

The successful integration of a distributed energy system into a larger centralized grid, enables the distributed energy system support typically in the form of ancillary services, load shedding, consumption resources and reliable dispatchable DER. Given that the microgrid introduces on-site generation, bidirectional power flow as well as storage, it can be seen as a valuable resource to the grid. The enabled participation in demand-response programs can lead to reduction of load when the strain on the grid is high, as well as the possibility of exporting power to the grid to maintain stability [11]. Further, the self-sustaining character of the microgrid can enable it to work as its own entity if it needs to be load-shed from the grid. Other examples of ancillary services provided by the microgrid to the centralized grid include reactive power power/voltage control and active loss balancing [12]. A microgrid could also be used as a primary reserve for the centralized grid as described in [13].

3 Future roles of TSOs, DSOs and microgrids

As described earlier, 55% of future connections are expected to take place outside of the centralized grid. It is highly likely that this will lead to some situations where the centralized grid will reach the area of the microgrid. Situations will more commonly occur where the centralized grid and microgrids are co-existing. This can lead to several outcomes, ranging from the microgrid providing services to the centralized grid, to providing customer back up service and distributing the electricity locally to abandonment of the microgrid equipment (such as for example solar panels, inverters or other components in the microgrids).

Decentralized grids do not need to be considered as “competing” with the centralized grid in seeking solutions for electrification. Instead, a microgrid can be seen as a building block in creating an electric grid that is “smart” (see Figure 7). 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 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 [7].

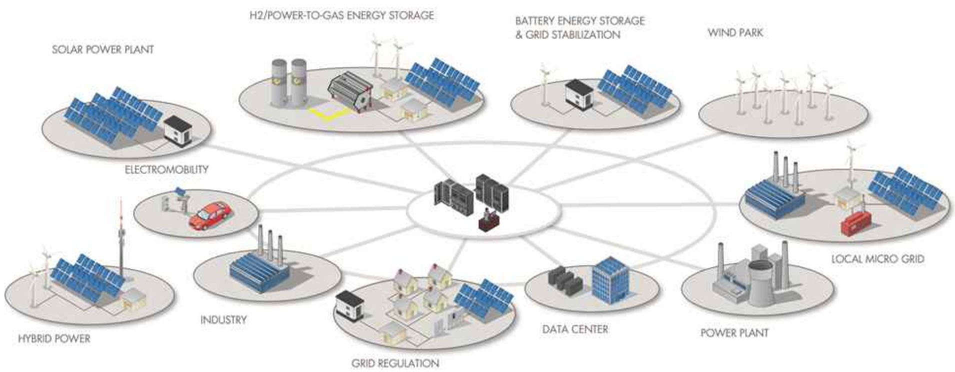

Figure 7 Distributed Energy systems integrated in a larger grid [14]

4 Case Studies

This chapter aims to present case studies on the interaction between the centralized grid and decentralized electrification. Case studies include Malaysia, Canada, India, South Africa and Uganda. The case studies have been carried out by means of a combination of targeted interviews and a study of relevant literature.

4.1 Case 1 – Malaysia

4.1.1 Background

Malaysia consists of two regions which are separated by the South China Sea, namely Peninsular Malaysia and Malaysian Borneo. 80% of the population resides on Peninsular Malaysia, where the power system reaches almost 100% of the inhabitants. Malaysian Borneo consists of Sabah and Sarawak with an electrification rate of 94.1% and 91.0% respectively [15].

During the last 5-year plan (2010-2015), the supply of electricity to rural areas in Malaysia increased from 92.5% to 98.2%. Most rural electrification projects provided electrification through connections to the centralized grid. Alternative decentralized energy systems such as microgrids based on hydro, solar-hybrid (with diesel backup systems) and/or biomass has been utilized to electrify remote areas [15].

During the current 5-year plan (2015-2020), national electrification aims to reach 99% of the population. For rural villages that are located too far from the centralized grid, electricity supply will be provided through microgrids. Collaborations with relevant communities to ensure sustainability will be promoted by the Government and partnerships with NGOs will also be formed to provide electricity supply for rural communities. It is concluded that early involvement from communities is important to reduce the cost of development and maintenance of the microgrid [16].

4.1.2 Microgrids

Microgrids are an important tool to achieve rural electrification in Malaysia, as reflected in the current 5-year plan. According to Dr. Ali Askar Sher Mohamad [17], there are three main actors initiating microgrids for electrification in Malaysia, being:

- The Ministry of Rural and Regional Development
- The Ministry of Education
- NGOs

The Ministry of Rural and Regional development conducts the electrification of remotely located villages. Microgrids are deemed the most feasible option when the villages are located 10-30 km or more from the centralized grid [17]. Villages located at this distance usually have accessibility issues due to poor infrastructure. This makes the task of electrification time consuming and labor intensive. After construction of the microgrid infrastructure, ownership and maintenance responsibilities are handed over to the utilities accountable for overseeing the area, under the Rural Development National Key Result Area (RD NKRA) programme [15]. Since the microgrids are often remotely located, the ownership takeover has been the source of a number of issues. A number of years after implementation, when equipment such as batteries start to break down and maintenance becomes a necessity, the lack of involvement from the utilities can lead to these stranded assets becoming a problem, according to Dr. Ali Askar Sher Mohamad [17]. These problems have led to microgrids being considered as inferior to grid connection by customers. However, some general guidelines for policies and regulations are being developed together with the utilities in order for the microgrids to serve as an asset to the centralized grid in the future [17].

The Ministry of Education have realized some electrification projects where the main focus has been to electrify schools, in order to ensure that education in rural areas does not lagging behind the modernization strategy of the country [18]. According to Dr. Ali Askar Sher Mohamad [17], the schools receive a budget from the Ministry for the maintenance. Despite efforts from the schools, unfortunately it has been shown that most of the PV systems breakdown within a year or two, and the systems end up running entirely on diesel.

Some rural electrification projects with a focus on community involvement in Malaysia have been conducted by NGOs [10]. No permits are applied for, since this is not clearly required in the law, according to Dr. Ali Askar Sher Mohamad [17]. The microgrids are usually quite small, being around a few kW each, serving lighting loads, charging of mobile phones, etc with no industrial loads. The maintenance of these rural microgrids is done by the people living in the villages with help from the NGOs.

While these projects are speeding up the electrification rate in the country, some issues have arisen in the government-microgrid owner relations, including:

- No external monetary support for Operation and Maintenance (O&M). Therefore, it is important to include this aspect in the business models for the microgrids.
- Unclear legislation leading to microgrids operating without any contact with the government, primarily to avoid being subject to regulation and taxes.
- In the situation of damage to the microgrid due to other infrastructure projects, no money is paid back to the microgrid owner, primarily as a result of the unclear legislation.

4.1.3 Main Findings

While rural electrification in Malaysia has generally been successful, much work is still to be done and insights from completed projects abound.

- The Ministry of Rural and Regional Development and the TSO/DSOs should develop specifications together. There should also be clear legislation and regulations that create a sense of ownership of the microgrids to avoid them becoming stranded assets. This work has been initiated.

- The poor condition of some microgrids creates perception and reputational risks and centralized solutions are considered to always be the best solution for electrification.
- No or unclear legislation could lead to some independent microgrids operating without any contact with the government.
- Monetary support for O&M of microgrids could enable bigger repairs in cases of the breakdown of equipment. However, O&M requirements should also be factored into the business planning process.

4.2 Case 2 – South Africa

4.2.1 Background

South Africa is a country with a population of 54 million people. Electrification in South Africa currently reaches 84% of the population with a goal of 100% electrification by 2025. The South African TSO, Eskom, generates approximately 95% of the electricity produced in South Africa, which makes them the country´s largest electricity producer. The remainder is generated by municipalities and independent power producers (IPPs). The Renewable Energy IPP capacity is approaching 7% of total generation capacity [19].

The South African national electrification programme was rolled out in 1994 by Eskom and the municipalities in order to increase energy access in the country. The programme was administered by the South African Department of Energy and it has reduced the percentage of un-electrified households to 14% (from approximately 50% in 1994) [20]. 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 [21].

According to Eskom, a distance of roughly 230 km and up is where the levelized cost of electricity in microgrids becomes competitive with grid extension [22]. The cost of microgrid and centralized grid extension in South Africa is also discussed in [23]. 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 [24]. 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 [22].

4.2.2 Smart Microgrid Pilot Design

Roughly 11% of the population is 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 Living Standard Measures (LSM[4]) of 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 [22]. A simulation of the requirements for a proposed hybrid off grid pilot site consisting of 34 rural homes can be found in [25].

For the low-income population in the LSM 1-4 group, a connection to a microgrid means rural access to electricity, and all of the associated economic and social benefits, before the centralized grid reaches them. This solution provides electrification of the rural communities without adding additional stress on the centralized grid, which is already strained.

The Eskom rural site design targets 30 kW of PV for 14 houses with a load of about 30kW in a village. The microgrid will also contain battery storage of 90 kWh. The system will provide 10 kW to be shared by the 14 homes directly from PV during the day. The surplus of PV generation will be used for charging battery for evening use. A smart active network management system will be used to control the system. In addition, a small system of 14 kW PV and storage will be added for an industrial load like a fruit packing house. The industrial load will be operated only during the day [22].

For inhabitants in the LSM 5-7 group, microgrids can enable integration of small scale DER onto the grid. The microgrid can also provide grid strengthening at the end of the line. Further on, the communities are not as dependent on the grid, as a way of resilience. The communities can also be load shed (running in island-mode) for days at a time if required in order to maintain grid integrity.

For the LSM 8-10 group, in addition to the possibilities experienced by the lower LSM categories, smart control and metering of microgrids is foreseen. This includes various ancillary services such as demand management and load control, which help reduce the strain on the centralized grid. The microgrid can also aid with selling energy back to the grid when production is higher than consumption.

The pilots are planned to be built during 2015-2016 [22].

The "Smart Microgrid Pilot" project is not the first set of microgrids launched in South Africa, but previous attempts have experienced problems with the handover phase and finding economically sound financial models [24]. Bad experience has led to customers viewing decentralized solutions as inferior to the centralized grid [22].

[4] The SAARF Living Standards Measure (LSM) is the most applied segmentation tool in South Africa. It divides the population into 10 LSM groups, 10 (highest) to 1 (lowest). The tool does not consider race, age, gender or any other variable used to categorize people. Instead, it groups people according to their living standards [41].

The difficulties faced by the previous attempts were according to [22], caused by a number of factors, including:

- Timing: when launching the early microgrid projects the technology was not sufficiently mature, with limited understanding of renewables by ordinary people impacted by this technology.
- Lifestyles/Change in need: Rural areas use more technology today than they did at the time of the early microgrid projects, such as mobile phones, satellite TV, and internet access.

To avoid a similar negative scenario, 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.

4.2.3 Main Findings

Main findings when analyzing the situation for microgrids, centralized grids and their interaction in the South African environment include:

- Eskom sees microgrids as a means 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.
- Since Eskom is both the owner of the centralized grid and the microgrid, the risk of stranded microgrid assets is carried by the same entity; and it is in their interest to keep utilizing the equipment.
- The importance of customer/community engagement, training and a clear message of what could be expected in terms of electricity delivered, costs etc. has been identified as very important to project success.

4.3 Case 3 –Uganda

4.3.1 Background

Uganda is a country in sub-Saharan Africa with a population of 37.6 Million people and an electrification rate of 18.2% [26]. The ministry responsible 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% (i.e. consumers utilizing electricity in their homes, businesses or institutions) from the current level of about 5% [27]. The majority of the new connections will be made through expansion of the grid (1.28 million new connections). 140,000 connections are expected through microgrids. Hence, the government is following both a centralized and decentralized track.

The ambition to electrify the country as fast as possible, while limiting the cost, has led to a governmental program to increase the involvement of third parties, handled by the Rural Electrification Agency (REA). The REA invests in the extension of the national grid but also provides subsidies for the development of microgrids. The Electricity Regulatory Authority (ERA) grants licenses and Power Purchase Agreements (PPA) to large power plants (above 0.5 MW). Small decentralized microgrids require an exemption from ERA. This exemption of license enables the microgrid operator to sign an agreement with REA for a subsidy and a lease of the microgrid which belongs to REA. This leasing agreement ensures that the National Grid does not distribute electricity in the area, lowering the risk for stranded assets. The leasing agreement is directly linked to the license and expires when the license expires.

Figure 8 Biomass gasification power plant in a microgrid operated by Pamoja Energy Ltd

4.3.2 Regulatory

As indicated, Uganda is following both a centralized and decentralized track for electrification. The REA provides subsidies for the development of microgrid infrastructure and meters to support entrepreneurs to build off-grid systems. This leads to the REA owning the grid, whereas the entrepreneur is allocated a leasing agreement to operate it.

The REA is also responsible for grid extension. However, the distribution market is privatized, meaning that DSOs operate under leasing agreements with the REA. The DSOs are permitted to make new connections within a range of 1 km from the grid.

Energy Service Companies in Uganda also need a license (or an exemption of license) from ERA to generate and distribute power. This license enables the electricity utilities to obtain subsidies and leasing agreements with REA. This leasing agreement gives the right to operate a micro-grid for a defined 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. The leasing system is a strategy for the government to attract investment in both centralized and decentralized power [28]. This approach also decreases the risk of stranded assets for the microgrid operator, since the microgrid plans are developed together with REA. The REA and ERA are currently working on making the licensing and leasing processes a unique procedure.

4.3.3 Actors

Mostly private investors, but also NGOs, are active in the rural electrification area in Uganda. The ERA grants licenses and PPAs and the REA provides subsidies and leasing agreements for the development of microgrids.

One of the companies that are active in the field, Pamoja Energy Ltd, operates microgrids for rural electrification. Pamoja has been operating power plants under license from ERA since 2014. Nicolas Fouassier, director of Pamoja Energy Ltd, indicated that the company received subsidies and a leasing agreement from REA for two sites in 2015 [28]. In their case, site selection was based on the ability to pay, industrial loads and access to local biomass resources for the power plants. There is a high interest in obtaining electricity in the villages, which is why their microgrids have been well received [28]. Clear social benefits have been seen after the building a microgrid in a village. The rationale points to the fact that electrification demonstrates village progress, leading to an increase in interest for the village, increasing willingness to invest, improved land value etc.

4.3.4 Microgrids

Today most microgrids in Uganda are built to provide energy access in rural areas. Microgrids mainly support household demand for lighting loads and mobile phone charging, but some small industrial loads in the villages are also be supplied with electricity. The size of the microgrids is often less than 100 households and maximum 10 kW.

Maintenance of the grid and connection of new customers can only be performed by certified persons. This is currently executed by personnel certified to work on the national grid.

4.3.5 Main Findings

- Uganda has an established policy for co-operation 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. This can increase the willingness to invest in microgrids.

- The electrification of villages can lead to an increased value, with villagers investing more in their houses as a consequence, even though electricity access is limited to certain hours of the day.

4.4 Case 4 –Canada

4.4.1 Background

Canada is a sparsely populated country where 100% of the population has access to electricity. Some communities receive electricity through off-grid energy systems due to being distanced from the centralized grid (although these communities are only a minor part of the total electrified households). There are about 300 off-grid communities and among these are some 200 remote Aboriginal communities. Most of the Aboriginal communities range in size from under 100 to 1000 inhabitants, with some communities numbering up to almost 4000 people. The load differs between the communities, but roughly half are below 1 MW in size and the other half are between 1 and 4 MW in size, with a few larger than that. For the Aboriginal communities, the loads are almost entirely residential and commercial. The size of the other off-grid communities or cities can go up to about 20 000 people.

Diesel generators are relied upon to provide electricity to these communities. As mentioned in the introduction, diesel generation has several drawbacks particularly related to health and environment. Issues associated with diesel generation (such as high cost of generation and getting the fuel to the site) result in constrained energy provision being a bottleneck for the development of these communities.

4.4.2 Centralized grid and microgrids

This case example comes from northwest Ontario where 27 remote first nation communities are located. Of these, 25 are not connected to the provincial electricity grid, using off-grid electrification solutions based on diesel generation. Diesel generation costs are often three to ten times higher than the cost of the generation in the provincial grid [29]. Due to the drawbacks associated with diesel generation and the fact that many of the generation stations are reaching the end of their lifetime [30], three strategic options for ongoing energy supply for the remote communities have been assessed by Ontario Power Authority (OPA), in collabortaion with the communities [31]:

1. Off-grid decentralized energy system - using diesel generation (Status Quo)

2. Off-grid decentralized energy system - using integrated solutions of renewable generation and the existing diesel solutions, including the possibility of connecting hydro generation to community clusters.

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. Short-term but labor intensive jobs such as the construction of a transmission line compared to less labor intensive, long-term jobs of maintaining a community microgrid was an aspect that was also taken into consideration [30]. The financial study process of determining feasibility of connecting the remote communities to the provincial grid can be seen in Figure 9.

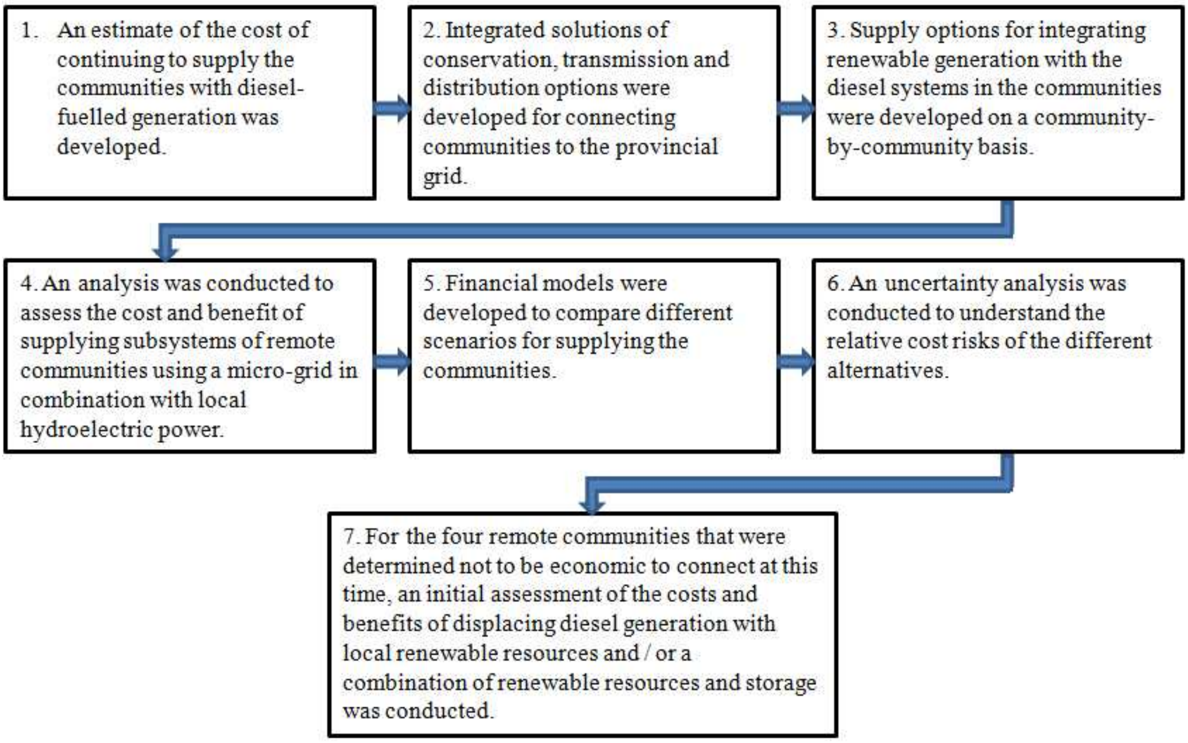

Figure 9. Study process for deciding feasibility of grid connection of remote communities **[29]**.

Of the 25 communities assessed, 21 were considered feasible to connect to the centralized grid with a transmission line, based on these criteria. For the off-grid energy systems including renewable generation, maintained diesel generation was considered a necessity to retain the grid integrity (operability requirements and meeting load), and hence the transmission line was considered a better alternative from the environmental perspective [31]. This is partly due to the high percentage of hydro and nuclear in the generation mix.

For the 21 communities assessed, the generation curves of locally available renewable resources, especially wind and solar, was found to not match well with the projected community demand, and would need to be coupled with diesel generation [29]. Introducing storage as an alternative to address the mismatch of the load and the generation curve of renewable resources was not included in the investigation of a connection to the grid, as compared to a renewable-diesel microgrid connection. However, it was included in the assessment of options for the 4 communities for which a connection to the transmission grid was found to not be economically viable.

These 4 communities were deemed unfeasible for connection to the provincial grid due to distance. 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 sources (micro hydro, wind, solar) combined with battery storage and baseline diesel generation [29].

Already some attempts have been done in the field of remote diesel-renewable hybrid microgrids. A community whose diesel system is at 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 renewable energy microgrid solutions [32].

4.4.3 Main Findings

In the investigation of the most economically-, environmentally- and technically beneficial solution, case to case studies were done comparing different decentralized solutions and a connection to the centralized grid.

- The study process presented in Figure 9 outlines the feasibility study of grid connection on a case-to-case basis for each community.
- The plans of connecting the 21 communities to the centralized grid included one feeder line to each community. It is therefore concluded that diesel generators may be required to increase the reliability of service. It is possible that hybrid renewable-diesel microgrids could also provide increased reliability for those communities and lower repair time during winter. However, the economics of the combined connection and renewable-diesel hybrid solution was not part of the IESO assessment.
- With the typical technical requirements and performance characteristics of distributed renewable and diesel generation, hybrid microgrids are not necessarily optimized for environmental benefits. The Ontario case highlights some of the difficulties of comparing the alternatives of grid connection to microgrids, which aspects that should be considered and the various system scenarios to be compared. In this case load growth, cost and environmental benefits were the three weighted factors.
- The possibility of future job creation was an important factor to stimulate community involvement.
- Even in countries with 100% electrification, microgrids can play an important role in serving remote isolated small communities.
- Moving from diesel generation to using renewable energy sources in combination with energy storage, can save costs.

4.5 Case 5 – India

4.5.1 Background

India has the fourth-largest energy producing capacity in the world, with an installed capacity of 284,303 MW [33]. However, in 2010, 36% of the population (404 million people) still had no access to electricity [34]. In addition, the centralized grid has had problems ensuring stability and adequate and consistent supplies to avoid major load shedding. One example of poor "grid resilience" is the major black out of 2012 which left approximately 670 million people without electricity supply [35].

The goal in India's 12th 5-year plan is to achieve electricity access for all by the year of 2017 leading to the government initiating a range of programs of work with associated financing and funding [36]. The main driver for deployment of decentralized energy systems in India is to electrify the large part of the rural population that is either under-electrified or does not have access to power at all. As a consequence of this strategy, India is one of the leading countries in the field of microgrids, with over 100 deployed systems, of which 32 existing systems use diesel generation.

The government of India is also devoted to the continued expansion of the centralized grid. However, there is an implicit understanding that some rural parts of the country are unlikely to be reached by the centralized grid within the foreseeable future and hence are better suited to microgrid systems [37].

4.5.2 Centralized grid and microgrids

There are several initiating actors in the field of microgrids in India. These include:

- NGO Entrepreneurs (for example Husk Power Systems and Simpa Networks)
- Utility Companies (for example Tata Power)
- Government actors

The system of payment has been an important consideration for actors [37].

Most microgrids are being developed in communities located far from the grid. Therefore, the potential interaction with the centralized grid has not been realized as yet. However, in cases where the microgrid will be operating in parallel with the grid, it can offer improved reliability due to the frequent power outages on the main grid.

Some of the microgrids will be 48 V DC systems. DC microgrids can be completely off-grid or isolated from the utility grid through Grid Interlinking Converters (GC). The GC option makes the utility grid a dispatchable source whose power and voltage can be fully controlled [38]. However, grid connection could be a problem in the future, especially for the DC microgrids that are not designed for integration with the centralized grid.

4.5.3 Smart Connected Microgrids

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 MW peak microgrid in the region of Tamil Nadu. This microgrid will have the option to be connected to the centralized grid, as well as to operate in island mode. It also provides services such as load shedding and demand-response with the support of an installed 5MWh battery. The system will connect 29 000 customers and is planned for inception in early 2016 [39].

4.5.4 Policy & Regulatory Framework

There is currently no consolidated policy in place for the decentralized energy systems sector. There have been indications that a Renewable Energy Act will be developed which would include all decentralized energy systems in a single framework. The lack of policy can give a degree of freedom to the actors in the field, but can also make it difficult to secure funding due to the unclear regulatory future [37]. The role of the Central Electricity Regulatory Commission (CERC) is critical in the provision of rules and regulations for development, funding, ownership and operation of such smart grid.

4.5.5 Main Findings

- In India, microgrids are built primarily to provide energy to all within the foreseeable future but also to increase sustainability 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 also provide a legal framework to mitigate the risk of future stranded assets due to central grid takeover or central grid competing against microgrids for the same customer base.

- Lack of policies, revenue models and finance mechanisms are seen as barriers to the development of microgrids.

4.6 Comparison of cases

Cases	Electrification Rate	Main Findings
Malaysia	86%	• The Ministry of Rural and Regional Development and the TSO/DSOs should develop specifications together. There should also be clear legislation and regulations that establish a sense of ownership of the microgrids to avoid becoming stranded assets. This work has been started. • The poor condition of some microgrids creates perception and reputational risks and centralized solutions are considered to always be the best solution for electrification. • No or unclear legislation could lead to some independent microgrids operating without any interaction with the government. • Monetary support for O&M of microgrids could enable bigger repairs in cases of the breakdown of equipment. However, O&M requirements should also be factored into the business planning process.
South Africa	84%	•Microgrids can be a means to increase resilience and reliability in the centralized grid, but also serve as a way to reach out to households that are not feasible to electrify within a reasonable time through grid extension. • Meeting the needs of the specific targeted customers affects the microgrid design. • Since the national utility, Eskom is both the owner of the centralized grid and the microgrids, the risk of stranded microgrid assets is carried by the same entity. Since the owner of the centralized grid also owns the microgrid assets it is in their interest to keep utilizing the equipment. • The importance of customer/ community engagement, training and a clear message of what could be expected in terms of the nature of electricity delivered, costs etc. has been identified as a key element in project success.
Uganda	18.2%	• Uganda has an established policy for co-operation with private companies to increase the number of connected customers, utilizing rural 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. This can increase the willingness to invest in microgrids. • The electrification of villages can lead to an increased value, with villagers investing more in their houses as a consequence, even though electricity access is limited to certain hours of the day.
Canada	100%	• With only one feeder line from the centralized grid, the microgrid systems could also provide increased reliability. • The demonstrated case highlights some of the complexity when comparing the alternative of grid connection with microgrids, and which are the aspects that should be considered. In this case load growth, cost and environmental benefits where the three weighted factors. • The possibility of future job creation is an important factor for community involvement. • In countries with 100% electrification, microgrids could still play an important role. • Moving from diesel generation to using renewable energy sources in combination with battery storage can save costs in a microgrid setting.
India	64%	• In India, microgrids are built primarily to provide energy to all within the foreseeable future, but also to increase sustainability 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 also provide a legal framework to mitigate the risk of future stranded assets due to central grid takeover or central grid competing against microgrids for the same customer base. • Lack of policies, revenue models and finance mechanisms are seen as a barrier to the development of microgrids.

5 Issues related to integration of microgrids into the grid

As described in the previous chapters, many countries are proceeding to expand the centralized grid and at the same time are trying to reach many unserved costumers through distributed solutions. The effective interaction of the grid and microgrids requires a specific and detailed plan of how to proceed when the two grids meet. If no such policy or regulations exist, investors will be reluctant to invest in microgrids given the likelihood of stranded investments once the centralized grid expands into the area of the microgrid [40].

There are tremendous opportunities for the centralized grid and microgrids to support each other in a manner that is beneficial for all actors. However, current reality reflects fundamental issues in the interaction and integration of grids and microgrids, compounded by limited practical experience of the successful interconnection of centralized grids and microgrids.

Technical constraints that inhibit the integration of microgrids into distribution grids include specific elements such as dual-mode switching functionality (going from islanded to grid-connected mode and back again), reliability, power quality and protection (for equipment and individuals).

In order to reach the full potential of microgrids, several questions remain:

- How can markets be established where the decentralized energy systems help to support the centralized grid, both in increasing the number of connections but also through providing ancillary services during periods of grid connection? What are the supportive policies and regulations tailored to each market's nuances?
- What technical, policies and regulatory solutions are needed for this to become a reality?
- What market barriers are still to be resolved from a local and global perspective?
- What market enablers need to be put in place?
- What regulatory support is needed for decentralized grids to thrive as a supporting entity rather than as a competitor to the grid?

6 Conclusions

An increasing number of microgrids are likely to be implemented in the future; both for the purpose of reaching the UN goal of Sustainable Energy for All, but also as a functioning cell of the centralized grid for the provision of ancillary services. Examples of ancillary services include increased resilience, demand side management and facilitation of the selling of excess microgrid 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 and as a way to avoid load shedding when the centralized grid is strained. A further benefit of microgrids is the speed of construction (weeks to months), whereas it takes several years before the centralized grid is extended. Absolute capital investment per kilometer of central grid extension may also be higher than a microgrid system designed to serve a community autonomously. Even though the benefits are clear, microgrids can sometimes be considered to be inferior to a reliable centralized grid given that energy access is not always unlimited.

Several questions should be raised regarding the interaction of the centralized grid and microgrids in cases where they co-exist or where the centralized grid is extended to reach the location of the microgrid. A number of main conclusions drawn from analyzing these questions are presented here[5] with the main conclusions underlined for emphasis:

Interactions between microgrids and the centralized grid

1. The risk of isolated microgrid stranded assets, in instances where the centralized grid reaches the area of microgrids, can be mitigated through effective upfront planning that ensures that connection to the centralized grid is technically feasible, should it be required at a later stage. Such planning also increases the potential for the decentralized energy system to become a valuable contributor to the grid, leading to an enhanced business case for the microgrid stakeholders.

2. In general, specifications must be agreed on by all involved stakeholders: the utilities, the funding parties, the engineering and construction teams, and the operations and maintenance team; thereby increasing the likelihood of a successful handing-over.

3. Effective policies and regulations also decrease the risk of the deployment of poorly managed microgrids. Poorly planned and managed microgrids give new technologies an undeserved negative reputation, thereby increasing the risk of potential new renewable resources not being used.

Decision parameters for stakeholders when deciding between top-down and bottom-up electrification in unelectrified areas

1. When evaluating the best alternative for the electrification of a rural area, distance alone is not the only criterion 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 the evaluation process.

2. Governments that provide clear regulation and co-operate with private companies to increase the number of connected customers, using both decentralized electrification and

[5] It is worth noting however that the actual practical experience of connecting microgrids to centralized grids is still l imited.

grid extension, can be instrumental in ensuring that optimal solutions to electrification requirements are reached.

3. In countries with a limited number of isolated communities, a case-to-case evaluation is beneficial. However, in countries where this approach would be too costly or time consuming, simplified methods are often such as distance to centralized grid, population density, number of potential industries etc.

Design differences and requirements for microgrids, depending on the intended purpose and the need of the end customer

1. Building a strong relationship with the customer, as well as understanding the customer requirements in a specific area should be in focus when designing the microgrid. A further important criterion is that of ensuring a sustainable revenue model to support investment funding as well as the O&M of such projects. Each microgrid design differs with respect to the capacity, potential need of energy storage, type of production, the level of grid intelligence, the communication possibilities etc.

2. For the design of a microgrid that does not have a connection to the central grid, consideration should be given to the likelihood of a potential grid connection becoming a reality. Such planning enables the consideration of the potential increase in energy demand when specifying the electrical requirements of the equipment (cable ratings etc.). The possibility of the provision of ancillary services to the centralized grid should also be kept in mind in aspects such as the design of the communication system.

6.1 Preparation for future grid connection of microgrids

Based on the knowledge drawn from the analyzed cases, a best practice model can be formulated regarding preparations for connection of microgrids to the centralized grid. Insights from a technical perspective include preparing the microgrid right from the planning stage for integration into the centralized grid, allowing for the direct connection of the microgrid when the centralized grid reaches the area of the microgrid. The microgrid can then operate as a cell to the centralized grid. For this option to become a reality, the microgrid equipment needs to comply with the technical requirements of the centralized grid[6]. The specific technical requirements should be evaluated in detail for each case and the consequences of the interaction between the microgrid and the centralized grid should be analyzed. Further, the roles of the microgrid owner, the centralized network operator, governmental actors and local stakeholders should be addressed to ensure that an interaction framework defining ways of interacting with each other is put in place.

[6] No such generic guidelines exist today and they would probably need to vary for each country. However, they shou ld include cable dimensions that can handle the new requirements, communication systems that can interact with the operation system of the centralized grid (i.e. demand response, peak shaving and voltage regulation) and converters that can handle the connection to the main grid.

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