Microenergy Systems

Mikroenergie-Systeme

Research Group – Microenergy Systems (MES)

Mini-Grid Research Team

An Impulse for a Discussion on Mini-Grids and Electrification

Based on years of experience, the MES Research Group has initiated a new team to enhance research work on the issue of mini-grids and electrification, considering the unique perspective of microenergy systems. This paper from the research team aims to provide a first impulse for the discussion about electrification, with a focus on the micro-perspective and the opportunities of bottom-up distribution networks.

We seek to start joint collaborations on this issue. Therefore, we invite the scientific and practitioner community to continue this discussion with us, and we look forward to your comments.

Thank you for your interest!

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A proposition for a process view on electrification related to mini-grids: Off-Grid swarm electrification as a holistic Bottom-up approach for basic energy supply

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Introduction

Considering the fact that everybody uses energy on the household or business level, the task of electrification should always proceed from the existing uses and, in particular, the existing needs for energy. Additionally, given that up until now most of the countries that are not within the group of so-called developed countries have rarely been successful in electrifying or, better stated, in supplying their population with reliable and stable electricity supply, it seems necessary to rethink existing electrification approaches. Assuming that these have been mostly top-down approaches based on the concept of conventional electrification through transmission and distribution networks, this paper proposes a paradigm shift in the perspective towards addressing the electrification challenge. The concept will be referred to as “swarm electrification” and can be considered a bottom-up approach that views electrification as a process with different phases. Starting with existing energy uses at the micro level, in particular the existing electrical applications of households or micro-enterprises, this process view includes micro-grids and interconnected micro-grids, and finally also the national grid connection.

For this, it is important to analyze the existing grid-based approaches, in particular mini-grids, referring to the pros and cons of the approach in order to define an adapted way in which new distribution networks can be sufficiently suited to accommodate and tap into existing energy uses.

The following paper will provide an initial insight into a process view of off-grid swarm electrification and advocate the importance of changing the perspective from top-down to bottom-up, as a viable means of reaching those not yet empowered with a basic and reliable supply of electricity.

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GRID-CONNECTIONS SEEN FROM THE MICRO-PERSPECTIVE

The field of rural electrification surges forward this year with a new burst of energy provided by the recent announcement from the United Nations General Assembly to declare this the Decade of Sustainable Energy for All. This springboard event presents a chance for the development sector and energy entrepreneurs the world round: to learn from the myriad challenges facing current rural electrification models, and to seek out, experiment with, and evaluate new methods for effective rural energy programs, which truly contribute to sustainable economic development.

In the past years, mini-grids have become a more and more attractive approach for rural electrification compared with the extension of electrical transmission infrastructure to connect rural areas to the centralized grid. In the World Energy Outlook 2011, the International Energy Agency developed a scenario for universal electricity access by 2030. This "Energy for All Case" expects only 30% of rural areas to be connected to centralized grids, whereas 70% of rural areas are connected either with mini-grids or with small stand-alone off-grid solutions. [1] The IFC estimates that 30 million households could be profitably served by mini-grids, representing a global market of $4 billion dollars. [2] Often seen as an alternative to extending centralized grid infrastructure to rural areas, mini-grids can provide for their own generation, distribution, storage, control, consumption and business models, independent of the central network. With the ability to incorporate multiple generation sources of varying capacities, mini-grids are able to deliver a sufficient amount of power to micro-, small- and medium-enterprises (MSMEs) for productive economic uses, such as running electromechanical machinery, manufacturing and service enterprises. Additionally, the distribution infrastructure installed within an alternating current (AC) mini-grid constellation can enable a simplified interconnection to central grids from a technical point-of-view. There are many benefits to grid-based electrification.

However, although they are often considered a decentralized energy supply solution for rural community electrification, traditional mini-grids rely on extensive planning periods, high capital costs, and medium-scale centralized generation and distribution technologies of a relatively complex nature. Literature shows that a principle problem facing both mini-grid deployments and extensions of central grid connections to remote areas is the inability to recover associated capital costs. Mini-grids can employ fairly complicated business models, requiring extensive site planning, land demarcation, institutional setup, regulation and certification of consumptive appliances, and often the management of fuel supply chains. Grid extension projects, similarly, attract significant social and political friction in regard to the planning and prioritizing of transnational transmission lines and transformation stations through rural environmental areas. The costs for infrastructure of this scale become quickly prohibitive over long distances, project timelines are uncertain, and point-to-point infrastructure can be highly susceptible to natural disasters. Tariffs in both models are often only able to cover operating and maintenance costs, and therefore significant government subsidies and/or international donor funds become necessary [3]. Even in that case that either model is operated profitably, the payback period for initial investment is exceedingly long. Both mini-grid as well as grid extension approaches tend to employ the planning and strategy tools and methods of centralized energy solutions.

Whereas grid extension is often seen as the solution for modern societal development, implying access to government money as well as modern infrastructure such as roads, education and healthcare, distribution of small-scale devices carry the stigma of being a less comprehensive electrification solution. The implication may be that grid infrastructure will never be extended to an area where small-scale energy devices, such as solar home systems (SHS) or diesel generators, already provide electrification for households. Since grids are able to deliver a larger amount of power for productive use, this may be decrease end-user acceptance of small-scale systems. However, grid-based electrification solutions face a variety of barriers and reliability issues in regard to energy service issues as well (Table 1).

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Table 1 - Barriers facing grid-based electrification approaches.

Energy Service Issues	Mini-grids	Central Grid Extension
Timeline	Typically requiring extensive planning and community organizing before implementation, in general not flexible	Timeline uncertain, and grid extension might never reach very remote areas
Cost Recovery	Large capital costs for generation and storage technologies lead to a high-risk business case	Large capital costs for transmission infrastructure unmatched by relatively small consumption
Financing	Government subsidies or international donor funding required if cost recovery is not possible. end-users pay fixed tariffs for consumption.	
End-user Acceptance	May be perceived as second rate electrification scheme with main grid extension becoming unlikely	May be seen as highest quality electrification option, but lack of personal investment reduces sense of ownership
Reliability	Depends on commitment of utility, sources of energy, personal investment of all stakeholders and capacity of system devices	Remote areas face frequent outages, are first to be shed in the case of excess demand, and are highly susceptible to natural disasters

Top-down supply-driven perspectives to electrification are based on the notion that state-owned utilities or central grid operators should provide all electricity infrastructure and services. This approach views end-users as passive consumers and results in unidirectional interaction, regulation of consumption and restrictive supply conditions. In that regard, the focus is generally on centralized energy systems, thus ignoring the various forms of energy production and consumption (e.g. cooking, heating, use of batteries etc.) detached from the grid. In these off-grid scenarios, people utilize a variety of energy sources to meet their basic needs and run their enterprises. These sources are often thermal in nature (biomass, kerosene, paraffin, liquid fuels) and sometimes provide electrification as well, such as fuel-burning gensets. The sources of energy, and indeed the daily expenditures on the part of the people utilizing them, often remain hidden to the strategy of the planner with an approach that follows the logic of centralized energy supply. Centralized approaches are hardly able to consider individual demand and financial opportunities of the end-users. This results in several operating problems in terms of dimensioning and technology adaption, causing lower end-user acceptance and satisfaction.

Besides extension or development of grid infrastructure, other approaches to rural electrification include decentralized micro- or small-scale energy devices. Building on many years of experience in this field, we have come to favor a bottom-up approach to rural energy solutions, with a demand-driven focus, centered on the end-user's context, including their needs, activities, and existing consumption patterns. We see empowerment of households and micro-enterprises as a core requirement for the development of a self-sustaining rural energy program. For example, productive use of the electricity supply has been recognized as central in contributing to capital cost recovery and economic development. [4] The provision of end-user financial and technical services integrates stakeholders with a closer more consistent proximity to the end-users themselves, such as in the case

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of rural microfinance banks and their rural clients. Such mechanisms help to ensure the maintenance and longevity of small-scale energy devices and the potential for effective adaptation to end-user needs. **Box 1** lists some other important off-grid energy service issues. In short, a user-centered, demand-side-focused, bottom-up approach to rural energy programs brings many advantages to achieve long-term viability.

CENTRAL ISSUES CHARACTERIZING OFF-GRID ENERGY SERVICE

- End-user acceptance and appropriate technology adaptation
- Service-based infrastructure, including financial and technical services
- Income generation and substitution of existing end-user energy expenditures
- Environmentally sound technologies to protect health of people and ecosystems

Box 1 - Selection of central issues characterizing off-grid energy access.

In order to overcome barriers in the electrification process this paper therefore advocates combining effective aspects of user-centered and bottom-up approaches together with the benefits of mini-grid solutions. We envision a process-based approach for individual households, enterprises and communities aiming to achieve interconnected and comprehensive electrification services, one that begins with the end-user, their current economic activities and their existing sources and patterns of energy consumption. Rather than starting with large injections of international donor funding or government subsidies to pursue a top-down implementation of a centrally planned mini-grid or the extension of central grid infrastructure, the process should begin bottom-up with the small-scale financing of end-users and communities themselves. These individual nodes should not only be consumers of the electricity supply, but rather also play an active role in the production of electricity, thereby moving away from the role of purely passive consumers towards that of pro-sumers in an active distribution network.

BUILDING FLEXIBLE MICRO-GRIDS FROM THE BOTTOM UP

With recent advances in Information and Communications Technologies (ICT) and Smart Grid Technologies, this bottom-up interconnected electrification approach becomes feasible. Micro-grids, or small-scale interconnectable low-voltage supply networks that manage their own supply, storage and consumption of energy, form the building blocks of a highly flexible and reliable network. These nodes can be connected together and/or connected to central grid infrastructure, but they are also able to run independent of these interconnections. Modern power control devices enable the integration of any number of distributed generation systems and loads while maintaining a highly consistent electrical voltage and minimizing frequency fluctuations in AC grids. [5] Smart metering and intercommunication allows for real-time measuring of power flows to optimize the system. Standardized measuring and monitoring components as well as modular component architecture provide the opportunity for flexible customization and communication of system maintenance requirements, while keeping the per-system effort low. Advances such as these allow for the conception and realization of individual intelligent control units, which can be implemented at the household and micro-enterprise level for a relatively low cost, and form the basis for an interconnected bottom-up micro-grid. [6]

In order to implement a successful community-based micro-grid, several aspects have to be considered. One key factor is to build on existing resources, for example previously purchased SHS, diesel generators, batteries or other small-scale energy devices, to ensure the commitment and acceptance of stakeholders who already have invested in some kind of electrical equipment. Therefore, a wide variety of electricity sources would have to be compatible with the intelligent control units, including technologies such as biomass gasification, liquid fuel generators, micro-hydro, photovoltaics and small-scale wind. Then, we propose a three-phase process.

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The first phase starts with the rapid and efficient deployment of SHS or other small-scale energy devices with integrated storage and intelligent control devices to households and businesses via end-user microfinance and the provision of long-term locally available technical services. Through this phase, a first level of electrification and electrical energy storage is reached which provides for the basic needs of households and micro-entrepreneurs, however the ability to grow demand or meet larger-load productive uses is still insufficient at this point. This initial deployment of small-scale island systems can presumably proceed much faster than in the case of long-term top-down project planning.

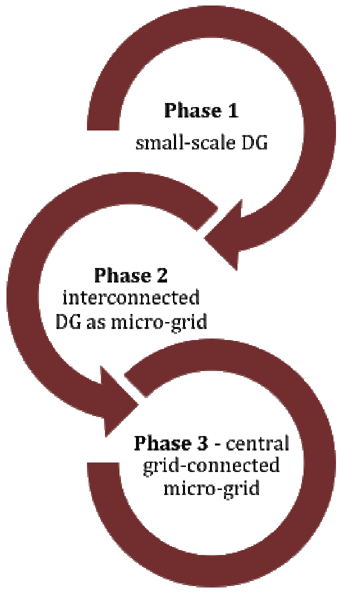

Figure 1 - Three-phase development of grid-connected autonomous micro-grids.

In a second phase of micro-grid development, the individual nodes are connected together, thereby providing balancing of all systems, in that they are able to share the swarm of generation capacity from all individual systems. Community-based financing may be sought from a group of individuals for this phase, or additional investment may proceed from MSMEs interested in larger productive uses of the growing electricity supply. A consistent baseload consumption profile could be achieved through the integration of such productive users, thereby also allowing for the integration of more distributed generation (DG) with improved opportunities for efficiency and cost recovery. It is also important to note that this phase may be able to implemented as an entirely direct current (DC) grid. DC appliances offer higher efficiency, DC/AC inverters could be avoided in the system, and new developments in DC motors allow for the possibility to provide for productive uses with a DC electricity supply as well.

In a third phase this micro-grid can connect to other micro-grids and/or to central grid networks. The interconnection would provide for an even further stabilizing effect, and the bottom-up system architecture would ensure that all nodes are still able to island and operate independently, in the case that, for example, a natural disaster causes outages in other grids or knocks out interconnecting transmission lines. With generation and storage capacity and a distribution network already in place in the micro-grid, connection to other grids will be more likely for two reasons. First, costs for a grid extension are reduced because the only cost factor remaining now is the extension of the transmission network. Second, the micro-grid is an active distribution network that can also feed into the system rather than just consume. This makes it very attractive for central grid operators as their generation capacity would not have to be increased, and the distributed storage capability of the micro-grid would also provide a buffer in the case of excess supply conditions.

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CHALLENGES AND OPPORTUNITIES IN FINANCING

In comparison to top-down rural electrification measures, the bottom-up micro-grid approach has key advantages in financing as well as in the development perspective of the infrastructure. First, all investment happens in a flexible time scale. This considers unpredictable changes in demand that may stay constant for years and then increase suddenly with new developments in productive activities or acquisition of machinery. Second, the modular nodal design of the bottom-up approach is most suitable to integrate new generation and storage equipment into the micro-grid with low risk of failures causing outages for others. In a system with decentralized and consumer-based generation and storage, the network itself is not a supply network but rather a balancing network. Together with modern ICT, this allows for targeting payment issues in an automated way. For example, if prosumer A uses power of prosumer B today and tomorrow the other way round, at the end of the month they only pay the difference. In any case, however, the opportunity exists for a variety of innovative market approaches to address the question of payment and tariff models.

The development process of autonomous micro-grids should provide comprehensive end-user electricity service delivery independent of central grid infrastructure, bringing a strong degree of satisfaction and commitment among end-user prosumers. The technical service network for proper installation, maintenance and capacity building, developed during initial microfinancing of small-scale systems should grow consistent with the demand for energy equipment and distribution infrastructure, as a vital component of any self-sustaining energy program is the availability of adequate long-term technical and financial services.

SUMMARY

In light of the multiple global initiatives driving rural electrification and sustainable development today, especially the growing importance placed on sustainable energy supply by the United Nations as an important catalyst in the effort towards achieving their Millennium Development Goals, rural energy programs and practitioners around the world have a new opportunity to address the issue of sustainable energy access for all. We advocate a bottom-up user-centered perspective in the pursuit of sustainable and effective models. For rural electrification strategies, grid-based solutions can offer great potential to provide stable and sufficient electricity supply for productive uses, which play a key role in bolstering economic development. Small-scale energy systems can provide rapidly deployable, affordable, and flexible solutions, which can address end-users needs on a highly adaptable basis. The vision presented here to combine benefits of both methods with a process-based approach to grid development can be likened to the concept of swarm intelligence, where each individual node brings input and value to create a conglomerate of value even greater than the sum of its parts. This model could be called swarm electrification, and promises new implications for the current state of advancements and thinking in grid-based electrification, and perhaps the future of the electrical grid is really one built from the bottom-of-the-pyramid up.

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Glossary:

Prosumer
an end-user who is **pro**ducer and con**sumer** of electricity for the grid.

Mini-grids
are standalone grids usually supplied by centralized generation from different sources (diesel, hydro, solar, hybrid) and storage. The capacity of the grid allows for productive use.

Micro-grids
are autonomous grids that can be operated on or off the main grid. The capacity of the grid allows for productive use.

Solar Home Systems
are end-user based generation (solar photovoltaics), storage and energy management units that run basic loads such as lighting and cell phone chargers. Larger systems also allow loads such as televisions and refrigerators, however the usage of mechanical appliances is limited.

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