Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 103 (2016) 363 – 368

Energy Procedia

Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid, 19-21 April 2016, Maldives

Against the odds: The potential of swarm electrification for small island development states

Mathias Koepke[a], Dr. Sebastian Groh[b*]

[a]*Research Group MicroEnergy Systems, TU Berlin, Straße des 17. Juni, Berlin, Germany*
[b]*ME SOLShare Ltd., Dhaka, Bangladesh*

Abstract

The paper builds on earlier observations using system complexity theory to explain the characteristics of a swarm electrification approach using existing small, distributed renewable energy generation infrastructure integrated into a grid. The concept is based on swarm intelligence where information and electricity flow between neighbors to achieve a compounding network effect, in that they are linked together to form a microgrid but at the same time showing a high degree of resilience as each node/ household can also operate independently. The paper contrasts this approach with traditional stand-alone and minigrid systems in small island development states using the multi-tier framework of measuring energy access and taking into account the particularities that these have, especially with regards to infrastructure and geography. The authors make use of qualitative and quantitative results from first practical applications of swarm electrification in Bangladesh.

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.

Keywords: small island developing states, swarm electrification, bottom-up village grids, multi-tier framework of measuring energy access, minigrid, solar home systems

1. Introduction

Much has been written in past years on electrification strategies for rural communities of the global South. While the discussion is manifold with regards to the characteristics to consider, there are three main approaches that prevail in the literature: individual, stand-alone systems such as solar home systems (SHS) or lanterns, different typologies of minigrids usually composed of one or more generation units while serving up to several hundreds or thousands of end-users, and main (national) grid extension [1].

* Corresponding author. *E-mail address:* sebastian.groh@me-solshare.com

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.
doi:10.1016/j.egypro.2016.11.300

This paper introduces an alternative concept called swarm electrification (SE) and compare it to mini-grid approaches for small island development states (SIDS) using the multi-tier framework of measuring energy access. Insofar, SIDS are regarded as cases in which electrification efforts face unique sets of challenges, according to Dornan [2]. These challenges will be used as a comparison metric for the above mentioned electrification strategies, namely SHS, minigrids and SE. The authors build this comparison on experiences with first real-life applications of SE present in Bangladesh.

1.1. Swarm electrification

Swarm electrification (SE) was introduced only a few years ago by researchers from the TU Berlin [3, 4]. SE builds on the usage of existing stand-alone energy infrastructure – mainly SHS – in order to create a smart low-voltage DC grid from them in which connected parties can act not only as consumers of electricity but feed energy into this small grid, becoming producers and consumers at the same time (prosumers). The complex characteristics of this approach vis-à-vis aforementioned others have been extensively covered by Groh and Koepke [4], and only the most relevant shall be reiterated here:

- **User centeredness**
  - An SHS owner or a person merely connected to the grid might consume, produce, and store electricity depending on own technical capacities installed and own preferences.
  - The community operates or owns the power grid and trades electricity among itself.
  - The users decide on their economic decisions regarding energy utilization and grid structure.
- **Organic growth and usage of legacy infrastructure**
  - The grid is not dependent on initial system design or engineering from central entities, hence growing organically when more people connect. SE is thus a step-wise approach in contrast to one-off systems, giving the possibility to smoothly transition from one access tier to the next.
  - Legacy infrastructure such as diesel gen-sets or SHS can be incorporated into the SE grid, avoiding stranded investment. Also, the grid itself can be connected to others (i.e. national grid).
- **Adaptive system characteristics**
  - Such as prices (and thus incentives), grid typology and size, operational structure, etc.

In short, swarm electrification (SE) smoothens the transformation from single, stand-alone SHS to microgrids without producing obsolete legacy infrastructure. This efficiently enhances electricity access due to the possibility of sharing and trading of electricity, reduces the extra investment to reach this point of enhanced access while simultaneously leaving ownership and value creation in the community. Section 2 will compare SE with respect to more clearly identifiable characteristics concerning SIDS.

1.2. Electrification in SIDS

In this sub-section, we intend to provide an overview to understand the electricity access situation in SIDS as one of the difficult localities to electrify with the national grid as pointed out by Hazelton et al. [5] and what particular challenges exist compared to rural areas in other countries. First, SIDS are not homogenous, as described by Timilsina and Shah [6]. They vary in size, population / density, geography (distance to neighbor islands or the mainland), and economic situation. Hence, access to energy - electricity and other carriers - as well as demand vary a lot. However, SIDS have some characteristics in common which are usually associated with barriers to sustainable and universal electricity access:

- SIDS are below world average regarding their energy consumption. The latter means limited demand and thus **a limited market size** for energy companies who cannot reach economies of scale [6].
- **Locational disadvantage**: SIDS are often located far from the mainland. Large distances result in infrequent and instable deliveries to the islands, high costs of these deliveries, and disadvantages in access to information and markets [2]. This means that a large portion of people lives too far for a centralized grid to reach them, favoring decentralized approaches such as SHS or minigrids [7].

- **Energy use is largely fossil-fuel based,** which is expensive (due to long transport), unreliable (infrequent) and economically risky (volatile prices), usually affecting the poorest households the most who already spend more money on energy when not electrified vs. electrified counterparts [2].
- Traditional forms of **government and small capacities** thereof [2], making it difficult for these governments to solely focus on energy; ultimately delaying adoption of needed policies. Additionally, limited budgets make subsidies for energy provision against other goods a trade-off.

Though some of these properties apply to many developing-country contexts, SIDS are special in that they combine all of them. The next section will use a matrix of these special characteristics and identify which electrification approach is suitable to solve them best per category.

2. Methodology

We reviewed existing literature comparing electrification strategies in general and how SIDS are coping with them. From this, a number of indicators clustered in categories was extracted, serving as focal points of comparison. Here, we focus on SHS and mini-grids as existing approaches as well as SE as a potential alternative. The table in appendix A shows the indicators and their origin in an overview.

3. Results from the comparison of electrification approaches

We compare stand-alone SHS, renewable (or hybrid) mini-grids and SHS-based SE as electrification approaches according to the aforementioned categories. The leading question is to what extent each of these approaches is able to cope with the specific issues represented by the indicators.

3.1. Market suitability

Concerning market suitability, two points are determining the SIDS rural, off-grid markets, which are different from others in mainland, rural electrification: extraordinarily long distances and no mass market. As people are not used to using electricity, and energy provisions in houses and communities are usually limited to lighting and cooking [1], a fitting approach should be able to only offer these services in the first place to not drive costs up without matching demand. However, energy use is rising over time [1, 4]. Accordingly, purchasing a new system to cover higher demand could probably cause redundant infrastructure. SHS are limited in their supply capabilities and are usually not meant to extend, except for some newer plug-and-play systems. Therefore, SHS (and especially solar lanterns) are rather suitable for a limited, non-growing demand; one that is not present in most cases in reality as the access tier framework [15] illustrates. Mini-grids are usually designed to cover higher demand and access tiers [4] with the likelihood that the system is oversized, leading to high levelized cost of electricity from the start with no matching demand that can be used productively. SE bridges this gap, letting people use a limited amount of electricity in the beginning that enables them to reduce high costs of fossil fuels [2] while offering to extend the systems through interconnection later on. In this way, supply meets demand at every point in time. However, the unit cost of energy of well-designed mini-grids may be lower though.
Economies of scale are needed for SHS to justify sales and after-sales service provision. Both get cheaper when expensive visits to islands can be clustered. Hence, in a growing but immature market, this is unlikely the case from the beginning, SHS have a disadvantage here. To a lesser extent, this holds for SE as it builds on these SHS. Mini-grids are usually designed once and need no frequent visits. However, the problematic of necessary over-design leaves operators with the challenge of running them profitably [1].
Given the low purchasing power, both government subsidy schemes as well as repayment schemes over longer periods are important [2, 6]. The rise of net-metering in grid-connected DG (decentralized generation), may provide an incentive for people to reduce their bills [6]. SHS can be equipped with mobile payment modules for instalment payments and can also be subsidized, with respective government policies [8]. The same holds for SE, which relies on ICT inclusion anyway [4] so that mobile payment is a logical component. An advantage of SE here is that the user as a prosumer (selling electricity) has a larger market-based economic incentive. Ultimately, this may reduce loads and thus investment and unit costs.

3.2. Technical appropriateness

Technical appropriateness relies on a variety of factors. Remote communication and monitoring of systems are crucial for operators to cope with the problem of large distances. Principally, this can be done with either of the electrification approaches. However, SHS are often designed to meet lowest cost and do not include these features. In order to succeed in this market, remote communication and monitoring of systems are deemed necessary. The same holds for setting aside funds for operation and maintenance (O&M), preferring a mobile payment infrastructure or community payment collections (mini-grids).
Meeting a higher demand (more hours of electricity, larger loads, more power) is necessary to unravel the potential that electrification has [1]. Minigrids perform best here. Concerning SE, Groh et al. [3] discuss the potential to cash in on produced and shared electricity directly, making this option attractive very directly to end-customers while reaching higher electricity access tiers is more difficult.
Modular systems are less prone to natural disasters which is important in SIDS [2]. SHS and SE with its DG units are advantageous to minigrids which normally have one larger, centralized generation unit.
Finally, hardware compatibility [9] is a major factor contributing to decreased cost and higher overall resilience as one technician could maintain and repair a multitude of systems. Running a SHS market approach, this would result in a monopoly which is not seen favourable otherwise. SE, though able to connect different types of SHS, is able to reduce the cost of service through concentrated (one operator) monitoring [10]. Minigrid operators serve more customers with one single generation unit, decreasing the cost of potential service. However, specialized design leads to reliance on the operator to care for O&M.

3.3. User centeredness

User-centeredness is crucial to engage communities and create ownership that is reflected in both the technical care users take of a system as well as the experience of economic benefit. The role that a user centric approach needs to take in rural electrification out of systemic reasons has been explained [4].
The potential to act as a prosumer and thus directly feel the economic benefit of producing electricity, is possible with SE and to a lesser extent (cooperatively owned) with minigrids. SHS are not able to provide this incentive. This is directly transferred to the willingness-to-pay and the first-hand knowledge about the energy system. A system in which one knows both sides (producer and consumer) allows for an improved evaluation of opportunities. A user owning an SHS might use an inefficient lamp as long as the power is sufficient to use it. However, if that user can sell the excess in an SE approach, the awareness rises, thus increasing overall system efficiency and resource allocation even without outside intervention.
Community ownership has been deemed difficult with regards to minigrids [5]. Especially when an operator owns the system and sells electricity, there can be occasions (misuse, too high demand, slow O&M response) that may disrupt the management and running of the grid. On the contrary, locally owned and operated minigrids may suffer from a lack of training or problems to retain skilled staff as well as conflicts over usage of energy. SE uses a meter per every household so that this would be avoided. Furthermore, SE offers an incentive to treat the overall system well as the single (owned) system benefits from it as well. An overarching important element, both in terms of size as well as typology, is payment flexibility. Pay-As-You-Go (PAYG) solutions have significantly improved payment behaviour and as such revolutionized collection methods and efficiency [11], a crucial aspect considering large distances. Increased payment both for up-front payments as well as amount and frequency of instalments has led to payments ahead of the plan, making sure the available income is not spent otherwise.

Table 1 in appendix A also shows the results of the analysis in an overview, indicating a positive property of an approach with plus signs, neutral with a zero and a negative with minus signs, respectively.

4. A peek into the first results from Bangladesh

SE has been implemented in Bangladesh by ME SOLShare Ltd since 2014 by connecting existing SHS to a small swarm grid with eight units. It has shown great potential to overcome mentioned challenges, especially those referring to minigrids, as shown by Magnasco and Groh et al. [10, 12]:

- **Reaching higher access tiers** – which are explained e.g. in [15] – is possible although results from tests with productive equipment (water pumps, mills) are still awaited
- Remote monitoring of system health **reduces necessity to visit the sites very often**
- **System health** (especially battery) can be improved, reducing time and money for O&M
- **Sunk cost** from SHS are **avoided** while **additional income** is gained by system owners as they trade a significant share of electricity produced, ultimately reducing the unit cost of electricity of SHS
- Prior non-users access electricity (tier 0 to 1) from their neighbors cheaper than with SHSs (around 0.1 $ per day) in the short term; the effect **becomes more beneficial for SE with a rising demand**

Based on 106 observations from SHS customers in Bangladesh, an average tier assignment of 1.52, so just between tier 1 and tier 2 is found for SE [12]. Remarkably, 70 observations with regional grid access exhibit an average - significantly lower - assignment of only 1.38. The question arises whether SE can increase this gap and surpass grid extension with regards to quality and quantity of electricity. While in the first trials, this shows that SE is a promising concept that could be applied to SIDS contexts. The above mentioned achievements are crucial to cope with the difficult characteristics in SIDS which require community-owned approach with well-set economic incentives to be successful in future.

5. Conclusion

Our paper used prior work on the concept of SE to investigate its potential for application in a SIDS rural electrification context. A literature review of recent publications in the field of electrification for SIDS yielded a set of indicators used to compare SE with stand-alone SHS and minigrids. SE is a new concept and in its customer validation phase as of the moment. Though empiric results are limited, we could conclude that the approach might yield some essential advantages over SHS as stand-alone systems and minigrids. Whereas the former lack from the potential of reaching higher energy access tiers and thus unable to unravel the full development potential of electricity access [1, 12], the latter usually suffers from rigid one-time engineering and lack of profitability and ownership [1, 4]. SE shows structural advantages in the investigated categories and could prove a higher-tier access vs. regional grid access.
However, more research must be following in order to fully understand the potential of the concept with regard to SIDS, such as an intensive desk-based case study and expert interviews to cover e.g. the consumer and government position on such an approach or the actual cost attached when connections are made between far-away households. A business model adapted to a market with no or a low number of households owning an SHS and with a great remoteness factor must be developed, accordingly.

Acknowledgements

We thank the ADB for its assistance to ME SOLShare Ltd. to set up a pilot in Bangladesh from which this paper benefitted and the possibility to participate and present the work in Applied Energy REM2016.

References

[1] Baldwin E, Brass JN, Carley S, MacLean LM. Electrification and rural development: issues of scale in distributed generation. *WIREs Energy Environ;* 2015; 4:196–211. doi: 10.16/wene.129

[2] Dornan M. Reforms for the expansion of electricity access and rural electrification in small island development states. *AIMS Energy*; 2015; 3 (3): 463–479. doi: 10.3934/energy.2015.3.463

[3] Groh S, Philipp D, Edlefsen Lasch B, Kirchhoff H. Swarm Electrification: Investigating a Paradigm Shift Through the Building of Microgrids Bottom-up. *Decentralized Solutions for Developing Economies, Springer Proceedings in Energy;* 2015; S. Groh et al. (Eds.). doi: 10.1007/978-3-319-15964-5_1

[4] Groh S, Koepke M. A system complexity approach to swarm electrification. *Yearbook 2014. Energy for Sustainable Development – Mini-grid and Hybrid Systems*; 2014; Moeller B, Golba M, Boie W, Uhorakeye T. (Eds.). University of Flensburg. Flensburg, Germany.

[5] Hazelton J, Bruce A, MacGill I. A review of the potential benefits and risks of photovoltaic hybrid mini grid systems. *Renewable Energy*; 2014; 67: 222–229.

[6] Timilsina GR, Shah KU. Filling the gaps: Policy supports and interventions for scaling up renewable energy development in Small Island Developing States. *Energy Policy*; 2016. http://dx.doi.org/10.1016/j.enpol.2016.02.028i

[7] Dornan M. Access to Electricity in Small Island Developing States of the Pacific: Issues and Challenges. *Renewable and Sustainable Energy Reviews*; 2014; 31:726-735.

[8] Dornan M. Renewable Energy Development in Small Island Developing States of the Pacific. *Resources*; 2015; 4: 490-506. doi:10.3390/resources4030490.

[9] MacDonald J. IT Power Renewable Energy Consulting. Renewable Energy in Small Island Grids. Case study – Tuvalu. Presented at: Off the beaten path: rural energy & remoteness. Webinar. 09/03/2016.

[10] Magnasco La Torre A. Optimization of Grid Operation and Resources in Bottom-up Swarm Electrification. Unpublished Thesis. Hochschule für Technik und Wirtschaft Berlin; Berlin; 2016.

[11] Moreno A and Bareisaite A. Scaling Up Access to Electricity: Pay-as-You-Go Plans in Off-Grid Energy Services. *Livewire*. 2015/34. The World Bank Group. Washington.

[12] Groh S, Pachauri S, Rao N. You are what you measure! But are we measuring itright? An empirical analysis of energy access metrics. *Energy for Sustainable Development*. Submitted. 2015

[13] Price M. Findings from the Indonesian Smart Villages Workshop on Energy for Islands. *Smart Village Briefing*. 2016; 10. Cambridge.

[14] Reynolds T, Murray BT, Kolodinsky J, Howell J. Contrasting self-reported willingness to pay and demonstrated purchase behavior for energy-saving technologies in a small island developing state. *Energy for Sutainable Development*. 2015; 27: 18–27.

[15] Bhatia M and Angelou N. Beyond Connections: Energy Access Redefined. Executive Summary. *ESMAP Technical Report 008/15*. 2015. Washington. USA.

Appendix A. Table with categories and indicators

Table 1. Explanation and sources for categories indicators; results of the comparison

Cat.	Indicator	Explanation	Source	SHS	Minigrid	SE
Market suitability	Supply flexibility	Is the approach able to cope with low but rising demand?	1, 3	--	-	++
	Installation cost	Installation cost, initial capital expenditure, potential to avoid sunk cost	2, 4, 9	0	--	+
	Economies of scale	Given the limited market size, are economies of scale needed?	6	--	+	0
	Cost of service	Cost of maintenance and repair provision, given large distances	2, 5	--	-	-
	Cost of electricity	Levelized cost of energy for end-users	2	-	+	0
	Low cost repayment	In case of loan or fee-for-service: low cost for collection of payments?	5, 8	+	+	+
	Profitability	Sales and service must be cost-covering for provider	1, 2	0	-	+
Policy	Government subsidy	Given low economic power, can a subsidy scheme be implemented?	4, 6	+	+	+
Technical appropriateness	Setting aside funds for O&M	Saving money for necessary system O&M costs is an issue for locally operated systems and needs improved mechanisms	2, 5, 13	0	0	+
	Modular system	Modularity and reliance on several options reduces risk from damaging due to natural disasters; transport cost for technicians and equipment	2, 5	-	--	+
	Remote monitoring and communication	Potential to cope with long distances using ICT; potential to communicate with and monitor the system	4, 5, 7	0	-	++
	Supply meeting higher demands	Meeting demand for extended hours; meeting rising demand for productive use appliances	1	-	++	+
	Support and training	Support to install, repair and maintain equipment (incl. proper usage)	8	0	-	-
	Hardware compatibility	Hardware to be maintained and connected to a potential grid must be compatible; reducing need for multiple suppliers visiting sites regularly	9	-	-	0
User centeredness	Prosumer potential; payment flexibility	Is it possible to use own systems to reduce cost from electricity purchase?	4, 6	-	0	+
	Willingness to pay	As WTP is often over-reported, is the approach able to create an awareness of value of energy provision?	14	0	-	++
	Ownership	Community can be engaged effectively; skilled labor can be retained	5, 9, 13	0	0	+
	Business model	How easy can a business model be adapted? What are the implications?	5	--	--	+