IDCOL R&D Initiative under Renewable Energy and Energy Efficiency Projects

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DRAFT FINAL REPORT

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Community Based Decentralized DC Nanogrids for Combined Household and Productive Use

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Short Summary

In its development plan, titled Vision 2021, dated half a century after its struggles for independence, the Government of Bangladesh has made the provision of access to electricity and achieving economic and social well-being of all citizens through a low carbon strategy a central goal. Universal access to electricity by the year 2020, with improved reliability and quality, is its declared goal. To support this ambitious target, IDCOL decided to use a fund from the World Bank under Rural Electrification and Renewable Energy Development Project (REREDP) to support the R&D initiatives. Against this background, the present R&D project was awarded by IDCOL to a consortium of local and international scholars as well as the German-Bangladeshi start-up company, ME SOLshare Ltd., proposed to test different.

In the framework of this R&D project, different topologies of solar powered smart DC nanogrids have been developed and piloted in rural Bangladesh. The project owes its innovative character due to the following achievements:

1. A comparative assessment has been performed of three different topologies, namely
    a) *Central storage and generation couple with smart supply and demand response system*
    b) *Central storage and generation in interconnected nanogrids*
    c) *Decentralized storage and generation in peer-to-peer bottom-up nanogrids*.

2. A new Pay-As-You-Go and (PAYG) and Cash-In-As-You-Go (CAYG) technology has been successfully tested within the nanogrids.

3. Higher power DC appliances like water pumps and rice hullers have been successfully incorporated into SHS-based low voltage nanogrids.

In depth data analysis revealed that topology c) peer-to-peer bottom-up nanogrids stood out by far for several reasons. Among them was a significantly higher power reliability and flexibility. Moreover, during the project implementation, serious problems were faced with the site selection. Paradoxically enough, among the main reason was the high penetration of SHS in Bangladesh. Due to its penetration there seems to be little scope for a DC nanogrid catering for basic energy needs which cannot integrate existing SHS in a smart manner. It became evident that the concept with its strictly centralized generation and storage points in its initial design for basic energy services was not be the right concept for Bangladesh, but rather for countries like India, Myanmar, and Nepal, where the SHS penetration is much lower. A better fit was found in a model that can materialize on the existing infrastructure but still cater for better energy services. The shift to a PAYG/ CAYG service model has a huge potential for Bangladesh, especially when taking into account the current collection efficiency problems many of the POs are currently facing. Another crucial success factor is the amount of initial capital investments required. As shown during this project, a low initial investment leads to lower financial risks for the investor, which was especially emphasized by UBOMUS. This makes the tested DC nanogrid concept competitive with larger mini-grid approaches, where huge investments and subsidies are currently required. This is particular true since now the door has been opened for various higher

powered loads. As a next step a range of new DC appliances are being installed, such as fridges, ice making machinery, corn hullers and threshers, compressed oxygen machines for rural health clinics, among others.

We are convinced that an intelligent integration of the existing and upcoming SHS in the market for future nanogrid design combining key productive use activities will enable Bangladesh once more to set a global paradigm of a successful innovation based rural electrification strategy with international renown. We further strongly believe that, provided all technical standards are met, the SOLbox can make here a significant contribution to the country's ambition to provide (improved) energy services for all by 2021.

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Introduction

Solar PV is widely used in Bangladesh due to its continuous declining price in the world market and soft loan scheme introduced by Infrastructure Development Company Limited (IDCOL) of Bangladesh. IDCOL has already installed close to 4 million solar home systems (SHS) up to date. Installation of Solar Home System (SHS) under IDCOL finance has become a very successful program benefitting millions of off grid rural households. People at rural areas are now convinced that solar PV system helps to make their life a better one.

At the same time there is an ambitious goal to push forward the installations of minigrids. This, however, often culminates in double infrastructures with dead weight loss as many SHS are often abandoned in favour of minigrid electricity services. Keeping these impulses in mind, Centre for Energy Research (CER) of United International University (UIU), Institute for Decentralized Electrification, Entrepreneurship and Education of the Ulm University of Applied Science (id-eee), the department for Sustainable Electric Networks and Sources of Energy at the Technische Universität Berlin (SENSE), Renewable and Appropriate Energy Laboratory at University of California Berkeley (RAEL), and ME SOLshare have been developing a comprehensive research on community based decentralized DC nanogrids for combined household based on existing resources. The overall objective of the project was to develop an innovative approach for community based decentralized DC nanogrids for rural electrification. Significant support for site selection and implementation was received by local POs, such as GHEL and UBOMUS.

The developed approach enables integration of local generation and storage capacities (like Solar Home Systems) by connecting SHS and centralized storage and generation capacities into a DC nanogrid. The DC nanogrid allows electricity sharing through bi-directional power flows which leads to extremely flexible DC nanogrids which can be constantly adjusted to local demands in a short term period. The approach has the advantage that local generation and storage capacities are used more efficiently and additionally, by utilizing community rooftops for creating a nanogrid, land needed for solar arrays can be significantly reduced. The proposed approach enables the utilization of excess energy that results from the design configurations of SHS for rainy and non-rainy seasons, in a bi-directional DC nanogrid. This additional electricity can be used to power households that so far could not be reached through solar home systems, possibly due to limited resources.

Energy Landscape in Bangladesh

Recent metrics suggests that globally about 17% of the world population or 1.166 billion people lack access to the electricity grid. Most of this un-electrified population resides in Sub-Saharan Africa and South Asia (87%), and in rural areas (85%) [IEA/WB, 2014]. With its 66.6 million off-grid people, Bangladesh ranks third among the countries with the highest electrification deficit and has been considered a high impact country to reach the SE4ALL goals. In 1971, the year of its independence, a mere 3% of the population of Bangladesh had access to grid electricity. Today, the share has increased to almost 60%. In the last couple of years Bangladesh's GDP has been growing at a steady rate between 6% and 7% [World Bank, 2013].

In its development plan, titled Vision 2021, dated half a century after its struggle for independence, the Government of Bangladesh (GoB) has made the provision of access to electricity and achieving economic and social well-being of all citizens through a low carbon strategy a central goal [GoB, 2012]. Universal access to electricity by the year 2020, with improved reliability and quality, is its declared goal. Direct current (DC) solar home systems (SHS), currently consisting of a 20 to 85Wp solar panel, battery, and charge controller, have successfully started an electrification process for large parts of the Bangladeshi rural population through the Infrastructure Development Company Limited's (IDCOL) national SHS program [IDCOL, 2015]. Close to four million SHS are already installed through microcredit schemes implemented by Partner Organizations (POs), who used to expand their customer base at a rate of 45,000 up to 70,000 systems per month, making Bangladesh an internationally acclaimed role model.

However, recent statistics show a dramatically declining market [Groh & Taylor, 2016]. Also, many households with an SHS do not fully utilize the electricity stored in their battery, resulting in a full battery by midday, and thereby limiting the generation potential of their systems by up to 30% [Kirchhoff, 2014]. At the same time, some households require electricity beyond what their systems can supply, especially during the rainy season, while others cannot afford a complete SHS at all and remain trapped in energy poverty. Mondal and Klein [2011] further point to the limits of SHS in terms of its potential to directly affect an individual household's ability to improve its income generation. Moreover, the last months have shown serious shortcomings in post-paid end-user financing resulting in stumbling collection efficiencies throughout the sector.

There is a need for more cost effective, reliable and flexible electricity supply (also in terms of payment). In rural areas of Bangladesh, settlements tend to consist of various clustered areas where households are built closely together in a dense pattern. Hence, it is common to see clusters of households and small businesses with SHS. Further, entrepreneurs have taken up this challenge and are acting as mini-utilities based on diesel generators supplying neighboring houses as well as small businesses. In summary, the current SHS scheme has revealed the following shortcomings from an end-user perspective:

- not inclusive enough to reach down to the poorest segments,
- lack of flexibility in terms of usage patterns and payment methods,
- productive use remains very limited,
- excess capacity: generated energy gets lost while battery is full.

Recently, a range of AC minigrids have been designed, and are in the first implementation stages, in addition to the Sundarbans case which already has a track record of such systems. Based on these developments, the following challenges have been observed:

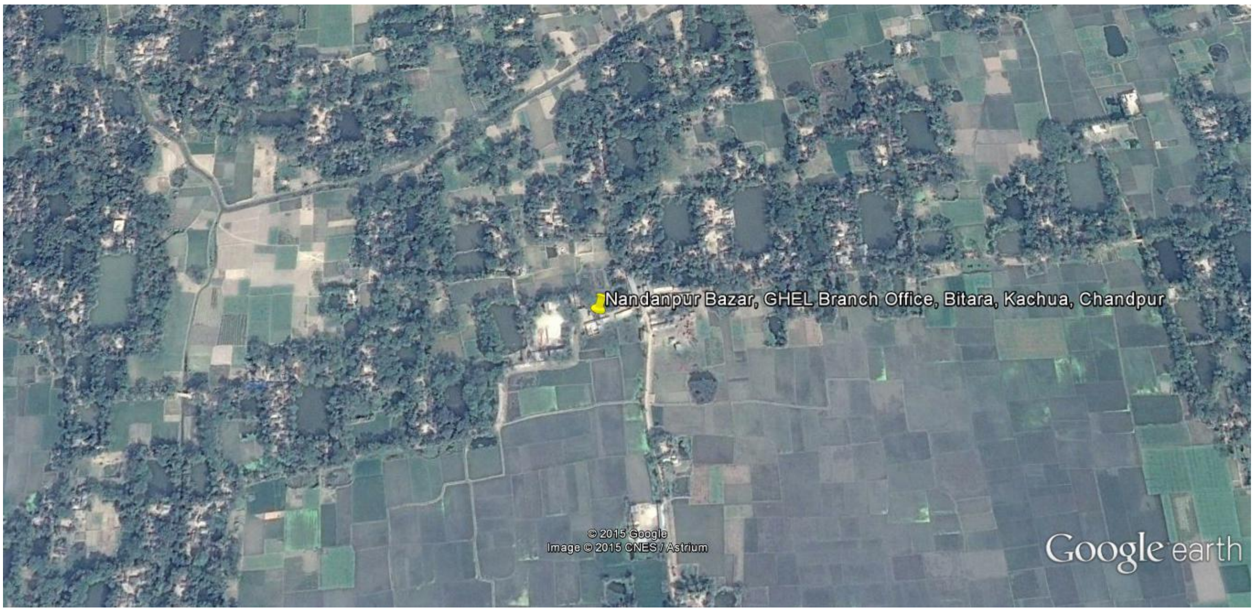
- demand tends to grow once AC electricity is available,
- pace of growth is hard to determine,
- oversized systems are not economically viable,
- undersized systems might fail to adequately perform and therefore hinder social acceptance and economic development,
- productive use is enhanced with larger electrical loads,
- the creation of parallel infrastructures should be avoided.

This project aims to address these limitations by introducing, developing, implementing and investigating an innovative approach, namely solar DC minigrids, which may provide the basic infrastructure required to transition to the swarm electrification concept [Groh et al. 2015].

Site Survey

Summary Report on Site visit in Kachua, Chandpur, Bangladesh

Site 1
Name of Location: Nandanpur Bazar and adjacent villages.
GPS Location: 23°23'28.99" N 90°49'08.14" E



Description:
This area is a grid connected area, electricity access provided by REB. About 60% of the households are connected to the grid but according to the villagers, supply of electricity in grid is not continuous and they only have a few hours of supply in a day. This reason discourages other people not to get electricity from grid. On the other hand, some households have SHSs in

their house as a backup source of electricity. No shop in the bazar has connected to the grid, they use SHSs.

Nanogrid Feasibility: Households are very close to each other and one cluster of a village consists of minimum 15 houses.

Site 2:

Name: Ainpur Abhoy Para, Bitara, Kachua
23°24'06.72" N 90°52'09.23" E

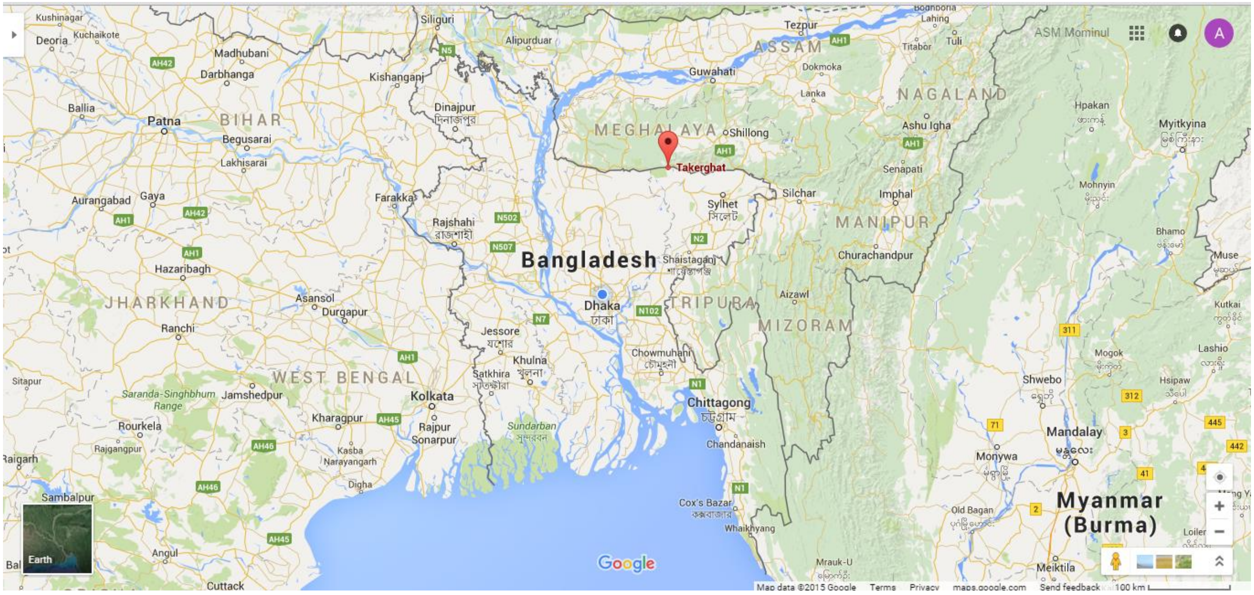
Grid Access: Grid network is very close. Few households took connection by using long service lines. Villagers said that some people came several times to take measurements for electrification.
Description: This village is still waiting for grid. People have their willingness to get access to electricity. Households are very close to each other which make the site potential for Nanogrid. SHS penetration is about 50%.

23°24'30.33" N 90°51'58.97" E

Comment: The site is very potential for implementing the nanogrid. There are several potential clusters are there to implement several nanogrids. People are well off and they want more than basic lighting access like TV and Fan. During our visit, we saw people taking refrigerator to their household in that area.

Summary Report on site visit Takerghat, Tahirpur Upozila, Sunamganj, Sylhet Division

Location:



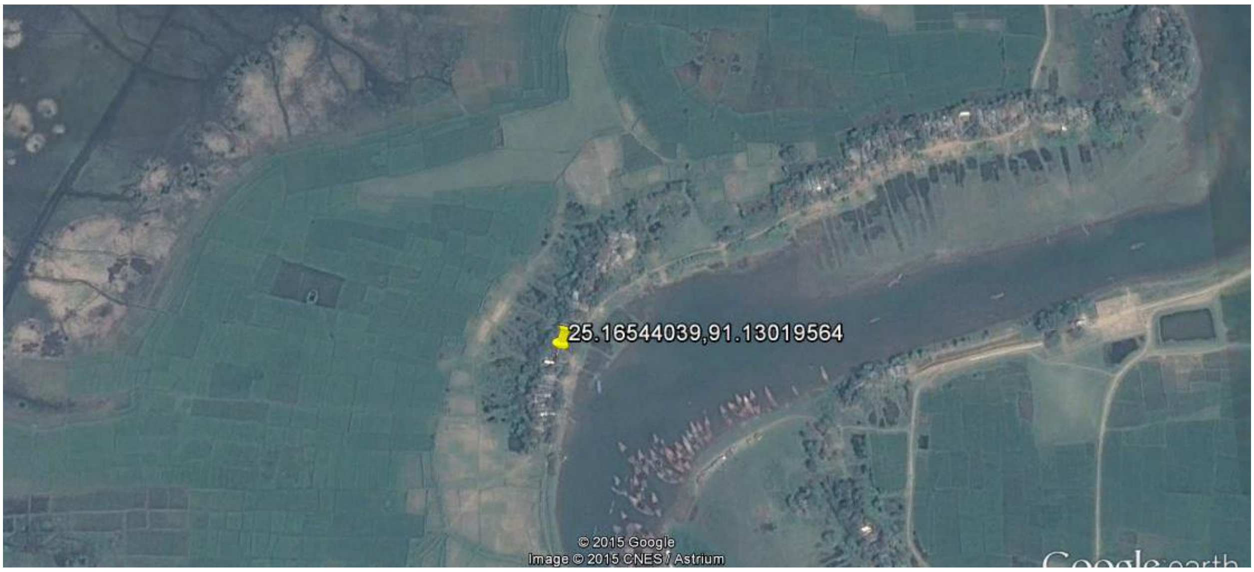
Visited locations:

1. Sripur Bazar (25.15747662,91.13296271)
2. Nawabpur (25.16544039,91.13019564)
3. Modonpur (25.16123406,91.13002767)
4. Lakma Poschim Par (25.19217501,91.15583544)
5. Lal’er Bon (25.16843501,91.16789362)

Sripur Bazar (25.15747662,91.13296271)

Around 300 shops are there in the Bazar. Small shops were our target as there are some big shops having more than one SHS and generator conncection for their appliances. We conducted couple of meetings with the bazar committee and explaind about our system. Many of the shop owners are interested in our system but the diesel generator operator was describing negative sides of our grid.

Nawabpur (25.16544039, 91.13019564)



Approximate number of housholds: 60
SHS penatration: above 70% as we saw and people said.
Comment: People showed their interest to take connection from our nanogrid but they will discuss among themselvs and let us know their decision soon.

Modonpur (25.16123406,91.13002767)

Approximate number of sousholds: 50
SHS penatration: around 90% as we saw and people said.
Comment: Peolpe showed their interest to take connection from our nanogrid but they will discuss among themselvs and let us know their decision soon.

Lakma Poschim Par (25.19217501,91.15583544)

Approximate number of housholds: 80
SHS penatraton: above 90% as we saw and people said.

Comment: People showed their interest to take connection from our nanogrid but currently they are not able to pay.

Lal'er Bon (25.16843501,91.16789362)

Approximate number of sousholds: 120
SHS penatraton: Above 80% as we saw and people said.
Comment: People showed their interest to take connection from our nanogrid but they will discuss among themselvs.

<u>Overall comment:</u>

SHS penatration his very high (average penetration would be 80%) but people are interested to use more loads therefore are interested to use nanogrid as well.

<u>Summary Report on site visit Janjira Thana of Shariatpur District</u>

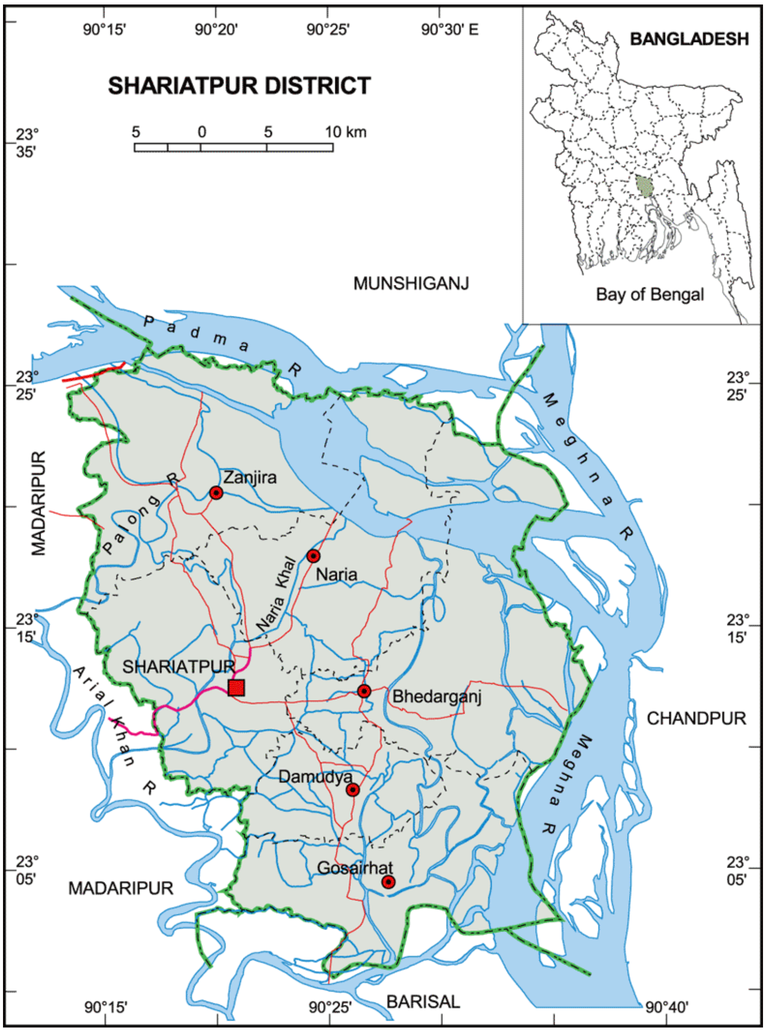


Figure 1: Map of Shariatpur District (Map Source: www.shariatpur.gov.bd)

The sites are:

1. Singkandi, Purbo Naodoba Union, Janjira, Shariatpur (23.40110066,90.2757174)
2. Poylan Molla Village, Purbo Naodoba Union, Janjira, Shariatpur (23.40034965,90.29353738)
3. Shakimali Matborkandi, Shener Char Union, Janjira, Shariatpur (23.33180364,90.26893166)
4. Ahadi Boyatikandi, Janjira, Shariatpur (23.34479359,90.31287079)

These locations are pinned on the Google map below.

Figure 2: Visited 4 sites (pinned), (google maps)

1. Site 1: Singkandi, Purbo Naodoba Union, Janjira, Shariatpur (23.40110066, 90.2757174)
This village consists of two small clusters having 6 and 13 households. Out of these 19 households only two are without solar home systems. These SHSs are ranging from 20Wp to 120Wp and some of the SHSs are not purchased from IDCOL PO. About 30% of these systems are paid off which are bought from IDCOL PO.
The field trip team has discussed with some of the users about the current energy perspective with their SHSs.


Mr. Liakat Matbor (Phone: 01748768026) (House Position: 23.40111296 N, 90.27560294E) currently uses a 40 Wp system and he says this is sufficient to him during winter but he wants fan as well during summer. "When grandchildren come from Dhaka then they want to watch TV which I cannot use with my system", he added. Mr. Abu Salam Matbor (Phone: 01734706218) (House Position: 23°24'07.66" N 90°16'33.50" E), he has a 120Wp system and he is not a IDCOL PO customer. He says he can use everything and according to him he has lots of surplus energy which he never uses. In this site, the field trip team found that the people having no SHS are far (about 50 meter) from our target SHSs and many people will leave or move to other place for resettlement. Ttherefore the team decided not to install the pilot site.

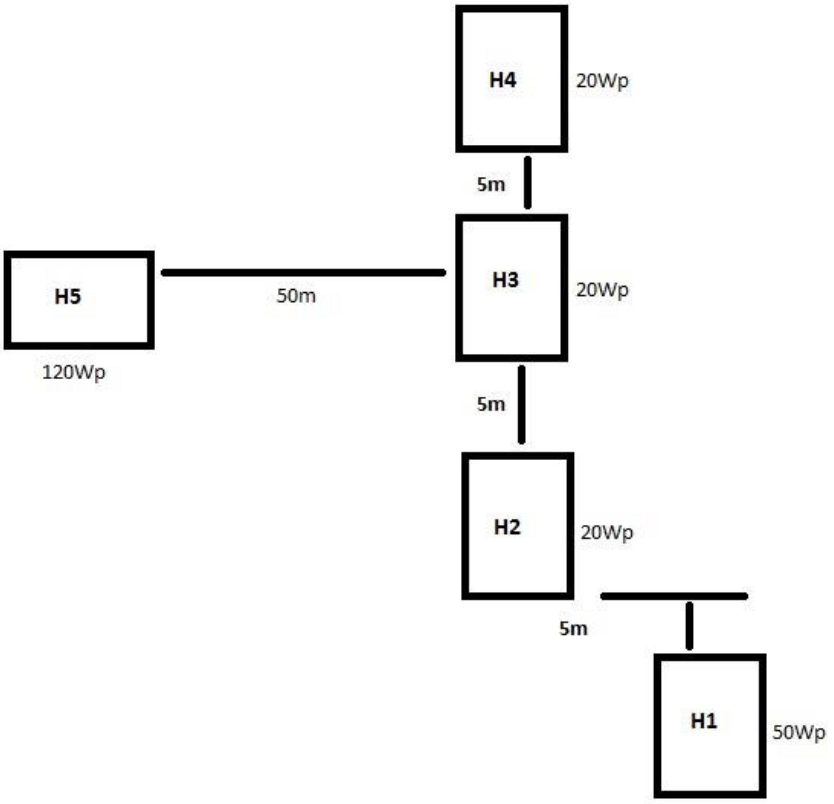


Figure 3: Orientation of Households

2. Poylan Molla Village, Purbo Naodoba Union, Janjira, Shariatpur (23.40034965N, 90.29353738E)

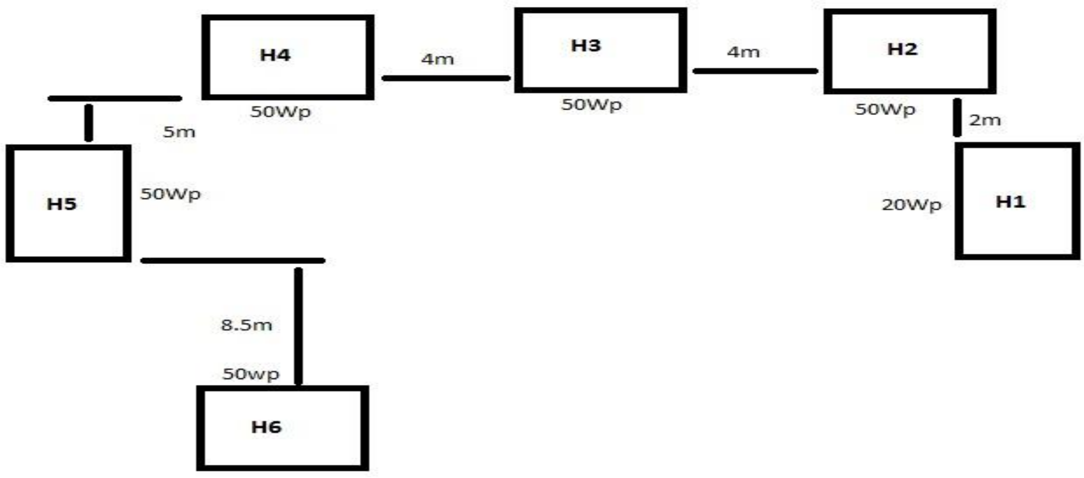


Figure 4: Orientation of Household

In this village cluster only rich people live. They have very nice duplex houses and all of them have 50Wp systems. This site is pretty ideal for implementing the nanogrid as the household orientation is suitable, e.g. close to each other. The team didn't find any household without SHS. Couple of people have been interviewed they liked that idea and they will be happy to host the nanogrid with their system. Name of interviewed persons are Mr. Julhas Matbor (Phone # 01772799742) and Mr. Munir Hossain (Phone # 01759435915).

3. Shakimali Matborkandi, Shener Char Union, Janjira, Shariatpur (23.33180364N, 90.26893166E)

This village cluster consists of 6 households and all of them have SHS. One house having no SHS which belongs to another cluster nearby. Owner of this house said, "I can afford a Solar Home System but I have nowhere to install it as my premises is full of shadow", I will definitely take a connection from your nanogrid" he added. People of this site are very interested in the concepts of the nanogrid system and they expressed their interest to host this system in their household and share electricity to their neighbor. The cluster Head Abul Kalam matbor (01794604626) said that they are pleased if the systems are installed in their house.

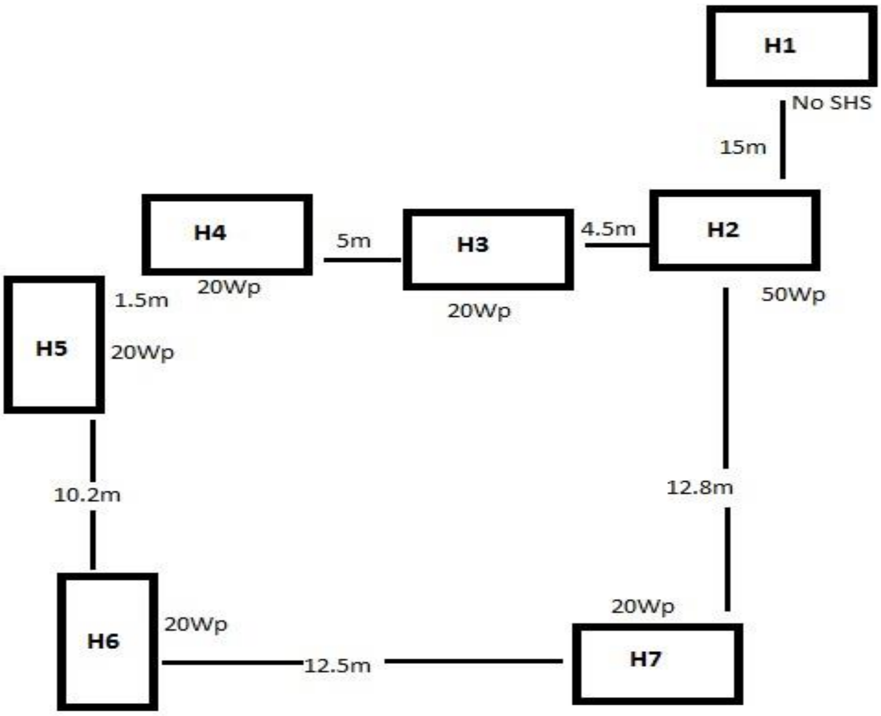


Figure 5: Orientation of Households

4. Ahadi Boyatikandi, Janjira, Shariatpur (23.34479359N, 90.31287079E)
This village cluster is long in length but houses are not so concentrated. There are about 9-10 houses in this cluster having 90% SHS penetration. The house having no SHS is not interested to have SHS as he uses light bulbs from his father's SHS.

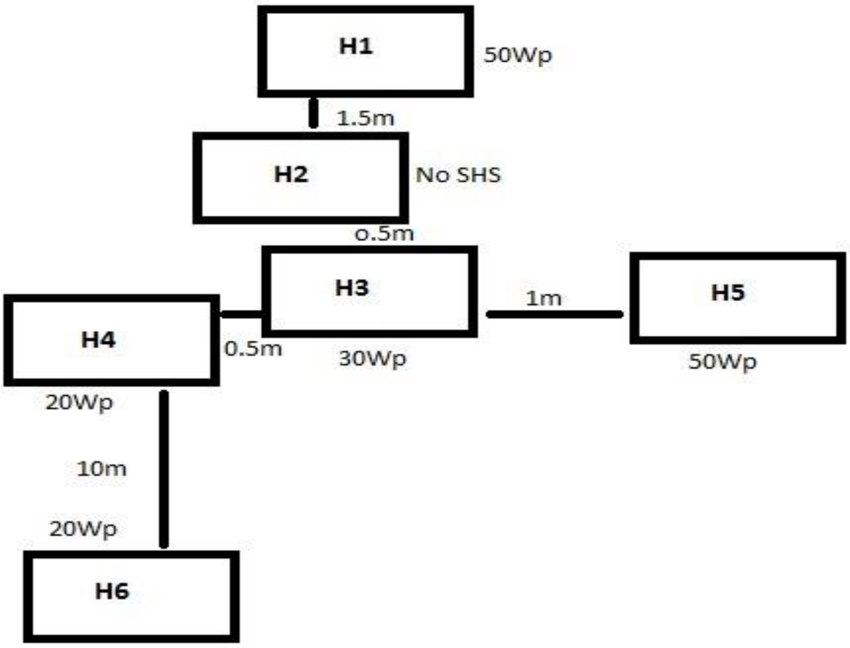


Figure 6: Household orientation

The field trip team found that 3 sites are feasible for the nanogrid project among 4 sites visited by the team. In site 2 and 4 team didn't team didn't find any user without SHS, therefore the team decided to exclude them. Site 3 is suitable from all required perspectives for the nanogrid. Therefore, the team recommends implementing the project at site 3.

Technology

Topology A: Central storage and generation couple with smart supply and demand response system

The basic technology concept of a solar DC nanogrid is actually quite straightforward, and can be understood with reference to figure 1. Electrical energy for a village is produced and stored at a centrally located solar photovoltaic array and battery bank. Each house in the village is connected through an energy meter, via a low-voltage direct-current distribution network to the central energy supply.

This concept has certain advantages over both solar home systems, and larger AC mini-grids. Firstly, compared to solar home systems, a village level nanogrid provides villagers with a level flexibility and choice which cannot be achieved with individually owned SHS. The centralized generation and storage infrastructure of a nanogrid, along with smart energy meters means that customers can choose to purchase a monthly energy package which suits their usage requirements and their available budget. Secondly, compared to an AC mini-grid, a DC nanogrid can provide comparable levels of energy services for a much lower hardware cost. If the consumers only need basic energy services (tiers 1 and 2 according to the SE4All global tracking framework, such as lighting, phone charging, and cooling fans), then these services can all be provided by low-voltage DC appliances. Since solar photovoltaic panels produce direct-current (DC) electricity, and batteries use DC electricity, and modern LED lighting requires DC electricity, and modern DC-DC converters can cheaply and efficiently convert between different DC voltages, then there is really no technical reason to use alternating current (AC) in such a mini-grid at all.
There is another compelling benefit to using DC electricity in such a nanogrid as well. That is that customers cannot connect energy hungry and inefficient appliances to the nanogrid, thus overloading the energy generation and storage infrastructure as so often happens in the case of AC mini-grids.

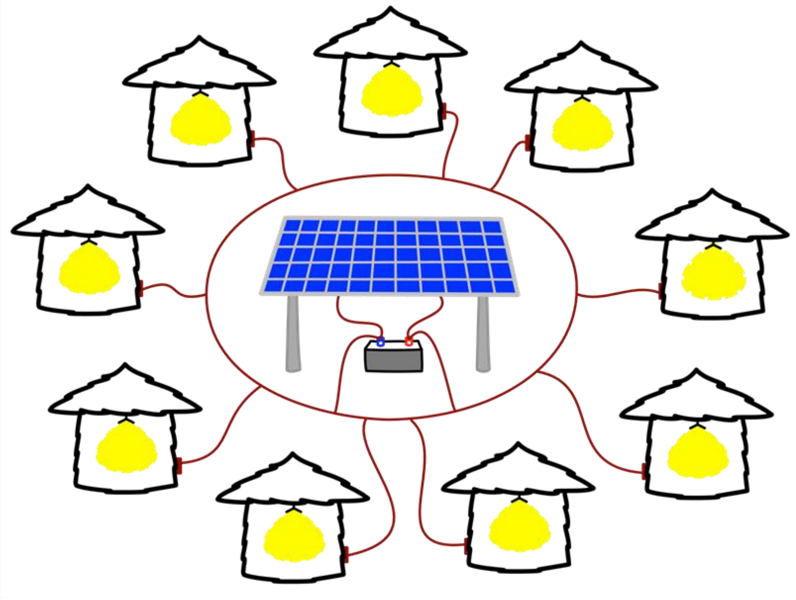


Figure 7. Schematic representation of a village-level solar DC nanogrid.

In order to implement a smart tariffing and smart metring concept within the project, smart meters (PM10) and status transmitters (PT20) were procured as core elements of the DC nanogrid. After requesting three companies for an offer, the German company Balance of Storage Systems AG was assigned with the procurement of 5 status transmitters and 110 smart DC meters. The PT20 was installed together with a charge controller, the battery bank and the PV panels at the central generation and storage point of each grid (figure 3). Smart meters were installed in each household (figure 4).

In the initial set up, the PT20 transmitter was programmed in order to signal three different consumption tariffs to the PM10 energy meters. The PM10 was programmed in order to give the end-user a fixed budget of electricity consumption per day. The speed in which the budget runs down when energy is consumed is defined by the current tariff which is signaled by the PT20. Each day, the daily electricity budget was reset 6 hours after sunset. The three tariffs were defined as the following and were signaled to the end-user with simple icons on the display of the PM10:

- *Daytime tariff*: During the day, when the sun is shining but the battery is not fully charged yet, electricity is offered in the standard tariff. This means, the bar on the display of the PM10, which represents the daily budget for electricity consumption, runs down in normal speed. The sun on the display shows that electricity is currently consumed in the daytime tariff.

- *Excess tariff*: Is a cheaper tariff, which is occurs when the sun is shining but the battery is already fully charged. In this state, electricity world actually be lost if not directly consumed by the end-user. During the excess tariff, electricity can be consumed two times cheaper than during the daytime tariff. The excess tariff is signaled to the end-user by showing a sun with a smiley on the display of the PM10.

- *Night tariff*: After sunset, electricity can only be consumed from the battery. As the battery is the most expensive investment in a DC nanogrid, providing energy after sunset is more expensive than during daytime. This is reflected by the night tariff, where electricity is provided with a price that is double the price during daytime tariff. The night tariff is signaled to the end-user by showing a moon on the display of the PM10.

Further information on the functionality of the PM10 and PT20 can be found in Annex 2.

Figure 8. Energy meter and light switches installed next to old hurricane lamps in Kachua.

Topology B: Central storage and generation in interconnected nanogrids using PAYG

The second topology utilizes interconnection of nanogrids of close proximity. The nanogrids are designed as in topology one, but are connected to each other, allowing for automatic load balancing between the units. This is achieved by using a passive droop control approach that enables balancing of power flows from the two central generation and storage points.

To allow for clear tariff-signal communication in this interconnected configuration, and additional hardware component was needed. This device was designed in Bangladesh and also allows for the implementation of a "Pay as you go" operation, hence called "SOLshare PAYG Box". The tariff signal communication is operated as in topology A, however without a night tariff, as most loads are light and entertainment devices which are mostly used during the night. In addition, instead of receiving a daily quota, each meter receives an energy balance after payment of an energy fee. After receiving the payment, the PO agent uses the "Top-Up-Box", which was also developed in Bangladesh, to write the new balance into the meter. The respective technology parts are represented in Figure 8. Smart Meter technology for PAYG system topology B. The PAYG technology allows the individualisation of energy usage in a public infrastructure. As an example of the payment rate, Figure 7 shows an example of one meter's balance and the corresponding load curve. The users sometimes tops up once per month, sometimes only every two months, depending on the balance left on the meter. Load patterns for energy access tier 1 users are very uniform as there is little flexibility in usage. Additionally, the dimming function of the LED lights is not used in this tier.

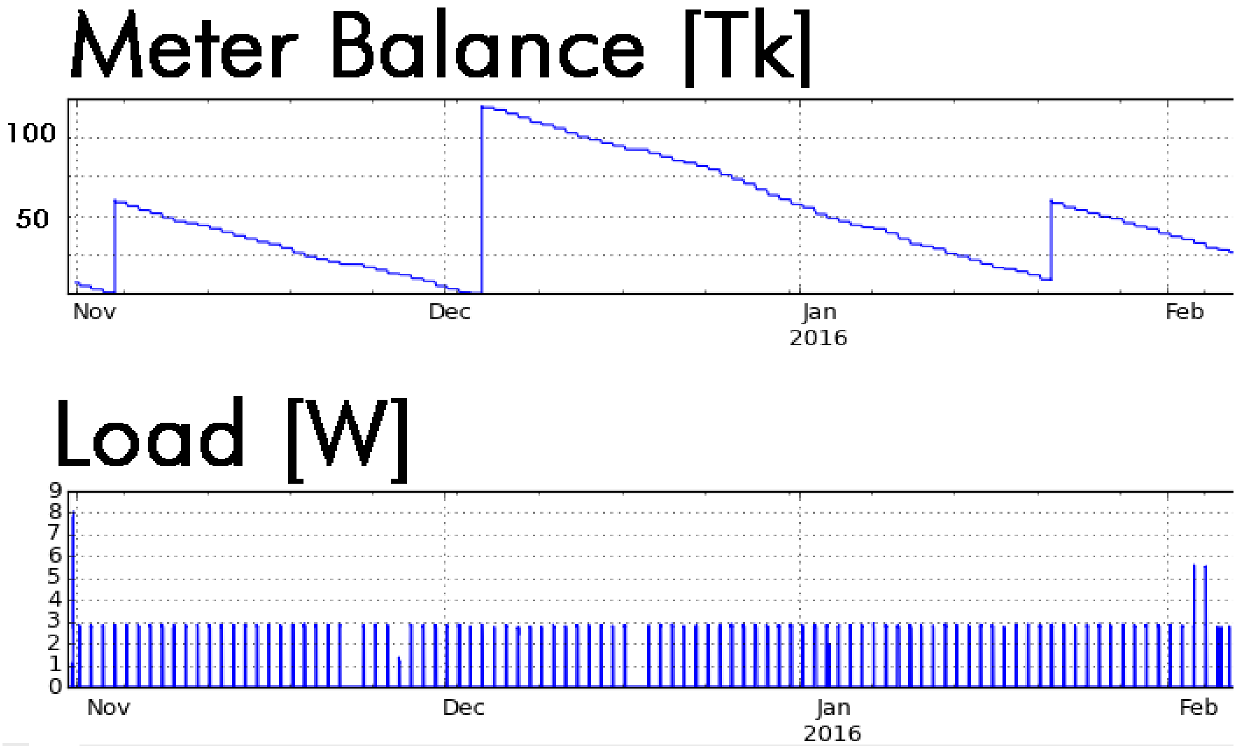


Figure 7. Example of Meter Balance and Load Data for one User.

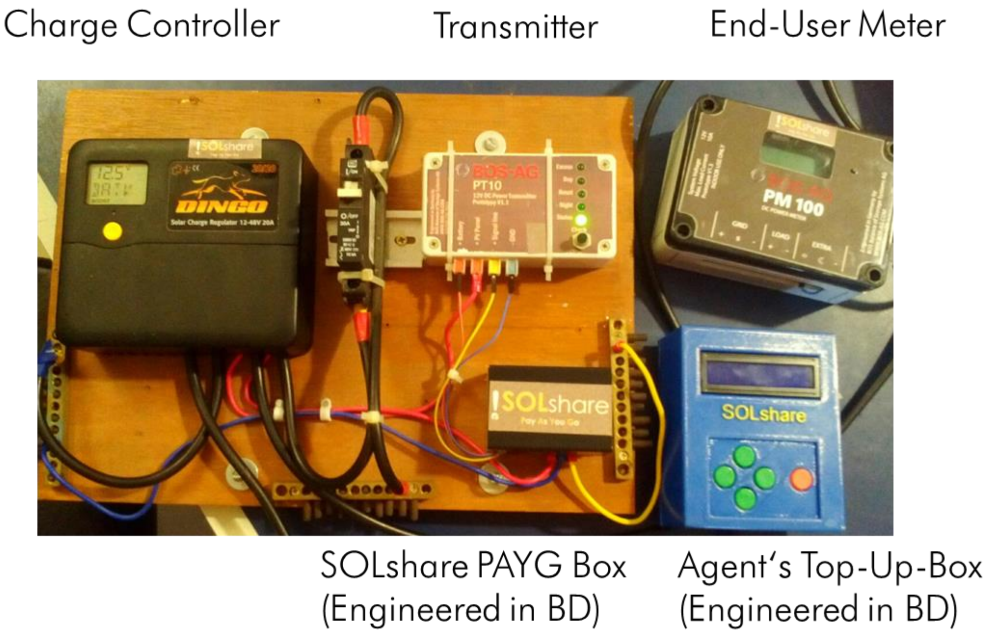


Figure 8. Smart Meter technology for PAYG system topology B.

Figure 9. User with PAYG Meter.

Topology C: Decentralized storage and generation in peer-to-peer bottom-up nanogrid

Households that have their own SHS do not only face the problem that their electricity supply is limited; their generation capacity is also underutilized during most time of the year. This is due to battery capacity limits and varying electricity generation in different seasons. Other households do not have any access to electricity at all. Connecting these households to a nanogrid is the next logical step. This will create a more cost-effective, energy efficient, reliable and flexible energy supply. In contrast to mini-grid approaches, SOLshare nanogrids are decentralized in terms of energy storage and energy generation, which enables the grid to grow dynamically in a step by step approach. As a result, performance risks are lowered due to risk diversification. Furthermore, already installed generation and storage capacities, like SHS, can be integrated. This is especially relevant for countries like Bangladesh, where more than 4 million SHS are already installed in the field.

As the performance of existing SHS improves in a SOLshare nanogrid, it will also enable end-users to use new kinds of technologies and devices that require more power than a typical SHS can provide. This includes services related to education, for example the ability to provide sufficient light for a classroom. Entertainment devices such as TV's, DVD players and computers are possible with SOLshare, which increases the quality of life as well as social interaction and gives access to more information. Additionally, higher capacities and increased reliability of energy supply will facilitate the utilization of more devices related to productive use and thereby increase productivity and income. Possible devices are water pumps, mills, and fridges, among others. As SOLshare nanogrids are based 100% on renewable energies, there is also a substantial environmental impact due to the reduction of CO_2 emissions.

Productive Use Appliances

In order to make full use of decentralized nanogrids based on existing SHSs, it is essential to think beyond the use of household appliances towards the productive use of the (excess) electricity in the system. In turn, this requires a deep understanding of activities, schedule and routines of single users and communities where the grids are installed out of two main reasons. First, productive use (PU) appliances are costly and will only be adopted (and thus return a long-term benefit) when they meet current needs and demands. Secondly, these larger appliances are usually designed for community use, meaning that the resources are best used in joint activities. The successful introduction of PU appliances will enable Bangladesh once more to set a global paradigm of a successful innovation based rural electrification strategy with international renown.

The following concrete applications have been identified to mirror the demand realities of rural Bangladeshi communities:

DC Solar water pump

DC solar water pumps serve the purpose of irrigating crops and provide drinking water, both communal and individual, on a community basis. Different from manual pumping used as of now, the electrical pumps can easily serve higher water demands and ease the physical burden of the population, effectively freeing up time. In addition, more water can be pumped, allowing for more intensive agriculture or the planting of different crops. This can lead to higher yields and consequently higher income obtained from agricultural activities beyond subsistence farming.

Main specifications:

- Size (wattage): 375 W
- Water flow per hour (compared to manual pumping): approx. 2m³/h at 10m head
- Estimated time of use per day: 2-6 h/day depending on solar irradiation and electricity purchase
- Business model: 12 Tk/h of usage [same rate as 6HP diesel pump rent at 150Tk/h]

DC rice huller

As a second main PU activity in Bangladesh, rice hulling has been identified, reflecting the predominant status of rice farming vis-à-vis other crops in Bangladesh's farming sector. DC rice hullers will ease the time and physical burden of farmers preparing harvested rice for usage. In addition, rice hulled with modern hullers can show significantly less broken rice corns, thus improving the quality of the rice. Together with potential time savings more land or existing land can be used for faming more intensely. This can result in higher income from selling rice, ultimately justifying the initial investment in the huller.

Figure 10. DC rice huller during field demonstration

Main specifications:

- Size (wattage): 550W
- Rice hulled per hour (compared to manual hulling): 30-40kg/h
- Fuel saved per hour (compared to diesel huller): 1l/h
- Estimated time of use per day: 1h total operation, more can be achieved through electricity purchase
- Business model: 2Tk/kg (tbc)

Implementation Results

Grid 1, 2 (topology B) and 3 (topology A) in Sunamgong

The DC nanogrid was implemented in Sunamgong in November 2015. It consists of three central storage and generation units that supply for several households, as shown in Figure 1. Each of them has 140 Wp installed PV panels and a battery bank of 250 Ah at 12 V. Grid 1 and grid 2 are interconnected at a distribution box, thus enabling to exchange power among these two grids (topology B). Grid 3 is formed as topology A

The households are connected to the central unit via distribution boxes and each household has one smart energy meter. The meter distinguishes between two different tariffs: the day tariff when battery is not fully generated and the excess tariff when the batteries are fully charged. During excess times, the tariff is double as cheap as during the normal day tariff.

At the beginning, grid 1 and 2 started with seven households both, grid 3 with three households. Six months later, grid 1 and 2 count ten households, whereas grid 3 has 17 households.

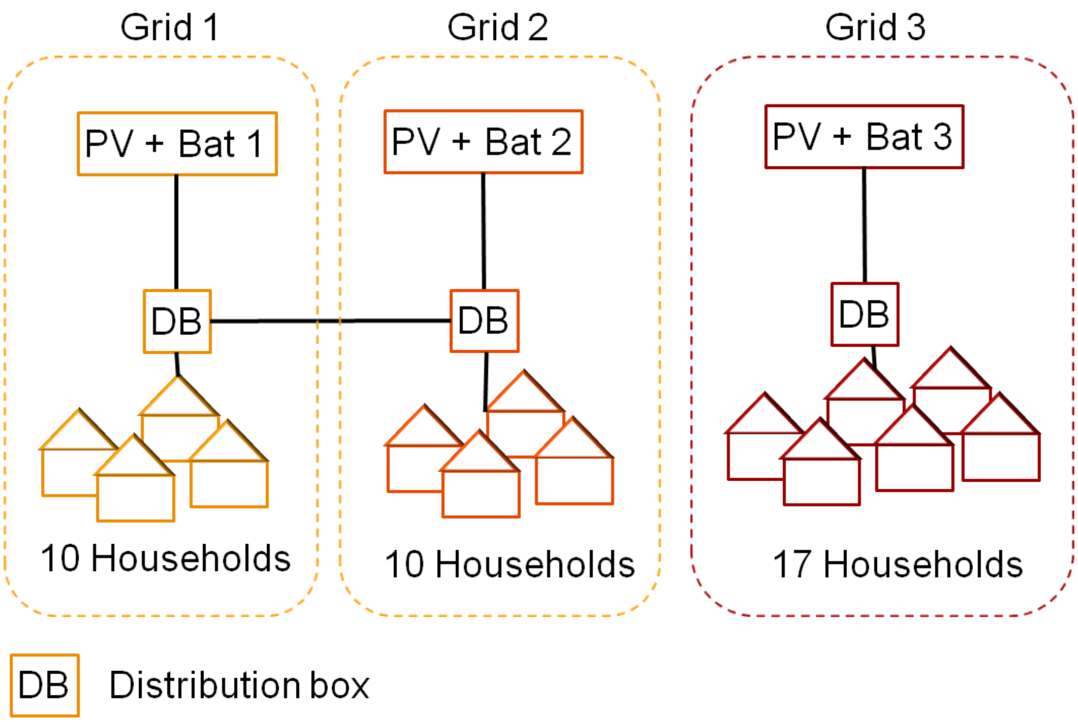


Figure 11. Grid topology of the nanogrids in Sunamgong.

Grid 4 in Matlab (topology A)

Grid 4 lies in Matlab and is also created by a central storage and generation unit in August 2015 as described in topology A. It uses 140 Wp PV and 250 Ah battery (12 V) to electrify 14 households without SHSs. Each household has the same smart meter with the two tariff functions as in the nanogrid of Sunamgong.

SOLshare grid in Shariatpur (topology C)

The nanogrid in Shariatpur is built with the help of a bottom-up approach (topology C). It consists of eight individual decentralized generation and storage units that are interconnected as seen in Figure 12. The peer-to-peer topology enables by means of a controller unit (SOLbox see appendix for further information) power exchange between the houses. Seven households already had a

SHS, one household did not have access to electricity before the SOLshare nanogrid started operation in November 2015.

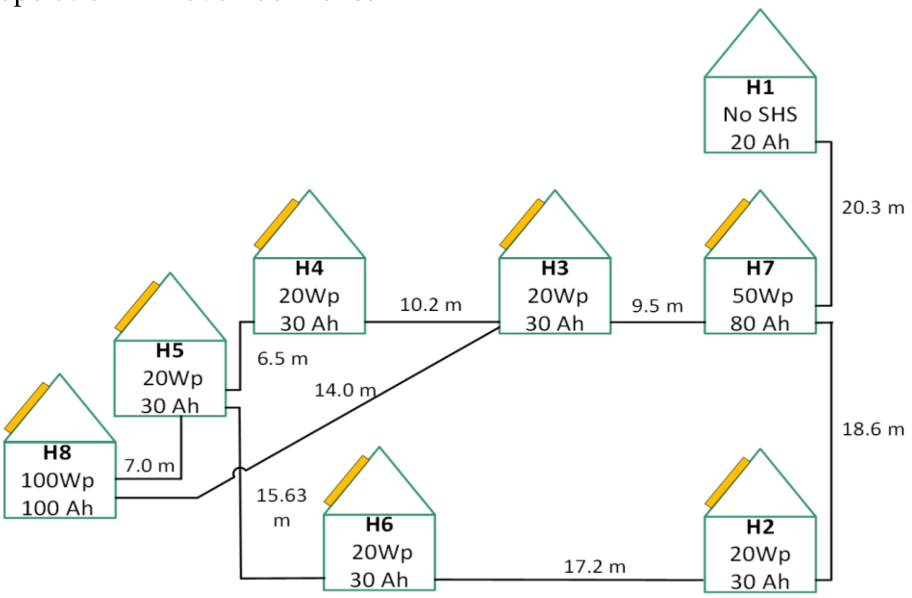


Figure 12. Grid topology of the SOLshare nanogrid in Shariatpur.

<u>Data evaluation</u>

Overall, an average utilization ratio of 70-83 % (see Figure 152) is reached, whereby grid 2 and grid 1 achieve higher results than grid 3 since they are interconnected and can balance out the demand and supply better. The SOLshare grid reaches 78 % in terms of the utilization ratio. Although excess energy is used for supplying the neighbors and thus the generation capacities are better used, the SOLshare grid has the capacity to cover the demand of additional loads.

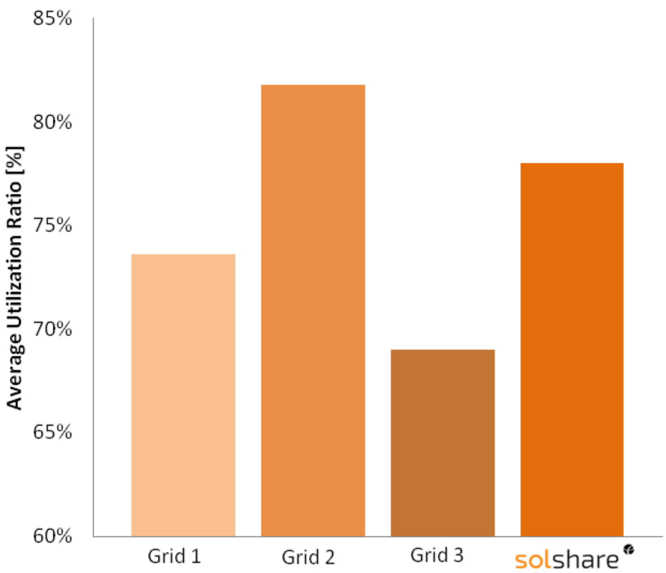


Figure 13. Average utilization ratio of grid 1,2 3 and the SOLshare nanogrid.

In Figure 13 the loads of a typical user from the nanogrids are visualized. It shows that lighting and phone charging are the most important appliances, although a few users also have a fan. One user from the SOLshare grid is able to supply a TV. This results in an average daily consumption per household from 1.2 to 2.6 Ah. Relative to the installed loads, grid 2 and the SOLshare grid have the highest consumption.

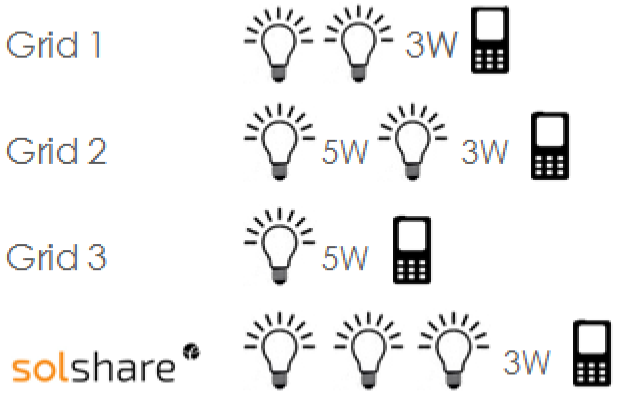


Figure 14. Appliances of a typical user from grid 1, 2 3 and the SOLshare grid.

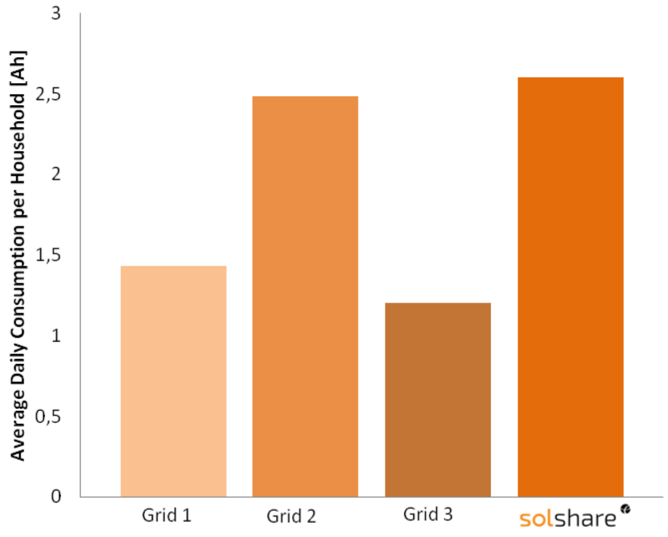


Figure 15. Average daily consumption per user.

The users' demand of the SOLshare grid can be covered totally. Therefore, the state of battery charge (SOC) indicates the power reliability of a nanogrid. In the observed time period, the users did not experience a load switch-off due to an insufficient power supply, as shown in Figure 15. All in all, the battery was mostly medium to fully charged and excess energy was generated. Even the household without an own energy generation source (H1) achieved very high results. A user experienced only a load switch-off when the credit was insufficient. Concluding, the users from the SOLshare nanogrid benefit from high power reliability.

Grid 1 also provides a constantly sufficient energy supply. The grid was switched-off only 0.1 % of the total time (Figure 16). Whereas the users in grid 2 encountered in 4.4 % of the time a black out and grid 3 in 4.9 % of the time. This corresponds to approximately 1 hour of black outs per day.

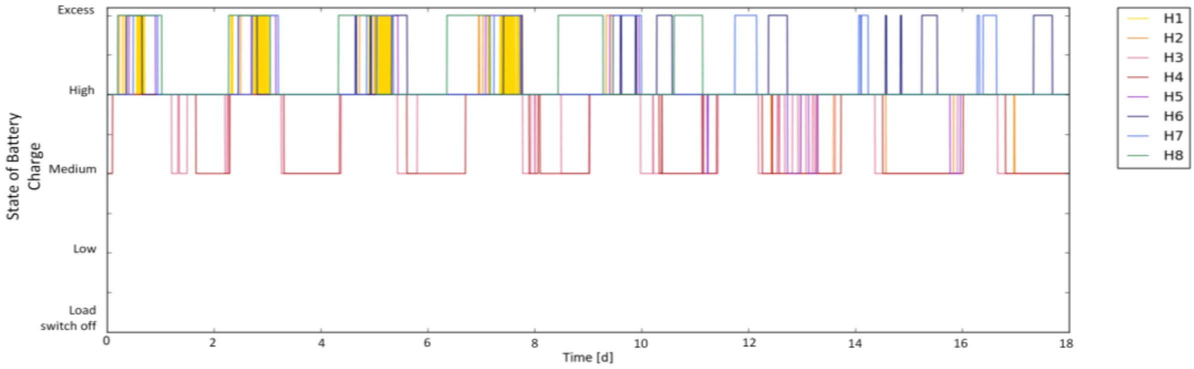


Figure 16. State of battery charge of all users in the SOLshare nanogrid.

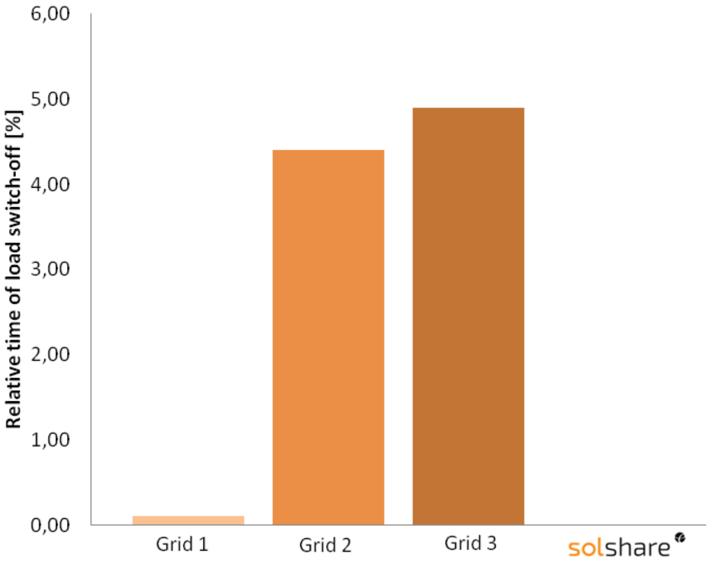


Figure 17. Relative time of power cuts in grid 1, 2, 3 and the SOLshare nanogrid.

Nanogrids aim at reducing excess energy in order to supply neighboring loads. In Figure 17, the days of excess energy occurrence is visualized. It shows that excess energy occurs almost every day in grid 1, 2 and 3, but the amount of daily excess energy varies a lot. The amount of excess energy for the SOLshare nanogrid is not quantified.

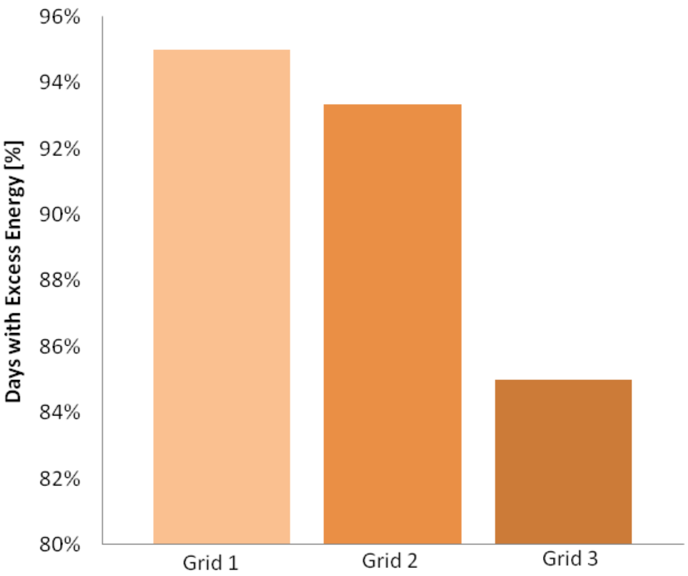


Figure 18. Days of excess energy occurence in grid 1, 2 and 3.

In terms of top-up frequency of credit for buying electricity, all grids achieve a similar result. The average value is 2 times a month. Looking deeper into the electricity metering of grid 1, 2 and 3, it is found, that 2/3 of the electricity is bought at the normal day tariff. 1/3 is bought as the cheaper excess energy (Figure 18).

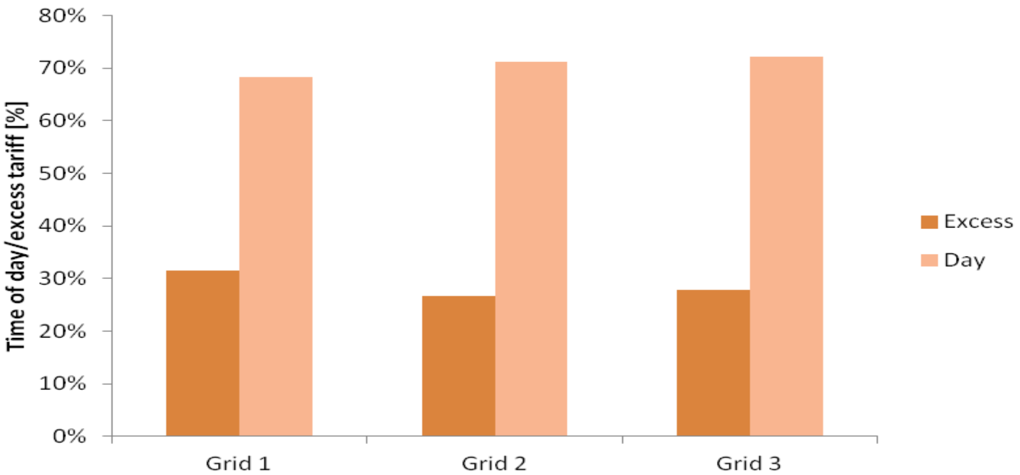


Figure 19. Relative time of day tariff and excess tariff in grid 1, 2 and 3.

Conclusion & Outlook

In the framework of this R&D project, different topologies of solar powered smart DC nanogrids have been developed and piloted in rural Bangladesh. The project owes its innovative character due to the following achievements:

4. A comparative assessment has been performed of three different topologies:

    d) *Central storage and generation couple with smart supply and demand response system*

    e) *Central storage and generation in interconnected nanogrids*

    f) *Decentralized storage and generation in peer-to-peer bottom-up nanogrids.*

5. A new Pay-As-You-Go and (PAYG) and Cash-In-As-You-Go (CAYG) has been successfully tested within the nanogrids.

6. Higher power DC appliances like water pumps and rice hullers have been successfully incorporated into SHS-based low voltage nanogrids.

The data analysis provides results in different aspects of nanogrid and performance. All underlying nanogrids achieve similar values for the average ratio. By looking at other indicators, conclusions in terms of generation, storage and load capacities differ indeed. For example, grid 3 suffers from load switch-offs in some moments although excess energy occurs in other moments. Thus, it requires an expansion of load as well as for generation and storage capacities at the same time to achieve an efficient and reliable nanogrid. Grid 1, on the other hand, does not encounter a load switch-off and has the highest number of days with excess energy indicating that the grid is able to supply for additional loads. Although grid 1 and grid 2 are connected, they perform differently in terms of power reliability and efficiency. Whereas grid 1 achieves a high power reliability, grid 2 experiences black outs. This shows that the power exchange between the interconnected grids is not working sufficiently to balance out the demand and supply differences. The SOLshare nanogrid, in turn, performs very well regarding power reliability and flexibility. Due to sharing electricity all users can de supplied and even the household without PV panel reaches a highly charged battery level. The SOLshare nanogrid has the capacity to supply for additional loads in order to reduce excess energy generation and increase grid efficiency.

During the project implementation, serious problems were faced with the site selection. Paradoxically enough, among the main reason was the high penetration of SHS in Bangladesh. Due to its penetration there seems to be little scope for a DC nanogrid catering for basic energy needs which cannot integrate existing SHS in a smart manner. It became evident that the concept with its strictly centralized generation and storage points in its initial design for basic energy services was not be the right concept for Bangladesh, but rather for countries like India, Myanmar, and Nepal, where the SHS penetration is much lower.

For Bangladesh, a much higher potential can be found for DC nanogrid concepts that are able to integrate SHS into the grid infrastructure. This was confirmed by all stakeholders involved in this project. Such a concept could make use of the existing four million SHS already in the field and upgrade the performance of the same in order to allow for a gradual tier improvement.

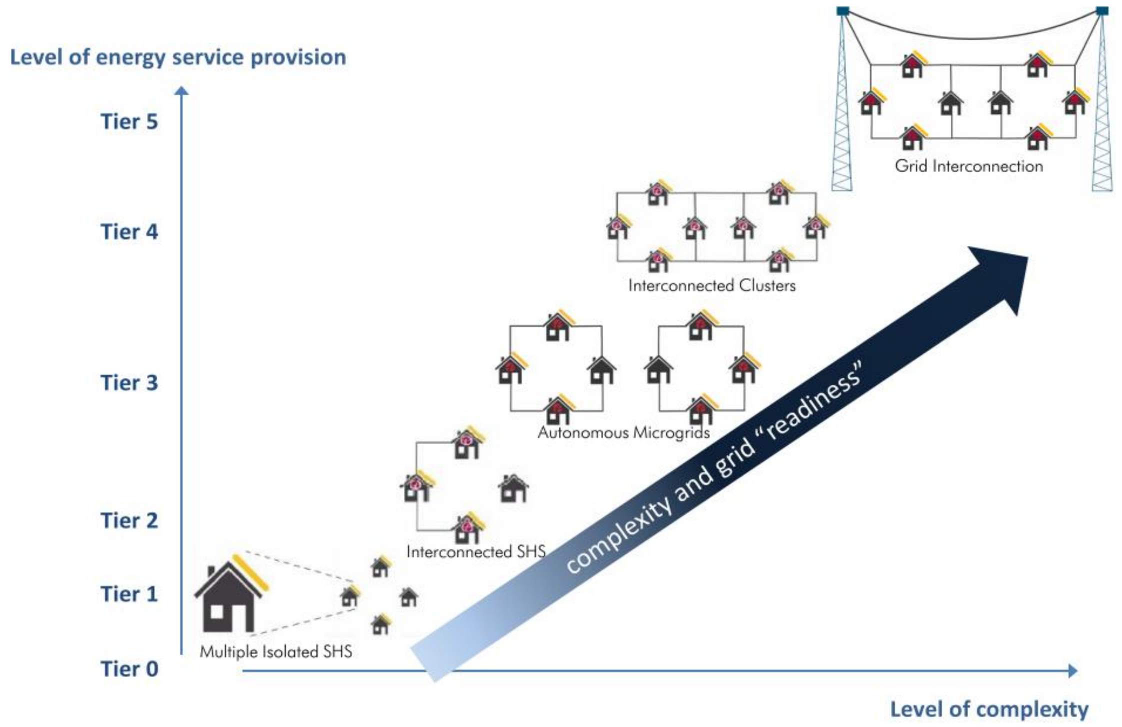


Figure 19. Swarm electrification as a step by step tier improvement process. Source: Groh & Koepke, 2014

The x-axis here reflects the increasing complexity of such an approach whereas the y-axis is based on the multi-tier framework to measuring electricity access as proposed by ESMAP for the SE4ALL Global Tracking framework and discussed in Groh et al. 2015 (ESMAP, 2014; Bhatia & Angelou, 2015; Groh et al. 2016). This scheme includes users without their own SHS in a Pay As You Go model, as well as allows energy services that need lots of more power than a SHS can currently supply. Such a concept was partly already implemented through the interconnection of two of the nanogrids which facilitated smart power sharing, grid stabilization and load balancing. However, the real breakthrough came with the field tests of typology c (Decentralized storage and generation in peer-to-peer bottom-up nanogrids) where additionally PAYG and CAYG, as well as several productive use appliances have been successfully tested.

The shift to a PAYG/ CAYG service model has a huge potential for Bangladesh, especially when taking into account the current collection efficiency problems many of the POs are currently facing. Another crucial success factor is the amount of initial capital investments required. As shown during this project, a low initial investment leads to lower financial risks for the investor, which was especially emphasized by UBOMUS. This makes the tested DC nanogrid concept competitive with larger mini-grid approaches, where huge investments and subsidies are currently required. This is particular true since now the door has been opened for various higher powered loads. As a next step a range of new DC appliances are being installed, such as fridges, ice making machinery, corn hullers and threshers, compressed oxygen machines for rural health clinics, among others. We strongly believe that, provided all technical standards are met, the

SOLbox can make a significant contribution to the country's ambition to provide (improved) energy services for all by 2021.

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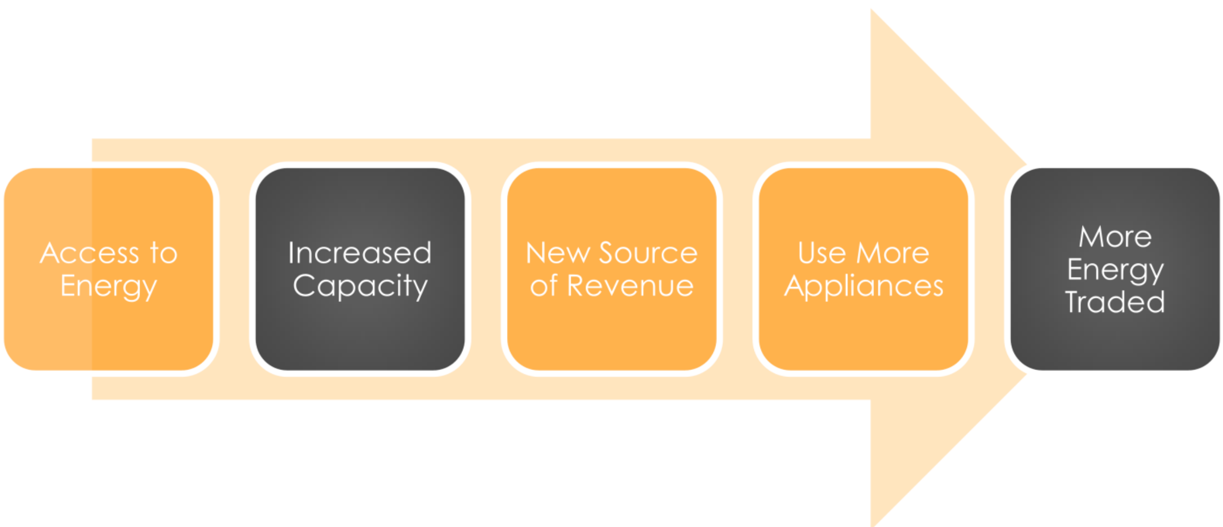
Appendix

The SOLbox

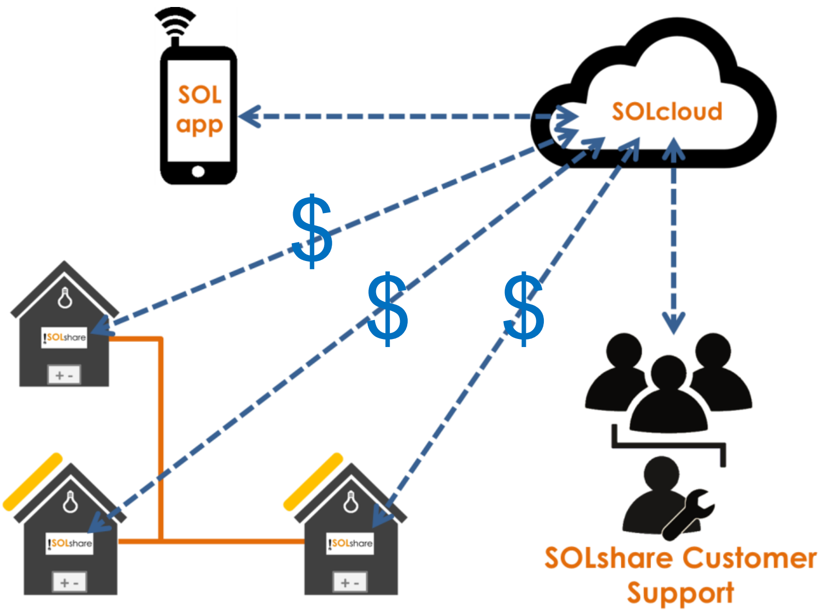
- Enables local electricity buying & selling
- Novel Bi-Directional Metering Technology
- Plug-and-Play; can be set up by End-User
- Compliant with all existing SHS hardware
- Integrates with the SOLCloud & SOLApp
- Provides End-User Mobile Payment Flexibility

High Usability. User-friendly design, with simplified interface.

Enhanced Monitoring. Seamless tracking for advanced con



The SOLcloud and SOLapp



- Data-Management Services
- Mobile-Payment PAYG/ CAYG Back-End
- Grid Management Services
- Machine Learning Data Analytics
- Local Agent Administrative App
- Customer Support Infrastructure

Smart Grid Management and Data Analytics

Secure Transaction Services and Communication Protocols

Financing Agreement

This Financing Agreement has been executed on this 2nd day of August 2015 (hereinafter referred to as the 'Agreement')

BETWEEN

Infrastructure Development Company Limited, a non-bank financial institution, having its registered office at UTC Building (16th Floor) 8 Panthapath, Kawran Bazar, Dhaka 1215, Bangladesh, represented by its Executive Director and CEO, Mr. Mahmood Malik (hereinafter referred to as 'IDCOL' which includes his successors and assigns)

AND

Center for Energy Research, United International University, having its office at UIU Bhaban, House no. 80, Roadno. 8/A, Satmasjid Road, Dhanmondi, Dhaka 1209, represented byits Director, Mr. Shahriar Ahmed Chowdhury, Center for Energy Research(hereinafter referred to as 'the Research Institution', which includes its successors and assigns)

WHEREAS

A. IDCOL promotes dissemination of renewable energy technologies and is currently financing different types of solar energy based program/projects nationwide including Solar Home System Program and Solar Mini Grid Projects funded by various development partners;

B. Pursuant to a Financing Agreement dated 30 June 2014 (Credit no 5514-BD) (Credit no 5158-BD) between the Government of Bangladesh ('GOB') and International Development Association ('IDA') and thereunder a Subsidiary Grant Agreement dated 15 September 2014 between GOB and IDCOL, IDCOL has received financing for its Renewable Energy Program,

C. IDCOL has decided to provide financial support up to USD 550,000 (USD Five Hundred and Fifty Thousand), or at a revised amount as subsequently agreed between both parties in writing, to be sourced from the International Development Association of the World Bank for research and development projects based on renewable energy;

D. Pursuant to the invitation of Application for prospective research project, the Research Institution submitted its Expression of Interest (EoI) and based on the EoI, IDCOL has selected it through a competitive process for implementing the Project (defined below) and IDCOL has decided to extend grant support upto 73% of the Project Cost to the Research Institution for establishment of the Project;

NOW therefore, IDCOL and the Research Institution hereby have agreed to execute this Agreement on the following terms and conditions:

Section 1 : DEFINITIONS AND INTERPRETATIONS

1.1. DEFINITIONS

The capitalized terms used in Agreement, unless otherwise defined shall have the following meaning:

a. "Availability period" means, unless otherwise agreed by the parties in writing, the period that shall be available from the date of this Agreement to the date falling 9 (nine) months thereafter for IDCOL's Grant under Section 3.01;

b. "Business Day" means days during which Banks are open in Dhaka;

c. "Disbursement" means the disbursement of Grant under section 5 which is disbursed from time to time by IDOCL to the Research Institution under this Agreement;

d. "Funding Entity" means IDA as mentioned in the preamble of this Agreement;

e. "GOB" means Government of People's Republic of Bangladesh

f. "Grant" means the subsidy agreed to be provided by IDCOL to the Research Institution for capital buy-down of the Project under this Agreement and sourced out of fund of the Funding Entity;

g. "Disbursement Milestones" means the milestonesmutually agreed between the parties as attached in Schedule 5 to this Agreement upon achievement of which disbursements will be made under section 5;

h. "Project" means the research project as described in details in Schedule I to this Agreement which will be implemented by the Research Institution under this Agreement;

i. "Project Activities" includes procurement, installation, construction, operation and maintenance of the Projectand implemented by the Research Institution;

j. "Project Cost" means costs of the Project for procurement of equipment, construction and other related worksas described in Schedule IInot exceeding BDT 7,680,000(taka seven million six hundred and eighty thousand only) including all applicable taxes and government dues;

k. "Termination Notice" means the notice to be given by either party to the other party under section 11

1.2. INTERPRETATIONS

In this Agreement, unless the context otherwise requires -

(a) headings are for convenience only and do not affect the interpretation of this Agreement;

(b) words importing the singular include the plural and vice versa;

(c) a reference to a natural person includes any company, trust, joint venture, association, corporation or other body corporate and any authority;

(d) a reference to a Section, Article, party or Schedule is a reference to that Section, Article, party or Schedule to this Agreement;

(e) a reference to a document includes an amendment or supplement to, or replacement or novation of, that document but disregarding any amendment, supplement, replacement or novation made in breach of this Agreement; and

(f) a reference to a party to a document includes that party's successors and permitted assigns.

Section 2 : THE PROJECT

2.1. The Project under this Financing Agreement is meant to develop a robust and affordable DC nanogrid:

(a) enabling the integration of local generation and storage capacities by connecting SHS and centralized storage;

(b) allowing electricity sharing through bi-directional power flows which can be constantly adjusted with the variation of the local demand in a very short span of time;

(c) allowing an efficient use of local generation and storage;

(d) reducing the land requirement by using community roof tops; and

(e) enabling the utilization of excess energy from solar irradiation addressing the limitation of standalone systems.

Section 3 : IDCOL GRANT

(a) IDCOL agrees to provide Grant up to 73% of Project Cost, but not exceeding BDT 5,584,000 (taka five million five hundred eighty four thousand)only to the Research Institution and the Research Institution agrees to receive these Grant in accordance with the terms and conditions of this Agreement.

(b) IDCOL Grant shall be used exclusively to meet part of the Project Cost as agreed in Schedule-II.

(c) Notwithstanding any other provisions in this Agreement, any un-disbursed Grant shall be cancelled and the Research Institution shall not be eligible for the unutilized Grant.

(d) The Research Institution shall ensure the financing of remaining 27% of the Project Cost from its own or any third party source.

Section 4 : DISBURSEMENTS

(a) The Research Institution may request for Disbursement of the Grant under Section 3 by delivering to IDCOL, at least five (5) Business Days prior to the proposed date of

Disbursement, through a Disbursement Request in form attached hereto as Schedule III, and a receipt substantially in form attached hereto as Schedule IV.

(b) Upon submission of the Disbursement Request by The Research Institution, IDCOL shall disburse the Grant in favour of The Research Institution in its account mentioned in the Disbursement Request upon fulfilment of the Condition Precedents set forth in Section5;

(c) The number of Disbursements shall not be more than 4 (four) subject to fund requirement and implementation progress of the Project and to be drawn within the Availability Period.

(d) Notwithstanding anything contained in this Agreement, IDCOL shall disburse Grant only against the costs incurred by The Research Institution at actual for the procurement, installation and construction of the Project as per the specification stated in Schedule VII.

Section 5 : CONDITIONS PRECEDENT

A. Conditions Precedent for First Disbursement

In addition to the Conditions Precedent under Section 5 (B), the obligation of IDCOL to make first Disbursement to The Research Institution is subject to, the fulfilment of following preconditions unless otherwise waived by IDCOL in writing:

1) copies of the following documents have been submitted:

(a)Registration certificate of The Research Institution;

(b) Resolution of Board of Trustees enabling The Research Institution:

(i) to carry out the Project Activities;

(ii) to enter into this Agreement;

(iii)to receive Grant from IDCOL hereunder

(iv)to nominate its Authorized Representative under section 14and

(v) to authorise its authorized signatory with his specimen signature attached for execution of this Agreement;

B. Conditions Precedent for All Disbursements

Unless otherwise waived by IDCOL in writing, the obligation of IDCOL to make any Disbursement under this Agreement is subject to the fulfilment of following preconditions, namely that,

1) The Availability Period has not expired;

2) Numbers of the Disbursement Requests have not exceeded the maximum number of Disbursements as stated under Section 4 (c);

3) Disbursement Milestones as per Schedule 5 for respective Disbursement has been achieved;
4) supporting documents showing the utilization of the disbursed Grant as and when applicable money receipt, copy of Letter of Credit if any, distinctive photographs of the equipment procured and installed under the Project Activitieshave been delivered;
5) no Event of Default has occurred, is continuing or likely to occur;
6) Representations and Warranties made under section 6 of this Agreement are true on and as of the date of the relevant Disbursement;
7) no change in the condition of The Research Institution has occurred which is likely to materially or adversely affect the operation of the Sub-project; and
8) no litigation or other proceedings has been current, or is likely to be instituted, which if adversely determined would materially affect the operation of the Project;

Section 6 : REPRESENTATIONS AND WARRENTIES

6.1. The Research Institution represents and warrants as follows:

(a) *Status.* it is trust created under the Trust Act, 1882 and validly existing under the laws of the People's Republic of Bangladesh. It has license from the University of Grant Commission under the Private Universities Act 2010;

(b) *Power*. it has the power to own its assets, carry on its business as it is being conducted and to enter into and perform its obligations under this Agreement;

(c) *Authority*. it has the authority to enter into and perform, and has taken all necessary action to authorize the entering into, performance and delivery of, this Agreement, other Transaction Documents;

(d) *Dedicated Staff*. it has adequate and trained dedicated staff to operate the Project successfully;

(e) *Validity*. this Agreement constitutes, or when executed in accordance with its terms, shall constitute, its legal, valid and binding obligation enforceable against the Research Institution in accordance with its terms and, so far, the Research Institution is aware, is in full force and effect;

(f) *No Conflict*. the execution, delivery and performance by it of this Agreement shall not–

(i) violate or conflict with any law, rule or regulation or governmental approval or judicial order to which it is subject in any material respect;

(ii) violate or conflict with the constitutional documents of the Research Institution;

(iii) violate or conflict with any existing contractual undertakings of the Research Institution with any third parties including public or private entities;

(iv) cause any limitation on it or the powers of members of the board of trustees (whether imposed by any of its constitutional documents or by any law, order, judgement, agreement, instrument or otherwise) to be exceeded; or

(v) oblige the Research Institution to create or result in the existence of any Encumbrance over any of its assets or result in any breach of any law, order, judgement or agreement.

(g) *Authorizations and Approvals*. all material authorizations required in connection with entering into, performance and validity and enforceability of this Agreement have been obtained and are in full force and effect so far as the Research Institution is aware and no steps have been taken to revoke or cancel any such authorizations obtained or effected;

(h) *Immunity*. the Research Institution, its properties and assets do not enjoy any right of immunity from set-off, suit or execution in respect of its obligations under this Agreement;

(i) *Proceedings*. No litigation, arbitration or administrative or other proceedings are current, or to its knowledge, pending or threatened which, if adversely determined, would have a material adverse effect on the Project;

(l) *Funding by others*: it has not received any funding from any other donors or funding agencies to carry out the Project Activities.

(m)*Good title toassets:*

(i) the Research Institution has good title to all its assets and possession over the assets that will be used for the Project and there is no encumbrance over those assets of the Research Institution and the Research Institution is not a party to nor is it or any of its assets bound by any order, agreement or instrument under which the Research Institution is or in certain events may be required to create, assume or permit to arise any encumbrance.

(ii) the Research Institution has all the necessary rights, easements, licenses and interests to enable it to use its assets for the Project;

(n) *No misleading information:* the Research Institution has disclosed fully in writing to IDCOL all facts relating to itself which it knows or should reasonably know and which are material for disclosure to IDCOL in the context of this Agreement.

6.2.The representations and warranties in Section 6.1 shall be deemed to be repeated, updated *mutatis mutandis* at each such date, on the date of each Disbursement Request, on the making of each disbursement and on the first day of each interest period.

Section 7 : UNDERTAKINGS OF THE RESEARCH INSTITUTION

The Research Institution undertakes that it:

(a) shall procure that IDCOL be allowed access to inspect by itself, or jointly with GOB and/or Funding Entity, the Laboratory, Project Activities and any relevant records and documents;

(b) shall furnish to IDCOL:

i. the implementation status showing the progress as per the Disbursement Milestones under Schedule 5;

ii. such other additional financial or other information as IDCOL or any Funding Entity may from time to time request

(c) shall carry out the Project Activities with due diligence and efficiency and in accordance with sound technical, economical, financial, managerial, environmental and social standards and practices satisfactory to IDCOL and the Funding Entity, including in accordance with the provisions of the Anti-Corruption Guidelines applicable;

(d) shall enable IDCOL and any Funding Entity to inspect the Sub-project or Sub-project Activities, its operation and relevant records and documents at any time with or without any prior written notice.

Section 8 : EVENTS OF DEFAULT

8.1. It shall be an event of default on the part of the Research Institution, if,

(a) *Breach of Representations and Warranties.* it commits breach of any Representations and Warranties under Section 6

(b) that IDCOL determines to have material and adverse effect on the Project;

(c) *Breach of Undertakings.* it commits breach of any undertakings under Section 7 that IDCOL determines to have material and adverse effect on the Sub-project;

(d) *Government Action*. GOB takes any action to nationalize, expropriate or confiscate the the Research Institution and/or its assets;

(e) *Cessation of License:* the license of the Research Institution obtained from its regulatory authority and/or under any other law has been ceased or not renewed;

(f) *Insolvency proceedings by and/or against the Research Institution.* any insolvency, bankruptcy or reorganization proceedings is undertaken by the Research Institution that has not been discharged within thirty (30) days of its institution;

(g) *Force majeure event.* any force majeure events such as fire, riot, strike, earthquake, flood, cyclone and other natural perils occurs rendering the implementation of the Project fully or partially not possible for more than 90 days without restoration or repair.

(h) *Failure and/or Denial to operate.* it fails and/or denies to performs its duties and obligations under section 2 and Section 7.

8.2. Upon the occurrence of any Event of Default, IDCOL shall have the right to suspend the undisbursed Grant under section 9 and/or terminate the Agreement under Section 10;

Section 9 : SUSPENSION OR CANCELLATION OF GRANT BY IDCOL

Notwithstanding anything contained in this Agreement, IDCOL may at any time suspend the un-disbursed amounts of all Grant immediately under this Agreement giving a written notice of 15 days to the Research Institution, if -

(a) the Research Institution fails to draw the full sanctioned amount of Grant within the Availability Period and/or by maximum number of Disbursement Requests under Section 4 (c);

(b) disbursements under the any grant agreement among GOB and any Funding Entity and any subsidiary grant agreement between GOB and IDCOL as referred to in the preamble to this Agreement is suspended or terminated for any reasons;

(c) it becomes unlawful for IDCOL to give effect to any of its obligations under this Agreement;

(d) a right of suspension or cancellation arises under Section 8.2

(e) the GOB or any Funding Entity suspends or terminates the right of IDCOL to use the proceeds of the Grant for the Project;

(f) the Research Institution fails to perform any of its obligations under this Agreement;

Section 10 : TERMINATION OF THE AGREEMENT

(a) Any party may terminate this Agreement by giving a 90 (ninety) days' notice in writing to the other party in the event of the failure by the other Party to perform any of its obligations under this Agreement amounts to a fundamental breach of this Agreement and fails to remedy the same within 90 days of receipt of the written notice ('Termination Notice');

(b) Either Party shall be entitled to terminate the Agreement by giving a written notice if the other Party becomes bankrupt or otherwise insolvent.

(c) In case of termination of this Agreement by the Research Institution on any ground or by IDCOL on the ground any Event of Default and/or failure of the Research Institutionto remedy the default under this Agreement within the period of Termination Notice, IDCOL will have the right to take back the equipment procured and/or installed under this Agreement, provided that if the Research Institution wants to retain the equipment, it will pay to IDCOL the depreciated value of the equipment at the time of termination by either party. The annual depreciation will be at the rate of 20% (twenty percent).

Section 11 : OWNERSHIP OF THE PROJECT AND ITS TECHNOLOGIES

Any studies, reports or other material, graphic, software, technology or otherwise developed by the Research Institution under the Project shall belong and remain the property of the Research Institution provided that the Research Institution shall not claim any royalty for dissemination of the Project and/or the studies, reports or other material, graphic, software, its technologies or otherwise, technology relating to the Project:

a. from any person within the territory of Bangladesh;

b. from IDCOL irrespective of place, time and mode of dissemination

Section 12 : GOVERNING LAW AND JURISDICTION

This Agreement is governed by and shall be construed with the laws of the People's Republic of Bangladesh ("Governing Law") and the Court of Law of People's Republic of Bangladesh will have the exclusive jurisdiction in case of any dispute arisen between the parties under this Agreement.

Section 13 : ENTIRE AGREEMENT

This Agreement and other documents contemplated hereby shall supersede any prior expressions of intent or understandings with respect to the transactions contemplated herein.

Section 14 : AMENDMENT AND WAIVER

(a) Any provision of this Agreement may be amended by mutual agreement of the parties in writing.

(b) Any waiver of any right under this agreement must be in writing and signed by the parties.

Section 15 : AUTHORIZED REPRESENTATIVE

The Research Institution hereby nominates its Director, Center for Energy Research ("CER") (the Authorized Representative) as its authorized representative including but not limited to represent the Research Institution, perform any undertakings, make communications and be communicated for any correspondence regarding this Agreement provided that neither the Research Institution nor the Authorized Representative shall assign its rights and/or obligation under this Agreement without prior written consent of IDCOL.

Section 16 : COUNTERPART

There shall be 2 (two) original copies of this Agreement one of which will be retained by IDCOL and the other one shall be retained by the Research Institution.

Schedule I: The Project

(Refer to Section 1)

Under renewable energy initiative, IDCOL started its Solar Home Systems Program in January 2003 with a view to providing access to electricity in the off-grid areas of the country. The program now stands as the largest off-grid renewable energy program of the world. IDCOL also has country-wide programs in domestic biogas, solar irrigation, solar mini-grid, biomass and biogas based electricity generation. IDCOL has recently taken initiative to finance energy efficient (EE) technologies under which nationwide Improved Cook Stove (ICS) program has been launched and some energy efficient brick kiln projects have also been financed.

IDCOL offers a comprehensive range of subsidy and concessionary loans to these viable renewable energy or energy efficiency programs/projects. In addition, IDCOL provides support for feasibility analysis, training and capacity building as well as promotion and awareness campaign.

Many of the renewable energy technologies are technically viable and proven, but their initial investment costs are very high compared to those of fossil fuel based technologies. As such, renewable energy technologies are still evolving in terms of technological maturity and cost competitiveness. IDCOL has recently received USD 1 million fund from the World Bank under Rural Electrification and Renewable Energy Development Project (REREDP). This fund will be used to support the R&D initiatives. In this regard, IDCOL invites Expression of Interest (EoI) from national entities interested to conduct R&D activities for improvement of existing renewable energy technologies as well as for development of new renewable energy solutions for Bangladesh.

Looking at the increasing importance of renewable energy, IDCOL is willing to support research and development (R&D) activities with a view to improving the existing renewable energy technologies as well exploring other viable renewable energy options in Bangladesh context. 100% grant fund will be provided to approved R&D proposals.IDCOL sought to receive EOIs from various R & D entities for proposals which include but are not limited to the following technologies:

- Solar energy (hybrid cold storage, micro/nano grid, solar irrigation with alternate use of solar energy, solar dryer, battery charging station, rooftop system, solar thermal etc.);
- Solar-powered vehicles (for road and water communication);
- Wind energy (both utility-scale and micro generation);
- Geothermal energy;
- Micro-hydro;
- Energy from biomass (combustion, anaerobic digestion and gasification);
- Bioenergy (waste to energy, bio-sludge, community biogas projects, landfill gas etc.);
- Energy storage systems on renewable power sources;
- Energy Efficient boilers and other machineries for different industries;
- Any other relevant fields.

Schedule II: Project Cost

(Refer to Section 1)

SN	Items of Expenditure	Unit	Quantity	Unit Cost (BDT)	Estimated Cost (BDT)	% of Estimated Cost
a)	**Revenue Expenditure**					
1	***Pay of Officer***					
1.1	Principal Investigator	Man-day	166	10,000	1,660,000	21.6%
1.2	Co-Investigators	Man-day	246	7,000	1,722,000	22.4%
1.3	Research Engineers	Man-month	4	25,500	102,000	1%
2	***Pay of Staff***					
3	***Supplies and Service***					
3.1	Local Transport	LS			220,000	3%
3.2	Travel and accommodation for International Experts	No.	2	300,000	600,000	8%
4	***Repair and Maintenance***					
Total Revenue Expenditure					**4,304,000**	56%
b)	**Capital Expenditure**					
5	**Acquisition of Assets**					
5.1	System Integration	unit	1	400,000	400,000	5%
5.2	Prototyping	unit	1	480,000	480,000	6%
5.3	Productive use appliance testing	unit	1	400,000	400,000	5%
Capital Expenditure - Local					1,280,000	17%
5.4	Hardware sourced from outside				2,096,000	
Total Capital Expenditure					**3,376,000**	**44%**
Total Cost (a+b)					**7,680,000**	100%
c) Contingencies (max. 2% of the total cost)						
Grand Total (a+b+c)					**7,680,000**	100%
	To be sourced from IDCOL				**5,584,000**	**73%**

Schedule III: Disbursement Request
(Refer to Section 5 (a))

[The Research Institution's LETTERHEAD/LOGO]
[Address]
[Date]

Executive Director and CEO
Infrastructure Development Company Limited (IDCOL)
UTC Building (16th Floor)
8 Panthapath, Kawran Bazar
Dhaka 1215.

Dear Sir:

Request for Disbursement No. [ ]

Please refer to the Financing Agreement dated [ ], between Centre for Energy Research, United International University (the "Research Institution") and IDCOL.

All terms defined in the Financing Agreement shall bear the same meanings herein.

The Research Institution hereby requests the Disbursements, on or before [ ], of the following amount, in accordance with the provisions of Section 4:

Item	Amount (Taka)
IDCOL Grant	
Total	

The Research Institution requests that such amount be paid to [*insert account number of the Account*] at the [*Name of Account Bank*] for expenditures enclosed herewith under theProject [*attach the list of expenditures for which the Disbursement Request has been made along with all supporting documents*].

For the purposes of Section5 (b) of the Financing Agreement, the Research Institution hereby certifies as follows:

1. Section 5 (c) of the Financing Agreement is complied with;

2. No Event of Default as described under Section 8 of the Financing Agreement has occurred, is continuing or likely to occur;

3. Representations and Warranties made under Section 5 of the Financing Agreement true on and as of the date of the relevant Disbursement;

4. No change in the condition of the Borrower has occurred which is likely to materially or adversely affect the carrying out of the Sub-project;

5. No litigation or other proceedings has been current, or is likely to be instituted, which if adversely determined, would materially affect the operation of the Sub-project; and

6. We have not received, or shall not claim, any grant, subsidy, or financing from any funding agency, donor or other third party, except IDCOL, for the Project.

The certifications above are effective as of the date of this request and shall continue to be effective as of the date of Disbursement. If any of these certifications is no longer valid as of or prior to the date of the disbursement hereby requested, the Research Institution shall immediately notify IDCOL and shall repay the amount disbursed upon demand by IDCOL if Disbursement is made prior to the receipt of such notice. In case of any certification given above is found to be wrong or change subsequently but not been notified to IDCOL by the Research Institution, the Research Institution shall immediately repay the amount disbursed to it by IDCOL pursuant to this Disbursement Request

Yours faithfully,

____

By
[*Name of the authorized signatory of the Authorized Representative*]
For and on behalf of the Research Institution

Schedule IV: Receipt of Disbursement
(Refer to Section 4)

[THE RESEARCH INSTITUTION'S LETTERHEAD/LOGO]
[Address]
[Date]

Executive Director and CEO
Infrastructure Development Company Limited (IDCOL)
UTC Building (16th Floor)
8 Panthapath, Kawran Bazar
Dhaka 1215.

Dear Sir:

Request for Disbursement No. [ ]

We, [*name of the Research Institution*], hereby acknowledge receipt of the sum of Taka [ ] disbursed to us by Infrastructure Development Company Limited (IDCOL) under the Financing Agreement dated [ ] signed between ourselves and IDCOL.

Yours faithfully,

____
By
[*Name of the Authorized Representative*]
For and on behalf of the Research Institution

Schedule V: Disbursement Milestones

(Refer to Section 4)

	Disbursement Milestones	**Percentage**	**Amount (BDT)**
Phase 1:	Upon Signing of Agreement	25%	1,396,000
Phase 2:	After Submission of Field survey report (identifying potential sites for nano grids)	25%	1,396,000
Phase 3:	After completion of the development of the equipment in the lab	25%	1,396,000
Phase 4:	After Installation of the system to the off grid areas and submission of the final report	25%	1,396,000

Proposal by the Consortium

Proposal for Research and Development Initiatives/Ideas under Renewable Energy and Energy Efficiency Projects

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Community Based Decentralized DC Nanogrids for Combined Household and Productive Use

Title of the project: Community Based Decentralized DC Nanogrids for Combined Household and Productive Use

Principal Investigator: Mr. Shahriar Ahmed Chowdhury
Director, Centre for Energy Research and
Assistant Professor, Department of EEE
United International University, Bangladesh
Email: shahriar.ac@gmail.com
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Co-Investigator 1: Prof. Peter Adelmann
Founding Director, Institute for Decentralized Electrification, Entrepreneurship and Education
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Co-Investigator 2: Prof. Dr. Kai Strunz
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Co-Investigator 3: Prof. Dr. Daniel M. Kammen
Founding Director, Renewable and Appropriate Energy Laboratory at the University of California, Berkeley
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Co-Investigator 5: Hannes Kirchhoff
Ph.D Cand. in Electrical Engineering
Postgraduate School Microenergy Systems
Technische Universität Berlin, Germany
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UNITED INTERNATIONAL UNIVERSITY

solshare
Create a network. Share electricity. Brighten the future

Executive Summary

Solar PV is widely used in Bangladesh due to its continuous declining price in the world market and soft loan scheme introduced by Infrastructure Development Company Limited (IDCOL) of Bangladesh. IDCOL has already installed more than 3.5 million solar home systems (SHS) up to date and plans to reach a target of 6 million SHS by the year 2016. Installation of Solar Home System (SHS) under IDCOL finance has become a very successful program benefitting millions of off grid rural households. People at rural areas are now convinced that solar PV system helps to make their life a better one. At the same time there is an ambitious goal to push forward the installations of minigrids. This, however, often culminates in double infrastructures with dead weight loss as many SHS are often abandoned in favour of minigrid electricity services. Keeping these impulses in mind, Centre for Energy Research (CER) of United International University (UIU), Institute for Decentralized Electrification, Entrepreneurship and Education of the Ulm University of Applied Science (id-eee), the department for Sustainable Electric Networks and Sources of Energy at the Technische Universitaet Berlin (SENSE), Renewable and Appropriate Energy Laboratory at University of California Berkeley (RAEL), and ME SOLshare are going to develop a comprehensive research on community based decentralized DC nanogrids for combined household and productive use based on existing resources.

The overall objective of the project is to develop an innovative approach for community based decentralized DC nanogrids for rural electrification. The developed approach will enable integration of local generation and storage capacities (like Solar Home Systems) by connecting SHS and centralized storage and generation capacities into a DC nanogrid. The DC nanogrid allows electricity sharing through bi-directional power flows which leads to extremely flexible DC nanogrids which can be constantly adjusted to local demands in a short term period. The approach has the advantage that local generation and storage capacities are used more efficiently and additionally, by utilizing community rooftops for creating a nanogrid, land needed for solar arrays can be significantly reduced. The proposed approach enables the utilization of excess energy that results from the design configurations of SHS for rainy and non-rainy seasons, in a bi-directional DC nanogrid. The excess energy will be used for supplying water irrigation pumps and agro-processing DC devices, like husking mills/grinders, grain mills/grinders, grain threshers and corn peelers. Furthermore, the excess energy can be used for giving electricity access to households without SHS and for supplying additional electricity to households which already have a SHS. Enabling households to share electricity generated from their SHS also creates new business opportunities from selling electricity to end-users in a bi-directional nanogrid.

Development activities, testing procedures and pilot implementation are co-developed and closely monitored by our strong international research team. All R&D activities are Dhaka-based in the new DC technology laboratory of the Centre for Energy Research at the UIU as well as in the facilities of ME SOLshare. By having ME SOLshare, a young Dhaka based company as a implementation partner, we ensure that the research results will be directly used for commercialization purposes. ME SOLshare further co-funds all hardware expenses of the project.

We are convinced that an intelligent integration of the existing and upcoming SHS in the market for future nanogrid design combining key productive use activities, such as water pumping and agro-processing with household electrification, will enable Bangladesh once more to set a global paradigm of a successful innovation based rural electrification strategy.

Team CVs

Mr. Shahriar Ahmed Chowdhury

Mr. Chowdhury is Director at the Centre for Energy Research and Assistant Professor of Electrical and Electronic Engineering (EEE) department of UIU, obtained his B.Sc. in EEE from Bangladesh University of Engineering and Technology (BUET). He worked at Dhaka Electric Supply Authority (DESA) and Bangladesh Power Development Board (BPDB) from 1997 to 2007, where he was responsible for distribution system planning and design, load management, Grid system control and protection, Grid substation maintenance and SCADA systems. He completed his M.Sc. in Renewable Energy from University of Oldenburg, Germany with the highest marks in the graduating class in 2006. He has developed a dry fabrication process for CIGS thin film solar cell with the best performance in terms of efficiency at the time in Germany as part of his M.Sc. thesis work. Mr. Chowdhury has designed and initiated a course in Renewable Energy for the first time in Bangladesh for the undergraduate students of EEE department in 2007. In 2008 and 2011, he (as team leader) performed the technical auditing of the SHSs installed all over Bangladesh under the IDCOL RERED project (the project is jointly funded by WB, ADB, IDB, GIZ, KfW and JICA). The technical audit identified the technical status of the installed SHSs, their weaknesses and came up with suggestions for possible improvement in design and practices. In 2009 Mr. Chowdhury has supervised the finalist student project for IEEE International Future Energy Challenge in Illinois Institute of Technology, Chicago, USA. In September, 2010 he has established the Centre for Energy Research in UIU focusing on Renewable Energy research in Bangladesh. He is a guest lecturer/researcher in Renewable Energy of University of Oldenburg, Germany and keeps in constant touch with the latest developments in renewable energy technologies. He has completed renewable energy projects like Installation of Solar PV panel assembling plants, Solar-Diesel hybrid power systems solution for off grid BTSs of mobile phone operators, Solar diesel hybrid mini grid system design (So far 7 solar minigrids in the range of 100 to 200 kWp), Feasibility study to set up battery manufacturing industry in Bangladesh, Feasibility study to provide energy to poor rural households with renewable energy technologies, Bangladesh off grid energy sector assessment etc. He has recently completed a project “Bangladesh Energy and Emission Calculator 2050” funded by UK department of Energy and Climate Change and in association with the Power Division of Ministry of Power Energy and Mineral Resources. Mr. Chowdhury is also involved as Energy / Renewable Energy Expert in ADB supported project “Supporting Implementation of Bangladesh Climate Change Strategy and Action Plan” and Netherland Government supported project “Development of Bangladesh Delta Plan 2100”. He is working as the team leader of national consulting team for implementation of an 8 MWp grid connected Solar PV system at Kaptai and a 4.2 MWp off grid Solar-Wind-Diesel hybrid power system at Hatiya island of Bangladesh. Recently Mr. Shahriar has designed and developed solar PV driven rickshaw and solar PV driven ferry boat. Mr. Chowdhury has initiated a bi-yearly International Conference on the Development in Renewable Energy Technology.

Prof. Peter Adelmann

Peter Adelmann was born and educated in Germany. He received his diploma in Electrical Engineering from the University of Applied Sciences (UAS) Ulm in 1986. Since 1988, he has been a lecturer at UAS Ulm in photovoltaics and stand-alone solar systems. In 2003 he was made a Professor at UAS Ulm. From 1991 till 2000 he was the director of the solar electronic department at Steca GmbH. In 2001 he founded Phocos AG, and was CEO of this company until 2008. Both of these companies were market leaders for solar battery charge controllers. Since 2004 he has been a member of the IEC TC 82. He has been a senior consultant for various organisations and companies including GIZ, World Bank, The United Nations, The European

Commission Energy Initiative, Bosch, Multi-contact, Solarworld, Phaesun, and others. Since 2010 he has been a senior consultant for off-grid PV systems at the Solar Energy Research Institute of Singapore (SERIS) at the National University of Singapore (NUS). He will take the lead role in this project.

Prof. Dr. Kai Strunz

Prof. Dr. Kai Strunz is professor at the Technische Universität Berlin and holds the chair for Sustainable Electric Networks and Sources of Energy (SENSE). His research activities center around smart grid concepts and projects, with a focos on electric vehicles, transmission grid codes and smart controls for distribution DC grids. Before he was an Assistant Professor of Electrical Engineering at the University of Washington in Seattle from 2002 to 2007 and worked as a research engineer at Electricité de France (EDF) in the Paris area. He received the Dr.-degree with summa cum laude from Saarland University in Germany in 2001. On behalf of the German Federal Ministry of Economics and Technology (BMWi), Prof. Strunz is an expert advisor in the Working Group on New Technologies for the Grid. In IEEE, he is Chairman of the IEEE PES Subcommittee on Distributed Generation & Energy Storage and Chairman of the IEEE Subcommittee on Research in Power & Energy Education. For the IPCC (Intergovernmental Panel on Climate Change), he acted as Review Editor from 2009 to 2011. While in USA, he received the National Science Foundation (NSF) CAREER award in 2003.

Prof. Dr. Daniel M. Kammen

Dr. Kammen is the Class of 1935 Distinguished Professor of Energy at the University of California, Berkeley, with parallel appointments in the Energy and Resources Group, the Goldman School of Public Policy, and the department of Nuclear Engineering. He was appointed the first Environment and Climate Partnership for the Americas (ECPA) Fellow by Secretary of State Hilary R. Clinton in April 2010. Dr. Kammen is the founding director of the Renewable and Appropriate Energy Laboratory (RAEL), Co-Director of the Berkeley Institute of the Environment, and Director of the Transportation Sustainability Research Center. He has founded or is on the board of over 10 companies, and has served the State of California and US federal government in expert and advisory capacities. He was educated in physics at Cornell and Harvard, and held postdoctoral positions at the California Institute of Technology and Harvard. He was Assistant Professor and Chair of the Science, Technology and Environmental Policy Program at the Woodrow Wilson School at Princeton University before moving to the University of California, Berkeley. Dr. Kammen has served as a contributing or coordinating lead author on various reports of the Intergovernmental Panel on Climate Change since 1999. The IPCC shared the 2007 Nobel Peace Prize. He serves on the Advisory Committee for Energy & Environment for the X-Prize Foundation. During 2010-2011 Kammen served as the World Bank Group's Chief Technical Specialist for Renewable Energy and Energy Efficiency. He was appointed to this newly-created position in October 2010, in which he provided strategic leadership on policy, technical, and operational fronts. The aim is to enhance the operational impact of the Bank's renewable energy and energy efficiency activities while expanding the institution's role as an enabler of global dialogue on moving energy development to a cleaner and more sustainable pathway. He has authored or co-authored 12 books, written more than 300 peer-reviewed journal publications, testified more than 40 times to U.S. state and federal congressional briefings, and has provided various governments with more than 50 technical reports. Dr. Kammen also served for many years on the Technical Review Board of the Global Environment Facility. He is a frequent contributor to or commentator in international news media, including Newsweek, Time, The New York Times, The Guardian, and The Financial Times. Kammen has appeared on 60 Minutes (twice), Nova, Frontline, and hosted the six-part Discovery Channel series Ecopolis. Dr.

Kammen is a Permanent Fellow of the African Academy of Sciences, a fellow of the American Physical Society. In the US, he serves on two National Academy of Sciences boards and panels.

Dr Sebastian Groh
Dr. Groh holds a PhD from Aalborg University (Denmark) where he wrote his thesis on the role of energy in development processes, energy poverty and technical innovations. He is living and working in Bangladesh as the director of two start-up companies, ME SOLshare Ltd. and ME Fosera BD Ltd.. He teaches at Independent University Bangladesh and Eastern University. Dr. Groh is further project manager at MicroEnergy International (MEI) since 2009, a Berlin based consulting company focusing on the linkage between microfinance and sustainable energy supply. Previous to his work at MEI, he worked on the trading floor at Commerzbank in Frankfurt, at ProCredit in El Salvador and Planet Finance in India. Dr. Groh received his Bachelor in Economics from University of Mannheim (Germany) and Universidad Carlos III de Madrid (Spain) as well as a Masters in International Economics from the University of Goettingen (Germany), University of Pune (India) and Universidad José Matías Delgado (El Salvador). Dr. Groh further received an executive training on strategic leadership for microfinance from Harvard Business School and is a Stanford Ignite Fellow of 2013 from Stanford Graduate School of Business.

Mr Hannes Krichhoff
Hannes Kirchhoff if a researcher and PhD-candidate at MicroEnergy Research Group (MES) and the Department for Sustainable Electric Networks and Sources of Energy (SENSE) of the Technische Universität Berlin. His research focus are bottom up DC microgrids and decentralized control concepts. Hannes is also part of the Competence Center for Energy and Technology at Micro Energy International, a Berlin-based consultancy, where he has worked on analyzing suppliers and technologies, evaluating supply chains, assessing energy programs and designing validation tests for energy equipment. Before joining MEI, Hannes worked for CAMCO Clean Energy in their Tanzanian office, assisting in project developments for biomass generation plants as well as solar home system projects as well as in the process engineering team at Schott Solar CSP's factory in Bavaria focusing on process optimization and supplier relations. Originally from Germany, Hannes has lived in different parts of the world including the U.S., South Africa, France and Tanzania. He holds a B.Sc. in Energy and Process Engineering and a M.Sc. in Renewable Energy Systems from the Technische Universität Berlin. Hannes speaks English, French and German.

Affiliation

United International University (UIU)

United International University, UIU, (www.uiu.ac.bd), a leading private university of Bangladesh, was established in September 2003. Within a very short period of time, it has been successful in attracting the best quality faculties with higher education from different parts of the world including USA, UK, Australia, Germany and Japan. Presently, there are about 100 full time faculties and more than 5500 registered students studying in different fields of business, economics and engineering. UIU has been established with a view to creating an educational institution with a difference. Its goal is to provide quality education in the fields of Science, Engineering and Business, and at the same time to produce skilled professionals with high standard of human/moral values. Befitting infrastructure, congenial environment, well equipped laboratories and highly qualified experienced faculty members are preconditions for quality education. UIU is committed to provide all these necessary components to make it an educational institution of international standing.

So far the energy sector is concerned and the renewable energy in particular, UIU has significant expertise and experience. UIU is the pioneer in introducing a course on renewable energy at the undergraduate level and plans to open up specialized courses in future.

Arrangements are being made to establish links with renowned universities of Asia, Europe, Australia and North America and very soon UIU will have credit transfer agreements with a number of internationally reputed universities. UIU has all the capabilities to pursue the never ending quest for educational excellence.

Centre for Energy Research, UIU

The Centre for Energy Research (CER) has been established in 2010, and state of the art Renewable Energy Laboratory is under development. UIU has been involved in different renewable energy related activities like designing low cost high efficiency circuits for LED lamps, microcontroller based solar charge controller with maximum power point tracking, designing diffused reflectors for solar PV panels for enhanced power output etc. UIU was given the contract to perform the technical auditing of the SHSs (Solar Home Systems) installed all over Bangladesh under IDCOL (Infrastructure Development Company Limited) program for two successive assignments (2008 and 2011). UIU regularly organizes a bi-yearly International Conference on the Developments in Renewable Energy Technology (ICDRET, www.icdret.uiu.ac.bd). So far, 1st, 2nd and 3rd conferences were held in December 2009, January 2012 and January 2014 respectively. All these conferences were attended by large number of participants from home and abroad. Many of the organizations including GIZ (German Technical Assistance), DAAD (German Technical and Educational Exchange Program), IFC (International Finance Corporation), and IDCOL sponsored/supported the conference. Berkeley Rural Energy Group (BREG) and Renewable and Appropriate Energy Laboratory (RAL) of University of California, Berkeley, USA; Technical University of Berlin, Germany; The Energy and Resources Institute (TERI), Delhi, India; Virginia Tech University, USA, University of Oldenburg, Germany; Kathmandu University, Nepal were the co-organizer of the event. IEEE-PES was the technical co-sponsor and 21 companies from home and abroad sponsored the conference. The 4th ICDRET will be held in January 2016.

Institute for Decentralized Electrification, Entrepreneurship and Education (id-eee)

Id-eee was established in spring 2012 to build an organizational platform for off-grid electrification projects and for the related educational activities on local levels. The institute is part of the Ulm University of Applied Science in Germany. With the help of an organizational body, id-eee bundles the know-how of experts and coordinates their activities within a broad project umbrella and in a very effective way. The institute‘s objective is to support the sustainable economic and social development of less developed rural areas especially in Africa, Asia and Latin America. Based on the principle of help for self-help, multinational and interdisciplinary projects are initiated, carried out or coordinated and last but not least, evaluated to support decentralized electrification. Id-eee aims to introduce off-grid solar systems as a cheap, safe and environmentally friendly alternative to the use of fossil energies. Based on this, the institute understands rural electrification as a way to improve family life, to deliver options for new kinds of power application, to offer additional job opportunities and finally to increase skill levels of involved people. In Asia, id-eee has implemented projects in Indonesia, India, Philippines, Nepal and Cambodia. The offered services include education and trainings for entrepreneurship, technology development and consulting, project management, and business model development.

TU Berlin, Department for Sustainable Electric Networks and Sources of Energy
The department for Sustainable Electric Networks and Sources of Energy at the Technische Universitaet Berlin (SENSE) is one of the leading research institutions for electricity networks and smart grid technologies. SENSE has strong expertise in modelling of pioneering power and energy system concepts that are characterized by sustainability, economics, and robustness. In particular, SENSE opens up forward-looking solutions for the integration of renewable energy and storage in local as well as global network and market structures. As the underlying fundamental paradigms, SENSE develops and discovers ground-breaking methodologies of simulation and optimization for the planning as well as operation of integrative energy systems.
Optimization of networks with renewable energy and storage is one of the core research activities. Network infrastructures have traditionally been dominated by large power plants with controllable output. For the large-scale integration of intermittent renewable energy sources, SENSE researches system-wide storage concepts, and in this context, also illustrates the technical as well as economic feasibility. Other research activities include optimization of networks with renewable energy and storage, cache-storage in power systems, non-sampling stochastic network modelling, multi-scale modelling of networks, benchmarking of distributed energy systems, and optimal horizon planning of distribution networks.

TU Berlin, Postgraduate School Microenergy Systems
The Postgraduate Program Microenergy Systems at the Technische Universität Berlin, is a multi-disciplinary research group, that devotes itself to the analysis of the planning, the potential assessment, the design of products and services, the implementation, the use and the impacts of small scale energy systems in structurally weak areas. Our approach focuses on concepts for a decentralized energy supply on household or community level, where production and consumption of energy are spatially interlinked. Going beyond the technical artifacts, the approach looks at energy systems as socio-technical systems embedded in a social, political, economical and ecological environment. Our focal point is the user – meaning that research questions are directly or indirectly derived from users' needs and the question how to address them with appropriate energy solutions.

University of California, Berkeley, Renewable and Appropriate Energy Laboratory

The Renewable and Appropriate Energy Laboratory (RAEL) is a unique new research, development, project implementation, and community outreach facility based at the University of California, Berkeley in the Energy and Resources Group and the Department of Nuclear Engineering. RAEL focuses on designing, testing, and disseminating renewable and appropriate energy systems. The laboratory's mission is to help these technologies realize their full potential to contribute to environmentally sustainable development in both industrialized and developing nations while also addressing the cultural context and range of potential social impacts of any new technology or resource management system. The work in RAEL is guided by the principles of use-inspired basic research, interdisciplinary approaches to the needs that energy services can provide, and a dedication to understanding and addressing the opportunities and risks in the implementation of novel energy generation and management programs. At one level, the goal for RAEL is to update, integrate and nurture a collaborative synthesis of E. F. Schumacher's Small is Beautiful appropriate technology and development philosophy with the energy industry as it exists today. On another level, it is to promote sustainable development that includes deep cuts in greenhouse gas emissions and resource consumption.

ME SOLshare Ltd.

ME SOLshare Ltd. was founded in 2014 as an affiliate of the German consulting company MicroEnergy International GmbH. SOLshare targets Bangladeshi households and small businesses in densely populated off-grid villages. These communities need a flexible, stable, and sufficient electricity supply for lighting, phone charging, entertainment and business generating activities at an affordable price point. The main activities of SOLshare are the design, management of manufacturing and sale of an innovative charge controller for Solar Homes Systems (SHS) which manages interconnection between multiple users to a decentralized, low voltage DC micro-grid and facilitates electricity trade. To enable electricity trade between SHS users, SOLshare will also offer back-end data management as part of the company’s core activities.

Objective of the Project

The overall objective of the project is to develop an innovative approach for community based decentralized DC nanogrids for rural electrification. The developed approach will enable integration of local generation and storage capacities (like Solar Home Systems) by connecting SHS and centralized storage and generation capacities into a DC nanogrid. The DC nanogrid allows electricity sharing through bi-directional power flows which leads to extremely flexible DC nanogrids which can be constantly adjusted to local demands in a short term period. The approach has the advantage that local generation and storage capacities are used more efficiently and additionally, by utilizing community rooftops for creating a nanogrid, land needed for solar arrays can be significantly reduced.

The underlying concept for the proposed approach is based on technical limitations of solar based electricity systems like SHS or mini-grids. Generally, these standalone systems are designed for the month with the lowest sun peak hours per day. These technical circumstances result in a surplus of electricity especially during the non-monsoon season, averaging in a total of 30% per year. The proposed approach enables the utilization of this excess energy in a bi-directional DC nanogrid. The excess energy will be used for supplying water irrigation pumps and agro-processing DC devices, like husking mills/grinders, grain mills/grinders, grain threshers and corn peelers. Furthermore, the excess energy can be used for giving electricity access to households without SHS and for supplying additional electricity to households which already have a SHS.

Enabling households to share electricity generated from their SHS also creates new business opportunities from selling electricity to end-users in a bi-directional nanogrid.

By having ME SOLshare, a young Dhaka based company as a implementation partner, we ensure that the research results will be directly used for commercialization purposes. ME SOLshare further covers all hardware expenses of the project.

Present state of the art

DC technology has started to shape the landscape in electricity access scenarios for many years. A strong technology pull for more efficient devises has accompanied the overwhelming success of solar home system programme in Bangladesh. The technological advances for DC technology have however, for a long time been limited to the domestic scale, hence solar home systems and small solar home systems. Both globally as well as regionally, in particular in South Asia, DC technology is now taken to a next level for a distribution system for clusters and small villages. These approaches are however limited to the energy flow to the user, making them strictly consumers. The proposed nanogrid has the ability for bi-directional power flows, making the users producers and consumers at the same time. Such a concept, were users become “prosumer”, has been advocated strongly in the smart grid community worldwide. However, actual implementation is for the most part limited to R&D projects and AC technology. This is largely due to the economics of battery storage technology and the limited willingness to purchase storage capacity on an individual basis. Bangladesh however, has already more than 3.6 million households that have shown the world that it is viable to invest into generation and storage technology. This existing infrastructure is now to be integrated into a productive-use-centred nanogrid that allows its users to save and earn money through the trade of electricity locally. This concept of a local sharing-based energy market has not been tested yet and represents a ground-braking innovation.

Academic works have been published for this sector. For the technical implementation, components need to be integrated for a grid-access-box/smart meter. These components are readily available on the market and previous work of the authors will lead to a time-effective implementation of the research plan.

Description

Renewable energy based rural electrification is easier and more appropriate in DC format as number of renewable energy to electricity conversion technology are in DC formats and other conversion technology can be coupled easily in DC format.

In addition, there are several advantages of DC based electrification over conventional AC system (Groh et al. 2014b); (Paul Savage, 2011). For example,

- Larger AC mini grids have been found not to be financially sustainable in Bangladesh (Bhattacharyya S, 2015).
- A large number of traditional electric appliances which run on AC 220V can also run on DC in similar voltage range without any modification for example, mobile phone charger and laptop charger, incandescent lamp, LED and CFL lamp and so on.
- DC systems eliminate the AC-DC conversion loss and about 33% (weighted average) of energy can be saved avoiding the conversion of AC to DC (Karina Garbesi, 2011).
- Conventional AC cooling fans (ceiling fan) consume more power than from the same output of ceiling fans made of modern DC ceiling fans (Brushless DC motors).
- A 120-220V DC system can easily transmit DC electricity up to a kilometre range similar to an AC system (SOLARIC system (Islam, 2014)).
- The 12 V DC from a battery can also easily be converted to 120-220 V using a DC-DC converter with minimal efficiency loss
- In any underground transmission system DC is also more cost effective than AC, as the AC cable sizing needs to consider several issues like line inductance, capacitance etc.
- To scale a power system for increasing capacity in an AC system is complex as it needs proper synchronization. On the other hand, DC system can easily be scaled up by adding devices in parallel

Another advantage of DC solar grids, compared to AC solar grids, is the wide range of possible grid topologies, due to an increased flexibility of interconnections. Considering the method of generation and storage there could be four different options for solar DC isolated grid system, such as:

- Central generation and central storage
- Central generation and distributed storage
- Distributed generation and central storage
- Distributed generation and distributed storage

DC solar grids with distributed generation and distributed storage (see Figure 1) are the most flexible grid topology and have the advantage of including SHS.

Figure 20: DC nanogrid with distributed generation and distributed storage

In this topology, households with shade free roof tops will be considered to install solar PV on their roof, but bigger solar arrays as used in a minigrid can also be included. Batteries in every household as well as battery banks can be included to store energy from solar radiation during day time and provide backup at night. This option can save space of installing solar panel thus this option is suitable for those areas which do not have sufficient space to install solar PV altogether. Furthermore, a country like Bangladesh where the penetration of solar home system is very high and the replacement of solar home system with another mini-grid system is difficult, this topology can play an effective role.

Households and solar arrays generate power from solar PV and are connected directly to the distribution grid. The distribution of PV power is done at higher voltage to reduce the distribution loss. Individual households, water pumps and devices for agro-processing will draw power from the distribution line to charge their battery or directly consume electricity. A charge controller associated with a DC-DC converter controls battery charging and discharging. The systems will provide energy to the grid only during the daytime. Consumers have their own storage system according to their demand. An energy meter will be associated with the system to calculate the energy consumed by the user.

New and existing solar home systems can be incorporated with the system. Excess energy can be sold to those who cannot afford to finance to solar home systems. Scaling of the power system is very simple through adding a large system and new systems. The approach is applicable to those places where solar home system penetration is high which makes Bangladesh the ideal candidate.

Methodology

This research project will use methods from engineering and economics to demonstrate the usability of nanogrid structures for decentralized electricity generation and distribution for the application in productive use applications. The project is structured as qualitative study with the three cases. The three cases reflect on a diversity of implementation options of the approach. All lab testing will be done in Dhaka, in a joint research between the newly developed DC testing laboratories at the Centre for Energy Research at UIU jointly with ME SOlshare. Testing procedures are being developed and monitored by our strong international research team, as well at the implementation of the three pilots.

In the first case, a nanogrid with 20 households is established, where approx. a share of 75 % of the households already have an SHS, but approx. 25 % do not yet. These houses will be included in the grid with a small battery and a DC/DC converter and smart meter functionality. This grid topology is a demonstration of sharing-based infrastructure on the basis of country-wide installed SHS. The second and third case apply the *anchor-load method*. In this method, one large load is placed into the mini-grid which is used for productive use. In our case this anchor load will be a shallow solar water pump (case 2) and a rice hulling mill (case 3). Altogether, at least three nanogrid case study sites will be established, at least 60 households will be connected to one of the three nanogrids.

Impact of the project

In Bangladesh, around 15 million households in rural areas are not connected to the national grid. Around 3.6 million households, out of these 15 million, use Solar Homes Systems (SHS) to generate electricity. The proposed DC nanogrids are designed to integrate households with SHS and households without SHS into a nanogrid. For these 15 million households the situation can be significantly improved through a more stable and reliable electricity access.
At present there are around 1.75 million irrigation pumps in Bangladesh. Of these, 1.5 million are run on diesel, while 0.25 million are electricity based. For these pumps during the irrigation season, approximately 1,500 MW of electricity and 1 billion litres of diesel are required. If the diesel-run pumps are converted into solar powered pumps, foreign currency worth 784 million USD can be saved every year. Integrating irrigation pumps based on electricity into the DC nanogrids can make a significant contribution for replacing diesel irrigation pumps.
By integrating other devices for agricultural use like husking mills/grinders, grain mills/grinders, grain threshers and corn peelers the productivity of agricultural production in rural areas can be dramatically increased, leading to better food supply and additional income opportunities. Furthermore, the integration of machinery in the food production chain in rural areas will lead to higher quality of food products, shifting parts of the food value chain to the community level.

Project Cost

	COST *all figures in BDT*	Co-FUNDING ME SOLshare	 IDCOL
Hardware Sourcing	**2,096,000**	**2,096,000**	**0**
DC-DC converter 12V-48V, bi-directional	520,000		
charge controllers with data logging feature	400,000		
meters	400,000		
controller units for central loads	80,000		
data retrieval equipment	16,000		
PV modules	160,000		
Batteries	136,000		
solar water pump	120,000		
grain grinding mill	64,000		
UV resistant cabling equipment	200,000		
Dhaka Lab R&D	**1,280,000**	**0**	**1,280,000**
System Integration	400,000		
Proto-typing	480,000		
Productive use appliance testing	400,000		
Field Activities	**1,256,000**	**0**	**1,256,000**
Baseline Survey	96,000		
Demand Assessment	120,000		
Community Capacity Building	320,000		
Installation case 1	240,000		
Installation case 2	240,000		
Installation case 3	240,000		
Monitoring and Evaluation	**720,000**	**0**	**720,000**
On-site monitoring	240,000		
Remote data analytics	240,000		
Comparative Assessment	240,000		
Preparation of Commercial scale-up	**312,000**	**0**	**312,000**
Technical Feasibility Assessment	104,000		
Economic Feasibility Assessment	104,000		
Social Feasibility Assessment	104,000		
Supervision &Coordination (@15% of all costs above)	**849,600**	**0**	**849,600**
Contingency (@10% of total of all costs above)	**566,400**	**0**	**566,400**
Miscenallious	**600,000**	**0**	**600,000**
International Travel and Accommodation	600,000		
Project TOTAL	**7,680,000**	**2,096,000**	**5,584,000**

Time frame for implementation

	2015/ 2016									
ACTIVITY	**Approval**	**1 month**	**2. month**	**3. month**	**4. month**	**5.month**	**6. month**	**7. month**	**8. month**	**9. month**
Material Sourcing										
In-lab research and proto-typing of 60 grid-access boxes and smart meters										
Productive Use Appliances testing										
Baseline Survey; Demand Assessment; Community Capacity Building										
Installation case 1										
Installation case 2										
Installation case 3										
Monitoring and Improvement										
Preparation for Commercial scale-up										

Note on Other Sources of Funding

It should be carefully noted that the consortium received earlier financial support from GIZ (Piloting and evaluation of smart DC nanogrid concepts in order to procure some of the equipment used in the four nanogrids installed in Kachua and Takerghat. Whereas the GIZ project focus was lying on the centralized storage and generation within a DC nanogrid and the required procurement for the same, this project support by IDCOL had its emphasis on testing of different topologies, including the new framework in Shariatpur, and as well as including productive use technologies.