

## DC MICROGRIDS FOR ENERGY COMMUNITIES IN THE DEVELOPING WORLD

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### ABSTRACT

*The main problem of energy supply in the developing countries is that a very large portion of their rural population still does not have access to a secure supply of electricity.*

*DC microgrids seems an attractive solution due to lower capital, operation, engineering and maintenance costs. Many developing countries have shown interest in the development of such systems in order to improve the quality of their inhabitants' life, together with the development of the local economies (creation of new jobs) through the creation of local energy communities. This paper reviews the conditions under which DC microgrids provide an attractive option for local energy communities in the developing world. It also reviews the best practices of DC local energy communities in developing countries and highlights relevant issues, e.g. regulatory framework, standardization, protection, secure supply etc. that have to be faced, in order to establish DC microgrids in rural areas*

### INTRODUCTION

Nowadays, the AC microgrid concept in the distribution grids is well established. The emerging scenario of a DC microgrid, though, is a concept whose wide application is still under investigation and research.

The main technical advantages of the DC microgrids are:

- The incorporated Distributed Generations (DGs) can be easier coordinated, as their control is based on DC voltage without the need for synchronization.
- The corresponding primary control is notably less complex as there is no need for reactive power flow control. Yet, the DC link can suffer from harmonics.
- DC system does not experience high fault currents as the contribution to faults by the converters of the power electronic interfaced load or DGs is limited.
- As the DC electronic domestic loads dominate today, unnecessary AC/DC power conversions are avoided as most DGs generate DC outputs. This has a direct effect on system cost and losses. Also, the converters used for the DC microsources interface, are mostly transformer-less reducing further the size and cost of the system.[1]

In the latter context, the DC microsources (mostly Renewable Resources) may be grouped together in DC microgrids structures and the multi microgrid system gets connected to the upper distribution LVAC grid. The connection of the DC microgrids to an upper LVDC

network opens further interesting prospects.

Ref. [2] has carried out a theoretical analysis about efficiency of the LVDC distribution and DC usage in house installations. It is shown that efficiency is not improved, if only the residential installations are replaced by DC-insulating a hybrid DC microgrid-AC network. Instead the combination of DC power in houses and the LVDC distribution system would be more efficient than the present AC.

In Ref. [3] there is a clearer vision of the above statement. It is proven that the hybrid DC MG-AC network may have a lower efficiency (2-3%) than a comparable full AC network, when the load and generation are not well matched. In case that the load and generation profiles are matched, then the hybrid enjoys an efficiency advantage of 2-3% over the AC. The total energy savings, though, of a DC MG e. g in a residential application, is more than 30%, combining both the savings of possible DC-based appliances with the avoided AC-DC conversion within those appliances.

In Ref. [4] it is reported that the DC system capital cost is less than the corresponding AC system. This economic difference may not appear as a strong incentive in large applications. However, in smaller applications of developing countries with less capital, this fact may be decisive.

It has to be mentioned that the rural sectors of the developing countries, that are less connected to fuel supplies are more likely, also, to be served by DC. PVs into DC microgrids will offer electricity access in the simplest way, even in the remotest places where the interconnection to the main grid is costly. As a result, people of these regions will have the opportunity to light their homes, charge their mobile phones and use other electronic devices in order to stay connected with the rest of the world.

This paper is structured as follows. The challenges of the wide application of DC microgrids are reviewed next and some of the best practices of DC local energy communities in developing countries are reviewed. The last section concludes the paper and gives an insight about the future of the DC applications.

### ISSUES AND CHALLENGES OF DC APPLICATIONS IN RURAL AREAS

In spite of all the advantages of DC microgrids and their potential, there are some factors that are slowing down their wide-spread use.

One of the main reasons is that until very recently, there has been almost no standardization for LVDC systems. Lately, EMerge Alliance- an open industry association -

is developing standards leading to the rapid adoption of DC power distribution in commercial buildings [5]. Below some identified existing LVDC standards are presented:

- **IEC 60034-19:** Rotating electrical machines - Part 19: Specific test methods for d.c. machines on conventional and rectifier-fed supplies
- **IEC 60998 series:** Connecting devices for low-voltage circuits for household and similar purposes
- **IEC 61660:** Short-circuit currents in d.c. auxiliary installations in power plants and substations - Part 1: Calculation of short-circuit currents. The identification of new correction multiplicative factors may be necessary if the standard were used for LVDC short-circuit studies and not DC auxiliary components.
- **IEEE 946:** Recommended practice for the design of DC auxiliary power systems for generating stations
- **IEC TS 62735-1:2015:** Direct current (DC) plugs and socket-outlets for information and communication technology (ICT) equipment installed in data centres and telecom central offices - Part 1: Plug and socket-outlet system for 2,6 Kw
- **ETSI EN 300 132-3-1:** Power supply interface at the input to data/telecom equipment Sub-part 1 of Part 3: Direct current source up to 400 V
- **IEC 62196-3:** Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicles - Part 3: Dimensional compatibility and interchangeability requirements for d.c. and a.c./d.c. pin and contact-tube vehicle couplers
- **Rebus:** Open standard for DC electricity distribution in homes, commercial buildings, campuses, and other settings
- **IEC 61347-1:2015 (under revision):** Lamp controlgear - Part 1: General and safety requirements
- **IEC 61347-2-3:2011 (under revision):** Lamp control gear - Part 2-3: Particular requirements for a.c. and/or d.c. supplied electronic control gear for fluorescent lamps

Another challenge faced by developing countries is the financially viable way, electricity can be delivered to low income communities. The sparsely populated rural areas and the geographical limitations make the grid expansion a rarely sustainable investment. This challenge was tackled in Ref. [7]-[8] by the design of the most appropriate DC microgrid topology using the HOMER software. Ref. [9] studies the installation of a DC microgrid in Pakur, India. The main finding of this paper

is that energy sustainability and low cost will be addressed only with the proper load growth being predicted and proper siting of the resources. It also highlights the societal implications that a DC project may have and how governmental policies and subsidies can boost the DC applications through PVs integration.

Ref. [10] claims that reliance on subsidies and such incentives can disrupt fledgling market conditions and hinder developing community adoption of the desired technology. To that end, the authors explore some of the distinctive socio-economic design challenges of microgrid design in a rural electrification context and highlight the importance of more complex financial models for economic viability than leveled cost of electricity. The consumer-side metrics are focused on household-level payment minimization.

Ref. [11]-[12] highlight the fact that traditional DC architectures, such as central resources with central storage and central resources with distributed storage tend to increase the system cost. To tackle this, they propose a scalable architecture of mini grids providing a sustainable future solution that will keep the system cost in manageable margins. The proper DC microgrid energy management contributes greatly to the optimization of the system operational costs and Ref. [13] proposes an intelligent central control to tackle it.

Another challenge of the DC rural installations is their sustainable mode of operation. Earning revenues by directly selling power to the villagers cannot be seen as a sustainable income generation source for an enterprise according to [14]. For this reason, Ref. [15] proposes different business models that may grow due to the DC microgrids installation.

Also, protection of the DC microgrids is of great importance and as Ref. [16] underlines, the cost effective and reliable DC micro-grid protection is at an infant state compared to AC system protection.

Finally, the Smart grids Research Unit (SmartRUE) of the National Technical University of Athens (NTUA) is active in the wide area of DC microgrids and their role in rural electrification [17], [18]. One of the research areas of the group is the concept of solar home systems (SHS) that has emerged as a new and cost-effective way of supplying power to remote off-grid households. SHS is typically comprised by DC sources (Solar Pico Systems etc.), loads (LED Lamps, radios, mobile phone charging) and a small storage system (batteries). The possibility of interconnected multiple SHS into small DC clusters and furthermore the interconnection of multiple DC clusters together is promising for electrifying large rural areas.

The Table below shows the main challenges for adoption of DC.

TABLE 1. CHALLENGES OF RURAL DC

NETWORKS

Main challenges	Ways to tackle them	
Lack of standardization	Standards and guidelines	Practical implementation
High cost system	Proper design on topology, energy management, architecture	Different business models on attracting new revenues

**BEST PRACTICES OF DC NETWORKS IN THE DEVELOPING WORLD**

Several countries have already shown interest in the development of DC systems in order to improve the quality of their inhabitants’ life together with the development of the local economy.

**India:** A solar powered microgrid was installed in 2014 and operates in Dharnai village in Bihar, one of India’s poorest states by Greenpeace organization. The DC microgrid supplies homes, street lighting for roads and water pumps. Dharnai is the first village in India where all aspects of life are powered by the 100 kW solar system i.e. 450 homes of 2,400 residents, 50 commercial operations, two schools, a training centre and a health care facility is supplied by the PV panels while, a battery bank ensures power availability at all times. Fig.1 shows a solar DC water pump and rooftop mounted PVs at the background.



Fig.1 Solar DC pump in the first DC microgrid village of India.[19]

**Bangladesh:** Bangladesh has experienced a notable growth of RES installation in recent past. More than 1.6 million solar home systems, of a 50 Wp average, have been installed up to August 2012, and there is a target of 4 million systems with an estimated generation of 200MW to be reached by the end of 2015. The most common solution is the solar home installations. These systems comprise of standalone PVs, battery and a charge controller to supply the DC domestic loads (i.e. DC lights, LED lights, DC radio etc.). These installations are DC isolated grids that due to their small size they are

called DC mini grids. In the future it is expected that these mini grids will interconnect with each other to form a DC network.

**Lao PDR:** More than 70% of the population of this country lives in rural areas with little or no access to electricity. So far over nine thousands of community systems and solar home systems have been installed. Laos aims to implement 15 solar village grids to provide energy access to at least 10,000 rural Laotians and contribute to the Lao Government’s target of 90% electrification by 2020. In 2013, a 6.5kWp solar plant was completed that distributes electricity to nearly 500 people in a remote village in Luang Prabang Province of Laos. The solar plant distributes electricity to households, the community center and five street lights forming a DC mini-grid. In 2014 three PV systems were installed at two schools in Xayaboury province to provide access to reliable electricity in the remote area of northwest Laos. The electricity is used for lighting, ceiling fans, mobile phone charging and computers and printers at the schools’ office and dormitories.

**Sierra Leone:** 13 solar PV power plants were installed in 2013 throughout different rural areas of Sierra Leone, a country with an electrification rate of less than 10 percent. The solar PV projects – twelve 5 kWp plants and one 16 kWp plant supply the centers and schools loads such as computers, internet and other communications tools to improve education opportunities. In specific at Kambia Growth Centre, a 16 kWp solar plant is serving its internet cafe with an internet server with 7 computers, a cassava crushing machine, a gari processing machine, a rice milling machine, a freezer and a 40-inch television in the sport center.

**CONCLUSION**

DC microgrids appear as an appealing approach for integrating RES and storage in rural applications. Especially, the LVDC networks in the rural areas of developing countries seem to be a promising direction in aspects of technical and economical viability. The multiple energy conversions are eliminated while the maintenance needs are minimal. In these potential developments, some barriers, like lack of standards have to be faced before the DC networks break through the real world.

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