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The role of electrical energy storage in sub-Saharan Africa

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ABSTRACT

In developing countries, energy is recognized to be essential for promoting equitable growth, fostering social inclusion and preserving the environment. Nevertheless, the current state of the energy sectors of developing countries still represents a major hindrance to the fulfillment of this goal. In this frame, electrical energy storage may allow a cost-effective exploitation of renewable sources in order to cope with the improvement of the power supply service via local national grids, but mainly it may become a building block of rural electrification through integration within off-grid systems. This paper focuses on electrical energy storage in sub-Saharan Africa providing an overview of the main aspects of this theme. Indeed, the specific features of the power sector in sub-Saharan Africa are analyzed about the framework of application of electrical energy storage. The typical technologies implemented in this context and the status of the market as well as of the economic models to support the diffusion of storage together with renewable energy technologies are highlighted. Moreover, an overview of technical aspects such as storage capacity sizing and interface converters for integration with renewables are described. Finally, an experimental application of a hybrid micro-grid in rural Tanzania is presented. With this paper, our aim is to provide an overall view, within the main technical and non-technical aspects, of electrical energy storage in a context – sub-Saharan Africa – which has a huge potential, both in market terms, but also with regards to the possibility to develop and implement alternative technical solutions which may be integrated in the power systems of high income countries as well.

Contents

1. Sub-Saharan Africa energy scenario

Energy demand in sub-Saharan Africa (SSA) has grown by 45% from 2000 to 2012, but access to modern energy services, though

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increasing, remains limited [1]. Per capita average electricity consumption is comparable to the amount consumed by a 50 W light bulb operating on a continuous base. This amount is hardly enough to cover the daily basic need of single households and it cannot meet community as well as productive energy needs. The power sector is not adequate, nor reliable in the majority of the SSA countries: frequent power shortages are threatening the development of the productive sector, while the losses in poorly maintained transmission and distribution networks are often twice the world average and they contribute to increase the overall primary energy consumption [1]. Moreover, electricity tariffs are high and due to the poor quality and quantity of the supply, the use of back-up and emergency petrol/diesel generators increases the final electricity costs and has environmental consequences.

Besides, according to the New Policy Scenarios (NPS) of IEA, the SSA grid-based generation capacity (currently 90 GW) will grow four times by 2040 [2]. Renewable energy technologies (RET) are expected to play a major role in this growth: hydropower has large technical potential and additional capacity might contribute in mitigating the average electricity costs and phasing out oil-fired power. PV and wind markets are expanding while attention to geothermal source is also growing [1]. Again in the NPS, off-grid solutions (like home/community based systems or micro-grid) will provide electricity to 70% of those gaining access in rural areas. In particular, two-thirds of off-grid systems in rural areas are expected to be powered by PV, small hydropower or wind.

Many governments of SSA are becoming aware of these changes and are promoting reforms to remove regulatory and political barriers to enable RET penetration into the power sector. Nevertheless despite this positive trend, even in the most favorable scenario, a significant gap in the distribution of resources will remain across SSA with special reference to the urban-rural disparity [3]. This means that especially at rural level the strategy for scaling up access to electricity needs to be redesigned, overcoming the dichotomy between centralized and off-grid electrification approaches and probably aiming at integrating small-scale RET in local micro-grids or connecting them to the national grid. In this a frame, electrical energy storage (EES) can play a relevant role.

In this regard, in this paper we provide an overview of the main aspects of application of EES in SSA with particular reference to the context of rural areas. In particular, we bring attention both to technical and non-technical issues underlying the key factors that differ from SSA and high income countries. In Section 2 two typical electrification approaches (top–down and bottom–up) are introduced, an overview of the different frameworks of applications of EES within these approaches is provided and the typical EES technologies solutions are discussed. In Section 3, an overview of the market situation and economic models to properly support RET and EES in rural areas is provided. In Section 4 the focus is on technical aspects; specifically the classical approaches for EES

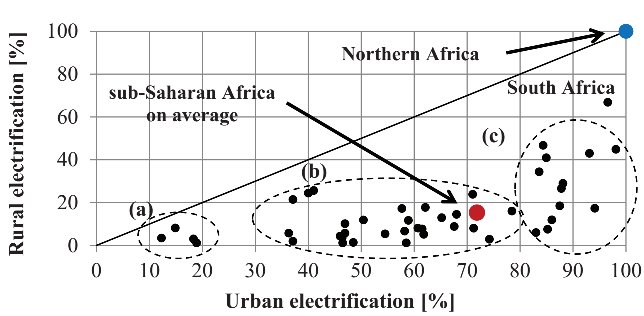

Fig. 1. SSA countries representation according to rates in urban and rural electrification (2012) [2,4].

capacity sizing are describe together with basic models for dynamic analyzes as well as typical architectures of interface converters for EES integration with RET. Finally, in Section 5 the Energy4Growing project and the related experimental application of a hybrid micro-grid integrating RET and EES in a rural school of Tanzania is presented.

2. Overview of EES applications in sub-Saharan Africa

Two different approaches can be recognized for electrification process in SSA with reference to the urban-rural dichotomy: namely *top–down* and *bottom–up* approaches. Accordingly, EES can play different role.

2.1. Top–down and bottom–up electrification approaches

A key element to understand the situation of electric power systems in SSA lies in the different conditions of urban and rural areas. In this regards, considering the electrification rates of these two areas the situation of SSA countries is presented in Fig. 1. The graph shows that, on average, SSA countries have about 72% and 15% electrification rates for urban and rural areas respectively. Moreover, four groups can be recognized.

(a) A number of countries report the poorest conditions – namely South Sudan, Central African Republic, Chad and Liberia – they are also tail-end in the Human Development Index ranking [5] and, despite very low values (urban and rural rates below 20% and 10% respectively), they show a urban–rural disparity.
(b) The majority of SSA countries lie in the range of 35–80% urban electrification rates and below 25% in rural ones. Hence it is clear the trend in SSA to first address urban areas while secondly coping with rural electrification.
(c) A number of countries report urban electrification rates above 80%: some have rural electrification below 20%, while others reaching up to 50%. In this latter case, countries with medium Human Development Index such as Ghana, Gabon, Equatorial Guinea, and Cabo Verde are reported.
(d) South Africa, exceptional in SSA as for income level, reports the highest electrification rates; nevertheless also, in this case a disparity between urban and rural areas can be recognized.

Lastly, the conditions of Northern Africa countries that report 100% electrification both in urban and rural contexts are highlighted. It is worthwhile to notice that these figures result from data employed by international institutions and retrieved by local statistical offices and/or governmental bodies. Accuracy of these data, mainly for rural areas, may be questionable. Indeed, while for urban areas data reflects the connections to the local national grids (i.e. users are registered for bill payments), in rural areas electrification related to small isolated systems is probably not considered. Nevertheless, these data reflect the general different conditions between urban and rural areas and lead to highlight two different technical approaches to provide electric power: *top–down* and *bottom–up* .

We refer to the *top–down* approach as regards the electrification process which has been historically followed in SSA as well as in high income countries based on the paradigm of centralized electrical systems [6–8]: large hydropower or fossil fuelled plants interconnected by a transmission grid which supplies power to consumers through radial distribution grids. Nevertheless, while high-income countries reached 100% electrification rates with this approach, SSA countries are still facing considerable difficulties in increasing electrification rates. In particular, rural areas are the most afflicted by this situation, since governments paid more