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Development of Micro-Grid in Sub-Saharan Africa: an Overview

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Abstract – *The slow growth in electricity production in the last four decades has left Sub-Saharan Africa region in partial darkness marked by unreliable power supplies and insufficient generating capacity.*
This has been the greatest barrier to the economic and industrial growth in this part of the world and has left many people, in search of a greener pasture in other regions. In the last few years, Sub-Saharan Africa started to provide opportunities for micro-grid (MG) initiative by bringing electricity access to remote rural and sub-urban communities in the region. The MG concept is seen as a viable energy strategy due to the fact that Africa is endowed with both renewable and non-renewable resources that are primary sources for MG. This paper reviews and discusses the MG idea, recent development of MG, in Sub-Saharan Africa, MG potential and pilot projects across some part of Sub-Saharan Africa. Also, the benefits, challenges and solutions for a successful MG implementation in the region are discussed. ***Copyright © 2015 Praise worthy Prize S.r.l. - All rights reserved.***

***Keywords**: Access to Electricity, Electrification Rate, Micro-Grid, Distributed Generation, Protection, IEEE Standard 1547, Sub-Saharan African*

I. Introduction

Electrical energy is the life blood of every nation's development and economic growth. According to [1], access to electricity is fundamental to fulfilling basic social needs, driving economic growth and fueling human development.

However, as a catalyst of industrial and economic development, it can also stand as the greatest barrier for technological and economic advancement in any nation.

This has been the set-back in moving Africa into its rightful place in the world economy [2]. Electricity demand in Sub-Saharan Africa is about 153kWh per capita and it is estimated to reach 235 kWh in 2020, which is still low compared to the global average of 2,730 kWh recorded in 2009 [3]. Sub-Saharan Africa is in the midst of power crisis, the region's power generation capacity is lower than that of any other world region, and capacity growth has stagnated compared with other developing regions such as Latin America, Caribbean, Eastern Asia and Pacific, Middle East, North Africa and Southern Asia [4].

According to [5], approximately 622 million people do not have access to electricity in Africa, out of which 621 million are from Sub-Saharan Africa while approximately 1 million people are from Northern Africa. This is why Sub-Saharan African has the lowest household electrification rate in the world. The electrification rate is defined as the connection of households in a particular geographical area as a percentage of the total households in the area [6].

Therefore, the national electrification rate of a country is defined as the connection of households in a particular country as a percentage of the total households in the country. Economic development cannot be achieved without energy; and it cannot be sustained unless the energy is reliable, and secure [7].

The unreliable trend in electricity production has influenced an increasing number of people, which now rely on traditional biomass to meet their energy needs. Also, the increasing demand for electricity in the Sub-Saharan Africa is beginning to drive some African countries such as Nigeria, Uganda, Ivory Coast, Togo, Senegal, Tanzania, Kenya and Mozambique into full or partial electricity deregulation to enable new technology and small scale generating plants to spring forth.

The objective of deregulation is to give customers better options to choose their electricity providers with reduced cost and increased reliability [8]. One of the alternative solutions to the electric power crisis in Sub Saharan Africa would be the use of distributed generation (DG) in micro-grid setup. DG is understood as an integrated or standalone use of small modular electricity generation resources by utility customers and/or third parties in applications that benefit the electric system, specific end-use customers or both [9]. During the last decade, many electrical power systems around the world have been deregulated and DG is predicted to play an increasing role in the electric power system of the future, in particular, DG based on renewable energy [10].

As a means of modernizing and strengthening electric power networks, DG sources are primarily used to increase generating adequacy of the system at distribution levels [11]. Due to the large push in research and development of DG technologies, many DG types

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are currently available in the market ranging from residential to commercial/industrial DGs. The application of DG in power system has resulted in some technical challenges such as voltage rise, reverse power flow, etc.[12]-[14].

These impacts have affected the operation of the power system. There are still many technical challenges that must be overcome for the DGs integration to be cost-effective, efficient and reliable. However, MG remains one of the best possible options of DG applications. Utilities are now beginning to look at the feasibility of employing MG technologies as a possible solution to solve many of today's generating capacity concerns. Most MGs are renewable-based; therefore due to the massive solar resources in Africa, photovoltaic based MG can be seen as the most viable option, if properly applied. It will also help in mitigating the CO_2 emission and reduce the carbon blueprint in Africa.

This paper is organized as follows: section 2 presents the general concept of MG, overview of some literature regarding its development and improvement, while section 3 looks at the MG potential in Africa.

The energy situation, status and development of MG in Sub-Saharan Africa are discussed in section 4. Section 5 discusses the benefits of applying MG in Sub-Saharan Africa while section 6, discusses the challenges of implementing MG in the region. Also, the solutions for successful implementation of MG in Sub-Saharan Africa are presented in section 7.

II. Micro-Grid Concept

MG is a new concept developed to bring out the tremendous potential of distributed generation into the mainstream power sector. It is seen as an extension of distributed generation because of its composition which comprises of different distributed generator sources, both renewable and non-renewable as shown in Fig. 1.

According to [15], MG are localized grouping of electricity generation, energy storage, energy control and conversion, energy monitoring and management, and load management tools, which can operate while connected to the traditional grid or function independently. The concept of MG is referred to as a single electrical power subsystem associated with a small number of distributed energy resources, both renewable and/or conventional sources, including photovoltaic, wind power, hydro, internal combustion engine, and gas turbine together with a cluster of loads [16]. For some, MG holds the promise of becoming the basic building block in the implementation of the next generation smart grid infrastructure. However, as is the case with most new technology, there will be significant implementation challenges to overcome [17].

MG and DG technologies are developing rapidly and with the enormous potential of solar resources, these technologies seem to be the most viable if properly harnessed to meet the yearning need for electrical energy in Sub-Saharan Africa.

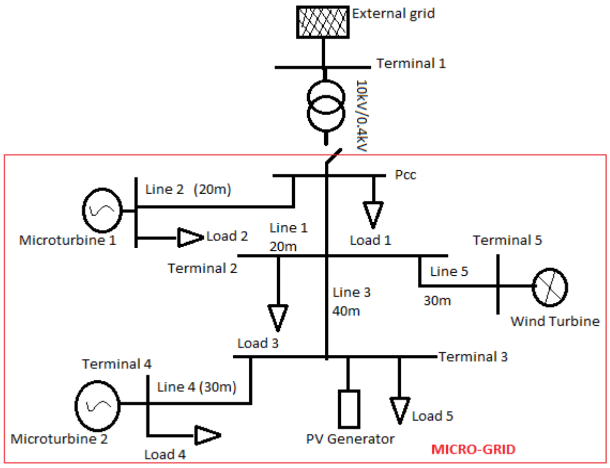

Fig. 1. A typical low voltage micro-grid configuration [18]

II.1. Overview of Research on the Development of Micro-Grid

Due to the importance of the MG concept in providing effective real time demand management and supplying electrical energy to customers, it is essential for researchers to develop a standardized approach for MG architecture and investigate its limitations so as to provide solutions that will enable effective utilization of MG.

There is ongoing research to address some of the issues of MG such as:

- Protection issues,
- Energy Storage,
- Control of MG, and power quality improvement
- Economics, and management of the micro-grid to provide secure operation.

Protection is one of the major issues in MG due to the fact that most renewable distributed generators are connected to the MG through power electronic converters and these converters limits the output current during fault condition. This may slow the response time of the overcurrent relay [19].

To curb the issue of protection in MG, the authors in [19], proposed a new reverse time relay characteristic based on the admittance of the line to isolate the faulty part of the network. Conceptually speaking, the line admittance is the only parameter that determines the tripping of both the downstream and upstream of the feeder, that is, disconnection of the fault on the MG as well as disconnection of the MG from the Utility grid.

Due to interior voltage sag caused by short circuit fault in MG, the authors in [19], also developed a voltage compensator strategy by coordinating dynamic voltage restorer (DVR) and electric vehicle charging stations (EVCS) to compensate and restore voltage at sensitive load.

In [20], central protection unit is developed to communicate with every single relay and DGs so as to monitor the currents of DGs and fault currents in any location of the MG. The essence of the communication link is to detect the direction of fault current and isolate it

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properly. In [21], a central protection system with current limiter and communication link is used to detect and isolate faults on the MG. The current limiter is introduced to quickly detect the fault current and initiate a limiting action before the fault current builds up to its prospective value.

Energy storage is an indispensable part of MG for storing excess energy. The stored excess energy is then used to supply power when there is a shortage. It can also be used to prevent voltage sags [22]. Energy storage is one area of MG that has attracted a lot of attention in recent years. Some of the known energy storage devices are flywheels, energy capacitors and batteries. In [23], the authors designed multi-type composite energy storage system with a charge-discharge controller using the characteristic of the multi-type composite energy storage device to regulate power and enhance the PV system in the MG. The essence of the storage scheme is to optimize the performance of the energy storage system for a better use in MG. In [24], the authors proposed a battery control strategy that will minimize the flow of power from the utility to the MG. The control strategy can also curtail the local bus voltage within a set voltage level in the MG.

Control of MG is the most important area of MG development and integration into the power system network. Control is essential in MG because most of the distributed energy sources use power electronic converters for grid integration. Researchers have come up with different control strategies and algorithms.

The authors in [25] introduced *P,Q* and *V,f* control strategies to deliver stable power (active and reactive) when the MG is operating in an islanded mode.

The voltage and frequency are controlled with the *Q-V* and *P-f* droop methods. The authors in [26], proposed a novel control strategy using a proportional resonance controller with adjustable resonance frequency, droop controller and a negative sequence output impedance controller to improve the power quality of the MG. The proposed control method shares the negative sequence current among the DG units of the MG. This allows each negative sequence controller to adjust the negative sequence output impedance of its DG such that the negative sequence current of the line is minimized to improve power quality.

II.2. Making the Micro-grid a Standard

One major challenge in MG is the lack of standardization and universalization. To effectively coordinate the developments in the electricity sector with respect to distributed generators, IEEE set up standard coordinating committees to develop drafts to assist with distributed generation integration into the power system.

The standard document is developed within the IEEE Societies and the standard coordinating committee of the IEEE standard association (IEEE-SA) [27].

These standard IEEE documents may be superseded at any time by the issuance of new editions or may be amended from time to time. The first standard draft by the committee is IEEE 1547.1, which deals with the rules governing the integration of distributed generation into the electrical power system. The committees also develop a standard draft IEEE 1547.3 [27], which is the guide for monitoring, information exchange, and control of distributed resources. In 2011, IEEE adopted standard 1547.4 [28], which is the guide for design, operation, and integration of distributed resources with the electric power system. The standard provides best ways and guidelines for implementation, planning and operation of islanded systems.

In order to make the MG widely acceptable, IEEE 1547.7 [29] was developed and it serves as a guide for DG and MG impact studies on a power grid. The standards play a major role in the standardization of MG. In order to create standard and universal MG architecture, the Consortium for Electric Reliability Technology Solutions (CERTS) developed the MG test bed (architecture) and investigated the optimal MG design with the American Electric Power so as to demonstrate the integration of small energy sources into the MG. The idea is to reduce custom field engineering solutions needed to operate MG.

The aim of the CERTS architecture is to bring down cost and to improve flexibility, stability, security, of different DGs technologies and load that are connected to the MG. The development of these standard documents is meant to enhance the growth of MG and its usage around the world.

III. Micro-Grid Potential in Africa

Africa is endowed with resources vast enough to meet all its energy needs and yet the potential remains untapped [30]. It is very well endowed with enormous amount of non-renewable and renewable energy resources. The understanding of renewable energy sources and their performance potentials can stimulate renewable energy development [31]. Africa with high solar potential is still lagging behind in the application of solar technologies to meet its energy needs.

According to [32], solar energy reaching the earth on tropical zones is about 1kWh/m^2/day and in countries within 3200km of the equator. Most countries in Africa are situated in the tropical zone of the world, and receive an average of 6-8 kWh/m^2/day of solar irradiation which is among the world's highest [33]. The use of such energy for solar systems will be a viable alternative for electricity generation in Africa.

Recent studies have shown the availability of a significant amount of solar resources for possible DG and MG applications in some Sub-Saharan African countries such as Nigeria, South Africa, etc. [34], [35]. There have also been some studies on wind resources in some locations in North Africa such as Algeria, and Egypt [36], [37], [38] as well as in some countries in Sub-Saharan Africa such as South Africa, Nigeria, Mauritius, Lesotho, Cap Verde, Eritrea, Somalia etc.,

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[33], [39], [40]. These studies show that there are good wind resources in these locations. With the vast range of natural and renewable resources, the opportunities of DG and MG will not only provide access to household electricity in rural and urban areas, but also contribute to increase income generation and development of small scale industries.

IV. Development and Status of Micro-grid in Sub-Saharan Africa

Distributed generation and its application in MG is one of the most viable options for generation capacity increase in Africa to solve raising urban and rural electricity needs. Taking advantage of the readily available solar radiation in the application of DG can solve the unreliable and epileptic energy scenario in Africa, most especially in Sub-Saharan African region.

In Africa most of the renewable MG technologies will excel in rural applications because of low consumption together with long distance of rural and suburban communities from the electric power grid. Africa has many opportunities of autonomous MG potentials.

For example, solar power in Kenya has been found to be more economical than grid supplied electricity when the load is located 9 kilometers or more from the electricity grid [41].

In the last few years, Sub-Saharan Africa has implemented various MG projects across the continent as will be discussed below. Most of the MG is solar PV based and are deployed in rural communities that are isolated from the power grid.

IV.1. Implemented Micro-grid Project in Selected Countries in Sub-Saharan Africa

Due to the poor energy generation scenarios as illustrated in Fig. 2, and increase power demand and poor national electrification rate in most Sub-Saharan Africa countries, these countries now look at the new concept of MG to solve their energy problem.

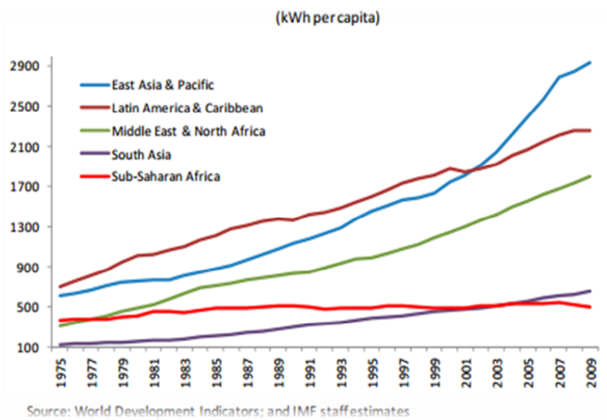

Fig. 2. Sub-Saharan Africa: Electricity Production Compared to Other Regions, 1975–2009 [4]

It is only recently that African countries are encouraging the use of MG to supply power to remote locations and increase reliability in urban areas. Presently, there are a few autonomous (standalone) and non-autonomous (grid-connected) MGs in some part of Africa that are designed to feed the grid during peak hour. The energy situation and recent development of MG across some Sub-Saharan Africa countries like Nigeria, Kenya, Zambia, Tanzania, Ghana, Cape Verde, Equatorial Guinea, Uganda and South Africa are discussed below.

IV.1.1. Micro-Grid Projects in Nigeria

Nigeria is heavily dependent on limited installed available fossil fuel plants for electricity production. Currently, the generation capacity of the conventional power plants is less than 4000 MW [42].

The power utility cannot cope with the increasing electricity demand of over 160 million people. According to the International Energy Agency (IEA) 2010 - 2012 [5], [43], [44] the percentage of Nigerian population without access to electricity grew from 79 million people in 2010 to 93 million people in 2012, (see Fig. 3). The national electrification rate also drops from 50% in 2010 to about 45% in 2012 as shown in Fig. 3. This is due to the shortage of gas to the thermal plants. This shortage is usually caused by the vandalisation of the gas pipelines.

Fig. 4 shows the varying trend in urban and rural electrification rates in Nigeria. It can be seen from this Fig. 4 that there is a large drop in urban electrification rate and an improvement in the rural electrification rate as of 2011 when compared to 2010. By 2012, urban electrification rate Improved by 55% compared to 35% in 2011, while rural electrification drops below 35% from 60% in 2011. This is due to poor maintenance of rural electrification projects. It is predicted by World Bank, that electricity access in Nigerian is expected to grow from 51% in 2012 to more than 55.6% in 2015 [45].

Presently, the majority of Nigerians population relies on traditional biomass and private generator set such as petrol and diesel generators to meet their power demands. However, these generators are costly and expensive to maintain. Most of the population does not have access to electricity in 2012 live in the rural areas.

This situation can be attributed to geographical remoteness from the grid and poor investment in electricity generation, transmission and distribution by the utility company. Due to the poor electrification rate caused by these challenges, some federal, state government and non-governmental organizations in Nigeria initiated the off-grid or MG rural electrification initiatives in the last 10 years.

Some of these initiatives gave birth to what is known as the Jigawa State Alternative Energy Trust Fund and Sokoto State energy research Centre among others [46].

These entities have been using renewable energy resources most especially photovoltaic (PV) and small

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wind turbine to provide electricity in remote areas.

Table I, shows the list of pilot PV based and hybrid MG projects, provided by the government agencies in Nigeria [42], [46]. These projects have provided electricity to thousands of people and health care centers in some rural communities across Nigeria. These projects have slightly improved the national electrification rate in rural communities, mostly in the Northern Nigeria.

Due to government action and private initiatives, there is an improvement in the rural electrification rate in the country. The achievement from these small PV based MG can stimulate initiatives for bigger MG projects in the near future.

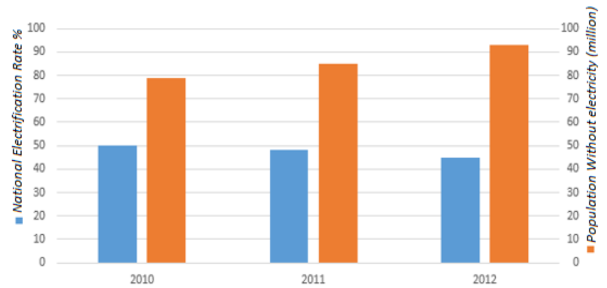

Fig. 3. Nigerian Electricity access from (2010-2012) [5], [43], [44]

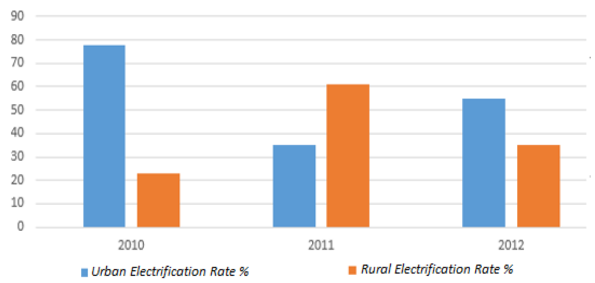

Fig. 4. Urban and rural electricity access in Nigeria for urban and rural areas from (2010-2012) [5] [43] [44]

TABLE I
PILOT MG PROJECTS IN DIFFERENT PARTS OF NIGERIA

Project Description	Location	Rating in kW	Energy Source
Electrification	Itumbuzo, Abia State	2.85	Solar PV
Electrification	Laje, Ondo State	5	Solar PV
Electrification	Kwalkwalawa, Sokoto	7.2	Solar PV
Electrification	Sayya Gidan Gada, Sokoto	5	Wind
Electrification	UDUS City Campus, Sokoto	1.5	Solar PV
Electrification	UDUS NUNET, Sokoto	2	Solar PV
Electrification	Kaduna	5	Solar PV
Electrification	Durumi, Abuja	3	Solar PV
Electrification	3 Mechanized Brig. Kano	1	Solar PV
Electrification	Kaduna	1.5	Solar PV

IV.1.2. Micro-Grid Projects in Kenya

Kenya is the financial hub and the biggest economy in Eastern Africa. However, the majority of its people lack access to electricity most especially in the rural areas. Kenya's installed generation capacity was 1773MW as of May 2014 and the peak demand increase to about 1453MW from 1236MW in 2011 [47].

According to [5], [43], [44], the population without access to electricity in Kenya between 2010-2012, was estimated to be about 33-35 million people out of a population of 38.5 million in 2010 and 43.13 million people in 2012, respectively. This is shown in Fig. 5.

This figure also shows an increase of about 1% in electrification rate in 2012 when compared to 2011. Electricity access improves slightly in rural area from 5% in 2010 to 7% in 2012 as shown in Fig. 6. However, there is a big gap between urban electrification rate and rural electrification rate. Electricity access in Kenya in 2012 is about 19%. However, it is predicted by World Bank to remain at 23% in 2015 [45]. There is a shortage of electricity supply in the rural areas of Kenya and this has brought about the MG initiative for off-grid rural communities. Today many rural communities in Kenya are powered by PV and wind based MG. In 2014, there are 18 operational MGs with a total installed capacity of 19MW operated by the Kenyan utility [47].

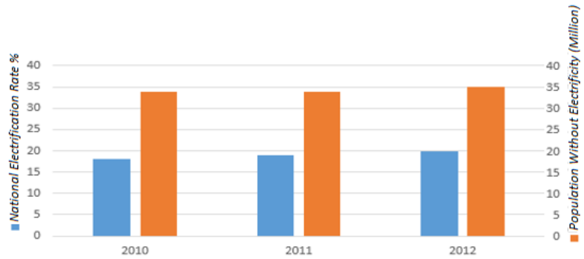

Fig. 5. Kenyan Electricity access from (2010-2012) [5] [43] [44]

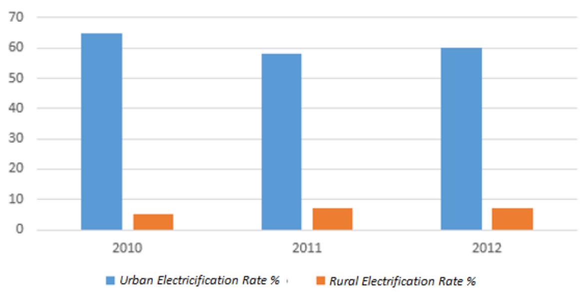

Fig. 6. Urban and rural electricity access in Kenya from (2010-2012) [5] [43] [44]

There are also privately owned MGs mainly installed across Kenya and most of the MGs are solar based. In 2011, two photovoltaic (PV) based non-autonomous MGs rated about 515kW and 60kW were installed in the United Nation Environmental Program (UNEP) complex and the SOS children's village at Mombasa, respectively.

The PV based MG was designed mainly for the United Nation building, but feeds excess electricity to the grid during weekends and public holidays [48]. There are also on-going MG pilot projects in some villages and islands in Kenya [49], [50].

The ongoing project is a joint collaboration between the government of Kenya, PowerGen (micro-grid Company), Kiva (non-profit organization) and access-energy to provide electricity using autonomous MG in some rural communities in Western Kenya.

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There are also collaboration between the Kenyan government and non–governmental organization like Kiva to supply electricity to hundreds of people in rural communities. An example of such communities is a commercial trading village called Olalialumtia, Maasai Mara, which is 100km and three hour drive from Kenya national grid.

Powerhive which is a MG solution provider is also managing four MG pilot project with a proprietary technology platform that streamlines MGs development and customer management. The MG are situated in the villages of Mokomoni, Nyamondo, Matangamano and Bara Nne. The MGs are capable of supplying power to larger clusters of customers such as welders, carpenters and millers [51]. Some of the installed MG and their locations are listed in Table II.

TABLE II
DIFFERENT PILOT MICRO-GRID PROJECTS IN SOME PARTS OF KENYA

Project Description	Location	Rating in kW	Energy Source
Electrification	UNEP, Mombasa	515	Solar PV
Electrification	SOS,Village Mombasa	60	Solar PV
Electrification	Tawawiri Island	1.41	Solar PV
Electrification	Remba Island	PV (2.16), Wind (1)	Hybrid
Electrification	Olalialumtia, Maasai	1.4	Solar PV
Electrification	Oloshi Oibor	PV (4), Wind (3)	Hybrid
Electrification	Mokomoni	1.5	Solar PV
Electrification	Nyamondo	10	Solar PV
Electrification	Matangamano	20	Solar PV
Electrification	Bara Nne	50	Solar PV

IV.1.3. Micro-Grid Projects in Zambia

According to IEA (2010–2012) [5], [43], [44], Zambia improves its national electrification rate in 2011 by 3.2% when compared with 2010 (2%). The electrification rate further increase by 4% in 2012 (see Fig. 7).

Fig. 7 shows steady improvement of the country national electrification rate with a sharp reduction in the Zambian's population that do not have access to electricity in 2012 compared to 2011. On the other hand rural electrification also increased by 11% in 2012 when compared to the previous year (see Fig. 8). According to World Bank [45], the Zambia electrification rate is expected to increase from 21.8% in 2012 to above 22.1 % in 2015. As the call for rural electrification gets intensified, the Zambia government has now established the rural electrification authority which is focusing on MG. The rural electrification authority is in collaboration with the World Bank to provide electricity in rural areas through the promotion of renewable energy mini-grids (collection of MG).

This has led to the development of MG in some part of Zambia. There are also privately initiated MG in some rural areas in Zambia. An example of such MG is the Sinda village MG which is situated in the eastern province of Zambia [52]. The MG is made up of 0.78kW solar DC grid with the lumeter metering system.

The MG was installed through the collaboration between Powergen, Kiva, access-energy and Zamsolar. Also in 2013, Oscar nominated actor Mark Ruffalo unveils Africa's first solar-powered, high school MG in Zambia [53]. The MG is a 24kW photovoltaic array with battery storage system.

It was spearhead by a U.S based not-for-profit organization, Empowered by light (EBL). The initiative will provide clean power to 100% of the campus. The MG will service more than 600 students [53].

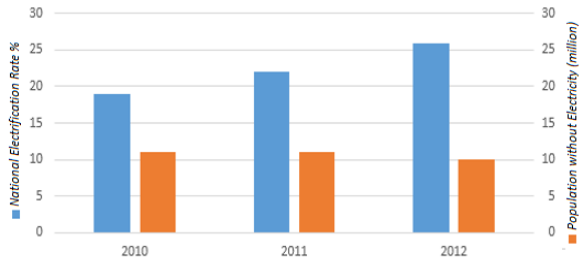

Fig. 7. Zambian Electricity access from (2010-2012) [5], [43], [44]

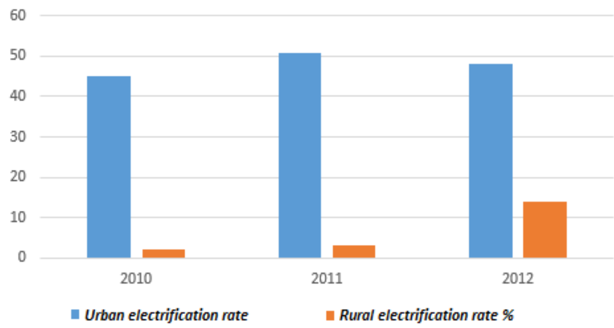

Fig. 8. Urban and rural electricity access in Zambia from (2010-2012) [5], [43], [44]

IV.1.4. Micro-Grid Projects in Tanzania

Over 35 million people out of a population of 47.78 million in Tanzania do not have access to electricity between 2010 and 2012 [5], [43], [44]. The poor electricity access is reflected in the national electrification rate, which was 15% in 2010 and 2011, and 24% in 2012 as seen in Fig. 9.

Fig. 10 shows slight improvement in the rural electrification rate from about 3% in 2011 to about 7% in 2012. The urban electrification rate was about 71% in 2012 and improvement of about 48% when compared with 2011. It can be seen that the electrification rate in 2012 is better than previous years and it is expected to grow above 15.3% by 2015 according to World Bank [45].

As a means to improve electricity access in rural areas, the Tanzania government is planning to install pilot MG project in Lake Eyasi, outside the beautiful Ngorogoro crater to provide complete social services using a solar powered system [54]. The Tanzanian government is also deploying diesel generator powered mini-grid (collection of micro-grids) to improve electricity access in rural communities. Some towns in

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remote regions of Tanzania are served by 13 national utility mini-grids, almost entirely powered by diesel generators [55].

Currently, there is an ongoing pilot, MG project in Malolo village and three nearby sites [56].

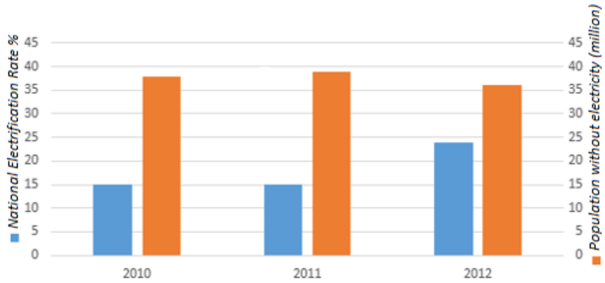

Fig. 9. Tanzanian Electricity access from (2010-2012) [5] [43] [44]

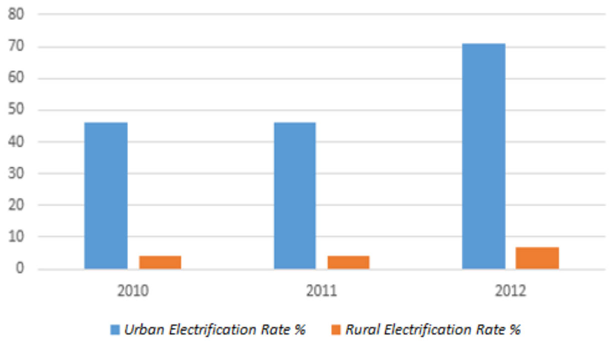

Fig. 10. Urban and rural electricity access in Tanzania from (2010-2012), [5] [43] [44]

IV.1.5. Micro-Grid Projects in Ghana

Ghana reduced the number of people without access to electricity from 10 million in 2010 to 7 million in 2012 which is unprecedented [5] (see Fig. 11).

The national electrification rate was improved from 61% in 2010 to 72% in 2012 [5], [43], [44]. Ghana also achieved an impressive 90% electrification rate in the urban areas in 2012 and 52% electrification rate in rural areas in the same year as shown in Fig. 12.

There are still people in the remote rural communities who do not have access to electricity. However, the World Bank predicted that the electricity access will grow above 64.1% in 2015 from 61% in 2012 [45].

The challenges of remote rural communities in accessing electricity have brought about the private MG initiatives (by Persistent energy Ghana (PEG)). Currently, PEG is bringing green energy to Ghanaian households that earn between $1 and $6 per day by installing solar powered MG in under-electrified region. PEG also plans to expand into island communities in the Volta and the Northern regions of Ghana.

It has also plans to install additional micro-grids in 50 villages, for a total of 5,000 households and 300 villages, for a total of 30,000 households by 2014 and 2015 respectively [57].

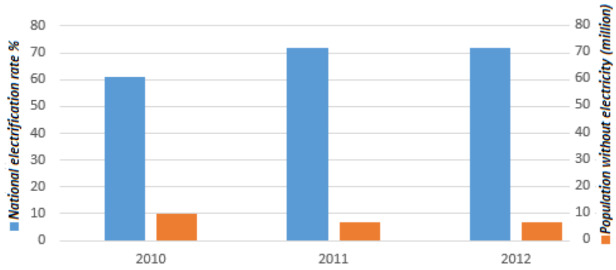

Fig. 11. Ghana Electricity access from (2010-2012) [5] [43] [44]

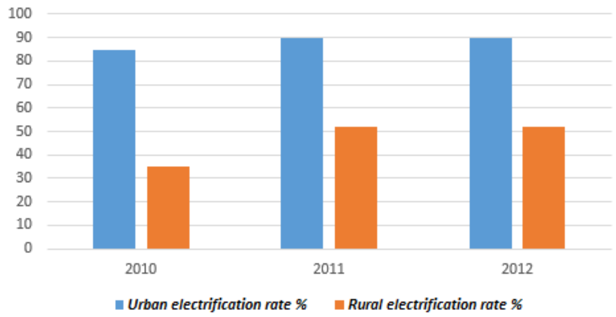

Fig. 12. Urban and rural electricity access in Ghana from (2010-2012), [5] [43] [44]

IV.1.6. Micro-Grid Projects in Cape Verde

Cape Verde is located in the Atlantic Ocean, 400 kilometers from the coast of West Africa. It has a total population of 542.000 inhabitants, with a population growth rate of about 1.8%. About 70% of the population in Cape Verde live in the rural area. The country energy supplies come from petroleum product, wind, butane gas and firewood. Firewood alone account for about 57% of household's energy needs and the demand for wood exceeds the generating capacity of the existing ecosystem [58]. Electricity access in Cape Verde is almost 100% in urban areas and 94% in the rural areas as of 2012 [5].

Due to the reliance on firewood and imported fossil fuel, the government of Cape Verde has set up plans to increase energy production from renewable resources through private-sector investment and government-supported projects. Cape Verde intends to generate at least 50% of electricity from renewable sources by the year 2020 [58]. One of the renewable projects is a 27.3kW solar photovoltaic MG on the island of Santo Antao (Cabo Verde) financed under the ACP-EU energy facility program which is led by a private water company Aguas de Porta [59]. The MG is designed to supply 60 homes in a village.

IV.1.7. Micro-grid Projects in Equatorial Guinea

Equatorial Guinea is located on the west coast of Africa. Electricity generating capacity varies in Equatorial Guinea, from 15.4 megawatts (MW) to 45.4 MW capacity [60]. The power supply is unreliable, due to aging equipment and poor management, as

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demonstrated by regular blackouts in Malabo [60].

As a result, small diesel generators are widely used as a back-up source of power supply. Some villages and rural areas are equipped with private generators.

According to [5], Equatorial Guinea has about 66% national electrification rate with a 93% urban and 48% in rural electrification rates (see Fig. 13). To improve electricity access, the government of Equatorial Guinea is collaborating with MAECI solar power and water, Princeton power systems and General Electric (GE) to install the largest self-sufficient 5-MW solar MG on an island in Annobon province. The MG will provide reliable electricity to the whole island [61]. This development will divert an average of 15-20 cent spent by residents on supplementary power for better use [61].

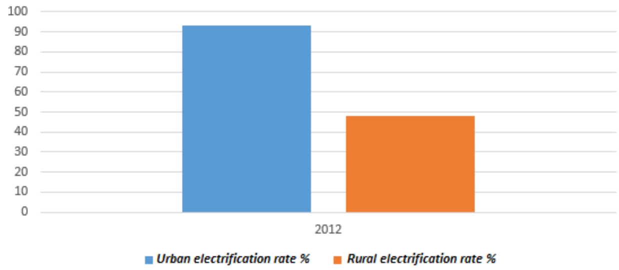

Fig. 13. Urban and rural electricity access in Equatorial Guinea in 2012 [5]

IV.1.8. Micro-Grid Projects in Uganda

Over 30 million people out of a population of 36.35 million people in Uganda do not have access to electricity as of 2012. According to [5], [43], [44], the national electrification rate improve by 6% from 9% in 2010 to 15 % in 2012 (see Fig. 14). The rural electrification rate in Uganda also improv by 4% from 3% in 2010 to 7% in 2012 (see Fig. 15). This means that about 93% of the rural population do not have access to the electricity in 2012. These communities used private diesel generators which are expensive and unhealthy to meet their electricity demand. In order to provide electricity access in rural areas in Uganda, private entities and government are installing MGs in the rural areas.

An example of such MG is a solar MG supported by world wide fund for nature (WWF) that is installed in Kayanja Nyakiyumbu Subcount Kasese district of Uganda by joint energy and environment project (JEEP).

The MG will supply electric power to 88 households, a hotel and a video hall [62]. These are some of the MG that have been installed across Uganda. As the technology develops, there will be increased installation and usage in the region.

IV.1.9. Micro-Grid Projects in South Africa

South Africa is the largest electricity producer in Sub-Saharan Africa and is therefore vitally important to the region, especially the countries in the SADC region. In 2012, South Africa has a national electrification rate of 85% with 8 million people [5] out of 52.27 million people do not have access to electricity as of 2012.

The electrification rate in urban and rural areas are 88% and 82 % respectively [5]. The country still has some informal settlement without access to electricity.

South Africa has a lot of informal settlement and direct current (DC) MG will be ideal for installation in these settlements. Due to the lack of electricity in these informal settlements, the Sustainability Institute Innovation Lab (Pty) Ltd, (SIIL), a division of the Sustainability Institute, has developed the iShack Social Enterprise to deliver smart, sustainable and scalable energy utilities to poor, underserviced communities [63]. The iShack Project uses off-grid energy produced by DC MG technologies.

The DC MG is used to provide electricity in Enkanini, in Stellenbosch [63]. The DC MG provides household electricity to power lights, television and other small media appliances. The iShack roll-out started in October 2013 and by April 2015, electricity had been delivered to over 800 households [64].

Also grid connected MG will be suitable for South Africa to deliver reliable service, example of such MG is the Echelon Corporation MG in Clearwater mall in Johannesburg [64], which integrates distributed generation to compensate for disruptions in utility-supplied power. DC MG will be a viable energy solution to grid failed rural, urban and peri-urban residential areas in South Africa. According to World Bank [45], electricity access will grow above 85.4% recorded in 2012 by 2015.

V. Benefit of Applying Micro-Grid in Sub-Saharan Africa

Sub-Saharan Africa accommodates about 13% of the world population and approximately 30% of this population do not have access to electricity [49].

The majority of the people that do not have access to electricity live in the rural areas because more attention is place on the delivery of electricity to the urban areas which are close to the utility grid. This has affected the social and economic growth of the rural areas [65].

Electrification of the rural area is imperative because, it will open a window of opportunity for these people to the rest of the world through the access to media. It will also favor industrial activities, agricultural development and income generation [66]. In the last decade, some countries in the region, though limited in number, have made remarkable steps towards providing electricity to the rural and sub-urban areas using renewable and non-renewable MG. Examples of these countries are Kenya, Tanzania, Uganda, Cape Verde etc. This form of energy generation (Renewable MG) comes with a lot of benefits to utilities, society and the rural population. Some of the benefits are economical benefits, environmental, social (e.g. job creation), technical (e.g. reduced transmission and distribution losses, and reliable power supply), etc.

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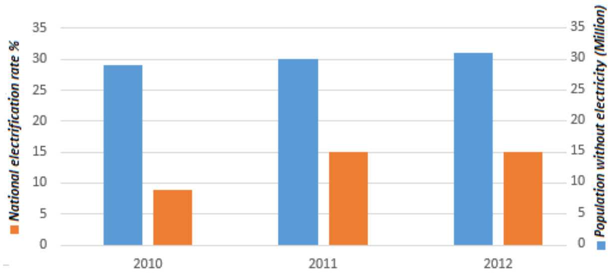

Fig. 14. Uganda Electricity access from (2010-2012), [5] [43] [44]

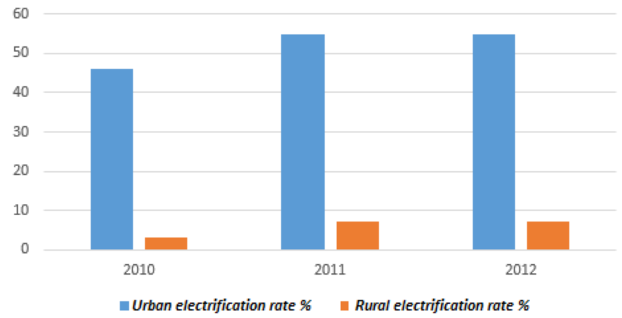

Fig. 15. Urban and rural electricity access in Uganda from (2010-2012), [5] [43] [44]

V.1. Economic Benefits

The application of MG will enable economic development in Sub-Saharan Africa most especially in the villages and remote locations. MG will provide new business opportunities for rural dwellers and also improve agricultural productivity, incorporate specific market base application for health, and small businesses.

With the introduction of the MG, it is expected that utility companies will have better economic benefits due to the fact that there will be an improvement in their operating efficiencies which will then lead to reduction in operation, maintenance and capital cost [42].

MG can also boost, direct foreign investment in some countries in the region. The MG potential in the region can encourage investors to build solar plants and parks which will create wealth in the region. Example of such investments ARE listed in Table III.

TABLE III
SOME OF DIRECT FOREIGN INVESTMENTS IN SOLAR MANUFACTURING PLANT [68] – [72]

Company	Type of Investment	Investment Cost (Million)	Country
International Solar Utilities	Solar Park	$750	Ghana
Ubbink East Africa	Solar Factory	$2.7	Kenya
FUNAE	Solar Factory	$13	Mozambique
JVG Thoma Plant	Solar factory		Nigeria
Karshi-Abuja solar plant	Solar Factory	$96	Nigeria

These investments will increase MG installations and will reduce kerosene usage for lighting, which constitute cost burden on rural dwellers. MG in rural areas can boost the local economy by enabling SME's such as carpentry workshops and tailoring enterprises to increase productivity, which will in turn improve the quality and quantity of goods made, thereby supplying more cheap goods in the local market and boosting more sales resulting in increasing business revenue [67].

V.2. Environmental Benefits

MG will promote and enable the use of renewable energy resources such as solar energy, wind energy, etc. Although these renewable sources are intermittent in nature, they have minimal environmental impact unlike conventional fossil fuel power plants. Sub-Saharan Africa countries are endowed with both natural and renewable resources most especially solar, and wind resources, that can be effectively incorporated in the form of MG to meet part of our energy needs most especially in the rural areas of Sub-Saharan Africa.

Due to the low electrification rate couple with low income in rural areas in Sub-Saharan Africa, the majority of the rural population now resolved to use unclean energy sources (e.g, kerosene lamps and firewood) for household applications which result in an increase in household air pollution [33]. In Sub-Saharan Africa, firewood account for about 70 – 90% of the region primary energy source [73].

According to a working paper by the Stockholm Environment Institute in 2008 [74], over 95.6%, 91.3%, 89.1%, 87.7%, 98.5% and 88% percent of the population in the rural household in Tanzania, Uganda, Senegal, Zambia, Malawi and Kenya respectively are dependent on firewood for primary fuel for cooking. According to report from world health organization (WHO) and international energy Agency (IEA), it is estimated that 1.5 million people dies from prematurely dearth annually from household air pollution caused by the use of biomass inefficient stoves [33]. The electrification of rural areas in Sub-Saharan Africa based on MG will reduce dependency on kerosene lamps and traditional biomass for cooking which will in turn reduce premature death. It will also reduce the region carbon blueprint

V.3. Job Creation

The promotion and increase application of MG will provide job opportunities for developed countries with DG manufacturing plants. This means that the increase integration of MG will lead to more investment opportunities in complementary sustainable technologies and promote more job opportunities in the manufacturing industries in the developed countries [75].

For developing countries in Sub-Saharan Africa, the implementation of MG in remote locations will promote the training of inhabitant to operate and maintain the MG as well as the collection of tariff from customers, thereby creating jobs for villagers. In some cases, the DG manufacturing plants are built in these developing countries and they can also provide thousands of direct jobs (White collar and manufacturing) or indirect jobs like construction, operators and maintenance for the local

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people in the region. Table IV, shows jobs created by solar investment and solar manufacturing plants in some countries in Sub-Saharan Africa [76] – [79] MG will also attract small to medium enterprises (SME) in the remote rural areas in the long run, which will eventually create local employments.

TABLE IV
DIFFERENT JOBS CREATED BY SOLAR MANUFACTURING PLANT AND SOLAR INVESTMENT IN SOME LOCATION IN SUB-SHARAN AFRICA [76] – [79]

S/n	Solar Plant & solar investment	Capacity (MW)	Direct Jobs	Indirect Jobs
1	FUNAE Solar Plant, Mozambique	15	80	700
2	Ubbink B.V /Largo invest., Kenya		80	
3	PN Solar plant, Tema, Ghana	600	350	300
4	International Solar Utilities, Ghana	600	2000	6000
5	PSC Solar, Ogun, Nigeria	10	20 (training)	1000
6	JVG Thoma Plant, Sokoto, Nigeria	10	Expect to create Jobs	
7	Karshi-Abuja solar plant, Nigeria	15	Expect to create Jobs	

V.4. Reduction of Transmission and Distribution Losses

The application of MG in Sub-Saharan Africa can significantly reduce both transmission and distribution losses. It can also relieve utilities of the cost of expanding the power system to remote locations.

According to [80], an average transmission and distribution infrastructures of a power system amounts to 6 - 8% of total generation losses. It is estimated that in Africa this amount is even higher, above 15% due to ageing transmission infrastructure.

If the MG can cover its own demand, energy need, transmission and distribution losses will be reduced to less than 1% under normal circumstances. Since most MG sources are renewable based, the reduction in energy losses will significantly contribute to low CO_2 emissions.

V.5. Reliable Power Supply

Power system reliability is a major problem in most countries in Sub-Saharan Africa and this can be improved with the introduction of MG in urban, sub-urban and rural communities in the region. Most national grids in Sub-Saharan Africa cannot meet their demands for electricity delivery at all times. According to [81], power system reliability is a major task in Nigeria because its national grid is affected by lightening, high winds and unusually hot weather which lead to continuous outages and brownouts. However, the implementation of MG will reduce the stress of increasing demand on aging electricity infrastructures. MG will therefore improve power system reliability in the region.

VI. Challenges of Micro-Grid Implementation in Sub-Saharan Africa

To benefit from the numerous advantages of MG mentioned above, some barriers or challenges need to be overcome. From the author's perspective, barriers like lack of skilled personnel, financial constraints, and complicate regulatory requirements and policies need to be addressed for effective actualization and implementation of MG in the region.

VI.1. Lack of Skilled Manpower

MG is a relatively new technology that involves systematic control architecture with a cluster of renewable energy sources.

It is a complicated system that requires experience and skilled personnel to effectively coordinate, and manage the day to day running of the system. For Sub-Saharan Africa, there is still a lack of skilled engineers, scientist, technologist and managers with the needed skills to undertake maintenance and effective operation of the MG. However, there are training courses on renewables energies and MG in some countries in Sub-Saharan Africa such as Senegal [82] and South Africa.

VI.2. Financial Constraint

One key barrier to the actualization of MG project is funding. This is due to the fact that MG technology is new and there is scepticism in the financial sector as to whether MG projects would be reliable, feasible and financially viable in the region.

Financing renewable projects in Sub-Saharan Africa is also complicated by the short payback periods.

According to [83], "banks don't focus on the viability of a project, but rather on the financial situation of the company developing the project". This situation has affected small companies that are willing to invest in renewable based MG projects in some of the countries in the region.

VI.3. Complicated Regulatory Requirement and Policies

One of the major constraints for the implementation of MG in Sub-Saharan Africa is regulatory barriers in some countries in the region. Most of the countries in the region have strict bureaucratic processes involving several government officials and agencies making approval for project implementation difficult.

The process can be complicated and can take several months. Requirements like right of way, land ownership, technical concerns and safety are some of the issues that must be overcome by investors and developers when implementing MG in the region.

Other implementation barriers include unavailability of right policy for renewable energy and MG deployment. Most countries in the region do not have

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effective renewable and MG policies for implementation.

In some countries, policies on renewable energy have been developed. However, due to political instability, such policies are difficult to implement [65].

VII. Solution for Successful Implementation and Promotion of Micro-grid in Sub-Saharan Africa

In this section, we suggested some solutions for MG implementation and promotion. These suggestions will successfully promote MG growth in the Sub-Saharan Africa. The suggested solutions are:

- Sub-Saharan Africa should address the lack of skilled manpower by building capacity to develop MG market.
- The legal and regulatory barriers should be addressed by providing policies that will reduce trade barriers and also ensure that these policies are followed.
- Financial institutions in the region can initiate stage-base financing and a seed-funding market place to provide tiered funding to enterprises entering this new market [83]
- There should be collaboration between entrepreneurs, MG developers, and financial institution to build capacity and skills management to successfully manage micro-grid investment in the region.
- Create awareness of the linkage between energy availability and health, and also provide information on the potential of renewable energy market.

VIII. Conclusion

Sub-Saharan Africa, with more than half of its population without electricity access can take advantage of this new energy strategy called micro-grid (MG) to improve electricity access in rural and suburban areas in its region. MG application will reduce CO2 emission, pollution and global warming due to the fact that most the primary energy sources of MG are renewable. Although MG comes with its own challenges, it is expected that the efficiency of MG will be improved in the near future to allow a widespread implementation across Sub-Saharan Africa. In Sub-Saharan Africa, national governments should invest heavily in MG, increase renewable energy research and implementation, create integration policies and establish policies for enabling vibrant market structure for customer driven MG. Individual countries in the region can also provide incentives for customer driven MG in remote rural locations while solving the energy needs of its population in those areas.

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