Microgrids For Sustainable Electricity Supply In African Countries

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***Abstract*— Africa is blessed with renewable energy resources. It is becoming increasingly needful to take advantage of these resources, especially as it relates to electricity supply. Electricity availability has been closely linked with economic growth in many countries. Yet, many rural communities do not even have electricity supply of any form and many urban areas do not have a reliable electricity supply.**

A number of solutions have been proposed to solve the energy crisis in Africa. One common observation is the abundance of renewable energy sources. Microgrids provide a platform to integrate several Distributed Energy Resources (DERs) using centralized control. African Communities can take advantage of their abundant resources by using Distributed Generation which can be fuelled by locally available materials. Solar energy, wind energy and biomass abound in many communities for localized electricity generation; backup systems from fossil fuel generation are readily available in form of diesel and petrol generators. Energy Storage Systems facilitate the integration of variable renewable energy sources by storing energy at low-demand periods for later use during high-demand periods. Microgrids also incorporate Energy Management Systems to promote energy efficiency.

Microgrids have been installed in many parts of the world with high success rates. Governments can take advantage of Microgrids for Rural Electrification projects without incurring significant Transmission and Distribution costs associated with large scale power systems. The benefits of Microgrids are numerous and they can be designed to meet specific community needs.

This paper explores Microgrid applicability in African countries and the use of renewable resources for electricity generation to facilitate a sustainable energy future.

Keywords—Microgrids; Renewable Energy Sources; Africa; Distributed Generatiion; Energy Storage Systems

I. Introduction

Electric Power is an important resource for development. In the US, the Electric power system accounts for 4% of the Gross Domestic Product (GDP). [1] Many African countries have low GDPs, and although this is multifaceted, electricity (or insufficiency of it) plays a significant role. Therefore, an improved electricity sector could boost the economy and facilitate the achievement of sustainability goals. Of the 850 Million people in Africa, 10% are grid-connected and 90% are disconnected from the grid. Africa accounts for 13.4% of the world's population but only uses about 3% of the world's electricity consumption. [7] This disparity is saddening and indicates the need for strategic improvement.

Generally, the traditional Electric Power System is subdivided into generation, transmission and distribution. Electricity has always been produced in large quantities due to economy of scales. The electric energy generated is not intended to be utilized only at the generation region. It is transferred at high voltages to other regions for consumption. This transfer over large distances is term electricity transmission. Finally, substations step down high voltage electricity received, to make it safe for distribution. Electricity is distributed at lower voltages to industrial, commercial and residential consumers.

Microgrids alter this traditional arrangement. They incorporate generation into the distribution system, closer to the consumer. This eliminates the need for a transmission system and the losses associated with it

The Microgrid concept can be very useful in political propaganda. Governments can set up microgrids in fulfillment of rural electrification promises. This can be particularly beneficial to rural farmers, for storage of farm produce and can facilitate the use of Information Technology in Agriculture.

II. Microgrid Definition

A Microgrid is a cluster of interconnected loads and microsources with electrical boundaries operating as a single controllable entity. [2] [6] These microsources, in recent times, are commonly referred to as Distributed Generation. Microgrids can be operated in the Grid-connected or Islanded mode where the Microgrid is connected to the main utility grid in the Grid-connected mode, and disconnected in the Islanded mode.

The traditional Generation-Transmission-Distribution system has been challenged due to concerns about the reliability, resiliency and economic operation of power systems. Reliability issues are high frequency, low impact occurrences. Resiliency issues are low frequency, high impact occurrence, such as natural disasters and terrorist attacks. With clusters of Distributed Energy Resources scattered in many areas, it is more difficult to have a total collapse of the power system. The large generating units are like the proverbial "eggs in a basket".

III. MICROGRID COMPONENTS

A typical Microgrid consists of Distributed Energy Resources, Loads. A Microgrid is different from a regular backup system. Microgrids need to have the following distinct characteristics: clearly defined electrical boundaries, a master controller, and critical loads that do not exceed the generation capacity. [3]

Distributed Energy Resources consist of Distributed Generation and Energy Storage Systems. Distributed Generation (DGs) are small-scale energy resources used to locally supply electricity. Energy Storage Systems store energy during a certain period for use at a later period. There is a need for ESSs because of the intermittence of certain Distributed Generation, especially those from renewable energy sources.

A. Loads

Loads play a major part in determining the needs of the system. Loads can be residential, commercial or industrial. Also, very importantly, loads are classified as critical or non-critical loads. Critical loads need to be supplied at all time while non-critical loads can be modified during load shedding, demand response, etc. They are also referred to as fixed and flexible loads.

B. Master Controller

The master controller provides Centralized Control. It controls and operates the other components of the Microgrid. It ensures the economic and reliable operation of the system. It is integral to the Microgrid.

C. Point of Common Coupling (PCC)

This serves as the interface between the Microgrid and the utility grid. When the PCC is closed, the microgrid is connected to the utility grid. The microgrid is disconnected from the utility grid when the PCC is open.

D. Ancillary Components

These components facilitate the reliable and economic operation of the Microgrid. They include smart switches, protective devices, and communication, control and automation systems. [3]

IV. BENEFITS OF MICROGRIDS

Some of the benefits of implementing microgrids are as follows:

- Reliability: For microgrids connected to the utility grid, blackouts can be eliminated when there are disturbances in the system because of the availability of local generation and energy storage. [5] These create redundancy because of the different available electricity sources. Reliability is further improved in smart microgrids. [5]

- Integration of Renewable Sources: Due to certain factors (such as the variability of renewable energy - sources), it is challenging to directly integrate them into the utility system. Since there is an electrical boundary between the microgrid and the utility grid, it is easier to integrate the renewable energy sources for electricity generation.

- Demand Response: These are strategies implemented on the demand side of the power system to control the load. Demand response is easier to implement in Microgrids as the system is seen as a single entity to be controlled.

- Power Quality: With the availability of Distributed Generation, Energy storage, and an efficient Master controller, electricity can be supplied at best frequency and voltage quality.

- Energy Arbitrage: The Microgrid can supply electricity back to the grid or bilateral contracts at higher costs than the cost of obtaining the electrical energy

- Cost Savings: Microgrids provide significant cost savings in both the initial installation and operation in power systems. The cost savings in installation are gotten from the elimination of transmission and distribution infrastructure. In operating a Microgrid with renewable energy sources, the cost of fuel is also drastically reduced.

V. RENEWABLE RESOURCES

With growing concerns about the emission of Greenhouse gases, more environment-friendly alternatives are being sought. Most electricity generation is from fossil fuels, and fossil fuels significantly pollute the environment. The increased use of renewable energy sources for electricity generation would reduce these harmful emissions.

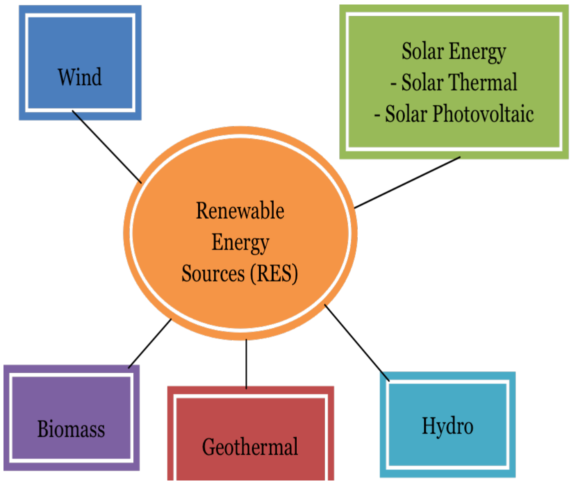

Fig. 1. Some Viable Renewable Energy Sources for Microgrids

Renewable energy sources have low operating costs. Therefore, they are more economical to operate on the long term; although initial capital costs may be high.

Renewable Energy Sources for Electricity generation in microgrids include:

a) Solar

Solar Energy can be used for electricity generation by Solar Thermal and Solar Photovoltaic (PV) means. Solar Thermal generation is obtained by concentrating energy from the Sun to produce steam and generate electricity. Photovoltaic Cells convert light energy into electrical energy.

b) Wind

Wind turbines generate electricity from wind energy. The wind rotates the blades which are connected to the turbine. The turbine generates electricity.

c) Biomass

The most viable sources for electricity generation using biomass are organic sources of food, forest production, fiber and animal manure. A steam cycle can be used to convert the biomass into steam, which is used to turn a turbine that generates electricity. Another method is to convert the solid biomass into fuel gas. [4]

d) Geothermal

This involves using the heat in the earth's crust to generate electricity.

e) Hydro

Hydro power generation is a popular renewable energy source that has been available for several years. The force of water is used to drive a turbine which generates electricity

VI. Renewable Resource Availability in some African Countries and Microgrids in Developing Countries

Many African countries have great potential for Renewable Energy electricity generation. Most African countries have abundant solar energy. Also, wind energy is a viable energy source. Rural communities can utilize biological waste for biomass generation. Biomass can also be used to generate electricity in urban regions.

Although these resources are abundant, there are challenges with the adoption and integration of these resources. The advantages of RES electricity generation include:

- Reduction of operation costs. Fossil fuel Power Plants require fuel to run continuously. With RES generation, the cost of fuel is eradicated, which significantly reduces operation costs. In the long run, the initial high capital cost of installation is offset but by low operation costs

- RES are environmentally friendly as there is little or no emission of Greenhouse gases.

Incorporating these Renewable energy sources into Microgrids is highly beneficial. As improvements are being made on the Electric Power systems, a major challenge is that many of these systems have been fully built and have been operational for years in more developed countries.

Many developing countries do not have adequate electricity infrastructure for reliable electricity supply. Therefore, the improvements on the electric power system can be applied to these countries without having to remove already established infrastructure. One of such improvements is the Microgrid Concept.

VII. MICROGRIDS FOR RURAL ELECTRIFICATION

One of the benefits of Microgrids mentioned earlier is the deferral of transmission and distribution upgrades. In rural areas that have never had electricity supply, it may be more cost efficient to build Microgrids. Many of these areas are in obscure regions with challenging terrains that make implementation of transmission systems problematic. Also, locally available and naturally occurring resources can be considered in planning the Microgrid system. The systems can be designed and tailored to meet the specific needs of the community.

VIII. SOME CASE STUDIES

a. Rural Migrogrids: Ololailumtia Microgrids

A Microgrid was installed at Ololailumtia village in Kenya 75km from the nearest power lines. The village has a population of about a thousand people, a few of which had 1-3kW gasoline generators. Two microgrids were installed with a capacity of 2.1kW of PV with Energy storage provided by a 9.6kWh sealed lead-acid bank. The microgrids cost about $15,000. Energy-efficient LED lighting was also added to the microgrid. [9]

b. A Campus Microgrid: The Illinois Institute of Technology, Chicago Microgrid

The Microgrid consists of 300kW of Solar Generation, 8,000kW of Natural Gas Turbines, 8kW of Wind Generation, and 4034kW backup generation. There also Energy Storage devices such as the 500kWh battery and other small size energy storage devices. It is connected via two substations to the utility grid. The Master-Controller operates a three-level hierarchical control. [8]

The improvements are remarkable. Energy efficiency has been improved by 6.51%, CO_2 emissions have been reduced by 6.58% and significant cost savings. [8]

IX. CONCLUSION

Microgrids have been found to have so much potential in many regions. African communities are not left behind. In fact, it may be easier to implement Microgrids in some parts because the power systems in these areas need to be freshly built. Hopefully, the concept of Microgrids in African countries will be explored more as a solution to Africa's Electricity inadequacy.

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