RENEWABLE ENERGY DISTRIBUTED ELECTRICITY GENERATION AND MICROGRID IMPLEMENTATION IN RURAL VILLAGES: A REVIEW

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ABSTRACT

There is a growing concern over the unprecedented increase in the demand for electrical energy to elicit all sort of development in any part of the world. Beside the electricity needs for industrial development, much is also desired to satisfy domestic energy consumption. Presently, as much as 2 billion of human populations around the world live without access to modern energy (electricity) and approximately 98% of them dwelling in developing countries. More to this ugly pervasiveness is that rural and remote areas in developing countries are the major victims. This condition of energy deficiency vehemently justifies the socio-economic disparity between industrialized and developing countries on wider geographical range as well as urban and rural areas on a local scale. By analysis of documented evidence, there is need to swiftly change the current pattern of energy exploitation in developing countries to counteract the poor energy access scenarios. This paper previews renewable energy (RE) distributed generation (DG) and microgrid (MG) for rural electrification purposes. It also highlighted some important issues regarding effective DG implementation which could be applicable in rural energy design and planning procedures. Finally, some conceptual discussions related to RE distributed generation and integration in MG is outlined.

Keywords: renewable energy, rural, distributed generation, micro-grid.

1. INTRODUCTION

From the focal point of diverse and dynamic nature of modern development, the demand for energy has been consistently increasing from time to time. By this declaration, relying on fossil fuels alone will continue to add to the problem of unsustainable rural energy planning and management especially in developing countries. Progress in the energy sector of developing countries has not been moving rapidly as expected. This is due to poor strategic planning and many other integrated factors. The understanding of the fundamental role of energy revealed that the general development constraints in many developing countries emerged from the turning point of insufficient energy access. Presently, the characteristic features of energy in developing countries which strongly account for their insufficient energy utilization issues compared to that of industrialized countries are:

- Illogical and uneconomic use of energy resource and conversion technologies.
- Numerical increase in the rate of energy consumption towards growth in population and the staring desire to promote socio-economic development.
- Excessive use of combustible biomass (fuel wood and charcoal) resource for domestic energy consumption in rural areas while more of petroleum resources are used for urban electricity services.
- Inadequate power system reliability and stability which often lead to system failures and shortage of electric power produced.
- Continuously growing energy concern due to low average energy consumption per capita.
- Low pace of rural electrification.
- Inadequate electricity subsidy programs and widespread uneconomic reality of rural electrification by traditional grid extension concept stemming from high economic cost.
- Energy supply constraint sometimes resulting from fossil fuels price fluctuation and shortages.
- Insufficient energy funding mechanisms.
- Poor technical performance and low efficiencies of electricity infrastructures.

In response to these basic challenges, the concept of microgrid (MG) for integrating Distributed Generation (DG) system is fast becoming significant for reliable and sustainable renewable energy (RE) exploitation. In ideal situation, this conception also allows for incorporating energy storage systems (ESS). ESS is used to optimize energy consumption. Further, MG development in modern power sector had brought another emerging idea called smart grid (SG). This new electrical power grid delivers energy to consumers using intelligent technologies especially for flexible operations and easy communication among the various interconnected system components. A typical example of a flexible micro-grid system with RE systems is shown in Figure-1.

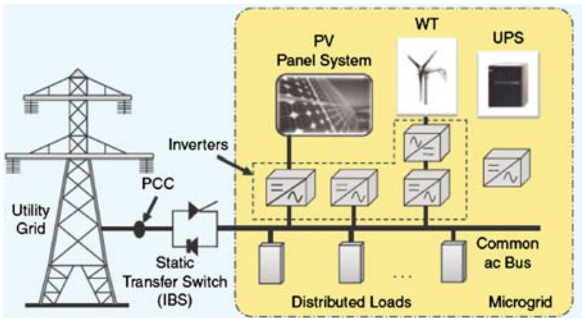

Figure-1. Typical structure of a flexible micro grid with some renewable sources [1].

DG encourages the development of a new grid technology, called microgrid, which is seen as one of the keystones of the future SG [2] and the entire power sector. A microgrid is a localized combination of electricity generations, energy storages, and loads [3] whereas a distributed generation is a power generation technique whereby electricity is generated close to the consumers' residence and supply via a local distribution network. This system of power generation completely voids the necessity to build a transmission line and it is the best option under which rural energy especially off-grid remote locations can be planned. However, electricity generation based on renewable energy sources (RES) are optimally exploited using this technology. In modern power sector, power system reliability monitoring, demand side management (DSM) and supply side management (SSM) is an issue of necessity. In this regard, additional advantage could also be derived especially on the condition that MG is designed with an intelligent (smart) technology.

In this paper, a review based on RE distributed generation as related to MG conception is presented. Proceeding sections cover issues regarding different RES used for power generation in rural domains and some other conceptual approaches that can be used to tackle rural electrification. The study is concluded with RE distributed generation in MG and the advantages of connecting distributed generators together for MG operation.

2. RE RESOURCES FOR DISTRIBUTED RURAL ELECTRIFICATION

Although, electricity may not bring development on its own but it is a very much desired commodity and a precondition to economic development in long-term perspective [4-6]. In this context, electrification of a rural community induces a window of opportunity for other developments. Though, energy demand in rural area is significantly low which makes its planning processes a bit simple based of available local resources. The prospect for RE exploitation for rural energy is presently high compared to interest in relying on foreign fuel or grid extension for electricity generation. This is because there is associated high cost of fuel importation or grid extension to rural areas. Wind power turbine, solar photovoltaics, biomass-based power plants and micro-hydro power systems are the basic renewable energy technologies (RETs) used for power generation in rural and remote communities without access connections to centralize grid systems. Since power density of most RES is low, therefore DG is usually an economically generation technology employed. Furthermore, in some community several renewable energy DG systems are connected together to meet up with power demand of consumers and such configuration is called renewable energy microgrid system (REMGS). Rural electrification is a phenomenon of electrical energy provision to rural and remote households. Several issues have incited the quest for rural electrification in developing countries which include the followings:

- Minimize inequalities in electricity access between urban and rural
- To increase the spate of socio-economic progress in rural and remote locations
- To promote sustainable development in line with global standard
- To satisfy the electricity need of the increasing human population in rural areas.

2.1. Solar energy

It has been estimated by [7-8] that technical solar energy has resource potential that far exceeds the total global energy demand. Solar energy is a kind of energy from the sun which can be converted to electricity using either photovoltaic system (PV) or solar power plant. Solar energy today is widely captured for electricity production using solar photovoltaic power system especially in sun rich countries. Early development of solar photovoltaic-based power generation was operated in a very small-scale to supply electricity to single or cluster of small number of residential homes. Today, large solar power grid integrated systems have been developed. This rapid development in the solar technologies for electricity production has favored a drastic drop in the cost of procurement in the last few decades. Reference [9-11] buttress this fact by unveiling that the cost of high power band solar modules has decreased from about \$27, 000/kW in 1982 to about \$4000/kW in 2006; the installed cost of a PV system declined from \$16, 000/kW in 1992 to around \$6000/kW in 2008. This landmark reduction in cost, climate change reductions obligation and policies, and Kyoto directives for clean development mechanism (CDM) are the basic vehicles envisaged to encourage more solar electricity generation across the globe. Currently, in developing countries like India, China and some other Southeast Asia, the uses of off-grid solar energy for combating rural energy deficiency is growing rapidly. In many other regions of the world, investment towards the development and promotion of solar power generation are being sustained using different workable policies. Some of the policies are fashioned towards exploring large scale of solar energy for either distributed electricity generation or grid-connected power supply. In the trend of future energy development based on RES application, solar energy will make a major contribution especially in the voluntary target to reduce greenhouse gas emission.

2.2. Wind energy

A wind power system is a device that converts the kinetic energy of blowing wind to alternating current electricity with the aid of an aero-wind turbine system illustrated in Figure-2. Power generated from wind was the fastest growing technology in the 90s and currently wind power doubles every 3 years [12-15] and globally more efforts are being currently sustained to assess suitable sites for wind power generation [16-23]. In 2010, the global capacity of wind power generation was estimated to be 196 GW with 1.9 TW forecasted by 2020 [12-13]. Apart from being used for onsite electricity generation, wind turbine systems in the form of large wind farms have also being used for grid connected supply of electricity especially in Europe, India, China and United States. The contribution from wind power system in these countries is significant especially as a means of cutting the emissions of carbon dioxide from thermal power generation. Therefore, apart from being used to solve rural energy problem, wind power system manufacturing in now a huge investment for some of these countries as the penetration of the system into power sector increases.

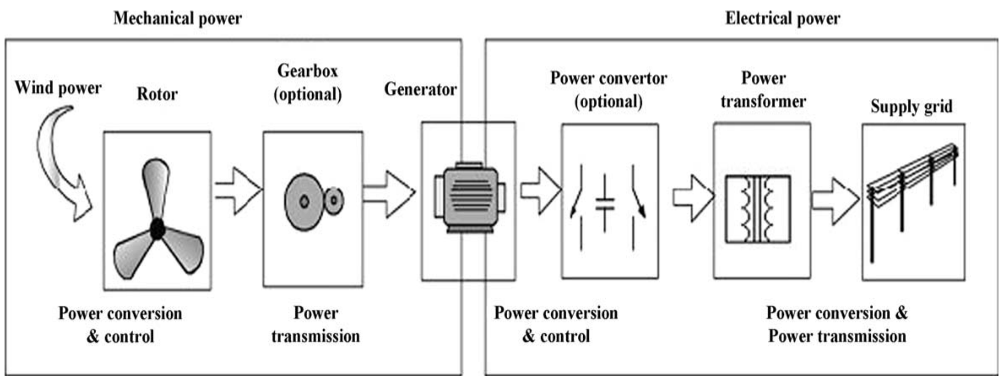

Figure-2. Main components of wind turbine system [24].

2.3. Bioenergy

Bioenergy obtained from biomass sources derived from trees, agro-forest residues, grasses, plants, aquatic plants and crops are versatile and important renewable energy feedstock and chemical industry [25]. Unlike solar, wind and hydro, biomass for bioenergy production have the advantage of multiple feedstocks from varieties of sources from within the natural environment. Mainly, there are two basic pathways for conversion of biomass to energy namely thermochemical and biochemical pathways. Conversion technologies employed depend on the nature of feedstock available, cost, system efficiency and technological adaptability. Biochemical technology for bioenergy production such as anaerobic digestion is more suitable for wet biomass while thermochemical processes are a reliable conversion pathway for dry biomass with rich lignocelluloses content. Examples of thermochemical conversion are gasification, pyrolysis and combustion. Biomass resources are available almost in every part of the world and are most suitable for distributed generation of electricity at various capacities. In rural communities, agricultural residues and forest biowastes generated are good feedstock for bioenergy production. In urban centres, municipal solid waste (MSW) generated is another major source of biomass for energy production. MSW for power generation is presently on the rise in island countries with limited space waste disposal like Singapore, Japan and Taiwan.

2.4. Small hydropower

In general hydropower or hydroelectricity is an electricity infrastructural arrangement whereby the kinetic energy in rapidly flowing water is captured and converted into an energy output. The potential output of power generated determines the category of hydropower generated. Small hydropower systems (SHS) are smaller versions of medium-scale and large-scale hydropower systems (LHS) under which we have ‘small’, ‘mini’, ‘micro’ and ‘pica’ hydropower systems representing increasing degrees of smallness [26]. Although there is no consensus classification on the different categories of hydropower but Indian Ministry of New and Renewable Energy (MNRE) [27] classified small hydropower stations based on power ratings: Micro-hydropower (up to 100kW), Mini-hydropower (101kW-1MW) and Small hydropower (1MW-25MW). In many developing countries, rural energy demand fall within the range of these distribution capacities thereby making micro, mini and small hydroelectricity another meaningful renewable alternative methodology.

3. ISSUES IN RURAL ENERGY DG AND MG IMPLEMENTATION

Currently, most rural energy systems are planned in the form of energy and environment for sustainable development. Development in a society is conveniently measured nowadays with the quantity of energy consumed in that domain. Therefore, energy is considered as a vehicular input parameter for national economic development [28]. Since contemporary energy demand and supply still rests on fossil fuels which cannot easily be supplied to rural communities, then interest on renewable sources for rural energy consumption emerged with accorded priority. This was theoretically envisioned to be capable to shore-up enthusiasm for emissions reduction and sustainable development. Sustainable development can be broadly defined as living, producing and consuming in a manner that meets the needs of the present without compromising the ability of future generations to meet their own needs [29]. To guarantee sustainable development in a society, quantitative and qualitative energy supply is an inevitable conception. Energy development is increasingly dominated by major global concerns of air pollution, fresh water contamination, coastal pollution, deforestation, biodiversity loss and global climate deterioration [28]. With these worrisome consequences, energy stakeholders have actively and openly suggested the need to increase RE adoption for realistic sustainability.

RE adoption strategies begins with the uses of effectual policy issues to address promotion of RE application, dissemination of RE technologies, RE funding apparatus, remarkable increase in the current status of energy utilization and rural electrification and diversification of all energy resources. Many evidences based on rural energy feasibility studies have shown that sustainable design of RE system can enhance energy security in rural areas as well as mitigate carbon dioxide emissions. Furthermore, adoption strategies can also be encouraged through green energy portfolio standard (GEPS), feed-in-tariffs (FITs), local government subsidy, tax waiver mechanism, mass deployment of Kyoto incentives and reduction in high carbon economy through high carbon tax.

Beside the fact that most rural energy systems in developing countries are mainly isolated renewable power system, in some cases grid-connected renewable power are used especially in China, Malaysia, Bangladesh and India. Some grid connected system supply electricity to local rural villages and the excess generated is fed into the public grid to avoid waste of energy generated. In majority of countries using grid-connected RE system solar, biomass and wind energy system are mostly favored with high rate of incursion into the power sector. Solar based power system is widely used for small-scale energy application than wind power system especially for rural energy lighting. Centralized microgrid distributed power generation systems have thrived well in some RE rich regions of industrialized and developing countries.

3.1. Implementation of RE distributed power generation energy systems

Electricity deregulated regimes had encouraged both the electric power distribution and MG energy service companies to stimulate investment on DG of electricity in rural and isolated communities of developing countries. In the context of its ability to reduce cost of energy produced, DG has been the most vital electrification option for rural areas. DG is almost a product of liberation of vertically integrated electricity sector. It is a new paradigm shift and optimal system expansion strategy with potential capability to minimize retail electricity costs and maximize their profits at the same time [30]. DG is an emerging technological outset where a distribution network can be changed from a passive feature to an active architecture to suit the need of customers. Long as RE resources are more common in rural areas than urban domains, RE technologies in the like of biomass power, solar photovoltaic, wind turbine power systems, fuel cells, microturbines and others can be utilized for energy application through DG. Implementation of rural distributed power generation system is a cost-effective project due to the fact that only generation and distribution infrastructures are needed to dispatch energy to the rural consumers. Besides the advantages of distributed generation mentioned so far, other benefits of DG are:

- Location of distributed generation is not usually restricted by the decision of stakeholders which is the case of load center construction.
- It eliminates the necessity for transmission line construction.
- It has the potential to provide additional power without any corresponding increase in generation capacity of an existing centralize power station.
- It can generate revenue within a short period of time.
- It has the tendency to ensure reliable and secure electric power supply services.
- It is suitable for combined heat and power (CHP) service delivery.
- It is the most suitable generation technology for renewable power consumption.

3.2. Rural based micro-power grid system with smart energy management network

Rural energy planning, implementation and management are often considered to pose severe challenges. A study from the International Energy Agency (IEA) [31] pointed out that a power system based on a large number of reliable small DGs can operate with the same reliability and a lower capacity margin than a system of equally reliable large generators. This declaration is vehemently advocating for MG perception in power sector. MG energy system can be exploited to accelerate energy supply development in rural and remote areas due to their low quantity of power demand. However, incorporation of smart grid network makes easier the burden for management and control services. Smart management network is a sub-control infrastructure in a power system that guarantees advanced management and control functions against unwarranted power system security threat. Operation of smart management network covers the entire spectrum of energy system from generation to the end points of consumption of the electricity [32]. Therefore, smart management in power system takes lead of the smart infrastructure to pursue

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various complex managements. The functions are mainly related to energy demand-supply equilibrium, load scheduling, system protection, energy efficiency upgrading, emission control, operation cost lessening, and utility maximization. In view of the fact that most operators of rural energy facilities are not well knowledgeable engineers or technicians, then a MG with smart management network is essential for energy system development to avoid exorbitant cost of repair and maintenance costs.

3.3. Integrated energy resource planning (IERP)

Integrated resource planning is one of the basic measures to ensure that project plan in meeting demand for electricity at affordable cost is upheld. Adequate energy planning and resources management can provide useful assistance to energy supply scenarios and negative environmental consequences. Integrated energy resource planning is the combined development of electricity supplies and demand side-management (DSM) options to provide energy services at minimum cost including environmental and social costs [33]. This significantly enable energy service providers to efficiently managed the amount of electrical energy needed by the customers thereby eliminate unnecessary generation of electricity. IERP highly depends on inherent stakeholders' decision-making and electricity demand in a society. As an inevitable commodity, energy stands the chance to be influenced by factors such as political pressure, economic condition, demand and supply structure. To satisfactorily deliver electricity to potential customers, the demand must be matched with the supply structure. This will ensure proper coordination of the marketing situations and the potentials for future expansion of any existing power system supply arrangement in meeting the continuous growth in demand.

3.4. Sustainable investment guide

In developing countries, rural energy investment guide is usually not well fortified to suit energy demand of the rural customers. For energy investment guide to sustainably meet its design purposes, it must carry enough information required by the investors in the sector to initiate prospective opportunity for rural electrification. Sustainable rural investment guide should accommodate information with respect to policy framework, electrification targets, grants and subsidy for rural electrification programmes, rural energy investment guarantee and institutional framework for monitoring and control.

3.5. Collaboration with international development agencies and non-governmental organizations

In the last few years a good number of internationally brainstorming rural energy projects have emerged. It has been verified beyond doubt that centralized commercial grid cannot be economically expanded with effective coverage for rural electricity provision. Presently, many international agencies and non-governmental organization alike have actively participated in rendering electricity services to remote villages. Such rural electrification projects are undertaken through rural-based stand-alone RE, home-based renewable electricity installations and village centralized mini-grid electrified system using RE systems. United Nations Industrial Development Organization's (UNIDO), United States Agency for International Development (USAID), World Bank, and some regional bodies has made mark in support for energy provision in rural areas of developing countries. UNIDO with a mandate to convert useful resources into sustainable technically benefiting projects and programs initiated International Centre for Application of Solar Energy (CASE). The fundamental objective of CASE is to accelerate solar power consumption among developing countries especially for energizing homes, water pumps, household appliances and street lights. Not limited to solar energy alone, CASE also aims at promoting the application and commercialization of other renewable energy resources in developing countries [34].

3.6. Integration of rural energy with rural development programs

It is no doubt that rural development is synonymous to rural energy provision. Energy access to rural populace in developing countries is a critical prerequisite for the development of modern infrastructures in rural districts. Massive reliance on biomass by the majority of human population in rural areas of developing countries for cooking can be attributed to letdown of poor planning and integration of rural energy with rural development. There are basic needs for redesigning of prevailing energy infrastructural systems with the intention to integrate energy service into rural development programs so as to expand access to modern energy.

4. RE DISTRIBUTED GENERATION INTEGRATION IN MG

A more efficient way to implement the emerging potential of DG and its associated load is by MG subsystem [35] utilizing RES in remote areas with no access connections to central utility grid. This is because of the advantages attached to MG being a cluster of different DG systems.

DGs connected in MG have the impending capability to initiate a much richer set of tools for providing not only heat and power, but also enhance reliability, security, flexibility and power quality [36]. From an economic point of view, MG is a less expensive network investment and contributes to sufficient generation due to its ability to control internal loads and generation [37-39]. In MG power generation configuration, several generators using different renewable energy systems (RES) can be connected together for synchronized output with easy control mechanism which is called microgrid central controller (MGCC). MG introduction have many other advantages such as improved local reliability, decrease feeder losses, sustain local voltages, offer increased efficiency using combined heat and power (CHP) plant, voltage sag correction and perform uninterruptible power supply function [40-41].

In DG for MG integration, various distributed energy resources (DERs) technologies such as fuel cell (FC), photovoltaics (PV), wind turbine power (WTP) system, micro-turbines, biomass based internal combustion engines and micro-hydro power plant are used to supply distributed loads. MG energy management system can integrate different management concepts such as policy, marketing, load forecast, energy resource forecast and customers demand level. Figure-3 illustrates interrelated energy management system in a MG power system. The entire management and control coordination relies centrally on human mental input. Therefore, a control interaction mechanism called human-machine interface (HMI) is mainly required especially for real time data analysis. Since MG and DG systems are both located at the downstream of the distribution point, both concepts share some reasonable level of considerations for the exploitations of DERs and distributed energy storage system (DESS) to supply different kind of electricity users.

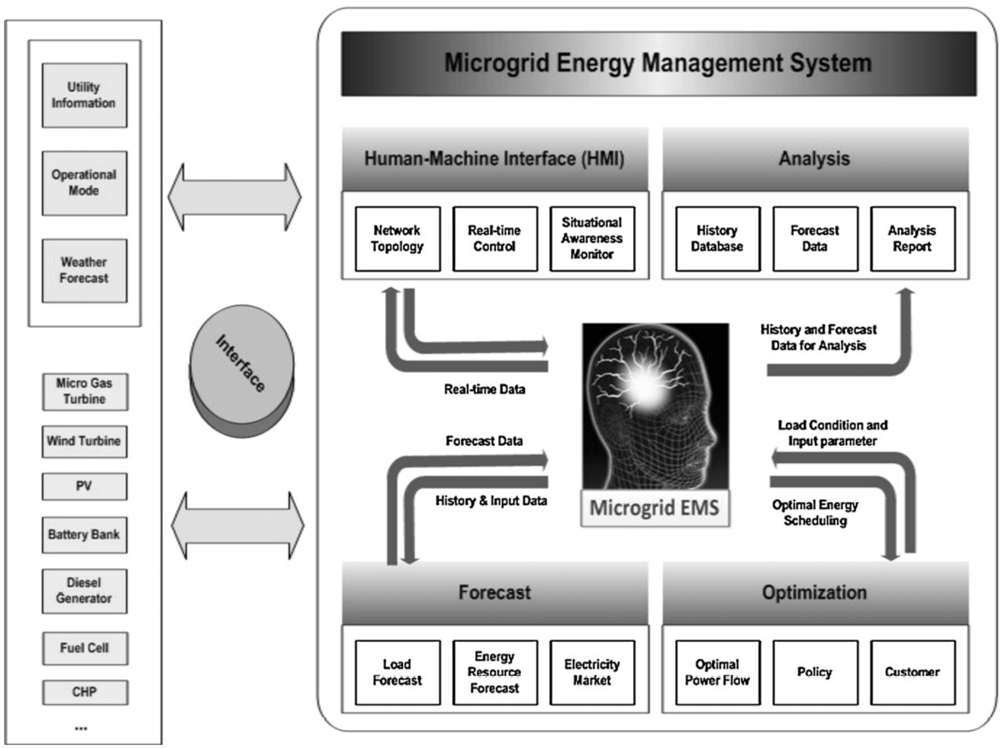

Figure-3. An illustrative of micro-grid (MG) EMS [42].

7. CONCLUSIONS

Sustainable energy for rural development has become an inevitable proposition to promote modern civilization in developing countries. In developing countries, access to grid electricity does not guarantee reasonable coverage to rural areas due to high cost of project execution. This validates needs for much to be done to exploit viable RE alternative within the reach of rural localities. In order to surmount the threatening energy pressure in many developing countries due to increase need for energy applications in the future, RE exploitation is indispensable and should be embraced especially in developing countries. Therefore, suitable frameworks with the potential to help in planning and design of rural energy have been suggested in this work. More research work is also required to tackle important areas like RE-based rural electricity funding and sustainability models, development policies, government support and among other externalities.

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