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Microgrid Architecture for Integration of Renewable Energy Sources To Derive Optimum Power – Problems and Issues

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ABSTRACT

This work reviews problems and issues relating to the integration of DERs in a Micro-grid system in the islanded and grid connected mode. Issues relating to the deployment, integration architecture and optimization of renewable energy resources to obtain clean, reliable and abundant electricity at an affordable cost to the consumers are studied. Useful information relating to the IEEE standards for DER integration is presented. An overview of the Government of India Schemes for providing technical and financial support to the Micro-grid development in rural India is also included.

Keywords: DER, DG, Islanded Micro-grid, Power Quality, Active Power Filter, Smart Grid

I. INTRODUCTION

Access to clean, abundant and reliable electricity at an affordable cost is vital for the sustenance, improvement of living conditions, socio economic development and quality of life of the rural masses. India cannot grow in the absence of electricity access in villages. The rural community must be supported by the young engineering fraternity to benefit from the deployment, integration and optimal use of the renewable energy resources and uninterrupted support of reliable electricity in abundance at economic cost without discrimination. This alone can pave the way to improve quality of village life, boost rural industrialization, eradication of youth unemployment and holistic development of the country in the real sense [2].

To enhance electricity access in rural India, micro-grid technology with distributed energy resources (DERs) and distributed generation (DG) architecture is becoming the emerging power system technology replacing conventional, hierarchical based, centralized generation in the geographically isolated rural locations inaccessible or economically difficult to connect with the main grid system. Micro-grids are small, self-sufficient, power systems with loads fed through radial distribution capable of operating in either islanded or in the grid connected mode. The DER architecture implies that energy resources within the micro-grid area are geographically scattered or distributed to curtail capital and maintenance costs of the long distance transmission lines, minimizes network congestion, reduce problems due to the voltage drop and energy losses in the conducting wires and provide greater autonomy and control to the electricity user. It can also be connected in the grid connected mode, thus facilitating both options for operation, grid connected and off grid mode. This provides flexibility to the power system and prevents outages of the grid due to local fault in the micro-grid system and failure in local area due to natural disasters or disruptions of the entire system. A typical traditional Power system retrofitted with Micro-grid equipped for augmenting electricity capacity of the power system is depicted in Figure 1 indicating its major components. It typically comprises of distributed generation units with inverters and incorporates controls that allow flexible operation of the DG. The DERs in the micro-grid may have DERs of different varieties of renewable energy sources. More than one micro-grid may be retrofitted to the traditional system. However, each individual Micro-Grid is self-sufficient and is capable of self-management under interconnected and isolated conditions as well as performing automatic islanding (resynchronisation) in events of contingency (restoration).

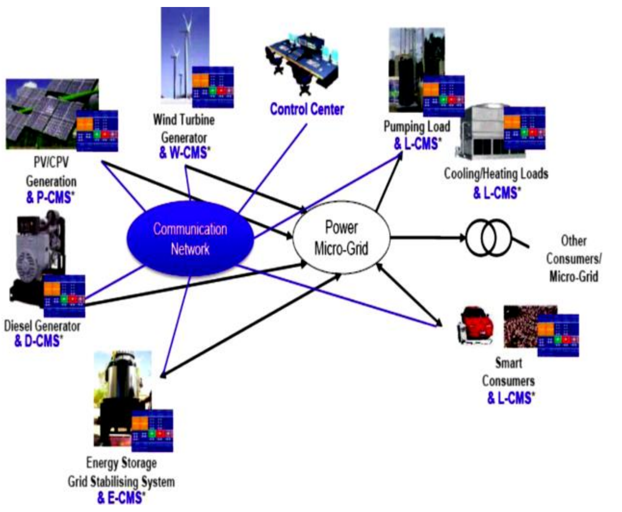

Figure 1. Major Components of a Microgrid System

Figure 2 depicts energy pathways in a typical renewable power micro-grid in grid connected mode with the utility grid[17] [2013]. The crux lies in the application of capture and conversion technologies and electronic interfaces especially designed for optimum results.

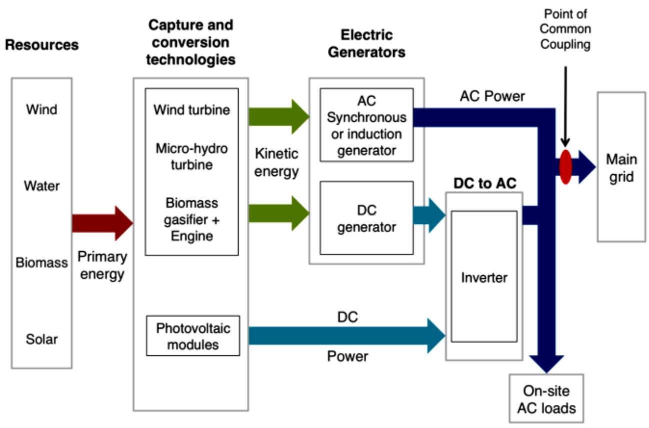

Figure 2. Energy pathways in a renewable power mini-grid connected with the utility grid[17] [2013].

Fig.3 illustrates a comprehensive micro-grid architecture showing renewable and non-renewable DGs, energy storage devices, different types of micro-grid loads, interfaced DERs, interconnected micro-grids, stability and control systems, and communication systems. A point of common coupling (PCC) is the interconnection of a macro-grid and the distribution/generation side of a micro-grid as per figure 2.

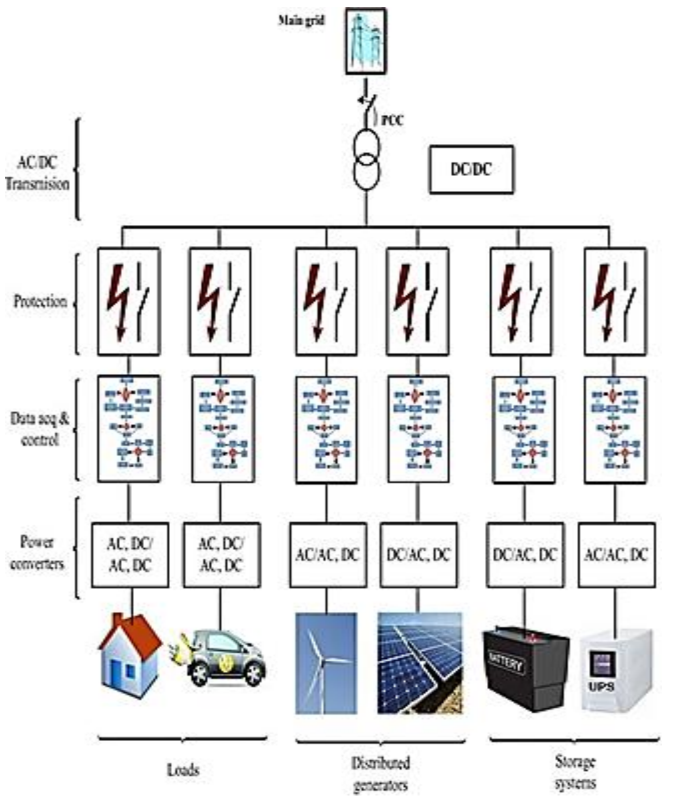

Figure 3. Micro-grid Distribution Model[11] with DGs, DERs, interconnected micro-grids, and ICT.

II. METHODS AND MATERIAL

1. Literature Review

Numerous publications and researches relating to increase in penetration of renewable energy and integration of DERs have appeared in the literature. The white paper[1] published by the Power Systems Engineering Research Center of the Arizona State University[1] [2010] describes challenges faced by power system industry in the integration, planning and operation of economical and reliable electricity service. It recommends increased penetration of renewable energy and more focus on human resource development, education and research on integration issues to cope with increase in the skill requirements for energy system integration in the coming years. Raffael Buhler[2][2010], recommends replacement of the existing 'fit and forget' approach in the integration of DERs by either of the three more scientific approaches, namely the VPP (virtual power plant), micro-grids, or energy hubs and gives SWOTs analysis of these approaches. The research concludes by establishing multi-energy carrier approach in the energy hub concept to be the best approach for DER integration. The concept using energy hub approach identifies all energy inputs, outputs, flows and conversion possibilities and searches holistic solutions for optimal output under the specified conditions, including the steady state and transient. Manzar Ahmed et.al[3] [2015] in their research captioned'Integration of Renewable Energy Resources' have investigated complete micro-grid model analyzing steady state and transient responses to changing inputs including power sources with their power electronic circuitry and load as a single controllable entity providing both electricity and heat output to its local area. Models of fuel cell, micro-turbines, wind turbine and solar cell are separately analyzed in the work. This research proves that the wind power and fuel cell power can support micro-grid distributed generation and weak grids, add grid voltage and improve power quality.Andrew Krioukov et. al [4] consider intermittent nature of the renewable energies, like wind and solar as alternative to the other forms of energy in which supply follows loads, thus adjusting power consumption in accordance with the variations in renewable energy supply just like in internet data centers running batched data analytic workloads in accordance with the load scheduling. Using simulations driven by real life batch workloads and wind power traces, the research demonstrates that simple electricity supply-following job schedulers can yield 40-60% better renewable energy penetration than supply-oblivious schedulers. In short, the research by Krioukov et. al [4] gives a real life demonstration to build supply- following loads using data analytics computer clusters which truly form the basic building block for supply following loads. The research by Duong Quoc Hung [5] [2014] on Smart Integration of Distributed Renewable Generation and Battery Energy Storage attempts to develop methodologies for strategic planning and operations of high renewable DG penetration along with an efficient usage of BES units presenting three alternative analytical expressions to identify the location, size and power factor of a single DG unit with a goal of minimizing power losses. The webinar presentation content on Clean Energy Solutions Centre:[6][2015] Integrating Variable Renewable Energy into the Grid Key Issues andEmerging Solutions provides useful hints and information on integration of energy resources with cleanliness and environmental safety. The Technical Report on IEEE 1547 and 2030 standards for DERs interconnection and interoperability with electricity grids [7] is the guideline document for integrating DER and micro-grid installations. The research articles by VSKMurthy Balijepalli et. al [8] [2010] and SSMurthy[9]provide survey of the techno-economic issues and government policies on adaptation and popularization of DER integration and Deployment of Micro-grids in India. Articles by DV Avasthi and G Singh[18,19,20][2015, 2014,2014] suggest adaptation and promotion of DER based micro-grid systems for promoting universal electricity access and to cope with electricity crisis and unemployment problem in the country.

2. Requirements For Successful Integration Of The Standalone DERs

The successful integration of the DERs in a micro-grid system should:

1. Provide seamless integration of DERs with increased penetration of renewable based energy into the power system for an abundant, clean and affordable electricity accessible to all.
2. Minimize environmental pollution and global warming by utilizing low-carbon technology
3. Establish an efficient electricity-demand and grid management mechanism aimed at reducing peak loads, improving grid flexibility, responsiveness and security of supply in order to deal with increased systemic variability;
4. Introduce energy storage capacity to store electricity from variable renewable sources when power supply exceeds demand to make the system self-sufficient, flexible, versatile and secure,
5. Introduce high levels of energy conservation and energy efficiency by meeting electricity and heat energy requirements of the consumers from the DGs locally, reduce feeder loss, and provide voltage support.
6. Ssupply uninterruptible power with a high level of power quality

III. RESULTS AND DISCUSSION

1. Challenges in DER Integration For Standalone Micro-grid And Smart Grid

DER integration is a challenging task for micro-grid system. Its operation in the off- grid mode envisages the system to cope with numerous challenges and issues, technical, social and economic. Additional requirements are imposed in the grid connected operation including compliances relating to interconnection, interoperability and ICT, The ultimate aim is to derive clean and environment friendly energy with highest degree of reliability, power quality, sustainability, minimum cost with smooth operation of the system. A broad overview elaborating challenges and issues relating to DER integration for standalone micro-grid systems is outlined below.

2. Technical Challenges

In off-grid mode, the challenges involved in the smooth integration of DERs aim to derive environment friendly and sustainable, optimum energy at low cost with highest degree of reliability and power quality sustainability at low cost. The micro-grid power system must be able to accomplish these stipulated attributes in a smooth and convenient way with appropriate choices and proportion of available DERs in the energy basket, seamless integration and transition of DERs output, system stability and control, storage of energy to combat power failure and blackout situations, Use of Enabling technologies, Protection issues, Power Quality and other miscellaneous energy management issues like metering etc; must also to be given due weight. Of course, many amongst these issues overlap and yet considered as separate entities to ensure comprehension and completeness. Various issues in the design of off-grid DER integration under the micro-grid dispensation are as follows.

2.1 Making appropriat choice in the proportioning of DERs in the micro-grid's basket[11] [2014]

A balanced energy portfolio is a must for micro – grids to minimize cost of energy which is paramount in managing energy cost in the DER based micro-grid systems. In most cases, it may involve combining a bulk energy source (such as a PV array), energy storage, and dispatchable generation (such as diesel or CHP).

2.2 Seamless integration and transitioning of the DERs and load[11][2014]

The micro-grid system must provide seamless integration and transitioning of the DERs and load without phase and frequency drift both in the off-grid and grid connected modes. The system should either smoothly match with the utility conditions or black out during each of the switching states without disturbances in the switching transition. In the absence of proper synchronization, a reconnection could damage the generator or load inside the micro-grid in the off-grid mode, or may cause problems to the surrounding systems in the event of grid connected system.

2.3 System Stability and Control[11][2014]

Controlling energy balance in most cases presents the greatest challenge for micro-grid systems unlike the conventional systems employing rotating machines. These systems use DERs possessing orders of lesser inertia creating problems in mechanical balancing. This is more so, where micro-grid systems with high percentage of renewable energy are deployed. The control algorithms and demand response of micro-grid systems in these cases must respond much more fast to preserve energy balance and system stability and maintain compatibility in the architecture and functionality. Alternatively, additional energy storage modules should be provided in the system to maintain energy balance and stability which again would mean substantial additional cost of the micro-grid system.

2.4 Energy Storage And Management issues

The importance of energy storage and its management dominates the scene due to higher penetration of renewable DERs into the micro-grid system and to combat possibilities of electricity failure and black-outs. Energy storage is needed to cope with a variety of factors such as the increasing use of demand response, environmental concerns and electric vehicles steadily dominating electricity consumption. Electricity storage also helps to ensure the required grid and frequency stability at various time scales and operating conditions.

2.5 Power Electronic Circuitry And Interfacing issues[11][2014]

Power electronic circuits in the micro-grid systems need fast-acting power electronic interfaces in the presence of DERs to regulate voltage and frequency and ensure proper load sharing among diverse energy sources when operating in islanded mode. In grid connected mode, the micro-source and central micro-grid controllers are expected to regulate the exchange of energy both ways with the grid, monitor grid conditions and ensure proper separation. Micro-source controllers suitable for the task should be implemented with inverters, which could support various states with minimum energy loss at the switching stage.. A voltage or current controller with interfacing for grid connected or intentional islanding is equipped with appropriate algorithm for switching for performing this task. Detection algorithms can be designed to distinguish between islanding events, change in the loads and load-shedding conditions. The re-closure algorithm is provided for DGs to resynchronize with the grid. These algorithms are versatile enough to maintain voltages within the standard permissible levels during grid-connected and islanding operation modes. Provision for interfacing output for conversion or inversion into the desired forms and maintaining reliability and quality of the output power is provided in the power electronic circuitry. The ultimate purpose is to accomplish seamless transition from one state to the other within minimum time and with minimum loss of energy.

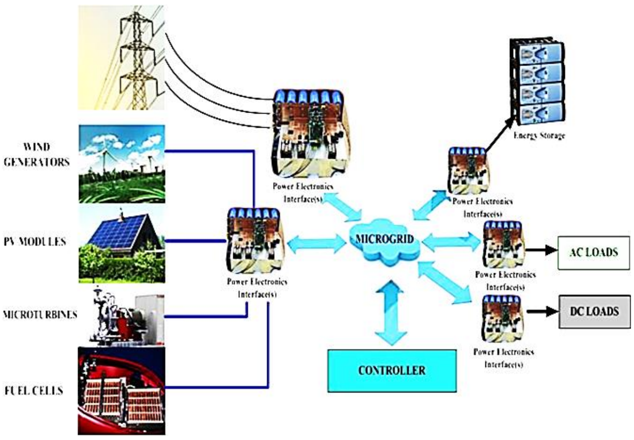

Figure 3 : Power electronics interface in a Micro-grid

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2.6 Enabling Technologies[8][2010]

Modular generation by the DERs stipulates seamless integration and smooth transition between events caused due to variations in the input energy and output loads in response to the transients. Multi agent system (MAS) approach is a fertile area for research gaining momentum to analyze phenomena relating to the smooth integration of DERs in a standalone micro-grid dispensation. Use of enabling technologies like waste heat generation, advanced Fischer Tropsch Synthesis, energy efficient sensors and power electronic switches etc. in the micro-grid architecture is prevalent to realize sustenance of environment, energy efficiency and instantaneous response of the control mechanism to the changing load conditions respectively. Application of these technologies optimize energy costs, reduce downtime, maximize energy efficiency and reduce hardware requirements.

2.7 Protection Issues[3][2015]

Protection issues are important in DER integration of Micro-grid as these are in the power systems with conventional energy resources. These include provisions to eliminate possibilities of false tripping of feeders, nuisance tripping of protective devices, blinding of protection, increase or decrease of fault levels with connection and disconnection of DERs, unwanted islanding, prevention of automatic reclosing and out-of-synchronism reclosing etc. etc.; Compatibility with island mode and insulation coordination need also be given due weightage in the protection circuitry.

2.8 Power Quality[21][2008]

Power quality at consumer terminals is an important obligation of the service provider implying availability of interruption free, sinusoidal voltage of unvarying amplitude and frequency. The nearer the electric power is to meet these requirements, the better is the quality. The biggest glitches in power quality maintenance occur due to the voltage unbalance, harmonic content, increased reactive power demand, and frequency deviation. The permissible power quality limits are set by the standards framed by the IEC (Int Electrotechnical Commission) and IEEE (Institute of Electrical & Electronics Engineers. The techniques commonly used for power quality improvement include PSO, synchronous reference frame based current control loop and conventional PI regulator, Static VAR Compensator (SVC) and Shunt Active Power Filter (SAPF)' Droop control technique and Dump load methods etc.etc;. The particular method applied shall depend upon for specific case shall be decided on the basis of power quality problem in each individual case.

2.9 Challenges Relating To The Conformity With The IEEE Standards[7] [2014]

Standards provide a common portfolio for a variety of generation technologies without which the issues related to interfacing, interoperability and integration of the energy sources for optimum energy output shall be impossible to realize. The most important standards for grid-connected DG/DER systems are IEEE P1547, IEEE 929-2000 and IEEE 519.The standards for interconnecting micro-grids with neighbouring grids and the main grid system is given in the IEEE SCC21 2030 series. Strict adherence to these standards would enable smooth handling of the following aspects: **I**mpacts of voltage, frequency, power quality, •Inclusion of single point of common coupling (PCC) and multiple PCCs, • Protection schemes and modifications,

- Monitoring, information exchange and control,
- Understanding load requirements of the customer,
- Knowing the characteristics of the DG/DER,
- Identifying steady state and transient conditions,
- Understanding interactions between machines,
- Reserve margins, load shedding, demand response,
- Cold load pickup, additional equipment requirements, and
- Additional functionality associated with inverters.

3. Social Challenges

Electricity access is too much of luxury for a sizable cross section of the country's population living in villages, especially those living in geographically inconvenient and inaccessible locations too uneconomical to connect with the grid due to the prohibitively high cost of transmission and distribution network and energy losses. The biggest challenge before the country is to provide clean, reliable, affordable and abundant electricity services to this deprived section of the society to improve their quality of life, productivity and economic prosperity. Quite many of them would be prepared to pay for electricity services but the possibility of getting clean, reliable, affordable, abundant and environment friendly energy through DER based Islanded Micro-grid systems is alien to them. The need of the hour is to improve their awareness and make electricity infrastructure development a movement in rural India. Implementation of this would bring to the fore several social and economic challenges and issues as listed below.

3.1. Capacity building and awareness generation in Green buildings and campuses:

Integration of renewable DERs in micro-grid systems can potentially generate environment friendly high grade energy at affordable cost and enhance capacity of the electricity infrastructure. Realization of this entails politico-social willingness and cooperation of those at the helm of affairs, education and awareness of prospective consumers and service providers' expertise at the local level. Wholehearted cooperation all to accomplish universal electricity access should be the main motto of everyone associated with electricity service.

3.2. Grooming skilled engineering and technician workforce:

Grooming skills is essential to provide effective workforce in the engineering and technician cadres in varius skill areas in which expertise is needed. This shall rid crisis of human resource in the handling of jobs related to development of infrastructure and , maintenance of plant, machinery and services that the consumers need for effective functioning of the micro-grid utility organization.

3.3. Indigenization and technological improvements:

There is need to implement best practices, update technology, indigenization and standardization of the components in each specialization relating to renewable energy. Efforts to indigenize and standardize components relating to renewable technologies should be stepped up with the help of professionals to slash down the cost of import. Best practices must be developed to optimize generation at low cost without hassle and dependence on foreign knowhow to suit local environment.

3.4. Entrepreneurship Development in Energy[18,19,20] [2015,2014, 2014] through Government support:

The task of providing universal electricity access and strengthening electricity infrastructure and services in rural India is a herculean task. It is therefore not advisable to leave it solely to the Government initiative. The indispensable need of electricity must be fulfilled through active involvement and support not only from the Government, but also from the young technocrats who can immensely contribute as the professional entrepreneurs, managers, engineers and technicians in the energy business. Their participation at various levels shall not only mitigate employment problem but also enrich energy infrastructure of the country and bring industrialization and prosperity to India in general and rural segment of the society in particular. The Government at the centre and in the states and the Gram Panchayats as well as financial Institutions are urged to simplify financial and administrative procedures to streamline cash inflow in order to facilitate young entrepreneurs involve themselves in the nation building process. . The Government can act as facilitator to establish small enterprises and make these young technocrats as providers of electricity infrastructure and services. Their efforts shall not only enrich villages with energy but also help employment generation, industrial productivity and economic development in rural India. The fraternity of young entrepreneurs, managers, engineers and technicians are called upon to make optimum use of training and financial support from Government Schemes like Deendayal Upadhyay Gram Jyoti Yojna(DDUGJM), Rajiv Gandhi Grameen Vidyutikaran Yojana, Village Energy Security Programme and other facilities to become partner in progress of the country through enrichment of electricity infrastructure in rural India and make universal electricity access a successful venture through effective DER integration of renewable energy systems in the microgrids.

4. Future Scope

Integration of DERs in micro-grid systems is the practical problem requiring simulation and merger of technologies for design optimization. The second author of this paper stipulates simulation work using intermittent DERs in the micro-grid system with this study and simulation and design of smart grid systems in the latter stage of research.

IV. CONCLUSION

The study has given a broad overview of DER integration to enhance renewable energy thrust in India for strengthening universal electricity access and rural electricity infrastructure in the country. Problems and issues relating to the DER integration in the micro-grid architecture are investigated and the technical, social and economic challenges in the practical implementation of DERs based micro-grid systems have been analyzed in detail. Practical implementation for integration of DERs and creation of micro-grid systems to combat electricity crunch envisages entrepreneurship and financial support from Government agencies which get a brief mention in the paper. The fraternity of young technocrats are called upon to perform this sacred task to upgrade quality of life and industrialization and productivity and bring resurgence to the Indian economy which is also a highlight of this paper.

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