Hybrid Micro Grid Systems - Drivers & Challenges

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Abstract
Increasing environmental concerns, consumer expectations in terms of reliability & better quality of power supply and improving economics of distributed energy resources (DER) based on renewable, is making Micro Grid a viable proposition. Hybrid Micro grid utilising diversity of various energy resources including Wind, Solar, Biomass, and Energy Storage Batteries is found to be a better solution than single source Micro grid system. However, integration of multiple resources poses many issues & challenges. Moreover, present distribution system offers many technical & operational glitches for successful integration of Micro Grid Technologies. Paper addresses such challenges, issues and solutions. The Micro Grid resources optimization is generally being done based on self-sufficiency criterion which utilizes the grid support only in the event of contingencies like fault, generation disruptions (DER) etc. Paper also discusses various resources optimization techniques to serve the net load requirements in all time of the Day (TOD).
Keywords: Distributed Energy, Black Start, net load, Islanding, MGCC, PSO, Genetic Algorithm

1. Introduction

The growing energy demand in developing nations has triggered the issue of energy security which has made essential to utilise the untapped potential of renewable resources. As a result, the solar photovoltaic and wind generation technologies have made significant progress in the last decade and many megawatt scale solar parks and wind farms have been added to the Grids.

In the view of increasing environmental concerns and consumer expectations in terms of reliability & satisfactory power quality, energy access to farthest located consumers, increasing technical & commercial losses (AT&C) etc. is indicating need of paradigm shift from centralized electricity system to decentralised & distributed electricity system. These challenges give a thrust to Micro grid Concepts. Micro Grid is realised through utilizing the potential of distributed renewable energy resources where various small power systems working as independent "Micro Grids" may be established which can cater to several consumers' loads through small size distributed energy resources. In other means, Micro grids are modern, small-scale version of centralized electricity systems which generates, distributes and regulates the flow of electricity to a set of consumers at the local level itself. From generation point of view, with the advancement of renewable generation technologies, small generating units exploiting renewable sources through Solar PV panels, wind turbines or biomass plants have already been commercialised at distribution level. However, at most of the places Micro Grids are realised through Single resources generation like Solar PV along with Battery Storage systems.

As the renewable resources generally suffers with the limitations of intermittency and variability, use of more than one distributed resource i.e. resource diversity, improves reliability and security of power supply. Thus hybrid Microgrid system is preferred over the use of single resource Microgrid System, but challenge lies in integration of all such resources based generations to meet consumer demand with reliability, security and best of quality.

The hybrid Microgrid may consists of Solar Photovoltaic array (PV), Wind turbine (WT), Biomass Gassifier (BG) and Battery Energy Storage (BES). The figure1 shows grid-interfaced Hybrid Microgrid architecture. In such systems, two types of control i.e. sources control and load control is designed. Source control is achieved primarily through generation control of Biomass Gassifier or Battery energy storage systems which serves as flexible generation whereas Solar PV and Wind, considering its nature of resources, is never controlled or backed down. At the time of supply exceeding demand, flexible resources like Biomass is asked to back down/shut down and balance excess energy is used to charge the batteries for utilisation in times of lower generation by other resources like Wind/Solar. Thus energy storage batteries provide an economical and/or logistical advantage by making better use of off-peak hours to supply the daily energy needs in peak hours. In case of demand exceeding the generation, batteries provide immediate power response dynamically to the net load fluctuations as Biomass Gassifier gives comparatively slower responses, but longer duration support. Moreover in case of further deficit, demand side management through Advanced Metering Infrastructure (AMI) controlling consumer non-critical load is achieved. In real terms, design of Microgrid should be based on self-sufficiency criterion that means in normal scenario, energy is not drawn from the main grid. In such concepts, grid interfacing is provided only to support Microgrid in case of contingencies or unforseen eventualities' so that consumers are not deprived off the electricity.

The distributed generators (DG) in Microgrid are generally inverter-based that has very low inertia. Unlike, rotating DGs, the low inertial inverter based DGs have tendency to respond very quickly causing large transients. These transients of high magnitude are not favourable for stable operation of Microgrid. However, due to their fast response, the inverter based sources ensure the supply of dynamic load regardless of slow rotating machines which requires seconds of response time to transients [11]. Therefore, this aspect needs to be taken care while designing architecture of Microgrid.

Considering different characteristics of various distributed resources, their optimal sizing & selection requires judicious choices based on techno-economic considerations. The choices of DGs are based on case to case basis which also require detailed study of historical data of resource availability of Wind/Solar. However, the unit sizing/optimisation is done by various optimisation methodologies which are discussed in section II. In section III, the paper outlines some technical and operational challenges for Microgrid interface into present power system.

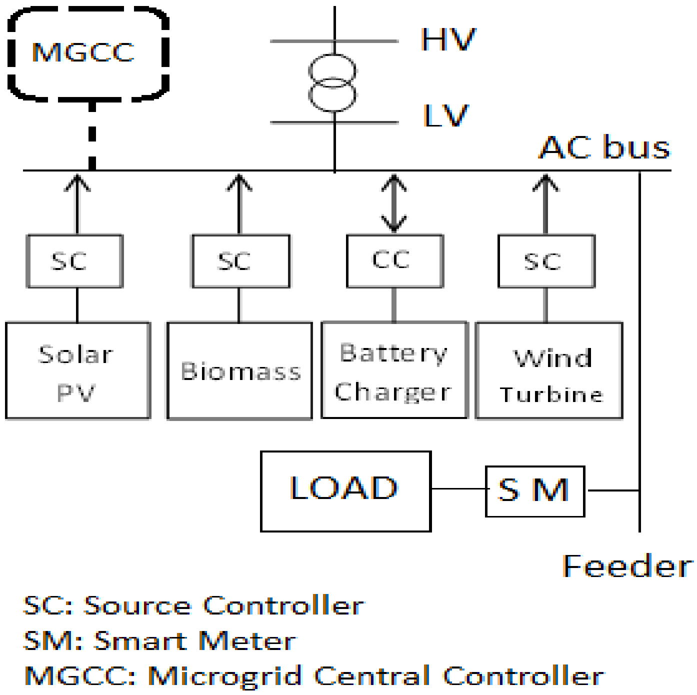

Fig. 1 Grid-interfaced Microgrid architecture

2. Resources optimization techniques

Resource optimisation is carried out with objective of fitting the load curve at any point of time which means providing reliable power supply to the consumers all the time of the day. Apart from technical considerations, economical aspects including capital cost as well as operation cost of DGs is also given due weightage.

For standalone hybrid system, typical tangent method is used to fix size of wind generator, PV panels and the capacity of the battery [1]. Recently, various optimization methodologies are being exploited for unit sizing in Microgrid system. In research work by Xu et al, the Genetic Algorithm (GA) has been used to optimize the size of PV panels, wind generator and capacity of battery. In some research works, Evolution strategy and Particle Swarm Optimisation (PSO) techniques have also been used to arrive at minimum cost [3, 4]. The references [1, 2] show GA technique provides better performance as compared to other literature. These optimization methods need mathematical formulation of non-linear cost minimising objective function and constraints achieving certain reliability conditions.

3. Technical hallenges

Microgrid, as a new field of research, is in the evolutionary stage. Many pilot projects have been tested in laboratories worldwide but very few have been replicated in the field. In field, apart from technical challenges, regulatory barriers are also present which makes commercialization of Microgrid model implementation quite difficult then as imagined [5].

In Micro Grid System, the Microgrid Central Controller (MGCC) resides at the centre of Microgrid architecture, acting as a brain of the entire system. MGCC monitors and controls the operations over SCADA network utilising Information and Communication Technologies (ICT). MGCC facilitates all the functions of Sources as well as Load control to achieve load-generation balance all the time.

However to improve reliability, the Microgrid system is grid interfaced even if the unit sizing of distributed generations large enough to make Microgrid system autonomous. As a result, the increased flexibility in grid interfaced Microgrid architecture using advanced features of the Information and Communication Technologies (ICTs) for controls and operations creates huge complexities and technical challenges in the Microgrid system. Moreover, Micro Grid being much weaker in terms of short circuit strength, as compared to conventional grid, any parameter variation may lead to have big impact on health of the system.

The intentional islanding required in grid interfaced Microgrid system requires DGs to operate in dual mode of operations i.e. PQ mode and PV mode. The hybrid system having DGs located at different locations must also be equipped with black start capability. The fault current observed in the system also varies with grid-tied and off-grid conditions which makes the protection strategy for Microgrid architecture to be different from one in present power system. Given these limitations and requirements in Microgrids, the three major technical challenges are identified in Microgrid systems which are discussed as under:

4. Operation support in Grid tied and islanded conditions

In grid-tied condition, the DG has to work in PQ mode where the source controller of DG controls the output current. In this condition, Voltage and frequency of Micro grid is governed by grid parameters and therefore DGs have to follow the Superior Grid. In islanded condition, when the Microgrid is in isolated state from the utility grid, DG has to transition in PV mode controlling Voltage & frequency of its own autonomous mode. In hybrid system, where more than one DG is present, all DGs are operated in parallel in master-slave configuration. A Microgrid following master-slave strategy needs only one energy source to operate in PV mode when utility grid is absent. However, the master slave configuration makes all other DGs dependent on a single source acting as master. The highly centralized controlled system is always vulnerable because in case the master fails, the whole Microgrid could suffer collapse. The solution is to make other DGs also capable of taking over the role of master in such situations. The transition between the modes is needed to be seamless in order to improve the quality of power supply. The Microgrid system consists of two types of DGs: inverter-based DGs and rotational-machine-based DG. The Inverter based DG has low output impedance and can change between modes – current and voltage modes very fast but produces large transients during mode transfer [6]. However, the rotational-machine-based DGs balance the voltage and to adjust current sharing, by using droop control method. Therefore, the challenge is to operate hybrid system with inverter based DGs by utilising fast inverters while avoiding large transients during mode transfer.

5. Black start capability

Black start phenomenon is to start the Microgrid system from complete shutdown state. It is a challenging task to black start a Microgrid system because it requires complete analysis of system's state. Moreover start of DGs and connection of loads requires certain procedure to be followed. It involves step-by-step connection of DGs and loads to the LV grid on the basis of overload capacity. However, in comparison to conventional power restoration, the Microgrid restoration process is much simpler due to reduced number of variables (switches, DGs, and loads) [6].

The capability of black start is needed in remote areas where utility grid is absent and where utility grid outages are very frequent.

In Microgrid system, bottom-up approach to black start is more preferred as it reduces the restoration times [6]. The MGCC equipped with black start software plays central role by registering conditions of system and following a set of rules during the restoration period. The rules and conditions define a sequence of control actions to be carried out.

The DGs in Microgrid system always need reference voltage and frequency to operate. So, DG acting as master needs to produce reference voltage and frequency for other DGs must be present. The bottom-up approach includes building up of low voltage network, connecting DG, controlling voltage and frequency, connecting controllable loads and MG synchronization with upstream grid, when it is available, in sequence.

6. Protection strategy

The protection scheme of Microgrid is much more complex and challenging than conventional power system because of the requirements of both grid-interfaced and grid-isolated modes in Microgrid and also, the existence of the two types of faults - internal and external faults. The need of differentiation between the types of faults demands the formulation of overall new protection strategy for the Microgrids. The Microgrid system has load current/fault current ratio smaller in comparison to the conventional system [6]. The conventional power systems comprising of synchronous generators provide large fault currents that are helpful for fast and efficient fault protection. Whereas, the inverter based DG can provide fault current up to only two –three times the rated current which is insufficient when fault is in upstream network. For this, it needs oversizing of inverters but it is not a preferred option due to economic reason. If the protective relay designed for small fault currents has to satisfy the Microgrid operation, this might lead to nuisance tripping. To avoid this problem, following protection strategies are under research for Microgrid.

Adaptive protection schemes which can change relay settings in real time [10]. This would ensure the protection of Microgrid but it requires very fast communication network. The other way is to design Microgrid to enter it in island mode before any protection action could take place in response to an internal fault [5]. This strategy would eliminate the need of adaptive relay setting but it creates heavy dependence on correct and timely opening of Point of Common Coupling (PCC) switch. The malfunctioning of communication link to PCC might lead to selectivity issue of nuisance tripping from internal protection devices in response to an external fault. So, neither of these two solution appears to be the direct solution to protection of Microgrid.

However, the protection scheme using differential relays in place of overcurrent relay is seen by many researchers to be a more promising solution [8]. The difference between the two transformers across the device passing through the relay, when get exceeds a certain threshold value, the line gets tripped. Under this scheme, the fault location identification with different fault types (earth fault, phase to phase fault, etc.) and the line fault differentiation from DG faults can be achieved. The differential relays show highest selectivity and operate only for internal faults but they also require reliable communication for instantaneous data transfer between terminals of the protected element.

Although Differential relay scheme is suitable scheme to Microgrids but differential relays are too costly to deploy for all equipment. The differential relays are generally used to protect important piece of equipment such as distributed generators and transformers [9]. So, any single scheme will not address the protection system requirement of Microgrid. It should be mix of at least two of above proposed to improve the reliability of operation keeping as low as possible. One common requirement of almost all protection mechanism is a high speed communication network to enable the communication of devices with each other and determine the location of fault and nature of the fault.

The limitation of overcurrent relays in Microgrid and high cost associated with differential relays has opened scope for voltage based protection mechanism in Microgrid. The voltage based protection relays trips in the case of overvoltage and under voltage scenario.

7. Conclusions

The paper investigates technical & operational challenges and probable solutions for Hybrid Microgrid systems comprising various distributed energy resources. The load -generation balance in such system is achieved through Source control as well as Load control through AMI solutions. Various algorithms can also be used towards resource optimization for evolving best solutions based on techno-economic considerations.

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