MICROGRIDS – Large Scale Integration of Micro-Generation to Low Voltage Grids

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INTRODUCTION

Key economic potential of the installation of Distributed Generation (DG) at customer premises lies in the opportunity to utilise locally the waste heat from conversion of primary fuel to electricity. Therefore there has been a significant progress in developing small, kW-scale, CHP applications. These systems are expected to play a significant role in the local generation of Northern EU countries. PV systems are expected to become increasingly popular in Southern EU countries. The application of micro CHP and PVs potentially increases the overall efficiency of utilising primary energy sources and consequently provides substantial environmental gains regarding carbon emissions, which is a critically important benefit in view of meeting the Kyoto objectives. Furthermore, the presence of generation close to demand could increase service quality seen by end customers.

From the Utility point of view, DG located close to loads reduces flows in transmission and distribution circuits with two important effects: loss reduction and ability to potentially substitute for network assets. Thus, the application of distributed energy sources can potentially reduce the demand for distribution and transmission facilities. The inability to control an increased number of distributed sources however creates huge difficulties in operating and controlling the distribution network. Microgrids offer the possibility of coordinating the distributed resources in a more or less decentralized way, so that they behave as a single, controlled entity. In this way, distributed resources can provide their full advantages in a consistent way.

Microgrids comprise Low Voltage (LV) distribution systems with distributed energy sources, such as micro-turbines, fuel cells, PVs, etc., together with storage devices, i.e. flywheels, energy capacitors and batteries, and controllable loads, that behave as a coordinated entity, thus offering considerable control capabilities over the network operation. These systems are interconnected to the Medium Voltage Distribution network, but they can be also operated isolated from the main grid, in case of faults in the upstream network. Thus, Microgrids can provide network support in times of stress by relieving congestions and aiding restoration after faults. From the customer point of view, Microgrids provide thermal and electricity needs, and in addition enhance reliability, reduce emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially lower costs of energy supply.

This paper outlines the key issues regarding technical and economical operation of Microgrids and provides some findings of the EU funded project “MICROGRIDS – Large Scale Integration of Micro-Generation to Low Voltage Grids”, EU Contract ENK5-CT-2002-00610 [1].

IMPACTS OF MICROGRIDS ON SERVICE QUALITY

Present distribution networks are designed such, that performance of the MV and LV networks have a dominant impact on the quality of service seen by the end customers, while faults in HV distribution and transmission networks do not normally affect the continuity of supply of customers connected to MV and LV networks. In the majority of EU countries, more than 80% of the customer interruptions and the customer minutes lost have their cause at MV and HV levels. One of the key benefits of Microgrids is the potential to increase service quality by providing generation redundancy, where most needed. The capability of Microgrids to operate in islanding mode can potentially relieve the effects of faults in the upstream networks. This capability requires sophisticated protection, control and communication infrastructures, in order to be able to isolate external faults and provide stable autonomous operation.

Given that average customer in the EU experiences about 1 outage per year lasting for about 60 minutes, it is important to answer if the introduction of Microgrids, can be justified on this basis. The analysis showed that considering typical asset lifetime and discount rate, islanding operation of small-scale DG, such as 2kW DG supplying one household, would in average permit an expenditure of around €45 to upgrade the system for islanding operation, while a 1MW network area of commercial customers would support an investment of around € 300,000.

Some Microgrids could, in addition to the main activity of generating electricity, market the islanded operation service and open up a secondary income source. In present networks, islanding operation is expensive since the costs of the generation plant and additional system automation and control must be borne. However, in future, large numbers of DG could already be connected to actively managed Microgrids.

IMPACTS OF MICROGRIDS ON EXPANSION PLANNING

Microgrids have the ability to postpone the reinforcement of high voltage distribution and transmission circuits as DG is located close to loads and there is likely considerable correlation between generation and local loads. Furthermore, the number of generators will be very large, so that the status of individual units will not make a particularly strong impact on the overall aggregate output. Clearly, Microgrids will play a critical role in replacement strategies of distribution and transmission networks. The exact evaluation of the effect of Microgrids on the network capital expenditure needs to be carefully studied.

MICROGRIDS OPERATION

Technical challenges associated with the operation and control of Microgrids are immense. Effective energy management is a key to achieving vital efficiency benefits by optimising production and consumption of heat, gas and electricity. The coordinated control of a large number of distributed sources with probably conflicting requirements and limited communication is a very challenging problem imposing the adoption of distributed intelligence techniques.

Furthermore, the management of instantaneous active and reactive power balances, power flow and network voltage profiles imposes unique challenges in the context of Microgrids. Traditionally, power grids are supplied by sources having rotating masses and these are regarded as essential for the inherent stability of the systems. In contrast, Microgrids are dominated by inverter interfaced distributed sources that are inertia-less, but do offer the possibility of a more flexible operation. A further particular problem of Microgrids is the high resistance to reactance ratio of the low voltage networks, resulting in strong coupling of real and reactive power. Hence the control of voltage and frequency can no longer be considered separately.

A key challenge of Microgrids is to ensure stable operation during faults and various network disturbances. Transitions from interconnected to islanding mode of operation are likely to cause large mismatches between generation and loads, posing a severe frequency and voltage control problem. Storage technologies, such as batteries, ultra-capacitors and flywheels may become important components of Microgrids, with the duty to provide stable operation of the network during network disturbances. Maintaining stability and power quality in the islanding mode of operation requires the development of sophisticated control strategies and needs to include both generation and demand sides.

Microgrids Control Levels

In order to achieve the full benefits from the operation of Microgrids, as outlined in the Introduction, it is important that the integration of the distributed resources into the LV grids, and their relation with the MV network upstream, will contribute to optimise the general operation of the system. To achieve this goal, a hierarchical system control architecture comprising three critical control levels, as shown in Figure 1, can be envisaged [1]. The different control levels comprise:

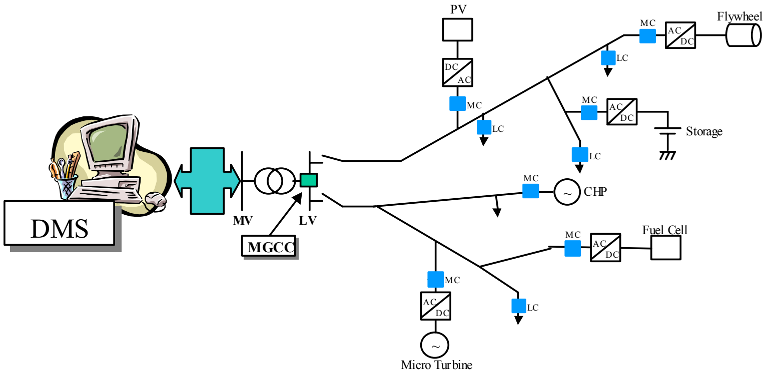

Figure 1 – Micro-Grid control architecture

- Local Microgenerator Controllers (MC) and Load Controllers (LC)
- MicroGrid System Central Controller (MGCC)

- Distribution Management System (DMS).

The ***Microgenerator Controller*** (MC) takes advantage of the power electronic interface of the micro source and can be enhanced with various degrees of intelligence. It uses local information to control the voltage and the frequency of the Microgrid in transient conditions. MCs have to be adapted to each type of micro source (PV, fuel cell, micro turbine, etc.) Local *Load Controllers* (LC) installed at the controllable loads provide load control capabilities.

The ***Microgrid Central Controller*** (MGCC) functions can range from monitoring the actual active and reactive power of the distributed resources to assuming full responsibility of optimizing the Microgrid operation by sending control signal settings to the distributed resources and controllable loads.

MicroGrids connected on the feeders of ***Distribution Management Systems*** (DMS) should ideally look like concentrated loads. The issues of autonomous-non-autonomous operation of the MicroGrids and the related exchange of information are new important issues. Disconnection and re-synchronization of Microgrids during and post-fault periods need to be evaluated.

It is clear that in order to operate a Microgrid in a coordinated manner it is important to provide a more or less decentralized decision making process in order to balance demand and supply coming both from the distributed resources and the MV distribution feeder. There are several levels of decentralization that can be possibly applied ranging from a fully decentralized approach to a basically centralized control depending on the share of responsibilities assumed by the MGCC and the MCs and LCs. These levels need to be explored and relative benefits identified.

Islanded vs. Interconnected Mode of Operation

In interconnected mode of operation, decisions on local generation are based on maximization of the Microgrids value, according to the availability of the primary energy sources and the energy prices. Network restrictions, namely capacity of the MV/LV transformer or LV network congestions have to be of course respected.

When failures occur in the MV or HV system, the Microgrid is automatically transferred to isolated islanding operation, supplied by itself. Seamless transition between the interconnected to the islanding mode is crucial for uninterrupted continuity of supply. With an intelligent distributed approach, MCs and LCs act as independent agents and making efficient use of the local resources maintain system operation in islanded conditions.

If a system disturbance provokes a general blackout at the upstream HV or MV networks, such that the Microgrid is not able to separate and continue in islanding mode, and if the MV system is unable to restore operation in a specified time, the MCs can provide local Black Start capabilities, exploiting autonomous agent concepts. Moreover, the MGCC can support re-connection during Black Start, helping in this way the upstream DMS system that is managing the MV distribution network.

Management of voltage and frequency

In isolated operation mode frequency and voltage control are challenging problems. The conventional power system employs conventional droops, as shown in Figure 2. In principle, this concept can be also adopted by the MCs of the DG, in order to provide load sharing capabilities. However, this is not straightforward to implement in Microgrids due to the close coupling of P&Q effects. For example, voltage regulation based on reactive power injection alone is impossible, unless excessive amounts are available. It has been shown, that the concept of Figure 2 can be effectively applied, as long as the frequency and voltage droops have the same sign.

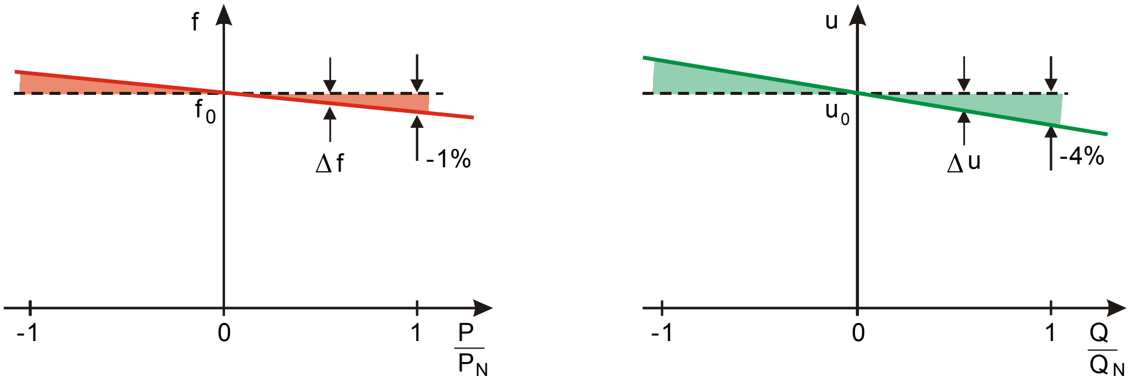

Figure 2. – Frequency and Voltage Control via droops

The role of IT

IT tools can play an important role in the operation and control of Microgrids. A future decentralized system might require information from any MC or LC attached to the power grid, such as how much power it consumes or it might produce. In addition, many new technologies under development could make even small users of electricity more responsive to changes in operating conditions, as well as to electricity prices. Internet links with embedded software are expected to be widely used to provide the necessary communication. Switching at various locations in any such system will again utilize embedded IT to provide a highly re-configurable network architecture.

MICROGRIDS DESIGN

Standardisation of technical and commercial protocols and hardware

In order to promote a ***mass scale*** development of Microgrids, it is essential to develop standards of technical and commercial protocols that will allow easy installation of distributed energy resources with “plug and play” capabilities. MCs and LCs with inherent frequency and voltage control capabilities, ride-through capabilities during frequency variations and voltage dips and fault current capabilities should be standardized.

Moreover, flexible power electronic interfaces open possibilities of Microgrids operating at variable frequencies. It is also possible to consider Microgrids that will be entirely operated on direct current (DC) interfaced to the main grid via DC-to-AC converters.

Safety and Protection

Grounding of the distributed energy sources of the Microgrid, and the transformer connecting it to the utility network, must be carefully analyzed and appropriate rules need to be developed, so that the same level of safety as conventional systems is achieved. Analysis and design tools for safety assessment should explicitly model the grounding and bonding of the Grid circuits.

Protection must respond in order to isolate the Microgrid from the main utility, as rapidly as necessary, to protect the Microgrid DGs and loads. This requires the development and installation of suitable electronic static switches. In addition, the unique nature of the MicroGrid design and operation requires a new look into the fundamentals of relaying. A related issue is the prospect of increased use of power electronic based devices within the Microgrids network, e.g. solid state circuit breakers with fault current limiting capabilities to interconnect microsources.

Modelling and simulation of Microgrids

Microgrids include a wide variety of generator technologies (micro generators, fuel cells, PV, wind turbines) and storage devices (batteries, flywheels, ultra-capacitors, etc.) mostly coupled via power electronic interfaces. Modelling of these components in steady-state and transient conditions is far from trivial. Furthermore, Microgrids may use single-phase circuits and be loaded with single-phase loads. These factors generate unbalanced conditions that can be accentuated with the interaction of dynamic loads such as induction motors. To model these effects, a suitable analytical tool has been developed that represents the system with its three phases, the neutral conductors, the ground conductors and the connections to ground and includes models of various microsources.

CONCLUSIONS

The coordination of DG and storage devices connected at LV grids is essential in order to integrate them in the overall network operation and control. This is achieved through the operation of Microgrids. This paper presents benefits and key technical challenges of Microgrids. Although clear benefits are undisputable, there is considerable difficulty to quantify them. Moreover, the challenging technical problems in the design, operation and control of Microgrids are briefly outlined and some key findings and prospects briefly presented.

REFERENCE

1. “MICROGRIDS – Large Scale Integration of Micro-Generation to Low Voltage Grids”, EU Contract ENK5-CT-2002-00610, Technical Annex, May 2002, also http://microgrids.power.ece.ntua.gr

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