Management of MicroGrids

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Abstract

This paper describes the research presently under development regarding the integration of several microsource types in LV distribution networks. Such research is financed through an EU R&D project and tackles several scientific and technological related problems in the fields of microsource electrical modelling, power system LV operational impact analysis, monitoring and control, power quality and network reliability, protection coordination and personnel safety, communications, economical and electrical market driven procedures and definition of new interconnection standards.

1. Introduction

In the last 20 years the power system industry witnessed an important change in the conventional centralized paradigm of operation as a result of a large scale integration of dispersed generation (DG) either at the MV or at the LV distribution levels. In the last years this change became more perceptible mainly due to the connection of a large amount of generation sources at the MV level. In the years to come such a scenario is also going to happen in LV grids through the interconnection of small modular generation sources forming a new type of power system, **the MicroGrid**. MicroGrids can be connected to the main power network or be operated autonomously, if they are isolated from the power grid, in a similar manner to the power systems of physical islands.

Depending on the primary energy source used, on the micro generator dimension and on the type of power interface these micro sources can be considered as *non-controllable, partially controllable (e.g. renewable sources that can reduce output only)* and *controllable (e.g. small co-generation units and storage units*). To the utility the MicroGrid can be thought of as a controlled cell of the power system. To the customer it can be designed to meet his special needs and provide additional benefits, such as improved power quality and reliability, increased efficiency through co-generation and local voltage support.

This new scenario of operation requires the development of applied research at several levels to profit from the capabilities that these generation devices offer and develop efficient strategies to manage these MicroGrids. Among other issues this includes dealing with microsource electrical modelling, power system LV operational impact analysis, monitoring control, power quality and network reliability, protection coordination and personnel safety, communications, economical and electrical market driven procedures and, of course, the definition of new interconnection standards.

To provide support for the future scientific and technological EU needs in this field, the 5th RTD framework programme included these topics in its research priorities. The **MicroGrids** project came out with a research proposal, to be carried out by several European research institutions and companies, in order to tackle the problems that challenge the integration of large amounts of different microsources in LV distribution networks. This **MicroGrids** research project is entitled "Large Scale Integration of Micro-Generation to Low Voltage Grids – MicroGrids" [1]. The project was launched in January 2003, has a duration of 36 months, is coded as NNE5 – 2001 - 00463 and the research is being conducted under the contract ENK5 – CT – 2002 – 00610.

2. Technical and economical advantages of microgeneration

The development of Microgeneration and MicroGrids is very promising for the electric power industry since several advantages are easily foreseen namely at the following four levels:

- Environmental issues – the environmental impact of microsources is expected to be smaller than large traditional thermal or hydro stations. Apart from that, the physical closeness of consumers regarding microsources can contribute to increase the awareness of consumers towards the use of energy. Another important environmental contribution will be in the reduction of Greenhouse Gas (GHG) emissions and the mitigation of climate change due to the creation of technical conditions to increase the connection of RES at the LV level. This will be achieved by the synergy of these sources with storage devices and their efficient coordinated control, both at a local and at the MicroGrid level. RES and micro-sources are characterized by very low emissions. This is well known for RES, it is also true for micro turbines, due to the close control of the combustion process (NO_x reported less than 10 ppm).
- Operation and investment issues - reduction of the physical and electrical distance between generation and loads. This can contribute to:
  - improve the reactive support of the whole system thus enhancing the voltage profile;
  - remove distribution and transmission bottlenecks;
  - reduce losses in upstream higher voltage networks;
  - reduce or, at least, postpone investments in new transmission and large scale generation systems;

  Contribution for the reduction of the losses in the European electricity distribution systems will be a major advantage of microgeneration. Taking Portugal as an example, the losses at the transmission level are about 1,8 to 2 %, while losses at the HV and MV distribution grids are about 4%. This amounts to total losses of about 6% excluding the LV distribution network. In Portugal in 1999 the consumption at the LV level was about 18 TWh. This means that with a large integration of micro-generation, say 20% of the LV consumption, a total reduction of losses of, at least, 216 GWh could be achieved. The Portuguese legislation calculates the avoided cost associated with CO_2 pollution as 370g of CO_2/kWh produced by renewable sources. Using the same figures, about 80 ktones of avoided annual CO_2 emissions can be obtained in this way. Microgeneration can therefore reduce losses in the European transmission and distribution networks by 2-4%, contributing to a reduction of 20 million tones CO_2 per year in Europe.
- Power quality - increase of system reliability and, in general, of power quality due to the decentralization of supply, to the better match of supply and demand and to the reduction of the impact of transmission and large scale generation outages. Increase in reliability levels can be obtained if microgenerators are allowed to operate autonomously in transient conditions, namely when the distribution system operation is disturbed upstream in the grid. In addition, in an emergency state, Black Start functions can minimize down times and aid the reenergization procedure of the bulk distribution system.
- Market issues - possible development of market driven operation procedures of the microsources leading to the reduction of market power of already established generation

companies and to the possible contribution of the microsources to the provision of some ancillary services. Contribution for energy price reduction can also be obtained through a widespread microgeneration. The wholesale price of electricity average is about 30-45 Euros/MWh, while retail price is about 90-100 Euros/MWh. Transmission and distribution networks are responsible for the difference and the appropriate economic balance between network investment and dispersed generation could reduce the long term prices of electricity for end consumers by about 10%. Further price reduction can be achieved by optimizing Microgeneration operation, i.e. generating locally power at expensive peak loads and purchasing power from the Grid when it is economically more attractive.

However, the development of **MicroGrids** still faces several challenges, difficulties and potential drawbacks, as the following ones:

- High cost of distributed energy resources – this eventually requires some kind of subsidies to induce investments, at least during a transitory period. Although this can be justified as a kick off measure, in the long term it would certainly be seen as a distortion regarding market rules;
- Technical difficulties - these are related with the lack of experience and presently technical inability to control a significant number of microsources, thus requiring more research on dispatch real time models, dynamic models for several devices, simulation of real time operation and control, design of protection schemes. Specific telecommunication infrastructures and communication protocols need to be developed to help managing, operating and controlling these MicroGrids.
- Absence of standards – since this is a new potential area, there are not yet available standards for several crucial issues as power quality data for several microsource generation, standards and protocols to enable the integration of microsources in electricity markets. Safety guidelines and protection guidelines are also lacking.
- Administrative and legal barriers – in general there is lack of legislation and regulations to frame the operation of microsources. In some countries, as in Portugal, there is already specific legislation namely establishing the tariffs to be paid to microgeneration, basically adopting an avoided cost strategy leading to subsidised tariffs. Although important, this can only be seen as a first step aiming to induce the investments in this area. A new step would have to be adopted in the future so that one would go from a simple microsource integration in LV newtorks – actually much similar to the integration of dispersed generation in MV networks – to the real possibility of establishing a **MicroGrid**, that is an association of a LV network, microsources and electrical loads able to operate in an interconnected mode or in an autonomous isolated way. In this sense, several issues have to be co-ordinated with the MV distribution company such as dispatch voltage/Var control strategies, real time management and ancillary services provision, operation upon unplanned events and during black start, electrical equipment safe work practices.

An effort in the harmonization of standards and rules is therefore foreseen as a result of the growth of microgeneration. Specific telecommunication infrastructures and communication protocols need to be developed to help managing operating and controlling these MicroGrids.

Other economic advantages can result from the growth of Microgeneration due to the social and economical impacts that may result from the creation of new jobs need to produce, install and maintain these generation devices.

3. The MigroGrid concept and the MicroGrids project

3.1. The MicroGrid concept

Following the increasing penetration of dispersed generation in MV networks, the connection of microgeneration to LV networks starts to be investigated, and in some cases subjected to pilot experiences. In this sense, a **MicroGrid** can be defined as a low voltage distribution system to which small modular generation systems are to be connected. In some sense, a **MicroGrid** corresponds to an association of electrical loads and small generation systems through a LV distribution network. This means that loads and sources are physically close so that a **MicroGrid** can correspond for instance to the network of a small urban area, to an industry or to a large shopping center.

In terms of the currently available technologies, the microgeneration systems can include several types of devices as fuel cells, renewable generation as wind turbines or PV systems, microturbines (typically in the range of 25-100 kW) powered by natural gas or biofuels. One of the most promising applications of this new concept corresponds to the combined heat and power – CHP – applications leading to an increase of the overall energy effectiveness of the whole system.

Apart from a LV distribution network, microgeneration devices and electrical loads, a **MicroGrid** may also include storage equipment (as batteries, ultracapacitors and flywheels), network control and management systems and heat recovery systems aiming at recovering waste heat to power CHP applications. These late devices contribute to improve the energy effectiveness of the **MicroGrid** and to economically justify the required investments.

In order to highlight the **MicroGrid** concept under development in the **MicroGrids** project, Figure 1 illustrates a LV distribution network connected to the secondary winding of a MV/LV transformer. This **MicroGrid** example includes:

- several feeders supplying electrical loads;
- several microgeneration systems as a PV system, a fuel cell, a CHP system and a microturbine;
- a flywheel and a capacitor as storage devices;
- several control and management equipment. In the first place, the whole network is controlled and managed by the **MicroGrid Central Controller**, MGCC, installed in the LV side of the MV/LV substation. The MGCC has a number of crucial functions that will be detailed later in this section and can be seen as the interface between the **MicroGrid** and the main distribution network. In a second hierarchy control level, each microgeneration and storage device are locally controlled by a **MicroSource Controller**, MC, and each electric load is locally controlled by a **Load Controller**, LC. The proper operation of the whole system obviously requires communication and interaction between two sets of devices:
    - the LC and MC on one hand, as interfaces to control in some way loads, through the application of an interruptability concept, and microgeneration active and reactive power production levels;
    - the MGCC, on the other hand, as local central controller that tries to promote an adequate technical and economical management policy and provides set points to the LC and MC;

At the same time, it is expected that the MGCC would be able to establish some dialog with the Distribution Management System, DMS, located upstream in the distribution network, contributing to improve the management and operation of the MV distribution system.

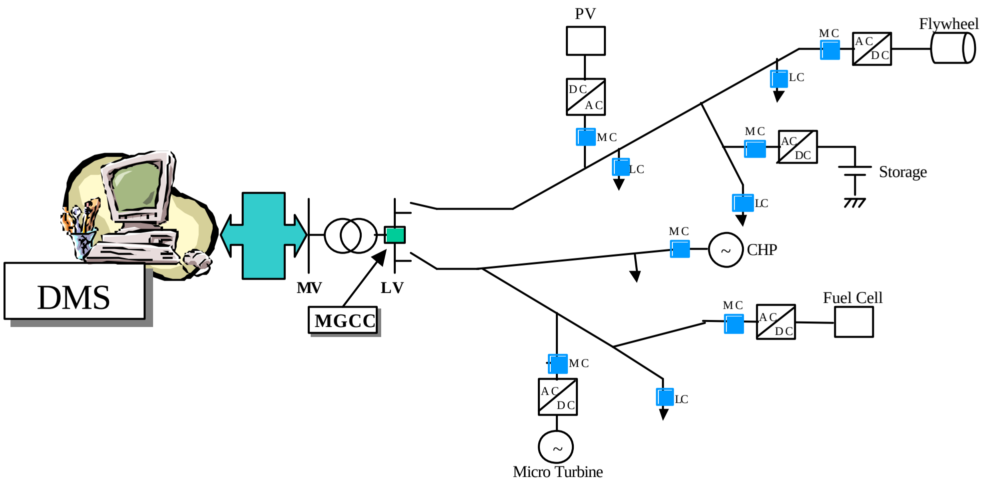

Figure 1 – Illustration of a microgrid with several microsources, electrical loads and control and management equipment.

At the current research status, it is assumed that the **MicroGrid** can be operate in two main situations:

- Normal Interconnected Mode – the **MicroGrid** will be electrically connected to the main MV network either being supplied by this network totally or partially (depending on the generation allocation procedures adopted to operate the microsources) or injecting power to the main MV grid (in case the relation between the microsources installed capacity and the electrical loads allows this type of operation);
- Emergency Mode – in case there is a failure in the main MV network, the **MicroGrid** can have the capacity to operate in an isolated mode, that is, to operate in an autonomous way, similar to the power systems of physical islands.

Regarding the MGCC, its main functions are:

- during Normal Interconnected Mode the MGCC collects information from the microsources and loads in order to automatically perform a number of operations on the **MicroGrid** as forecasting studies, economic scheduling of microgeneration, security assessment evaluations, demand side management functions and interface with the Distribution Management System;
- in Emergency Mode a change in the output power control of the microgenerators is required, since they change from a dispatched power mode to a frequency control of the isolated grid. In such an event, the MGCC reacts as a secondary control loop, after the initial reaction of the MC. It is also important for the MGCC to have accurate knowledge of the type of loads in the grid (eventually to adopt interruption strategies) and to use storage support from batteries, flywheels or supercapacitors. As a whole, the MGCC is also responsible for a local black start. The black start functions ensure an important advantage of the **MicroGrids** in terms of improved reliability and continuity of service.

The MC and LC are local microsource and load controllers aiming at contributing to the economic scheduling activities, to the local control of storage devices, to the load tracking activities, to the management of loads with interruption or peak shaving possibilities. In an advanced stage in which the microgeneration and electrical loads are fully integrated in electricity markets, the local controllers can also be in charge of preparing selling or buying offers to communicate to the MGCC. The MGCC will then aggregate the different received offers and will transmit them to the marker operator.

3.2. The MicroGrids Project

The main objectives of the **MicroGrids** project include:

- contribute to increase the penetration of renewable energy sources and other micro-sources, in order to reduce the GHG emissions;
- study the operation of **MicroGrids** both in the normal operation mode when connected with the main MV network and in the emergency mode in islanding conditions, that may follow faults;
- optimise the local **MicroGrid** generation capabilities interacting both with local controllers and with the DMS system. In order to define the operating strategy of the grid both in the normal interconnected mode and in the emergency mode it is necessary to use information on:
    - local electric and heat requirements;
    - electricity and gas costs;
    - wholesale market data and clearing results;
    - special grid needs;
    - demand side management requests;
    - congestion levels;
- define, develop and demonstrate control strategies in order to ensure the most efficient, reliable and economic operation and management of **MicroGrids**. This includes the simulation and demonstration of **MicroGrid** operation on laboratory conditions;
- define appropriate protection and grounding schemes in order to ensure the safe operation and the efficient fault detection, isolation and operation in islanding situations;
- identify the needs and develop the telecommunications infrastructure and protocols required to communicate among the controllers installed in the field and the MicroGrid Central Controller;
- identify the economic benefits resulting from the development and operation of **MicroGrids** and propose methods allowing to quantify those benefits in a systematic way;
- identify the legal, regulatory and administrative frameworks eventually in force in the EU countries and propose appropriate legal, regulatory and administrative measures to induce or to remove barriers to the establishment of **MicroGrids**. This activity should cover the co-ordination between the **Microgrid** and the already existing MV network and the possible adoption of market mechanisms to frame several issues related to the **MicroGrid** operation;
- and finally, the projection of **MicroGrid** development on distribution feeders in Greece, Portugal and overseas France, quantifying via simulation the environmental, reliability and economic benefits resulting from their operation.

This project is being developed by a consortium coordinated by the National Technical University of Athens (NTUA) from Greece, and includes Electricidade de Portugal (EDP), Electricité de France (EDF), the Public Power Corporation of Greece, the Instituto de Engenharia de Sistemas e Computadores do Porto (INESC Porto, Portugal), the University of Manchester Institute of Science and Technology (UMIST, UK), the Institute fur Solare Energieversorgungstechnik (ISET, Germany), SMA Regelsysteme GmbH (Germany), URENCO Power Technologies Lda (UK), GERMANOS SA (Greece), Association pour la Recherche et le Developpment des Methods et Processes Industriels (ARMINES, France), Fundacion LABEIN (Spain) and the Electric Power Research Institute (EPRI, USA).

A complete list of the objectives, work-packages, phasing and participants of this project can be obtained in the site http://microgrids.power.ece.ntua.gr.

4. MicroGrid simulation platforms

The consequences of the integration of microgeneration in LV networks need to be evaluated since new generation conversion systems (most with electronic interfaces) will be used under unbalanced operating conditions. These conditions result not only from the fact that some of the microgenerators are single phase connected but also from the characteristics of LV loads and circuits. This requires the development of a simulation platform able to simulate the steady state and dynamic operation of unbalanced, three-phase with neutral networks including micro generation sources.

For this purpose adequate models for simulating the operation of the different micro sources and storage devices, including the corresponding power electronic interfaces, are now under development. The first step of the simulation platform is the development of an unbalanced, three phase load flow algorithm. Further to this, the tool needs to be flexible enough to enable the integration and testing of control strategies, aggregation of micro source models, and the simulation of disturbances. The disturbances of concern are sudden connection / disconnection of loads and microgenerators in the Microgrid, faults in the upstream MV network, in the LV grid and in the micro generators. Such a tool should be therefore able to evaluate the stability conditions for these disturbances having in mind that islanding operation conditions are one of the key issues under study in this project.

Traditionally, grids are based on rotating masses and these are regarded as essential for the inherent stability of the systems. In microgrids most of the microgenerators are connected to the grid through inverters without directly connected rotating masses, although the use of flywheel energy storage coupled through an inverter is foreseen. This involves a different conceptual evaluation approach that requires specific control strategies.

The identification of control strategies for frequency, voltage and emergency operation is being tackled in this project by analyzing balanced and unbalanced operation.

A balanced model for all components was developed using a MatLab Simulink environment providing in this way a first simulation platform. The full simulation platform, able to deal with unbalanced operating conditions, is being developed from scratch under MatLab, including a specific Database and adopting a mathematical formulation where very fast transients are not considered but the main dynamics of the micro sources are kept.

An example of the model for balanced operation developed so far using MatLab Simulink is described in Figure 2. It regards a LV network with 2 feeders leaving a MV/LV substation, having two groups of loads and microsources concentrated at the extreme of each one of the feeders. These units are a small Diesel with 70 kW, two fuel-cells (50 and 100 kW), two micro-turbines with induction machines (50 and 100 kW) and two PV arrays of 10 kW each. The models adopted to describe the behaviour of these generating devices are described in detail in [2]. In the MV/LV substation a distribution transformer was included adopting a simplified equivalent model assuming magnetizing currents as negligible. For illustration purposes, Figure 3 describes the model used to represent the dynamic behaviour of a SOFC fuel cell, similar to the one described in [2,3], assumed to be connected in the extreme buses of the each feeder of this test grid. Fuel cells are equipped with batteries installed in the DC side of the microsources.

Some of the issues that are being studied using this platform are related with the identification of adequate control strategies for load following and for islanding operation and namely stability evaluation following several disturbances. One of the critical disturbances is related with defaults in the MV grid followed by a fast disconnection of the LV grid from the MV side. During islanding operation the MicroGrid will also have to face sudden disconnection and / or connection of loads and should be able to operate in a stable way following such events.

Micro source generators, when in islanding mode, are participating in voltage and frequency control to balance production versus consumption through microsource controller's autonomous functions. These controllers exploit the conventional proportional concept of frequency and voltage droops which use the grid voltage and frequency for control purposes, as shown in Figure 4 [4]. This technique has certain similarities with the primary control of the conventional generators in integrated grids.

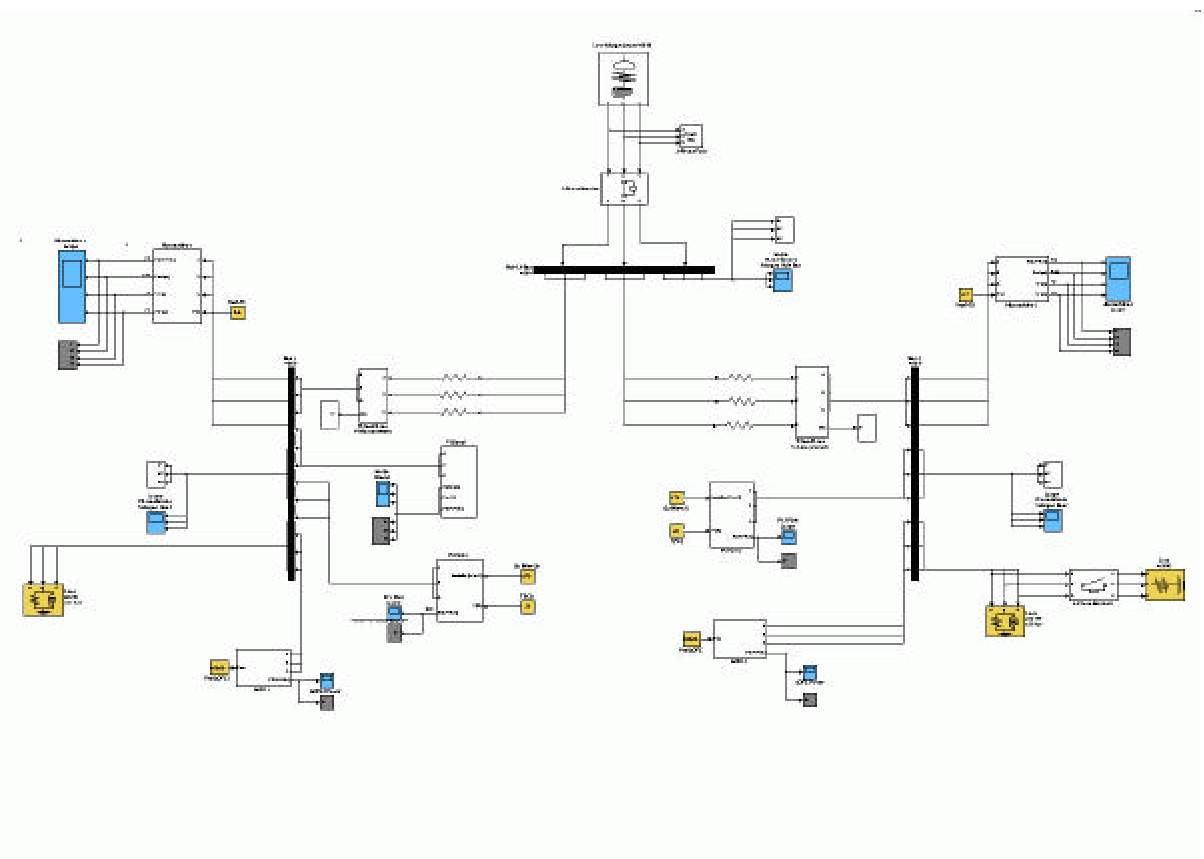

Figure 2 – Example of a MicroGrid in the MatLab simulink environment.

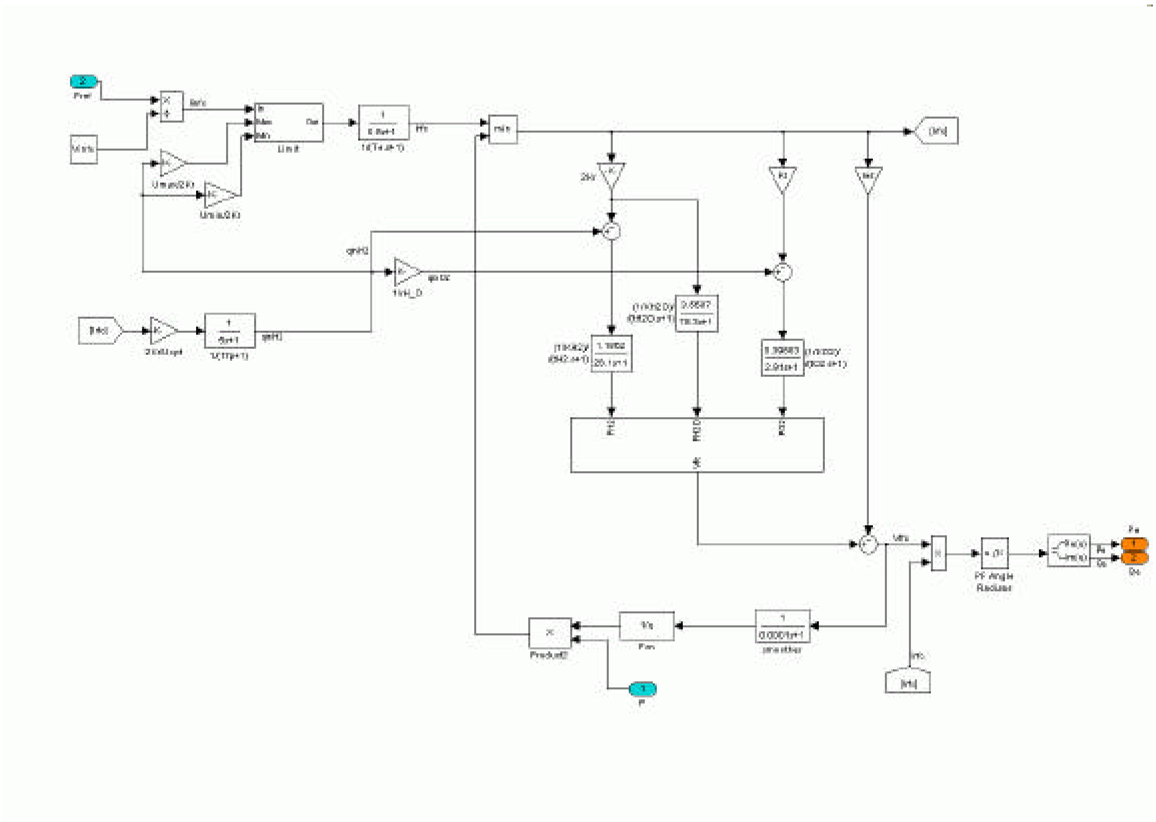

Figure 3 – Detailed representation of the fuel cell dynamic model.

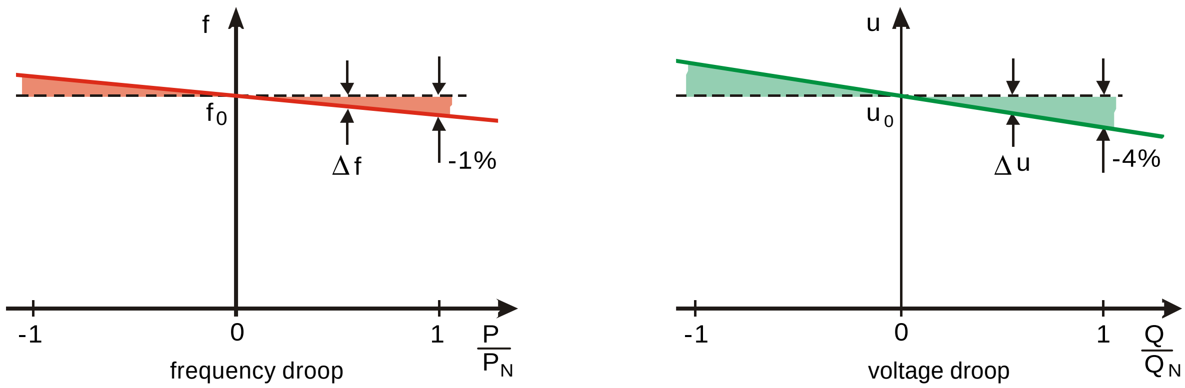

Figure 4 – Frequency and voltage control droop concepts adopted for autonomous frequency and voltage control.

Some results obtained with the developed simulation platform for a 70 kW disconnection of active load followed by its re-connection after 1 second are described next. Figures 5, 6 and 7 describe respectively the frequency behaviour and power outputs from one of the 100 kW fuel cells and one of the micro-turbines (with an 100 kW induction generator). In the case of the fuel cell, the active power output of the cell and the inverter output are depicted for illustration purposes.

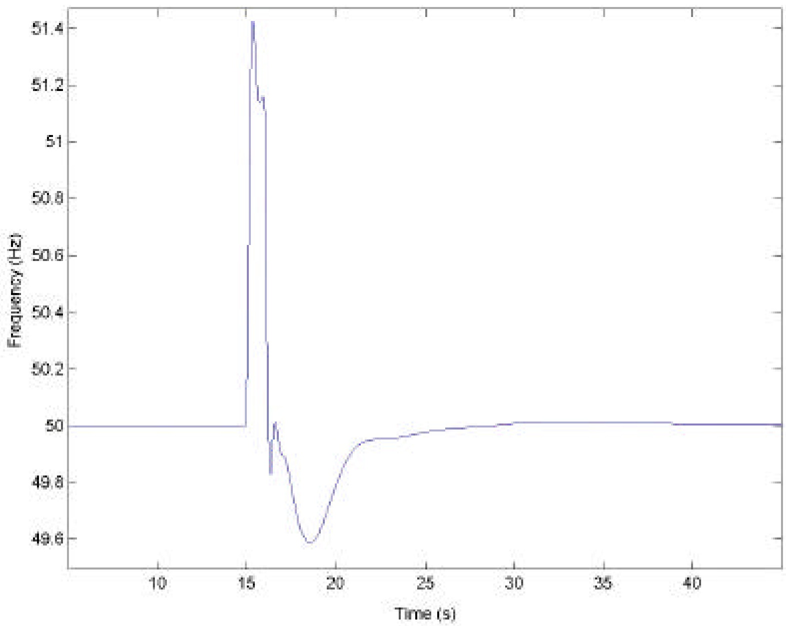

Figure 5 – Frequency change experienced in the microgrid system following the simulated disturbance under islanding conditions.

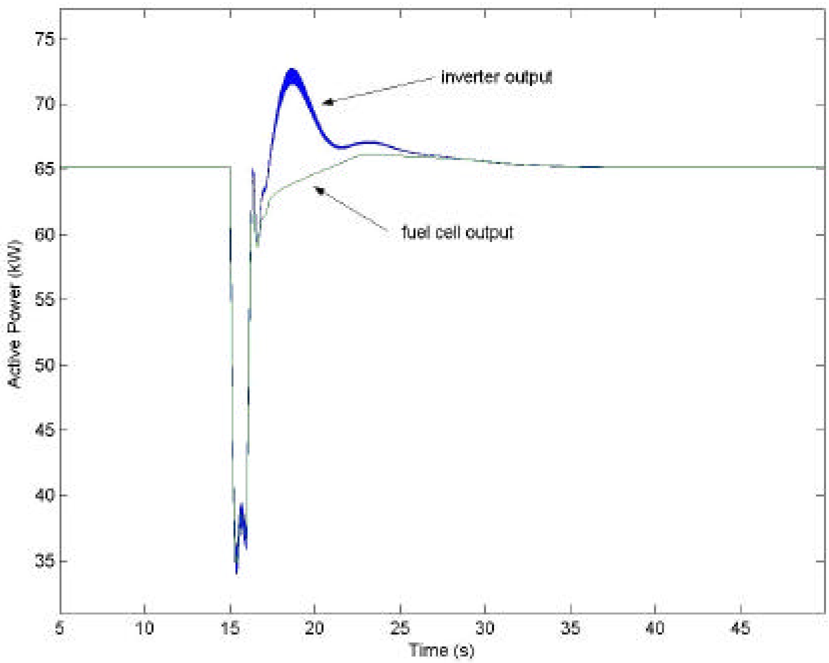

Figure 6 - Fuel cell power output and inverter power output.

As it can be observed from Figure 6, the inverter power output shows a very fast response to the changes in frequency, being proportionally controlled according to a given frequency droop, as described in Figure 4. When the load is disconnected the fuel cell inverter adapts its output to the new load conditions reducing the power drawn from the fuel cell in the same way. When the load increases the fuel cell output shows a slower response due to the electrochemical behavior of the fuel cell but the inverter is able to react in a very fast way to the frequency changes, exploiting the energy stored in the battery that is coupled in the DC side of the generating device.

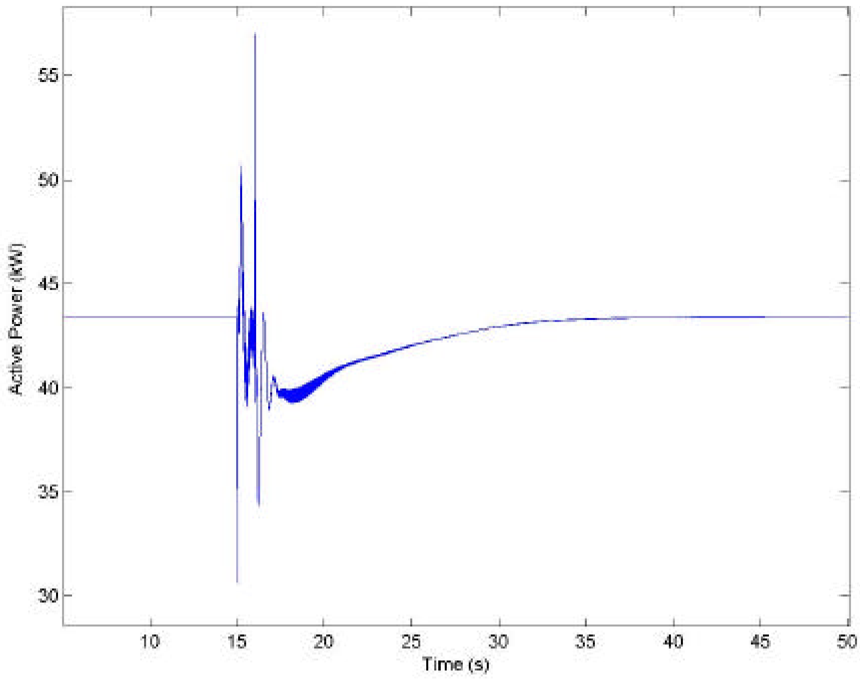

Figure 7 – Micro-turbine power output.

The micro-turbine is not participating in the frequency control since it is directly coupled to the grid through an asynchronous generator. Fast changes in the active power output can be observed in Figure 7 following the disturbances due to the transient fluctuations of frequency and voltage in the microgrid.

This simulation platform is now being used for further identification of control strategies under islanding operation or load following conditions as well as for black start.

5. Management and control

In this section we will address the management and control facilities included in the MicroGrid Central Controller, MGCC, to operate the network in normal interconnected steady state operation. In this case, one aims at developing tools covering the short-term load and heat forecasting, short-term generation forecasting, the economic scheduling, security assessment, demand side management, interface with market agents and interface network monitoring.

At the current level of development, the above tools are being developed according to the following general ideas:

- Short term forecasting tools for electrical loads, generation capabilities and heat – this is being tackled using neural networks or persistence methods considering a forecasting horizon of some hours. Regarding generation capabilities, this includes wind and PV generation forecasts, that is, forecasts for what can be considered volatile resources. The resulting information will be used both to schedule local generation and to prepare selling bids from local generation;

- Economic scheduling – as referred in the previous paragraph, the microsource controllers can prepare bids for each source and communicate them to the MicroGrid Central Controller. The MGCC will then use this information either to allocate power by the local sources according to some predefined operation strategy with the distribution company or can adopt market driven approaches that will be described in a more detailed way in section 6;
- Development of on-line security functions – it aims at analysing on-line security for each of the economic scheduling functions eventually considering reliability, steady state security or dynamic security criteria. These functions will be implemented using AI tools as Decision Trees or Neural Networks. One of the important results from these functions is the amount of frequency responsive spinning reserve required for safe operation when the mains connection is lost. This is seen as an input to the economic scheduling function;
- Demand Side Management Functions – These functions will also be integrated in the economic scheduling function. In this way, interruptible loads will be used in conjunction with the generating to determine the amount of power that the MicroGrid should draw from the distribution system.

These functions are specially designed for the normal interconnected operation mode. The emergency isolated operation mode is much demanding in terms of dynamic simulations and will be described in section 7. As referred before, there are still several issues that are under discussion within the consortium. As examples, we can refer the forecasting horizon required by the electrical loads, heat and volatile generation sources given the possible adoption of market approaches to perform the economic scheduling. If some sort of market approach is in fact adopted, one should consider that wholesale electricity markets are typically run one-day ahead. This means that a 24 hour forecast would be required. In any case, the economic scheduling approach is itself under discussion since one may argue that:

- the blocks of energy eventually available from microsources are too reduced to be marketable;
- and that the current microsource generation costs are still too high in order for them to be competitive with other traditional large scale generation.

Under this reasoning, the development of micrograds would require a more regulated eventually subsidised approach, at least during a transitory period. However, since this project has a three year horizon and microgrids will hopefully be developed in the next 10 to 15 years one may expect that microsource generation costs get reduced and, in fact, turn themselves competitive with other technologies. Therefore, it is our opinion that the opportunity given by the MicroGrids project should be used to study strategies and to develop tools to be used not only in the near future but, in fact, in the next decade. That is why section 6 is specially devoted to the development of operation strategies of microgrids under market rules.

6. Operation including market rules

There are several scenarios foreseen for the operation of the microgrids in the future power markets that can be basically grouped in two main possibilities:

1) The Microgrid serves the needs of its own loads including all local ancillary services, e.g. requires zero reactive power from the grid. In this case, the MGCC decides about

the source of the power required, i.e. local generation or central generation based on the current market values.

2) The Microgrid maximizes its value by communicating energy bids to the market, probably via an aggregator.

In the latter case, the microsource controllers prepare bids for each source and communicate them to the MicroGrid Central Controller. The MGCC uses this information to prepare an aggregated bid curve under the form of a step-wised curve as in Figure 8.

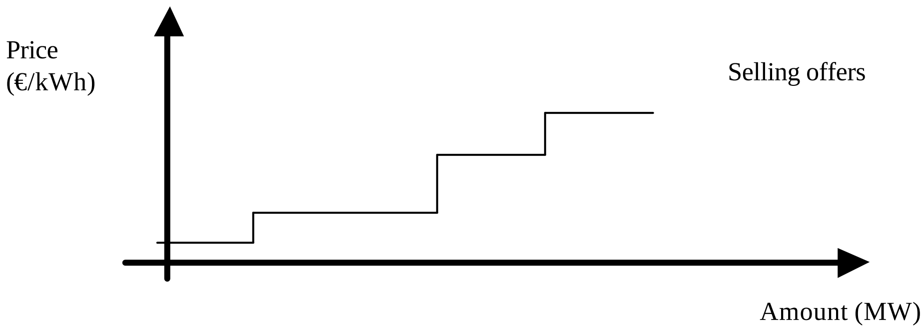

Figure 8 – Aggregated selling curve resulting from the selling offers communicated by the microsource local controllers.

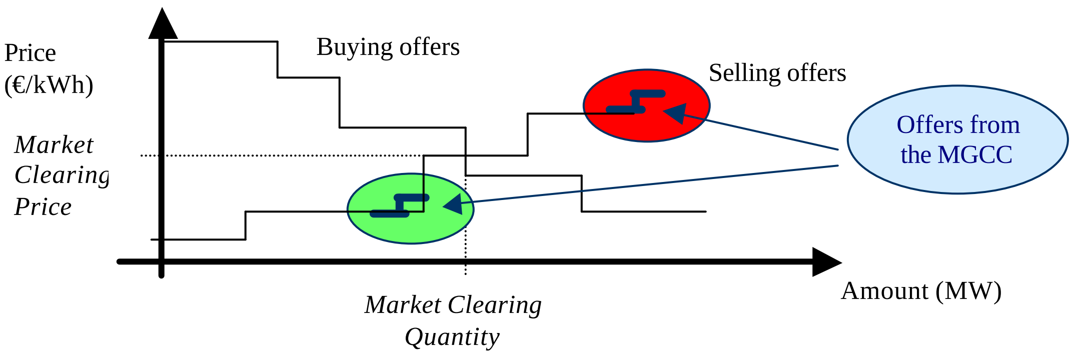

Figure 9 – Result of the market matching algorithm including the selling offers presented by the MGCC.

This aggregated curve is then used to present a selling offer to the Market Operator. The whole set of selling offers received by the Market operator is sorted according to the increasing order of the marginal prices. This leads to a global selling curve as in Figure 9. The intersection of the selling bid curve with the buying bid curve leads to the Market Clearing Price and to the Market Clearing Quantity as shown in Figure 9.

The result of the market matching algorithm is communicated back to the MGCC. As seen in Figure 9, in this illustrative situation one of the offers presented by the MGCC was accepted and another one was rejected. If several selling offers are accepted, the MGCC will then desegregate the accepted part of the initial bid curve by the local micro-sources. The desegregation phase will be conducted considering the increasing marginal prices presented in the initial bid and taking into account congestion constraints. If some congestion is detected, the MGCC computes sensitivity coefficients of the flows in the congested branches regarding generation injections in order to identify the most reduced changes in injections regarding the ones resulting from the market that, in any case, will eliminate the detected congestion situations.

7. Islanding operation and contributions for black start

When failures occur in the MV or HV system, the distribution network may break into isolated "islands", each of which must be supplied by itself. With an intelligent distributed approach where the micro controllers (MC and LC) will act, in a very fast way, as independent agents and making an efficient use of the local resources, it will be possible to maintain system operation in an islanding condition. Moreover, a special feature of the MicroGrid central controller must concern re-connection during Black Start. Regarding this issue, the following special functions will be investigated and developed.

7.1. Frequency control and Load Shedding

In isolated operation, load-tracking problems arise since micro-turbines and fuel cells have slow response to control signals and are inertia-less. A system with clusters of micro sources designed to operate in an island mode requires some form of storage to ensure initial energy balance. The necessary storage can come in several forms; batteries or supercapacitors on the dc bus for each micro source; direct connection of ac storage devices (batteries; flywheels, etc, including inverters). Such energy storing devices have been modeled and included in the simulation platform in order to test their impact and importance in these operating conditions.

When grid connected, the loads in the MicroGrid receive power both from the grid and from the micro sources depending on the operating conditions. With loss of the grid due to voltage drops, faults, blackouts etc. the MicroGrid switches to island operation. This will require an immediate change in the output power control of the micro-generators as they change from a dispatched power mode to one controlling frequency of the islanded section of network. The identification of adequate control strategies for the local MC is being developed in conjunction with load shedding strategies, not only for helping controlling frequency, but also for safeguard of the system operation.

7.2. Black Start functions

Two types of Black Start functions are needed:

- Local Black Start of the MicroGrid after a general system black out;
- Grid reconnection during Black Start.

If a system disturbance originates a general black out such that the MicroGrid was not able to separate and continue in islanding mode, and if the MV system is unable to restore operation in a specified time, a first step in system recovery will be a local Black Start. The strategy to be followed is a matter for investigation and will involve the MGCC, the MCs and the LCs, using predefined rules and exploiting autonomous agent concepts.

A special feature of the MicroGrid Central Controller concerns re-connection during Black Start, helping in this way the upstream DMS system that is managing the MV distribution network. During faults on the main grid the MicroGrid may be disconnected from the main Utility and will continue to operate with as much connected DG, as possible. During reconnection, the out-of phase reclosing is one of the issues of concern. The development of local controllers in close co-ordination with the MicroGrid Central Controller functions need to be developed and evaluated from the dynamic operation point of view through studies to be performed in the simulation platform.

These Black Start functions contribute to assure an important advantage for power system operation in terms of reliability as a result of the presence of a very large amount of dispersed generation.

8. Grounding and Protection Coordination

Any faults on the utility side may generate substantial ground potential rise, even if the energy sources operate at low voltage (230 or 380 volts). This means grounding of the distributed energy sources, and the transformer connecting the MicroGrid to the utility network, must be carefully analyzed and appropriate rules need to be developed, so that one can maintain the same level of safety as achieved in conventional systems. Analysis and design tools for safety assessment should explicitly model the grounding and bonding of the Grid circuits namely when the MicroGrid is operating under islanded conditions.

Protection must respond to both system and MicroGrid faults. If the fault is on the utility grid, the desired response may be to isolate the MicroGrid from the main utility as rapidly as necessary to protect the MicroGrid loads. The speed of isolation is dependent on the specific customer's loads on the MicroGrid. If the fault is within the MicroGrid, the protection system isolates the smallest possible section of the radial feeder to eliminate the fault. Most conventional distribution protection is based on short-circuit current sensing. Power electronic based micro sources can not normally provide the levels of short circuit required. Micro sources may only be capable of supplying twice load current or less to a fault. Some conventional overcurrent sensing devices will not even respond to this level of overcurrent, and those that do respond will take many seconds to react, rather than the fraction of a second that is required.

The unique nature of the MicroGrid design and operation requires a fresh look into the fundamentals of relaying. One approach that is quite powerful is to develop a real-time fault location technique that will identify the exact location of the fault much more accurately than the classical relaying is capable of doing under any circumstances. These methods may prove too costly. Low cost approaches based on zero sequence detection (using voltage) and differential current and/or other voltage methods are promising. These approaches are not in common use on distribution systems but can provide the required functions. In some countries, like in Portugal, zero sequence voltage relays are showing to be effective in MV networks to assure disconnection of dispersed generators from the grid when resistive phase to earth short circuits occur. Such strategy is presently being addressed under these LV operating conditions by performing simple short-circuit simulation studies taking into account the specificities of LV four wired networks and the different types of micro sources, namely the ones with inverters.

9. Conclusions

This paper describes the main issues to be assessed to increase the penetration of microgeneration in LV grids. MicroGrids, as active LV networks, can potentially provide a large number of benefits to the Power Utility by increasing its efficiency of operation and improving reliability and quality of service at the consumer level. However, a large number of technical problems need to be addressed carefully, requiring a considerable amount of research, presently being carried out in the MicroGrids project under financing of the EU.

Some preliminary results are also presented in this paper regarding conceptual approaches under development and numerical results from dynamic simulation of a MicroGrid test system.

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