Investigation of Regulatory, Commercial, Economic and Environmental Issues in MicroGrids

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***Abstract*— Concepts of MicroGrids are proposed to address primarily various issues related to integration of small scale renewables and electricity supply reliability. With an active management control approach and ability to operate in islanding mode, a cluster of micro generators, electricity storage and electrical loads can be operated within the MicroGrids framework to provide higher supply reliability to highly value customers. Solutions are required not only to make these concepts technologically feasible and safe to operate but also to be commercially viable and attractive, economically efficient and supported by electricity regulations. This paper summarises the results of investigations on various economic, regulatory and commercial issues faced by the development of MicroGrids in MICROGRIDS project. The potential economic benefits and contributions to environment from applications of MicroGrid technologies are also presented and described in this paper.**

I. Introduction

Development of environmental friendly and highly efficient power generation has become significantly important after increasing awareness of detrimental effects caused by emissions from hydrocarbon based power stations on the sustainable of environment. At the same time, demand of reliable electricity supply grows continuously along the use of electricity equipments in most of strategic activities. However, the increased frequency of blackouts occurred across Europe and America raise deep concerns and need solutions.

Distributed Generation (DG) has potential to be the required solutions for the two problems above. However, applications of DG in large scale have faced complex challenges that need to be solved before the benefits of DG can be realised. In addition to technical problems, commercial and regulatory challenges have been significantly slowing down the rate of DG deployment in present systems. Solutions are required for these problems to enable further significant progress on developing reliable and sustainable power systems in future.

Abilities of integrating the operation of small scale DG (micro generation) resources, maintaining the capability of utilising these resource capacities to supply local load and to isolate faults in other systems are the important features of MicroGrids [1]-[2]. In order to promote economically efficient allocation of these resources, energy and ancillary service markets can be developed inside the MicroGrids. Promising results have been obtained during the simulation of such market, which will be explained in the next section.

The results from other investigation including assessment of regulation in a number of European countries (UK, Spain, Holland, and Greece), development of methodologies to allocate losses in MicroGrids and to quantify the economic and environmental benefits of MicroGrids will be described in section III, IV and V respectively.

II. Market simulation

Traditionally, the System Operator (SO) despatches all generating units by instructing each unit to operate at a particular state. As an alternative to that operation philosophy, SO could inform the generators about the prices associated with the level of energy and ancillary services that the SO, on the behalf of the customers, is willing to pay. Instead of being determined by SO, the generators have the autonomy to determine the optimal level of energy and ancillary services they are willing to produce at the given price. Assuming each generator wants to maximise their profit, the generators will produce up to the point where their marginal operation costs are equal to the price offered by the SO.

The main advantage of this approach is to decentralise the despatch decision to each unit; although, the system coordination is still vitally required and could be achieved through the price signal given by the SO. With the decentralised control approach, the control independency of each unit is preserved. This feature is extremely valuable especially if the unit needs to be operated in isolated mode.

However, this alternative approach requires micro generation and electrical storage facilities to response firstly against the disturbances before SO sends new prices information to re-dispatch generation. The response will be determined by droop characteristics of kW output to frequency and kVAr output to voltage. Due to the new operating point, new bids are submitted to SO to be considered for the next dispatch decisions. With the pricing feedback given by control units (micro generators, storage and responsive loads) to SO, this control approach can be classified as a closed loop price signal [3]. It is important to bear in mind that if it is required, there will be no technical difficulty to implement the traditional approach in the MicroGrids.

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A. *Study system*

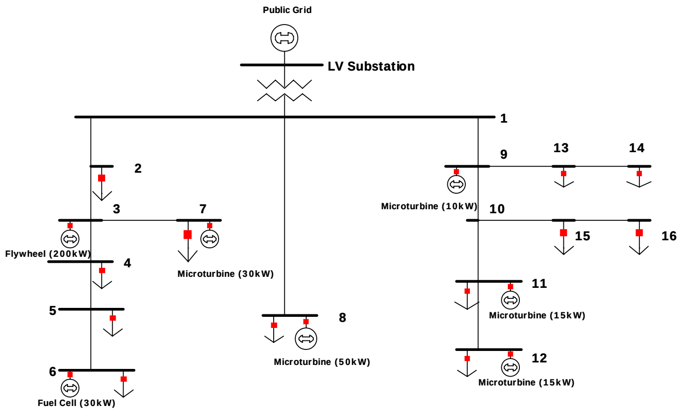

Fig. 1 MicroGrid LV test system

Figure 1 illustrates a LV test system derived from the NTUA MicroGrid system [4]. The test system contains 6 controllable micro sources (1 fuel cell and 5 micro turbines) and a flywheel located at bus 3. Non-despatchable generators such as a small-scale wind generator (15 kW) and some PV cells (3 kW units) were modelled as negative loads. The MicroGrid is connected to public grids (bus 17) via a LV transformer.

B. *Simulation algorithm*

A simulation algorithm based on sequential steady state Optimal Power Flow has been developed to demonstrate the possibility of operating real time electricity market inside a MicroGrid to achieve the most economic operation dispatch of a number of micro generators taking into account operating constrains. The OPF algorithm calculates the optimal dispatch for each time step (T). The algorithm is still limited for a 3-phase balanced system.

C. *Simulation result*

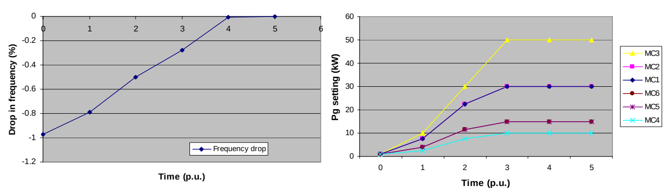

Fig. 2 Restoration of frequency and generation re-dispatch

An extreme case was considered. Initially, the MicroGrid imported all power from the main grids for economic reasons. At t=0, loss of mains protection detects the disconnection from the main grids due to the fault in the main. The flywheel immediately supplied the loads in the MicroGrids and the MGCC re-dispatched micro generation by increasing nodal prices. Output of micro generators then started to replace the output of flywheel before it was fully discharged.

Figure 2 shows the restoration of system frequency after the loss of the grid connection. At t=0 (the time when the public grid was disconnected from the MicroGrid), frequency was drop 0.97% and the MGCC instructed all MC to switch on generating units. At t=1, all MC started to generate based on their droop characteristics. This graph shows that the frequency was restored gradually to the nominal frequency. At t=4, there was no significant drop in frequency that can be observed.

III. Regulatory Issues

The evaluation of present regulatory framework in various countries in Europe including Holland, UK, Spain, and Greece were conducted during the project. Generally, the present regulatory practices have addressed sensibly the technical requirement for connecting DGs to distribution systems in order to maintain safety and power quality. This includes the development of new standards associated with DG technologies, connection practices, protection schemes, ancillary services and metering. Administrative processes such as application for new connection have also been standardised and disseminated with an aim to make the process transparent for DG developers and investors while maintaining DSO's monitoring ability to ensure that the necessary connection standards are not compromised.

Besides connection policies and development of technical standards, various policies were also designed to provide financial supports and favourable market environments to stimulate DG growth such as financial incentives for small generators in the forms of government grants, exemption of transmission use of system charges and transmission losses charges, climate change levy exemption, and Renewables Obligation. Incentives are also given to the DSO to facilitate more small scale generation including micro generation in their network.

However, it is evident that DG especially micro generators still face a number of barriers such as:

- a relatively low electricity prices which discourage new investment,
- a relatively high capital cost for renewables technology,
- a relatively high connection cost due to deep connection charges policies,
- lack of market support mechanisms which allow DG to access freely electricity market, reward DG according to its service to the network, minimise the financial penalty for imbalances due to the use of intermittent Renewable Energy Sources,
- lack of incentives/force for DSO to change their passive operation philosophy which limits the amount of DG that can be connected

Therefore, commercial questions such as creation of a level playing field, development of market for aggregators, and cost reflective network pricing to acknowledge the costs and benefits of distributed generation to the networks in addition to the key technical questions such as active management of distribution networks, coordination of the operation between MicroGrids and public electricity systems, and islanding mode operation are still required to be addressed and solved. More radical changes may be necessary to facilitate efficient integration of the operation and development of MicroGrids in the systems, in order to extract the additional value of micro grids in terms reducing of the overall system operating costs, network investment deferral, service quality and reliability improvements and provision of a variety of services to support network operation during various disturbances.

IV. Allocation of Losses

There are several methods to allocate losses that have been investigated and analysed including proportional allocation, marginal allocation, unsubsidised marginal allocation, proportional sharing allocation, allocation using the impedance matrix, incremental allocation of active losses [5]-[7] and loss allocation based on the results of OPF problems.

A. Simulation result

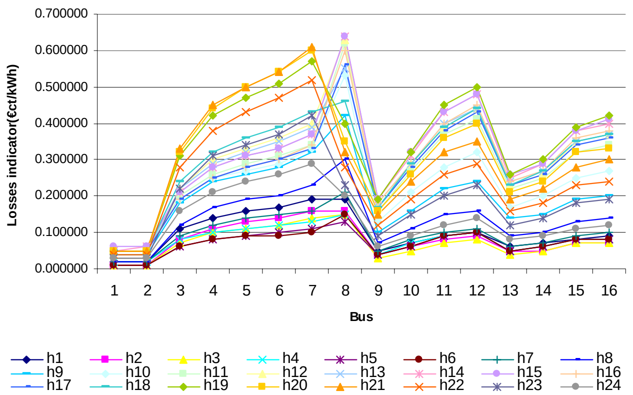

Fig. 3 Losses indicators (all micro sources were off)

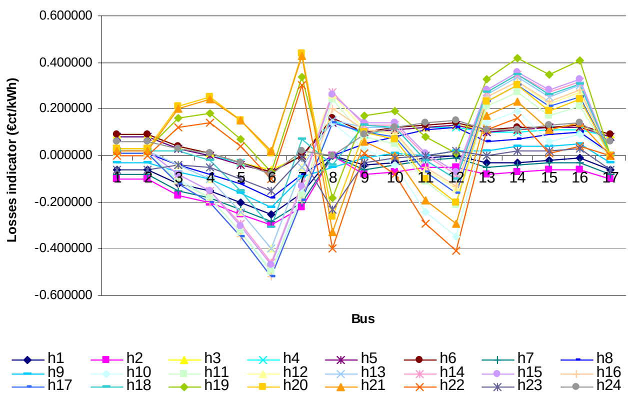

Fig. 4 Losses indicators (with micro sources)

Figure 3 and 4 show the economic indicators that measure the contribution of losses to operation costs from each demand customer in the MicroGrid without and with micro sources respectively for different loading conditions. The indicators were obtained by subtracting the nodal charges for each node with the nodal charges at the marginal generator node. A positive or negative indicator associated to a node means that losses and the cost of losses will increase or reduce respectively for additional power taken from the node.

V. Economic Benefits of MicroGrids

In order to quantify the economic and environmental related benefits of MicroGrids, there were several methodologies and case studies that have been developed and conducted during the project including:

(i) The development of a methodology based on Linear Programming problem to maximise the value of micro CHP by co-optimising the schedule of electricity and heat generation taking into account seasonal variations in domestic heat and electricity demand, electricity prices, gas prices, room insulation, and ambient temperature. The method was used to quantify the economic benefits of replacing old conventional boilers with new domestic CHP, and the break even period of investment. The case studies demonstrate promising results indicating that 20% - 23% saving in energy bills can be realised if domestic CHP is used as an alternative to ordinary boiler. The method was also used to quantify the impact of increased efficiency in the domestic utilisation of gas and electricity on the reduction of CO2 emission. It is demonstrated that on European scale, 65 million tonnes of CO2 reduction per annum can be achieved with 50 M installation of domestic CHP.

(ii) the development of a generic urban and rural distribution network to investigate and quantify impact of micro generation on distribution systems. The model can incorporate typical characteristics of the networks such as length, impedance, capacity, yardstick costs, network loading, demand and generation distribution for various voltage levels. Various case studies have been performed on the generic network to quantify the benefits of MicroGrids in terms of losses reduction, power factor correction services by providing reactive support**,** increasing spare capacity and deferring new network investment. The results of the studies demonstrate different value of implementing MicroGrids in rural and urban network, and different value for domestic CHP and PV technology.

VI. Conclusion

The paper will describe the results obtained from investigating regulatory, commercial and economic issues of MicroGrids including the potential economic and environmental benefits that can be achieved. The final paper will include further discussion of the methodologies and results.

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