12 years operation of the Gaidouromantra Microgrid in Kythnos island, COI-3869

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Abstract. The concept of "Microgrid" is one of the most promising architectures expected to support the transition from present to future smarter Electricity Grids by integrating large amounts of Renewable Energy Sources. The numerous benefits of microgrids have attracted attention and during the last decade several projects and researches have focused on this field. One of the first microgrids operating since 2001 was developed through European projects and is located at Gaidouromantra valley, in Kythnos island. It was designed and constructed in order to electrify vacation houses. The system in Gaidouromantra, Kythnos is a 3-phase Microgrid composed of the overhead power lines and a communication cable running in parallel. It is electrifying 12 houses with a 1-phase electrical service. The grid and safety specifications for the house connections respect the technical solutions of the Public Power Corporation, which is the local electricity utility. In this paper the Gaidouromantra microgrid development over the years, operational experience and lessons learnt are presented.

Keywords: Microgrids, Distributed generation, Photovoltaics, operational experience

1 Introduction

The need for increased penetration from RES (Renewable Energy Sources) as well as the transition from the current to the future smarter Electricity Systems has led to research of alternative technologies and architectures which will support and allow a smooth change into the future power systems by exploiting at the maximum possible degree the benefits from RES and DER (Distributed Energy Resources), reducing also the related problems [1]. One of the most interesting and promising architectures, expected to play critical role in the next years is the 'microgrid'. By definition, microgrids are parts of the LV (Low Voltage) distribution grid with some specific features as mentioned in [2-4]:

- Incorporation of different types of small power sources such as micro-turbines, fuel cells, PVs (PhotoVoltaics), etc. called MicroSources, together with storage devices, (i.e. flywheels, energy capacitors and batteries), and controllable loads.
- They are interconnected to the MV (Medium Voltage) distribution grid through transformers and static switches and due to this they can also operate in isolated mode, in case of faults in the upstream network.
- From the customer's point of view, microgrids can provide both thermal and electricity needs, and in addition enhance local reliability, reduce gas emissions, improve power quality by supporting voltage and reducing voltage dips, and potentially minimize costs of energy supply.

The pilot microgrid system, which is used to electrify a cluster of houses, is located in Gaidouromantra-Kythnos (Figure 1) [5]. Specifically, it electrifies 12 vacation houses and one control room in a small valley in Kythnos, an island in the cluster of Cyclades situated in the middle of the Aegean Sea. The installation of the system began in early 2001, as part of the projects PV-MODE, JOR3-CT98-0244 and MORE, JOR3CT98-0215. The grid and safety specifications for the house connections respect the technical solutions of the Public Power Corporation, which is the local electricity utility. In the following paragraphs the Gaidouromantra microgrid development over the years, operational experience and lessons learnt are presented. Some of the most important features of the system are the following:

- The system is permanently islanded because there is no physical connection with the public utility.
- The main electricity generators are PVs.
- The consumption profile deviates from normal household profiles because the houses are used only in holidays and equipped with high efficiency loads.

Figure 1: Wide area view of the Gaidouromantra microgrid in Kythnos island.

In the framework of the project MORE MICROGRIDS (FP6 Project no. 019864) [5] the system was upgraded with power converters capable to deal with the strenuous conditions of islanded mode control and it was used as a test field for investigation of different control strategies. An agent-based software/hardware for centralized and de-centralized control was developed, adapted and installed at the microgrid site. It was composed of an Intelligent Load Controller (ILC) used to monitor the status of the house power line, monitoring Voltage, Current and Frequency values in order to coordinate the energy management of the microgrid.

Five ILCs were installed in corresponding houses. Each ILC was controlling two switches connected to equivalent power sockets in each house. The main objective of this application is to control the operation of non-critical loads. Several houses in the Gaidouromantra microgrid are equipped with water pumps, which are responsible for replenishing a water tank and in this way supplying water for use to the residents of the houses. The water pump is considered as a non-critical load and therefore, in case of power shortage, it should be disconnected. Additionally, each ILC system features a Wi-Fi interface that enables it to wirelessly connect to a Local Area Network. The general goal of the control system installed in the Kythnos test site during the latest project MORE MICROGRIDS was the efficient energy management. The primary goals can be separated in two sections the technical and the electrical:

• The technical goal is to check a quite complex control system in a real environment.

• The electrical goals included minimization of the diesel generator usage and load operation during hours with PV energy excess.

A performance monitoring campaign was also realised at the Gaidouromantra microgrid.

2. System Configuration

2.1 System configuration

The power system of Gaidouromantra covers the needs of 12 houses. The main parts of the microgrid are briefly described below and a single line schematic diagram is presented in figure 2:

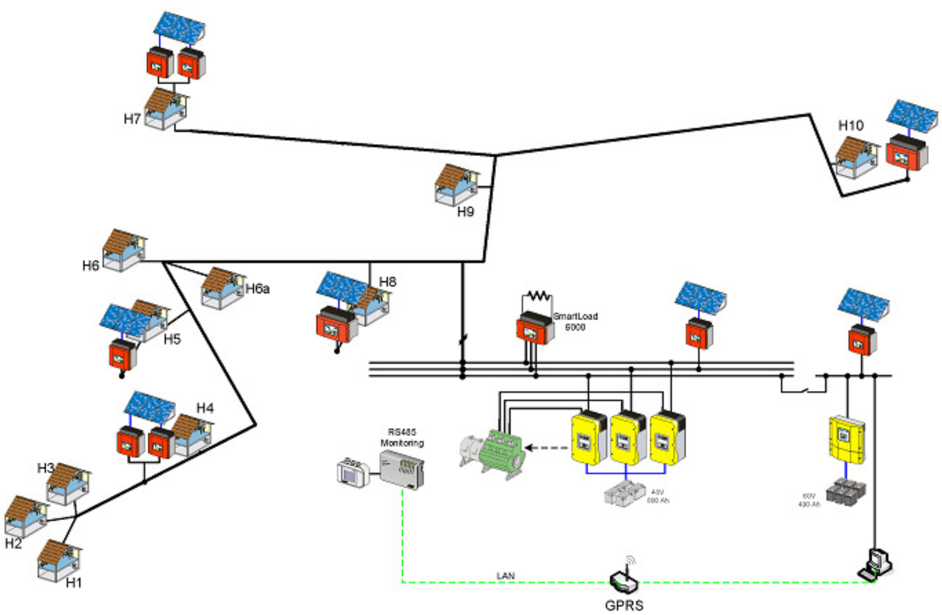

Figure 2: Single line schematic diagram of Gaidouromantra microgrid, Kythnos island.

- PV generators: The system includes 7 distributed PV arrays (as in figure 1) with 11kWp total installed power.

- Two Lead-Acid (FLA) Battery banks, with 1000Ah/48V (main), and 480Ah/60V (secondary). The main system is managed through three single phase battery inverters (SMA-SI5048) while the secondary through one single phase inverter (SMA-SI4500). During the day, the two storages are connected together at the AC side. During the night, the two banks are disconnected and the secondary system covers the control and monitoring equipment needs. The 3-phase configuration and the interconnection between the main and the back-up system are changeable according to each project requirements.
- Three-phase, 9kVA diesel back-up generator which is controlled by the Battery Management System (BMS) when State Of Charge (SOC) $<30\%$.
- Loads (refrigerators, lamps and dwelling pumps) represented as ohmic and inductive constant and programmable loads.
- The microgrid includes Load Controllers for protection against overloading or extreme battery discharge. These devices are triggered from the frequency and shed loads when frequency goes under 49,14Hz. The load reconnection takes place at least two minutes after the frequency restore, in a random order to prevent instant reconnection of all the consumers. It is worth mentioning that in the frame of More-Microgrids a new generation of Intelligent Load Controller was installed in conjunction with the already existing equipment. These devices offer a number of capabilities regarding load and source management but their operation was not modeled in the specific study.
- A Sunny Webbox was also installed with a GPRS link.

2.2 Battery inverter operation

Battery inverters play the most critical role in the system operation because they perform the energy management by regulating frequency either for load shedding or PV power derating. In addition they manage the diesel generator start-up. In the specific system the frequency is used as communication signal between the power units in order to manage the generated/consumed energy and hence to extend the battery lifetime. There are three states of operation according to the battery state of charge:

a) when SOC falls under 30%, the diesel generator is set in operation and charges the batteries. In this case the battery inverter follows the generator frequency.

b) When SOC falls under 15% the frequency becomes 47Hz in order to trigger the load controllers and shut down the loads.

c) If the battery voltage increases leading to high SOC, the frequency changes from 50 to 51Hz and then gradually according to the SOC from 51 to 52 Hz. As the grid forming frequency by the Sunny Island is increasing the Sunny Boy PV inverters respond to the frequency by shifting out of the maximum power point of operation and thus derating their active power output down to zero at 52Hz.

3. Social and Operational experience

3.1 Social studies for Gaidouromantra settlement PV powered microgrid

A socio-technical and socio-economical evaluation study, was realized by the University of Magdeburg in 2003, financed by ISET e.V. and University of Magdeburg and supported by the PV department from the Centre for Renewable Energy Sources and Saving, (CRES) [6].

A follow-up study was realized in 2008 in order to evaluate the progresses and changes during this period as well as new challenges for the sustainable usage of the microgrid PV hybrid powered systems. The study was realized with the support from the of the PV department of CRES [7].

The initial projects (PVMODE and PV-MORE: 1998-2001) that funded the design, procurement installation and operation of the systems were considerably technically-oriented, in comparison with a people-centered approach. In general, the findings confirm good cooperation of the users that were satisfied with the local technician service but the users have shown a grid-oriented energy culture and not a culture of autonomous energy supply.

3.2 Operational experience and natural disaster events

The microgrid in Gaidouromantra, Kythnos island, has been in operation for 12 years, since April 2011. The main battery bank was replaced in 2009 after 8 years of operation. During the last two years of operation of the old battery bank the electrolyte consumption was significantly increased, requiring frequent filling (every 2-3 months) with distilled water. Furthermore, the scarce use of the diesel generator increased its wear and in addition although careful measures were taken for effective cooling of the diesel generator, it is considered that the recent breakdown of it is due to the insufficient cooling because whenever it was operating, it was summer time when the settlement was mostly populated and the ambient temperatures were high.

Throughout the years of the microgrid operation the installation sustained and overcame one severe water flood due to a very heavy rain that destroyed and covered with rocks and earth yards, plants and rock partitions walls between plots. In this case the microgrid system did not suffer any damage. Then in the June of 2012 there was a wild bush fire, under very high speed winds, in the southern part of the island that passed through the valley and destroyed two houses, one of the 2 kWp distributed PV arrays which was located near house No 7 (figure 2) and finally burning and consuming one of the wooden poles of the overhead electric grid.

Figure 3: The lower half of the grid pole is missing, consumed by the fire.

Figure 4: A view of the Gaidouromantra valley after the wild bush fire in June 2012.

The system after shutting down due to short circuits in the power cables at the burnt PV array and the two houses. It was restarted 2 days later after the faults were cleared. CRES arranged for the replacement of the power grid pole, the repair of the grid points were faults occurred due to the fire and in the coming weeks is planning to visit and replace the

PV array that was burnt. All expenses were covered by CRES except the PV modules that were donated by Suntech Greece S.A. The lesson learnt in this case was that the PV arrays should be mounted at least 2 meters high from the ground far from bushes and trees in order to avoid their destruction. This was attested by the survival of the other PV arrays.

Figure 5: Burnt PV array and inverters.

4. Conclusions and perspectives

In conclusion, over the years it was noted that most of the users accepted the system well and were very cooperative during the tests. The selection of a local electrician from the phase of system installation has proved to be very valuable for the project service and maintenance, the support of the users in case of problems and the fast intervention in various emergencies that have occurred, such as natural disasters, etc. The following ideas and concepts may be the basis for future R&D project on this microgrid site:

• Development of the required safety, protection measures, communication and control of a smart active (bi-directional) Low voltage to Medium voltage transformer.

• Optimization of microgrid operation in islanded and inter-connected mode.

• Development of microgrid specific standards for power quality monitoring will be needed, especially for the islanded operation.

• Efficient and reliable Agent based Intelligent Load Controller operation for a large number of houses.

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