INTERCONNECTION OF SOLAR POWERED MINI-GRIDS — A CASE STUDY FOR KYTHNOS ISLAND

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ABSTRACT: The introduction of a substantial penetration from renewable energy sources in the power mix of the Greek islands grids is of great importance. This fact is justified because the island grids are autonomous and are mainly fed by diesel generators, that increase dramatically the energy production cost. Although the wind and solar potential in these areas is excellent, the strong seasonal demand fluctuations as well as the technical minimum restrictions of the thermal stations, pose a barrier. The implementation of a hybrid system with battery storage and an intelligent management system in Kythnos island, are considered to be an effective solution to this problem. The scope of this paper is to examine some grid impact issues for two case studies involving the increase or renewable energy source penetration in the grid of this island.
Keywords: Hybrid, Rural Electrification, Stand-alone PV Systems, Interconnection Issues

1 INTRODUCTION

In the framework of the EU funded project DISPOWER , CRES in collaboration with ISET and Econnect LTD has undertaken the task to study interconnection issues of mini-grids and other renewable energy source units with the main power system of Kythnos. These issues concern the interaction with the grid as well as economic and statutory matters. From a grid point of view issues to be examined include:

- Voltage profile
- Active and reactive power flows
- Thermal (current) loading on circuit elements
- Transient stability (maintenance of synchronism)
- Dynamic stability (damping of electromechanical oscillations between generators)
- Voltage stability and reactive power control
- Frequency control

As a first approach, ISET has carried out a preliminary simulation of a generic medium voltage grid of one of the Greek islands. The simulation was carried out with the software program ATP/EMTP. The objective was to study the grid behaviour if several renewable resources, such as solar PV and wind, would be integrated at various points. As a result, the voltage at a node increases after the PV injection and the increment is sensitive only in the lightly loaded network conditions. However, with the proposed injection of 10–25kWp, the increase is well within the limit. Also, on the lightly loaded condition with fully compensated reactive power, voltage increase at the node of wind generator (600 kW rated) is about 11% at the rated wind power. This is slightly more than the design limit. Moreover, the thermal capacity of the main conductors is well within limit. In fact, it is only loaded by about 20% in the heavy load condition.

A similar approach has been used for the examination of the actual Kythnos island grid. For the system analysis, a software tool developed in the Information Division of CRES has been used[1]. This tool is basically a GIS application that uses an interface with PSSE software in order to carry out such analysis. In the following paragraphs a short description of this work will be presented, followed by its application and the derived results for the problem under consideration.

2 KYTHNOS POWER SYSTEM

The design objectives for the Kythnos power supply system are [2]:

- A large portion of renewable energy generation
- Operation without diesel sets in times with low consumer load
- Fully automatic operation of the entire system including the diesel sets
- Very stable voltage and frequency in all operating modes
- Total remote control of the entire system

A schematic diagram of the Kythnos power system is shown in Figure 1. The renewable energy is provided by a small wind farm (5x33kW), a 500 kW Vestas wind turbine and a 100 kWp photovoltaic system. It should be mentioned that the 5x33kW wind farm as well as the photovoltaic unit are outdated. The battery plant combined with a 12-pulse converter can be used to cover the power deficit in case that a diesel or the large wind turbine is switched off unexpectedly. In the diesel-off mode, the battery inverter is used for frequency control. The dump load unit is interfaced with the power system with another 12-pulse converter. Its main task is to shave power peaks from the wind turbines, in order to stabilise voltage and frequency and avoid high loads on the battery storage. The phase shifter machine is used to control grid-voltage in the diesel off mode.

All these units are connected via step-up transformers to a 15KV medium voltage overhead grid. The annual average of load served from this grid is about 600 kW. However, strong seasonal fluctuations exist. This is evident from the power consumption figures, for the year 2000, provided in Table 1 [3].

Min. load in winter	300 kW
Max. load in winter	1000 kW
Min. load in summer	600 kW
Max. load in summer	2000 kW

Table 1: Power consumption in Kythnos (2000)

3 AC HYBRID SYSTEMS AND MICROGRIDS

3.1 Technological concept

A powerful approach to achieve the autonomous, local electricity supply based on a mixture of conventional and renewable energy sources was introduced with the ”Modular Systems’ Technology” (MST) [4]. Its principles are:

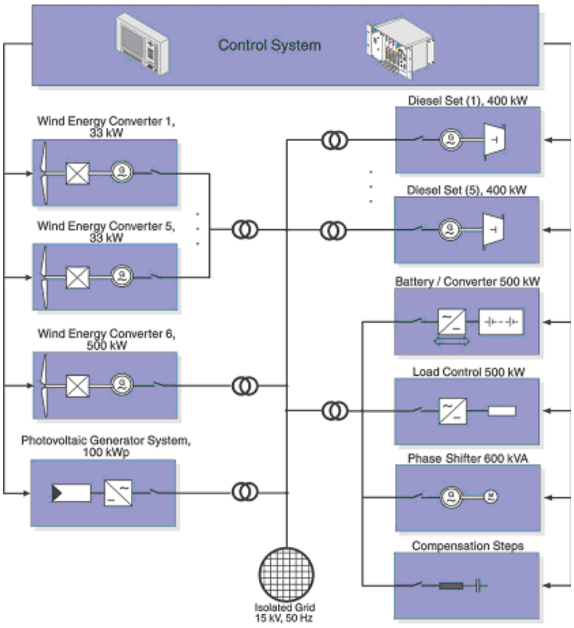

Figure 1: Kythnos power system block diagram.

- energy coupling on an ac bus bar
- standardised information exchange and
- a central supervisory control.

The MST allows to set up expandable systems and enables the easy adaptation to different supply situations. Storage systems are of outstanding importance in systems with a high share of renewables, and in many cases storage systems are coupled by means of an inverter. In [5] a concept for the multi-master parallel operation of inverters was developed. It features reactive power/voltage and active power/frequency droops similar to those commonly used in utility grids and is fully in conformance with MST. Moreover expensive bus systems for communication become obsolete by using the grid quantities frequency and voltage for the co-ordination of the components. Components following these ideas are commercially available and increasingly experience is gained from field tests and system operation [6].

3.2 Application and field test on Kythnos

The system on Gaidouromantra, Kythnos is a 1-phase mini grid with overhead power lines and a communication cable running in parallel, electrifying 12 houses in a small valley in Kythnos. The settlement is situated about 4 kilometres away from the closest pole of the medium voltage line of the island. Instead of extending the medium voltage network to this location it was decided to build up a local electricity supply.

After a reconfiguration of the system in 2003 the supply systems consists of 3 battery inverter running in master-parallel mode and form a 1-phase mini-grid. 5 PV systems mounted on different roofs are connected to the ac-line, a diesel genset is available for backup, see Figure 2 and [7].

The inverters as well as the other components connected to the system follow active power/frequency droop curves. The variation of the grid frequency is used for both, primary control of the system and for the energy management. For energy management purposes the set point of the frequency is varied accordingly. One example is shown in Fig. 3.

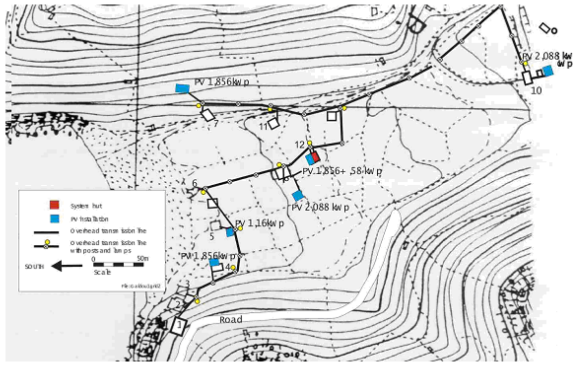

Figure 2: The house numbers, size and location of the PV arrays at the settlement of Gaidouromantra in Kythnos.

no. of supplied houses	12
no. of phases	1
no of inverters	3
rated power	10 kVA
peak power	20 kVA
grid frequency	48–52 Hz
multi master operation	yes
supply after failure of one inverter	yes
installed PV power	9 kWp
utilised diesel power	4,5kVA (1-phase)

Table 2: Data of the supply system of Gaidouromantra

Econnect have supplied and installed 12 distributed intelligent load controllers (DILCs) that are connected directly to the supply incomers of 12 dwellings. These DILCs operate autonomously and sense variations in supply frequency. As the inverters in the Kythnos system are operating in droop mode, the frequency will vary with inverter loading. The variations are analysed and then a switching decision is made, either to disconnect the dwelling if the system is overloaded, or to reconnect it if surplus power is available. The DILCs have been operating successfully for over 12 months.

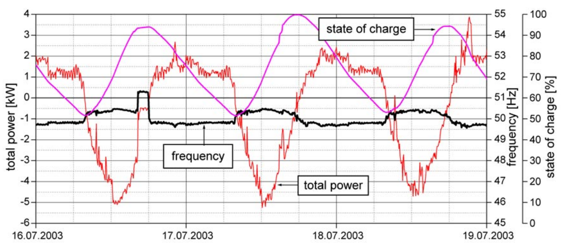

Figure 3: System control in a micro-grid by means of varying system frequency: In case of power surplus the battery is charged and the positive energy balance is indicated by a higher system frequency ($\approx 50.5Hz$). When the battery is nearly completly charged the system frequency is raised additionally by the energy management system ($\approx 51.3Hz$). This is recognised by the PV inverter and the PV power is limited in order to avoid overcharging of the battery.

The field tests demonstrate the successful implementation of the MST concepts and the multi-master operation of inverters. The grid and safety specifications for the house connections respect the technical solutions of the Public Power Corporation, which is the local electricity utility. The reason for such a decision was taken on the grounds that potentially the mini-grid may be connected at some point in time to the rest of the island grid. Due to the compatibility of the mini-grid with the main island grid the potential interconnection of both grids may in future be performed with minimal adaptation effort.

4 GIS APPLICATION

A schematic diagram of the Geographic Information System (GIS) application structure is shown in Figure 4. The core of the system is based on the integration of ESRI MapObjects and Borland-Delphi technology. There are four subsystems inside the core, the Editor module, the Map Generation and Query module, the Scenario Manager module and the Electrical Studies module. The core interfaces with three different types of databases. The databases used are the network SDE Layers Database, which include general geography information and other spatial related information such as RES potential, shape files where the nodes and the segments of the digitised network are stored and the Access database.

The Editor module is used to digitise the electrical network using as a reference the hardcopy map of the network. As a first step, the map provided by the electric utility is scanned, in order to be used as a background for the digitisation. Specific tools of the module are used, in order to insert the necessary elements that constitute the network. Such elements are: nodes, lines or cables, transformers and capacitors.

GIS are ideal tools for the production of thematic maps. Depending on the application, the Map Generation and Query module provides the capability of visual presentation of information related to the available RES potential or load flow results.

The Scenario Manager Module helps to define different scenarios for each electrical network. These scenarios may concern different topologies, different loads or generation units. Finally, the Electrical studies module creates automatically text files in PSSE format, according to the electrical network database. This file is used as an input file for the PSSE load flow program. After the establishment of the load flow solution, the results can be exported to a text file or they can return to the GIS application. Such an option allows a better visual inspection of the results and is very helpful for the identification of the cases where a violation of electrical variable limits (node voltages, thermal loading of circuit elements) appears.

5 STUDY CASES

As it was mentioned in a previous paragraph, the 5x33 kW wind farm as well as the 100kWp central photovoltaic system, are outdated. The latter fact in addition to the EU and Greek government incentives for private investments in the field of renewable energy sources, were the motivation to examine two scenarios for the increase of the renewable energy penetration in the Kythnos island grid. Both of them do not take into account the abovementioned renewable energy units. The first scenario involves the installation of 10 photovoltaic systems, distributed across the island grid. The maximum power that can be injected from each photovoltaic system is 130 kWp. The second scenario involves the installation of an 800 kW wind generator at the south end of the medium voltage grid. The location of the new wind generator, considered being interesting because it is away from the central power station and as a consequence it constitutes a worstcase scenario, regarding the impact on the voltage profile. Additionally, this location is favourable from a wind potential point of view, as it was seen from an inspection of the wind potential thematic map in the GIS application. A diagram of the Kythnos medium voltage grid, with the location of the old generation units and those considered by the two scenarios is shown in Figure 5. The issues examined for these scenarios are:

- The influence of the power injected from the renewable energy units on the grid voltage profile.
- The influence of the power injected from the renewable energy units on the thermal loading of the overhead conductors.

Distributed generation units, in general, affect the power flow and thus also voltage drops in the distribution system where they are connected. In a radial network, which is the case of Kythnos also, an increased distributed generation penetration and real power production first relieves the upstream parts of the network since the local distributed generation units supply the downstream loads. The reduced loading of parts of the network tends to flatten the voltage profile. If the real power production is higher than the demand of the downstream loads, the power will be exported up through the overlying network. An increase in distributed generation real production adds stress to the upstream network, which again gives greater voltage drops. The sign of these voltage drops is the opposite of those in a feeder without DG and voltage now decreases when moving upstream.

For the first scenario, a load-flow analysis has been conducted for different levels of power injected from the photovoltaic stations. Figure 6 (top) shows voltage variation from the nominal value, for five of the buses where the photovoltaic units are connected. The photovoltaic unit power is defined as a percentage of the maximum power of 130kWp. The grid is assumed to be lightly loaded. The observed voltage rise is well within the limit posed by the EN-50160 standard, which is $\pm 10\%$. Considering a heavy load condition for the grid (Figure 6, bottom) it can be observed, that the voltage at the inspected buses is below the nominal value, due to voltage drops caused by the load currents. The increment of the power injected from the photovoltaic stations, results in an improvement of the voltage profile, due to the earlier explained reasons. For the second scenario, the voltage increase in the wind generator bus is about 6%, for a lightly loaded grid, at the rated wind generator power and fully compensated reactive power.

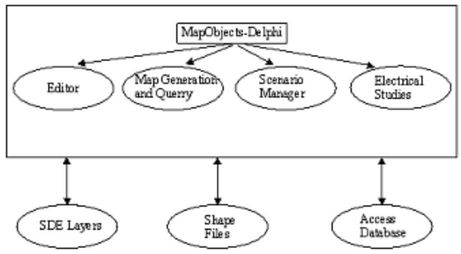

Figure 4: GIS application structure.

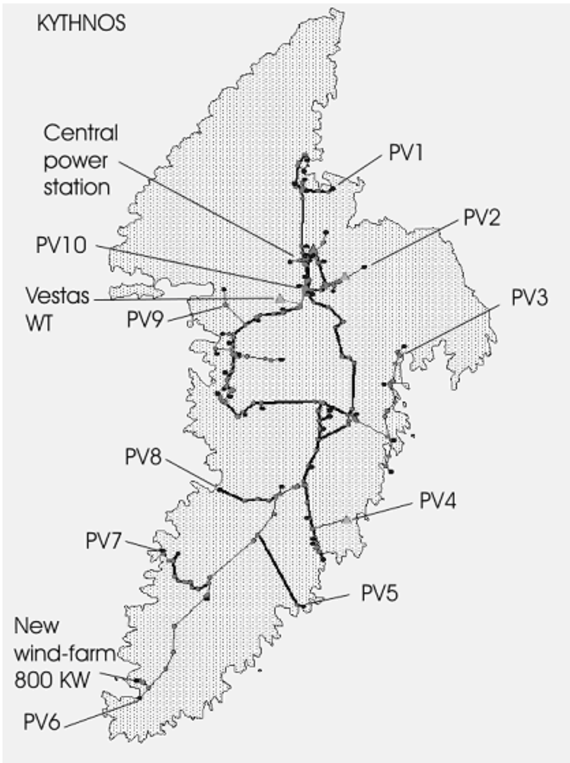

Figure 5: Kythnos medium voltage grid and the power sources locations.

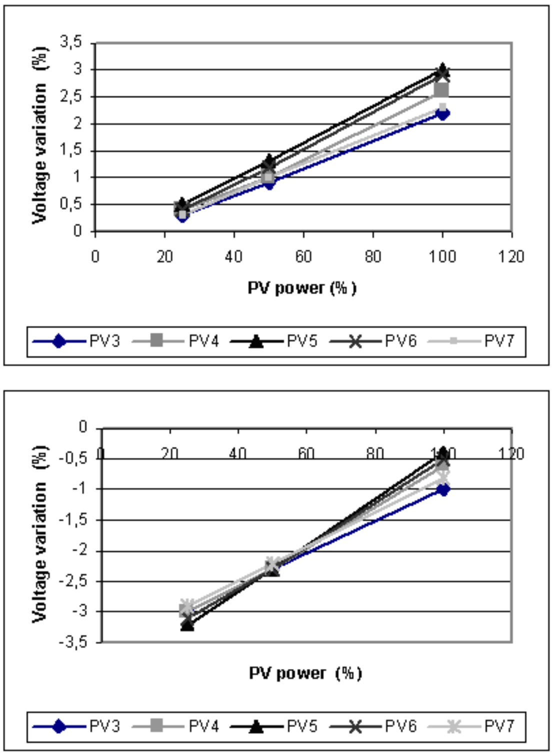

Figure 6: Voltage variation as a function of photovoltaic power injection, for the light load condition (top) and heavy load condition (bottom).

Additionally, the calculated loading of the lines is well within limits. In fact, for the heavy load condition, the maximum loading is about 25% of the conductors thermal limit.

6 CONCLUSIONS AND FURTHER WORK

The introduction of the considered renewable energy source units does not cause any problems, regarding the steady state operation of the grid. On the contrary, in the heavy loaded grid condition, an improvement of the general situation has been observed. In order to study the dynamic behaviour of the grid, a set of issues will be investigated. For the first scenario, it will be examined if the anti-islanding protection of the photovoltaic inverters can have a detrimental effect on the power system stability. Such a situation can probably arise if, for example, a voltage dip will activate the protection of the inverters. For the second scenario, the influence of the new wind generator on the power quality, as well as the dynamic interaction with the grid under fault conditions will be examined. Finally, for both of the scenarios, voltage and frequency regulation issues will be considered. This task is necessary due to the increase of the renewable energy penetration.

For local electrcity supply small hybrid systems and mini-grids are an alternative to grid extension. These systems can be build compatible to the main island grid and therefore offer the future option of interconnection with the main grid.

References

[1] M. Psalidas, D. Agoris, E. Pyrgioti, V. Kilias, P. Stratis, K. Tigas: ”Geographic Information System for the Digitisation and Management of Electrical Networks”, Proceedings of the 38th UPEC 2003, Thessaloniki, Greece.

[2] G. Betzios: ”The Hybrid System of Kythnos, one year operation experience from June 2000–2001”, Renewable Energies for Islands-Towards 100% RES Supply, 14–16 June 2001, Chania, Crete.

[3] Ph. Strauss, W. Kleinkauf, J. Reekers, G. Cramer, G. Betzios: ”Kythnos Island — 19 years of renewable energy integration”, Renewable Energies for Islands — Towards 100% RES Supply, 14–16 June 2001, Chania, Crete.

[4] W. Kleinkauf, J. Sachau, ”Components for Modular Expandable and Adaptable PV Systems”, 12th European PVSEC 1994

[5] F. Raptis, ”Design of Operational Control for Stand-Alone Grids with Renewable Energies”, Presentation at ISET, October 1994

[6] Ph. Strauss, A. Engler, ”AC Coupled PV Hybrid Systems — State of the Art and Future Trends”, 3rd World Conference on PV Energy Conversion, May 2003.

[7] M. Landau, A. Engler, R. Geipel, T. Heinzemann, M. Rothert, Ph. Strauss, ”Vernetzung stromrichterdominierter PV-Hybridsysteme”, 19. Symphosium Photovoltaische Solarenergie, Staffelstein, March 2004.

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