Impact of increasing penetration of PV and wind generation on the dynamic behaviour of the autonomous grid of the island of Kythnos, Greece.

Stathis Tselepis, Aristomenis Neris
CRES, 19th km Marathonos Avenue, Pikermi, Athens 19009, Greece
Tel. +30-210-6603369, fax +30-210-6603318, email: stselep@cres.gr

1. INTRODUCTION

The introduction of a substantial penetration from Renewable Energy Sources (RES) in the power mix of the Greek islands grids is of great importance. This fact is justified because island grids are autonomous and are mainly electrified by diesel generators, something that dramatically increases the energy cost and the pollution in environmentally sensitive areas. Although the wind and solar potential in these areas is excellent, a number of technical issues pose a barrier. These issues are related to the degree that the limited capabilities of frequency and voltage regulation in the island grids can cope with the fluctuating power injected by RES generators as well as the dynamic behavior of RES generators during grid disturbances. The implementation of a hybrid system with battery storage and an intelligent management system in Kythnos island, has been proved to be an effective solution to this problem [1]. However, today a significant part of the renewable energy sources and other power equipment is outdated and additionally it should be worthwhile to further increase the penetration of renewable resources in the island. In this context, results are presented in this paper from the assessment of the dynamic behaviour of the Kythnos island grid for two scenarios of increased RES penetration. The first one concerns the interconnection of a number of distributed PV generators and the second one the connection of a large wind turbine equipped with an asynchronous generator.

2. KYTHNOS POWER SYSTEM

The design objectives for the Kythnos power supply system were [2] as follows.

- A large portion of renewable energy generation
- Operation without diesel sets in times with low consumer load (diesel-off mode)
- 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. Five diesel generators, producing 400kW each, constitute the main power source of the island. These generators are equipped with electronic speed controllers and automatic load sharing devices for parallel operation with fixed frequency (isochronous mode). 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 if a diesel or the large wind turbine, is switched off unexpectedly. In the diesel-off mode the following system 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 damp power peaks from the wind turbines, in order to stabilize 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.

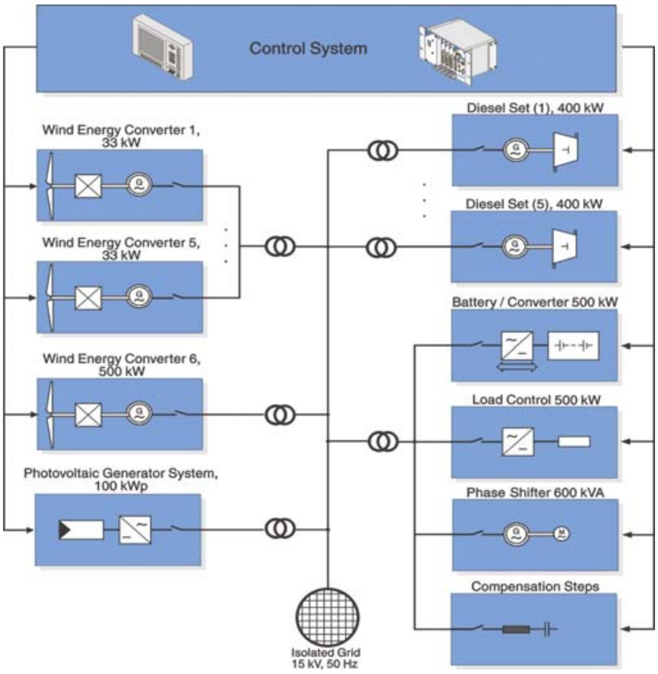

Figure 1. Kythnos power system block diagram.

3. DYNAMIC BEHAVIOR ASSESEMENT

For the examination of the grid dynamic behavior, when a significant penetration from renewable resources exists, a model of the Kythnos power system was developed in the Simulink® environment, using the Power System Blockset ® library (Figure 2).

This model utilizes a simplified representation of the grid that includes only the main nodes, a model of the local power station with the diesel generators and models for the renewable resources (wind turbine and PV systems) as well as for a battery storage inverter. The maximum RES penetration considered was 33% (640kW) for both the PV and wind case. This limit has been chosen in order to have adequate spinning reserve that will be able to provide the necessary security margins for the system operation. One of the examined disturbances was a three-phase fault, with a 150msec duration, that was applied in a specific node away from the power station. In the case of PV systems, an under-voltage protection was included in their model in order to study the frequency and voltage dynamic behaviour of the power system when the fault is cleared. For all the examined PV penetration levels (0-33%) the power system behaviour was stable, since sufficient spinning reserve existed in order to cope with the loss of PV power.

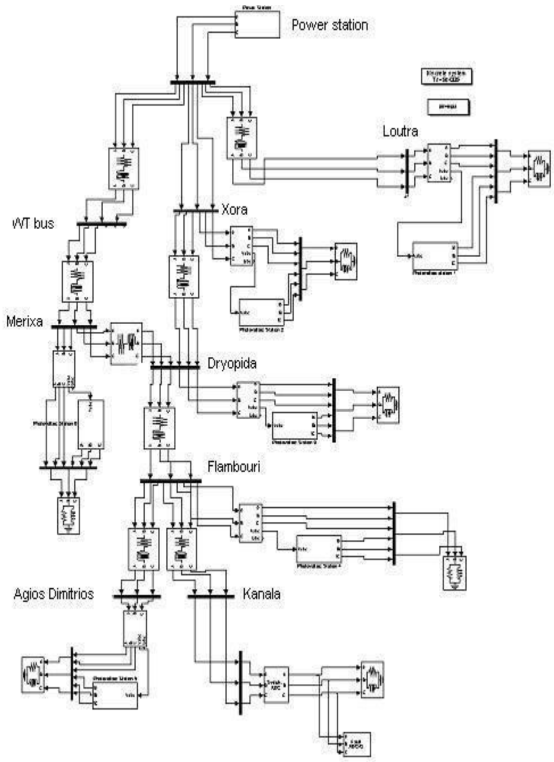

Figure 2. SIMULINK model for the Kythnos island grid.

For the wind turbine case and the same disturbance, protection systems of the wind turbine were not taken into account in order to study the system behaviour. When the fault is applied, the voltage depression (Figure 3) causes a sudden reduction of the electrical output of the diesel generators and the wind turbine (Figure 4). As a result the frequency of the system (Figure 3) increases. In addition during the dynamic event, the reactive power absorbed from the wind turbine increases (Figure 4). For the examined fault scenario the system is stable as can be seen from the figures, since all system variables quickly return to pre-fault values.

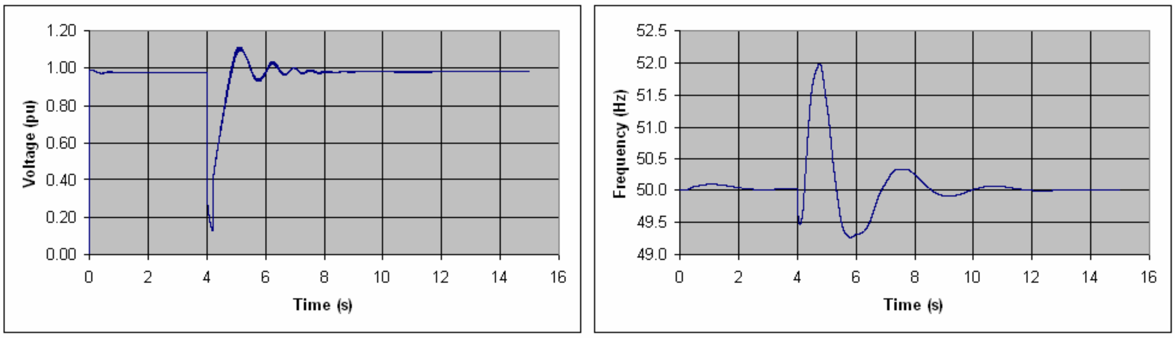

Figure 3. System voltage response for a three phase fault

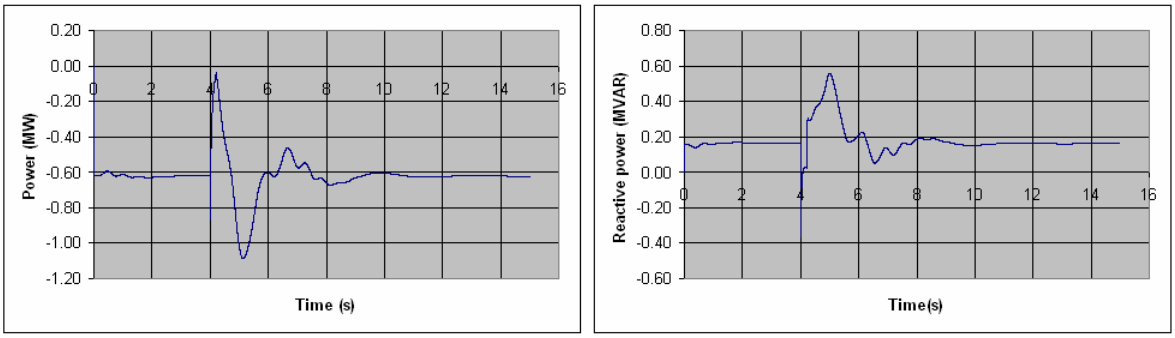

Figure 4. Wind turbine active and reactive power for a three phase fault.

Critical clearing time for a short circuit fault is an issue for power system stability. This time is defined as the maximum duration of a short circuit that does not lead to loss of stability of the generators. A number of simulations have been performed in order to determine this parameter for the examined system. From these simulations turned out that the clearing time for which the wind turbine retains its stability is about 600ms.

4. ALTERNATIVE SOLUTIONS FOR SPINNING RESERVE REDUCTION

Due to the high cost of the energy produced by the diesel generators it is highly desirable to achieve a reduction of this reserve without sacrificing the safety of the power system operation. Two solutions to this problem were examined. The first solution is related to the use of PV power electronic inverters with disturbance ride-through capability. Today these grid interfaces are disconnected quickly when a voltage disturbance takes place in order to avoid islanding situations and protect themselves. Reconnection takes place several minutes later. Disturbance ride-through capability means, among other things, that the grid interface should stay connected during the disturbance or it should be reconnected quickly after the disturbance [3]. The second option of rapid reconnection for disturbance ride-through has been simulated [4]. Figure 5 shows voltage and frequency response of the power system for the same three-phase fault disturbance but with one diesel generator less. Both variables present a stable behaviour, since voltage recovery is fast and the reconnection of PV inverters helps to maintain the power balance. This fact shows that in order to achieve an increased PV penetration in island grids, disturbance ride through capability could be a promising solution.

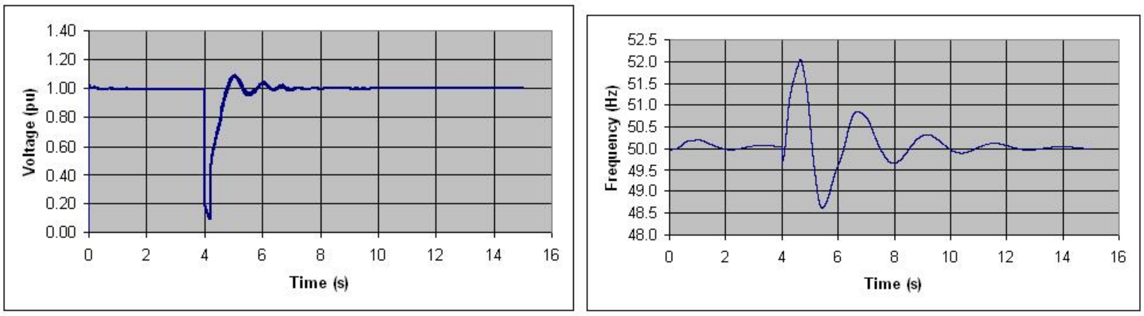

Figure 5. System voltage and frequency response for a three-phase fault (PV case with reconnection).

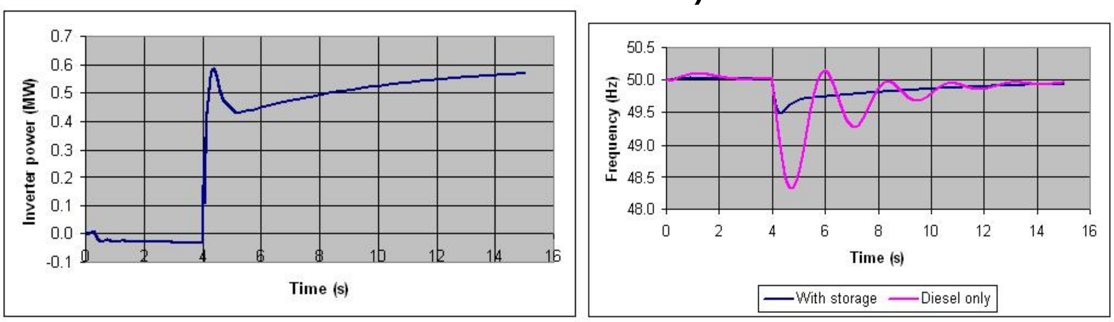

Figure 6. Battery inverter power and frequency response for the wind turbine disconnection.

The second solution is related to the use of battery storage that will replace the spinning reserve provided by the diesel generators. As it was mentioned earlier, battery storage already exists in the power system of Kythnos island but it is interfaced with the grid using a thyristor based inverter. Today, taking into account the evolution of power electronics, the replacement of the existing inverter with a shelf-commutated one based on IGBTs (Insulated Gate Bipolar Transistors) would add a number of benefits related to more reliable behavior and the capability to assist the voltage control of the system. A model of such a battery inverter was introduced in the Kythnos power system model. Figure 6 depicts simulation results from a studied case concerning the disconnection of the wind turbine due to high wind conditions. When the turbine is disconnected (at t=4s) the battery inverter power increases fast in order to compensate for the power deficit that was created. As a result, a better frequency response can be observed for the battery inverter case, where the system operates with a diesel generator less, compared to the case with diesel generators only.

5. CONCLUSIONS

In this paper simulation results have been presented, concerning the impact of RES penetration in the dynamic behaviour of the Kythnos island autonomous grid. For the considered scenarios, it was found that the power system presents a stable behavior provided that enough spinning reserve is available in order to cover the power deficit. This is very important, especially for the case of the wind turbine disconnection due to high wind, which can be a very common event in Greece due to gusting winds.

Two solutions have been proposed in order to achieve a safe operation of the power system with reduced spinning reserve. An initial assesment of system stability showed promising results for their applicability.

6. REFERENCES

[1] Thomas Degner, Philipp Taylor, Dave Rollinson, Aristomenis Neris, Stathis Tselepis, "Interconnection of solar powered mini-grids - a case study Kythnos island, Greece". Visual presentation 7BV 3.40 at the 19th European Photovoltaic Solar Energy Conference and Exhibition, Paris, 7–11 June 2004.

[2] Ph.Strauss, W.Kleinkauf, J.Reekers, G.Gramer, G.Betzios, " Kythnos island- 19 years experience of renewable energy integration", International Conference "Renewable energies for islands, towards 100% RES supply", Chania-Crete, Greece, 14-16 July, 2001.

[3] J.G.Slootweg, "Wind power modelling and impact on power system dynamics", PhD Thesis, 2003, Technical University of Delft, http://eps.et.tudelft.nl.

[4] S. Tselepis, A. Neris, "Dynamic behaviour of the autonomous grid of the island of Kythnos, Greece, due to large penetration of PV and wind systems". Proceedings of the 20th European Photovoltaic Solar Energy Conference and Exhibition, Barcelona, Spain, 6-10 June 2005.