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Dynamic performance assessment of wind energy pump storage units in Crete's power system

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Abstract. Large scale integrating of wind power generation into a grid may raise serious stability issues. In this case energy storage systems seem to be suitable for balancing power and energy between the inconstant wind parks generation and the grid. In this paper, the impact of high wind power penetration on the dynamic performance and stability of power systems is investigated. More precisely, the focus of this study is to assess the operation of pump storage systems in the autonomous power system of a large island such as Crete. Results of this study show that it is possible to achieve a large wind power penetration without significant dynamic security problems, if wind energy pump storage units are in operation.

Introduction

In island systems, dynamic performance and stability is a crucial issue and a major concern, since mismatches in generation and load and/or unstable system control might lead to frequent system failures, [1, 2]. Although, renewable and especially wind parks exploitation appear particularly attractive, they present an unpredictable character and problems may appear when integrating it in a large scale, [3-5]. Moreover, the integration of a substantial amount of wind power in autonomous power systems needs careful consideration, so as to maintain a high degree of reliability and security of the system operation.

The main problems identified concern operational scheduling (mainly unit commitment) due to high production forecasting uncertainties, as well as steady state and dynamic operating problems. These problems may considerably limit the amount of wind generation that can be connected to the island systems, increasing the complexity of their operation. Thus, next to the more common angle and voltage stability concerns, frequency stability must be ensured [6]. This depends on the ability of the system to restore balance between generation and load following a severe system upset with minimum loss of load. Energy storage could eliminate these problems. Especially, pumped storage units can contribute, as the extra energy provided by the wind turbine is used to pump water from an inferior basin into a superior one, which is then released when more power and/or energy is needed [7, 8]. Pumped storage presents many advantages like long time storage period without losses, fast response in load demand, high storage capacity, and good efficiency at high power level, while it is the only successfully implemented storage method for high power levels.

In this case, dynamic simulation studies must be among the first steps in determining the level of wind power penetration in isolated power systems, [9]. Thus analytical studies are required in order to derive security rules and guidelines for the optimal operation of these complex systems, [10]. Studies on the dynamic stability of the isolated power system are necessary, monitoring voltage and

frequency calculations under several abnormal operating conditions, e.g. start-up or sudden disconnection of wind generation, wind fluctuations, short circuits on the network etc, hydro units and pumps operation. The new operating and planning policies imposed by the current demands for increased efficiency and economy, dictate the need to operate the power system in a more stressed way and to consider more effective means of providing a given level of reliability and stability, [11-13]. Moreover, in order to operate optimally within the new conditions, the possibilities of providing a required level of security have to be accounted for. This is directly linked to the provision of remedial actions, in case of insecure situations. For dynamic security, unlike steady state security, remedial actions can only be preventive leading to load shedding or generation rescheduling. Results of this study show that wind energy pump storage units could successfully provide adequate and fast spinning reserves and/or pumps load disconnections as potent remedial actions to improve system stability.

Study Case

As it is well known [1-5] island power systems face increased problems related to their steady state operation and dynamic performance, since mismatches in generation and load and/or unstable system frequency control might lead to system failure much easier compared to conventional interconnected systems.

This study deals with the autonomous power system of Crete island, where renewable energy sources exploitation, especially wind and solar energy, are significant. Crete island has already a considerable amount of installed wind park and PV plants with almost 18% contribution in annual energy balance. However, the integration of a higher percentage of RES penetration, especially of wind power, needs careful consideration, so as to maintain high levels of reliability and security of the system operation [6].

Conventional generation is based on three (3) oil-fired thermal power units with total capacity of 700 MW approximately. Additionally, there are 23 wind parks installed with nominal power of 170MW across the island as it is depicted in Fig.1. Furthermore, 1200 small PV plants of 80kW nominal power each are already installed (Fig. 2) giving 80MW in total.

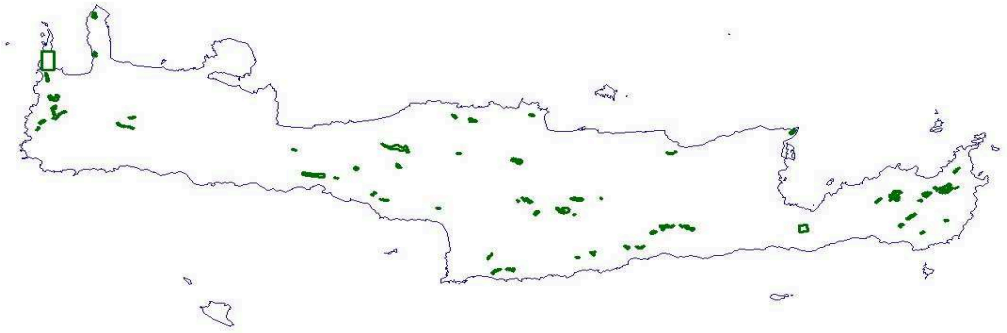

Figure 1 Wind parks allocation in power system of Crete

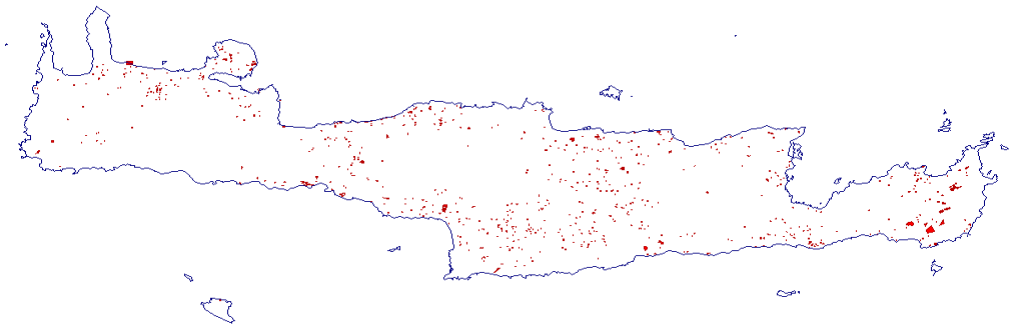

Figure 2 PV plants allocation in power system of Crete

Since 2000 the annual wind energy share has been steadily above 10%. Since 2009, installation of more wind farms and PV Plants increased energy share over than 16%. Thus considering the current situation even now power system operators have to tackle with significant dispersed generation and high RES penetration. Consequently, even though during the low consumption periods minimum load demand is greater than current system technical minimum, the combination of RES power generation and the technical minimum of the base units exceed frequently the island demand. As a result, wind power is curtailed to maintain the secure operation of the steam units. Thus autonomous power system of Crete has been an excellent representative for dynamic performance estimations.

Dynamic Performance Analysis and Results

An analytical model of the examined power system has been implemented in PowerWorld Simulator as it is presented in Fig. 3 for the simulation of the transient operation of the examined power system, under several operating conditions. Future scenarios of even higher RES penetration with the contribution of pump storage units as it is shown in Fig. 4 are included in this final model.

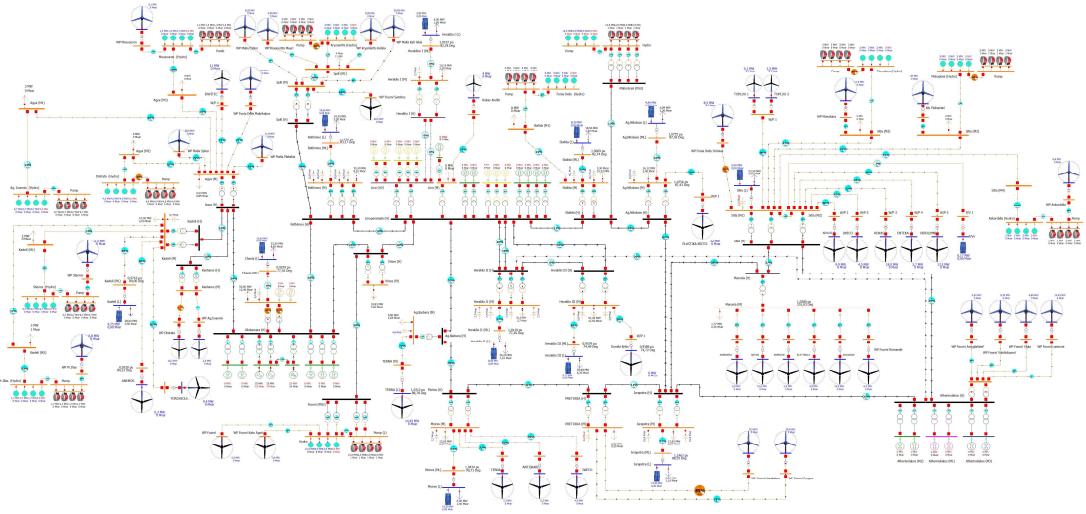

Figure 3 Simulation model

In this case energy storage system consists of pump storage units (PSUs) which are considered in operation with nominal power up to 100MW. These units are used both as pumps and as hydro generator contributing to the operation planning and control of the examined power system.

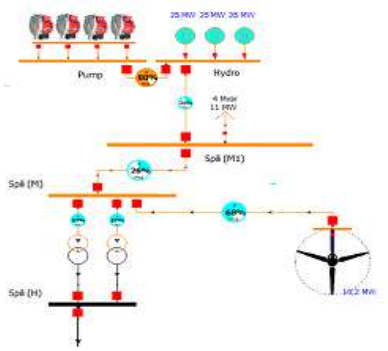

Figure 4 One of the PSU that is about to be installed

Extensive transient analysis studies are conducted in order to assess the dynamic behavior of the system under various disturbances. In case of significant and sudden wind power variability voltage and frequency variations are recorded. In Fig. 5 the variation of voltage at the main wind

park substation, are shown. The frequency follows the wind power changes, while the voltage profile follows an opposite trend. It can be easily seen that in case of ultra-high penetration of RES the power system remains satisfactorily stable if PSUs are in operation.

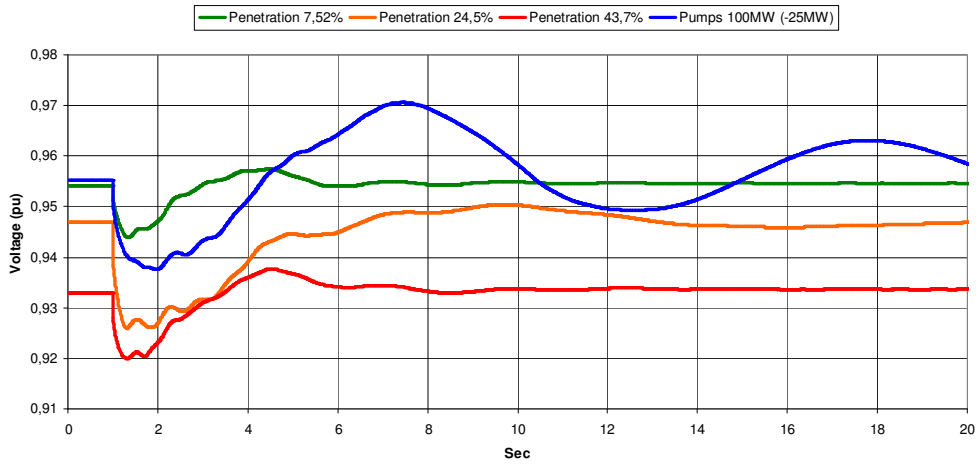

Figure 5 Voltage variations

In Fig. 6 the frequency change in five different scenarios under the same disturbance is depicted. More precisely, the first three scenarios correspond to the three levels of RES penetration: (a) 7.5%, (b) 24.5% and (c) 43.7%. While in the next two scenarios the pump storage units are considered to operate (d) as hydro generators in their technical minimum and (e) as pumps that consume exclusively wind energy. The frequency behavior and the dynamic performance in general of the examined power system are clearly improved by the use of PSUs. Especially in case of PSUs operation as pumps the use of controlled load shedding enforce significant system stability.

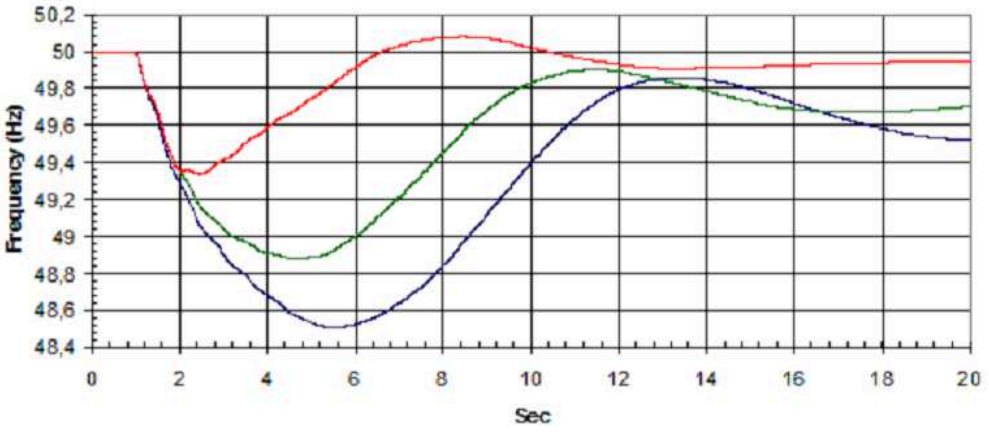

Figure 6 Frequency fluctuations in three different operation scenarios

Summary

The objective of this paper was to investigate and analyze the dynamic performance of a representative island system as power system of Crete with the assumption of even higher wind and PV power penetration levels. Review of several studies [14-17] and corresponding results indicate that the re-dispatch strategy has an important impact on the transfer margin of a system, although it has an upper limit of contribution. It is well known that wind turbines and PVs are non-dispatchable power sources with different operational characteristics than conventional power units. Thus, high levels of such power sources generation create issues of grid control, making percentage of PES penetration one of the most crucial parameters for the system stability.

In this study several simulations have been performed to investigate the stability of the power system with high percentage of RES power penetration (up to 45%). More precisely, frequent and significant disturbances of the system as short circuit, sudden disconnection of conventional power units as well as wind parks and strong wind velocity fluctuations have been simulated. As a second step the parallel operation of pump storage units have been analyzed in order to assess the level of their contribution to dynamic performance of the system. Results have shown that the deviations of the power system voltage and frequency remain acceptable under many examined perturbations without PSUs. However, the situation depends on the scheduling of the power units and the amount of allocated spinning reserve. In contrary the system remained stable in all the examined cases when PSUs have been considered in operation.

Concluding although installation of a large amount of RES (mainly WTs and PVs) in an island such as Crete affect significant the transient stability of the power system, they should not considered as a principal and a main obstacle to an adequate secure and reliable operation. The stability of a power system can be maintained even if high penetration of wind and solar power exist by additional system measures, control enhancement, preventive actions and even more with energy storage systems. It is a fact that these issues of both additional system measures and energy storage systems are particularly important for the dynamic performance of the system; therefore their contribution should be further investigated and their exact benefits to be clarified.

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