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The role of pumped storage systems towards the large scale wind integration in the Greek power supply system

G. Caralis*, D. Papantonis, A. Zervos

National Technical University of Athens, School of Mechanical Engineering, Fluids Session, 15780 Zografou, Athens, Greece

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ABSTRACT

In the recent years, the debate on the necessity of pumped storage systems in the Greek power supply system has started. In the current decade, the Greek power system will gradually try higher RES penetration, mainly due to wind energy and photovoltaics integration. Variability of wind and PV generation and the current structure of the Greek power system introduce technical constraints, which should be taken into consideration in the forthcoming large scale RES integration. This paper examines the ability of the Greek power system to absorb renewable power and the necessity of pumped storage systems. The feasibility of pumped storage systems is discussed in three different scenarios of wind–photovoltaics integration. Results show that for the gradual increase of variable output RES, pumped storage systems are required, but the feasibility of pumped storage systems is not proved in the intermediate scenarios of RES integration.

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1. Introduction

Wind energy represents a rapid growth worldwide and is the most commercially and economically competitive renewable energy source. Several power systems in the world are supplied and will be supplied in the near future by large fractions of wind energy. As regards the wind share at a national level, Denmark, Spain and Portugal are leaders with 24%, 14.4% and 14% of annual contribution respectively [1]. Denmark achieves this rate, thanks to the large interconnections with other major European grids, while Portugal, due to the parallel operation of several hydroelectric stations. The autonomous power system of Crete represents a 14% annual wind energy contribution which could be considered as an upper technical limit in such cases [2].

In Greece, the achievement of national targets will be based primary on wind farms development, and secondarily on photovoltaics, because the former is considered as a more mature, efficient and economic technology in relation to the latter. Despite their high cost, photovoltaics contribute in the summer midday peak demand, and provide the power system with beneficiary distributed generation very close to the consumption. The national target for the penetration of RES is set at 40% of gross electricity consumption by 2020 [3]. According to the national action plan [4] the achievement of this target will be reached with 7500 MW of

* Corresponding author.
E-mail address: gcaralis@mail.ntua.gr (G. Caralis).

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wind installed capacity and at least 2200 MW photovoltaics. This constitutes a very high RES penetration degree, which excess the current international experience and requires special management and innovative technical and regulatory solutions. The Greek power system is characterized by large lignite-fired units' contribution, by limited interconnections with the rest of Europe, and a rather limited capacity of hydroelectric plants.

2. Current situation and prospects

In the Greek power system of the mainland, the cumulative capacity of conventional and hydro power units is 11,234.3 MW, according to official figures of the Hellenic Transmission System Operator (HTSO). The electrical system of the mainland consists of 33 conventional units, of which 22 lignite (5288 MW), 4 oil (750 MW), 4 combined cycle units (1630 MW), 3 units of natural gas (507.8 MW), and several hydroelectric plants (3058.5 MW). Hydro plants have an annual contribution of 5 TW h in a typical hydraulic year, and definitely are used for peak supply.

In the current work, except of the "current status" scenario with 1000 MW wind and 100 MW PV capacity, three scenarios of wind–PV penetration are examined (3000–500, 5000–1000 and 8000–2000 MW). The optimum locations for the wind capacity is achieved by the results of a parallel work [5] and are presented in Fig. 1. This sitting has been achieved by the use of an optimization genetic algorithm aiming at the most effective integration of wind energy in the Greek territory, and adopting the gradual islands' wind potential exploitation via their interconnections with the mainland.

As reference year in the current work is considered a typical year with annual electricity demand 60 TW h, and peak demand 11.0 GW. The analysis is based on hourly demand time series of 2006 (with recorded annual energy and peak demand 49 TW h and 10.3 GW), after appropriate conversion to meet the reference year. Annual data of 2006 are used, as long as simultaneous time series of wind velocity across the whole territory are available for the same year. These wind time-series have been reproduced by systematic application of a mesoscale weather prediction model [6,7]. Next, for a desirable wind power installed capacity at each area and using a representative wind turbine power curve, hourly time series of the cumulative available wind power production can be reproduced on an annual basis. By this way probable correlation between wind power production and load demand are taking into consideration. In Fig. 2, annual time series of demand and electricity generation from wind and solar, and their respective duration curves are presented.

3. Simulation of the Greek power supply system

3.1. Basic concept

The aim of the current approach is to estimate the electricity production from renewable energy sources that can be absorbed directly from the Greek power system. RES power absorption or equivalently its complement RES power curtailment, is an important issue which should be taken into consideration, as soon as affects directly the renewable electricity supply. For this purpose the Greek power system is simulated.

The methodology examines the steady-state operation of the Greek power system and takes into account the specific characteristics of demand, the technical features of conventional and hydro power plants and the technical constraints for the smooth and safe operation of the system. For the application of this methodology, the units' commitment and load dispatch should be first clarified. In the perspective of the gradual increase of renewable energy sources in the Greek power system, it is clear that management rules and operational principles will differ from the current practice.

First of all as regards the management of variable production renewable energy technologies, wind power curtailment may occur and could be established through a central control system by the Hellenic Transmission System Operator, as it has been already established in the autonomous Greek islands. On the contrary, curtailment of photovoltaics power cannot be so easily occurred due to distributed generation by many small units and the absence of the required controllers. Over and above, electricity production with Photovoltaics, always very close to the demand and predictable, is – up to now – too expensive type of energy to be curtailed and should be absorbed in priority.

Technical constraints regarding the commitment, the load dispatch and the safe operation of the system are considered. Conventional units cannot be charged under their technical minimums. For lignite-fired units, this limit is considered at least 70% of their nominal power. While, for gas-turbines and diesel generators this limit is 30% of their nominal power.

It is assumed that wind and load forecast models are systematically used by the Transmission System Operator. Then load demand, wind and PV power availability and variability are considered sufficiently predictable. In this model, the power dispatch and the schedule of conventional power stations are defined, recognizing two main categories of conventional units; base load units and peak load units. The former concerns heavy lignite power units and the latter gas turbines and diesel power units. The number of base load units to be committed is defined by the expected low demand of the next 15 days.

Peak load units are characterized by their ability to provide quick response and to undertake the variability of demand and RES production. Then, a first approach of the number of peak demand units to be committed is related to the expected variability of demand and RES power generation for the hours ahead. This means that if high variability of load demand and RES generation is expected for the hours ahead, more flexible peak load units are required to be committed to ensure the safe operation of the power system.

A special methodological treatment is considered for hydropower. Today, in Greece, hydro plants operate during peak hours which always occur in summer. In the near future, their generation should be properly adjusted not only with peak demand, but also with the variability of rest RES power generation. Wind power curtailment may occur in low demand or in windy periods. During low demand hours hydro power plants are switched off. During peak demand periods, if there is wind power surplus, hydro power plants may reduce their operation saving water for peak demand periods of low wind. So, wind power plants could save water in the hydro plants' reservoirs and hydro generation will not constrain wind power absorption.

In order to have results in the safe side, a dynamic limit related with the permitted instantaneous penetration of wind power is considered to ensure the stability of the system in emergency case. For example a sudden fall of wind or a sudden storm over all the wind power plants, could lead in total loss of wind generation. Although such cases are considered improbable to occur, this dynamic limit ensures that other units, already committed, will be able to increase their production before the system collapse. In this analysis the base value of the allowed instantaneous wind power is set to 60% of the load demand.

Load demand, wind and photovoltaics generation are taken into consideration through the annual time series. Especially the time series of wind production has been derived using wind speed time series reproduced by a meso-scale weather forecast model systematically applied in the whole country. Thus, given the installed wind power in every region and representative power curve, the output of wind power is calculated. Aggregating the output of wind power