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An advanced model for the efficient and reliable short-term operation of insular electricity networks with high renewable energy sources penetration

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ABSTRACT

This paper presents an overview of the different methodologies and mathematical optimization models developed in the framework of the EU-funded project SiNGULAR towards the optimal exploitation and efficient short-term operation of RES production in insular electricity networks. Specifically, the algorithms employed for the creation of system load and RES production scenarios that capture the spatial and temporal correlations of the corresponding variables as well as the procedure followed for the creation of units' availability scenarios using Monte Carlo simulation are discussed. In addition, the advanced unit commitment and economic dispatch models, that have been developed for the short-term scheduling of the conventional and RES generating units in different short-term time-scales (day-ahead, intra-day, and real-time) are presented. Indicative test results from the implementation of all models in the pilot system of the island of Crete, Greece, are illustrated and valuable conclusions are drawn.

Contents

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1. Introduction

The increased use of energy from Renewable Energy Sources (RES), together with Demand-Side Management (DSM), energy savings and increased energy efficiency, constitute important parts of the package of measures needed to reduce Greenhouse Gas (GHG) emissions that will help Europe comply with the Kyoto Protocol. The European target "20–20–20" implies [1]: (a) a reduction in European Union's (EU) greenhouse gas emissions of at least 20% below 1990 levels, (b) 20% reduction in primary energy use compared with projected levels, to be achieved by improving energy efficiency, and (c) 20% of EU energy consumption to come from renewable resources.

The latter goal motivated the EU countries to incentivize the increase of RES installed capacity, with particular emphasis on generating electricity from wind and more recently from solar resources. Large RES plants have already been constructed and operated across Europe, whereas the integration of new small and large RES projects continues aggressively. The share of RES in the electricity production is expected to increase to 30–35% by 2020 [2].

A large share of the recent RES installed capacity has already taken place in insular electricity grids, since these regions are preferable due to their high RES potential. However, the increasing share of RES in the generation mix of insular power systems presents a big challenge in the efficient management of the insular networks, mainly due to the limited predictability and the high variability of renewable generation, features that make RES plants non-dispatchable, in conjunction with the relevant small size of these networks.

In this context, the recently launched collaborative project SiNGULAR (Smart and Sustainable Insular Electricity Grids Under Large-Scale Renewable Integration), an EU-funded project under the 7th Framework Programme (FP7) aims at investigating the effects of large-scale integration of RES and DSM on the planning and operation of insular (non-interconnected) electricity grids, proposing efficient measures, solutions and tools towards the development of a sustainable and smart grid. Different network operation procedures and tools, based on innovative approaches of predictive electricity network operation, are being developed. A set of electricity network planning procedures and tools are also being developed to implement robust insular electricity network planning. The goal is the generation of effective solutions and information so that the integration of insular and highly variable energy resources is maximized. The operation and planning tools and procedures are being applied in different insular electricity grids across Europe (pilot sites), allowing the development of generalized guides of procedures and grid codes specific for future generation of smart insular electricity grids.

Among others, in the framework of SiNGULAR, various methodologies and software tools are being developed and implemented for the optimal short-term scheduling of insular electricity networks, taking into account the stochastic nature of various system and unit parameters, such as the system load, the RES production, the unit availability, etc.

In this paper, an overview of the different methodologies and mathematical optimization models developed towards the optimal exploitation and efficient short-term operation of RES production in insular electricity networks is presented. Specifically, the algorithms employed for the creation of system load and RES production scenarios that capture the spatial and temporal correlations of the corresponding variables as well as the procedure followed for the creation of units' availability scenarios using Monte Carlo simulation are discussed. In addition, the advanced unit commitment and economic dispatch models, that have been developed for the short-term scheduling of the conventional and RES generating units in different short-term time-scales (day-ahead, intra-day, and real-time) are presented.

The remainder of the paper is organized as follows: Section 2 describes the scenario generation and scenario reduction procedures for the description of the uncertain system parameters, namely RES generation, system load and units' availability. Section 3 describes the proposed advanced mathematical optimization models, namely unit commitment and economic dispatch models, for the short-term scheduling of the conventional and RES generating units in different short-term time-scales. In addition, indicative results from their coordinated implementation in the insular power system of Crete, Greece, are presented. Finally, in Section 4 valuable conclusions are drawn and indicative emerging methods and tools to address the challenges of the integration of large amounts of RES in insular electricity grids are highlighted.

2. Scenario generation methodologies

2.1. Scenario generation for RES injection

In order to create scenarios for RES injection, time series analysis methodologies are employed. Specifically, a process that combines a scenario generation technique of an original (extended) set of scenarios with a technique to reduce the number of scenarios is followed. An additional methodology for creating spatial cross-correlated scenarios is also applied.

The scenario generation technique of the initial (extended) set of scenarios using time series analysis techniques is based on a sampling approach. Specifically, the appropriate forecasting model for the random process under study (e.g. PV or wind power generation) is first determined. This forecasting model can be either a seasonal Autoregressive Integrated Moving Average (ARIMA) model or an Artificial Neural Network (ANN) model. In the following paragraphs the basic features of both forecasting models are presented and the adopted scenario generation procedure is described.

2.1.1. ARIMA models

A class of time series techniques, namely ARIMA, can be employed for the short-term forecasting of RES injection. ARIMA is a method first introduced by Box and Jenkins [3] and is one of the most popular methods for time series forecasting.

In general, for stationary time series a simple Autoregressive Moving Average model, ARMA (*p*, *q*), is used, whose analytical mathematical expression is as follows:

$$y_t = \sum_{j=1}^{p} \varphi_j y_{t-j} + \varepsilon_t - \sum_{j=1}^{q} \theta_j \varepsilon_{t-j} \quad (1)$$

where $\varphi_1, \varphi_2 ..., \varphi_p$ are the p parameters of the autoregressive polynomial and $\theta_1, \theta_2 ..., \theta_q$ are the q parameters of the moving average polynomial. The term ε_t in the Eq. (1) stands for an uncorrelated normal stochastic process with zero mean and standard deviation σ. The stochastic process ε_t is also referred to