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Intermittent non-dispatchable renewable generation and reserve requirements: historical analysis and preliminary evaluations on the Italian electric grid

G.L. Guizzi, L. Iacovella, M. Manno*

University of Rome "Tor Vergata", Rome, Italy

Abstract

Intermittent renewable generators, mostly solar photovoltaic (PV) and wind power plants (W), have been growing across the Italian electric grid at an unprecedented rate over the last years. At the beginning of 2013, GSE (state-owned company supporting renewable energy sources) surveyed 16,4 GW of installed PV systems and 8,1 GW of wind farms, covering a significant share of Italian electric demand, which has been ranging between 21 GW and 54 GW over the same year.

Such a relevant amount of installed intermittent power generators, fostered by priority dispatch, has already had relevant effects on the electricity market, in both its two components: the energy market (MGP) since the end of 2013 has been steadily lowering its single national purchase price (PUN), even recording zero purchase prices; at the same time, the amount of resources needed to establish reserve margin on the dispatching services market (MDS) has increased, due to a growing amount of intermittent generators penetrating on the grid, at a yearly rate of 5%, as shown from our historical analysis.

A preliminary evaluation method of reserve requirements was developed taking into account forecast variability in electric load and intermittent renewable generation. The model was used to evaluate the growth of reserve requirements with an expected larger share of renewable generators. The magnitude of this relevant parameter was assessed, thus estimating the addressable penetration of energy storage systems and virtual power plant needed to overcome renewable intermittency.

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Keywords: Reserve; requirement; forecast; renewable; integration; standard deviation.

* Corresponding author. Tel.: +39-06-72597215
E-mail address: michele.manno@uniroma2.it

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1. Introduction

The large amount of variable renewable energy sources (vRES) installed capacity, mostly photovoltaic and wind, has deeply changed the shape of net load (or residual demand), which represents the demand that must be met by

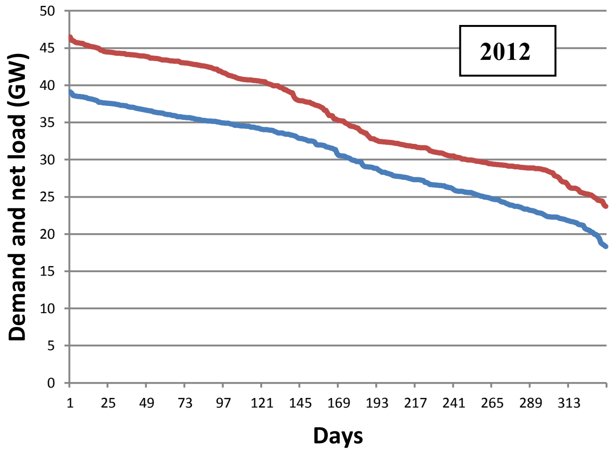

Figure 1: Net load duration curve (2012). Red lines stand for overall electric demand, while blue lines represent net load.

non intermittent dispatchable generators along the merit order to determine the energy price, considering a competitive market.
Two of the main effects comes mostly from PV installations:

- a deep residual demand reduction during the central hours of the day
- a related growth in residual demand slope at night time

vRES installed capacity has already shown a deep impact on residual demand duration curve (as we can see from Fig.1) as well as on day ahead energy market. In fact energy prices at evening hours have been raising due to solar PV lack of production during these hours and, at the same time, a shift in conventional power plants merit order was introduced, changing after several years the typical market paradigm and thus resulting in the exit of several conventional power plants from this bidding market.

At the same time, vRES have impacted on the dispatching services market requiring an additional amount of operating reserve (needed to balance on real time electric grids, making second by second the amount of demanded power exactly equal to the amount of available power). This is due to the stochastic behavior of vRES production, which assumes different features for wind and photovoltaic resources.

The importance of vRES impact should be assessed considering how it is intensified by the exit of several power plants from the day ahead bidding market, which reduces spinning reserves and forces conventional power plants to an increased number of startings, often to provide only dispatching services.

The Italian code for transmission, dispatching, developing and security of the grid (Grid Code), provided by Terna, defines how the grid could be operated on real time using reserves differentiated by rapidity with which they can respond: primary, secondary and tertiary from the most to the less responsive, varying from a few minutes to one hour. Primary reserve is a mandatory and automatic requirement for all producing power plants, meanwhile secondary and tertiary come from dispatching services market (MSD). MSD structure contains a three steps day ahead programming market (MSD ex-ante) and 5 steps operating during the day (MB).

Day ahead reserve requirements in terms of tertiary reserve, which contains secondary reserves, are sized by the grid operator to face combination of three main phenomena:

- Forecast errors on electric demand
- Forecast errors on vRES production
- Unscheduled conventional power plants outages

Reserve requirement, communicated by Terna, have been increasing in the last years. Data series from the last three years (with reference to the whole Italian electric system) were analyzed. This analysis highlighted the rise from a mean value of 3400 MW in 2011 to 3760 MW in 2013 (+10,5% with 5.1% CAGR). A significant share of this increase has been registered during summer months, underlying also an amplified requirement of reserve in the first hours of the day when photovoltaic plants start producing (Fig.2).

Nomenclature

CAGR	Compound Annual Growth Rate
EES	Electrochemical Energy Storage
MB	Mercato di Bilanciamento
MGP	Mercato del Giorno Prima
MSD	Mercato dei Servizi di Dispacciamento
NL	Net Load
P_{INST}	Installed Capacity
PV	Solar Photovoltaic
PUN	Prezzo Unico Nazionale
VPP	Virtual Power Plants
vRES	Variable Renewable Energy Sources
W	Wind

2. Preliminary model

Planning and operating a power system is based on probabilities and risks. Reserves in power systems, with or without vRES power, are generally determined so that variability within a certain probability are covered, for example more than 97 % of the variability.

Standard deviation σ tells about the variability of time series, since it is the average deviation from the mean value μ:

$$\sigma = \sqrt{\frac{\sum_{i}^{n} (x_i - \mu)^2}{n}}$$

For a normal distribution, the standard deviation is a measure indicating that about 68% of the data is inside ±σ of the mean value. Taking a range of ±3σ will cover 99% meanwhile ±4σ will cover 99.99% of all variability. For hourly variations, the mean value is 0 by definition.

The forecast errors variability of load and vRES production can be assumed to be uncorrelated, as for independent stochastic variables following a Gaussian distribution centered on a zero mean value. This way, standard deviation of net load time series (σ_{NL}) can be determined by the square root sum of the standard deviations of load (σ_L), wind power (σ_W) and photovoltaic (σ_{PV}) time series:

$$\sigma_{NL} = \sqrt{\sigma_L{}^2 + \sigma_W^2 + \sigma_{PV}^2} \quad (1)$$

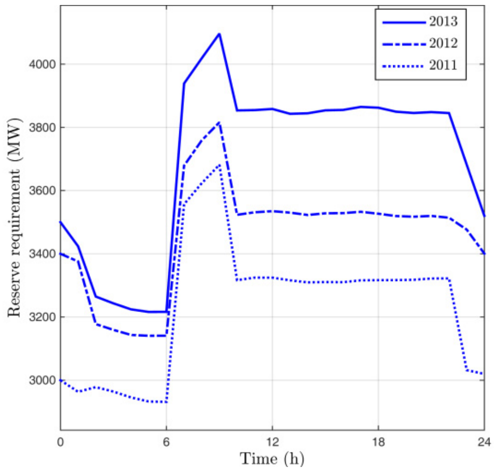

Figure 2: Results from the historical analysis on Terna's communicated reserve requirement (on July)

The distribution of the variations of this three variables is not usually strictly a normal distribution. However, equation (1) has been checked for several sets of data and it has produced accurate results for the standard deviation of the net load [1].

It is not uncommon for the system operator to carry in preservative ways regulating reserves equal to 5σ or 6σ, where σ is the system variability measured as standard deviation of the load variability. This could lead to an overestimation of reserve needs, often associated to a growth of grid operating costs perceived as costs introduced by vRES energy production.

Some other studies (for example [2]) have used ±2σ as the preferred metric to calculate load following requirements for wind variable renewable generation.

Standard deviations were combined into our preliminary model on the basis of their temporal evolution, which involves different stages of the MSD ex-ante. Variables (load, wind, photovoltaic) specific standard deviations are outlined as follow.

Daily demand profiles subtend a fundamental shape, which occur repeated with slight variations within days. Grid operators are thus allowed to forecast demand level with high level of accuracy thanks to a wide use of historical data. This is extremely useful for quantifying reserve amount, because it means that σ_L depends on time

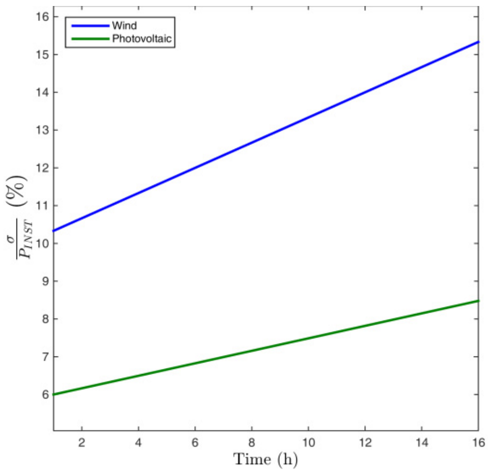

Figure 3: Standard deviations temporal evolution for vRES (expressed as share on installed capacity).

but in a repetitive and well known way. Moreover, the time scale characterizing changes on an aggregated national load curve has orders of magnitude which allows to characterize the standard deviation of electric demand forecast using only data coming from historical series.

Data from "on field" studies in Germany (W) and US (PV) were used to evaluate vRES standard deviations. These studies collected data in a synchronous way from a wide set of vRES power plants among the countries.

They were used because of the difficulty and unavailability of finding similar data sets for Italian power plants. Both the terms σ_{PV} and σ_{W}, were analyzed by these studies to show how the standard deviation evolves with time along a forecast timeframe.

A deep wind power production analysis is provided by Focken et al. [2], highlighting both spatial and temporal effect on the accuracy of wind power forecast. The study was conducted among thirty German wind farms. It shows how a saturation standard deviation could be reached within few hundreds of wind turbines. This means that enlarging data collection to a larger portion of wind farms (located many kilometers away one from each other) a stable behavior could be reached.

Solar photovoltaic standard deviation was evaluated using the results from the "Western Wind and Solar Integration Study Phase 2", elaborated Zhang et al. in "Metrics for Evaluating the Accuracy of Solar Power Forecasting" [3]. Its aim was to develop a suite of generally applicable, value-based metrics of solar forecasting for a comprehensive set of scenarios. Ranging from a single plant (100 MW of installed capacity) to the whole Western Interconnection (64495 MW), 60 minutes solar power plant output were used as actual data to be compared with one hour ahead and one day ahead forecasts.

Reserve requirements are also needed as a back-up for unexpected power plants outage, which can be estimated using a probabilistic approach. Within the forecast period, the probability of outages could be considered to increase almost linearly at a rate of approximately p=0.17 %/h (lower for steam power plants, larger for open cycle gas turbines). A more accurate estimate of reserve requirement could be reached using combinatory calculations. Often grid operators follow a different methodology to overcome unexpected outages. They quantify reserve margin as large as the largest conventional power plant. We followed this more conservative hypothesis.

3. Results

The temporal evolutions of standard deviations in (1) were coupled with Italian Grid operator programming timeframes, outlined by MSD temporal phases. This means that during the forecast period each term follows a specific trend, generally increasing during the timeframe with the exception of load.

There are three phases on the MSD ex-ante market, respectively:

- MSD1, lasting 13 hours with the maximum forecast extension of 16 hours
- MSD2, lasting 4 hours
- MSD3, lasting 7 hours

during which we assumed specific standard deviations evolutions. Load, wind and solar combine in the described timeframes by means of equation (1), meanwhile global amount of reserve requirements contains an additional term for conventional plants outages, evaluated taking as a reference the capacity of operating largest power plant.

Figure 4 (left) shows yearly mean value (for each day) of expected reserve needs in MW, resulting from the application of the method outlined before on the Italian electric grid. Installed capacity of vRES at the end of 2013 have been evaluated as 16 GW of solar photovoltaic and 8 GW of wind. As a consequence of the market structure, each day shows a peak at the end of the largest period of forecast. At the same time, working days have the same trend as weekends, but they account for slightly more reserve. Figure 4 (right) shows the comparison of results from the model to reserve amount communicated by Terna on its website. The comparison was made considering only July's Tuesdays (2013). The daily mean value calculated from the model is 3300 MW, meanwhile from Terna's data it turns out to be 3760 MW. It can be seen how the model predicts lower value for the reserve requirements, with the exception of the central part of the day when larger values are expected, because of the longer forecast period from the previous MSD1 session.

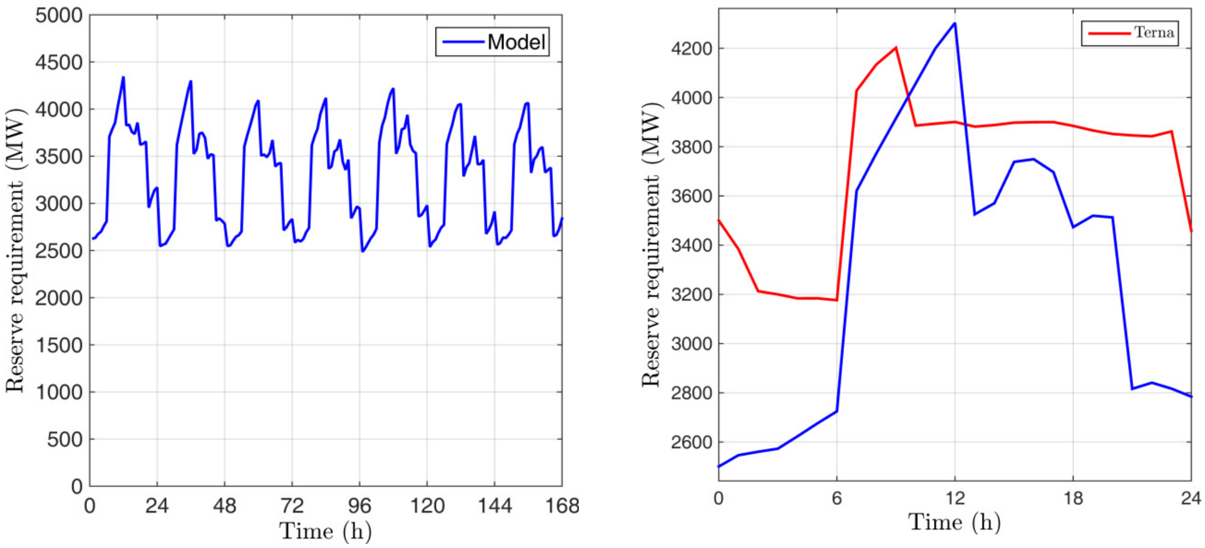

Figure 4: On the left, mean yearly estimated amount of reserve requirement for the Italian electric grid for 2013. On the right side, daily comparison with data communicated by Terna.

4. Conclusions

The results have been compared with current data showing similar magnitude of reserve requirement, even with the outlined differences. This permits an extension of the model, which has been applied to next years expected vRES installed capacity.

In a mid term time horizon, 20 GW of solar photovoltaic and 12 GW of wind could be expected to be installed in the Italian electric grid. In this scenario, model evaluations leads to an increase of operating reserve of about 900 MW, rising from current 3760MW to reach 4200 MW.

By that time, it will be hard to see a significant deployment of innovative technological solutions aiming to allow a better integration of vRES into electric grids. Those are mostly electrochemical energy storage and virtual power plants. Economic and regulatory factors should be overcome, the firsts with reference to EES while the second to VPP. Infact VPPs, which permits a coordinated management of renewable and conventional power plants, are technically ready (as the Germany experience shows) in a cost effective way. In Italy VPPs don't yet have the regulatory framework needed for their deployment. Nonetheless, even if probabilities to see EES and VPP by that time are low, the potential capacity of their installations could be quantified using the model here described.

Preliminary features of the model comes mainly from assumptions concerning vRES production, meanwhile the methodology as well as load evaluations are firm in their hypothesis. For these reasons, further improvements can be developed as soon as vRES simultaneous data, at least for extended part of the Italian grid, will be available.

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