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LARGE-SCALE INTEGRATION OF RENEWABLE ENERGY SOURCES: TECHNICAL AND ECONOMICAL ANALYSIS FOR THE ITALIAN CASE

Matteo Giacomo Prina[1,2,*], Giulia Garegnani[1], David Kleinhans[3], Giampaolo Manzolini[2], Roberto Vaccaro[1], Stefan Weitemeyer[4], David Moser[1]
[1]Institute for Renewable Energy, EURAC Research, Viale Druso 1, 39100 Bolzano (BZ), Italy
[2]Dipartimento di energia, Politecnico di Milano, Via Lambruschini, 4, 20156 Milano (MI), Italy
[3]NEXT ENERGY, EWE Research Centre for Energy Technology at the University of Oldenburg, 26129 Oldenburg, Germany
[4]University of Oldenburg, 26111 Oldenburg, Germany
[*]Phone: +39 0471 055587; Fax: +39 0471 055699;
E-mail: MatteoGiacomo.Prina@eurac.edu
Giulia.Garegnani@eurac.edu
david.kleinhans@next-energy.de
giampaolo.manzolini@polimi.it
roberto.vaccaro@eurac.edu
stefan.weitemeyer@uni-oldenburg.de
david.moser@eurac.edu

ABSTRACT

The integration of high shares of variable renewable energy sources is an aspect that is acquiring importance as it can lead to integration problems. The three main options to achieve this task are the enlargement and reinforcement of the grid, the use of storage devices, and demand side management. A modelling approach is applied in this study to evaluate the impact of storage systems in the case of high penetration with renewable energy and to achieve the highest renewable energy integration at the lowest costs.

PURPOSE OF THE WORK AND APPROACH

This paper deals with the problem of large-scale integration of variable renewable energies sources (RES) into the electric grid. The best mix of variable renewable energies sources is analyzed from a technical and economical point of view. The impact of storage system on this integration is also studied by evaluating, through an optimization approach, the best combination of renewable energy capacity and electric storage systems to reach the highest renewable energy integration with the lowest total costs. Using long-term power generation and load data with hourly resolution, the methodology is applied to the Italian case.

SCIENTIFIC INNOVATION AND RELEVANCE

Weitemeyer *et al.* have developed a modelling approach to evaluate the impact of storage devices and their contribution to go towards a 100% renewable energy system, and applied the model both to the German [1] and to the entire European electricity system [2]. The novelty of the present paper is given by the expansion of this existing model, studying the impacts and the possible interplay between low capacity, high efficiency, storage and large capacity, low efficiency storage devices. For this purpose a multi objectives optimization approach is developed to evaluate the best combinations of the two different types of storage and renewables under total annual costs minimization and the maximization of renewable energy integration function.

PRELIMINARY RESULTS AND CONCLUSIONS

Preliminary results not considering storage systems show that for the Italian case, under the considered assumptions, the combination of variable renewable energy sources that produce the highest value of renewable integration, is 55% of wind and 45% of photovoltaic. These values change only slightly when costs are considered. The technical approach found that even a low capacity of high efficiency storage system improves considerably the RES integration. Seasonal storage devices are only needed when high capacity of renewables are installed. The analysis will be completed with an optimization model to study which combinations of renewable and storage produce the best values of integration at the lowest costs.

EXPLANATORY PAGES

In order to reach a future power system, close to 100% renewable generation, high penetration of generation from wind and solar sources is foreseen and, thus, issues related to the non-dispatchable power production must be faced. This paper investigates the large scale integration of renewable energy sources (RES) from a technical and economical point of view, applying the model to the Italian case. The data set, on which the analysis is based, is composed by data series with hourly resolution for the period from 2009 to 2014, i.e. six years of data are taken into account. Limitations and constraints of the national transmission grid are not taken into consideration. Just as in [1, 2] the production from variable renewable energy sources is matched with the demand load time series $L(t)$, which is available from ENTSOE [3]. The remaining electricity not covered by RES is produced by fully flexible power plants. Electricity generation which cannot be fed into the system is curtailed. The generation data for Italy, on-shore wind $w(t)$ and solar $s(t)$, are taken from the STRATEGO project outputs [4]. The Eq. 1 gives the mismatch between generation and demand [1]:

$$\Delta_{\alpha,\gamma}(t) = \gamma\big(\alpha w(t) + (1-\alpha)s(t)\big) - L(t) \qquad (1)$$

The parameters α and γ express the share of wind and solar power generation of the overall electricity demand. The parameter α expresses which percentage of the electricity generation from RES is covered by wind and, thus, the factor $(1-\alpha)$ expresses the part covered by solar power. The parameter γ is the average renewable energy power generation factor. $\gamma = 1$ value means that the electricity demand can be covered by RES on an annual basis (i.e. without taking into account contemporaneity of production and demand). The mismatch function, Eq. (1), is now analyzed with respect to the resulting overall integration of renewables in the system. For this purpose the absolute values of negative values of $\Delta_{\alpha,\gamma}$ are accumulated and weighted by the average load, which yields the required share of backup energy as a function of α and γ. Consecutively a renewable integration function $RE(\alpha, \gamma)$ is defined as 1 minus the required share of backup energy. $RE(\alpha, \gamma)$ is by definition between 0 and 1 and measures the share of renewable integration. For details on the approach it can be referred to [1].

Figure 1 shows the resulting renewable integration function $RE(\alpha, \gamma)$ as function of the parameter γ for Italy. In this first case storage systems are not considered. Until $\gamma=0.3$ there is a small overproduction and the curves rise linearly like the perfect integration one. At higher values the curves bend down due to overproduction (implying curtailment) that occurs more frequently during the considered time span. The worst case with respect to the integration is the curve with $\alpha=0$, which is the only solar power case. It results a $RE(\alpha, \gamma)$ value of 0.45 at $\gamma=1$. The other extreme, the only wind power case, $\alpha=1$, produces at $\gamma=1$ a value of $RE(\alpha, \gamma)$ equal to 0.48. In absence of storage, the optimum α that allows for the best integration of renewables is $\alpha=0.55$. The indicator used in the optimization to find the best α was the integral of the curves between $\gamma=0$ and $\gamma=2$. In absence of storage, the optimum α that allows for the best integration of renewables is $\alpha=0.55$. This value is rather low in comparison to results obtained for Germany (cf. [1]).

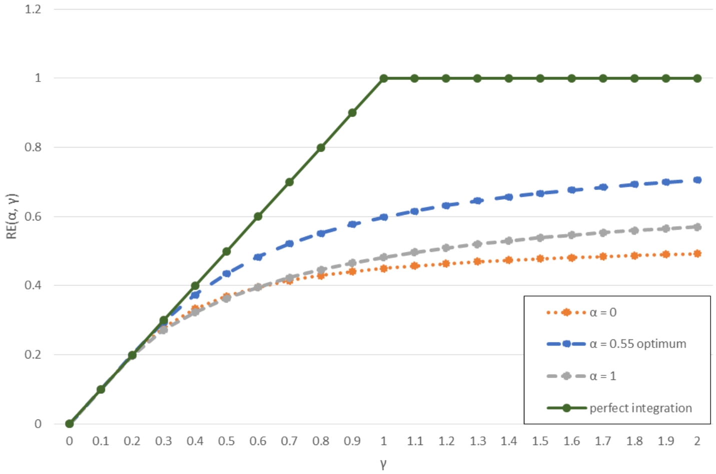

Figure 1 Renewable integration function $RE(\alpha, \gamma)$ for different value of α, not considering the role of storage.

Storages in the system can directly affect the mismatch function, Eq. (1), and by this means improve the integration of renewables. The storage system is modelled through the following parameters: η is the round-trip efficiency of the fully flexible storage system and H is the size of the storage (for details regarding the storage modeling, it can be referred to [1]). For analysis, sizes of the storage are assumed equal to 0, 2, 4, 6, 8, 10, 12, 14, 24, 36, 48, 72, 168, 360, 720, 1440 average load hours (av.l.h.). For Italy 1 av.l.h. is equal to 36.9 GWh. Figure 2 shows the renewable integration function at the increasing of the storage size for η=0.8 (left panel), which would correspond to e.g. a pumped-hydro or battery storage system. It is important to underline that the highest value of the storage capacity produces an almost linear increase of RE(α, γ) with γ , albeit at a lower slope compared to the perfect integration one due to storage losses. The right panel of Figure 2, graph on the right, shows the renewable integration function for two different storage classes: highly efficient storage with low capacity (H= 4 av.l.h. = 0.15 TWh, η=0.8) that could describe a pumped-hydro or battery storage system and a large storage with low efficiency (H= 168 av.l.h. = 6.21 TWh, η=0.3) that could describe a seasonal storage based on synthetic hydrogen. Until γ=0.4 overproduction is negligible and thus storage system are not needed. After this threshold, for a share of α equal to 0.55, a small but efficient storage can increase the integration of RES until γ=1. For higher values of γ a seasonal large and lower efficient storage leads to higher values of RE(α, γ) compared to a small but efficient storage, which is consistent with the results obtained for Germany as described in [1].

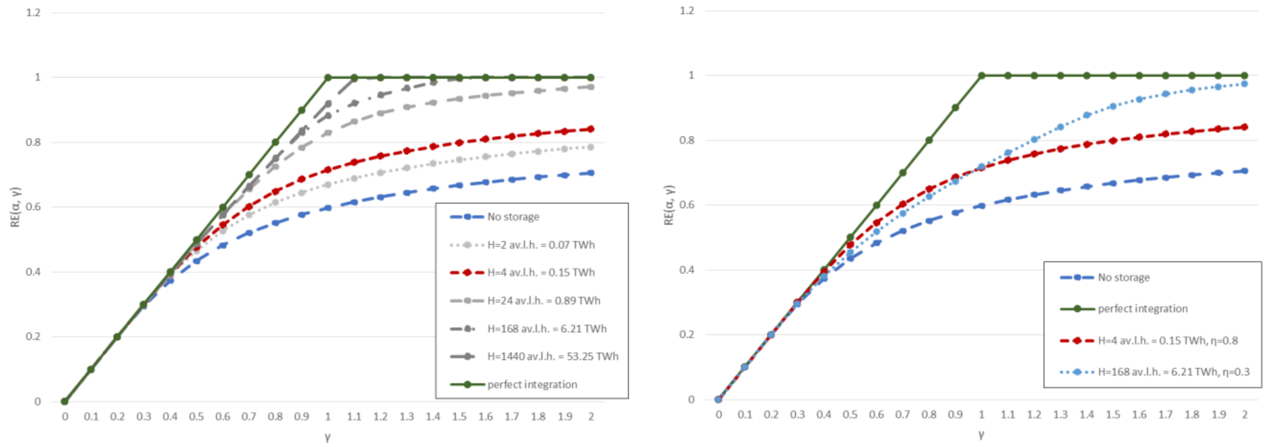

Figure 2 Renewable integration function RE(α=0.55, γ) for different types and capacity of storage, utilizing the optimum α, equal to 0.55.

After this technical analysis based on [1], the methodology is further developed and an optimization analysis (yet preliminary), evaluating also economic aspects, is presented. The objectives of the minimization analysis are: total annual costs and the share of demand covered by fully flexible power plants or (1 - RE(α, γ)). Firstly, the best value of α for each γ has been assessed not considering storage systems. The draft costs of the different technologies are shown in Table 1. The costs of the remaining back-up energy are not taken into consideration.

Technology	*Investment cost [€/kW]*	*O&M cost [%]*	*Lifetime [years]*
Wind	1300	3	20
Photovoltaic	2000	2.1	20

Table 1 Parameters for the economic analysis [5].

Preliminary results are shown in Figure 3. In order to reach a RES integration of almost 40% the solution with 100% wind is selected because is the cheapest technology. No overproduction occurs in this first part with only wind power and the PV capacity remains equal to zero due to the higher costs. In order to reach higher values of RES integration at low costs a combination of production from wind and PV is needed. The best share of wind and PV, in order to maximize the RES integration and minimize the total annual costs, stabilizes between 60% and 70% of wind production and 40-30% of PV production. The required capacity to reach 70% of RES integration without storage, at the best total annual costs, would be 220 GW of wind power and 210 GW of PV. It is important to underline that the current values are based on theoretical calculation and is not considered any territorial constraints or potential installed values of the Italian energy system.

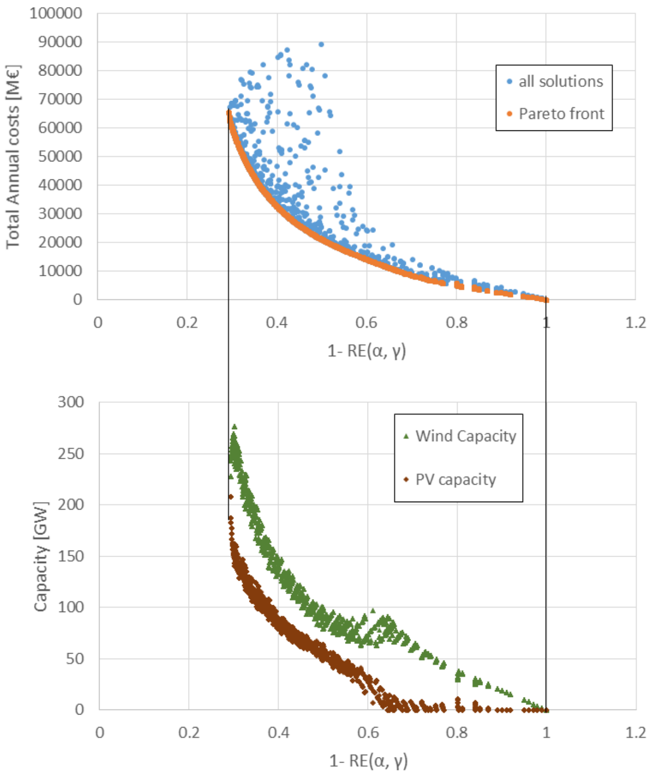

Figure 3 The graph on the top shows the results of the optimization analysis. On the bottom, the graph shows the trend of the PV and wind capacity (depending on the inputs of the model: α and γ) of the simulated solutions on the Pareto front.

The analysis will be completed with an optimization model to study not only the best value of α, as has been done in this previous analysis, but the best combination of α and the capacities of two different types of storage for each γ, considering as objectives of the optimization analysis the total annual costs of the system and the RES integration achieved.

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