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Intermittent and stochastic character of renewable energy sources: Consequences, cost of intermittence and benefit of forecasting

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ABSTRACT

Solar and wind energy are inherently time-varying sources of energy on scales from minutes to seasons. Thus, the incorporation of such intermittent and stochastic renewable energy systems (ISRES) into an electricity grid provides some new challenges in managing a stable and safe energy supply, in using energy storage and/or 'back-up' energy from other sources. In such cases, the ability to accurately forecast the output of "unpredictable" energy facilities is essential for ensuring an optimal management of the energy production means. This review syntheses the reasons to predict solar or wind fluctuations, it shows that variability and stochastic variation of renewable sources have a cost, sometimes high. It provides useful information on the intermittence cost and on the decreasing of this cost due to an efficient forecasting of the source fluctuation; this paper is for engineers and researchers who are not necessarily familiar with the issue of the notions of cost and economy and justify future investments in the ISRES production forecasting.

1. Introduction

The growth of the market of photovoltaic and wind energy systems over these last years is always continuing with 50 GWp of PV plants and 62.7 GW of wind turbines installed in 2015 (+ 25% for PV and + 22% for wind energy compared with 2014). Thus, the total capacity respectively in Europe and in the World reached 94.6 GW and 227 GW for PV [1] and 141.7 GW and 432.56 GW for wind energy plants at the end of 2015 [2].

As the part of electricity produced by PV and wind energy systems increases, the need for these two intermittent and stochastic renewable energies systems (ISRES) to be fully integrated into electricity grids arises. Thus, one of the main challenges for the near future global energy supply is the high integration of renewable energy sources [3]. The stochastic and intermittent behavior of solar and wind resources pose numerous problems to the electricity grid operator which will be discussed in the Section 1, these problems have then a negative impact on the production cost.

As defined by the business dictionary in 2015 [4], "cost is usually a monetary valuation of (1) effort, (2) material, (3) resources, (4) time and utilities consumed, (5) risks incurred, and (6) opportunity forgone in production and delivery of a good or service". This definition may be adapted to our problematic: cost is relative to an under or overproduction cost due to the random and fluctuating variation of solar and wind resources what make less secure the electricity production and distribution because not always available or non guaranteed.

Decreasing or smoothing these "unpredictable" variations need to use energy storages and back-up energy production means able to compensate immediately the power variations; then, backup generators must often stay switched-on for being able to maintain promptly the production/consumption balance; moreover, PV and wind energy systems must sometimes be switched off when their electrical production exceeds a certain percentage of the global production.

It is obvious that such difficulties induced by the intermittence of wind speed and solar radiation will lead to an additional production cost compared with conventional production. Presenting costs is a very difficult task because it depends, on various parameters such as the country and on legal incentives, on the situation of the electrical network (connected, partially connected or remote grid), on meteorological conditions of the implementation site, etc.

The objective of this paper is to present an overview, affordable by non-economic specialists, on intermittence extra-costs and on the positive influence of a reliable production forecasting on the production cost for wind and solar production. This would allow to help to justify future investments in the ISRES production forecasting in showing the

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benefits of forecasting for utilities. Predicting with a good accuracy the electrical power produced by wind or PV farms (and consumed by the load) allows to anticipate the actions of the electrical grid operator, to improve the electricity balance management and especially to ensure better safety of the electrical grid.

Predicting accurately the intermittence of renewable sources creates a cost-effective access to these energy resources. The reasoning is as follows: the intermittence of solar and wind resources is costly [5,6], sometimes very costly; a good forecasting of these intermittences allows to manage more efficiently the overall electrical system; then, the negative cost impact of these ISRES on the electrical network is decreased and at last, the cost effectiveness of PV and wind energy systems is increased.

Evaluation and forecasting of ISRES power help developers of renewable energy power plants to decide more easily where to install and how to operate them most efficiently by reducing the use of conventional electricity production means as much as possible.

In this paper, we will answer to the following questions:

- Why does the integration of ISRES into an electrical grid pose technical problems to the energy manager?
- Why is the price of the electricity not constant?
- Why do the variability and the behavior of the solar and wind sources induce a cost and what is the order of magnitude of this cost?
- Why does forecasting PV and wind production improve the management of the electrical system and decrease the integration cost of ISRES?

This review paper syntheses the physical reasons to predict solar or wind fluctuations, it shows that the variability and stochastic variation of ISRES have a cost, sometimes and often high. It provides useful information on the intermittence cost and on the decreasing of this cost due to an efficient forecasting of the renewable source fluctuation, for engineers and researchers who are not necessarily familiar with the issue of the notions of cost and economy.

2. ISRES integration into an electrical grid

The uncertainty and variability of wind and solar resources pose problems for grid operators. This variability requires additional and complex actions to balance the system. A greater flexibility in the system is necessary to accommodate supply-side variability and the relationship to generation levels and loads.

The electrical operator has often some difficulties to maintain the production/consumption balance with conventional and manageable energy production means, mainly in small and/or no interconnected electrical grid (as island ones). The reliability of the electrical system then becomes dependent on its ability to accommodate expected and unexpected changes (in production and consumption) and disturbances while maintaining quality and continuity of service to the customers [7].

Even if no ISRES are integrated in the electrical network, energy and power reserves are needed, they can be divided in two categories: contingency reserve, used in case of specific event (such as power plant switch-on) and no-event reserves used continuously (due, for instance, to unreliable load prediction) [8]. These reserves (contingency and no-event ones) are started at various time scales: within 1 min (primary reserve) using spinning generators, from 1 min to 1 h (secondary/tertiary reserves) and more than 1 h [9]. ISRES introduction in an electrical network only affects the non-event reserve particularly due to the imperfect forecast of their production [8].

Already, it appears that a predicted and anticipated event is easier to manage. The electrical energy operator needs to know the future of the electrical production and consumption with various temporal horizons (Fig. 1) [10,11].

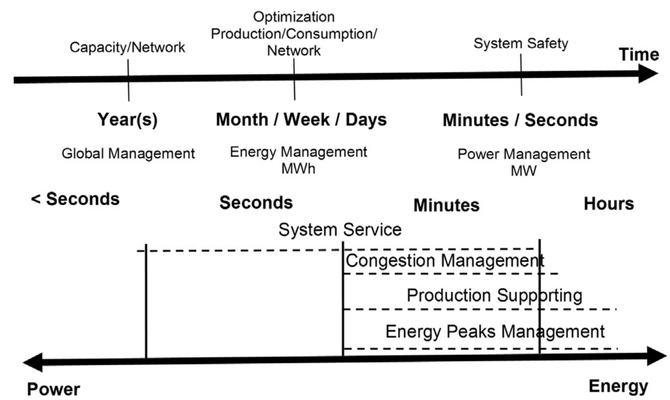

Fig. 1. Prediction scale for energy management in an electrical network [10,11].

The integration of ISRES into an electrical network intensifies the complexity of the grid management [10,12,13]. The intermittence and the uncontrollability of ISRES production bring also problems such as: voltages fluctuations, local power quality and stability issues [14–16].

Sufficient energy resources in reserve are required to accommodate significant up or down ramps in ISRES power generation to balance energy generated and energy consumed. When ISRES power generation is available during low load levels, conventional generators need to turn down to their minimum generation levels, with a bad efficiency and a high production cost. Balancing the energy generated and the energy consumed at all times creates costs and even more, if ISRES are integrated in the electrical network at a high level.

In case of a rapid decrease (or increase) of ISRES production, an instantaneous increase (or decrease) of the delivered electrical power by a connected production mean has to occur and/or a starting of a new production mean is needed; but the rise speed in power (ramp rate) of an energy plant and its starting time is not instantaneous [17,18]. Then, an activation of a new production system or a modification of the operating regime must be anticipated [7,17].

Bird et al. [16] highlighted this need for flexibility for a high penetration of wind energy: with an utilization of wind energy, conventional generators must meet the net load (net load = demand minus wind energy) and, sometimes, this net load change or ramp is quicker than the load alone; then, the remaining generators are operating at a low output level (called “turndown”) with a low efficiency [13,19], increasing the cost of electricity production, this is another effect of intermittence on the extra cost. PV production is often more in line with load [20] but during an evening load peak, the loss of a PV production after sunset increases the ramping needs to balance the evening demand [16]. ISRES power on electric grids requires all thermal fossil plants to turn on and off more often and to change their output levels more frequently to adapt it to the load with two major consequences: an increase in wear-and-tear on the units and a decrease in efficiency of about 4% (in the range of 0–9% [8]), with a thermal stresses on equipment. A limit in the percentage of ISRES production in the overall electrical production had to be introduced and induced several curtailments for wind and PV production. Variability and uncertainty of ISRES power generation increase the cost of maintaining the short-term energy balance in power systems [21].

A complete impact analysis of ISRES on the electrical grid was performed, based on observed and modelled data and on a bibliographical study, it concluded that [8]:

- the primary reserve must be increased by 0.6% (0.3–0.8%) of the wind capacity;
- all the reserves must be increased by 7% (6–10%) of the installed wind capacity;
- wind curtailments occur for a penetration rate up to 30% with a loss of production between 0.4% and 3.5% of the wind energy