Evaluation of Weather Forecast Uncertainty for HV Grid Operational Resilience Improvement

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***Abstract*— The quality of any electricity transmission service is based on the ability to ensure continuity of the electricity supply in compliance with adequate voltage and frequency values over time. Similar or higher levels of power quality must be warranted also in presence of higher RES penetration, growth of energy consumptions, peak power requests and increasing presence of electronic components in building and industrial sectors. However, the electricity grid, by its nature, is exposed to a wide range of threats and attacks, which are often related to negative weather conditions and are not easy to predict in terms of location and intensity. The consequence of unexpected adverse weather events may impact on the resilience of the HV electrical grid.**

The development of predictive models has always been of interest to the Italian electricity sector and allows utilities to understand the potential consequences of an event and plan to mitigate these consequences before it occurs.

In the present paper, comparisons between traditional weather forecasting systems (forecast day-1 and final data) and the additional information achieved by local meteorological stations are reported with the aim to evaluate the real precision of the actual forecasting systems from the perspective of improving the resilience of the HV grid.

Keywords — electrical resilience, operational resilience, weather forecasts, HV electrical grid, Internet of Things.

I. Introduction

Many of the external threats to the electrical system can be associated with adverse weather conditions or with wildlife and vegetation that may come in contact with its infrastructural components.

Thunderstorms, strong winds, wet-snow and other negative weather conditions are certainly the most common and potentially serious natural threat to the electrical system. For this reason, the main electrical operators, as the Italian TSO Terna, adopt weather forecasting systems based on the data made available by specialized commercial providers.

These weather forecasting providers process different variables of weather elements such as ambient temperature, wind speed and rainfall amounts, both in terms of probabilistic forecasts (typically from day-1 to day-7) and final data. These data are provided for a wide large-scale geographical mesh, typically of few kilometres of side. In fact, it should be noted that these data are interpolated through specific models based on data coming from weather stations located somewhere on the territory. In general, these systems provide acceptable forecasts even if the estimation is not centred with local conditions with the effective position of HV overhead lines and other electrical facilities.

In recent years, Terna has started an experimental real-time project based on local sensors placed on transmission towers. These distributed stations are able to provide inputs for processing local meteorological information to be used for different purposes, such as assessing grid operational status, fault location and evaluation of dynamic rating of HV overhead lines. A larger use of these stations will open a window on the future of the Internet of Things Technology (IoT).

II. Weather Forecast

Electricity transmission network has been built over time based on regulations and standards that have set reference values for weather events to be considered. However, there is no guarantee that the electrical grid is able to withstand the meteorological stresses under extreme weather conditions which have become more frequents in recent years, due to the climate changes.

In this framework, reliable weather forecasts and alerts are essential to make the electrical system more resilient, estimating and reducing, as much as possible, the impact of extreme weather events on the electrical infrastructure. Short-term weather forecasts also play an important role in the framework of operational resilience when decisions must be made in real or near-real time [1-3]. This type of forecasting requires an extremely careful and complex process.

For this reason, in response to extreme natural phenomena, the reliability of different weather forecast models must be taken into account. It is known [4] that not all models produce coincident weather forecasts and for this

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reason, even if there is a convergence trend in 24h and 48h, forecasting systems make use of multiple models to produce their output. In particular, different models (e.g. GFS: Global Forecasting System del National Oceanic and Atmospheric Administration (NOAA), GEFS: Global Ensamble Forecasting System National Oceanic and Atmospheric Administration (NOAA), IFS (ECWMF): Integrated Forecasting System del European Center for Medium range Weather Forecast, EFS (ECWMF): Ensemble Forecasting System del European Center for Medium range Weather Forecast, ICON: ICOsahedral Nonhydrostatic model del Deutscher Wetterdienst, etc.) are used and integrated into an ensemble multi-model which processes the different outputs weighted on their reliability. More in detail, the forecast is refined using model output statistics (MOS) statistical analysis methodologies in order to significantly reduce the systematic-type gap that weather forecast models tend to develop with respect to what is subsequently observed by monitoring networks (measured data).

In addition, the resolution of currently available weather forecasts is based on interpolation systems made of meshes that can reach few kilometres of side. The most common ones have a resolution of 4x4 km and are often obtained by a downscaling technique from wider models with a lower resolution (e.g. 20x20 km). Finally, in recent years meteorological providers have developed very short-term (nowcasting) forecasting systems filled with weather models and real-time monitoring tools such as satellites, weather radars, ground monitoring stations, lightning monitoring networks and vertical profilers of the atmosphere.

III. Terna Internet of Things

The goal of the Terna project (called #IoT4TheGrid) is to realize an integrated system of real-time measurement, collection and processing data about the operation of power lines, by means of the implementation of sensors on transmission towers. This infrastructure will enable continuous monitoring of grid operation by collecting and integrating data from heterogeneous sources into a single central platform to be used by control rooms.

Expected benefits are increased awareness on system operation, assessment of dynamic thermal rating on OHLs and reduction of fault detection and restoration times in case of events such as snow and ice sleeves formation, falling trees, storms and earthquakes.

Towards this aim, data and alarms from the sensors installed on each transmission tower (e.g., push/pull sensors, tilt and vibration sensors and weather stations) are collected and sent to a nearby centralizing device able to transmit them to a central platform available to control rooms. Both the tower sensors and field devices are powered by batteries and recharged through integrated photovoltaic panels.

By collecting information uniformly and cross-referencing it, it is possible to exponentially increase the effectiveness of the solutions but, above all, to have a much greater depth of analysis and overview of processes and territory. At the same time, the project promotes both financial and environmental sustainability, thanks to the use of a single infrastructure for multiple purposes, and social sustainability, enabling local governments and businesses to provide services in an interconnected system. The challenge is a complex one, especially for the multifaceted nature of IoT nowadays in Italy. In operational terms, skills to manage such a market, one without functional and long-standing solutions, are absolutely essential [5].

IV. Weather Forecast Comparative Analysis

In this paper, comparisons between traditional weather forecasting systems (forecast day-1 and final data) and the information achieved by local meteorological stations are reported with the aim to evaluate the accuracy of the actual weather forecasting systems from the perspective of improving the resilience of the high voltage electricity grid. Local meteorological parameters as wind speed and ambient temperature have been extracted from available data of Terna experimental project “IOT 4 the Grid” [5] and compared with the corresponding values obtained from the forecast models of the day-1 and the actual data supplied by the weather provider. It should be mentioned here that these data are part of a complex database consisting of numerous acquired parameters, such as, for example, the ones from push/pull sensors, tilt and vibration sensors, etc.

In Figs. 1 and 2 are reported comparisons between the values detected by the weather forecasting system (day-1 forecast and final data) and the values locally measured by IoT sensors for a city in southern Italy in the month of December 2020 (place and timing were selected as an example). IoT data are related to a HV tower (150 kV) located in the territory of the city considered. The comparison was made on both wind speed (Fig. 1) and ambient temperature (Fig. 2).

Fig. 1 (wind data) shows a considerable difference among these values, both positive (15-18 December) and negative (24-31 December) with differences of more than 30-50 km/h. From Fig. 2, it can be seen that differences in temperature may be smaller but still significant for the dynamic rating of the OHL.

These differences may have impacts on the alarm phases of any resilience study as well as on the assessments of the dynamic rating of the OHL. It should be mentioned here that Terna anyway adopts algorithms able to take into account wind speed and direction, ambient temperature and sun radiation values to set right emergency and warning power line limits in terms of max ampacity [6-8]. In addition, Terna relies on weather forecasts to carry out mid- and short-term risk analyses to evaluate possible impacts of phenomena such as snow sleeves and storms on the transmission system. These risk assessments are then used to develop strategies for preparation, mitigation and service restoration.

In the framework of the present study, attention was also paid to the evaluation of the distribution of differences between weather forecasting systems (final data) and local measurements in terms of wind speed (Fig. 3) and ambient temperature (Fig. 4). Typical comparisons show trends of differences which follow asymmetric Gaussian distributions, in which final data from weather provider present both positive and negative errors of different entities. It should be noted that these trends were assessed only considering a limited number of different locations (7 sites in southern Italy) for the period of a typical month (December 2020). Obviously, the aforementioned comparisons are reported as case studies and deserve more careful analysis, taking into account a larger amount of data and extending the time frame analysed.

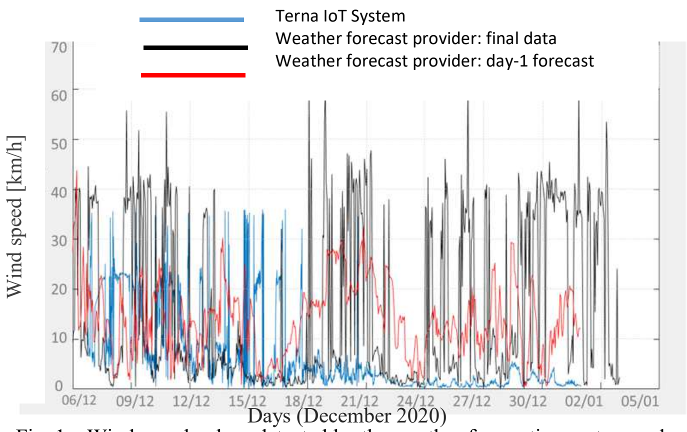

Fig. 1. Wind speed values detected by the weather forecasting system and the values measured by Terna IoT sensors for the month of December 2020 in a city in southern Italy.

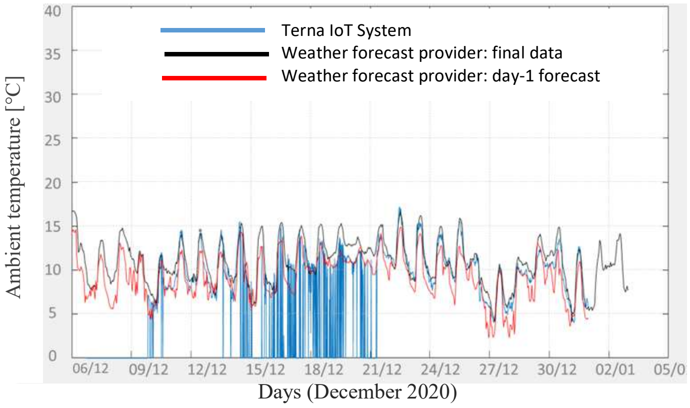

Fig. 2. Ambient temperature values detected by the weather forecasting system and the values measured by Terna IoT sensors for the month of December 2020 in a city in southern Italy. The null value spikes (Terna IoT System) are due to unavailable temperature values.

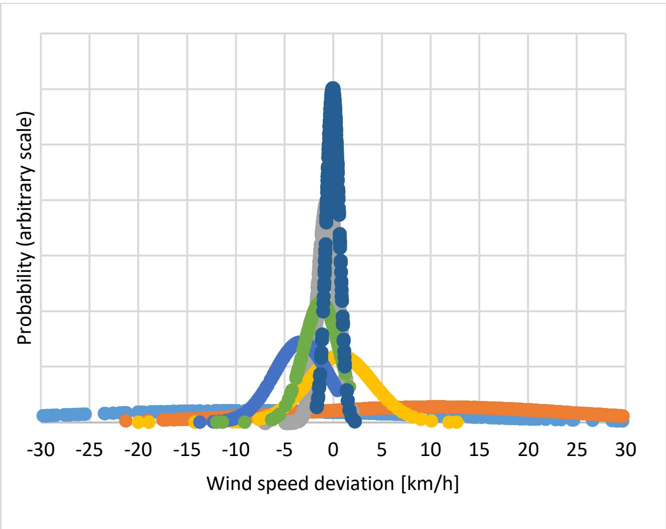

Fig. 3. Trend estimation of the probability of the deviation of the forecast data at 24h of the wind speed (curves in different colours represent 7 sites in southern Italy, December 2020)

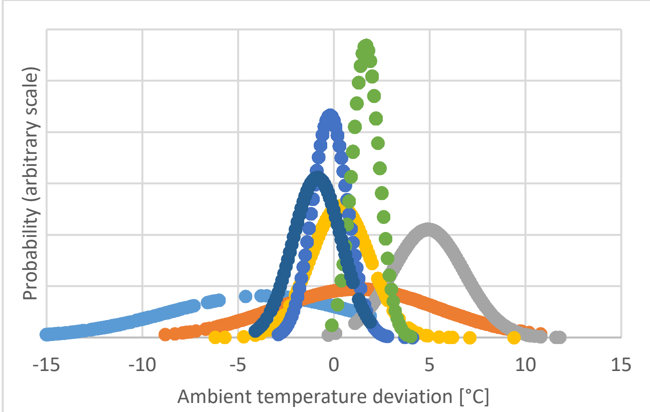

Fig. 4. Trend estimation of the probability of the deviation of the forecast data at 24h of the ambient temperature (curves in different colours represent 7 sites in southern Italy, December 2020)

As further investigation, Figs. 5 and 6 depict the cumulative distributions (%) of the deviation (absolute value in °C) between local records obtained by Terna local meteorological sensors and final values released by weather forecasting system provider from the same period and place (December 2020). The comparisons were extended to 7 experimental sites in the southern Italy. From these figures it is possible to note that the average value (at 50%) of the deviation between the IoT data (local sensors) and the weather forecasting system provider may reach up to 15-20 km/h for the wind speed and about 4-6 °C for room temperature. More analyses are anyway needed to have a more precise estimation of the deviation.

Starting from Figs. 5 and 6, mean deviations in terms of wind speed and temperature may be evaluated. For the site represented by the curve in orange, these deviations (at 50%) are equal to 15 ± 12 km/h (wind speed) and 5 ± 3 ° C (ambient temperature). In Fig. 7 is summarized in a graph the uncertainty of the forecasts, normally made available by the weather forecast provider, when compared with locally acquired measurements.

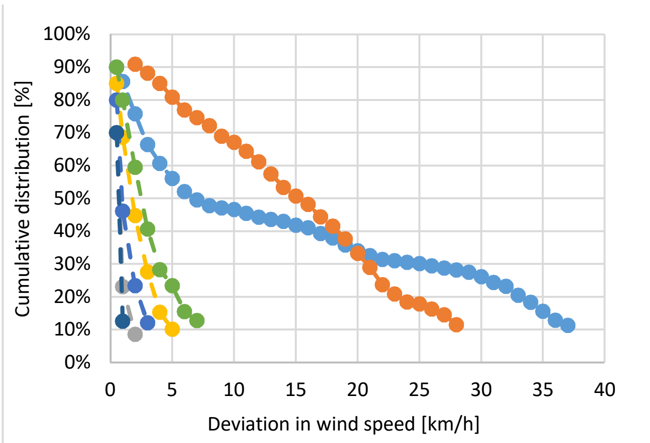

Fig. 5. Deviation of the cumulative distribution (absolute value) between the value recorded by the IoT system and the final values of the weather forecasting system provider (considering the closest coordinate) of the wind speed in 7 Terna experimental sites in southern Italy (curves in different colours).

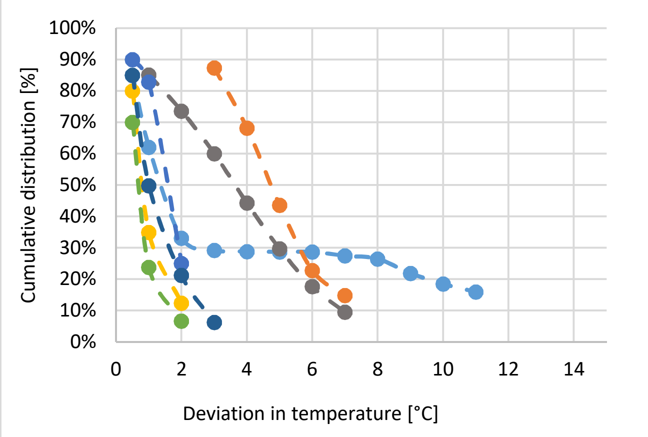

Fig. 6. Deviation of the cumulative distribution (absolute value) between the value recorded by the IoT system and the final values of the weather forecasting system provider (considering the closest coordinate) of the ambient temperature in 7 Terna experimental sites in southern Italy.

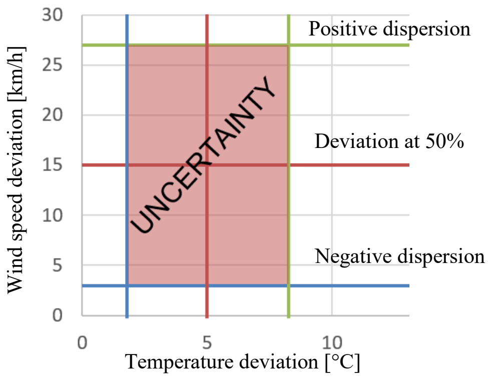

Fig. 7. Uncertainty range between the final data of the weather forecast and the data recorded by the Terna IoT system in terms of wind speed and ambient temperature.

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Conclusion

Reliable weather forecasts and alerts are essential to make the electrical system more resilient, estimating and reducing, as much as possible, the impact of extreme weather events on the electrical infrastructure. Short-term weather forecasts also play an important role in the framework of operational resilience when decisions must be made in real or near-real time. This type of forecasting requires an extremely careful and complex process. These forecasts are normally supplied by specialized providers.

In addition, the main electrical operators, like the Italian TSO Terna, are evaluating the use of local meteorological stations to gain more precise information useful for both resilience aspects and dynamic rate evaluation.

The present paper, comparisons among commercial weather forecasting systems (forecast day-1 and final data) and local meteorological stations data have been reported with the aim to evaluate the reliability of the forecasting systems.

First comparisons made in the framework of research work carried out in cooperation with the University of Roma “La Sapienza”, have shown as both short term forecast (day-1) and final data may be affected of an appreciable deviation when compared with the data made available by local meteorological stations. More analyses are anyway needed to have a more precise estimation of such results deviations.

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