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Weather forecasts for microgrid energy management: Review, discussion and recommendations

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HIGHLIGHTS

- Weather information is a fundamental input for microgrid scheduling.
- A wide variety of weather information has been incorporated into prior microgrid studies.
- The diversity of procedures to implement weather data in microgrid energy management systems are analyzed.
- Discussion and recommendations for future works are conducted.

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ABSTRACT

Meteorological conditions determine the renewable energy generation and, to a lesser extent, the load of microgrids. Weather forecasts are thus necessary to establish optimal plans according to the operational objectives and priorities of each microgid. Weather forecast errors are also responsible for deviations from these plans, thereby being an important source of uncertainty in the scheduling process. Despite this, weather information plays a secondary role in most of microgrid studies. This paper provides a general overview of the use of meteorological data in microgrids, focusing on the implementation of weather forecasts in microgrid energy management systems. Data sources, methodologies, uncertainty approaches and results from a selection of papers with complete information about the forecast context are analysed in detail. Additionally, similarities and differences regarding other energy forecast applications apart from microgrids are discussed. Finally, on the basis of the above, a list of recommendations for future implementations of weather forecasts in microgrid energy management systems is presented.

1. Introduction

A microgrid (MG) is conceived as a small-scale power system comprising a set of loads and distributed energy resources including photovoltaic (PV) panels, wind turbines (WTs), conventional generators and energy storage systems. MGs can operate in both grid-connected and stand-alone modes and have proved to be efficient in smoothing the effects of the intermittent generation associated with renewable energy sources (RES) [1]. They are therefore considered key elements to promote the power system integration of RES and the subsequent reduction of environmental pollutants associated with conventional energy sources. MGs enable local energy management strategies adapted to the particular characteristics of the system (devices, configurations, load patterns or atmospheric conditions of the site), enabling an individualized optimization of the use of energy sources. Such a detailed optimization would become intractable from the viewpoint of the independent system operator (ISO). However, benefited by the regional dispersion of the generation units [2] and the large numbers of connected loads [3], ISO operations and schedules entail a lower degree of uncertainty. In the case of MGs, uncertainty is amplified by the local nature of the problem, and particularly impacts RES and load estimations. In this sense, Olivares et al. associated the first main technical challenge in MG control to the “schedule and dispatch of units under supply and demand uncertainty” [4].

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The scheduling process determines the necessary operations for an optimal MG management, addressing the given objective. This includes minimization of operation costs, maximization of RES, reduction of emissions and assurance of reliability. The schedule is established for a specific time horizon (scheduling horizon) based on predictions of different parameters of interest related to demand, generation or electricity cost. Errors inherent to these predictions produce deviations from the optimal plans and the subsequent worsening in MG operation. Probabilistic or scenario representations are used to describe uncertainty in predictions, and stochastic approaches, as robust optimization [5] or two-stage stochastic optimization [6], are then applied to the determination of the optimal schedule. The rolling horizon strategy also helps in minimizing the uncertainty derived from forecast errors. In this method, only the first steps of the optimal schedule are implemented. Then, a new schedule is recalculated considering the updated data. The implemented operations are thus based on updated information and shorter forecasting horizons, thereby reducing the uncertainty [7].

Weather information is of high value in MG scheduling, since meteorological conditions determine RES generation, and to a lesser extent, the system load. Weather forecast errors, derived from the difficulties in accurately modelling atmospheric processes, are also responsible for a relevant part of uncertainty in MG operation. The characterization of both meteorological context in which MG operates and the weather forecast errors seems to be necessary for an optimal design and validation of the proposed MG management methodologies. Without this, the obtained solutions might be based on ideal representations of the MG working conditions and will not address possible contingencies derived from the operation under real sequences of meteorological scenarios. Despite weather forecasts being referenced as primary inputs in microgrid energy management systems (MEMS), they play a secondary role in MG studies because the main focus is on the electrical, computational or economical aspects of the problem. To illustrate, MG reviews cover control [8,9], architectures [10,11], protection [12,13], storage [14], or computational optimization techniques [15]; but to the authors' knowledge, no review has been conducted for the utilization of weather information in MEMS. Additionally, in studies where weather information is described, there is a general lack of details and uniformity that complicate the interpretation of the approaches, the comparisons among the studies and the extrapolations of results. Thus, the extraction, clarification, and organized description of the meteorological frameworks used in MG research are not a trivial or easy task. In this framework, the main contribution of this review is the analysis of MEMS from a meteorological perspective, in order to clearly define the approaches currently applied to this problem, analysing their pros and cons and providing support for future studies for an efficient implementation of weather forecasts.

This major contribution can be itemized into the following more specific contributions:

- A general contextualization of meteorological data in MG applications, paying special attention to the representativeness of the tested meteorological scenarios.
- A detailed analysis of sources and procedures for the implementation of weather forecasts in MEMS.
- A comparison and discussion of the results regarding additional literature apart from MGs in order to detect strengths and weaknesses in weather forecasts for MEMS.
- Recommendations for an appropriate use of weather forecasts and descriptions of meteorological information in MG energy management studies.

The rest of this paper is structured as follows. Section 2 presents a general overview of the revised papers, providing a context to support the remaining sections. Sections 3 and 4 provide, respectively, a detailed description of the wind and solar forecasts used for MG management based on a restrictive selection of papers. Section 5 is focused on weather forecasts for load predictions. Section 6 synthesizes and discusses the previous sections, completing the information with additional literature beyond MG research. Section 7 provides some recommendations for the application of weather forecasts in MGs and Section 8 contains the summary and conclusions.

2. Preliminary overview

The core of this review comprises about 190 works (from 2014 to the submission date) in which both MEMS and weather forecasts are somehow associated. Approximately 20% of these studies focus on energy policy or very particular aspects that cannot be considered in line with the present review. The remaining papers follow a similar structure: (i) a MG is described, (ii) a methodology for the optimized management of this MG is proposed, and (iii) a test is conducted to corroborate the benefits of the proposed methodology. This set of papers constitutes the preliminary object of our analysis.

Regarding the MGs described in these papers, the grid-connected mode is the most frequent operation mode (65% of studies). Standalone MGs represent 25% of cases, and the remaining case studies tested both modes of operation. There is an important diversity of configurations, as each MG implements different elements for energy generation and/or storage. Battery energy storage system is included in 80% of cases; diesel generators (28%), microturbines (25%), and fuel cells (20%) are other frequently considered elements. Due to its central role in this review, note that RES generation is present in all revised papers. Concretely, wind and solar hybrid systems represent 57% of the described MGs. Solar and wind generation are considered as unique RES in 29% and 14% of cases respectively.

Another relevant aspect regarding the meteorological context is the duration of the tests. The test period was one day or shorter in 50% of the papers. In the solar case, these periods are frequently associated with irradiance profiles of completely sunny days. Under these conditions, the validity of the proposed methodologies for a continuous long-term operation cannot be corroborated, especially of those focused on dealing with uncertainty in RES and load estimations. Thus, robustness against uncertainty must be tested with data from longer periods including partially clouded days and gusty periods, which are the most unfavourable scenarios from the weather forecast viewpoint. Only under these conditions can it be assured that the proposed solutions are appropriate for overcoming the real situations of high uncertainty. Tests longer than one day and shorter than one month are performed in 32% of the revised papers. In these cases, the MEMS is tested in a more significant way, although the possible effects of seasonality are neglected. Again, if the tested periods involve atmospheric stability, the uncertainty derived from weather forecasting errors would not be properly assessed. The remaining studies perform longer tests, covering one year in some cases, in order to assure representativeness in the tested meteorological scenarios is assured.

Regarding forecasts, RES and load predictions are considered in all examined studies. In many cases, the forecasted information also includes other parameters such as electricity prices, building occupancy or charge of electric vehicles. All these forecasts can be classified into four categories depending on the way they are obtained. The following classification will be referenced along the text:

- Arbitrary: The test is based on synthetic data specifically designed for the experiment, with different degrees of similarity with reality.
- Historic: Forecasts are simulated from historical series, which can be treated as perfect forecasts or modified by introducing some variability to simulate errors inherent to real forecasts.
- Local forecasts: They are generated by processing the updated measurements of the system's operation, including meteorological conditions of the site. The implemented forecasting models are typically based on statistical or machine learning approaches.