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Recent techniques to model uncertainties in power generation from renewable energy sources and loads in microgrids – A review

K. Prakash Kumar, B. Saravanan*

School of Electrical Engineering, VIT University, India

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ABSTRACT

Renewable energy, particularly solar and wind energies are associated with high degree of uncertainty due to climatic conditions. A proper modelling and analytical treatment of these uncertainties play a key role in taking operational and financial decisions by the microgrid operator. A number of models are proposed and tested successfully in literature to model these energy uncertainties. This article presents a survey of some of the latest analytical and approximation techniques reported in literature to model the uncertainties in microgrid environment. The article mainly focuses on the methods which are applied in particular to the study of uncertainties in Renewable energy availability, heat demand and load demand. Different models, their main features, relative merits and demerits, application in literature, etc are reviewed and presented in form of a table for a quick view. The review shows the inadequacy of uncertainty modelling methods applicable to Renewable sources, both in terms of number and accuracy. It also envisages the scope and need for more flexible models for specific applications.

1. Introduction

The increasing global demand for energy and imposed sanctions on carbon emissions have hard-pressed energy derivation from the Renewable Energy Sources (RESs) leading to reshaping of energy sector, changing its form from fully centralised generation-transmission-distribution shape to accommodate distributed generation-distribution-consumption. The reshaping process is reinforced by the advances in energy harnessing technologies from locally available RESs and Distributed Generations (DGs). Attracted by the granted provisions like subsidised policies of the governments, reduced costs of energy derivation from solar and wind generators, increased capacities of the wind turbines from kW to MW, efficient energy derivation technologies like multi-fuel CHP generators, increased storage facilities etc., [1,3], the deployment of distributed generation to meet the loads locally by utilizing the local resources gained potency. This trend led to the concept of Microgrid (MG). A MG enables a large scale deployment of DGs at the distribution level in a conventional utility grid, without requiring major modifications to the existing distribution system. The DGs deployed include RESs like solar PV generators, wind turbines, solar thermal units, combined heat and power units (CHPs), fuel cells, mini and micro turbines either hydro run or solar thermal run and conventional sources like diesel generators, gas turbines etc.. The major drawback of the RESs is the inherent uncertainty in power availability due to climatic conditions. But RESs are one of the most promising solutions to the energy requirement and environmental challenges of the new era [4,5]. Added energy supply, environmental friendliness and other associated economic benefits are the credits of RESs while high degree of unpredictability of energy availability is its major debit. In the presence of RESs, maintaining system integrity with respect to stability, reliability and energy balance is critically challenged by special operational conditions like reverse power flows, over voltages, harmonics, increased faults, stability problems, complicated protection schemes etc. In fact, the output from the RESs cannot be controlled by the operator except for curtailing the power [6,7]. Moreover the energy management will become critical in a MG due to possible conflicting requirements [8].

Higher penetration levels of the RESs into microgrids have changed the way in which the microgrids are operated. The situation has enforced the need for reassessment of the classical methods in addressing the randomness of the grid operating parameters. The classical optimization techniques and their extensions, which prove to be fairly convergent and accurate under deterministic conditions, fall short in computational ability in the MG environment, owing to wider range of uncertainties in operating variables [9–11]. For any optimization technique, whether classical or advanced, drawing a conclusive result for the problems depends on how best the uncertainties in the power availability of Renewable Energy Sources are computed. In fact,

* Corresponding author.
E-mail addresses: kprakash.poly@gmail.com (K.P. Kumar), bsaravanan@vit.ac.in (B. Saravanan).

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neglecting the influence of the uncertainty can affect the total operation schedule such that the final optimal solution may not be the best operating point in reality [12]. The deterministic methods of energy scheduling which do not consider the uncertainties can no more be relied upon in microgrid scenarios [13]. A few studies have proved that the operational cost realized with the implementation of probabilistic methods are lesser compared to costs realized with deterministic methods [13]. As such, a lot of research is carried out and many advanced computational techniques are evolved to estimate the uncertainties in MG environment. A few Fuzzy mathematical programming based models and their extensions are proposed and successfully tested [15]. Stochastic frameworks, which use probability distributions for description of uncertainty are increasingly adopted with fair degree of success in uncertainty modelling [12,15]. A few interval programming models are also proposed, which use intervals for modelling uncertainty [15].

This paper presents a review of such techniques very recently developed and adopted to solve the problem of modelling and estimating uncertainties in power availability from RESs/DGs in a MG environment.

The structure of the remaining article is as follows. Section 2 presents a infrastructure required in a MG for data acquisition for estimating uncertainties. Section 3 presents different recent methods used to model and estimate the uncertainties in a MG environment. The conclusions are drawn in Section 4.

2. Architecture of a microgrid

A microgrid is defined as “a cluster of DG units, loads both controllable and uncontrollable, storage systems and communication, aggregated to mimic a "single virtual generating unit" that can act as a conventional one and capable of being visible or manageable on an individual basis” [2]. The architecture of a basic MG is as shown in Fig. 1. The Energy Management System (EMS) forms the first line of the control system. The load controllers (LC) and the generator controllers (GC) form the second line. The MG is connected to the main utility grid at a point called Point of common coupling (PCC). The PCC will be generally on the primary side of the distribution transformer and will have all the interfacing facilities as required to connect the MG to the utility grid. The separation device (SD) is usually a high speed low voltage breaker, whose state decides the mode of operation of MG, i.e., grid connected mode or islanded mode. The energy storage services (ESS) are deployed to mitigate the intermittency of power availability in the MG, whose charging/discharging functions are controlled by storage controllers (SC). The EMS will have a bidirectional flow of information and control signals from/to PCC, SD, LC, GC and SC units. The dotted lines show the flow paths of information and control signals and the solid lines show the flow path of power.

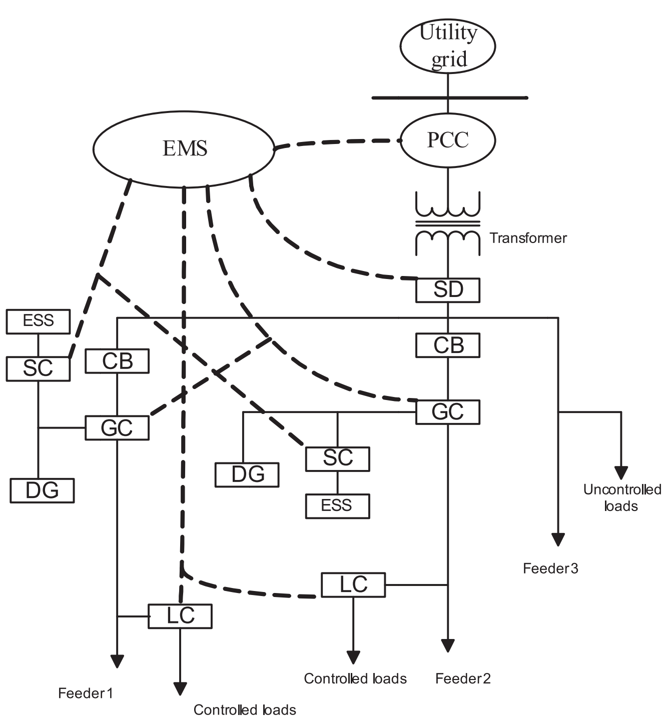

Fig. 1. Basic architecture of a microgrid.

2.1. Data acquisition infrastructure of a MG

A few uncertainty modelling techniques depend on latest data recorded a few minutes or an hour before for future projection of the operating parameters. Some other models use present forecast errors for future estimates, for example a Three Estimate Method subtracts a fraction of present forecast error in estimating a forecast for future. These models require real time data acquisition from the remote units. Moreover this data is also needed by the EMS to make operation and control decisions. Similarly the control signals from the EMS should be communicated to the remote control units. This needs an advanced metering and communication structure [13]. As such, the authors feel it appropriate to present here the basic data acquisition infrastructure needed in a microgrid. Fig. 2 gives an understanding of the basic structure of the required architecture and its basic components are as detailed below.

2.1.1. Smart meters/sensors

These meters are addressable meters with a definite IP address and are accessible to the EMS through Power Line Carry (PLC) communications. Installed at the controllable loads in the customer premises, they measure the load parameters, digitize the measurements, convert it into data and communicate to the Data concentrators. Both single phase and three phase meters are used depending on the requirement. The meters installed at the premises of medium and large customers may be directly connected to the utility by GPRS.

2.1.2. Data concentrators (DC)

The Data concentrators are usually installed at the common distribution transformer which supplies a bunch of customers. These units integrate the smart meters with the central meter data management system through the PLC communication system. The communication between the EMS and the smart meters is through the data concentrators.

2.1.3. Meter data management/repository (MDMR) system

This is fundamentally a data management and repository system which processes the unprocessed data received from smart meters/sensors from the remote units and records it for future reference. The utility operator and the EMS mainly depend on this data management system for the data input for decision making and for generation of control signals.

2.1.4. Customer energy management system

The customer energy management system which is installed at the customer premises is an integration of House energy Scheduler, energy price information system, smart meters and some microcontrollers. The system is addressable and is accessed by the utility operator/EMS, receives control commands from the EMS for energy management within the customer premises and communicates with the EMS.

3. Methods being used recently to model uncertainty in load and generation

The microgrids are associated with high uncertainty in load and