Smart Grid Implementation of Demand Side Management and Micro-Generation

Sasa Z. Djokic, The University of Edinburgh, UK
Igor Papic, University of Ljubljana, Slovenia

ABSTRACT

This paper analyses the influence and effects of demand side management (DSM) and micro-generation (MG) on the operation of future “smart grids.” Using the residential load sector with PV and wind-based MG as an example, the paper introduces a general methodology allowing to identify demand-manageable portion of the load in the aggregate demand, as well as to fully correlate variable power outputs of MG with the changes in load demands, including specific DSM actions and schemes. The presented analysis is illustrated using a detailed model of a typical UK LV/MV residential network.

Keywords: Aggregate Load Models, Demand Side Management, Micro-Generation, PV and Wind-Based Generation, Smart Grids

INTRODUCTION

In order to improve overall system performance, future electricity networks (so called “smart grids”) will feature significantly increased levels of flexibility and control. Two of the main areas that can be exploited for that purpose are active control of system loads, through the application of demand side management (DSM), and application of micro-generation (MG) technologies, whose outputs should be fully correlated with the actual load demands. Wider implementation of both DSM and MG will result in their increased impact and effects, and this paper introduces a practical methodology which can be used for the required analysis and assessment.

Although this may not be obvious, the analysis of DSM and MG is similar in many aspects. In both cases, a large number of small in size and highly dispersed individual units, connected in parallel to low voltage (LV) networks, should be included in the analysis. Furthermore, the assessment of both DSM and MG should take into account high levels of temporal and spatial variations, as their electrical characteristics change on a both short-term scale (e.g., minute-by-minute, or hourly variations) and long-term scale (e.g., daily, weekly, or seasonal variations), as well as from one (geographic or network) location to another. Accordingly, the analysis of both DSM and MG is connected
with uncertainties, and requires assessment of related stochastic variations. Finally, when they are present in high numbers, e.g., in a large urban area, or as an aggregate representation at a medium voltage (MV) bulk supply point, the aggregate effects and potential benefits of both DSM and MG can be significant.

This paper analyses the influence and effects of combined implementation of DSM and MG on the operation of future “smart grids”. It presents a detailed model of a typical UK LV/MV residential distribution network (both configuration and parameters) with the corresponding description of the load mixes and daily load curves. The paper shows how aggregate residential load model can be built using only a few general categories of loads, allowing, at the same time, to identify demand-manageable portion of the load in the aggregate demand. Two most common types of renewable MG technologies are considered in the paper: micro/small photovoltaic (μPV) generation systems and micro/small wind turbine (μWind) generation systems. The presented analysis also includes a detailed assessment of the variations of input solar and wind energy resources. Based on the estimated range of these variations, the outputs of aggregate μPV and μWind models are calculated and correlated with daily load demands. This is illustrated on practical example of Midlothian region in Scotland, UK (around the city of Edinburgh), where presented results are given for the maximum system loading conditions (i.e., winter peak demand). Essentially, the paper introduces a new methodology for obtaining improved and more accurate aggregate system load models, allowing to correctly represent not just the connected loads, but also all supply network components and all distributed generation units connected downstream the point of aggregation.

THE PROPOSED AGGREGATION METHODOLOGY

In power system analysis, bulk load supply points (BLSPs) at 11 kV, 33 kV or higher voltage levels are typically represented by aggregate system load models. In order to be accurate, these aggregate models should correctly represent not just the supplied loads, but also all network components (e.g., cables, transformers, or reactive power control elements), as well as all distributed generation units connected downstream the point of aggregation.

Aggregation of highly dispersed loads and MG units in typical distribution networks is not a simple task and there is virtually no work in this area in existing literature. In order to fill this gap, an aggregation methodology is introduced in this paper and discussed for residential load sector, where end-use loads and MG units are connected in parallel in LV networks. Figure 1 illustrates the general process of aggregation, which starts at LV level and proceeds to higher, i.e., MV levels (Collin, 2011a).

The proposed aggregation methodology requires three sets of input data: a) measured or estimated load/demand curves and statistical information on the load structure, which should be represented with the models of the main categories of loads, b) information on network configurations and network components, represented by the corresponding network model, and c) measured or estimated input energy resources of involved MG technologies, which, based on their structure, should be represented with the corresponding MG models.

AGGREGATE LOW VOLTAGE RESIDENTIAL LOAD MODEL

There are two general ways of obtaining load curves (also known as demand curves) decomposed in the corresponding structure/mix of loads. The first one is “bottom-up” approach, in which measured or estimated demands of individual LV customers are represented through the percentage contributions of different types of equipment in their demands. Demands of individual customers are then aggregated at the BLSP. The second approach is “top-down”, in which measured or estimated aggregate demands at BLSPs are directly decomposed into the assumed corresponding load structure,