The Energy Mix at the years 2020 y 2030


Chairs: Edgardo D. Castronuovo
Víctor Hernández Jiménez
Fernando Soto Martos
Julio Usaola García

Secretary: Ignacio A. Calle

More information: ecastron@ing.uc3m.es

Support:
Coordinated Control of Micro-generation and Demand-side Management in Smart Grids

Ignacio Hernandez-Gil, Student Member IEEE, Irinel-Sorin Ilie, Adam J. Collin, Student Member IEEE, Jorge L. Acosta, Student Member IEEE, Barry P. Hayes, Student Member IEEE and Sasa Z. Djokic, Senior Member IEEE.

Abstract—This extended abstract analyses possible benefits of coordinated implementation of micro-generation (MG) and demand-side management (DSM) on the overall performance of distribution networks, particularly quality of supply of low-voltage residential customers. Detailed network representations and improved aggregate load/MG models are used to assess changes in active/reactive power flows, system losses and voltage profiles due to the introduction of MG with/without energy storage and implementation of DSM schemes. The extended abstract also discusses how coordinated control of MG and DSM, as one of the important functionalities of future "smart grids", may provide distribution network operators with an efficient solution for improving system reliability and maintaining continuity of supply.

Index Terms—demand-side management, micro-generation, energy storage, distribution network modelling, power system performance, quality of supply, reliability, smart grids.

I. INTRODUCTION

FUTURE electricity networks (so called "smart grids") will introduce significant changes in ranges and levels of system-user interactions, and will shift actual system operating and loading conditions well outside the traditional limits. Two important changes expected in future “smart grids” are wider implementation of demand-side management (DSM) and higher penetration levels of renewable-based micro and small-scale generation (i.e. micro-generation, MG) technologies.

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. The assessment of both DSM and MG should take into account high levels of temporal and spatial variations, as their electrical characteristics change on 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/network location to another. 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.

Based on the results of the previous work [1]-[3], this extended abstract analyses possible benefits of coordinated implementation and control of MG (with and without energy storage) and DSM on the overall performance of the future flexible and actively controlled "smart grids". Particular attention is given to power quality and reliability analysis, i.e. the delivery of an uninterrupted and high-quality supply of electrical energy to the residential load sector customers.

II. DISTRIBUTION NETWORK CONFIGURATION

Due to their volume and complexity, primary (MV) and secondary (LV) distribution networks are often represented by lumped aggregate models in power system analysis ([4] provides more details). However, for the correct analysis of the effects of MG and DSM on quality of supply performance, these networks should be represented in greater detail.

Distribution networks differ from each other in both characteristics and configurations (e.g. fault levels and source impedances, transformer ratings, feeder types/lengths, etc.). Previous work in [4] identified four sub-sectors of the UK residential load sector (highly-urban, i.e. metropolitan areas; urban, i.e. city areas; sub-urban, i.e. town areas; and rural, i.e. remote or rural areas), together with their corresponding typical MV/LV network configurations. “Smart grid” studies usually consider urban loads and urban network configurations as they represent a significant percentage of all residential customers. This extended abstract, however, considers sub-urban loads/networks, as they represent another considerable portion of residential customers. Typical UK-based sub-urban network configuration is shown in Fig. 1, while Tables I and II provide more details for the modelled sub-urban network components.

### Table I

<table>
<thead>
<tr>
<th>Operating Voltage (kV)</th>
<th>Feeder Type</th>
<th>Max. Feeder Length (km)</th>
<th>Cross section (mm²)</th>
<th>R/km</th>
<th>X/km</th>
<th>B/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>O/H line or Mixed</td>
<td>15</td>
<td>150</td>
<td>0.11259</td>
<td>0.18363</td>
<td>8.4263E-05</td>
</tr>
<tr>
<td>0.4</td>
<td>O/H line or Mixed</td>
<td>0.3</td>
<td>95</td>
<td>0.14658</td>
<td>0.26189</td>
<td>1.2207E-05</td>
</tr>
</tbody>
</table>

### Table II

<table>
<thead>
<tr>
<th>Operating Voltage (kV)</th>
<th>Vector Group</th>
<th>Rating (MVA)</th>
<th>R (p.u. on 100MVA)</th>
<th>X (p.u. on 100MVA)</th>
<th>Min</th>
<th>Max</th>
</tr>
</thead>
<tbody>
<tr>
<td>11/0.4</td>
<td>Dyn11</td>
<td>75</td>
<td>0.14</td>
<td>1.3</td>
<td>0.82</td>
<td>1.043</td>
</tr>
<tr>
<td>11/0.4</td>
<td>Dyn11</td>
<td>0.2</td>
<td>7.5</td>
<td>22.5</td>
<td>0.95</td>
<td>1.05</td>
</tr>
</tbody>
</table>

This work was partially supported by the UK Engineering and Physical Sciences Research Council (EPSRC), Project EP/G0052530/1.

All authors are with the Institute for Energy Systems, School of Engineering, the University of Edinburgh, Kings’ Buildings, Edinburgh, Scotland, UK (Contact E-mail: i.hernando-gil@ed.ac.uk).
At sub-urban locations, distribution network is of medium strength with a radial configuration in normal operation (open arrangement). The MV feeders are overhead lines (O/H), while the LV feeders can be either O/H or cable lines. The feeder lengths, which are longer with respect to highly-urban and urban networks, will influence optimal voltage regulation. This is due to the lower density of housing and increased distance from the MV substation. All these characteristics result in a lower reliability performance than in the highly urban and urban networks. This will be discussed in the further text, especially regarding the influence of MG and DSM on experienced number and duration of supply interruptions.

III. AGGREGATE SUB-URBAN RESIDENTIAL LOAD MODEL

Residential load mix will vary depending on the characteristics and location of the load, as well as on the time of the day, day of the week and season of the year. The load profile used in this paper represents aggregate LV sub-urban residential customers in the UK for average (i.e. spring/autumn) loading conditions (Fig. 2), where maximum loading conditions (100% of the peak load) occur during the winter.

IV. AGGREGATE MICRO-GENERATION MODEL

Using an example of urban and sub-urban residential areas in Edinburgh, UK, this paper analyses PV and wind-based MG systems, which are the most common in the majority of European countries (more details are provided in [2] and [6]). The combined power outputs of both PV and wind-based MG are shown in Fig. 3, for a "typical" day in spring season (corresponding to average system loading conditions, 21st of March). For the chosen day, wind speed and solar irradiance measurements for the previous 14 days and next 14 days are processed to determine the expected ranges of variations in the available resources of Edinburgh. These results are then used to calculate MG outputs (assuming equal contribution/installed capacity of PV and wind-based systems), based on aggregate MG models developed and presented in [2].
A relatively low penetration level of MG is assumed: 10% of the peak residential demand, where 1 p.u. in Fig. 3 corresponds to 10% of the peak residential demand. The aggregate PV/wind MG is analysed for two general scenarios:

- "Uncontrolled MG" scenario – daily MG outputs are calculated for average solar/wind energy inputs; MG is not controlled and DSM is not implemented.
- "DSM + Energy storage" scenario – all MG outputs (for average solar/wind energy inputs) are stored during the day and used in coordination with applied DSM scheme.

V. "SMART GRID" PERFORMANCE ASSESSMENT
When a permanent fault occurs in distribution networks, faulted component, or faulted part of the network will be disconnected by the protection system. Distribution network operators (DNOs) will try to reconfigure the network in order to maintain continuous supply to all customers, but this may not be possible due to design limitations (distribution networks are typically not designed with "n-1" security criterion). As a consequence, part of the supplied loads will be shed in order to maintain supply to the other system loads (e.g. to prevent overloading in the healthy part of the network). For the affected residential customers, these actions usually result in long interruptions. However, "smart grid" functionalities, such as the coordinated control of MG and energy storage with the implementation of DSM, may provide DNOs with an efficient solution for maintaining continuous supply to either all, or substantially higher number of customers.

A. DSM scenario
If one of the 33/11 kV 5 MVA transformers in the primary substation (Fig. 1) fails when demand is greater than the power rating of the other operating transformer (e.g. 2/3 of the peak load), all customers may still be supplied if an intelligent DSM scheme is adopted by the DNO. During this contingency, one transformer could only be able to supply the load for a limited period of time, due to possible overloading conditions. Therefore, the additional use and coordination of energy storage from connected MG could further help to supply the excessive loads until the normal supply is established.

This paper considers that only "wet loads" are suitable to participate in DSM. The "wet loads" are composed of 22% dishwasher load, 31% washing machine load, 31% tumble dryer and 16% combined washer-dryer load, [6] and [7].

Considered “DSM” scenario is defined to shift a moderate amount of 40% of all wet loads present during the evening peak (18:00-22:00, Fig. 2) to late night hours (02:00-06:00). This is a typical DSM scheme for reducing peak load. As all LV customers are represented by the same aggregate demand profile, the load reduction is assumed to be equally shared.

VI. PRELIMINARY RESULTS
This section presents some preliminary results for the previously discussed "smart grid" scenarios (active/reactive power flows, voltage profiles, and reliability performance).
Reliability indices must be reported annually by DNOs to the energy regulators, in order to assess the performance of their supply systems. System Average Interruption Frequency Index (SAIFI) and System Average Interruption Duration Index (SAIDI) are used to quantify the number and duration of long interruptions, while short interruptions are assessed by Momentary Average Interruption Frequency Index (MAIFI). The presented results correspond to a long simulation period (equivalent to hundreds of years of actual network operation). The failure rates of power components are assumed to have exponential distribution, with the maximum operating lifetimes of 40 years, [3]. In addition, this analysis has acknowledged actual residential demand profiles of the loads (Fig. 2), rather than using simplified bulk load models.

The mean values of the three calculated indices for the base case are 8.6 and 48.5 interruptions per customer and per year for SAIFI and MAIFI respectively, and 48.2 hours per customer and per year for SAIDI. These values are improved with the contribution of MG outputs as the probability of experiencing fewer interruptions is higher. The new values for SAIFI, MAIFI and SAIDI are 8.1, 45.8 and 42.2 respectively.

VII. CONCLUDING REMARKS AND FURTHER WORK

The analysis presented in this extended abstract shows how the deployment of MG with/without energy storage and implementation of realistic DSM scenarios can improve performance of residential MV/LV networks. Reductions in active and reactive power demands are observed, alongside the improvements in voltage profiles and OLTC settings.

The results obtained for the proposed “smart grid” scenarios in the sub-urban residential load sector prove that these might be an efficient tool for DNOs to reduce network congestion and improve quality of supply. Significant improvements in reliability performance are experienced when coordinated control of DSM and aggregate PV/wind MG is introduced.

VIII. REFERENCES


