Title: Deliverable 2.2 “Benefits of controlling EVs and PV”

Synopsis: This report presents a quantitative assessment of the benefits of adopting control of EVs and PV systems considering different control strategies, penetration of low carbon technologies, and penetrations per feeder, and types of LV networks.

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Executive Summary

This report corresponds to Deliverable 2.2 “Benefits of controlling EVs and PV” part of Work Package 2 “Control of Low Carbon Technologies” of the iCASE project “Active Management of LV Networks” jointly funded by EDF R&D and EPSRC.

The Active Management of LV Networks project has been established in order to investigate the effect of applying active management techniques to increase the ability of low voltage networks to accommodate higher number of low carbon technologies (LCTs), in particular photovoltaic (PV) systems and electric vehicles (EVs). The project will focus on the utilisation of on-load tap changing transformers and coordinated control of LCTs themselves and other technologies to control voltages and congestion in the network.

Deliverable 2.1 presented a literature review on different approaches to manage low carbon technologies (EVs and PV systems) so far proposed by researchers and industry, particularly those that have been implemented through trials. This report, Deliverable 2.2, will provide the quantification of benefits from controlling PV systems and EVs adopting decentralised (i.e., local) and centralised control approaches. The performance of each proposed control approach is investigated using a Monte Carlo framework considering 11 penetration levels (0 to 100%) for each LCT.

A summary of the main aspects of this report is presented below.

PV Control

- **PV Inverters.** The basic characteristics and specifications of the inverters modelled in this report are discussed. Three control functions (i.e., Volt-Var, Volt-Watt and active power limitation) already embedded in the most common commercial residential-scale PV inverters are described. The possible interactions with these control functions are also discussed.

- **Decentralised Voltage Control.** The adoption of decentralised voltage control using the Volt-Var and Volt-Watt control functions is carried out on seven French LV networks considering different penetration levels of PV systems for different days in summer (i.e., lowest demand days). The performance of these two control functions is investigated for 15 different control set-points by applying a Monte Carlo Analysis.
  
  - **Volt-Var Control without over-rated inverters.** The analysis demonstrates that the adoption of any of 15 Volt-Var curves results in a similar slight reduction of EN50160 non-compliant customers. However, overall, the utilisation level of transformer and feeders is increasing and voltage rise problems cannot be solved because the ability of the inverters to absorb reactive power is significantly limited during periods of high generation (where voltages are high), i.e., the rated KVA power is almost reached.

  - **Volt-Var Control with 10% over-rated inverters.** The analysis demonstrates that the application of Volt-Var control with over-rated inverters (10% more in this case) can provide better voltage management (i.e., significant reduction of EN50160 non-compliant customers) without the need of curtailing any generation. This is due to the fact that an over-rated inverter gives the ability to absorb reactive power even at peak generation periods. However, the utilisation level of transformer and feeders is significantly increasing.

  - **Volt-Watt Control.** The analysis demonstrates that this approach is more effective in managing voltages. Indeed, most of the curves show that the penetration level of PV systems can be potentially shifted to 100% without facing any voltage problems. The analysis also shows that a single Volt-Watt curve can be found that provides the best trade-off between voltage issues and the required volume of curtailment among all the investigated LV networks. In terms of the transformer and feeder utilisation levels, the
analysis shows that the utilisation levels are always kept below 100%, except of some curves where assets are still overloaded at high penetration levels.

- **Decentralised Thermal and Voltage Control.** The adoption of a more conservative Volt-Watt curve is applied on the LV_02779 in order to solve both voltage and thermal issues at the same time. The adoption of Volt-Watt control with a more conservative Volt-Watt curve is able to eliminate voltage problems (i.e., all customers compliant with EN50160) and keep the transformer and feeder utilisation levels below 100% for all PV penetration levels. The results clearly show that the Volt-Watt control function can be applied in order to efficiently manage both voltage and thermal impacts. This, however, requires each LV network to be assessed independently given the different thermal capacities.

- **Centralised Thermal Control.** The benefits of adopting a centralised control logic that caps generation outputs to manage thermal issues in LV networks is investigated on seven French LV networks. Results are discussed in particular for LV_02779.
  
  - **Proposed Control Logic.** A centralised thermal control logic using limited network information is proposed. The control logic considers active power measurements at the transformer and head of each feeder (each phase), the household demand data (smart meters) and the installed PV capacity per feeder (per phase). It essentially calculates the maximum power (i.e., percentage of $P_{\text{max}}$) that the PV systems (per feeder) in a network are able to generate in order to keep the transformer and feeder utilisation levels below 100%.
  
  - **Stochastic Analysis.** The proposed centralised thermal control is in general able to keep the maximum utilisation level of both transformer and feeders of LV_02779 below 100% for all PV penetration levels. This however is achieved with the expense of curtailing up to 30% of generation at the highest penetration level (100%). Nonetheless, voltage problems still exist across all penetration levels (except high penetration levels - i.e., 100%) above 30% albeit with a reduced number of non-compliant customers.

- **Combined Centralised Thermal and Decentralised Voltage Control.** The benefits of adopting a centralised control logic that caps generation outputs combined with a decentralised Volt-Watt control to manage both thermal and voltage issues, is investigated on seven French LV networks. Results are discussed in particular for LV_02779.
  
  - **Proposed Control Logic.** The previously described centralised thermal control logic and Volt-Watt control are used simultaneously. For the latter, the curve adopted considers the highest voltage “idleband” so curtailment only occurs when voltage is close to the voltage limits.
  
  - **Stochastic Analysis.** The analysis shows that the utilisation level of both transformer and feeders are always kept below 100% (for all penetration levels) and in general asset utilisation levels are slightly lower compared to the centralised thermal control. In terms of non-compliant customers, the combined centralised thermal and decentralised voltage control is able to eliminate all voltage problems. Thus, the adoption of such a control can increase the hosting capacity of PV systems to 100% without facing any thermal or voltage issue.

**EV Control**

- **Centralised EV charging point management.** The benefits of adopting an implementable, centralised control algorithm to manage EV charging points is investigated in order to mitigate thermal problems in LV networks considering and extending the approach adopted by the UK project “My Electric Avenue (MEA)”. The disconnection/connection of EV charging points depends on an EV ranking method which considers available information (i.e., state of charge – SOC, desired final SOC – DFSOC, time the EV will be used again, total time of charging).
The performance of the EV charging point management is investigated adopting four EV ranking methods by applying a Monte Carlo Analysis and adopting a 1-minute control cycle on seven French LV networks. Results are discussed in particular for LV_02779.

- **Control Algorithm.** At every control cycle, the algorithm adopts a hierarchical corrective (from feeder to transformer) and a hierarchical preventive (from transformer to feeder) approach to disconnect or reconnect (per phase) EV charging points, respectively. The disconnection/connection of EV charging points depends on an EV ranking method which ranks the EVs based on the available information. The centralised EV charging point management can be set up (depending on the available information) to use one of the following EV ranking methods.
  - Ranking based on the total charging time (MEA)
  - Ranking based on the remaining required charge (Pa)
  - Ranking based on the EV charging delay (Pb)
  - Ranking based on the available time to charge (Pc)

- **Stochastic Analysis.** The adoption of the centralised EV charging point management is able to keep the utilisation level of both transformer and feeders below 100% for all EV penetration levels and naturally help to reduce the number of non-compliant customers. In general, the analysis shows that the application of the centralised EV charging point management can be a potential solution to manage thermal issues while maintaining high EV user satisfaction. In addition, the investigation of different EV ranking methods showed that almost the same performance can be achieved with minimum information using the MEA ranking method (i.e., considering only the total EV charging time) compared to the other EV ranking methods that require significantly more information and, therefore, more infrastructure (i.e., SOC, DFSOC, time to use the EV again). Overall, the results demonstrate that the studied EV management approaches can play an important role in promoting the adoption of EVs without the need of network reinforcements.
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