ASSESSING THE PROS AND CONS OF DIFFERENT OPERATING ENVELOPES IMPLEMENTATIONS ACROSS AUSTRALIA

Arthur GONÇALVES GIVISIEZ
The University of Melbourne
Australia
arthurgivisiez@ieee.org

Luis F. OCHOA
The University of Melbourne
Australia
luis.ochoa@unimelb.edu.au

Michael Z. LIU
The University of Melbourne
Australia
mliu@ieee.org

Vincenzo BASSI
The University of Melbourne
Australia
vbassiz@ieee.org

ABSTRACT

As the adoption of residential distributed energy resources (DERs) increases, the opportunity of providing services by DER owners (via aggregators) also increases. However, the flows of electricity resulting from high volumes of services can cause technical issues in distribution networks, such as significant voltage rise/drop and/or thermal issues, particularly at low voltage (LV) levels. In this context, the use of operating envelopes (OEs) – time-varying limits at the customer connection point – is considered a potential solution to ensure network integrity whilst facilitating DER services. Nonetheless, OEs can be implemented in different ways since, in practice, the available infrastructure/data to distribution companies is what defines the most appropriate approach. To assist distribution companies, this paper assesses the pros and cons of different OE implementations tailored to different availability of infrastructure/data using as case study distribution companies across Australia.

INTRODUCTION

As the adoption of residential distributed energy resources (DERs) – such as solar photovoltaic (PV), batteries, and electric vehicles (EVs) – increases, the opportunity of providing services by DER owners (via aggregators) also increases. Once the portfolio of aggregators grows, it is expected that high volume of services will cause technical issues in distribution networks, such as overvoltage or undervoltage and/or thermal issues, particularly at low voltage (LV) levels [1]. In Australia and other countries, distribution companies have attempted to address similar issues by imposing fixed export limits (e.g., 5kW per phase at the connection point of customers with PV [2]). However, having a fixed limit throughout the day and for all customers is not ideal since depending on the time and location, it may limit customers (and services) more than necessary. In some cases, fixed limits might also not be enough to ensure network integrity.

A natural evolution of fixed limits are the operating envelopes (OEs), which consist of time-varying limits for individual active customers (i.e., aggregator-managed customers) that can be imposed at their connection points for exports/imports [3-5]. Ideally, to calculate OEs, the distribution company may use network information (e.g., electrical models, SCADA, smart meter measurements) to build a model that can run multiple power flows, making it possible to calculate the maximum export/import limits per active customer. Once calculated, these operating envelopes are sent to DER aggregators, which must use OEs as limits when managing their DER portfolio. However, for this calculation to be accurate, it requires accurate network models (including topology, impedances, phase connections) and operational monitoring down to the LV network, which is a great challenge for many distribution companies in Australia and around the world. Furthermore, there is also great diversity in the available infrastructure among distribution companies within the same country, which hinders the possibility of having a single type of OE implementation. Consequently, it is important for distribution companies and other stakeholders (e.g., aggregators, system operators, etc.) to understand the pros and cons of different OE implementations to they can make informed decisions.

This paper presents findings from the project "Assessing the Benefits of Using Operating Envelopes to Orchestrate DERs Across Australia", funded by the Commonwealth Scientific and Industrial Research Organisation (CSIRO) as part of the "Australian Research for Global Power Systems Transformation (G-PST)" [6]. The project aims to carry out an assessment of the benefits and drawbacks of different OE implementations likely to be seen across Australia. Two main findings are presented:

- The spectra of the available electrical models, available monitoring data (i.e., network and customers), and available forecast across Australian distribution companies.
- The assessment of a simple OE implementation tailored to limited infrastructure/data availability.

AVAILABLE INFRASTRUCTURE/DATA ACROSS AUSTRALIAN DISTRIBUTION COMPANIES

All distribution companies of Australia were surveyed to

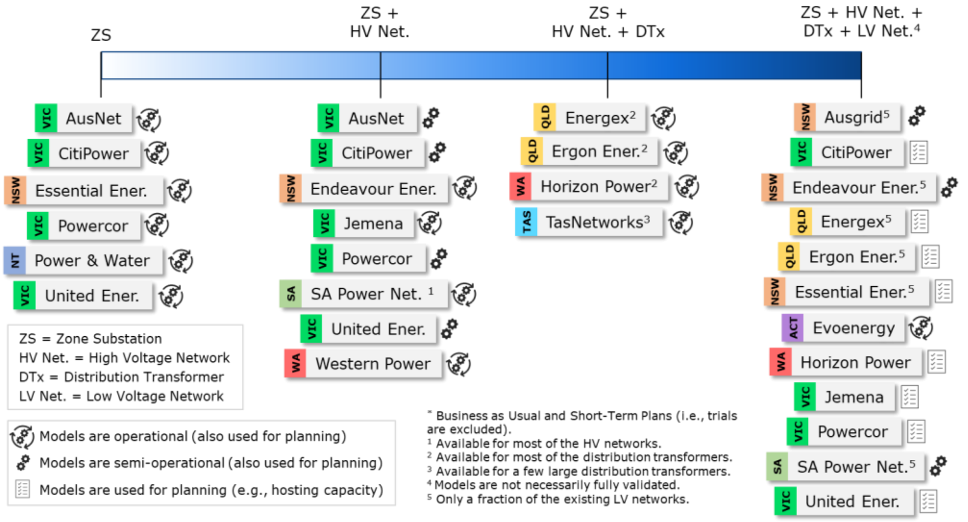

Figure 1. Availability of Electrical Models.

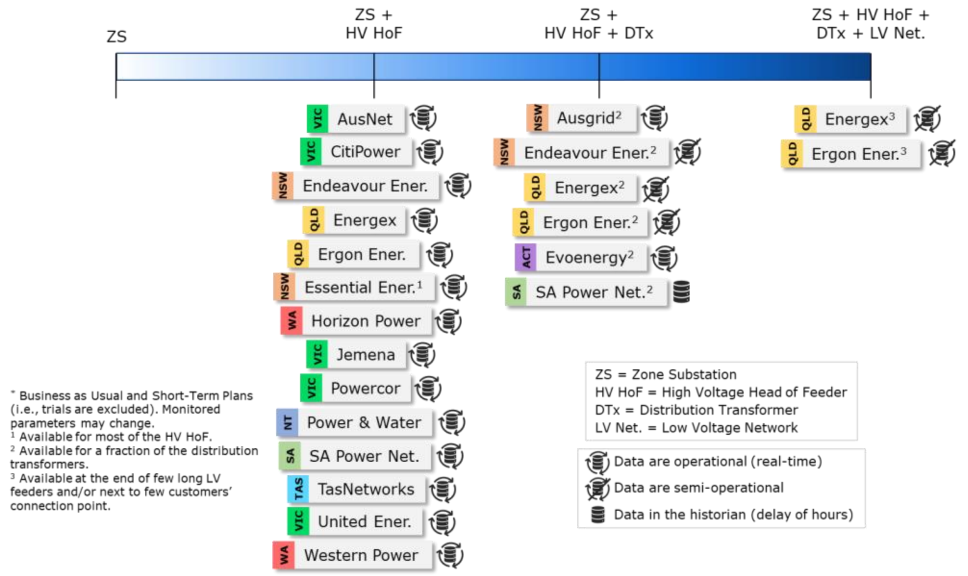

Figure 2. Availability of Network Monitoring.

better understand their available electrical models, available network and customers monitoring, and available forecast. The focus of the survey was on the medium voltage (MV) – also known as high voltage (HV) in Australia – and LV networks, where the OEs are most likely to be implemented first. From the survey, four spectra were created to show where each distribution company stands in terms of available infrastructure/data. In general, there is a large diversity on the available infrastructure/data they have, which confirms the need to assess different OE implementations. It is worth noting that all distribution companies are moving towards the modernisation of their infrastructure/data availability (e.g., more monitoring, better electrical models). However, each one of them has their own pace, which is subject to their regional requirements and characteristics. Details of the collected information are given below.

The spectrum of availability of electrical models is presented in Figure 1. In general, the spectrum shows a large diversity of available electrical models among the distribution companies. Nevertheless, around 75% of the distribution companies have some type of electrical models down to the LV network, meaning that they have the capability of creating electrical models that could run power flows and eventually be used to calculate OEs. However, most of the LV network models are not necessarily fully validated, meaning that using these models to calculate OEs could probably lead to ineffective values (i.e., they might not avoid network problems or might over constrained customers).

The spectrum of availability of network monitoring is presented in Figure 2. In general, the spectrum shows that all distribution companies have operational monitoring at the head of the HV feeder, which does not help on the

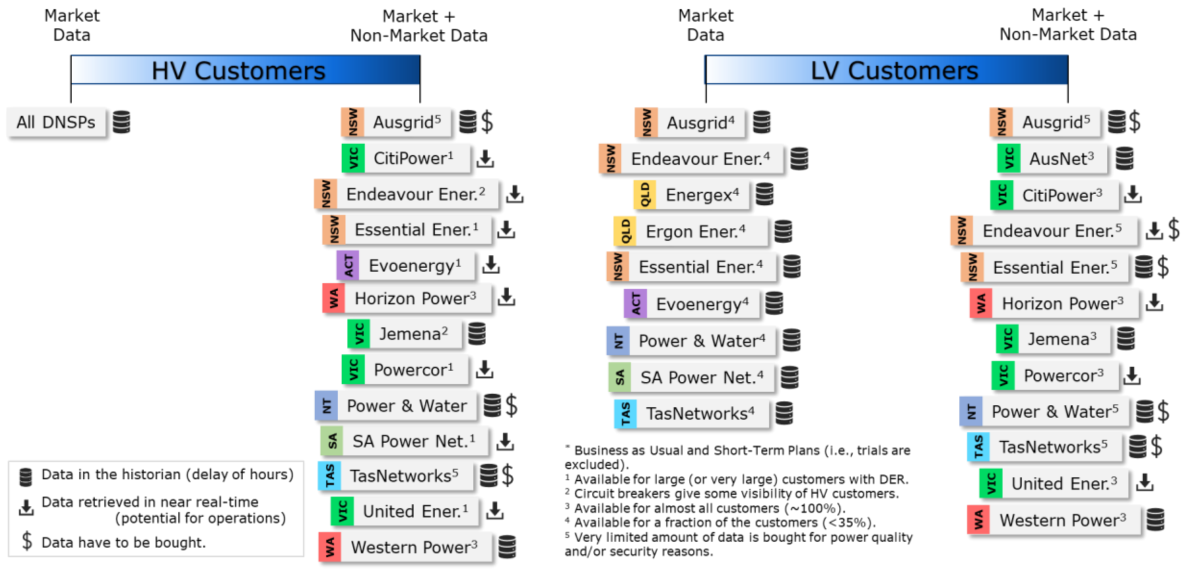

Figure 3. Availability of Customer Monitoring.

calculation of OEs for customers connected to the LV. Nonetheless, around 37% of them have been investing on increasing the monitoring at the LV network, which is important as with more LV monitoring, it is possible to capture more parameters (e.g., demand, voltages) required to calculate the OEs.

The spectrum of availability of customer monitoring is presented in Figure 3. There are two types of customer monitoring data that a distribution company can have: market data (i.e., half-hourly energy consumption [kWh]) and non-market data (i.e., active/reactive power and voltage every few minutes). In general, all distribution companies have access to market data, but non-market data – which is required for calculating OEs – is not always available to them. Only distribution companies from the states of Victoria and Western Australia have full access to this data (as they own and operate the smart meters), while distribution companies from other states usually must buy this data from a third party.

The spectrum of availability of forecast is presented in Figure 4. Almost all distribution companies make forecast to the HV head of feeder. This forecast is intended for planning, so it is usually done for a few periods of the year and for maximum demand (and in recent years for minimum demand too). However, the forecast techniques used for the aggregated demand of thousands of customers and for specific times of the year are unlikely to be adequate for the more granular (a distribution transformer or even individual customers) and operational (e.g., every 5 minutes a few hours ahead) purposes of OEs. Around 25% of the distribution companies are trying to develop forecast that are closer to the end customer, but they are facing challenges on creating accurate and granular forecast for such situations, when the diversity factor is considerably reduced.

Finally, to provide a more holistic description of the infrastructure/data availability of Australian distribution companies, an overall spectrum was also created from the four spectra, as presented in Figure 5. The distribution companies were clustered based on the diversity of available infrastructure/data. Four clusters were identified: *Moderate Transition*, *Fast Transition*, *Very Fast Transition*, and *Step Transition*. These clusters will be used to associate potential OE implementations according to available infrastructure/data.

OPERATING ENVELOPES

Operating envelopes are time-varying limits for individual active customers (i.e., aggregator-managed customers) that can be imposed at their connection points for exports/imports. Once calculated, these operating envelopes are sent to DER aggregators, which must use OEs as limits when managing their DER portfolio. This should allow the network to operate within acceptable technical limits, thus guaranteeing the delivery of bottom-up services.

Operating envelopes can be implemented in different ways, and they will vary in terms of complexity and accuracy. The complexity relates to the required infrastructure/data (e.g., electrical models of the electricity network and monitoring data such as smart meter data) and how elaborated is the calculation of the OE, while the accuracy relates to how precise the OE calculation is. In the coming subsections, two ways to implement operating envelopes are presented.

Ideal Operating Envelope

The ideal OE is the most advanced and, hence, accurate OE approach. However, it needs a full electrical network model and full monitoring of customers, which makes its

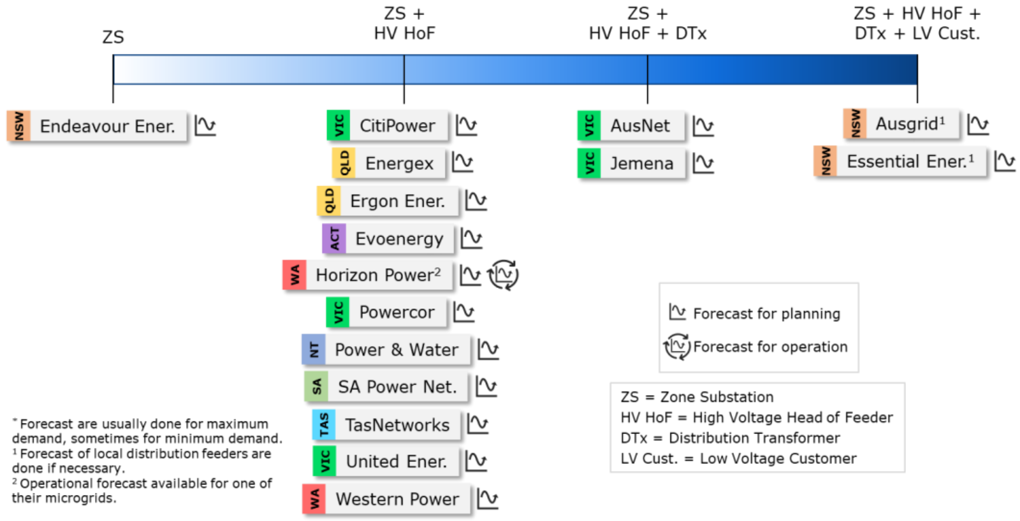

Figure 4. Availability of Forecast.

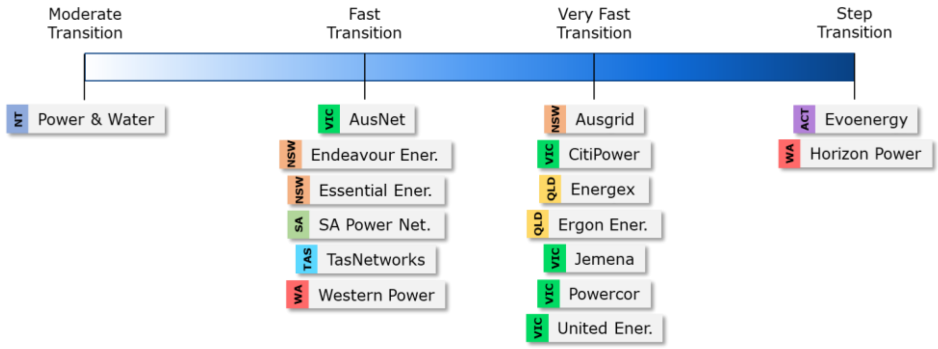

Figure 5. Overall Spectrum.

implementation complex. If the model and monitoring data are correct, it can not only guarantee the operation of the network within technical limits (i.e., voltage and thermal) but also the maximum export/import limits. This OE approach has the potential to be used by distribution companies with very advanced availability of infrastructure/data (i.e., distribution companies in the *Step Transition* and *Very Fast Transition* clusters).

The inputs to the ideal OE algorithm consist of the (forecasted) voltage magnitude at the head of the LV feeder, net demand (active and reactive power) of passive customers (households who are not active customers) and net demand (reactive power) of active customers. By using the electrical models together with these input data, operating envelopes can be obtained by carrying out heuristic algorithms (series of power flows calculations exploring exports/imports up the point network limits are breached) or optimisation techniques. Details in [4, 5].

A Simple Implementation: Asset Capacity & Delta Voltage OE

The asset capacity & delta voltage (AC_ΔV) OE needs limited monitoring (only at two points of the LV network) and the capacity of one asset (the distribution transformer), which makes its implementation much simpler. Although it usually does not solve all the problems and it may not always work (it changes case by case), it can work considerably well. This OE implementation has great potential to be used by distribution companies with less availability of infrastructure/data (i.e., distribution companies in the *Moderate Transition* and *Fast Transition* Clusters). However, this approach can also be of interest to other distribution companies wishing to adopt simple yet cost-effective alternatives.

The inputs to the AC_ΔV OE algorithm are the (forecasted and historical) active power and (historical) voltage magnitude at the distribution transformer, and (historical) voltage magnitude at the critical customer (i.e., the most affected by voltage variations) of the LV network. First, the forecasted active power is used to estimate the spare capacity on the LV network. Second, the historical data is used to create two sensitivity curves, one that relates the total active power on the LV network to the voltage at the distribution transformer, and another that relates the total active power on the LV network to the voltage drop from the distribution transformer to the critical customer. These two sensitivity curves are used to estimate the voltage at the critical customer for a series of OE values that explores exports/imports up the point network limits are breached.

CASE STUDY

In this case study both the ideal and AC_ΔV OE are implemented in a realistic LV network and assessed to see their effectiveness on maintaining the network operation within technical limits. To achieve this, the OEs are first calculated using the methods previously explained. Then, power flows are run assuming that the OE values are fully utilised by active customers.

Australian Distribution Network

This study uses a real 22kV MV feeder in Victoria, Australia. The MV feeder starts at the 66kV/22kV primary substation transformer, where the 66kV (1.0 p.u.) is considered constant. The transformation ratio of the 79 distribution transformers is 22kV/0.433kV with off-load tap changers at the middle position (not affecting the ratio) – overall providing a natural boost of around 8% from the nominal voltage of 0.4kV which is common in Australia. Pseudo-LV feeders are created based on the distribution company design principles [7]. This is necessary because the actual LV feeder models are not available. In total there are approximately 3,374 customers across all the pseudo-LV feeders, mostly residential single-phase connections.

Following the Victorian Electricity Distribution Code, voltages at residential customers connected to the LV network have to be between 216V and 253V. The nominal rating of assets is used to assess thermal issues.

Simulation Considerations

A LV network (with 114 customers) of the Australian MV feeder was selected to have OEs implemented. This LV network is considered to have a penetration of 5% of PV systems (i.e., 5% of the 114 customers have PV systems), which belongs to passive customers. These PV systems have a capacity of 5kW. Another 20% of the customers are considered to have PV systems and batteries, these are active customers, the ones that engage with aggregators. The combined capacity of the PV systems and batteries are 10kW, which also becomes the maximum export of the OEs. In addition, houses are considered to have a fuse of 14kW, which becomes the maximum import of the OEs.

Results

Given that the ideal OE is considered the benchmark and that the AC_ΔV OE is very similar to the ideal, it suggests that the simpler OE can be as effective as the ideal OE in avoiding technical issues.

The voltages at all customers after fully applying the calculated ideal OE for export/import to active customers are shown in Figure 6. As expected, all voltages are kept within the technical limits. Figure 7 shows similar results but for the AC_ΔV OE. Around 95% of the customers have voltages within the statutory limits but 5% are beyond the

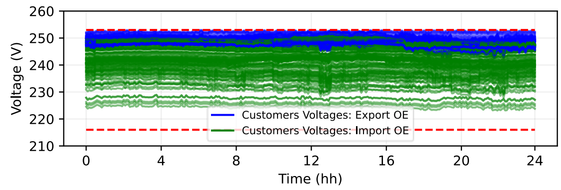

Figure 6. Ideal OE: Export/Import Customer Voltages.

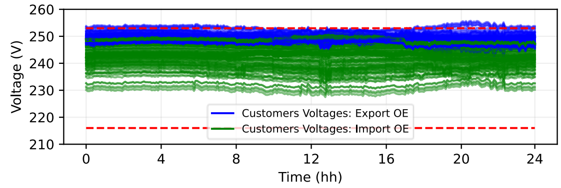

Figure 7. AC_ΔV OE: Export/Import Customer Voltages.

upper limit of 253V. Nonetheless, the maximum excursion is less than 3V, which may be considered a good enough value in practice. In addition, although not shown here, there is not excursion of thermal limits in any of the OE implementations.

CONCLUSIONS

The results presented in this paper suggests that full electrical network models and full monitoring of customers (i.e., 100% smart meter penetration) is not necessarily needed to calculate adequate OEs. Simpler OE implementations that require very limited knowledge of the electrical network and very limited monitoring have great potential to be good enough (not perfect though) to solve excessive voltage rise/drop and asset congestion of LV feeders. This is good news for many distribution companies in Australia and around the world that have limited infrastructure/data availability.

REFERENCES

[1] K. Petrou, A. T. Procopiou, L. F. Ochoa, T. Langstaff, and J. Theunissen, "Impacts of Price-Led Operation of Residential Storage on Distribution Networks: An Australian Case Study," presented at the IEEE Milan PowerTech, Milan, Italy, 2019.

[2] M. Rankin and B. Colavizza, "Export limits for embedded generators up to 200 kVA connected at low voltage: standard operating procedure," AusNet Services, 2017.

[3] K. Petrou, M. Z. Liu, A. T. Procopiou, L. F. Ochoa, J. Theunissen, and J. Harding, "Managing residential prosumers using operating envelopes: an Australian case study," presented at the CIRED 2020 Berlin Workshop, Berlin, Germany, 2020.

[4] M. Z. Liu, L. F. Ochoa, T. Ting, and J. Theunissen, "Bottom-Up Services & Network Integrity: The Need for Operating Envelopes " presented at the CIRED 2021 - The 26th International Conference and Exhibition on Electricity Distribution, 2021.

[5] M. Z. Liu, L. F. Ochoa, P. K. C. Wong, and J. Theunissen, "Using OPF-Based Operating Envelopes to Facilitate Residential DER Services," *IEEE Transactions on Smart Grid,* vol. 13, pp. 4494-4504, 2022, doi: 10.1109/TSG.2022.3188927.

[6] "Assessing the Benefits of Using Operating Envelopes to Orchestrate DERs Across Australia." https://electrical.eng.unimelb.edu.au/power-energy/projects/assessing-the-benefits-of-OEs-across-Australia.

[7] A. T. Procopiou *et al.*, "On the role of integrated MV-LV network modelling in DER studies," presented at the CIRED 2020 Berlin Workshop, Berlin, Germany, 2020.