Voltage-Controlled Frequency Regulation System - Milestone 1

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1. Summary

This document is the Project Performance Milestone 1 Report for the United Energy (UE) Voltage-Controlled Frequency Regulation System (the Project). The Project will demonstrate a new capability to deliver delayed-FCAS services for the NEM under ARENA's Advancing Renewables Programme (2019/ARP007). It fulfils an obligation under the Knowledge Sharing Plan to provide an update on the status of the delivery of the Project including sharing of results and lessons learnt.

This report documents the major achievements of the Project since its commencement in June 2019. These achievements include:-

1) Development of the technical solution design
    a. Engagement with AEMO on performance requirements and communication channels for FCAS dispatch and market registration;
    b. Finalisation of technical specifications for frequency monitoring devices;
    c. Specification of the Dynamic Voltage Management System (DVMS) algorithm enhancements to enable the Project's FCAS capability; and
    d. Reviewed voltage-spread profiles for zone substations to identify further low-voltage works.
2) A regulatory assessment for FCAS participation; and
3) An initial assessment of the business case revenue and cost streams associated with the technology.

Any parties interested in discussing the contents of this report directly with United Energy are encouraged to contact United Energy at planning@ue.com.au.

The milestone reports are available on United Energy's website.

2. Background

The objective of this ARENA-funded project is to demonstrate the capability of UE's Dynamic Voltage Management System (DVMS) technology (developed under ARENA's Demand Response programme), in a new way to deliver FCAS services to the Australian Energy Market Operator (AEMO) and the National Electricity Market (NEM).

This Project will demonstrate the use of the technology for "Delayed Raise" and "Delayed Lower"[1] contingency FCAS by providing voltage-reduction demand-response capability to ramp power output in response to frequency disturbances on the power system. UE aims to bring an additional 30MW of raise service capacity to the NEM through this proof of concept project, testing it over the summer months of 2019/2020 and into 2020.

This outcome can be achieved by leveraging the DVMS, enhancing its algorithms and expanding its capacity in its current roles of providing power quality compliance, solar photovoltaic export enablement, and Reliability and Emergency Reserve Trader (RERT) support, to also demonstrate it can provide FCAS. UE plans to use frequency measurements to instruct the operation of the DVMS to provide the response times and change in active power required to support the FCAS delivery.

Figure 1 shows the end-end overview of the UE voltage-controlled frequency regulation system, which is currently under development. It is an automatic closed-loop system which has smart meters and data analytics as key to its operations, with voltage and frequency monitors to inform its response performance.

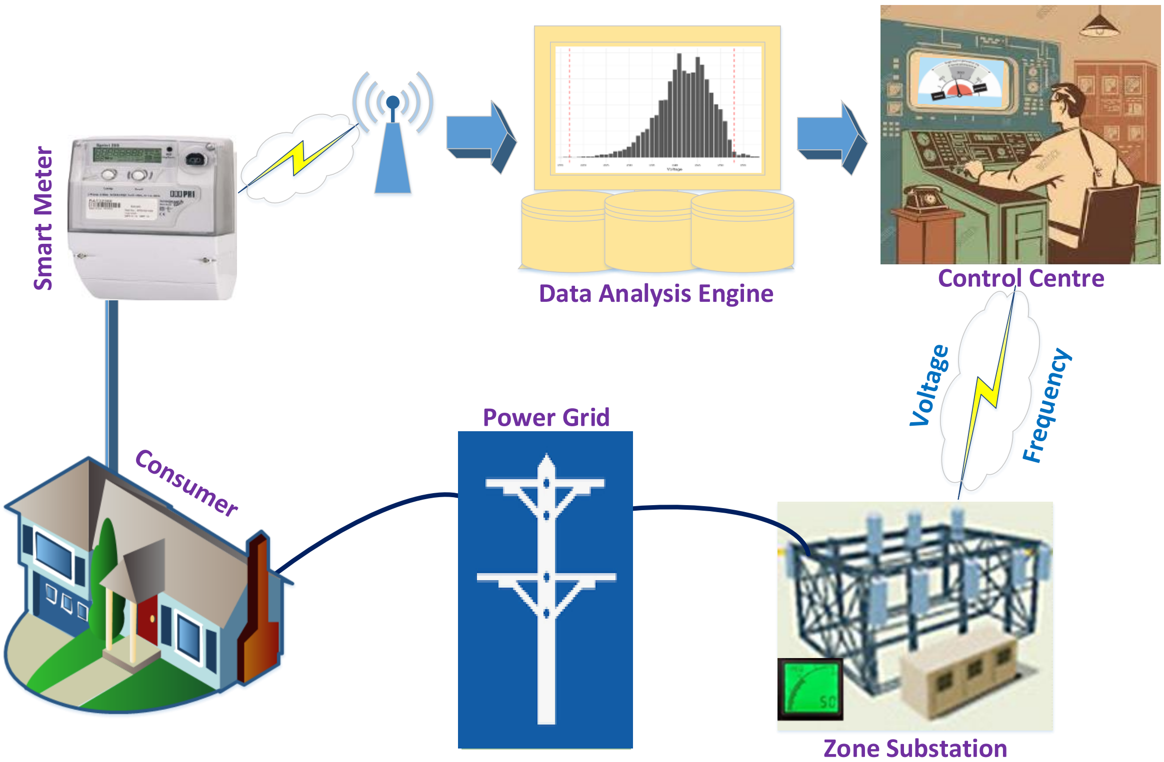

Figure 1: United Energy's Voltage-Controlled Frequency Regulation System

UE intends to deliver the FCAS capability through the use of automatic, remote-controlled, voltage control at 47 zone substations. This service will use the existing fleet of smart meters deployed across the distribution network to provide time-lagged customer voltage data from all connected smart meters to enable reductions (or increases) in voltage while maintaining voltage compliance during the FCAS event. UE will reduce/increase the voltage across the network to demonstrate 30MW and 1MW of Delayed Raise and Delayed Lower contingency FCAS within 5 minutes, respectively.

[1] Delayed Lower contingency FCAS will be delivered when DVMS is operating in Demand Response mode only as a proof of concept. The normal mode of operation will be to provide Delayed Raise contingency FCAS.

The diversification of this solution makes it highly reliable. The solution is diversified across 47 sites, meaning that an outage (planned/unplanned) of equipment or communications at any one site dilutes the total magnitude of the FCAS by only (1/47). Furthermore, as UE plans to continue to maintain voltages so as not to deteriorate compliance during an FCAS event, there is no requirement for UE to seek approval from customers to undertake such an FCAS dispatch. Therefore, every customer[2] within UE's service area will be participating and contributing to FCAS delivery without any impact in the way their equipment operates. This diversification of load contributes to a predictable and secure FCAS outcome. UE intends to use the high-frequency SCADA UE boundary metering to verify dispatch for settlement purposes.

Since the voltage reduction or increase is applied across all of UE's service area, with customers totalling more than 680,000 in number, customers from all sector types are contributing to the change in demand. While the demand change varies from customer to customer, UE has undertaken system tests (and will demonstrate through further system tests for ARENA and AEMO) that the aggregate demand change is sufficient to provide an average of 30MW of FCAS delivery during the event period.

DVMS utilises AS 61000.3.100 to regulate the voltage and deliver regulatory voltage compliance and demand response. A similar method will be deployed to deliver FCAS. When AEMO requires a "Delayed Raise", they seek to increase the supply of active power delivered into the system (MW), while in this situation UE can deliver the same service by lowering the amount of load consumed by customers (MW) by reducing the voltage level on the distribution network. The system is able to provide the FCAS service by switching between the two modes of operation (V99% and V1%) as shown in Figure 2.

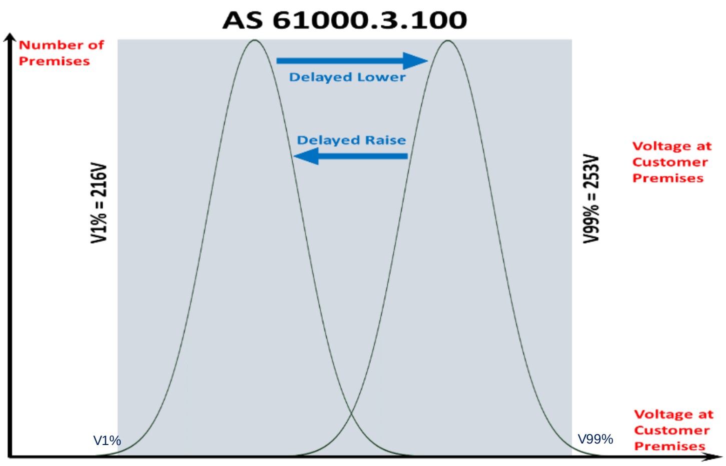

Figure 2: Method Employed in United Energy's Voltage-Controlled Frequency Regulation System

For more information about DVMS and how it is designed and operated, refer to UE's website.

[2] Except UE customers serviced by Ringwood Terminal Station 22kV and UE customers supplied by other DNSPs.

3. Technical Solution System Overview

During normal operation, voltages will be set to regulate to V99%. To deliver Delayed Raise contingency FCAS services, voltages will be toggled temporarily to regulate to V1% for a maximum of 10 minutes, with the full response delivered in less than 5 minutes. This is illustrated in Figure 3.

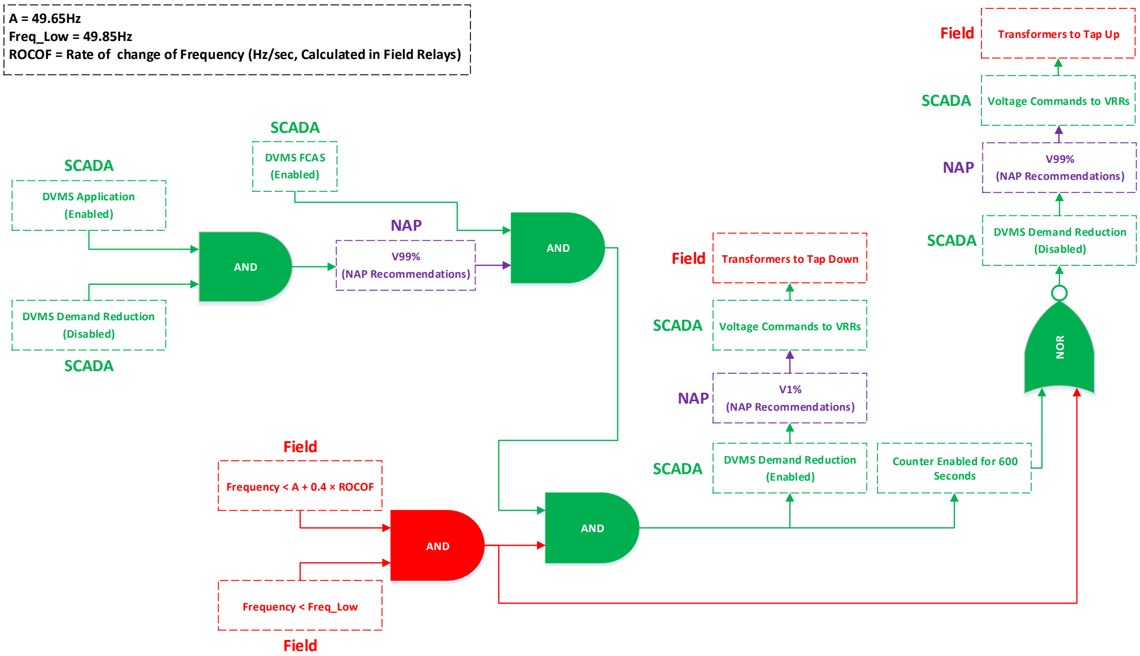

Figure 3: Algorithm for UE's Voltage-Controlled Frequency Regulation System for Delayed Raise Contingency FCAS Delivery

As a proof of concept for delivery of Delayed Lower contingency FCAS services, when DVMS operates in V1%, voltages will be toggled to V99% for a maximum 10 minutes as demonstrated in Figure 4.

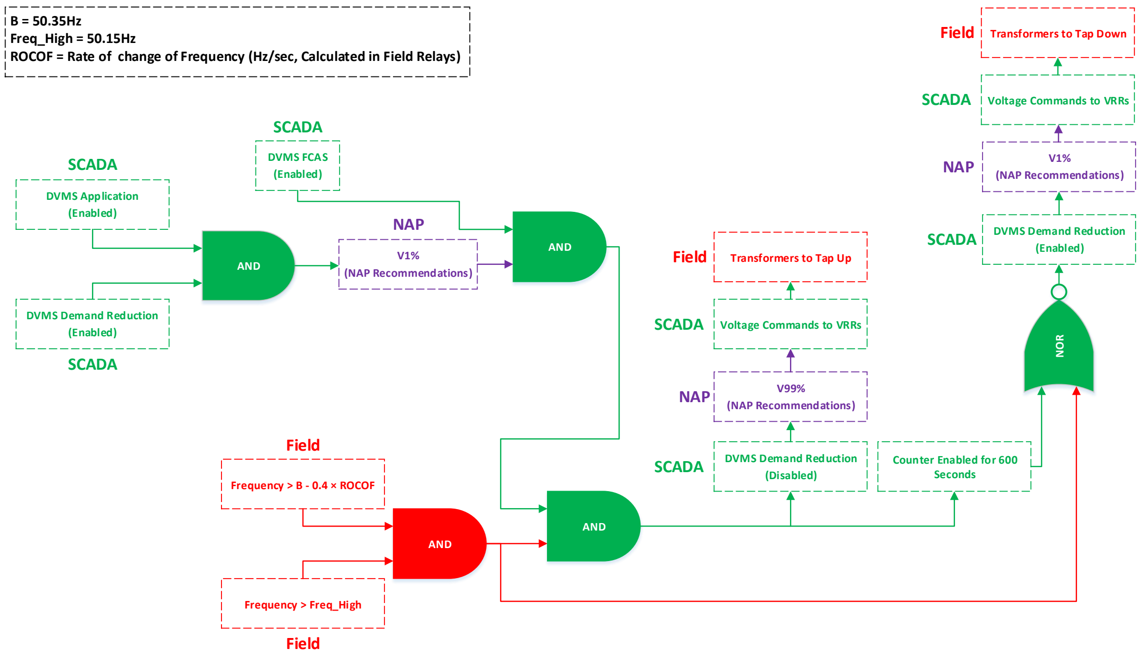

Figure 4: Algorithm for UE's Voltage-Controlled Frequency Regulation System for Delayed Lower Contingency FCAS Delivery

3.1. SCADA and NAP Enhancements

The current Network Analytics Platform (NAP) algorithm deployed for DVMS alters target set-points on zone substation transformers to vary network voltages on the distribution network and optimise the populations of smart meter voltage profiles. Two modes of operation currently exist – V99% for normal operation and V1% for demand response mode.

For this Project, an FCAS functional service is required within DVMS to now respond to both an AEMO dispatch/enable signal and the network frequency observed close to the nominal point of the aggregate system.

A scope of works has been developed to design and evaluate various control algorithms to meet the FCAS requirements. The high-level scope of works for DVMS enhancements is comprised as follows:

- Replace the SCADA to NAP connection with ICCP[3] and build the required monitoring and automation to improve the speed of the data transfer to NAP.
- Replace the NAP to SCADA connection via ICCP to avoid DVMS sending controls through a number of jump hosts, and enable faster control of new voltage set points to the field.
- Improve speed performance of the DVMS algorithm within NAP to shorten the time between when SCADA is toggled to Demand Reduction mode and when the transformers are at their lowest tap position.
- Modify code in NAP to allow for network abnormal configurations including transfer of feeder / parts of feeders to other zone substations and keep DVMS operational.
- Update the SCADA displays, controls and status points.
- Implement the above logics in the frequency sensing relays and SCADA.
- Develop documentation and operational protocols around the DVMS enhancements and FCAS.

As a distributed system, the Project requires development and modification of sub-system interfaces to interconnect components that deliver the FCAS services. Importantly the operation of the system needs to be harmonised with the rest of the operational systems (such as SCADA and DMS[4]) that support delivery of DNSP services by the business. Broadly speaking during a nominal FCAS dispatch period various operational processes would toggle the frequency control mode requiring operational systems to be informed of and adapt to the change of status.

The scope of works for SCADA enhancements has been developed for implementing the Project on the UE distribution network. It is planned to complete these works prior to the summer 2019/20 and they comprise of the following:

The current and proposed architecture for the interface between SCADA and NAP are given in Figure 5 and Figure 6.

[3] Inter-Control Centre Communications Protocol.
[4] Distribution Management System.

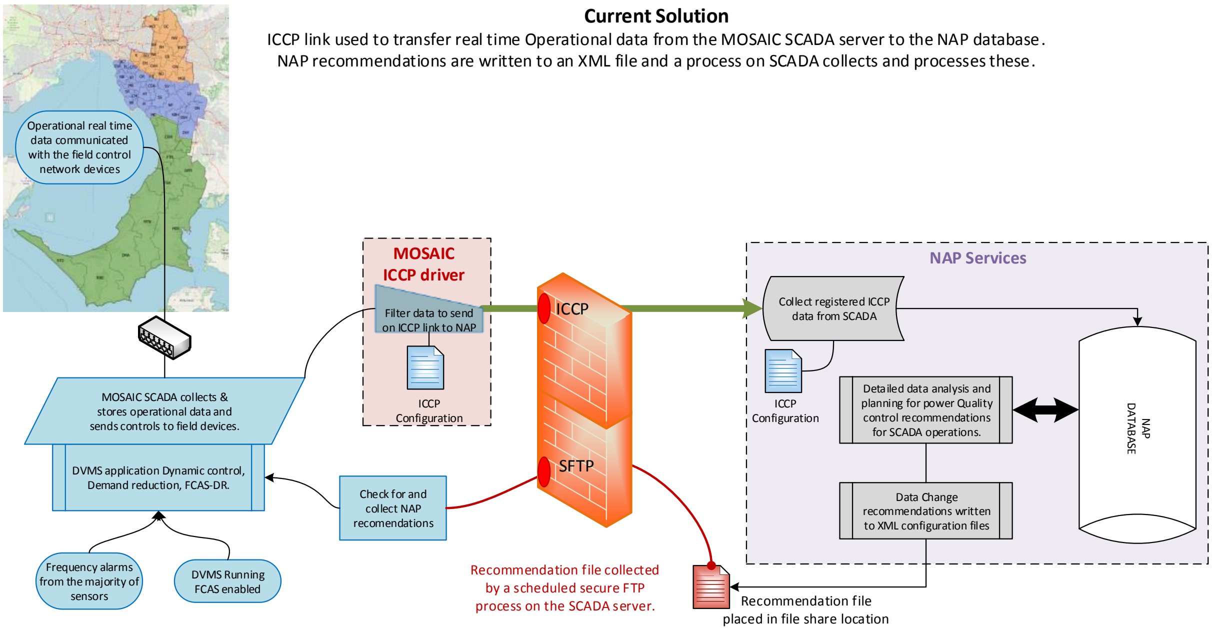

Figure 5: Current SCADA and NAP Interface for United Energy's Voltage-Controlled Frequency Regulation System

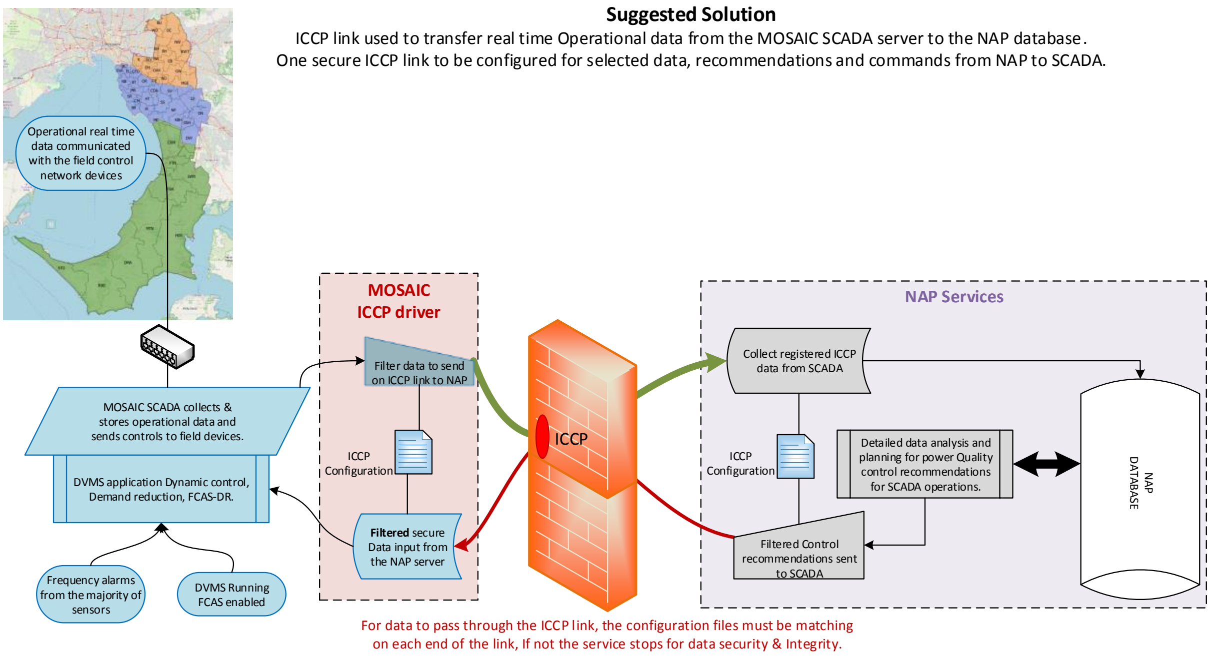

Figure 6: New SCADA and NAP Interface Proposed for United Energy's Voltage-Controlled Frequency Regulation System

3.2. Frequency sensing devices

After completing a detailed technical assessment, it was determined that the Schweitzer SEL-751A feeder protection relays are suitable to implement the functions below to meet AEMO's requirements for frequency (f) and rate of change of frequency (ROCOF) sensing in the field:

- **Delayed Raise Contingency FCAS Delivery:**
  - If Local Frequency (f) < 49.85Hz; and
  - Local Frequency (f) < Frequency Deviation Setting + Frequency Rate of Change Multiplier × Local Frequency rate of change (ROCOF)
- **Delayed Lower Contingency FCAS Delivery:**
  - If Local Frequency (f) > 50.15Hz; and
  - Local Frequency (f) > Frequency Deviation Setting + Frequency Rate of Change Multiplier × Local Frequency rate of change (ROCOF)

where:

- Frequency Deviation Setting is setting allocated within the range shown in Table 3 of the AEMO's "Market Ancillary Service Specification" (MASS) document. The values of Frequency Deviation Setting for the UE distribution network are 49.65Hz and 50.35Hz for Delayed Raise and Delayed Lower contingency FCAS, respectively.
- Frequency Rate of Change Multiplier is equal to the value in Table 3 of the AEMO's MASS which is 0.4 for regions other than Tasmania including UE's service area.
- Local Frequency rate of change is the measured rate of change of Local Frequency (ROCOF).

The above conditions should be satisfied to either switch the "Delayed Raise"/"Delayed Lower" signals to "Armed" state in MOSAIC SCADA and consequently deliver this contingency FCAS.

Figure 7 shows the proposed SEL-751A feeder protection relay for the Project's implementation.

Figure 7: SEL-751A Relay to be deployed for UE's Voltage-Controlled Frequency Regulation System

It is planned to install 6 × SEL-751A feeder protection relays to sense frequency and ROCOF in different locations of the UE distribution network. Prior to installation of these relays in the field, UE intends to conduct proof-of-concept testing in the Burwood laboratory to ensure these relays would have all of the required functionalities to monitor and record frequency and ROCOF as per the AEMO technical specifications. It is also planned to conduct end-end test from the relays to NAP via SCADA post installation.

3.3. Low-voltage opportunistic works

Opportunistic works have been identified across the UE distribution network to tighten up the distribution of voltages from the population of smart meters to assist in achieving the required FCAS response. These works can be categorised into the below groups:

- Adjusting the tap settings of distribution transformers;
- Balancing the load across phases along the low-voltage circuits;
- Checking and correcting any loose connections; and
- Relocating load connections across low-voltage open points.

UE has conducted an analysis on the performance of DVMS to date (since its commissioning in late 2018) to identify the zone substations whose distribution substations could be targeted for further low-voltage opportunistic works. Under this analysis, the voltage spread of smart meter voltages at the zone substation, number of available taps of the zone substation transformers, and the magnitude of maximum demand of the zone substations have been taken into consideration in the ranking of sites. As a result of this analysis, the zone substations with the widest voltage spread, the highest number of available transformer taps and the largest demand have been prioritised and summarised in Table 1. Implementing the LV opportunistic works at selected distribution transformers on these zone substations will maximums the benefits of these works in the field and improve performance outcomes.

Table 1: Impact of Low-Voltage Works on Voltage Spread (V99% minus V1%) of worst sites

Zone Substation	Peak Demand		Average Demand	
	Prior	Post	Prior	Post
Doncaster (DC)	39V	34V	21V	20V
East Burwood (EB)	39V	33V	21V	19V
Moorabbin (MR)	40V	36V	21V	20V
Nunawading (NW)	42V	37V	20V	19V
West Doncaster (WD)	36V	30V	21V	19V

The voltage profile changes of the selected zone substations at peak demand are illustrated below.

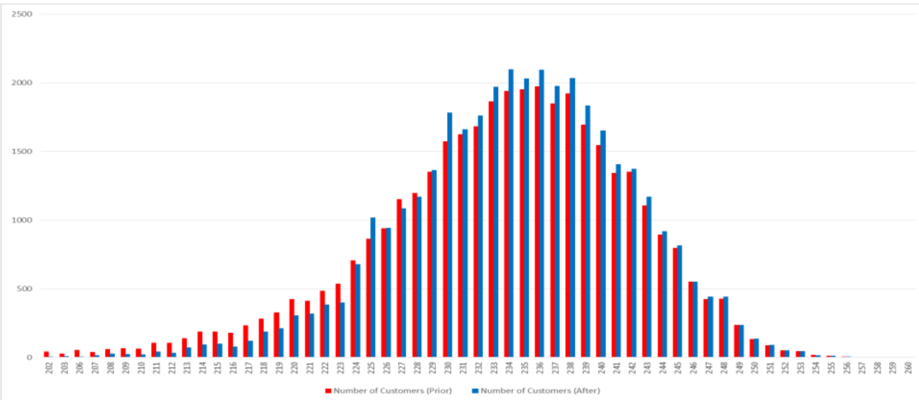

Figure 8: Peak Voltage Profile Prior and Post LV Works - DC

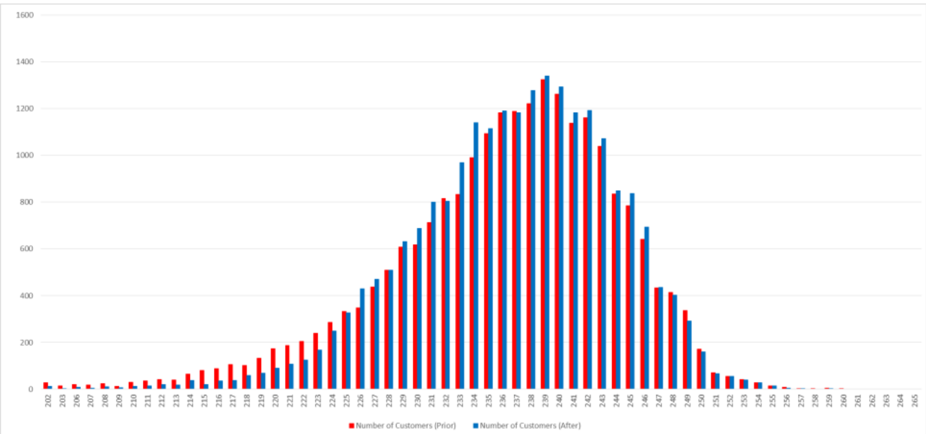

Figure 9: Peak Voltage Profile Prior and Post LV Works - EB

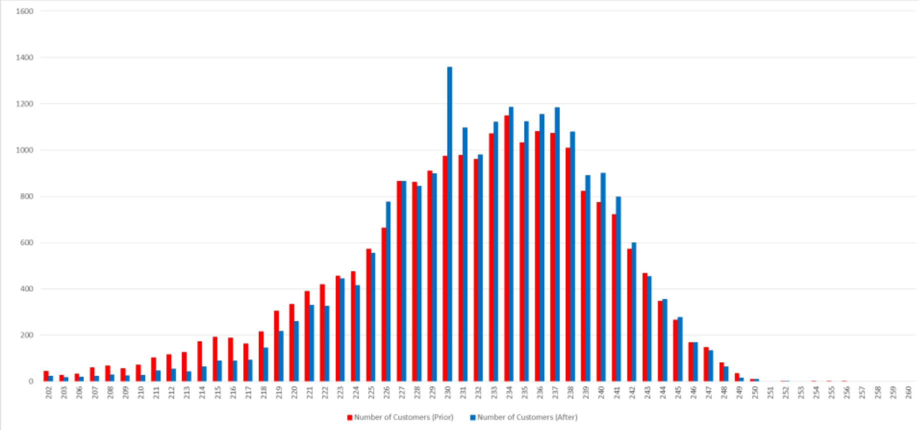

Figure 10: Peak Voltage Profile Prior and Post LV Works - MR

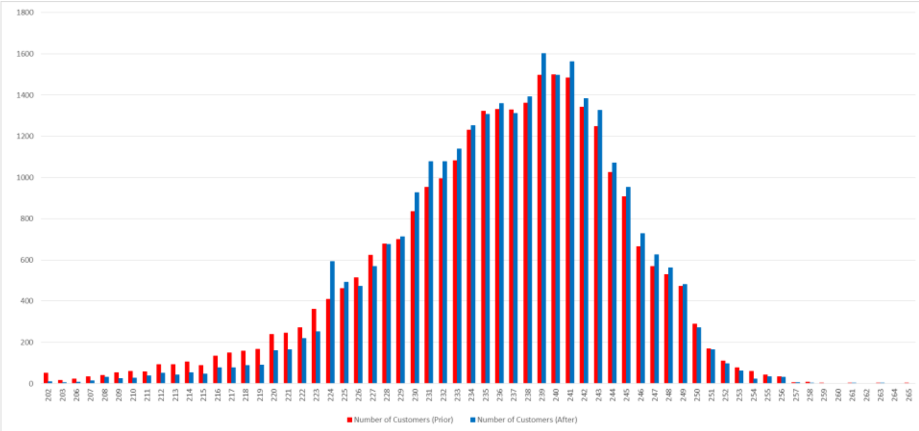

Figure 11: Peak Voltage Profile Prior and Post LV Works - NW

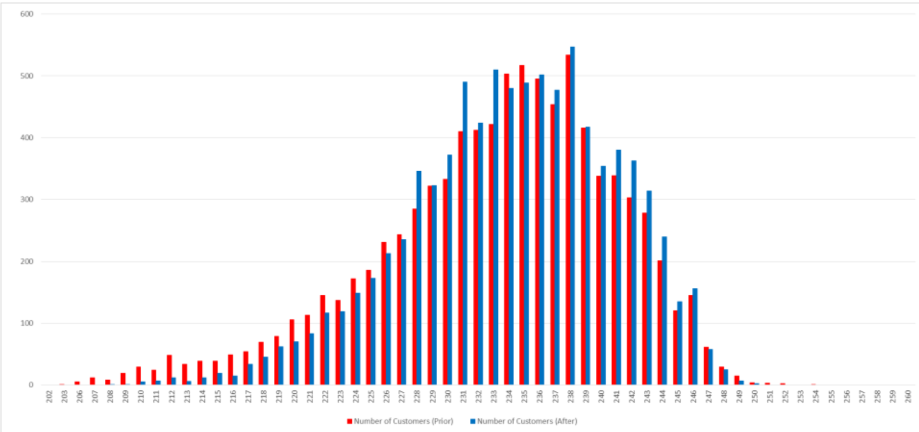

Figure 12: Peak Voltage Profile Prior and Post LV Works - WD

4. Regulatory Assessment

UE has undertaken a regulatory assessment that has concluded that the provision of FCAS by UE for this Project is not prohibited under the current regulatory framework and is entirely consistent with the Australian Energy Regulator's (AER) Ring-Fencing Guideline.

Previously we have participated in the Reliability and Emergency Reserve Trader (RERT) market and no issues were raised by AER or our auditors who recently completed our 2018 ring fencing audit. As observed on the 24th and 25th of January 2019, this participation by UE delivered significant value for customers at a time when the market was unable meet customers' electricity demand expectations.

Regarding the relevant sections of the Ring Fencing Guideline in the context of FCAS:

- Voltage control on the distribution network is a distribution service and the method under which UE is providing FCAS is by using voltage control – under the Guideline, distributors are permitted to provide distribution services.

- Functional separation provisions in the guideline (i.e. using separate staff and separate office locations to provide FCAS) do not apply. Functional separation does not apply to staff that cannot use information about the network or customers in an unfair, or discriminatory manner. At the time of providing FCAS we lower, and then monitor network voltage levels to ensure they stay within the requirements of the Electricity Distribution Code. This voltage information would not assist other FCAS providers, which either provide FCAS by generating more electricity or reducing their load. Hence the voltage information does not provide us with an unfair advantage over competitors.

- Branding restrictions apply – this would mean UE should not contract to provide FCAS under the 'United Energy' brand. The purpose of this restriction is to prevent distributors' (or their affiliates) from having an advantage in competitive markets by being associated with a regulated entity. This can be dealt with by one of three ways:

    - Seeking an appropriate service classification for FCAS during the AER's service classification process (currently underway), which would apply from 2021.

    - Seeking a waiver from the AER.

    - Reporting an immaterial breach – the only purchaser of the FCAS is AEMO, and AEMO is aware of all market participants' roles. It does not procure services based on misconceptions of affiliations. Hence, while this could be a technical breach of the guideline, it would not result in any market harm.

The AER has not disputed our position to date in our discussions with them around RERT or FCAS.

5. Business Case Assessment

There are eight markets in total, covering contingency and regulation FCAS. UE is intending to participate in the 'Delayed Raise' and demonstrate a proof of concept for 'Delayed Lower' (5 minute – R5M and L5M, respectively) contingency FCAS markets as part of the Project.

FCAS revenues have been forecast by using historical data and back-substituting different operating strategies into those data sets. It should be recognised that historical FCAS pricing may not be an accurate reflection of future pricing. The used data covers the period from 01/01/2017 to 30/11/2018 as shown in Figure 13.

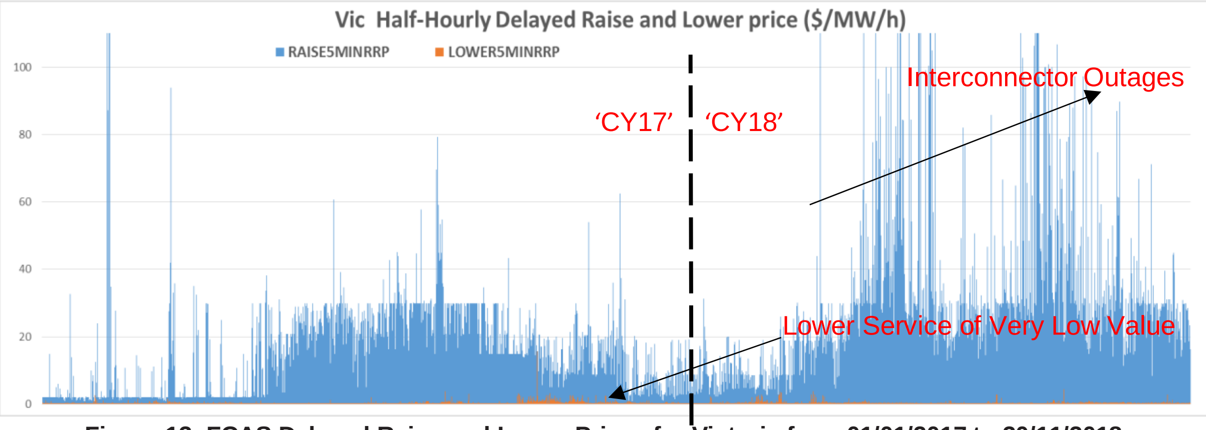

Figure 13: FCAS Delayed Raise and Lower Prices for Victoria from 01/01/2017 to 30/11/2018

The above data set shows that the "Delayed Raise" services generate revenues up to $100/MW/h for events whereas the "Delayed Lower" services are of very low value. To maximise the business case opportunity from using DVMS for FCAS services, the opportunity should focus on the provision of "Delayed Raise" services.

Detailed analysis of the above mentioned Victorian FCAS price data found that on average, the "Delayed Raise" (R5M) price was highest for the half-hour ending 19:00 (i.e. 7:00 pm or the 38th half-hour of the day), with the highest "Delayed Lower" (L5M) price occurring at 4:00 am on average. Instances of high prices during outage events were also noted (shown in $/MW/h):

- $1,293 (16:00 10/2/2017)
- $404 (10:30 07/6/2018)
- $240 (18:30 18/6/2018)
- $226 (18:00 19/6/2018)

This price data and the findings of the analysis forms a key input for the proposal and as such, a number of operating strategies were envisaged to generate revenue from the FCAS market to offset and minimise the additional costs of tap changer maintenance associated with providing the service, broadly ranging from being available at set times throughout the day to capturing morning and evening peak price periods or focusing on just the evening peak price periods.

UE's fleet of zone substation transformers (specifically the on-load tap changers) are ultimately the plant that delivers the increase or decrease of load. This is achieved by the fact that for much of UE's system demand, there is a direct relationship between changes in voltage and changes in demand. When the voltage is changed, so is the power consumed, typically with a ratio of 0.7%/%. The transformer on-load tap changers have a number of voltage set-points available, which was originally designed to maintain a constant voltage in response to load fluctuation throughout the day and system events. UE has taken this functionality a step further and facilitated a dynamic voltage change capability that can be harnessed for other purposes, by manipulating the system voltage (by relatively small amounts to remain within allowable limits).

The transformer on-load tap changers are mechanical devices whereby maintenance is proportional to the number of operations. Each time the voltage is altered by the tap changer, an "operation" is recorded. Whilst it varies between tap changer manufacturers, when a certain number of operations are reached, the unit must be withdrawn

from service and maintenance must be done. The number of operations will either increase or decrease the frequency of maintenance activity (more operations will cause more frequent maintenance).

By extension, this added functionality represents a limitation on the plant used to deliver FCAS and as such, UE's proposed operating strategy was limited to operating on average one time per day. The rationale behind the once-daily dispatch is to avoid too much extra duty on the transformer on-load tap changers. Given the fleet of on-load tap changers is diverse (i.e. different manufacturers and maintenance intervals), the maintenance intervals are set to cater for the fleet as a whole. Figure 14 shows the business-as-usual operations of on-load tap changers on the UE distribution network.

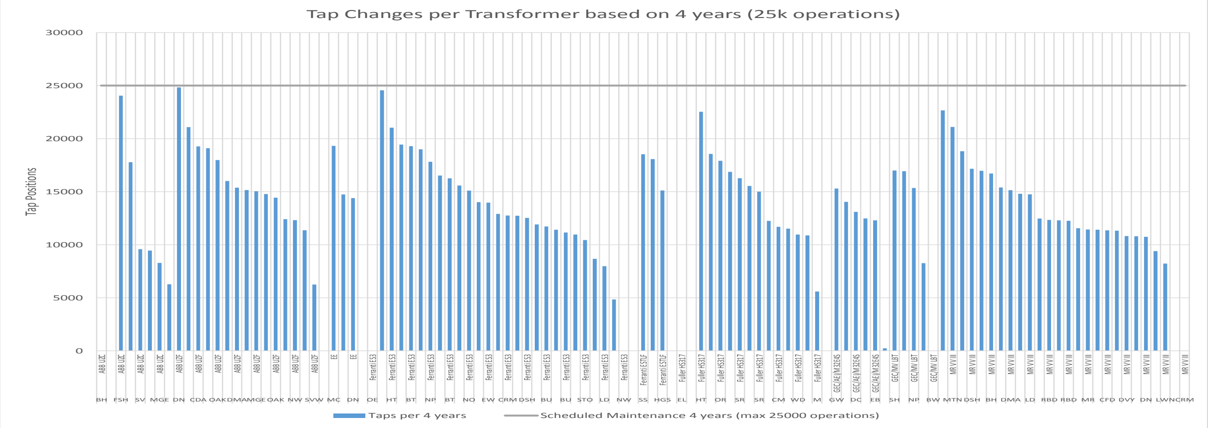

Figure 14: 'Business as Usual' Tap Changer Operations by Class

As such, there is a "headroom" of operations that UE can utilise (over and above those needed to maintain system voltage for business-as-usual) to deliver FCAS as shown in Figure 15.

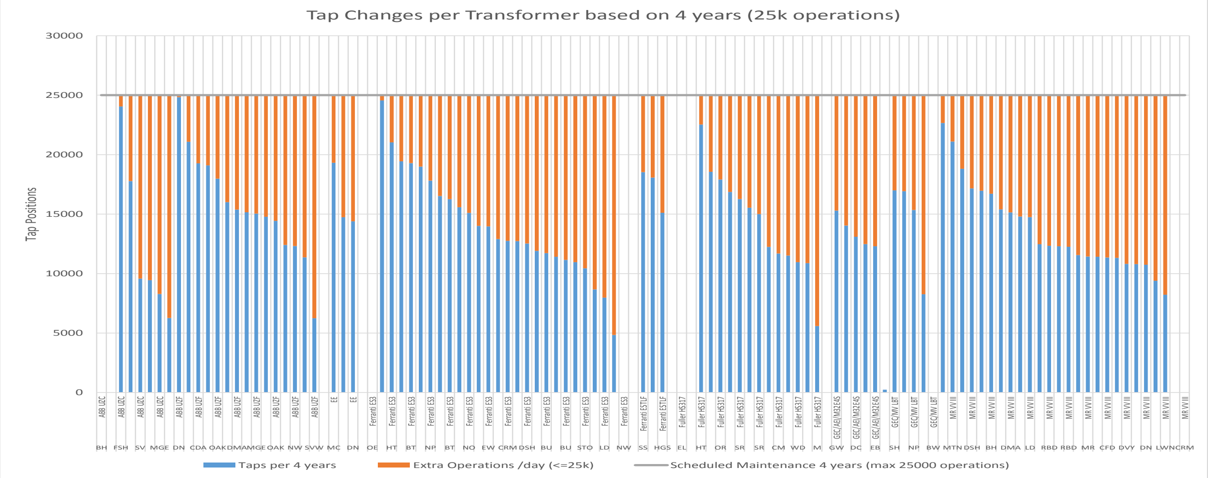

Figure 15: Extra Tap Changer Operations with Proposed FCAS Operating Strategy

UE's current knowledge and trials indicate that to change the load by 1MW, 9 operations of the tap changer(s) are required on average. By modelling the effect of the extra operations, UE concludes that it can deliver 30MW of FCAS raise whilst remaining within the headroom if this is done no more than once per day. Going beyond these limits would incur extra duty and have the impact of shortening the on-load tap changer maintenance cycle, thereby incurring extra maintenance costs.

Within these boundaries, two key strategies are used for forecasting purposes:

1. Enabling daily during one 30-minute period that typically (i.e. on average) sees high FCAS pricing- the half hour ending 19:00.
2. A best case scenario, where UE enables during (and captures with perfect foresight) each daily peak FCAS price during one 30 minute period.

In summary, the annual revenues from Figure 16 for FCAS services would have been equal to the values given in Table 2.

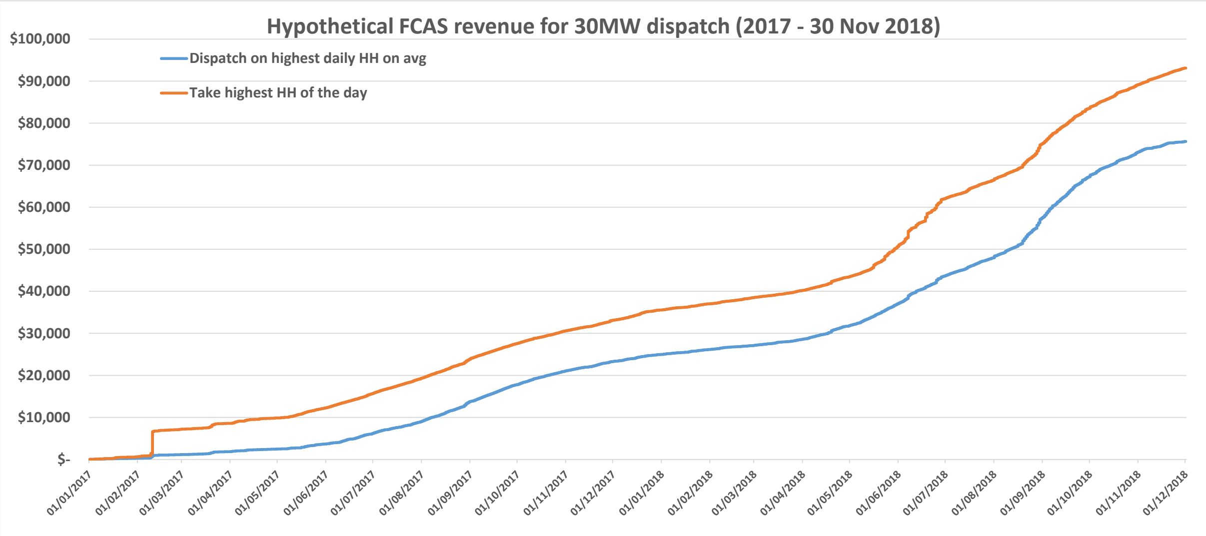

Figure 16: Results from Back-Substitution of Operating Strategies into Historical Data

Table 2: Revenue Summary from Back-Substitution of Operating Strategies into Historical Data

Year	Dispatch Strategy 1	Dispatch Strategy 2
2017	$25k	$36k
2018 (excl. December)	$51k	$58k

Note that the high price of February 10th 2017 is captured with strategy 2.

These revenues are achieved by UE acting as a “price-taker” and dispatching according to one of two strategies outlined above. It is assumed that with a capacity of 30MW, UE would not be a large enough player in the FCAS market to materially alter price outcomes – i.e. it is unlikely to be a “price-setter”. Thus it is also assumed that high prices could be foreseen (i.e. during AEMO’s pre-dispatch or via an appropriate bid) and a dispatch instruction completed accordingly.

The calculation of half-hourly revenue is therefore:

- Raise Revenue: (R5M Price x 30) / 6
- Lower Revenue: (L5M Price x 30) / 6

  Where the capacity available is 30MW and there are six five-minute dispatch intervals in the half-hour settlement period

The total revenue for the half-hour is the sum of the revenues for the raise and lower services.

In summary, the forecast takes into account the modelling of operating strategies with historical data. To this end, UE believes that in the best case with perfect foresight, an annual net revenue of $47k, could be earned using Strategy 2 (the average of the 2017 and 2018 historical revenue from Strategy 2 as shown in Table 2).

6. Lessons Learnt

Being at the commencement of the trial, there is much to learn during the trial not only about the performance of the technology solution, but also the business case needed to facilitate DNSPs using voltage control to provide FCAS services more broadly across the NEM on an ongoing basis. UE will be a unique participant in that it is a regulated network business and is likely to be the only participant in the market initially which does not have energy generating capacity.

FCAS prices are key to supporting participants in the FCAS market. Providing FCAS requires sufficient revenues to be able to offset the capital and operating cost associated with setting up and delivering the service. Furthermore for regulated network businesses like UE, the costs associated with FCAS cannot be passed through as standard control services, but must be entirely derived through the revenue generated from FCAS, noting that the capital costs for this particular trial is being funded by ARENA. Despite this, the advantage of DNSPs having much of the plant and equipment required to deliver FCAS already installed, such as tap changers, smart meters, analytics platforms, SCADA platforms, and voltage regulation relays, means that upfront capital costs can be reduced. The upfront costs are associated with the smart technology overlays and meeting AEMO's frequency metering, data collection and reporting requirements, which are unlikely to be significant. Furthermore the only likely non-administrative costs associated with operating the service is the additional tap changer duty maintenance, which again is unlikely to be significant. Introducing this new form of FCAS control technology has the potential to provide significant value to customers, if it can be delivered at a low cost.

The DVMS technology that underpins the UE FCAS solution has proven to deliver significant customer value outcomes already. These include:

- Delivering step change improvements in steady-state voltage compliance by dynamically adjusting voltages at zone substations using voltage feedback from customers' smart meters. This has value for customers in terms of improved customer appliance and equipment life;
- Delivers demand response services to the NEM via RERT using voltage reduction. This capability delivered value for customers on the 24th and 25th of January 2019 where it was activated to avoid customer supply interruptions for generation shortfalls; and
- Allows higher penetrations of customer solar photovoltaic (PV) systems to be connected to the distribution network by automatically and dynamically varying voltages in response to variations in solar PV output. This has significantly reduced customer complaints around inverter tripping, avoided expensive network upgrades, and allowed UE to maintain the generous 10kW per phase export limit on automatic connections. This is despite a doubling of the rate of new solar PV connections observed in the last year triggered by the Victorian Solar Homes rebate program. This means that more than 99% of solar PV systems are not export limited when connecting to UE's network

FCAS is likely to be another benefit of this technology, and will be demonstrated by this Project.

7. Glossary of Terms

The following terms are referenced within this document:

Term	Description
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
AMI	Advanced Metering Infrastructure (Smart Meters)
ARENA	Australian Renewable Energy Agency
DVMS	Dynamic Voltage Management System
FCAS	Frequency Control Ancillary Service
HV	High Voltage
ICCP	Inter-Control Centre Communications Protocol
IED	Intelligent Electronic Device
LV	Low Voltage
MASS	Market Ancillary Service Specification
NAP	Network Analytics Platform
NCC	Network Control Centre
NEM	National Electricity Market
OLTC	On-Load Tap Changer
RERT	Reliability and Emergency Reserve Trader
ROCOF	Rate of Change of Frequency
SCADA	Supervisory Control and Data Acquisition
UE	United Energy