United Energy Demand Response Project Performance Report - Milestone 7

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1. Summary

This document is the United Energy Demand Response Project Performance Report for the ARENA Advancing Renewables Programme – Demand Response programme (RB006). It fulfils an obligation under the Knowledge Sharing Plan to provide an update on the status of the delivery of the Dynamic Voltage Management System (DVMS) rollout project including sharing of results and lessons learnt.

This report documents the major achievements of the project since the release of the last milestone report. These achievements include completion of:-

1) AEMO tests to confirm United Energy's demand response reserve capability for the last period;
2) Summary of issues and their resolutions identified during installation and operation of the DVMS; and
3) Knowledge sharing activities relating to the findings of the project during the period.

To minimise duplication of content, this report should be read as a continuation of the milestone 1, 2, 3, 4, 5 and 6 reports.

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. Testing Demand Response Reserve Capability

United Energy (UE) undertook a summer 2019 period demand response test with AEMO. The objectives of the tests were to i) confirm UE's demand response reserve capability achieves the required 30MW for RERT, and ii) ensure the ITT (Invitation to Tender) and activation communication channels were operating correctly and acted on within the required period of time of 30 minutes and 10 minutes, respectively.

2.1. Seventh test – 26th November 2019

AEMO called a seventh test with UE on 26th November 2019 for a 2-hour period starting 1300 market time for a capability of 30MW.

Figure 1 shows the high-frequency sampling rate measurements of the total demand included in UE's demand response portfolio, before, during and after the test.

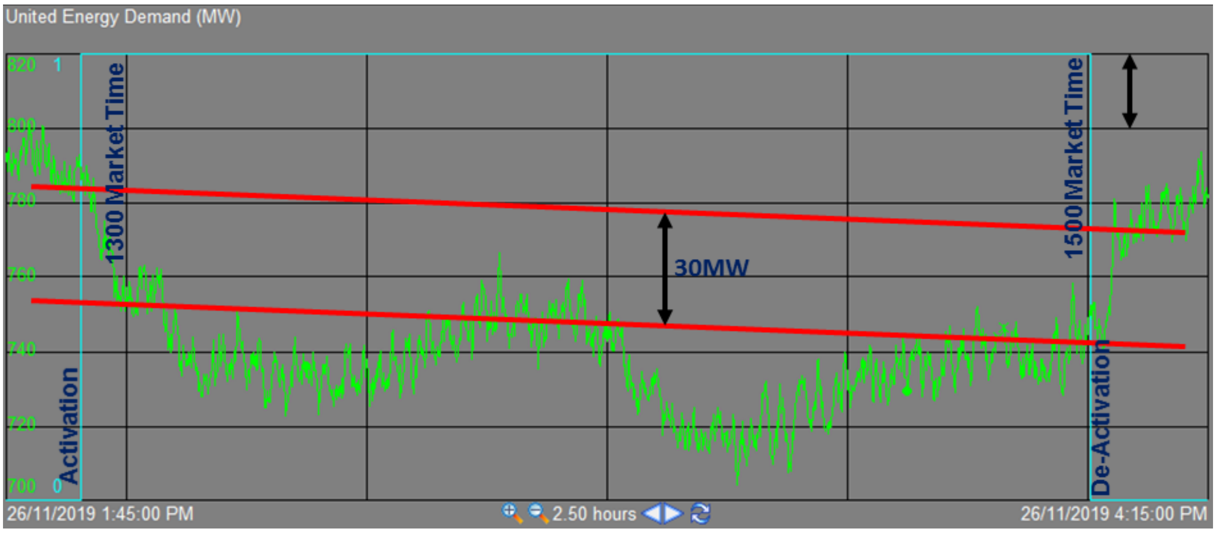


Figure 1 Test on 26th November 2019 showing demand response due to voltage reduction (2.5 hour window)

Activation of the demand response by way of voltage reduction is evident in the time before the event start date (1300 market time) with demand falling from 785MW at 1255 to around 755MW at 1300. Therefore, the coincident time demand reduction achieved in the first interval is 785MW – 755MW = 30MW. Subsequent intervals also achieved demand reductions of at least 30MW.

Deactivating the demand response was undertaken by restoring network voltages which occurred from 1500 market time with demand rising from 745MW at 1500 to around 775MW at 1505. Therefore, the coincident time demand reduction in the final period is 775MW – 745MW = 30MW.

In summary, high-speed SCADA measurements (presented above) provide evidence that UE delivered at least the required 30MW of demand response capability for all half-hour periods and that the communication process to receive and accept the ITT, and the subsequent activation of the demand response reserve capability have been successfully demonstrated.

Figure 2 illustrates the relativity of the demand response performance to the total demand levels on the UE network during the entire day on which the test was conducted.

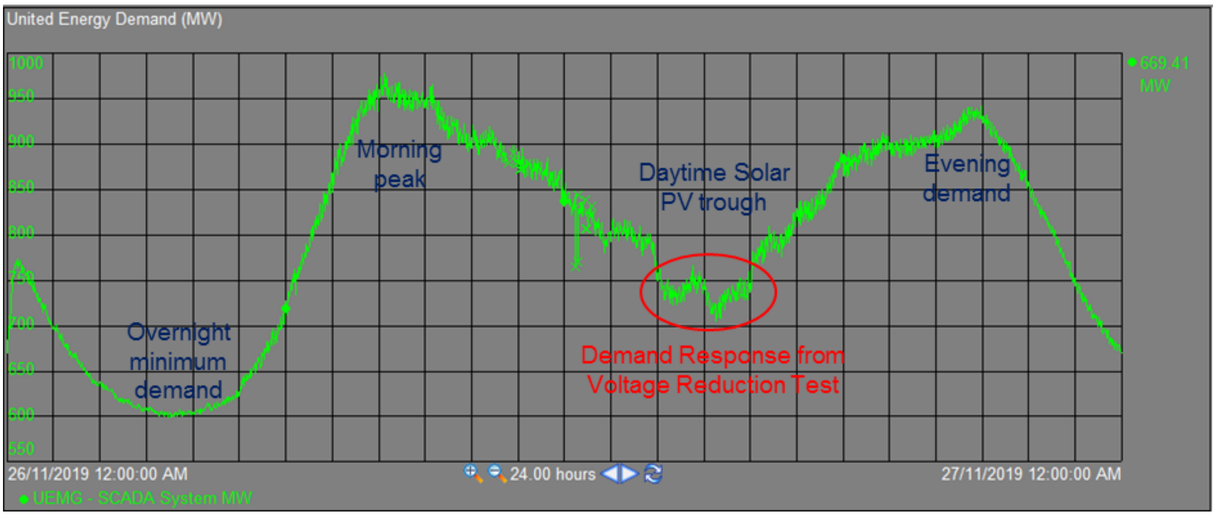


Figure 2 Test on 26th November 2019 showing demand response due to voltage reduction (24 hour window)

3. Lessons Learnt from Field Works

To implement the DVMS project, a technical scope of works was developed to upgrade (existing DR-T3 to new DR-E3) or install new (A. Eberle REG-D) voltage regulation relays (VRRs) at all zone substations (total 47) within the UE distribution network, and to configure the SCADA communications to achieve the DVMS functionality.

The below sections summarise the issues which were identified and rectified/being rectified during the commissioning and operation of the DVMS at different zone substations. It should be noted that this milestone report includes the major issues only.

3.1. Over-voltage alarms generated by zone substation bus supervision relays

Traditionally, on hot days when the demand on the network increases, some customers in particular the ones located at end of the low-voltage (LV) circuits receive under-voltages due to the voltage drop along the supplying circuits. As a result, the DVMS using the feedback from all AMI meters supplied by the zone substation will send a command to select a higher voltage set-point of the VRRs at the zone substation.

This results in selecting the highest voltage set-point by the DVMS for majority of 11kV and 6.6kV zone substations. The highest voltage set-points, Dynamic Voltage Level 1, for 11kV and 6.6kV zone substations are set to 11.66kV (11kV +6%) and 7.00kV (6.6 +6%), respectively.

Whenever a 11kV or 6.6kV zone substation is operating at Dynamic Voltage Level 1, bus over-voltage alarms are likely to be triggered because of the combined effects of:

- Voltage regulation bandwidth (typically 1%);
- Phase unbalances (typically 0.5%);
- Measurement accuracy of bus supervision relays (typically 0.5%); and
- Measurement discrepancies between the two or three low-tension bus voltage transformers (VTs) (typically 0.5%).

Hence, this caused a larger number of over-voltage alarms received during the 2018/9 summer. These nuisance alarms caused inconvenience and confusion for the Network Control Centre (NCC) and needed to be minimised.

Proposed solution

Prior to implementing the DVMS, the over-voltage settings of bus supervision relays for 11kV and 6.6kV zone substations were set to +6% of float voltage setting rather than +7% of the nominal voltage as summarised in Table 1.

Table 1: Over-voltage settings of bus supervision relays

Zone Substation	Prior to DVMS		Post DVMS		
	Float Voltage	Bus Supervision OV Set-Point	Float Voltage	Existing Supervision OV Set-Point	Proposed Supervision OV Set-Point
Beaumaris (BR)	11.40kV	12.08kV	11.44kV	11.77kV	12.00kV
Bentleigh (BT)	11.65kV	12.35kV	11.44kV	11.77kV	12.00kV
Bulleen (BU)	11.30kV	11.98kV	11.20kV	11.77kV	12.00kV

Zone Substation	Prior to DVMS		Post DVMS		
	Float Voltage	Bus Supervision OV Set-Point	Float Voltage	Existing Supervision OV Set-Point	Proposed Supervision OV Set-Point
Burwood (BW)	11.32kV	12.00kV	11.22kV	11.77kV	12.00kV
Caulfield (CFD)	11.50kV	12.19kV	11.28kV	11.77kV	12.00kV
Cheltenham (CM)	11.50kV	12.19kV	11.35kV	11.77kV	12.00kV
Elsternwick (EL)	11.30kV	11.98kV	11.26kV	11.77kV	12.00kV
East Malvern (EM)	11.36kV	12.04kV	11.24kV	11.77kV	12.00kV
Elwood (EW)	11.35kV	12.03kV	11.30kV	11.77kV	12.00kV
Gardiner (K)	11.50kV	12.19kV	11.44kV	11.77kV	12.00kV
Mentone (M)	11.15kV	11.82kV	11.10kV	11.77kV	12.00kV
Moorabbin (MR)	11.40kV	12.08kV	11.24kV	11.77kV	12.00kV
North Brighton (NB)	11.50kV	12.19kV	11.44kV	11.77kV	12.00kV
Oakleigh (OAK)	11.44kV	12.13kV	11.30kV	11.77kV	12.00kV
Oakleigh East (OE)	11.44kV	12.13kV	11.24kV	11.77kV	12.00kV
Ormond (OR)	11.50kV	12.19kV	11.44kV	11.77kV	12.00kV
Surrey Hills (SH)	6.92kV	7.26kV	6.88kV	7.06kV	7.26kV
Sandringham (SR)	11.60kV	12.30kV	11.45kV	11.77kV	12.00kV
West Doncaster (WD)	11.50kV	12.19kV	11.35kV	11.77kV	12.00kV

Since the overwhelming majority of the 11kV zone substations had had voltage regulation set-points (float voltages) greater than 11.31kV prior to the DVMS, therefore it was proposed to relax the over-voltage supervision set-point to +9% of the nominal voltage which would be 12kV. The proposed over-voltage set-point of 12kV was no higher than the previous values. The only exceptions were BU, EL and M zone substations, which would see slight increase in over-voltage set-points.

For the 6.6kV zone substation (SH) it was proposed to deploy the over-voltage set-point of 7.26kV which had previously applied to the bus supervision relays. This set-point is equal to 10% of the nominal voltage of 6.6kV.

Relaxing the over-voltage supervision set-points to +9% (for the 11kV zone substations) and 10% (for the 6.6kV zone substation) has resulted in reducing most, if not all, the nuisance over-voltage alarms that have been received on hot days.

3.2. Loss of ancillary power supply at zone substation

After conducting demand reduction test on North Brighton zone substation (NB), both station normal and standby supply phase failure relays tripped due to selecting a low voltage set-point by the DVMS and the entire station service ancillary power supplies went off supply. The first action taken for investigation of this issue was to check the tap positions of the station services transformers and also the settings of the station normal and standby supply phase failure relays. As a result of this investigation, it was decided to tap up both station services transformers by one tap (2.5% = 6.25V) to increase the voltage level supplied to the station normal and standby supply phase failure relays. However, this action did not prevent the relays from tripping when the DVMS was operating in demand reduction mode. As the next step, the applied settings to the station normal and standby supply phase failure relays were tested and one of the relays was found faulty which was replaced with a new one. In order to ensure operating the DVMS in demand response mode would not cause any relays tripping, the below instructions were proposed to be followed:

- Place the analog switch for Umax[V] at 260V for both normal and standby phase failure relays;
- Adjust the analog switch for Umin [%Umax] in such a way that both normal and standby phase failure relays operate at 216V with a tolerance of ±0.5V; and
- The other settings of the relays shall be remained unchanged.

Figure 3 shows the normal and standby supply phase failure relays installed at NB zone substation.

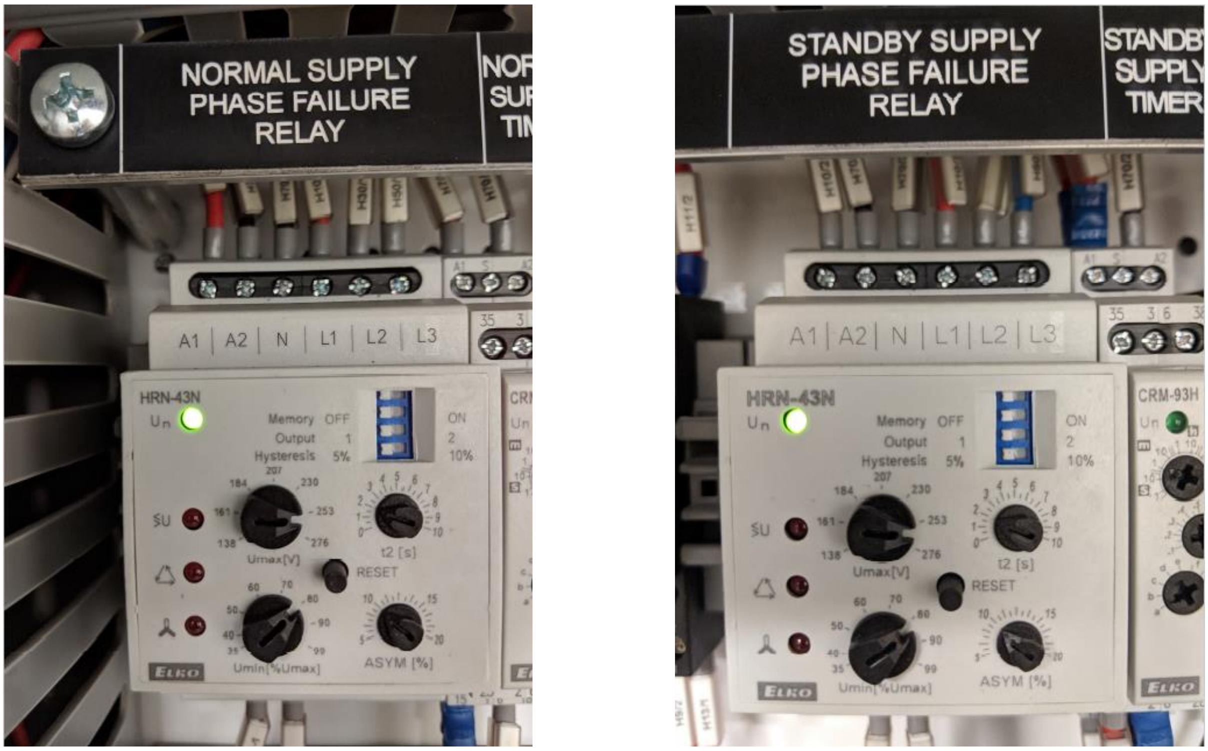


Figure 3 Normal and standby supply phase failure relays at Brighton zone substation (NB)

The proposed settings were successfully tested on the relays and since applying the new settings on the station normal and standby supply phase failure relays, operating the DVMS in demand reduction mode has not caused any issues for NB zone substation.

3.3. Over-voltage and under-voltage warning alarms

The NCC received a large number of voltage-related warning alarms for some zone substations when the DVMS was commissioned. These alarms were triggered on percentages above nominal voltages (±5%) rather than the previous float voltages. The warning alarms were problematic when the DVMS was switched off or operating during high-demand periods when the voltage on the network was boosted. Therefore, it was concluded that there was no value in using such alarms for a voltage that was well within the Victorian Electricity Distribution Code limits and the alarms were removed from SCADA. The SCADA over/under operating alarms are still operational.

Figure 4 shows some of the over-voltage warning alarms received by a zone substation prior to removing them from SCADA.

Notes	Field	System Date/Time	Description	State	Priority	Type	Categor	Originat	Area
	False	08/08/2018 21:23:43.000	#3 22/6.6kV Trans R-W Phase Voltage 6.94 kV [In Alarm List at 08/08/2018 21:23:43]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 21:20:43.146	#3 22/6.6kV Trans R-W Phase Voltage 6.94 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 19:52:07.293	#3 22/6.6kV Trans R-W Phase Voltage 7.03 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 19:52:05.280	#2 22/6.6kV Trans R-W Phase Voltage 7.03 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 17:46:07.040	#3 22/6.6kV Trans R-W Phase Voltage 7.01 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 17:45:18.518	#2 22/6.6kV Trans R-W Phase Voltage 7.00 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 15:16:32.000	#2 22/6.6kV Trans R-W Phase Voltage 6.98 kV [In Alarm List at 08/08/2018 15:16:32]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 15:13:32.408	#3 22/6.6kV Trans R-W Phase Voltage 7.00 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 15:13:32.408	#2 22/6.6kV Trans R-W Phase Voltage 6.98 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 14:39:48.000	#3 22/6.6kV Trans R-W Phase Voltage 6.98 kV [In Alarm List at 08/08/2018 14:39:48]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 14:39:36.000	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV [In Alarm List at 08/08/2018 14:39:36]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 14:36:48.614	#3 22/6.6kV Trans R-W Phase Voltage 6.98 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 14:36:36.506	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 12:09:04.825	#3 22/6.6kV Trans R-W Phase Voltage 7.02 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 12:08:46.382	#2 22/6.6kV Trans R-W Phase Voltage 6.96 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 11:06:47.927	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 09:05:41.000	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV [In Alarm List at 08/08/2018 09:05:41]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 09:05:39.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 08/08/2018 09:05:39]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 09:02:41.724	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 09:02:39.711	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 06:49:33.841	#3 22/6.6kV Trans R-W Phase Voltage 7.01 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 06:49:33.841	#2 22/6.6kV Trans R-W Phase Voltage 7.01 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 06:12:43.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 08/08/2018 06:12:43]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 06:09:43.259	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 05:06:48.000	#2 22/6.6kV Trans R-W Phase Voltage 6.94 kV [In Alarm List at 08/08/2018 05:06:48]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 05:06:46.000	#3 22/6.6kV Trans R-W Phase Voltage 6.94 kV [In Alarm List at 08/08/2018 05:06:46]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 05:03:48.720	#2 22/6.6kV Trans R-W Phase Voltage 6.94 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	08/08/2018 05:03:46.707	#3 22/6.6kV Trans R-W Phase Voltage 6.94 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 22:47:48.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 07/08/2018 22:47:48]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 22:44:48.883	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 20:02:40.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 07/08/2018 20:02:40]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 19:59:40.331	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 17:58:10.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 07/08/2018 17:58:10]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 17:55:10.207	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 17:22:52.000	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV [In Alarm List at 07/08/2018 17:22:52]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 17:19:52.432	#2 22/6.6kV Trans R-W Phase Voltage 6.95 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 11:59:36.960	#2 22/6.6kV Trans R-W Phase Voltage 7.03 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 07:11:42.758	#3 22/6.6kV Trans R-W Phase Voltage 6.99 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 07:11:42.758	#2 22/6.6kV Trans R-W Phase Voltage 7.00 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 06:52:24.419	#3 22/6.6kV Trans R-W Phase Voltage 6.98 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 06:50:43.546	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 05:13:58.000	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV [In Alarm List at 07/08/2018 05:13:58]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 05:13:53.000	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV [In Alarm List at 07/08/2018 05:13:53]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 05:10:58.082	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 05:10:54.057	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 04:42:21.422	#3 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	07/08/2018 04:42:21.422	#2 22/6.6kV Trans R-W Phase Voltage 6.97 kV	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	06/08/2018 22:36:41.000	#3 22/6.6kV Trans R-W Phase Voltage 6.94 kV [In Alarm List at 06/08/2018 22:36:41]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity
	False	06/08/2018 22:34:34.000	#2 22/6.6kV Trans R-W Phase Voltage 6.94 kV [In Alarm List at 06/08/2018 22:34:34]	Over Warning Limit	Analog Warning	alarmAbnormal	point	dataproc	Electricity

Figure 4 Numerous over-voltage warning alarms received post commissioning the DVMS in a UE's zone substation

3.4. Discrepancies on maximum transformer winding temperature readings

After upgrading the existing DRMCC-T3 with DR-E3 relays, it was noticed that some of the maximum transformer winding temperature readings for the zone substations did not match anymore and there was a high level of discrepancies between the values. Further investigation revealed that some default settings were applied to the

DR-E3 units instead of specific specifications of the transformers. Applying the transformer settings solved this issue.

Figure 5 shows the readings for maximum oil and winding temperatures of two zone substation transformers prior to and post implementing the DVMS. As this figure shows, there were some discrepancies after upgrading the DR-E3 relays. All of the identified reading discrepancies were resolved.

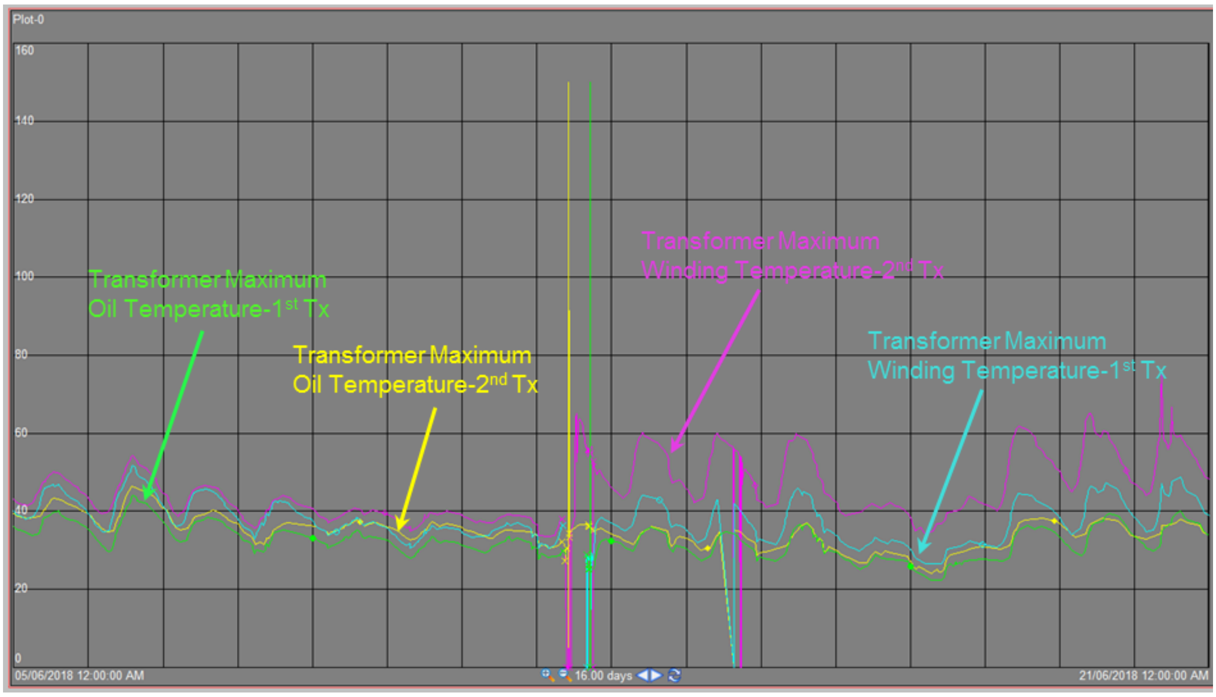


Figure 5 Readings for maximum oil and winding temperatures of two zone substation transformers prior to and post implementing the DVMS

The investigation outcomes on readings of maximum oil and winding temperatures for some other zone substation transformers are given in Section 7.

3.5. High-voltage customers complaints

Part of the DVMS trial in order to study the impact of dynamically regulating the voltage, in particular under-voltages, on high-voltage (HV) customers, all of the HV feeders supplied by Clarinda zone substation (CDA) were modelled in PSS/SINCAL as described in the milestone #2 report. According to the modelling results, in a peak demand day V_{sp7} (the lowest dynamic voltage set-point) was the only voltage-set-point that would cause under-voltages received by the HV customer. However, this voltage set-point is not defined for peak demand days. Therefore, it was concluded that rolling out the proposed dynamic voltage set-points onto the UE's zone substations would not cause any under-voltage issues for HV customers.

However, as a result of switching the DVMS from power quality mode to demand response mode during peak demand times, some HV customers contacted the NCC and informed UE that they received under-voltages and consequently, their protection devices either tripped or alarms. This occurred due to lack of UE's visibility on the supplying voltage levels to these customers given the absence of smart meters at these sites. While the DVMS takes the feedback from the AMI meters located adjacent to HV customers into account to generate voltage set-points for the supplying zone substation, some investigation were undertaken to ensure such HV customers would not receive any non-compliant voltages. After reviewing the voltage measurements captured by customers' monitoring devices, it was found that the received voltages were within the Code limits as shown in Figure 6.

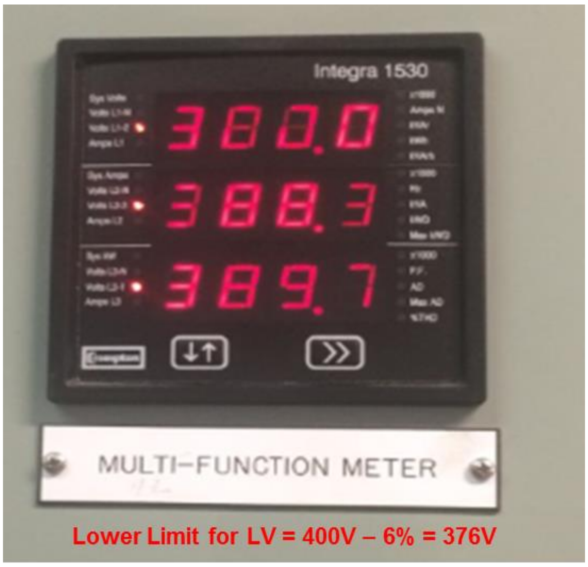


Figure 6 Voltage readings by HV customers' monitoring devices during demand reduction mode of UE's DVMS

Therefore, it was suggested to the impacted customers to revisit their protection settings and set them to alarm only when the voltage excursions go beyond the limits of the Victorian Electricity Distribution Code. Also, to assist those customers, some adjustments were applied onto the network analytics platform (NAP) voltage threshold settings (maximum and minimum). Since then, UE did not receive any customer complaints in this regard.

3.6. Excessive number of tap changes performed by zone substation transformers

It was noticed that the number of tap changes for some zone substations increased after commissioning the new relays under the DVMS rollout. After analysing the data, it was found that the number of tap changes did not match with the number of recommendations from the NAP which were generated to change the voltage set-points. Therefore, the field investigation commenced and it was revealed that this issue was on the contaminated OLTCs[1] contactors for the zone substations at which the VRRs have been replaced with A. Eberle REG-D units.

Some of these zone substations also received a large number of OLTC master control failed alarms. After analysing the relay logs, it was concluded that there was no general design issue and most likely the root cause of this issue would be the contaminated contacts of the tap changers. The initial plan was to clean the contacts of the OLTCs and monitor the results over a couple of weeks. This solution improved the situation and no or few number of OLTC master control failed alarms received after completing the maintenance. However, after a few weeks these alarms were raised again and also the number of tap changes were increased significantly.

Whilst the root cause could be traced to dirty wiper contacts at the OLTC to position resistance chain, it was noted that prior to installing A. Eberle REG-D relays, in many of the old VRR arrangements, a TPT-194 transducer was used to convert tap position resistance into 4-20mA used by the OLTC RTU[2].

One option of the TPT-194 was a 3-wire connection to the tap position resistor chain that had been the connection arrangement previously used at the question zone substations. This was in contrast to the recommended A. Eberle REG-D connection, where all possible connections only used two of the three terminals at the resistance chain. Another potential issue with the A. Eberle REG-D relay was that the output voltage was limited to 10V max, whereas the TPT-194 output voltage was 20V max or 50V max (depending on option chosen).

Therefore, it was proposed to trial the 3-wire connection of the TPT-194 at Sandringham zone substation (SR) in order to prove that this arrangement would give resultant measured voltage which was largely unaffected by the presence of wiper contact resistance. This transducer is shown in Figure 7.

[1] OLTC = On-Load Tap Changer.
[2] RTU = Remote Terminal Unit.

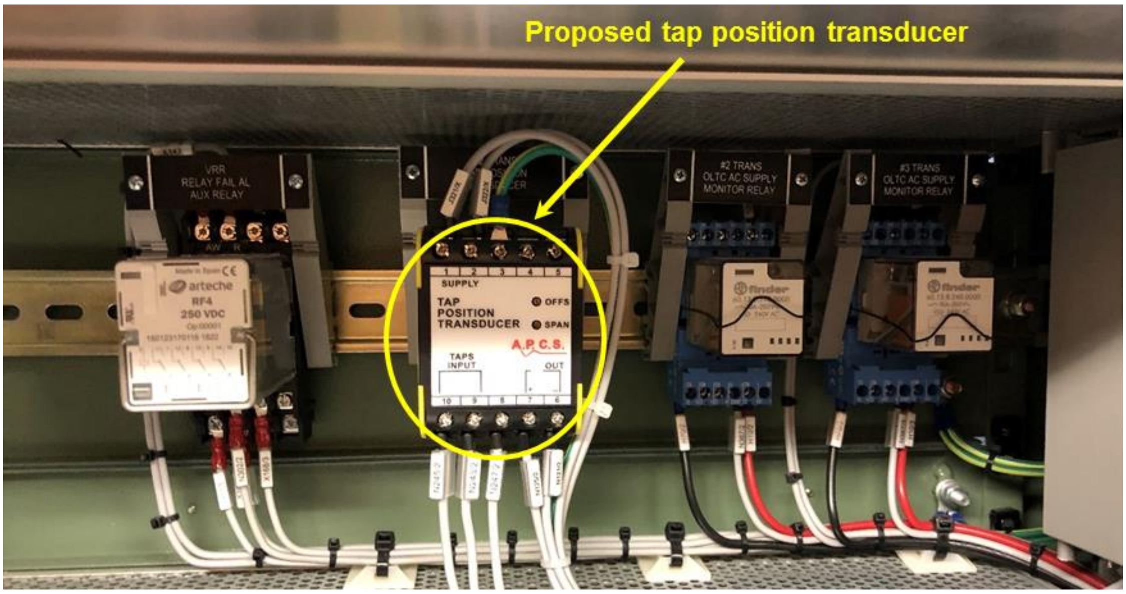


Figure 7 Tap position transducer proposed for zone substation with A. Eberle REG-D voltage-regulating relays installed

After trialling this arrangement, it was observed that the issues at SR zone substation were resolved. As a result, it is planned to implement this arrangement on the zone substations that experience excessive number of tap changes and also OLTC master control failed alarms.

Therefore, the following works have been proposed to address these issues:

- Upgrade the transformer tap position circuit via a transducer upgrade on the power transformers across the zone substations managed by the A. Eberle REG-D VRRs.
- The transducer needs to be A.P.C.S. type with the exact model to be selected by Service Provider as part of detailed design. Where a different transducer type is required, the Service Provider shall propose an alternative and seek endorsement from UE prior to proceeding with procurement and finalisation of the design. The upgraded tap position indicator (TPI) circuit shall be immune from electrical noise and not be susceptible to indicating incorrect/spurious/phantom/erroneous tap positions.

It is expected that by completing the above works, the numerous 'phantom' OLTC operations which in turn has flooded the NCC with 'out of step' and 'master control fail' alarms as well as driving unnecessary tap changes on the parallel transformers will be mitigated. These issues are generating costly fault callouts, more frequent maintenance of OLTC equipment as well as potentially limiting our ability to participate in the RERT events.

3.7. Zone substation transformer OLTC low-tension supply isolation

As part of the DVMS rollout project, majority of the zone substations which utilised legacy MD3311 OLTC RTU for low-tension bus voltage regulation were upgraded to a voltage regulation scheme based on A. Eberle REG-D relays.

In the previous MD3311-based voltage regulation scheme, an OLTC isolation switch was provided on the OLTC control panel in the control room for each transformer for the purposes of isolating the 400VAC and 230VAC supply into the OLTC mechanism box. The tap-change-in-progress (TCIP) contact in the OLTC mechanism box was wetted with AC supply. The OLTC isolation switch allowed the OLTC mechanism box to be safely isolated for maintenance works. The tap position resistor circuit was supplied at 20VDC or 50VDC (depending on the zone substation) and it was not isolated by the OLTC isolation switch. Figure 8 shows the OLTC isolation switches which were used by the legacy MD3311 OLTC RTUs.

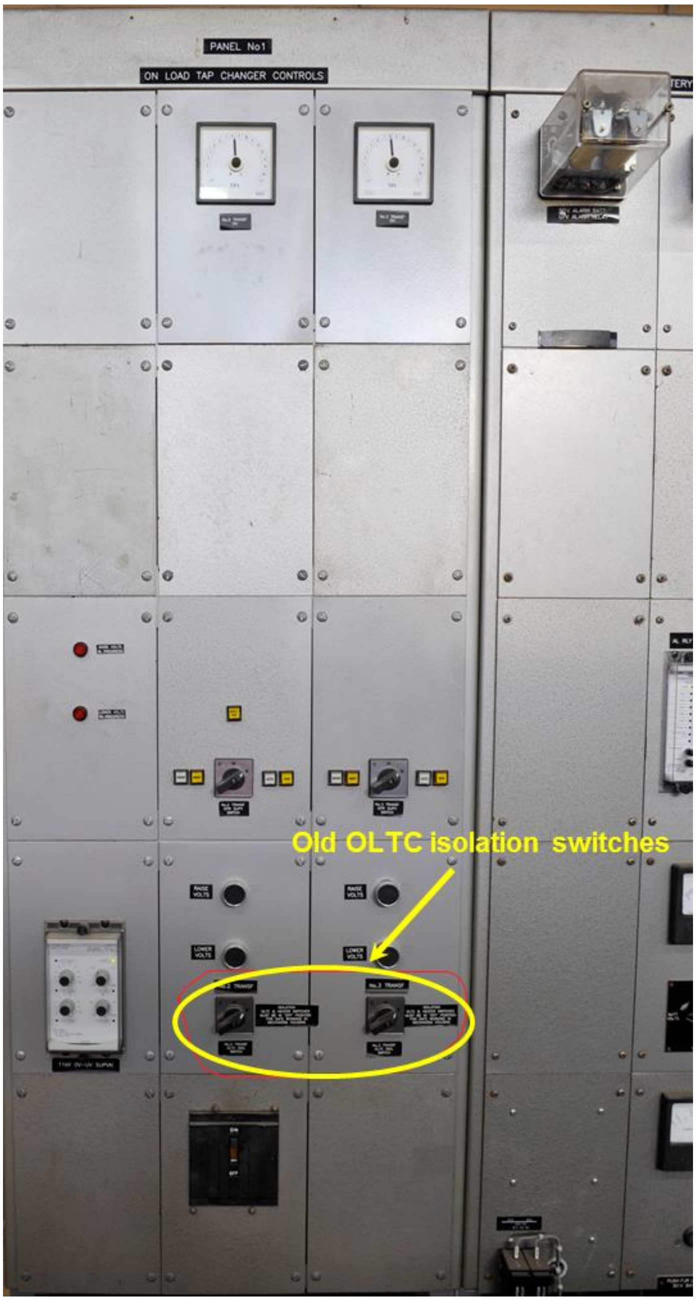


Figure 8 OLTC isolation switches utilised by legacy MD3311 OLTC RTUs

In the new A. Eberle REG-D-based voltage regulation scheme, an OLTC isolation switch is no longer provided. However, all 400VAC and 230VAC supply in the OLTC mechanism box can still be isolated via dedicated miniature circuit breakers (MCBs) either in the VRR cubicle or at the main 400VAC board. The TCIP contact is now wetted by the 110V or 240V station DC supply.

For safe isolation of the OLTC mechanism box, the agreed interim solution was to switch off the 110V/240 VDC MCB supplying the A. Eberle REG-D relay, which would also remove the DC wetting supply on the TCIP contact. Until the permanent solution is implemented, this interim procedure will be followed.

A consequence of switching off the supply to the A. Eberle relay was that other A. Eberle relays in the zone substation would switch from automatic to manual voltage regulation mode as they would see the A. Eberle REG-D relay was no longer communicating (i.e. ELAN error). This means that UE NCC would have to perform manual voltage control for other transformers still in service whilst maintenance was being carried out on one transformer.

This issue as well the ones described in Section 3.6 were costly to manage and could introduce risk of transformer failure as alarms and operations were less reliable and may be ignored. Therefore, UE has proposed to arrest these issues as far as reasonably practicable (AFAP) to ensure UE meets its regulatory obligations in the best interest of the business and customers. Therefore, the below works have been proposed for implementation:

- Installation of dedicated MCBs to provide a practical and safe means of VRR OLTC equipment DC circuit isolation issue for the impacted power transformer:
  - MCBs shall be selected for DC voltage and suitably rated for the application.
  - MCBs shall be graded with upstream circuit protection (either MCB or fuse).
  - For applications with the A. Eberle REG-D VRR, the MCB shall be located within the protection panel in the zone substation control room.
  - For applications with the Dynamic Ratings DR-E3 VRR (where required), the MCB shall be located within the protection cubicle mounted on the transformer.
  - Alternative locations for the new MCB may be required on a case by case basis but shall be discussed as part of the single-line diagram (SID) process and COM[3] review so as to ensure the intended requirements are met and all stakeholders are satisfied.
- Installation of dedicated panel mounted 'CB maintenance' switches to provide a simple and safe means for fitters and operators to isolate the circuit breaker status changes from the VRR scheme during circuit breaker maintenance. These switches are required at all zone substations on transformer incomer and bus-tie circuit breakers:
  - Switches shall be suitably rated for the application.
  - The switch shall be Santon type with the exact model to be selected by Service Provider as part of the detailed design process. Where a different switch type is proposed, the Service Provider shall seek endorsement from UE prior to proceeding with procurement and finalisation of the design.
  - For applications with the A. Eberle REG-D VRR, the switches shall be located on the protection panel in the zone substation control room.
  - For applications with the Dynamic Ratings DR-E3 VRR (where required), the switches shall be located within the protection cubicle mounted on the transformer.
  - Alternative locations for the new switches may be identified or deem more suitable on a case by case basis but shall be discussed as part of the SID process and COM review so as to ensure the intended requirements are met and all stakeholders are satisfied.
  - The status of these new switches shall not be provided to the NCC via SCADA.
  - Each new switch shall be labelled 'XXX CB Maintenance' where XXX shall be the circuit breaker designation, for example '#1 TR 22kV', '1-2 22kV BT', etc.
- A training package shall be developed by the Service Provider and presented to UE's incumbent faults/maintenance contractor such that fitters, operators, testers and other personnel understand the purpose and correct operation of the new MCBs and switches. Any relevant field procedures shall be updated.
- A similar awareness package shall be developed by the Service Provider and presented to UE's NCC and Asset Management staff.

The proposed MCB for OLTC isolation switch is shown in Figure 9.

[3] COM = Constructability, Operability & Maintainability.

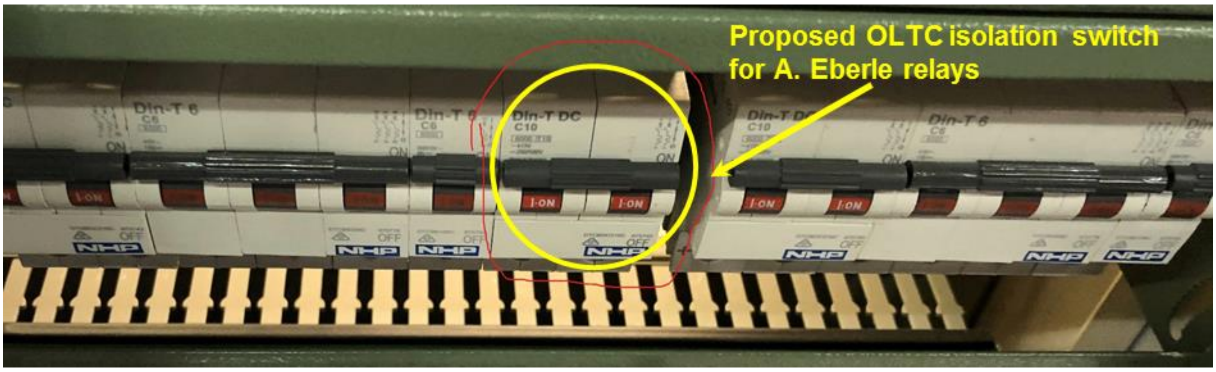


Figure 9 A miniature circuit breaker used as an OLTC isolation switch

3.8. Voltage hunting due to settings of circulating current operating mode

Further investigation on the excessive number of zone substation transformer tap changes revealed that the inverse time curve applied to the A. Eberle REG-D relays using circulating current mode was not well-suited (too fast) as shown in Figure 10. This operating mode is described in Section 8.

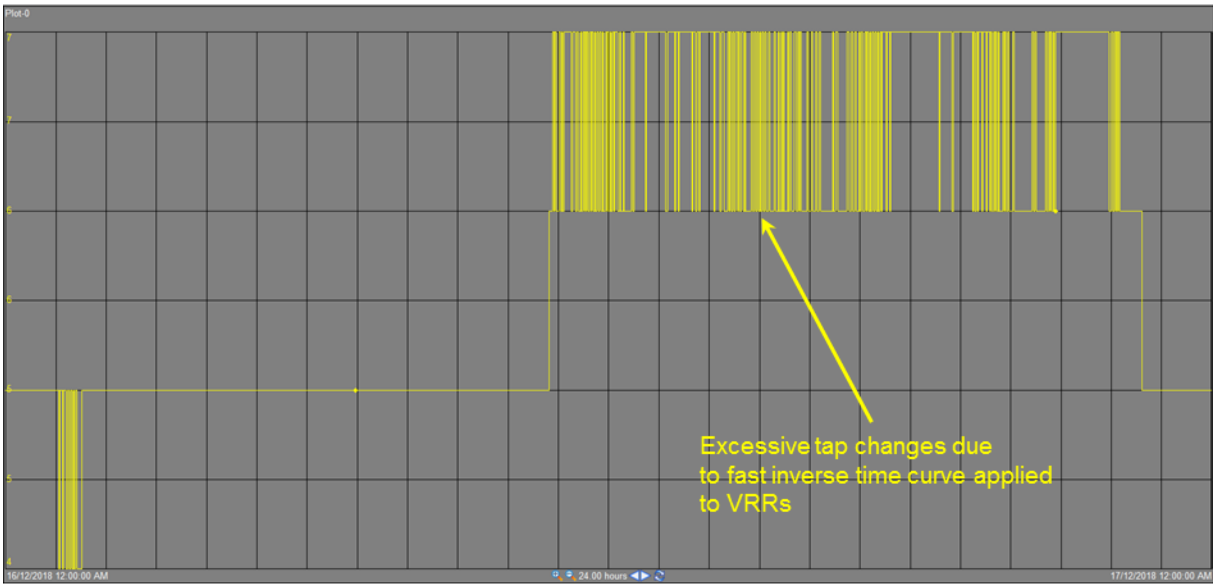


Figure 10 Excessive number of tap changes due to fast inverse time curve of circulating current operating mode of voltage regulating relays

After preliminary investigation, the project team decided to trial a slower curve at 4 zone substations. The trial outcomes confirmed reducing the frequency of tap changes as shown in Figure 11.

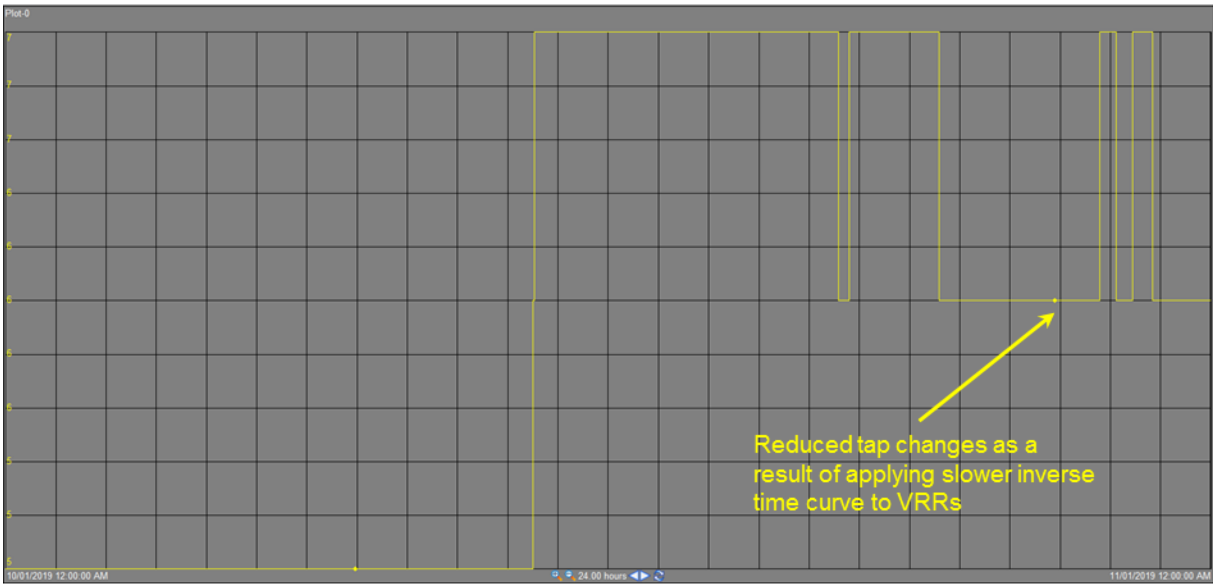


Figure 11 Reduced number of tap changes post applying slower inverse time curve onto voltage regulating relays operating in circulating current mode

Therefore, the new slow curve was implemented onto additional zone substations that were using circulating current mode. The modified settings for one of the transformers are given in detail in Section 9.

4. Impact of DVMS Operation on Life of On-Load Tap Changers

This section of the report evaluates the impact of dynamic voltage regulation on the lifetime of zone substation transformer OLTCs. In order to conduct this evaluation, the numbers of tap operations prior to (CY2017) and post (CY2019) implementation of the DVMS technology are taken into consideration.

Table 2 summarises the average daily number of tap operations for different zone substations in the 2017 and 2019 calendar years. The average daily numbers of tap operations for different months of these two years are given in Section 10.

Table 2: Average daily number of zone substation transformer tap changes prior to and post implementing the DVMS

ZSS	CY2017	CY2019	Change Rate
Beaumaris (BR)	10	11	7%
Bentleigh (BT)	11	11	2%
Box Hill (BH)	17	13	-26%
Bulleen (BU)	6	10	54%
BW (BW)	10	9	-13%
Carrum (CRM)	10	15	60%
Caulfield (CFD)	11	11	1%
Cheltenham (CM)	11	14	27%
Clarinda (CDA)	12	13	10%
Dandenong (DN)	12	19	55%
Dandenong South (DSH)	14	22	54%
Dandenong Valley (DVY)	11	17	51%
Doncaster (DC)	9	23	165%
Dromana (DMA)	13	14	3%
East Burwood (EB)	13	20	54%
East Malvern (EM)	11	9	-15%
Elsternwick (EL)	N/A	9	N/A
Elwood (EW)	12	11	-7%
Frankston (FTN)	15	15	0%

ZSS	CY2017	CY2019	Change Rate
Frankston South (FSH)	7	12	59%
Gardiner (K)	13	12	-9%
Glen Waverley (GW)	13	20	52%
Hastings (HGS)	10	17	74%
Heatherton (HT)	11	19	76%
Keysborough (KBH)	13	10	-20%
Langwarrin (LWN)	13	21	61%
Lyndale (LD)	16	18	13%
Mentone (M)	20	16	-20%
Moorabbin (MR)	17	19	15%
Mordialloc (MC)	15	10	-30%
Mornington (MTN)	14	32	132%
Mulgrave (MGE)	14	10	-27%
Noble Park (NP)	12	14	20%
North Brighton (NB)	12	22	76%
Notting Hill (NO)	10	11	5%
Nunawading (NW)	11	21	93%
Oakleigh (OAK)	10	19	82%
Oakleigh East (OE)	N/A	35	N/A
Ormond (OR)	10	15	55%
Rosebud (RBD)	20	17	-13%
Sandringham (SR)	10	21	99%
Sorrento (STO)	13	13	-2%
Springvale (SV)	11	18	56%
Springvale South (SS)	11	13	25%
Springvale West (SVW)	15	19	24%

ZSS	CY2017	CY2019	Change Rate
Surrey Hills (SH)	10	10	0%
West Doncaster (WD)	8	24	208%
AVERAGE	**12**	**16**	**32%**

According to Table 2, operation of the DVMS has resulted in additional tap operations by an average of 32%. This is mainly due to the impact of solar PV systems during day times at which the DVMS needs to change the voltage set-points at zone substations. The average daily tap operations are also demonstrated in a graphical format in Figure 12.

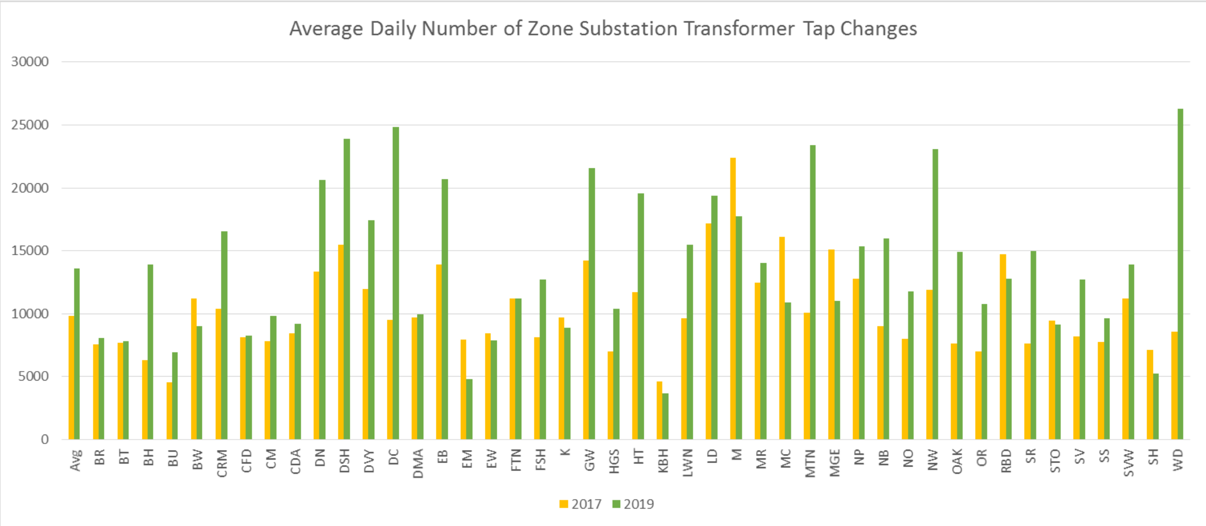


Figure 12 Average daily number of zone substation transformer tap changes prior to and post implementing the DVMS

It should be noted that UE is still resolving some of the issues related to the excessive number of tap changes and this has impacted the figures demonstrated in section.

In order to calculate the maintenance costs associated with additional number of tap changes due to the DVMS operation, the below assumptions are taken into consideration here. It should be noted that the below assessment is a high-level analysis and more detailed investigations need to be conducted to estimate the cost associated with the DVMS operation.

- Average number of tap changes for a zone substation transformer (without DVMS in service):

  25,000 per 4 years = > 6,250 (25,000/4) per year = > 17 (6,250/365) per day.

- Service cost associated with OLTC operation:

  $20,000 per 4 years = > $5,000 ($20,000/4) per year = > $14 ($5,000/365) per day.

- Maintenance cost for each tap operation:

  $0.80 ($14/17).

- Cost to replace a zone substation transformer[4]:

  $2.2m.

- Total number of tap changes for a zone substation transformer over its lifetime (without DVMS in service):

[4] NPV is not considered here.

500,000.

- Number of services for a zone substation transformer over its lifetime: 20 (500,000/25,000).
- Cost of each tap operation for a zone substation transformer over its lifetime: **$4.40** ($2.2m/500,000).
- Total cost estimated for each additional tap operation: **$5.20** ($0.80+$4.40).

Table 3 summarises the financial impact of the DVMS technology on zone substation transformers.

Table 3: Estimated financial impact of DVMS operation on zone substation transformers

ZSS	CY2017	CY2019	Estimated Additional Cost
Beaumaris (BR)	10	11	$1,898
Bentleigh (BT)	11	11	$0
Box Hill (BH)	17	13	-$7,592
Bulleen (BU)	6	10	$7,592
BW (BW)	10	9	-$1,898
Carrum (CRM)	10	15	$9,490
Caulfield (CFD)	11	11	$0
Cheltenham (CM)	11	14	$5,694
Clarinda (CDA)	12	13	$1,898
Dandenong (DN)	12	19	$13,286
Dandenong South (DSH)	14	22	$15,184
Dandenong Valley (DVY)	11	17	$11,388
Doncaster (DC)	9	23	$26,572
Dromana (DMA)	13	14	$1,898
East Burwood (EB)	13	20	$13,286
East Malvern (EM)	11	9	-$3,796
Elsternwick (EL)	N/A	9	N/A
Elwood (EW)	12	11	-$1,898
Frankston (FTN)	15	15	$0
Frankston South (FSH)	7	12	$9,490

ZSS	CY2017	CY2019	Estimated Additional Cost
Gardiner (K)	13	12	-$1,898
Glen Waverley (GW)	13	20	$13,286
Hastings (HGS)	10	17	$13,286
Heatherton (HT)	11	19	$15,184
Keysborough (KBH)	13	10	-$5,694
Langwarrin (LWN)	13	21	$15,184
Lyndale (LD)	16	18	$3,796
Mentone (M)	20	16	-$7,592
Moorabbin (MR)	17	19	$3,796
Mordialloc (MC)	15	10	-$9,490
Mornington (MTN)	14	32	$34,164
Mulgrave (MGE)	14	10	-$7,592
Noble Park (NP)	12	14	$3,796
North Brighton (NB)	12	22	$18,980
Notting Hill (NO)	10	11	$1,898
Nunawading (NW)	11	21	$18,980
Oakleigh (OAK)	10	19	$17,082
Oakleigh East (OE)	N/A	35	N/A
Ormond (OR)	10	15	$9,490
Rosebud (RBD)	20	17	-$5,694
Sandringham (SR)	10	21	$20,878
Sorrento (STO)	13	13	$0
Springvale (SV)	11	18	$13,286
Springvale South (SS)	11	13	$3,796
Springvale West (SVW)	15	19	$7,592
Surrey Hills (SH)	10	10	$0

ZSS	CY2017	CY2019	Estimated Additional Cost
West Doncaster (WD)	8	24	$30,368
TOTAL	**199,655**	**275,210**	**$309,374**

According to Table 3, an additional annual cost of $310k is estimated due to operating the DVMS. It should be noted that a number of factors contribute to this additional cost such as the age and type of OLTCs. For example, the associated tap operation cost for a transformer built in 1960 will be higher than that for a 2020 zone substation transformer.

5. Knowledge Sharing Activities

Since the last milestone report, UE has participated in the following events and shared the learnings of this project with the broader industry:

- ARENA Insights Forum in Melbourne on 21st November 2019.
- ARENA Year 2 Programme for DVMS Demand Response Workshop between Oakley Greenwood and UE on 17th January 2020.
- CitiPower/Powercor and UE Future Network Workshop – Enable a Network that Meets Customer's Needs on 6th March 2020.
- ARENA Demand Response Post-Summer Roundtable on 25th March 2020.
- Updated the knowledge sharing webpage on the UE website for the purposes of sharing our project performance reports and provided input into the ARENA knowledge sharing insights website content.

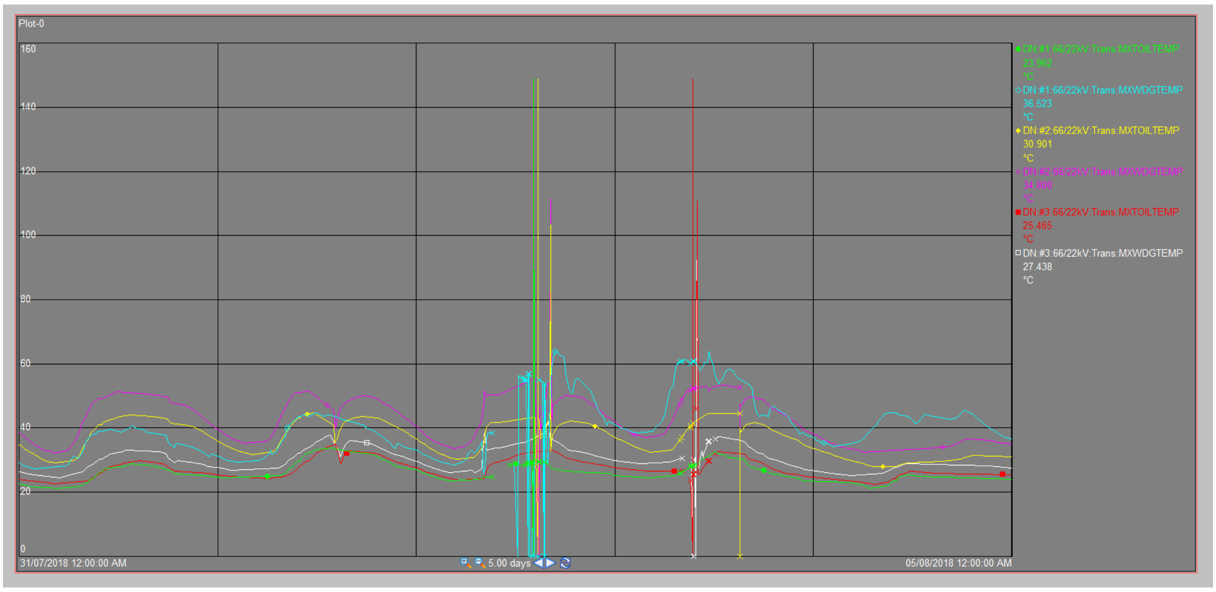
6. Glossary of Terms

The following terms are referenced within this document:

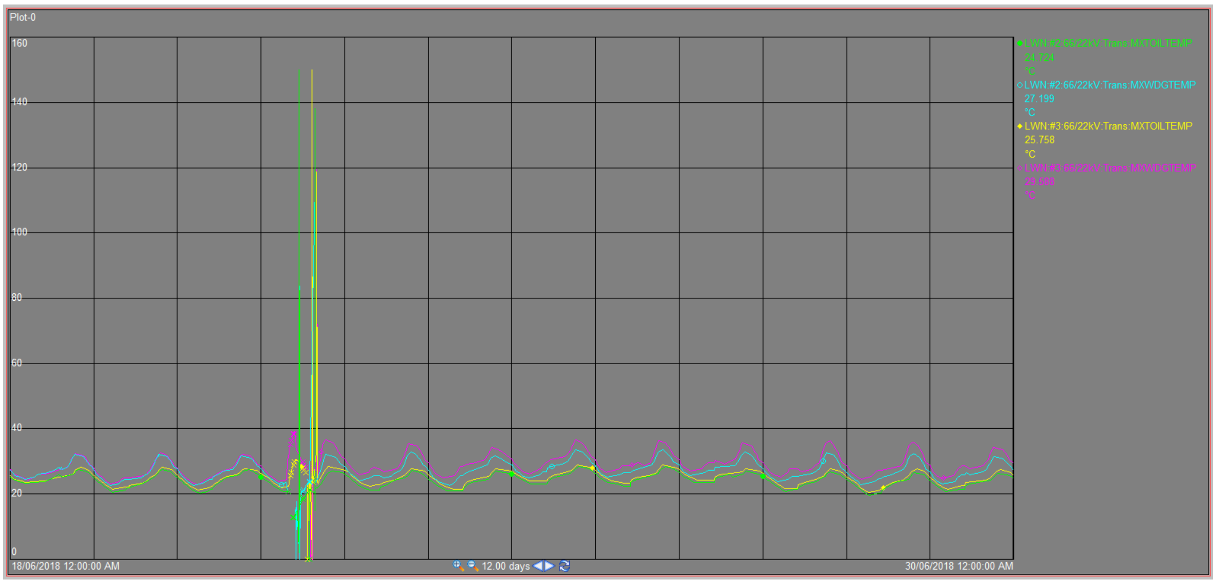
Term	Description
AEMO	Australian Energy Market Operator
AMI	Advanced Metering Infrastructure (Smart Meters)
ARENA	Australian Renewable Energy Agency
DR	Demand Response
DVMS	Dynamic Voltage Management System
HV	High Voltage
LV	Low Voltage
MW	Mega Watt
NAP	Network Analytics Platform
NCC	Network Control Centre
NEM	National Electricity Market
OLTC	On-Load Tap Changer
PV	Photo-voltaic
RERT	Reliability and Emergency Reserve Trader
RMIT	Royal Melbourne Institute of Technology
SCADA	Supervisory Control and Data Acquisition
UE	United Energy
VRR	Voltage Regulating Relay

7. Appendix A – Maximum Oil and Winding Temperature Readings for Zone Substation Transformers

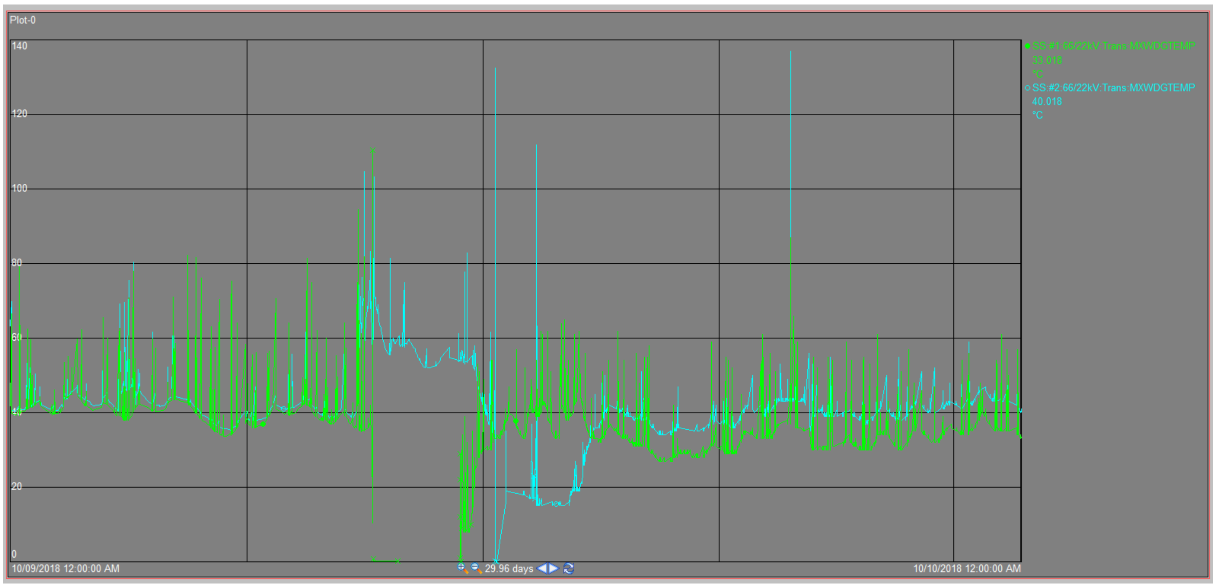
<u>Dandenong Zone Substation (DN) – Transformer #1</u>



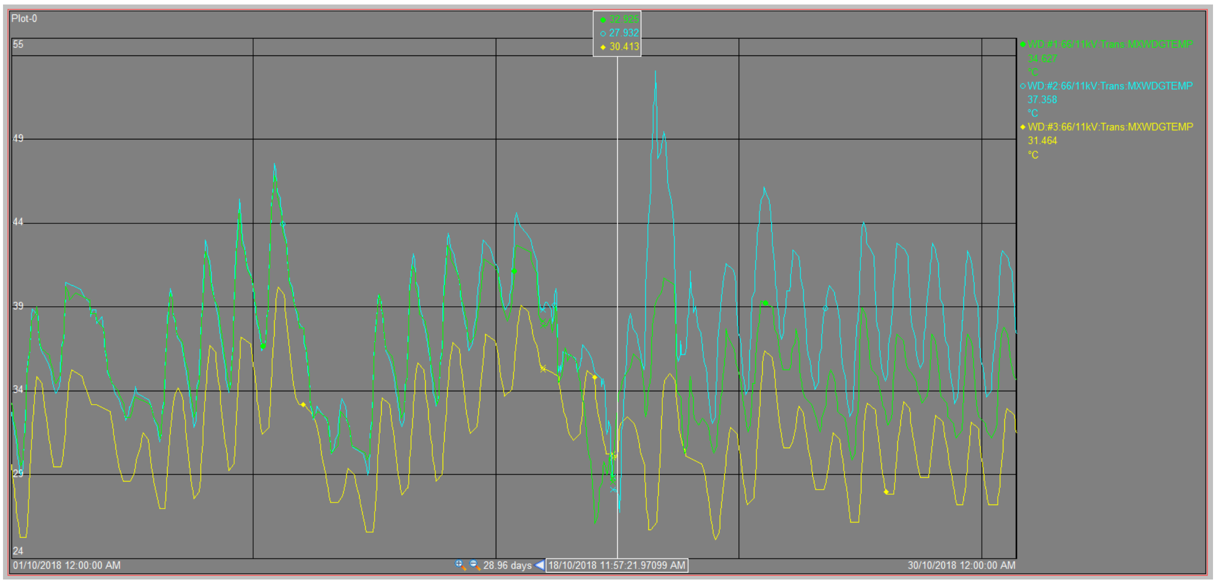
<u>Langwarrin Zone Substation (LWN) – Transformer #3</u>



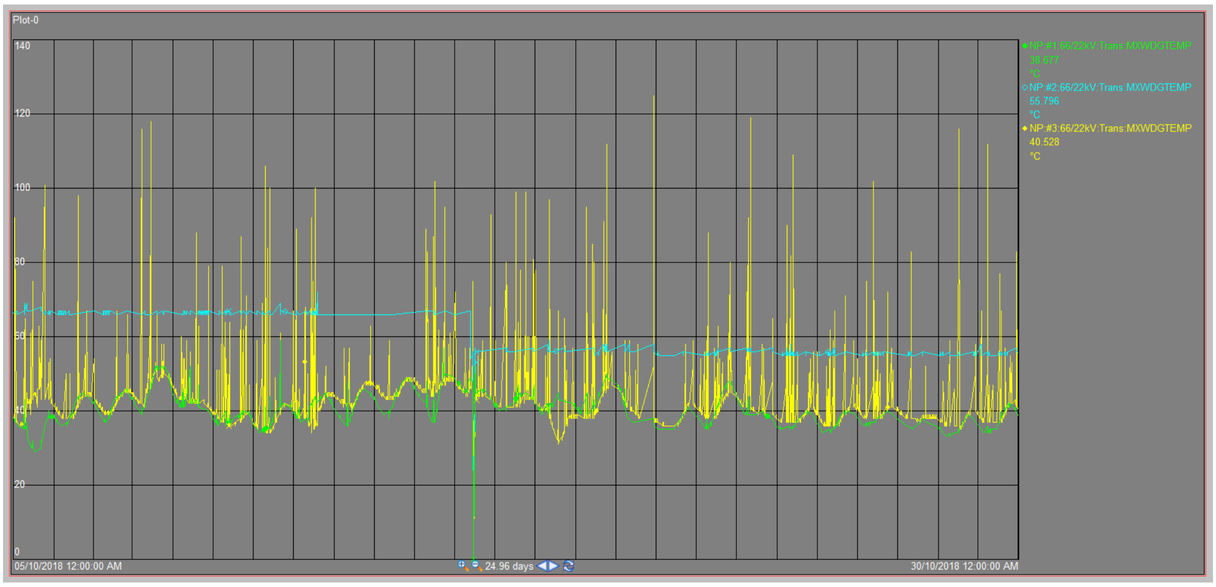
Springvale South Zone Substation (SS) – Transformer #1



West Doncaster Zone Substation (WD) – Transformer #2 and #3



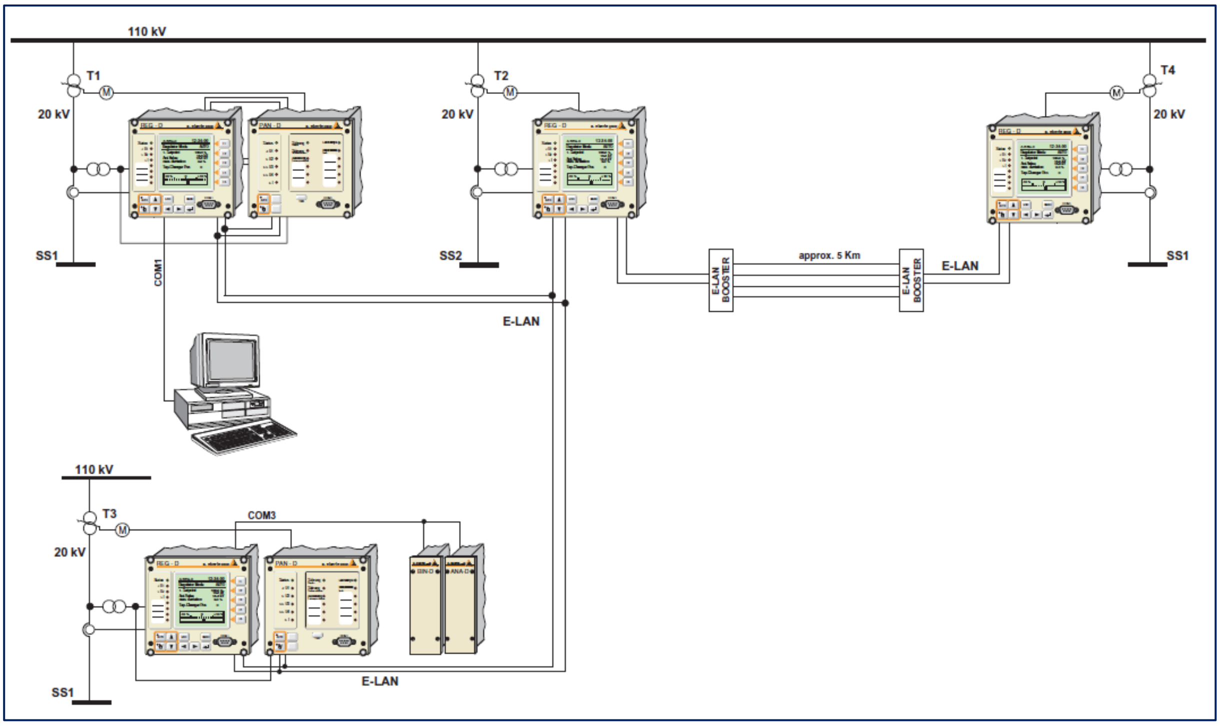
<u>Noble Park Zone Substation (NP) – Transformer #2</u>



8. Appendix B – Circulating Current Operating Mode of Voltage Regulating Relays

The zone substation transformers are configured to operate in parallel via circulating current (∆ISinφ) method. Circulating current method of parallel control of transformers allows OLTCs to independently tap, adjusting the output voltage and minimising the circulating current (I_{CIRC}) in the parallel group.

The parallel scheme is achieved in the REG-D relays by use of the E-LAN communications between the REG-D's and the Paragramer function as shown below:



The Paragramer function monitors the status of the circuit breakers and bus ties to determine which transformers are connected in parallel. Transformers that are not in parallel will be in independent mode. It should be noted that within a circulating current parallel group, individual transformers can be on different taps – this is not a problem!

REG-D ∆ISinφ settings are:

- Transformer group list for all units on the parallel program;
- Permissible I_{circ};
- Parallel program activation;
- Number of transformers; and
- Permissible difference of taps.

In order to have the circulating current operating mode performing correctly, the below considerations need to be taken into account:

- All regulators must have the same firmware to ensure correct parallel functionality.
- E-LAN connection between all regulators must be established for communications across the ELAN.

- Paragramer feature must be enabled in the REG-D to show the transformers single-line diagram on the display.
- REG-D relays must be added to the group list to ensure regulators function correctly in parallel scheme.
- Logbook will give indication of time stamped events such as PG_CB (incomer circuit breaker) status which are useful for diagnostic/fault finding conditions.
- Ensure the current transformer (CT) inputs have the correct polarity (which can show the correct value of circulating current).

9. Appendix C – Modified Permissible Circulating Current and Voltage Bandwidth Settings to Minimise Hunting

Parameter	Configuration/Setting Details
System/Device	Parameter Perm. I_{circ} set to 67A Station ID: A: for #1 Transformer Device Name: TRANS1 for #1 Transformer.
Basic Values/Basic	**<u>Set-Point Value:</u>** 1: Reference Voltage = V_{float} = 22.30kV = 111.5V_s 2: Voltage Reduction for Emergency Stage 1 = 3% of V_{float} = 22.30kV x 0.97 = 21.63kV = 108.155V_s 3: Voltage Reduction for Emergency Stage 2 = 5% of V_{float} = 22.30kV x 0.95 = 21.19kV = 105.925V_s **<u>Time Behaviour:</u>** Time Program: 00:INTEGRAL Time Factor: 2.3 Bandwidth: 2.2% (0.88 x %TAP) – Note: %TAP = 2.5% (Raise = 109.05V_s, Lower = 113.95V_s) This will provide a delay of 69s @ 2.2% Deviation, 38s @ 4% Deviation, 25.3s @ 6% Deviation, 15.2s @10% Deviation.
Parallel Operation	Program: 01:dI x sin(φ) Group List: Member-01:A (#1 Trans) Group List: Member-02:B (#2 Trans) Group List: Member-03:C (#3 Trans) Program-Activation: 3 Transformer (3 Transformers in Group).
Current Influence	Way of Current Influence: None
Tap Changer	Maximum Time TC in Operation: 15 sec Inverse Tap Changer: No Tap Limiter: Minimum Tap Position = 1; Maximum Tap Position = 9 Tap Limiter: 00:OFF.
CT/VT Configuration	Voltage: 00:L1L2 (Red-White Phase Volts) VTR: 200 (22kV/110V) Current: 00:L2 (White Phase Current) CTR: 120 (600/5)

Parameter	Configuration/Setting Details
	Nominal Current Value: 5A.
Functions	U-Nominal = 110V Block: 00:OFF.
Limits	Inhibit High: 126.5V = 115% = 25.3kV (Prevents all tapping) Over-Voltage: 10% = 22 x 1.1 = 24.2kV(Prevents Tap Up) Under-Voltage: -10% = 22 x 0.9 = 19.8kV(Prevents Tap Down) Inhibit Low: -15% = 22 x 0.85 = 18.7kV(Prevents all tapping) Overcurrent: 210% = 600A x 2.1 = 1260A
Time Delays	Inhibit High: 2 sec Over-Voltage: 0 sec Under-Voltage: 0 sec Inhibit Low: 2 sec Overcurrent: 0 sec.
Dynamic Voltage Set-Point Levels (To be set in H-Code)	Dynamic Voltage Level 1 - 1.06pu = 116.6V_s = 23.32kV Dynamic Voltage Level 2 - 1.04pu = 114.4V_s = 22.88kV Dynamic Voltage Level 3 - 1.02pu = 112.2V_s = 22.44kV Dynamic Voltage Level 4 - 1.00pu = 110.0V_s = 22.00kV Dynamic Voltage Level 5 - 0.98pu = 107.8V_s = 21.56kV Dynamic Voltage Level 6 - 0.96pu = 105.6V_s = 21.12kV Dynamic Voltage Level 7 - 0.94pu = 103.4V_s = 20.68kV Dynamic Voltage Level Timeout = 30 min.
Designer Comments	Perm I_{circ} changed from 50A to 67A Bandwidth changed from 2% to 2.2% To maintain the same inverse time curve, Time Factor changed from 2.5 to T1/30/BW = 150/30/2.2 = 2.3 for 2.2% bandwidth.

10. Appendix D – Monthly Tap Operations of Zone Substation Transformers Prior to and Post Implementing the DVMS

Table 4: Average daily numbers of zone substation transformer tap changes in CY2017 (prior to implementing the DVMS)

ZSS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BR	11	14	12	7	10	11	12	10	9	8	11	9
BT	12	14	12	7	11	12	12	12	9	8	10	8
BH	20	25	22	11	16	17	14	19	18	16	18	14
BU	7	10	9	4	4	6	7	7	6	5	6	5
BW	12	11	12	7	8	8	9	12	12	11	11	11
CRM	9	10	10	8	10	11	11	10	10	6	11	9
CFD	17	16	14	9	14	13	12	5	9	8	10	9
CM	13	15	13	7	10	11	10	10	9	10	11	10
CDA	13	13	14	9	11	16	10	10	10	9	12	12
DN	12	16	14	9	11	11	12	12	11	12	15	12
DSH	9	12	11	8	8	8	7	8	20	18	39	22
DVY	8	12	12	11	11	9	14	12	10	11	12	10
DC	9	11	11	5	8	9	12	12	9	7	8	6
DMA	13	15	14	10	12	16	16	15	14	10	13	11
EB	19	17	14	8	12	13	14	11	11	10	14	11
EM	14	13	12	7	9	10	9	11	11	12	11	12
EL	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
EW	12	15	14	9	9	12	13	10	10	10	14	11
FTN	14	18	18	11	15	18	19	16	15	11	16	13
FSH	8	8	8	5	7	8	10	8	8	6	7	6
K	16	20	19	10	11	12	13	11	12	10	14	13

ZSS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
GW	17	17	14	9	12	14	14	13	12	11	14	11
HGS	10	10	11	7	8	10	12	11	10	8	9	8
HT	12	16	12	7	11	11	11	10	9	9	11	9
KBH	13	16	14	10	12	13	14	13	12	11	13	10
LWN	12	14	15	10	13	16	16	15	14	8	14	11
LD	16	15	14	13	15	15	18	16	16	16	18	16
M	22	20	16	14	15	16	27	26	18	16	31	25
MR	16	22	19	12	17	19	19	19	15	13	18	14
MC	18	20	15	12	14	15	15	14	13	13	15	13
MTN	13	13	14	10	13	17	18	16	15	10	14	13
MGE	12	17	16	10	12	15	16	14	15	13	14	12
NP	14	16	15	10	10	13	11	11	10	9	12	10
NB	11	16	14	14	10	14	13	13	11	9	14	10
NO	14	13	12	6	8	9	10	10	9	9	12	10
NW	13	15	14	8	9	10	9	11	12	11	11	10
OAK	14	12	11	7	8	10	9	11	10	11	12	11
OE	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
OR	12	11	11	7	8	9	8	9	10	11	11	11
RBD	22	22	20	16	20	20	23	20	21	17	21	20
SR	12	14	12	7	10	11	12	11	9	8	11	8
STO	20	20	19	14	14	14	12	10	10	8	9	7
SV	13	15	14	9	9	13	11	10	9	9	11	12
SS	12	15	14	9	10	11	10	9	9	9	11	9
SVW	16	20	20	12	13	16	14	14	14	13	18	15
SH	11	10	10	8	8	11	10	10	11	9	9	10
WD	7	11	7	4	7	8	9	10	9	10	7	6

Table 5: Average daily numbers of zone substation transformer tap changes in CY2019 (post implementing the DVMS)

ZSS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
BR	11	10	9	7	10	14	14	16	10	11	13	8
BT	15	10	9	6	9	14	14	13	9	10	13	6
BH	15	12	10	7	10	13	15	14	15	18	14	10
BU	14	11	9	5	8	11	12	10	7	8	12	7
BW	14	12	12	7	12	11	5	5	6	9	9	6
CRM	18	14	14	11	18	18	21	20	15	11	12	10
CFD	14	10	12	8	9	12	14	14	12	11	11	7
CM	17	15	21	8	7	20	12	12	11	14	17	11
CDA	13	12	11	9	11	14	16	14	12	13	17	10
DN	23	20	19	14	16	19	27	24	18	16	17	13
DSH	22	17	16	12	14	15	19	20	19	20	73	11
DVY	20	16	14	12	13	17	21	23	15	14	17	15
DC	37	80	8	8	9	11	12	11	9	11	16	69
DMA	15	11	12	12	12	15	17	17	15	13	12	11
EB	24	18	16	18	12	20	27	22	17	22	21	14
EM	11	8	7	6	11	17	15	N/A	30	10	10	5
EL	15	9	8	8	8	12	10	11	7	9	9	6
EW	10	9	7	7	10	29	13	12	12	6	8	7
FTN	16	14	13	12	15	20	23	22	17	15	11	9
FSH	23	9	9	7	11	15	17	15	10	9	9	8
K	16	17	11	10	13	13	12	12	14	11	10	9
GW	20	17	11	15	18	29	33	38	22	13	12	9
HGS	16	17	17	58	11	16	21	19	25	20	12	8
HT	15	9	114	8	7	12	13	21	15	9	12	7
KBH	13	9	9	7	8	12	13	11	9	11	12	8

ZSS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
LWN	25	19	19	15	20	26	31	28	21	18	18	15
LD	20	15	15	13	13	18	29	26	17	17	16	13
M	21	17	15	13	12	19	21	18	13	17	19	12
MR	22	18	15	13	17	23	26	24	17	19	23	14
MC	13	10	12	8	9	11	11	11	10	11	11	7
MTN	29	22	22	31	37	37	55	41	30	29	31	19
MGE	11	8	9	6	8	11	17	16	11	10	8	7
NP	32	10	9	7	16	15	16	12	11	12	15	11
NB	27	21	20	17	22	23	23	24	19	24	24	17
NO	18	12	10	9	9	10	12	12	8	11	10	8
NW	25	22	20	14	20	25	26	24	20	21	22	15
OAK	28	22	20	14	15	19	22	22	17	20	19	14
OE	N/A	N/A	N/A	N/A	2	15	20	18	9	146	14	17
OR	13	25	25	7	14	16	26	14	8	10	11	10
RBD	18	14	15	13	16	24	26	24	18	16	14	12
SR	17	108	16	8	9	13	15	18	15	17	13	7
STO	14	9	12	10	12	15	18	18	14	11	10	9
SV	19	15	14	13	17	20	24	18	15	20	22	14
SS	15	11	8	8	10	13	13	10	13	17	25	16
SVW	23	17	16	14	16	21	23	26	15	20	23	15
SH	25	9	6	5	5	10	10	9	4	6	12	11
WD	17	10	10	10	28	75	89	11	9	10	10	9