United Energy Demand Response Project Performance Report - Milestone 5

11.06.19

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Contents

1. Summary

This document is the United Energy (UE) 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) zone substation works with DVMS enabled and performance tuning undertaken at these sites;
2) low-voltage remedial works to tighten voltage distributions and maximise demand response delivery;
3) AEMO tests to confirm United Energy's demand response reserve capability for the last summer period;
4) delivery of RERT demand response services for AEMO on two occasions - 24th and 25th January 2019;
5) development of a draft capability diagram for the operation of the DVMS; and
6) 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 and 4 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 UE's demand response reserve capability

UE undertook summer 2018/19 period demand response tests with AEMO. The objectives of the tests were to :-

1. confirm UE's demand response reserve capability achieves the required 30MW (compared to the previous requirement of 12MW); and
2. 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. Fourth Test – 27th November 2018

AEMO called a fourth test with UE on 27th November 2018 for a 2-hour period starting 1200 market time for a capability of 30MW.

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

Activation of the demand response by way of voltage reduction is evident in the time before the event start date (1200 market time) with demand falling from 920MW at 1140 to around 890MW at 1200. With underlying demand at the time just prior to activation decreasing at 0.066MW/minute, the coincident time demand reduction achieved in the first interval is 920MW – 890MW - 0.066MW/minute x 35 minutes = 27MW. Subsequent intervals achieved demand reductions of at least 30MW.

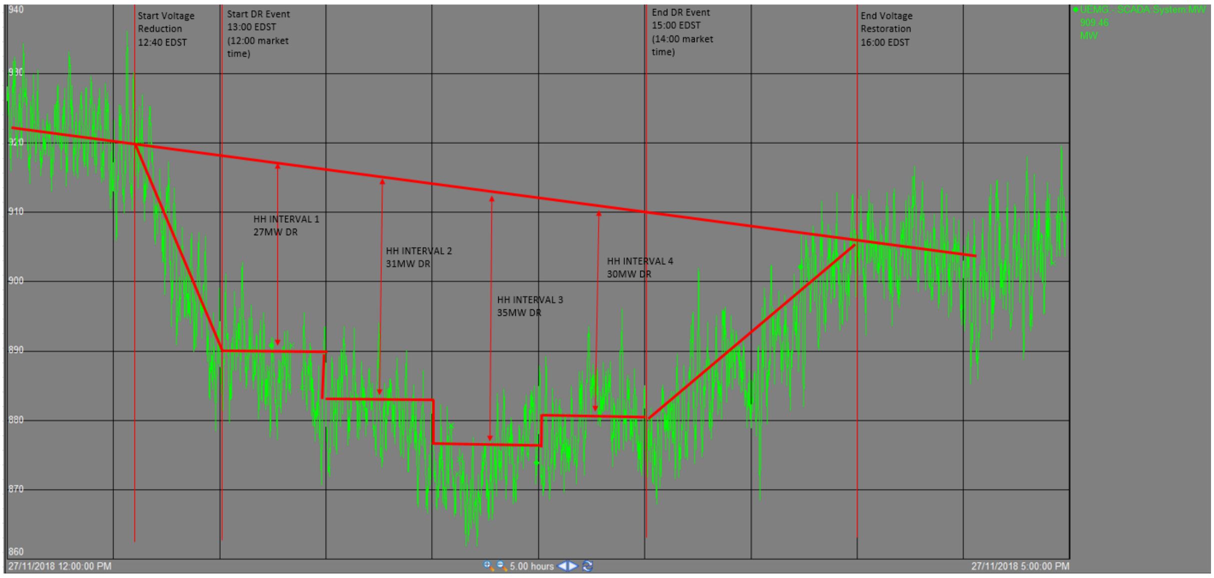


Figure 1 Test on 27th November 2018 showing demand response due to voltage reduction

Deactivating the demand response was undertaken by restoring network voltages which occurred from 1400 market time with demand rising from 880MW at 1400 to around 905MW at 1500. With underlying demand at the time decreasing at 0.066MW/minute, the coincident time demand reduction in the final period is 905MW – 880MW + 0.066MW/min x 75 min = 30MW.

With the DVMS acting to limit the size of the voltage reductions to allow customer voltages to remain within the regulatory limits, the demand response magnitude delivered varies throughout the test window with the deepest response delivered in the third half-hour period.

An example of how DVMS is regulating customer voltages with Demand Response (DR) mode on and off on the day of the test is shown below at the 11kV East Malvern (EM) zone substation.

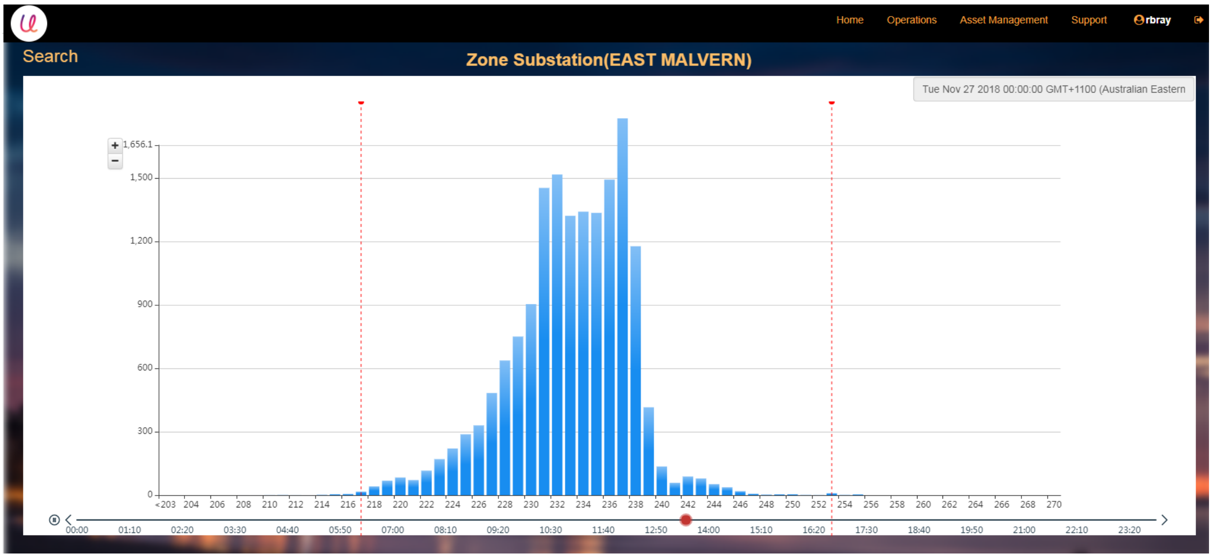


Figure 2 During DR test, showing customer voltages regulated at lower end of regulatory voltage band

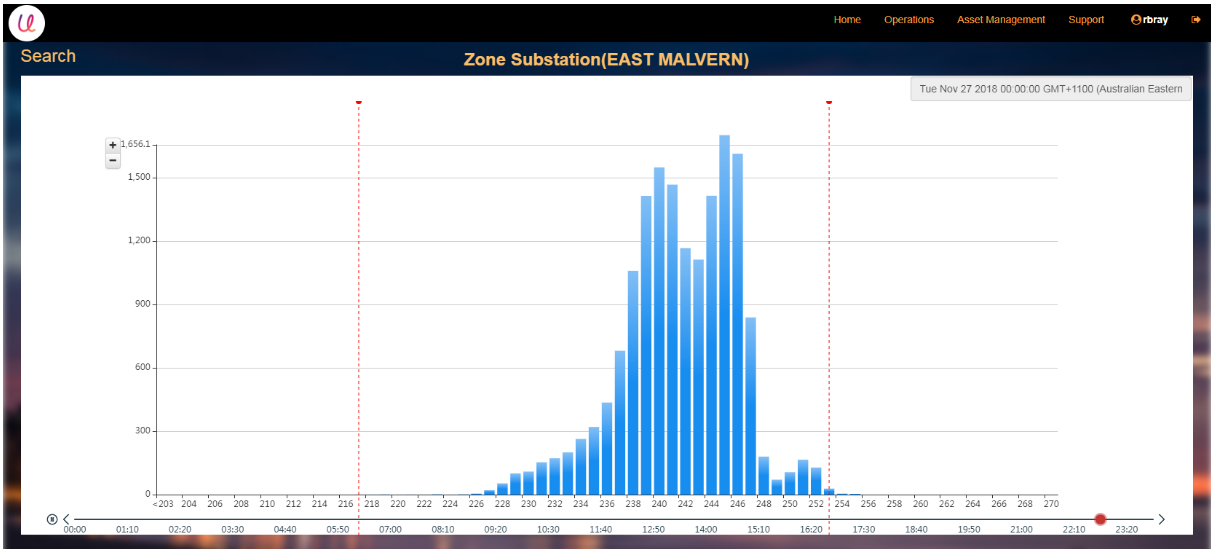


Figure 3 After the DR test showing customer voltages regulated at upper end of regulatory voltage band

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 except the first period, 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. The issues of the first half hour period are detailed below. The issues were resolved soon after the test and a subsequent test undertaken in January.

UE were unable to achieve the full 30MW in the first half hour interval during the AEMO test due to a data bandwidth bottleneck problem encountered between the analytics engine/data warehouse (NAP/OSI PI) and the real-time SCADA system (MOSAIC). This resulted in a slower than normal tapping down of transformers as NAP did not have up to date information to drive transformer taps faster during the activation, with the transformers still tapping down even during the first half hour of the event period. This delay effect from the data bottleneck diluted the demand response delivered in the first half hour period.

An example of this delay in tapping is shown below, again for the EM zone substation.

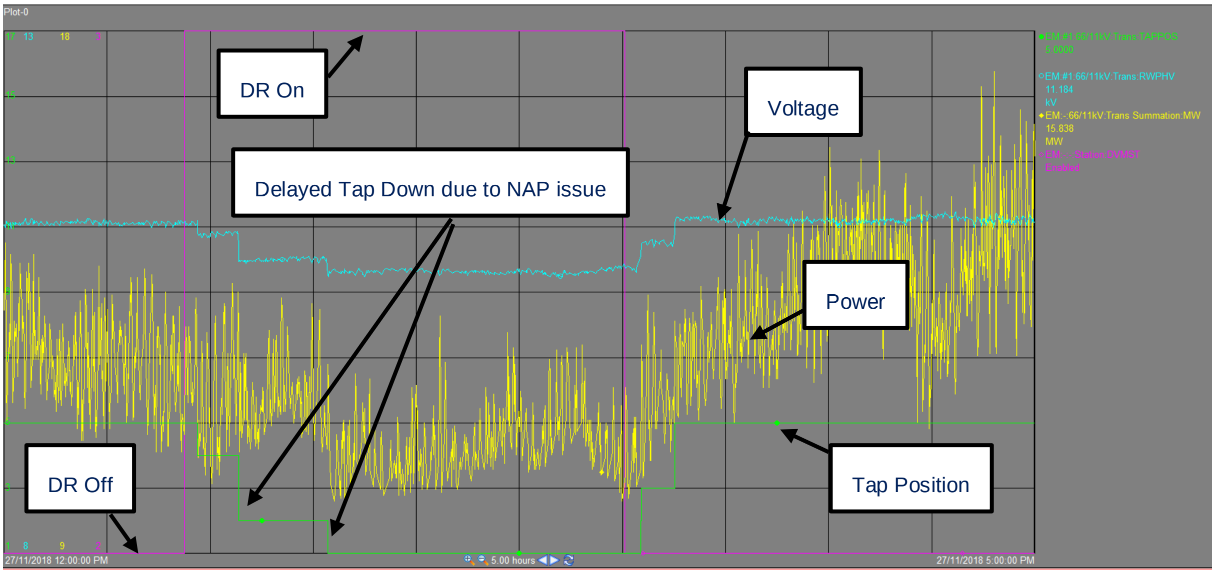


Figure 4 Test showing delayed tapping issue

The delayed tapping down is clearly evident with three tap change steps over a period of 40 minutes.

This issue was promptly identified and rectified subsequent to the AEMO test by increasing the data capacity between the systems and fine-tuning the activation algorithm in the analytics engine. The changes were retested internally on 10th December 2018, resolving the delay issue. The same EM site is used to present the results of the rectification (on the same time scale but using two brief demand response windows), showing a substantial improvement in tapping performance.

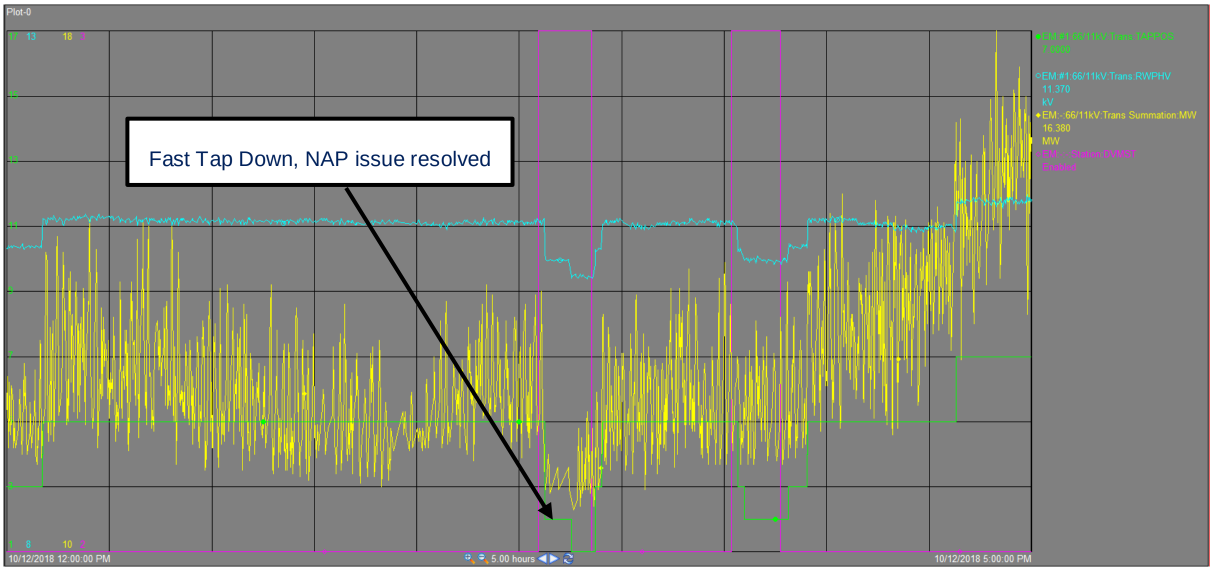


Figure 5 Test showing delayed tapping issue resolved

The tapping down is now clearly much faster, reducing to two tap change steps over a period of 10 minutes.

The AEMO test which was conducted during a period of light load revealed a possible limiting factor in the performance of the system. The magnitude of the demand response available during light load periods is limited not only by the magnitude of the low demand itself, but also from available tapping range of many zone substation transformers. Under light load, transformers typically operate closer to the bottom end of their tapping range, which could limit the size of the voltage reduction available. This is clearly illustrated in the EM example above, where the tap change from normal operation to demand response operation went from tap 5 down to tap 1 (the bottom tap). UE has subsequently addressed this issue by applying more optimal voltage settings at the upstream terminal stations which now offer a wider tapping range for the zone substation transformers at light load.

This end of tapping range limitation is however not expected to be applicable at periods of high demand, with transformers likely to be operating much higher in their tapping range to cater for voltage drops through the network. This is illustrated below over a period of 4 days when a high demand day was experienced on 7th December 2018. For the EM example below, the taps are likely to be operating around tap 8 compared to a low demand day of tap 5. This provides an additional voltage margin for demand response of 3 taps x 1.025% step = 3.1%.

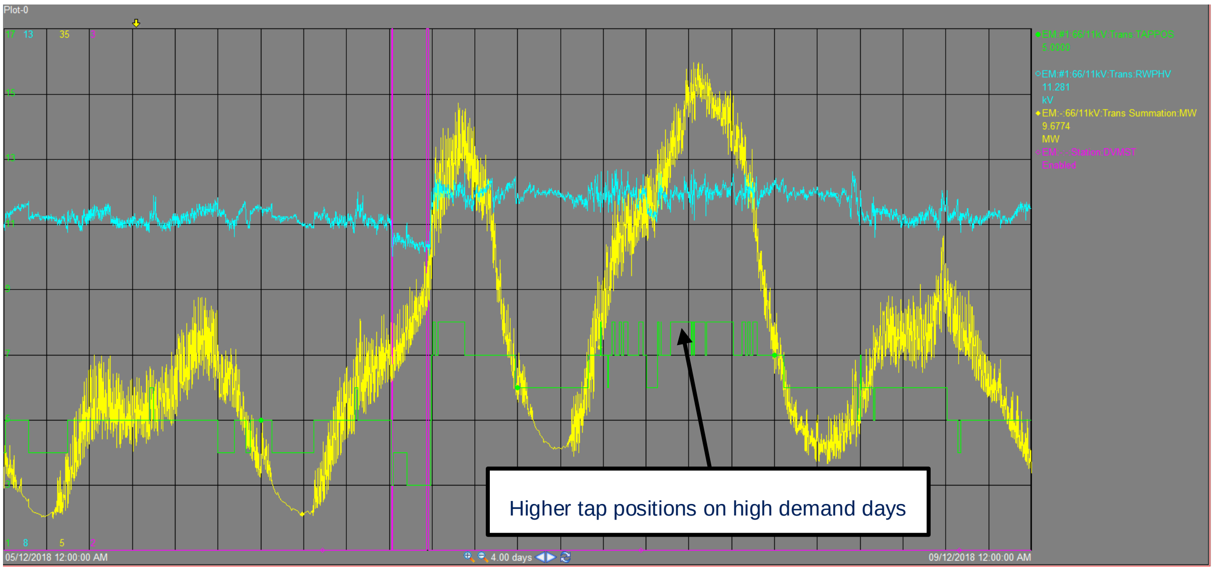


Figure 6 Greater tapping range available for DR on high demand days

On such days, the voltage reduction would be limited not by the tapping range, but by the available margin from the spread of customer voltages, which can be controlled through the low voltage network remediation works presented in the Milestone 3 report. This information is useful in developing up a capability diagram for the operation of the DVMS and is discussed in Section 4 of this report.

2.2. Fifth Test – 21st January 2019

AEMO called the fifth test with UE on 21st January 2019 following rectification of the Activation Time delay observed in the fourth test. This test was called for a 2-hour period starting 1400 market time for a capability of 30MW.

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

Activation of the demand response by way of voltage reduction is clearly evident in the time before the event start date of 1400 market time with demand falling from 1125MW at 1350 to around 1100MW at 1404. With underlying demand at the time just prior to activation increasing at 1.1MW/minute, the coincident time demand reduction achieved in the first interval is 1125MW – 1100MW + 1.1MW/minute x 14 minutes = 40MW.

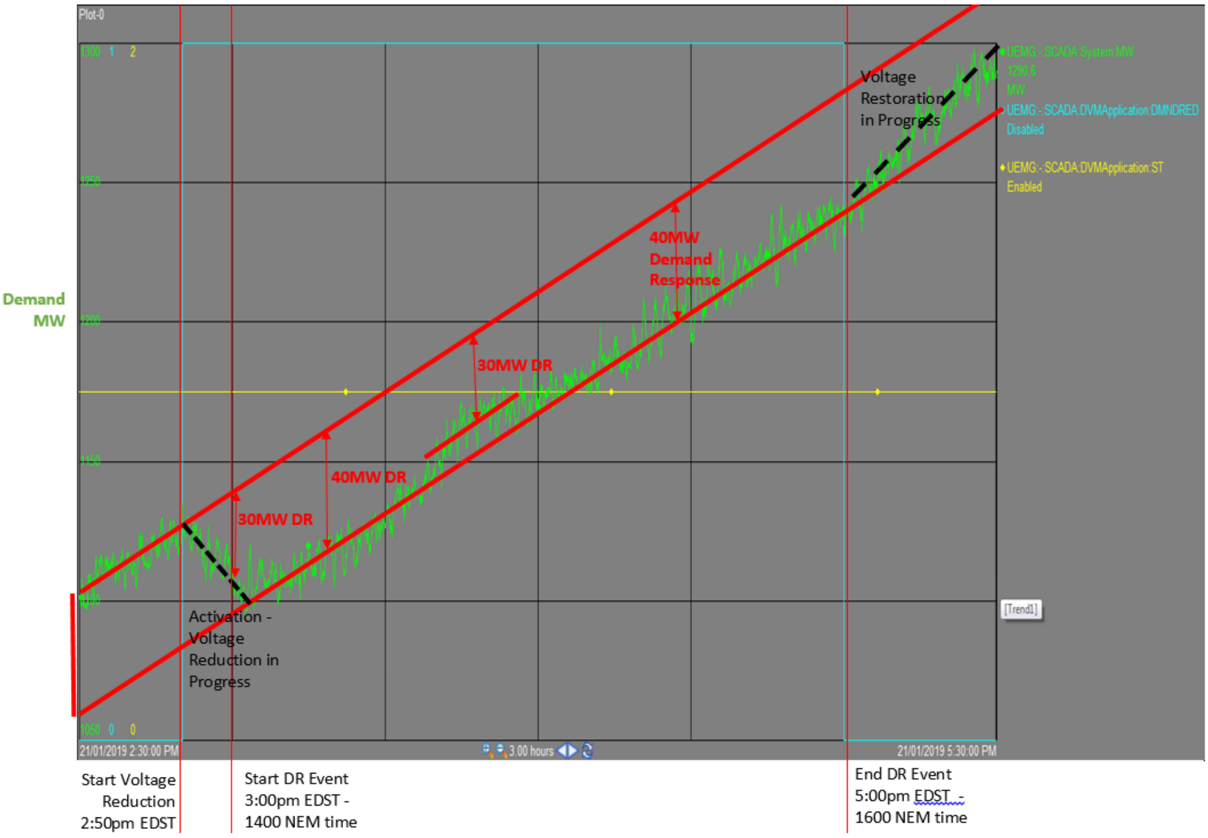


Figure 7 Test on 21st January 2019 showing demand response due to voltage reduction

With the Dynamic Voltage Management System acting to limit the size of the voltage reductions to allow customer voltages to remain within the regulatory limits, the demand response magnitude delivered varies throughout the test window between 30 and 40MW, with the second half hour period delivering the lowest response of 30MW.

Comparison with the baselining method performance is shown below.

ARENA/AEMO DR Baselining for United Energy										TEST DATE	Mon 21/01/2019											
s	Start trading interval (hh:mm AM/PM)			03:00 PM	EDST																	
	Contracted Demand Response MW			30																		
	Simulated Demand Response MW			0																		
Site	PI tag reference			1	\\PIPROD\UEMG:-SCADA:System:MW																	
S	Number of selected days			10						2 hour Demand Response window												
	Trading interval starting time (EDST)	11:00 AM	11:30 AM	12:00 PM	12:30 PM	01:00 PM	01:30 PM	02:00 PM	02:30 PM	03:00 PM	03:30 PM	04:00 PM	04:30 PM	05:00 PM	05:30 PM	06:00 PM	06:30 PM	07:00 PM	07:30 PM	08:00 PM		
t	Trading interval t	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10		Baseline Dates
cti	MW at time interval t on selected day i																					
i=1	Thu 06/12/2018 15:00	1097.9	1125.4	1147.6	1180.4	1205.7	1239.2	1275.5	1313.6	1344.3	1384.7	1460.8	1516.4	1548.0	1577.2	1587.4	1592.5	1570.4	1534.3	1479.4		Thu 06/12/2018
2	Fri 07/12/2018 15:00	1496.6	1535.7	1550.5	1576.6	1604.2	1647.1	1695.7	1713.4	1725.9	1798.8	1840.4	1844.2	1843.3	1814.8	1753.0	1714.3	1676.2	1629.0	1576.4		Fri 07/12/2018
3	Mon 24/12/2018 15:00	797.2	817.9	842.6	866.0	892.5	922.8	955.5	992.8	1031.6	1079.8	1131.5	1181.0	1221.4	1253.9	1254.6	1253.1	1227.1	1196.7	1141.9		Mon 24/12/2018
4	Thu 27/12/2018 15:00	958.5	1009.9	1064.3	1119.7	1165.9	1218.1	1260.2	1305.8	1352.6	1404.4	1457.5	1499.6	1525.9	1547.5	1524.3	1488.3	1426.1	1370.9	1299.9		Thu 27/12/2018
5	Fri 28/12/2018 15:00	1217.2	1268.8	1258.3	1252.7	1240.8	1205.7	1235.7	1234.5	1262.1	1305.9	1343.4	1403.7	1395.2	1396.6	1375.4	1332.8	1264.3	1189.1	1129.6		Fri 28/12/2018
6	Thu 03/01/2019 15:00	782.0	792.6	801.4	816.9	834.1	851.1	874.1	900.7	927.0	966.0	1007.5	1052.7	1091.9	1134.6	1156.8	1176.7	1171.3	1153.1	1113.6		Thu 03/01/2019
7	Fri 11/01/2019 15:00	874.2	885.8	882.1	908.9	928.6	951.1	972.4	984.7	1006.7	1041.1	1077.3	1106.4	1126.4	1153.6	1164.9	1172.2	1152.6	1117.6	1068.8		Fri 11/01/2019
8	Mon 14/01/2019 15:00	1180.3	1221.3	1272.6	1332.5	1390.1	1446.3	1491.1	1535.4	1576.3	1621.9	1659.0	1682.5	1688.3	1696.8	1678.4	1660.6	1619.8	1558.8	1473.2		Mon 14/01/2019
9	Thu 17/01/2019 15:00	1184.8	1218.2	1230.5	1231.2	1244.9	1280.9	1311.7	1329.2	1358.2	1329.2	1330.7	1359.5	1352.5	1349.1	1332.2	1319.3	1296.2	1286.8	1256.0		Thu 17/01/2019
i=S	Fri 18/01/2019 15:00	1232.7	1218.2	1192.8	1186.2	1184.0	1180.9	1152.4	1117.5	1117.8	1112.6	1094.3	1095.2	1093.8	1078.8	1042.6	1021.9	986.2	963.6	932.9		Fri 18/01/2019
ct0	Mon 21/01/2019 15:00	987.0	1001.4	1011.8	1031.0	1056.1	1077.3	1099.8	1115.7	1113.5	1156.1	1188.0	1223.8	1268.0	1299.5	1298.6	[-11059] Nc	[-11059] Nc	[-11059] Nc	[-11059] Nc	R Dat	Mon 21/01/2019
	Baseline error ^2			4.9	33.9	7.2	45.4	151.5	282.0													
	Raw							12.3	16.8	46.5	38.1	42.0	40.1	10.4	-9.5							
bt	Unadjusted baseline for time interval	1082.1	1109.4	1124.3	1147.1	1169.1	1194.3	1222.4	1242.8	1270.3	1304.4	1340.2	1374.1	1388.7	1400.3	1386.9	1373.2	1339.0	1300.0	1247.2		
ct-bt		-95.2	-108.0	-112.5	-116.1	-113.0	-117.0	-122.6	-127.1													
a	Adjustment Factor	-110.3																				
Bt	Adjusted Baseline	971.8	999.1	1014.0	1036.8	1058.8	1084.0	1112.1	1132.5	1160.0	1194.2	1229.9	1263.8	1278.4	1290.0	1276.7	1262.9	1228.7	1189.7	1136.9		
Dt	Calculated Delivered Reserve							12	17	30	30	30	30	10	0							
Dt'	Actual Delivered Reserve								0	34	26	30	30	-2								

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.

3. Delivery of RERT Services

UE delivered RERT services for AEMO on two occasions during summer 2018/19:-

1. 30 to 42MW delivered on 24th January 2019 for 4 hours; and
2. 30 to 42MW delivered on 25th January 2019 for 4.5 hours.

3.1. First RERT Activation – 24th January 2019

AEMO called a live RERT activation with UE on 24th January 2018 for a 4-hour period starting 1700 market time for a capability of 30MW. The UE service area demand at the time was 1930MW, significantly greater than the demand at the time of the test period events. At this level of demand, the demand response could potentially be much larger than the demand response delivered during the testing at light load, however the key constraint in the magnitude of the demand response delivered shifts from available tapping range to the customers' voltage distribution spread. UE was able to achieve up to 42MW of demand response that day. Figure 8 shows the activation which occurred on the 24th using high-frequency SCADA metering of the UE service area demand. Activation status of the demand response mode in DVMS is shown in blue and is triggered 10-minutes before 1700 market time when we received instruction from AEMO to dispatch (noting that the timestamp on the chart below is in Melbourne local daylight savings time).

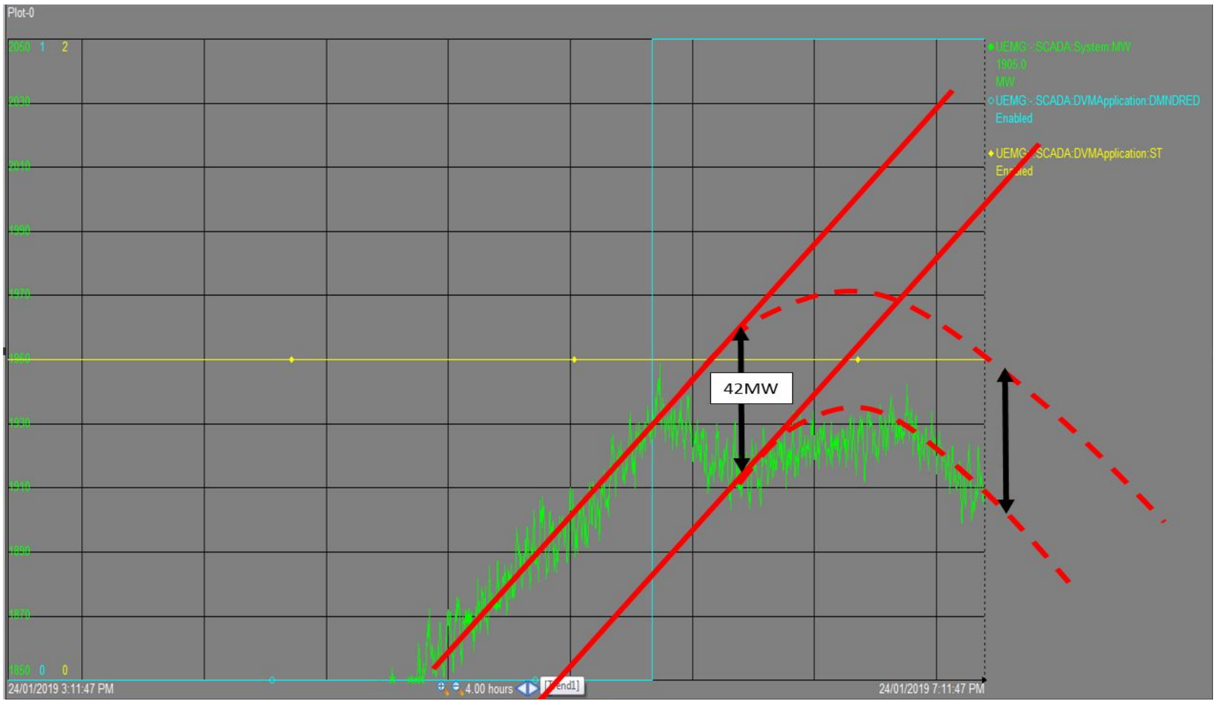


Figure 8 Activation on 24th January 2019

The tapping of our zone substation transformers starts about 1 minute later, with the voltage reduction arresting the increasing demand (shown in green) at the time, forcing it to decline until further tapping down is inhibited by DVMS - which is designed to minimise the number of customers on the lower end of the voltage distribution at each zone substation receiving voltages outside of allowable voltage limits – i.e. maintaining compliance with AS 61000.3.100. Following completion of all tap downs across the fleet of zone substations, the aggregated UE demand then begins to rise on its original rate of change (solid red lines), albeit from a point 42MW lower than what it would have otherwise been.

The UE demand peaked that day just prior to activation, but would have normally peaked about 1 hour later. This is illustrated with the rate of change in demand increase slowing to the point it starts to decline as the evening arrives (dashed red lines).

Figure 9 illustrates how the demand response performance was observed throughout the duration of the 4-hour RERT period. Being a long dispatch period, the known thermostat effects of voltage reduction on demand (as discussed in Milestone 3 report) contributed to a decline in the delivered demand response throughout the duration of the dispatch with the lowest demand response of 30MW delivered at the end of the period.

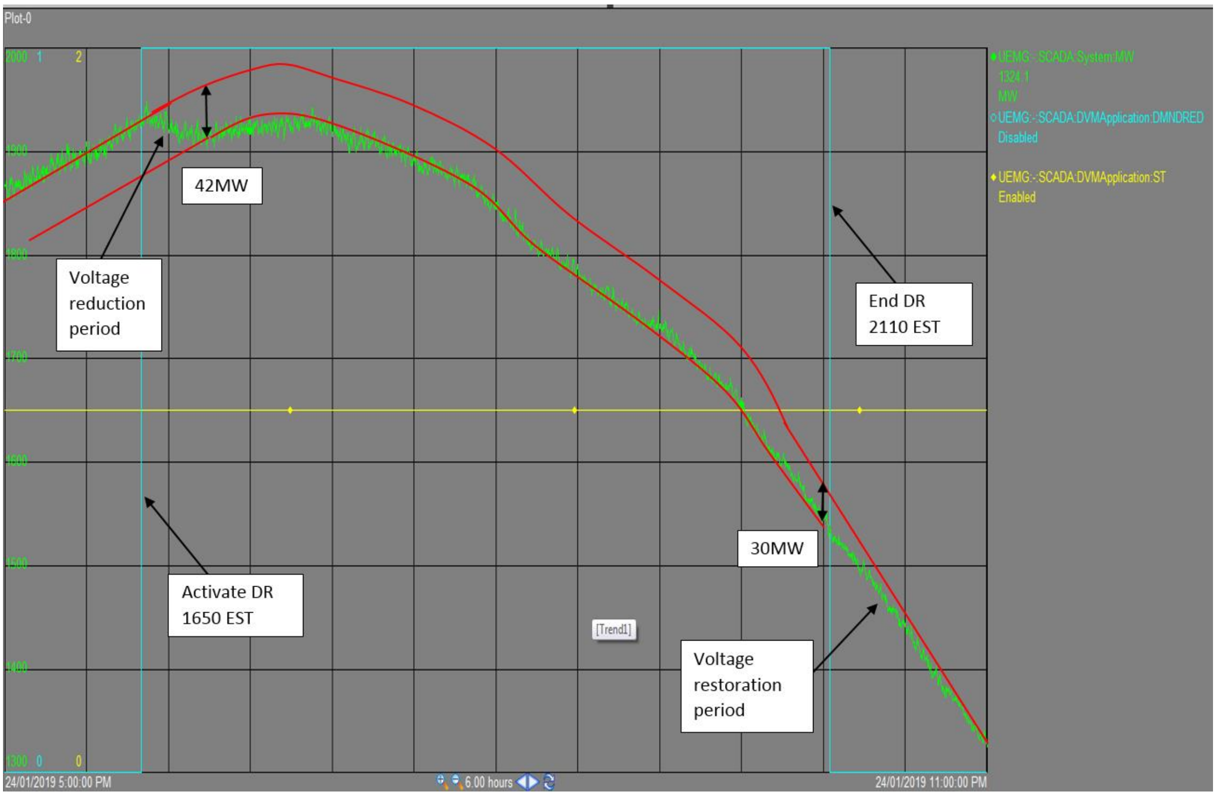


Figure 9 Demand Response Window on 24th January 2019

The RERT services delivered by UE and others on the 24th January was sufficient to avoid the need for load shedding on this day. This was a major achievement for the ARENA programme in delivering its intended objectives and a great outcome for the community.

3.2. Second RERT Activation – 25th January 2019

AEMO called a second live RERT activation with UE on 25th January 2018 for a 4.5-hour period starting 1100 market time for a capability of 30MW.

The UE service area demand at the time was 2016MW, higher than the peak of the previous day due to the extremely high overnight temperatures experienced in Melbourne. UE was able to repeat the 42MW of demand response achieved the previous day upon activation on 25th.

Figure 10 shows the activation which occurred on the 25th using high-frequency SCADA metering of the UE service area demand. Activation status of the demand response mode in DVMS is shown in blue and is triggered 5-minutes before 1100 market time (noting that the timestamp on the chart below is in Melbourne local daylight savings time) when we received instruction from AEMO to dispatch. While a 10 minute activation time is required, it should be noted that the activation instruction from AEMO was by way of a phone call at 1055. The normal activation SMS from AEMO was delayed and arrived later.

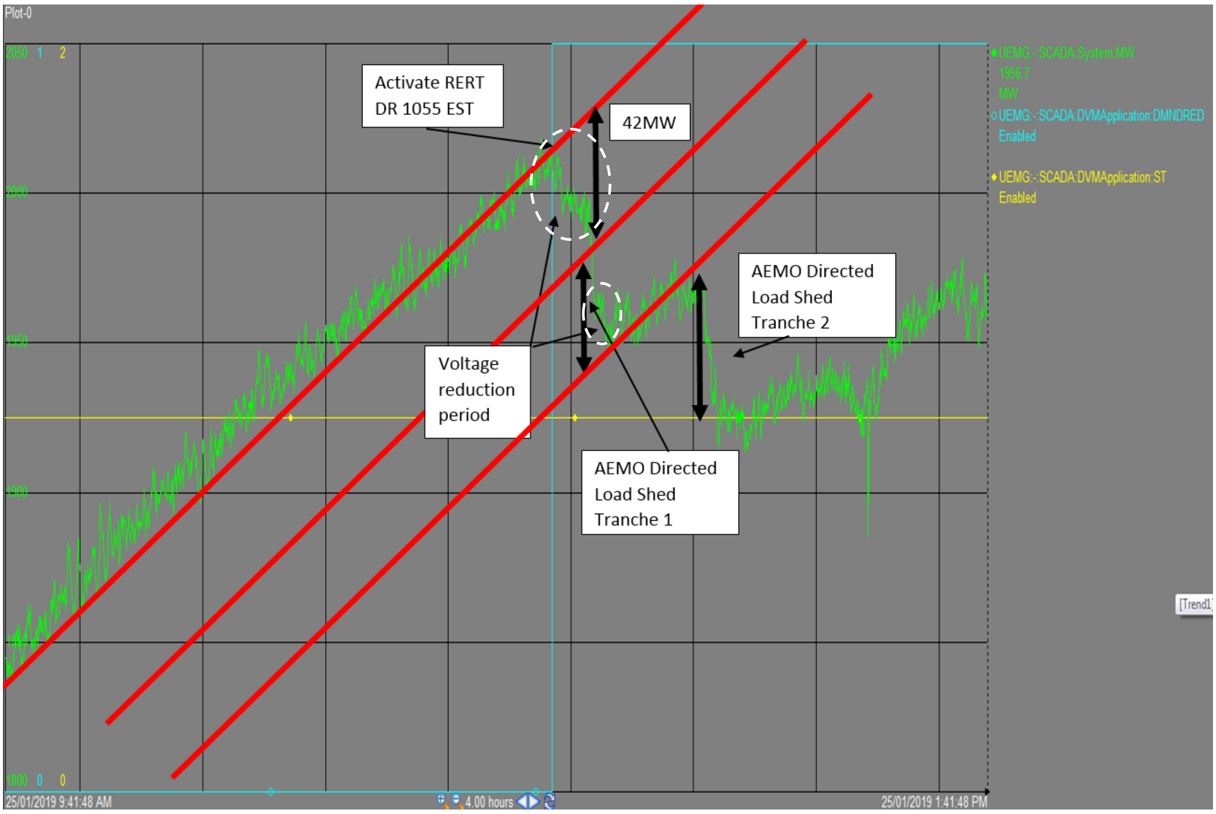


Figure 10 Activation and Load Shedding on 25th January 2019

While the RERT services delivered by UE and others on the 25th January did not avoid the need for load shedding, the beneficial impact of the demand response in minimising the load shedding can be seen in Figure 10.

The tapping down of our zone substation transformers starts upon activation at 1055, with the voltage reduction arresting the increasing demand (shown in green) at the time, forcing it to decline with a demand response of approximately 30MW by 1104. At 1104 UE received instruction from AEMO via AusNet Transmission to commence load shedding and this is illustrated in the 27MW step down in demand at 1104 indicated by Tranche 1 in Figure 10. Between 1104 and 1110, further tapping down of transformers is occurring to provide a total demand response contribution from voltage reduction of 42MW.

Following completion of all tap downs across the fleet of zone substations at 1110, the demand then begins to rise on its original rate of change (solid red lines), albeit from a point 69MW (comprising of 42MW of demand response plus 27MW of load shedding) lower than what it would have otherwise been. At 1130 UE received instruction from AEMO via AusNet Transmission to commence further load shedding and this is illustrated in the 36MW step down in demand at 1130 indicated by Tranche 2.

The UE demand peaked that day just prior to activation, but would have normally peaked at 2095MW at about 1245 once the cool weather change arrived. This would have exceeded the record maximum demand observed back in 2009.

The reason the UE maximum demand did not reach a new record peak on the 25th is due to the combined effects of the demand response and load shedding and is illustrated in Figure 11.

Without the cool change arriving in Melbourne at 1245, the UE demand would have expected to peak at around 2223MW at 1600.

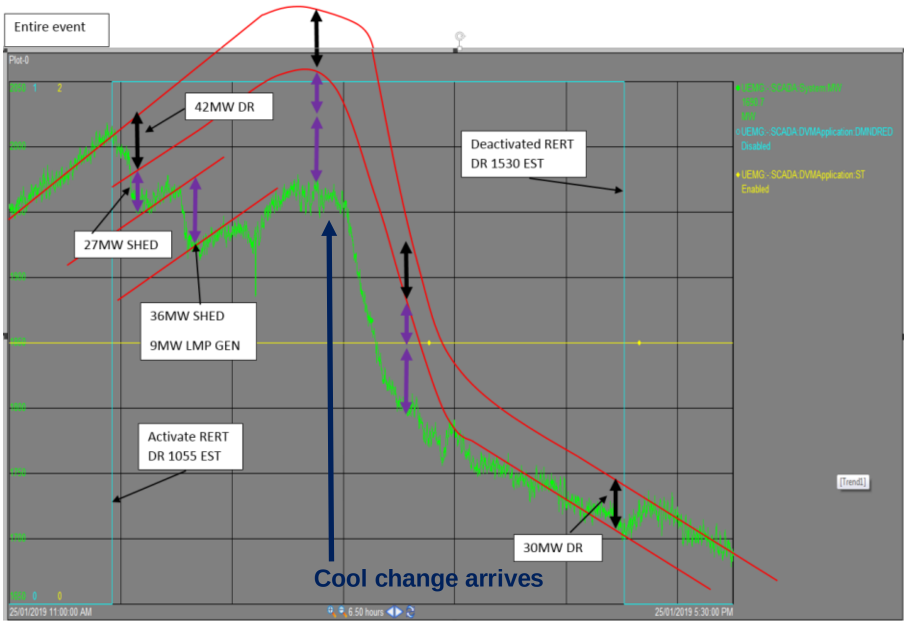


Figure 11 Demand Response Window on 25th January 2019

Figure 11 shows the impact of the demand response (black arrows), the two tranches of the AEMO-directed load shedding (purple arrows) and the rapid reduction in demand upon arrival of the cool change to Melbourne. Load shed during the period was progressively restored with all load restored in full by 1356 market time. A summary of the load shedding blocks is provided below (noting times are in Melbourne local daylight savings time).

Load Shedding Block	Feeder Name	Load (MW)	Start Time	End Time
Block 1	RD10	2.04	25/01/2019 12:02	25/01/2019 13:50
	BR1	3.76	25/01/2019 12:04	25/01/2019 13:11
	BT5	1.56	25/01/2019 12:04	25/01/2019 13:13
	CFD23	5.08	25/01/2019 12:04	25/01/2019 13:11
	EW2	2.96	25/01/2019 12:04	25/01/2019 13:09
	EW9	3.34	25/01/2019 12:04	25/01/2019 13:11
	BU1	2.89	25/01/2019 12:04	25/01/2019 13:13
	EL11	4.15	25/01/2019 12:04	25/01/2019 13:08
	HT4	0.9	25/01/2019 12:04	25/01/2019 13:14
Sub Total (MW)		26.68		
Block 2	EW8	1.36	25/01/2019 12:32	25/01/2019 13:34
	LD3	2.4	25/01/2019 12:32	25/01/2019 13:37
	OAK23	3.34	25/01/2019 12:32	25/01/2019 13:37
	EL7	2.66	25/01/2019 12:32	25/01/2019 13:34
	EL8	4.04	25/01/2019 12:32	25/01/2019 13:34
	HT10	2.76	25/01/2019 12:32	25/01/2019 13:35
	OR25	2.59	25/01/2019 12:32	25/01/2019 13:37
	BT9	2.72	25/01/2019 12:34	25/01/2019 13:42
	EB12	2.87	25/01/2019 12:34	25/01/2019 13:38
	BR4	3.78	25/01/2019 12:34	25/01/2019 13:40
	SH22	1.93	25/01/2019 12:34	25/01/2019 13:40
	SH34	1.86	25/01/2019 12:34	25/01/2019 13:40
	DN10	4.15	25/01/2019 12:34	25/01/2019 13:42
Sub Total (MW)		36.46		
Block 3	BT14	3.34	25/01/2019 13:07	25/01/2019 14:14
	BT6	2.71	25/01/2019 13:09	25/01/2019 14:14
	CFD12	4.68	25/01/2019 13:10	25/01/2019 14:15
	CFD14	7.33	25/01/2019 13:10	25/01/2019 14:18
	BH22	4.75	25/01/2019 13:12	25/01/2019 14:19
	SH24	0.86	25/01/2019 13:14	25/01/2019 14:19
Sub Total (MW)		23.67		

Block 4	MTN31	8.11	25/01/2019 13:33	25/01/2019 14:32
	BW32	2.16	25/01/2019 13:35	25/01/2019 14:32
	KBH32	7.96	25/01/2019 13:36	25/01/2019 14:41
	EB14	3.22	25/01/2019 13:38	25/01/2019 14:41
	FTN13	2.97	25/01/2019 13:39	25/01/2019 14:43
	EM10	2.85	25/01/2019 13:39	25/01/2019 14:41
	K10	2.33	25/01/2019 13:39	25/01/2019 14:43
	WD16	1.15	25/01/2019 13:41	25/01/2019 14:45
	K2	3.51	25/01/2019 13:41	25/01/2019 14:43
	OE9	1.18	25/01/2019 13:41	25/01/2019 14:32
	SR14	1.55	25/01/2019 13:41	25/01/2019 14:43
Sub Total (MW)		36.99		
Block 5	DMA21	4.47	25/01/2019 14:13	25/01/2019 14:54
	NB25	4.44	25/01/2019 14:15	25/01/2019 14:54
	BW33	3.14	25/01/2019 14:17	25/01/2019 14:55
	BU10	4.05	25/01/2019 14:17	25/01/2019 14:55
	BT2	3.36	25/01/2019 14:18	25/01/2019 14:55
	EL5	2.82	25/01/2019 14:18	25/01/2019 14:55
Sub Total (MW)		22.28		
Block 6	BR6	2.54	25/01/2019 14:40	25/01/2019 14:55
	CDA22	6.03	25/01/2019 14:40	25/01/2019 14:55
	M21	2.33	25/01/2019 14:40	25/01/2019 14:56
	EL10	4.49	25/01/2019 14:40	25/01/2019 14:56
	K6	4.6	25/01/2019 14:42	25/01/2019 14:56
	SR11	1.9	25/01/2019 14:42	25/01/2019 14:56
	SS13	4.03	25/01/2019 14:42	25/01/2019 14:56
	OAK32	1.23	25/01/2019 14:45	25/01/2019 14:56
Sub Total (MW)		27.15		

Once again being a long dispatch period, the thermostat effects contributed to a decline in the delivered demand response throughout the duration of the dispatch with the lowest demand response of 30MW delivered at the end of the period. This is illustrated in Figure 12, which shows the voltage restoration period which was triggered at 1532 once UE confirmed with AEMO that the RERT service was no longer needed.

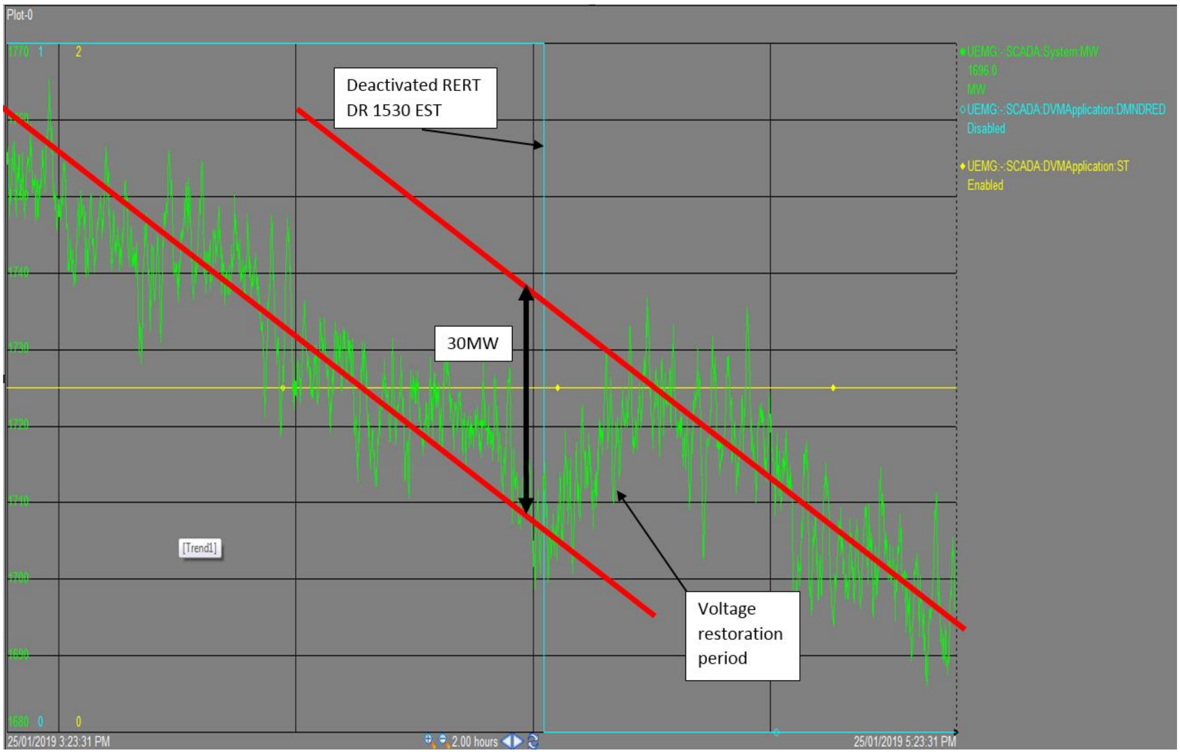


Figure 12 Restoration on 25th January 2019

4. UE DVMS Demand Response Capability

UE has undertaken sufficient demand response tests and RERT live events now over a wide range of network demand to start to develop a capability diagram of the DVMS in being able to deliver demand response. The diagram as of June 2019 can be presented in Figure 13.

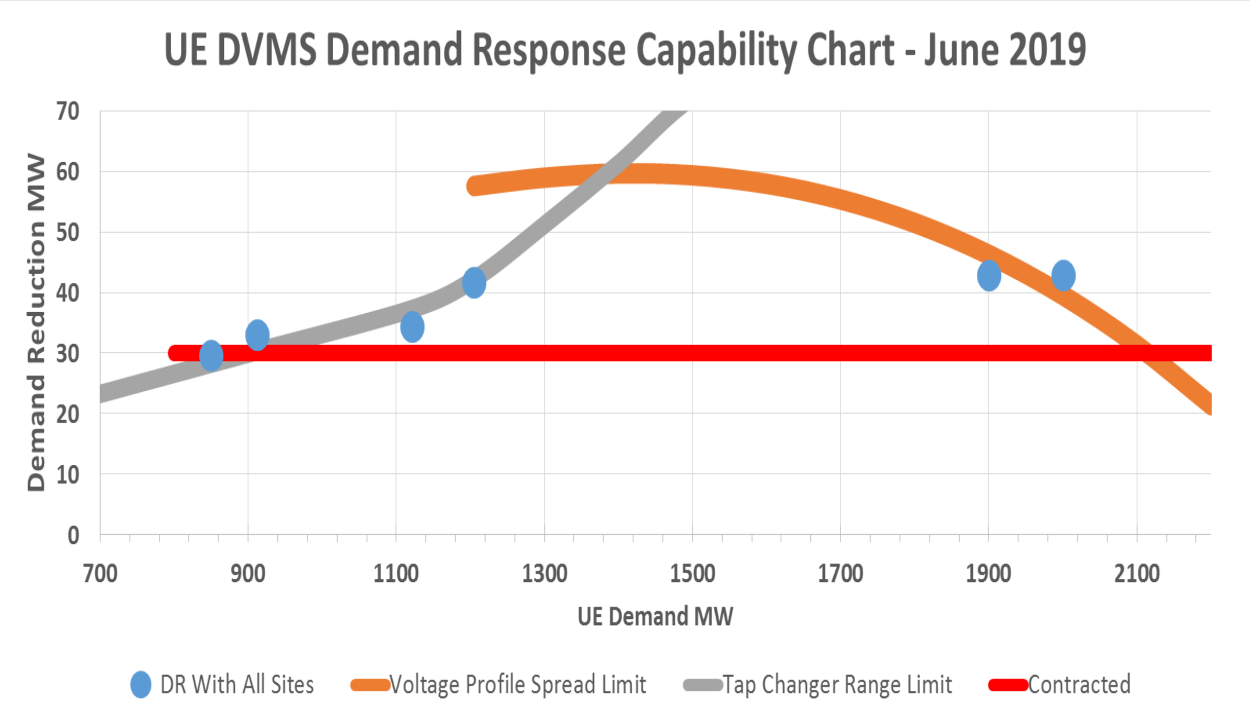


Figure 13 UE DVMS Demand Response Capability Diagram

Overlayed on the chart are the event results (in blue) for which customer voltages are maintained within AS 61000.3.100, and the AEMO contracted demand response requirement for UE (in red).

It can be observed that the magnitude of the demand response at low demand levels is limited by the available buck tap positions on our fleet of zone substation transformers (indicated by the grey line), whereas at high demand levels, the magnitude of the demand response is limited by the spread of customer voltages across our fleet of smart meters at each zone substation (indicated by the orange line).

UE is intending to undertake testing before the end of the programme to confirm the demand response capabilities at demand levels between 1300MW and 1800MW which suggest (at this stage) the points at which the maximum demand response capability can be delivered up to around 60MW.

The constraint equation for the customers' voltage-profile spread limit which is a reflection of the voltage drops which occurring through the distribution network as a result of network impedances can be approximated by:

$$\mathbf{DR_{MW}\ (voltage\ profile\ spread\ limit) = UE\ Demand_{MW} * dP/dV_{\%/\%} * (216_{V} - V1\%_{V}) / 230_{V}}$$

where dP/dV is the elasticity of active power to voltage (refer to Milestone 2 report) = 0.69 %/%.

The constraint equation for the zone substation tap range limit is a reflection of the available tap positions on the zone substation transformers can be approximated by:

$$\mathbf{DR_{MW}\ (tap\ range\ limit) = UE\ Demand_{MW} * dP/dV_{\%/\%} * (tap_{\#} - 1) * 1.25\%}$$

where $tap_{\#}$ is the average tap position at the UE $Demand_{MW}$ and 1.25% is the transformer tap step size.

5. Low-voltage distribution remedial works

5.1. Overall network impact of remedial works

The main driver for DVMS is to be able to dynamically move the voltage profile of each zone substation on the UE distribution network toward the lower limit of 216V (V1%) that is defined in Australian Standard 61000.3.100-2011 in order to deliver demand response service to minimise any customers outside of the stipulated regulatory limits.

Without implementing the LV remedial works, the voltage profiles for different UE's zone substations would experience under-voltage and over-voltage operating conditions when the operation mode of DVMS is changed from V99% (253V) to V1% (216V) or vice versa. In order to successfully deliver the required demand response level (30MW) via DVMS, the load profile of network is required to be altered to become 'taller' and 'narrower' to allow for the tap changes at zone substations to occur and the customers to remain within the voltage limits. This goal can be achieved by conducting a series of LV network works including changing the tap settings of distributions transformers, load balancing, relocating LV open points, network augmentation and connection checks.

Figure 14 and Figure 15 depict the LV network voltage profile averaged across all UE zone substations at time of maximum demand during summer 2018/19 prior to and post implementation of these LV remedial works respectively. The voltage profiles were obtained by averaging the voltages at 5:00pm EDST on 4 days where the temperature was above 35°C.

Figure 14 indicated that UE had a legacy steady state voltage compliance issue at maximum demand which has only been revealed (and can only be fixed) since the visibility provided by the smart meter rollout programme. This issue is likely to be common across all distribution networks in the NEM and stems from the lack of visibility of LV network voltages and the cumulative effects of this since the construction of the networks during the 20th century.

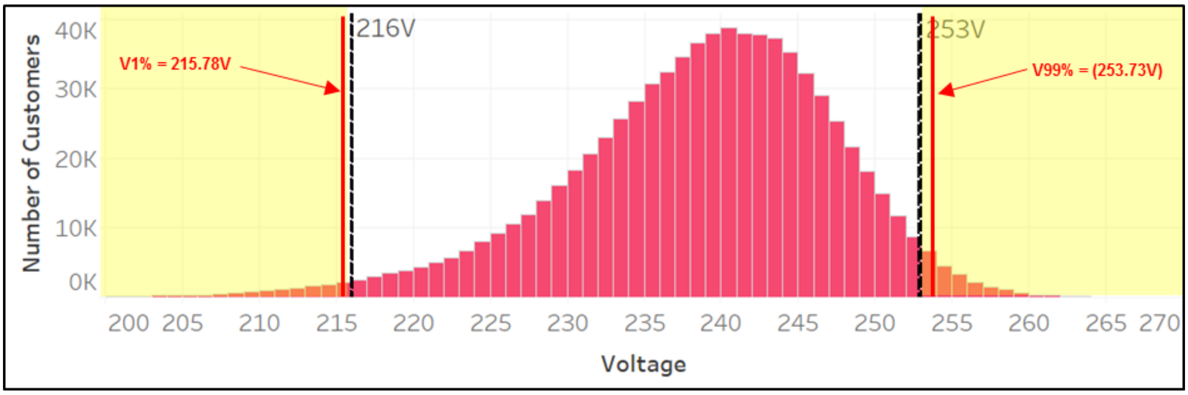


Figure 14 Voltage Profile of the UE Distribution Network Prior to LV Remedial Works (Peak Demand)

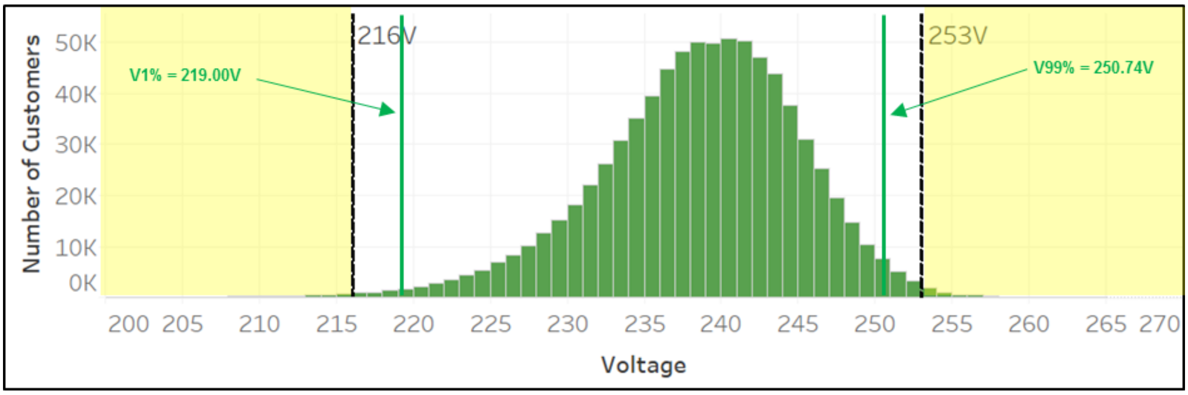


Figure 15 Voltage Profile of the UE Distribution Network Post LV Remedial Works (Peak Demand)

Figure 15 highlights the total effect of the LV remedial works performed (tap changes at distribution transformer level, load balancing, etc.) has had on the network. As it can be observed, the tails of the bell curve are now shorter in length, with more customers being pushed into the middle of the range. The LV remedial works have made UE's

population of LV voltages not only compliant with AS 61000.3.100-2011, but provided the additional margin needed to provide voltage reduction demand response capability.

Table 1 summarises the impact of these LV remedial works on voltage profiles across the selected 4 peak demand days.

Table 1: Network Voltages across 4 Peak Demand Days

Parameter	Prior to LV Remedial Works	Post LV Remedial Works	Improvement	
			(V)	(%)[1]
V1%	215.78V	219.00V	3.22	1.40
V50% (Median)	238.90V	238.32V	–	–
V99%	253.73V	250.74V	2.99	1.30
TOTAL	–	–	6.21	2.70

Voltage spread is calculated as the difference between the 99th percentile value (V99%) and the 1st percentile value (V1%).

For multiphase sites, the reported voltage spread is the maximum of the voltage spread values across all phases. For LV sites, it is expressed in percent of nominal voltage of 230V.

From demand response perspective, a lower value means better performance as it will indicate a narrower voltage profile for the zone substation. The voltage spread is a good indicator of how the voltage population distribution of each zone substation has been reduced in width, which in turn, allows DVMS to better shift the distribution up or down as required. Initially, a targeted V1% value of 223V was established for LV remedial works, while V99% remained 253V, to allow a voltage reduction margin down to V1% of 216V for RERT.

Therefore, the targeted spread value for each zone substation at peak demand was 30V (253V-223V), compared to the allowed spread as per the Victorian Electricity Distribution Code of 37V (253V-216V).

Only a subset of distribution substations from the total population needed to be targeted for LV remedial works to achieve this result.

As shown in Table 2, the voltage spreads at all remediated distribution transformers have improved after the LV remedial works were implemented.

[1] The reference is the nominal voltage of 230V.

Table 2: Impact of LV Remedial Works on Voltage Spread on the UE Distribution Network

Voltage Spread	Prior to Implementation of LV Remedial Works	Post Implementation of LV Remedial Works	Improvement	
			V	(%)[2]
Median	38.22V	32.05V	6.17	16.14
Maximum	45.67V (RBD)	36.64V (NW)	9.03	19.77
Minimum	28.85V (DSH)	20.83 (DSH)	8.02	27.80

According to Table 3, the voltage spread across the zone substations from the remedial works decreased by 6.17V with the greatest improvement occurring at Rosebud zone substation (RBD), with the voltage spread being reduced by 14.39V. Surrey Hills zone substations (SH) had the least improvement where the voltage spread decreased by only 0.29V.

Table 3 also summarises the improvement of voltage spread from the LV remedial works with respect to the number of zone substations.

Table 3: Voltage Spread Improvement – Zone Substation

Voltage Spread	Zone Substation		Improvement
	Prior to Implementation of LV Remedial Works	Post Implementation of LV Remedial Works	
≤ 37V (Allowed Voltage Spread)	33%	100%	67%
≤ 35V	13%	89%	76%
≤ 30V (Targeted Spread)	4%	20%	16%
≤ 25V	0%	2%	2%

On average, the voltage spread before was 37.95V which fell to 31.74V after the LV remedial works, a decrease of approximately 16.36%. For the complete list of voltage spread by zone substation, refer to Appendix A – Voltage Spread for Zone Substations.

5.2. Distribution transformer tap changes

In 2018 and 2019, 625 distribution substations were to have their transformer tap settings altered in order to achieve a target V1% of 223V in V99% mode at the zone substation level.

Of the 625 sites listed for needing a tap change, 537 substations have successfully had their tap setting changed correctly. Of the remaining sites, 80 have been attempted, but due to one reason or another, were unable to be completed and 8 have not yet been attempted.

Table 4 breaks down the work carried out.

[2] The reference is the initial value.

Table 4: Status of Distribution Transformer Tap Changes on the UE Distribution Network under DVMS Project

Status		Number of Distribution Substation	Total
Successful		537	85.92%
Unsuccessful	Not Yet Completed	8	1.28%
	Seized Tap Screw	52	8.32%
	Highest/Lowest Tap Setting	8	1.28%
	Incorrect Tap Change	9	1.44%
	Maintenance Defect	8	1.28%
	Other	3	0.48%
Total		625	100%

52 distribution substations had their tap screw seized, meaning operators were physically unable to change the tap setting as the bolt had galled itself to the lock nut. Once a bolt has seized, it is typically impossible to remove without cutting the bolt or splitting the nut.

8 sites were already on their lowest or highest tap setting when the service orders were sent out and thus, unable to be changed.

9 sites had their tap settings changed incorrectly. After checking the zone substation voltages these sites are located on, it was determined that no further work would be necessary as the zone substations were adequately within V1% and V99% settings.

2 sites were not tapped up high enough, and a further service order was raised, and work completed in February 2019. Due to a variety of reasons, 11 sites were deemed unsafe to work on.

8 of these sites were unsafe due to maintenance defects, and 3 because of bees residing in the pole.

Table 5 shows how many sites were tapped up/down and to what extent.

Table 5: Number of Distribution Transformer Tap Changes broken down by Direction and Amount of Change

Voltage Spread	Voltage Change (V)	Number of Distribution Substation	Total	Total Number
Tapped up	+6.25	331	61.64	367
	+12.50	36	6.70	
Tapped down	-6.25	147	27.37	170
	-12.50	23	4.28	
Total		537	100	537

Figure 16 depicts a map of all distribution substations across the UE network that were to have their transformer tap setting changed. The colour of each dot represents if the work was completed, or not, and why.

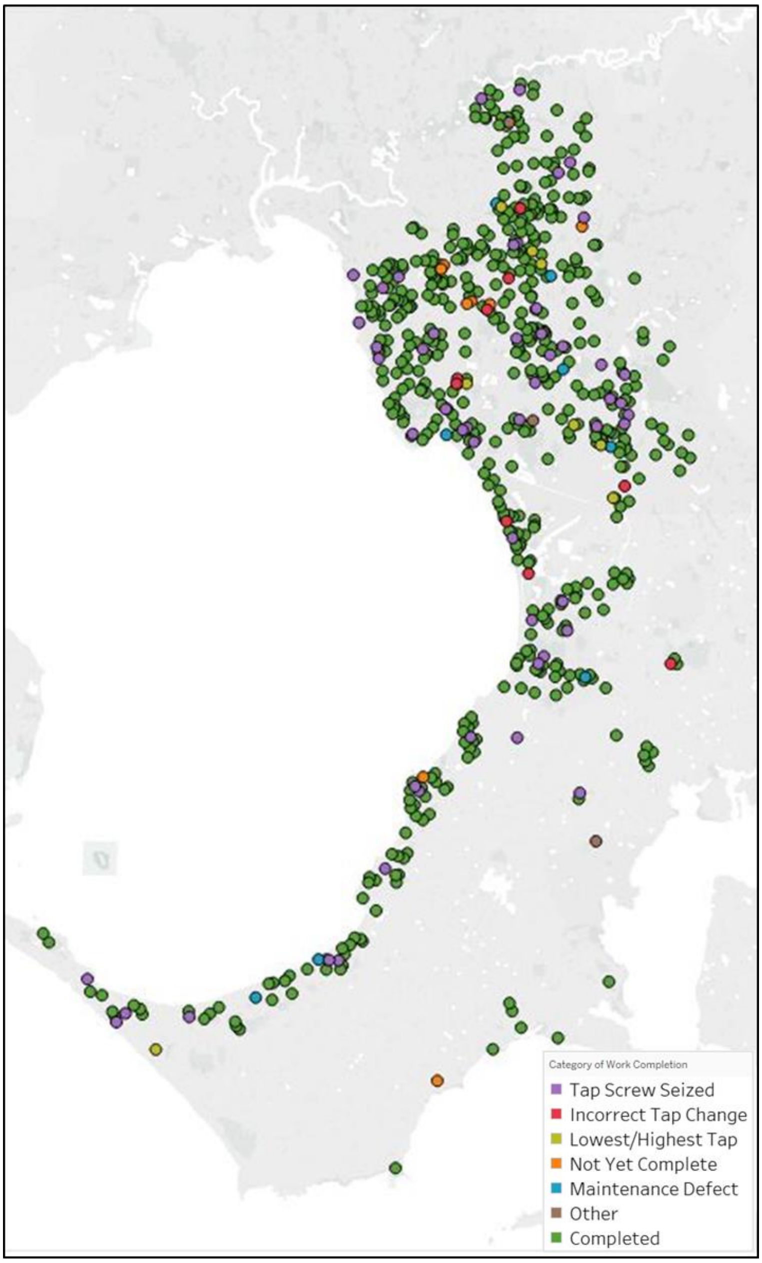


Figure 16 Geographic Location of Distribution Substations where Tap Changes Occurred

Of the sites that were not completed, alternative sites were not provided as the objectives to reduce the voltage spread to a desired value were achieved within the sites that were completed.

For distribution substations experiencing under-voltages, the tap changes that were organised enabled the voltage to rise on 331 distribution substations by 6.25V, and 36 distribution substations to rise by 12.5V.

For distribution substations experiencing over-voltages, a voltage drop on 147 distribution substations of 6.25V was achieved from tap changes and on 23 other distribution substations, 12.5V.

Figure 17 depicts the effect of changing the tap settings at distribution transformers that required a tap change (either raise or lower) on 2 peak demand days (19/01/18 and 03/02/19). Sites that had to have multiple types of LV remedial works done (i.e. tap change and load balance together) were not included in this plot. The customers impacted by these distribution transformer tap changes had a sample size of only 5.3% of total customers on the UE distribution network.

According to Figure 17, prior to the tap changes occurring, the voltage histogram on the 19th of January 2018 had voltages that were on the extreme ends of the spectrum.

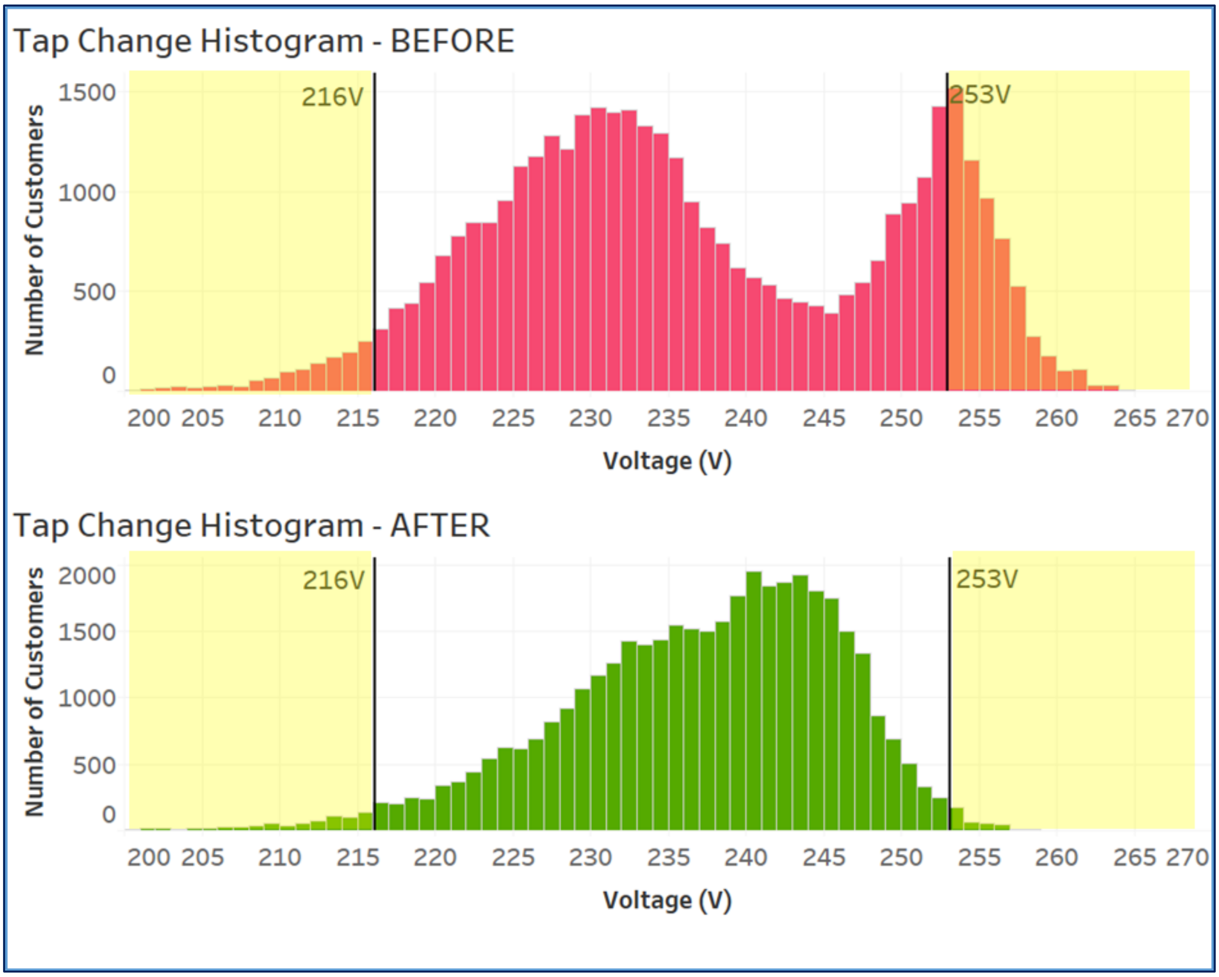


Figure 17 Voltage Histograms for Distribution Substations with Tap Changes Prior to (19/01/18) and Post (03/02/19) Implementation

For those sites that were experiencing under-voltages, their transformers were tapped up (green) in a bid to shift the distribution to the right. For those sites that were experiencing over-voltages, their transformers were tapped down (red) in order to shift the distribution to the left. These changes are demonstrated in Figure 18.

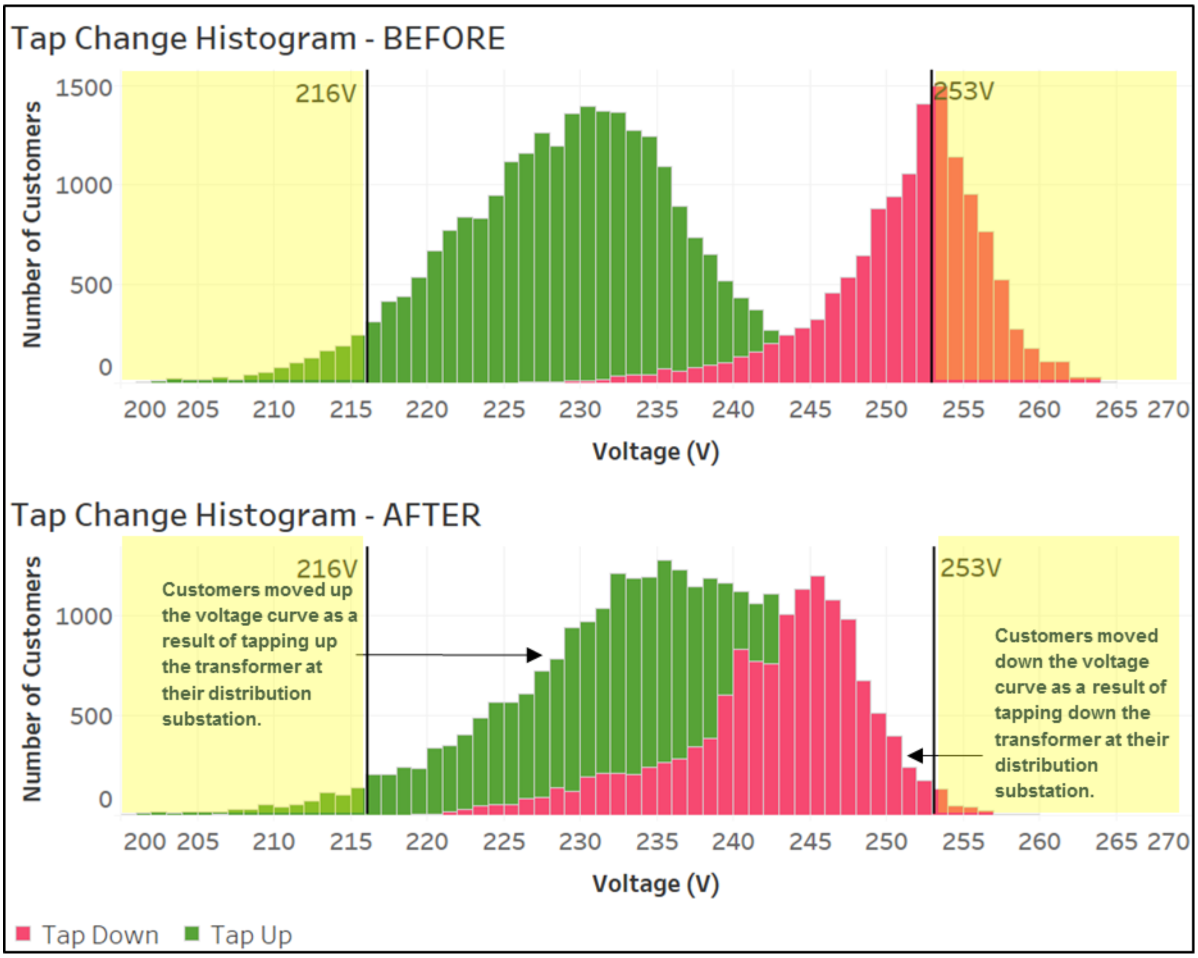


Figure 18 Voltage Histograms for Distribution Substations that were Tapped Down and Up Prior to (19/01/18) and Post (03/02/19) Implementation

After the tap changes occurred, the voltage profiles shifted from being on the ends, to being in the middle of the voltage limit range.

Table 6 summarises the impact of distribution transformer tap changes and also DVMS on V1%, V99% and Voltage Spread values.

Table 6: Impact of Distribution Transformer Tap Changes and DVMS on V1% and V99% (Excluding other LV Remedial Works)

Voltage Parameter	Prior to Distribution Transformer Tap Changes	Post Distribution Transformer Tap Changes	Improvement	
			V	(%)[3]
V1%	211.8V	213.0V	1.2	0.52
V99%	259.4V	252.8V	6.6	2.87
Voltage Spread	47.6V	39.8V	7.8	16.38

[3] The references for V1%, V99% and Voltage Spread are 230V, 230V and the initial value.

According to this table, implementing distribution transformer tap changes have improved all of the values including V1%. It should be noted that V99% was dropped due to both distribution transformer tap changes and operation of DVMS on the network and this is the reason of smaller improvement of V1%. In other words, even after the voltage drop as a result of DVMS operation, V1% had a slightly higher value before the LV remedial works compared to after completing these works.

In order to check whether the correct tap changes occurred, field datasheets for each distribution substation were analysed. The substation name, and date the tap change occurred was input into a distribution substation voltage and current plotting tool, and the output was observed. As Figure 19 and Figure 20 depict, a visual step up or step down in voltage can be observed when the distribution transformer tap changes were successfully completed.

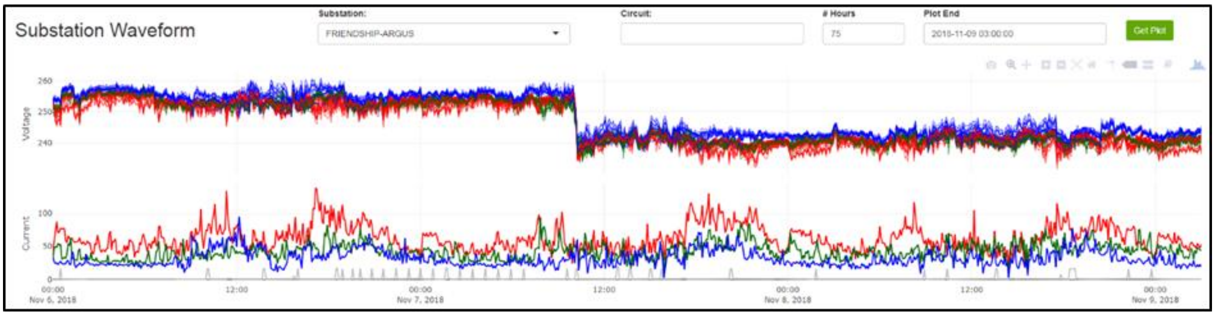


Figure 19 Voltage and Current Waveforms of a Distribution Transformer that was Tapped Down by 12.5V on 07/11/2018

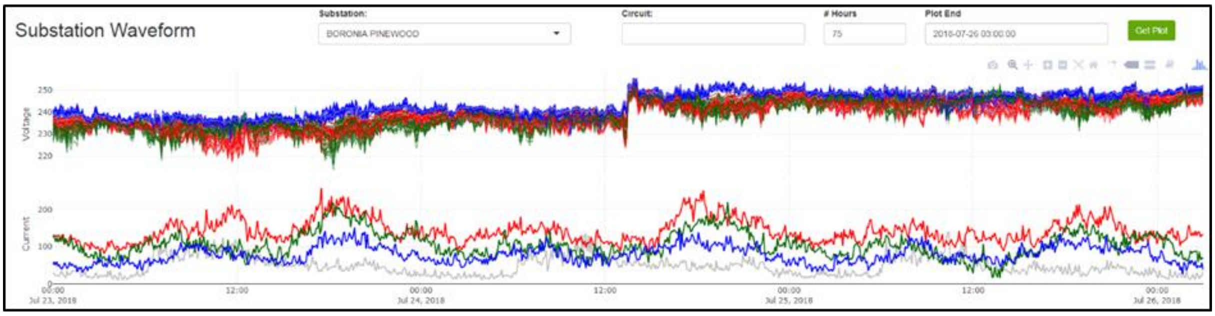


Figure 20 Voltage and Current Waveforms of a Distribution Transformer that was Tapped up by 12.5V on 24/07/2018

Moreover, in addition to the comments on the DTTC sheets, the service operators who worked at the various sites also included pictures of the transformer settings before and after, as well as the distribution transformer nameplate ratings. After analysing all the available information for each distribution substation, a breakdown of whether the tap changes were successful or not was calculated.

For more information on the procedure deployed for changing the distribution transformer taps, refer to Appendix B – Distribution Transformer Tap Change Procedure.

5.3. Load balancing

UE changed the phase grouping of over 9,000 customers in order to better position the voltage and current waveforms at their respective distribution substations.

This was done by initially plotting the current waveform at a particular distribution substation. A load imbalance would be observed, and the distribution substation would be earmarked as needing its load balanced. As the example in Figure 21 depicts, the load at the distribution transformer was unbalanced, Phase Group 1 was heavily loaded while Phase Group 3 was lightly loaded.

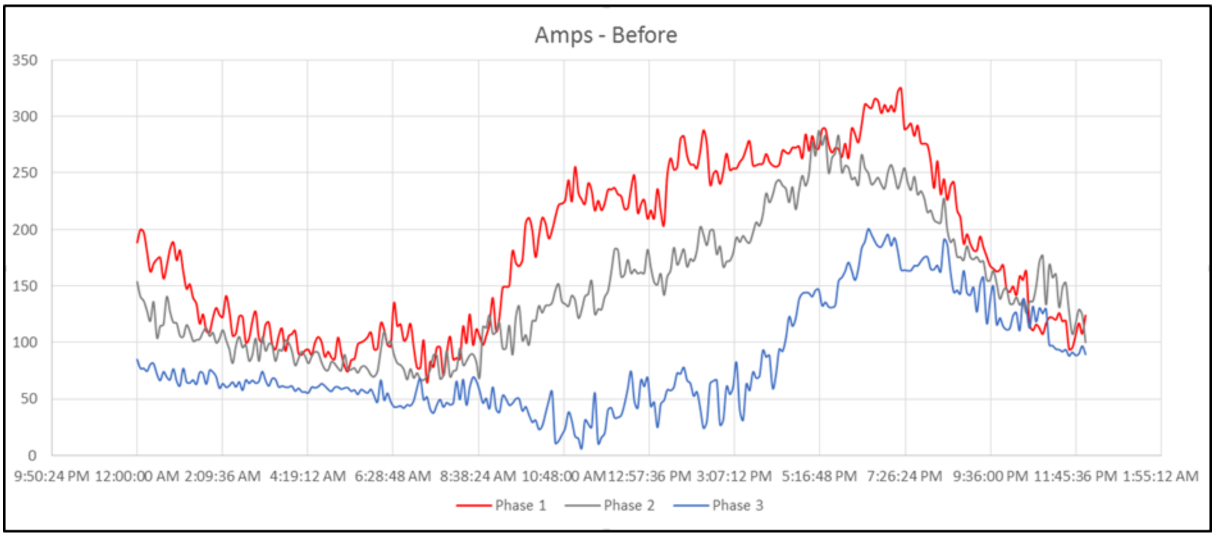


Figure 21 Actual Current Prior to Performing Load Balancing at Distribution Substation as at 19/01/18

As a result, 4 customers who were originally on Phase Group 1, were set to switch to Phase Group 3, and the estimated, balanced load depicted in Figure 22.

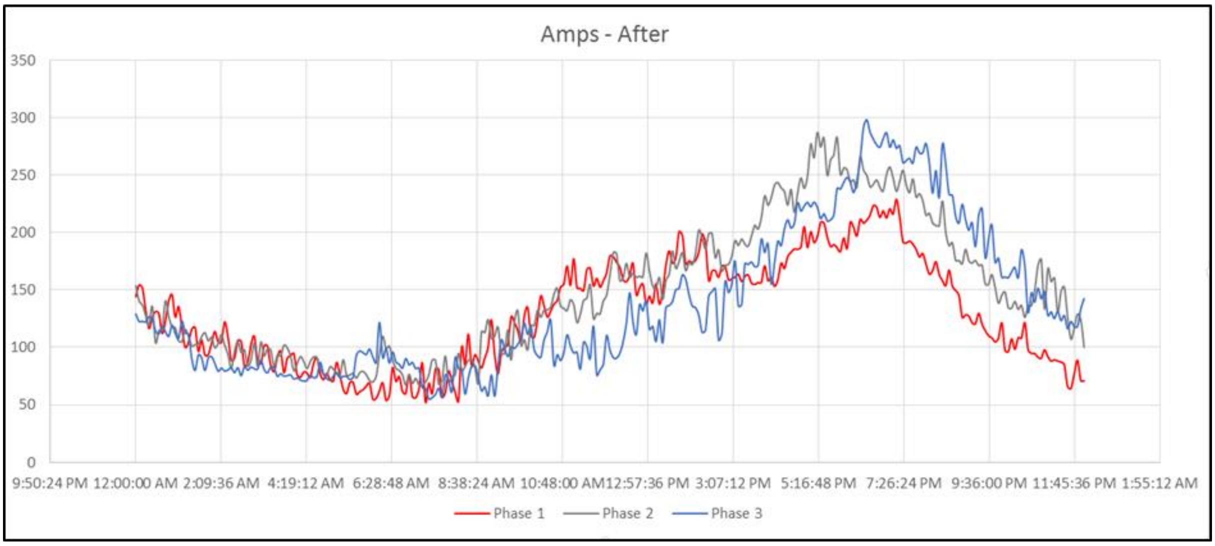


Figure 22 Estimated Current Post Implementing Load Balancing at a Distribution Substation

Figure 23 shows how the network voltage histogram has changed on the worst sites that required load balancing (normalised for any associated tap change that may have also been applied).

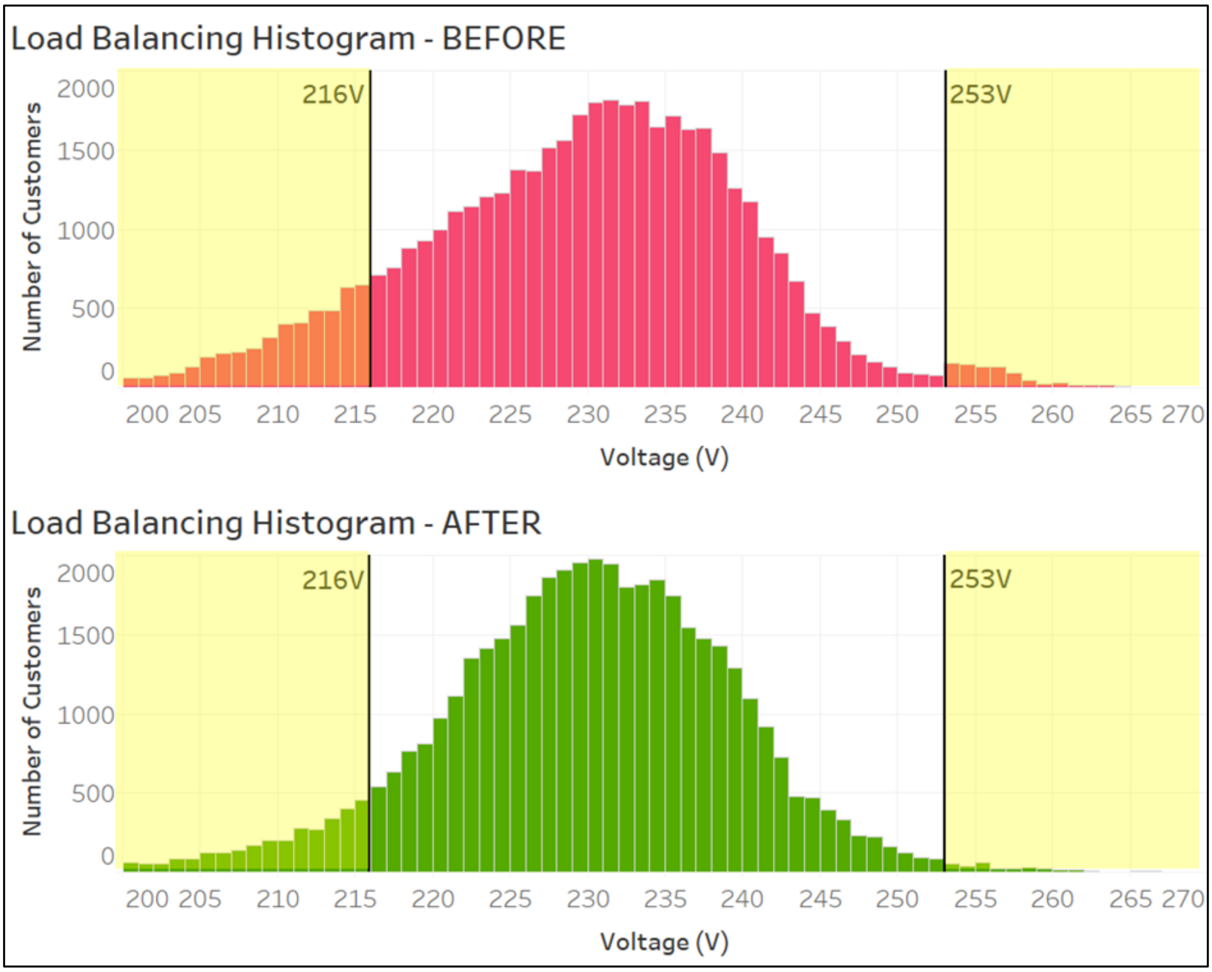


Figure 23 Effect of Load Balancing on the Network, Before (19/01/18) and After (03/02/19) LV Works

The effect on the network is summarised in Table 7.

Table 7: Impact of Load Balancing and DVMS on V1% and V99% (Excluding other LV Remedial Works)

Voltage Parameter	Prior to Distribution Transformer Tap Changes	Post Distribution Transformer Tap Changes	Improvement	
			V	(%)[4]
V1%	204.4V	204.0V	-0.4	0.17
V99%	255.5V	251.3V	4.2	1.83
Voltage Spread	51.1V	47.3V	3.8	7.43

According to this table and similar to distribution transformer tap changes, implementing load balancing have improved all of the values including V1%. It should be noted that V99% was dropped due to both load balancing and operation of DVMS on the network and this is the reason of negative improvement of V1%.

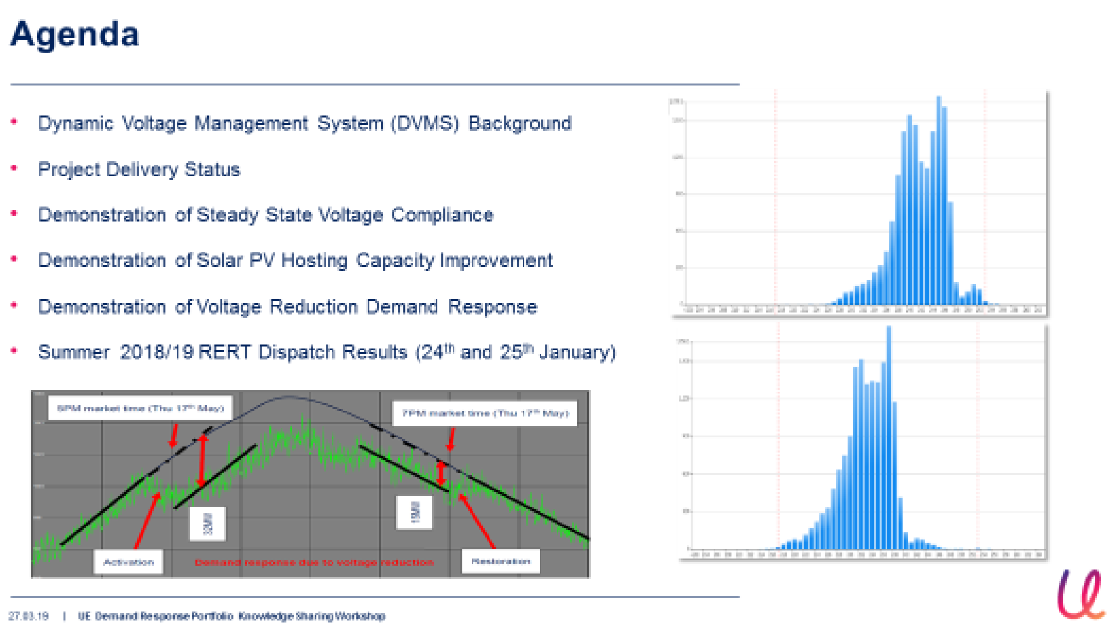
[4] The references for V1%, V99% and Voltage Spread are 230V, 230V and the initial value.

6. Knowledge Sharing Activities

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

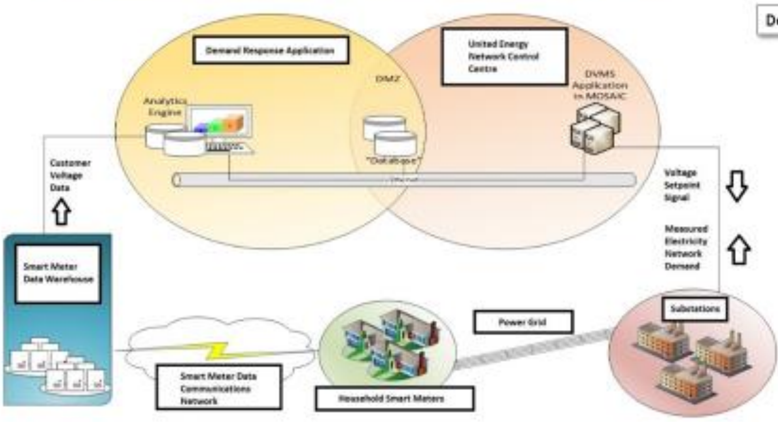
- UE and AGL Demand Response Knowledge Sharing Workshop on 6th February 2019.
- UE and SA Power Networks Knowledge Sharing Workshop on 7th February 2019.
- UE and AGL Demand Response Knowledge Sharing Workshop on 26th March 2019.
- Presented at ARENA Demand Response Portfolio Knowledge Sharing Workshop on 27th March 2019.
- Presented at TasNetworks Future Networks Distribution Forum in Hobart on 9th April 2019.
- Presented at RMIT Industry Lecture for Advanced Power System on 27th May 2019.
- 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.

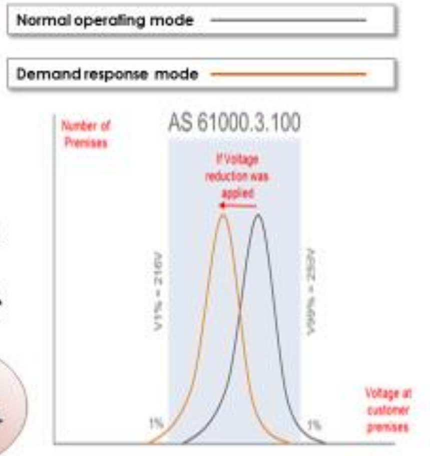
6.1. ARENA Demand Response Portfolio Knowledge Sharing Workshop



Dynamic Voltage Management System (DVMS) Background

- Using Smart Meters to deliver simultaneous Steady State Voltage Compliance, Demand Response Capability and Increased Solar PV Hosting Capacity



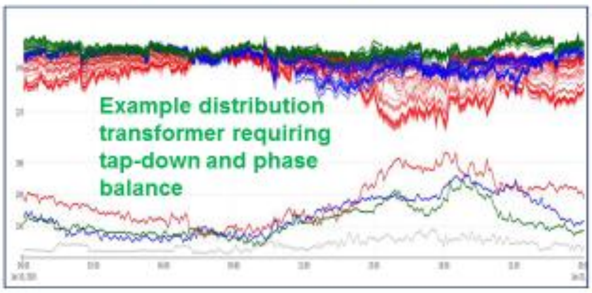


27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

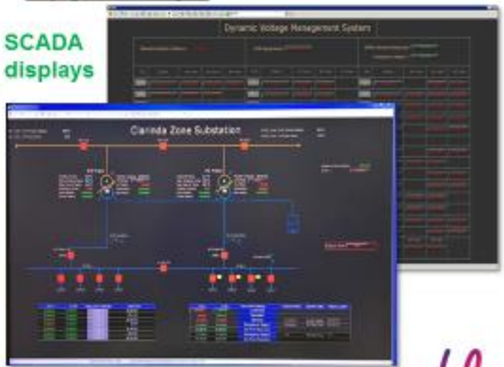
Project Delivery Status

- Project ahead of schedule with 46 of 47 zone substation relay replacements completed and DVMS enabled at all of these.
- Distribution works for phase balancing, tap changes and loose connections completed in full.
- Plan to commission last site, fine-tune performance and troubleshooting some minor technical issues during 2019.

Relay replacements

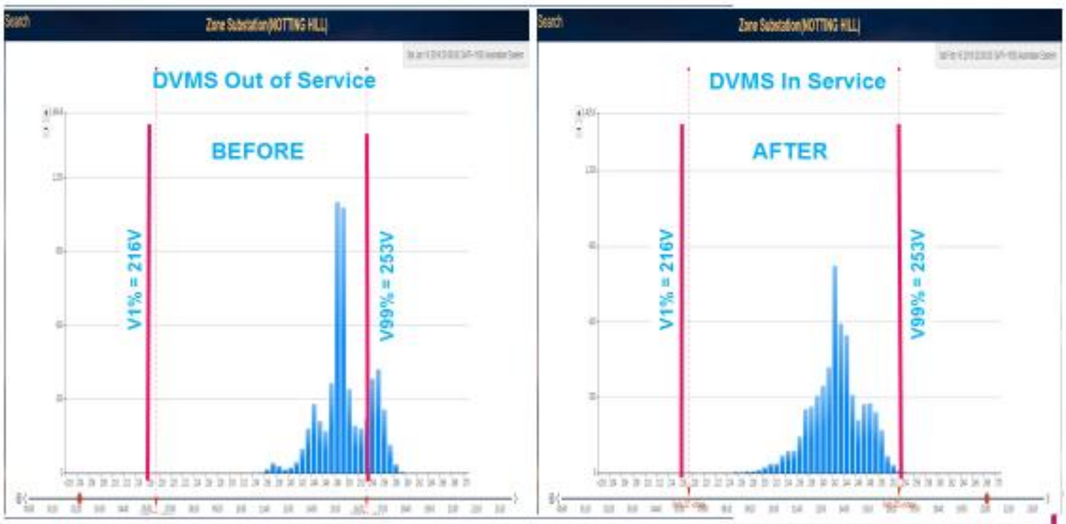


SCADA displays



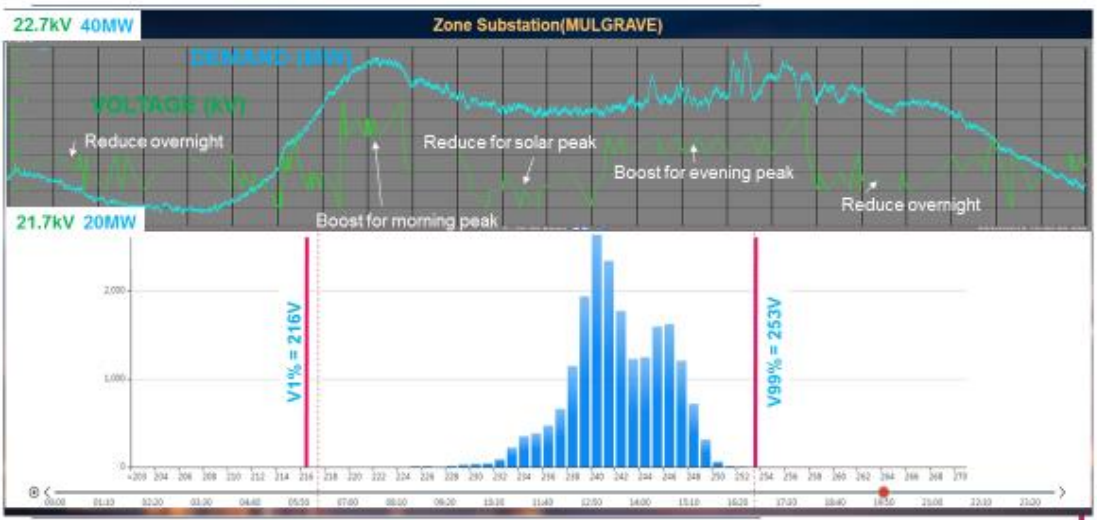
27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

Dynamic Voltage Regulation – Steady State Voltage Compliance



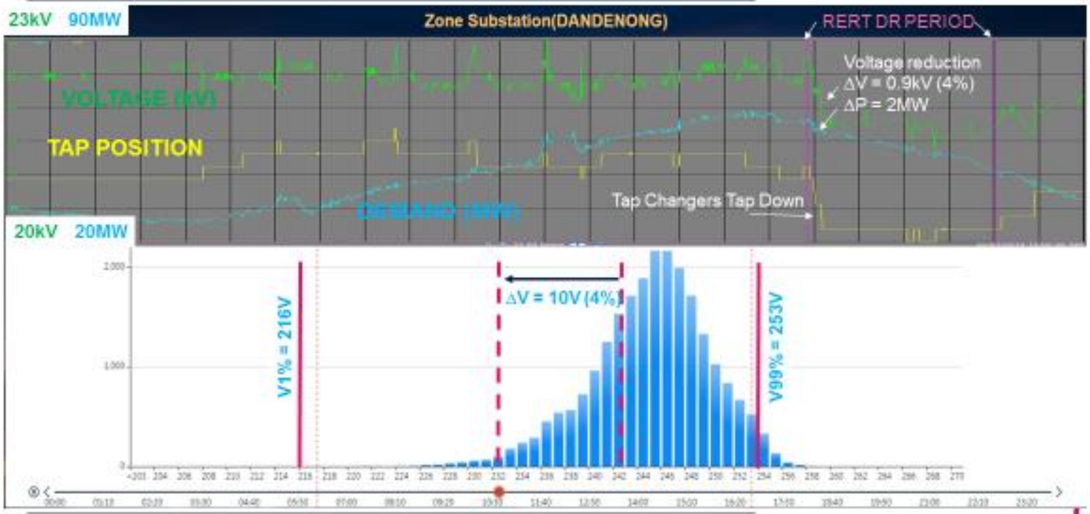
27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

Dynamic Voltage Regulation - Solar Hosting Improvement



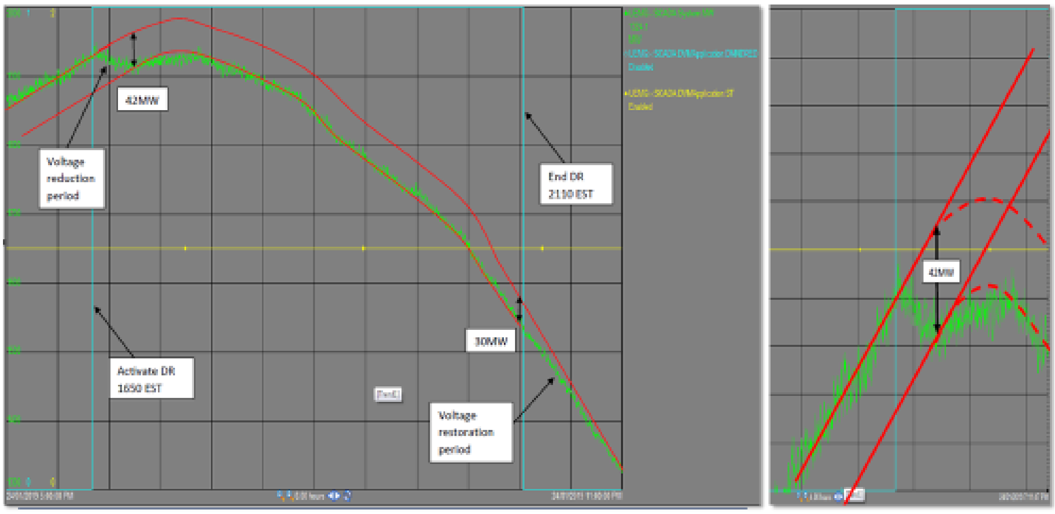
27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

Dynamic Voltage Regulation - Voltage Reduction DR



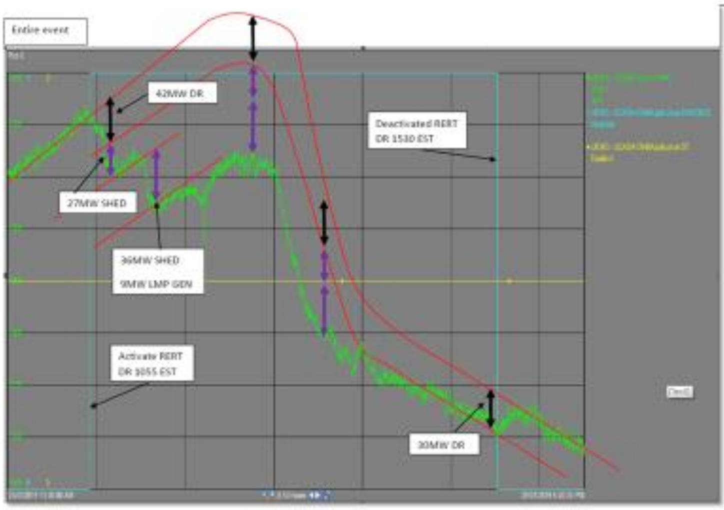
27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

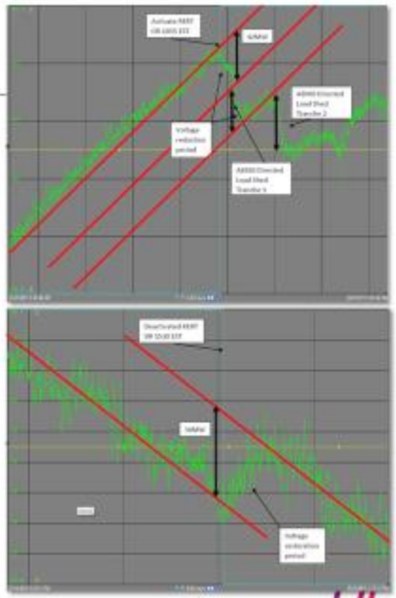
RERT Dispatch – 24th January 2019



27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

RERT Dispatch – 25th January 2019





27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

Conclusions

- Smart meter analytics coupled with voltage regulation has enabled us to deliver Dynamic Voltage Management capability.
- UE has successfully tested this capability and has deployed to all but one zone substation during 2018.
- We can apply conservation voltage reduction to deliver large-scale demand response capability minimising the risk of violating regulatory voltage limits.
- Have demonstrated demand response services for AEMO's SN RERT with 10-minute activation time.
- Quality of supply compliance is achievable (steady state over-voltage and under-voltage).
- Allows for higher penetration of solar PV by automatically adapting (on a population basis) to new solar PV connections and variable solar PV output.

27.03.19 | UE Demand Response Portfolio Knowledge Sharing Workshop

7. 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
CDA	Clarinda Zone Substation
CPU	Central Processing Unit
DVMS	Dynamic Voltage Management System
EM	East Malvern Zone Substation
FOC	Fibre Optic Connector
GIS	Geographical Information System
HMI	Human-Machine Interface
HV	High Voltage
IED	Intelligent Electronic Device
I/O	Input and Output
IU	Interface Unit
LAN	Local Area Network
LV	Low Voltage
NAP	Network Analytics Platform
NCC	Network Control Centre
OLTC	On-Load Tap Changer
OT	Operating Technology
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition

Term	Description
SDVMA	SCADA Dynamic Voltage Management Application
SF	Steel Frame
SIOS	SCADA Input / Output Schedule
SNTP	Simple Network Time Protocol
TPI	Tap Position Indicator
UE	United Energy
VRR	Voltage Regulating Relay
VT	Voltage Transformer

8. Appendix A – Voltage Spread for Zone Substations

Table 8: Voltage Spread Improvement on Each Zone Substation

Voltage Spread	Voltage Spread		Improvement	
	Prior to LV Remedial Works	Post LV Remedial Works	V	%
BH	42.71	33.25	9.46	22
BR	37.79	31.05	6.73	18
BT	36.50	34.35	2.16	6
BU	38.48	33.06	5.42	14
BW	39.18	33.74	5.44	14
CFD	38.92	32.05	6.87	18
CM	38.17	25.53	12.64	33
CRM	40.79	30.51	10.28	25
DC	39.73	35.98	3.75	9
DMA	40.45	31.69	8.76	22
DN	35.97	33.38	2.59	7
DSH	28.85	20.83	8.03	28
DVY	35.17	27.40	7.77	22
EB	39.97	34.03	5.94	15
EL	36.84	30.70	6.14	17
EM	37.50	35.48	2.02	5
EW	29.82	26.41	3.41	11
FSH	39.46	33.78	5.68	14
FTN	37.05	30.34	6.72	18
GW	37.96	32.78	5.18	14
HGS	39.13	32.05	7.08	18
HT	38.83	28.08	10.76	28
K	37.10	32.60	4.49	12
KBH	33.56	29.64	3.92	12
LD	35.94	28.68	7.26	20

Voltage Spread	Voltage Spread		Improvement	
	Prior to LV Remedial Works	Post LV Remedial Works	V	%
LWN	35.68	28.56	7.12	20
M	37.00	31.49	5.51	15
MC	39.99	31.27	8.72	22
MGE	38.60	31.54	7.06	18
MR	40.91	35.51	5.40	13
MTN	41.45	32.82	8.63	21
NB	37.46	31.74	5.72	15
NO	33.69	31.21	2.47	7
NP	38.26	33.49	4.76	12
NW	39.02	36.64	2.38	6
OAK	39.33	31.50	7.83	20
OE	40.01	36.59	3.41	9
OR	35.71	32.87	2.84	8
RBD	45.67	31.27	14.39	32
SH	34.76	34.47	0.29	1
SR	41.10	32.09	9.01	22
SS	38.28	32.38	5.90	15
STO	44.24	32.18	12.06	27
SV	34.38	28.98	5.40	16
SVW	36.32	31.64	4.69	13
WD	38.17	34.56	3.62	9
AVERAGE	**37.95**	**31.74**	**6.21**	**16**

9. Appendix B – Distribution Transformer Tap Change Procedure

First, according to the load on the distribution transformer and the number of LV circuit parallels, the capability of supplying the supplied customers via adjacent distribution transformers by closing the open points (LV paralleling) shall be identified. If this capability is feasible, then changing the tap setting can be carried out without customer outages.

If paralleling cannot be performed due to the technical limitations, a notification regarding the outage and transformer shutdown shall be submitted to customers supplied by the distribution transformer at least four (4) working days prior to carrying out the works.

UE Network Control Centre (NCC) shall also be notified regarding this work on the transformer at least fourteen (14) working days before the works can be carried out and their approval shall be sought prior to commencing work.

On arrival on site, field crews shall:

- Record existing tap setting of the distribution transformer in the relevant DTTC sheet in MS Excel format;
- Record the time and measure on-load voltage and current of each phase at LV side of the distribution transformer with the existing tap setting before transferring any customers to adjacent distribution transformers. The readings from these tests will be recorded in the DTTC sheet.

All of the programmed (and alternative – if applicable) distribution transformers are required to have their voltages tapped down or up by the magnitudes advised by UE. In other words, by carrying out the tap change, output voltages of the transformer will decrease or increase by the advised voltage levels.

The most common tap settings of the distribution transformers installed on the UE distribution network are summarised in Table 9, Table 10 and Table 11.

Table 9: Voltage Tap Settings for Distribution Substations with 9 Positions

TAP SETTING WITH 9 POSITIONS		
Tap Position	**HV Voltage (%)**	**LV Voltage (%)**
1	103.75	100
2	102.50	100
3	101.25	100
4	100.00	100
5	98.75	100
6	97.50	100
7	96.25	100
8	95.00	100
9	93.75	100

Table 10: Voltage Tap Settings for Distribution Substations with 7 Positions

TAP SETTING WITH 7 POSITIONS		
Tap Position	**HV Voltage (%)**	**LV Voltage (%)**
1	110.00	100
2	107.50	100
3	105.00	100
4	102.50	100
5	100.00	100
6	97.50	100
7	95.00	100

Table 11: Voltage Tap Settings for Distribution Substations with 5 Positions

TAP SETTING WITH 5 POSITIONS		
Tap Position	**HV Voltage (%)**	**LV Voltage (%)**
1	102.50	100
2	100.00	100
3	97.50	100
4	95.00	100
5	92.50	100

If tap setting of any transformer has different positions, voltages of the transformer shall be tapped down/up by as close to the advised tap as possible. For such a transformer, the tap settings shall be recorded in the DTTC sheet.

For example for 1 tap down, for transformers with 7 and 5 tap positions, they shall be tapped down by 1 tap (2.50%) and for those ones with 9 tap positions, they shall be tapped down by 2 taps (total 2.50%).

After changing the tap setting, field crew shall:

- Record new tap setting of the distribution transformer in the relevant DTTC sheet in MS Excel format;
- Measure off-load voltage of each phase at LV side of the distribution transformer with the new tap setting and record them with the time stamp in the relevant DTTC sheet in MS Excel format;
- Record the time and measure on-load voltage and current of each phase at LV side of the distribution transformer with the new tap setting after transferring all of the customers from adjacent distribution transformers. The readings from these tests will be recorded in the DTTC sheet in MS Excel format.
- Take clear photos of the transformer name plate and tap change switch and attach them to the folder of the DTTC sheets to be submitted to UE Network Planning.

After completion of the work, the DTTC sheet filled in with the requested information in MS Excel format with the taken photos shall be submitted to UE Network Planning & Strategy at planning@ue.com.au. The following document naming convention shall be followed:

- DTTC – SUBNAME [the distribution transformer tap change sheet]
- NAMEPLATE – SUBNAME [photo of transformer name plate]
- TAP_CURRENT – SUBNAME [photo of current tap position – after tap change]
- TAP_ ORIGINAL – SUBNAME [photo of original tap position – before tap change]

The procedure for adjusting tap settings of the UE distribution transformers is summarised in the flow chart illustrated in Figure 24.

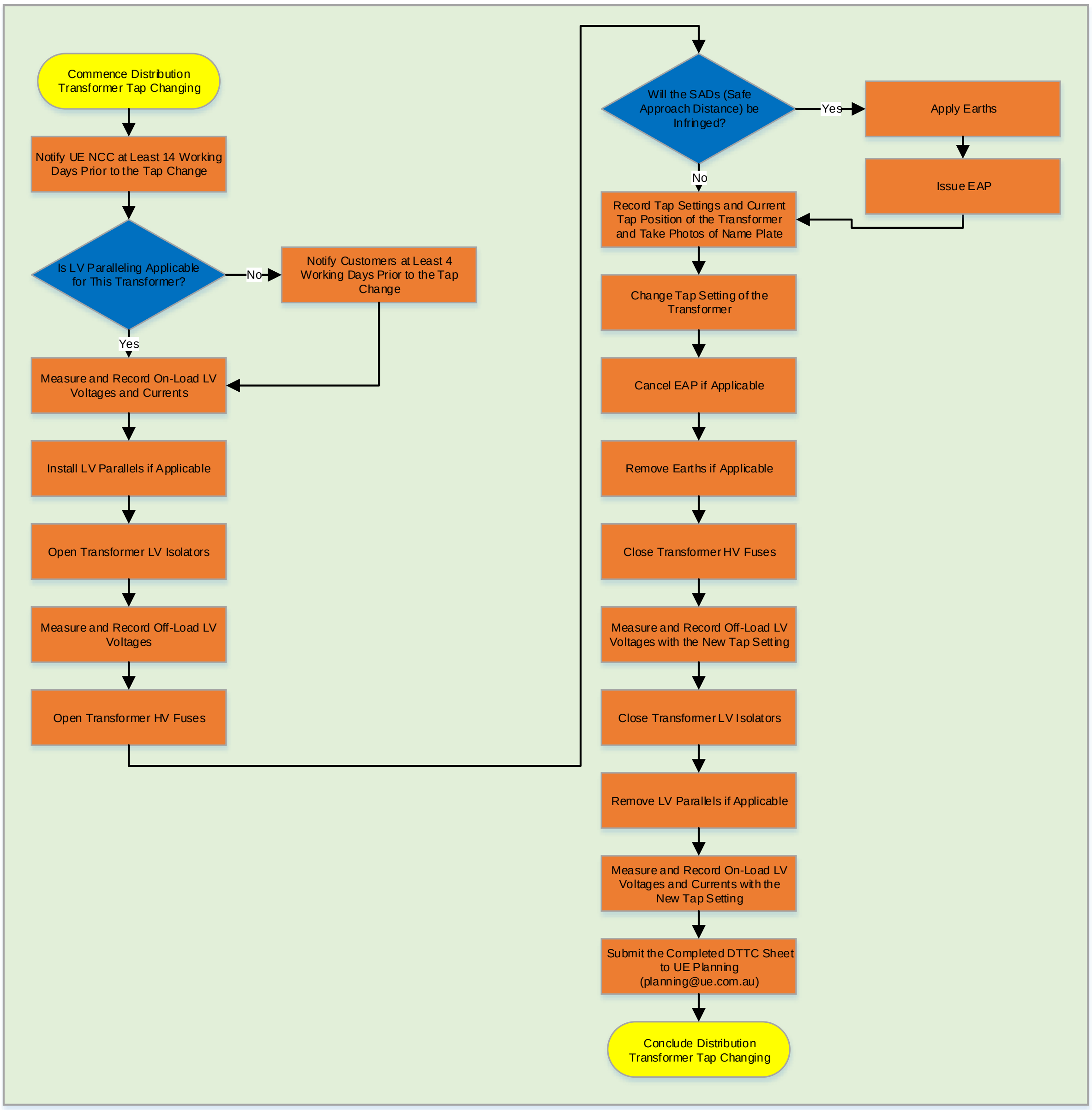


Figure 24 Procedure for Adjustment of Tap Settings of the Distribution Transformers on the UE Distribution Network

Figure 25 and Figure 26 shows the samples for the photos of the transformer tap change and also the tap change switches, respectively which shall be taken and submitted to UE for our records[5]. It should be noted that all of the information on the name plate and also the number of the tap change switch shall be legible.

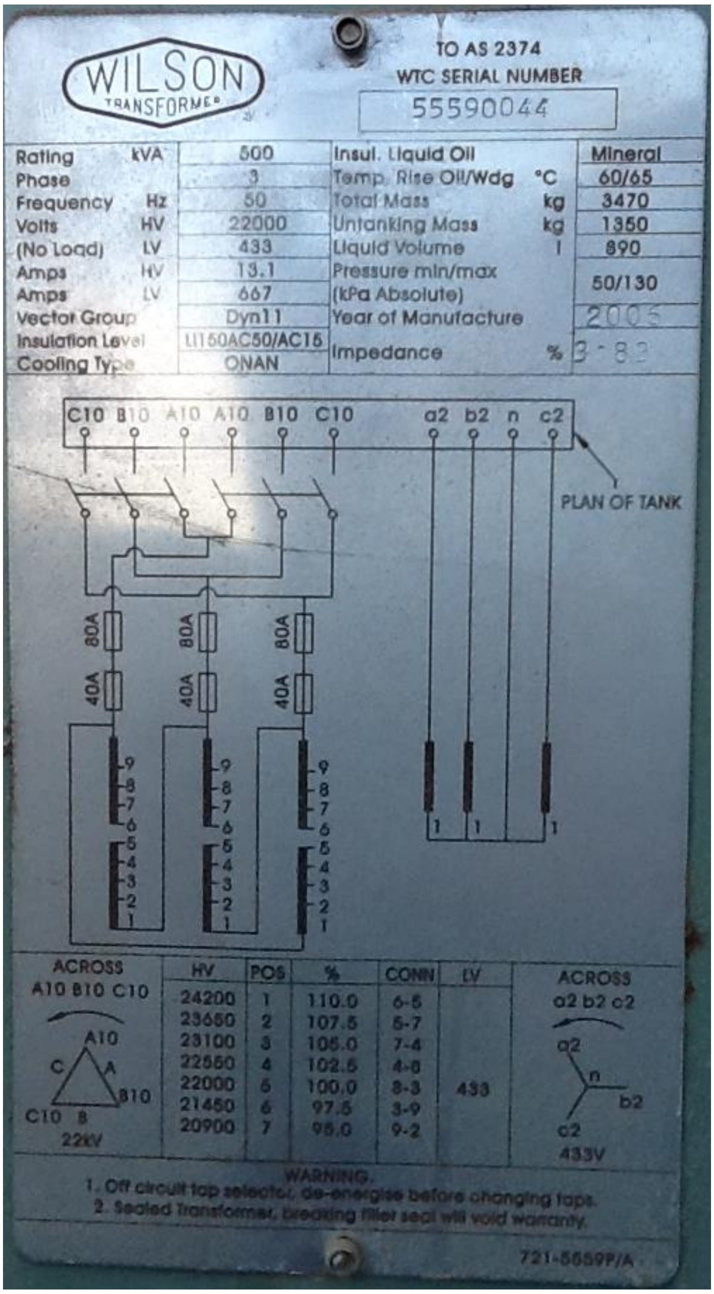


Figure 25 An Approved Sample Photo of a Distribution Transformer Name Plate Legibly Showing All of the Technical Specifications

[5] The need for such photos is due to the fact that there are some discrepancies for the number of tap positions on the transformer name plate and the tap change switches for some distribution transformers on the UE distribution network and the photos will assist in identifying such discrepancies and recording the correct number of tap positions

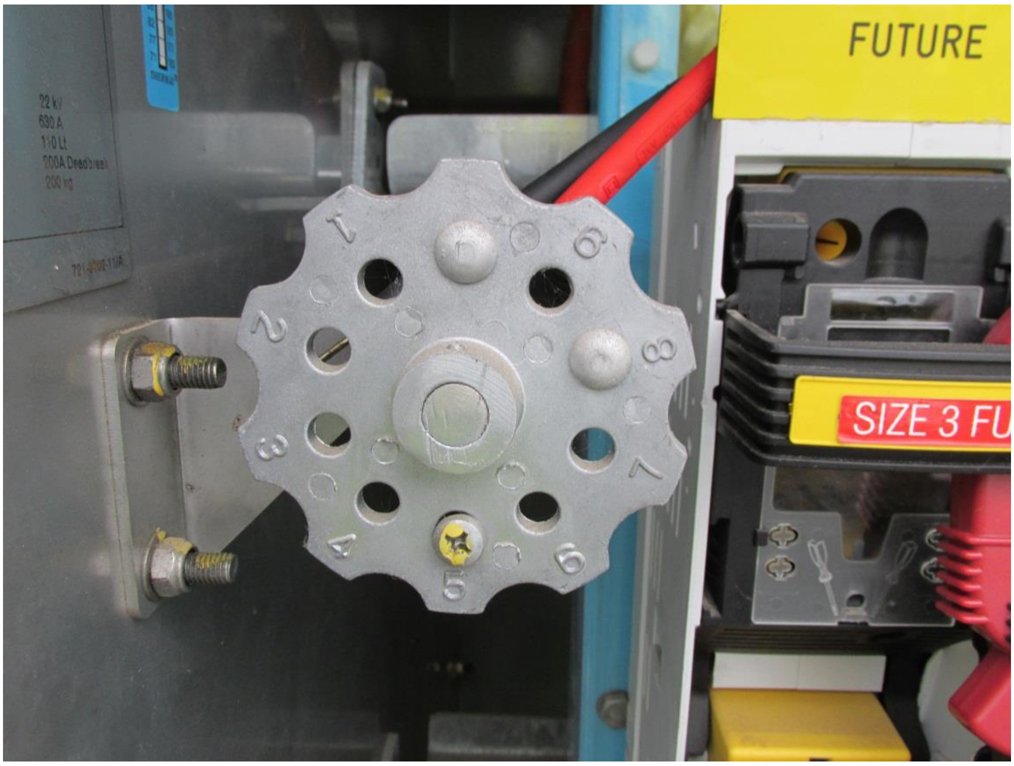


Figure 26 A Sample Photo of a Distribution Transformer Tap Change Switch Legibly Showing All of the Tap Positions

Table 12 shows the template of the DTTC sheets which needs to be filled in with the requested information for every individual transformer nominated for this project and shall be submitted in MS Excel format to UE Network Planning.

Table 12: Template of the Distribution Transformer Tap Changing Sheet

This form must be completed for all jobs related to distribution transformer tap changing. All details must be completed accurately and submitted to United Energy at the end of each job.

UNITED ENERGY

UE FM 181 – DISTRIBUTION TRANSFORMER TAP CHANGING SHEET						
Name of Distribution Substation:				**Date:**		
Transformer Type:						
Voltage Levels (V):	HV:			LV:		
Make:						
Serial Number:						
Impedance:						
kVA Rating:						
LV Fuse Size (A):	Circuit 1:	Circuit 2:	Circuit 3:	Circuit 4:		
LIS Number:						
Pole Type if Applicable:						
Surge Diverter:	Type/Model:					
	Number:					
Photos of Name Plates:	☐ Attached		Photos of Tap Change Switch:	☐ Attached		
Number of Tap Positions:						
Current Tap Setting:						
New Tap Setting:						
On-Load Measurement with Current Tap Setting:	Voltage				Current	Time
	RN (V)		RW (V)		R (A)	
	WN (V)		WB (V)		W (A)	
	BN (V)		BR (V)		B (A)	
					N (A)	
Off-Load Measurement with Current Tap Setting:	Voltage					Time
	RN (V)		RW (V)			
	WN (V)		WB (V)			
	BN (V)		BR (V)			
Off-Load Measurement with New Tap Setting:	Voltage					Time
	RN (V)		RW (V)			
	WN (V)		WB (V)			
	BN (V)		BR (V)			
On-Load Measurement with New Tap Setting:	Voltage				Current	Time
	RN (V)		RW (V)		R (A)	
	WN (V)		WB (V)		W (A)	
	BN (V)		BR (V)		B (A)	
					N (A)	
General Comment:						
Completed By:			**Company:**			
Signature:						