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Coober Pedy Renewable Hybrid Project

First Year Performance Report

September 2018

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1. EXECUTIVE SUMMARY

Energy Generation Pty Ltd ("**EnGen**"), a wholly owned subsidiary of Energy Developments Pty Limited, is the owner and operator of the Coober Pedy Renewable Hybrid Project (the "**CPRHP**"). The CPRHP commenced commercial operations on 1 July 2017 and is the exclusive supplier of power to the town of Coober Pedy. This is a high profile project for EnGen as well as local, state and federal governments, and the renewable energy industry in general.

Following an initial settling period, the CPRHP has achieved average renewable energy penetration of 70% which is in line with expectations. EnGen considers this to be world-leading performance for a megawatt-scale remote energy hybrid power project. Importantly, this level of performance has been achieved without adversely impacting power quality or reliability - unplanned outages reduced in 2017-18 (the first year of operation of the CPRHP) compared to previous years when the township was supplied solely by diesel-fired power.

This Report provides an overview of the performance of the CPRHP during its first year of commercial operations.

2. INTRODUCTION

2.1 Project Background

Electricity demand in Coober Pedy averages 1.4MW and reached as high as 3.1MW in 2011.

EnGen owned and operated the Coober Pedy diesel-fired power station supplies 100% of the town's electricity.

In 2013, EnGen began investigating the potential to integrate renewable energy into the existing power station to reduce diesel consumption in Coober Pedy. EnGen submitted an Expression of Interest to the Australian Renewable Energy Agency's ("**ARENA**") Regional Australia's Renewables Industry Program (IRAR) in November 2013 which ultimately led to the execution of a Funding Agreement with ARENA in July 2014.

Construction of the CPRHP commenced in September 2016 and commercial operations commenced on 1 July 2017.

2.2 ARENA Funding Agreement

The CPRHP is supported by up to $18.4 million in funding from ARENA (out of a total project cost of $39 million). As part of the ARENA funding arrangements, EnGen is required to (among other things) share knowledge developed during the development, construction and operation of the CPRHP.

2.3 Location

Figure 2-1 below provides an overview of the location of the CPRHP and associated infrastructure, including connecting power lines.

The wind turbine location was selected to ensure compliance with Coober Pedy Airport height restrictions, minimise the distance from the power station to reduce transmission losses and capital costs, avoid the sterilisation of opal resources and take into account the requirements that arose from cultural heritage surveys conducted in conjunction with traditional owners.

Figure 2-1. Project Site Overview

3. YEAR ONE PERFORMANCE

3.1 Overview

During the feasibility stage, the expected performance of the CPRHP was estimated using long term data sets for renewable resources (solar and wind), as well as detailed energy modelling. As a result of this process, it was expected that the CPRHP would achieve, on average, 70% renewable energy ("RE") penetration over its 20 year life.

The key performance metrics and a comparison with first year performance are shown in Table 3-1. Coober Pedy Renewable Energy (RE) Contribution Summary. Further details are provided in Section 3.6.

In summary, following an initial three month settling period, the CPRHP has performed in line with expectations regarding RE penetration, achieving an average penetration of 70.7%.

The achieved renewable contribution is a function of the match between the load, wind and solar generation and the performance of the enabling technologies. The customer load was marginally below the design assumption (~2.5%). Annual average wind speed was close to design estimates of 7.6 m/s at 80 metre hub height but the profile did vary from design slightly lowering the energy yield. The solar resource was 7% higher than design estimates. Losses have been slightly less than design, primarily due to lower flywheel parasitic energy on the Diesel Un-interruptible Power Supply (DUPS) than originally estimated.

Importantly, the construction of the CPRHP and first year of operations was achieved without any material safety incidents.

Table 3-1. Coober Pedy Renewable Energy (RE) Contribution Summary

Parameter		Units	Full year Jul 2017 to Jun 2018		9 months post settling Oct 2017 - Jun 2018	
			Design	Actual	Design	Actual
Load & System Performance						
	Customer Load	MWh	11,840	11,570	8,955	8,725
	Potential Renewable[1]	MWh	16,826	16,728	12,853	12618
	Renewable curtailed or spilled[2]	MWh	7,138	7,886	5,525	5,616
	System losses	MWh	1,400	1,000	1,059	833
	Net RE to customer	MWh	8,288	7,842	6,269	6,169
	Net RE to customer	%	70.0%	67.8%	70.0%	70.7%
	Time at 100% RE (ZDO)	%	50%	39%	50%	48%
	Longest continuous period of 100% RE[3]	hrs		71.5		
Potential Wind Generation						
	Wind speed at 80 m hub height	m/s	7.6	7.6	7.6	7.6
	Potential Generation[1]	MWh	14,643	15100	11,172	10,744
	Potential Capacity Factor	%	41%	42%	41%	40%
Potential Solar PV						
	Solar Resource (GHI)	kWh/m2	2,067	2,211	1,654	1,765
	Potential Generation[1]	MWh	2,183	2,487	1,681	1,874
	Potential Capacity Factor ac	%	22.7%	25.8%	23.3%	26.0%
Battery Energy Storage System (BESS)						
	Annual Discharge	MWh	142	117	108	96

Notes

1. “Potential Renewable/Generation” refers to the theoretical renewable generation available given the ambient climatic conditions, equipment installed and estimated losses. Potential wind generation is calculated using the turbine’s power curve with losses applied. Potential solar generation is calculated using measured irradiance and *PVSyst*. Estimates are as received at the diesel power station after transmission losses.
2. During periods of high ratios of energy to load, the production from wind or solar output may be curtailed rather than generated electricity being spilled through the resistor.
3. This record was set in July 2018.

The actual net contribution to customer load from each of wind and solar depends on allocation of the “spill”. Wind is often spilled as it frequently exceeds the load at night, and either solar or wind may be spilled during high renewable generation during the day. During periods of high ratios of renewable to load, the production from wind and/or solar output may also be curtailed by reducing the power setpoint.

Figure 3-1 to Figure 3-4 compare the modelled and actual RE contributions to customer load for a summer and winter day (with spill allocated to wind first). This is an average of all days in the respective month and, as such, always shows some residual diesel generation. However, the CPRHP has actually run with 100% renewable and no zero diesels operating (“ZDO”) for approximately 48% of the post-settling portion of the first year. This compares well with design estimates of around 50%. See Section 3.6.2 for further daily performance data.

Overall the system is performing as expected with some room for further improvement.

The advanced control system and enabling technologies ensure power quality (system frequency and voltage) is maintained, while managing renewable intermittency and maintaining power reliability.

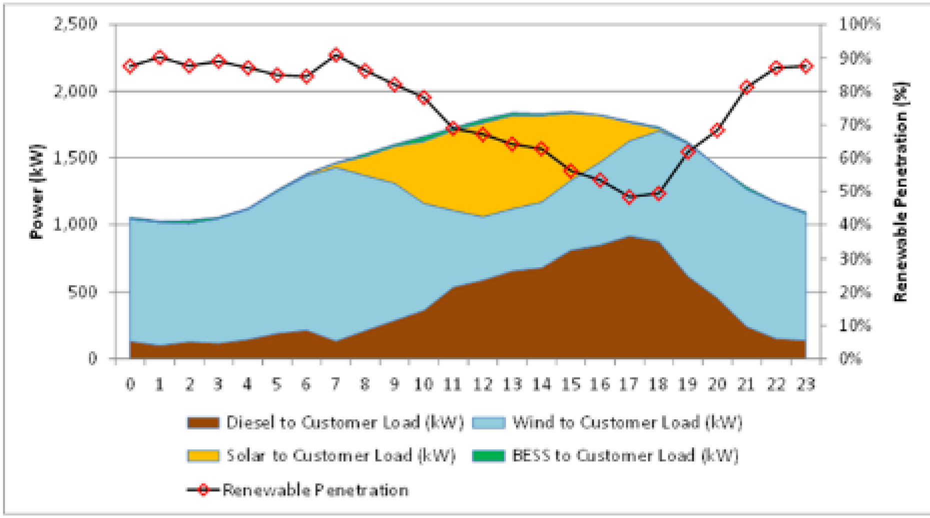

Figure 3-1. Average Day in January (Design)

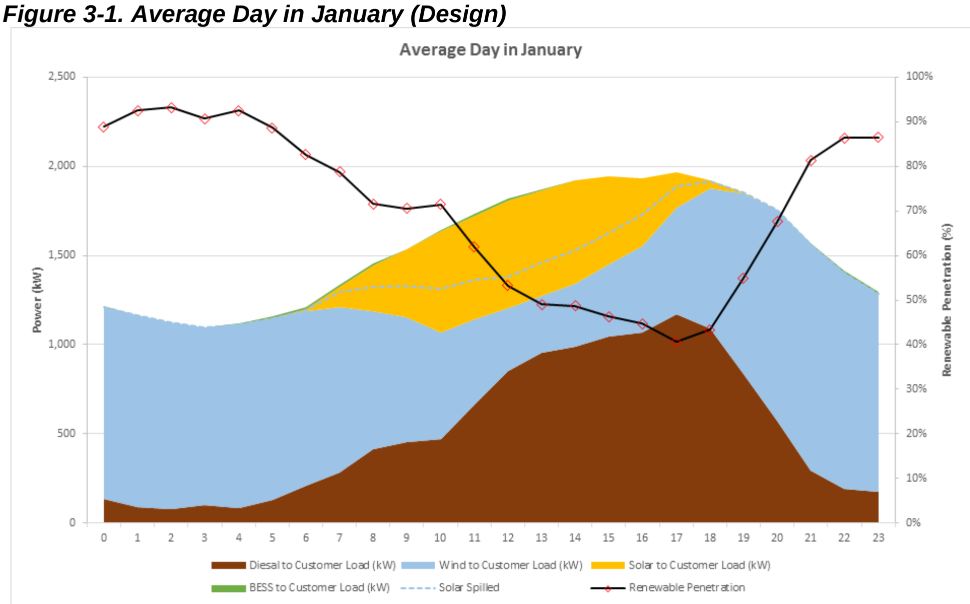

Figure 3-2. Average Day in January (Actual)

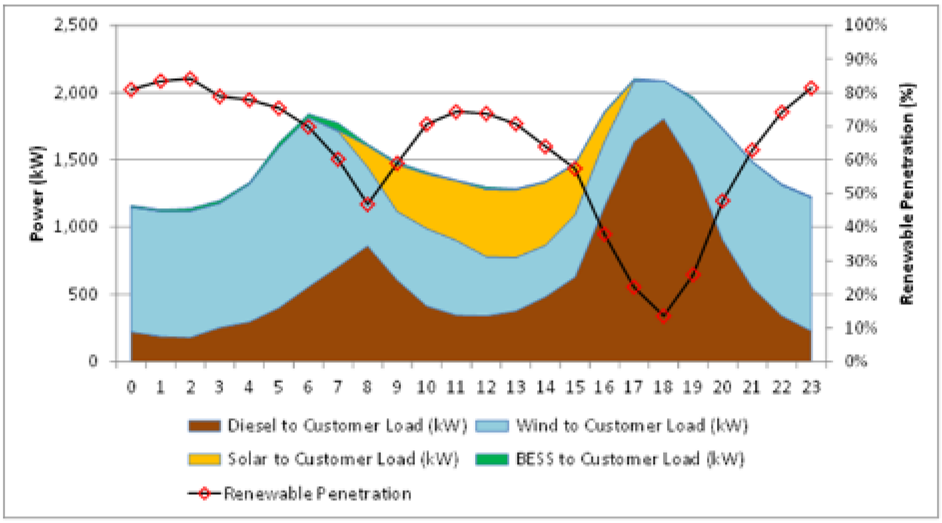

Figure 3-3. Average Day in July (Design)

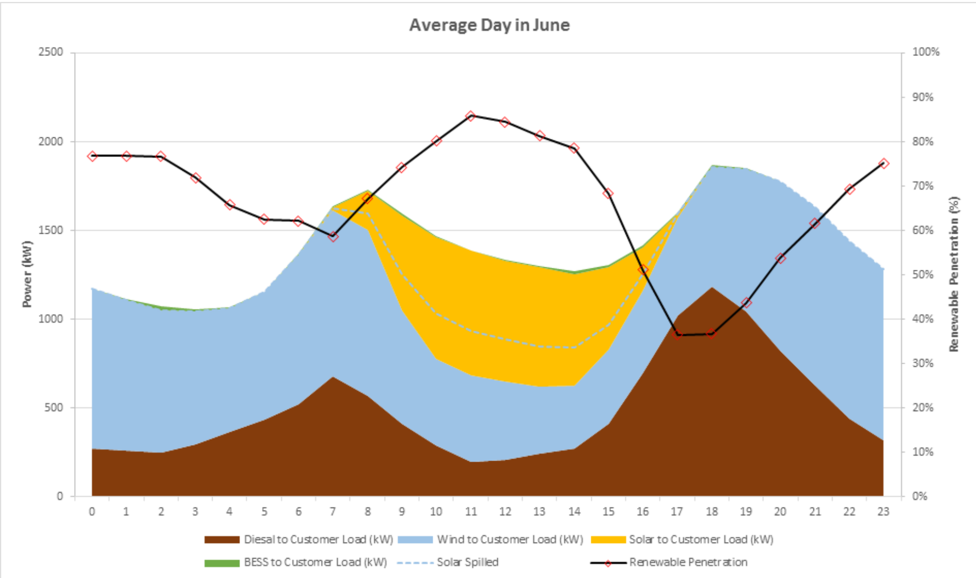

Figure 3-4. Average Day for June 2018 (Actual)[1]

[1] June 18 was selected for comparison as July 2017 was during tuning in the settling period.

3.2 Solar

3.2.1 Solar Irradiance

During the feasibility study, the solar resource was largely estimated using satellite based data. There was no site-based monitoring data available, although some output data was obtained from an 80 kW District Council of Coober Pedy (DCCP) owned PV array at the water treatment plant.

Solar irradiance is now measured by three devices alongside the solar array:

- Global Horizontal Irradiance (GHI) Pyranometer - Zipp and Konen CMP10 integrated into Luft WS510-UMB
- Plane of Array (POA) Pyranometer - Zipp and Konen – CMP11
- Plane of Array (POA) Reference Cell – First Solar Calibrated FS3 110 W module (as used in the solar farm) with Atonomics RDE200 Interface

Table 3-2 compares the design and measured solar resources to June 2018.

Solar GHI irradiance in FY 2018 was 7% higher than the expected long-term average with the biggest uplifts occurring during the winter months.

Table 3-2. Design and Measured Solar Irradiance

	Solar Irradiance GHI		Solar Irradiance Global POA		
	Design Year	Pyranometer[1]	Design Year	Pyranometer[1]	Reference Cell[1]
	kWh/m2	kWh/m2	kWh/m2	kWh/m2	kWh/m2
Apr 2017		146		180	181
May 2017		131		182	184
Jun 2017		101		147	147
Jul 2017	106	122	147	178	176
Aug 2017	135	151	172	197	195
Sep 2017	172	174	200	201	198
Oct 2017	215	225	223	228	226
Nov 2017	213	241	202	203	204
Dec 2017	241	233	219	213	213
Jan 2018	227	247	211	222	223
Feb 2018	204	210	203	204	206
Mar 2018	194	212	217	233	233
Apr 2018	146	159	182	196	197
May 2018	121	131	168	183	181
Jun 2018	94	107	132	156	154
FY 2018	**2067**	**2211**	**2276**	**2414**	**2404**
Oct to Jun 2018	**1654**	**1765**	**1756**	**1838**	**1836**

Notes:

1. Data quality is high with 100% availability in most months. Nov and Dec 2017 were 77% and 89% respectively due to loss of power supply to the monitoring units. Gaps were filled with Coober Pedy Airport BOM data.

3.2.2 Solar System Performance

Solar PV Performance Ratio ("PR") to date has exceeded design expectations. The expected PR in the first year was 80.2%[2]. The measured PR was 82.6%. The better than expected performance is primarily due to actual soiling (~ 2%) being less than design soiling (5%).

The solar inverter can follow a setpoint very rapidly. Once curtailed, the output can be regained within seconds and hence provides a rapid response to wind or load changes. Hence, solar generation is preferentially curtailed over wind generation.

Solar was curtailed for 39% of daytime periods in FY 2018 and performance assessment is limited to non-curtailed periods, which may introduce some bias in the performance assessment.

Generally, the availability of the solar system has been high and within expectations. However, there have been a number of outages in the first year that are not expected to reoccur in the future. These events pushed overall availability to below 94%.

These outages comprise:

- A seven day outage resulting from initially overly conservative transformer protection settings. The extended outage time was impacted by OEM availability and the remoteness of the site
- A four day outage after a lightning strike to the power station damaged control equipment which prevented hybrid operation
- A 12 day outage as a result of an inverter power stack replacement requirement
- Several days across a number of events due to communication issues

3.3 Wind

3.3.1 Wind Speed

The wind resource for design was estimated from analysis and correlation of:

- 20 year wind speed records from the Coober Pedy Airport at 10 metres
- 11 months of data from the 60 metre wind monitoring mast installed by EnGen in May 2014 close to actual WTG site (5km from airport). The monitoring mast included anemometers at 10 metres, 40 metres and 60 metres enabling wind shear to be estimated at the wind turbine hub height of 80 metres
- Mesoscale modelled wind data from 3 Tier from 1981 to 2014

The results of the analysis predicted long term average wind speeds of 7.1m/s at 60 metres and 7.6m/s at 80 metres.

A Sonic Detection and Ranging ("SODAR") wind monitoring device (Fulcrum 3D FS1) was installed 340 metres west of the southernmost wind turbine as the primary source of wind speed for operational performance assessment. The site is very flat and non-complex therefore, this was viewed as appropriate and cost-effective approach rather than an 80 metre wind mast.

Some of the anemometers on the 60 metre wind mast failed in October 2017 and it was not considered cost effective to replace them[3].

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[2] The design PR was 79.5% with 5% soiling and 95% availability. The *PVSyst* model was updated to reflect the as built system increasing expected yield slightly. The measured PR has only been considered for non- curtailed periods and hence 100% availability. The PR value for comparison becomes 80.2%.

[3] The wind mast was always intended to be a temporary installation.

Table 3-3 shows the monthly average measured wind speeds since monitoring began from the mast and SODAR and compares with the long term projected design averages.

The average wind speed has been in line with the long term expected average. The three year average 60 metre wind mast for FY 2015 to FY 2017 was 7.1 m/s, matching the design value.

The FY 2018 60 metre and 80 metre wind speeds were 7.1 m/s and 7.6 m/s aligning with the design values. However, the measured 80 metre wind speed profile showed a slightly different distribution with a higher number of higher wind speeds and a lower number of mid-range wind speeds.

The overall uncertainty of wind mast and SODAR measurements is around 2 to 3%[4]. Analysis of the 60 metre wind and 60 metre SODAR data in the 13 month period of overlap showed the average mast wind speed was 0.6% higher than the SODAR, which is within the measurement accuracy band.

The SODAR records valid data measurements for only 80 to 90% of periods. This is a limitation of SODAR technology, which is known to be increased in desert environments. It has also been observed that the SODAR error rate is increased at lower wind speeds. This is being further investigated with the SODAR supplier Fulcrum 3D. Backfilling the missing periods with nacelle wind speed measurements or other data sources reduces the SODAR average in the years measured to date.

[4] Uncertainty is defined as one standard deviation expressed as % of mean wind speed.

Table 3-3. Design and Measured Wind Speeds

Period	Wind speed 60m (m/s)			Wind speed 80m (m/s)		
	Design Year	Mast	SODAR[1]	Design Year	SODAR[1]	SODAR (Gap filled)[2]
FY 2015		6.9	n/a		n/a	
FY 2016		7.2	n/a		n/a	
Jul 2016	5.8	6.8	n/a	6.5	n/a	
Aug 2016	6.9	7.5	n/a	7.5	n/a	
Sep 2016	7.9	8.2	n/a	8.3	n/a	
Oct 2016	7.9	8.8	9.1	8.4	9.8	
Nov 2016	7.8	7.5	7.8	8.2	8.3	
Dec 2016	7.5	7.7	7.7	7.8	8.1	
Jan 2017	7.7	7.4	7.6	8.3	7.9	
Feb 2017	7.4	7.6	7.7	7.8	8.2	
Mar 2017	6.9	7.3	7.4	7.4	7.9	
Apr 2017	6.0	5.9	6.0	6.6	6.4	
May 2017	6.3	6.8	7.0	6.8	7.5	
Jun 2017	6.4	6.0	6.2	7.1	6.4	
FY 2017[3]	7.1	7.0	7.5	7.6	7.9	
Average in periods of overlap[4]		7.5	7.5			
Average FY 2015 to FY 2017		**7.1**				
Jul 2017	5.8	7.5	7.8	6.5	8.4	7.8
Aug 2017	6.9	8.1	8.2	7.5	8.8	8.3
Sep 2017	7.9	8.1	8.0	8.3	8.5	8.2
Oct 2017	7.9	n/a	7.9	8.4	8.4	8.2
Nov 2017	7.8	n/a	7.0	8.2	7.3	7.3
Dec 2017	7.5	n/a	7.5	7.8	7.8	7.6
Jan 2018	7.7	n/a	8.1	8.3	8.5	8.4
Feb 2018	7.4	n/a	7.4	7.8	7.8	7.7
Mar 2018	6.9	n/a	7.3	7.4	7.7	7.5
Apr 2018	6.0	n/a	6.6	6.6	7.1	7.0
May 2018	6.3	n/a	7.0	6.8	7.6	7.4
Jun 2018	6.4	n/a	6.1	7.1	6.4	6.2
FY 2018	**7.1**		**7.4**	**7.6**	**7.9**	**7.6**[5]
Oct to Jun 2018	**7.1**		**7.2**	**7.6**	**7.6**	**7.5**

Notes:

1. The average availability of SODAR data at 60m and 80m was 87% and 81% respectively for FY 2018. The nature of the SODAR measuring process means many data points are filtered out when not meeting minimum quality criteria. Desert environments are known to be challenging for SODAR.
2. The gaps in data have been filled using the average of the four nacelle mounted anemometers on the 2 wind turbines, or if also unavailable, wind output projected from other SODAR heights.
3. Average of all available data in period. The mast appears lower than SODAR due to the different data periods.
4. Average in periods of date overlap between the SODAR and mast assessed in 10 minute averages.
5. The gap filled average is lower because the filled periods have lower average windspeed. The SODAR data error rate is noticeably higher at lower wind speeds. This is being investigated further with Fulcrum 3D.

3.3.2 Wind Turbines

The wind turbine output aligns with the modelled design performance, but within the limits of the band for wind speed measurement accuracy.

The wind turbines were curtailed for approximately 40% of time in FY 2018 and were not despatched for a further 7% of time (due to wind turbine outages or control system constraints). Wind turbine availability exceeded expected availability of 95%.

Significant outage events included:

- Three days of outage on two occasions resulting from relay faults in the nacelle; one of which was on Christmas Eve, which impacted OEM response times
- Approximately 220 hours spread across 18 days and both turbines for high temperature shutdowns. The wind turbines are designed to de-rate from 40ºC and shutdown at 42ºC (measured outside the nacelle). While this was allowed for in the design wind energy yield assessment, it is a little higher than expected
- Six days after lighting strike to CPRHP damaged control equipment preventing hybrid operation. The wind turbines were re-enabled two days after the solar

The assessment of wind turbine performance is limited to non-curtailed operating periods (approximately 60% of the time). Applying the measured gap-filled SODAR wind speed through a simple wind turbine performance with average design losses, shows slightly variance, but within the wind speed measurement error.

The estimated *Potential Wind Generation* noted in Table 3-4 was generated by processing wind speed in 10 minute periods through the performance model to estimate potential generation in curtailed periods. For this process the model has been calibrated with measured performance in non-curtailed periods to best represent the generation received at the diesel power station HV switchboard.

3.4 Diesel Station

All of the eight existing diesel fired generating units have been retained to ensure that the station is capable of meeting load requirements. This is because there are occasions when there is no wind or solar generation, meaning full customer load must be met by diesel-fired generation.

The average diesel load and number of diesels on-line has reduced significantly since commencement of operations of the CPRHP as shown in Table 3-4.

Since October 2017 the CPRHP has run on a “zero-diesel” basis for 48% of the time.

The average engine load has decreased from around 75% to 50% of a nominal 530kW rated capacity.

The engines also spend a lot of time running at minimum load, which is currently set at 30% of rated capacity. Running at lower average load means the average heat rate (fuel efficiency) has deteriorated by around 3.5%, which is in line with expectations.

There has been no observable maintenance impact of running the engines at lower loads, but it is too early to assess any long-term impacts. This will continue to be monitored over future years.

Table 3-4. Average Diesel Engine Load: Pre and Post Hybrid

	Year	Engine hours	Average Engine load	% of rated load	Average Fuel efficiency
		hrs	kW	%	l/kWh
Pre hybrid	FY 2015	30,188	392.9	74%	0.260
	FY 2016	32,058	374.7	71%	0.261
	FY 2017	31,190	392.3	74%	0.260
	Average	**31,145**	386.6	73%	**0.260**
Post hybrid	**FY 2018**	**15,577**	**268.4**	**51%**	**0.269**

Notes:
1. Gross at generator terminals

3.5 Enablers and Hybrid Control System

Overall, the suite of enabling technologies and overarching control system have performed well and been very effective in managing renewable variability while maintaining power quality and reliability. The enablers include the Dynamic Resistor (DR), Diesel Un-interruptible Power Supply (DUPS) and Battery Energy Storage System (BESS).

3.5.1 Dynamic Resistor

The DR has performed well after some initial issues concerning the HVAC failing to control high temperatures in the DR Control Container Module. The air conditioning system was modified and an additional unit and ducting installed to improve performance. The system is now performing well.

3.5.2 Diesel Un-interruptible Power Supply

The DUPS have been performing well. One or two DUPS are on in synchronous generator mode most of the time. Engagement of the clutch and starting of the diesel engine to provide real power occurs infrequently, but like any stand-by generator has high reliability when called upon. The DUPS undergo a test run for one hour every month.

The DUPS protection has tripped on Phase Imbalance on two occasions after the customer load exceeded the power quality specification. EnGen is working with District Council of Coober Pedy to resolve these load issues.

3.5.3 Battery Energy Storage System

The power delivery and response of the BESS has met expectations with the BESS demonstrating it can provide rapid response to sudden load changes and rapidly switch from charge to discharge.

The BESS has suffered from reduced availability due to HVAC issues resulting in the required humidity conditions not being maintained within the BESS container. The OEM is working to resolve the issues.

The CPRHP can still achieve “zero diesel” operations (“ZDO”) when the BESS is unavailable. However, the overall control system is restricted in its ability to maintain ZDO in such circumstances. This is because if the discharge capacity of the BESS is not available to provide “Operating Reserve”, then even if the BESS is never called upon to discharge, it must be replaced by DR spill or on-line diesel generator capacity.

3.5.4 Hybrid Control System

The Hybrid Control System monitors the entire CPRHP and sends power setpoint commands to the diesel, wind, solar and enabling technology sub-controllers. It has demonstrated its ability to manage all situations encountered to date. The system was tuned during the settling period to achieve very stable and robust operation. The system will generally keep operating with one or more components out of service, but with a reduced RE penetration.

Ongoing review of system performance will assess if further fine tuning can increase the overall RE energy utilisation without unduly increasing operational risk.

3.6 Overall System Performance and Renewable Energy Contribution

The CPRHP commenced commercial operations on 1 July 2017. The renewable penetration ramped up over the initial three month settling period (July – September 2017).

Table 3-5 shows the monthly performance of the CPRHP for FY 2018. It separates performance for the whole year and performance for the year after the settling period. RE penetration has exceeded 70% for the post settling period.

While performance has met expectations, there is scope for further improvement which is continually being pursued. Areas for improvement include:

- Improving availability of all system components, particularly the BESS
- Fine tuning of control set points to turn diesel generators off more quickly and make increased use of BESS capacity
- Reducing periods of manual control intervention with additional diesel generators running as confidence is gained in system performance and the management abnormal events

Around 40% of total renewable generation is currently being spilled/curtailed. There is potential to utilise the spill in the future via energy storage and smart load management.

Table 3-5. Coober Pedy Renewable Hybrid Monthly Performance

Month	**Potential Solar**	**Potential Wind**	**Actual Solar Generated**	**Actual Wind Generated**	**Total potential RE**	**Total RE generated**	**Resistor spill**	**System losses**	**RE to customer**	**Diesel to customer**	**Total Load**	**RE% of Customer Load**	**Hours of ZDO**
	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	MWh	%	hrs
Jul 2017	193	1432	86	637	1625	723	255	26	442	597	1039	43%	0
Aug 2017	211	1498	130	879	1709	1009	354	70	584	353	938	62%	25
Sep 2017	209	1425	146	1131	1634	1277	560	88	628	240	868	72%	292
Oct 2017	231	1432	166	1242	1663	1408	590	102	716	172	887	81%	436
Nov 2017	206	1133	153	1015	1339	1169	439	93	636	271	908	70%	318
Dec 2017	213	1270	177	838	1483	1015	356	79	579	397	976	59%	241
Jan 2018	218	1421	158	1175	1639	1333	466	101	766	383	1149	67%	365
Feb 2018	202	1146	151	1056	1348	1207	413	91	703	293	997	71%	340
Mar 2018	234	1184	209	1110	1417	1319	471	101	746	225	971	77%	390
Apr 2018	202	1056	181	947	1258	1128	374	96	657	266	923	71%	386
May 2018	197	1183	190	973	1381	1163	366	91	704	194	897	78%	349
Jun 2018	170	921	156	825	1091	981	238	79	662	354	1017	65%	313
FY 2018 Total	**2487**	**15100**	**1903**	**11830**	**17587**	**13732**	**4883**	**1017**	**7824**	**3746**	**11570**	**67.6%**	**3454**
Post Settling Period (Oct 2017 - Jun 2018)	**1874**	**10744**	**1540**	**9183**	**12618**	**10723**	**3713**	**833**	**6169**	**2556**	**8725**	**70.7%**	**3137**

3.6.1 Daily Modelled vs Actual Comparative Performance

Figure 3-5 below shows the daily system performance during June 2018 and compares it with a simplified theoretical target model that processes load, wind speed and solar irradiance data at 10 minute intervals to estimate the overall renewable contribution that could be achieved. The model simplifies the actual operation of the control system applying average allowances for equipment availability, turbine wake losses, and other operational constraints over the whole year. As a result, modelled performance does not align with actual performance on a daily basis, but more accurately aligns with actual performance over longer term periods. Daily performance charts for each month of the post settling period (from October 2017 to June 2018) are shown in Appendix 1.

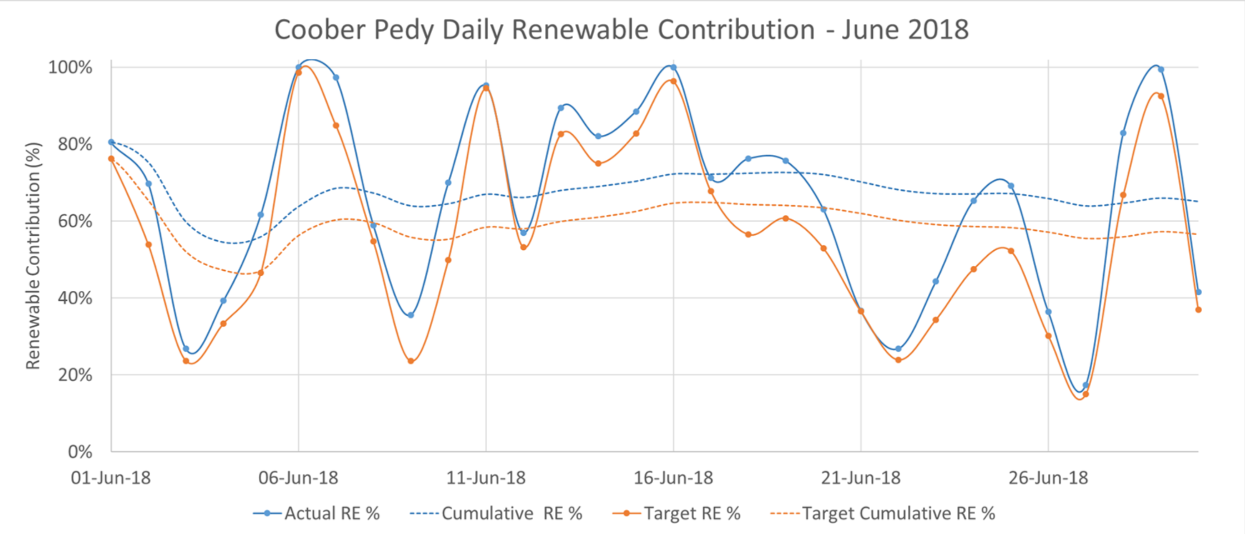


Figure 3-5. Daily RE% Contribution for June 2018

3.6.2 Daily RE Contribution Profile

Figure 3-1 to Figure 3-4 show the average RE penetration across the day for summer and winter periods.

The actual daily profile can vary significantly from day to day from 0% RE penetration to 100% RE penetration (ZDO). The uninterrupted ZDO record is currently 71.5 hours. Even so, there are some general trends worth noting:

- The wind blows stronger and more consistently at night, with ZDO often achieved. Wind typically reduces sometime during the day and often around dusk
- Coober Pedy is generally sunny so increased solar penetration often complements the reduction in wind penetration during the day to largely meet the load
- As solar penetration declines at the end of the day, diesel generation increases until the wind returns sometime in mid to late evening. The cycle then starts again

The daily RE contribution and profile is often a function of how long the wind persists into the day. Figure 3-6 to Figure 3-8 below shows three days where the RE contibution changed from 95% to 78% to 60%, with the duration of diesel generation ranging from a few hours to 16 hours.

In Figure 3-6, as the solar resource declined in the afternoon, the BESS contributed power which enabled ZDO to continue until around 18:00 when the diesel generators were started. The wind returned at approximately 21:00, returning the system to ZDO.

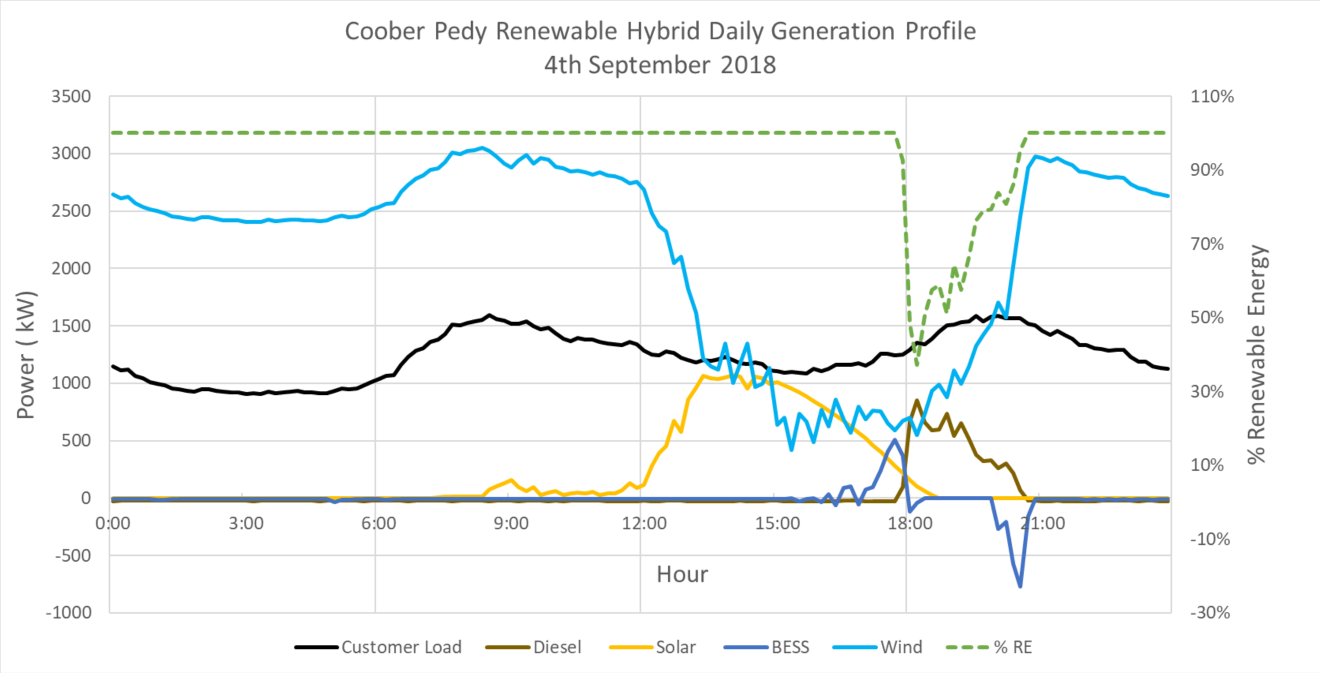


Figure 3-6. Generation Profile for 4 September 2018

In Figure 3-7 the wind reduced earlier in the morning but the solar resource was sufficient to enable ZDO until approximately 12:00 when the BESS contributed power enabling ZDO until 14:00. The wind returned early in the evening and ZDO was reached again by midnight.

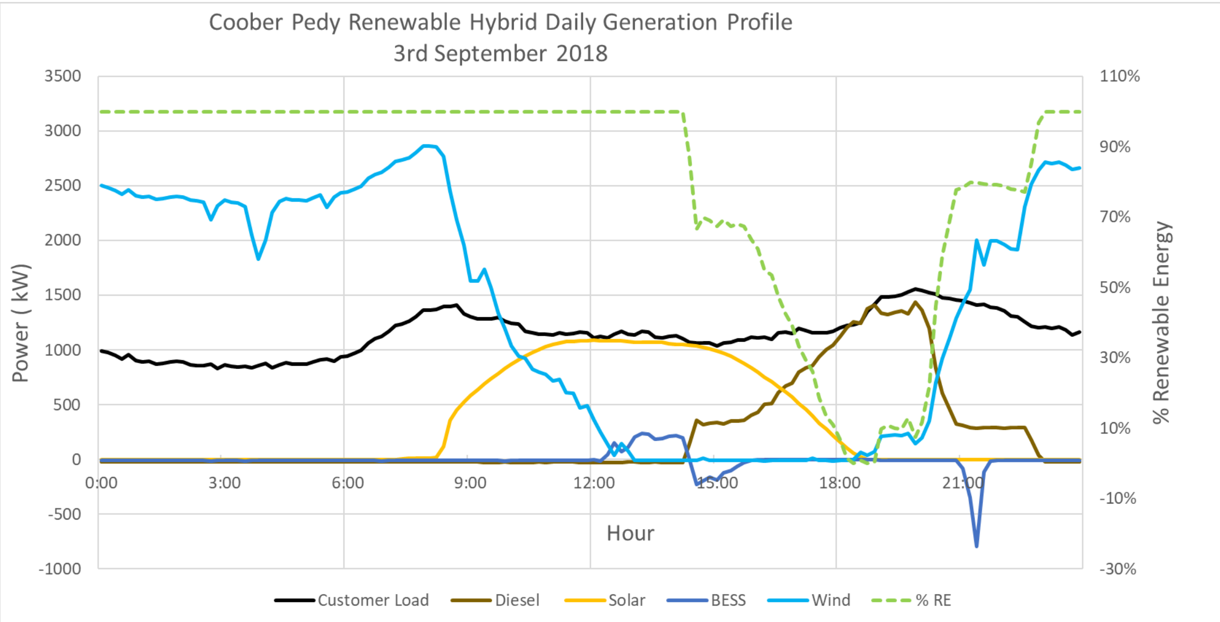


Figure 3-7. Generation Profile for 3 September 2018

In Figure 3-8 the wind speed reduced before sunrise and the diesel generators were required for most of the day until the wind returned enabling ZDO by midnight.

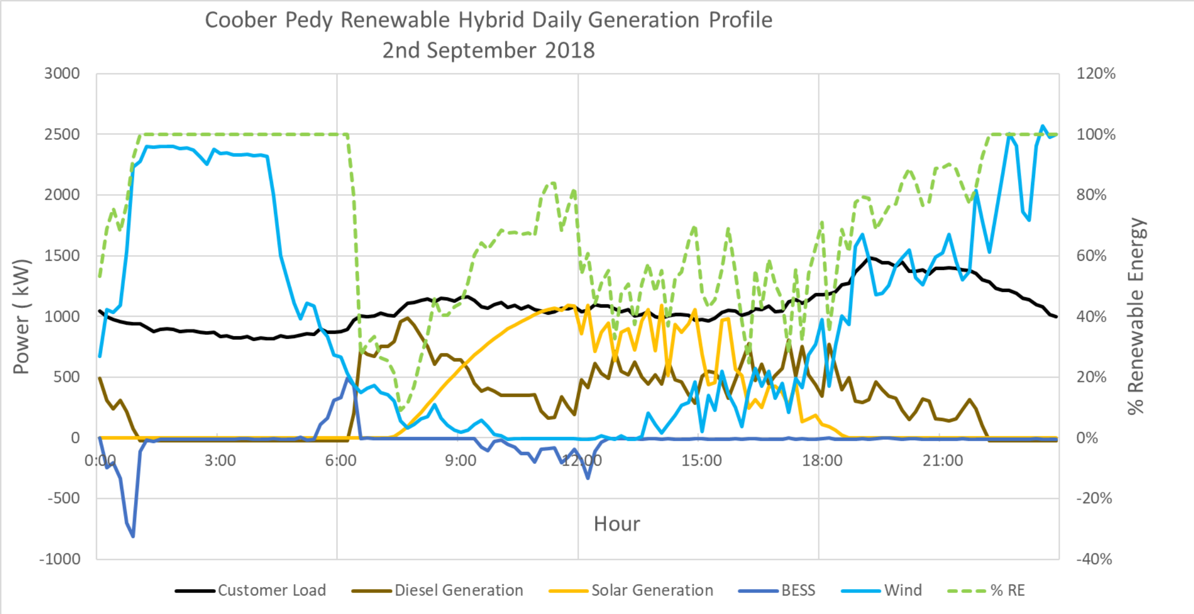


Figure 3-8. Generation Profile for 2 September 2018

3.7 Management of Renewable Energy Variability

The combination of the DUPS, DR and BESS is very effective at managing the variability of wind, solar and load.

Figure 3-9 shows a two hour period of ZDO with highly intermittent wind and solar being effectively managed. The frequency remained in a band between 49.8 to 50.2 Hz throughout this period.

There have been no trips or out of frequency specification events due to normal RE and load variability since hybrid operation began.

The process by which system components contribute to manage variability as RE penetration increases is described below.

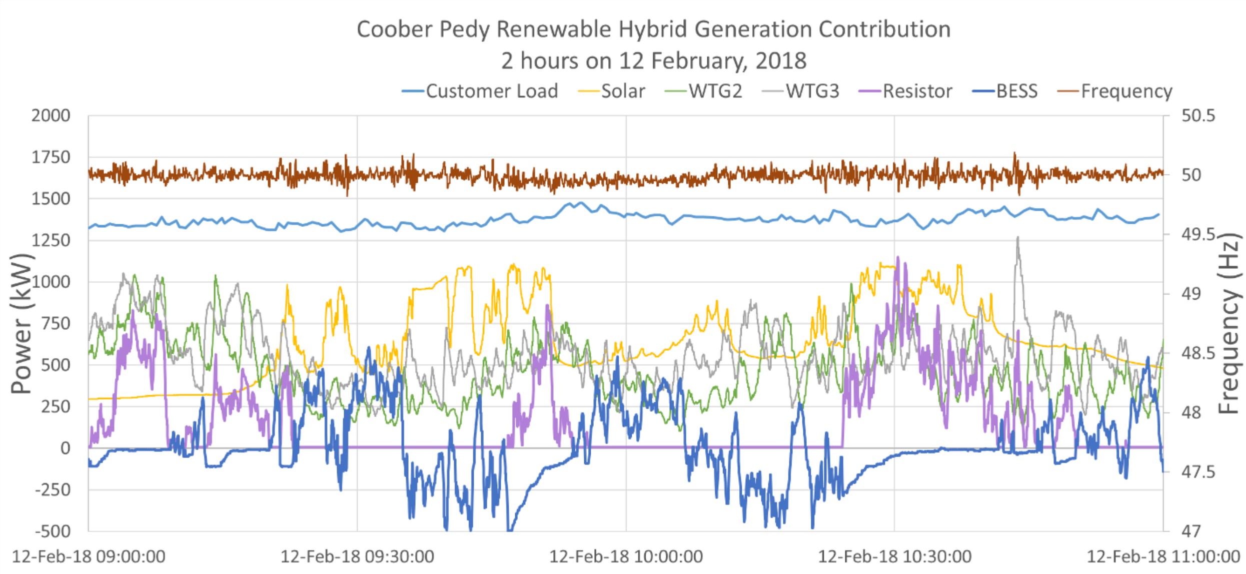


Figure 3-9. Coober Pedy Renewable Variability on 12 February 2018

At low RE levels the diesel generators manage variability without the DUPS engaged.

As RE penetration increases and diesel generators are turned off, the first DUPS is engaged followed by the second, at setpoints determined by the control system. The DUPS add inertia to the system to replace the diesel inertia and respond passively to system variations without any control system direction. When switched on the DUPS continuously and passively switch between injecting and absorbing power.

If the frequency falls below pre-set limits the DUPS clutch engages and within seconds the DUPS diesel engine starts, injecting real power to address power shortfalls and maintain frequency.

While events of significant power shortfall are relatively rare (e.g. generator trips and extreme RE variability), the DUPS clutch typically engages several times a day without injecting any significant power. In most cases the frequency dip is short and the clutch disengages again after a minute or so. However, the DUPS are always ready to inject power up to rated capacity of 1700 kVA should the event be sustained. The DUPS have been called upon to avoid a likely outage on many occasions since operations began.

As the renewable energy penetration increases, the diesel generators are sequentially turned off and ultimately forced to minimum load. When the diesel generators reach minimum load, the excess RE generation is spilled through the DR. The spill through the DR effectively provides "spinning reserve", just like a diesel engine would. When the spill though the DR is high enough, the last diesel generator can be turned off. At this point the DR and/or BESS are in control of system frequency and the system is in ZDO.

If RE penetration falls rapidly, the DR unloads first to maintain the load balance. If the RE penetration continues to fall and the DR load is exhausted, the BESS discharges to make up the shortfall. As the RE penetration increases again the process reverses and the BESS charges. This cycle can be seen in Figure 3-9. The BESS is providing effective "spinning reserve", even if it is not called upon to discharge and therefore its value is more than just the energy is discharges. The BESS often keeps the system in ZDO for several hours, despite the relatively small BESS energy capacity.

The control system monitors "state of charge" (SOC) and discharge power of the BESS and activates a diesel generator start before BESS reserves are exhausted.

3.8 Management of Contingency Events

Contingency events such as a load feeder trip, diesel generator trip or wind or solar feeder trip are extreme variability events. Such events occurred during the first 12 months and the system has proved to be very resilient, particularly the DUPS, which have been called on a number of occasions and likely avoided a customer outage.

A few examples are outlined below.

Lightning strike and feeder trips on 30 November 2017

- With customer load of 1400 kW and the system in ZDO, Feeder 1 tripped from 754 kW. The DUPS and resistor managed the loss with frequency rising to 50.6 Hz
- A few minutes later the second feeder tripped from 695 kW and auto-reclosed within seconds. The system stayed on line with the frequency managed within range 49.5 to 50.5 Hz

PV Inverter failure from 916 kW on 25 January 2018

- With a customer load of 1990 kW and 4 diesel generators and 1 DUPS online, the solar tripped from 916 kW. The DUPS engaged while extra diesel generators were started. The frequency dipped to 48.8 Hz. The BESS was not called upon in this case

3.9 System Reliability

For the first year of operation the CPRHP has provided better power reliability than the diesel-only station.

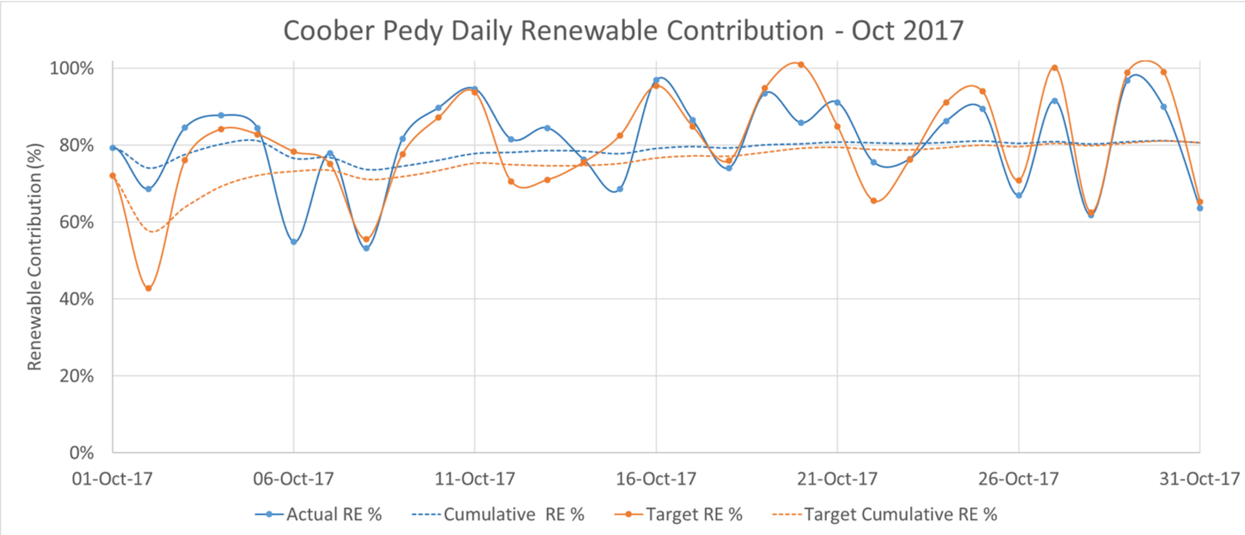
Table 3-6 shows the reliability of the Coober Pedy power station over the past four financial years. For the first full year of operation of the CPRHP both the number and the duration of unplanned outages decreased. Furthermore, three of the four unplanned outages in FY 2018 occurred during the settling period, so operation post October 2017 has been better. There were additional unplanned outages due to faults in the Coober Pedy electrical network, not the CPRHP, and these are not shown in table 3-6.

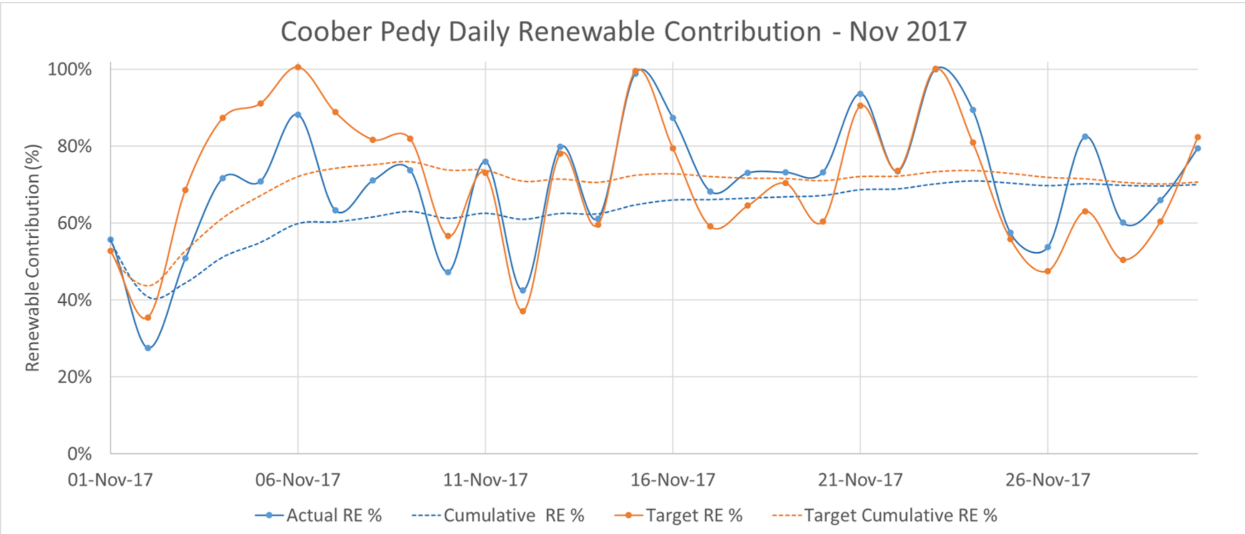
Five planned outages, of several hours each, were required during construction and commissioning to switch over to a completely new HV switchboard and cut in the various components. These were scheduled in consultation with DCCP to minimise the impact on Coober Pedy residents.

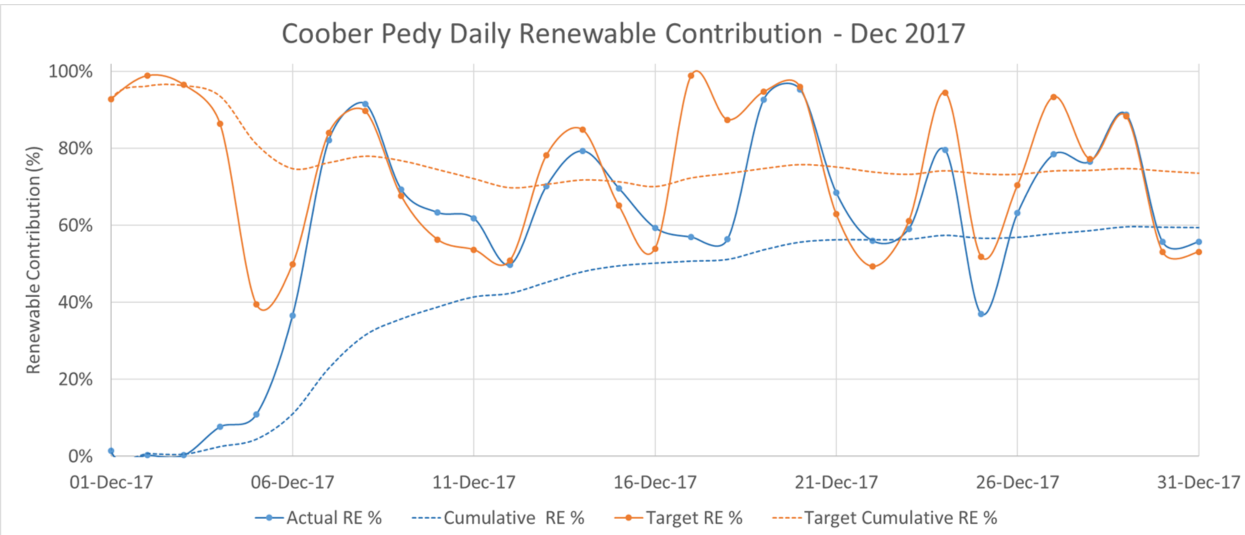
Table 3-6. Coober Pedy Power Station Unplanned Outage History

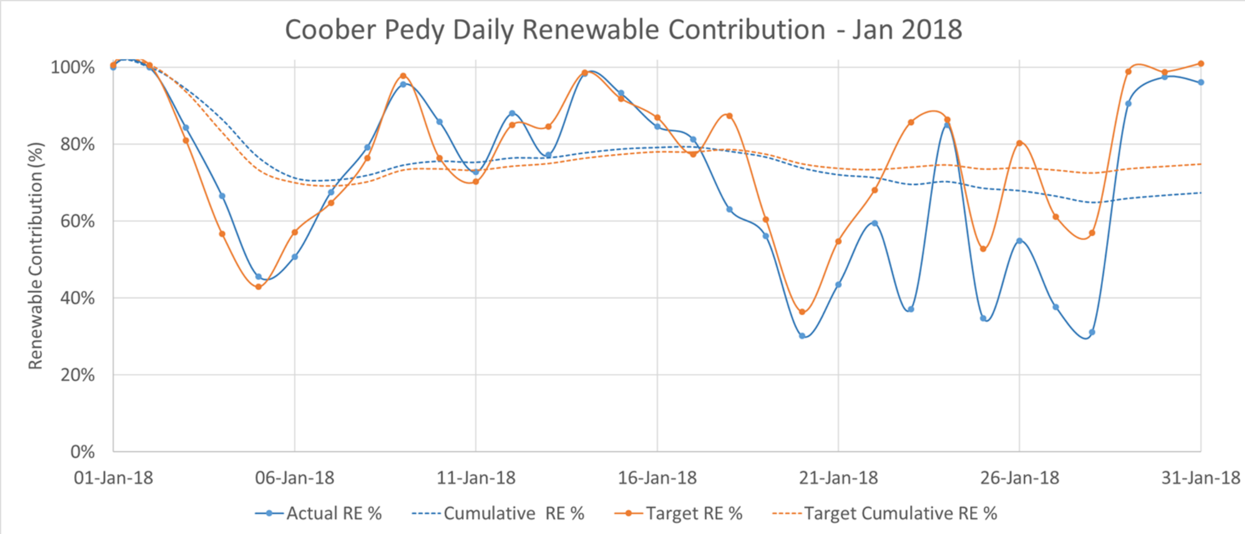
	Year	**Unplanned Outages**	
		Number	Duration (hrs)
Pre Hybrid	FY15	4	3.5
	FY16	5	1.1
	FY17	4	4.2
	Average	**4.3**	**2.9**
Post Hybrid	**FY18**	**4**	**0.47**

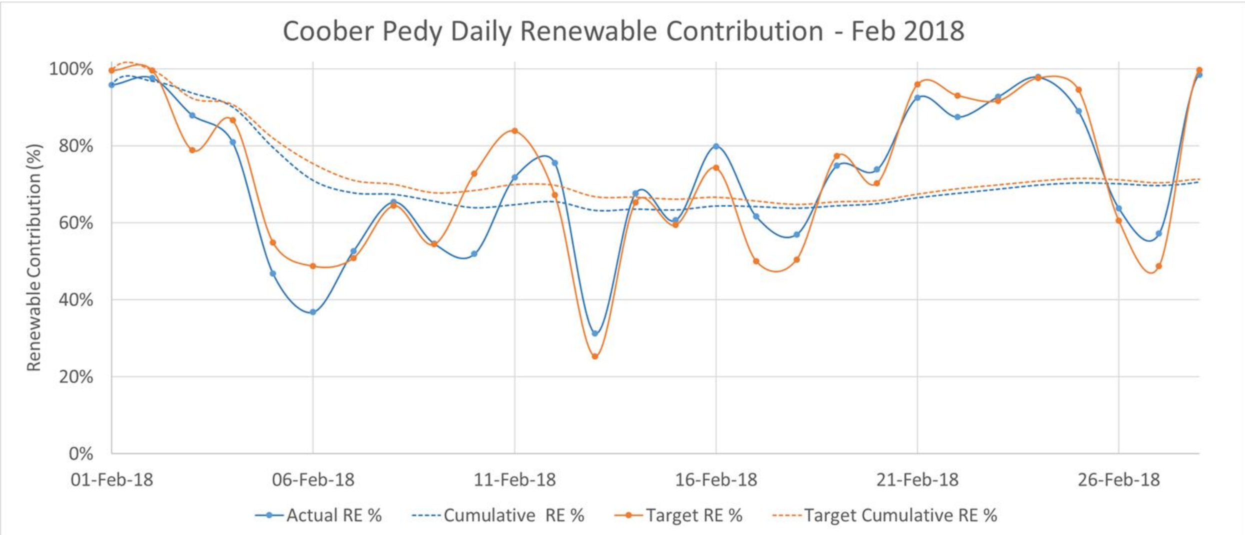
APPENDIX 1 – DAILY RE PERFORMANCE BY MONTH

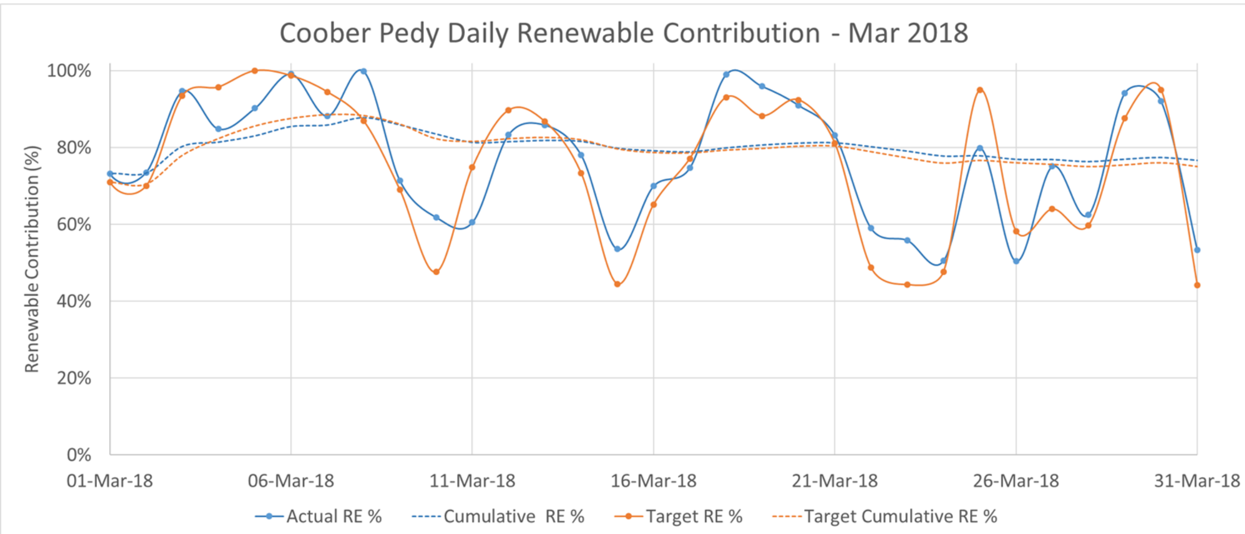







Coober Pedy Daily Renewable Contribution - Jan 2018
Renewable Contribution (%)
100%
80%
60%
40%
20%
0%
01-Jan-18
06-Jan-18
11-Jan-18
16-Jan-18
21-Jan-18
26-Jan-18
31-Jan-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %


Coober Pedy Daily Renewable Contribution - Feb 2018
Renewable Contribution (%)
100%
80%
60%
40%
20%
0%
01-Feb-18
06-Feb-18
11-Feb-18
16-Feb-18
21-Feb-18
26-Feb-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %


Coober Pedy Daily Renewable Contribution - Mar 2018
Renewable Contribution (%)
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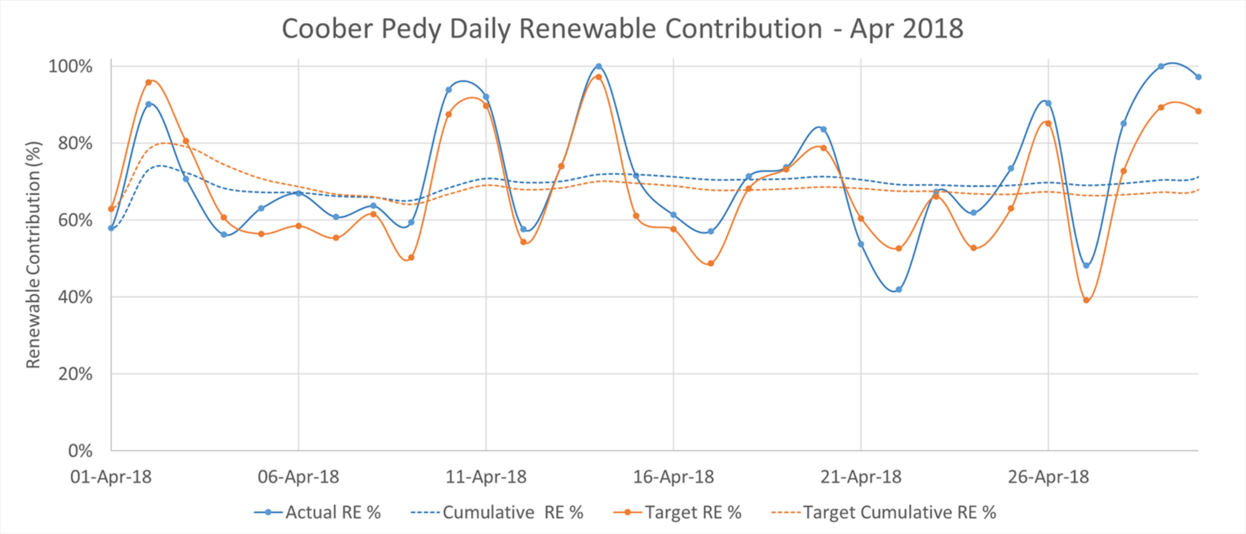
60%
40%
20%
0%
01-Mar-18
06-Mar-18
11-Mar-18
16-Mar-18
21-Mar-18
26-Mar-18
31-Mar-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %


Coober Pedy Daily Renewable Contribution - Apr 2018
Renewable Contribution (%)
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60%
40%
20%
0%
01-Apr-18
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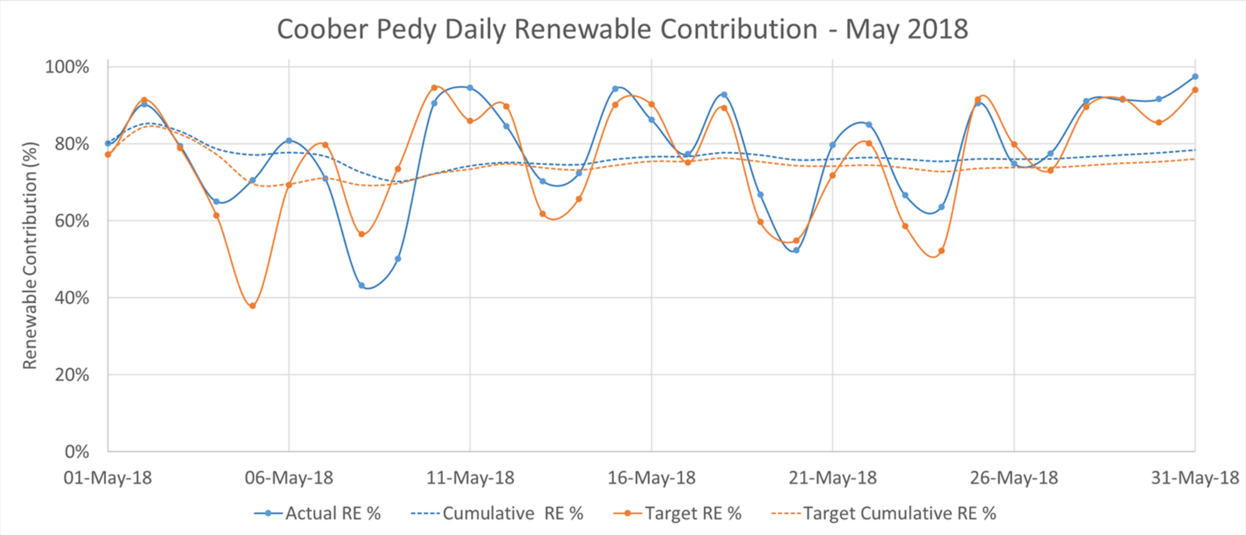
11-Apr-18
16-Apr-18
21-Apr-18
26-Apr-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %


Coober Pedy Daily Renewable Contribution - May 2018
Renewable Contribution (%)
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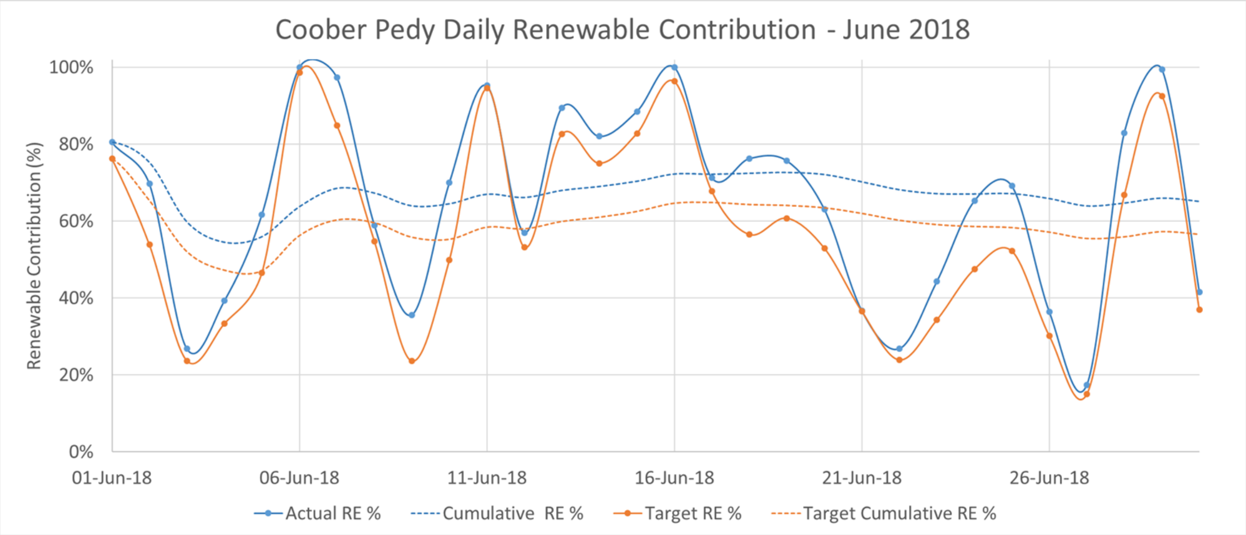
60%
40%
20%
0%
01-May-18
06-May-18
11-May-18
16-May-18
21-May-18
26-May-18
31-May-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %


Coober Pedy Daily Renewable Contribution - June 2018
Renewable Contribution (%)
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80%
60%
40%
20%
0%
01-Jun-18
06-Jun-18
11-Jun-18
16-Jun-18
21-Jun-18
26-Jun-18
Actual RE %
Cumulative RE %
Target RE %
Target Cumulative RE %