Case Study

Remote Area Power Supply (RAPS) ESV Trial

28 March – 18 December 2011

24 February 2012
Background

As a result of the Victorian bushfires of Saturday 7th February 2009, the 2009 Victorian Bushfires Royal Commission was established to investigate the causes and responses to the bushfires.

The Government, through Energy Safe Victoria (ESV), established a Powerline Bushfire Safety Taskforce. The taskforce examined a range of options for reducing the risk of bushfires being caused by electricity infrastructure. These included:

1. Targeted replacement of SWER and 22kV lines in highest bushfire risk areas with other network and alternative technologies that deliver reduced bushfire risk, including aerial bundled cable, underground cable and remote area power supplies;
2. Enhanced fault protection systems to minimise fire starts from fault currents;
3. Faster identification and location of faults to enable more rapid fire-fighting response;
4. Installation of backup power supplies to enable selective and occasional de-energisation of high risk power lines on catastrophic fire risk days without compromising power supplies to affected users.

RedFlow was selected to supply and install their Remote Area Power Supplies (RAPS) as part of trialing the 1st option. The RedFlow RAPS were used to investigate the viability of taking customers off-grid permanently to enable the permanent removal of powerlines from high-risk areas that service only small numbers of customers.

Ten households, each with one Remote Area Power Supply (RAPS) system, were selected as sites for the ESV trial. Five of these systems were installed during late 2010, with the other five following in March 2011. All systems were online by 28 March 2011. The RedFlow RAPS were designed to the specification of an average daily load of 15kWh.

Figure 1: RedFlow Remote Area Power Supply (RAPS) installed at Site H
Executive Summary

As a result of the Victorian bushfires of Saturday 7th February 2009, the Victorian Government, through Energy Safe Victoria (ESV), established a Powerline Bushfire Safety Taskforce. In order to investigate the feasibility of taking customers off-grid in rural Victoria, RedFlow was selected to supply and install 10 of their RAPS energy storage systems.

These were officially in operation as part of ESV trials for a period of 9 months from March to December 2011. Each residential system comprised a diesel generator, solar panel array and hybrid zinc bromide/lead acid energy storage. The operational results and benefits of these RAPS systems were analysed, and the lessons learnt presented. This produced the following key conclusions:

- The effectiveness of the RAPS system in greatly reducing the diesel runtime of each generator to below 15% of the time for most sites.
- The effectiveness of the RAPS system to significantly reduce the SAIDI figures of half the trial sites.
- The significant effect that reduced solar exposure during winter, as well as poor locations of solar panels during installation can have on the performance of the entire RAPS system.
- The need for a diesel generator to back-up the solar generation.
- The importance of informing the customer/participant prior to the commencement of the trial of realistic outcomes to expect in terms of solar generation and diesel generator use. Customers/participants should also be made aware of the possible changes to their electricity usage behavior that may be required in order for the RAPS system to operate most effectively.
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1 Introduction

The aim of this project was to determine if it is feasible to install RAPS systems for residential electricity customers to enable permanent de-energisation of high risk power lines in rural Victoria. The role of energy storage in this project was to reduce the diesel generator run time by time-shifting the energy generated by the solar panels.

In summary, this project has shown that it is technically feasible to take residential customers who are currently connected to the grid and provide their electricity needs from an off-grid renewable energy-based system. This allows parts of the electricity network to be de-energised and thus reduce the risk of bush fires in remote areas.

This Use Case provides an overview and analysis of the performance of RedFlow’s RAPS used at the 10 selected sites in the ESV trial on backup power supplies in rural Victoria. It will cover the period from 28 March to 18 December 2011.

Each household was provided with a RedFlow RAPS system that included a diesel generator, a 3.2kW or 4.8kW PV solar panel array and a RedFlow hybrid zinc-bromide module (ZBM) and lead acid (LA) Power+BOS energy storage system (ESS). These elements are shown below in Figure 2. RedFlow used their remote terminal unit (RTU) with their HOST and DataViewer programs to remotely monitor the performance of each system.

The households are named with the convention of “SITE A” to “SITE J”. Eight of the ten households remained as participants throughout the trial. One household, SITE A, opted out of the trial in early June due to low solar output from its panels and the resultant high diesel usage of its generator. SITE B opted out of the trial in early October for similar reasons. Therefore, only partial information is presented for these two sites in this report. However, those households who have opted to keep their RAPS systems after the trial did so because they received satisfactory outputs from their solar panels and were happy with the volumes of diesel consumed by their generators.
All households were located in total Victoria, Australia. They are shown in the map below in Figure 3:

This Use Case has been divided into sections of Operation, Results and Lessons Learnt. Each section deals with the subsystems of each household’s system: Diesel Generation, Solar Generation, Household Usage and Energy Storage.

Appendix A contains a list of abbreviations used in this Use Case.

Appendix B is an in-depth list of each of the 10 trial sites.

A summary table of each site and its effectiveness and appropriateness for the trial is given below.
<table>
<thead>
<tr>
<th>Site</th>
<th>Status at 18 Dec 2011</th>
<th>Bushfire Reduction Effectiveness</th>
<th>Appropriateness for Trial</th>
<th>Commercial Feasibility</th>
<th>SAIDI during Trial Period</th>
<th>Customer Satisfaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITE A</td>
<td>Not Operating</td>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night</td>
<td>Poor placement of solar panels resulted in high diesel run time Average daily household load of 15.2kWh at maximum of system design</td>
<td>Not feasible (diesel costs too high and outweigh electricity bill savings)</td>
<td>SAIDI: 1026 mins</td>
<td>These customers were not satisfied with the results of the trial (namely, their high diesel consumption) and as a result, exited from the trial early in June.</td>
</tr>
<tr>
<td>SITE B</td>
<td>Not Operating</td>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night</td>
<td>Poor placement of solar panels resulted in high diesel run time Average daily household load of 22.0kWh too high for system design</td>
<td>Not feasible (diesel costs too high and outweigh electricity bill savings)</td>
<td>SAIDI: 1128 mins</td>
<td>These customers were not satisfied with the results of the trial (namely, their high diesel consumption) and as a result, exited from the trial in October.</td>
</tr>
<tr>
<td>SITE C</td>
<td>Operating</td>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night</td>
<td>Poor placement of solar panels resulted in high diesel run time Average daily household load of 16.0kWh at maximum of system design</td>
<td>Not feasible (diesel costs too high and outweigh electricity bill savings)</td>
<td>SAIDI: 120 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE D</td>
<td>Operating</td>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night</td>
<td>Poor placement of solar panels resulted in high diesel run time Average daily household load of 13.0kWh suited to system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 12 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE E</td>
<td>Operating</td>
<td>Could be taken off the grid permanently to allow for total de-energisation of power lines</td>
<td>Average daily household load of 13.8kWh suited to system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 0 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>Site</td>
<td>Status at 18 Dec 2011</td>
<td>Bushfire Reduction Effectiveness</td>
<td>Appropriateness for Trial</td>
<td>Commercial Feasibility</td>
<td>SAIDI during Trial Period</td>
<td>Customer Satisfaction</td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------</td>
<td>---------------------------------</td>
<td>---------------------------</td>
<td>------------------------</td>
<td>---------------------------</td>
<td>------------------------------------------------</td>
</tr>
<tr>
<td>SITE F</td>
<td>Operating</td>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night</td>
<td>Poor placement of solar panels resulted in high diesel run time</td>
<td>Not feasible (diesel costs too high and outweigh electricity bill savings)</td>
<td>SAIDI: 336 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE G</td>
<td>Operating</td>
<td>Could be taken off the grid permanently to allow for total de-energisation of power lines</td>
<td>Average daily household load of 8.9kWh highly suited to system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 12 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE H</td>
<td>Operating</td>
<td>Could be taken off the grid permanently to allow for total de-energisation of power lines</td>
<td>Average daily household load of 14.0kWh suited to system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 1908 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE I</td>
<td>Operating</td>
<td>Could be taken off the grid permanently to allow for total de-energisation of power lines</td>
<td>Average daily household load of 13.0kWh suited to system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 84 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
<tr>
<td>SITE J</td>
<td>Operating</td>
<td>Could be taken off the grid permanently to allow for total de-energisation of power lines</td>
<td>Average daily household load of 15.5kWh at maximum of system design</td>
<td>Possibly feasible (diesel costs significantly lower than electricity costs)</td>
<td>SAIDI: 972 mins</td>
<td>These customers remained participants throughout the trial.</td>
</tr>
</tbody>
</table>

Table 1: Summary table of ESV sites
2 Operation

2.1 Energy Storage

There was one RedFlow RAPS system installed at each trial household. The Power+BOS (see Figure 4) as the storage component of each system, comprised 2 ZBMs (see Figure 5), a bank of LA batteries (see Figure 6) to augment storage, an inverter and other various power electronics.

These systems provided a time-shifting capability to store energy generated by the solar panels for use at times of peak demand (typically mornings and evenings). The energy storage also allowed the diesel generators to operate for shorter periods and at more efficient outputs by storing any energy not immediately used by the household load.

The priorities in operation of the ESS and its control of power flows are given below:
1. The household loads must be satisfied under all circumstances.
2. This power will first come from solar PV generation if it is present.
3. If this generation is not sufficient or available, the ZBM will discharge at the required power output (maximum 5kW through inverter) until it is completely depleted (i.e. 0% state of charge (SOC)).
   If solar generation is larger in magnitude than the household consumption, the surplus power will be used to charge the ZBM until it reaches its nominated maximum SOC (this was usually set to 100%).
4. If solar generation is not sufficient to power the household consumption and the ZBM is depleted, the system will start discharging the LA batteries at the required rate (maximum 5kW through the inverter) until they have reached their minimum allowable SOC.
5. If solar generation is not sufficient to power the household consumption and the ZBM and LA batteries are very near depletion, the system will start the diesel generator. This power will first go to household loads. If there is surplus generation remaining, this is used to charge the LA batteries. The generator will stop operation when the LA batteries have reached a set SOC.

**NOTE:**
1. The ZBM is only charged using surplus power from solar and not from the diesel generator.
2. The ZBM is first used as a source of extra power because of its operational requirements to strip at least every second night. In order to do this, the ZBM must be fully discharged.
3. The LA batteries are only charged using surplus power from the diesel generator, and not from solar.

Figure 7 below shows the layout of the ESS which contains both lead-acid and zinc-bromine batteries. Due to the nature of the SMA inverter, there is more data available for the LA batteries than for the ZB batteries.
2.2 PV Solar Generation

Each household who participated in the ESV trial were provided with a solar PV array of either 3.2kW or 4.8kW size. These were also installed either on the rooftop of residential buildings, or on purpose-built padmount slabs. Some of the solar installations are shown in Figure 8 and Figure 9.

The ESS were not fitted with a current transformer (CT) to measure solar output and hence, the energy generated by the PV solar panels at each site was determined by balancing all other measured inputs and outputs to each system:

\[
\text{Household Use + LA Losses} - \text{Diesel Generation} = \text{Solar Generation} - \text{Other Losses}
\]

This does mean that figures for solar generation include an error due to any losses in each household and ESS. Despite this, the calculated figures give a good indication of how the solar panels performed. Throughout the rest of this report, ‘solar generation’ will refer to solar generation minus other losses.

2.3 Diesel Generation

Each household who participated in the ESV trial were provided with a 7kVA Yanmar diesel generator (see Figure 10). The diesel generator was brought into operation when there was insufficient solar generation to power the household, and the energy storage was also depleted.

Figure 8: The solar installation at SITE E

Figure 9: The solar installation at SITE G

Figure 10: The diesel generator used for each site of the ESV project
The pictures below (see Figure 11) show the generator unit manufactured by RedFlow with a weatherproof enclosure, a larger fuel tank with remote fuel level monitoring and a 7kVA Yanmar diesel generator.

Figure 11: Open generator enclosures from SITE C and SITE I
3 Results

3.1 Energy Storage System

The charge to discharge efficiency of the LA batteries was consistently high over the ten sites. This is shown in the graph below (see Figure 12) where the average efficiency ranged from 85% to 92%.

![Average LA Battery Efficiency](image1)

Figure 12: The average LA battery efficiencies of the duration of each site's participation in the ESV project

The use of the ZB battery, however, results in a smoothing in the LA SOC curve. This reduces stress on the LA batteries, which do not react well to regular deep discharging. This is shown in the graph below (see Figure 13), which shows the effect of the ZB batteries over the month of July for SITE J as an example. Also shown in the graph is the solar exposure for the ESV trial area over the course of the month (data from the Australian Bureau of Meteorology). The effect of high solar exposure over a period of more than one day shows a noticeable reduction in diesel generator operation, a deeper charge of the ZB batteries and a smoothed LA charge curve.

![LA SOC Smoothing due to ZB Use](image2)

Figure 13: The effect of using a ZBM on LA SOC curves
The RAPS systems were operational for the vast majority of the trial period. The graph below (see Figure 14) shows the total outage time over the entire trial period for each household, both in hours and as a percentage of the total trial period. This includes time that systems had an outage due to RAPS system error and insufficient diesel in the generator (customer controlled).

![Total RAPS Outage Time](image)

*Figure 14: The total RAPS outage time over the course of each site’s participation in the trial*

### 3.2 PV Solar Generation

The total solar generation over the course of the trial is given in the graph below (see Figure 15). This shows that there was a great deal of difference in the electricity generated by each household’s solar panels.

![Total Solar Generation](image)

*Figure 15: The total solar generation over the course of each site’s participation in the trial*

The table below (see Table 2) summarises factors that influenced the level of electricity generated at each test site. It should be noted that SITE C had a great deal of vegetation and trees shielding its solar panels, while the property of SITE F was located behind a hill, which also reduced its solar exposure. Additionally, SITE A to SITE G had their solar panels installed on roof-tops, with some at sub-optimum angles, while SITE H to SITE J had padmount solar panels with a good horizon. SITE I’s solar panel was of the high 4.8kW rating and was positioned in a favourable location, resulting its high output.
### Table 2: An overview of the sites’ solar installations and factors affecting performance

<table>
<thead>
<tr>
<th>Site</th>
<th>PV Array Size</th>
<th>PV Mounting</th>
<th>PV Placement</th>
<th>Average Daily PV Generation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td></td>
<td>2.55kWh</td>
</tr>
<tr>
<td>B</td>
<td>4.8kW</td>
<td>Rooftop</td>
<td></td>
<td>4.66kWh</td>
</tr>
<tr>
<td>C</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td>Under trees – undermined PV output</td>
<td>3.11kWh</td>
</tr>
<tr>
<td>D</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td></td>
<td>4.13kWh</td>
</tr>
<tr>
<td>E</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td>Property located behind a hill – undermined PV output</td>
<td>8.88kWh</td>
</tr>
<tr>
<td>F</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td></td>
<td>3.55kWh</td>
</tr>
<tr>
<td>G</td>
<td>3.2kW</td>
<td>Rooftop</td>
<td></td>
<td>5.50kWh</td>
</tr>
<tr>
<td>H</td>
<td>4.8kW</td>
<td>Padmount</td>
<td></td>
<td>6.86kWh</td>
</tr>
<tr>
<td>I</td>
<td>4.8kW</td>
<td>Padmount</td>
<td></td>
<td>10.88kWh</td>
</tr>
<tr>
<td>J</td>
<td>4.8kW</td>
<td>Padmount</td>
<td></td>
<td>9.53kWh</td>
</tr>
</tbody>
</table>

The graph below shows how each household performed on a daily average kWh per kW of capacity basis. As can be seen, there is still a great deal of discrepancy between the households, which are a result of the issues raised in Table 2 above.

**Figure 16: Average daily solar generation taking into account the size of each solar installation**

Weather also has a large impact on the performance of the solar panels. The graph below (see Figure 17) shows the direct relationship between solar exposure (taken from the Australian Bureau of Meteorology) and the average solar panel output over the operating sites over the course of the trial. It is clear that the output of the solar panels is much lower in winter than in the warmer spring and autumn months which receive more solar exposure.

**Figure 17: The effects of solar exposure on solar generation**
In summary, increasing the size of the PV solar panel system and installing it in the correct location and orientation will result in significantly higher solar panel outputs. This in turn results in reduced diesel generator runtime, as discussed in the following section. It is important to note, however, that a generator will always be required as a backup.

### 3.3 Diesel Generation

There were large discrepancies between the percentages of time that the generators were operating. As can be seen below (see Figure 18), while the majority of generators were operating for under 15% of the total trial time, SITE A and SITE B in particular had generators that ran for over one quarter of the time. This means that the energy storage in the RAPS system enabled a significant reduction in diesel run time, compared to a system with no storage. Such a system would have required the diesel generators to operate during most of the day, with the possible exception of times of the highest solar exposure, when the solar panels produced an adequate output to power the household load.

![Diesel Generator Run Time](image)

The weather also had a direct effect on the operation of the diesel generators. This can be seen in the graph below (see Figure 19), which shows the seasonal variation in the average generator run time for all ten households (reduced to nine households once SITE A had withdrawn from the trial, and then eight households when SITE B also withdrew), compared to the average monthly solar exposure (data taken from Bureau of Meteorology) for the area. There is a clear inverse relationship displayed in the graph. The need for diesel generation increases during the winter months due to the reduced solar exposure that limits the output of the solar panels.
The graph below (see Figure 20) shows the average diesel consumption, generation and run time for each system over the course of the trial. Both the generation and run time parameters use the left axis, while the consumption parameter uses the right axis.

The graph below (see Figure 21) shows the total daily diesel consumption, generation and run time for each system over the same time period. It can be seen that SITE A’s total diesel parameters are relatively low because of its early exit from the trial. Its average figures given in the graph above shows are calculated over only the period during which it was participating in the trial.
From the data presented above, it is clear that there were great differences between the ten households in terms of diesel generator operation. This is primarily due to significant variations in individual household electricity use compared with the amount of electricity generated from the PV solar array. Other factors also played a role, and these will be discussed later in the report.

Furthermore, as shown below (see Figure 22), there was also some variance in the efficiency of each generator. The efficiencies of the vast majority of generators were between 0.4 L/kWh and 0.6 L/kWh. However, the efficiency of SITE H’s generator appears to be far superior at just below 0.1 L/kWh. RedFlow believes this is an incorrect value because the fuel gauges in the ESS could not measure the level of fuel accurately below 10L. Since SITE H did not use their generator as often as other households, it is believed that fuel was often used below this 10L level and as such, was not recorded and could not be used in the analysis.
3.4 Household Load

Each RAPS system was installed to supply each respective household with its required electricity without grid support throughout the trial. The total load used by each household over the course of the trial is given in the graph below (see Figure 23).

![Total Load Usage by Household](image)

*Figure 23: Total household load usage*

Further to this, the graph below (see Figure 24) shows the average daily load used by each household over the course of the trial. It can be seen that SITE A and SITE B’s average consumption was relatively high, despite their total consumption being low due to its exit from the trial.

![Average Daily Load Usage by Household](image)

*Figure 24: Average daily load usage*

It is thus clear that most households remained at an average daily consumption of about 15kWh or less. However, SITE B significantly exceeded this figure, contributing to its high diesel generation totals.

There did not seem to be a significant seasonal variation in the household loads. This is illustrated in the graph below (with average maximum temperatures taken from the Bureau of Meteorology) (see Figure 25) where the average loads of all operational households fluctuated between about 85 kWh/week and 115 kWh/week. There was, however, a continual slight reduction in load usage over the course of the trial. RedFlow has assumed that this is because the households were learning to limit their energy consumption as the trial progressed, knowing that less electricity usage would result in less diesel consumption.
3.5 Overall System Performance

As can be seen in Table 1, this trial was conducted over a variety of different households with varying loads and generation capacities. This resulted in mixed results of success between the different trial sites.

The first point of difference was the respective outputs from each of the solar panel arrays. While there were two sizes of solar panel arrays used in the trial (3.2kW and 4.8kW), the outputs of each system did not necessarily reflect these differences in size. This was chiefly due to the poor installation locations and angles of several of the arrays. This included installing arrays in areas which received shade for much of the day, and also installing them at angles that did not point directly at the sun. In the case of SITE F, the location of the entire property was not conducive to an efficient output of its solar panel array since it was situated behind a hill that shielded the property from sunlight for a significant period of the day. However, in general, those sites with the larger-sized solar panels required less diesel generator runtime to power the load sufficiently.

Another point of difference was the variation in load consumption between the 10 households. This ranged from approximately 9kWh for SITE G to 22kWh for SITE B on average per day. This greatly affected the success of the ESS in limiting the diesel generator run time at each site. Coupled with the fluctuations in solar power output, this meant that the use of diesel generators varied greatly. While SITE B used its generator most (for about 32% of the trial period), SITE I used its generator for less than 3% of the trial time. It must be noted, however, that RedFlow’s ESS were designed to the specification of an approximate average daily load of 15kWh. All households for which this held were able to limit their diesel generator run time to less than 15% of the trial period. Furthermore, had the solar panels been installed in more favourable locations, and their outputs been higher, this could have been reduced even further.

The last significant point of difference between the trial sites is their respective System Average Interruption Duration Index (SAIDI) figures over the course of the trial (see Table 3). These ranged from 0 minutes for SITE E, to 1908 minutes for SITE H. A large proportion of outages were due to insufficient diesel in generators. RedFlow has installed “low fuel” warning systems for other customers, and these can be adapted for any future systems for ESV. When comparing these SAIDI figures to those reported by Powercor and SP Ausnet in those areas, 5 of the trial sites experienced better results during the trial. This is shown by the blue highlighting in Table 3.
### 3.5.1 RedFlow Technical Support

Over the course of the trial, RedFlow has provided continuing technical support to ESV and the trial residents. The allocated amount of time was originally one hour per week, but RedFlow generally exceeded this allowance during most of the trial. Included in this time was monitoring done by RedFlow of its own accord to ensure all systems were working as expected. This was separate to any investigations arising from customer or ESV enquiries. Specific customer-related enquiries have taken RedFlow a few hours each week to address. Together with RedFlow’s internal monitoring, RedFlow estimates that it has spent approximately ten hours per week in providing technical support for this project towards the end of the trial period. This figure was higher toward the start of the trial, when customers were not familiar with the RAPS systems, or how to most efficiently allow them to operate.

### 3.5.2 Remote monitoring

As part of the trial, all the systems were monitored. Figure 26 below shows typical data that was collected.

![Figure 26: A graph of some monitored parameters of a system](image-url)

<table>
<thead>
<tr>
<th>Site</th>
<th>Previous Electricity Distributor</th>
<th>Distributor SAIDI (2009/2010 annual averages)</th>
<th>Trial SAIDI (extrapolated data for annual average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SITE A</td>
<td>Powercor</td>
<td>283 minutes</td>
<td>4104 minutes</td>
</tr>
<tr>
<td>SITE B</td>
<td>Powercor</td>
<td>283 minutes</td>
<td>1934 minutes</td>
</tr>
<tr>
<td>SITE C</td>
<td>Powercor</td>
<td>283 minutes</td>
<td>160 minutes</td>
</tr>
<tr>
<td>SITE D</td>
<td>Powercor</td>
<td>283 minutes</td>
<td>16 minutes</td>
</tr>
<tr>
<td>SITE E</td>
<td>SP AusNet</td>
<td>362 minutes</td>
<td>0 minutes</td>
</tr>
<tr>
<td>SITE F</td>
<td>SP AusNet</td>
<td>362 minutes</td>
<td>448 minutes</td>
</tr>
<tr>
<td>SITE G</td>
<td>SP AusNet</td>
<td>362 minutes</td>
<td>16 minutes</td>
</tr>
<tr>
<td>SITE H</td>
<td>Powercor</td>
<td>283 minutes</td>
<td>2544 minutes</td>
</tr>
<tr>
<td>SITE I</td>
<td>SP AusNet</td>
<td>362 minutes</td>
<td>112 minutes</td>
</tr>
<tr>
<td>SITE J</td>
<td>SP AusNet</td>
<td>362 minutes</td>
<td>1296 minutes</td>
</tr>
</tbody>
</table>

Table 3: SAIDI information for the ESV trial sites
This data was then collated into weekly reports sent to ESV engineers. Figure 27 below shows an energy balance report for both SITE G and SITE I.
4 Lessons Learnt

4.1 Energy Storage System

The use of energy storage in the RedFlow RAPS system was very effective in reducing the diesel run time of each generator. In most cases, the diesel generator would have had to run for almost 100% of the time to power the household load, without the use of energy storage. An exception to this may have been in the middle of the day when the solar panels produced enough electricity to power the household load adequately. In the case of SITE H, whose diesel generator only operated for less than 5% of the trial period, the reduction in diesel run time could have been more than 95%. In conclusion, there were several lessons learnt by RedFlow from this trial, which included:

- The effectiveness of the RAPS system to adequately power the load – outage times were negligible for many of the trial sites.
- There was a significant reduction in diesel generator run time, compared to a system that did not utilize energy storage.
- The energy storage was able to effectively time-shift generation from the solar panels to use at times of peak demand, namely during the morning and evening.
- While the LA batteries were used extensively in this trial, the use of ZB batteries smoothed the LA charge/discharge SOC curve, thereby reducing stress on the LA batteries.
- The RAPS systems, especially those utilising two ZB batteries, may have had storage with a larger capacity than required for this application. In future, smaller capacities would probably suffice.
- Customers/participants should be made aware of the complexity of the RAPS systems, and the large amount of time and engineering that would need to be invested into creating live view monitors for them to monitor the systems themselves.
- Since the trial systems were deployed, RedFlow has developed improved designs that make better use of the diesel generator for charging the batteries more rapidly. This has led to further reductions in diesel generator runtime and consumption in the latest systems that will be deployed with future customers.

4.2 Solar Generation

For many customers taking part in the ESV trial, the solar panels underperformed compared to prior expectations. This was due to a range of factors, including poor placement of panels during installation, and the fact that most of the trial period occurred at times of low seasonal solar exposure, thereby undermining the performance of the solar panels. Consequently, there were many lessons learnt by RedFlow regarding solar generation when integrated with RAPS systems. These included:

- Solar panels need to be installed in effective locations. Care needs to be taken prior to installation to find the most advantageous position on a property for a solar panel array. As well as this, some properties were on the wrong sides of a large hill etcetera, making these areas unsuitable for any kind of effective solar panel array. In particular, the following parameters should be seriously considered when placing solar panels:
---

- angle to the sun – taking into account the position of the sun over the course of a day, and the seasonal variations of this.
- obstructions in the near vicinity of the solar panels – i.e. any shade from trees, buildings or hills during any time of the day.
- appropriate location of the entire property.
- maintenance required to ensure current conditions remain the same – e.g. any tree-cutting or pruning that may be required.

- Solar panels cannot be completely relied upon to generate ALL electricity required to power the household load. While solar generation at SITE H, for example, was almost completely adequate, this was not the case for most of the trial sites.
- Customers/participants should be made aware of these points, as well as given some past statistics, prior to an agreement being made to take part. This eliminates surprises over the course of a RAPS’ operational lifetime, and better informs the customer/participant of the realistic outcomes to expect.

### 4.3 Diesel Generation

For many customers taking part in the ESV trial, the diesel generator was used more often than they anticipated, leading to more frequent replenishment of the diesel tanks. All in all, the main lessons learnt by RedFlow regarding diesel generation during the trial included:

- Diesel generators need to run more in winter than in summer. This is due to the reduction in output from the solar cells. Therefore, customers/participants should be prepared to fill diesel tanks more frequently during months of lower solar exposure.
- Diesel generators need to run for a significant portion of the day when either:
  - solar generation is very low – due to low solar exposure during winter and/or poor placement during installation of solar panels
  - household load is large
- The efficiency of diesel generators varies between 0.4L/kWh and 0.6L/kWh
- Customers/participants should be made aware of the maintenance and diesel refueling demands of a diesel generator.
- Customers/participants should be made aware of these points, as well as given some past statistics, prior to an agreement being made to take part. This eliminates surprises over the course of a RAPS’ operational lifetime, and better informs the customer/participant of the costs and maintenance involved.

### 4.4 Household Load

There was a realization for many of the customers taking part in the trial that a significant change in their energy usage behavior was required to successfully operate their electricity systems off-grid while still keeping their diesel usage low. RedFlow has observed the following major lessons to be learnt from this trial:

- High household load usage greatly hinders reduction in diesel run time, and significantly increases the need to operate diesel generators to supply the requirements of the load.

---
• Load profiles with higher usage during the middle of the day reduce the need to start generators since this is the time of highest solar output. While the RAPS system can time-shift this energy from the solar panels, there are losses associated with storage and inverters etcetera. Large demand at peak times also increases the need to operate diesel generators.
• There needs to exist a willingness in customers/participants to change their habits to reduce energy usage and demand profiles, and thereby reduce stress on the diesel generators and RAPS system.
• Customers/participants should be made aware of these points, as well as given some past statistics, prior to an agreement being made to take part. This eliminates surprises over the course of a RAPS’ operational lifetime, and better informs the customer/participant of the realistic outcomes to expect.
5 Conclusions

Overall, this project has shown that it is technically feasible to use an off-grid renewable energy-based system to take residential customers off their normally-connected grid electricity supply. This allows parts of the electricity network to be de-energised and thus reduce the risk of bush fires in remote areas.

Overall, RedFlow has learnt many valuable lessons over the course of the ESV trial, and will use these to improve upon their technology for future RAPS applications. These have included:

- The importance of informing the customer/participant prior to the commencement of the trial of realistic outcomes to expect in terms of solar generation and diesel generator use. Customers/participants should also be made aware of the possible changes to their electricity usage behavior that may be required in order for the RAPS system to operate most effectively.
- The significant effect that reduced solar exposure during winter, as well as poor locations of solar panels during installation can have on the performance of the entire RAPS system.
- The need for a diesel generator to back-up the solar generation.
- The effectiveness of the RAPS system in greatly reducing the diesel runtime of each generator to below 15% of the time for most sites.
- The effectiveness of the RAPS system to significantly reduce the SAIDI figures of half the trial sites.
### Appendix A – List of Abbreviations

- **CT** - Current Transformer
- **ESS** - Energy Storage System
- **ESV** - Energy Safe Victoria
- **LA** - Lead Acid
- **PV** - Photovoltaic
- **RAPS** - Remote Area Power Supply
- **RTU** - Remote Terminal Unit
- **SAIDI** - System Average Interruption Duration Index
- **SOC** - State of Charge
- **ZBM** - Zinc Bromide Module
Appendix B – List of Trial Sites
**SITE A**

---

<table>
<thead>
<tr>
<th>Status at 18 Dec 2011</th>
<th>Not Operating</th>
</tr>
</thead>
</table>

**Bushfire Reduction Effectiveness**
- Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night

**Appropriateness for Trial**
- Poor placement of solar panels resulted in high diesel run time
- Average daily household load of 15.2kWh at maximum of system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>3.2kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>2.55kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>6.5 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>55.8L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>12.96kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.65 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>15.18kWh</td>
</tr>
</tbody>
</table>

**Commercial Feasibility**
- Not feasible (diesel costs too high and outweigh electricity bill savings)

**Power Quality and Reliability**
- Not Improved
  - SAIDI during Trial Period: 1026 minutes
  - Previous Electricity Distributor: Powercor
  - Distributor SAIDI (2009/2010 annual averages): 283 minutes
  - Trial SAIDI (extrapolated data for annual average): 4104 minutes

**Customer Satisfaction**
- These customers were not satisfied with the results of the trial (namely, their high diesel consumption) and as a result, exited from the trial early in June.
### SITE B

**Status at 18 Dec 2011**

<table>
<thead>
<tr>
<th>Bushfire Reduction Effectiveness</th>
<th>Not Operating</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appropriateness for Trial</strong></td>
<td></td>
</tr>
<tr>
<td>- Poor placement of solar panels resulted in high diesel run time</td>
<td></td>
</tr>
<tr>
<td>- Average daily household load of 22kWh too high for system design</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>4.8kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>4.66kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>7.82 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>10.6L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>18.03kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.59 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>21.79kWh</td>
</tr>
</tbody>
</table>

**Commercial Feasibility**

- Not feasible (diesel costs too high and outweigh electricity bill savings)

**Power Quality and Reliability**

<table>
<thead>
<tr>
<th>SAIDI during Trial Period</th>
<th>1128 minutes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Previous Electricity Distributor</td>
<td>Powercor</td>
</tr>
<tr>
<td>Distributor SAIDI (2009/2010 annual averages)</td>
<td>283 minutes</td>
</tr>
<tr>
<td><strong>Trial SAIDI</strong> (extrapolated data for annual average)</td>
<td>1934 minutes</td>
</tr>
</tbody>
</table>

**Customer Satisfaction**

- These customers were not satisfied with the results of the trial (namely, their high diesel consumption) and as a result, exited from the trial in October.
### SITE C

#### Status at 18 Dec 2011

- **Operating**

#### Bushfire Reduction Effectiveness

- Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night

#### Appropriateness for Trial

- Poor placement of solar panels resulted in high diesel run time
- Average daily household load of 16kWh too high for system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>3.2kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop (shielded by vegetation)</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>3.11kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>3.80 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>6.3L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>14.07kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.45 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>16.54kWh</td>
</tr>
</tbody>
</table>

#### Commercial Feasibility

- Not feasible (diesel costs too high and outweigh electricity bill savings)

#### Power Quality and Reliability

- Improved
- **SAIDI during Trial Period** 120 minutes
- **Previous Electricity Distributor** Powercor
- **Distributor SAIDI** (2009/2010 annual averages) 283 minutes
- **Trial SAIDI** (extrapolated data for annual average) 160 minutes

#### Customer Satisfaction

- These customers remained participants throughout the trial.
### Status at 18 Dec 2011

Operating

### Bushfire Reduction Effectiveness

Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night

### Appropriateness for Trial

- Poor placement of solar panels resulted in high diesel run time
- Average daily household load of 13kWh suited to system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>3.2kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>4.13kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>2.19 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>3.4L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>8.39kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.41 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>12.20kWh</td>
</tr>
</tbody>
</table>

### Commercial Feasibility

Possibly feasible (diesel costs significantly lower than electricity costs)

### Power Quality and Reliability

- **SAIDI during Trial Period**: 12 minutes
- **Previous Electricity Distributor**: Powercor
- **Distributor SAIDI (2009/2010 annual averages)**: 283 minutes
- **Trial SAIDI (extrapolated data for annual average)**: 16 minutes

### Customer Satisfaction

These customers remained participants throughout the trial.
SITE E

Status at 18 Dec 2011

- Operating

Bushfire Reduction Effectiveness

- Could be taken off the grid permanently to allow for total de-energisation of power lines

Appropriateness for Trial

- Average daily household load of 13.8kWh suited to system design

|PV Array Size| 3.2kW|
|PV Mounting| Rooftop|
|Average Daily PV Generation| 8.88kWh|
|Average Daily Generator Runtime| 1.44 hours|
|Average Daily Diesel Consumption| 2.0L|
|Average Daily Generator Output| 4.97kWh|
|Diesel Generator Efficiency| 0.41 L/kWh|
|Average Daily Household Load| 13.79kWh|

Commercial Feasibility

- Possibly feasible (diesel costs significantly lower than electricity costs)

Power Quality and Reliability

- Improved

- SAIDI during Trial Period: 0 minutes

- Previous Electricity Distributor: SP AusNet

- Distributor SAIDI (2009/2010 annual averages): 362 minutes

- Trial SAIDI (extrapolated data for annual average): 0 minutes

Customer Satisfaction

- These customers remained participants throughout the trial.
### SITE F

**Status at 18 Dec 2011**

<table>
<thead>
<tr>
<th>Bushfire Reduction Effectiveness</th>
<th>Operating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Could be taken off the grid during the day when bushfire risk is high and returned to the grid at night.</td>
<td></td>
</tr>
</tbody>
</table>

**Appropriateness for Trial**

- Poor placement of solar panels resulted in high diesel run time.
- Average daily household load of 12.7kWh suited to system design.

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>3.2kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop (property located behind a hill)</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>3.55kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>2.60 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>4.9L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>9.13kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.54 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>12.27kWh</td>
</tr>
</tbody>
</table>

**Commercial Feasibility**

Not feasible (diesel costs too high and outweigh electricity bill savings).

**Power Quality and Reliability**

- SAIDI during Trial Period: 336 minutes
- Previous Electricity Distributor: SP AusNet
- Distributor SAIDI (2009/2010 annual averages): 362 minutes
- Trial SAIDI (extrapolated data for annual average): 448 minutes

**Customer Satisfaction**

These customers remained participants throughout the trial.
### Status at 18 Dec 2011

**Operating**

#### Bushfire Reduction Effectiveness

Could be taken off the grid permanently to allow for total de-energisation of power lines

#### Appropriateness for Trial

- Average daily household load of 8.9kWh suited to system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>3.2kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Rooftop</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>5.50kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>1.12 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>15L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>3.47kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.51 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>8.82kWh</td>
</tr>
</tbody>
</table>

#### Commercial Feasibility

Possibly feasible (diesel costs significantly lower than electricity costs)

#### Power Quality and Reliability

- Improved
- SAIDI during Trial Period: 12 minutes
- Previous Electricity Distributor: SP AusNet
- Distributor SAIDI (2009/2010 annual averages): 362 minutes
- Trial SAIDI (extrapolated data for annual average): 16 minutes

#### Customer Satisfaction

These customers remained participants throughout the trial.
SITE H

Status at 18 Dec 2011

Bushfire Reduction Effectiveness
Could be taken off the grid permanently to allow for total de-energisation of power lines

Appropriateness for Trial
- Average daily household load of 14kWh suited to system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>4.8kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Padmount</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>6.86kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>2.01 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>0.6L *</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>6.53kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.09 L/kWh *</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>13.12kWh</td>
</tr>
</tbody>
</table>

Commercial Feasibility
Possibly feasible (diesel costs significantly lower than electricity costs)

Power Quality and Reliability
Not Improved

SAIDI during Trial Period
1908 minutes

Previous Electricity Distributor
Powercor

Distributor SAIDI
(2009/2010 annual averages)
283 minutes

Trial SAIDI (extrapolated data for annual average)
2544 minutes

Customer Satisfaction
These customers remained participants throughout the trial.

* = Data is not accurate

32
### Status at 18 Dec 2011
- Operating

### Bushfire Reduction Effectiveness
- Could be taken off the grid permanently to allow for total de-energisation of power lines

### Appropriateness for Trial
- Average daily household load of 13.0kWh suited to system design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Array Size</td>
<td>4.8kW</td>
</tr>
<tr>
<td>PV Mounting</td>
<td>Padmount</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>10.88kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>0.70 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>1.3L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>2.2kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.61 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>13.06kWh</td>
</tr>
</tbody>
</table>

### Commercial Feasibility
- Possibly feasible (diesel costs significantly lower than electricity costs)

### Power Quality and Reliability
- Improved
  - SAIDI during Trial Period: 84 minutes
  - Previous Electricity Distributor SAIDI (2009/2010 annual averages): 362 minutes
  - Trial SAIDI (extrapolated data for annual average): 112 minutes

### Customer Satisfaction
- These customers remained participants throughout the trial.
### Status at 18 Dec 2011

**Operating**

### Bushfire Reduction Effectiveness

Could be taken off the grid permanently to allow for total de-energisation of power lines

### Appropriateness for Trial

- Average daily household load of 15.5kWh at maximum of system design

<table>
<thead>
<tr>
<th>PV Array Size</th>
<th>4.8kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>PV Mounting</td>
<td>Padmount</td>
</tr>
<tr>
<td>Average Daily PV Generation</td>
<td>9.53kWh</td>
</tr>
<tr>
<td>Average Daily Generator Runtime</td>
<td>1.92 hours</td>
</tr>
<tr>
<td>Average Daily Diesel Consumption</td>
<td>2.6L</td>
</tr>
<tr>
<td>Average Daily Generator Output</td>
<td>5.79kWh</td>
</tr>
<tr>
<td>Diesel Generator Efficiency</td>
<td>0.46 L/kWh</td>
</tr>
<tr>
<td>Average Daily Household Load</td>
<td>15.29kWh</td>
</tr>
</tbody>
</table>

### Commercial Feasibility

Possibly feasible (diesel costs significantly lower than electricity costs)

### Power Quality and Reliability

Not Improved

- SAIDI during Trial Period: 972 minutes
- Previous Electricity Distributor: SP AusNet
- Distributor SAIDI (2009/2010 annual averages): 362 minutes
- Trial SAIDI (extrapolated data for annual average): 1296 minutes

### Customer Satisfaction

These customers remained participants throughout the trial.