



“The speed at which this game-changing solution has progressed from the drawing board to the field is testament to the clever Australian design and its potential to bring more renewable energy to off-grid Australia”

ARENA Chief Executive  
Ivor Frischknecht  
The Courier Mail,  
13 August 2014



This project is supported by the Australian Government through the Australian Renewable Energy Agency (ARENA). ARENA was established by the Australian Government as an independent authority on 1 July 2012 to make renewable energy technologies more affordable and increase the amount of renewable energy used in Australia.

ARENA is funded to 2022 to invest in renewable energy projects, support research and development activities, and increase industry and community knowledge about renewable energy. More information is available at [www.arena.gov.au](http://www.arena.gov.au)



Redispan  
DfMA™

This project is led by Laing O'Rourke, an \$8billion-turnover global construction company dedicated to engineering excellence. With operations in Australia for more than 50 years, Laing O'Rourke delivers building construction, railway services, materials handling, marine and civil infrastructure and a range of support services to clients in the oil and gas, resources, transport, defence, health, commercial and industrial sectors. Laing O'Rourke is the largest privately-owned construction and engineering firm in Australia. More information is available at [www.laingorourke.com](http://www.laingorourke.com)

In addition to the parent company, two wholly-owned subsidiaries of Laing O'Rourke are involved with this project:

- Select Plant Hire owns and manages one of Australia's largest ranges of equipment with a current asset net book value of \$150 million. Select Plant Hire manages over 200 diesel generators across Australia with major current deployments including Ichthys Cryogenic Tanks (Northern Territory, 2MVA), Northern Water Treatment Plant (Queensland, 600kVA) and APLNG (Queensland, 1,150kVA).
- Redispan manufactures and markets Design for Manufacture and Assembly (DfMA) modules, chiefly conveyor systems for materials handling applications.

The chief contact point for this project is Laing O'Rourke's Clean Technology Leader Dr Will Rayward-Smith ([wraywardsmith@laingorourke.com.au](mailto:wraywardsmith@laingorourke.com.au))



SUNPOWER®



POWER TECHNOLOGY  
ENGINEERED SOLUTIONS



The following parties were appointed by Laing O'Rourke and ARENA to support in the successful delivery of this project:

- ABB for the supply of solar PV inverters and integration control system;
- SunPower for supply of solar photovoltaic panels;
- Power Technology Engineered Solutions for support services in detailed design, test planning and control system commissioning;
- Screw-pile International for design and supply of screw-piles; and
- Huber+Suhner for the supply of modular wiring

# History

In late 2013, Laing O'Rourke conceived the idea of a modular solar-diesel hybrid plant manufactured off-site and efficiently installed on-site. There are benefits in quality, programme, safety, cost and risk to be realised by using this modular technology. Furthermore, the modular nature of the innovation enables the plant to be easily packed-up and re-deployed to a different site, thereby facilitating temporary installations.

Laing O'Rourke progressed the idea through concept design and early-stage feasibility to achieve Technology Readiness Level<sup>1</sup> (TRL) 3 and, in early 2014, presented the concept to ARENA, seeking the support of the Australian Government, critical to enabling further product development.

On 6 March 2014, Laing O'Rourke and ARENA signed an equal-contribution Funding Agreement, in the form of an Emerging Renewables Program (ERP) Measure, to progress the technology to TRL 7 through detailed design and prototyping.

In June 2014, Laing O'Rourke presented the outcomes of the ERP Measure to ARENA, having also identified and planned the first commercial deployment of the technology. The success of the first Measure led to Laing O'Rourke and ARENA signing a second ERP Measure on 14 July 2014 to progress the technology to TRL 9 and Commercial Readiness Index (CRI) 3 through manufacture and first commercial deployment of a large-scale system.



Upon completion of the first ERP Measure, a Product Development Report was made available to the public via the ARENA Knowledge Bank.

In February 2015, the demonstration plant, consisting of 120kW<sub>ac</sub> of solar and 1MW of diesel, was successfully transported, assembled and commissioned in less than one week. Time-lapse footage of the process was made available to the public via the ARENA YouTube channel <https://youtu.be/-ZOR1trhJD8>.

In April 2015, the patented technology was trademarked SunSHIFT and the website <http://www.sunshift.com.au> launched, providing a market face for the product and associated business models.

## Purpose of this document

This document is produced upon completion of the second ERP Measure to serve as an update to interested parties and the general public on the progress that has been achieved thus far. Such knowledge sharing will continue through any further phases of collaboration between ARENA and Laing O'Rourke.

<sup>1</sup> See <http://arena.gov.au/resources/readiness-tools/> for further information regarding readiness tools.

# Table of contents

<b>02</b>	<b>History</b>
<b>02</b>	<b>Purpose of this document</b>
<b>04</b>	<b>Disclaimer</b>
<b>04</b>	<b>Intellectual property</b>
<b>04</b>	<b>Table of abbreviations</b>
<b>04</b>	<b>Executive summary</b>
<b>05 1</b>	<b>Introduction</b>
<b>05 1.1</b>	Benefits of solar
<b>06 1.2</b>	Solar power penetration & energy contribution
<b>06 1.3</b>	Benefits of SunSHIFT over traditional
<b>07 1.4</b>	SunSHIFT module types
<b>07 1.4.1</b>	Diesel generator(s)
<b>07 1.4.2</b>	Diesel fuel tank(s)
<b>07 1.4.3</b>	Integrator
<b>08 1.4.4</b>	Solar sub-array(s)
<b>08 1.4.5</b>	Energy Store(s)
<b>09 1.5</b>	The demonstration plant and its first deployment
<b>10 2</b>	<b>Implementation</b>
<b>10 2.1</b>	Fabrication
<b>11 2.2</b>	Logistics
<b>12 2.3</b>	Installation
<b>12 2.3.1</b>	Placement of the Integrator
<b>13 2.3.2</b>	Installation of the screw-piles
<b>14 2.3.3</b>	Placement of the solar sub-arrays
<b>15 3</b>	<b>Operation and performance</b>
<b>16 3.1</b>	Solar output compared to forecast
<b>19 3.2</b>	Curtailment of solar
<b>20 3.3</b>	Cloud events
<b>21 3.4</b>	Fuel efficiency of solar-diesel vs diesel-only
<b>22 4</b>	<b>Societal impact</b>
<b>22 5</b>	<b>Next steps</b>
<b>23 5.1</b>	Process with potential clients
<b>23 5.2</b>	Laing O'Rourke project team
<b>24 5.3</b>	Thanks to ARENA

# Disclaimer

While considerable efforts have been made to ensure that the information contained in this report is fair and accurate, Laing O'Rourke, ARENA and any other persons involved in the preparation of this report:

- a) exclude all warranties and representations, express or implied, whether statutory or otherwise, with respect to the accuracy, completeness or currency of the information contained in this report; and
- b) assume no liabilities with respect to any loss or damage suffered as a result of the use of or reliance on any information in this report. Users should undertake their own detailed investigations and determinations relating to the subject-matter of this report.

## Intellectual property

Laing O'Rourke has title to and intellectual property rights in this report and its subject matter including, patents, trademarks, copyright, registered and unregistered design and patent application rights. Any reader or user of this report must use all reasonable endeavours not to infringe Laing O'Rourke's intellectual property rights in this report and its subject matter.

## Table of abbreviations

<b>ARENA</b>	Australian Renewable Energy Agency
<b>BOM</b>	Bureau of Meteorology
<b>CRI</b>	Commercial Readiness Index
<b>DfMA</b>	Design for Manufacture and Assembly
<b>ERP</b>	Emerging Renewables Program
<b>HMI</b>	Human Machine Interface
<b>PV</b>	Photovoltaic
<b>TRL</b>	Technology Readiness Level

## Executive summary

- Laing O'Rourke and ARENA have successfully demonstrated the world's first fully re-deployable solar-diesel hybrid plant – taking a concept from the drawing board to commercial demonstration in less than one year.
- Fabrication, transport, assembly and operation have all been successfully demonstrated, all without safety incident or damage to equipment.
- The demonstration plant is performing as per forecasts and has achieved a total system efficiency of 0.22810 litres of diesel fuel per kWh of electricity exported to the user.
- A survey has evidenced its positive impact on workforce morale, with 70 of 84 survey respondents agreeing with the statement “it is good to work for a company trying new technology on my project”.
- Laing O'Rourke and ARENA have now branded the system SunSHIFT and are in discussions around any future phase of collaboration in commercial roll-out.

# 1 Introduction

This Demonstration Report builds upon the Product Development Report released in 2014 via the ARENA Knowledge Bank.

We have now branded our product SunSHIFT and we start by reviewing:

- the benefits of introducing solar to diesel mini-grids (Section 1.1);
- the key terminology of solar power penetration and energy contribution (Section 1.2);
- the benefits of SunSHIFT over the traditional in-situ approach (Section 1.3);
- the different SunSHIFT modules (Section 1.4); and
- the SunSHIFT demonstration plant and its first deployment (Section 1.5).

We then describe and share knowledge gained from the successful implementation of the demonstration plant:

- fabrication (Section 2.1);
- logistics (Section 2.2); and
- installation (Section 2.3).

We evidence the correct operation and strong performance of the first SunSHIFT plant (Section 3) and the positive impact that the plant has had on the morale of the construction workers within the accommodation village powered by the first plant (Section 4).

We conclude with:

- the process of working with potential clients (Section 5.1);
- the Laing O'Rourke team behind SunSHIFT (Section 5.2); and
- the ARENA team (Section 5.3).

## 1.1 Benefits of solar

Solar power is now cheaper than diesel-generated electricity<sup>2</sup>. The inclusion of solar within a mini-grid represents an opportunity to save money without impacting reliability.

- Reduce diesel fuel consumption
- Reduce exposure to fuel price volatility
- Reduce frequency of fuel tank refills
- Reduce truck movements in remote locations
- Reduce fuel spillage risks and increase safety
- Reduce runtime of diesel generators
- Increase plant lifetime
- Reduce CO<sub>2</sub> emissions
- Create carbon credits
- Reduce noise levels
- Increase air quality
- Fleet-manage diesel generators to operate more efficiently (optional)

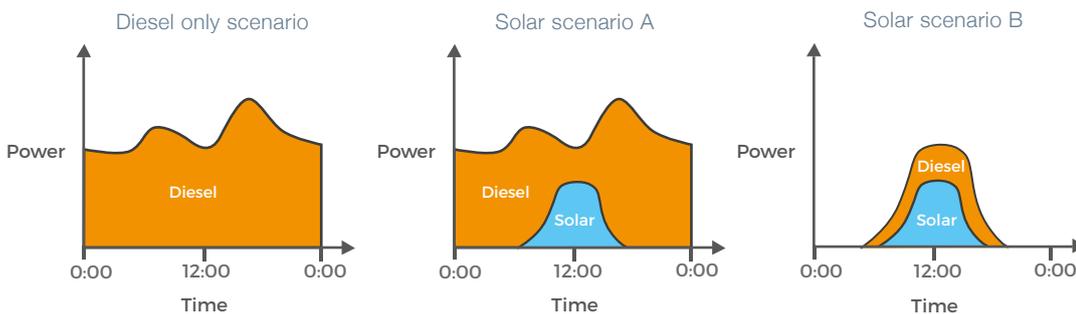
<sup>2</sup>Bloomberg New Energy Finance Summit 2013, Solar for the win (over diesel), Jenny Chase.

# 1.2 Solar power penetration & energy contribution

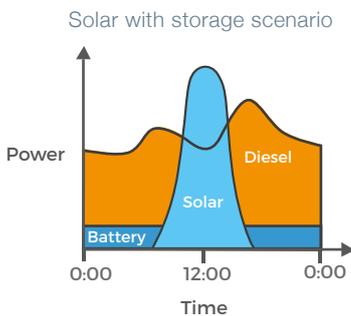
SunSHIFT acts as an additional energy source and integrates with the new or existing diesel infrastructure.

There are two metrics for solar within a mini-grid. The first is the solar power penetration – this is the maximum % of power that comes from solar and typically occurs at the solar midday. The second is the solar energy contribution – this is the overall contribution of energy that comes from solar.

Without energy storage, the solar is exported straight to the mini-grid for immediate consumption. A solar power penetration of 60% may be achieved. If the load profile has a high night-time load then the energy contribution may be as little as 10% (Solar scenario A). However if the load profile is aligned with the daytime solar generation then an energy contribution of as high as 50% may be achieved (Solar scenario B).



With energy storage, it is possible to achieve a solar penetration upwards of 50% (Solar with storage scenario) and ultimately an energy contribution of 100% may be achieved if the battery and solar are large enough.



# 1.3 Benefits of SunSHIFT over traditional

SunSHIFT with its Lego™ block approach to mini-grids has the following benefits over the traditional in-situ approach:

## Traditional

- Thousands of components
- Bespoke design
- Complex procurement, logistics and planning
  
- Often complex ground preparation required
- High on-site labour requirement
- Complex on-site works
- No ability for re-deployment

## SunSHIFT

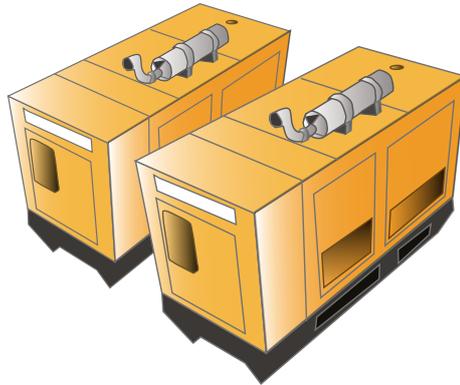
- ✓ Only a handful of module types
- ✓ Quick selection of off-the-shelf modules
- ✓ Off-site storage provides single source of mod ready for containerised transport to site
  
- ✓ Minimal ground preparation
- ✓ Low on-site labour requirement
- ✓ Safe modular on-site assembly
- ✓ Fully re-deployable

## 1.4 SunSHIFT module types

SunSHIFT consists of 5 different modules types that are configured together according to the particular deployment's requirements.

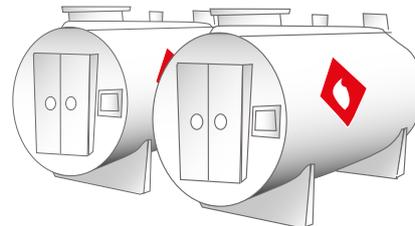
### 1.4.1 Diesel generator(s)

- Provided by the client or by SunSHIFT.
- New or existing.



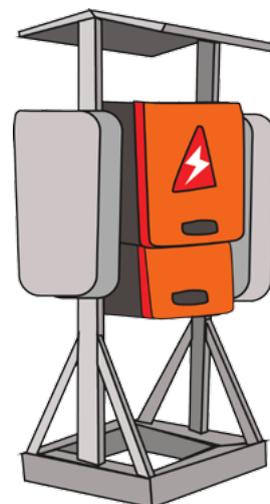
### 1.4.2 Diesel fuel tank(s)

- Provided by the client or by SunSHIFT.
- New or existing.



### 1.4.3 Integrator

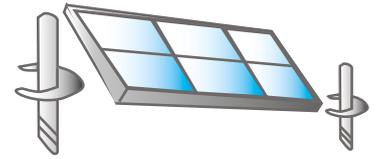
- Integrates the solar and any optional energy storage with the diesel generator(s).
- Ruggedised for transport, Cyclone Region D capable, weather-protected and may be either pad-mounted or secured to the ground with a screw-pile<sup>3</sup>.
- Houses the switchboard and the control system (ABB Microgrid Plus System) upon a galvanised steel frame.
- The control system monitors the loading of the generator(s) and reduces the solar farm's output when necessary to ensure i) that the diesel generator(s) are never below minimum loading and ii) that the diesel generator(s) have sufficient spare capacity in a cloud event.
- The control system may control the diesel generator(s) if desired. Such control has the advantage of realising further diesel fuel savings through i) optimisation of the diesel fleet and ii) reducing any solar curtailment by informing the generators about the spinning reserve requirement.
- Optional on-site touchscreen as Human Machine Interface (HMI).
- Solar exported to the mini-grid is metered.



<sup>3</sup>Screw-piles are the preferred ground-restraint. However, under certain soil conditions, alternatives such as rock-anchors may be employed.

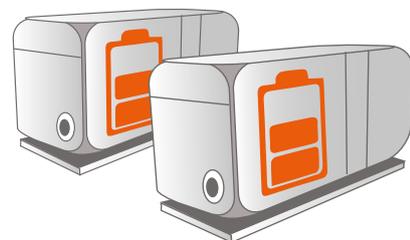
## 1.4.4 Solar sub-array(s)

- Each 20kW<sub>ac</sub> sub-array consists of either 24 identical 3-panel solar modules or 12 identical 6-panel solar modules, 1 inverter module and multiple screw-piles<sup>3</sup>.
- Each solar module includes either 3 or 6 highly-robust, highly-efficient (20.4%) monocrystalline silicon solar panels manufactured by the US panel manufacturer SunPower™.
- The solar module has maximum tilt angles 40°, 30°, 20° and 15° for the Cyclone Regions A, B, C and D respectively.
- Ruggedised and compact for transport with 12 solar modules fitting into a standard 20ft flat-rack container, which may be easily unloaded on-site using a side-loader.
- Plug-and-play fly-leads quickly connect the solar modules to form the necessary reticulation back to the inverter module.
- The inverter module is ruggedized for transport, Cyclone Region D capable, weather-protected and may be either pad-mounted or secured to the ground with a screw-pile<sup>3</sup>.
- All modules may be craned or forklifted, with stacks of three solar modules per lift.
- Sub-array, inclusive of row spacing, has electrical power density of 83W/m<sup>2</sup>.
- Requires zero to minimum ground preparation and is suitable in undulating terrain.
- Site remediation is also minimal when removing/relocating the sub-arrays.
- Once the modules are placed upon the screw-piles and the fly-leads connected there is no further on-site construction activity to be done.



## 1.4.5 Energy Store(s)

- Optional lithium-ion battery and inverter container(s) for achieving higher solar penetration and greater diesel fuel savings
- Designed for fast injection and absorption of power



# 1.5 The demonstration plant and its first deployment

The demonstration plant has been deployed at a 550-person construction worker accommodation village in remote Queensland, approximately a 90 minute drive from Roma (Figure 1). The plant provides all electrical power to the village and its vital stats are summarised in Table 1.



Figure 1 Aerial view of the accommodation village prior to installation of the SunSHIFT demonstration plant.

Item	Value
Optimised Configuration	6x sub-arrays (each sub-array has 24x 3-panel solar modules & 1x inverter module) totalling 120kW <sub>ac, rated</sub> 3x 400kW <sub>ac, rated</sub> and 1x 300kW <sub>ac, rated</sub> diesel generator 1x diesel tank and bunding 1x Integrator 0x Energy Store
Cyclone region	A
Soil condition	Ground is generally underlain by up to 200mm of high plasticity clay fill of hard consistency, overlying up to 1.2m of natural high plasticity clay of firm to stiff consistency. The natural clay is overlying Extremely Weathered Sandstone of very low to low strength.
Solar module screw-pile density	Placed after every third solar module (due to low cyclone rating and good soil conditions)
Forecast solar used	180MWh/year
Forecast diesel saving	50,000L/year
Forecast CO <sub>2</sub> saving	130T/year
Commercial arrangement	Weekly hire

Table 1 Vital stats of the demonstration plant and its first deployment.

## 2 Implementation

Through careful planning, risk identification and treatment, use of Safe Work Method Statements (SWMS) and Job Safety Analyses (JSA) there were zero safety incidents during the fabrication, transport and on-site assembly.

A solar-powered time-lapse camera was mounted on a nearby communications mast in order to capture footage of the entire installation process. The time-lapse footage was shared via the ARENA YouTube channel (<https://youtu.be/-ZOR1trhJD8>) and is linked via the SunSHIFT website (<http://www.sunshift.com.au>).

### 2.1 Fabrication

#### Knowledge shares

- All steelwork was hot-dip galvanised. We found it important to accommodate for the coating thickness within our design. For example, hinged elements may be stiff in operation if coating thickness is not considered within the design.
- Each SunSHIFT module has its own digital model that has evolved during the design development. Any changes to the model should be reviewed by all engineering disciplines to ensure that there are no unintended knock-on effects. For example, an increase in height to the Integrator requires the cabling lengths to be increased. Such interdependencies can be automated within the digital model.
- The digital model can be used to simulate how humans will interact with the product. This can prevent issues that otherwise would have been uncovered after fabrication and when the product is in operation. For example, the digital model identifies that a clash occurs between the solar panel and a piece of steelwork if the solar panel is tilted beyond 45°. That piece of steelwork may be re-positioned in the digital model to avoid such a clash occurring.
- Electrical cables have a radius of curvature. It is important to consider this radius when designing electrical cabling, otherwise the cables become difficult to install and may in fact become damaged. For example, there are fly-leads that connect adjacent solar modules. We found it important to make these fly-leads longer than just the distance between the two sockets.

The demonstration plant included multiple steelwork items that were manufactured off-site by Redispan in Newcastle (Figure 2). Laing O'Rourke has engineered the inverter modules and Integrator to have the same structural steel frame in order to reduce engineering and design costs and increase economies of scale during manufacture. The steelwork included 7 such frames (for 6 inverter modules and 1 Integrator) and 144 3-panel solar modules.

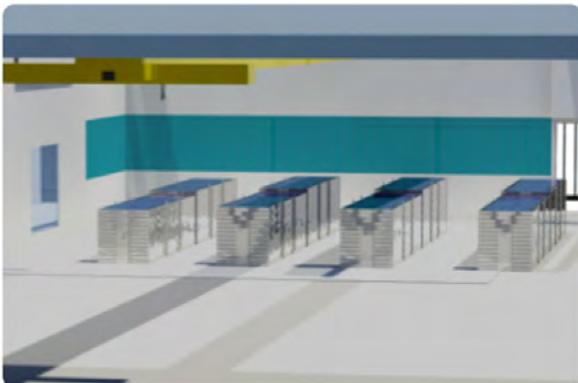


Figure 2 The planned and actual fabrication of solar modules.

## 2.2 Logistics

### Knowledge shares

- When transporting modules in Queensland, we found it important to consider the State-specific regulation that two modules may not be transported side-by-side if they collectively exceed 2.5m in width. [See item 8.6.3 and definition 3 of the Guideline for Excess Dimension Version 8 published by Queensland Government's Department of Transport and Main Roads]
- A logistics work-package that requires an additional crane for unloading trucks introduces the risk of crane unavailability and potential for demurrage as the trucks wait to be unloaded. The inclusion of a side-loader should be considered so that the trucks may self-unload.
- A re-deployable plant requires an on-site storage solution for those items accompanying the plant – for example the transport straps and shackles.

Items were transported from the fabricator Redispan to the site for first deployment as shown in Figure 3.



Figure 3 Containerised transport from the off-site storage to site for assembly.

## 2.3 Installation

### Knowledge shares

- There is a tolerance associated with the installed position of the screw-pile head. This tolerance was incorporated into the design of the solar farm structure so that no clashes arose between the structure and the screw-piles during installation.
- The risk associated with in-ground works may be mitigated through conducting geotechnical investigations with test pits and boreholes.
- Work-packages should be carefully staggered and designed to minimise interdependencies, therefore reducing the risk of stand-down days for any labourers/machinery. We found it important to have the screw-pile and module placement packages staggered and independent.
- Consider inspecting any third-party supplied machinery prior to contract execution and mobilisation to the remote site. We found this important to avoid costly delays in case the machinery did not comply with our strict and high safety standards.
- Critical path analysis and value stream mapping are key techniques for reducing the programme and costs. We found these to be a particularly worthwhile due to the remote nature of the deployment where labour and machinery are particularly expensive.

The installation of the plant involved:

1. Placement of the Integrator;
2. Installation of the screw-piles;
3. Placement of the inverter modules and solar modules.

### 2.3.1 Placement of the Integrator

The first item of plant deployed was the Integrator, shown in Figure 4. In the case of the first deployment of the demonstration plant, the Integrator module was bolted directly onto the pre-existing concrete slab.



Figure 4 Front and side views of the Integrator bolted directly onto the concrete slab.

## 2.3.2 Installation of the screw-piles

We installed 66 screw-piles as the ground restraint for the solar sub-arrays. This was identified in the earlier Product Development Report as the most practical, economical and safe solution (Figure 5).

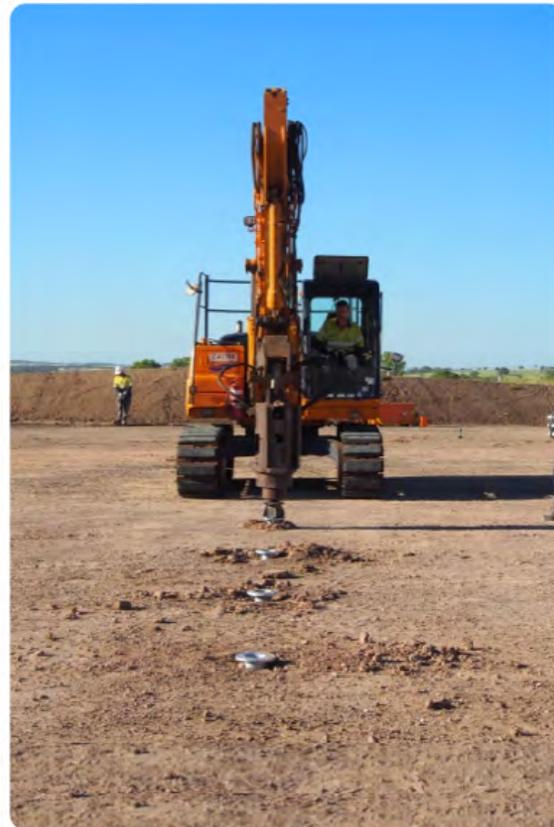


Figure 5 The planned and actual installation of screw-piles.

## 2.3.3 Placement of the solar sub-arrays

The inverter modules were fast to deploy simply slotting over the screw-piles (Figure 6).



Figure 6 Installation of inverter modules.

We used a flatbed truck with Hiab (loader crane) to carry 24 3-panel solar modules and to quickly place the solar modules in rows (Figure 7).

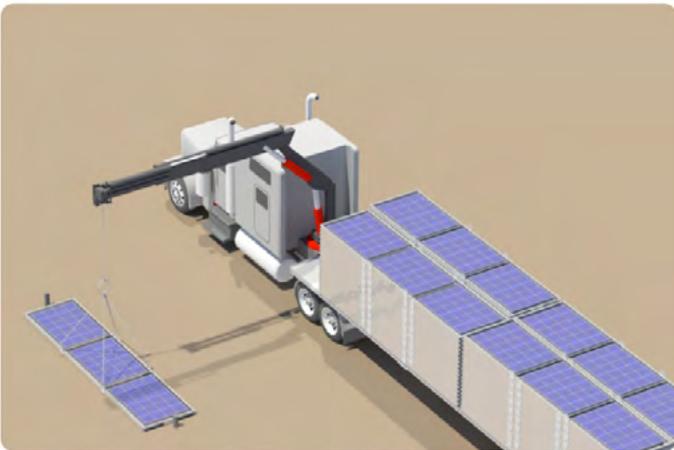


Figure 7 The planned and actual installation of solar modules.

The panels were then tilted and plug-and-play fly-leads were plugged between adjacent solar modules. The system was completed and energised (Figure 8).



Figure 8 The planned and actual completed solar farm.

# 3 Operation and performance

## Knowledge shares

- A low level of solar power penetration does not necessarily mean a low level of solar energy contribution. If loads are shifted to be in-line with the solar output, there is an opportunity to increase the number of solar modules and therefore increase the solar energy contribution, whilst keeping the same solar power penetration. For example, hot water heating is a load that is easy to shift to the daytime through the use of timers.
- To enable diagnosis of any power outages, it is important to have an Uninterruptable Power Supply (UPS) within the Integrator such that data continues to be logged during the power outage.
- The system was originally configured to provide static spinning-reserve of 80kW for step loads from the village plus a dynamic spinning-reserve equal to 100% of the real-time PV output for cloud events. During commissioning on-site, it was observed that even on a day with complete cloud cover the PV still produces about 20% of its rated output. As a result the dynamic spinning-reserve was reduced to 80% of the real-time PV output.
- At the feasibility stage, it is important to consider data access to the site for remote monitoring, estimate the bandwidth requirements and identify back-up options for data connection.
- During installation, it is important to give a basic level of training to site staff who will work with the remote team if any issues arise during operation. This avoids high mobilisation costs associated with remote sites. The Human Machine Interface (HMI), i.e. the touchscreen on the Integrator, should be designed for ease of use by these local operatives.

The Integrator logs performance data locally onto a hard drive and remote access is provided via a Virtual Private Network (VPN) connection and online dashboard. The homepage of the online dashboard is a single-line diagram of the plant (Figure 9). In addition to providing data access, that VPN connection provides the ability for complete remote control of the system – for example changing any parameters within the controllers or turning off/on generators.

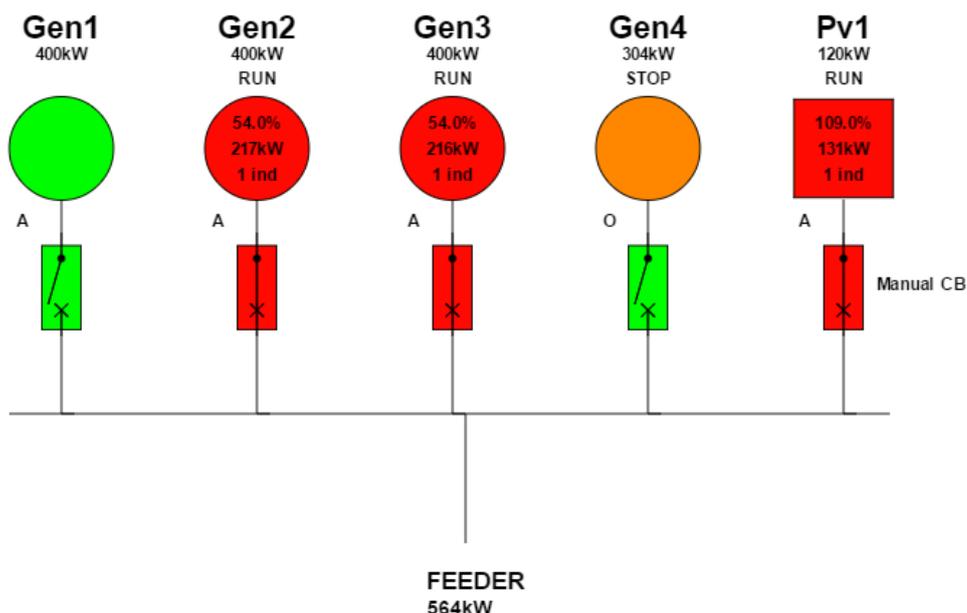


Figure 9 Screenshot of the remote monitoring online dashboard showing the contribution from each of the diesel generators (Gen, Gen2, Gen3 and Gen4) and the solar farm (Pv1) to the mini-grid with a demand of 564kW.

The performance data analysed in this Demonstration Report is for the 81 days from 21/2/2015 to 11/5/2015 (inclusive).

# 3.1 Solar output compared to forecast

We visualise the contribution from the solar PV to the mini-grid using a heat map (also commonly referred to as DMap) in Figure 10. The heat map shows higher solar power around the midday and zero power outside daylight hours as expected.

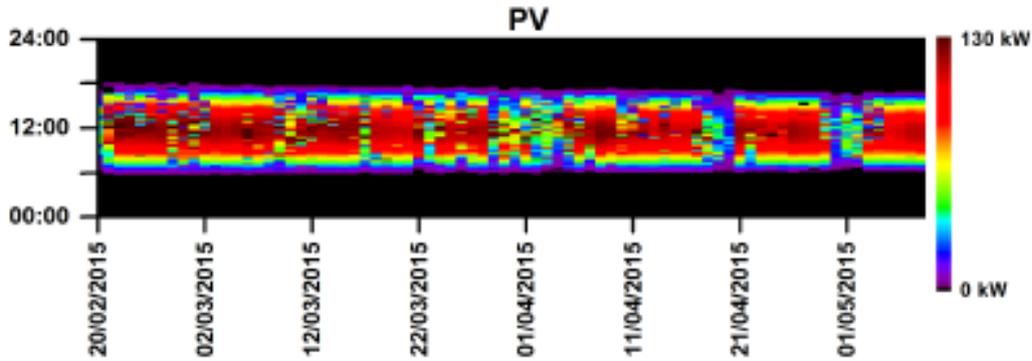


Figure 10 Solar power at ten minute intervals is plotted over the date range 21/2/2015 to 11/5/2015 (inclusive).

In late 2014, we used PV simulator software to forecast the output of the solar farm. The simulated performance and the actual performance are compared in Figure 11. There is strong agreement between the simulated and actual performance showing that the SunSHIFT system is performing well.

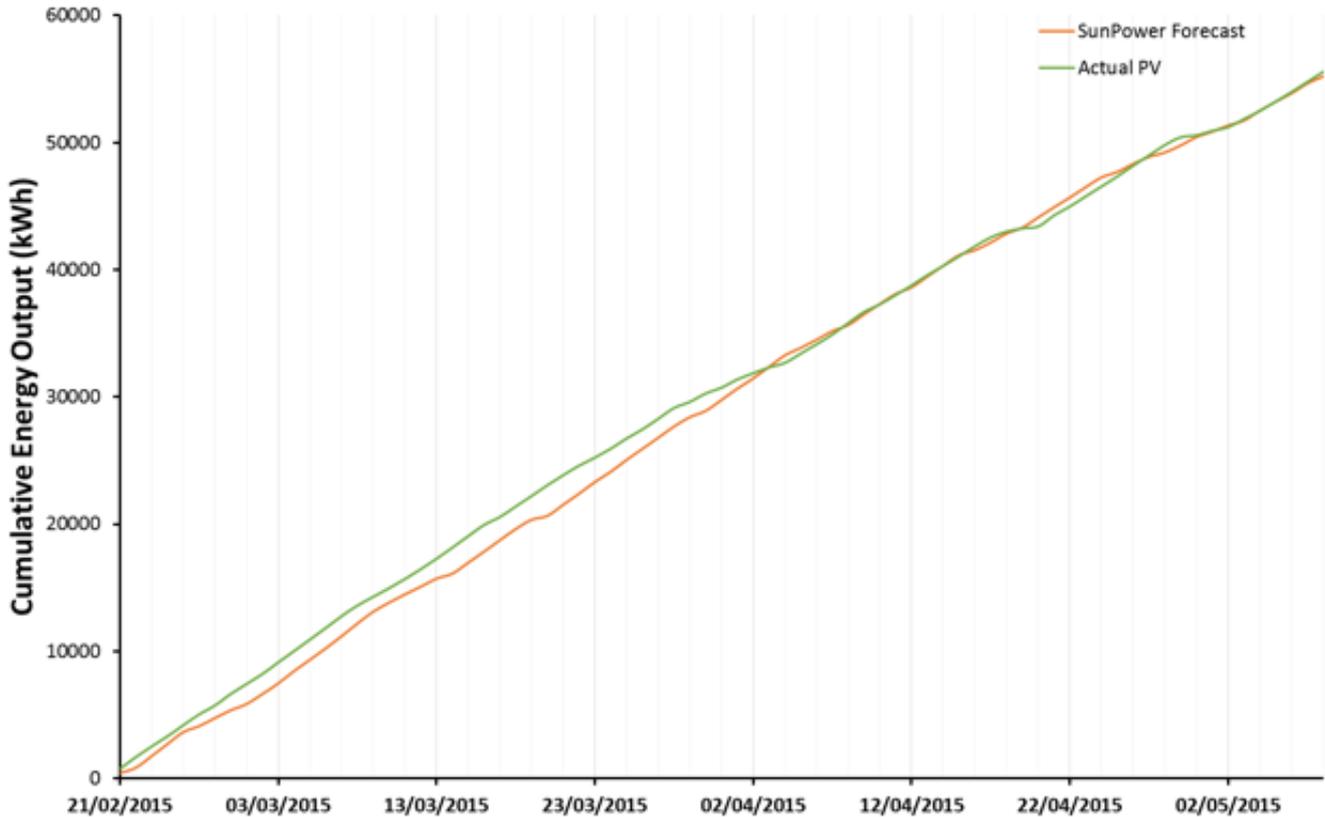


Figure 11 The cumulative energy output (kWh) of the solar farm is plotted over time for both the actual performance and forecast performance.

A further source of benchmarking is provided by the Bureau of Meteorology (BOM). Each BOM weather station records daily solar exposure ( $\text{kWh}/\text{m}^2$ ). The nearest BOM weather station to the first deployment is called Two Ways (ref 043098). The BOM measurements and the metered output of the solar farm are plotted over time in Figure 12. There is good agreement between the peaks and troughs. The correlation between the two series is explored further in Figure 13, plotting BOM measured solar exposure on the x-axis and metered output of the solar farm on the y-axis. The strong correlation highlights that the SunSHIFT system is performing well.

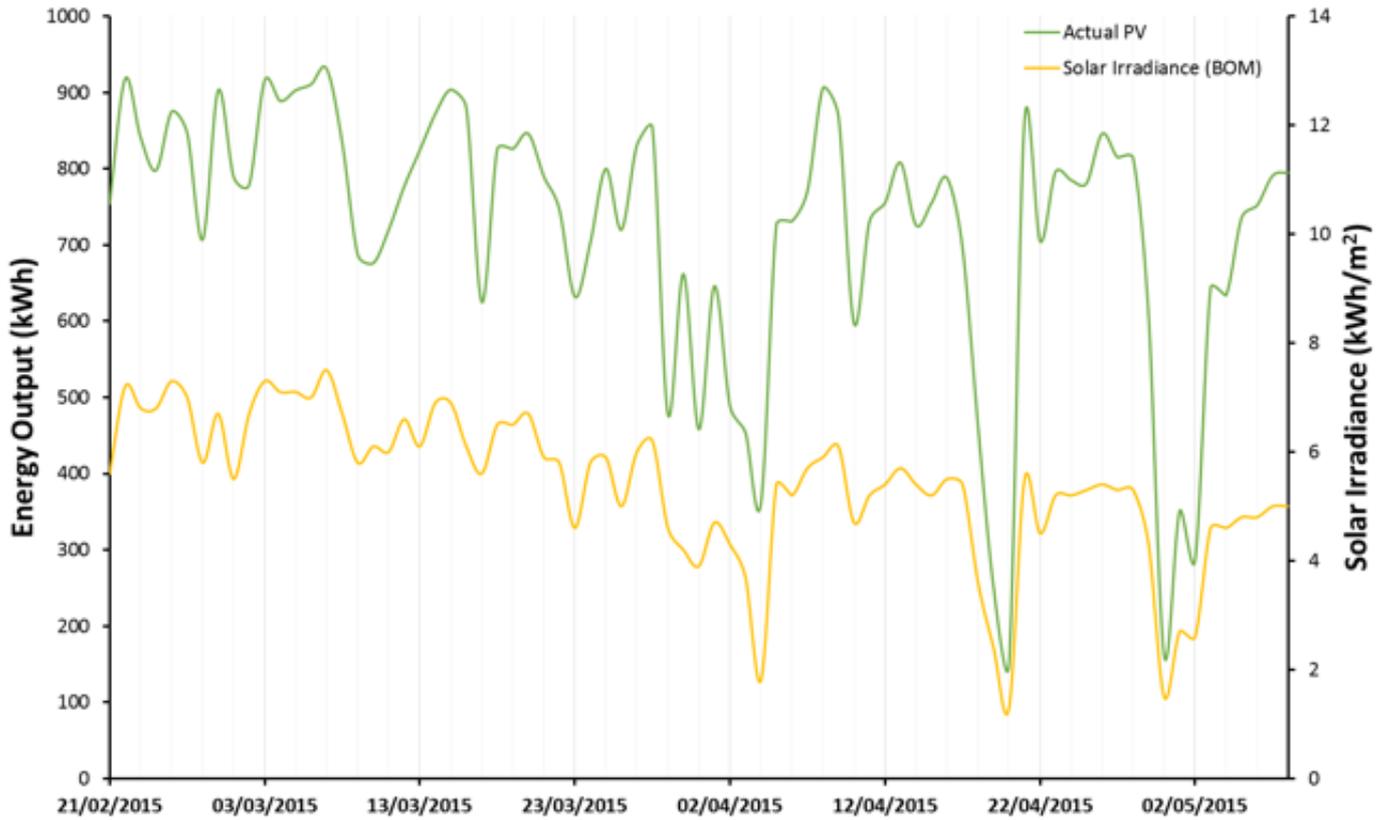


Figure 12 The metered daily actual solar PV output (green) and the BOM-measured daily solar exposure (orange) are plotted over time.

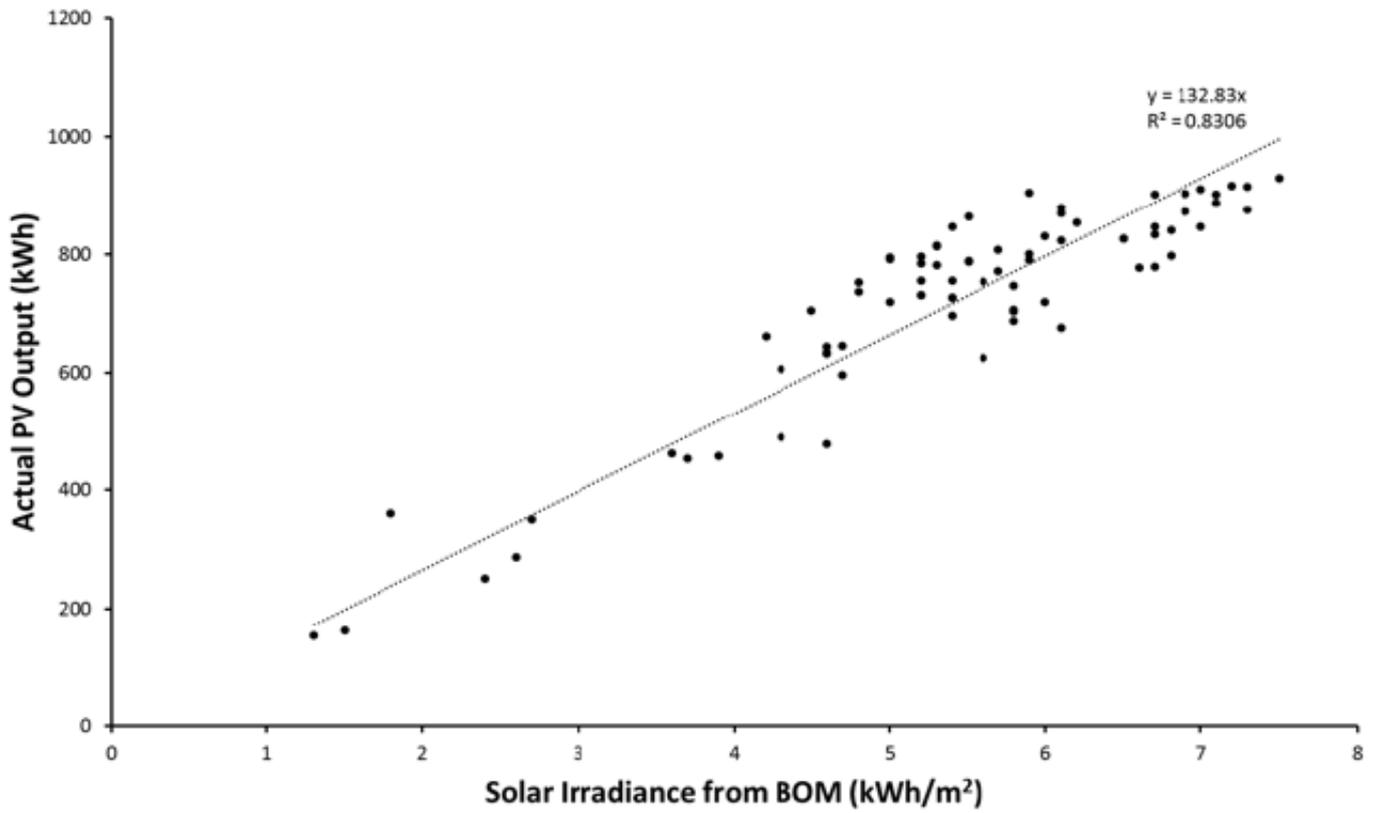


Figure 13 Each day in the date range 21/2/2015 to 11/5/2015 (inclusive) is plotted as a single marker. A linear trendline is shown with the coefficient of determination  $R^2 = 0.8306$ .

## 3.2 Curtailment of solar

Curtailment of solar is where some of the available PV power is dumped and not exported to the mini-grid. It is important that the SunSHIFT system protects the minimum loading of the diesel generators; if the demand for power is less than the minimum loading of the online diesel generator plus the available solar power then solar curtailment occurs. Rather than curtailing solar, it may be used to charge an Energy Store if deployed.

We now look at a particular example to demonstrate that the SunSHIFT system is curtailing solar correctly. Our example of solar curtailment occurred at 14:12:20 on 1/6/2015 and is plotted in Figure 14:

1. At 14:12:20 there is a 20kW reduction in the demand (plotted black).
2. The online diesel generator (Gen3, plotted blue) temporarily drops below its target minimum loading (100kW).
3. The Integrator responds by curtailing the solar output (plotted orange) and increasing the loading of the diesel generator.
4. At 14:12:25, just 5 seconds after the change was seen in the demand, the diesel generator is back above its target minimum loading.

This example demonstrates that the SunSHIFT system is curtailing solar correctly in order to protect the minimum loading of its diesel generators.

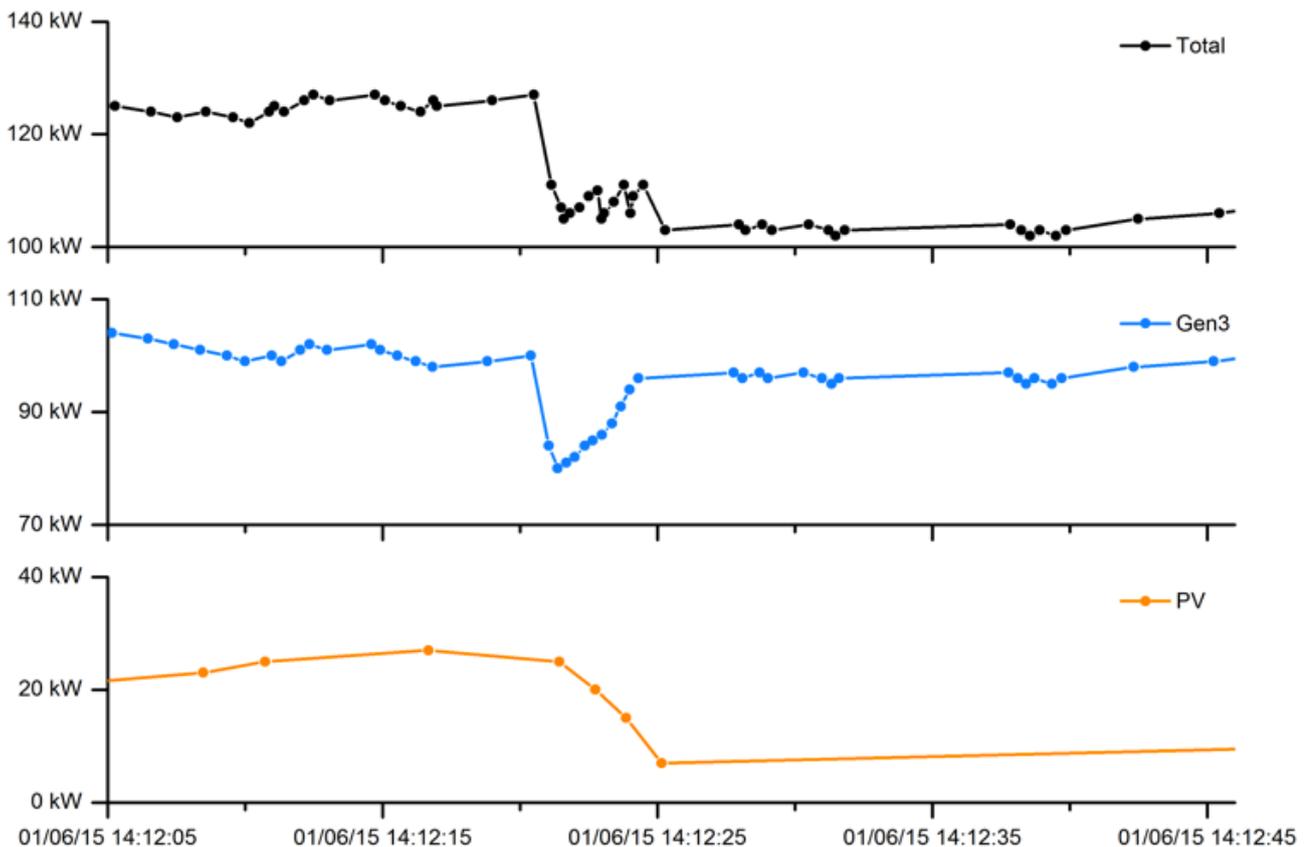


Figure 14 The curtailment of PV occurs at 14:12:20 1/6/2015 in order to protect the minimum loading of the diesel generator.

## 3.3 Cloud events

A cloud event is where a cloud passes over the solar farm and reduces the solar power suddenly. It is important that the SunSHIFT system maintains stability (power, voltage and frequency) to its user during such cloud events. The SunSHIFT system does this by ensuring that there is always sufficient spinning reserve in the diesel generator fleet to cover any sudden loss of solar output.

The spinning reserve requirement has been configured to provide static spinning-reserve of 80kW for step loads from the village plus a dynamic spinning-reserve equal to 80% of the real-time PV output for cloud events.

We now look at a particular example to demonstrate that the SunSHIFT system is maintaining spinning reserve correctly. Our example cloud event occurs at 13:06:30 on 5/4/2015 and is plotted in Figure 15:

1. From 13:00 to 13:06, there are several cloud events that cause the solar output (plotted light blue) to decrease. During these cloud events, the online generator (Gen3, plotted orange) increases its power to meet the demand (plotted dark blue).
2. At 13:06:30, there is a severe cloud event and, over a period of 9.1 seconds, Gen3 increases its power from 202kW to 325kW, achieving a ramp rate of 14kW/s.
3. There is now just a spinning reserve of 75kW which is insufficient and so the Integrator instructs a second generator (Gen2, plotted grey) to come online.
4. At 13:07:10, Gen2 comes online. As Gen2 and Gen3 are of equal size, they share the load equally.
5. Shortly after 13:20, Gen2 is able to turn itself off as the solar is contributing a significant level of power, a single generator is able to cover the spinning reserve requirement and Gen2 has satisfied its minimum on-status duration.

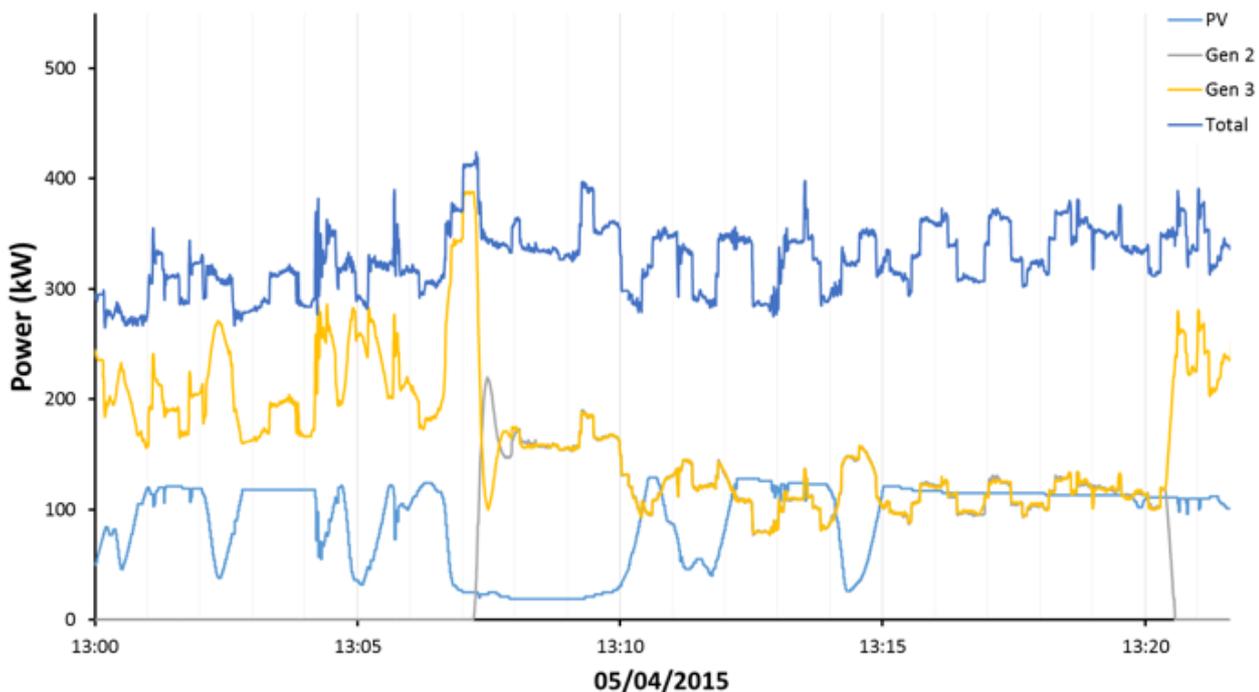


Figure 15 The most severe cloud event occurs at 13:06:30 5/4/2015.

## 3.4 Fuel efficiency of solar-diesel vs diesel-only

The SunSHIFT system reduces diesel fuel usage in three ways:

1. The output of the SunSHIFT solar sub-arrays displaces diesel fuel.
2. The SunSHIFT Integrator offers fleet management services, optimising the use of the diesel generators.
3. SunSHIFT's diesel generators are selected on whole-of-life costs, not just capital costs, and are therefore efficient.

We can look at the fuel efficiency of the demonstration plant to determine its effectiveness.

Compared to an adjacent camp (with a diesel consumption rate of 0.35520 litres/kWh), the SunSHIFT demonstration plant has saved 74,700 litres of diesel in the 81 day period from 21/2/2015 to 11/5/2015 (inclusive), equivalent to reducing emissions by 166 TCO<sub>2</sub>e.

During this time period:

- The SunSHIFT plant exported 588,056.2 kWh of electricity to the mini-grid, of which 55,933.2 kWh came from the solar farm – i.e. a solar energy contribution (Section 1.2) of 9.5%;
- The inverters consumed 57.7 kWh of electricity for their operation, equivalent to just 0.1% of the solar electricity exported;
- The Integrator monitored the diesel fuel consumption rate of each of the diesel generators and metered a total of 134,138.3 litres of diesel fuel consumed;
- The fuel consumption rate for the SunSHIFT demonstration plant was therefore 0.22810 litres/kWh.

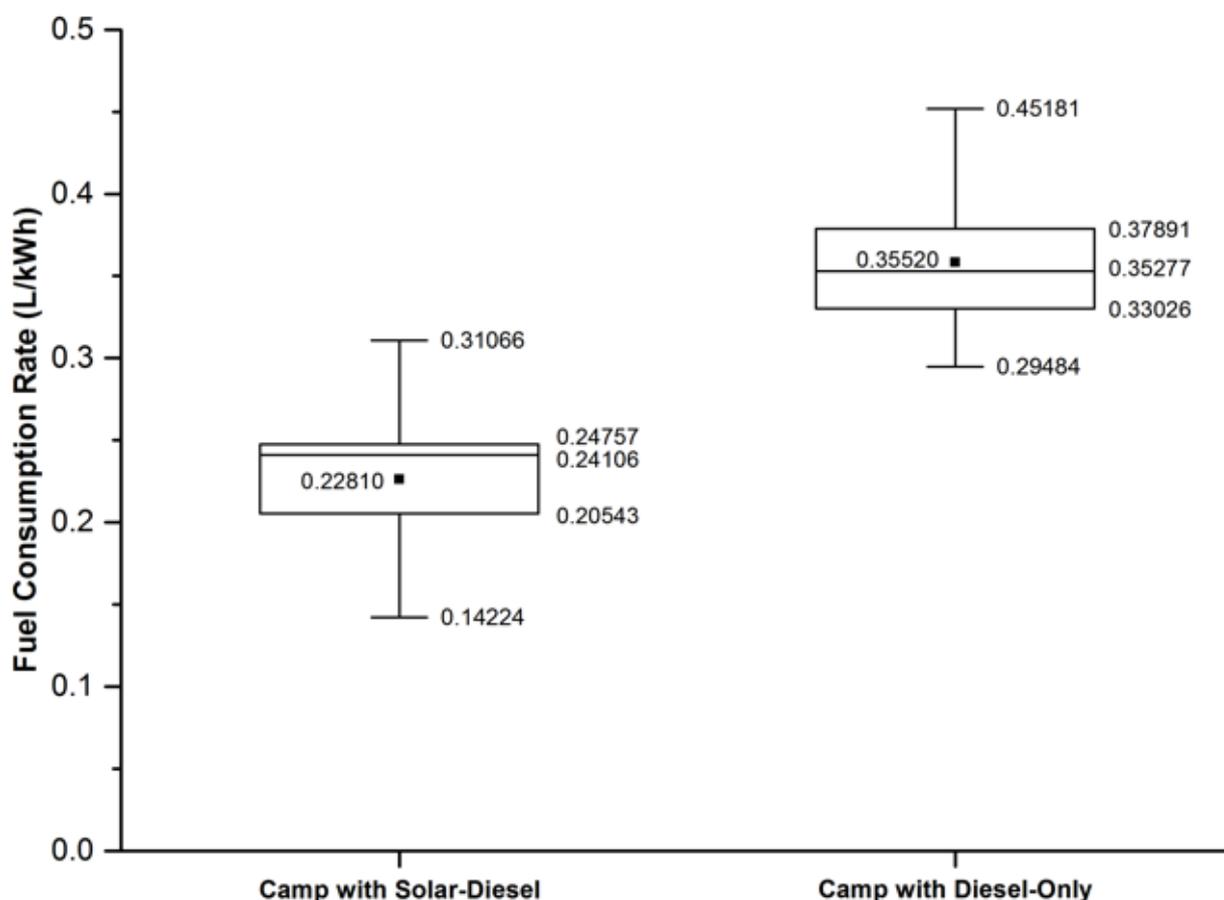


Figure 16 The fuel consumption rate (litres per kWh electricity exported to the mini-grid) of the SunSHIFT demonstration plant and the diesel-only system at an adjacent village. The whiskers of each box are the minimum and maximum (excluding outliers). The bottom and top of each box are the first and third quartiles and the band inside is the median. The square marker represents the average fuel efficiency across the entire time period.

# 4 Societal impact

Laing O'Rourke conducted a survey across 58 blue-collar workers and 26 white-collar workers within the accommodation village that is powered by the SunSHIFT demonstration plant.

The results shown in Figure 17 highlight a positive impact on workforce morale and show a strong consensus that SunSHIFT has the potential to positively change remote power generation in Australia.

The average ranking of priorities shown in Figure 18 reveal the importance that those individuals place on reducing carbon emissions above other objectives.

The re-deployable solar farm at the Combabula site is the first of its kind in the world. Does this make you think:



Solar-diesel power plants have the potential to positively change how we generate and use power in remote Australia.



Figure 17 Results for two questions of the survey, showing the number of people responding.

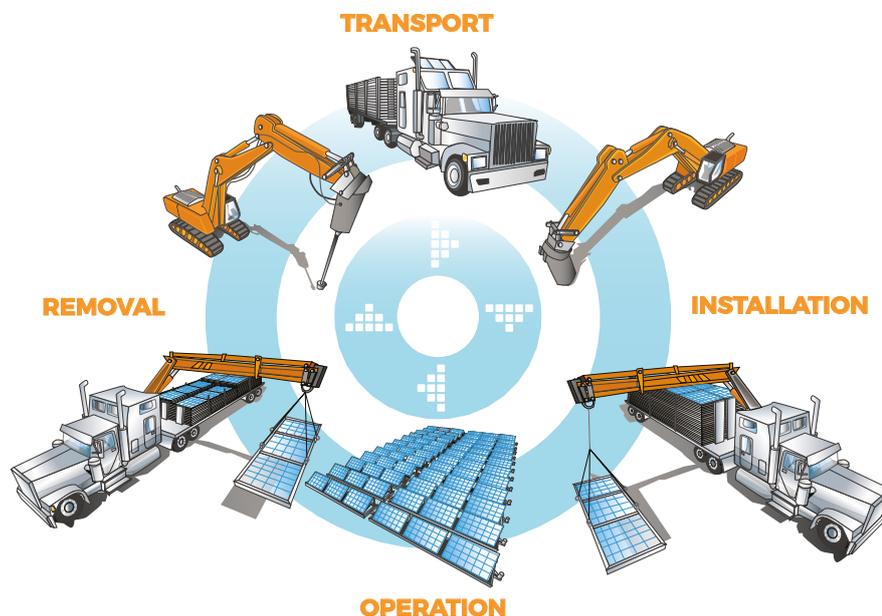
Rate the following in terms of what matters most to you (5) to what matters least to you (1)



Figure 18 Results for one question of the survey, showing the mean average response.

# 5 Next steps

In summary, Laing O'Rourke and ARENA have successfully developed, manufactured and deployed the world's first large-scale fully re-deployable solar-diesel hybrid plant, now branded SunSHIFT.



# 5.1 Process with potential clients

SunSHIFT's process of working with clients is as straightforward and as modular as the system itself.

1. Client questionnaire
  - The client completes a two-page questionnaire including geographical information, diesel fleet and electrical load data.
2. Optimal selection of modules
  - SunSHIFT uses the leading specialist software to rapidly determine the optimal configuration for the client.
3. Execution of the commercial agreement
  - The client's preferred model is discussed and is likely to be either a purely ongoing service (e.g. purchasing the electricity produced each month), a purely upfront service (e.g. purchasing the plant upfront) or combination of the two. The contract covering the upfront and the ongoing services is agreed. An Installation Operational Manual (IOM) is provided.
4. Transport, minimal pre-works and on-site assembly
  - SunSHIFT transports the modules via containers from off-site storage to the site where SunSHIFT safely and rapidly assembles and commissions them.
5. Additional services
  - SunSHIFT offers remote monitoring via a web-based dashboard, operation & maintenance and relocation services.



# 5.2 Laing O'Rourke project team

**Project Leader** Will Rayward-Smith

**Senior Electrical Engineer, Construction Manager** Michael Read

**Site Engineer** Lindsay Collier

**Principal Mechanical Engineer, Project RPEQ** Brad Lawson

**Corporate Development** Paul Ward

**Senior Electrical Engineer** Michael Read

**Hub Electrical Lead, Project RPEQ** Mark Knight

**Procurement Manager** Simon Randell

**Commercial Manager** Anthony Moore

**Select Plant Hire General Manager** Andy Higgs

**Logistics Team** Bianka Dimkoska, Jaimie Ward

**Site Team** Conor Hanlon, Paul Gillespie, David Pfeffer, Andrew Payne, Enda Conneely, John Cosgrove

**Finance** Peter Bracken, Mark Wilson, Andrew Henderson

**Engineering Team** Stephen Cornish, Jessica Breen, Esmaeil Ajdehak, Ranji Premaratne, Sudipta Kumar Bej, Francis Canlas, Robert Weston, Angus McFarlane, John Stehle, James Glastonbury, Nicole Waterman, Yuffrey Huang

**Manufacturing Team** Stuart Morris

**Analyst Team** Pingshun Huang, Lewis Cowper

**Graphics and Digital Engineering** Dinh Tran, Nigel O'Neill, Mohamed Haddad, Sofia Castillo

**Legal and Intellectual Property** Maria Guarnieri, Simon Fisher

**Communications** Jeremy Yancey, Serena Di Marni

The Laing O'Rourke team has identified several key commercial knowledge shares.

## Knowledge shares

- Successful deployment requires the coordination of multiple stakeholders, both internal and client-side, to efficiently complete many actions. It is essential that information flows, points of contact and responsibilities of different parties are clear and documented from the start. This is particularly important for new unfamiliar technologies where the processes are not yet well understood and are in fact to be defined by the different parties involved.
- In the scoping of activities, it is essential to define the “battery limits” of different parties’ activities and make sure that the interfaces are actively managed.
- Particularly with unfamiliar technologies at an early stage of development, it is important to create shared ownership and consult with stakeholders from a very early stage. The first discussion with the users at the demonstration site took place in December 2013, 14 months ahead of the installation. Furthermore, it is important to listen to all stakeholders to ensure community acceptance of the project. The community survey was conducted shortly after installation to canvas the community for their opinion of the technology and capture any issues.
- For the commercialisation of products/services, it is important to first listen to the market's needs and requirements and then to shape a value proposition that addresses those needs and requirements. Furthermore, it has been useful to have a market-facing brand (i.e. the SunSHIFT brand) that players in the market can share easily amongst themselves and also look-up easily for further information.
- It has been beneficial to take the public and the market on the journey from concept, through product development to demonstration. Interest in SunSHIFT has steadily increased and the project is well known in the market, which has aided discussions with potential customers. This has been achieved through working collaboratively with ARENA on public talks, reports, videos and press releases.

## 5.3 Thanks to ARENA

Laing O'Rourke wishes to thank ARENA for its enabling support of and collaboration in this project, delivering a game-changing technology to off-grid Australia.

Laing O'Rourke would like to acknowledge publically the great work and professionalism of the individuals within ARENA, both those behind the scenes and those with whom Laing O'Rourke has had direct contact with, namely Ivor Frischknecht, Ian Kay, Anthony Dobb, Francis Meehan, Yang Shen, James Webber, Simon Woods, Chris Twomey, James Hetherington, Dan Sturrock, Gabriele Sartori, Judith Ion and Anita Goldspink.



Download the free augmented reality app,  
LORAR+, for iOS and Android devices (keyword: LORAR).  
In LORAR+, enter the SunSHIFT code "SUN", then aim your  
device's camera at the image on the front cover of this report.