# Energy Storage used for Diesel Reduction and Renewables Integration in Remote Telecom Applications

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## Abstract

An energy storage solution using lead-acid UltraBattery technology installed at a remote telecom tower has delivered significant reductions in fuel and ancillary costs allowing payback in well under 24 months. The storage and diesel control algorithms developed for the project allow a generator, previously running at low output 24/7, to run only in a few short blocks each day and at optimal output. Renewable smoothing installations using the same storage technology have shown that further savings are possible once fluctuations in renewable supply are managed by the battery. The remote-monitored, telecom-specific storage solution has achieved in-the-field fuel savings of between 30% and 60% over 10 months of operation. The work is directly applicable to other single-diesel installations – including work sites and agricultural applications.

## Introduction

This paper describes the successful installation of battery energy storage at an off-grid telecom in Australia. The design, by a Sydney-based energy storage company, has a payback period of around 12 months and has reduced diesel fuel use on the telecoms site by over 50%. Significant further savings were achieved due to reduced fuel-transport and generator-maintenance costs.

| *A world of towers* | |
|---|---|
| *Total telecom towers installed globally* | **5 million** |
| *Diesel generators in the telecoms industry* | **4 million** |
| ***Off-grid towers*** | |
| *Off-grid towers already installed globally* | **650,000** |
| *New off-grid towers installed annually* | **75,000+** |
| ***Weak grid regions (on-grid but needing frequent diesel backup)*** | |
| *Estimated towers in weak-grid regions globally* | **1 million+** |
| *Number of towers installed in India* | **400,000+** |
| *Number of towers installed in Africa* | **100,000+** |
| ***Powering towers*** | |
| *Estimated number of towers with solar PV* | **55,000** |
| *Power provided by generators to off-grid towers* | **2.7 GW** |
| *Diesel used by the world's off-grid towers **daily*** | **21 million liters** |

*Various sources, chiefly [1, 2]*

The project is considered significant because there are estimated to be over five million telecom towers and more than four million diesel generators throughout the telecoms industry globally. The generators are largely used to power telecoms infrastructure in off-grid or weak-grid locations. Electrically these are broadly similar to the tower described above and the battery system and power management algorithms designed for this Australian project have direct relevance to remote towers the world over.

Essentially every one of the world's 650,000 or so off-grid towers is reliant on diesel generation 24-hours a day, and the number of off-grid towers continues to grow at a rate exceeding 75,000 per year – so over 200 new diesel powered off-grid towers are appearing every day. It is estimated that the world's off-grid towers use over 20 million liters of diesel fuel daily.

The frequency of refueling trips and maintenance-visits to remote telecom towers lead to a particularly high delivered cost of energy. Even though off-grid telecom towers often employ solar photovoltaic (PV) panels, this generally only offsets a relatively small fraction of total energy use. Solar PV will allow the generator to reduce its output, but PV output is usually not consistent enough to allow the generator to switch off entirely.

Additionally, many of India’s existing 400,000 towers as well as those in the rapidly-growing African industry (currently with around 100,000 towers) use diesel generators regardless of whether a grid connection is available due to issues regarding power reliability

## Case Study 1: The remote tower problem

It is not easy to reduce running costs at remote tower sites. Telecom tower owners have extremely low tolerance for interruptions since a tower outage will inconvenience large numbers of customers and potentially prevent critical communications getting through. Therefore a reliable 24-hour power source matching the load is required. The method used to provide this has traditionally been to run a generator sized for the peak load, 24 hours per day.

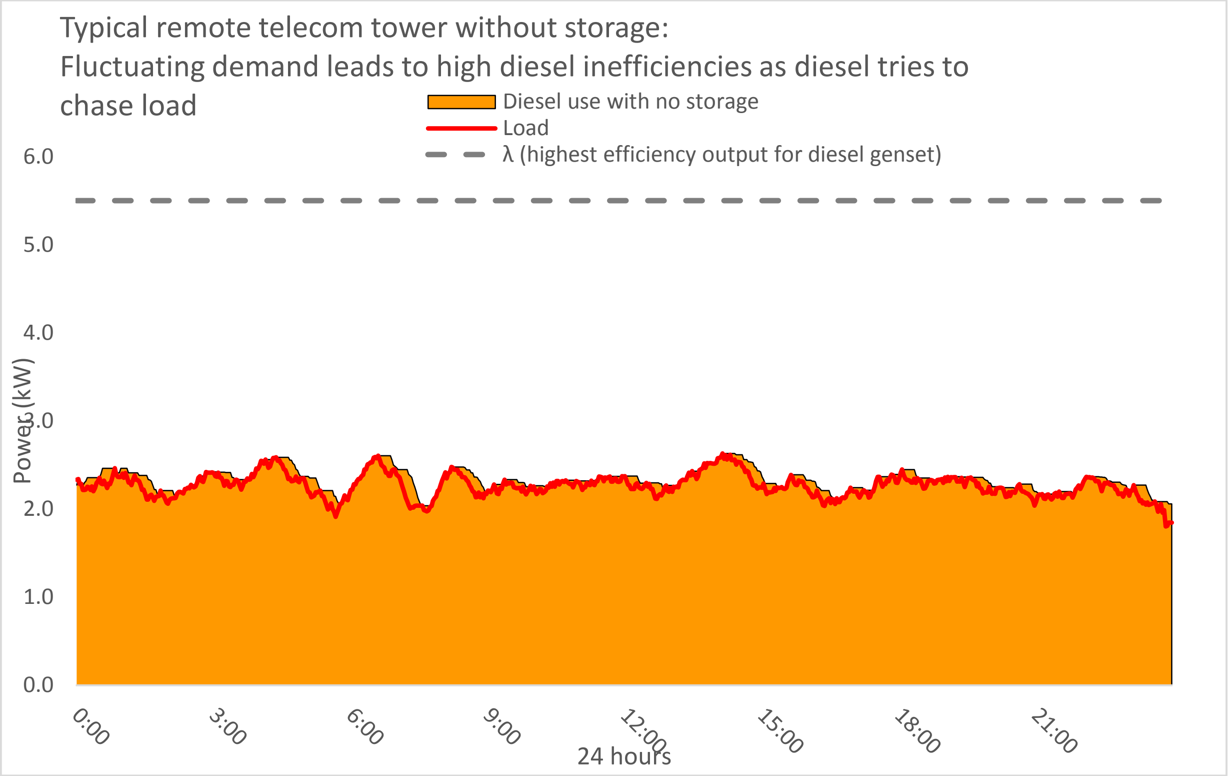

**Figure 1. No energy storage, no solar. Generator "chases" load.**

Figure 1 shows typical tower operation. The installed solution (described below) had operational characteristics similar to this, prior to energy storage being installed. A reasonably constant load is present most of the day, but the generator is sized for a much larger load to account for the occasional peak or to cater for future growth in the tower’s capacity. Note that the generator must always produce equivalent power (or slightly more power) than demanded by the load.

The underlying principal of energy storage in off-grid applications is to reduce generator run time and run the generator at its highest efficiency output. Once batteries have been installed the load/generator profile looks markedly different:

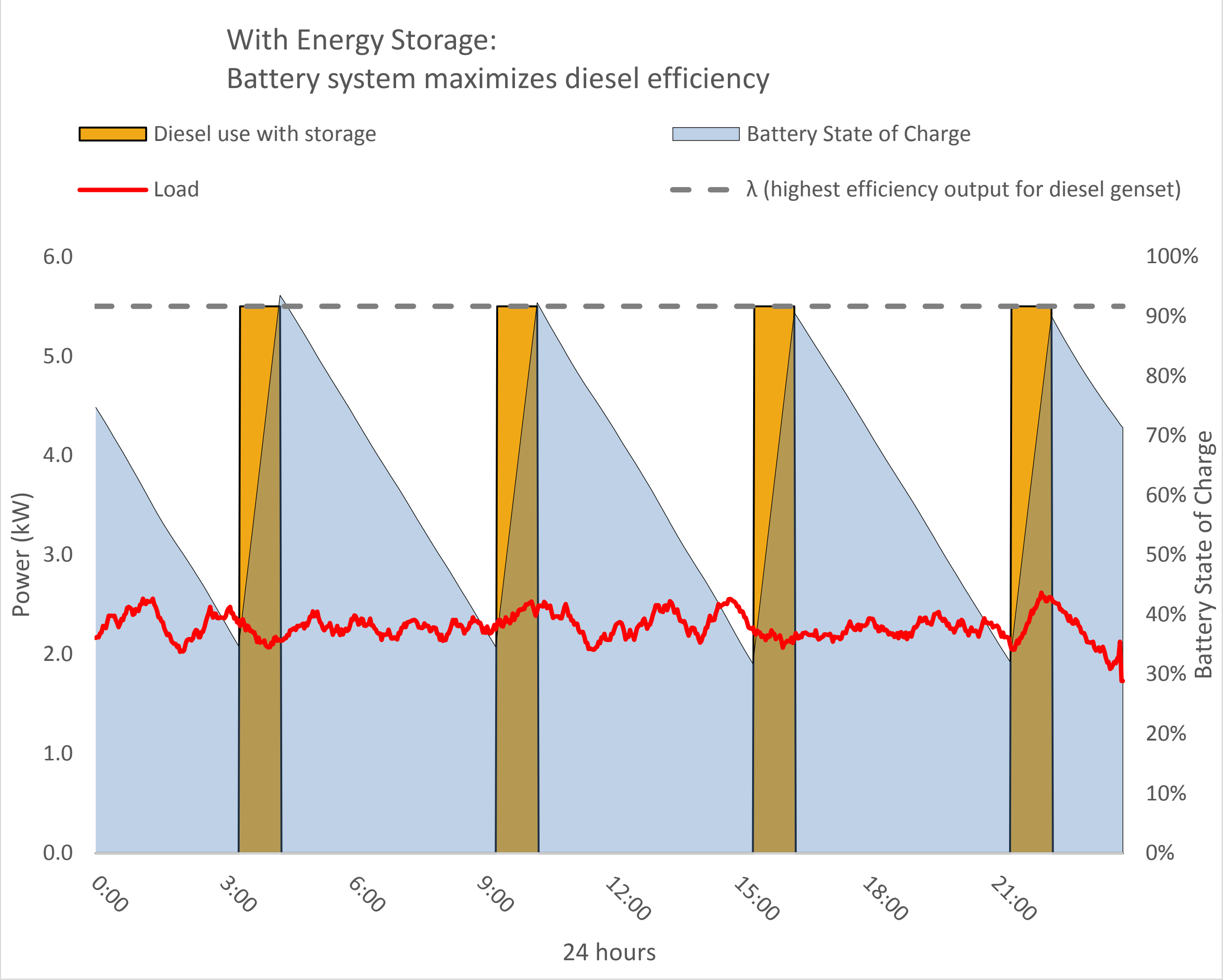

**Figure 2. Diesel/load system with battery storage**

From Figure 2 it is clear that the diesel generator has changed its mode of operation from constant low-power output to several short bursts of high-power output.

A suitable energy storage system allows the diesel generator to run at its most efficient power output, where more of the chemical energy in the diesel is converted into electrical energy. Figure 3 shows a typical efficiency curve for a small generator. The region of the load curve typically used by a generator running at low output is shaded red. In constant idle (toward the left hand end of the curve in Figure 3) efficiency falls sharply toward zero. There is a clear efficiency dividend if the generator may be encouraged to run at its “sweet spot” which is generally at the high end of its maximum power output (and here marked with a cross).

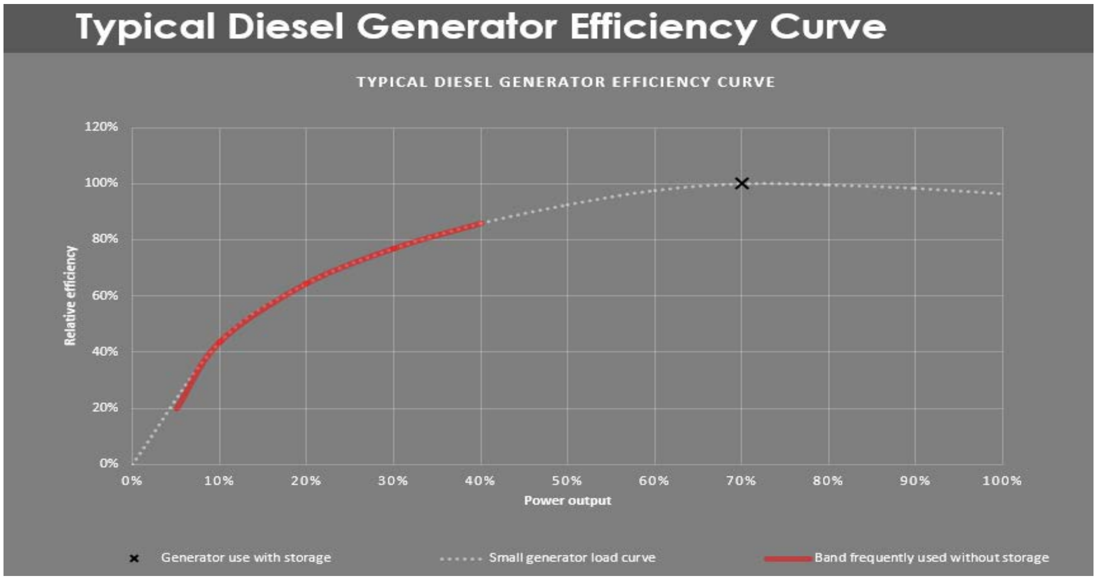

Figure 3. Effect on generator efficiency of various power output levels.

## Case Study 2: The remote tower with PV

When a telecom tower is augmented with a PV system, the operator can generally save fuel costs during the day. That situation is shown in Figure 4. (A wind turbine may also suit in some locations, in which case there would be a different profile to the load/generation graph, but the outcome is not dissimilar in terms of overall savings.) The installed telecoms solution (below) has no renewable component, although the designers are confident a renewable/battery/diesel solution is applicable to telecoms having previously created smoothing systems using the same battery technology for diesel, PV and wind (separately and combined).

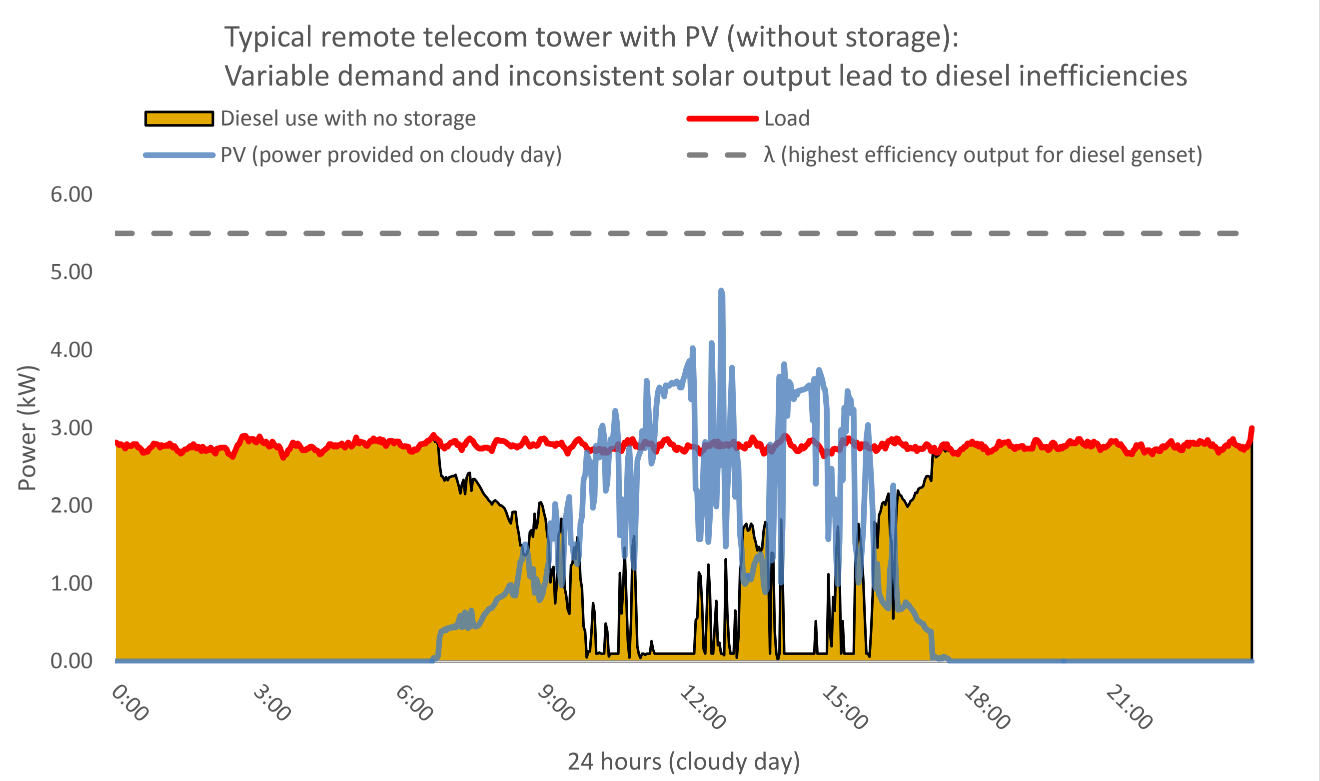

Figure 4. With PV installed, the generator uses marginally less fuel, but still runs 24 hours per day.

Despite the fact that many remote towers are in sunny locations (for instance dispersed across arid regions of Africa, India and Australia) there is often only marginal gain from installing PV panels, since the PV output is rarely consistent enough to allow the generator to switch off during the day. Rather the generator will constantly ramp up and down to match the difference between PV and load. This tends to push the generator into the low-efficiency region of operation and the net effect is that not nearly so much fuel has been saved as might be calculated using a simple sum of solar energy collected during the day.

But energy storage can make a significant difference in this situation as well. Figure 5 shows the interplay between components over a typical cloudy day in such an installation.

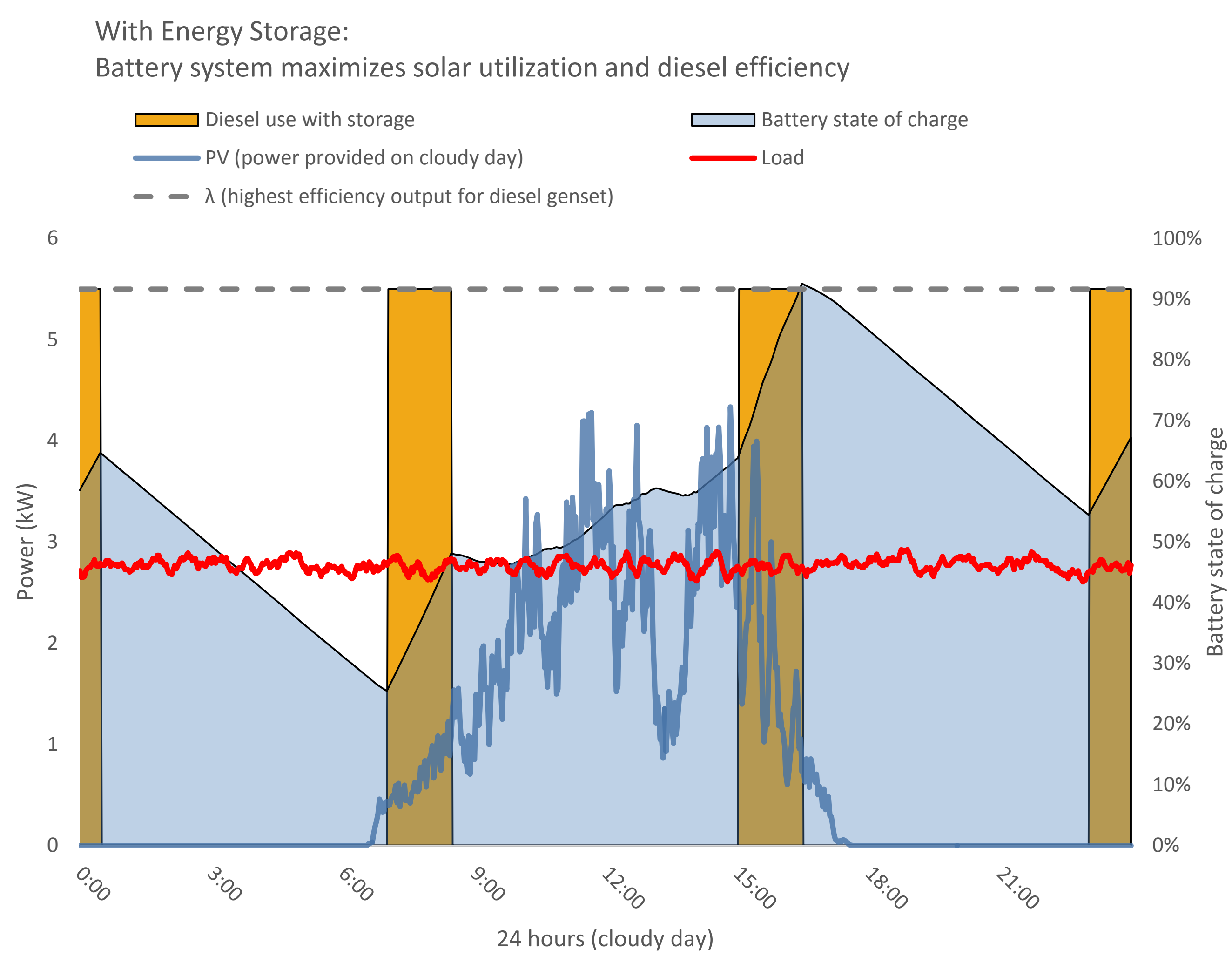

**Figure 5. System with PV and energy storage installed**

Here the battery is cycling to allow the generator to run for short periods at full output, as before, but now the battery is also taking account of the fluctuating solar power signal. The battery charges and discharges as required to keep the power to the load matched to its demand at any given moment, but the generator is decoupled completely from the load and the solar simply being switched on by the battery management system either based on battery state of charge or some other algorithmic method.

## Requirements of the battery

In order for the energy storage systems described above to work the battery must be a partial state of charge device, capable of discharging and, particularly, charging at high rates (to match full generator output during charging and minimize generator run time). It must also be able to charge and discharge continuously and in rapid alternations of charge / discharge in order to perform the solar smoothing indicated in Figure 5 above.

The fast and consistent cycling required makes this application poorly suited to traditional VRLA technology. Furthermore the rapid charge rates (necessarily faster than the discharge rate) would be difficult for most lithium-ion chemistries which generally charge slower than their discharge rates.

The battery used in the field tests described below is the UltraBattery designed by Australia's science agency, the Commonwealth Science and Industrial Research Organisation (CSIRO) and manufactured by US battery maker East Penn Manufacturing.

This hybrid cell is based on a VRLA design with the addition of an asymmetric carbon-based ultracapacitor built in to the negative electrode (Figure 6).

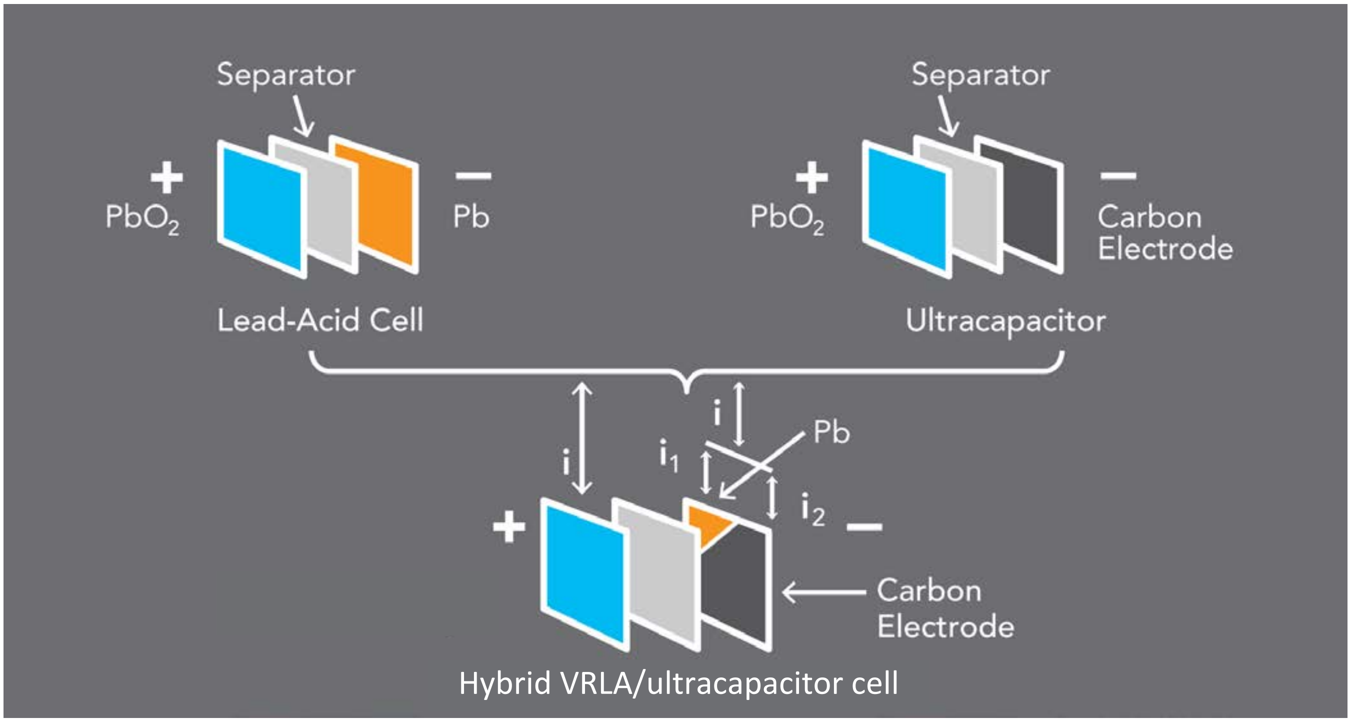

**Figure 6. Hybrid VRLA/ultracapacitor cell schematic design**

The ultracapacitor's presence changes the way the VRLA accepts and delivers charge and also mitigates against permanent sulfation of the negative electrode, which is a typical progressive failure in VRLA cells that have not been brought to sufficiently high state of charge. Sulfation is the major reason why VRLA cells are generally not well-suited to partial charge cycling applications.

The fast charge rates of the battery are also due to the presence of the ultracapacitor, but are not simply related to the charge rate of the ultracapacitor. In fact the cell accepts and delivers charge at rates above that of either traditional VRLA or ultracapacitor. That is, an ultracapacitor and VRLA wired together in parallel would not perform in the way the hybrid cell performs since there is a chemical interaction between the ultracapacitor and VRLA devices.

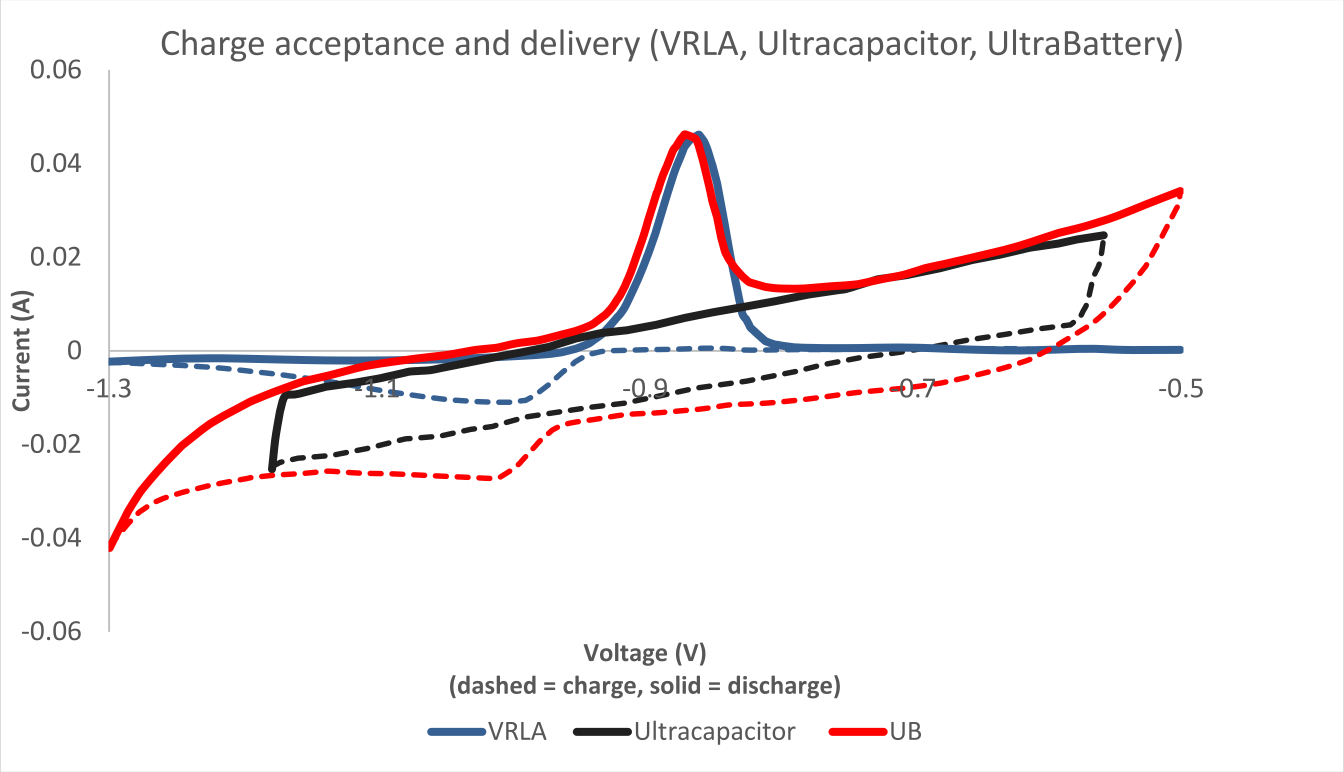

**Figure 7. Comparing charge acceptance and delivery**

Figure 7 shows the charge acceptance and delivery at various voltages (here compared with a reference electrode) of a standard VRLA, a typical ultracapacitor and the hybrid cell under discussion. The dashed lines show the devices being charged. The VRLA cell has lower charge acceptance across much of the range compared with the ultracapacitor's (in general) higher charge acceptance. The hybrid cell, however, accepts higher currents than the sum of both VRLA and ultracapacitor across most of the voltage range. This gives the cell good characteristics for diesel cycling as the generator can be run at high output, where efficiency is greatest.

### Implementation of telecom solution

The installation now running in rural Australia combines a nominally 14 kW diesel generator with a battery system comprising 16 individually monitored 12 V monoblocs. An inverter manages the power flow between the generator, batteries and the AC power demand onsite. The main AC load is rectifier power, which runs the telecommunications equipment. The second important load is air conditioning, which automatically maintains temperature within the building to a set point.

There are also some auxiliary loads such as lighting. An energy monitoring system measures temperature inside and outside a site hut, total AC Power and the principal loads (rectifier and air conditioner). Auxiliary power usage can be calculated by subtracting principal loads from the total power measurement.

The installed system is shown in Figure 8 with the 16 batteries at left and the inverter and switchgear at right.

**Figure 8. Cabinet showing battery installation**

## Power management (charge/discharge) algorithm

Battery monitoring and power management are carried out with minimal intervention except to tweak the algorithm or change parameters when desired. All warning alarms are delivered via email and full site data is available to be sent at any desired interval. The project has been implemented using a simple charge/discharge algorithm which measures battery state of charge (SoC) and turns the generator on at low SoC values. This limit is variable but has been set at 50% initially. Lower SoC will be tested to gauge the effect on efficiency after a full year of site data has been collected. The generator is run at its rated peak efficiency setting powering the load directly and using the rest to charge the battery. When the SoC hits 90% the generator is switched off and the site runs from the batteries. Again 90% is an arbitrary figure, which will likely be lowered to 80% after a year of operation since, like most batteries, the cell is most efficient in the mid-range of charge, below 80% SoC.

The site in question is unsuitable for PV installation due to shading. However due to the successes at this site other remote sites in more sunny locations are being examined for a second installation.

## Results

The project has demonstrated that energy storage is a successful investment strategy for tower owners and others running single-diesel loads in remote environments. It has been determined that the fuel usage on this site has been reduced by approximately 40% in summer and well over 50% in winter when air conditioning loads are not present. The fuel savings and ancillary cost savings from (e.g. fuel deliveries and maintenance) give the project a break-even period of just over 12 months.

This is significantly better than published desktop studies, for instance by Indian Saviva Research in 2012/13 whose study *Hybrid Energy Systems for Telecom Towers* [3] estimated the total cost of ownership for an off-grid tower with the inclusion of energy storage (Figure 9).

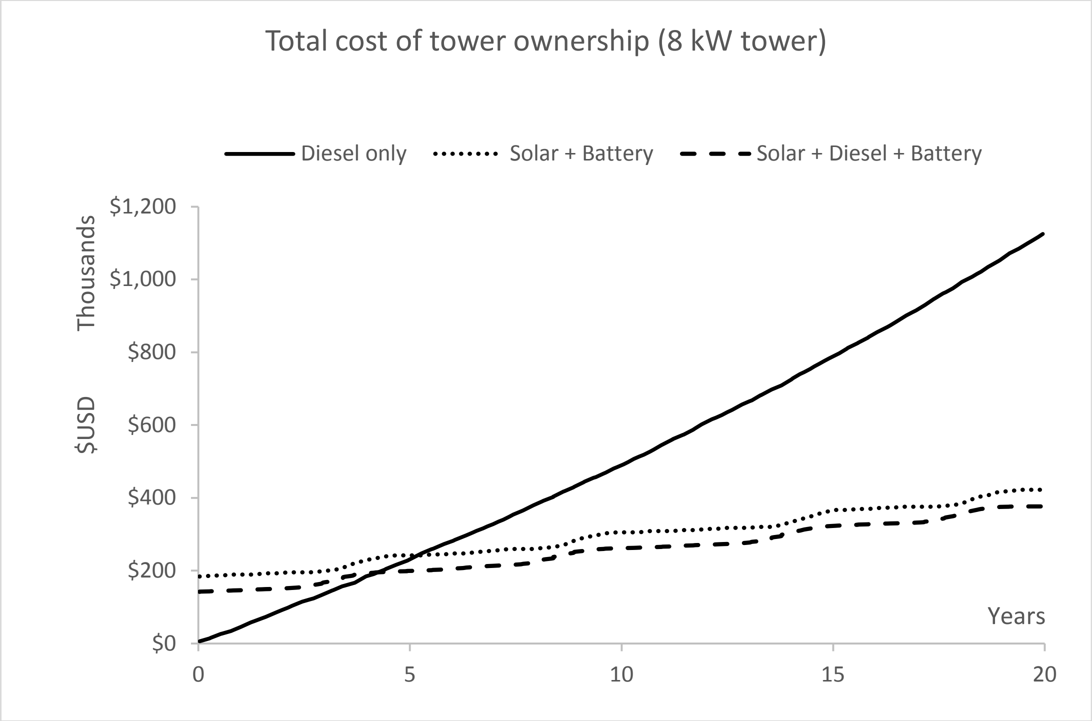

**Figure 9. Cost of ownership of off-grid tower (adapted from data in Saviva Research, 2013 [3])**

The Saviva model took into account all costs (diesel fuel, projected diesel fuel price increases, replacement batteries, power control system maintenance, diesel maintenance etc.) and found typical payback periods of four to six years. Some variation is to be expected since the Saviva model was based on Indian labor costs.
The system designer's internal modelling (for western markets) had suggested faster payback times were possible since delivery and servicing costs are significantly higher once typical Australian, North American or European wages are factored in. The modelling has in fact been validated by the results from this installation. In the modelling (as in the installed system) the hybrid technology described above, rather than traditional lead-acid technology, was assumed. Again this reduced the overall cost of ownership (compared to the Saviva data, which modelled traditional VRLA cells) due to increases in efficiency, lifetime throughput, operating temperature, remote monitoring and purpose-built monitoring and power management algorithms. (It is noted that internal modelling has not as yet shown that a battery and PV system alone – with no diesel – might create the savings suggested by Savavi's modelling.)

## Fuel use

On installation of the battery system the reduction in fuel use on site was immediate and dramatic. In Figure 10 fuel usage is compared against the usage in the month before the batteries were installed. This May 2014 figure was typical of the winter fuel usage on the site. The fuel data are approximate since instantaneous fuel measurements are not possible, hence usage is estimated from volumes delivered.

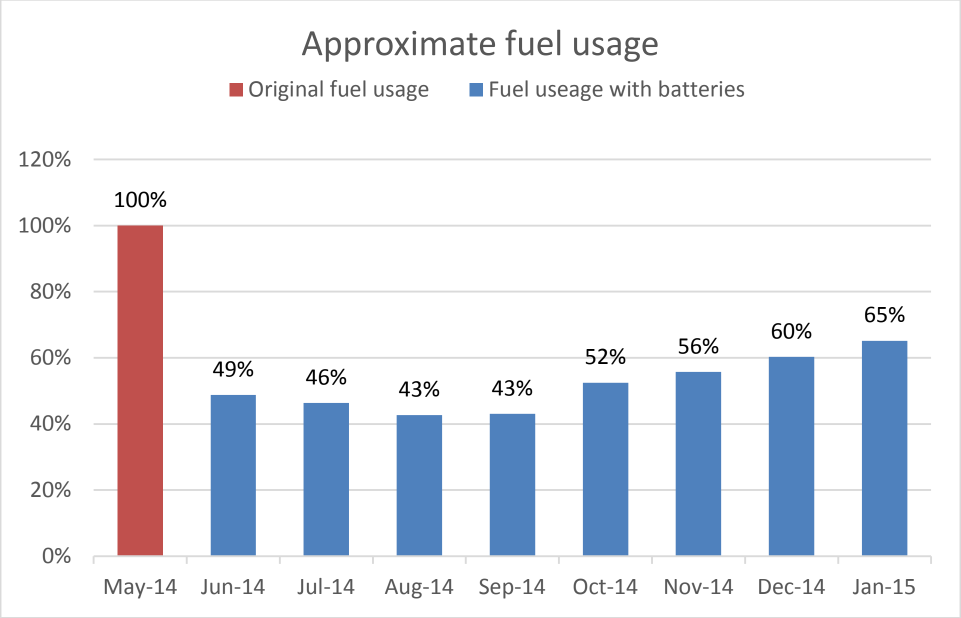

**Figure 10. Site fuel usage since system installation in June 2014 (compared with previous winter usage)**

It is clear from Figure 10 the effect of the air-conditioning load as the Australian spring and summer start, from October onward. A significant aspect of this project has been to validate the temperature performance of the battery chemistry in the field. Laboratory results have suggested that the hybrid cells can run in a warmer temperature than standard VRLA cells and, given the significance of air conditioning to the overall load, there is much to be gained in efficiency terms from raising the set-point of the air conditioning unit. Because of the need to maintain service on this site the on-site experimentation with reducing air-conditioning is to be carried out incrementally but recent bench testing and modelling indicates that running at higher temperatures may make greater fuel reductions possible with no negative effect on site performance.

The remote (3G) monitoring of the battery system has proved to be of great benefit to the installation as a whole since several generator and inverter issues were picked up by the battery’s site monitoring and successfully rectified with site visits thus avoiding site shut down (which is likely to have occurred without such remote monitoring).

## Efficiency

The efficiency of the storage system is particularly important in remote sites where the delivered cost of energy is extremely high and moreover comes with a significant carbon footprint.

The cells used in this project have DC-DC efficiencies around 95% for partial charge cycling. This efficiency is rate-dependent with a range generally between 85% and 99% for cycling applications considered suitable for the cell.

The efficiency measurements taken on site reflect the AC-AC efficiency of the battery/inverter unit and also of the site as a whole. Individual battery efficiencies are not measured on site and have not been calculated from gathered data. Efficiency measurements are graphed in Figure 11 below. As with the fuel data shown above there is an efficiency measurement given for the month prior to the installation of the battery system.

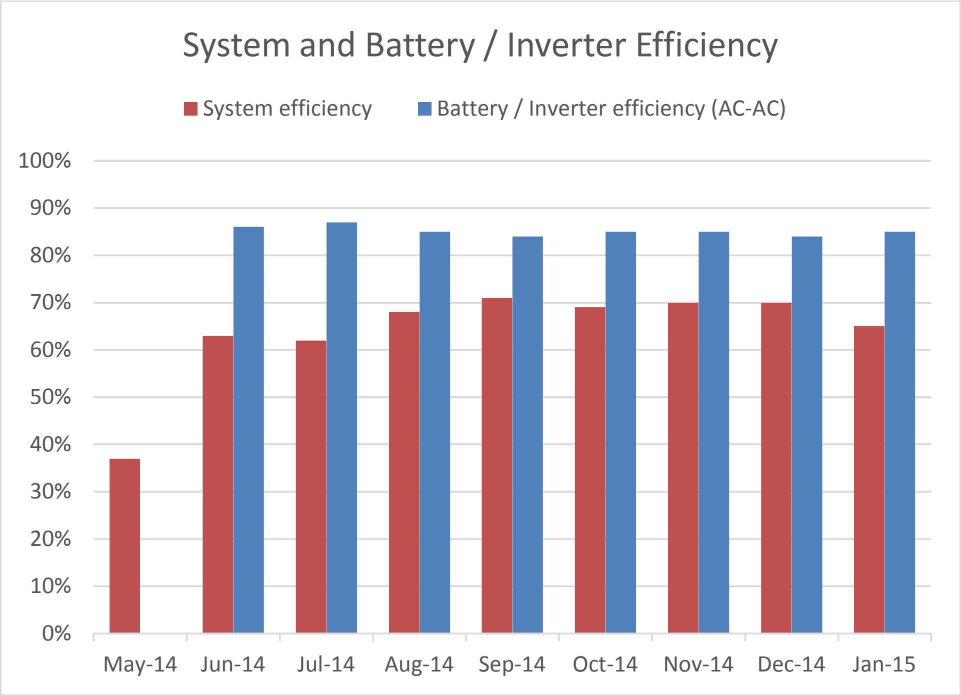

**Figure 11. Efficiency data from site**

The battery/inverter unit runs at a reasonably consistent 85% efficiency throughout the year while the site efficiency has varied between 60 and 70%. Compared with the site prior to the installation of energy storage, overall efficiency has improved markedly, almost doubling in magnitude in some months.

## Benefits of storage

Energy storage, when operated effectively, can create particularly large savings in remote telecom tower applications. The high delivered cost of energy and maintenance on remote sites lead to a range of savings and the modular nature of energy storage means systems can usually be adapted to best suit the particular load case while factoring in local fuel, servicing and battery system costs.

The table below summarizes how a battery system (coupled with a power management algorithm) improves the energy utilization of remote single diesel installations:

| | ***Most desirable use case*** | ***Typical use case seen in remote tower installations*** | ***How Storage helps*** | ***Outcome with Storage*** |
|---|---|---|---|---|
| ***Diesel efficiency*** | Diesel generator runs at λ (optimum efficiency point) and turns off completely between runs. | Generator output is typically at 30% - 50% of rated generator output, rarely (if ever) running at peak fuel efficiency. | The generator runs for set periods at peak fuel efficiency and switches off between runs. | Fuel savings and reduced maintenance. The generator only runs for limited hours at its most efficient setting. |
| ***Solar power utilization*** | Smooth solar signal so generator operates at a steady continuous output. | Shade from clouds and trees causes fluctuations and generator is forced to match the difference between load and solar output. | Battery acts as a shock absorber and supplements the difference between load and solar output. | PV fluctuation is decoupled from generator performance. Maximum solar energy utilization. |

Figure 12 shows that an optimal energy storage solution is achieved when battery costs, fuel costs and maintenance costs are balanced.

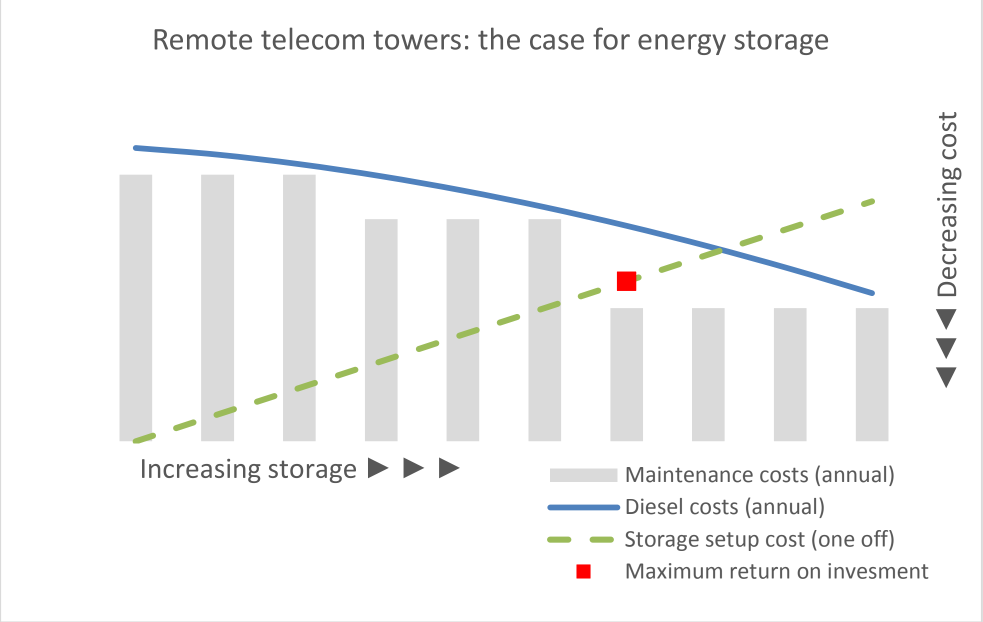

**Figure 12. The correct sizing of a battery system in a remote environment is important for good economic outcomes**

The system described in this paper is based on an advanced cycling battery and introduces:

- proprietary power management algorithms;
- individual battery monitoring; and
- remote power system monitoring

to give the control and monitoring necessary to achieve this balance.

It is imperative that any storage system for remote telecom (or other single diesel microgrid installation) takes into account:

- modelling of the energy flows and financial flows of the system to allow a correctly sized solution to be created with reasonable payback periods;
- “sensitivity” modelling of the installation with variously sized combinations of PV (or wind) and battery.

The results of such modelling has indicated to us that the ideal energy storage system for a remote site reliant on diesel, battery, inverter and perhaps renewable operation will be one that allows:

- partial state of charge operation, which gives constant availability and versatility to either cycle more than once a day and, additionally, firm renewable intermittency;
- fast charge and discharge rates, which allows the battery size to be minimized while maximizing charge acceptance and delivery; and
- the ability to remotely monitor battery and generator operation, which will minimize downtime and allow the proper understanding of the effects of parameter settings and localized climatic conditions.

## References

1. Energy Storage Journal, (2013, November), Ringing the Changes, Karen Hampton
2. Lux Research (2013, July), Batteries Included: Gauging Near-Term Prospect for Solar/Energy Storage Systems
3. Saviva Research, LLC. (2013, May). Hybrid Energy Systems for Telecom Towers. Saviva Research Review.