# PRUDENT ENERGY

**Storage for a sustainable future**
**The Global Leader in Advanced Energy Storage**
An ISO9000/14000 company

## VRB™ Energy Storage Solutions to reduce Opex and Total Cost of Ownership on Off Grid and Poor Grid Sites

Tom Tipple

# Prudent Energy

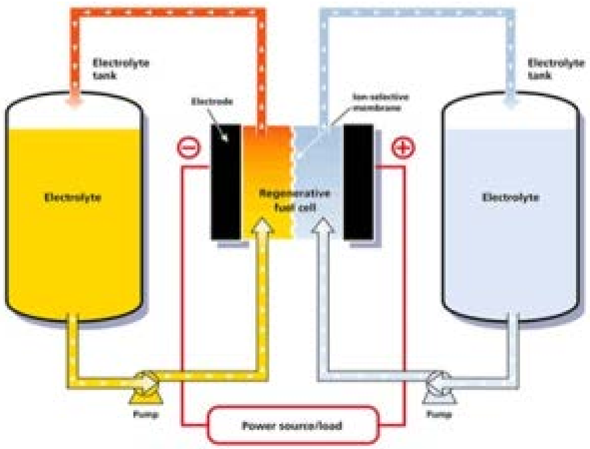
## Company Overview

- **Prudent Energy** provides the proprietary VRB energy storage system (VRB-ESS™) for grid, renewable energy storage and remote cellular site applications
- Founded in 2007, PE acquired technology rights from VRB Power Systems Inc in 2009.
- Head Offices in Washington DC; R&D in Canada and manufacturing plant in China.
- ISO9000/14000 accredited manufacturing.
- Employees: ~175
- 39 patents globally. Trademarks include VRB, VRB-ESS, VRB kW-ESS.
- Investors Include: DFJ, DT Capital, Northern Light, Sequoia Capital, Mitsui, CEL (French) and Jafco. Management about 10%

## Hi Tech Manufacturing Facility in China

## Global

# What is the VRB™ Energy Storage System?



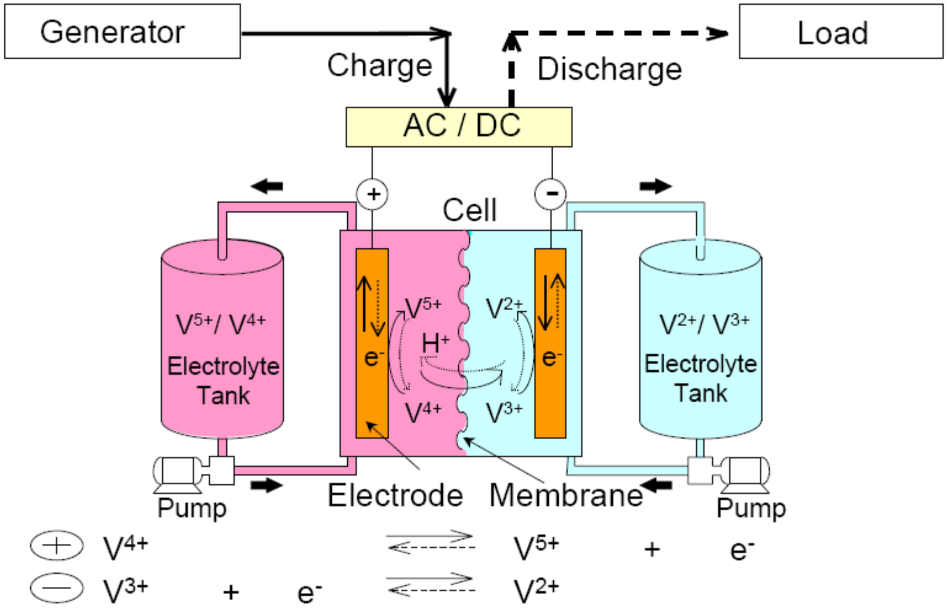

*Concept of a Redox Flow Battery System*

- A **flow battery** that rapidly charges and discharges when electrolytic liquids pass across a conductive membrane
- A **patented process** based on the **red**uction and **ox**idation of different ionic forms of the element **Vanadium**
- **No degradation** on deep cycling performance, to any State of Charge (SOC), > 10,000 cycles
- Recharge rate is > 4 times quicker than VRLA batteries – typically 5 hours for complete charge
- Long Life (10+ years) - electrolyte **never** wears out
- Exact State of Charge (SOC) is always known
- Temperature range up to 40ºC
- Very low maintenance
- Long duration storage independent of power
- Closed loop no hydrogen emissions – clean technology, **no disposal issues**
- Green technology attracts **zero import duty** in many countries



Prudent Energy

# How does it work?



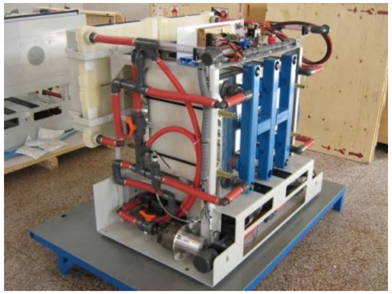

**Vanadium** forms stable, concentrated electrolytic solutions in **four neighbouring oxidation states**. The different states can be clearly identified by changing colours.

Oxidation states of vanadium, from left +2 (lilac), +3 (green), +4 (blue) and +5 (yellow

- During battery charge, **V3+** ions are converted to **V2+** ions at the **negative** electrode through the acceptance of electrons.
- Meanwhile, at the **positive** electrode, **V4+** ions are converted to **V5+** ions through the release of electrons. Both of these reactions absorb the electrical energy put into the system and store it chemically.
- During discharge, the reactions run in the opposite direction, resulting in the release of the chemical energy as electrical energy

# Products & Solutions

**Leveraging its proprietary cell stack design, Prudent Energy offers two product lines to address different energy storage applications**

| Two Product Lines | | |
|---|---|---|
| | **MW Class system** | **kW class System** |
| |  |  |
| **Cell Stack** | • Multi-cell stacks | • Single cell stack 6kWp |
| **Capacity** | • 200kW Module<br>• Up to MW-class system | • 20kWh (420Ah)<br>• 40kWh (840Ah) |
| **Application** | • Wind Farm / PV<br>• Grid Expansion / Enhancement<br>• Behind the meter | • Telecom Base Station<br>• Remote Area Power Supply |

# Legacy Off Grid Sites

- Historically off-grid sites use 2 x Diesel Generator running 24 hour cyclically.
- Generators oversized to manage load surges and spikes, on average running at 50% of available capacity
- Inefficient, high diesel consumption, constant fuel delivery charges, open to fuel fraud.

- Frequent and costly maintenance visits to service generators in remote inaccessible sites.
- Average annual operating costs per site for fuel + O&M is approximately $44,000
- Average 3 year replacement cycle for generators
- Requirement to reduce opex on low ARPU / remote sites

# Current Situation – Off Grid Hybrid Power

- The objective is to store the spare load capacity available in Generators
- Generators are most efficient when under maximum load.
- Early hybrid power solutions used regular VRLA batteries for cost, convenience and availability.

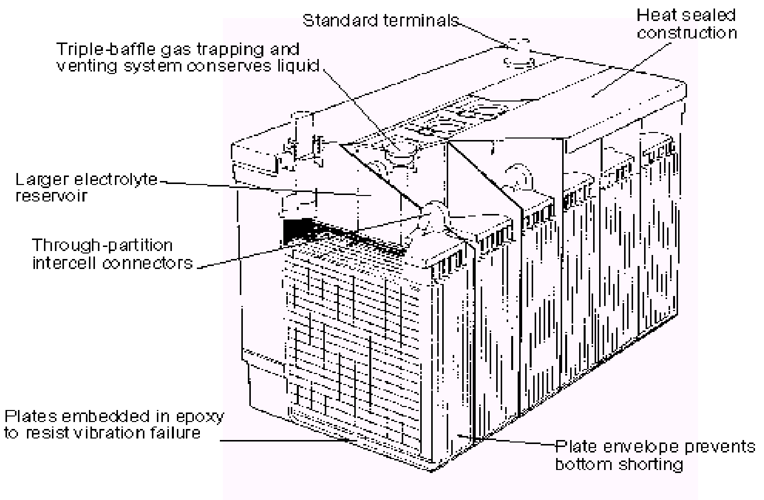
- Poor performance in reliability and short lifespan led to a move towards gel batteries, but much higher cost for small improvement on performance.
- Batteries dimensioned to provide close to 1800 cycles or up to 3 years of use before replacement.
- For 20kWh of capacity a 1000Ah battery @48V is required as only 50% maximum DOD is acceptable for standard VRLA or Gel batteries

# Lead Acid Battery – Disadvantages

**Originally designed for SHORT shallow cycles as a BACK-UP device to bridge to Generator**

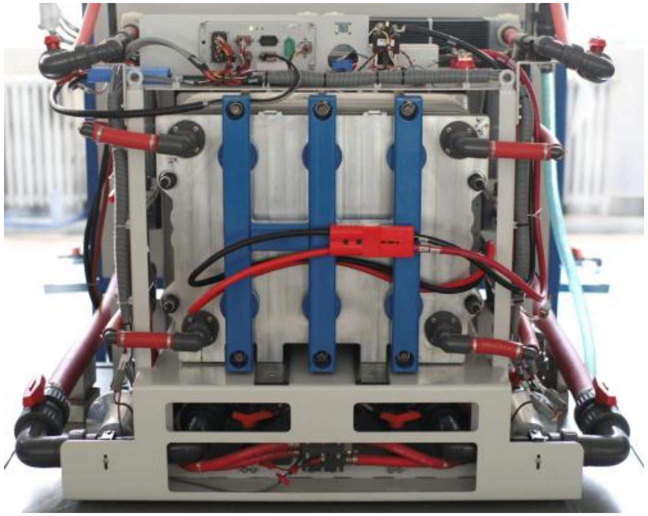
- Conventional LEAD acid batteries **cannot be recharged very quickly** and **do not** deep cycle beyond 50% without permanent damage and rapid loss of life.
- Therefore, a **MUCH** larger battery bank (x2 or x3) is required to make a system recharge fast (10 hours). This is expensive and inefficient.

- Lead Acids also require significant cooling and replacement every 2 - 3 years.
- They are thus **not an economical** choice.
- You cannot accurately measure the State of Charge so matching load is difficult, i.e. when do you reach 50% DoD



# Hybrid Power using VRB™ Energy Storage

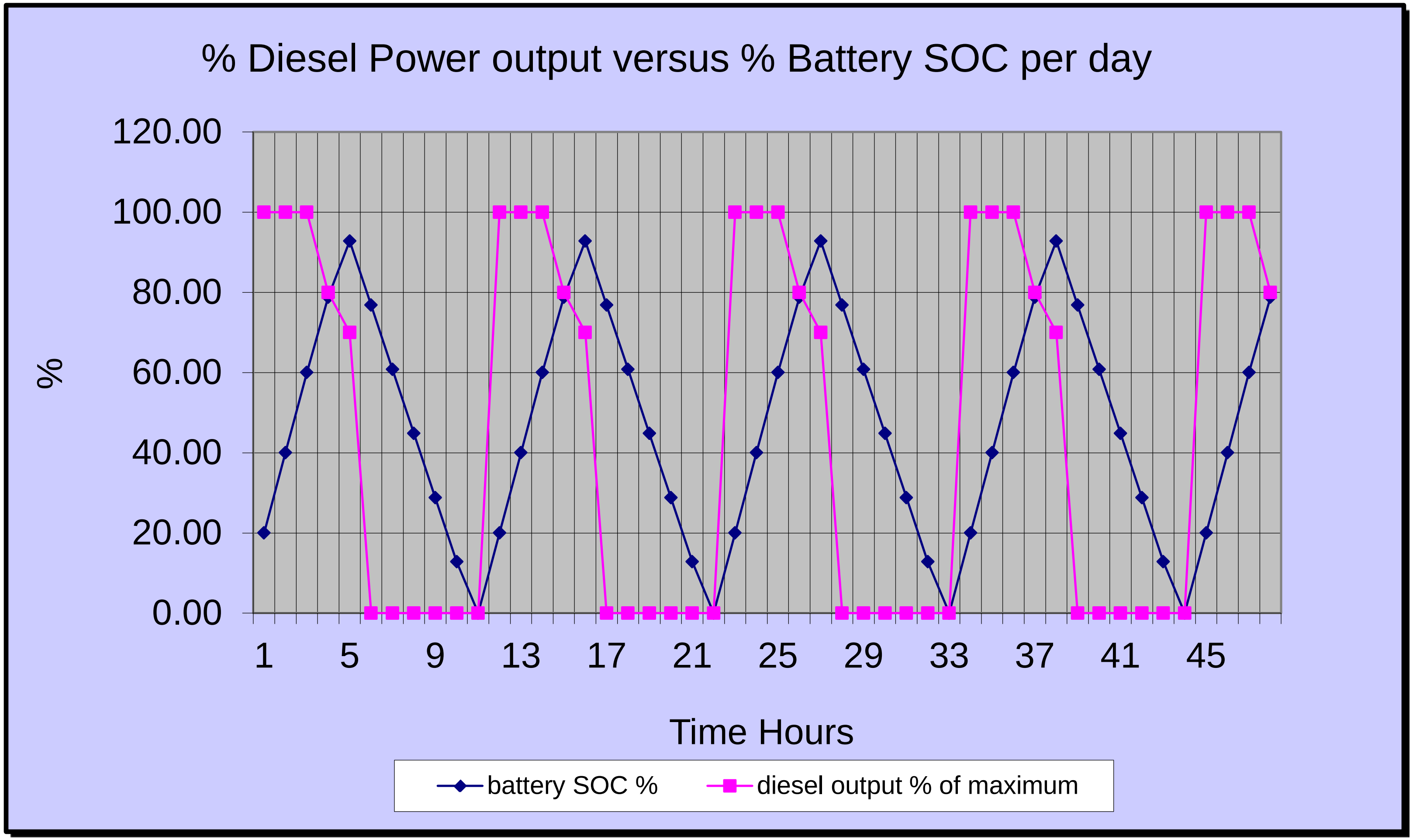
- **Unlimited** deep cycle capability to any State of Charge (SOC)
- Charge / discharge ratio is near 1:1
- Typically 5 hours to fully charge a 20kWh system
- Electrolyte has at least 10 year life



- VRB™ has a straight line constant current charge profile to 90% SOC, **no smart charge controller** required
- High temperature range (up to 40ºC) lowers site power cooling requirement
- No disposal issues, cleantech energy, low import duty

The technological argument for using VRB™ Energy Storage is strong, but does is make commercial sense?

# OPEX Fuel saving – Diesel runtime AND fuel usage reduced




Generator run time savings are substantial if VRB™ only charged to 90% of capacity. Charge time = 5 hours, Discharge time = ~ 5 ½ hours for a 4kW site load

# Total Cost of Ownership comparison for an off-grid site

| Off Grid Site solution Diesel and Battery | Dual Generator No Deep Cycle | Deep Cycle VRLA Solution | Deep Cycle VRB-ESS™ Solution |
|---|---|---|---|
| Principle of operation | Generators run 100%. Often Two diesels installed as backup for cycling so load shared. Diesels operate inefficiently sized for AC load plus BTS and to recharge batteries. Batteries only used as UPS for RBS. Air conditioning maintains 25C environment. | Single generator runs 50% to charge the VRLA battery run load for part of the day and then turns off. Batteries last about 2 years due to degeneration of capacity. Air conditioning maintains 25C environment. Deep cycle VRLA batteries only cycle to 50% DOD, therefore 1200Ah battery needed for 600Ah capacity | Diesel runs to fast charge the VRB-ESS™ to 90% SOC and runs site load for part of the day - then turns off. One diesel required as VRB™-ESS can discharge 100% each cycle without limitation. No battery cooling required therefore lower average site loading |
| Average Site Loading, kW | 5 | 5 | 4 |
| Generator capacity kVA | 12.5 | 12.5 | 12.5 |
| Aavailable Battery Power, Ah | 0 | 600 | 450 |
| Charge time per cycle, h | | 10 | 5 |
| Discharge time per cycle, h | | 5.76 | 5.4 |
| Discharge time : Charge time ratio | | 58% | 108% |
| Daily run time of diesel average hours | 24 | 15.23 | 11.54 |
| Number of cycles per day | n/a | 1.52 | 2.31 |
| US$ cost per liter of diesel | 1.4 | 1.4 | 1.4 |
| Average fuel consumption per site (litres/h) | 2.8 | 3.24 | 3.24 |
| Annual diesel consumption per site per (litres) | 24,528 | 18,009 | 13,645 |
| Fuel Delivery costs per site/ annum | 1500 | 952 | 721 |
| Total Cost of diesel per annum US$ | $35,839 | $26,165 | $19,825 |
| O&M costs per annum on DG and batteries | $10,512 | $6,670 | $5,054 |
| **Total Annual OPEX Cost** | **$46,351** | **$32,835** | **$24,879** |
| **Total percentage Annual OPEX saving** | | **29%** | **46%** |
| Diesel life in years before replacement | 2.57 | 4.05 | 5.34 |
| CAPEX replacement cost Diesel engine US$ | $12,000 | $12,000 | $12,000 |
| Battery or stack life to replacement | 5 | 3 | 10 |
| Initial Battery / VRB-ESS Cost | $1,000 | $12,000 | $25,000 |
| Battery Replacement cost after 3 years | $0 | $12,000 | $0 |
| **TCO after 5th year INCLUDING initial CAPEX** | **$256,116** | **$202,995** | **$160,623** |
| **TCO percentage savings** | | **21%** | **37%** |

# Total Cost of Ownership / ROI Evaluation for Off Grid Sites

## 5 Year TCO Calculation

| Off Grid Site solution Diesel and Battery | Dual Generator No Deep Cycle | Deep Cycle VRLA Solution | Deep Cycle VRB-ESS™ Solution |
|---|---|---|---|
| Total Annual OPEX Cost | $46,351 | $32,835 | $24,879 |
| Total percentage Annual OPEX saving | | 29% | 46% |
| TCO after 5th year INCLUDING initial CAPEX | $256,116 | $202,995 | $160,623 |
| TCO percentage savings | | 21% | 37% |

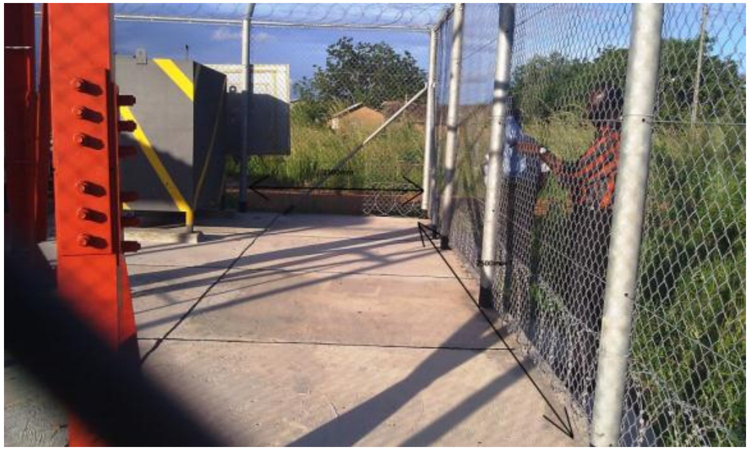
## 3 Year TCO Calculation

| Off Grid Site solution Diesel and Battery | Dual Generator No Deep Cycle | Deep Cycle VRLA Solution | Deep Cycle VRB-ESS™ Solution |
|---|---|---|---|
| Total Annual OPEX Cost | $46,351 | $32,835 | $24,879 |
| Total percentage Annual OPEX saving | | 29% | 46% |
| TCO after 3rd year INCLUDING initial CAPEX | $154,070 | $119,397 | $106,374 |
| TCO percentage savings | | 23% | 31% |

Based on EXW pricing. No import duty considerations

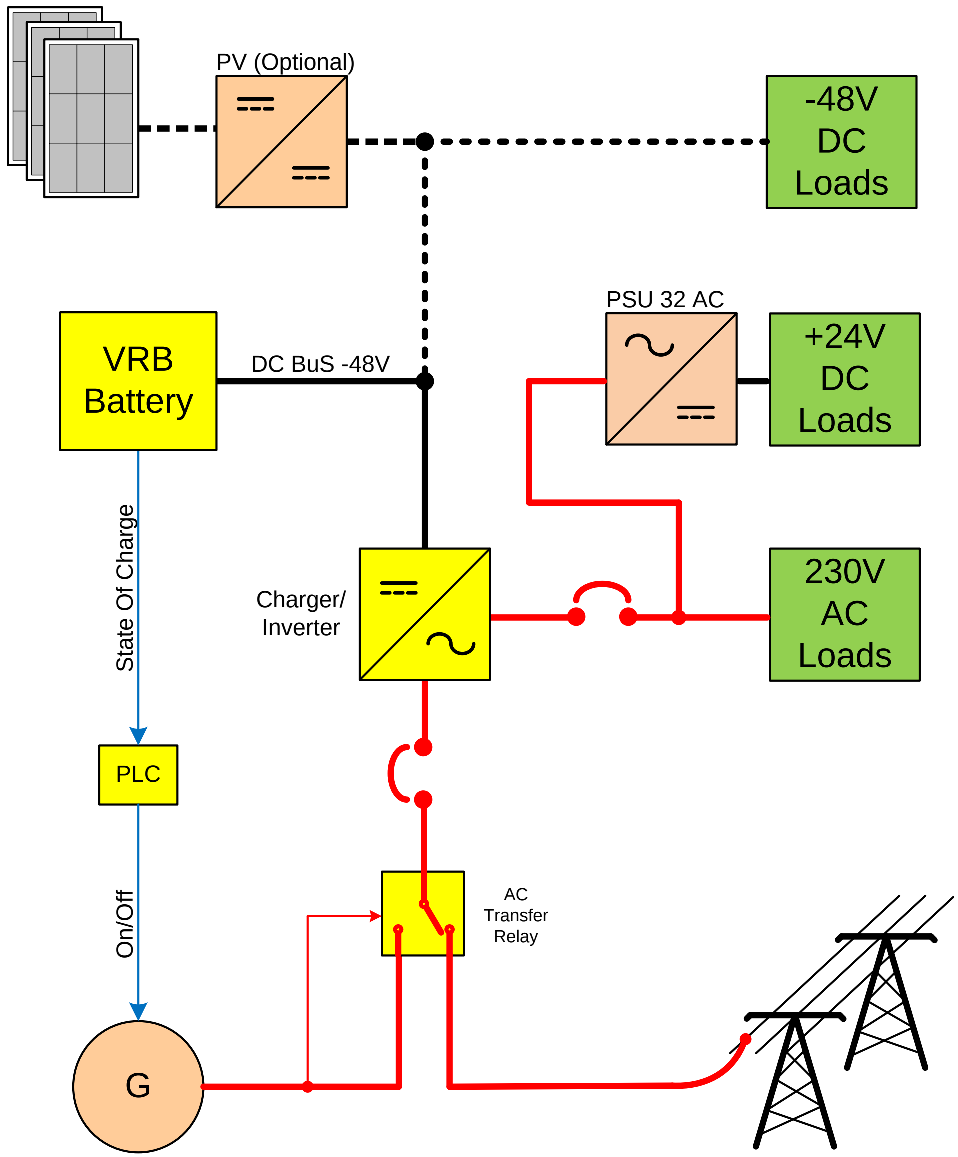
# Poor Grid Sites

- Large number of poor grid sites in Africa!
- Poor grid definition
  - Complete loss of grid power
  - One or more phase loss
  - Very low voltage
- How long will an outage last?

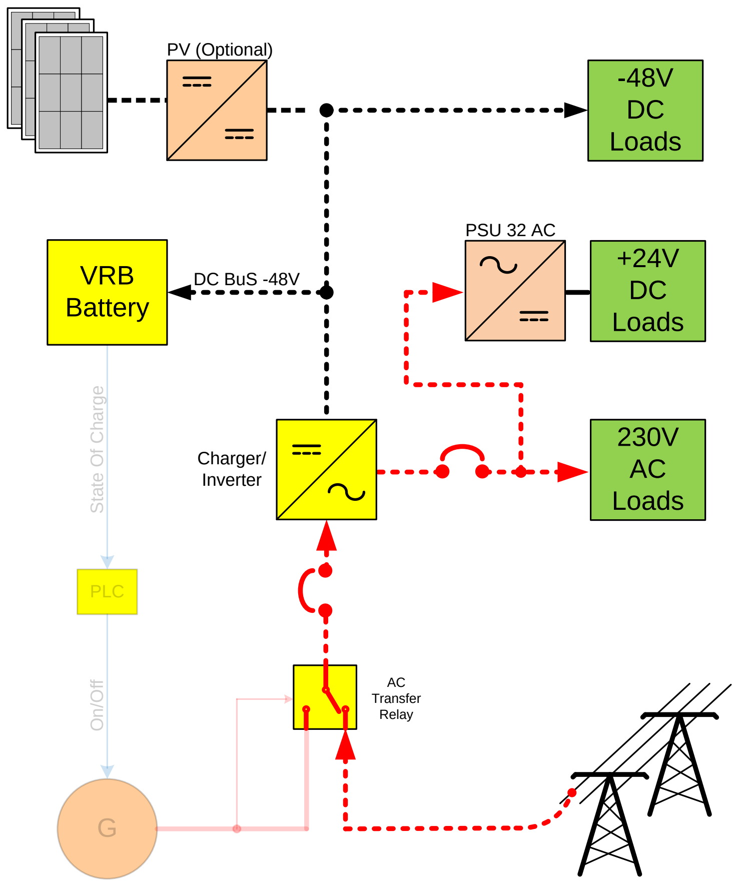


- An Energy Storage Solution **must** be able to manage short outages (UPS) as well as indefinite outages
- How poor does a poor grid site need to be before a hybrid solution becomes economically viable?

# Poor Grid Installation Schematic for Outdoor Sites

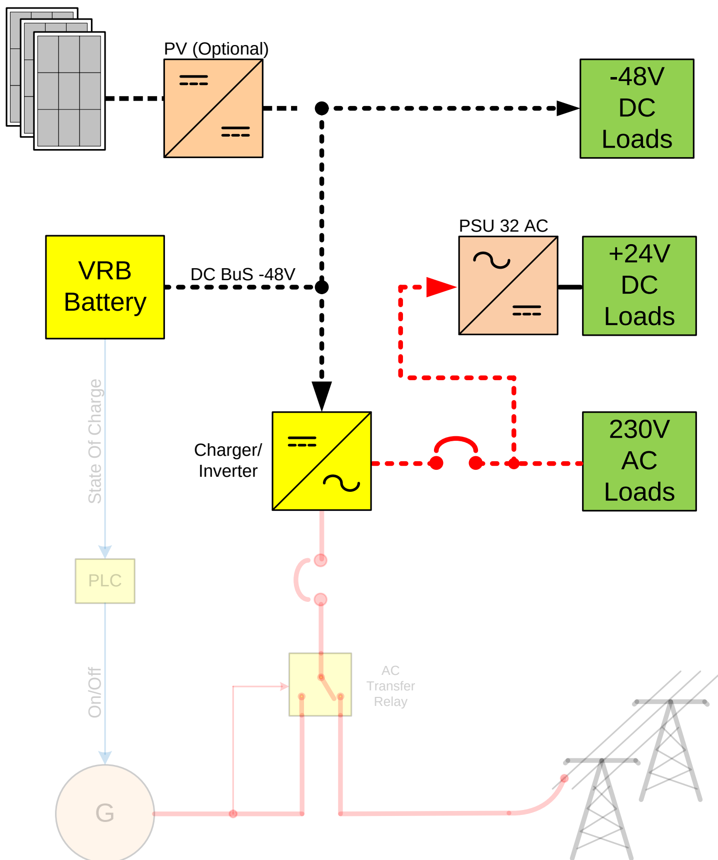


# Poor Grid Installation Schematic



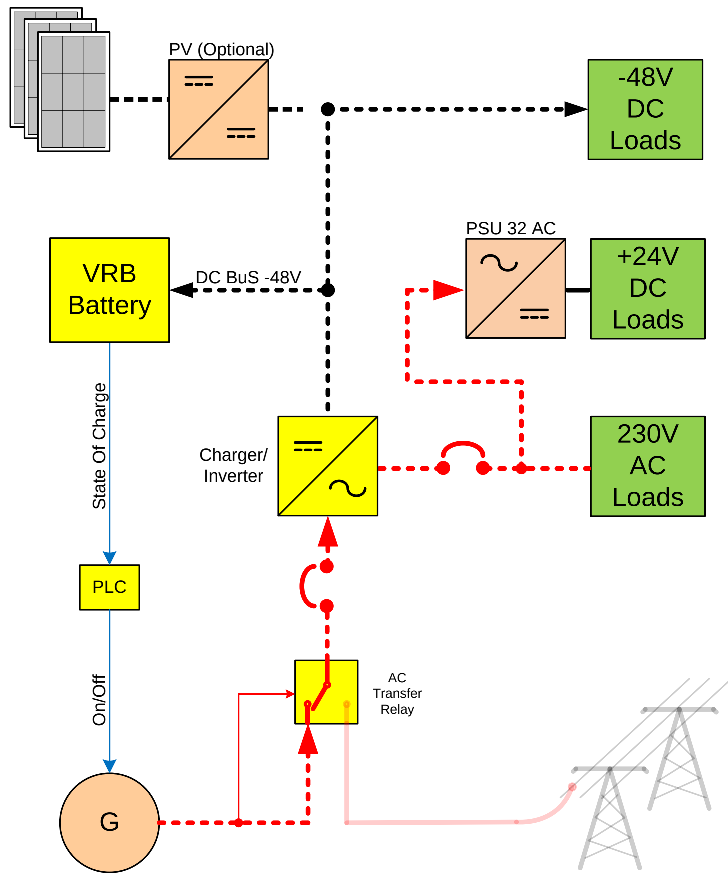

In normal operation the power is supplied from the utility grid. The AC power is channeled via Inverter/Charger to the loads and the battery is being charged, as per diagram below

# Poor Grid Installation Schematic




When the grid voltage drops below allowable limit, the Inverter starts generating AC power from the energy stored in VRB™ Battery. This switch over happens within 8mS, short enough not to interrupt load operation. The power will continue to be powered from the battery per diagram above

# Poor Grid Installation Schematic




If the energy from the VRB™ drops below predetermined SOC level and the utility power is still unavailable (or not stable enough), the system controller will provide a command for the Generator to start. The energy flow will now be as per diagram below

# Estimated Diesel Run Time Savings for a 5kW site

| Duration of grid outage (hours) | Diesel Run Time (existing) | Diesel Run Time with VRB | Percent saving |
|---|---|---|---|
| 1 | 1 | 0 | 100 |
| 2 | 2 | 0 | 100 |
| 3 | 3 | 0 | 100 |
| 4 | 4 | 0 | 100 |
| 5 | 5 | 1 | 80 |
| 6 | 6 | 2 | 66 |
| 7 | 7 | 3 | 57 |
| 8 | 8 | 4 | 50 |
| 9 | 9 | 5 | 44 |
| 10 | 10 | 6 | 40 |
| 11 | 11 | 6 | 45 |
| 12 | 12 | 6 | 50 |
| 13 | 13 | 6 | 54 |
| 14 | 14 | 6 | 57 |
| 15 | 15 | 7 | 53 |
| 16 | 16 | 8 | 50 |
| 17 | 17 | 9 | 47 |
| 18 | 18 | 10 | 44 |
| 19 | 19 | 11 | 42 |
| 20 | 20 | 12 | 40 |
| 21 | 21 | 12 | 43 |
| 22 | 22 | 12 | 45 |
| 23 | 23 | 12 | 48 |
| 24 | 24 | 12 | 50 |

These figures represent a worst case scenario.

If grid outage is for 4 hours, then restored for a period of 6 hours before the next outage, the generator will not be used at all.

Reality is somewhere in between

Each “poor grid” site requires a power audit to justify ROI

# VRB-ESS for Off Grid and Poor Grid Sites

- An OEM 20kWh VRB-ESS™ costs around $25k
- A “hardened” system costs around $32k
- A “hardened” system + PV costs around $50k
- Combined VRB-ESS™ & PV attracts zero import duty

- Sites with up to 5kW average loading
- Modular systems for tower leasing (5kW, 10kW, 15kW, 20kW) will be possible in the future
- Proven technology, opex and TCO savings
- No disposal issues
- >10,000 cycles

# PRUDENT ENERGY

**Storage for a sustainable future**
**The Global Leader in Advanced Energy Storage**
An ISO9000/14000 company

Tom Tipple
VP, Prudent Energy
tom.tipple@pdenergy.com
+44 7900 268957