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White Paper

Understand Hybrid Generator – Battery Systems

For off-grid applications powered by diesel generators, move to cyclic operation to save costs

Telecommunications operators in Africa, India and other developing countries face severe challenges in powering mobile base station (BTS) sites in remote areas.
In many cases, the sites are simply too far from the AC grid for AC mains powering to be economic. Other sites have AC power, but it is extremely unreliable.
These sites are often powered by small diesel generator sets, running continuously.

Sealed lead acid (VRLA) batteries provide back up power to generator maintenance, start up and cover the occasional case when fuel runs out.

Ongoing costs are high, and include:
- Direct fuel cost
- Truck rolls. Refueling is usually needed every one or two weeks, at a high cost for a very remote site.
- Generator maintenance.
- Generator replacement. In continuous duty a small generator may only last two years.

By changing the way the generator is controlled, an operator can achieve significant savings in running costs. This is called "hybrid operation", where the generator only runs part of the time, and the battery runs the load while the generator is off.

This white paper explains hybrid operation and how to use it to save operating costs at sites that have with no AC or very unreliable AC, and are primarily powered by diesel generators.

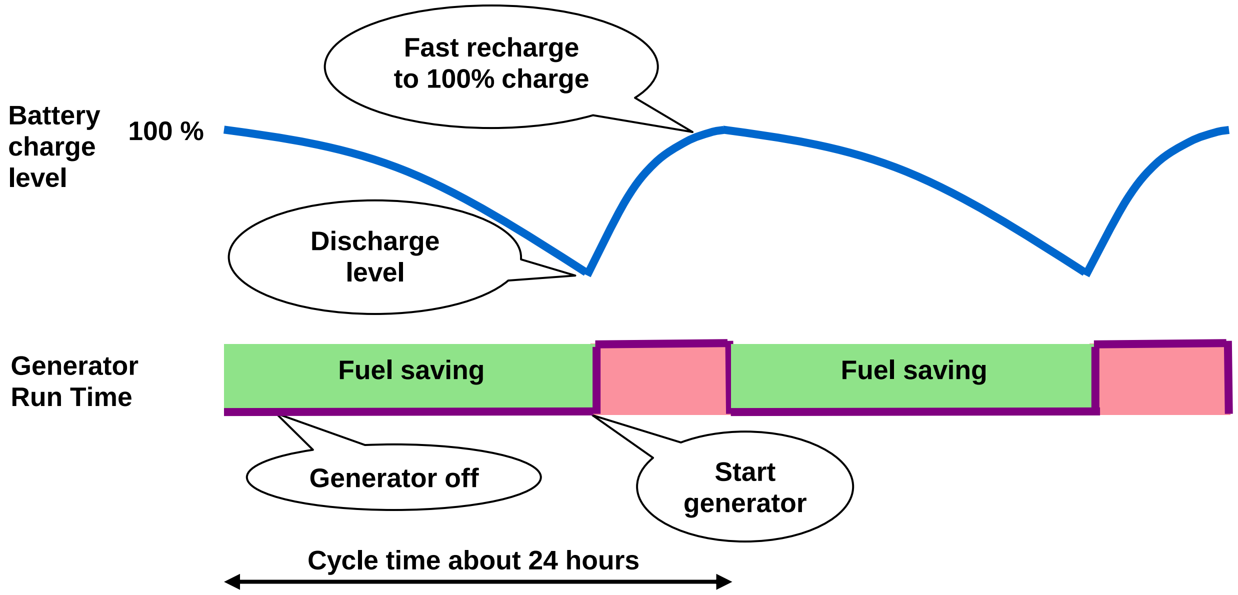
1. Overview

In the conventional diesel-powered system the generator has capacity for running the load and recharging the battery. To ensure a reasonable recharge time, the generator must be sized much greater than the load. But most of the time the generator is just powering the load, running at anywhere from 30% to 60% of maximum load.

The hybrid system changes this so that the generator is always running at close to full load. How?
It only operates to charge the batteries. Once the batteries are charged, it stops.

This is the operating sequence:

- The system starts with a fully charged battery.
- The generator is turned off and the battery takes the load.
- Once the battery has discharged to a set level, the generator starts again and quickly recharges the battery.
- The generator is turned off again and the cycle repeats.



Typically the generator will run for about 50% of the time or less. For the rest of the time, the battery is discharging.
A full cycle can take around one day.
But this all depends on the characteristics of battery, generator and load, and how operation is optimized. *More on this later.*

2. Where is the saving?

Direct Fuel costs
Consider this example:
An 11kVA generator in standard duty (full time) at a load of 40% load takes 2.2 liters per hour, or 370 liters per week.
Change this to hybrid operation at 80% load, 50% duty cycle.
Then the fuel use is 3.65 liters per hour, or 306 liters per week at 50% duty cycle. This gives a 17% fuel saving.

Using cyclic rated batteries, it is possible to go to a smaller recharge time (a lower duty cycle) and get further cost savings, up to 30%.

Refueling cost
Along with the reduced fuel consumption comes a corresponding reduction in truck rolls for refueling. For remote sites, the cost of bringing fuel to a site is likely to be higher than the direct fuel cost.

Generator maintenance interval
Instead of running 100% of the time at moderate load, the generator runs at full load for 50% of the time or less. The generator service interval is based on run time (not load), so the service interval is now at least twice as long. This provides a direct saving in truck rolls. Generator life is similarly increased, so replacement costs are much lower.

3. Batteries

Is there a downside to this fuel saving?
Definitely. The battery system is now being cycled daily, leading to some reduction in the battery life.
Many VRLA batteries are only rated for a few hundred deep cycles. Others can tolerant frequent cycling and still provide a long life.

So here are the tradeoffs:

1. High quality batteries with a cyclic rating are needed.
2. Battery life will be somewhat reduced. But this reduction depends on the battery type, how deep the cycle is, the recharge rate, average temperature, etc.
3. Some energy is lost in the recharge process. However, this is not significant compared to the savings.

In practice, with 50% depth of discharge, well controlled temperature and a good cyclic rated battery, we can expect a life of three years or more. This needs to be factored into the calculated savings as part of an overall cost – benefit analysis.

4. Optimization

The fuel saving is based on “fine tuning” the use of the generator and battery for best efficiency.
To get the best out of the system, start by understanding these parameters as they relate to your application. Then look at the interactions between the parameters.
Fine tune each for the best performance, bearing in mind tradeoffs between OPEX (running cost) and CAPEX (initial purchase and replacement costs).

Depth of discharge
Adjust the depth of discharge to balance battery life against the time running on batteries. The deeper the discharge, the longer the system runs on battery and the larger the fuel saving.
But if the discharge is too deep, then the battery life is shortened too much. A good choice for a cyclic rated battery is 50% depth. Other batteries not rated for cyclic duty may need to have a shallower discharge.

Generator loading
In an ideal world, the generator is matched exactly to the load and battery recharge.
In practice, the size is rarely exactly right, and some compromises have to be made, such as slightly over-sizing the generator.
Beware of pushing the load too close to the generator rating. Start-up surges and load variation could mean that a system with no reserve capacity fails to start under some conditions.

Recharge rate
The shorter the recharge cycle, the longer time on battery and potentially the higher fuel savings. But if the recharge rate is too high, an oversized generator may be needed.
Also, some batteries will not accept such a high recharge rate without shortening their life.
The optimum recharge rate will achieve good battery life, and at least 50% of time on battery.
Accurate control of recharge rate is essential.

Full recharge
If the batteries are not fully recharged every cycle, their capacity will "staircase" down each cycle until finally the system will fail.
Ensure that the length of the recharge cycle is accurately controlled in such a way that the battery is always fully charged at the end. Any time spent on charge after that is unnecessary run time for the generator, resulting in additional fuel used.

Equalization
Some batteries in cyclic application will benefit from an equalize charge. This is a periodic limited overcharge of the battery. It can restore capacity to some extent.
But not all batteries need equalization. Check the data sheet!

Monitoring
Using remote management, the network operator or service organization can prove the hybrid cost savings, ensure operation remains optimal, manage the response to faults, and support battery warranty claims.
This information should be available remotely:

- **Charge / discharge cycle logs**
  Prove the battery is fully charged at each cycle. See also the section below on battery warranty.
- **Fuel use logs**
  Is the system fuel use actually as predicted?
- **Alarms**
  A full set of alarms on DC power, generator, fuel, and battery state enables the operator to manage site issues and prevent small problems escalating to outages.

5. System Control

How do we ensure all these operating parameters are maintained accurately?
The system controller must accurately manage charge and discharge cycles, including charge voltage, charge duration, charge rate and depth of discharge.
Eaton® DC power systems use the system controller, such as the SC200, to manage the hybrid cycle.

Discharge
The controller accurately integrates the amperes discharged from the battery with time, to give an ampere-hours discharged total for the discharge / charge cycle.
When this reaches the planned depth of discharge (say 50% of the nominal battery capacity), the controller closes a contact to start the generator.

Recharge
While the generator is running, the ampere-hours of charge into the battery are counted. When the ampere-hours recharged equals the ampere-hours discharged, plus a small factor to allow for inefficiencies, the charge is terminated.
During the charge, the charge voltage is elevated ("Fast Charge") to give the minimum recharge time. This charge voltage is temperature compensated.

6. Battery Warranty

Since hybrid systems cycle the batteries every day, battery manufacturers will insist on full data to support any battery warranty claim.

Data that may be asked for includes
- Number of cycles
- Duration of each charge and discharge cycle
- Ambient and battery temperature history
- Maximum discharge depth

A full featured controller with large data log will be needed to provide this information. It should be possible to extract the log into a spreadsheet for full analysis and warranty support.

For instance, the Eaton SC200 stores 10,000 data log records, and features dual-rate logging.
The normal rate log provides a long term record of ambient temperatures and other operating conditions. The fast rate log provides a detailed record of each charge and discharge.

7. Environmental control

Air conditioning and other environmental issues must be considered.
During discharge, there is no AC present to power air conditioners.
To maintain temperature during the discharge period (which is at least 50% of the time) the options include:

- Use inverters from the DC bus.
- Use DC powered air conditioners to improve efficiency and possibly reduce total cost by eliminating inverters.
- Use heat exchangers to reduce energy consumption. This is only practical for smaller outdoor cabinets.
- Use temperature-controlled DC extractor fans to cool the equipment. This is potentially the most energy-efficient, but is not suitable for many environments. In environments with high dust or salt spray air content, this will shorten equipment life.

Any solution will have trade-offs between reliability, performance, cost, and efficiency.
The local climate and other environmental issues may dictate a particular solution.

8. Other energy sources

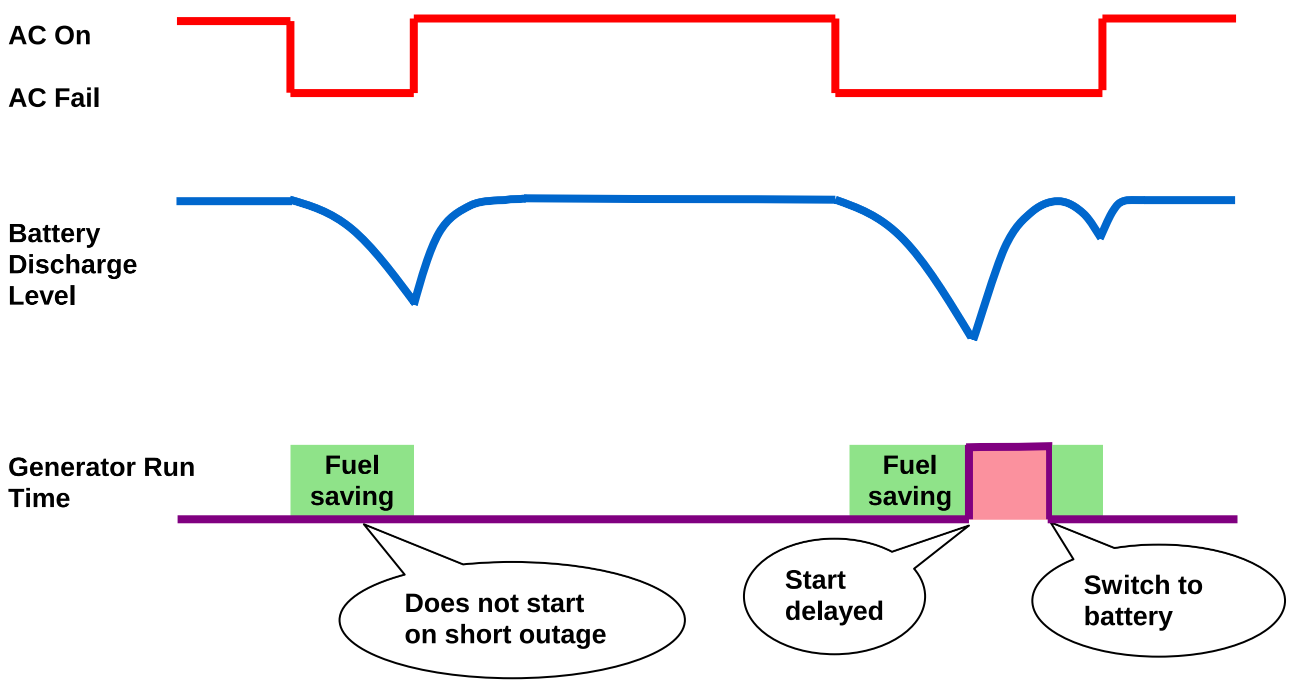
This paper is focused on the hybrid Diesel generator – battery solution.
Of course, further fuel savings are possible using solar and / or wind power combined with battery storage and diesel generator backup.
However, these are not always practical.

- Space may not be available
- Capital cost may be too high
- Solar panels may present a tempting target to thieves.

Fuel cells are another alternative, and outside the scope of this paper, as the fuel use tradeoffs will not be the same.

9. Grid-tied applications

Hybrid technology can provide even larger savings if AC mains supply is available.
Then the batteries can be used to "ride through" an AC failure, without any need to start the generator.
The generator only needs to start for longer AC failures.



Fuel savings will depend on the frequency and duration of AC outages.
In theory, if all outages are less than the battery backup time, then fuel saving is 100%. Of course, this is unlikely to be achieved. But savings of more than 50% are likely.

10. Conclusions

For a remote telecom site powered by a diesel generator, the hybrid solution can provide significant fuel and other OPEX savings.
Tight control and monitoring of the charge and discharge cycles is essential. A fully featured controller such as the Eaton SC200 is needed.

To ensure the potential savings are achieved, carefully review and understand tradeoffs. Optimize the charge and discharge cycles, bearing in mind the characteristics of generator, batteries and load.

A detailed cost / benefit analysis should be done, covering capital costs (generator, battery, control, monitoring) and operational costs (fuel, generator servicing, battery replacement, truck rolls, etc.).

About the author

Simon Sloane is a product manager in Eaton's Telecommunications Solutions Division (TSD).
He has worked in the DC power field for over 20 years, moving from power supply design to controller development to his present role as managing Eaton DC power system software products, including controllers and remote management software.

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About Eaton

Eaton Corporation is a diversified power management company with 2007 sales of $13 billion. Eaton is a global technology leader in electrical systems for power quality, distribution and control; hydraulics components, systems and services for industrial and mobile equipment; aerospace fuel, hydraulics and pneumatic systems for commercial and military use; and truck and automotive drive train and power train systems for performance, fuel economy and safety. Eaton has 82,000 employees and sells products to customers in more than 150 countries. For more information, visit www.eaton.com.

About Eaton's Telecommunications Solutions Division

Eaton's Telecommunications Solutions Division provides DC power systems; associated products and services; hydraulic-magnetic circuit breakers and distribution modules to the telecommunications and other critical power industries.
DC power solutions include 24V and 48V DC power systems, battery monitoring and control systems, cabinets and enclosures, and a wide range of services including remote monitoring, turnkey integration services and site support.

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