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WHITE PAPER

Addressing persistent pain points of Hybrid deployments

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Abstract

The hybrid telecom power market has had more than 10 years to mature.

The CDC (charge-discharge-charge) principal is simple and well proven – discharge/charge the battery and thus make the generator operate at optimal efficiency, rather than being lightly loaded and running 24/7. Diesel savings of more than 50% are easily achievable, with savings of 70% not being unusual. Adding renewables such as solar (and wind) can take savings up to near 90% (and 100% in solar-only sites).

As simple as the principal is, it is fraught with problems:
- Lead acid batteries have long absorption phases and generally like to be 100% charged.
- Batteries become very expensive as they must be highly cyclic.
- The move towards shared tenancy sites creates high load requirement – and very, very large batteries.
- Each site requires fine tuning to ensure generators do not stall and optimal generator loading.
- Stalled generators.
- Difficulty to operate generators at optimum efficiency.
- Optimising solar harvest when used in conjunction with generators.
- Lack of remote visibility and control.
- Unbalanced phase loading on generators

Enatel's SYNERGi Hybrid Power System offers highly advanced solutions designed to minimise or eradicate these problems with one simple, easy to manage solution.

SYNERGi offers full and complete control of up to two generators, plus a partial grid connection.

Key features covered in this paper are:
- Solar Optimisation
- Dynamic Diesel Generator Power Optimisation and Anti-stall
- Dynamic three-phase balancing
- Single point monitoring and control
- Multiple Genset Start/Stop triggers

The Problems

As mentioned in the Abstract, the charge-discharge cycling of batteries to gain significant diesel fuel saving in off-grid applications is well known. However, the practical outworking of these solutions can be problematic, particularly in the site ownership model of the tower co industry where site loads increase due to multi-tenant occupancy.

There are two end results:
- Site visits/truck rolls
- Equipment replacement (including associated site visits)

Elaborating on typical problems on site. Firstly, there are two very live elements in most remote sites:

- The battery is a just a big chemical reaction that is ongoing 24/7, 365 days a year.

- The generator is a creation of hundreds of moving parts that happens to convert liquid potential energy into electrical energy.

As with any moving parts or live reactions, these are the items that need consistent maintenance and care. Then there is the thing that links all these elements together and finally processes the energy flow into a useable form that the load can consume - the power system.

Cyclic Use of Lead-acid Batteries

Lead-acid batteries are still the most widely used energy storage medium due to:
- Well known and understood (arguably) technology
- Very cost competitive
- Relatively easy to manage large arrays (series and parallel cells)
- Readily available

However, they have significant disadvantages:
- Cheaper batteries are not cyclic.
- Temperature-dependent.
- High temperature batteries are typically not high cyclic batteries.
- Even cyclic batteries are typically not discharged more than 40 or 50% to maintain a good cyclic life

- They're heavy. Remote sites with high loads and long autonomy requirements make logistics of deployment a headache.

- Lead acid batteries are often not well monitored (if at all) because they behave quite well in large arrays of series/parallel cells and BMS (battery management systems) are expensive. This can make them invisible to network managers until they fail.

- They have an impractical absorption phase that cannot be avoided. This means that any generator charging the batteries during this phase will run inefficiently.

Generators

The traditional AC generator has now been around for more than 100 years. It is well known, and spares are easily available so it is still the genset of choice. However, generators are complex electro-mechanical devices with many moving parts that are subject to wear and tear, and thus regular servicing/replacement requirements.

Nearly all features of SYNERGi are about these two devices – the battery and the generator.

Battery:

- General maintenance
- Ensuring it stays within optimum state of charge range
- Maximise life

Generator:

- General maintenance
- Ensuring peak efficiency power output
- Guarding against unnecessary stalls

However, there are conflicting operating conditions for maximising battery life and generator (i.e., fuel) efficiency. For example, battery life is largely governed by the number of charge-discharge cycles it is subject to and its depth of discharge. But the longer you can run on batteries, the less fuel you use.

SYNERGi gives the customer the ability to set parameters to give the best possible compromise between these conflicting requirements.

SYNERGi Features

The significant features that make SYNERGi unique are:

- Dynamic Generator Anti-stall
- Dynamic generator power optimisation
- Real-time phase balancing
- Solar optimisation
- Multiple concurrent generator start/stop conditions
- Dual generator control (including monitoring two diesel tanks)
- Integrated solar and wind converters and Inverters
- Single point monitoring and control

Then there are numerous other useful features:

- Ability to stop battery charge based on either low current or low float current (enables PSoC [partial state of charge] cycling)
- Ability to control lithium batteries (e.g., having voltage stop)
- Configurable number of re-start attempts if the generator does not start
- Commissioning Charge
- Periodic generator extended charge cycle (enabling PSoC with VRLA batteries)
- Periodic generator run (for use in large solar sites where the generator almost never runs)
- Full visibility of state of hybrid cycling
- Seamless inclusion of renewables
- Ability to include ATS (automatic transfer switch) in system (avoiding expensive 3rd party ATS's)

Field Experience

Enatel has hybrid systems operating all over the world. These cover a wide range of installation types from pure diesel, to solar, to solar and wind, with loads that vary from straight telco 48Vdc loads to inverters powering schools. The following are a series of plots demonstrating some of SYNERGi's features in practical applications.

Solar Optimisation

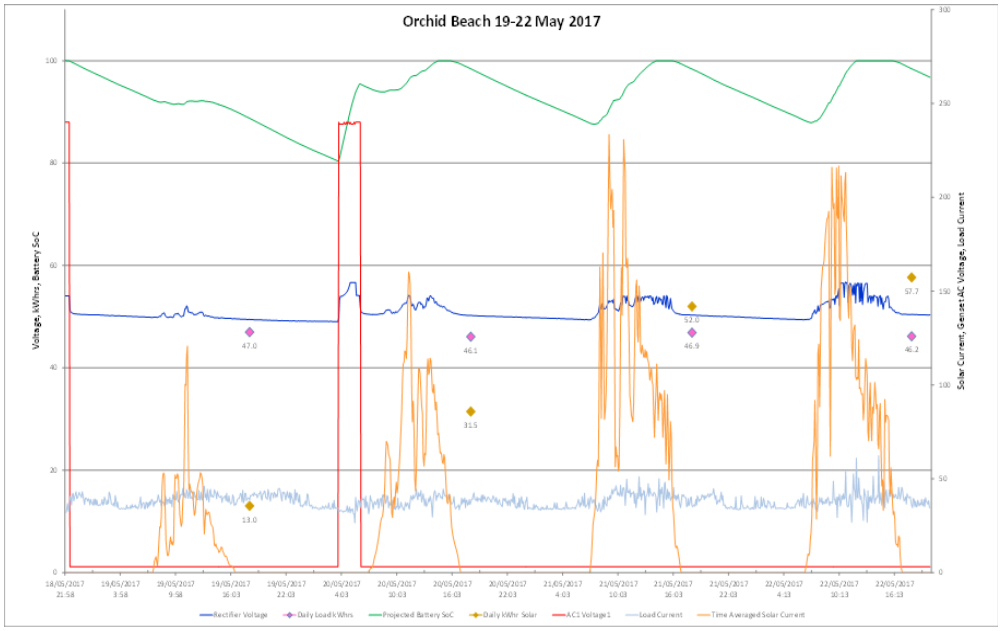
On systems where solar is deployed alongside generators, one frustration is that it is entirely possible to have both the generator running and good solar output at the same time. It would be a simple matter to turn the generator off while there is sunshine – but what happens on a cloudy day? Does the generator turn off and on continually? One could then decide to simply inhibit the generator during the day – perhaps only running it if the battery voltage gets too low. However – how do you cope with seasonal variation of sunrise/sunset? Or differences in panel orientation from site to site? Once again there would be the requirement to adjust and "tune" each site.

Enatel has developed a simple solution for this.

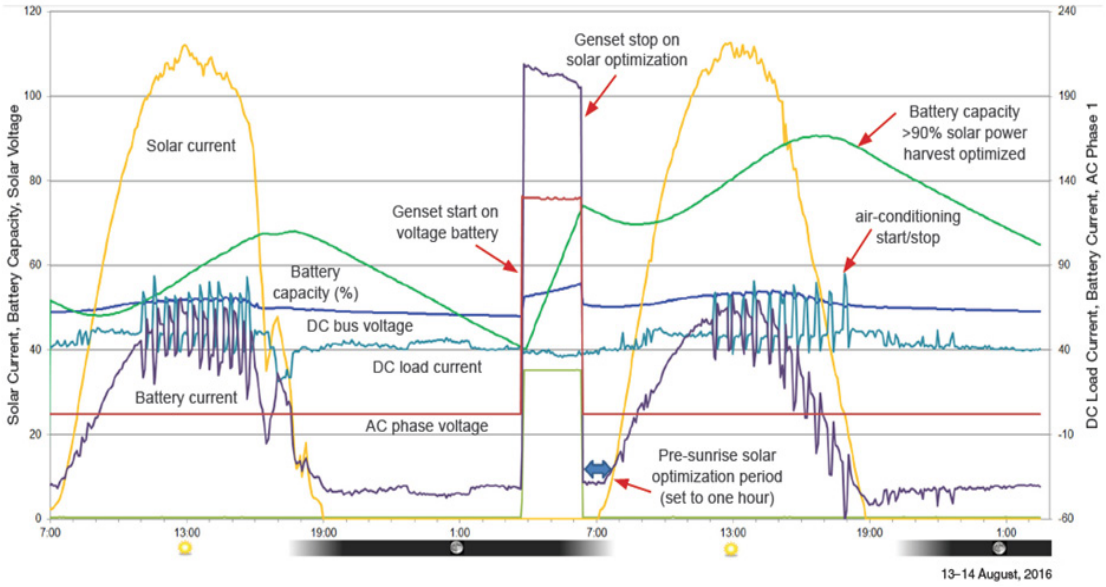
Firstly, an example of a site on Fraser Island in Queensland:

Site Load	2.45kW	2.45kW
Solar Energy Installed	6.8kW	17kW
Battery	4400Ahr (new)	4400Ahr (6 years old)
Generator	20kW	30kW
Fuel Use	250 litres/month	47 litres/month (>80% saving)

The plot below shows four days of operation from the 19th to the 22nd May 2017. The generator started early in the morning of the 19th. SYNERGi commanded the genset to stop one hour before sunrise. This prevented unnecessarily putting more charge into the battery than necessary. As can be seen, the battery was quite well topped up during that day, even though there was less than optimum sunshine. The following two days brought battery back to full capacity without the need for starting the generator again.

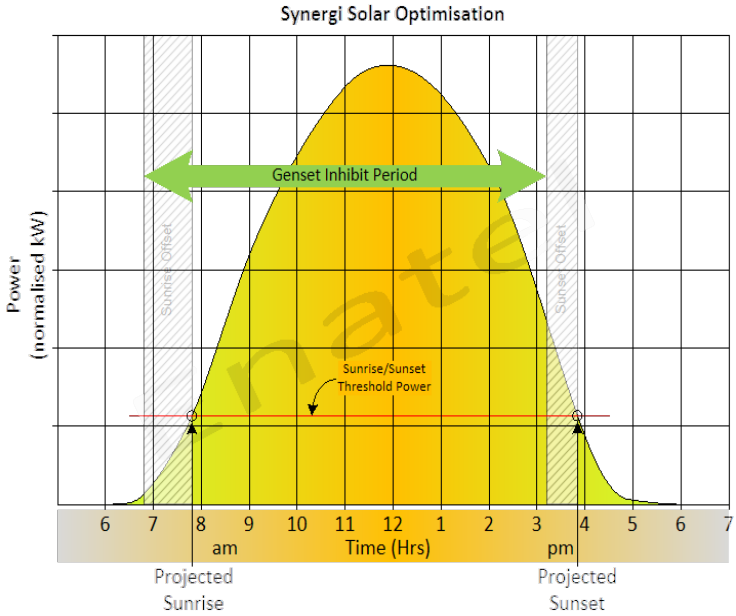


Another example of this in operation is shown here form a site deployed in the Sonora Desert in Mexico:



The results for this site are summarised here:

Site Load	4kW	2.45kW
Solar Energy Installed	6.2kW	6.2kW
Battery	1500Ahr	4400Ahr (reconditioned)
Generator	20kW	20kW
Fuel Use	2038 litres/month	275 litres/month (>80% saving)



So how does it work?
Enatel's solution is as simple as it is elegant. Rather than relying on things like clocks, individual site adjustments or accessing online forecasts, SYNERGi simply looks at the earliest sunrise over the last 10 days, and creates a start criteria during the "solar day".

As can be seen, SYNERGi creates a Genset Inhibit Period. This also includes a settable Sunset Offset time (where the Inhibit Period ceases prior to actual sunset – this can be useful if there has been little sun during the day, and therefore there is no reason to run the battery down to a lower capacity than necessary).
The user then hasthe option to select an extra-low voltage start threshold for the generator, with programmable genset stop conditions that can be one of three choices:

- Charge duration
- Battery capacity
- Low battery charge current

These stop conditions, if enabled, are completely independent to the normal genset stop conditions set on the Hybrid Cycle Setup page. This gives the operator a large amount of flexibility to optimise the settings based on overall network requirements, or site-specific requirements.

SYNERGi simply looks at the earliest time over the last 10 days to decide on the sunrise settings and the latest time for the sunset. In this way the seasons are followed throughout the year.

Should the SYNERGi controller be reset, these settings revert to the defaults specified on the Hybrid Solar Optimisation page.

Dynamic Generator Anti-stall

If a generator stalls, a site visit is required – and it often only requires a simple generator reset.

One problem with typical hybrid power systems is that during the charge phase of the batteries, the maximum power of the generator can be exceeded. This is often exacerbated with three-phase generators. To keep phases balanced, the rectifier modules should be deployed in multiples of three. But in doing so, often it is required to have more potential rectifier power than the generator is rated for.

There are a few ways around this, but none are ideal. These range from removing/turning off rectifier modules (creating phase imbalance), to hard-limiting power output. But what if the power output of the generator changes over time? Or from site to site as a roll-out is installed (e.g., altitude differences)?

Explanation of Anti-stall and MPP

Wouldn't it be nice to roll out an identical system for a given generator (or even series of generators), with identical settings from site to site? And then once installed, not have to spend time "tuning" the system for that exact site? SYNERGi offers this by dynamically monitoring maximum generator output, and adjusting the system power output to target the generator's peak efficiency. But much more than that, it can sense when the generator has entered a low power state, and adjust power output on-the-fly to ensure the generator doesn't stall.

These two features are unique to SYNERGi Hybrid. They form the basis for the Dynamic Diesel Generator Optimisation (D2GO).
The Anti-stall feature detects the load on the generator and, through Enatel's patented technology, reduces the DC output load, thus preventing the generator stalling.The following plot shows a genset start-up and optimisation cycle.
MPP is Maximum Power Point detection of the generator. Note that this can only occur if there is enough rectifier load (and by implication battery recharge) to overload the generator. Ancillary AC loads can also affect this such as AC air-conditioning. The MPP and Anti-stall features are explained referencing the plot below.

- At a certain point, the genset is triggered to start (this depends on the Start parameters set by the user – these could be based on Ahrs, bus voltage, time etc.).

- Once the genset starts, Synergi ramps up the DC voltage slowly …

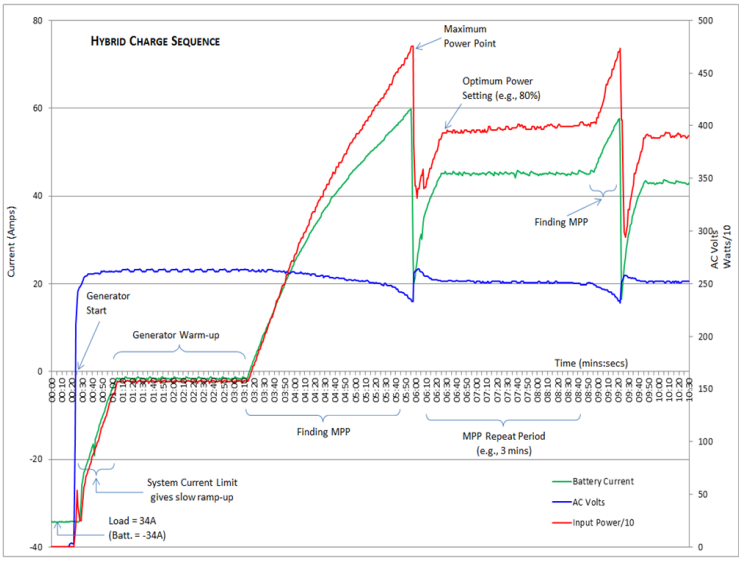
- … until the Warm-up Power is reached. After a defined warm-up period, SYNERGi slowly increases the DC bus voltage, thus increasing the battery recharge. This continues until the generator reaches its full load point, at which time the frequency drops as a result of the overload.

• The Maximum Power Point (MPP) is the trigger to SYNERGi to back off the DC bus voltage and decrease the load on the generator. The MPPis the true Standby power of the generator.

• SYNERGi sets the Optimum Power Point, which is defined by the user (typically 60 to 85%).

It is worth pointing out at this stage that any load set-point over 60% of this figure (i.e., 60% of Standby (as opposed to Prime) generator output) will give close to optimum efficiency in terms of kWHrs/litre of diesel.

A higher figure, say 85 or 90% will give a faster battery recharge, but battery life will be reduced due to the increased cycling. Also, at the higher loads there will be increased wear & tear on the generator, and it will have a shorter lifetime. A typical good compromise will be about 65 to 75%.



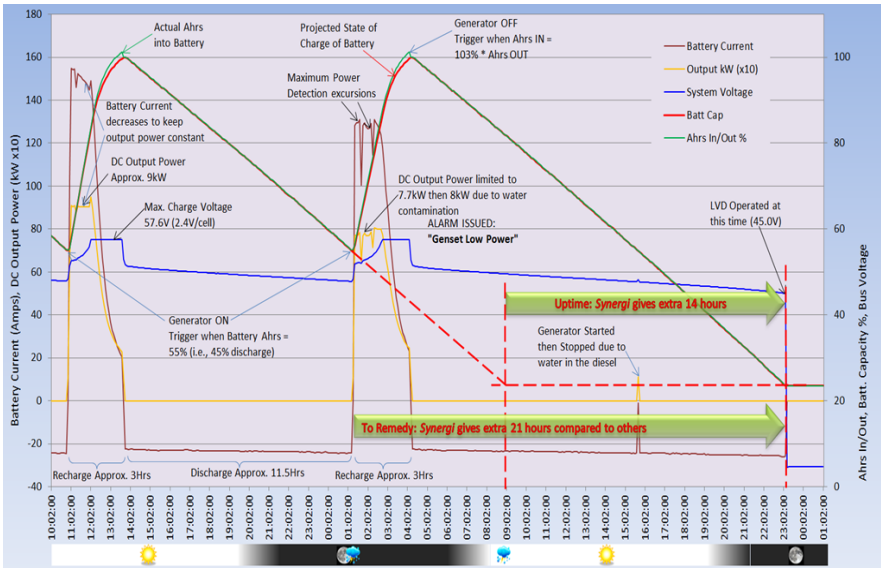
• Repeat MPP excursions can be made, and will typically be set (again it is a user setting) to an hour. The plot shows it at a relatively short repeat time of three minutes (for the sake of experiment).

It is worth repeating again that in some systems the number of rectifier modules supplied may not be enough to overload the generator (or may be close to it). In these cases the MPP function is turned off (see the check-box on the Generator Control page of the Configuration Software). However Anti-stall can remain active so that if the generator has a low power event (for example, contaminated fuel or blocked air-cleaner), SYNERGi will sense this and back off the DC load. This ensures the generator keeps running if at all possible, and will raise a Generator Low Power Alarm. This will give a technician more time to get to site and fix the problem.

One other major advantage of this is that the rectifiers can remain in multiples of three, thus retaining threephase balancing of the generator under all circumstances.

The next plot shows the efficacy of the Anti-stall logic. This plot shows the two charge-discharge cycles at a site in New Zealand.

First, note the green and red lines. These represent the battery state of charge (SoC). The system used here was with about 1.1kW of load, and 570Ahrs of battery. The battery SoC was used as the main trigger (Ahr counting), and the requirement for that battery is to recharge to 103%. The DC bus voltage is shown in blue, the battery current in brown and the DC power in orange. The load was constant power, so you can see as the bus voltage increases, the battery current decreases.



• During the recharge shown in the first cycle, the DC output was about 9kW. The AC input was about 9.5kW and the Optimal Generator Load setting was 85%. This made the practical Standby power output to be 11.3kW. The generator was a 13.5kVA unit, with a theoretical maximum of 11kW. This shows SYNERGi detecting a good match between practical and name-plate ratings.

During the first discharge period, there was an extended rainstorm. Due to the way, the extended diesel tank was set up, a small amount of water could enter the tank.

• At the time of the second start, it can be seen from the plot that the DC output power had to be limited to under 8kW. At this time, a Low Genset Power alarm could be raised to alert the NOC that there was a problem at site. Due to the D²GO (dynamic diesel generator optimisation) functionality, SYNERGi kept the genset operating when it would normally have stalled, thus being able to fully recharge the battery.

• An attempt at a third cycle is made. At this point the genset started briefly, however, the contamination was too great and it stopped again.

• The battery kept discharging until the battery low voltage disconnect operating, disconnecting the DC bus.

The result is SYNERGi demonstrating an extra 14 hours of site up-time compared to other control systems.

Optimising Generator Power

Arguably the most important thing to optimise is diesel fuel use. The use of diesel gensets is unavoidable with existing technologies. It goes without saying that 100% renewable energy would be the ideal target, but due to constraints of land area (for solar), turbine size and wind availability (for wind), size of energy storage, and the capital cost of these, the humble diesel generator remains the only practical energy delivery medium for the foreseeable future. This is exaggerated further by the larger site loads of the tower co industry that can have three, four or even more tenants on their sites.

That being the case, what can be done to ensure efficient consumption of the fuel source – i.e., diesel?

Although there has been significant uptake of DC gensets, they remain an expensive genset when comparing likefor-like output power with an AC genset. Furthermore, the only benefits they offer is to lower the genset speedand relative fuel consumption as the battery charges through its absorption phase.

During bulk charge phase, there is no advantage.

SYNERGi dynamically adjusts the power output of the genset during the bulk charge phase to ensure not only that the genset is not overloaded (or stalls), but also that it operates at its predetermined optimum power output level.

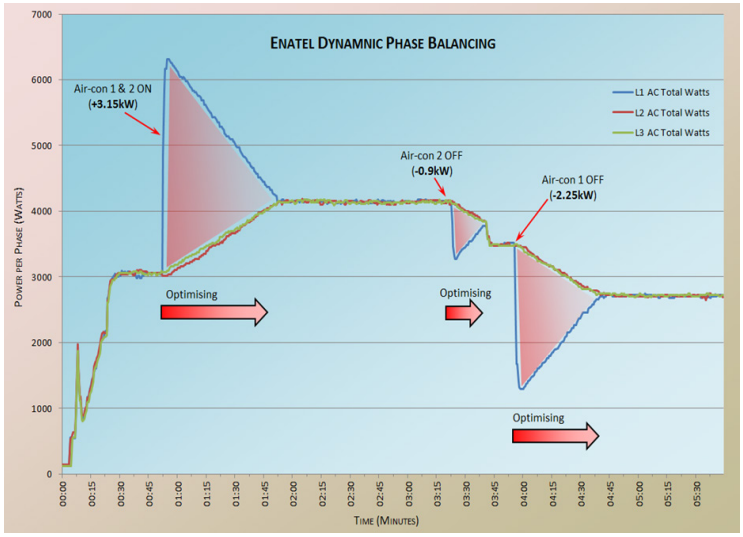
Dynamic Phase Balancing

Enatel's experience when talking to CTO's and the systems planners/operators of hybrid powered networks is that the unbalanced phase loading of generators is a significant roadblock. An unbalanced load on a generator causes an uneven loading of the alternator. As the magnetic forces are unevenly distributed around the rotor/stator – and in the exact same position every revolution of the machine – the bearings can wear unevenly. Over time the imbalance becomes a physical imbalance and genset will eventually start vibrating – with the consequential failure.

So how does SYNERGi implement Dynamic Phase Balancing? Simply put, because SYNERGi has control over the rectifier module outputs, it can adjust their outputs (in three groups to suit the phase loads) to ensure the AC input current is balanced from phase to phase. The only requirement is that current transformers are fitted to the AC input side of the power train (preferably at or near the genset).

As a result, SYNERGi can adjust the power draw on a "per phase" basis, and cater for imbalances due to things like single phase air conditioning loads, or an uneven number of rectifiers attached.

Below is a plot of Phase Balancing in operation:



This form of phase balancing has been patented by Enatel.

Monitoring, Control and Remote Site Visibility

There is no argument that being able to view in detail what is happening on-site is essential. There are numerous small problems that might be able to be solved with remote control, saving valuable truck rolls. Not only that, remote site analysis can result in the correct course of action and gear sent should a site visit be necessary.

Although it sounds straightforward, it is not.

It is Enatel's experience that establishing a remote IP link is one of the more difficult project tasks and it is incumbent on the mobile network operators and tower companies to ensure it happens.

SYNERGi has a full suite of remote access capabilities:

• Http/s web browser host built into the controller for basic system information.

• Remote Craft Tool access via Http/s and UDP. UDP is less bandwidth hungry than Http, and is ideal for the often quite narrow bandwidths experienced for the IP pipe.

• Full SNMP V1, V2c and V3. All alarms are available via Traps and a full set of “alarm words” are provided for alarm interrogation. Furthermore, a full suite of Gets for all analogue values and a full suite of Sets are provided for the ability to set any alarm thresholds or analogue value setpoints.

• A UDP scripting tool is also provided so that operators can automate the extraction of any analogue or logged values in the format that suit their specific database.

SYNERGi provides a very detailed site summary page when using the Craft Tool and those with experience in field operations will appreciate how much valuable information is handily collated on this single page.

From here one can tell at a glance what the current state of the site is with everything from the reason the genset was last started and stopped to fuel tank capacity (provided sensors are wired) to seeing the history of power provision and consumption for the last two days.

Looking After Your Batteries

As mentioned in the introduction, the batteries are a crucial part of the site infrastructure. Without their correct functioning, the whole site falls over. Plus they are expensive – in terms of capital, and in terms of installation.

Enatel’s design staff have been designing and manufacturing rectifiers and power systems since the inception of switch-mode technology – more than 30 years. Looking after batteries is what we do.

Hybrid cyclic applications add more complexity in terms of starting and stopping generators, but the essential need for battery care remains unchanged.

However, by its very nature, hybrid cyclic operation of the batteries changes the battery use model at its core. No longer can you use cheap AGM batteries. To get more than the standard 600 or so cycles, you must use batteries that are designed to be fit for purpose. There are many batteries that claim to have good cyclic life, and it is not the purpose of this paper to promote one over the over, or even one chemistry over the other.

What SYNERGi provides is flexibility to program the best possible cyclic regime for any given battery.
The options are:

Various Start & Stop thresholds:
• Voltage
• State of charge
• Time

Included are options for Partial State of Charging (PSoC). This is particularly useful for Lithium based batteries where 100% SoC is not required, and in fact is beneficial for the battery life. An extended charge to run the generator with different stop thresholds can also be set to periodically bring the battery back to 100% SoC if required. Additional to this is also the ability to periodically start the genset on a site that is primarily solar/renewable powered.

Conclusion

SYNERGi offers the industry an easy to deploy solution defined by the combination of a powerful, unique feature set (including genset anti-stall and optimisation, solar optimisation, and phase balancing), integrated renewables, and complete remote visibility and management.