ENATEL | energy

Dynamic Phase Balancing

By Murray Wyma, Enatel

Version 1.0

Release Date: August 2020

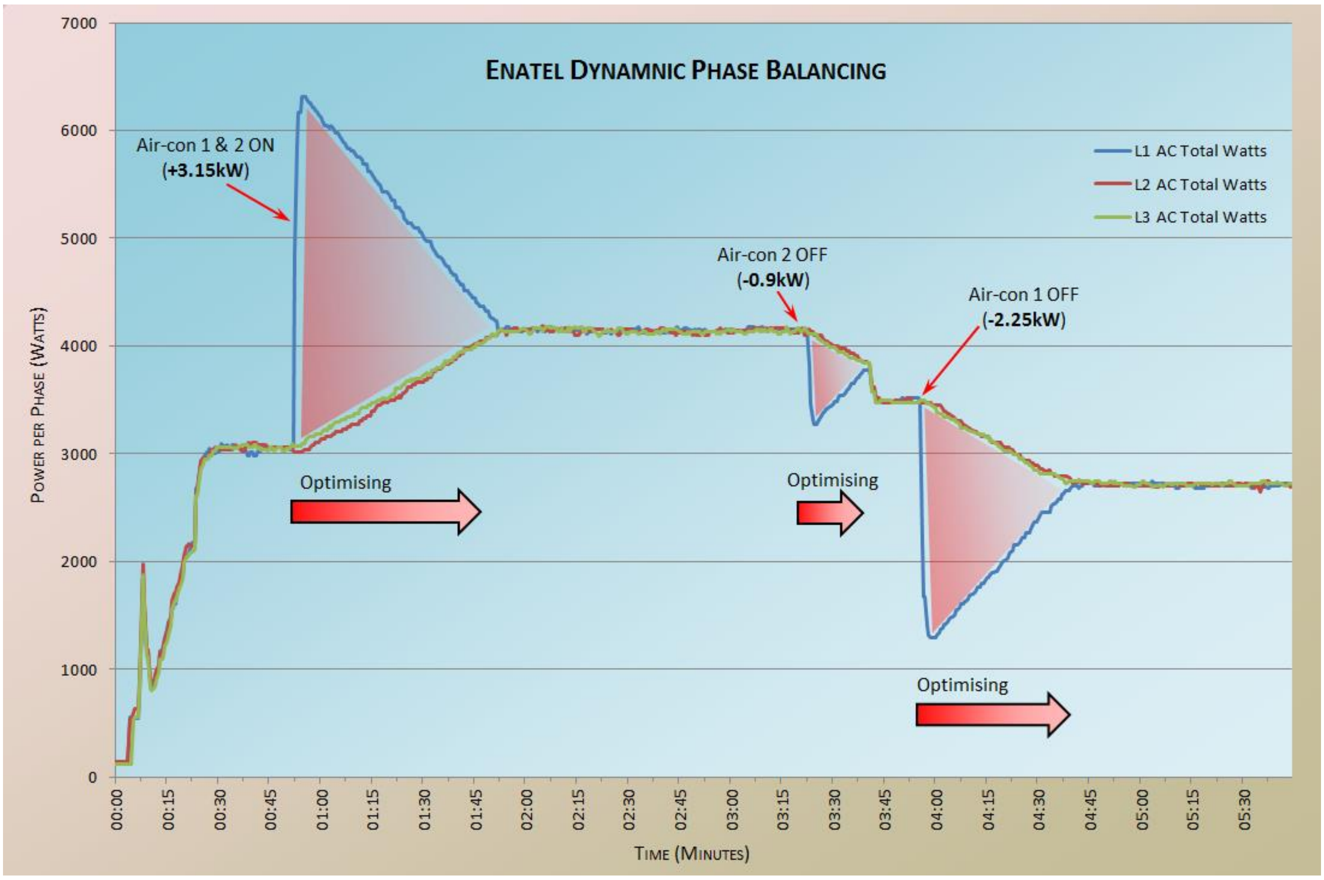
Phase Balancing Overview

Enatel's patented Dynamic Phase Balancing offers Telco users unique and previously unavailable features. This presents real cost-saving opportunities in its two main application fields – cellular BTS sites and off-grid generators:

- Maximise power draw from grid/generator
- Prevent upstream breakers tripping ("fast-response" mode)
- Balance phases due to tariff impositions
- Balance phases to prevent generator damage
- Balance phases due to uneven number of 1-phase rectifiers (i.e., rectifiers not in multiples of 3)

Put simply, the DC power system adjusts the output of its 1-phase rectifiers (spread across the 3 phases) to balance the 3-phase input at source.

Enatel's phase balancing feature utilises the system controller's ability to individually control the output of each set of rectifiers connected to each AC phase input to smooth out phase imbalances on the grid supply. An example of a system actively balancing phases is shown here:



In the plot above the response time is relatively slow. However, when the system senses the circuit breaker being overloaded, the response is much faster – fractions of a second – so the circuit breaker does not trip.

While the principal of balancing the phases is quite simple, the control detail is complex and due consideration must be taken of all modes of operation and corner cases.

Phase Balancing on BTS Sites

5G has promised faster, lower latency and of course much higher bandwidth capabilities. Although the power required per MB of data may have decreased, the sheer volume of data and the use of things like massive antenna arrays (MIMO), plus the need to run legacy equipment have seen the gross power requirements increase sharply.

A typical 4G site running a 3-sector, 12 radio system might require 6kW of power. However, a 5G site using a 64T64R MIMO antenna might require up to 12 or even 15kW, a massive 250% increase in power. Fundamental site requirements like the utility grid capacity (current rating) at site might need to be upgraded. This can be a costly and sometimes near impossible expansion. The cost could easily run from $20k to $100k (e.g. a BTS site on a golf course where running a new utility feed might cut across fairways).

A power system that can optimise the input power to the site so it can run near capacity might be very useful! Especially if is a simple broadening of the capability of a "plain old" BTS power system. This system might delay or even negate the need for upgrading the utility feed.

Enatel's phase-balancing feature can do just that. Not only can it limit the input current to the BTS, but it can also respond to uneven phase loading (hence the name) – and respond quickly enough to prevent the incoming circuit breaker from tripping. With this "set & forget" feature, the operator need not worry about single-phase air conditioners overloading any one phase – even while the standby battery is in recharge mode after a power outage, the phase-balancing feature ensures the incoming circuit is never overloaded.

As a result, Enatel's phase balancing feature enables the telco to:

- Delay AC grid feed expansion/upgrade cost (possibly negate it)
- Speed up 5G deployment by not waiting for planning approval and grid upgrade to occur
- Cope with unbalanced single-phase air-conditioners
- Cope with input surge currents associated with air-conditioner motors
- Avoid the cost of installing soft-starters for air-conditioners

Phase Balancing on Off-Grid Sites

Many off-grid systems use generators to supply load, be they cyclic (hybrid) or non-cyclic systems. Unbalanced phase loading on these sites can be due to single-phase air-conditioners, unbalanced customer loading (multiple tenants) and/or single-phase rectifiers not deployed in multiples of 3.

Three-phase generators operating with unbalanced loads create a number of problems:

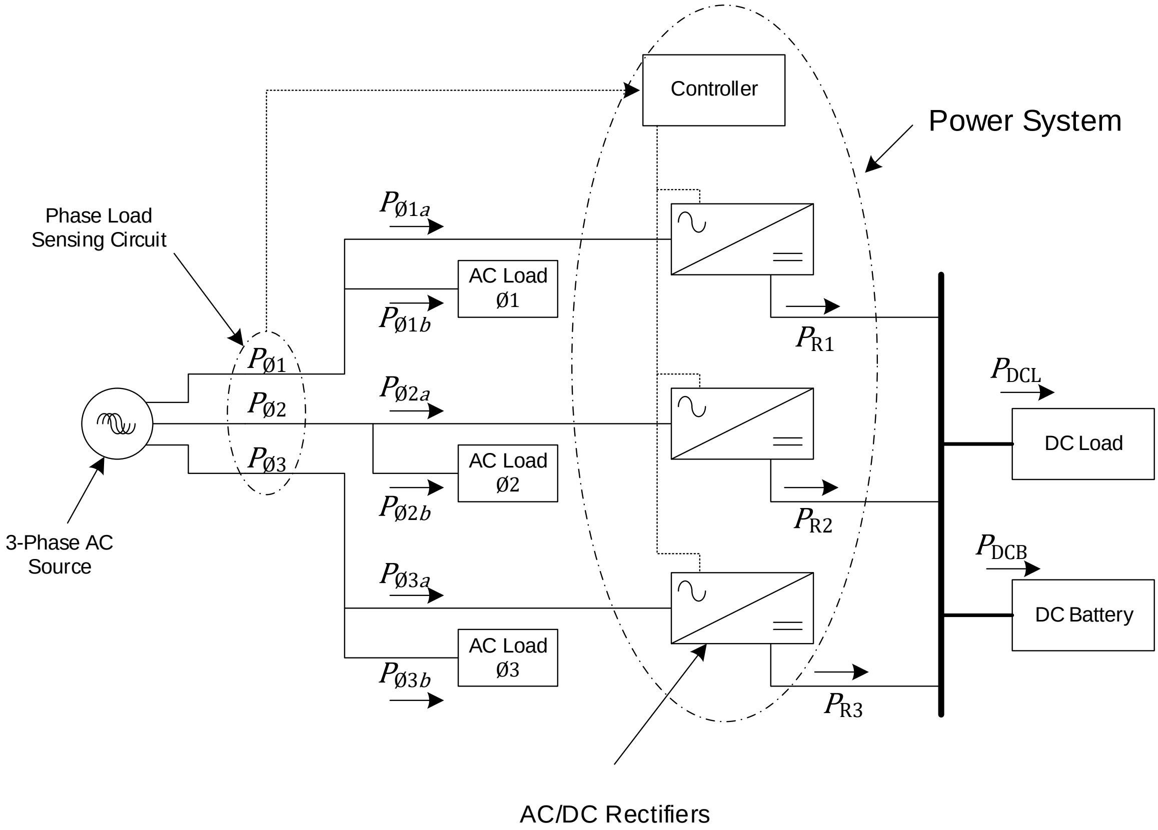
- Excessive rotor current heating.
- Excessive wear on bearings.
- Inability to operate the generator at optimum (or full) loads.
- Phase overload causes voltage collapse of that phase.
- High AC voltage in other phases.
- Generator internal shut-down upon detection of phase load imbalance.

Once again, Enatel's phase-balancing feature can overcome all of these problems. The system is physically no different to a "normal" 48Vdc power system using single-phase rectifiers, except for the addition of current transformers and an AC monitor card at the generator.

Implementation

The principal need to balance phases here is the requirement to present a balanced load at the source (generator or AC grid entry). Using the example where the imbalance is due to single-phase air-conditioning units, imbalance detection will be done via an AC Monitor connected at the grid entry with CTs.

The theoretical system setup and calculations are shown here:



The AC power paths can be represented by the following formulae:

$$P_T = P_{\emptyset 1} + P_{\emptyset 2} + P_{\emptyset 3}$$

$$P_T = P_{\emptyset 1a} + P_{\emptyset 1b} + P_{\emptyset 2a} + P_{\emptyset 2b} + P_{\emptyset 3a} + P_{\emptyset 3b}$$

Where:

P_T = Total AC Power as seen by the AC source.

$P_{\emptyset 1}, P_{\emptyset 2}, P_{\emptyset 3}$ = Total power presented to each phase of the AC source.

$P_{\emptyset 1}$ = Phase 1 AC load power presented by the Power System (similarly for phases 2 & 3).

$P_{\emptyset 1a}$ = Phase 1 AC load power presented by other loads than the Power System (similarly for phases 2 & 3).

$P_{\emptyset 1b}$ = Phase 1 AC load power presented by the Power System (similarly for phases 2 & 3).

The intention is that the Power System Controller can adjust its load phase-by-phase so that:

$$P_{\emptyset 1} = P_{\emptyset 2} = P_{\emptyset 3} = \frac{P_T}{3}$$

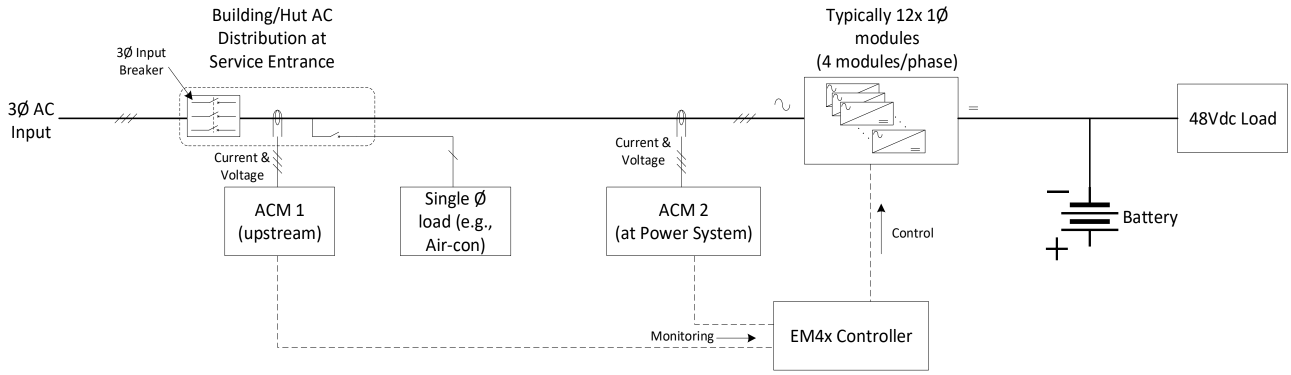
As the Power System Controller is measuring the AC Source power on each phase, measures the power into each of the Rectifier loads, and controls the output load balancing of the rectifier modules, the Controller can calculate $P_{\emptyset 1b}$, $P_{\emptyset 2b}$, & $P_{\emptyset 3b}$. As a result the controller can adjust the load power of Power System on each phase such that:

$$P_{\emptyset 1a} = \frac{P_T}{3} - P_{\emptyset 1b}$$

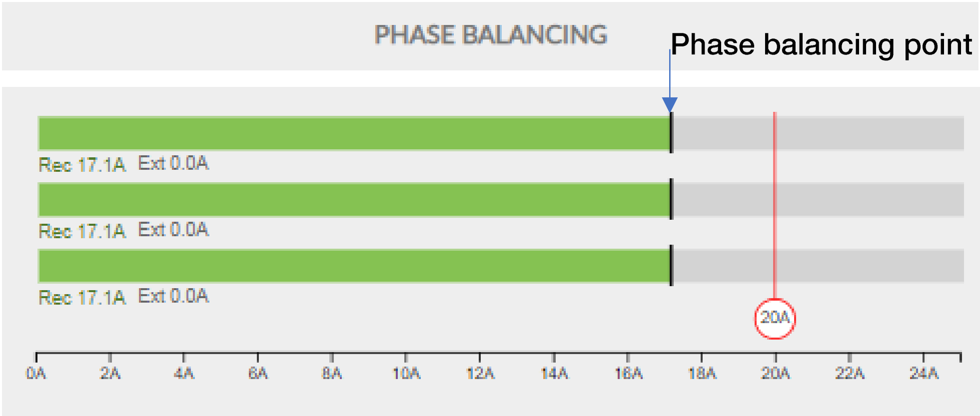
$$P_{\emptyset 2a} = \frac{P_T}{3} - P_{\emptyset 2b}$$

$$P_{\emptyset 3a} = \frac{P_T}{3} - P_{\emptyset 3b}$$

Practical implementation is shown here:

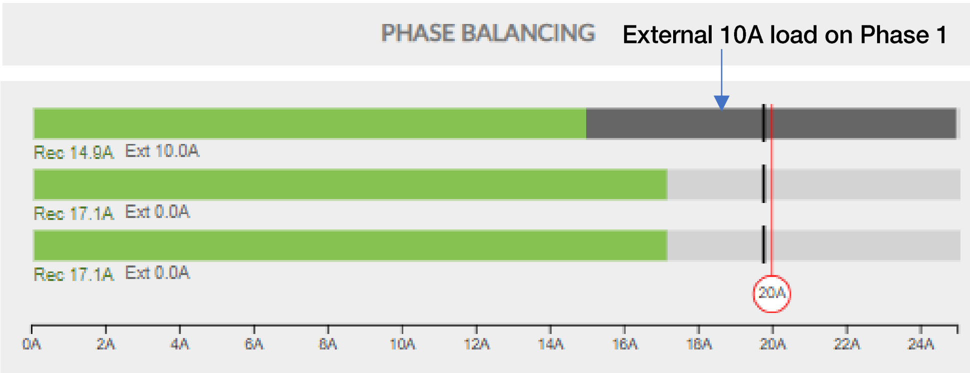


An inherently balanced system is shown here (a screen-shot from Enatel's EM4x Controller):



Where the AC input current to the rectifiers is 17.1A/ph (approximating a 12kWdc load). There is no "external" load, and the overall maximum current allowed is 20A. The balance point is shown by the solid dark line across each phase.

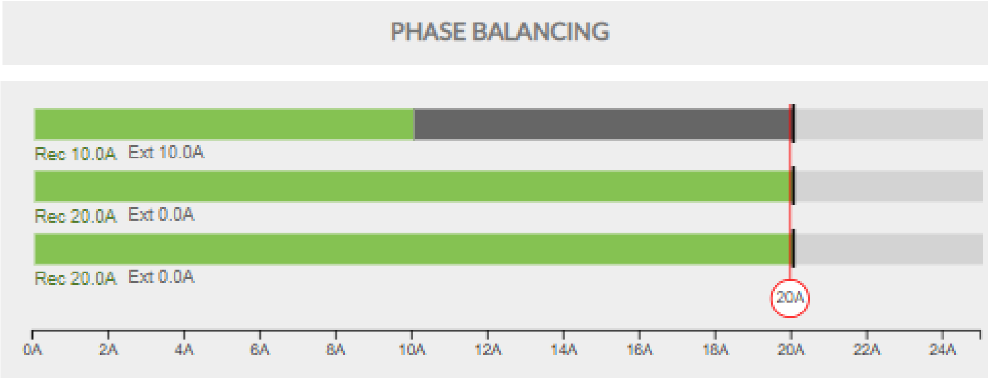
The following shows what happens when an external load of 10A is applied to phase 1. The moment an over-current is detected, the DC system will back off the DC load by reducing the output voltage. This may draw some load off the battery (depending on the magnitude and speed of response). In this example, Phase 1 is momentarily overloaded:



As the DC system starts to load the AC supply again, the rectifiers will be controlled by the monitor such that the phase currents are equalised.

After a few seconds the systems settles to a steady state where, in this case, the AC current is limited to 20A per phase. If the dc load cannot be sustained by the grid and rectifiers, the extra energy will be coming from the batteries.

A balanced system:



For the off-grid, AC generator systems, through use of the patented SYNERGi anti-stall & DGO optimisation feature, the overall power can be limited so as to avoid the generator stalling, whilst still providing a balanced load to the generator. Note that in this instance the battery recharge rate will be reduced (a completely benign event). In extreme circumstances, under adverse conditions, then the battery may be discharged while the “other” AC load is present. In this situation it is further possible to issue a control from the SYNERGi system to the “other” AC load to be either turned off, or only run for a limited time.