



SIZING A STANDBY GENERATOR

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SIZING A STANDBY GENERATING SET

In the **first** of this series of white papers, we look at how to select the correct rating for generating sets and why getting this right is so important from a financial and long-term operational point of view. We consider this from the point of view of the EN ISO 8528 standard and how that translates practically in a real-world situation.

Why are Standby Generators required?

The primary reason standby generators are included within the infrastructure of a building is to provide backup power to critical equipment or the entire building in the event of a prolonged utility failure. This utility failure can be anything from just a few seconds to hours or possibly days. The nature of the equipment being protected will often determine the operational period before refuelling the installation will be required.

The range and types of applications to which standby generators can be applied are manifold; these can be anything from

- An entire building or complex of buildings i.e. a data centre or a hospital
- In a specific area within a building i.e. critical IT equipment is often fed via a UPS
- Critical pumping or processing equipment i.e. water treatment works
- Life safety equipment i.e. sprinkler pumps, fireman's lift or fans to pressurise emergency evacuation stairs
- Chiller plant in a cold storage facility

All these different types of applications have their own specific set of operating requirements so this and the following white papers identify key things to be considered when sizing the generating set.



Selection Starting Point

The starting point of any design should be with the relevant product or application standard which in this case, it is **BS EN ISO 8528** which was updated in most part in 2018. As with any specification it only sets out the basic **minimum standards** the equipment needs to meet/performance too (some manufacturers exceed these) and frequently doesn't get updated quickly enough to ensure it keeps up to date in recognising more cutting-edge product developments. This for example could include new developments in engine performance, or market requirements hence it can look somewhat out of date even when newly published. I will give two examples by way of an illustration which we will look at in more detail in this series of white papers.

The standard does not require a generating set to be capable of achieving any specific level of first-step load acceptance as this capability is based on the Break Mean Effective Pressure (BMEP) that any particular engine can deliver. First step load acceptance is, in many cases, a key design performance requirement (e.g. pump starting).

Although having been improved and refined over many years many of the large engines used on generating sets have been in production for many years. Those that are of a newer design typically offer many advantages such as lower fuel consumption and hence lower emissions. Those improvements though can come at a cost, and this can be the first step load acceptance capability of the generating set.

Many design consultancy groups will have their own “standard specifications” for plant and equipment, and these will include the standby generating sets. Some of these documents don’t always reflect new product developments and technological innovation and hence fully reflect the impact and changes that come consequently. Such a document would typically consider a 60% first step to be the minimum requirement which can of course mean that more modern equipment can be excluded from consideration. Although a set fitted with a more modern engine may struggle to meet that 60% first step acceptance level when combined with modern Building Management or Energy Management Systems (BMS/EMS) with loads applied in a managed way the same performance can be achieved or even exceeded. Without taking this broader view the end user would risk losing out on the potential footprint reduction, fuel consumption and emission reductions and other benefits that could otherwise be available to him.

Power Rating Categories - BS ISO 8528 – 1; 2018 Section 14.3

For commercial reasons generating set manufacturers use the same engine (with model variations) across a range of power nodes/ratings. A single model of generating set can carry a number of different capacity ratings i.e. 1100kVA ESP, 1000kVA PRP and 700kVA COP (1) ; the set rating being dependant on the operational duty/type of loading applied to the generating set rather than the maximum engine capacity. The rating selection can therefore have a significant commercial impact on the overall capital and operational costs of a generating set package.

Section 14.3 of the standard covers the five different ways in which a generating set can be “rated” i.e. COP, PRP, ESP, LTP and DCP. Some of these ratings for example PRP (Prime) rated sets have their power ratings sets against the ability to deliver into a varying load and deliver an average load level over a 24-hour period whilst still being able to provide a 10% overload one hour in twelve. In the case of LTP and ESP rating, there is no overload capability but also a limitation on the number of running hours it can be operated over twelve months. It is important to note that how these ratings are allocated will vary from manufacturer to manufacturer based on engine performance, connected rating of alternator performance and maximum operating ambient temperature.

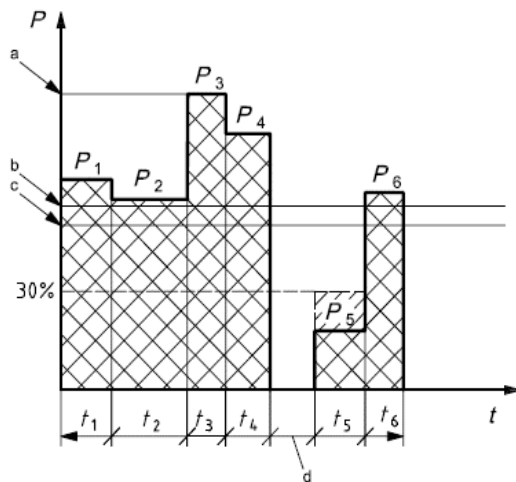
With this panoply of generating set capacities and rating options, it can be daunting for the design team to fix a clear course for this aspect of the design. For most European markets the grid is a very stable source of power, and it is very unlikely that power will be off for more than a few hours per year (testing included in this number) hence in theory an ESP-rated set should be an acceptable option, may those prefer the additional flexibility that the PRP option offers. Any of these ratings are valid but the final selection will be determined by and large by the type of application the set is to be used for.

One of the defining qualifications for the use of LTP or ESP (standby-rated) set is the maximum number of operating hours per year that the set is permitted to operate. Whilst the ISO standard sets minimum criteria the number of hours will be determined by the manufacturer and will typically be around 50 hours for LTP and vary between 250 and 400 hours per year. Given the reliability of the grid/mains supply, this may be considered to be more than adequate allowance.

Both the COP and PRP ratings permit the continuous running of the set (excluding maintenance downtime) within their defined operating parameters and for most applications, PRP is the preferred rating; one which offers maximum flexibility in operation.

Section 14.3.3 of the standard describes its operation as

“...being the maximum power which a generating set is capable of delivering continuously while supplying a variable electrical load when operated for an unlimited number of hours per year under the agreed operating conditions with the maintenance intervals and procedures being carried out as prescribed by the manufacturer.”



Key

t time
 P power

- a Prime Power (100 %).
- b Permissible average power during a 24 h period (P_{pp}).
- c Actual average power over a 24 h period (P_{pa}).
- d Stop.

NOTE $t_1 + t_2 + t_3 + \dots + t_n = 24 \text{ h}$.

Figure 1 – Illustration of PRP / Prime Rating (2)

This rating is probably the most widely used throughout the UK. This ranges from healthcare settings, life sciences, banking and most general commercial standby applications. The availability of a 10% overload for one hour in twelve is frequently seen as an important consideration and one which is heavily embedded in the NHS Technical Memoranda (HTM-06). The ability to run a generating set for extended periods without a running hours limit is of course also seen to be vital in a life-critical hospital environment.

Our consumption of data and use of web-based services has been growing rapidly for over 20 years now and it is critical to so many of our commercial and business activities making the loss of power to such infrastructure “no go territory”. Standards, some international and some privately generated, have been established to define some of those all-important design standards for the data centre environment. These standards include the various ways in which power is maintained in all aspects of this critical infrastructure be that IT or cooling. To that end some larger generating set/engine manufacturers have developed their own “Data Centre Power” rating ahead of such a rating being incorporated into the ISO standard.

In Western Europe, the grid will always be used as the “operational” source of power. This means that Data Centre Power (DCP) is the rating of generator most widely applied to generating sets used in this market sector with its operational duty cycle being defined as: -

“Data centre power is defined as being the maximum power which a generating set is capable of delivering while supplying a variable or continuous electrical load and during unlimited run hours.” (2)

The way in which manufacturers apply the COP and DCP ratings to their equipment will vary and does warrant investigation. It is dependent on the engine, the selected power mode, ambient operating temperature etc. some manufacturers use the ESP rating as their DCP rating, others use the PRP rating, and some add a further derating on the PRP rating. This selection can impact the footprint of the package, initial capital cost, engine fuel consumption and consequence emissions, PUE and general operational costs.

The Kohler KD range typically offers a match of DCP to ESP rating for European applications making it one of the most compact and cost-effective solutions on the market. (3)



Why getting this right is Important.

By way of an example to demonstrate how different ratings translate into the rating of a generating set we have used a Kohler-SDMO KD3500. This generating set carries an ESP/ standby rating of 3,500kVA, 2800kW which is the maximum output power that the set can deliver. Its PRP prime rating is 3,182 kVA, 2546kW so here we see that the prime rating can deliver a 10% overload and that takes us up to the 3500 kVA output level for one hour in 12 but an average not exceeding 75% of 3500kVA over 24 hours. If you want to run the set on a fixed non-varying load i.e. COP with for example an application of baseload or for peak lopping then set it cannot run at more than 2,380 kVA.

RATINGS 400 V - 50 Hz		
Standby	kVA	3500
	kWe	2800
Data Center / Mission Critical	kVA	3500
	kWe	2800
Prime	kVA	3182
	kWe	2546

All these ratings are for what is fundamentally the same generating set. There may on occasion be minor nuances, but it is fundamentally the same generating set, which carries different levels of rating depending on the application. Using the set outside of its design parameters can cause damage. So, when selecting a generator, understanding the application is critical in ensuring the generating set aligns with your specific loading requirements.

Do look out for our second white paper in this series continues to look at first-step load application in the context of the ISO standard and how to “right size” your generating set.

In the second of this series of white papers we look at generator “first step load acceptance”, and why getting this right is so important from a practical, operational and financial perspective. As with our previous white paper in this series, our starting point is with the EN ISO 8528 standard which was updated in most part in 2018.

Selection Starting Point

As with any standard EN ISO 8528 only sets out the basic **minimum standards** for the equipment (some manufacturers exceed these) and often doesn't move quickly enough in terms of recognising more cutting-edge product developments, for example in engine performance, or market requirements and can look somewhat out of date even when newly published.

The standard does not require a generating set to be capable of achieving any specific level of first step load acceptance as this capability is based on the Break Mean Effective Pressure (BMEP) that any particular engine can deliver. First step load acceptance is, in many cases, a key design performance requirement (e.g. pump starting).

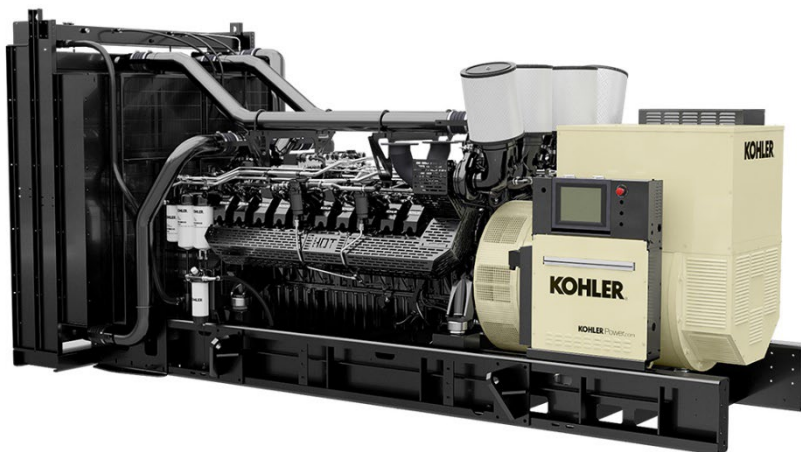
Although having been improved and refined over many years many of the large engines used on generating sets have been in production for many years. Those that are of a newer design typically offer many advantages such as lower fuel consumption and hence lower emissions. Those improvements though can come at a cost, and this can be the first step load acceptance capability of the generating set.

Many design consultancy groups will have their own “standard specifications” for plant and equipment, and these will include the standby generating sets. Some of these documents don't always reflect newer technologies and the changes that come as a consequence. Such a document would consider a 60% first step to be the minimum requirement which can of course mean that more modern equipment can be excluded from consideration.

First Step load Acceptance

What do we mean by the term “first step load acceptance”? Normally a building, a hospital, water treatment plant or data centre is running on the utility/mains supply. The standby generating set is in standby mode – the starting batteries are being charged and the jacket water heater is keeping the engine coolant and lubricant between 35 - 40C. Heating of the water jacket is necessary to enable rapid starting and load acceptance. The dynamic performance of the engine is somewhat different once under load and up to optimal operating temperature.

As we know the generating set is made up of several key components; to keep it simple the key components are the engine and cooling package, the alternator and the generating set control system.



Both the engine and alternator react to the application and rejection of an electrical load in different ways, so it is the generator control system which manages the two elements to ensure they work in a coordinated way. When we apply an electrical load to the alternator of a generating set, the load acts as a break on the entire system but the impact on each of the key elements is different however as they are connected on a common shaft the effects overlap.

For 50 Hz operation the engine is set to run at 1500RPM and when coupled to a 4-pole alternator provides an output of 50Hz (1800RPM for 60Hz output).

From a mechanical perspective, the application of a load to the alternator has the instantaneous effect of reducing the speed of the shaft and hence the engine. The control system responds to this by increasing the flow of fuel to ensure the engine returns to nominal speed as quickly as possible. This reduction in shaft speed is reflected in the alternator by a reduction in the frequency at the output terminals of the alternator (See Fig 1). The time it takes for the shaft speed and hence output frequency to recover depends on the size of the load applied i.e. how much inertial is drained from the system.

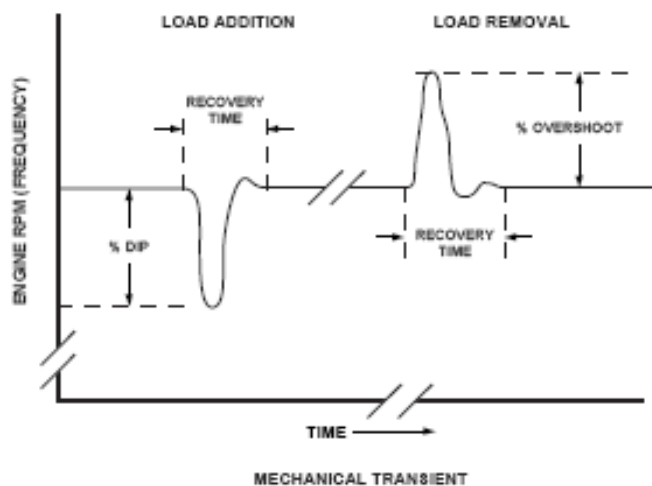


Figure 1 - Mechanical Transient Response (1)

- From an electrical perspective, the application of load to the alternator will have the effect of momentarily reducing the voltage at the output terminals. The Automatic Voltage Regulator (AVR) of the alternator will recognise this change and work quickly to ensure the output voltage is returned to its nominal state as quickly as possible. It can also be seen that when the load is removed, the shaft speed will momentarily increase impacting the output frequency of the set. The voltage likewise will also momentarily increase.

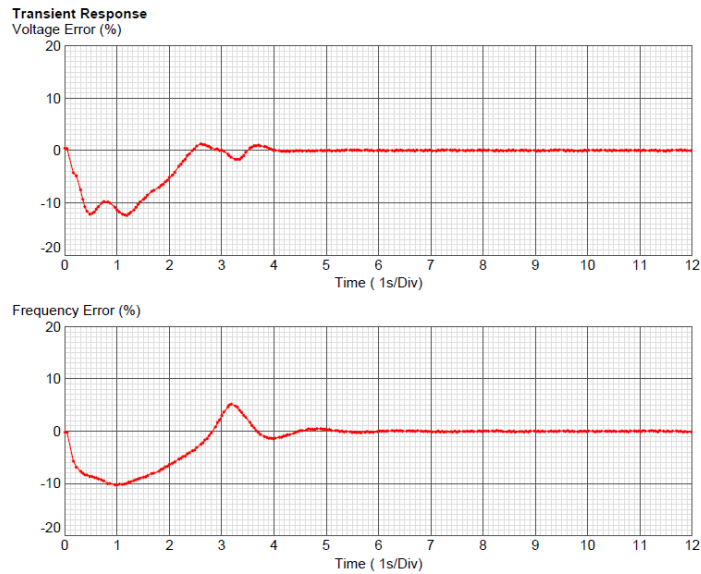


Figure 2 – Electrical Transient Response (Voltage and Frequency reduction under first step transient load application conditions)

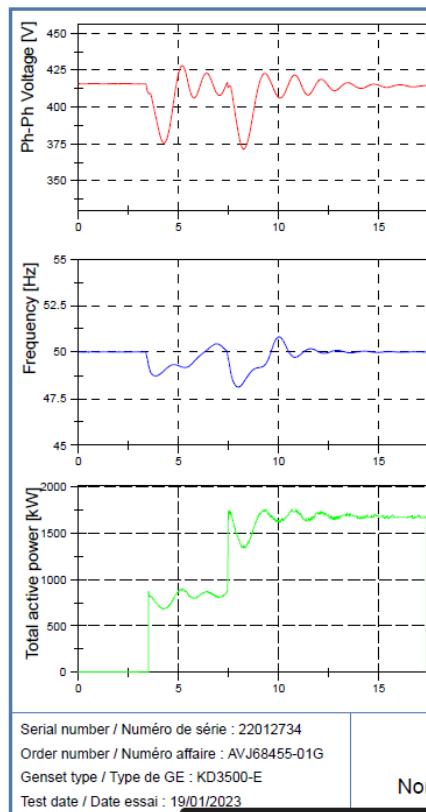


Figure 3 – Application of load using multiple load application method (two steps in this case)

Figure 2 below shows the effect of a 60% first-step load application on the output of a generating set in terms of reduction in both output voltage and frequency. Additionally, you will note the time taken for both the voltage and frequency to return to steady-state nominal conditions.

The ISO standard clearly defines the level of permitted voltage and frequency excursions and the associated recovery times under transient load application/rejection conditions under four different “governing classifications” G1 to G4. A general summary of these is shown in **Figure 3**.

	Class G1	Class G2	Class G3	Class G4
Frequency % Acceptance	–15	–10	–7	AMC
Frequency % Rejection	18	12	10	AMC
Voltage % Acceptance	–25	–20	–15	AMC
Voltage % Rejection	35	25	20	AMC
Time Seconds	5	5	3	AMC

Figure 4 – Load Application and Rejection Summary and associated Governing Classifications

We identified earlier that the BS ISO standard does not require the generating set to achieve any specific level of first step load acceptance as this is determined by the BMEP that the engine is able to deliver. Hence there is a wide variation between manufacturers and the engines used at various power nodes.

60% first step load acceptance for “any rating” of generating set has for a long time been considered to be an “industry norm” and is often written into many “standard” consultant specifications without specific regard to the actual operating requirements of the infrastructure or being qualified with the essential performance classification (G1-G4). The absence of this clarification leaves this open to interpretation.

The design of many of the larger engines (1500kVA +) used on the larger generating sets in healthcare, water treatment or particularly in hyperscale data centres have been in use for a very long time. Whilst they have been enhanced and improved over time (more electronic engine management, improvements in the combustion process, high pressure fuel injection, improved materials etc) but there are few truly “new” engines. Those that are, typically offer lower fuel consumption hence lower emissions, more compact footprint i.e., higher power density. etc. Those improvements though can come at a cost, and this can be the first step load acceptance capability of the generating set. Whilst these advancements are accepted within the standard the “industry norms” often do not keep pace with nor understand the changes nor embrace the advantages that they bring. This is often the case when we look at the data centre environment.

Governing Standards / Performance Class ISO 8528-1: 2018 - 8

The standard lays out four performance classes G1-G4 with G4 being the most onerous. In simple terms, the performance classes set out the maximum voltage and frequency deviations permitted on the application of a first set load and the time over which the generating set needs to return to a steady state condition and other operational considerations. It is in this area where it is the author's view that the standard, whilst seeking to provide an all-embracing minimum standard, is failing to keep up with product development.

With the harmonisation of standards across Europe, and to a lesser extent globally, the performance of electrical equipment generally has improved significantly, particularly concerning the efficient use of energy and reduction of reinjected waveform distorting harmonics prevalent in nonlinear devices of yesteryear. Such devices being the primary loads of any data centre such as UPS and inverter / soft start drives.

Class G2:

"This applies to generating set applications where its voltage characteristics are very similar to those for the commercial public utility electrical power system with which it operates. When load changes occur, there can be temporary but acceptable deviations of voltage and frequency." (1)

Class G3: speaks more about the "connected equipment making more severe demands on the stability and level of the frequency, voltage and waveform characteristics" and then sites examples such as Telecommunications and thyristor-controlled loads. Both rectifier and thyristor-controlled loads can need special consideration with respect to their effect on generator-voltage waveform" (1)

Class G4 similarly refers to "Data-processing equipment or computer systems" (1) as its examples.

It should be noted that all generating sets built to the ISO standard can offer a level of performance to all of the varying governing classifications (G1-G4) the only thing that changes is what that first step level is. By way of an example, a set capable of achieving 60% first step at G2 would say achieve 45% G3.

For the vast majority of applications then, G2 would be the optimum selection. You will note that the standard talks about "data processing equipment...." requiring a G3 or G4 solution; this is in the author's view an outdated element within the standard. Today most business / operationally critical equipment is protected by a UPS system. The UPS smooths the mains supply and maintains it within its specified voltage and frequency limits whilst at the same time isolating critical equipment from either the mains or generator source.

The only possible exception to this is if the client ever plans to run ICT equipment on the generator with the UPS in bypass or offline. There are other considerations if this is the case such as the risk of an overall leading power factor etc.

Break Mean Effective Pressure

Section five of ISO 8528 does not set out any specific level of first step load acceptance that any generating set must achieve. The first step load acceptance can achieve is predicated against the brake mean effective pressure that the engine can deliver. In layman's terms, that is the amount of torque that the engine can put into the shaft to which the alternator is connected. So, it is not a prescribed amount, so this varies from engine to engine and from manufacturer to manufacturer.

The reason for this is purely a commercial one. To make economic sense of generator ratings, manufacturers need to use the same engine on several different power nodes. So, for example, the engine that is used on a 1000 kVA generating could also be used on the 1250 kVA generating set, and so on.

The ability of that engine to respond to first step load acceptance is contingent on where it is used in relation to its maximum capacity and to the overall loading on the generating set. Using my earlier example, the 1000 kVA set would be able to accept a larger first step load than say the 1250kVA would be able to accept. This is because it is fundamentally the same engine, although its engine has been mapped differently and it is coupled to a larger capacity alternator with a slightly higher rotating mass and hence inertia. This is something that should always be validated on a product and project specific.

Load Acceptance in Mission Critical Environments

Each building and each type of application will have its own unique set of loads and hence starting and load management requirements. In some buildings the generator will only be sized for part of the building load in others it is a hospital or a data centre it will be the entire building. By way of a straightforward and uncomplicated example, we will take a large data centre where the electrical load is typically spilt into UPS and Cooling load.



A UPS system looks for stability of the input supply be it mains or generating set. When returning from battery supply to either mains or generator the UPS's input power requirements slowly ramps in over a period of 5-10 seconds (or longer), not in one single "lump" of load. Fig 5 shows the input current (blue trace) of a UPS transferring from battery supply to mains supply following a mains failure. In this case, the transfer occurs gradually over a 15sec period.

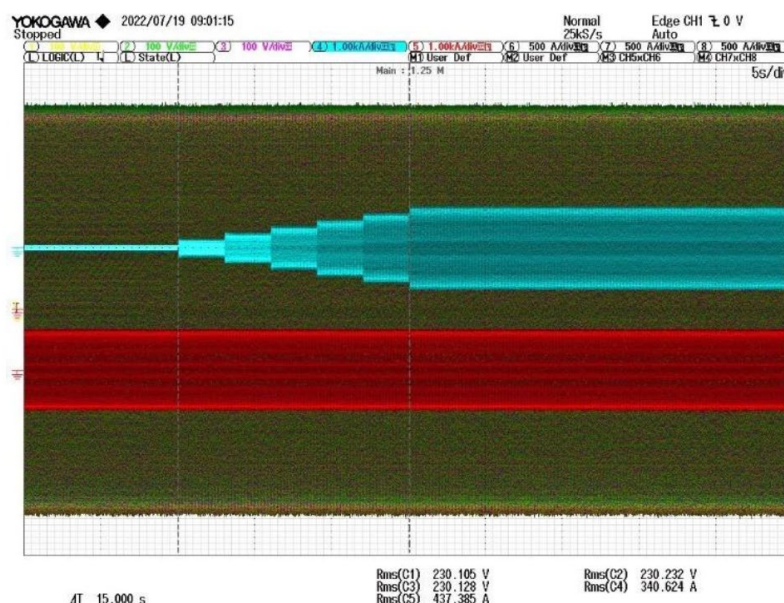


Figure 5 – UPS - Main input current characteristic

The cooling system has a UPS equivalent i.e., a buffer or reservoir vessel of cooling water which can maintain water temperatures within range for around 30 seconds. This buffer vessel is there to provide time for the generators to start and pick up the cooling / mechanical loads essential for the operation of the data centre. Some of the compressors and pumps within this system can be significant in size and can present some quite large load steps to the system; this though should have been catered for in the design.

A UPS typically doesn't know if it is being fed by mains or generating set; what it looks for is the stability of voltage and frequency that fall within its input supply design criteria. If the mains has failed and the generator supply is made available, the UPS will wait for a short period to ensure supply stability, the rectifier will be switched on and steadily ramp up the power being drawn from the input source after which there is a seamless transfer from battery supply to either mains or generator. This is what we call a walk-in or 'ramp'. Generators typically love this style of load application because it is a gentle increase in load, it does not represent a specific level of load step, it is a perfect way of applying a load and hence does not need to be considered a part of that first step load.

The other key load is the cooling plant. By its nature is very lumpy and hence depends on the type of input and switching methodology that is used which will determine how much of a load step this represents. However, the cooling can be staged on. In an ideal scenario, with a data centre cooling there is typically between 30 seconds and one minute to get the cooling back on. The generating set accepts the UPS load following which the cooling load can be added. As the engine is already under load then cooling load, it is then no longer "the first step", so the set is in a much stronger position to accept larger loads.

In the scenario described neither load is a real "first step load" application.

Most, but not all, new buildings ie hospitals, data centres etc have sophisticated Building and Energy management systems (BMS /EMS) either or both. The key points here are that these loads:

- Can and will be managed by the BMS/EMS in a controlled way
- When these loads are applied the generating set will already be "under load" meaning that the application of the cooling load "isn't a first-step load"

This means that the generator(s) never get close to seeing anything approaching a 60% load step negating the need for this measure and the associated G3 requirements that accompany them.

Right sizing your generating set

One of the key considerations when selecting an appropriate rating of a generating set is "first step load acceptance"; the generating sets ability to respond under mains failure conditions.

Now we are looking at the application to which the generating set is being placed. Typically, one of the unknown factors with many projects is what the building load will look like; something particularly true at the early project definition stages. To help break this down it is important to understand the methodologies with which load will be applied to the generating set.

In a lot of cases, the perceived wisdom is that the moment the generator breaker closes the entirety of the building load will be presented to the generating set. If the running load is above 60% of the generating set capacity, which is an ideal scenario then the generating set won't be able to take on its first step load acceptance which is typically around 60% of full load. A good analysis of the load will indicate that depending on the mix of the equipment that is being fed by the generating set, this may not necessarily be the case. With the utilisation of a good building management system, we can phase in the load on a staged basis rather than "all coming online" the moment the generator breaker/ contactor closes. Here we can

consider the example of the data centre outline above where the UPS is a “walk in/ramp load” and the cooling load is also staged back online.

Using this approach whilst first-step load requirements must still be considered in the design process it is likely that the rating of the set can be more closely matched to the running load rather than the “first step” load.

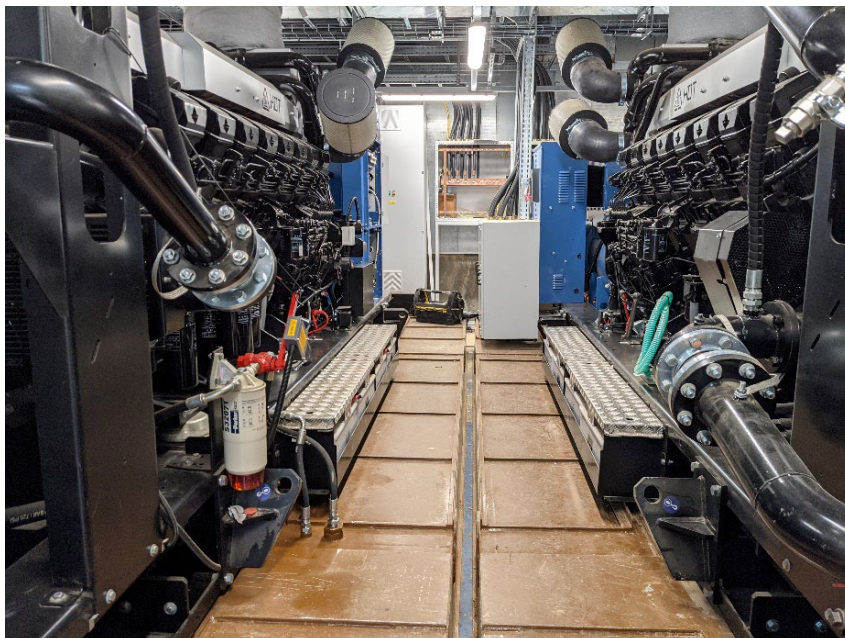
Summary

In this and our earlier paper on “sizing a generating set,” we have looked at some of the key dynamic performance criteria in the design of a generating set as set out in BS EN ISO8528. Considering the following things, the over sizing pitfalls of the past can be avoided:

- Selecting the correct rating for the set for the application i.e. PRP/ESP etc
- Understanding the set duty cycle
- The correct choice of governing classification
- Not only focusing on the first step load application
- Identifying the running load
- Methods of managing load application

Specifying a generator with an over-engineered first load step requirement will almost invariably result in an oversized generating set. Oversizing of the set itself not only increases the capital cost of the generator itself but also adds significantly to other installation costs such as: -

- Acoustic treatment be it attenuation or container (increasing footprint of package)
- Larger fuel system
- Emissions treatment and exhaust package
- Higher fuel costs
- Maintenance and general running cost
- Switchgear
- Cable installation



Generators oversized against their running load also run less efficiently and typically never achieve the correct operating temperature to ensure as complete a combustion process as possible. In turn, this makes the generator prone to maintenance and reliability issues linked with light load running (slobber) and will invariably result in both higher emissions and maintenance costs.

Many of the top generator manufacturers including Kohler have software programmes available to help the consultant and contractor with sizing their generator solutions.

Acknowledgements, Clarification, References and Bibliography.

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- (1) BS ISO 8528-1: 2018 sets out the minimum requirements which in the case of the COP rating is 70% of the PRIME rating. The actual rating will depend on the engine selected and engine manufacturer. The case of the Kohler KD range the COP rating is a minimum of 75% of the PRIME rating.
- (2) In this case the rating in BS ISO 8528 hasn't kept up with developments in the marketplace.
- (3) The engine configuration and much higher power output capacity per cylinder of the Kohler engine when compared to other engines means that the number of cylinders used is less making the engine much shorter. For example, the Perkins powered FG Wilson P2500 (2500kVA ESP / 2250kVA PRP / DCP 2250kVA) set has a V16 configuration. The equivalent Kohler engine, the KD2500 (2500kVA ESP/2250kVA PRP/2500kVA DCP) offers this power in a 12 cylinder format. The 12-cylinder format is used through to the KD2800. The philosophy of high-power output per cylinder continues through the range right up to the KD4500
- (4) Figure 5 - KUP - Kohler UPS
- (5) Figure 2 & 3 - Kohler Power Systems - France

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Geoff Halliday started his career as an apprentice working for Square D (later part of Schneider) before moving into the critical power sector where he has now worked for over 40 years, splitting that time equally between both the UPS and standby diesel generation sectors.

During this period Geoff has held several roles ranging from Customer Service Engineer, Project Manager, Technical Director, Sales Director through to Managing Director.

The Critical Power market exposes the individual to a wide and diverse range of market sectors ranging Health Care, Life Science, Water Treatment, Banking and Finance, Military, Manufacturing, Process Control through to Data Centres of all sizes. Drawing on his management skills, product knowledge and vast application experience amassed throughout his career Geoff now enjoys sharing his knowledge with others.