

UPS-Genset Compatibility

THE UNINTERRUPTIBLE POWER PROVIDER



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Abstract

UPSs (Uninterruptible Power Supply) and generator sets are frequently combined to supply continuous power to sensitive applications such as computers, telecommunication centres, industrial processes, hospitals, airports, etc. These two types of equipment offer complementary functions for the supply of critical loads.

A UPS provides quality power and isolates loads from upstream disturbances, in addition to supplying battery backup power that can last from a few minutes up to several hours. Beyond the battery backup time, the genset steps in to provide long protection.

Note however that a number of operating constraints weigh on gensets (start-up time, regulation, minimum operating times, etc.), in addition to installation and maintenance costs (fuel storage, special room, servicing, etc.).

What is more, use with a UPS involves a number of technical aspects that must be examined to ensure correct operation of the assembly.

To ensure cost-effective operation, the UPS-genset combination must be designed to ensure optimum economic conditions and compatibility of the technical characteristics.

This article examines the various points involved in determining the optimum combination in terms of purchase and operating costs.

UPSs and gensets in high-availability installations

The combination of a UPS (Uninterruptible Power Supply) and a generator set is an increasingly frequent solution used to supply sensitive loads such as computers, telecommunication centres, industrial processes, hospitals, airports, etc. These two types of equipment offer complementary functions for the supply of critical loads.

A UPS uses the double-conversion technique (rectifier/charger and inverter) to provide quality power and isolate loads from upstream disturbances. It also supplies battery backup power that can last from a few minutes up to several hours.

However, the longer the necessary backup time, the larger the battery installation, with the corresponding servicing requirements. For this reason, gensets are used to reduce the size of the battery in installations requiring long backup times. In the event of a prolonged utility power outage, the genset is started to supply the UPS before battery power runs out.

Note however that a number of operating constraints weigh on gensets (start-up time, regulation, minimum operating times, etc.), in addition to installation and maintenance costs (fuel storage, special room, servicing, etc.).

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To ensure cost-effective operation, the UPS-genset combination must be designed to ensure optimum economic conditions and compatibility of the technical characteristics.

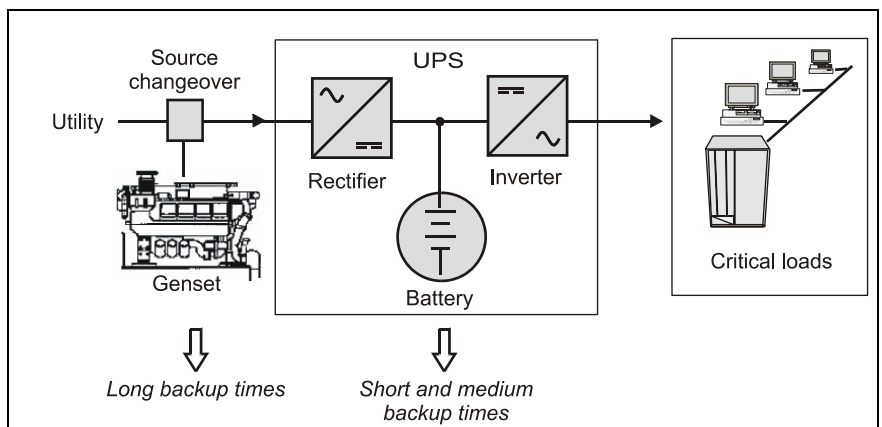


Fig. 1. UPS-genset complementarity.

UPS-genset compatibility

The purpose of this article is to examine the major technical and economic aspects that must be taken into account when setting up a UPS-genset combination.

On the basis of the discussion, a number of practical recommendations are provided for those who are interested in this solution.

Key points for a UPS-genset combination

UPS-genset combination

Figure 2 presents the classic diagram for a UPS-genset combination. It shows a double-conversion UPS as per international standard IEC 62040-3, the only topology suitable for the required power and performance levels.

The main criteria determining the compatibility of this combination are listed below.

- ▶ **UPS backup time**, given the constraints imposed by the genset.
- ▶ **Rated power values** of the genset (P_g) and the UPS (P_n), taking into account any harmonic currents drawn by the rectifier/charger.
- ▶ **Harmonic currents** drawn by the rectifier/charger and their effect on current distortion (THDI) at the UPS input and on voltage distortion (THDU) on the upstream busbars.
- ▶ **Genset start time**, i.e. the actual start time plus the time required to ramp up to full power, before the load is transferred.
- ▶ **Capacitive currents** (if any), at start-up, due to the harmonics filter at the UPS input, depending on the type of filter used.
- ▶ **Genset frequency stability** depending on regulation performance.
- ▶ **Discrimination** and the behaviour of the combination if a short-circuit occurs downstream.

The following discussion deals with the above points, keeping in mind economic factors in view of selecting the optimum combination in terms of the purchase and operating costs.

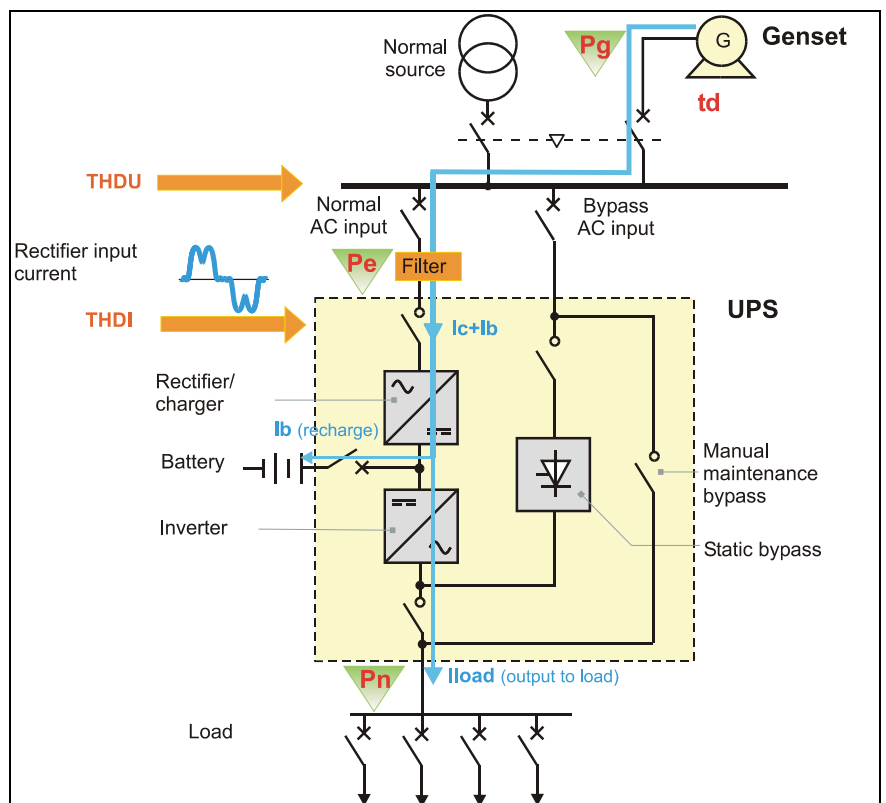


Fig.2. Operating characteristics that must be taken into account when designing a UPS-genset combination.

Key points for a UPS-genset combination (cont.)

UPS backup time

When should a genset be used?

The decision to use a genset depends on the quality of the utility distribution system, economic and/or safety risks inherent to the protected application and a cost comparison of different solutions, with or without a genset.

For each of these points, the following aspects must be considered.

▶ Quality of the utility distribution system - risks of downgraded voltage quality (due to other users causing disturbances, climatic conditions, etc.) that can result in repeated use of battery power and a reduction in the actual backup time available.

▶ Risks of extended outages - what guarantees does the utility provide and what backup means does it have at its disposal?

▶ Economic and/or safety risks involved - how critical are the protected applications and what is the cost of down time?

▶ Cost comparison between a solution with a battery and a solution with a genset. The analysis must take into account the power ratings, any possible load shedding, the available space, operating constraints (special rooms, noise, etc.).

☞ Practically speaking, gensets are useful for long backup times when the application requires at least 30 minutes to one hour or longer.

UPS backup time when a genset is installed

When a genset is available, UPS backup time must take into account the constraints weighing on the genset and the battery.

Genset constraints

▶ A genset must operate a minimum amount of time (at least 15 minutes) to avoid excessive wear, it must be started only when necessary.

▶ A normal genset requires approximately two minutes to start and ramp up to the point where the temperature is stable.

This process includes the following:

- the diesel motor driving the generator must start and reach its rated speed (eight to ten seconds),

- the motor and the generator must ramp up to full power (12 to 15 seconds),

- the operating temperature must stabilise (more than one minute).

▶ A genset may not start on the first try and may stall during the ramp-up period.

▶ A genset combined with a UPS must not start until approximately three minutes after utility power has been lost:

- to provide the distribution-system automatic devices (reclosers, etc.) with the time required to restore power, if possible,

- to avoid frequent and unnecessary starting of the genset.

Battery constraints

▶ The battery must enable continued operation over a time that is not:

- too short with respect to the backup time required by the application, in order not to underuse the battery and risk starting the genset too often,

- too close to the total battery backup time, in order to leave enough time for the genset to start and ramp up before the end of battery power.

▶ UPS batteries have standard backup times of five to ten minutes, at a very reasonable cost in terms of installation and operation.

Key points for a UPS-genset combination (cont.)

Conclusion

☞ Practically speaking, a backup time of ten minutes is well suited to gensets. It corresponds to a cost-effective, standard solution that ensures optimum use of the battery itself and the genset.

A ten-minute backup time provides:

- ▶ three minutes for the distribution-system automatic devices to work, after which it is clearly necessary to start the genset,
- ▶ two minutes for genset start, ramp up and temperature stabilisation,
- ▶ a margin to allow for a second genset start, if necessary,
- ▶ a second margin to take into account the real battery backup time (battery ageing, recharging due to a previous outage, etc.).

Rated power values

Factors in calculating power values

Selection of the respective power values must take into account the factors presented below.

UPS input current when charging the battery

Genset rated power must be sufficient to supply the UPS when the rectifier-charger is both supplying the load (I_{load} current) and recharging the battery (I_b current) (see fig. 2). This is the situation when the genset starts to supply the UPS, i.e. approximately three minutes after the beginning of the power outage, when the battery is partially discharged.

Possible harmonics and harmonic filter at the UPS input

To supply the inverter with DC current, the UPS is equipped with an SCR-based rectifier that draws harmonics which distort the sinusoidal waveform of the input current (see fig. 3) and the upstream voltage.

Distortion is measured as Total Harmonic Distortion (THD):

$$THD\% = (\text{rms value of all harmonics}) / (\text{rms value of the fundamental}) \quad \text{in } \%$$

Depending on whether current or voltage distortion is measured, the terms used are:

- ▶ THDI where I stands for current,
- ▶ THDU where U stands for voltage.

To eliminate the harmonic currents, UPSs are equipped with:

- ▶ either an input filter, which can be:
 - a passive LC filter, compensated or non-compensated, with or without a contactor,
 - a double-bridge or phase-shifting filter (harmonic recombination),
 - an active filter, derived from active harmonic conditioners.

These filters reduce distortion from approximately 30% to less than 5%.

- ▶ or a "clean" rectifier of the PFC (Power Factor Correction using control electronics) type that does not draw harmonics.

In this case (without a filter), THDI drops to under 3%.

Both solutions meet the requirements of standard IEC / EN 61000-3-4 for low-voltage devices drawing less than 16 A, i.e.:

- ▶ THDI < 5% at the UPS input,
- ▶ THDU = 5% on the upstream busbars,
- ▶ no individual harmonic order higher than 5%.

Key points for a UPS-genset combination (cont.)

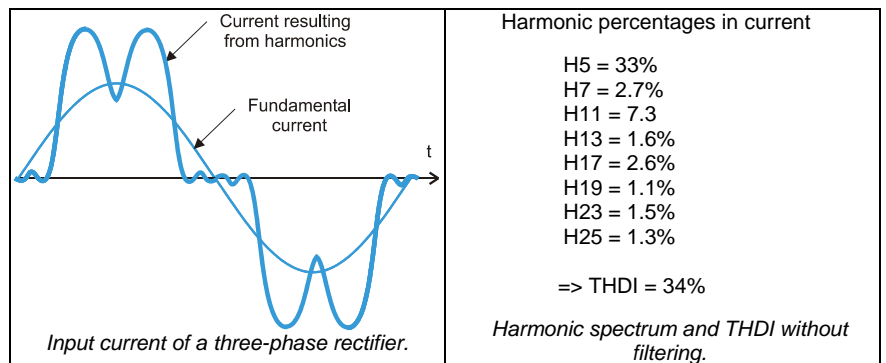


Fig. 3. Current drawn by an SCR rectifier.

Behaviour of a genset with harmonics

The genset generator is designed to supply linear loads.

The presence of harmonics makes it necessary to take action to ensure compatibility, due to the possible repercussions on the genset.

► Regulation difficulties. The distortion increases the rms value of the output voltage and thus disturbs genset regulation, which is based on the rms value of sinusoidal voltage. What is more, the high time constant of the flux variations in the windings makes corrections difficult.

► Temperature rise in generator winding because the harmonics increase the rms current.

► Amplification of the harmonics (1) with a number of consequences:

- an increase in voltage distortion (THDU, normally limited to 5%) on the upstream busbars during operation on genset power,
- a reduction in the input power factor (< 0.8).

(1) The subtransient reactance X''_d of a generator is approximately 10 to 12%, compared to 3 or 4% for the short-circuit voltage of a transformer. In other words, the output impedance of a genset is 2 to 4 times higher than that of a transformer. Each harmonic order k , a sinusoidal current k times the fundamental frequency, is amplified compared to normal operation on utility power with the output impedance of the transformer.

What are the possible solutions?

Oversize the genset

A classic solution to avoid the effects of harmonics is to oversize the genset. The power rating is 1.5 to 2 times greater than that of the UPS. This increase in power makes it possible to handle the temperature rise in coils, to ensure correct regulation and to obtain a higher output impedance.

It also means significantly higher initial and maintenance costs, even if only the generator is oversized.

Reduce the level of harmonics drawn by the UPS

A much more effective and less costly solution consists in selecting a modern UPS designed to reduce the level of harmonics drawn by the rectifier. This is possible using either:

► a built-in active filter optimised for the UPS power rating and input rectifier. This type of filter eliminates a large part of the harmonic spectrum and reduces the THDI to less than 3%,

► a clean PFC (Power Factor Correction) rectifier that draws a sinusoidal signal. The residual THDI is less than 2%.

These techniques, which virtually cut distortion in half with respect to the 5% recommended by the applicable standards, ensure excellent operating compatibility with the genset, whose power rating does not need to be oversized with respect to the UPS power rating.

Key points for a UPS-genset combination (cont.)

Conclusion

- ☞ Choose a UPS equipped with a built-in active filter or a PFC rectifier (drawing a sinusoidal signal) to avoid the negative effects of harmonics on a genset and the need to oversize the generator.
- ☞ The increase in cost is much less than that for genset oversizing.
- ☞ Make sure the genset power rating can also handle battery charging at genset start (see the example below).

Example

This example presents how to calculate the genset power rating, assuming that appropriate filtering is installed (active or PFC) and that load-shedding is not an option.

The rated power P_n (kVA) of a UPS is the maximum output power given an output power factor of 0.8. It is necessary to calculate the corresponding input power to determine the genset power rating.

A 100 kVA UPS supplies the load with a maximum output power of $100 \times 0.8 = 80$ kW.

Given UPS efficiency and the current required to charge the battery, the input power is greater than the output value.

For example, if the increase is 18% (value supplied by the manufacturer), the necessary input power is $P_e = 80 \times 1.18 = 94.4$ kW.

The genset must be sized to supply power P_g such that:

► if the input power factor is 0.8, then $P_g > 94.4 / 0.8 = 118$ kVA. In this case where both the input and output power factors are equal to 0.8, it is possible to calculate the result as $100 \text{ kVA} \times 1.18 = 118$ kVA.

► if the UPS has a PFC rectifier with a power factor close to 1 (> 0.95), then $P_g > 94.4 / 0.95 = 99.3$ kVA.

Genset start-up

Genset ramp-up

The genset cannot immediately supply the full power rating. It goes through a start-up phase before reaching steady-state conditions when it can supply the full rated load. The start-up phase lasts 5 to 10 seconds. The inrush current of the rectifier/charger must be regulated to avoid damaging the genset or stalling it during start-up.

- ☞ That is why high-performance UPSs have a time-delay function with a walk-in for the rectifier/charger (see fig. 4).

What is more, when utility power returns, the rectifier/charger can be gradually shut down (auxiliary contact) to avoid disturbing any other loads connected to the same busbars.

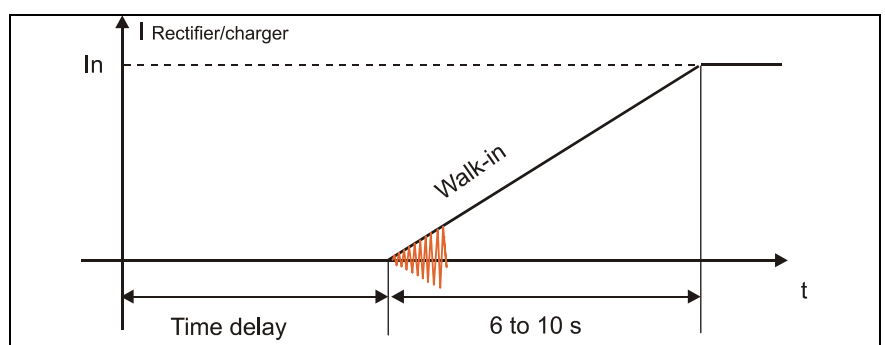


Fig. 4. UPS rectifier/charger input current during genset start-up.

Key points for a UPS-genset combination (cont.)

Capacitive currents

Genset start-up on an LC filter

A generator can supply only limited capacitive current (10 to 30% of I_n). This may cause problems if the UPS is equipped with an LC harmonics filter. The difficulty lies in the gradual start of the rectifier/charger on genset power, a time when the active power is equal to zero and the generator supplies only the capacitive current of the filter.

- ☞ Use of LC filters must be designed to ensure that operation remains within manufacturer specifications.
- ☞ Compensated LC filters or those with a contactor solve the problem.
- ☞ For THM and active 12-pulse filters or UPSs with a PFC rectifier, there are no compatibility problems.

There are a number of possibilities, depending on the type of filter.

LC filters

► Non-compensated

The LC circuit is tuned ($LC\omega^2 = 1$) to the most important harmonic order (IH5). This basic filter is not suitable if the genset cannot accept a capacitive current equal to 30% of the rectifier current. In this case, it is necessary to use the derating curves supplied by the generator manufacturer.

► Compensated

This filter has an extra inductor, in parallel with the capacitor, which reduces the capacitive energy that the genset must supply during start-up and under steady-state conditions.

► Non-compensated with contactor

This filter has a contactor to connect the LC line starting at a UPS percent load that is acceptable for the genset. It is suitable for installations with a genset that has a limited power rating with respect to the load.

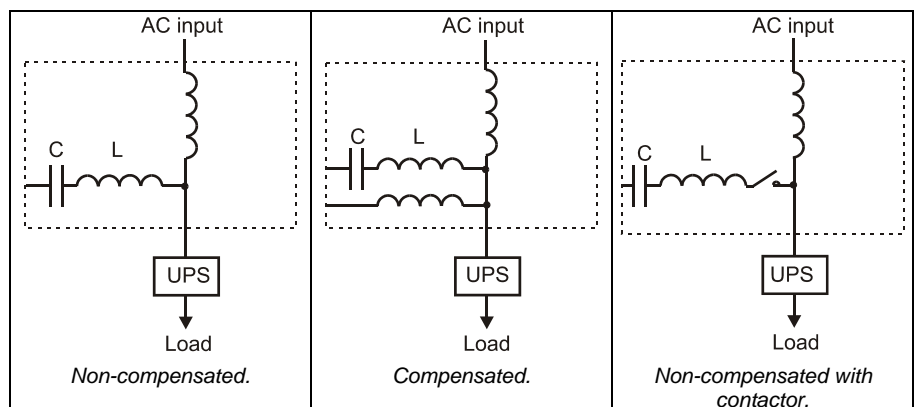


Fig. 5. The three types of LC filter.

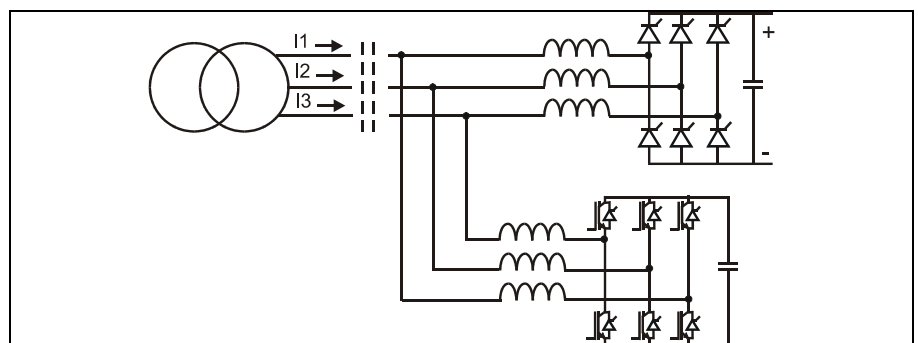


Fig. 6. Active 12-pulse filter.

Key points for a UPS-genset combination (cont.)

Genset frequency stability

The need for a double-conversion UPS

The genset has a diesel motor that drives the generator. The motor speed regulation system, which determines the frequency of the generator voltage, is not instantaneous.

As a result, the genset is sensitive to major load step changes which modify the speed of the diesel motor and consequently the frequency of the generator. This is the case in the following situations:

- ▶ when the genset motor is started and until it has reached its rated speed,
- ▶ when other loads supplied by the genset (elevators, air-conditioning units) are operated,
- ▶ when load-shedding occurs.

These situations can create problems with UPSs that interact with the distribution system (line-interactive UPSs) because their output frequency is identical to the input frequency. In this case, genset frequency variations can result in series of transfers to battery power (frequency outside tolerances), followed by returns to AC power (when the UPS has stabilised the frequency, but the genset has not yet stabilised). These transfers back and forth are called "hunting".

With double-conversion UPSs, the regulation of the output voltage eliminates this type of problem.

☞ Double-conversion UPSs are totally compatible with genset frequency fluctuations. This is not the case for line-interactive UPSs.

Discrimination upstream and downstream of the AC bypass

Double-threshold protection

The short-circuit power of a genset is lower than that of a transformer on the normal AC source.

When in operation, they both supply the normal AC input (rectifier/charger) and the bypass AC input of the UPS.

If there is a major inrush current downstream, for example during a fault, the required power may exceed the capacity of the UPS inverter. In this case, if the AC bypass (supplied by the distribution system or a genset) is:

- ▶ not available, the UPS limits the output current for one second, then shuts down if the overload continues,
- ▶ available, the transfer to the bypass takes place immediately and the inverter shuts down.

If transfer takes place, discrimination between the upstream protection on the bypass line and the protection downstream of the UPS should clear the fault.

This means that on the upstream protection device, it is necessary to have two thresholds correctly set and coordinated with the downstream protection devices:

- ▶ a high threshold for operation on utility power,
- ▶ a low threshold for operation on genset power.

Practically speaking, with circuit breakers correctly selected and set for use with UPSs, discrimination is ensured by the short-circuit power of the UPS, without requiring the upstream power. It is nonetheless necessary to provide for discrimination on the AC bypass line.

☞ Protection devices upstream of the AC bypass must have two thresholds, one for operation on utility power and one for operation on genset power, both correctly set to ensure discrimination with the downstream protection devices.

Conclusion

The need for a configuration with a double-conversion UPS

For many years, the UPS-genset combination required an oversized genset. The general solution was (and occasionally still is) to select a genset rated 1.5 times higher than the UPS power rating.

This avoided problems related to harmonics, temperature rise, voltage distortion, low power factors, high inrush currents during start-up, capacitive currents with LC filters, etc.

Today, however, this solution is unnecessarily costly and far from the best in technical terms. When combined with a few relatively low-cost options, the performance levels offered by modern double-conversion UPSs (the indispensable topology required for high power levels and frequency regulation), make it possible to select a genset with an equivalent power rating.

Selection of a built-in active filter or an active 12-pulse filter effectively eliminates the problems caused by harmonics during operation on genset power.

Another solution is to use a PFC rectifier that draws a sinusoidal signal. This type of rectifier offers in addition a high input power factor (> 0.90), thus ensuring optimum use of the genset.

☞ The power compatibility between modern UPSs and gensets means there is no longer any need to derate the genset.

☞ It is much less expensive to install a few advanced options on the UPS than to unnecessarily oversize the genset.

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Publication: MGE UPS SYSTEMS - 11/2005
Design and writing: P. Andréani - INTERDOC