Generator set and UPS compatibility

> White paper

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This document discusses problems that can be encountered in operating UPS equipment on generator set equipment, explains reasons behind some problems, and identifies steps that can be taken to minimize compatibility problems between generator sets and static UPS equipment.

Conventional wisdom, and associated problems

There is a "conventional wisdom" that a generator set provided for use with a UPS should be sized so that the generator set is always two to five times the capacity of the UPS.

One problem with that guideline is that there is no firm consensus in the industry of what exact number to use and little technical basis for a recommendation based on sizing alone. There have been observed cases where SCR loads as small as 3 kW have disrupted operation of a 100kW generator set. Would anyone suggest that generator sets be derated to cover that situation? Moreover, even if one follows that "rule", there is no guarantee that the generator set will successfully power the load. The UPS supplier generally can't offer an iron-clad guarantee that a specific generator set will work in an application, and the generator set supplier won't guarantee that a UPS will operate successfully on a specific generator set.

With as little as a "two times" derating factor, even if the load is successfully operated, the over-sizing of the generator set can result in unnecessarily high installation and equipment costs, excess facility space requirements and design costs, and potential operating and service problems with the generator set from under-loading the engine on the generator set.

Over-sizing alone will not guarantee successful operational performance, and will result in unnecessarily high installation and operation costs. So, what can be done to improve the cost, performance and reliability of power systems that include UPS and generator equipment? The answers lie in understanding the problems that can occur and what suppliers can do to prevent them from happening.

Generator set compatibility problems are most pronounced on small (under 100 kW) generator sets, and particularly on natural gas fueled generator sets. Problems most commonly occur when the UPS is the only load on the generator set, or is the single largest load on the system. Simply designing around situations that fit these situations could avoid many problems.

Generator set and UPS incompatibility is particularly mystifying when identical equipment at two separate sites may perform differently; and especially when the UPS and generator set will both perform normally until an attempt is made to run them together.

When a system failure occurs, it is a natural reaction to assume that something must be wrong in the performance of either the generator set or the UPS. That assumption is often not true. So, it is important to first understand that there are several different failure modes in the UPS/generator set compatibility problem, and then apply the appropriate solution to the specific problem encountered.

The first action is to be sure that the generator set and UPS equipment are both operating correctly. This may require testing of the genset under various loading conditions to validate load carrying capability and transient stability. From that point we can start to evaluate various possible compatibility issues by their failure mode symptoms. By categorizing these failure modes, some common areas of problems with generator sets can be identified:

- poor frequency stability due to misadjustments or component malfunction
- voltage regulator sensitivity — output voltage distortion
- poor frequency or voltage stability due to control loop compatibility issues
- Inappropriate filter selection or operation on a UPS

In addition, non-linear load heating effects should also be considered, in the interest of designing safe systems with acceptable life spans for the equipment involved. Heating effects will not have immediate effects but may cause premature alternator failure.

Symptom	Potential Problem
Fail to "lock on" to generator power	• improper generator frequency or voltage • poor generator frequency stability • unrealistic performance requirements
Instability of generator	• voltage regulator sensitivity • control loop compatibility • filter/control interaction • governor or AVR problem
Fail to sync bypass	• frequency or voltage out of range • poor frequency stability • unrealistic performance requirements • changes to total load on the system • generator output voltage distortion
Instability at specific load levels	• control loop compatibility
Instability at load changes	• control loop compatibility
Metering errors	• generator output voltage distortion
Loss of voltage control	• excess capacitance in filters vs. load

TABLE 1 – Typical symptoms and potential problems associated with generator sets operating with UPS loads.

Misadjustments

Generator sets that serve steady state linear loads, by nature of the power quality requirements of the loads, are normally not required to function at their peak steady state stability and transient response performance levels. They are often tuned at the factory fastest response to load changes. Consequently, the many adjustments that can be made in governor and voltage regulator circuits may not be optimized but overall system performance may still be acceptable. It is even possible that a generator set could be crippled by a partially functioning component (such as a sticking or binding actuator rod) and still function well enough to serve many loads.

Non-linear and other electronic loads often demand a higher level of stability (that is, a lower rate of change of frequency) than linear loads from a generator set. Consequently, it is possible that a generator set will start, power up a load bank, and carry some loads with no problems and still not carry specific UPS loads due to misadjustment or subtle component or system deficiencies. Or, a simple damping of especially the voltage regulation system response will allow stable operation.

These problems will be extremely difficult to detect at a job site, because there typically is not monitoring equipment available at the site that would allow a technician to detect these conditions. If no sample of proper performance is available, it is difficult to evaluate on-site performance to know whether it is acceptable, or deficient in some way. Finally, it may be necessary to test at varying load levels to find the point of instability that is causing an issue.

Generator sets used in UPS applications should be tested at the factory at rated load and power factor. Tests should include transient load testing at various load levels with verification of voltage dip and recovery times, and observation of the a damped response of the system on recovery after loading.

These results should be compared to prototype test data, to verify that the unit is performing in the proper fashion. Note that the absolute values are not necessarily as important as verifying the stability of the system, and the absence of malfunctioning components. Note also that it is reasonable to require rated power factor testing for the factory test, since steady state voltage regulation is affected by the power factor of the load.

When a stability problem is found at a job site and normal testing and diagnosis fails to uncover a problem, a full load test with a load bank at various loads can be helpful in verifying the ability of the system to perform properly. When this testing is done on the job site it is expensive and time consuming, but it is the only way to verify that the generator set is performing correctly. It is reasonable to consider designing provisions for easy load bank connection into the system for any equipment that serves non-linear loads, for both the generator set, and the UPS.

Voltage regulator sensitivity

A generator set uses an automatic voltage regulator (AVR) to monitor the output voltage of the generator set and control the field strength of the machine to maintain a constant voltage on the output of the generator set under varying steady state load conditions. FIGURE 1 illustrates a typical generator set design.

The voltage regulator senses output voltage level of the generator set directly from the output power connections and, based on a set reference point, changes output power to the generator exciter to maintain voltage. Note that the power to operate the voltage regulator is derived from the output of the generator set. This is termed a "shunt" type excitation system.

SHUNT-EXCITED ALTERNATOR

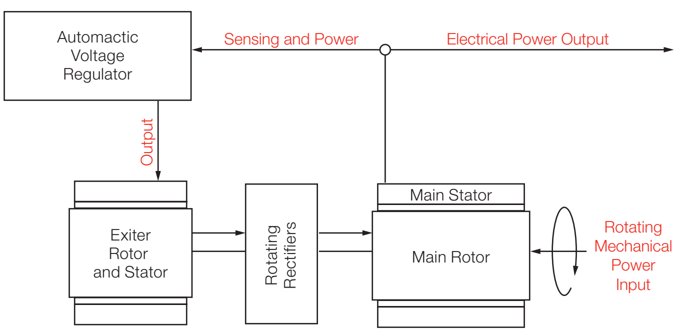

FIGURE 1 – In this schematic drawing of a shunt-excited alternator, note that the voltage regulator senses voltage level and draws excitation power from the output of the main field of the alternator.

Since the AVR directly senses the output of the alternator, it must be designed to operate successfully when the sensed voltage waveform is distorted by the powering of non-linear loads. The load current drawn by a UPS in normal operation does not follow a sinusoidal pattern. Consequently, the voltage waveform of the source supplying power to the UPS is also distorted. The waveform distortion effects, which can be a significant detriment in the operation of utility powered distribution systems due to heating effects, will have even more pronounced effects on generator sets.

This voltage waveform distortion can cause misoperation of generator sets with some voltage regulator types, especially AVRs that utilize SCRs to switch excitation power on and off. These AVRs provide good performance when powering linear loads, but can fail to operate in a situation where the voltage waveform is disrupted by non-linear loads. Under normal (linear load) conditions, the AVR will sense the voltage level on the output of the alternator and based on that voltage level will time the firing of the SCR so that a measured

FIGURE 2A

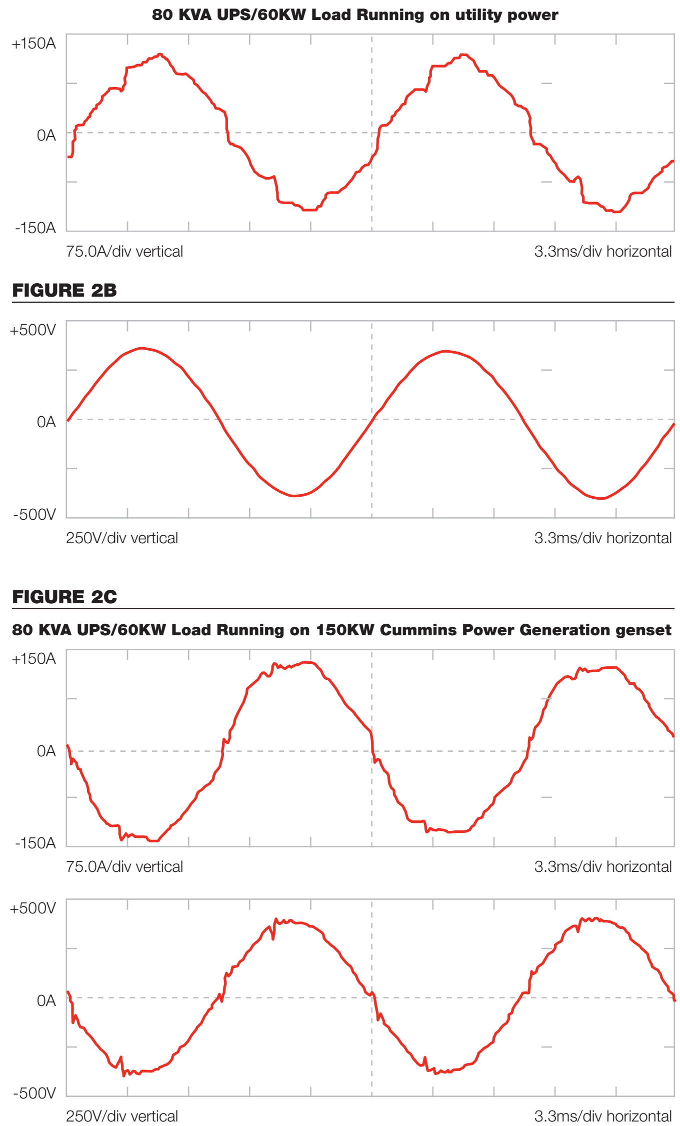

FIGURE 2 (a,b,c) – Comparison of current and voltage distortion seen at the input of an 80kVA UPS running with 60kW load while operating on the utility and on a 150kW genset with filters operating, and not operating. Total harmonic distortion of voltage is about 11.4% when running on the genset without filters.

amount of energy (the area under the excitation curve) will reach the exciter. (FIGURE 3a) Note that the SCR is "switched off' by self-commutation as the voltage waveform approaches its zero-crossing point.

Consequently, voltage level on the output drops; the AVR tries to increase voltage level by switching on the SCRs sooner, and overcompensates for the problem. The net result is that voltage level on the output of the alternator begins to oscillate. Since the actual kilowatt load on the engine is a direct function of the

SCR-CONTROLLED EXCITATION SYSTEM

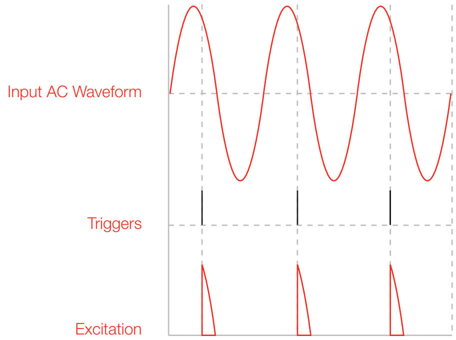

FIGURE 3a – Note that a single trigger input "turns on" the excitation power, and the AC voltage crossing turns it off. When that regulator is applied with non-linear loads, the waveform notching causes the SCR in the AVR to switch off at the incorrect time, so the exciter does not get the proper level of energy to maintain generator output voltage level (FIGURE 3b).

voltage, the AVR voltage variation results in real power pulsations to the engine of the generator set. These power pulsations cause pulsating governor action, and oscillating frequency, which makes the problem even worse, since most generator sets incorporate a voltage roll off with a change in frequency. The quickly changing frequency can also result in misoperation of UPS equipment. See "Control Loop Compatibility" in this paper.

Many governors on many generator sets were changed before the core problem was diagnosed. With the proper diagnosis in hand, the first attempts to correct the problem revolved around isolating the AVR from the waveform distortion by:

- applying filters to the AVR sensing input to prevent voltage distortion from reaching the AVR;
- applying isolation transformers to the AVR sensing input

These "solutions", however, were not always without side effects.

The same input filter that prevented waveform distortion from disrupting the SCR-based AVR also prevented the regulator from quickly responding to real KVA demands, in large motor starting applications, for example. So, even though the filter helped the system remain stable, it could prevent proper operation of other loads, unless the generator set was over-sized. Another problem with filtering was that it tended to be successful only when waveform distortion was not too severe-such as when total SCR load on the generator was only 30-50% of the total generator capacity.

The isolation transformers applied would not always be successful in removing enough of the waveform distortion to allow stable operation since specialized transformer arrangements are needed to successfully remove significant waveform distortions (other than the triplen harmonics).

Because of the limitations of filtering AVR inputs, many manufacturers designed high-speed voltage regulators that provided pulse width modulated output to the exciter of the alternator. These AVRs accurately sense true RMS voltage value and provide excitation power in short "bursts", rather than depending on commutation of the AC voltage waveform to switch off the excitation power. (FIGURE 3c)

Consequently, the amount of excitation power delivered to the exciter of the alternator is not affected by waveform notching, and the AVR is immune to operation problems related to waveform distortion.

Use of 3-phase sensing AVRs is also helpful in reducing the effect of waveform distortion on an alternator control system. It will be particularly effective when

SCR-CONTROLLED EXCITATION SYSTEM WITH DISTORTED INPUT VOLTAGE WAVEFORM

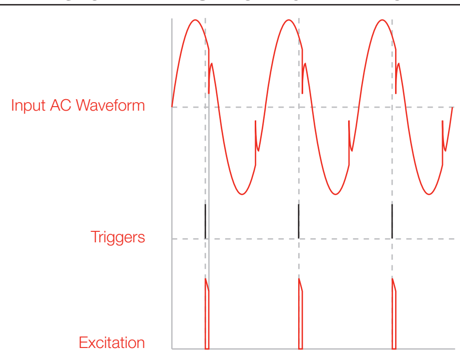

FIGURE 3b – Note that the single trigger turns on at the correct time, but waveform notching causes the AVR to 'switch off" power to the exciter too soon.

PULSE WIDTH MODULATED (PWM) EXCITATION SYSTEM

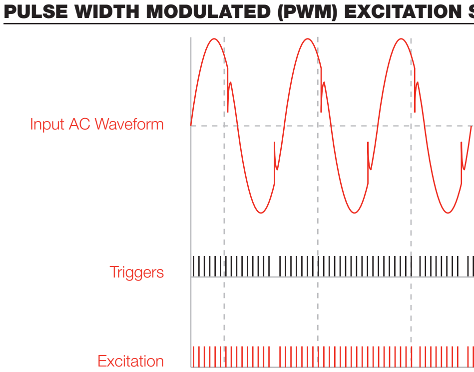

FIGURE 3c – Multiple triggers and pulsed output provide proper levels of excitation regardless of level of waveform distortion.

single-phase SCR loads are causing the system disruption. Three phase RMS sensing circuits are also helpful in maintaining reliable voltage regulation for generator sets serving non-linear loads, since they can accurately sense voltage level regardless of the magnitude of the distortion on the alternator output voltage waveform.

Another alternator system enhancement that has been applied is the use of permanent magnet generator (PMG) supported excitation systems. In a PMG-type generator set, the AVR draws power from a permanent magnet generator mounted on the alternator shaft, rather than from the alternator output. (FIGURE 4)

Since the PMG will provide constant power output as long as the alternator shaft is turning, and since it is completely isolated from load-induced voltage waveform distortion, the PMG will provide reliable isolated power supply for the AVR in situations where significant voltage waveform distortion is present.

ALTERNATOR WITH A PERMANENT MAGNET GENERATOR (PMG)

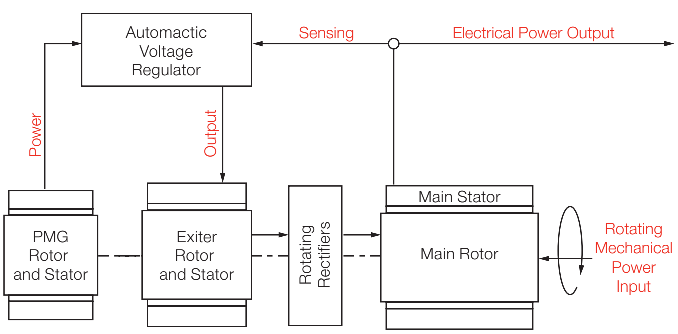

FIGURE 4 – Schematic drawing of an alternator with permanent magnet generator (PMG) for excitation support. Voltage regulator senses output voltage level from output of alternator, but excitation power is derived from the PMG.

Heating effects

Generator sets, like other building electrical components, are affected by the heating caused by non-linear loads. These heating effects include abnormal hysteresis, eddy current, and skin effect losses. Simply put, the alternator operates at a higher than normal internal temperature when serving SCR loads. Failure to properly size for the effects of non-linear loads can result in premature failure of the alternator due to abnormal heating in the machine.

Generator sets, however, are generally less affected than many loads and distribution system components. The primary issues in generator sets concern proper sizing and allowance for neutral conductors of appropriate sizes to be connected to the generator set.

Alternator derating for non-linear loads will be necessary only if the alternator standby rating and generator set rating is equal.

For example, it a 500kW alternator with class F insulation is provided on a 500kW generator set then with the generator set operating at rated load and power factor and carrying non-linear loads, the alternator would be operating at a temperature in excess of its rated temperature. This would lead to alternator overheating, and premature alternator failure.

However, if the same alternator were provided with class H insulation rather than class F, there would be a 20 degree centigrade margin of thermal protection added; so the alternator insulation temperature rating probably would not be exceeded even with the non-linear load applied. In a practical sense, virtually all generator sets are provided initially with oversized alternators in order to provide needed motor starting capability and to provide required voltage dip performance with the maximum load to be applied on the system (even though the load diversity is such that it is highly unlikely that the entire load will be applied to the generator set simultaneously).

Consequently, when non-linear loads are used in a facility and operated by a generator set there generally is excess capacity in the alternator design, so alternator overheating due to non-linear loads is not a major concern. However, if the total amount of nonlinear loads in the system is close to the steady state rating of the generator set, use of derated alternators can provide added capacity needed to operate the machine with non-linear loads applied.

Since alternator capacity is relatively inexpensive, this is not a significant burden to the first cost of the facility. Class H insulation provides additional high temperature resistance over Class F insulation systems.

The system designer should verify that an appropriately sized junction box and lug termination area is provided for those applications where an oversized neutral is specified.

Output voltage distortion

Facility designers generally are well aware of the potential impact of non-linear loads on the voltage waveform quality in their applications. The degradation in voltage waveform quality can result in heating effects and shortened life in motors, misoperation of some loads, and even “bypass not available” alarms in UPS equipment.

Power Generation

Because generator sets have a higher impedance than a typical utility service, these effects will be much more apparent while operating on generator power than when operating on the utility. (See FIGURE 2 for example) Therefore, while designers are aware of the potential problem, the major difficulty is determining what level of voltage waveform quality is required for successful system operation, and then specifying an alternator that will provide this level of performance.

This problem is further complicated by the fact that the magnitude of waveform distortion is affected by the type of device powered, the load level on that device, and the number and type of other loads that are operating on the distribution system. Testing of specific load devices on alternators with specific characteristic allows development of a graphical tool, which can be used to estimate resultant voltage waveform quality

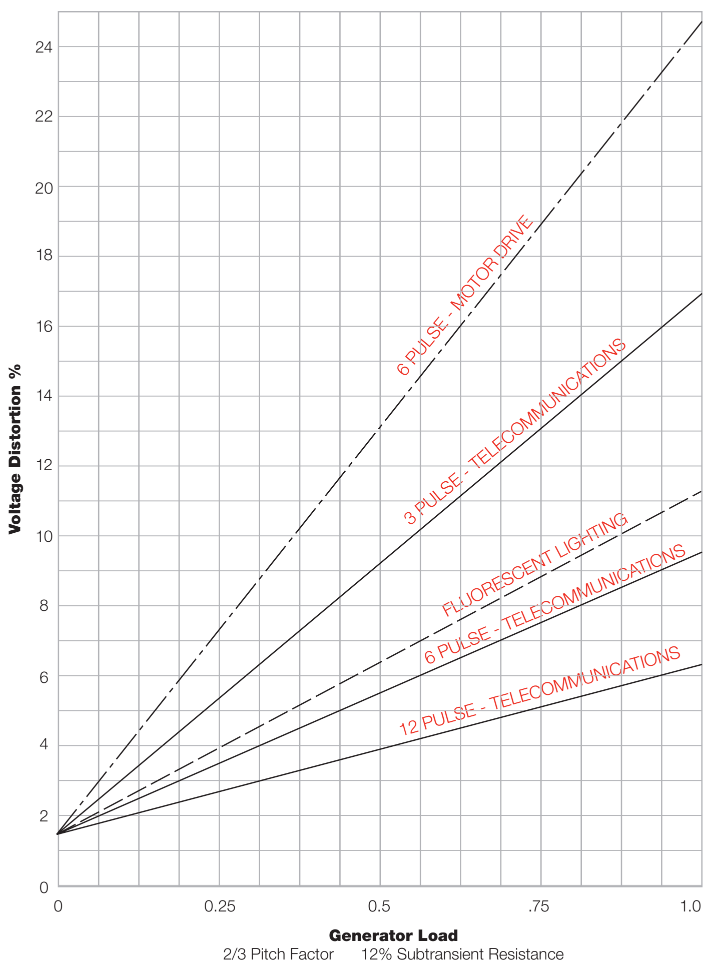

FIGURE 5 – Waveform distortion level of an alternator with specific non-liner loads can be estimated using charts such as this.

with specific magnitudes of non-linear loads, applied to an alternator. In FIGURE 5, a graph of this type is displayed. Note that, for example, with an alternator that has 50% of its rated load level as non-linear 6-pulse motor drives, voltage distortion of approximately 13% can be predicted. If the load is a 6-pulse telecom rectifier, the voltage distortion will be only about 5%.

A common design error is to attempt to reduce waveform distortion on a generator set to be within the requirements of IEEE519. (Approximately 5% THD voltage.) This standard is directed toward utility-power systems and will result in unnecessary over-sizing of alternators in many standby applications.

The actual voltage distortion seen in a generator self-powered circuit is directly related to the alternator sub-transient reactance (X”d). A generator set with low subtransient reactance will perform significantly better than a unit with higher reactance. For generator sets’ operating at under 600VAC a good recommendation is that X should not be greater than approximately 0.12 to 0.15 per unit. So, compared to the impedance of a typical utility supply, a generator required to meet IEEE519 might be twice as large as is required to successfully operate loads.

Filtering equipment located at the load device is also useful in reducing total voltage distortion. FIGURE 2 illustrates the impact of filtering in an application using an 8OKVA UPS and a 150kW generator set. Note that when filtering is applied, the voltage and current waveforms are much “cleaner.” Filtering should always be carefully applied, however, as it may have unexpected side effects. In FIGURE 2, the overall distortion is much lower, but the filtering resulted in additional zero-crossings, which can disrupt operation of some load devices.

In addition, filtering can have negative effects on generator sets, when the load on the filtered device and generator set is very low. In these situations, the total power factor of the load seen by the generator set may become leading, and the generator set may be unable to properly regulate its voltage.

Alternator pitch is sometimes mentioned as a factor in choosing an alternator with best performance on non-linear loads. In general, alternator pitch has little effect on the overall performance of the system, but if pitch of the alternator is specified, a 2/3 pitch machine is advantageous because these machines will generate no 3rd order harmonics, and the bulk of the naturally present waveform distortion in the alternator (when powering 3-phase loads will be in the 5th and 7th orders). This is an advantage to distribution circuits because 3rd order harmonics add directly in the neutral of the system, and can cause significant heating in delta/wye transformers, and neutral bus/cable systems.

The disadvantage of 2/3 pitch machines is that if 3rd order harmonics are induced in a distribution system powered by a 2/3-pitch alternator, they will tend to have greater heating impact on the alternator than other harmonic orders. However, since most loads seen by an alternator are 6-pulse, and since 6-pulse loads produce no 3rd order harmonics, this is not normally a significant issue. (2-pulse loads are typically single phase devices, and are separated from the generator set by a transformer, which normally isolates the generator set from 3rd order harmonics and their multiples (triplen harmonics). 12-pulse loads produce no triplen harmonics, and most of the distortion produced is in the 11th and 13th orders.

Alternators with all other pitches may have waveform distortion present at all harmonic orders, typically with the highest distortion in the 3rd order. Since all the injected 3rd order harmonics will add in the neutral of the system, and potentially cause heating effects that are additive to the heating caused by non-linear loads, Cummins Power Generation recommends that only 2/3 pitch alternators be used, to avoid this potential problem.

Since specifying alternator pitch may restrict the number of suppliers that can provide hardware for a specific project, many designers will elect to specify maximum permissible distortion on an alternator (powering linear loads.) A typical specification is to allow not more than a total harmonic distortion of 5% produced by the alternator, with no single harmonic level being more than 3%, with the alternator operating at rated load level with linear loads.

Generator set metering errors

AC output metering for generator sets is often average reading analog type, which will not indicate true RMS values when serving non-linear loads. The primary disadvantage of this is that an operator unfamiliar with the system may misadjust the generator set based on erroneous meter readings.

Digital true RMS metering sets are available and can be mounted on generator sets, but this metering is not particularly useful in monitoring and servicing the generator set because a flashing digital display doesn't as clearly indicate rate of change or maximum change of metered parameters under transient load conditions, and doesn't as clearly indicate stability of a metered function.

Since the primary function of the metering mounted on the generator set is to enhance the serviceability of the generator set, analog metering should be provided on the generator set in spite of the potential inaccuracy of its indicated values under some system operating conditions. Supplementary digital metering sets reading load conditions in switchboards or switchgear will accurately provide data necessary for operating personnel to monitor and manage system loads.

Control loop compatibility

When an SCR-controlled device operates, it depends on accurate timing of the firing of the SCR to accurately control output power of the rectifier. This firing time is critical because the SCR will be turned on at a specific time, but the “off’ command is derived from a zero-crossing event. In a utility power system this is not a major problem because the power source frequency is constant, so the major problems involved in the timing of the firing revolve around proper detection of the zero-crossing which may be somewhat masked by voltage waveform distortion.

On a generator set the frequency of the output voltage is not constant. It varies even with steady state loads on the machine and under transient load conditions it can vary considerably. The term slew rate is used to describe the rate of change of frequency.

You can begin to better understand the magnitude of potential compatibility problems between generator sets and SCR-based loads, when you realize that many load devices require that the slew rate will not exceed 0.5 hertz/second. When a load is applied to a generator set, slew rates of 10-15 hertz/second are not uncommon for short time periods.

If the frequency of the power source changes faster than the load device is designed to deal with the SCR firing will occur at the wrong time, resulting in either too much or too little energy transmitted to the load device. On the next timing cycle the load control logic may then start to make corrections for the error condition. At the same time that this is happening the generator set controls (the AVR and for engines with electronic governors, the electronic governor control) will start to make corrections to maintain engine speed and voltage. The generator set control system corrections can begin to resonate with the load system corrections.

When that happens, a control loop incompatibility exists. This incompatibility may be difficult to correctly diagnose, because its symptoms are very similar to other generator set control problems. The symptoms may occur immediately when the generator set tries to power up a specific load. In FIGURE 6 you can see an oscillographic tracing of a 200kW generator set output while attempting to power a 125KVA UPS. The top tracing is A-phase voltage, the second line is A-phase current, then B-phase voltage, B-phase current, and generator set excitation system current.

Prior to picking up this load, the generator set was stable under all steady state and transient conditions. The UPS input locked on to the generator set, and begin to ramp up load on the generator set. However, as load increased, the system became unstable, and the generator set governing system began to oscillate wildly.

It is tempting at this point to start making governor stability and gain adjustments, when in fact the generator set is simply responding to real load being applied to its output. This real load is pulsating due to errors in the firing of the SCRs in the load due to frequency changes in the generator set.

The control incompatibility is also difficult to diagnose because it can occur at any time and at any load level. In the example shown in FIGURE 6a, the generator set was running smoothly, and carrying the UPS load with no problem. Suddenly, for no apparent reason, the system began to oscillate as shown in this figure.

Another potential problem is that a rectifier in a UPS is a constant load device, so voltage reduction functions in generator set voltage regulators that are intended to reduce load on the engine to allow factor recovery from transient load conditions, will not function as expected. Reduction in generator voltage output does not result in reduced load unless voltage drops to such a low level that the rectifier switches off. In fact, the voltage reduction efforts by the generator AVR may make the performance of the system worse, especially when most of the load is UPS equipment. In those cases the volts/hertz roll-off function may need to be adjusted to occur at a significantly lower frequency.

This situation maybe difficult to diagnose since the stability and response characteristic of a generator set vary with ambient temperature, fuel type and condition, and many other factors. It is possible that the system can be stable one day and unstable the next. Obviously, one can't physically inspect any particular governor control, voltage regulator, or UPS circuit board, and deduce whether or not they will exhibit control loop compatibility problems. Similarly, understanding of the logic and control of one component in

OSCILLOGRAPHIC RECORDING OF A GENERATOR SET WITH UPS RECTIFIER RAMPING ON

FIGURE 6a – The top recording is an A-phase voltage. The second recording is an A-phase output current from UPS. The third recording is a B-phase input voltage to UPS, and fourth line is an input amperage to UPS rectifier.

the system will not provide enough information to solve the problem. A cooperative effort from all equipment suppliers will be needed to resolve these issues.

If compatibility is a potential issue on a site, it can be proven only by test and experience. The solutions to control loop compatibility problems may involve modifications to the SCR firing control logic, sizing of the generator set, or proper adjustment of the generator set controls. These generator set control adjustments will be more successful if the generator set has a broad adjustment range in both the engine speed governing and voltage regulation controls.

It should be noted that emergency/standby generator sets are typically designed and set up to provide fastest possible service to facility loads, and fastest possible transient performance response when a load is applied. Generator set manufacturers sometimes point out transient performance results with considerable pride in their work. This performance is achieved by pushing the generator set to respond so fast that it is unstable, and then backing off the adjustments so that it can be close to instability when running sensitive loads.

When powering UPS loads, fast response is not a prime concern. UPS equipment is very tolerant of voltage and frequency excursions, but very intolerant of fast changes in these parameters. So, setting up the generator set in a typical emergency/standby fashion may not result in best overall system performance, especially when the UPS is the major load on the emergency/standby system.

At the same time if the generator set is "detuned" for best performance with the UPS, it must be remembered that this will impact on the ability of the generator set to best service other loads in the system, particularly in the starting of large motors. Use of a motor starting/sizing procedure that incorporates actual generator set data along with an understanding of the requirements for successful motor starting can help to achieve in the best system performance adjustments.

OSCILLOGRAPHIC RECORDING OF A GENERATOR SET OPERATING UPS SHOWING SYSTEM OSCILLATION

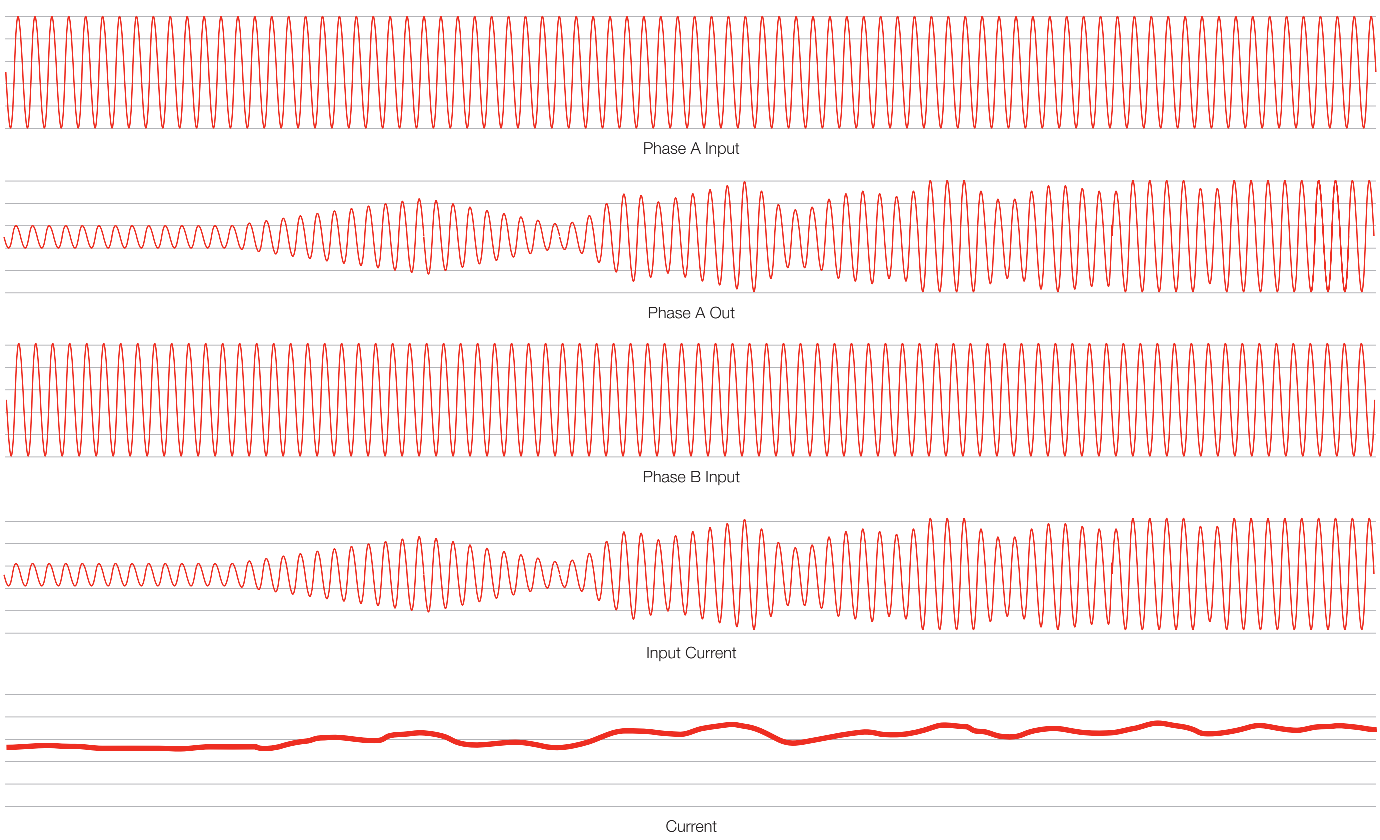

FIGURE 6b – The top recording is an A-phase voltage, second is an A-phase current, third is a B-phase voltage, fourth is a B-phase current, and the bottom recording is the voltage regulator output.

When readjustment of the generator set performance is necessary, it is desirable to begin by damping the gain on the AVR. The AVR responds much more quickly than the engine governing system, so is more likely to be the source of a problem than the governor, even when frequency changes appear to be the problem.

Another tactic that can be used to lessen the probability of control loop incompatibility is designing the system so that the generator set will not be loaded in such a fashion as to see large frequency transients, especially while the generator set is powering up the UPS after a power failure. This means that load steps that are applied to the system are as small as possible relative to the generator set size, and that the generator set is carrying other facility loads before the UPS ramps on. If frequency can be controlled to a plus or minus 0.5 hertz operating band by careful sizing and application of loads, control loop incompatibility will be less of an issue.

Some facilities have incorporated resistive load racks for generator sets that exclusively serve UPS equipment, so that some linear load is present on the generator set when the UPS begins the ramp on process. In general, a load bank sized for approximately 10% of the generator set standby rating should be sufficient to stabilize the system.

Finally, the solution to the compatibility between the system components may be most easily addressed in the UPS SCR-firing control logic. Many UPS systems now include control logic that compensates more effectively for rapid changes in input power frequency.

Generator set powered UPS system limitations

A generator set is not a utility power source and it can't duplicate the performance of the utility in powering a UPS and the UPS loads. In particular, consideration must be given to the fact that generator frequency will not be as constant as on the utility, and this will impact the performance of the overall system.

The best commercially available steady state performance from a reciprocating diesel engine driven

OSCILLOGRAPHIC RECORDING OF A GENERATOR SET RUNNING NORMALLY WITH A MINOR LOAD CHANGE

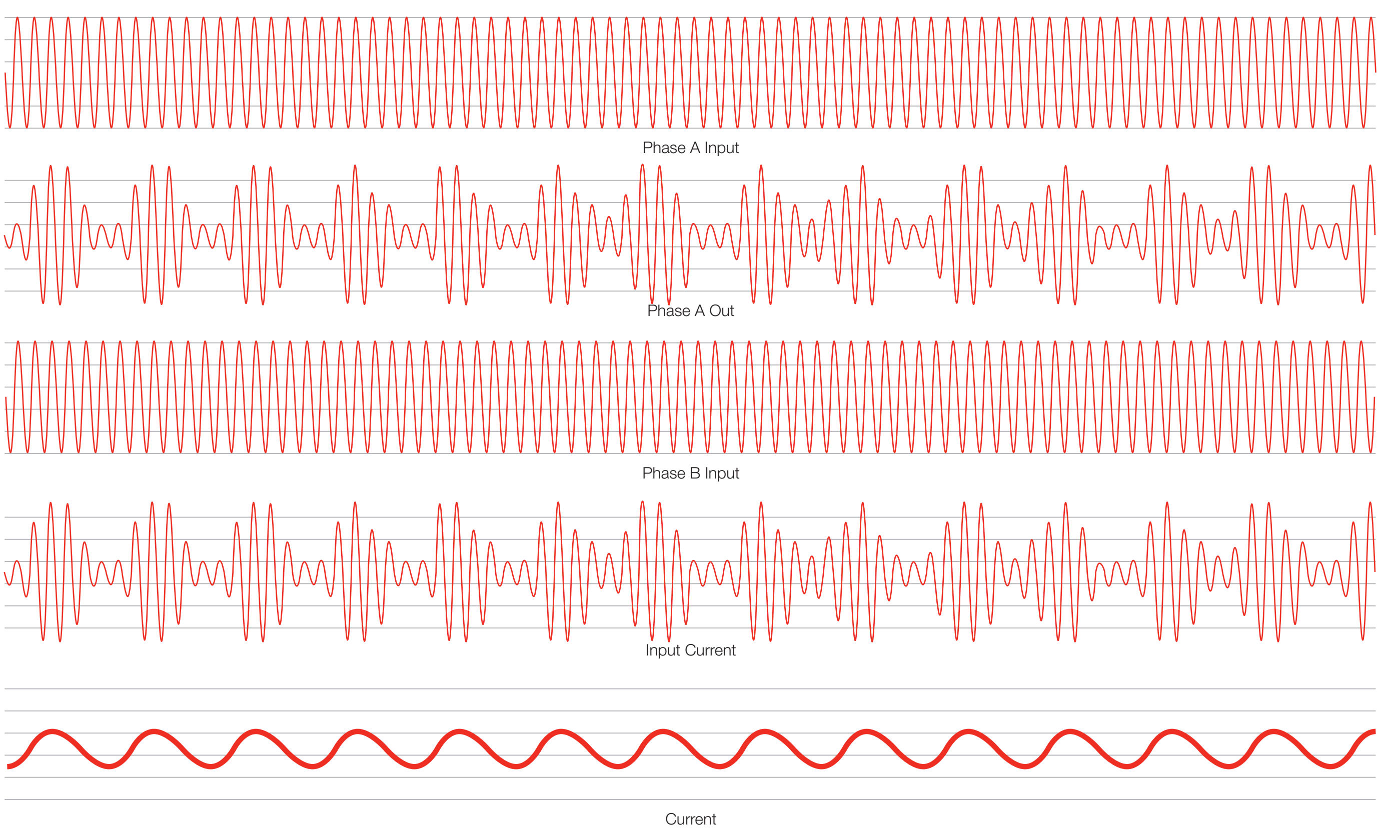

FIGURE 7 – Generator set running normally, and apparently stable, until a minor load change or frequency excursion initiates an oscillating condition. The top waveform is the generator phase A output voltage, second is the UPS output voltage, third is the generator phase B output voltage, and fourth is the current input to the UPS. Note that the AVR output is moving with the voltage and current variations.

generator set is 60 hertz plus or minus 0.25%. (Natural gas fueled generator sets may not be able to meet this level of performance.) On application of a load, voltage and frequency may dip up to 20-30%. The magnitude of the dip can be controlled by proper sizing of the generator set.

Generator sets may be provided with either droop or isochronous governors. In a droop-governed generator set, the frequency of the output is not a constant 50 or 60 hertz, but varies as a direct function of the load on the system. With droop-governed generator sets, the steady state frequency will vary from 3-5% from no load to full load, and generally, the steady state performance will not be as good as with an electronic isochronous governor.

The probable best slew rate (rate of change of frequency) that can be achieved by a generator set with a stable load is 1 hertz per second. When loads are applied to the generator set, the slew rate will usually exceed 3 Hz/second for a short period of time.

This impacts the system in two areas. First, when the UPS ramps on to the generator set after a normal power failure, the generator frequency will drop as load is applied. If the rate of load application is high enough the frequency of the generator set can drop to below the input requirements of the rectifier, causing it to be switched off the generator set, returning the system to battery power. The generator set frequency will then quickly correct, and the rectifier will ramp on again. This can lead to the appearance of instability in the generator set governing, when in fact multiple real load additions cause the frequency changes.

If this occurs, adjustment of the rectifier ramping time and ramping rate will minimize the frequency disturbance and allow the rectifier to stay on line with the generator set. Generator set frequency changes during load addition from other loads while the generator set is running the UPS can often cause “bypass not available” alarms from the UPS. When the UPS sees stable voltage and frequency on the input to its rectifier, it will synchronize the output of its inverter to the input, so that if the inverter failed, a static switch can instantly connect the load directly to the power source. When the source power supply frequency and voltage change, the UPS will attempt to follow those changes and remain synchronized with the source, unless the voltage and frequency change more than is acceptable, or the slew rate is too high. At that point, the UPS will interpret the input power as unacceptable and disable its automatic bypass ability (through the static switch) and issue a “bypass not available” alarm.

If a load is applied to the generator set serving a UPS the frequency and voltage change or slew rate may be unacceptably high, and a momentary “bypass disabled” alarm may result in the UPS. The voltage frequency, and slew rate acceptance ranges for bypass enable in the UPS are adjustable, but it is likely that normal operating performance of a generator set will not be suitable to maintain bypass enable capability under all load adding and shedding conditions.

The generator set normally will not be able to duplicate that voltage waveform performance of the utility, so care must be taken to provide enough generator set capacity so that waveform distortion level will be acceptable. When specifying systems that utilize existing equipment, care should be taken to be sure that the generator set or UPS could perform properly given the quality of power that can be provided by the generator set used.

Transfer switch and power transfer issues

Another emergency/standby power system component that can be misapplied in systems that power UPS equipment is the automatic transfer switch. Transfer switches can cause problems in the following areas:

- Oversized neutral requirements
- Ground fault sensing and UPS input sensing problems
- Nuisance UPS input breaker tripping

Facility designers should be aware that oversized neutral capacity in a transfer switch is not currently commercially available, so transfer switches must be derated for non-linear loads if a neutral of significantly greater capacity than the phase conductors is needed. This is less of an issue in 3-pole transfer switches, since there is a solid neutral connection between the sources.

UPS systems are independent power production sources that can be designed as either separately derived, or non-separately derived systems. That is, the neutral to ground bonding jumper can be either at the service entrance of the facility (not separately derived), or close to the UPS (separately derived).

In a UPS system that is powered only by the utility service, the primary considerations in this area are balancing potential added costs of a separately derived system with the benefits of system isolation offered by that design.

When the system operating voltage and facility capacity requires the use of ground fault protection, generally it will be necessary to design the facility to incorporate a separately derived UPS and generator system, which uses power transferred by a switched neutral (4-pole) transfer switch. When a single transformer serves a UPS system (either internally or externally), it will be necessary to switch the UPS load from generator source to utility source using a transfer switch that has a relatively slow operating speed. If the transfer switch opens the contacts on the generator set source, and then closes on the utility source before the residual voltage generated by the transformer decays, nuisance tripping and potentially even equipment damage can occur in breakers upstream from the transformer. To eliminate this problem, the "open" time on the transfer switch should be approximately 0.5 seconds. Most transfer switches with the capability of adjusting operating speed will allow customizing of this operating time to be as fast as possible without causing nuisance tripping in the system. The duration of the open time on switching of the transfer switch is not important to the UPS (as long as it's not too fast) because once power fails, it normally will wait for a short time to re-energize the system from its connected source.

Recommendations

The generator set provided to power UPS applications should include an automatic voltage regulator that is immune to misoperation due to waveform distortion. Three phase sensing regulators and separately excited alternators are recommended but not necessarily required for proper system performance.

Where available, class H generator set insulation provides an added protection against generator overheating over class F insulation. The lowest temperature rise alternator, that is practical for an application, should be provided in order to minimize voltage waveform distortion. Typically, this will be an alternator rated for 105C rise over a 40C ambient. The cost penalty for this enhanced rating will vary with generator size and manufacturer, but generally will be a 1% to 4% premium over units rated for maximum insulation temperature rise at their kW rating. Where available, the generator set should have a subtransient reactance of 15% or less. Remember that lower reactance results in better performance.

Specify UPS operating parameters that are compatible with generator set performance capability. Keep in mind that this will change with the size and type of generator set provided. Specify UPS with input filters (especially with 0-pulse UPS) to minimize voltage waveform distortion. A separate isolation transformer to serve the UPS (making the UPS a separately derived system) will be useful in avoiding operational problems with the UPS, providing better quality power to the load, and preventing ground fault sensing problems.

Specify program transition (open time = 0.5 seconds) for transfer switches feeding UPS loads - Generator sets usually will need electronic isochronous governors to provide 50 or 150 hertz output at all load levels and enable the UPS output to be synchronized to the generator power. (Governing systems that have droop operating characteristics will generally power up the UPS rectifier, but may not force operation close enough to proper operating frequency to allow sychronizing through the UPS statlc switch.)

Generator sets should be sized based on total load applied by the UPS. It should consider:

- UPS operating at full rated load, even if total load on the UPS is planned to do significantly less than 100% of the UPS rating. This is necessary because after a power failure, the system will current limit to 100-125% of the steady state rating of the UPS, in order to recharge the system batteries.
- Battery recharge rate after power restoration to the UPS.
- UPS operating power factor and efficiency at full load.
- The sizing should consider waveform distortion goals. A practical goal is to achieve a system with not more than 10% THD when operating on generator set power. Better performance in this area can be achieved by careful consideration of alternator size and capabilities.

The generator set supplier should help the system designer establish the proper size of the generator set, based on the performance requirements set by the system designer.

An emergency/standby power system design that incorporates a UPS system will have a significantly higher probability of success if the UPS is not the only load on the generator set. Addition of other loads of various types will reduce the relative transient load applied to the generator set by any one load, and improve the stability of the generator set, especially when the UPS it is powering is lightly loaded.

Generator sets and UPS equipment are not by nature incompatible (Owners and system designers trying to wade through incompatibility issues between suppliers may find this hard to believe, but it's true.)

Finally, other rectifier-based loads can have problems similar to UPS equipment when running on a generator set. The solutions described in this paper will be helpful in resolving operational problems when running rectifier-based equipment on a generator set.

For additional technical support, please contact your local Cummins Power Generation distributor. To locate your distributor, visit www.cumminspower.com.

About the author

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He has been employed by Cummins Power Generation for more than 30 years in various engineering and management roles. His current responsibilities include research relating to on-site power applications, technical product support for on-site power system equipment, and contributing to codes and standards groups. He also manages an engineering group dedicated to development of next generation power system designs.

PT-6014 (09/08) Formerly 900-0280

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