Power topic #6001 | Technical information from Cummins Power Generation

Impact of leading power factor loads on synchronous alternators

> White paper

By Gary Olson, Director, Power Systems Development

Our energy working for you.™

Cummins Power Generation

Many electrical loads incorporate elements that can impose a leading power factor on the power source. While these loads are typically not a problem for utility power sources, leading power factor can cause generator set failures or the failure of certain loads to operate properly on a generator set. This paper briefly explains the phenomena, and what can be done to address problems when leading power factor loads are present.

The problems seen when attempting to operate generator sets with leading power factor loads may seem mysterious, but in reality, they are not too much different from another energy absorption problem: the limited ability of a generator set to absorb real kW power from loads some elevator drives, and in crane applications.

A generator is physically unable to absorb more than a very small amount of real (kW) or reactive (kVAR) power. While the reverse kW power produced by a dropping load in a crane application drove the engine into overspeed conditions when it exceeded the ability of the engine to absorb it, the reverse kVAR load presented by leading power factor devices will drive the alternator into over voltage conditions.

Over the past years, generator set manufacturers have evolved their equipment designs to include use of digital automatic voltage regulator (AVR) equipment, separate excitation systems, and PWM-type control architecture to enable the generator set to produce and stable output voltage and successfully operate non-linear loads. At the same time, manufacturers of equipment that has non-linear load characteristics have begun to commonly employ filters to limit harmonic current distortion induced on the power supply. Capacitive elements are also applied in facilities to improve the power factor when operating on the utility source to avoid higher energy charges. While filters provide positive impacts on the overall power system, they can be very disruptive to generator operation.

EXAMPLE

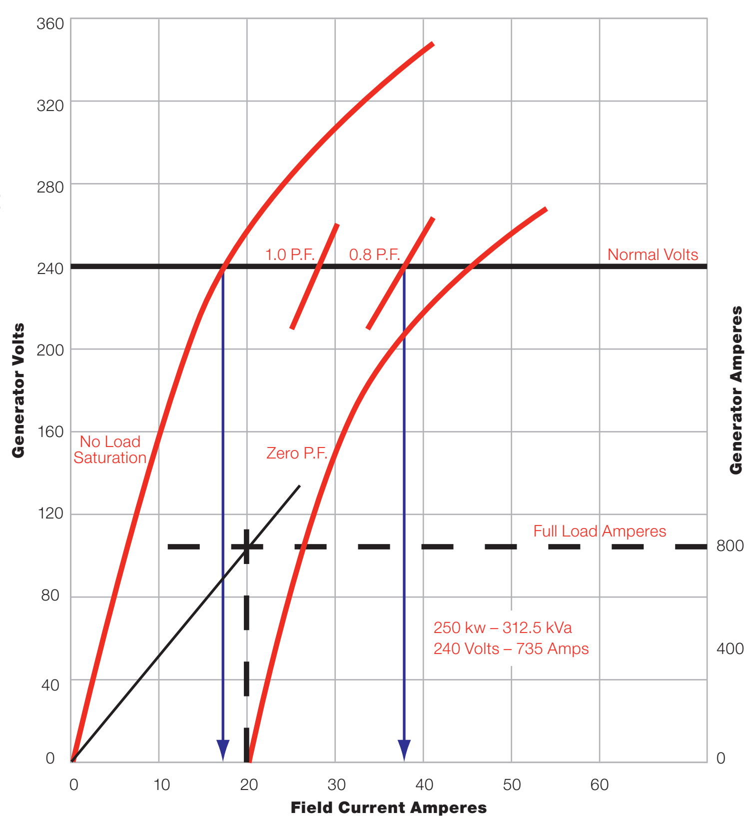

FIGURE 1 – In this example no load field required is 17 amps, while full load is approximately 38 amps.

The generator set AVR monitors generator output voltage and controls alternator field strength to maintain constant output voltage. Relatively low AVR output is required to maintain generator voltage at no load. In the figure shown, the no load exciter field current required is less than half the full load level.

Filter equipment is often sized for operation at the expected maximum load on the UPS or motor load. At light loads there may be excess filter capacitance, causing a leading power factor. Since rectifiers are commonly designed to ramp on from zero load to minimize load transients, leading power factor loads may be imposed on the system until inductive loads are added to the system or the load factor of the nonlinear load increases.

A utility supply simply absorbs the reactive power output because it is extremely large relative to the filter system and it has many loads that can consume this energy. With a generator set, however, the rising voltage from the leading power factor causes the voltage regulator to turn down and reduce alternator field strength. If the AVR turns all the way off it looses control of system voltage, which can result in sudden large increases in system voltage. The increase in voltage can result in damage to loads, or can cause the loads to fail to operate on the generator set.

A UPS is designed to recognize high voltage as an abnormal and undesirable condition, so it can immediately switch off its rectifier. When it does that, the high voltage condition is immediately relieved (because the filter is disconnected from the generator set) and voltage returns to normal. To the observer, the generator will seem to be unable to pick up the system loads.

Paralleling problems

Generator sets that are using in isolated bus paralleling systems have particular issues with leading power factor loads.

When loads are applied to a parallel generator bus, the total load on the system can be many times larger than the capacity of a single generator set. The generator sets close to the bus one at a time, so that if high loads (either leading or lagging) are applied before genset capacity is available, the generator bus can fail. With leading power factor loads, the failure mode will be due to either an over voltage condition or reverse kVAR shutdown. due to either an overvoltage condition or due to reverse kVAR shutdown.

Further, there is a tendency, particularly in data center applications, to group UPS loads together on a common bus. This concentrates the leading power factor load on one bus, so that if a large group of UPS load is applied to the first generator set available, it can easily be driven into an excess reverse var condition, which will result in overvoltage and shutdown. If multiple generator sets are on the bus and a large reverse var load is applied to the genset bus, the var load sharing control system can be disrupted, because not all load sharing control systems include logic for reverse kVAR load sharing. If reverse kVAR load sharing is not in the logic for the control system the system will typically cause one or more generator sets to exceed their reverse power limits, which can cause pole slipping.

Generator sets in a paralleling system are maintained in synchronism by their magnetic fields. When a leading power factor load is applied, the voltage of the genset or genset bus rises, and the voltage regulation system of each generator set reduces exciter power, reducing the strength of the magnetic field. If the field is switched off in an attempt to reduce voltage to an acceptable level, the generator set may slip a pole, which results in potentially catastrophic alternator damage.

The reverse kVAR limit of the aggregated generators is the sum of the reverse var limits of each generator. However, the reverse var settings may not be able to take advantage of all the capability of the alternators due to limitations in the VAR load sharing system.

Solutions

What can be done about this? First, we need to understand how much reactive power can be absorbed by the generator without negative impact. The ability of an alternator to absorb power is described by a reactive capability curve. FIGURE 2 shows a typical generator capability curve describing the capability of a machine to produce and absorb power. In this curve the kVAR produced or absorbed is on the X-axis (positive to the right). The Y-axis shows kW (positive going up). kVAR and kW are shown as per unit quantities based on the rating of the alternator (not necessarily the generator set, which may have a lower rating.

The normal operating range of a generator set is between zero and 100 percent of the kW rating of the alternator (positive) and between 0.8 and 1.0 power factor (green area on curve). The black lines on the curves show the operating range of a specific alternator when operating outside of normal range. Notice that as power factor drops, the machine must be de-rated to prevent overheating. On the left quadrant, you can see that near-normal output (yellow area) can be achieved with some leading power factor load, in this case, down to about 0.97 power factor, leading. At that point, the ability to absorb additional kVAR quickly drops to near zero (red area), indicating that the AVR is “turning off” and any level of reverse kVAR greater than the level shown will cause the machine to lose control of voltage.

In other words, if the machine is rated for operation at 1000 kVA and 0.8 power factor (600 kVAR rated), with a reverse kVAR level of 0.2 per unit (rated), you will exceed the machine’s capabilities. So, with more than 120 kVAR reverse reactive power and leading power factor lower than 0.97 (for most people a surprisingly low level) we have a problem.

The ability of a generator set to absorb reactive power is defined by a reverse kVAR limit, not a specific power factor.

The solution to this problem on this specific machine involves avoiding excess reverse kVAR levels through proper system design and operation:

- Modify the sequence of operation for the facility so that loads that require reactive power are present on the bus when the UPS ramps on to the generator. The reactive power produced by the filters will be consumed by the system loads, and the loss of voltage control is avoided. This requires a re-thinking of operating sequences in some cases because 1) perhaps mechanical loads rather than UPS will need to go on the generator first, or 2) loads will be required to be broken into smaller blocks of UPS and mechanical loads, rather than larger isolated buses of each.
- Turn off the filters when operating on the generator set or reduce the magnitude of filtering provided. If the generator is provided with modern digital excitation control, the filters won’t be needed to maintain stable generator operation, but may still be required to properly serve other loads.

ALTERNATOR CAPABILITY CURVE

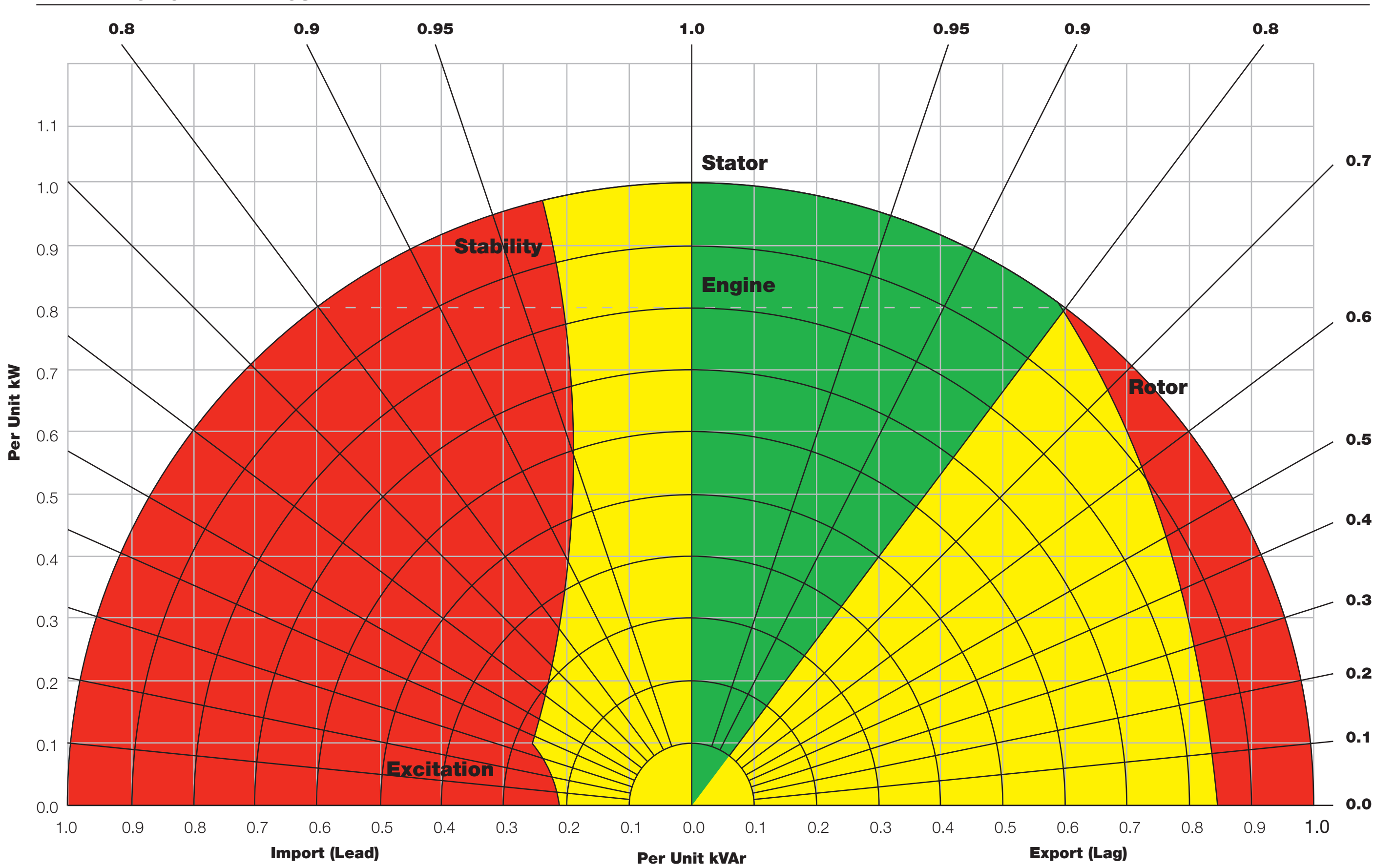

FIGURE 2 – Green area is normal operating range of a typical synchronous machine, yellow is abnormal but not damaging, and operating in red regional will cause damage or misoperation.

About the author

Gary Olson graduated from Iowa State University with a BS in Mechanical Engineering in 1977, and graduated from the College of St. Thomas with an MBA in 1982.

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.

The actual limits of reverse kVAR can vary considerably from machine to machine, both within a specific manufacturer's product line, and between equipment from different suppliers. A good rule of thumb for Cummins equipment is that it can absorb about 20% of its rated kVAR output in reverse kVAR without losing control of voltage. However, since this characteristic is not universal, it is advisable for a system designer to specify the reverse kVAR limit used in his design, or the magnitude of the reverse kVAR load that is expected. Note that this is not specified as a leading power factor limit, but rather as a maximum magnitude of reverse kVAR.

Alternators are physically limited in their ability to both produce and absorb power. When a leading power factor load is applied to an alternator at a site, misoperation of the generator, overvoltage, load misoperation, and alternator damage can occur. There is very little that the alternator supplier can do to resolve problems at a specific site other than to help a system designer understand the nature of the problem and the limits of the machine as installed. Most of the solution will come from changes in the system sequence of operation, or hardware changes that prevent disruptive reverse var conditions from affecting the generator set.

Conclusions and recommendations

> Synchronous alternators have limited ability to absorb kVAR from load devices, and exceeding this limit will result in generator set shutdown.

> Paralleling operations require careful consideration of the loading sequence to prevent reverse var conditions that can damage the generator set.

> Consider modifying system sequence of operation or limiting filter operation until adequate loads are in place to prevent reverse kVAR conditions on the genset.

> Specify the magnitude of reverse kVAR the genset must be able to absorb, not the power factor alone.

> In single generator applications protective devices can be set to the limits of the alternator. In paralleling applications both alternator limits and Var load share limits must be considered.

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

PT-6001 (Rev 9/09)

Cummins® Power Generation