

Sizing gensets for motor starting

A practical guide to understanding how motor-starting loads affect genset performance

By:

Dan Krueger
Senior Field
Applications Engineer
Kohler Power
Systems-Americas

Rick Van Maaren
Senior Staff Engineer
Kohler Power
Systems-Americas

Today's standby power loads are more complex than ever before. In many industrial and commercial applications, standby gensets must supply power to a mixture of linear and nonlinear loads in addition to large motor loads that cycle on and off. Of all the diverse loads a standby genset must supply, applications with motors present the most sizing issues. The dynamic interactions of motors and gensets – along with the impact of motor starters, system inertia, motor loading, frequency dip, genset preload and nonlinear loading – make manual genset sizing difficult, if not impossible.

Not only is sizing an application with large motors complex, but different genset manufacturers have different approaches for specifying a standby power system that will function reliably. Each major genset manufacturer has created genset-sizing software to help with this complex task, but due to manufacturers' differing approaches to motor starting, this software can yield quite different results – sometimes specifying a larger and more expensive generator or too small a generator than is necessary for

reliable operation. The purpose of this article is to explain how motors affect genset performance and how sizing software, such as Kohler Power System's QuickSize™, deals with motor loads. Armed with this understanding, power system specifiers will be able to select the most cost-effective and reliable genset for motor-starting applications.

BASIC CHARACTERISTICS OF MOTOR LOADS

Motor loads cause difficulty because a motor draws high current when started at full voltage. Starting current is typically six times a motor's rated full-load current, and this inrush current stays high until the motor reaches about 75 percent of rated speed. When a motor is started on normal utility power, the high inrush current will cause only a small voltage dip because the utility is a more robust voltage source. However, when a motor is started on genset power, the high inrush currents (measured in kilovolt-amperes or KVAs) can result in a large voltage dip that can inhibit the motor from reaching its operating speed.

The challenge, then, is to size the genset to handle the motor-starting load, but also

Letter Designation	KVA per Horsepower with Locked Rotor
A	0 - 3.14
B	3.15 - 3.54
C	3.55 - 3.99
D	4.0 - 4.49
E	4.5 - 4.99
F	5.0 - 5.59
G	5.6 - 6.29
H	6.3 - 7.00
J	7.1 - 7.99
K	8.0 - 8.99
L	9.0 - 9.99
M	10.0 - 11.10
N	11.2 - 12.49
P	12.5 - 13.99
R	14.0 - 15.99
S	16.0 - 17.99
T	18.0 - 19.99
U	20.0 - 22.39
V	22.4 and up

Figure 1: Locked Rotor Indicating Code Letters

Source: 2006 NEMA

to minimize the impact on the other connected loads that may be affected by voltage dips or frequency dips.

Therefore, when sizing a genset, it is critical to accurately predict voltage dips and to understand how much excess starting capability is available in the motor and what amount of voltage dip can be allowed. The most common methodology for sizing gensets for motor starting focuses on understanding allowable instantaneous voltage dips, as the primary criteria. However, there is one manufacturer that considers allowable sustained voltage dips as the primary criteria for motor-load starting.

The motor-starting KVA can be determined by the motor's nameplate. The National Electrical

Manufacturers Association (NEMA) sets design standards for motors and has established a NEMA code-letter designation for classifying motors according to the ratio of locked-rotor KVAs (LRKVAs) per horsepower. These code letters range from A to V, covering motors with an LRKVA-per-horsepower ratio of 3.14 or less to a ratio of 22.4 LRKVA-per-horsepower or more. See Figure 1.

For example, a 50 hp Code F motor requires 279.5 LRKVA per horsepower upon starting (50 hp x 5.59 LRKVA per hp = 279.5 LRKVA/hp). LRKVA is also known as "starting KVA" or "SKVA."

Small motors have a higher NEMA code letter and correspondingly higher LRKVA-per-horsepower requirement than large motors. Typical motor sizes and codes are shown in Figure 2.

VOLTAGE DIP

The KVA requirements of a motor running at full load and rated speed are normally less than one KVA per horsepower. With the possible exception of small motors, it would be overly conservative to size a genset set simply by matching the alternator's KVA to the motor's KVA. This would typically result in a genset with more than twice the capacity necessary. However, due to the dynamic interaction of the system components, several characteristics combine to make this approach impractical.

Size	Code	Locked Rotor KVA/HP
1 - 2 HP	L or M	9 - 11
3 HP	K	8 - 9
5 HP	J	7 - 8
7.5 - 10 HP	H	6 - 7
15 HP and up	G	5.6 - 6.3

Figure 2: Typical Code Letters for Various HP Motors

Source: 2006 NEMA

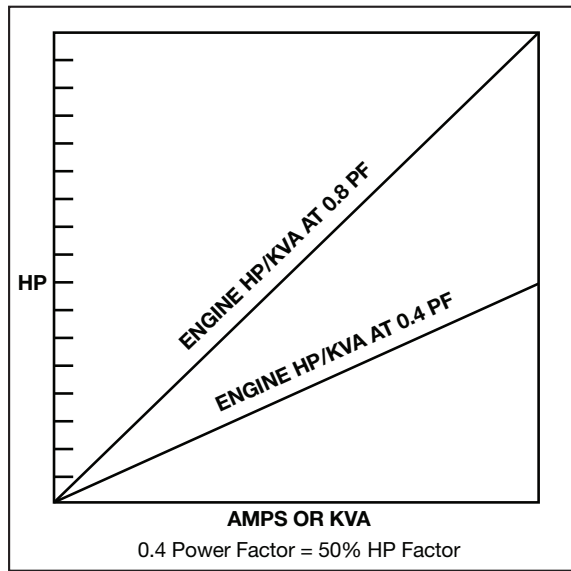


Figure 3: Engine Power Required for Low Power-Factor Load

Source: Kohler Power Systems

The first characteristic is power factor. Three-phase genset sets are usually rated in KVA at 0.8 power factor. Starting power factors of motors vary from 0.3 to 0.5 and increase towards unity as the motor accelerates and its KVA demand drops. With a 0.4 power-factor load, a typical genset is capable of producing nearly twice its continuous-rated KVA for the time required to accelerate a motor to the speed at which its KVA requirement drops sharply. The genset engine will not stall even though it is being asked to supply more than its rated KVA, because low power-factor loads (see Figure 3) do not require as much horsepower as higher power-factor loads. This genset characteristic allows satisfactory motor-starting results with a genset half the size predicted by the conservative approach, which matches the genset 0.8 power-factor KVA rating to the motor-LRKVA rating.

VOLTAGE DIP

The other characteristic that can substantially reduce the size of the genset needed for a particular motor-starting load is voltage dip.

Values for motor LRKVA are based on full-voltage starting. In practice, there is always a voltage dip when a motor is started on genset power, and there is even a small dip when a motor is started on utility power. When the voltage drops, inrush current is also proportionally reduced so that starting KVA is reduced as the square of the voltage dip. A 30 percent voltage dip reduces starting KVA by about 50 percent ($0.7 \text{ kilovolts} \times 0.7 \text{ amps} = 0.49 \text{ KVA}$).

At least for the first few cycles, the voltage dip is determined by the size of the load (i.e., the motor's LRKVA) and the reactance of the alternator – which is somewhat proportional to the total mass of copper and iron present in the alternator. The issue in sizing a genset is determining what voltage dip will be acceptable for a particular load when considering its effect on all components in the system, some of which may have unknown transient acceptance specifications.

A voltage dip can affect motors themselves, in addition to other loads on the system. For example, excessive voltage dip can cause control relays or magnetically held motor-starting contactors to drop out, or ultimately, cause the motor to not start at all. If the relays or contactors drop out, the load is removed from the genset, causing voltage to rise and the cycle to repeat rapidly. This can damage contactors if allowed to continue. Most control relays and motor-starting contactors will tolerate a 35 percent voltage dip. However, there are exceptions. Some relays or contactors will start to chatter if subjected to a voltage dip as little as 20 percent. Likewise, other voltage-sensitive loads need to be accounted for (e.g., UPS systems, medical equipment, HID lighting) in any genset-sizing exercise. To ensure satisfactory operation on a given standby power

system, consult the voltage/frequency limitations of control components from the manufacturers or suppliers.

Voltage dips also reduce the torque a motor can supply to its load. A common NEMA Design B motor will develop 150 percent of rated full-load torque during starting. Torque is proportional to the KVA delivered to the motor, so a 30 percent voltage dip that reduces KVA to 49 percent also reduces torque to 49 percent of its rating. If the motor starts unloaded – as most fans, centrifugal pumps and motors used with elevators do – this torque reduction produces no problem other than a somewhat longer acceleration time. Other types of loads, such as positive displacement pumps, may require more

MOTOR STARTERS CAN REDUCE VOLTAGE DIP

The high inrush current and high starting torque associated with full-voltage starting of motors on utility power may create problems with the equipment driven by the motor, or the voltage dips may raise objections from the electric utility. To circumvent these issues, many facilities use various types of motor starters for their motors. Some of these devices also benefit motor starting when running on genset power, often allowing a smaller genset to be utilized.

Reduced-voltage starters – Most reduced-voltage starters connect the load to the power source in two or more steps. The starters may be either “open”- or “closed”-transition starters, but only closed-transition, reduced-voltage starters are helpful when running on genset power. As seen in Figure 4, open-transition starters create an unacceptable spike in KVA demand when switching between steps occurs.

Part-winding starters – Part-winding starters are used with motors that have two identical windings intended to be connected in parallel. These windings can be energized in sequence to provide reduced starting current and torque. Since part-winding starters are inherently closed-transition starters, the maximum inrush current occurs at the moment the first winding is energized, and the maximum inrush KVA load on a genset set will be reduced to 60–70 percent of normal.

See Figure 5.

Autotransformer starters – This type of starter provides reduced voltage at

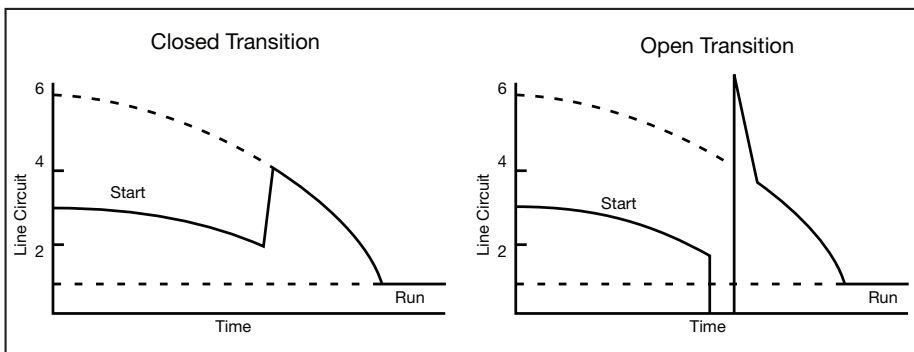


Figure 4: Closed Transition vs. Open Transition Starters

Source: Kohler Power Systems

torque than the motor can develop at reduced voltage, which prevents the motor from reaching full speed. Additional consequences could include tripping of breakers or overheating of the motor. To ensure proper motor starting in these applications, it is necessary to compare the torque curves of the pump and the motor at reduced voltage.

the motor terminals from a tapped 3-phase autotransformer and generally gives the best results with gensets. See Figure 6. Taps on the transformer provide selection of 80, 65 or 50 percent of initial line voltage to the motor terminals. Starting torque is reduced by the voltage squared to give 64, 42 or 25 percent of the full-voltage value, respectively. To avoid reducing starting torque to unacceptable levels, use either the 80 or 65 percent taps.

Solid-state (soft-start) starters – This type of starter is most popular and provides exceptional operating flexibility. It is a form of reduced-voltage starter that utilizes silicon controlled rectifiers (SCRs) to increase voltage at a predetermined rate. Limits on the starting current can also be adjusted to increase system performance. A note of caution: any performance prediction made at a specific value will change when the settings are changed in the field. Also, since solid-state starters utilize nonlinear SCRs, they can cause voltage distortion during motor starting that must be considered.

Wye-delta starters – Some motors have six leads that allow them to be connected in either

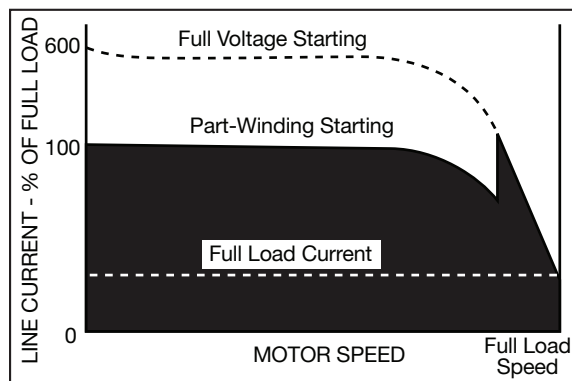


Figure 5: Part-Winding Starting
Source: Kohler Power Systems

wye or delta configurations. By connecting the motor winding in the wye configuration and using a voltage source corresponding to the delta rating, starting current and torque are reduced to

33 percent of the delta connected values. Use only with closed-transition starters, however. See Figure 7.

FACTORS AFFECTING REAL-WORLD MOTOR STARTING

Genset frequency dip – The genset’s engine cannot be ignored in motor starting due to the high horsepower demanded when a large motor is started. When the engine slows under load, frequency dips; this, in turn, increases the alternator voltage dip. The amount of impact on engine RPM during motor starting is dependent on the performance characteristics of a given configuration of engine and alternator. These factors are taken into consideration when running the sizing software based on a maximum allowable voltage and frequency dip.

Voltage regulator and excitation system response time – Thorough testing has revealed that in addition to the transient reactance of the

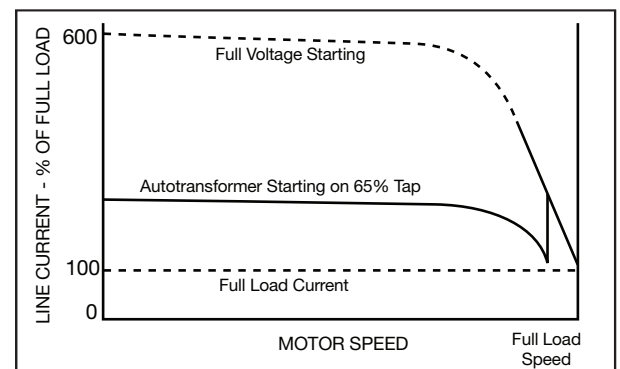


Figure 6: Autotransformer Starting
Source: Kohler Power Systems

alternator, voltage regulators and excitors affect voltage dip and recovery. A fast-responding excitation system can limit the initial voltage dip as shown in Figure 8.

On voltage dips of 35 percent or less, a fast-responding system will start the motor faster.

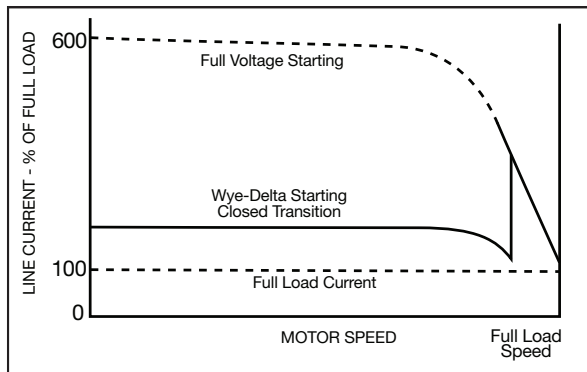


Figure 7: Wye-Delta Starting

Source: Kohler Power Systems

Preloaded genset – The pre-existing load on the genset can affect both the frequency dip and voltage dip during motor starting. For example, a 50 percent preloaded genset may dip an additional 2 percent compared to the published figure.

Nonlinear loads – Electronic motor starters and Variable Frequency Drives (VFDs) are nonlinear loads. VFDs are not actually a motor-starting problem but a potential harmonic distortion problem. Check the genset manufacturer’s sizing program to see if it predicts the voltage harmonics present when running nonlinear loads. This can be very useful for analyzing harmonic concerns.

MOTOR LOADING

There are two types of motor loading: high-breakaway-torque loads (i.e., unloaded motors) and high-inertia loads (i.e., loaded motors).

Unloaded motors – These tend to reach operating speed quickly. A few examples of unloaded motors include the following: centrifugal blowers, rotary and centrifugal pumps (starting under low head pressure), clutched motors and fan motors (starting with low restriction). To avoid improper

operation of magnetic motor starters and other equipment running on the genset, never exceed a 35 percent instantaneous voltage dip.

Loaded motors – These tend to take longer to accelerate and recover to full voltage, due to the initial loaded condition of the motor. With loaded motors, there is a more significant relationship between recovery voltage during motor starting and the genset’s ability to accelerate the motor to full speed and rated voltage. A few examples of loaded motors include the following: rock crushers, elevators, conveyors, single/multicylinder compressors and submersible pumps.

VOLTAGE RECOVERY VERSUS VOLTAGE DIP

Genset manufacturers differ on some of the fundamental criteria for proper genset sizing for motor starting. Most manufacturers focus on instantaneous voltage dip as the primary factor in genset sizing, while at least one manufacturer stresses voltage recovery during motor starting

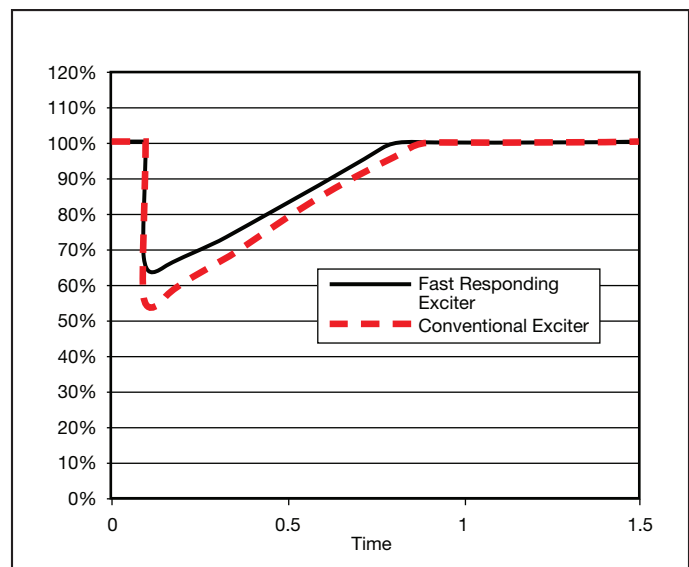


Figure 8: Motor-Starting Voltage vs Time

Source: Kohler Power Systems

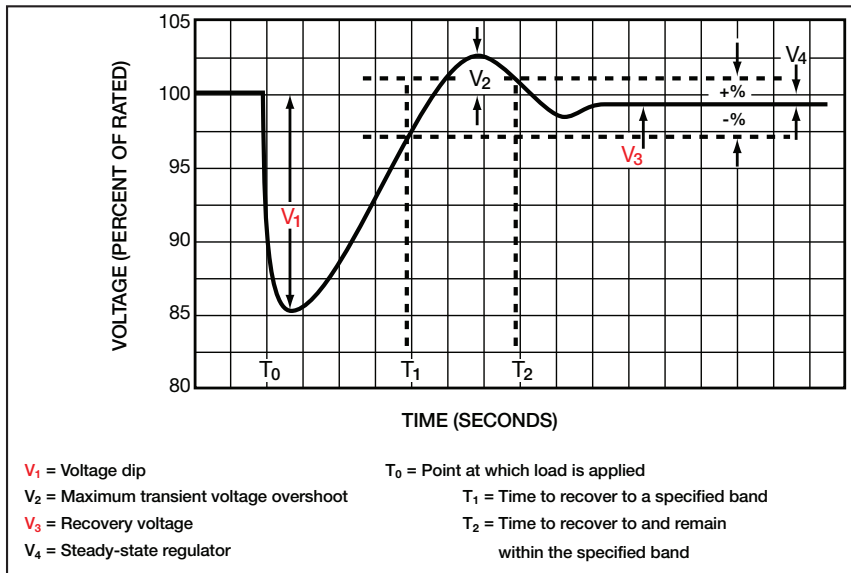


Figure 9 Generator Transient Voltage vs. Time for Sudden Load Change

Source: 2006 NEMA MG1 Part 32

as the primary driver for genset sizing, which can lead to confusing specifications. However, extensive field experience indicates that voltage recovery is more a function of exciter size than of main alternator size, and not a true representation of the genset's ability to start the motor.

While it is necessary to account for the extended acceleration time of motors starting under a loaded condition, addressing the required LRKVA at the maximum instantaneous voltage dip experienced by all the connected loads should remain the primary criteria. In lab testing with actual motors and very high inertia loads, researchers have found that because of the dynamics of motor inrush current and power factor changes, actual motor-starting capability is more closely correlated with instantaneous voltage dip than with voltage recovery. Both NEMA and MIL standards have recognized that the initial voltage dip is the primary criteria to be used in genset sizing.

FUNDAMENTAL CRITERIA FOR MOTOR STARTING

Regardless of what sizing method is used or how manufacturers specify motor-starting performance, the following fundamental criteria for motor starting must be accomplished – and in the following sequence – to successfully start a motor:

1. Sufficient LRKVA at the instantaneous voltage dip for inrush current –

The required LRKVA at the maximum permissible instantaneous voltage dip is considered to be the first step for motor starting by most genset and alternator manufacturers.

Typical motors are designed to sustain a 30 to 35 percent instantaneous voltage dip before the motor-starting contacts drop out. Many specifying engineers prefer a maximum 20 percent instantaneous voltage dip limit to ensure the motor will start and hold in the starting contacts.

2. Sufficient genset torque and power –

Next, the torque available from the genset must exceed the torque required by the motor load, or the motor will stall or never start.

3. Sufficient alternator excitation system strength –

The genset must have sufficient excitation system strength and adequate response to accelerate the motor and return it to operational voltage and speed. This third and final step addresses voltage recovery.

INSTANTANEOUS VERSUS SUSTAINED VOLTAGE DIP

While most genset manufacturers focus on instantaneous voltage dip as a primary criterion for genset sizing, at least one genset manufacturer writes specifications with a

different maximum motor-starting KVA value that allows the genset voltage to recover to 90 percent of rated voltage. This concept – known as “sustained voltage dip” maximum KVA – assumes that when the genset can recover to 90 percent of rated voltage, the motor will develop 81 percent rated torque, allowing the motor to accelerate to full speed in most applications. Real-world experience reveals that using a 90 percent sustained-voltage motor-starting KVA value can overstate motor-starting performance and lead to improper sizing of the genset due to dynamic conditions during motor starting.

Please see the graph below for a visual explanation.

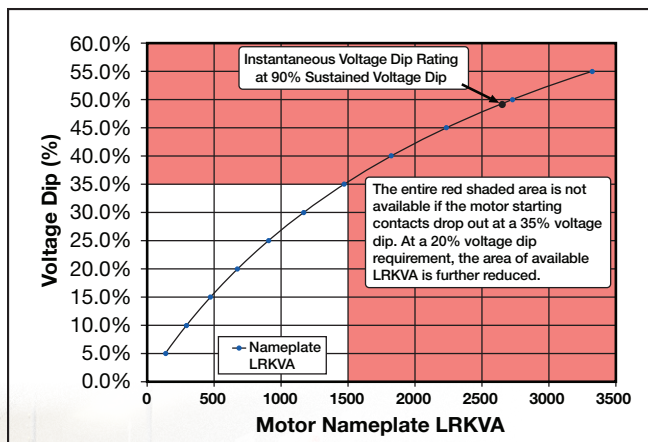


Figure 10: Motor Nameplate LRKVA vs Voltage Dip

Source: Kohler Power Systems

Caution - Maximum LRKVA based on sustained voltage of 90 percent can and usually does show a much larger value, but the voltage dip is typically greater than 35 percent. The LRKVA value at 90 percent sustained voltage can be excessively overstated, as it is of no use once exceeding either 35 percent instantaneous voltage dip or less, if required by the motor.

CONCLUSION

When using a genset to supply motor-starting loads, the interactions are dynamic and complex. For the most reliable and accurate results, the sizing exercise needs to consider the genset as a system, including the engine, alternator, voltage regulator and excitation system, along with motor starters. Dynamic conditions, such as systems inertia, motor loading, motor type and genset preload, are also important. By analyzing this dynamic system and evaluating the functions in real-world applications, specifiers will have a better understanding of how to properly predict motor-starting performance in a more consistent and reliable way.

Finally, due to the complexity of total system loads and the dynamics of the genset and motor-starting applications, it's important to utilize proven genset-sizing software to ensure performance of the entire system in its specific application.

QuickSize™ is Kohler's genset-sizing software; it includes industry-leading features, such as the ability to select gensets based on voltage dip, frequency dip and total harmonic distortion. These features allow the user to select the genset set that best fits his or her power requirements. The user can select different types of linear and nonlinear loads, including motors, VFDs, UPS systems, battery chargers, office equipment, air conditioning, miscellaneous loads, lighting and medical-imaging equipment.

QuickSpec™ is an industry-leading system specification writing tool from Kohler that can output a complete power system specification for gensets and transfer switches. QuickSpec outputs the specification into a rich text file that can be saved in Microsoft Word for easy editing and customization, allowing the user to integrate the power system specification into a complete building specification. To request access to the QuickSize and QuickSpec programs, contact the Kohler Power Systems distributor nearest you.

ABOUT THE AUTHORS



Dan Krueger is a Senior Field Applications Engineer with Kohler Power Systems-Americas. He has worked within the power generation industry for more than 15 years, in manufacturing, product and business management, and sales both domestically and internationally. Krueger joined Kohler in 1998, primarily working with the engineering community, supporting system sales and providing training on KOHLER® products and paralleling switchgear systems.



Rick Van Maaren is a Senior Staff Engineer with Kohler Power Systems-Americas. He has worked in alternator development of standby, marine, residential and mobile generator sets for more than 25 years. He holds a BSEE from Michigan Technological University, is a registered professional engineer in the State of Wisconsin, a senior member of the IEEE and a holder of four patents. He has authored an IEEE IAS paper titled “Rotor Lamination Design for Surface Permanent Retention at High Speeds” and a chapter of the EGSA *On-Site Power Generation* reference book titled “Permanent Magnet Generators.”

KOHLER®

To contact us by phone, call **+1-920-565-3381**
or visit us online at **KohlerPower.com**

Kohler Power Systems
Kohler, Wisconsin 53044
Printed in U.S.A.
G26-7 KPS 103 6/09