



Sizing Generators for Motor Starting

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INTRODUCTION

Today's standby power loads are more complex than ever before. In many industrial and commercial applications, standby generators 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 generator must supply, applications with motors present the most sizing issues. The dynamic interactions of motors and generators—along with the impact of motor starters, system inertia, motor loading, frequency dip, generator preload, and nonlinear loading—make manual generator sizing difficult, if not impossible.

Not only is sizing an application with large motors complex, but different generator manufacturers have different approaches for specifying a standby power system that will function reliably. Each major generator manufacturer has created generator-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 generator performance and how sizing software, such as Rehiko Power Solutions Center, deals with motor loads. Armed with this understanding, power system specifiers will be able to select the most cost-effective and reliable generator 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 generator 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 generator to handle the motor-starting load, but also to minimize the impact on the other connected loads that may be affected by voltage dips or frequency dips. Therefore, when sizing a generator, 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 generators 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-starting load.

Figure 1: Locked Rotor Indicating Code Letters
(Source: 2006 NEMA)

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	10.0–11.1
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

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 per horsepower (LRKVA/hp). These code letters range from A to V, covering motors with an LRKVA/hp ratio of 3.14 or less to a ratio of 22.4 LRKVA/hp or more. See Figure 1.

For example, a 50 hp Code F motor requires 279.5 LRKVA/hp upon starting (50 hp x 5.59 LRKVA = 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/hp requirement than large motors. Typical motor sizes and codes are shown in Figure 2.

Figure 2: Typical Code Letters for Various HP Motors
(Source: 2006 NEMA)

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

VOLTAGE DIP

The kVA requirements of a motor running at full load and rated speed are normally less than one LRKVA/hp. With the possible exception of small motors, it would be overly conservative to size a generator set simply by matching the alternator’s kVA to the motor’s kVA. This would typically result in a generator 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.

The first characteristic is power factor. Three-phase generator 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 generator 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.

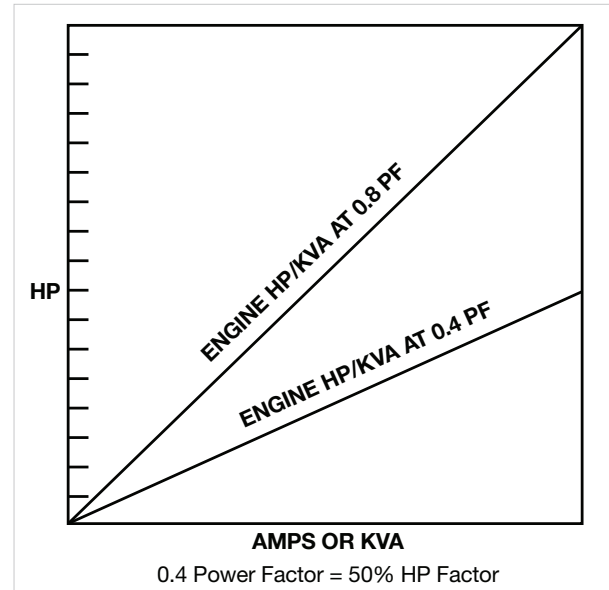
VOLTAGE DIP (CONT)

The generator 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 generator characteristic allows satisfactory motor-starting results with a generator half the size predicted by the conservative approach, which matches the generator 0.8 power-factor kVA rating to the motor LRKVA rating.

The other characteristic that can substantially reduce the size of the generator 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 generator 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 kilovolts x 0.7 amps = 0.49 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 generator 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 generator, 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 generator-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.

Figure 3: Engine Power Required for Low Power-Factor Load (Source: Rehiko)



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 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.

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 generator power, often allowing a smaller generator 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 generator 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 generator set will be reduced to 60–70 percent of normal.

AUTOTRANSFORMER STARTERS

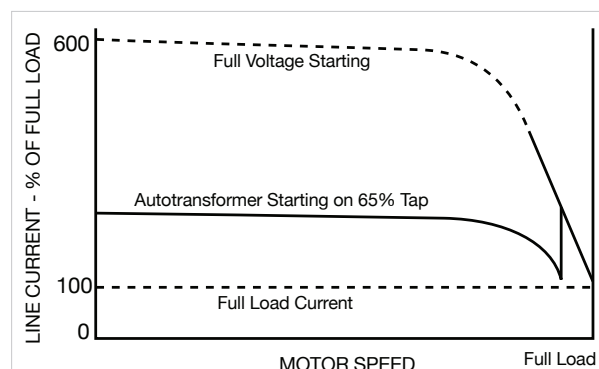
Autotransformer starters provide reduced voltage at the motor terminals from a tapped three-phase autotransformer and generally give the best results with generators. See Figure 5. Taps on the transformer provide selection of 80, 65, or 50 percent of initial line voltage to the motor terminals. Starting 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.

Figure 5: Autotransformer Starting

(Source: Rehlko)

Figure 4: Closed-Transition vs. Open-Transition Starters

(Source: Rehlko)



SOLID-STATE (SOFT-START) STARTERS

A solid-state starter is the 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 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 6.

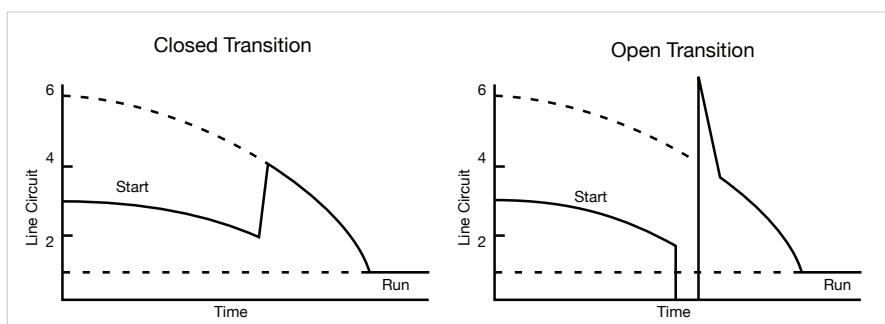
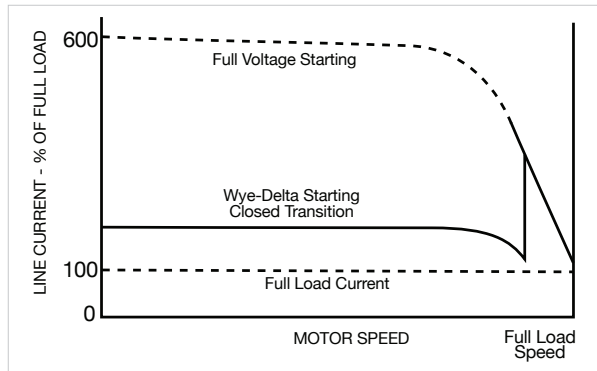


Figure 6: Wye-Delta Starting

(Source: Rehlko)



FACTORS AFFECTING REAL-WORLD MOTOR STARTING

GENERATOR FREQUENCY DIP

The generator'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 revolutions per minute (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 alternator, voltage regulators and exciters affect voltage dip and recovery. A fast-responding excitation system can limit the initial voltage dip as shown in *Figure 7*.

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

PRELOADED GENERATOR SET

The preexisting load on the generator can affect both the frequency dip and voltage dip during motor starting. For example, a 50 percent preloaded generator may dip an additional 2 percent compared to the published figure.

NONLINEAR LOADS

Electronic motor starters and Variable Frequency Drives (VFD) are nonlinear loads. VFD are not actually a motor-starting problem but a potential harmonic distortion problem. Check the generator 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

Unloaded motors 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).

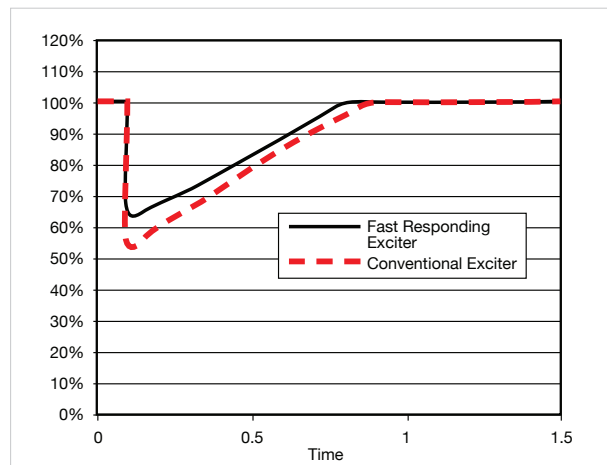
To avoid improper operation of magnetic motor starters and other equipment running on the generator, never exceed a 35 percent instantaneous voltage dip.

LOADED MOTORS

Loaded motors 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 generator'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.

Figure 7: Motor-Starting Voltage vs. Time

(Source: Rehlko)



VOLTAGE RECOVERY VERSUS VOLTAGE DIP

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

SUFFICIENT LRKVA

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

SUFFICIENT GENERATOR TORQUE AND POWER

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

SUFFICIENT ALTERNATOR EXCITATION SYSTEM STRENGTH

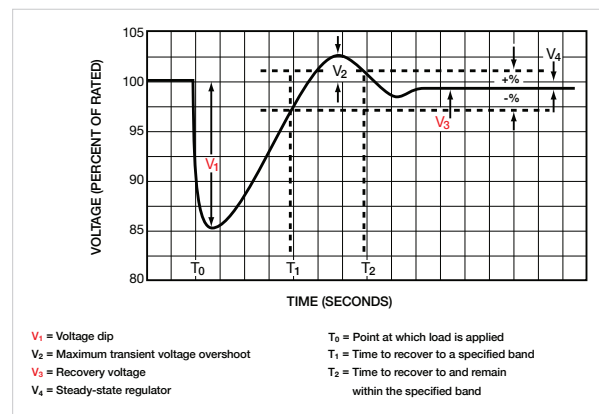
The generator must have sufficient excitation system strength and adequate response to accelerate the motor and return it to operational voltage and speed. This third and final step addresses voltage recovery.

INSTANTANEOUS VERSUS SUSTAINED VOLTAGE DIP

While most generator manufacturers focus on instantaneous voltage dip as a primary criterion for generator sizing, at least one generator manufacturer writes specifications with a different maximum motor-starting kVA value that allows the generator voltage to recover to 90 percent of rated voltage. This concept—known as “sustained voltage dip” maximum KVA—assumes that when the generator 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 generator due to dynamic conditions during motor starting. See *Figure 8*.

Figure 8: Generator Transient Voltage vs. Time for Sudden Load Change

(Source: 2006 NEMA MG1 Part 32)



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.

See *Figure 9*.

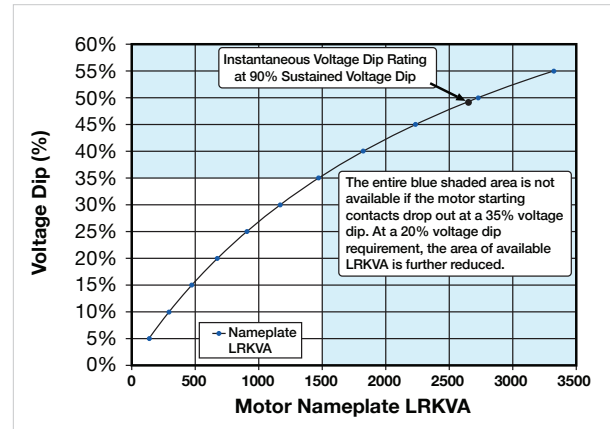
CONCLUSION

When using a generator 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 generator 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 generator 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 generator and motor-starting applications, it's important to utilize proven generator-sizing software to ensure performance of the entire system in its specific application.

Figure 9: Motor Nameplate LRKVA vs. Voltage Dip

(Source: Rehlko)



Power Solutions Center is Rehlko's intuitive generator sizing and specifying software. It includes industry-leading features such as the ability to select generators based on voltage dip, frequency dip, and total harmonic distortion. These features allow the user to select the generator 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, lighting, medical-imaging equipment, and more. For access to the Power Solutions Center, go to <https://www.powersystems.rehlko.com/sizing-program>.

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ABOUT REHLKO

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