MOTOR STARTING – A COMPLEX ISSUE IN GENSET SIZING

Gensets have to supply power to a mixture of loads in addition to large motor loads that switch on and off. Of all the loads a genset supplies, applications with motors present the biggest challenge in sizing. Not only is sizing an application with large motors complex, but different genset manufacturers present different approaches, often with different results i.e genset sizes. This article has been compiled to explain how motors affect genset performance and how sizing exercise attempts to select the most cost-effective and reliable genset for motor starting applications.

MOST COMMON METHODOLOGY FOR SIZING GENSETS FOR MOTOR LOADS

When starting a DOL motor, current at full voltage is typically six times a motor's rated full-load-amperes (FLA). This inrush of current continues 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 due to obvious reasons. However, when a motor is started on genset power, the high inrush currents can result in a large voltage dip that can hinder the motor from reaching its operating speed. The challenge, then, is to size the genset 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. This is why, the most common methodology for sizing gensets for motor starting focuses on understanding allowable instantaneous voltage dips.

The motor-starting KVA can be determined by the motor's nameplate. The National Electrical Manufacturers Association (NEMA) has established code-letter designation for classifying motors according to the ratio of locked-rotor KVAs (LRKVAs) per horsepower. These are also called Starting KVA (SKVA). See Figure 1.

Figure 1

Letter Designation	Starting KVA (SKVA) per Horsepower
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

For example, a 50 hp Code F motor requires 279.5 LRKVA upon starting (50 hp x 5.59 LRKVA per hp = 279.5 LRKVA/hp). LRKVA is also known as "starting KVA" or "SKVA." Typical motor sizes and codes are shown in Figure 2.

Figure 2

SIZE (HP)	CODE	LOCKED ROTOR KVA (LRKVA) PER HP
1 – 2	L or M	9 – 11
3	K	8 – 9
5	J	7 – 8
7.5 - 10	H	6 – 7
16 and UP	G	5.6 – 6.3

POWER FACTOR 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, an overly conservative approach is to size a genset set simply by matching the alternator's KVA to the motor's SKVA or LRKVA as shown Figure 1. This would typically result in a genset with more than twice the capacity necessary. There are several factors which need to be taken into account.

The first 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 till the motor accelerates to a 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 do not require as much horsepower as higher power factor loads.

Power Factor	Engine HP per KVA	Impact on the engine
0.8	X	The engine generates the rated KVA output
0.4	50% of X	The engine will generate two times its rated,name plate KVA output without any detrimental effect till the motor accelerates to its rated speed

<u>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.</u>

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 shown in Figure 1 & 2 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 kilovolts x 0.7 amps = 0.49 KVA).

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 response behavior. 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.

Figure 3

Voltage Dip	Reduction in inrush current at motor starting	Drop in Starting KVA	Drop in motor starting torque
30%	Same as voltage dip i.e 30%	0.7 x 0.7 = 0.49 i.e 50%	Same as KVA dip i.e 50%

As shown in Figure 3, voltage dips also reduce the torque a motor can supply to its load e.g. a compressor, centrifugal pump etc. 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.

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 avoid 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. The most common and popular is **Solid-state (soft-start) starters.**

FACTORS AFFECTING REAL-WORLD MOTOR STARTING

Figure 4 shows factors which affect motor starting in the real world situation

Figure 4

Genset Frequency Dip	Starting a large motor, results in drop in engine rpm, which results in a frequency drop, which results in a further increase in voltage dip
Voltage regulator and excitation system	A fast-responding excitation system can limit the initial voltage dip. On voltage dips of 35 percent or less, a fast responding system will start the motor faster. However, 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.
Preloaded genset	A preloaded genset can affect both frequency dip and voltage dip. For example, a 50 percent preloaded genset may result in an additional 2 percent dip compared to the normal figure.
Non linear loads	For example, Electronic motor starters and Variable Frequency Drives (VFDs) are nonlinear loads. VFDs do not constitute a motor-starting problem but a potential harmonic distortion problem.
Unloaded Motors	A few examples of unloaded motors include centrifugal blowers, rotary and centrifugal pumps (starting under low head pressure) and fan motors (starting with low restriction). These tend to reach operating speed quickly.
Loaded Motors	A few examples of loaded motors include rock crushers, elevators, conveyors, single/multi-cylinder compressors and submersible pumps etc These tend to take longer to accelerate and recover to full voltage. With loaded motors, there is a more significant relationship between recovery voltage during motor starting and the gensets ability to accelerate the motor to full speed and rated voltage.

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:

Figure 5

Requirement 1: Sufficient LRKVA / SKVA to cater for the instantaneous voltage dip for inrush current	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.
Requirement 2: Sufficient genset torque and power	The torque available from the genset must exceed the torque required by the motor load, or the motor will stall or never start.
Requirement 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.

As a thumb rules the following generator sizes will keep the voltage dip during the motor starting within acceptable limit:

Figure 6

Starting KVA Direct-On-Line (DOL) Motors	kVA= 6*rated kVA of the motor
Starting KVA Star-Delta Motors	kVA= 2*rated kVA of the motor

Most generators are capable of delivering 300% of the rated current for 10 seconds, which is sufficient time for most induction motors to get up to the rated speed. So for DOL starting a generator rated 2 to 3 times the kVA of the motor will easily supply the starting kVA of the motor and for a star/delta start even a generator sized just above the rated motor kVA will be sufficient.

GENSIZING FOR MOTOR STARTING ON A GAS GENERATOR:

A 540 KW compressor motor is to be started on a gas generator of 1500 KW which is preloaded to approximately 60% of its full load rating. Single-step-load-acceptance capability of the gas generator is 50%. The compressor efficiency is 96%; running power factor is 89%; SKVA is 3.0 per hp. Find out whether the generator size is sufficient to start the compressor motor.

Nominal compressor rating	540 KW
Compressor efficiency	96%
Full absorbed power of compressor	540 / 0.96 i.e 562.5 KW
Full load KVA requirement at power factor of 0.89	562.5 / 0.89 i.e 632
Full Load Ampere (FLA) at 400 V	632 x 1.44 i.e 910 Amperes
Full Load KVA at starting (LRKVA of 3 / hp)	632 x 3 i.e 1896
Full Load Ampere (FLA) at starting	2730 Amperes
Power Factor at starting	0.45
Compressor Impact at starting	1896 x 0.45 i.e 853 KWe
Generator preloaded 60%	1500 x 0.6 i.e 900 KW
Maximum impact generator can take at 60% preload	1500 – 900 i.e 600 KWe
Generator one-step-load-acceptance capability (torque load capacity)	50% i.e 750 KW < 853 KW required to start compressor

CONCLUSION:

Even when not preloaded at all, 1500 KW generator with single-step-load-acceptance capability of 50% will not take the impact load of 853 KWe anyway. Hence, customer must theoretically choose a machine of at least 1700 KWe output from single-step-load-acceptance perspective.

When preloaded to approximately 60% of its nominal rating the 1500 KW generator cannot accept the impact of 853 KWe for starting the 540kW compressor. Since it only has 600 KW (1500 KW less 60%) available at this preload and the requirement is additional 253 KW (853 – 600), the customer should theoretically opt for a gas generator of at least 1750 KWe (1500 + 253), and preferably 1800 KWe to absorb the starting torque of 540 KWe compressor. Deration characteristics due to temperature and higher altitudes will further affect the sizing exercise. So will the temperature and pressure compensation factors for the gas engines. Engine(s) with lower deration will meet the requirement that much more easily.

One way of overcoming the starting torque issue is that the customer should change the method of starting the motor. Possibly a change to some form of electronic soft start or Variable Speed Drive (VSD) would be beneficial.

Finally a word about shedding the compressor load as a single load step. There would be no problem at all with gas engines with a strong governing system such as that of Cummins offered by ESL. For further details, please contact us at customercare@eslpk.com