Power Generation

# Chapter 3

# Sizing

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# CHAPTER 3 CONTENTS

# 3 – ELECTRICAL LOAD IMPACT ON GENERATOR SIZING

## Overview

This section focuses on the impact of loads on generator set sizing. It is important to assemble a reasonably accurate load schedule early in the design phase of power generation projects because the load is the single most important factor in generator sizing. If all the load equipment information needed for sizing is not available early in the project, the first sizing calculations will have to be based on estimates and assumptions. This should be followed by recalculations when actual, more accurate information becomes available. Different load types – motors, uninterruptible power supplies (UPS), variable frequency drives (VFD), medical diagnostic imaging equipment and fire pumps, have considerable and different influences on generator set sizing.

## Applications and Duty Ratings

### Generator Set Duty Ratings

Determining the loads required to be supported by a generator set is a function of the type of application and required duty. Generally, there are three duty classifications for generator set applications, Standby, Prime or Continuous. These classifications are defined in Section NO TAG, *Preliminary Design*. Available ratings for generator sets vary according to these classifications. A generator set used in Standby applications is used as a backup to the primary (utility) power source and is expected to be used infrequently, so the Standby rating is the highest available for the set. Prime rated sets are expected to operate unlimited hours and the generator set is considered the primary source of power for varying loads, so the Prime rating is typically about 90% of the Standby rating. In Continuous duty applications, the set is expected to produce rated output for unlimited hours at constant load (applications where the set may be operated in parallel with a utility source and base loaded), so the Continuous rating is typically about 70% of the Standby rating. Load carrying capability of the generator set is a function of the expected life or interval between overhauls.

### Mandated and Optional Applications

Fundamentally, generator set applications can be lumped into two basic categories, those that are mandated by codes (legally required) and those that are desired for economics (generally associated with power availability or reliability). These categories will drive a completely different set of choices when decisions must be made regarding what loads to put on the generator set.

**Code Mandated**

These applications are typically those judged by authorities as emergency or legally required standby, where life safety and life support are paramount. These types of applications may be stipulated in building codes or codes specific to life safety, and typically involve facilities such as health care (hospitals, nursing care, clinics), high rise construction, and places of assembly (theaters, assembly halls, sporting facilities, hotels). Typically, the generator set will provide backup power to loads such as egress lighting, ventilation, fire detection and alarm systems, elevators, fire pumps, public safety communication systems, and even industrial process where power loss creates a life safety or health hazard. Other legally required systems are mandated when it is determined that loss of the normal utility power constitutes a hazard or will hamper rescue or fire fighting operations. To determine the minimum loads that must be supplied by the generator, confer with the local code authority and related standards. Additional optional loads may be applied to the generator in most applications if approved by the local code authority.

### Optional Standby

This type of system installation has become more frequent as power availability has become more critical. These systems power facilities like industrial and commercial buildings and serve loads such as heating, refrigeration, data processing communications, and critical industrial processes. Generators are often justifiable where loss of utility power could cause discomfort or interruption of critical process threatening products or process equipment.

### Prime and Continuous

Applications for generator sets that supply prime or continuous duty power are becoming increasingly prevalent in developing countries and for many distributed power generation applications. Many opportunities exist with utilities on the generation side and utility customers on the consumption side. Deregulation and more strict environmental regulations have electric utilities seeking alternative power production and distribution alternatives to new central generating plant construction like peak shaving and interruptible rate structures to satisfy increasing demand. Utility customers are using on–site generation to reduce utility peak demand and continue to pursue cogeneration opportunities where simultaneous demand for both electric power and heat exist.

In any case, one must be aware that generator sets generally are a small power source compared to the normal utility source and the load operating characteristics can have a profound effect on power quality if the generator is not sized properly. Given that a generator is a limited power source, whenever loads are connected to or disconnected from a generator, voltage and frequency disturbances must be expected. These disturbances must be maintained within limits acceptable to all connected loads. In addition, voltage distortion of the generator output voltage will result when non–linear loads producing harmonic currents are connected. This distortion can be considerably greater when operating on generator than when the load is supplied from the utility/mains and will cause additional heating in both the generator and the load equipment if not kept in check. Consequently, generators larger than required to supply adequate load running power are needed to limit voltage and frequency disturbance during transient loading and limit harmonic distortion where serving non–linear loads like computers, UPSs and VFDs.

Generator sizing software programs now allow precise generator set selection and provide a higher level of confidence for purchasing a system large enough for your needs – and no larger. While most generator set sizing exercises are best done with sizing programs such as GenSize from Cummins Power Generation (See Appendix A) – or with the help of a manufacturer's representative – it is still instructive to know what goes into selecting the right generator set for your application.

Besides connected load, numerous other factors affect the generator set sizing; starting requirements of loads such as motors and their mechanical loads, single–phase load imbalance, non–linear loads such as UPS equipment, voltage dip restrictions, cyclic loads, etc.

## Understanding Loads

### Load Running and Starting Requirements

The power required by many load types can be considerably higher while starting the load than required for continuous steady state running (most motor driven loads that don't employ some type of soft start equipment). Some loads also require higher peak power during operation than while running (welding and medical imaging equipment, for example). Still other loads (non–linear loads like UPS, computers, VFDs and other electronic loads) cause excessive generator distortion unless the generator is sized larger than what is required to power the load. The power source must be capable of supplying all operating power requirements of the load.

During starting or peak load operating conditions, sudden load transients can cause voltage and frequency disturbances harmful to the connected load or large enough to prevent successful starting or proper load operation if the generator is undersized. While some loads are quite tolerant of short term transient voltage and frequency disturbances, other loads are quite sensitive. In some cases, the load equipment may have protective controls that cause the load to shut down under these conditions. Although not as critical, other effects like lights dimming or momentary surging of elevators can be, at the least, disturbing.

A generator set is a limited power source both in terms of engine power (kW) and generator volt–amperes (kVA), regardless of the type of excitation system. Because of this, load changes will cause transient excursions in both voltage and frequency. The magnitude and duration of these excursions are affected by the characteristics of the load and the size of the generator relative to the load. A generator set is a relatively high impedance source when compared to the typical utility transformer. See further information in Section 4, *Equipment Selection.*

## Load Step Sequencing

In many applications, it may be advisable to limit the amount of load to be connected or started by the generator set at any one time. Loads are commonly stepped onto the generator set in sequence to reduce the starting requirements and, thus, the size of generator required. This requires load control and equipment to switch the load onto the generator[1]. Multiple transfer switches are commonly used for this purpose. Individual transfer switches can be adjusted to connect loads at different times using standard time delay transfer settings to stagger loads. A few seconds time delay to allow the generator to stabilize voltage and frequency is recommended between load steps. This, of course, will mean that any emergency or legally required loads will need to be connected first to meet code requirements. Loads requiring higher starting power, like large motor loads, should be started while minimum load is connected. UPS loads can be left to last since the UPS load is being carried on battery.

With that basic background, individual load operating characteristics are discussed below.

## Load Types

### Lighting Loads

Calculations of lighting are fairly straightforward, a summation of the lamp or fixture wattage or required wattage for lighting circuits, plus the wattage required for ballasts. Common lighting types are Incandescent – standard bulb–type lamp assemblies that typically use a tungsten filament, fluorescent – a ballast driven ionized gas lamp – also apply for gas discharge lighting, and discharge – low–pressure sodium, high–pressure sodium, etc. Tables 3–1 and 3–2 contain some useful representative data.

| TYPE OF LIGHTING | SPF | RPF |
|---|---|---|
| Fluorescent | 0.95 | 0.95 |
| Incandescent | 1.00 | 1.00 |
| High Intensity Discharge | 0.85 | 0.90 |

**Table 3–1.** Lighting Power Factors (Starting and Running)

| LAMP | BALLAST |
|---|---|
| 48 Inch T–12, 40 W, Preheat | 10 W |
| 48 Inch T–12, 40 W, Rapid Start | 14 W |
| High Output 40 W Fluorescent | 25 W |
| Mercury, 100 W | 18–35 W |
| Mercury, 400 W | 25–65 W |

**Table 3–2.** Ballast Power

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[1] Cummins Power Generation offers network–based cascading load–control systems.

### Air Conditioning Loads

Air conditioning loads are generally specified in tons. To estimate power requirements in kilowatts, a conversion of 2 HP/ton is used as a very conservative estimate of the total load for a lower efficiency unit. If you want a more exact size and know the individual component motor loads in the A/C equipment, sum them individually and come up with a demand factor for what loads are likely to start simultaneously.

### Motor Loads

There is a wide variety of motor types and types of loads connected to those motors, each of which affects the motor's starting and running characteristics. Following is a discussion of many of these differences and characteristics and their affects on generator set sizing choices.

#### Low– and High–Inertia

The moment of inertia of a rotating mass, such as a motor and its load, is a measure of its resistance to acceleration by motor starting torque. Starting torque requires more generator set engine power (SkW) than running load. Rather than having to perform calculations, however, it is usually sufficient to broadly characterize loads as high–inertia loads or as low–inertia loads for the purpose of determining engine power needed to start and accelerate motor loads. Therefore, low–inertia loads are those that can be accelerated when a service factor of 1.5 or less can be assumed, whereas, high–inertia loads are those where a service factor greater than 1.5 must be assumed. A higher service factor must also be assumed for mechanically unbalanced or pulsating loads. **Table 3–3** shows categorizations of common loads.

| Low–inertia Loads* | High–Inertia Loads** |
|---|---|
| Fans and centrifugal blowers | Elevators |
| Rotary compressors | Single– and Multi–Cylinder Pumps |
| Rotary and centrifugal pumps | Single– and Multi–Cylinder Compressors |
|  | Rock Crushers |
|  | Conveyers |

**Table 3–3.** Rotating Inertia Summary

*Exceptionally large fans or pumps that work against tall heads may not qualify as lo inertia loads. If unsure, assume High–Inertia.
**High–inertia loads include mechanically pulsating and unbalanced loads.

#### Over 50 HP

A large motor started across–the–line with a generator set represents a low impedance load while at locked rotor or initial stalled condition. The result is a high inrush current, typically six times the rated (running) current. The high inrush current causes generator voltage dip. This voltage dip is composed of the instantaneous transient voltage dip and the recovery voltage dip.

The instantaneous transient voltage dip occurs at the instant the motor is connected to generator output and is strictly a function of the relative impedances of the generator and the motor. Instantaneous voltage dip is the voltage dip predicted by the voltage dip curves published on the alternator data sheets[2]. These dip curves provide an idea of

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[2] Voltage dig curves for Cummins Power Generation equipment are available on the Power Suite Library CD.

what might be expected for the instantaneous dip, assuming frequency is constant. If the engine slows down due to a heavy starting kW requirement, the transient voltage dip may be exaggerated as the torque–matching characteristic of the voltage regulator rolls off alternator excitation to help the engine recover speed.

Following detection of the instantaneous transient voltage dip, the generator excitation system responds by increasing excitation to recover to rated voltage — at the same time as the motor is accelerating to running speed (assuming the motor develops enough torque). Motor torque, for induction motors, is directly proportional to the square of the applied voltage. Motor acceleration is a function of the difference between motor torque and the torque requirements of the load. In order to avoid excessive acceleration times, or motor stall, the generator must recover to rated voltage as quickly as possible.

The manner in which generator voltage recovers is a function of the relative sizes of the generator and motor, engine power (kW capacity) and generator excitation forcing capability. Several milliseconds after the initial transient voltage dip, the voltage regulator applies full forcing voltage to the generator exciter resulting in a buildup of the main generator field current in accordance with the exciter and main field time constants. Generator set components are designed and matched to achieve the shortest possible response time while maintaining voltage stability and avoiding engine overload. Excitation systems that respond too quickly or that are too “stiff” can actually overload the engine when starting large motors. Depending on the severity of the load, the generator should recover to rated voltage within several cycles, or at most, a few seconds.

For motor starting applications, both the initial transient voltage dip and the recovery voltage need be considered. A generator should be sized so that it will not exceed the initial transient voltage dip specified for the project, and so that it will recover to a minimum of 90 percent of rated output voltage with the full motor locked rotor kVA applied. Thus, the motor can deliver approximately 81 percent (0.9 x 0.9 = 0.81) of its rated torque during acceleration, which has proven adequate for most starting applications. In lieu of unique project specifications, a 35% starting voltage dip is considered acceptable in a generator set motor starting situation.

Various types of reduced–voltage motor starters are available to reduce the starting kVA of a motor in applications where reduced motor torque is acceptable. Reducing motor starting kVA can reduce the voltage dip, the size of the generator set and provide a softer mechanical start. As discussed next, however, caution must be used when applying these starters to generator sets.

### *Three–Phase Starting Methods*

There are several methods available for starting three–phase motors, as summarized in **Table 3–4** and as elaborated in the Appendix C – Reduced voltage Motor Starting. The most common starting method is direct, across–the–line (full voltage) starting. Motor starting requirements can be reduced by applying some type of reduced–voltage or solid–state starter, resulting in a smaller recommended generator set. However, caution must be used when applying any of these reduce–voltage starting methods. Since motor torque is a function of the applied voltage, any method that reduces motor voltage also reduces motor torque during starting. These starting methods should only be applied to low–inertia motor loads unless it can be determined that the motor will produce adequate torque for accelerating during starting. Additionally, these starting methods can produce very high inrush currents when they transition from start to run (if the transition occurs before the motor reaches operating speed), resulting in starting requirements approaching an across–the–line start. If the motor does not reach near–rated operating speed prior to transition, excessive voltage and frequency dips can occur when employing these starters with generator sets. If unsure how the starter and load will react, assume across–the–line starting.

*Variable Frequency Drives (VFDs)*

Of all classes of non–linear load, variable frequency drives, which are used to control the speed of induction motors, induce the most distortion in generator output voltage. Larger alternators are required to prevent alternator overheating due to the harmonic currents induced by the variable frequency drive, and to limit system voltage distortion by lowering alternator reactance.

For example, conventional current source inverter type VFD loads on a generator must be less than approximately 50 percent of generator capacity to limit total harmonic distortion to less than 15 percent. More recently, Pulse Width Modulated type VFD's have become increasingly more cost effective and prevalent and induce substantially lower harmonics. The alternator need only be oversized by about 40% for these drives.

| STARTING METHOD | % FULL VOLTAGE APPLIED (TAP) | % FULL VOLTAGE kVA | % FULL VOLTAGE TORQUE | SkVA MULTIPLYING FACTOR | SPF |
|---|---|---|---|---|---|
| Full Voltage | 100 | 100 | 100 | 1.0 | – |
| Reduced Voltage Autotransformer | 80<br>65<br>50 | 64<br>42<br>25 | 64<br>42<br>25 | 0.64<br>0.42<br>0.25 | –<br>–<br>– |
| Series Reactor | 80<br>65<br>50 | 80<br>65<br>50 | 64<br>42<br>25 | 0.80<br>0.65<br>0.50 | –<br>–<br>– |
| Series Resistor | 80<br>65<br>50 | 80<br>65<br>50 | 64<br>42<br>25 | 0.80<br>0.65<br>0.50 | 0.60<br>0.70<br>0.80 |
| Star Delta | 100 | 33 | 33 | 0.33 | – |
| Part Winding (Typical) | 100 | 60 | 48 | 0.6 | – |
| Wound Rotor Motor | 100 | 160* | 100* | 1.6* | – |

* – These are percents or factors of running current, which depend on the value of the series resistances added to the rotor windings.

**Table 3–4.** Reduced Voltage Starting Methods and Characteristics

For variable speed drive applications, size the generator set for the full nameplate rating of the drive, not the nameplate rating of the driven motor. Harmonics may be higher with the drive operating at partial load and it may be possible that a larger motor, up to the full capacity of the drive, could be installed in the future.

*NEMA Motor Code Letter*

In North America, the NEMA standard for motors and generators (MG1) designates acceptable ranges for motor starting kVA with Code Letters "A" through "V." Motor design must limit starting (locked rotor) kVA to a value within the range specified for the Code Letter marked on the motor. To calculate motor starting kVA, multiply motor horsepower by the value in **Table 3–5** that corresponds with the Code Letter. The values in **Table 3–5** are the averages of the specified ranges of values for the Code Letters.

| Code Letter | Factor | Code Letter | Factor | Code Letter | Factor |
|---|---|---|---|---|---|
| A | 2 | H | 6.7 | R | 15 |
| B | 3.3 | J | 7.5 | S | 16 |
| C | 3.8 | K | 8.5 | T | 19 |
| D | 4.2 | L | 9.5 | U | 21.2 |
| E | 4.7 | M | 10.6 | V | 23 |
| F | 5.3 | N | 11.8 | | |
| G | 5.9 | P | 13.2 | | |

**Table 3–5.** Multiplying Factors Corresponding with Code Letters

*Three–Phase Motor Design*

In North America, design B, C, or D type motors are three–phase squirrel–cage induction motors classified by NEMA (National Electrical Manufacturers Association) with respect to a maximum value for locked rotor current and minimum values for locked rotor torque, pull–up torque and breakdown torque. High Efficiency type motors are premium–efficiency three–phase squirrel–cage induction motors with minimum torque values similar to design B type motors, but with higher maximum locked rotor current and higher nominal full–load efficiency. See **Table 3–6** for nominal standard values for Design B, C, D and High Efficiency motors.

*Single–Phase Motor Design*

See **Table 3–7** for nominal standard values for single–phase induction motors.

### Uninterruptible Power Supply Loads

A static uninterruptible power supply (UPS) uses silicon controlled rectifiers (SCRs) or other static devices to convert AC voltage to DC voltage. The DC voltage is used to produce AC voltage through an inverter circuit at the output of the UPS. The DC voltage is also used to charge batteries. the energy storage medium for the UPS. The switching SCRs at the input induce harmonic currents in the generator set's alternator. The affects of these currents include additional winding heating, reduced efficiency, and AC waveform distortion. The result is a requirement for a larger alternator for a given kW output from the genset.

UPS devices can also be sensitive to voltage dip and frequency excursions. When the rectifier is ramping up, relatively broad swings in frequency and voltage can occur without disrupting operation. However, once the bypass is enabled, both frequency and voltage must be very stable or an alarm condition will occur.

Past problems of incompatibility between generator sets and static UPS devices led to many misconceptions about sizing generator sets for this type of load. In the past, UPS suppliers recommended oversizing the generator set by two to five times the UPS rating, but even then some problems persisted. Since then, most UPS manufacturers have addressed the problems of incompatibility and it is now more cost effective to require UPS devices to be compatible with the generator set than to significantly oversize the generator.

When sizing a generator use the nameplate rating of the UPS, even though the UPS itself may not be fully loaded, plus the battery charge rating. The UPS will typically have a battery charging capability of 10 to 50 percent of its UPS rating. If the batteries are discharged when the UPS is operating on the generator set, the generator set must be capable of supplying both the output load and the battery charging. Most UPSs have an adjustable current limit. If this limit is set at 110% – 150% of UPS rating, that is the peak load the generator set will need to supply immediately after a utility power outage. A second reason for using the full UPS rating is that additional loads up to nameplate rating may be added to the UPS in the future. The same applies to redundant UPS systems. Size the generator set for the combined nameplate ratings of the individual UPS devices in applications where, for example, one UPS is installed to back up another and the two are on line at all times with 50 percent load or less.

Due to being non–linear loads, UPS equipment induces harmonics in the generator output. UPS devices equipped with harmonic input filters have lower harmonic currents than those without. Harmonic filters must be reduced or switched out when the load on the UPS is small. If not, these filters can cause leading power factor on the generator set. See *Leading Power Factor Load* in the *Mechanical Design* section. The number of rectifiers (pulses) also dictates the degree of alternator over–sizing required. A 12 pulse rectifier with a harmonic filter results in the smallest recommended generator set.

Most UPS devices have a current–limiting function to control the maximum load that the system can apply to its power supply, which is expressed as a percentage of the full load rating of the UPS. The total load which the UPS applies to its power supply is controlled to that value by limiting its battery charging rate. If, therefore, the maximum load is limited to 125 percent and the UPS is operating at 75 percent of rated capacity, battery charging is limited to 50 percent of the UPS rating. Some UPS devices reduce the battery charging rate to a lower value during the time that a generator set is powering the UPS.

| HP | DESIGN *B, C &D* MOTORS | | HIGH EFFICIENCY MOTORS | | FOR ALL MOTORS | |
|---|---|---|---|---|---|---|
| | NEMA CODE LETTER* | EFFICIENCY (%) | NEMA CODE LETTER* | EFFICIENCY (%) | STARTING PF (SPF) | RUNNING PF (RPF) |
| 1 | N | 73 | N | 86 | 0.76 | 0.70 |
| 1–1/2 | L | 77 | L | 87 | 0.72 | 0.76 |
| 2 | L | 79 | L | 88 | 0.70 | 0.79 |
| 3 | K | 83 | L | 89 | 0.66 | 0.82 |
| 5 | J | 84 | L | 90 | 0.61 | 0.85 |
| 7–1/2 | H | 85 | L | 91 | 0.56 | 0.87 |
| 10 | H | 86 | K | 92 | 0.53 | 0.87 |
| 15 | G | 87 | K | 93 | 0.49 | 0.88 |
| 20 | G | 87 | K | 93 | 0.46 | 0.89 |
| 25 | G | 88 | K | 94 | 0.44 | 0.89 |
| 30 | G | 88 | K | 94 | 0.42 | 0.89 |
| 40 | G | 89 | K | 94 | 0.39 | 0.90 |
| 50 | G | 90 | K | 95 | 0.36 | 0.90 |
| 60 | G | 90 | K | 95 | 0.36 | 0.90 |
| 75 | G | 90 | K | 95 | 0.34 | 0.90 |
| 100 | G | 91 | J | 96 | 0.31 | 0.91 |
| 125 | G | 91 | J | 96 | 0.29 | 0.91 |
| 150 | G | 91 | J | 96 | 0.28 | 0.91 |
| 200 | G | 92 | J | 96 | 0.25 | 0.91 |
| 250 | G | 92 | J | 96 | 0.24 | 0.91 |
| 300 | G | 92 | J | 96 | 0.22 | 0.92 |
| 350 | G | 93 | J | 97 | 0.21 | 0.92 |
| 400 | G | 93 | J | 97 | 0.21 | 0.92 |
| 500 & UP | G | 94 | J | 97 | 0.19 | 0.92 |

**Table 3–6.** Three–Phase Motor Defaults: NEMA Code, EFF, SPF, RPF

| HP | NEMA CODE LETTER* | EFFICIENCY (%) | STARTING PF (SPF) | RUNNING PF (RPF) |
|---|---|---|---|---|
| SPLIT–PHASE | | | | |
| 1/6 | U | 70 | 0.8 | 0.66 |
| 1/4 | T | 70 | 0.8 | 0.69 |
| 1/3 | S | 70 | 0.8 | 0.70 |
| 1/2 | R | 70 | 0.8 | 0.70 |
| PERMANENT SPLIT CAPACITOR (PSC) | | | | |
| 1/6 | G | 70 | 0.8 | 0.66 |
| 1/4 | G | 70 | 0.8 | 0.69 |
| 1/3 | G | 70 | 0.8 | 0.70 |
| 1/2 | G | 70 | 0.8 | 0.72 |
| CAPACITOR START/INDUCTION RUN | | | | |
| 1/6 | R | 40 | 0.8 | 0.66 |
| 1/4 | P | 47 | 0.8 | 0.68 |
| 1/3 | N | 51 | 0.8 | 0.70 |
| 1/2 | M | 56 | 0.8 | 0.73 |
| 3/4 | L | 60 | 0.8 | 0.75 |
| 1 | L | 62 | 0.8 | 0.76 |
| 1–1/2 | L | 64 | 0.8 | 0.78 |
| 2 | L | 65 | 0.8 | 0.78 |
| 3 to 15 | L | 66 | 0.8 | 0.79 |
| CAPACITOR START/CAPACITOR RUN | | | | |
| 1/6 | S | 40 | 0.8 | 0.66 |
| 1/4 | R | 47 | 0.8 | 0.68 |
| 1/3 | M | 51 | 0.8 | 0.70 |
| 1/2 | N | 56 | 0.8 | 0.73 |
| 3/4 | M | 60 | 0.8 | 0.75 |
| 1 | M | 62 | 0.8 | 0.76 |
| 1–1/2 | M | 64 | 0.8 | 0.78 |
| 2 | M | 65 | 0.8 | 0.78 |
| 3 to 15 | M | 66 | 0.8 | 0.79 |

**Table 3–7.** Single–Phase Motor Defaults: NEMA Code, EFF, SPF, RPF

### Battery Charger Loads

Battery Chargers typically use silicon–controlled rectifiers (SCRs). A battery charger is a non–linear load, requiring an over–sized alternator to accommodate additional heating and minimize voltage distortion caused by battery charger induced harmonic currents. The number of rectifiers (pulses) dictates the degree of alternator over–sizing required. A 12 pulse rectifier results in the smallest recommended generator set.

### Medical Imaging Equipment (X–ray, Cat Scan, MRI)

Imaging equipment such as X–Ray, Cat Scan and MRI produce unique starting and running characteristics that must be considered when sizing a generator set. Peak kVA load (kVP x ma) and allowable voltage dip are the essential factors for sizing a generator set for medical imaging applications. Two additional factors must be understood for all medical imaging applications.

First, when the medical imaging equipment is powered by the generator set, the image may be different than when it is powered by the commercial utility line. The reason for this is due to the difference in voltage dip characteristics. As **Figure 3–1** illustrates, the dip will tend to be constant when the utility is the power source, and be deeper and more variable when the generator set is the power source. The generator set voltage regulator’s attempt to regulate the voltage will also affect the voltage dip characteristic.

Second, between the time the operator makes the adjustment for the image and takes the image, no large load changes should take place from elevators or air conditioning switching on or off.

Medical imaging equipment is usually designed to be powered by the utility source. Most equipment, however, has a line voltage compensator, adjustable either by the installer or the operator. In applications where the generator set is the only power source, the line voltage compensator can be adjusted for the voltage dip expected with the generator set. When the imaging equipment has been adjusted for utility power, the generator set will have to duplicate the voltage dip of the utility as closely a possible. From past experience, satisfactory images can be expected when the generator (alternator) kVA rating is at least 2.5 times the peak kVA of the imaging equipment. A voltage dip of 5 to 10 percent can be expected when sizing on this basis. Peak kVA and required generator set kVA for variously rated imaging equipment is listed in **Table 3–8.**

### Fire Pump Applications[3]

Special consideration must be given to fire pumps due to their critical status and special code requirements. The North American National Electrical Code (NEC) contains requirements limiting voltage dip to 15 percent when starting fire pumps. This limit is imposed so that motor starters will not drop out during extended locked rotor conditions and so that fire pump motors will deliver adequate torque to accelerate pumps to rated speeds to obtain rated pump pressures and flows. The generator set does not have to be sized to provide the locked rotor kVA of the fire pump motor indefinitely. That would result in an oversized generator set, which could lead to maintenance and reliability due to an under–utilized generator set.

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[3] This is Cummins Power Generation’s interpretation of the 1996 edition of NFPA Standard No. 20, Centrifugal Fire Pumps. Design engineers should also review the standard itself.

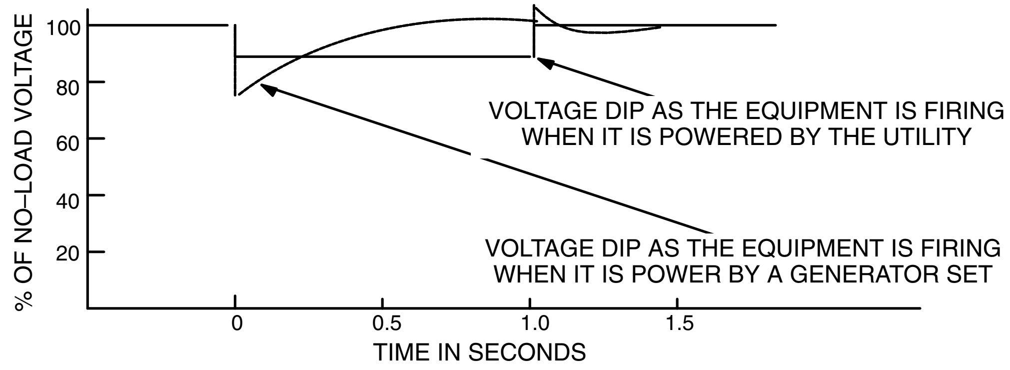

**Figure 3–1.** Voltage Dip in Medical Imaging Applications

| **IMAGING EQUIPMENT RATING** | | **PEAK kVA*** | **MINIMUM GENERATOR kVA** |
|---|---|---|---|
| Ma | kVP | | |
| 15 | 100 | 1.5 | 3.8 |
| 20 | 85 | 1.7 | 4.3 |
| 40 | 125 | 5.0 | 12.5 |
| 50 | 125 | 6.3 | 15.8 |
| 100 | 125 | 12.5 | 31.3 |
| 200 | 125 | 25.0 | 62.5 |
| 300 | 125 | 37.5 | 93.8 |
| 300 | 150 | 45.0 | 112.0 |
| 500 | 125 | 62.5 | 156.0 |
| 500 | 150 | 75.0 | 187.0 |
| 700 | 110 | 77.0 | 192.0 |
| 1200 | 90 | 108.0 | 270.0 |
| * – Multiply the peak kVA by the power factor (PF) to obtain Peak kW. If PF is unknown, assume 1.0. | | | |

**Table 3–8.** Generator Set Requirements for Medical Imaging Applications

Whenever a reduced voltage starter is used for a fire pump motor, regardless of the type, allow generator capacity for across–the–line starting. The fire pump controller includes either a manual–mechanical, manual–electrical, or automatic means to start the pump across–the–line in the case of a controller malfunction.

The additional generation capacity can be managed, if practical, by providing automatic load–shedding controls on low–priority connected loads so that otherwise idle generator set capacity for the fire pump may be used for those same loads. The controls should be arranged to shed loads prior to starting the fire pump.

Another option is to consider a diesel engine driven fire pump rather than an electric motor pump. The economics generally favor electric motor driven pumps, but the fire protection engineer may prefer a diesel engine drive. That way, the fire protection system and the emergency power system are kept entirely separate. Some engineers and insurers believe this improves the reliability of both systems. The cost of a transfer switch for the fire pump would be avoided. The generator set does not have to be sized to provide the locked rotor kVA of the fire pump motor indefinitely. That could result in an oversized generator set, which could experience maintenance and reliability issues from being under–utilized.

## Load Characteristics

### Load Voltage and Frequency Tolerances

**Table 3–9** summarizes the tolerance that various loads have for changes in voltage and frequency.

### Regenerative Power

The application of generator sets to loads having motor–generator (MG) drives such as elevators, cranes and hoists, require the consideration of regenerative power. In these applications, the descent of the elevator car or hoist is slowed by the motor–generator which “pumps” electrical power back to the source to be absorbed. The normal utility source easily absorbs the “regenerated” power because it is an essentially unlimited power source. The power produced by the load simply serves other loads reducing the actual load on the utility (mains). A generator set, on the other hand, is an isolated power source that has a limited capability of absorbing regenerative power. Regenerative power absorption is a function of engine friction horsepower at governed speed, fan horsepower, generator friction, windage and core losses (the power required to maintain rated generator output voltage). The regenerative power rating of the set appears on the recommended generator set Specification Sheet and is, typically, 10 to 20 percent of the generator set power rating. (The generator drives the engine, which absorbs energy through frictional losses.)

| EQUIPMENT | VOLTAGE | FREQUENCY | COMMENTS |
|---|---|---|---|
| Induction Motors | +/– 10% | +/– 5% | Low voltage results in low torque and increased temperature.<br>High voltage results in increased torque and starting amps. |
| Coils,<br>Motor Starters% | +/–10 | N/A | The holding force of a coil and its time constant of decay are proportional to the ampere–turns of the coil. Smaller coils may drop out within these tolerances for transient dip. A transient voltage dip of 30 to 40 percent for more than two cycles may cause coil dropout. |
| Incandescent Lighting | +10%, –25% | N/A | Low voltage results in 65% light.<br>High voltage results in 50% life.<br>Low frequency may result in light flicker. |
| Fluorescent Lighting | +/– 10% | N/A | High voltage results in overheating. |
| HID Lighting | +10%, –20% | N/A | Low voltage results in extinguishment.<br>High voltage results in overheating. |
| Static UPS | +10%, –15% | +/– 5% | No battery discharge down to –20% voltage.<br>UPS are sensitive to a frequency change rate (slew rate) greater than 0.5 Hz/sec.<br>Oversizing of the generator may be necessary to limit harmonic voltage distortion. |
| Variable Frequency Drives (VFD) | +10%, –15% | +/– 5% | VFD are sensitive to a frequency change rate greater than 1 Hz/sec.<br>Oversizing of the generator may be necessary to limit harmonic voltage distortion. |
| If voltage does not recover to 90 percent, undervoltage protective devices may lockout, overcurrent devices may interrupt, reduced voltage starters may lockout or step and motors may stall or not have acceptable acceleration. | | | |

**Table 3–9.** Typical Voltage and Frequency Tolerances

An insufficient regenerative power rating for the application can result in excessive elevator descent speed and overspeeding of the generator set.

*NOTE: Excessive regenerative loads can cause a generator set to overspeed and shut down. Applications that are most susceptible to this type of problem are small buildings where the elevator is the major load on the generator set.*

Generally, the regeneration problem can be solved by making sure there are other connected loads to absorb the regenerative power. For example, in small buildings where the elevator is the major load, the lighting load should be transferred to the generator before transferring the elevator. In some cases auxiliary load banks with load bank controls may be needed to help absorb regenerative loads.

### *Load Power Factor (PF)*

Inductances and capacitances in AC load circuits cause the point at which the sinusoidal current wave passes through zero to lag or lead the point at which the voltage wave passes through zero. Capacitive loads, overexcited synchronous motors, etc. cause leading power factor, where current leads voltage. Lagging power factor, where current lags voltage, is more typically the case and is a result of the inductance in the circuit. Power factor is the cosine of the angle by which current leads or lags voltage, where one full sinusoidal cycle is 360 degrees. Power factor is usually expressed as a decimal figure (0.8) or as a percentage (80%). Power factor is the ratio of kW to kVA. Therefore:

**kW = kVA x PF**

Note that three–phase generator sets are rated for 0.8 PF loads and single–phase generator sets for 1.0 PF loads. Loads which cause power factors lower than those at which generators are rated may cause GenSize to recommend a larger alternator or generator set to serve the load properly.

Reactive loads that cause leading power factor can be problematic, causing damage to alternators, loads, or tripping protective equipment. The most common sources of leading power factor are lightly loaded UPS systems using input line harmonic filters or power factor correction devices (capacitor banks) used with motors. Leading power factor load must be avoided with generator sets. The system capacitance becomes a source of generator excitation and loss of voltage control can become a problem. Always switch power factor correction capacitors on and off the system with the load. See Leading Power Factor Loads in the *Electrical Design* section.

### Single–Phase Loads and Load Balance

Single phase loads should be distributed as evenly as possible between the three phases of a three–phase generator set in order to fully utilize generator capacity and limit voltage unbalance. For example, as little as a 10 percent single–phase load unbalance may require limiting the three–phase balanced load to not more than 75 percent of rated capacity. To help prevent overheating and premature insulation failure in three–phase motors, voltage unbalance should be kept below about two percent. See Allowable Single–Phase Load Unbalance Calculation in the *Electrical Design* section.