Standby Generator Set and UPS Compatibility

CATERPILLAR®

Improving System Availability

Due to the growing presence of computers in all aspects of business life over the last several years, the tolerance for unreliable power delivery has decreased dramatically. **Whereas some level of computer downtime due to power disturbances was once endurable, today the cost of a power interruption has become so high that redundancy is required.** This shift in operation has in turn changed how backup power supplies are designed and used.

In the past, power outages were considered inevitable. If a backup energy source was in place, it was used to ride through the short interruptions and allow a graceful system shutdown during the longer ones. Now, however, more companies use sensitive computer modules to control business processes. If a power disturbance interrupts an unprotected load, the result could be a lost run of materials, damage to expensive machinery, dropped calls, loss of sales or a total systems failure that affects life safety operations.

The need for backup power supplies was underscored by the August 14, 2003, outage that affected more than 50 million electricity consumers in the northeastern United States and southern Canada. While this was an unusually large power disruption, the probability of frequent, small disturbances is high. The U.S. electric grid network delivers over 3 trillion kWh a year with roughly 99.9 percent availability. While this rate appears very high to the untrained eye, it actually translates into approximately 8 hours a year of downtime for the utility-connected customer. **The business process community demands availability beginning at six 9s (99.9999 percent) — or only 32 seconds of downtime a year**[1].

To ensure critical systems don't fail because of availability issues, companies are installing secondary electricity sources to both condition power and provide backup to ride through outages. The best source of conditioning and backup delivery of electric power is an Uninterruptible Power Supply (UPS). Two energy storage sources lead the industry — battery and flywheel — and either can be configured for use with an engine-generator for long-term electricity output that is limited only by fuel supply. A critical element of the UPS-generator relationship is compatibility. Too often, generators are the wrong size for the UPS, the 2 units are not synchronized or the start function fails. Any of these problems could leave the power consumer with no electricity and no options.

Backing Up the Primary Supply

Although battery- and flywheel-based UPS units such as the Cat® UPS with Kinetic Power Cell Technology (which is flywheel-based) were designed to serve the same functions — conditioning and maintaining power to the connected load at all times — they have several defining characteristics. For example, battery-based systems require extensive regular maintenance and testing to maximize life expectancy and performance. The Cat UPS, on the other hand, requires periodic service diagnostics and bearing cartridge replacement approximately every 3 years.

A primary advantage of a unit with Kinetic Power Cell Technology over a battery-cell unit is its reliability. **Studies have shown that 70 percent of UPS problems are battery related. This high battery failure issue also occurs when starting a generator set.** Considering that the base assumption for a backup power source must be that the generator will start and assume the required power load on the first try every time it is needed, a successful start rate of only 30 percent is unacceptable. The Cat UPS, however, increases generator and UPS system reliability when coupled with the generator set starting option.

Comparison: Kinetic Power Cell Technology vs. Batteries

	Kinetic energy storage system	Battery-based system
Ride-Through Time	15 seconds under full load. No degradation with use and climate conditions.	15 minutes under full load. Initial purchase runtime degrades with use and climate conditions.
Generator Set Compatibility	Generator set option increases system availability. Low harmonic distortion eliminates additional filters.	Requires oversizing generator set and purchase of UPS total harmonic distortion (THD) input filter. No options to support generator set starter batteries.
Recharging Energy Storage Supply	Recharges flywheel to 100 percent in less than 2.5 minutes. Low recharge current required. No degradation with recharging.	The more batteries are recharged, the less they'll discharge. High recharge current required. Recharge rate is typically 12 times discharge.
Transition of Input Power Sources	No control switching between UPS filter and charger. Simple open transition Automatic Transfer Switch (ATS).	Typically requires disabling charger and input THD filter when transitioning to generator set power. Requires center-off positioning ATS.
Reliability	Mechanical energy storage is predictable and does not require full load testing to verify performance capability.	Even a single cell failure results in system failure. Cause of 70 percent of UPS failures. Non-predictable failure mode. Must be periodically full load tested to verify performance capability.

Understanding Cat UPS

Before exploring how the Cat UPS with Kinetic Power Cell Technology improves on existing technology to provide the highest reliability rate in the industry, it is important to know how the transfer of power from flywheel to engine-generator set occurs.

In normal operation, the Cat UPS continuously conditions power from the utility for voltage sags, dips and surges, and regulates the incoming voltage while using a small amount of energy to keep the flywheel fully charged. This continues until the UPS senses a power disturbance. The flywheel then either supplies power to the critical load or consumes power from the supply to maintain a constant power supply to the connected load until normal input power conditions return.

Comparing Short-Term Protection

One of the most common arguments for battery-based UPS units is the additional ride-through time they provide. Battery strings typically afford 15 minutes of backup power at full load, while the Cat UPS with Kinetic Power Cell Technology has 15 seconds of stored energy at full load. Critics of flywheel UPS units believe more ride-through time is better, but this is not always true.

In truth, 15 minutes of stored power can actually create a false sense of security. Data gathered by the Electric Power Research Institute (EPRI) shows that **a battery-free UPS corrects 94.4 percent of all power disturbances that exceed limits set by the Information Technology Industry Council** (ITIC, formerly Computer and Business Equipment Manufacturers Association). A battery-based UPS with 15 minutes of backup corrects 96 percent[2,3]. The difference is less than 2 percent, which is not a significant amount of additional protection considering the much higher cost of operation in terms of maintenance costs, space required and time spent on upkeep.

The 15 seconds of backup time provided by the Cat UPS with Kinetic Power Cell Technology is ample time to start an engine-generator set. Proponents of battery systems argue that if the generator fails to engage in that 15 seconds, there is not enough time to repair and manually start it. **Failure analysis at nuclear power plants shows that in the vast majority of cases, 15 minutes is also not enough time to repair and retry generator start either**[4]. The mean time to repair a generator set was greater than 4 hours, making the additional 14 minutes and 45 seconds of backup power inadequate.

Making the Perfect Match

There have historically been a host of problems regarding compatibility between a UPS and its standby generator set, and they are more prevalent in battery-based double-conversion UPS systems. One of the biggest incompatibility issues is improper generator set sizing. Most system incompatibility problems involving generator sets and UPS systems arise because the equivalent selection and system design did not consider any power source other than a stiff utility system or “unlimited bus”. When problems do arise, particularly if the system performs satisfactorily on utility, it is very easy to erroneously conclude, “it must be the generator set because the UPS works fine on utility.” It is important to note that loads drawing harmonic currents cause distortion from the source — the source does not produce distortion.

Most battery-based UPS units use a rectifier/charger input control method that creates notches on the incoming power feed, whether it is from a generator set or the utility. These notches prompt problems with some types of generator set controls. Rectifier/chargers can also induce THD that could bring about excessive generator set heating. Manufacturers offer passive filters to address these issues, but the filters themselves can cause other problems, especially if the UPS is lightly loaded. Filters can circulate large reactive currents to an engine-generator set if any instability exists between the UPS and the generator set controls.

Filter capacitors can also create certain types of motors to "self-excite" and continue to run even after utility power has been lost, causing an out-of-control situation and safety risk.

In designing the Cat UPS with Kinetic Power Cell Technology, Caterpillar addressed each of these issues. Using kinetic power instead of a battery string to store energy eliminates most problems. Coupling the Cat UPS with a Cat generator set ensures appropriate sizing — at a smaller ratio than battery UPS units — and proper synchronization. The contributed THD is less than 4 percent, so line noise and generator set heating does not become a problem. **Derating or oversizing a generator set not only increases its cost, but also the cost of installation and ownership.**

Recharging the Temporary Backup Supply

Once the generator set takes over for the temporary backup source, recharging begins — another consideration of UPS-generator set compatibility that must be considered. The UPS begins losing stored energy as soon as the power disturbance is detected. As soon as generator set power is supplied to the UPS, it starts recharging. In doing so, a battery-based system acts as a large capacitor, and the in-rush of current to the batteries takes all available power from the battery charger (typically 25 percent of UPS output capacity). This could load step the generator's engine, causing a system failure and creating a "stop-restart cycle" where the generator set never begins to power the load and the batteries finally run down, cutting off backup power[5].

The Cat UPS with Kinetic Power Cell Technology, however, minimizes this type of problem. Once the generator set starts, it too begins recharging the flywheel while supplying power for the critical load. The amount of recharge current is only to 10 percent of the Cat UPS output capacity to obtain full recharge in less than 2.5 minutes. Fast recharge ensures sufficient energy is available during a transition between UPS input sources or multiple short-term utility problems that do not allow sufficient time for battery recharging.

Generating Reliability

Most generator set reliability problems are due to the starting function rather than the run operation. As discussed earlier, batteries are the weak link of battery-based UPS systems. Generator set batteries are also the root of most generator set reliability problems. Even if a battery string begins with a high rate of availability, it falls off rapidly because the cells deteriorate with each discharge, regardless of the length of time. With each use, they hold less charge, so that eventually the battery string is unable to either recharge completely or discharge properly. **Lead-acid batteries, for example, show a 20 percent failure rate in just 2 to 3 years, and more than 50 percent fail within 5 years.**

Unfortunately, even with regular testing and maintenance, there is no way to know exactly how much generator set starter battery power is available. With the generator set starting option, there is always a sufficient amount of starting power. Frequent generator set start testing does not affect system performance, life or dependability as it does with battery-powered starters. **By simply building in generator set starting redundancy, the Cat UPS with Kinetic Power Cell Technology increases system availability.**

Getting the Big Picture

Reliability is one of the major advantages of the Cat UPS with Kinetic Power Cell Technology over battery-based UPS units, but it’s not the only one. **The Cat UPS is also 96 to 97 percent energy-efficient, compared to 86 to 93 percent for battery systems.** Life expectancy of the system is nearly unlimited — with significantly lower maintenance. It can also withstand virtually any operating conditions. Whereas batteries must be kept at a constant 77° F (25° C) to optimize both life expectancy and performance, the Cat UPS works equally well anywhere from 0 to 104° F (-20 to 40° C). All these factors combine to keep the life cycle costs well below that of a battery-powered UPS.

Solving Power Quality Challenges

Caterpillar has been in the business of building engines and power solutions for more than 75 years. A global supplier and leading U.S. exporter, the company offers a broad range of products with fully integrated design packages. Caterpillar® electric power systems are unwaveringly dependable performers in all types of applications. When it comes to energy solutions, rely on Caterpillar. **With more than 250,000 generator sets installed worldwide, the company has the experience to support its knowledge base.**

The people behind the products keep Caterpillar on the leading edge of power technology. Company employees have earned more than 2,800 patents in the past 6 years. Their advanced technology is backed by a global dealer network with more than 1,500 independent, locally owned locations in 200 countries. With all these resources at its disposal, Caterpillar is the world’s top supplier of everything companies need to generate power and keep it on.

Endnotes

1. Peter Huber and Mark Mills, *The Huber Mills Digital Power Report,* April 2000.

2. "An Assessment of Distribution System Power Quality," Electric Power Research Institute (EPRI), TR-106249, May 1996.

3. Bradley S. Walter, "A Business Case for Battery-Free UPS in Industrial Applications," *Power Systems World,* Chicago, Ill., November 1999.

4. Real Availability Seminar, Cambridge, Mass., November 4-5, 2002.

5. Dexter Hansen, "Tips on Hooking up a Generator (genset [sic]) to a [sic] Uninterruptible Power System (UPS)," 2002.

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NORTH AMERICA
Caterpillar Inc.
Peoria, Illinois, U.S.A.
Tel: (309) 578-6298
Fax: (309) 578-2559

EUROPE, AFRICA, MIDDLE EAST
Caterpillar UK Limited
Vicarage Farm Road
Peterborough, UK
Tel: (44) 1733 583568
Fax: (44) 1733 584624

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Caterpillar S.A.R.L.
Moscow, Russia
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Fax: (65) 6662-8414

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Hong Kong
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Fax: (852) 2848-0223

JAPAN
Caterpillar Power
Systems, Inc.
Tokyo
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Fax: (81) 3-5786-3809

AUSTRALIA
Caterpillar of Australia Ltd.
Victoria, Australia
Tel: (61) 3-9953-9333
Fax: (61) 3-9338-9021

MEXICO, THE CARIBBEAN, SOUTH AMERICA
Latin America
Commercial Division
Miami, Florida, U.S.A.
Tel: (305) 476-6876
Fax: (305) 476-6850

E-mail: CAT_Power@Cat.com
www.catups.com

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Electric Power Generation

System Design

The need for emergency and continuous electrical power is increasing rapidly. Commercial or public structures are totally dependent on electrical energy sources. Personnel safety, environment, and production schedules are adversely affected by lack of power integrity.

Emergency or standby electrical sources usually conform to the normal utility supply, but these restrictions are not imposed with on-site power plants. On-site systems are tailored to exact installation requirements. Frequency, voltage, power levels, and distribution are selected to maximize system operating safety, reliability, and efficiency.

Equipment satisfying exact installation demands is defined in preliminary planning of building design. The power network extends throughout an installation. Early consideration of its requirements and capabilities avoids costly and time consuming design changes.

Utility vs On-Site Power

While the quality of utility power is considered acceptable for any application, certain operating tolerances are defined by organizations such as American National Standards Institute (ANSI) and International Electro-technical Commission (IEC). These are useful when comparing capabilities of on-site generator sets.

Utility Power — ANSI Standard

Service Voltage	95 - 105%	Range A
(Supply)	91.7 - 105%	Range B
Utilization Voltage	91.7 - 105%	Range A
(User)	88.3 - 105.8%	Range B

IEC Standard 38 recommends that under normal system conditions, voltage at supply terminals should not differ from nominal voltage by more than ±10%.

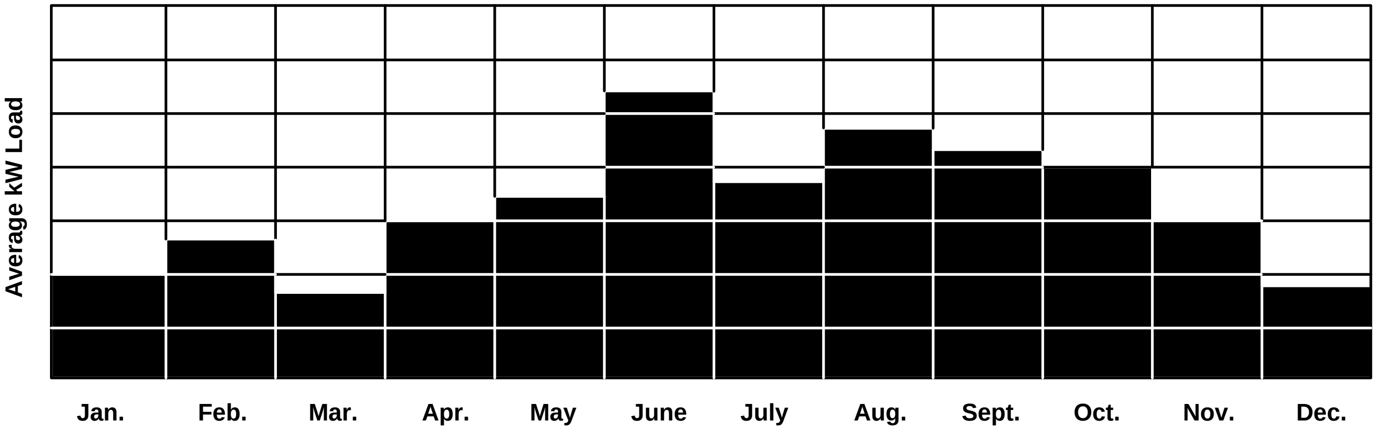
Service voltage is measured at the point where supplier and user systems are connected. Utilization voltage is measured at the line terminals of the user's equipment.

Generator Set Sizing

Capabilities of both engine and generator are considered individually and collectively when selecting generator sets. Engines produce horsepower (or kilowatts) while controlling speed or frequency. Generators influence engine behavior, but are primarily responsible for changing engine power into kilovolt-amperes (kV•A). They also must satisfy high magnetizing current draws (kVAR) of electrical equipment.

Complete analysis of loads and the sizing, applying, and specifying of generator sets is available from EPG Designer software.

Initial power system design considers generator set power required in kilowatts (kW). This summarizes all generator-connected loads. Rarely will all connected devices operate simultaneously, so total connected load may not necessarily be



Average monthly kW load curve showing seasonal variation required. For hospitals, however, National Electric Code (NEC) requires sizing to total connected emergency loads. In most other applications, if total connected load is used to size the generator set, system costs may be unnecessarily high.

Where generator sets supply standby power, separate circuits are provided for critical or emergency loads. These loads must be totally satisfied when normal power fails. Standby sets are sized to the emergency circuit's total connected load.

Ration of actual load to connected load is demand factor. This ratio changes with time. Size of the connected load is determined by adding nameplate ratings of all connected equipment.

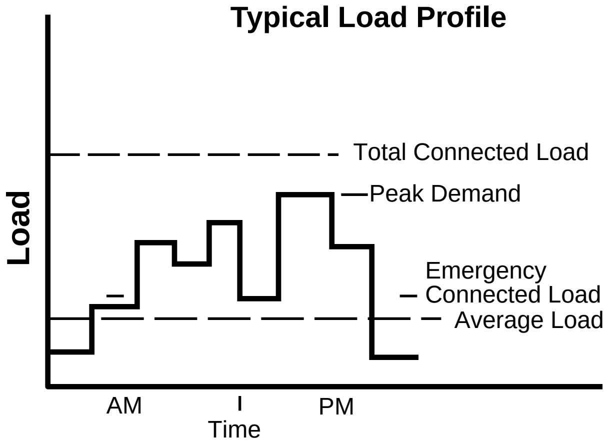


Figure 85

Duration of load must be established to select and operate the system at maximum efficiency. Chronological and duration load profiles best serve this purpose. Chronological daily load curve shows load demand throughout the day. The curve in figure 86 establishes peak daily demand and aids selection of engine size. It is also useful in programming units for operating economically.

Duration curves rearrange chronological curves and summarize daily load. Such curves are developed for a week, month, season, or year.

Power and Power Factor

Power is determined in AC circuits much the same way as DC circuits as long as the current and voltage are in phase. For purely resistive loads, the power in watts is found by multiplying the RMS voltage by the RMS current in amperes. When inductive or capacitive elements are present in the load, the product of voltage and current no longer gives a true indication of the actual power being consumed. In such cases a correction factor must be applied, known as the *power factor* of the load. The *apparent power* is the product of voltage and current, expressed in volt-amperes. The *actual power* is expressed in watts. The power factor is defined as the ratio of the actual power to the apparent power:

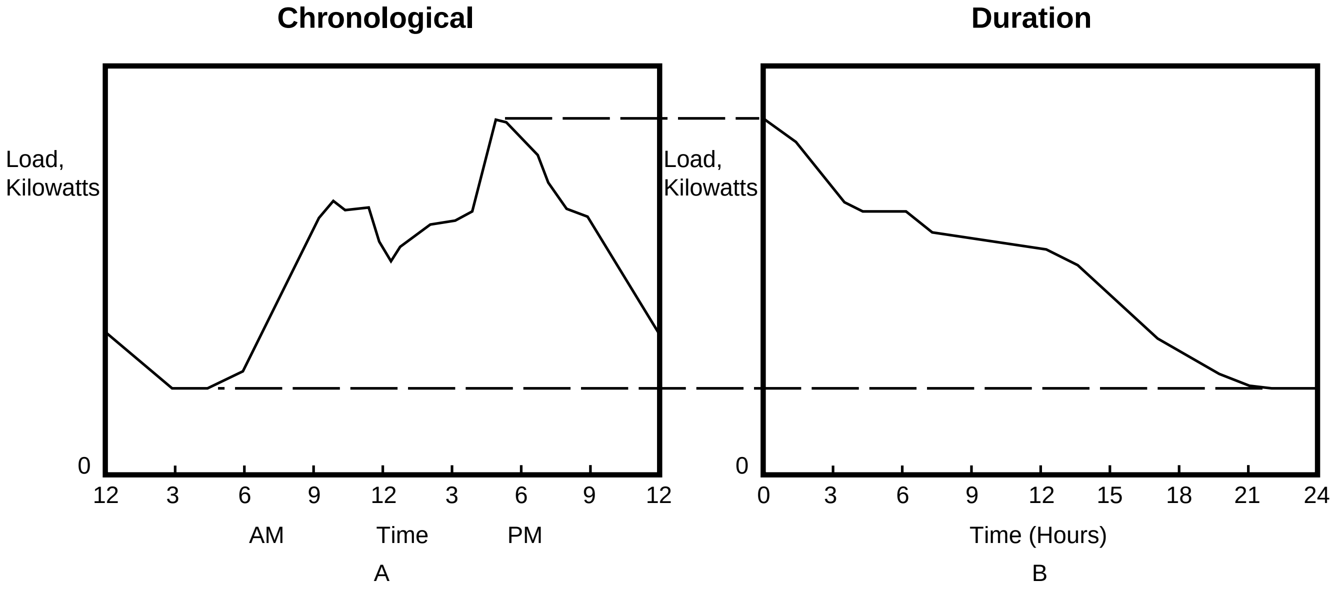


Figure 86

$$\text{Power Factor} = \frac{\text{Actual Power (watts)}}{\text{Apparent Power (V•A)}}$$

In magnetic circuits, current lags voltage. Figure 87a represents current lagging corresponding voltage by 60° (1/6 cycle). Where both are positive, or both negative, resulting power is positive. This is represented by shaded areas *above* the zero line, Figure 87c.

In mathematical terms, the power factor is equal to the cosine of the angle by which the current leads or lags the voltage. If the current lags the voltage in an inductive circuit by 60° the power factor will be 0.5 — the value of the cosine function at 60°. If the phase of the current in a load leads the phase of the voltage, the load is said to have a *leading power factor*; if it lags, it has *lagging power factor*. If the voltage and current are in phase, the circuit has a *unity power factor*.

It is apparent from the preceding formulae that if the power factor of a load is low, more current will flow at a given voltage to deliver a specified power to the load than if the power factor is unity. This fact is relatively unimportant in an ideal circuit where generators and conductors have no resistance.

In practical applications, however, resistances do exist. The wire with which the generator coils are wound and the wires which carry the current from the generator to the load both have finite resistance. The power dissipated in a resistance is a function of the square of the current. A small increase in current will cause a much larger increase in the power dissipated and, in this case, wasted. Electrical equipment, and insulation in particular, can withstand only a certain amount of heat. It is desirable to reduce the current flow as much as possible when delivering power to the load. With a power factor of 1.0, the current for a given power load is minimized. The full capacity of the equipment may be utilized to provide useful power to the load.

In situations where the load consists primarily of large electric motors, it may not be practical to achieve a unity power factor. The generator then must be designed to withstand loads having low power factors. The excess current that flows in a circuit with less than unity power factor is known as the reactive component of the total current. The portion of the apparent power which is due to this reactive component is termed the *reactive volt-amperes*. It represents the vector difference between the apparent power and the actual power. In power circuits, where voltages are often measured in kilo-volts (thousands of volts), this reactive component of the apparent power is denoted by the abbreviation *kVAR* or *rkVA* — reactive kilo-volt amperes. (Figure 87c and 87d gives the relationship between kW, kV•A and kVAR.)

Inductive load is a load which causes the current to lag the voltage.

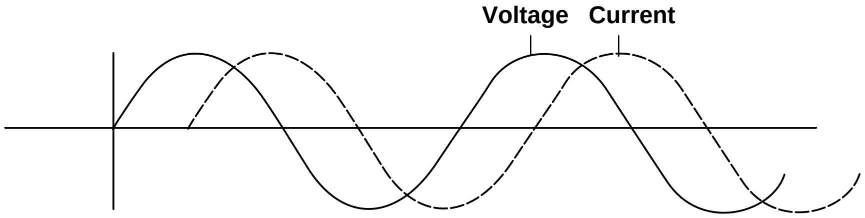


Figure 87a

Capacitive load is a load which causes the current to lead the voltage.

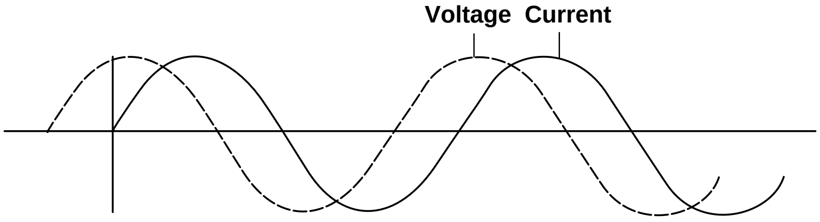
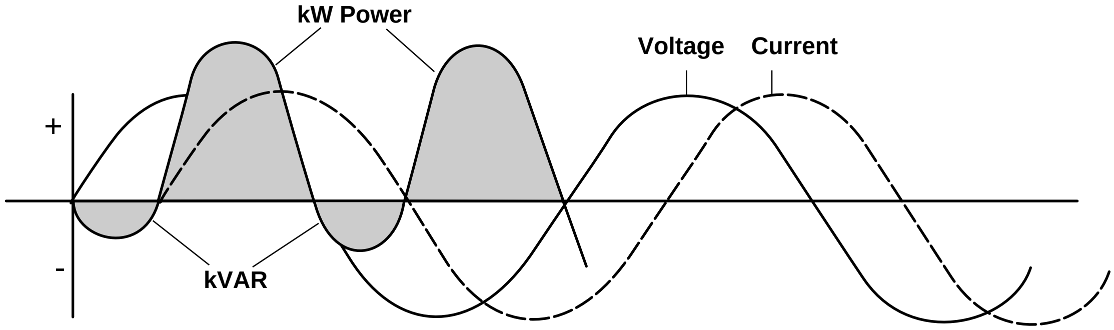


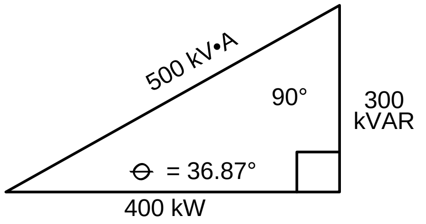
Figure 87b

Reactive load is the net result of inductive and capacitive loads on the same circuit which causes the current to shift out of phase with the voltage.
This, in turn, creates reactive load (kVAR) in combination with real power (kW).



The kW and kVAR do not occur at the same phase angle and to determine the kV•A must be added vectorily as represented below. The kV•A can be calculated by taking the square root of the sum of the squares of kW and kVAR or by dividing the kW by the cosine of the phase angle.

Figure 87c



kW/COS θ = kV•A
Sine θ kV•A = kVAR
COSE θ kV•A = kW

Where θ equals the phase relationship between current and voltage. Arc sine 36.87° = 400/500 - .8 which is the power factor.

Figure 87d

Power Factor of Typical AC Loads

Unity (or near unity) Power Factor		Lagging Power Factor		Leading Power Factor
Approximate Load	Power Factor	Load	Approximate Power Factor	Load
Incandescent Lamps (Power factor of lamp circuits operating off step-down transformers will be somewhat below unity)	1.0	Induction Motors (Rated load and speed)		Synchronous Motors (Are designed in standard ratings at unity, 0.9 and 0.8 leading power factor)
		Split Phase Below 1 hp	0.55 to 0.75	
		Split Phase, 1 hp to 10 hp	0.75 to 0.85	
		Polyphase, Squirrel Cage		
Fluorescent Lamps (with built-in capacitor)	0.95 to 0.97	High Speed, 1 hp to 10 hp	0.75 to 0.90	Synchronous Condensers (Nearly zero leading power factor. Output practically all leading reactive kV•A)
		High Speed, 10 hp and Larger	0.85 to 0.92	
		Low Speed	0.70 to 0.85	
Resistor Heating Apparatus	1.0	Wound Rotor	0.80 to 0.90	
Synchronous Motors (Operate at leading power factor at part loads; also built for leading power factor operation)	1.0	Groups of Induction Motors	0.50 to 0.90	Capacitors (Zero leading power factor. Output practically all leading reactive kV•A)
		Welders		
		Motor Generator-Type	0.50 to 0.60	
		Transformer-Type	0.50 to 0.70	
Rotary Converters	1.0			
		Arc Furnaces	0.80 to 0.90	
		Induction Furnaces	0.60 to 0.70	

NEMA suggests 0.8 pf for standard generator rating. Commercial applications combine motor loads with heating and lighting loads, so 0.8-0.9 pf may be assumed. Power factor of common loads is shown above.

kW and kV•A Requirements of Load

In selecting the correct size generator set for a given load, the load kV•A requirements are the most important factor. The generator set should have sufficient capacity to supply maximum load conditions after the load factor has been taken into account. It should also have reserve capacity to allow for motor starting and for some future expansion in load where indicated. Standard practice is that the generator set have 20 to 25 percent more capacity than required for actual maximum load conditions. It is assumed that single-phase loads will be evenly balanced on the phases of a three-phase generator set. If this cannot be accomplished, a larger capacity generator may be required to handle the extra kV•A load on the phases carrying single-phase circuits, in addition to the normal three-phase load. The problem is considered in more detail later in this section. In situations where the power factor of the load is significantly below the value the generator set kW output is rated, a larger capacity generator may be required to supply the additional kV•A. The line current requirements of the actual load must never exceed the generator nameplate rating.

Generator vs Engine Size

Normally a generator set is furnished with a generator which matches the engine output capability. Where power factors are low, however, it may be advantageous to select an oversized generator rather that specify the next larger size generator set. Since the engine horsepower output is related to kW and not necessarily to kV•A, for a given engine output, an oversized generator will supply essentially the same kW output as a normal generator, but will be able to tolerate a higher value of reactive kV•A because of its greater current-carrying capacity. Engine and generator performance are related by:

$$\text{ekW} = \text{pf} \times \text{kV•A}$$

$$\text{bkW} = \frac{\text{ekW}}{\text{eff}}$$

kV•A = kV•A output of generator
pf = power factor of connected load
ekW = electrical power
bkW = engine power
eff = generator efficiency

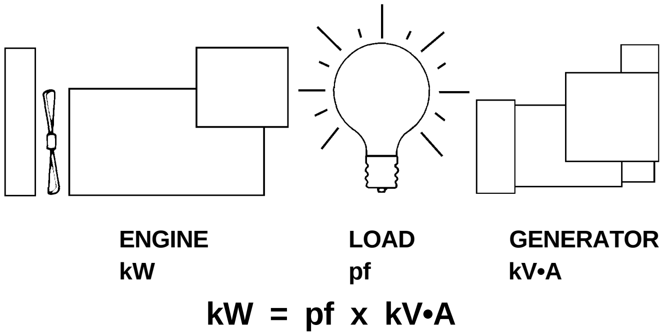


Figure 88

Engine Sizing and Selection

Engines are sized according to the actual power in kW required to meet the needs of the facility. The generator, on the other hand, must be capable of handling the maximum apparent power which is measured in kV•A. There are several ways in which the actual power can be identified. It can be calculated by adding the nameplate ratings of the equipment to be powered by the generator. If this is done, the efficiencies of the equipment must also be added. The actual power can be determined by performing a load analysis on the facility. This involves making a survey of the power requirements over a period of time.

Engine-Generator Set Load Factor

Load factor of a generator set is the sum of products of:

% of time x % of load

With: % of time = time at specific load/total operating time

% of load = specific load/rated load

Extended idling time and the time when the generator set is not operating does not enter into the calculation for load factor. Rating definitions for Caterpillar Generator Sets are on the following page.

Caterpillar Rating Definitions

Standby Rating:

Output available with varying load for the duration of the interruption for the normal power source.*

Typical Load Factor = 60% or less
Typical Hours per Year = 100 hours
Typical Peak Demand = 80% of standby rated ekW with 100% of rating available for the duration of an emergency outage.
Typical Application = Building Services standby and enclosed/sheltered environment.

Prime Rating + 10%:

Output available with varying load for the duration of the interruption for the normal power source.*

Typical Load Factor = 60% or less
Typical Hours per Year = less than 500 hours
Typical Peak Demand = 80% of rated ekW with 100% of rating available for duration of an emergency outage.
Typical Application = uncovered standby, rental, power modules, unreliable utility.

Prime Rating:

Output available with varying load for an unlimited time.**

Typical Load Factor = 60% to 70%
Typical Hours per Year = no limit
Typical Peak Demand = 100% of prime rating used occasionally.
Typical Application = industrial, pumping, construction, peak shaving or cogeneration.

Continuous Rating:

Output available without varying load for an unlimited time.***

Typical Load Factor = 70% to 100%
Typical Hours per Year = no limit
Typical Peak Demand = 100% of continuous rating used 100% of the time.
Typical Application = base load, utility, cogeneration, parallel operation.

Load Management when not Paralleled with the Utility:

Output available with varying load for less than 6 hours per day*.

Typical Load Factor = 60% or less
Typical Hours per Year = less than 500 hours
Typical Peak Demand = 80% of rated ekW with 100% of rating available for duration of an emergency outage.
Typical Application = interruptible utility rates, peak sharing.

Load Management when Paralleled with the Utility Under 200 Hours per Year:

Output available without varying load for under 200 hours per year and less than 6 hours per day.**

Typical Load Factor = 60% to 70%
Typical Hours per Year = under 200 hours
Typical Peak Demand = 100% of prime plus 10% rating used occasionally.
Typical Application = peak sharing or co-generation.

Load Management when Paralleled with the Utility Under 500 Hours per Year:

Output available without varying load for under 500 hours per year.

Typical Load Factor = 60% to 70%
Typical Hours per Year = under 500 hours
Typical Peak Demand = 100% of prime rating used occasionally.
Typical Application = peak sharing or co-generation.

Load Management when Paralleled with the Utility Over 500 Hours per Year:

Output available without varying load for unlimited time.***

Typical Load Factor = 70% to 100%
Typical Hours per Year = no limit
Typical Peak Demand = 100% of continuous rating used 100% of the time.
Typical Application = base load, utility, peak sharing, cogeneration, parallel operation.

Operating above these rating definitions will result in shorter life and higher generating costs per year. For conditions outside the above limits, please contact your local Caterpillar Dealer.

* Fuel Stop Power in accordance with ISO 3046/1, AS2789, DIN6271, and BS5514.
** Prime Power in accordance with ISO 8528. Overload power in accordance with ISO 3046/1, AS2789, DIN6271, and BS5514.
*** Continuous Power in accordance with ISO 8528, ISO 3046/1, AS2789, DIN 6271, and BS5514.

Generator Sizing and Selection

Like engines, generators must meet load demands. While engines provide power (kW) and frequency control, generators influence kV•A and voltage control.

This section is intended to help the customer through the generator selection and sizing process. A software program, EPG Designer, is available to consider sizing, applying and specifying options. The topics to be covered include: equipment considerations (motors, lighting, computers, etc.), application considerations (multiple gen sets, paralleling, standby gen sets, etc.), design considerations (generator set design, NEMA, harmonics, etc.), and transient response and stability.

Equipment Considerations

Allowable voltage and frequency variations depends on the type of equipment on line. Motor starting contractors may open if voltage drops below 65% of rated. Voltage dips less than 30% are sometimes commercially acceptable. The chart below summarizes typical equipment tolerances.

Motors

AC electric motors represent inductive loads with lagging power factors between 0.5 and 0.95, depending on size, type, and loading. Exceptions are synchronous motors which have unity or even leading power factors, depending on excitation.

Typical Equipment Power Tolerances

	Voltage				
Device	Variation	Duration of Interruption	Frequency Variation	Harmonics and Noise	Remarks
NEMA Induction Motors	± 10%	Varies With Load 30 Cycle Reclosure Usually Acceptable	± 5%	Increases Heat	Sum of Voltage and Frequency Not to Exceed ± 10%
NEMA AC Control Relays	± 10% Continuously Pickup On - 15% Hold in - 25% (Approximate)	Drops Out In One Cycle or Less	±5%	Insensitive	
Solenoids-Valves, Brakes, Clutches	± 30% to 40%	1/2 Cycle			
Starter Coils, Motor Contactors					
AC Pickup	-15%	Continuous			
AC Dropout	-40% to -60%	Continuous			
AC Burnout	-15% to 10%	Continuous			
DC Pickup	-20%	Continuous			
DC Dropout	-30% to -40%	Continuous			
Fluorescent Lights	-10%				Erratic Start
Incandescent Lights	-25% to +15%				Short Life
Mercury Vapor Lights	-50%	2 Cycles			Extinguished
Communications Radio, TV, Telephone	±5%			Variable Sensitive to Spike	
Computers	±10% -8%	1 Cycle	+ 1/2 Hz	5%	
Electronic Tubes	±5%			Variable	
Inverters	+5% at Full Load		±2 Hz	2% Sensitive to Spikes	May Require Isolating Transformer, Filters
Thyristor (SCR)	+ 10% at No Load, -10% Transient			Sensitive	
Rectifiers, Solid-State Diode	±10%			Sensitive	

Note: Final determination of power requirements must result from equipment supplier's specific recommendations

Motors draw starting currents two to eight times normal running current. Preloads on motors do not vary maximum starting currents, but do determine time required for motors to achieve rated speed and current and to drop back to normal running value. If motors are excessively loaded, they may not start or may run at at reduced speed. Both starting and running current are considered when analyzing total kV•A requirement.

Each motor is selected for particular characteristics, and each represents different types of starting and running loads.

Squirrel Cage

Most three-phase motors are squirrel-cage type. U.S. National Electric Manufacturers Association (NEMA) uses two methods of classification -- design and code. Motor nameplates normally carry both these designations, but there is no direct relationship. Most common NEMA designs are shown in chart below.

Wound Rotor (Slip Ring)

Wound rotor motors use slip rings, or collector rings, to connect rotor windings to an external switch-controlled resistor for starting current regulation. Usually these motors are started near unity power factor. Starting current is limited to 130% of rated operating current. They are applied on equipment starting under heavy load, or for variable speed operation. Because they have no code letter, exact operating performance must be obtained from the motor nameplate or manufacturer.

Synchronous

Synchronous motors maintain constant speed, synchronized with power line frequency. They are seldom found in sizes under 40 hp. Synchronous motor power factor is a function of load and excitation. Some produce leading power factors at full load to improve overall system power factor. Synchronous motors start as induction motors, so sufficient system capacity must be available to satisfy starting current demands.

Characteristics of specific synchronous motors are obtained from the motor manufacturer.

Design	Performance	Typical Uses
A	Starting current 6-7 x rated Starting torque 150% rated	General Purposes
B	Starting current 5.5-6 x rated Starting torque 150% rated	General Purposes Fans, blowers,compressors (starting unloaded), centrifugal pumps, generators
C	Double squirrel cage Starting current 5.5-6 x rated Starting torque 225% rated (high)	Reciprocating compressors (starting loaded), conveyors, elevators (high breakaway), crushers (starting loaded), positive displacement pumps
D	High resistance Starting current 5.5-6 x rated Starting torque 275% rated (high) high slip, not for continuous duty	Chippers, punch presses, hoists and cranes
F	Starting current 3.5-3.75 x rated Starting torque 125% rated	Limited to motors larger than 30 hp

DC Motors

Motors operating from direct current are used where speed control or heavy load starting capability is required, or where other system elements require a DC power source. Full load efficiencies vary from 86% to 92%.

DC motors have no power factor but, when driven through an SCR rectifier by an AC generator, the AC does have a power factor. To determine DC loads on an AC generator:

$$\text{DC amps} = \frac{\text{DC kW} \times 1000}{\text{DC volts}}$$

$$\text{AC amps} = \text{DC amps} \times 0.816$$

$$\text{AC kVA} = \frac{\text{AC volts} \times \text{AC amps} \times 1.732}{1000}$$

$$\text{Power Factor} = \frac{\text{DC kW}}{\text{AC kV•A}}$$

Apply DC motors at as high an rpm as practical to maximize the system power factor.

Silicon Controlled Rectifier (SCR) Systems

SCR control devices lend themselves to infinite speed control of motors, rectifiers, and uninterrupted power supplies (UPS). Used with limited power sources, such as engine-driven generator sets, SCR switching causes severe voltage and current waveform distortion. This adversely affects performance of the entire system.

Generator regulators can be confused by waveform distortion, causing voltage surges. Brushless generators with three-phase voltage sensing minimize distortion feedback. Additional regulator filters provide little improvement.

The SCR control may also be confused. Filtering of the control input improves controller performance.

Waveform notching may trouble other loads connected to the line. solid-state timing devices miscount; zero-crossing switches may malfunction.

Current waveform distortion can develop harmonic resonances in system equipment. This causes heating in motor and generator coils.

Rectifiers and UPS systems can limit distortion by employing multiple stages of SCRs. Unfortunately, increased costs discourage high pulse designs.

When planning systems incorporating SCR devices, the control manufacturer must be informed that a limited power source (generator set) will be used. The system can then be designed to minimize distortion problems.

Limiting SCR loads to 66% of a Caterpillar Generator's prime power rating assures regulator control and avoids harmonics caused overheating of the generator windings. Applications requiring higher load factors must be analyzed on an individual basis.

Motor Starting Load

Motors, either loaded or unloaded, draw several times rated full load current when starting. This is locked rotor current or starting kV•A (skVA). Refer to Figure 94 for locked rotor current of three-phase induction motors. skVA can be calculated from locked rotor current.

$$\text{skVA} = \frac{\text{V} \times \text{A} \times 1.732}{1000}$$

Motors generally exhibit low power factors (0.3 to 0.4) when starting. Load imposed on the engine during starting is calculated by:

$$\text{kW} = \text{Starting kV•A} \times \text{pf}$$

The typical motor starting curve in Figure 89 is affected by motor and generator design and load on the motor. Initial voltage dip depends mostly on motor and generator windings. Addition of series boost to the regulator, or use of a permanent magnet exciter, will not significantly decrease this dip.

Although unloaded motors impose high inrush current (skVA) in generators while starting, kW load on the engine is usually small.

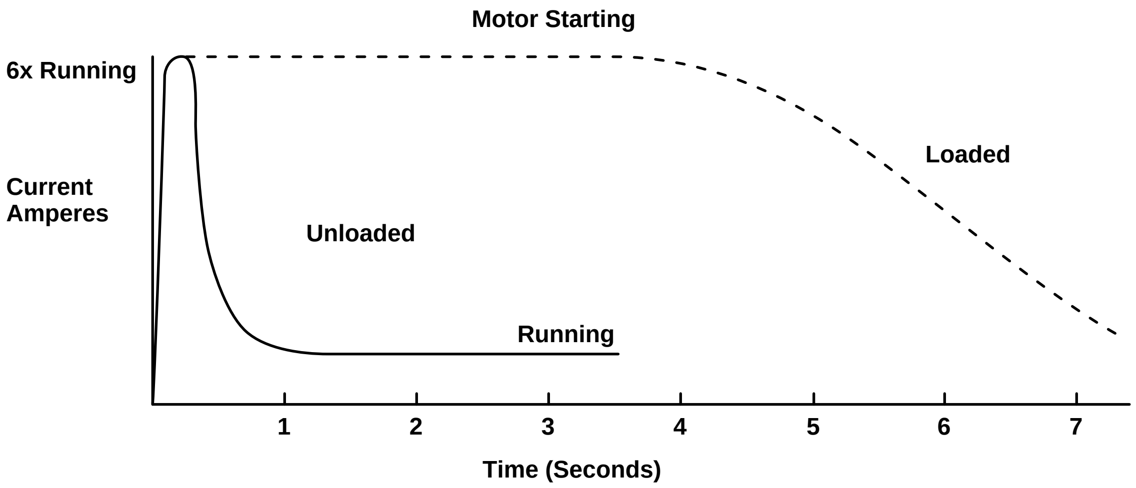


Figure 89

However, motors can draw more than rated kW during starting and acceleration to rated speed. Motors connected directly to high inertia centrifugal devices or loaded reciprocating compressors cause severe frequency excursions and lengthy motor run up. Comparing starting currents between loaded and unloaded motors shows the extended time loaded motors demand high current.

Effect of loaded motors on both engine and generator must be determined, particularly if large motors have high inertia loads and increase load during acceleration (for example, large centrifugal fans and pumps).

Motor Torque

Motor loads are established to determine if generator and engine have, respectively, adequate kV•A and kW. Motor load is torque required by load. This torque, in lb-ft (N•m), is usually related to speed. Motor load in horsepower equals:

$$hp = \frac{\text{lb-ft x rpm}}{5250} \text{ or } \frac{(\text{N}\bullet\text{m x rpm})}{7350}$$

The following torque requirements must be established (usually expressed as percent of running torque).

Starting (Breakaway) Torque

Maximum required to start rotation (torque available is a function of motor terminal voltage).

Accelerating Torque

Net difference at any speed between load required torque and motor available torque.

Minimum motor torque must exceed maximum torque demanded by connected load. Time necessary to achieve full rated speed is of utmost importance.

Small accelerating torque is usually caused by reduced voltage at the motor. Prolonged accelerating time with high current draw will reduce useful motor life. Figure 90 reflects typical motor capabilities.

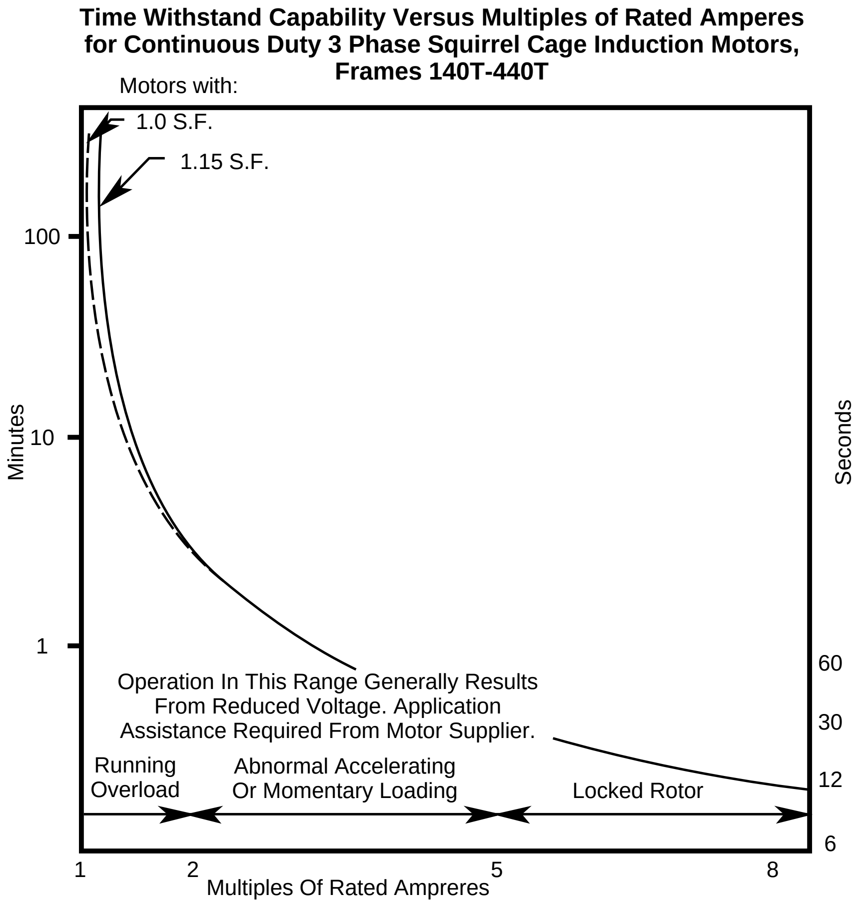

Time Withstand Capability Versus Multiples of Rated Amperes for Continuous Duty 3 Phase Squirrel Cage Induction Motors, Frames 140T-440T

Figure 90

Cold Start Time-Current Withstand Capability Of Squirrel Cage Motors

$$t^* = \frac{J\ (n^2 - n^1)}{9.55\ T_a}$$

Where: t = Accelerating Time, Seconds
n^2 = Final Speed, rpm
n^1 = Initial Speed, rpm
T_a = Available Motor Accelerating Torque (at Resultant Voltage Dip) lb-in N•m (lb-in)
J = Total Inertia Load, N•m•s^2 (lb-in-s^2) (including Motor Gear Drive, Etc.)

* Consult motor manufacturer if "t" exceeds 15 seconds.

Synchronous Torque

The steady-state torque developed by a synchronous motor at rated speed.

Peak Torque

Maximum a load requires from its driving motor.

Regenerative Power

Some motor applications, such as hoisting, depend on motors for braking. Motors then act as generators and feed power back to the generator set. If no other loads are connected to absorb this regenerative energy, only engine frictional horsepower can be relied on for braking. Exceeding frictional horsepower causes generator set overspeed.

Regenerative potential for a common application, elevators, is estimated by:

$$\text{Regeneration kW} = \frac{\text{Hoist Motor Horsepower} \times 1.8 \times 0.746}{0.9}$$

Where: 0.9 = Motor Efficiency
1.8 = Full Load Deceleration Factor

0.746 = Horsepower to kW Conversion

When combinations of connected load and engine frictional horsepower are not sufficient to restrain regenerative energy, load banks may be added. They activate by directional power relays.

Rated Output kW	Starting kV•A Ratio* Rated Output kW Column 1	 Column 2	 Column 3
Over 1-0 up to 2-5		10-5	
Over 2-5 up to 6-3		9-8	
Over 6-3 up to 16		9-2	
Over 16-0 up to 40	In Excess of Ratios Given in Column 2	8-7	
Over 40 up to 100		8-2	6-2
Over 100 up to 250		7-8	6-0
Over 250 up to 650		7-6	5-8
Over 630 up to 1600		7-4	5-6
Over 1600 up to 4000		7-2	5-4
Over 4000 up to 10000		7-0	5-2

* To obtain the ratio of starting current (locked rotor) to rated load current, multiply this ration by per unit efficiency and power factor at rated load.

British Standard 2613

Design	Starting kV•A (Locked Rotor) Not to Exceed
A	Column 1
B	Column 2
C	Column 2
D	Column 3
E	Column 3
F	Column 1
G	Subject to Agreement

Motor Starting Voltage

In-rush current to the motor causes a rapid drop of generator output voltage. In most cases, 30% voltage dip is acceptable, depending on equipment already on line. Degree of dip must be identified by an oscilloscope. Meters or mechanical recorders are too slow for this measurement.

Most Motors are identified by National Electric Manufacturers Association (NEMA) or British Standards to describe their motor starting characteristics.

Identifying Code Letters on AC Motors

NEMA Code Letter	Starting kV•A/hp
A	0.00 - 3.14
B	3.15 - 3.54
C	3.55 - 3.99
D	4.00 - 4.49
E	4.50 - 4.99
F	5.00 - 5.59
G	5.60 - 6.29
H	6.30 - 7.09
J	7.10 - 7.99
K	8.00 - 8.99
L	9.00 - 9.99
M	10.00 - 11.19
N	11.20 - 12.49
P	12.50 - 13.99
R	14.00 - 15.99
S	16.00 - 17.99
T	18.00 - 19.99
U	20.00 - 22.39
V	22.40 -

Note: Code letters apply to motors up to 200 hp.

Single-speed, three-phase, constant-speed induction motors, when measured with rated source voltage and frequency impressed and with rotor locked, must not exceed the following:

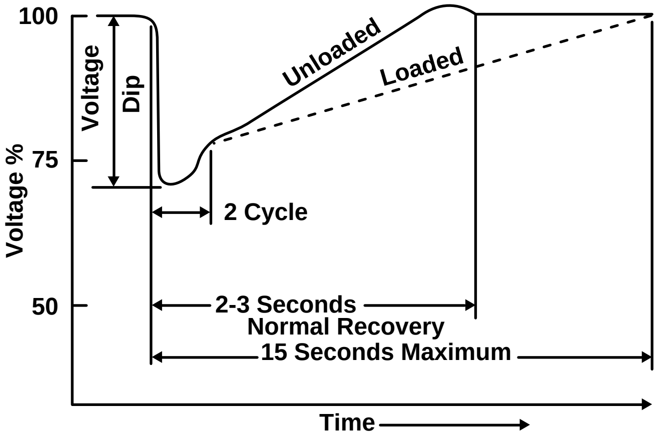


Figure 91

Starting Techniques

If motor starting is a problem, consider the following:

- Change starting sequence. Start largest motors first. More starting kV•A is available, although it does not provide better voltage recovery time.
- Use reduced voltage starters. This reduces the kV•A required to start a given motor. If starting under load, remember this starting method also reduces starting torque.
- Specify oversized generators.
- Use wound rotor motors. They require lower starting current, but are expensive.
- Provide clutches so motors start before loads are applied. While starting kV•A demand is not reduced, time interval of high kV•A demand is shortened.
- Improve system power factor. This reduces the generator set requirement to produce reactive kV•A, making more kV•A available for starting.

Locked Rotor Current - NEMA MG 1

Horsepower	60 Hz - 230 Volts Locked Rotor Current, Amperes*	Design Letters	Horsepower	50 Hz - 380 Volts Locked Rotor Current, Amperes**	Design Letters
1/2	20	B,D	1 or less	20	B,D
3/4	25	B,D	1-1/2	27	B,D
1	30	B,D	2	34	B,D
1-1/2	40	B,D	3	43	B,C,D
2	50	B,D	5	61	B,C,D
3	64	B,C,D	7-1/2	84	B,C,D
5	92	B,C,D	10	107	B,C,D
7-1/2	127	B,C,D	15	154	B,C,D
10	162	B,C,D	20	194	B,C,D
15	232	B,C,D	25	243	B,C,D
20	290	B,C,D	30	289	B,C,D
25	365	B,C,D	40	387	B,C,D
30	435	B,C,D	50	482	B,C,D
40	580	B,C,D	60	578	B,C,D
50	725	B,C,D	75	722	B,C,D
60	870	B,C,D	100	965	B,C,D
75	1085	B,C,D	125	1207	B,C,D
100	1450	B,C,D	150	1441	B,C,D
125	1815	B,C,D	200	1927	B,C
150	2170	B,C,D			
200	2900	B,C			
250	3650	B			
300	4400	B			

* Locked rotor current of motors designed for voltages other than 230 volts shall be inversely proportional to the voltages.

**The locked rotor current of motors designed for voltages other than 380 volts shall be inversely proportional to the voltages.

Figure 92

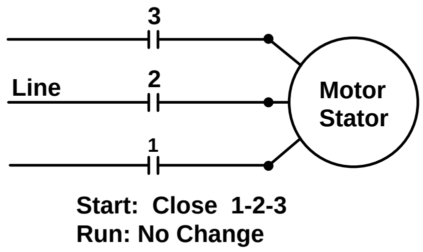
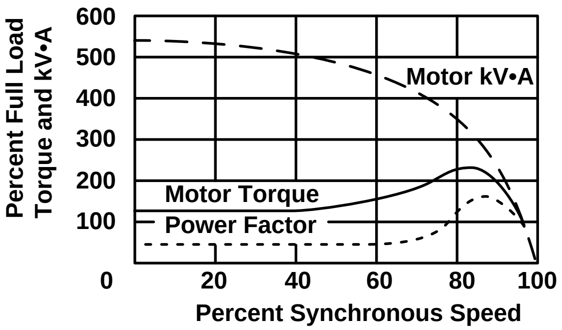


Figure 93



- Use a motor generator set. A motor drives the generator which, in turn, supplies power to the motor to be started. This system is applied in elevator service. The motor generator set runs continuously, and current surge caused by starting of the equipment motor is isolated from the remainder of the load.

Full Voltage Starting

Full voltage, across-line starting is simple, low cost, and preferred when system capacity and performance permits. Full line voltage is supplied to the motor instantly when the motor switch is actuated, see Figure 94. Maximum starting torque is available. The generator set must have sufficient motor starting kV•A capacity to limit voltage drop. If actual values of motor starting currents cannot be determined, approximately 600% of full load rated current is sometimes estimated.

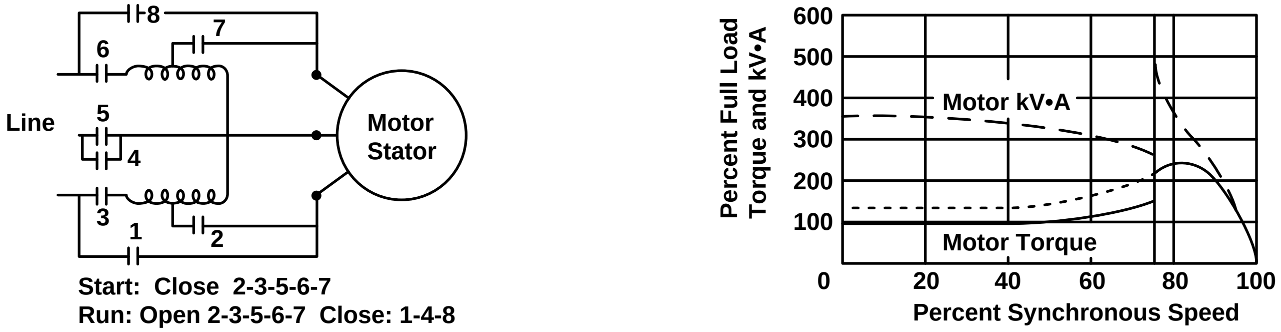
Reduced Voltage Starting

Reduced voltage starting decreases motor starting torque, see Figure 94. This detracts from the motor's ability to start and achieve rated speed when burdened by a load. Time to reach full operating speed also increases.

Reduction in motor torque is close to the square of voltage reduction. An 80% reduced voltage starter allows the motor, at start-up, to produce only 64% (80% voltage^2 – current drawn varies as the square of voltage) available full speed torque.

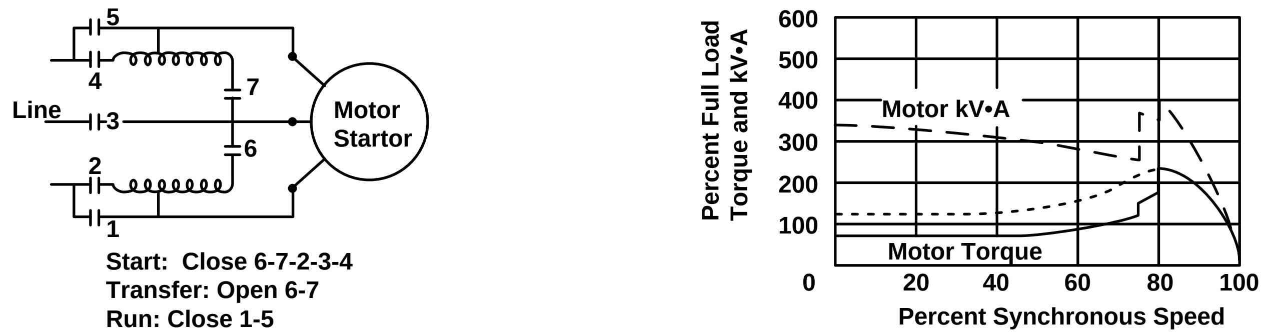
	Reduced Voltage Starters		
Type of Starter	**Motor Voltage % Line Voltage**	**Line Current % Full Voltage Starting Current**	**Starting Torque % of Full Voltage Starting Torque**
Full Voltage Starter	100	100	100
Autotransformer			
80% Tap	80	68	64
65% Tap	65	46	42
50% Tap	50	29	25
Resistor Starter			
Single Step (Adjusted for motor voltage to be 80% of line voltage)	80	80	64
Reactor			
50% Tap	50	50	25
45% Tap	45	45	20
37.5% Tap	37.5	37.5	14
Part Winding (Low speed motors only)			
75% Winding	100	75	75
50% Winding	100	50	50
Star Delta	57	33	33
Solid State	Adjustable		

Figure 94



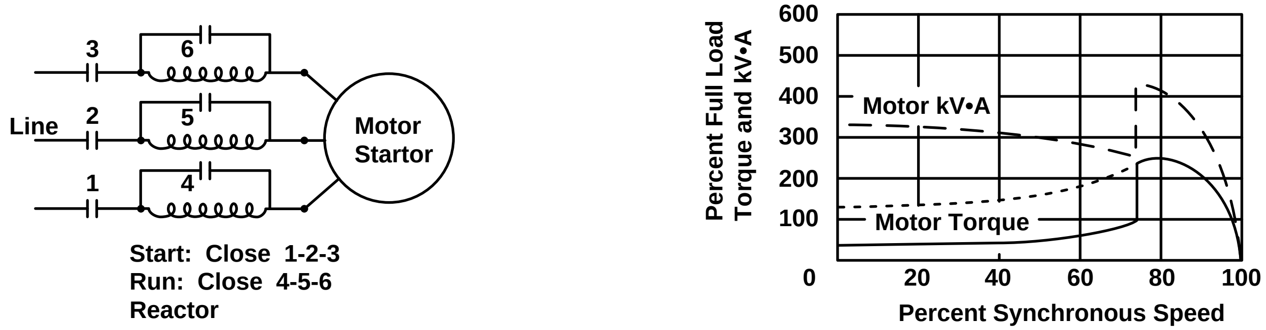
Start: Close 2-3-5-6-7
Run: Open 2-3-5-6-7 Close: 1-4-8

Figure 95



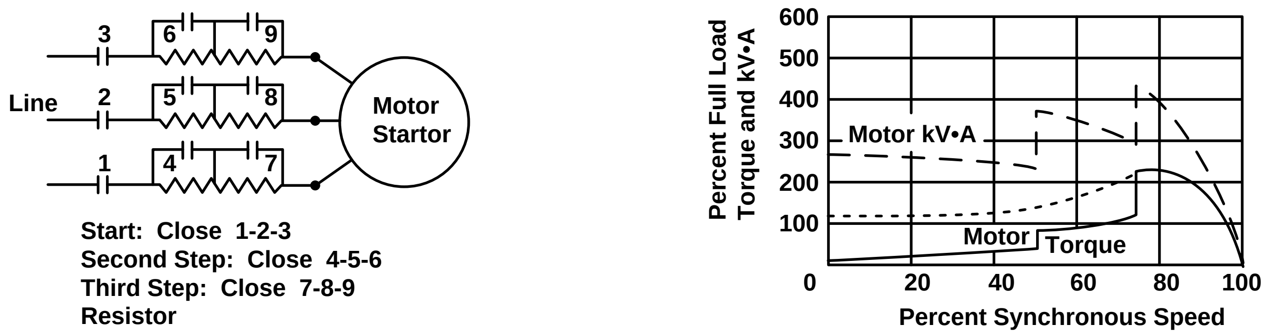
Start: Close 6-7-2-3-4
Transfer: Open 6-7
Run: Close 1-5

Figure 96



Start: Close 1-2-3
Run: Close 4-5-6
Reactor

Figure 97



Start: Close 1-2-3
Second Step: Close 4-5-6
Third Step: Close 7-8-9
Resistor

Figure 98

Autotransformer – Open

Autotransformer starters, also called autocompensators, provide higher starting torque per ampere than other types of reduced voltage starters. They are available for very large high and low voltage motors. The autotransformer primary connects to the supply line and the motor-to-low-voltage taps until reaching predetermined speed, see Figure 95. The autotransformer is then disconnected and the motor is connected directly to the line.

The simplest arrangement is open circuit transfer from reduced to full voltage, but it causes severe electrical and mechanical disturbances. kV•A, when connected directly to line, could exceed starting kV•A. This method is not recommended.

Autotransformer – Closed

An alternative, and increasingly popular method, is closed transition (Knorndorfer), see Figure 96. This technique minimizes shock and provides continuous positive torque during transfer to full voltage.

Autotransformer starters are magnetically controlled. Three taps on the transformer secondary are set for 50%, 65%, and 80% of full line voltage. Current drawn from the line will vary as the square of voltage at motor terminals. Thus, when the motor is connected to the third (80%) tap, line current will be $80\%^2$, or 64% of line current that would be drawn at full voltage. The starter requires approximately 25 kV•A per 100 motor horsepower as magnetizing current. This is added to the starting kV•A of the motor being started.

Reactor - Resistor

Reactor and resistor starters reduce voltage across the stator windings by inserting resistance or reactance in each leg of the circuit and short out when the motor reaches operating speed, see Figures 97 and 98. The added resistance imposes considerable load on the engine. This method provides smooth acceleration as the starting circuit is removed without momentarily disconnecting motor from line. However, line current equals motor coil current, resulting in poorer torque-to-kV•A ratios than autotransformer compensators. Reactor and resistor starters do provide closed transition starting and are normally lower priced than autotransformer starters.

Part Winding

A special motor has the stator wound with two or more parallel circuits, see Figure 99. These are successively connected to the line as motor speed increases. Closed transition starting and good torque-to-kV•A ratio is possible, but the technique is not suitable for small, high speed motors.

Wye (Star) Delta

The motor starts as a wye-connected motor and runs delta connected, see Figure 100. It has a simple motor connection with open transition transfer. Torque is limited to 33% of full voltage torque.

Solid State

The control varies the SCR conduction angle from 20% to 100%, controlling the voltage to the motor, generally from 40% to 80%. Some have a bypass option allowing across-line starting. Common control types include:

Voltage/time ramp - increases voltage until full voltage is applied across the motor terminals.

Current limit ramp - preset limit to current to 150-450% of motor full load amperage holds current constant during high torque start-up. Constant kVA is maintained, and sudden torque changes are eliminated. Initial voltage step, acceleration ramp, and current limit are usually adjustable, Figure 101.

Linear speed/time ramp - complex control with motor speed feedback which follows a prescribed speed ramp to full speed and load.

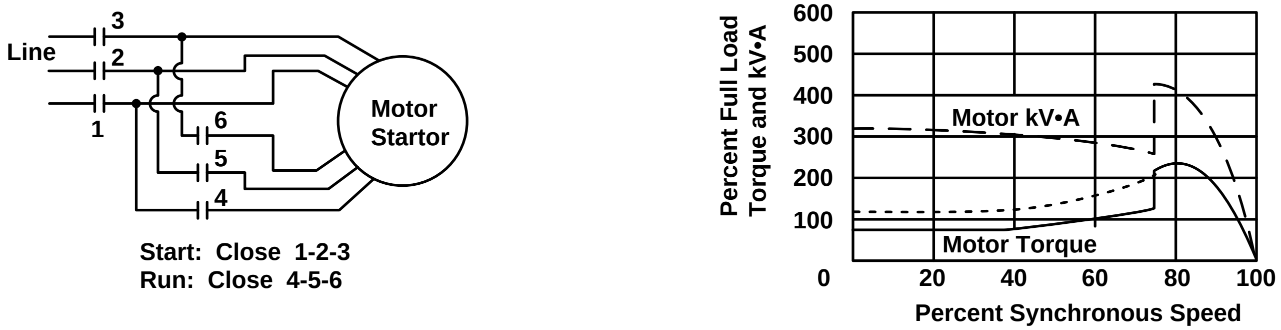


Figure 99

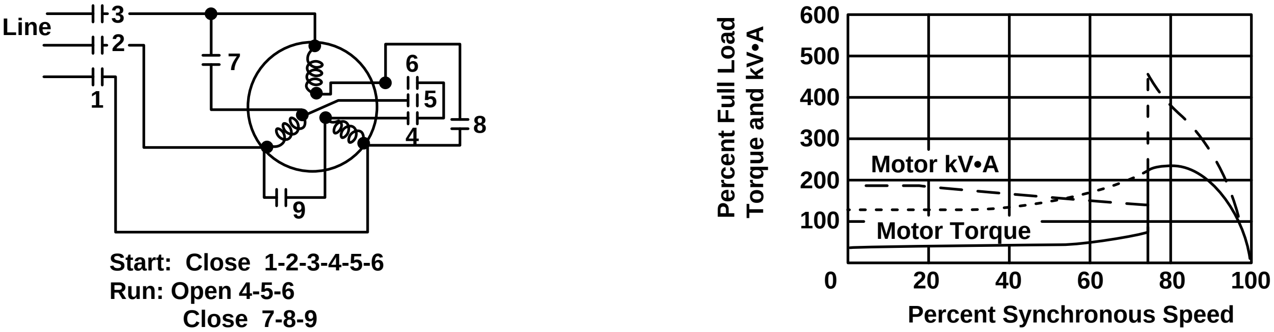


Figure 100

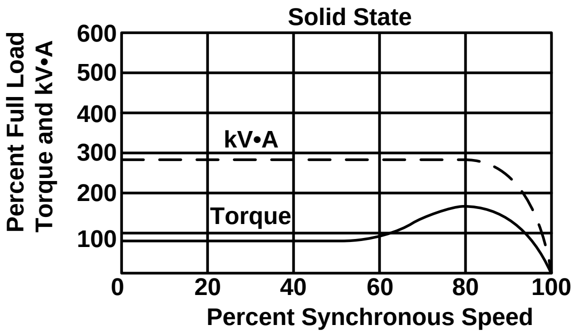


Figure 101

Lighting

Incandescent lamps are rated by voltage and wattage requirements. They operate on either alternating or direct current since power factor is unity. Current drawn by a lamp is found by dividing wattage rating by specified input voltage.

$$A = \frac{W}{V}$$

Incandescents draw high in-rush currents and are suitable in applications which require flashing or dimming, with operation over wide voltage ranges. Any voltage fluctuation affects lamp brightness. Extreme voltages shorten filament life.

Fluorescent lamps are also rated by voltage and wattage. Due to their ballast transformer, these lamps have slightly lower power factors (0.95 to 0.97). When either type light operates from stepdown transformers, power factor contribution of the transformer must be considered.

The human eye is sensitive to slight lighting fluctuations. A decrease of 1/2 volt on a 110-volt incandescent bulb is noticeable. A one-volt dip, if repeated, becomes objectionable. Figure 102 shows the range of observable and objectionable voltage dips, assuming direct illumination and medium-sized bulbs.

Voltage Level Fluctuation Limits

Cyclic	Cyclic Low Frequency	Frequent	Infrequent
10/sec 2/sec	2/sec 12/min	12/min 1/min	1/min 3/hr
Reciprocating Pumps Compressors Automatic Spot Welder	Flashing Signs Arc-Welders Manual Spot Welders Drop Hammers Planers Saws Shears Group Elevators	Single Elevators Hoists Cranes Wye-Delta Changes on Elevator Motor Generator Sets X-Ray Equipment	House Pumps Sump Pumps Air Conditioning Equipment Theatrical Lighting Domestic Refrigerators Oil Burners

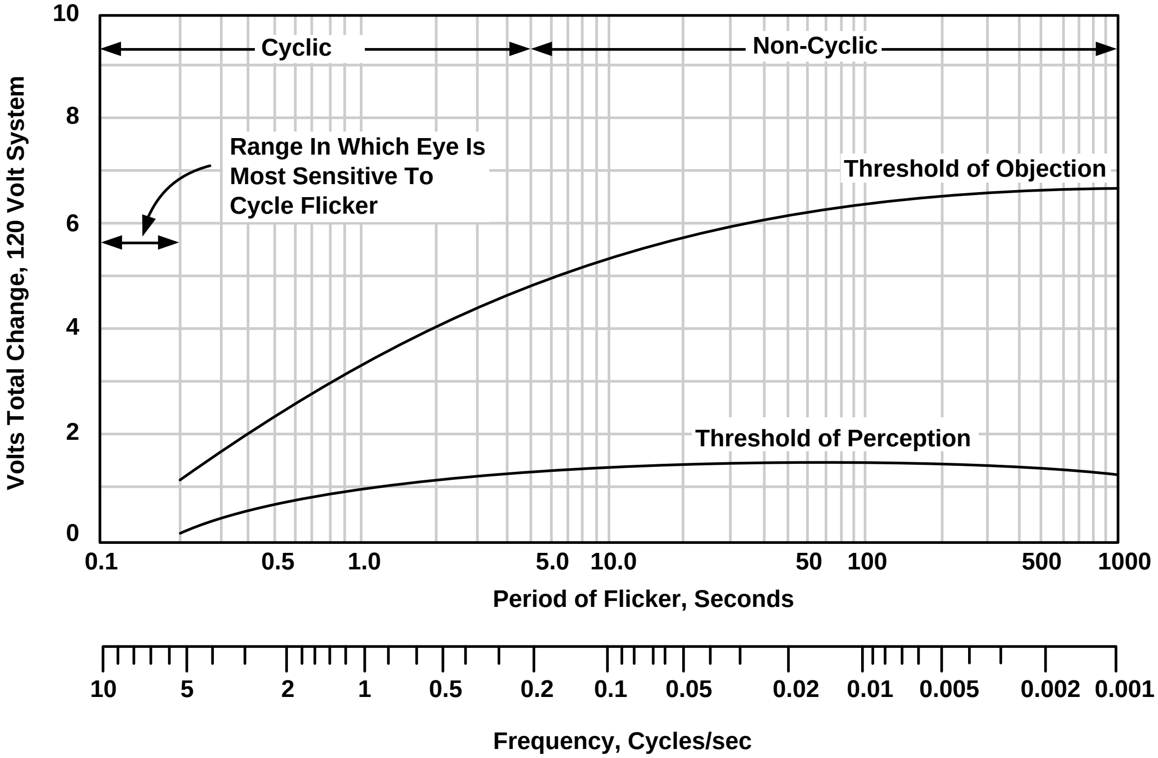


Figure 102

If indirect lighting is used with no incandescent bulbs below 100 watts, these values may be broadened. This is also true if all lighting is fluorescent rather than incandescent.

Reciprocating compressors seriously affect lighting quality. Torque pulsations vary motor current, causing sufficient voltage fluctuation to flicker lights. Unfortunately, this is a frequency to which eyes are extremely sensitive.

A commonly accepted figure for current variation limits for motor-driven reciprocating compressors is 66% of full rated motor current. This limits horsepower rating of compressor motors to about 6% of generator kV•A rating, objectionable light flicker. For example, a 30 hp motor may be used on systems having not less than 500 kV•A of generator capacity in operation.

Typical installation requirements are listed.

Typical Voltage Dip Limitations

Facility	Application	*Permissible Voltage Dip
Hospital, hotel motel, apartments, libraries, schools, and stores.	Lighting load, large Power load, large Flickering highly objectionable.	2% Infrequent
Movie Theaters (sound tone requires constant frequency. Neon flashers erratic.)	Lighting load, large Flickering objectionable.	3% Infrequent
Bars and resorts.	Power load, large Some flicker acceptable.	5% - 10% Infrequent
Shops, factories, mills, laundries.	Power load, large Some flicker acceptable.	3% - 5% Frequent
Mines, oil field, quarries, asphalt, plants.	Power load, large Flicker acceptable.	25% - 30% Frequent

* Greater voltage fluctuations permitted with emergency power systems.

Transformers

Transformers have inductive characteristics similar to motors when charging, with inrush (magnetizing) current as much as 20 times full load current when connected to an infinite power source. However, when energized from a limited source such as a generator set, the transformer flux will build in a few cycles even if the full inrush current is not available. The affect on the generator set can be ignored but, if voltage fluctuation to highly sensitive equipment must be closely controlled, kVA capability of the power source must include starting of this low power factor load.

Computers

When computers are a portion of the load, required power quality should be specified by the computer manufacturer prior to power system design. As a general rule, avoid heavy SCR loads, block loads, and large motor skVA on computer power lines.

Communications Equipment

Communication equipment includes broad ranges of electronic devices for transmission of information. Most common are radio and television broadcasting equipment, including studio units and transmitters, telephone equipment, and microwave relay transmitters. Generally, all devices pass their power supply through transformers. Therefore, the power factor is slightly less than unity. Most equipment tolerates frequency variations of ± 5%, except where synchronous timing devices are used. Voltage variations of ±10% are usually acceptable since electronic circuits sensitive to voltage variations contain internal voltage regulation devices.

Power for complex telephone systems is frequently supplied from building power mains. Since telephone operation can be essential to public safety, some units are supported from emergency power sources. Voltage and frequency stability requirements for telephone equipment are not severe, but solid-state battery chargers disturb system monitoring services.

Uninterruptible Power Supply (UPS)

Electrical loads sensitive to power disturbances during substation switching, voltage fluctuations, or total outages require absolute continuity of power. Continuity can be assured by isolating critical loads and incorporating one of the following:

- Assign a generator set solely to the critical load. Sudden load changes are sufficiently small to avoid speed changes.
- Isolate critical load through motor-generator set to avoid five-cycle power interruptions of utility, see Figure 103.

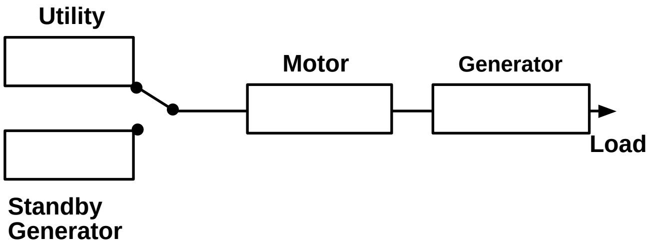


Figure 103

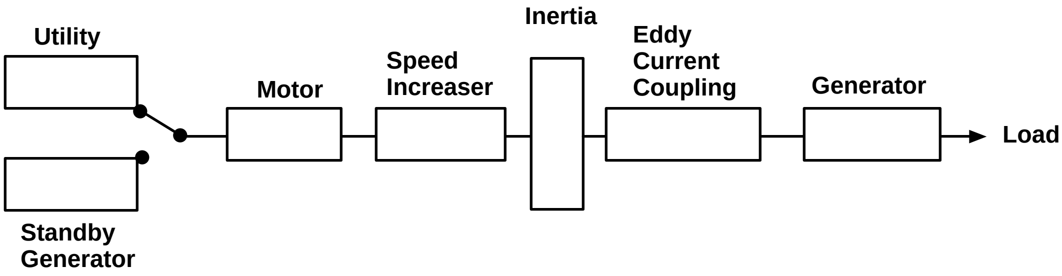


Figure 104

- Longer power interruptions require added inertia to maintain frequency until stand-by unit can assume load. Extreme control incorporates eddy-current coupling between over-frequency motor and synchronous generator, see Figure 104.
- Static systems isolate critical load through solid-state devices which use batteries to bridge power interruption. Refer to discussion of SCR systems, See Figure 105.

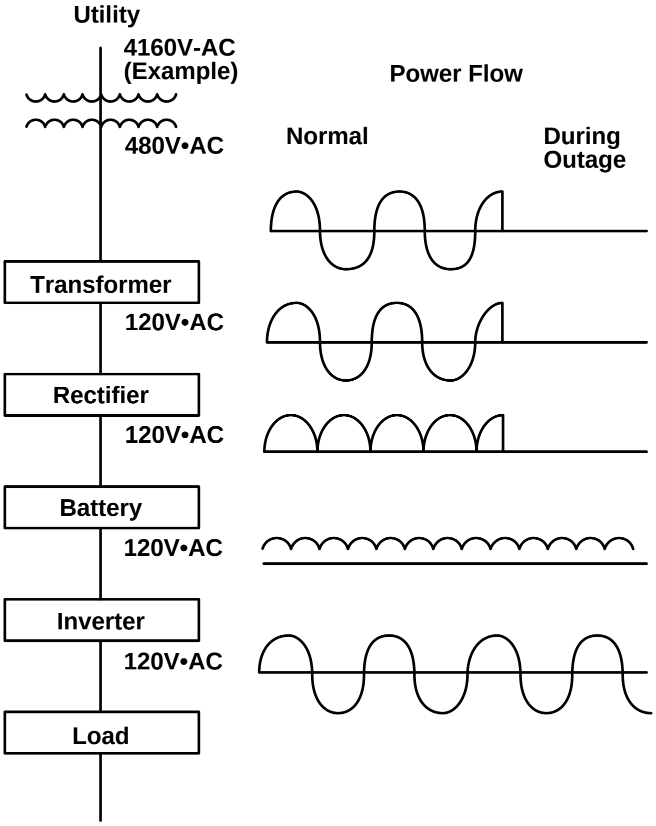


Figure 105

X-Ray Equipment

Although this equipment typically exhibits very high voltage requirements, current draw is small. Total kV•A at near-unity power factor results in low kW load demand.

These loads generally represent only a small part of generator set load, so x-ray pictures are not affected. As x-ray equipment is activated, in-rush kV•A should cause less than 10% voltage dip to maintain picture quality.

Application Considerations

Multiple Generator Sets

In some situations, the use of more than one generator set is mandatory. In others, it may prove more economical. Critical installations in which the prime power source is a generator set, requires backup power. A second generator set capable of carrying critical loads should be made available in case of primary set failure and for use during prime set maintenance periods.

Cases where multiple generator set installations may prove more economical are those where there is a large variation in load during the course of a day, week, month, or year. Such variation is typical in plants in which operations are carried on primarily during the day, while only small loads exist at night. The more closely a generator set comes to being fully loaded, the greater the fuel economy per kilowatt produced. Therefore, the use of a small unit to power light off-hour loads will often result in long-term fuel economy.

In installations where the load does not vary to the extremes encountered between day and night conditions, it is sometimes profitable to share the load between several small units operating in parallel. One or more of the units may then be shut down when the load is lighter, thereby loading the other units closer to capacity. For example, this type of system is advantageous where load demand is seasonal.

Paralleling

Usually identical generator sets operate in parallel without problems but, when paralleling unlike units, consider the effects of:

- Engine Configuration – Response to load changes will be affected by engine size, turbocharger, governor type, and adjustment. *Temporary unbalance of kW loads during load change is likely, but quickly stabilizes.*
- Generator Design – Circulating currents and harmonic currents add to basic load current, increasing coil temperatures, and causing circuit breaker tripping. *Circulating current is minimized by correct regulator adjustment. Harmonic interaction between generators must be calculated to determine compatibility.*
- Regulator Design – Automatic voltage regulation (AVR) of dissimilar design may be used when paralleling generators. *When constant voltage regulators are paralleled with volts-per-Hertz types, imbalance during transient load changes can be anticipated.* As load is suddenly applied, constant voltage units attempt to supply the total requirement. As the constant voltage generator drops frequency, the volts-per-Hertz unit begins to share load. The temporary load imbalance passes, and kW load is shared between generators.

Regulator Compensation

When two or more units are operating in parallel, the regulators must control the excitation of the alternators so they share the reactive load. Two ways are: Reactive Droop Compensation and Reactive Differential (cross current) Compensation.

Reactive droop compensation does not require wiring interconnection between regulators. During parallel droop compensation operation, the bus voltage droops (decreases) as the reactive lagging power factor load is increased.

Reactive differential (cross current) compensation requires the addition of interconnecting leads between the current transformer secondaries and allows operation in parallel without voltage droop with reactive load.

Cross current compensation can only be used when all the paralleling current transformers on all the generators delivering power to the bus are in the CT secondary interconnection loop. Because of this requirement, cross current compensation operation *cannot be used when a generating system is operating in parallel with the utility power grid. Utility voltage can vary enough to cause high circulating current in a paralleled generator.* kV•AR controllers must be used to adjust generator voltage to match utility and minimize circulating current.

Balancing Loads on Available Phases

If the electrical distribution system served by a three-phase generator set consists entirely of three-phase loads, the system is balanced. The coils making up the generator's three phases each supply the same amount of current to the load. If single-phase loads are added to the three-phase load, a condition of unbalance will exist unless the single-phase loads are equally distributed among each of the three phases of the generator set.

In many applications, balancing the single-phase loads may not be practical. If these loads are relatively small (10% or less of the generator set three-phase kV•A capacity), unbalanced single-phase loading is not cause for concern provided each of the three line currents does not exceed the generator set rating. The following problems illustrate the method of determining maximum single-phase load which may be safely drawn from a generator set simultaneously supplying single-phase and three-phase power.

Problem 1:

Find the amount of single-phase power which can be safely drawn from a three-phase, 125/216 volt, four-wire generator set, rated to deliver 100 kW at 0.8 pf. The coil current rating of the generator set is 334 amperes. Assume the single-phase load is connected from one line to neutral and has an operating power factor of 0.9 lagging, and that the generator set is also supplying a three-phase load of 50 kW at a 0.8 pf.

Solution:

1. Find the current drawn from each of the lines by the three-phase load.

$$P = \frac{\sqrt{3}V \times I \times pf}{1000}$$

$$I = \frac{P \times 1000}{\sqrt{3}V \times pf} = \frac{50 \times 1000}{1.73 \times 216 \times 0.8} = 167 \text{ amperes}$$

2. Find the coil current capacity remaining for the single-phase load.

$$334 - 167 = 167 \text{ amperes}$$

3. Find the single-phase power available.

$$P = \frac{V \times I \times pf}{1000} = \frac{125 \times 167 \times 0.9}{1000} = 18.8 \text{ kW}$$

Problem 2:

The generator set is rated to deliver 100 kW at a 0.8 pf. It is a three-phase machine with a coil current rating of 334 amperes. The three-phase load to be supplied is 50 kW at 0.8 pf. The single-phase load consists of both 125 and 216 volts circuits. The 125 volts load has a 0.9 pf and is connected from neutral to one leg. This leg is common with one of the two supplying 10 kW at a 0.8 pf to the 216 volts load, see Figure 106.

Solution:

1. The current drawn from each line by the three-phase load is found by the procedure used in step 1 of problem 1 to be 167 amperes.
2. The coil capacity available for single-phase loads is again 167 amperes.
3. Find the 216 volt single-phase load current.

$$I = \frac{P \times 1000}{V \times pf} = \frac{10 \times 1000}{216 \times 0.8} = 58 \text{ amperes}$$

4. Find the coil current capacity remaining for the single-phase 125 volt load.

$$167 - 58 = 109 \text{ amperes}$$

5. Find the 125 volt single-phase power available.

$$P = \frac{V \times I \times pf}{1000} = \frac{125 \times 109 \times 0.9}{1000} = 12.3 \text{ kW}$$

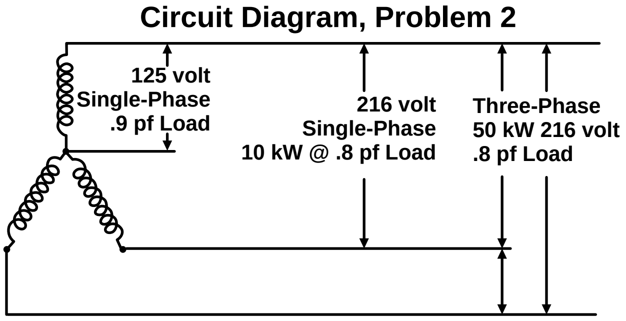


Figure 106