*By Keith Lane, PE, RCDD/NTS, LC, LEED AP,
Lane Coburn & Assocs., Seattle*

Specifying generators for mission-critical environments

Engineers must consider size, fuel capacity, and grounding when designing mission-critical standby power systems.

Standby generators are a key component of any mission-critical facility. There are many issues that need to be addressed when selecting and design the standby generator system. This article will cover three of the main issues: proper sizing, the fuel supply system, and proper grounding.

PROPER SIZING

When sizing a standby generator, the engineer must consider the total output in real power, the required compensation for harmonic content in the electrical distribution system, and large-motor startup requirements.

Generators are typically specified with a kW rating and an associated power factor. Together, these values indicate the maximum kW (real power) and kVA (apparent power). An engineer must consider both the engine and generator—individually, and as a system. Engines produce the real power, or horsepower, and control frequency. Generators change this mechanical energy into electrical energy (kVA) and must satisfy magnetization current (kVAR) within an electrical system.

In a purely inductive load, the current lags the voltage by 90 deg (see Figure 1). Power alternates equally between cycles of positive and negative. This means that power is being alternately absorbed and returned to the source. If the system is a mechanical generator, it would take practically no net mechanical energy to turn the shaft because no power would be used by the load.

Often, a more critical generator sizing parameter is the maximum starting kVA (skVA) and maximum starting kW (skW) allowed. The skVA depends on the maximum allowable voltage drop during starting and will be lower for more sensitive critical loads, or where lower maximum voltage drops are required by code.

It is common for a system stating kVA and maximum allowable voltage drop to drive the size of the generator. Motors can draw six times the full load amperes during startup. High efficiency motors can draw 10 times the full load current or more. This means that motor starting can dramatically affect the skVA required and may exceed the maximum skVA of a generator that would otherwise be large enough to serve the steady state load. This could require an oversized generator based solely on the motor-starting requirements.

Staggering the starting of large motors and/or providing soft starters or variable frequency drives (VFDs) can mitigate the voltage drop problem by reducing the inrush current and kVA. Staggering the starting of large motors can reduce the peak starting kVA to within limits of a smaller generator. When providing steps between loads, the designer must be aware of all codes and maximum allowable starting time delays for life safety and legally required standby loads.

Soft starters or VFDs can reduce the starting inrush current and kVA to half of that of an across-the-line starter. On the downside, these devices also use silicon-controlled rectifiers to chop up the ac sine wave, resulting in a nonlinear waveform. This nonlinear waveform, also known as harmonics, causes voltage distortion across the reactance of the generator and can cause unacceptable transient performance. Consequently, the results of harmonics will adversely affect the performance of the entire system. Voltage drop and voltage distortion will be much higher when a facility is under generator power than when on utility power. Typical generators have 15% to 20% internal reactive impedance, whereas utility transformers typically have between 2% and 5% internal reactive impedance.

UPS rectifiers usually do not draw a sine wave current from the power source. The more the current waveform deviates from a sine wave, the more total harmonic distortion (THD) the current waveform contains. Harmonic distortion can cause excessive heating at the generator and excessive voltage distortion across the entire system.

An engineer must be familiar with the various methods UPS and generator manufacturers use to make their UPS systems more user-friendly to generator systems. These methods include the use of:

- ✔ UPS with12-pulse rectifiers in lieu of 6-pulse rectifiers
- ✔ UPS with passive filters
- ✔ UPS with step loading or "walk-in" features
- ✔ Permanent-magnet generators with digital excitation controls
- ✔ UPS that reduce maximum input current.

A 6-pulse rectifier typically has about 30% THD, rich in 5th and 7th harmonics. A 12-pulse rectifier has less than half of the THD than that of a 6-pulse rectifier, and is rich in 11th and 13th harmonics.

UPS manufacturers can provide passive filters to reduce the THD seen by the generator. At low UPS loading, the static filter can provide an excessive capacitive component that is sent back to the generator. Unlike a utility source, a generator cannot absorb the voltage rise caused by the capacitance in the system. Theoretically, the generator's voltage regulator can lose control and raise the output voltage to the UPS. The UPS rectifier may turn off when it sees the rise in voltage. This disconnecting of the UPS rectifier will remove the additional capacitance in the system, which will allow the generator's voltage regulator to operate properly. This cycle can continue and the UPS will be unable to pick up the load under generator power.

This problem can be eliminated by evaluating the system to provide a smaller filter, which should be sized to provide no excitation at the lowest possible load. In addition, the filter can be completely removed under generator power with control circuitry. Strategically providing reactive loads in the system and connecting them to the generator prior to the UPS will allow these loads to absorb the capacitive component, which essentially redirects the capacitive component away from the generator.

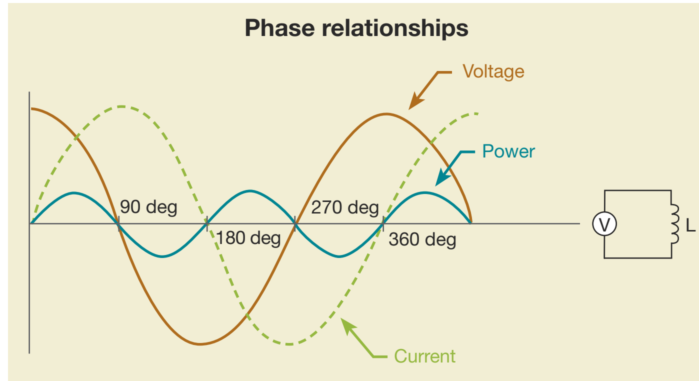

Figure 1. This illustration shows the relationship between generator voltage, current, and power. The current lags the voltage by 90 deg in a purely inductive load. Courtesy: Lane Coburn & Assocs.

A 100% step-loading of the UPS system to the generator in the case of a loss of utility power will cause sudden fluctuations in both frequency and voltage of a standby generator. Many manufacturers will offer a "walk-in" function. During a utility power outage, the load served through the inverter output from the utility source via the rectifiers will immediately switch to the UPS batteries. Once the generator is up to speed (voltage and frequency), the total load on the UPS system's batteries can be slowly applied to the generator. Typically, this can be programmed to occur over a 30-sec period. The walk-in feature greatly reduces the frequency

Figure 2. This illustration shows a portion of a one line diagram for a large high-rise building with multiple automatic transfer switches. These transfer switches include life safety, legally required standby, and optional branches. Courtesy: Lane Coburn & Assocs.

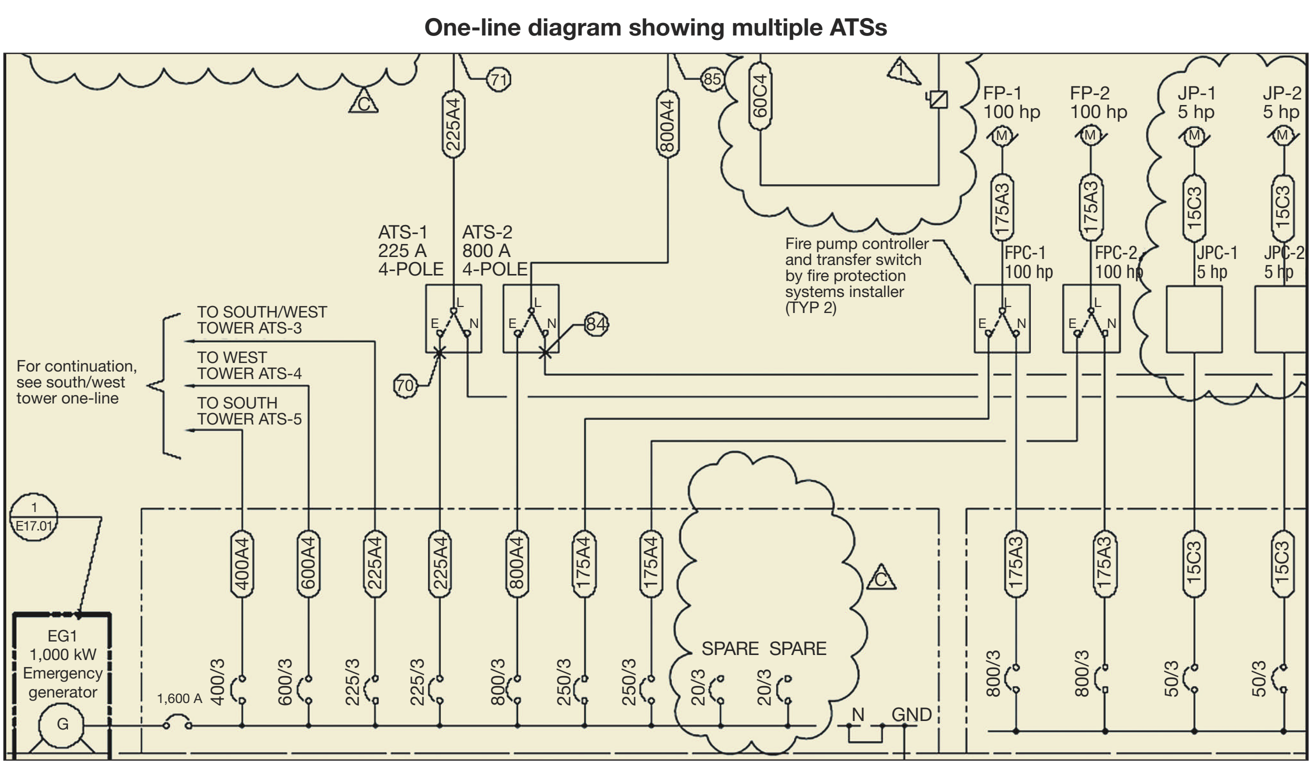

Table 1:
Generator ratings highlighting subtransient reactance

GENERATOR RATINGS		
	PMG stator	2.1 Ω
410.1a	No load exciter field Amps at 480 V Line-to-Line	0.79 A dc
420.1a	Short circuit ratio	0.617
421.1a	Xd synchronous reactance	2.25 pu 0.319 Ω
422.1a	X2 negative sequence reactance	0.212 pu 0.03 Ω
423.1a	X0 zero sequence reactance	0.063 pu 0.009 Ω
425.1a	X'd transient reactance	0.163 pu 0.023 Ω
426.1a	X"d subtransient reactance	0.119 pu 0.017 Ω
--	Xq quadrature synch reactance	1.1 pu 0.156 Ω
427.1a	T'd transient short-circuit time constant	0.162 sec
428.1a	T"d subtransient short-circuit time constant	0.011 sec
430.1a	T'do transient open-circuit time constant	2.55 sec
432.1a	Ta short-circuit time constant of armature winding	0.027 sec

Subtransient reactance should be 12% or less. This table represents a subtransient reactance of 11.9%. Courtesy: MTU

and voltage fluctuation on the generator output.

UPS harmonics can cause voltage waveform distortion at the generator. Permanent magnet generators that derive their own excitation can help to mitigate this problem. In addition, digital voltage regulators and digital excitation controls can further provide immunity to the harmonic effect of nonlinear loads.

Many UPSs allow the operator to set the maximum input current. After restoration of ac power, the rectifier/battery charger will power the inverter and simultaneously charge the batteries. The maximum possible input current to the UPS must be considered when sizing the generator. If an operator reduces the maximum input current, the total load on the generator is reduced, but the time to recharge the batteries is increased.

Waveform notching can be detrimental to solid-state timing devices that rely on zero crossing switches. To compensate for the voltage distortion from nonlinear loads, a larger generator with reduced impedance can reduce the effects caused by the nonlinear load.

The design engineer must be aware of the intended use of the on-site generator. Depending on the load factor, typical application, typical peak loading, and typical hours per year, the generator will require either a standby rating, a prime rating, or a continuous rating. In addition, code issues will drive the required rating of an on-site generator. Operating a generator beyond its rating will result in a shorter life and more expensive operating costs. It is important to reference a generator's intended use to the manufacturer's warrantee restrictions in regard to run time per year.

When specifying a standby generator for a data center or mission-critical facility, I recommend a subtransient reactance of 12% or less. The lower, the better.

Stepping the loads on a generator is a method used during the design process to reduce the required size of the generator. If all the loads are stepped on at the same time, the generator will be greatly oversized. Providing multiple automatic transfer switches and timing the transition several seconds apart is one method of ensuring a multistage start of the generator. Another method is to program a UPS system walk-in to ensure the entire load of the UPS is not slammed into the generator.

Most large data centers will use standby generators to serve the "optional" data center loads. These generators will not mix life safety, legally required standby, and optional load. But for small data centers within an office building, the same generator that is used for the life safety and legally required standby loads can also serve the optional load.

In these cases, there are three branches of automatic transfer switches that can provide convenient load stepping during generator startup (see Figure 2). This will typically reduce the required size of the generator. The transfer switches can be timed per the National Electrical Code (NEC) to start the life safety loads within 10 sec (NEC 700.12) and the standby loads within 60 sec (NEC 701.11).

Conservatively oversizing a generator because one does not clearly understand sizing requirements will not only add undo expense to a project, but it can also adversely affect system reliability. Most manufacturers recommend that diesel engines should not be run at less than10% of rated load for extended periods, and in general recommend that loads do not drop below 30% of the generator rating. Check manufacturer recommendations for specific installations.

THE FUEL SUPPLY SYSTEM

The engineer must also be aware of the minimum amount of on-site fuel supply required for an internal combustion prime mover serving as a power source for emergency systems.

The fuel supply system is a critical component of the standby generator system in a mission-critical facility. We typically see requirements ranging from 24 hours to 72 hours of fuel required. On the design side, a good rule-of-thumb when sizing the fuel supply is to assume 0.07 G/kW/hr.

For example, a 2,000 kW generator requires approximately 140 G/hr at full operation.

2,000 kW x 0.07 = 140 G/hr at full load

For large generators, the minimum amount of on-site fuel supply can

Separately derived source

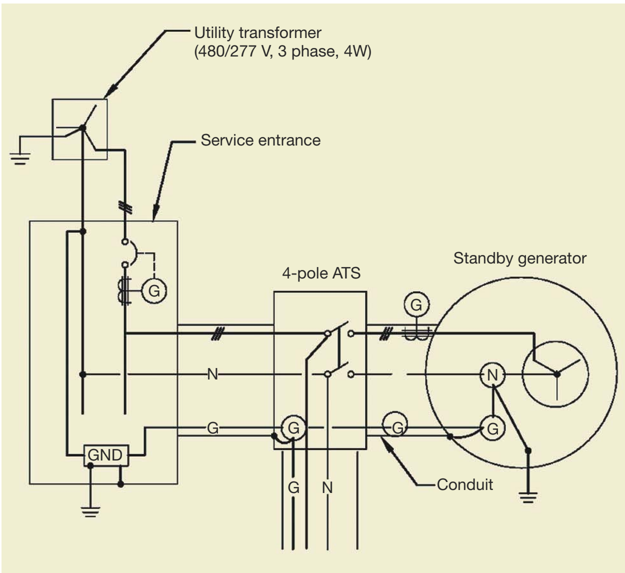

Figure 3. When the generator is considered a separately derived source, the neutral and ground are tied together at the generator and a 4-pole transfer switch must be used. Courtesy: Lane Coburn & Assocs.

Not a separately derived source

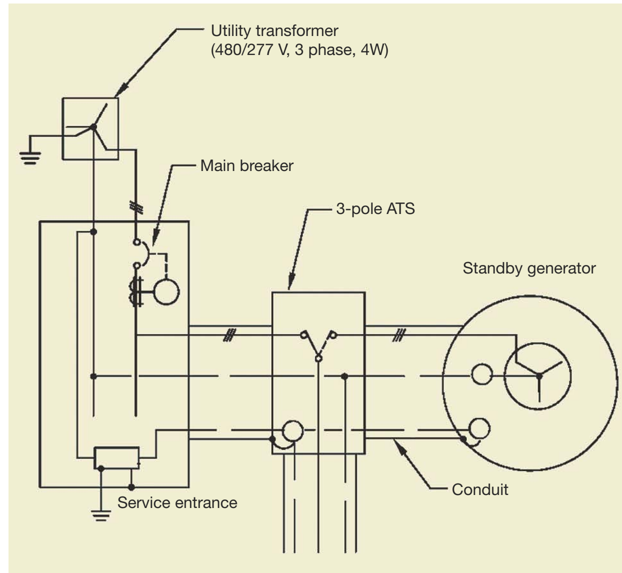

Figure 4. When the generator is not considered a separately derived source, the neutral and ground are not tied together at the generator and a 3-pole transfer switch must be used. Courtesy: Lane Coburn & Assocs.

exceed the limits set by building and/or fire codes, and can lead to additional system requirements. These additional system requirements include separate fuel supply systems; Class H, Div. 3 occupancies; or UL 2085 tanks with integral secondary containment.

Another consideration is the type of fuel tank. Single-wall tanks are UL-142 labeled and designed for storing flammable and combustible liquids. A UL 2085 tank may be required for situations when large amounts of fuel are necessary.

PROPER GROUNDING

Generator system grounding is an important criterion that must be understood to ensure proper operation of the critical systems.

The generator system can use either 3- or 4-pole transfer switches (see Figures 3 and 4). There are potential ground fault issues when using a 3-pole automatic transfer switch (ATS). The NEC requires a GFI breaker on the generator if the breaker is 1,000 A or more, and 480 V. If this is an optional generator, the generator breaker is required to trip during a ground fault. A generator serving a life-safety load has the options of alarm only and no tripping. One method of grounding a generator with a GFI is to bond the neutral and ground together at the generator, treat the generator as a separately derived source, and provide a 4-pole ATS.

Consider a GFI breaker on the main service and on the standby generator. In this example, the generator is not treated as a separately derived system, and a 3-pole ATS is used. There is a possibility under generator operation and a ground fault that the main breaker GFI could trip in addition to the generator GFI breaker. Under this circumstance, when the normal utility returns, the main breaker in the service could potentially trip, not allowing the utility to serve the facility.

A Modified Differential Ground Fault (MDGF) system can add significant complexity to a standby electrical distribution system. An MDGF system is required when there are multisource systems with 3-pole transformer switches. In some situations, additional source grounding cannot be controlled. An MDGF can provide ground fault selectivity even on very complex systems. Ⓟ

Table 2: UL 2085 tank properties

UL 2085 TANK TEST REQUIREMENTS	
Test	Withstand ratings
Prolonged fire test	Two hours at 2,000 F Maximum average temp. = 280 F
Hose stream test	Five minutes, 45 psig water stream after fire test
Bullet resistance	Five rounds, 150 grain, Caliber test 0.30, M2 Ball ammunition, 2,700 ft/sec impact velocity
Vehicle impact	12,000 lb applied over 1 sq ft @ 10 MPH
Leakage test	After successful completion of the above tests, leakage test is performed using 5.0 psig air; tank to hold air for 1 hr without leaking.

This table lists some of the UL 2085 tank properties. Courtesy: Underwriters Laboratories

ABOUT THE AUTHOR

Lane, PE, RCDD/NTS, LC, LEED AP is president and CEO of Lane Coburn & Assocs. LLC. and a member of the Consulting-Specifying Engineer Editorial Advisory Board.