Sizing Alternators for UPS Loads

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Types of UPS Systems

"Standby" UPS systems

A "standby" UPS passes the AC line power directly to the load with little or no power conditioning. When the AC line fails, it quickly switches the source of power from the line to its inverter output and runs from the battery until the utility returns and is stable. There is usually a brief (less than one cycle) interruption or disturbance as the inverter takes over. When running on AC, a separate battery charger draws line current to charge the battery.

Apart from the end load, the only source of harmonic currents is the fairly small load presented by the battery charger. This type of UPS does not present a significant harmonic or leading power factor load to the generator. However, if the generator power is not stable in voltage and frequency, the UPS may continually switch back and forth from battery to generator power when running on the generator, since it will detect voltage and frequency shifts as if they were line failures.

"Line Interactive" UPS systems

Similar to the standby UPS, this UPS feeds AC line power to the load when it is available, but it performs voltage regulation and filtering to provide better power quality to the load. The inverter runs continuously at a low level to perform this filtering. The disturbance on AC line failure is usually much less than a standby UPS.

This type of UPS may present a load of varying power factor when running on generator, but harmonics are usually not significant. It will have the same problems when run from a source of reduced voltage and frequency stability.

"Dual Conversion" UPS systems

In a "dual conversion" UPS, the incoming AC utility power is converted to DC with a rectifier and then back to AC with an inverter. The inverter always supplies all of the power drawn from the load, and the generator only sees the rectifier as a load. The rectifier also usually performs the battery charging function. When the incoming line fails, the battery supports the DC bus, and the inverter continues to supply power to the load, so there is no disturbance to the load power.

Because of the dual conversion, this UPS is not sensitive to transient changes in the generator frequency and voltage. If the generator output is within the settings of the UPS, it will try to maintain synchronization so that a smooth transfer may be made to raw generator power in the event of a failure of the UPS.

On the other hand, the rectifier used with the double conversion system may be a significant source of harmonic currents, and, if filters are applied, the power factor presented to the generator may be highly leading (discussed further below). Different types of rectifier present different degrees of challenge to the generator:

Six- and twelve-pulse rectifier

A six-diode bridge rectifier fed from the line-to-line AC voltage (we are only considering three-phase systems) will draw six pulses of current per cycle, two from each phase. Because this current is pulsed, it causes harmonics of the line frequency to appear in the current waveform. These harmonic currents interact with the impedance of the generator to produce harmonic voltages that may cause problems for other equipment connected to the same line. By using a transformer with a dual winding on the input, feeding two rectifiers, the current drawn by the rectifiers may be spread out so as to have lower harmonic current. This is called a twelve-pulse rectifier. A six-pulse rectifier draws about 30% total harmonic current, mostly fifth and seventh harmonics. A twelve-pulse rectifier draws about 11% harmonic current, mostly 11^{th} and 13^{th} harmonics.

Because these rectifiers draw high harmonic currents, filters are often added to bypass these currents and make the input current more sinusoidal. The large capacitors used in these filters cause the input power factor to be leading, which can cause problems with generator stability.

Active front end rectifier

By using an inverter similar to the output inverter as a rectifier, with some small filters, the input current waveform can be shaped to be a nearly perfect sine wave with approximately unity power factor. This type of rectifier does not usually cause any harmonic or power factor problems to the generator.

Harmonic Loading

Because the generator is small by comparison with the generation capacity of the utility, it has a much higher impedance than the utility, so any harmonic currents cause much larger harmonic voltages than they would operating on utility power. The impedance seen by the harmonics at the generator is the negative-sequence reactance or X2. This impedance is sometimes not found on the generator data sheet, but the subtransient reactance X”d is usually a fair approximation.

Apart from the problems caused by the harmonic voltages to other connected equipment, they can cause additional generator heating, mainly in the rotor.

The maximum amount of reactance (X2 or X”d) that should be specified in the generator varies depending on many factors such as:

1. How much of the load is UPS or other harmonic generating equipment.
2. How much harmonic current is produced by each UPS or other device.
3. How much voltage total harmonic distortion (THD) can be tolerated
4. How many generators can be online at any given time.
5. Presence of any other power sources.

6. Presence of harmonic filters or capacitors on the power system.
7. Transformer connections in the power system (by arranging to have some transformers connected delta-wye and some wye-wye, a considerable amount of fifth- and seventh-harmonic current cancellation occurs).

A full system harmonic analysis may be advisable to determine the actual reactance requirement. Using a rule of thumb such as 12% maximum risks either wasting money on an excessively oversize generator, or failure of the system to meet harmonic requirements. A very rough calculation can be performed to get an idea of the order of magnitude of impedance required. The formula is:

$$THD = 0.01379X_2\mathrm{P}$$

where THD is the total harmonic voltage distortion, X_2 is negative-sequence impedance, and P_H is the percent of load that consists of rectifiers. This assumes typical six-pulse load. For twelve-pulse the distortion is one half of the amount calculated. No account of the generator harmonics is taken, so they need to be added. No account is taken of transformer or cabling impedances, or the effect of filters or other system loads. Figure 1 is a nomograph that may be used to estimate the distortion according to the above formula.

Negative Impedance

Electronic loads in general, and UPS in particular, have a negative impedance characteristic in that, as voltage increases, the current drawn decreases and vice-versa. This is not usually a problem of itself, but it exacerbates any other problems involving system stability, since it is a positive-feedback mechanism (e.g. increasing voltage reduces current draw, which tends to increase voltage further). Generators are usually tested with fixed impedance loads, so performance in the real world may not be as good as it appeared during factory testing.

Load Transients

Sudden changes in load, such as a chiller switching on or off, cause abrupt sags or surges in the generator output voltage as well as changes in frequency as the engine slows down or speeds up. These changes may cause difficulties for standby or line-interactive UPS, causing them to switch to battery until the power stabilizes again. This can cause reductions in run time as the battery is depleted every time this happens, and can also cause premature battery failure from repetitive cycling.

The generator parameter that controls voltage transients is the transient reactance X'd. Lower X'd results in lower transient swings. The things that need to be known to calculate the voltage swings are the amount of applied or removed load and the power factor of that load. Particularly for motors (e.g. chiller pumps and fans), the starting current is usually much higher than the running current. The multiplier is indicated by the NEMA “Code” letter on the nameplate along with the running current.

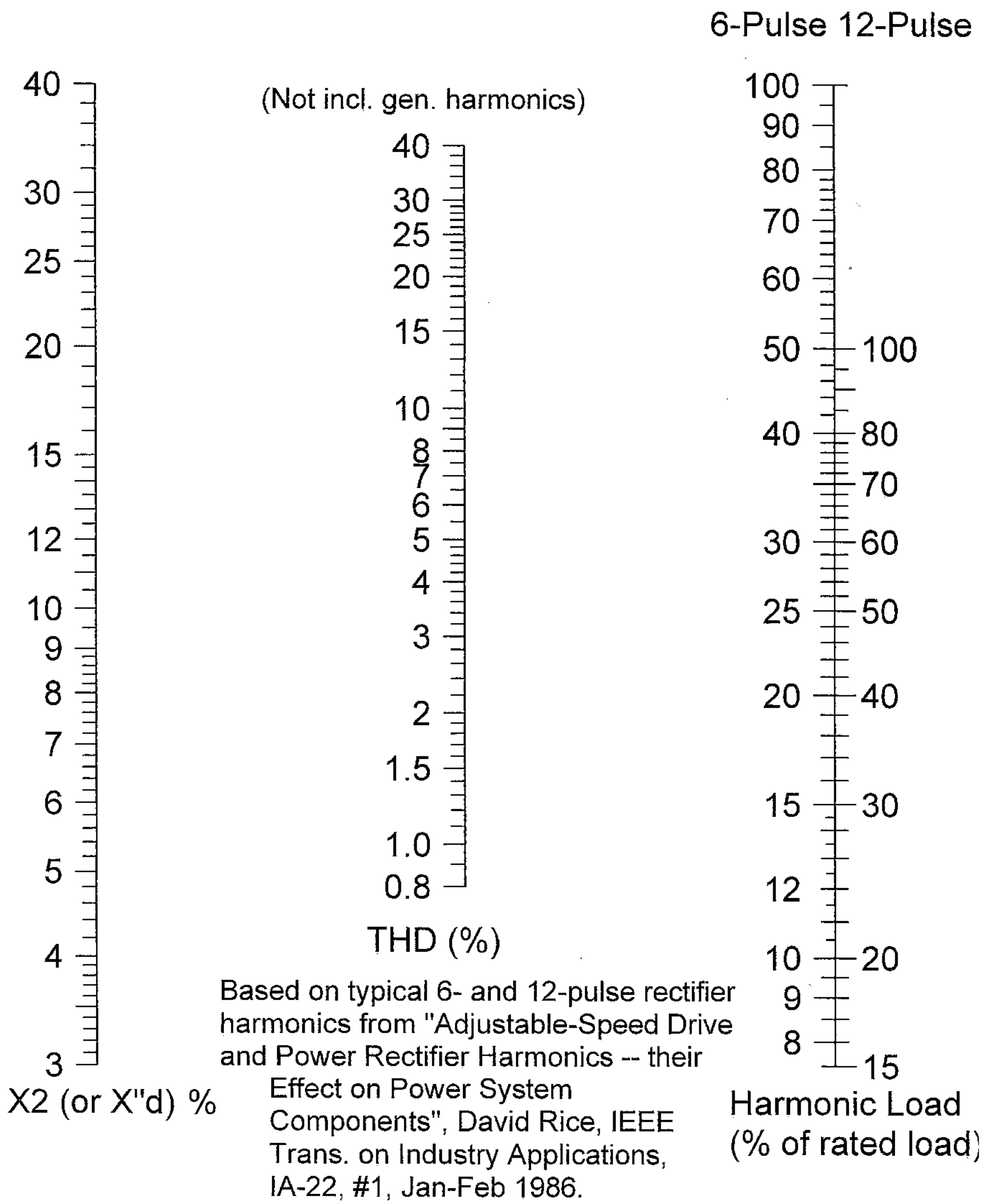

Figure 1. Nomogram for harmonic load calculation.

The frequency of the machine is controlled by the engine and is not influenced by the generator. There is some additional voltage transient caused by the frequency fluctuation, but the mechanical response of the engine with the generator inertia is usually quite a bit slower than the electrical generator response.

Power Factor

Power factor in electrical theory is defined as the ratio between the apparent power (the product of RMS current and RMS voltage) and actual delivered power (average value of instantaneous product of voltage and current, as measured by a wattmeter). Historically, power factor less than unity was considered to be caused by a phase difference between voltage and current, and was defined as the cosine of the phase angle between them. This is now known as "displacement" power factor.

In recent years the definition of power factor has been extended to cover other types of current that do not produce real power, particularly harmonic current. This "harmonic" power factor has a totally different effect on operation of alternators. Whereas displacement power factor increases or decreases the required field current of the alternator, harmonic power factor merely causes extra heating in the damper cage of the machine. We will not consider the harmonic power factor further in this paper.

Displacement power factor may be either leading or lagging with respect to the terminal voltage of the machine. Lagging power factor load requires an increase in alternator excitation (field) current in order to maintain rated voltage, while leading power factor load requires a decrease of excitation. To some extent this is beneficial, since it reduces rotor heating, but if the excitation is reduced too much, the voltage regulator may lose control of the voltage, which can increase to very high levels or oscillate.

The generator parameters that control this are saturated short-circuit ratio (SCR or, in Europe, Kcc) and saturated synchronous impedance Xds. These both represent the same quantity and are reciprocals of each other. High SCR and low Xds make the machine more stable. To a first approximation, if Xds is less than 1, or SCR greater than 1, the machine will be stable with any leading power factor down to zero. This usually requires a very oversize machine. For larger values of leading power factor the reactive capability curve should be consulted. This gives the power factor or leading VAR limit for all values of real load. A sample capability curve is shown in Figure 2.

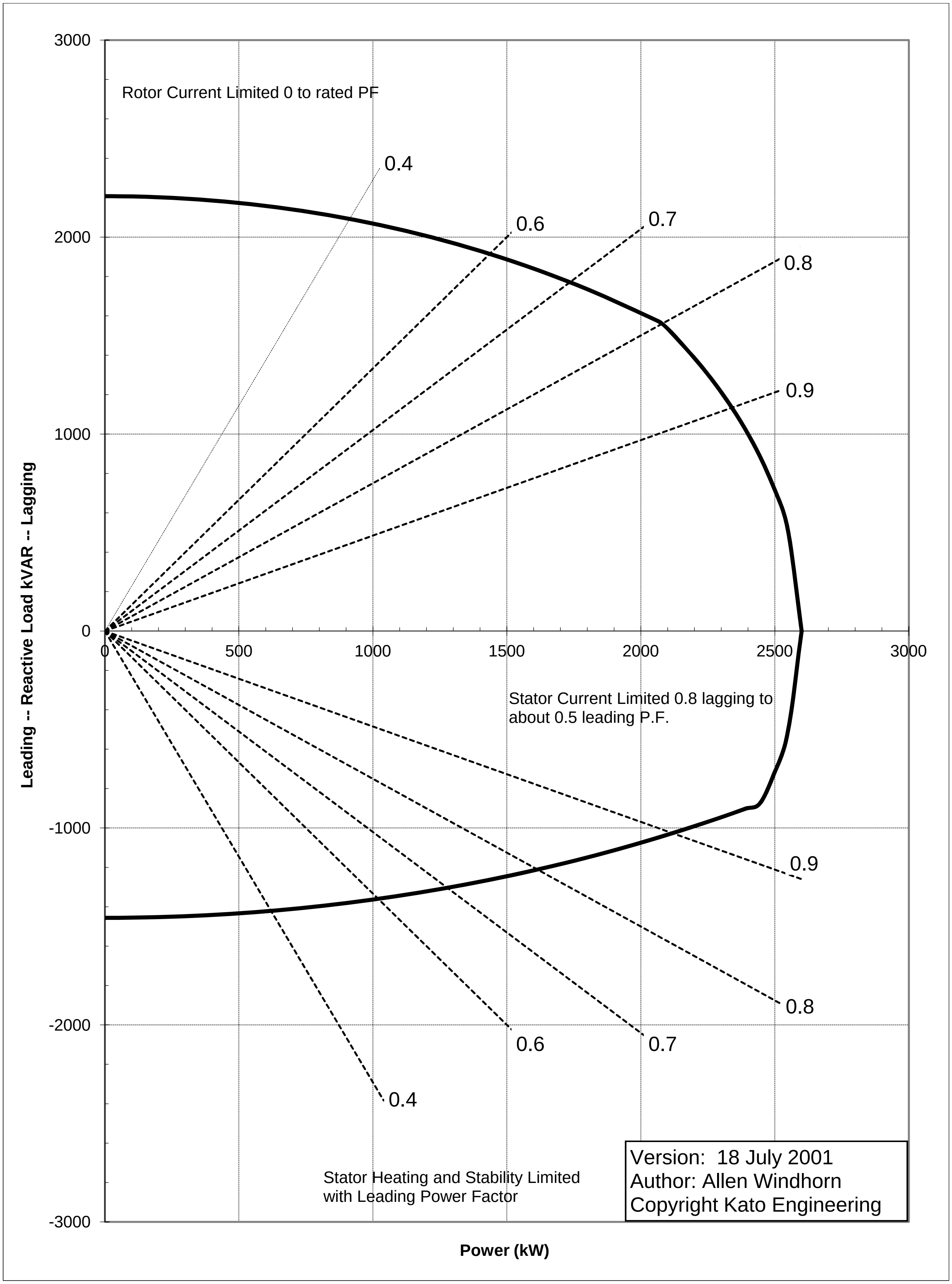

Figure 2. Sample Reactive Capability Curve.