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Power system considerations for cell tower applications

White Paper
By Wissam Balshe, Group Leader,
Sales Application Engineering

Industry predictions estimate that in 2011 and again in 2012, 75,000 new off-grid telecommunications cell towers will be built in developing countries. Over 50 million additional wireless subscribers are expected in Africa alone over the next two years. Experts in Asia and South America are estimating the wireless market to grow about 7–10% every year for the next five years. Most of these cell towers will need generator sets, either for emergency backup in urban areas or as the prime source of power in remote locations. This paper examines the factors to be considered in designing and configuring these generator sets.

The reliability of the grid

Because the power grid is not always reliable in many parts of the world, just extending the grid won't answer the need. Concerns about the reliability of the grid are especially common in rural regions of developing countries. But these concerns apply to the grid in many urban areas as well. Many so-called "standby" generator sets installed at urban cell towers are in fact running for several hours every day.

With the sustained rise of global energy prices, the fuel costs of running these diesel, natural gas or propane generators are a major piece of the total cost of ownership (TCO) for these cell towers. For example, the fuel cost (as a percentage of TCO) could be as high as 64% for a typical 12 kW diesel generator running for about eight hours per day. This cost is driving many telecom cell tower operators to consider other power system options, which are covered in the Market Trends appendix of this paper.

Power system configuration for cell towers

Let's consider the power system configuration, types of loads and important generator set features for any cell tower application.

Two telecom tower installations in Tanzania, Africa.

Power requirements for base transceiver stations (BTS) vary widely depending on a number of factors:

- Is the site indoor or outdoor?
- Is the location urban or rural?
- In which region is the site?

In light of these variables, it is unrealistic to create one load profile for all cell tower power system configurations. Figure 1 summarizes regional variations for most generator set system requirements.

Region	Duty	Load Profile
Africa	Prime	7.5–40 kVA, 1- & 3-phase, depending mainly on the size and number of air conditioning loads
Asia Pacific	Prime	25–40 kVA, 3-phase
Latin America	Prime	5–30 kW, 1-phase
Middle East	Prime	25–40 kVA, 3-phase
North America	Standby	20–60 kW, 3-phase

Figure 1 - Power system requirements by region.

One generator set or two

In most regions, a standby power system configuration typically uses 3-phase AC output power, where the single-phase loads are balanced equally among the three phases. Most cell tower operators in North America and Europe use one diesel-fueled generator for emergency backup to the main utility power. But in developing countries and prime power markets, two generators are typically used: one running continuously and alternating with the other generator set weekly, or whatever interval the automatic transfer switch (ATS) is set to use.

The differences in the size of transceivers, ambient environmental conditions, type of rectifiers and inverters used in the switch mode power supply (SMPS), number and size of batteries, and other factors (such as maximum allowable fuel tank size limit or design for future load expansion) are the major variables that need to be considered when selecting the generator set and power system configuration for the cell tower. At the same time, there are certain loads that every base transceiver station (BTS) will use. These loads are pictured in Figure 2, which shows a typical one-line electrical layout for a base station employing a 12 kW (15 kVA) generator set that would meet the demands of a cell tower in most regions.

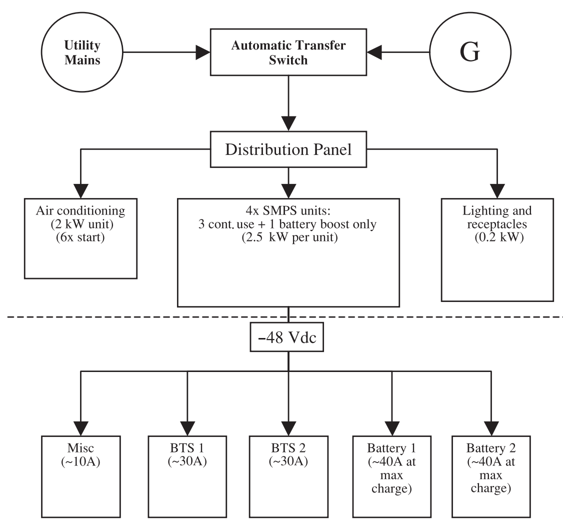

Figure 2 - Typical electrical layout for loads on a telecom base station.

As you can see, the load consists mainly of microwave radio equipment and other housekeeping loads such as lighting and air conditioning units. The actual BTS load used on the cell tower is powered via the SMPS, which is the direct current (DC) power plant. In some regions, such as India and East Asia, the SMPS is typically part of a more complex power interface unit (PIU), which includes the transfer switch and a static line conditioner to maintain the critical operation power input between the utility and generator(s). The PIU also protects the equipment from input power supply surges due to lightning, monitors the health of the battery and controls the charging rate of the battery banks. The rectifiers and inverters in the SMPS and PIU systems have minimal power losses, and run at efficiencies as high as 95–98% with a power factor close to unity.

Indoor units and air conditioning

When it comes to indoor base stations, air conditioning units play a major role in determining the size of the generator set needed. Most indoor BTS loads require air conditioning during the summer. Typically there will be two air conditioning units: a primary and a secondary unit. It is rare, however, for both air conditioning units to run at the same time, so in sizing the generator set, the engineer should assume it will start and operate only one unit at a time. For outdoor applications, there is no requirement for air conditioning, hence no need to supply a large alternator to meet the starting requirements of air conditioning units. A smaller generator set can be used.

Minimal harmonic distortion

Some harmonic distortion in the power system is to be expected when operating non-linear and rectifier-based loads such as those used in the SMPS. It is worth noting, however, that many telecom operators regard the power supply voltage output distortion as minimal, because of the fast switching frequency of the transistors used in the rectifiers. Voltage output distortion is also mitigated by the oversized alternators supplied on most generator sets to meet the locked rotor current requirements of the air conditioning motors. These oversized alternators help to reduce the total system impedance (reactance). Consequently, there is no further need to oversize the alternators as one would with other applications that use similar loads.

48V and -48V current

Although other voltages are possible, most radio transceiver loads used in telecom base stations run on a -48V DC bus. This practice originated in the early days of telephony, when 48V DC was found to be suitably high for long telephone lines but low enough to prevent serious injury from touching the telephone wires. Consequently, most electrical safety regulations consider DC voltage lower than 50V to be a safe low-voltage circuit. It is also practical, because this voltage is easily supplied from standard valve regulated lead acid (VRLA) batteries by connecting four 12V batteries (like those used in cars) in series, making it a simple system.

The positive grounded or -48V system is another survivor from earlier industry practice. Negative voltage on the line was found to be superior to positive voltage in preventing electrochemical reactions from destroying copper cables if they happen to get wet. Negative voltage also protects against sulphation on battery terminals. Sulphation, the buildup of crystals of lead sulphate, is the leading cause of early battery failure.

DC and AC loads, VRLA batteries

The distribution panel in Figure 2 also shows other essential AC bus loads that are energized from either the generators or utility mains. They consist mainly of air conditioning units (single- or 3-phase) and lighting (single-phase). Other typical AC loads that can be put on the generator include fuel pumps and ventilation booster fans in the generator room. Although not shown in Figure 2, it is also common to use DC-to-DC converters in the power system to provide +24V DC for certain loads, such as those used to run diesel room inlet or outlet air damper motors, remote monitoring, control systems, DC lights and/or DC-powered heaters.

In some configurations, a station of VRLA batteries is the standby source of power, usually running in parallel with a generator set, to save on fuel costs. In such configurations, the generator set operates only to charge the batteries when it senses that the DC bus voltage is low after a long outage. However, there are concerns over the reliability and actual reserve time available in using VRLA batteries when the float voltage is applied continuously — especially in prime power applications — because of the high number of cycles when the batteries discharge.

If such configurations are used, a battery management system should always be specified to continuously monitor the batteries' voltage and command the battery charger to provide the appropriate trickle charge to keep the batteries floated. Typically, the generator is not used to float the batteries, but rather to provide the high current needed for the battery charging or to supply the load directly if the batteries fail. Such hybrid systems that combine batteries with one or more generator sets may be fuel-efficient, but the batteries' maintenance costs and the added complexity need to be considered when analyzing the TCO; they may not be economical for typical standby applications.

Design factors: sizing the generator and alternator

The first thing power system designers need to address is size. They need to know the total steady-state requirements of all the equipment on the cell tower that will be powered by the generator set, and then match it with the right alternator to supply the locked rotor amp (LRA) requirements for starting the air conditioning units in the BTS room (for indoor installations). It's important to note that the LRA could be as high as *6 times* the rated full load amp (FLA) output of 3-phase motors, and up to *12 times* the FLA for single-phase motors.

Similarly, the alternator also needs to meet the steady-state reactive power requirements of all other loads in the BTS. This requirement explains why the alternator is typically oversized by about 150–200% of the actual kW needed to power the cell tower. The oversizing of the alternator also improves the transient voltage dip that occurs when starting the air conditioning units and minimizes the total harmonic distortion (THD) on the voltage output of the generator set caused by the rectifiers in the SMPS.

Keep in mind that oversizing the alternator may require a bigger engine or prime mover to drive it. This approach may be desirable because it allows for future growth on the tower if needed, but it might not be an energy-efficient solution. In addition to the higher capital cost, it will increase the operational costs to run the cell tower. A bigger engine will also have a higher fuel consumption rate, and mean additional maintenance and service costs (for example, to mitigate wet stacking and carbon buildup in the exhaust when running lightly loaded). A bigger engine will also emit more particulate matter (PM) in its exhaust.

Other factors to consider

There are other technical considerations to keep in mind when selecting the generator set.

- For BTS stations located in residential locations, a quiet generator set is required. This can be achieved by housing the generator set in a sound-attenuation enclosure. Specifying a critical muffler is not a complete solution, because there are other sources of noise besides the exhaust, e.g., the radiator fan.
- For rural and remote locations, the generator should have at least eight input/output dry contacts and relays for remote monitoring devices, as well as an oversized fuel tank and fuel pressure sensors.
- For sandy and dusty environments, heavy-duty air filters should be used.
- For wet and humid environments, specify aluminum enclosures and anti-condensation heaters to prevent insulation failures and short circuits between the windings in the alternator stator.
- For cold climates, engine block and oil heaters are required, especially for standby applications.
- Specify a permanent magnet generator (PMG) excited system for generator sets above 25 kW. A PMG will eliminate the effect of a distorted voltage output caused by the BTS non-linear (rectifier) loads on the generator set's automatic voltage regulator (AVR). It also has better field-forcing capabilities for air conditioning motor starting than a self-excited generator would provide.
- Use discharge recalculation dampers for cold climate sites to save energy costs in heating the generator room.

Alarms

There are shutdown alarms and warning alarms on the generator set. The shutdown alarms include overspeed, overvoltage, overcurrent, undervoltage, high engine temperature, overcrank, low oil pressure, and circuit breaker trip. The warning alarms notify the operator of the following:

- Loss of fuel pressure and fuel level (important because of vandalism and theft concerns in many remote locations)

- Low battery bus voltage
- Start switch not in auto
- Remote/manual start
- Engine oil temperature

Alarms can also be linked to other parameters that can help the operator flag any potential problems that could lead to the generator set shutting down, and potentially dropping its loads.

Factors to consider with the automated transfer switch

The automatic transfer switch (ATS) can be integrated with the generator set. This practice reduces installation costs, but it is not recommended, especially for prime power applications, because the generator sets in these applications are typically replaced every five to eight years, depending on region and duty. An integrated ATS would thus be replaced unnecessarily, adding to the TCO.

When used in a 3-phase, 4-wire system, a 4-pole simultaneously switched neutral ATS is recommended to isolate the grounded conductors. A neutral ATS prevents the possibility of nuisance tripping of the overcurrent devices and ensures proper grounding of the systems when a separately derived generator set is desired (a solidly grounded generator set with a bond between neutral and ground). A 4-pole ATS will avoid problems caused by unwanted multiple ground fault current paths created by improper system bonding, and ensure that ground fault protection equipment on both sides of the ATS is sensing 100% of the ground faults when they occur.

To protect equipment from damage when the cell tower is hit by lightning, which is very common, transient voltage surge suppressors (TVSS) should be used on the utility side and load side of the ATS. In addition, DC surge protectors should always be used on all communication and networking devices on both sides of the ATS.

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[1]Refer to the Cummins Power Generation white paper PT-6006, “Grounding of AC generators and switching the neutral in emergency and standby power systems, part two,” for more details on the grounding of AC generators.

Summary

There are no universal features recommended for all generator sets used in telecommunication cell tower applications, because requirements and duty ratings vary from region to region. In general, for standby applications in urban areas connected to a reliable utility grid, standard generator set features as required by local codes and regulations should be sufficient. In other words, there is nothing unique about a standby generator set used in such telecom cell tower applications. However, when specifying generator sets for prime duty applications, such as those used in remote cell tower applications and some urban sites in developing countries, an oversized fuel tank with fuel alarm sensors, and 8–10 dry contacts and relays for remote monitoring are recommended. A fuel-efficient engine, or the use of batteries to supply the BTS load for a few minutes of power interruption or during peak demand, will save fuel costs substantially, and lower the operating costs of running the cell tower.

Appendix: market trends

Certain trends in the telecom industry have a direct impact on generator set power requirements for cell towers. A recent survey by Cummins Power Generation shows that many telecommunication equipment vendors are making considerable investments in the development of more efficient equipment to reduce the capital expenses (capex) and operating expenses (opex) associated with standby power systems.

No air conditioning

Radio transceivers are being designed to handle high ambient temperatures, in order to eliminate air conditioning in the cell tower BTS shelter. The impact of this trend is substantial, because air conditioning more than doubles the size of generators needed for steady-state operation.

For example, in a typical cell tower, the BTS load itself requires only about 2 to 3 kW, but up to 12 kW generator sets are being used to meet the occasional peak power requirements for starting air conditioning units. Therefore, as the use of the high ambient switching radio equipment increases, the size of the generator set required to power future telecom cell towers will be reduced substantially.

Energy-efficient radio equipment

In addition to the reduction in the starting power requirements from eliminating air conditioning units, the steady-state power requirements are also being reduced. To cut capital and operating costs, telecom companies are investing heavily in the development of more energy-efficient radio equipment to reduce the total power consumption and hence, the size of the generator set and ATS required for the BTS station. This trend will lower the initial capital cost, and with smaller generator sets, will also reduce the operating (mainly fuel) costs of cell towers.

Building materials

To have an energy-efficient cell tower does not always require investing in new technologies for BTS equipment. Some telecom operators are switching to simpler cell tower designs. For example, the shelter traditionally was built from brick and concrete, but now many operators are using high-thermal-efficiency plastic, which reduces the energy costs for operating cell towers. All these new design considerations and technology improvements in BTS equipment and shelters are dropping the generator size needed for telecom cell towers from 12 kW to about 5 kW.

Policy changes and shared equipment

Certain trends in the telecom space are driven by public policy, which may have a direct impact on the power requirements of cell towers. For example, in many developing countries, governments are requiring the use of backup power at telecom sites due to the critical nature of their service during a national catastrophe. However, they are also requiring providers to share towers and equipment to reduce the number of towers and their environmental impact. Accordingly, multiple operators are entering into agreements to share infrastructure and support equipment such as the tower itself, shelters, generators and accessories, thereby reducing costs substantially. Third parties are also taking advantage of this trend, building cell towers and leasing space on them to multiple operators. These towers have separate radio equipment for each operator, but still share one generator.

This trend of sharing towers by different operators is reducing the number of cell towers needed to cover a region or network, but it is also increasing the size of the generators needed to run these towers. This increase in generator size is also being driven by the increased demand for 3G and 4G data services used by smartphones.

Alternative energy sources and DC generators

Finally, in response to government subsidies and fuel cost savings, telecom prime power markets are utilizing more renewable energy solutions to power their cell towers. Some towers are powered by wind turbines or photovoltaic (PV) solar cells, especially for small load sites (less than 2 kW). Other solutions use natural gas or variable-speed DC generator sets for better fuel economy and efficiency. However, due to the variability in wind speed across the globe, wind-only solutions are likely to be restricted to locations with abundant wind resources such as coastal and mountainous regions. The efficiency of PV is still an issue, and solar cells are more expensive than conventional power generators, hence less economical for large sites. Until green power sources become more economical and efficient, telecom operators will continue to use traditional generators to power their cell towers, but many will start combining the generator with wind and solar cell power sources. These hybrid energy systems will create new opportunities for DC generators, which explains why many telecom market analysts expect the DC generator set market to grow at an annual rate of 5–7% over the next decade.

Looking ahead

In the next 5 to 10 years, telecom equipment manufacturers will continue to reduce the power consumption of BTS equipment. This trend will mean smaller generator sets. Manufacturers will continue to explore hybrid power systems that use renewable energy sources or batteries running in parallel with generator sets.

Some generator set manufacturers will start developing DC or variable-speed generators to meet the increased fuel-efficiency requirements of cell tower sites. Most manufacturers, however, will continue to supply synchronous-speed AC generators with oversized alternators to meet the starting power requirements of air conditioning units, but these generators will be driven by smaller and more fuel-efficient diesel engines.

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About the author

Wissam Balshe, Group Leader, Sales Application Engineering — Commercial Products, joined Cummins in 2007 as a point of contact for generator set sizing, codes and standards, transfer switches and general standby power systems application considerations. He graduated from the University of Minnesota in 2002 with a B.S. degree in electrical engineering. He then worked for three years as an Uninterruptible Power Supply System Engineer and then two years as an Aerosol Technology Application Engineer, detecting and analyzing particulate matter from engine exhaust emissions.

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