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Transfer switch set up for reliability and efficiency, part 2: Characteristics of power failures

> White paper

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Many facilities that have generator sets (gensets) also have automatic transfer switch equipment (ATS) to automatically start the generator set on a power failure and automatically switch the load from the utility to the generator set and back again. To obtain the most reliable and efficient system operation, it's important to have the ATS properly set up so that it can sense power failure and operate in the best sequence for the system that is installed and the equipment it supports. PT-7016 part 1 explains how transfer switches operate and the time sequence of power failure and return. PT-7016 part 2 covers characteristics of utility power failures and the sensing of power failure sequences. PT-7016 part 3 looks at ATS setting best practices and features available on the equipment.

Characteristics of utility power failures

Most "failures" in the utility power supplied to a facility are not failures of the large central generator stations providing power, but rather failures in the power distribution system serving the facility. Failures can occur due to damage to part of the utility system, failure of a distribution component, or overload of the distribution system. For example, if a car drives off the road and knocks down a power pole, it's no surprise that customers who are served by the lines on that power pole will have a disruption in power. However, all the customers affected by the downed line may not have to wait until the line is repaired to get power back. Just as a facility with a generator set usually has equipment to automatically detect problems and respond, the utility distribution systems include equipment to automatically detect problems and return power to their customer as fast as is practical. These systems may re-route power from another source, or may attempt to re-feed the failed part of the system. In many cases the damaged part of the system is isolated so quickly that customers don't even notice a problem.

Some key points to remember about the nature of power failures include:

- Many utility power failures are very short in duration. 98% of reported power problems are of duration of 15 seconds or less. Since it typically takes 7 to 10 seconds to start an emergency generator, if you have no emergency loads you may want to extend your time delay on start to 10-15 seconds so that the generator set isn't signaled to start unless the power has failed for an extended time period. It's also possible that if your emergency loads are primarily egress lighting, you might be able to up-fit your facility with battery lighting so that the generator starting can be delayed for a little longer when power fails.
- The length of a power failure at a specific site often depends on the characteristics of the distribution system feeding that site. In areas where there are overhead power lines, short duration power failures are more common than in areas with underground power lines, which typically have longer outages when an outage occurs.
- When there is a total power failure at a site, it's common to have a subsequent failure a short time later, especially when utility services in the area are overhead rather than underground. It's also

possible that if your site can be fed by more than one utility service you could have another short failure a short time after power is restored from your failed service.

- Some power failures are not total power failures, but instead are partial failures that can be thought of as a degradation of power quality rather than a total power failure. National standards allow voltage to vary plus 5% and minus 10% from the normal voltage level without being considered “out of range”. For example, if normal voltage is 120 volts, the normal range of voltage that might be seen at customer sites would range between 108 and 126 volts. A power failure can be considered to have occurred when the voltage of the power served to a site is outside of that 108 to 126 volt normal range of power, because outside of that range customer load devices might start to operate poorly, or fail to operate. These power quality problems may or may not be severe enough to require a start of your generator set, and depending on the type of transfer switch equipment you have, they may or may not be sensed by the transfer switch.

Let’s look at a few situations that illustrate why these differences occur:

Storm damage

A homeowner’s electric power comes into the house through a series of overhead lines. The area, being residential and older, is nicely populated with large trees. During a summer storm a tree falls on a power line and breaks the line. What would the homeowner experience, and what might the neighbors see?

Well, assuming that the line was totally broken, the homeowner’s power would have failed immediately, and it would be down until the damage could be repaired. If the storm is widespread, repairs can take a long time, reflecting the need to keep trees around power lines trimmed back, even if it can make the tree somewhat less pretty.

The neighbors, though, might also be affected as much by the downed line. When an overhead line is damaged, the power system feeding the line can be exposed to a short circuit condition. Protective devices in the power lines feeding the downed line sense an overload condition, and open to turn off power to the damaged part of the circuit (like a circuit breaker in your house does when there’s a short circuit). Unlike your house, the utility device, called a recloser, will often try to automatically close again to serve other loads. This is because when there is a short circuit that is burning through the air and the current flow through the circuit is interrupted, the current flow is stopped. When the power line is reenergized, there is too much resistance in the failed circuit to restore current flow, so the power can be left on so that other customers on the same circuit continue to get power.

In this case, the neighbors would see a total power failure for a very short time (1-3 seconds, for example), and then a power restoration.

On the other hand, if that tree were still lying on the power line, when the line was reenergized the power might still be short circuited, and this would cause the recloser to open again. A recloser can be set up to open and try to reclose several times before it stays open and waits for the failed circuit to be repaired. If that occurred, the neighbors might see several brief power failures before a total, longer duration failure occurred.

It’s also possible that a fallen tree might damage only part of the utility equipment, causing a slightly different event. Since much of the utility distribution system is 3-phase there are typically 3 wires from the utility power sources branching out into the customer sites. If only one of the lines is down, customers served by that line will lose power, but customers in very close proximity may still have good power. For the lines to be fully repaired, the customers that are served by phases of the lines that are undamaged will need to be shut down for some time while the lines are repaired.

More importantly, customers that are served by 3-phase utility service and who experience a single phase failure will want to get their generator going and connect to the generator, even if only one phase of power is damaged. Single phase loss can cause serious damage to 3-phase motors in a short period of time, particularly if they are heavily loaded. Special care in selecting transfer switch voltage sensing equipment is necessary to sense single phase failures correctly.

Through either of these events, neighbors that are a bit further away might experience several short periods of low voltage on their service, and the overloaded power system voltage drops somewhat when a short circuit occurs. These might be so minor that they don’t even notice them, or they might be severe enough that their transfer switch starts their generator set. This is one of the cases that might result in a generator running for "mysterious" reasons when power appears to be good.

Damage due to animals in a transformer

Probably most people have been amused while watching the high-energy antics of a squirrel looking for food, but when a squirrel starts looking around a utility power transformer, you can have a power failure when the animal causes a short circuit in the transformer cabinet. Like in the previous example, the customers served by the failed transformer will experience a total power failure. This failure is likely to take several hours to repair, since crews will need to be dispatched to analyze, and then repair the failure.

Other customers, however, may also be affected. The overload that occurs during the transformer failure could cause protective devices in the utility power system to open and isolate the damaged part of the system. In some cases, though, power can be routed from another source to serve many customers, particularly when the failed transformer can be disconnected and safely worked on. However, if power is redirected from another source to serve customers, it's quite possible that when the transformer has been repaired the customers will have another short outage (under 5 seconds) while they are disconnected from the temporary service and reconnected to their normal service. Many utilities offer an information service to notify customers when service is fully restored so that they are not unnecessarily inconvenienced by multiple power failures. This would allow them to remain on generator service for a longer time, but avoid exposing their facility to another power failure.

Underground feeder failure

Underground feeder lines tend to be more reliable than overhead distribution wiring, but they will typically take longer to repair when there is damage. In situations where there is underground service (feeders) from a utility system to many loads, there can be another situation where it is normal to have multiple "failures" before power is finally back to its normal level of reliability.

If, for example, an underground feeder fails, all the customers served by that feeder will see one or more very brief outages as reclosers operate in an attempt to attempt to maintain service to loads. When the problem cannot be automatically cleared, the loads are disconnected from the utility grid, and crews must be dispatched to find and repair the problem. In many cases where there is an underground feeder failure, there are provisions for serving loads from more than one utility source. This allows crews to isolate problems and then serve loads from another source, in a similar fashion to the "squirrel" example above. When that situation occurs, the customers will again experience a short power failure once the damaged part of the system is repaired, when the loads are reconnected to normal service.

Because of the duration of repair times, an owner may want to consider having a larger on-site fuel supply available or have predefined plans to re-fuel the generator when failures occur.

Weather-related voltage dips

Not all power failures are related to equipment failures. Some failures can be attributed to weather conditions. For example, during high humidity conditions, such as fog (particularly in coastal areas), it's possible that the high voltage lines serving an area can experience a "flashover" condition. In these situations, the humid air between the lines reduces the resistance between the lines to the point that some power can jump between the lines, causing very short voltage disturbances. In a customer facility these may not be noticed or might appear to make the lighting flash briefly, but repeatedly over a relatively long period of time. In these cases, it might be a good idea to run a generator set, but the transfer switch equipment might not experience a failure for a long enough time to signal a generator set start (See "Problems in the normal failure sequence").

In general, as the load increases on the utility system, the voltage will tend to drop. Utility service providers will add capacity, and may implement other means to keep good voltage quality at a site. In spite of these efforts, heavy loads caused by high temperatures in a large geographic area can cause voltage levels to drop to close to abnormal levels or bounce in and out of abnormal range at a site as loads at that site turn on and off. Again, the voltage sensing equipment on the transfer switch may or may not be set to sense this type of problem and may not be able to sense the problem.

Things to remember about power failures

Obviously, the utility power system is large and complex and a customer can't be expected to understand it fully. However, it's advantageous for a customer to work with their utility service provider to understand the characteristics of the system feeding power to a critical facility. And when a failure does occur, communication can minimize the impact of a power failure. For example, some knowledge of the reason for the failure and the expected repair time can allow a user to anticipate the need for refueling generator sets or perhaps reducing the load on the machine to extend operating hours to critical loads.

Sensing a power failure

An automatic transfer switch must include devices to sense when the power fails, start the generator set, sense when the generator set source is operating at acceptable voltage (and sometimes frequency) level. The nature of these devices and their ability to detect power failure or power quality problems varies greatly from transfer switch to transfer switch. In general, older transfer switches and lower cost transfer switches will tend to have less capable sensing equipment and are more prone to operate improperly either by failing to detect the power problem or by sensing a failure that is not really there. More modern equipment and especially those ATS models with sensors that use microprocessor-based controls tend to more accurately detect problems.

The most accurate sensing systems have some common characteristics:

- They sense voltage on all phases of the power supply to a facility
- They are connected from the line (phase conductors) to the neutral conductors.
- They actively sense voltage conditions and compare them to references, rather than responding to operation of an electromechanical device. For example, a device that measures voltage and uses a microprocessor-based control system to decide whether or not to start the generator set will respond more accurately to a power failure than an ATS that used a simple AC relay to determine whether or not power is available.
- They have the ability to be precisely set and calibrated to common conditions on the utility service at the point of installation.

When power completely fails on all phases of supply simultaneously, it is easiest to detect the problem and respond appropriately. However, if power fails on a single phase, perhaps due to a blown fuse or short circuit on a single phase, it's possible that 3-phase motors and other loads on a circuit can maintain the voltage on the failed source at a high enough level to trick the ATS into thinking the voltage is OK. If this happens, the motor will often be overloaded and fail. If your facility has a lot of 3-phase inductive loads, it is particularly desirable to install a high quality line to neutral connected voltage sensors. It might also be prudent to have other protective functions in place that will disconnect sensitive loads from a partially failed source.

Ultimately, the question becomes, “What voltage level is acceptable for operation of my facility loads?” The answer to that question is not cut and dried, but varies considerably from site to site. For any specific load the manufacturer can probably tell you the magnitude and duration of voltage variation the load can tolerate.

Problems in the normal power failure sequence

Problems can occur because of improper set up of voltage sensors or as a result of less than optimal time delay settings (particularly time delay on start and transfer).

In our discussion of operation sequence we assumed that the ATS could make a positive decision about the quality of power provided and switch when the power failed. However, a power failure isn't just when the power completely fails. The voltage may brown out (drop to a lower than normal level but not fail completely) or a single phase may be lost. When this occurs, the ATS voltage sensors may or may not detect the problem.

In the utility distribution system it is normal to have a range of normal voltage levels across the distribution system serving multiple customers. So, it's normal to have different customers have different “normal” levels of voltage served at their site. For this reason, it's a good idea to have an understanding of the normal level of voltage at a specific transfer switch when you set up the voltage at the transfer switch. For example, if you assume that the voltage at a transfer switch is 120 volts, the typical setting for starting the generator set might be 85% of that level, or 102 volts. However, if the normal voltage level was significantly different than 120 volts, the transfer switch might start the generator set when it wasn't necessary or be delayed in its starting when power did fail.

About the author

Gary Olson graduated from Iowa State University with a BS in Mechanical Engineering in 1977, and graduated from the College of St. Thomas with an MBA in 1982.

He has been employed by Cummins Power Generation for more than 25 years in various engineering and management roles. His current responsibilities include research relating to on-site power applications, technical product support for on-site power system equipment, and contributing to codes and standards groups. He also manages an engineering group dedicated to development of next generation power system designs.

In our discussion of power failure conditions we assumed that the power failed and remained in a failed state. However, as we saw in the descriptions of typical power failures, we found that in many cases the power failed, returned, and then failed again. In a typical transfer switch the voltage sensors reset when power returns after a failure. So, for example, if the power fails and then returns before the time delay on starting has been completed, the ATS would reset and on a subsequent power failure (even if it occurred only a few seconds later), the ATS would wait until the entire time delay on starting was completed before commanding the generator set to start.

Some transfer switches can be set up to start the generator set and transfer the loads to the generator set, even if power has returned. So, if the generator starts the loads may be connected to the generator set for a long time even if normal power is available.

If the generator set is running and producing proper voltage and normal power fails, the time delay on starting and sometimes transfer is often bypassed, so that the loads are subjected to the shortest possible power failure. The rationale for this is that the time delay on starting is designed to keep the generator set from starting unnecessarily, so if it is already running it's kind of pointless to wait to start it. Similarly, if it is already running, the time delay on transfer, which is used to be sure that the generator power is stable before connecting the load, is also unnecessary.

On the other hand, if the generator set fails when the utility is available, most transfer switches will immediately connect the loads to the utility if the utility is available, using only the programmed transition time delay (if it is used in the transfer switch sequence). The rationale for this is similar to that in the previous situation. If the genset fails there is not much point in waiting to see if the utility source is going to stay good. Since the generator set has failed, you might as well try the utility source. Note that the transfer switch should not try to connect loads to a partially failed or browned out service. That might be just as damaging as leaving the loads un-powered.

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