Identifying Load Management System Applications; Part 3 of 3

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INTRODUCTION

Part one of this three-part series focused on appropriate applications of load management to help control load priorities and improve power quality to critical loads. Part two explored setting up load-management systems, determining load priority orders and methods of shedding loads. This third and final installment will explore seven methods for load-management.

SEVEN METHODS FOR LOAD MANAGEMENT

There can be many differences between load-management systems, but common design practices and setup procedures can be applied to most systems and applications. The following are functional descriptions, configuration tips and example scenarios for some of the more common techniques for load management:

1. Startup shed
2. Generator online load add
3. kW capacity load add
4. Engine failure shed
5. kW shed
6. Underfrequency shed
7. Time-based load staging

Each method is demonstrated by a timing diagram based on an example system *Figure 1*. The example system includes load ranges for each of the priorities based on maximum and minimum observed demand on each priority. The actual loads on the priorities can fall anywhere in this range, but they have been fixed throughout the examples for simplicity.

1. STARTUP SHED

Configuring the startup shed level allows initial loads to be removed from the power generation system before a generator connects to the paralleling bus. The primary purpose of startup shed is to prevent a generator from being overloaded as it closes to the bus. This is beneficial, for example, on a paralleling system where a single- generator is not able to support the entire load. This can also prove useful in single-generator systems with a number of loads where each provides a large inrush current because these loads can be staggered using time-based load staging to improve power quality.

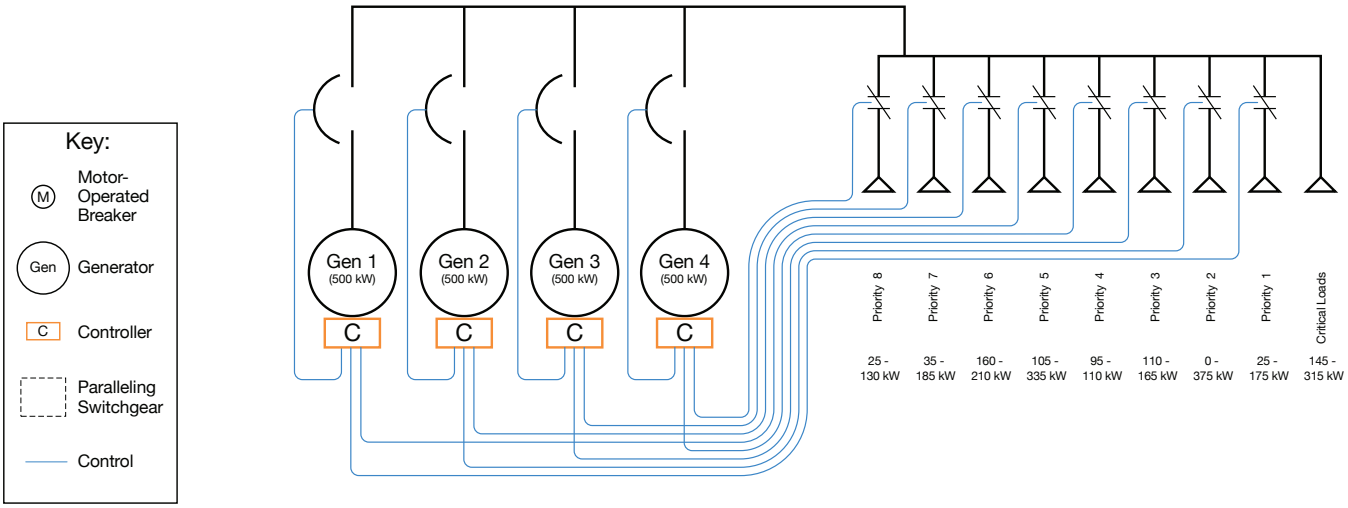
Example

The startup shed may be initiated on the receipt of a start signal from an external source or on the initiation of a start signal to the generators.

Configuration: Startup Shed Level = 1

Figure 2, all priorities except for priority 1 are shed in order to ensure that the first generator online is not overloaded. For example, the generators can support 500 kW each and priority 1, and the critical loads could provide from 170 kW up to 490 kW of load.

Figure 1: Startup Shed



Setup

The startup shed level should shed enough priorities that the power requirements of the remaining priorities should not exceed the capacity of the smallest generator in a multi-generator power generation system. Single- generator systems should not require startup shed in most cases, unless the load could potentially exceed the generator capacity or the generator is unable to provide full capacity immediately after startup. Dead-field paralleling systems may also be able to operate normally without startup shed, as long as load is shed by another means when a generator fails to start.

Some load-management systems automatically detect startup shed level. For example, some typical paralleling switchgear applications monitor load power requirements while on utility power source.

Advantages – Startup shed should shed load before a generator tries to feed it, potentially preventing overload of the first generator to connect to the load.

Disadvantages – Startup shed usually sheds loads regardless of the immediate load power requirements. If configured incorrectly, startup shed can remove too many loads and delay certain equipment from receiving power.

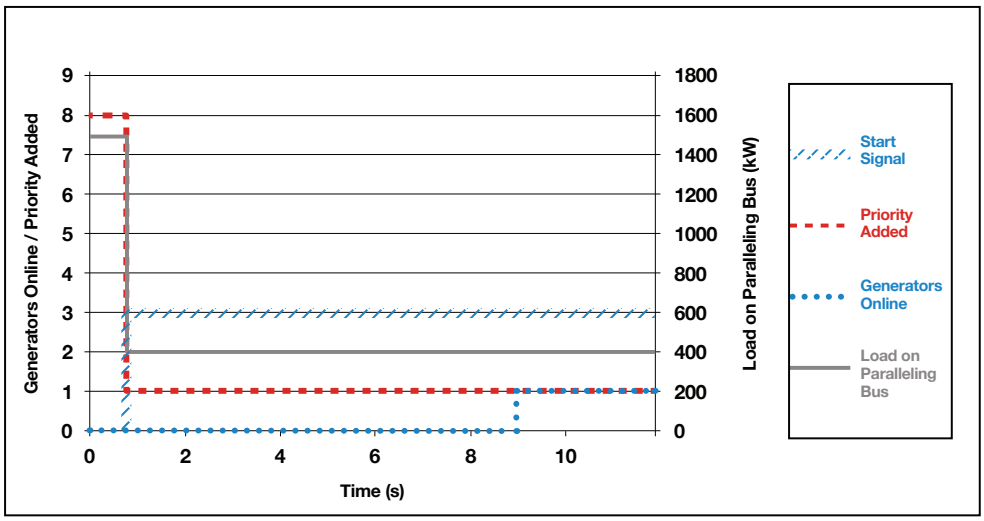
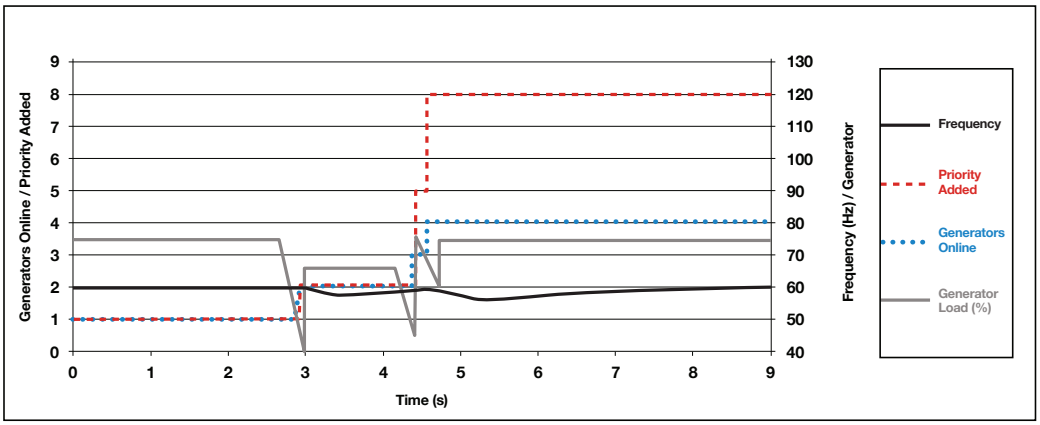


Figure 2: Startup Shed



GOL	Priority
1	1
2	2
3	5
4	6

Figure 3: GOL Add

2. GENERATOR ONLINE (GOL) LOAD ADD

Implementing load management based on the number of generators that are connected to the paralleling bus and thereby the generator capacity (called generators online or GOL) allows adding loads quickly when a connecting generator increases the capacity of the paralleling bus.

Loads may be added immediately when generators connect to the paralleling bus.

This should load the newly added generator very quickly and minimize the time that each load is without power.

Example

Figure 3 the generator's available capacity increases slightly as each generator comes online, but the immediate adding of the associated priorities minimizes the increase in available capacity. The generator frequency may dip considerably with the sudden increase in load since multiple priorities are added at once, but the load should receive power within a very short time of a generator coming online.

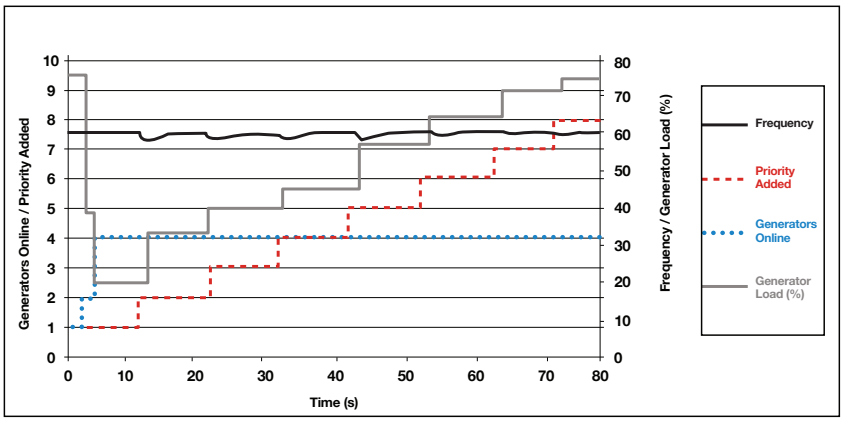
Setup

On load-management systems where the GOL add is a single priority per generator, it may be important to ensure that no priority exceeds the capacity of a single generator. On load-management systems where the GOL add allows multiple priorities to add with each connected generator, the maximum load of all priorities on a single generator connection typically should not exceed the capacity of a single-generator. Adding too many priorities at once may delay the synchronization of additional generators by causing a significant decrease in the bus frequency.

The GOL add delay provides a window for generators to parallel and come online before switching to a different load-adding technique (typically kW capacity load add). It should typically be configured long enough that all generators have a reasonable chance to synchronize and come online. Setting the GOL add delay too long may delay adding of additional priorities, so the delay should be minimized.

Advantages – GOL operation is usually quicker than kW capacity add and is generally considered to be simpler to configure and understand.

Disadvantages – GOL add does not consider the expected load of each priority or support the re-addition of loads that are shed due to underfrequency and overload conditions, making recovery from a configuration error or site change more difficult. Also GOL add may provide inconsistent performance in systems where generators differ in size.



Priority	Expected Load
1	175
2	375
3	165
4	110
5	335
6	210
7	185
8	130

Figure 4: kW Capacity Add (Fixed Time) (threshold=85%, kW addtime=10.0s)

3. KW CAPACITY LOAD ADD

Configuring load management based on kW capacity adds loads when the online generators can support them. For automatic load adding, this method generally only adds priorities up to a threshold. It is often used in conjunction with GOL load add in cases where the maximum potential demand of the load exceeds the capability of all of the generators.

Example

Figure 4 Loads are added after the generator capacity has been determined to be sufficient to support the load, including expected inrush.

Adding a single priority in sequence may minimize the disturbance to the generator frequency, but it comes at the cost of an additional time delay before the load is added.

The kW capacity load add system provides different performance from the generator online load add system, with preference for a given technique largely based on site requirements and expectations. The consistent timing of kW capacity load add generally makes it easier to define rough outage time for each load in the event of a utility outage.

Setup

The threshold for automatic load adding should generally be set below the kW shed threshold to avoid exceeding the kW shed threshold when adding a load (and causing load cycling).

It is important to configure the expected load requirements correctly for predictable operation within the load-management system. The expected load is typically set as the maximum power requirement a given priority can place on the power generation system, although it can also be configured as the priority's typical power requirement.

The expected load requirement allows the system to determine if enough capacity exists to support the load's power requirement before adding the load, preventing load cycling or degradation of power quality.

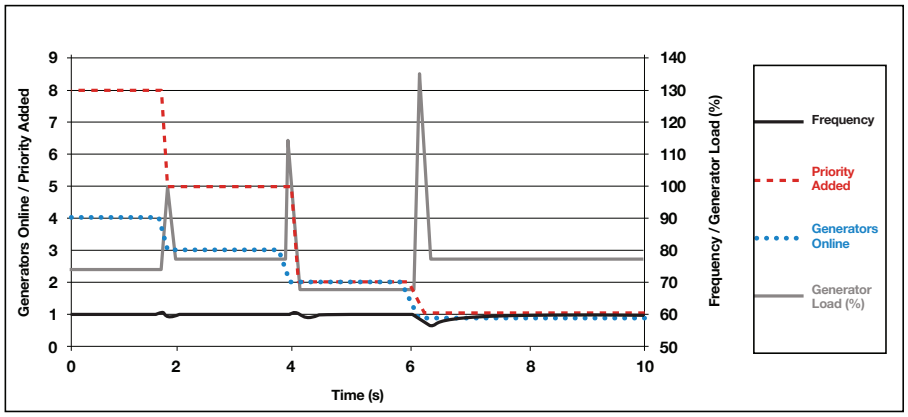
Increasing the kW capacity add delay allows time for the loads to initialize and ramp to full power requirements before the next priority adds. This also may provide more accurate information about the load's power requirements before adding additional priorities. Increasing the kW capacity add delay may also slow the rate that priorities are added, causing loads to be de-energized for longer.

Decreasing the kW capacity add delay allows loads to receive power faster, but may not allow sufficient time for the load's power requirement to stabilize before the next priority is added.

Many systems have a throw-over timer to switch from GOL load add mode to kW capacity add mode.

Advantages – Although kW capacity load add typically requires more time to add each priority than GOL add, it adds priorities based on feedback and knowledge of the loads, as opposed to a simple load add as soon as a generator is connected to the bus. It is robust to changes in the generator capacity, allows good recovery from a shed condition and supports various-sized generators.

Disadvantages – The kW capacity load add may be susceptible to configuration errors and take longer to add loads.



Failed Generators	Priority
1	5
2	2
3	1

Figure 5: Engine Failure Shed

4. ENGINE FAILURE SHED

Engine failure shed is initiated when a generator disconnects from the load while it is needed. Some examples of causes of an engine failure shed are:

- User interaction
- Generator protective shutdown
- Mechanical or system failure

Example

Upon generator disconnection from the load, engine failure shed removes load from the remaining generators to a level that they are able to handle. In *Figure 5*, the engine failure shed is set up to mirror the generator online add settings.

Engine failure shed may not coordinate well with load priorities in systems where generators are stopped or started based on the load demand (generator management). In particular, a first generator that has been stopped by generator management may not be considered a failed generator, but may be offline, such that if another generator fails, engine failure shed may not recognize that the first generator is offline and thus may not shed enough load for the remaining online generators to support what remains.

Setup

On load-management systems, engine failure shed can be configured to shed a given number of priorities or a given priority level.

On systems that only use GOL add, it is often beneficial to reverse the GOL add priority levels.

Advantages – Engine failure shed may be used to proactively avoid potential decreases in power quality.

Disadvantages – Engine failure shed may not account for load on the system when shedding, so the system may shed loads that could have easily been supported by the remaining generators. Further, the system may not seamlessly support various-sized generators in a system.

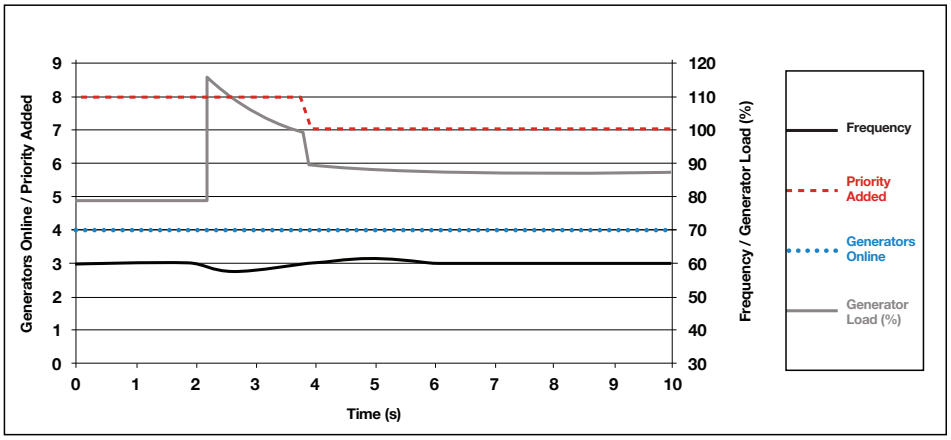


Figure 6: Motor Inrush (threshold=95%, shed time=2.0s)

5. KW SHED

kW shed detects overload conditions on the generator that could decrease power quality and upon detection shed loads accordingly. kW shed is generally based on the generator's rating and usually does not require poor power quality to detect an overload condition (although severe overloads often decrease power quality).

Some kW shed systems base the load on current, not on the real power (kW), and as such may be more sensitive to reactive loads. Such systems may, for example, detect motor inrush as a much higher number due to the low power factor of the power demand for a motor as it starts.

Example

Figure 6 shows a temporary overload condition due to motor inrush on a system where the kW shed logic is configured to shed load that may not be necessary or desired to shed. The example shows the direct online starting of a 250-kW motor driving a large axial fan on priority 2 of the example system, with the initial settings set to a sensitivity that results in shedding priority 8 when the motor starts.

The unintended shedding in *Figure 6* could be resolved by adjusting the shed time delay out to 2.8 seconds, but that change would cause the system to shed loads more slowly in an overload condition.

A second scenario, shown in *Figure 7*, is similar to the first scenario, only with one generator offline. The load-management system may need to shed load very quickly to minimize the detrimental effect on the power quality due to the overload condition.

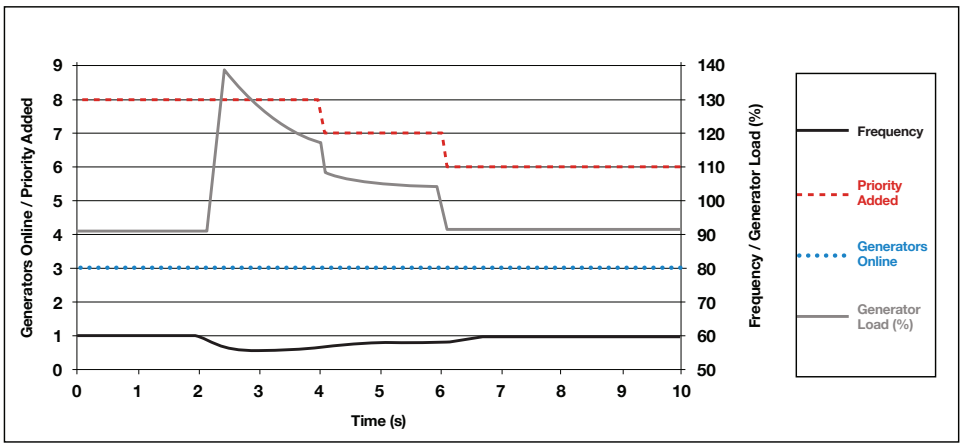


Figure 7: kW Overload Shed (threshold=95%, shed time=2.0s)

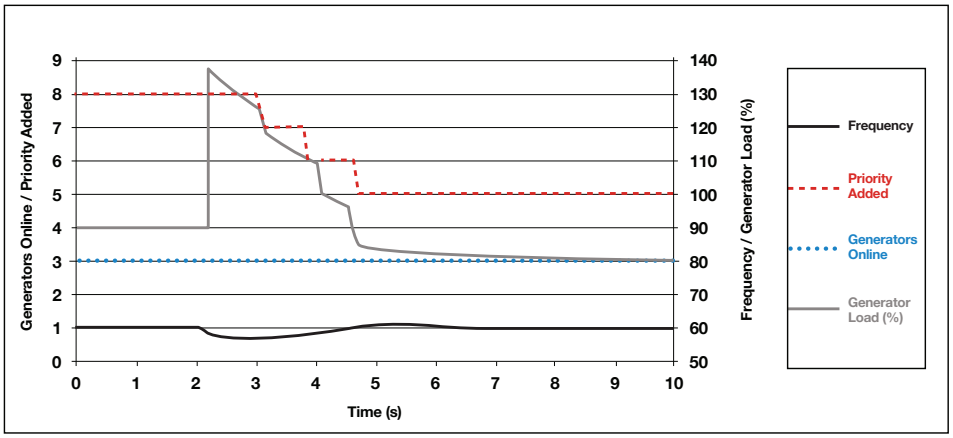


Figure 8: kW Overload Shed (threshold=95%, shed time=0.8s)

The load-management system in this scenario does not shed more loads than necessary, but the system is nevertheless overloaded for four seconds. In some cases, the generators may lose enough speed and voltage in four seconds to cause brownouts on the critical loads. Accordingly, it may be necessary to decrease the time delay to improve system performance.

Figure 8 shows an example where the time delay is decreased to allow the generator voltage and frequency to recover more quickly. However, decreasing the time delay increases the chance of unintentional load shedding on a switching load application and may result in shedding too many priorities as shown.

Figure 9 shows that the shed time of one second takes the load off the generators much more quickly, but will probably result in frequent load shedding due to switching loads.

Setup

To avoid add/shed cycling of a priority, the kW shed level typically should be above the threshold for automatic load adding. It is important to configure the time delay (1) short enough to permit all available priorities to shed before the power quality deteriorates enough to trip the generator's paralleling circuit breaker or to shut the generator down due to a protective function, and (2) long enough that loads are not shed unintentionally.

Intermittent loads may not reduce the load power requirement when shed, as they may not be drawing power at the time they are shed. In this case, the system will generally have to shed multiple loads to maintain the power quality.

Advantages – kW shed responds to real-time load changes and complements kW capacity load add.

Disadvantages – If a significant overload event occurs, power quality may decrease significantly before the kW shed acts.

The underfrequency shed and engine failure shed can often be used in conjunction with kW shed, offsetting the slow response from the kW shed method.

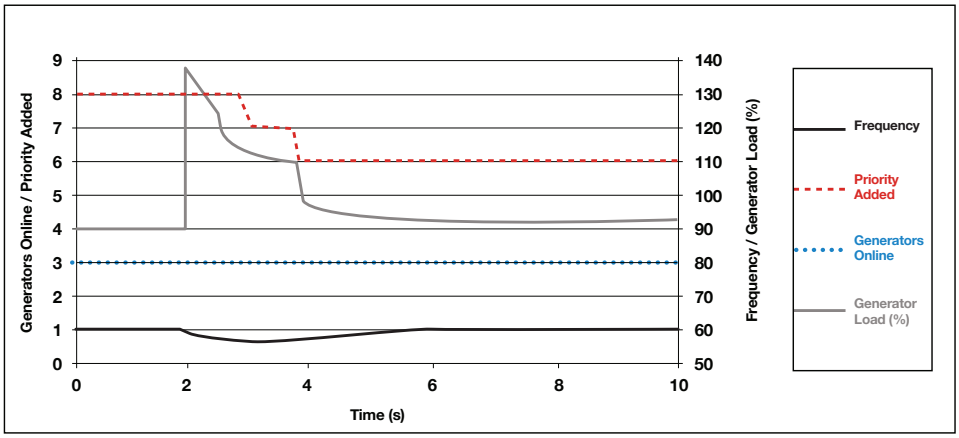


Figure 9: kW Overload Shed (threshold=95%, shed time=1.0s)

6. UNDERFREQUENCY SHED

Underfrequency shed removes load to avoid significant decreases in power quality due to any number of issues. Load priorities are shed when the generator frequency drops below a threshold for a sufficient amount of time. In paralleling systems, the generator should be connected to the paralleling bus to be included in the frequency calculation. The paralleling bus frequency is often used instead of generator frequency in paralleling systems.

Generators often use underfrequency unloading techniques to remove load from the generator as the engine speed falls to allow the frequency to recover. A common technique of under frequency shedding is volts/Hz and comprises a knee frequency below which the voltage is controlled to a target that decreases at a given percentage per cycle of frequency lost (see *Figure 10*). If the load on the generator system causes the frequency to drop below the knee of the volt/Hz curve, the voltage will drop. Underfrequency load shed provides a mechanism to minimize the time that critical loads receive low supply voltage.

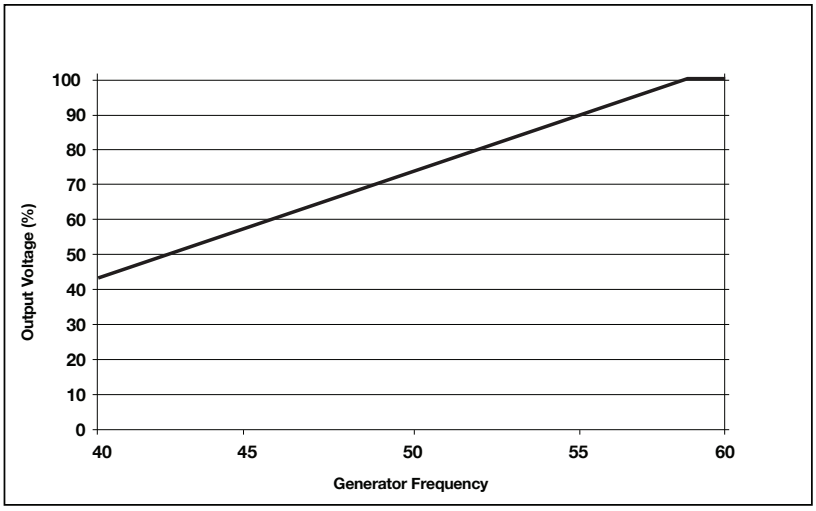


Figure 10: Underfrequency Shed (Volts/Hz) (knee frequency=59Hz, slope=3%/Hz)

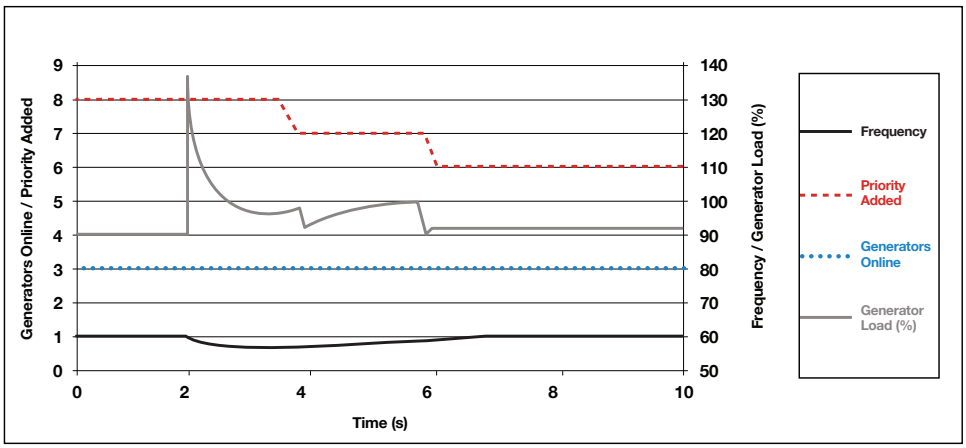


Figure 11: Under Frequency Shed (threshold=59Hz, delay=2.0s)

Example

Figures 11 and *Figure 12* apply to an under–frequency scenario caused by starting a large motor with a generator offline.

In *Figure 11*, the generator frequency remains below the knee of the volts/Hz curve (59 Hz) for over four seconds, meaning that the critical loads will experience lower input voltage for that time. An advantage to a long delay is that no priorities are shed that the system could otherwise support.

As shown in *Figure 12*, decreasing the underfrequency shed delay will result in quick voltage recovery while increasing the chance of unnecessary shedding.

kW shed logic may be active in addition to underfrequency logic in many applications, so actual timing may be quicker than illustrated in these examples.

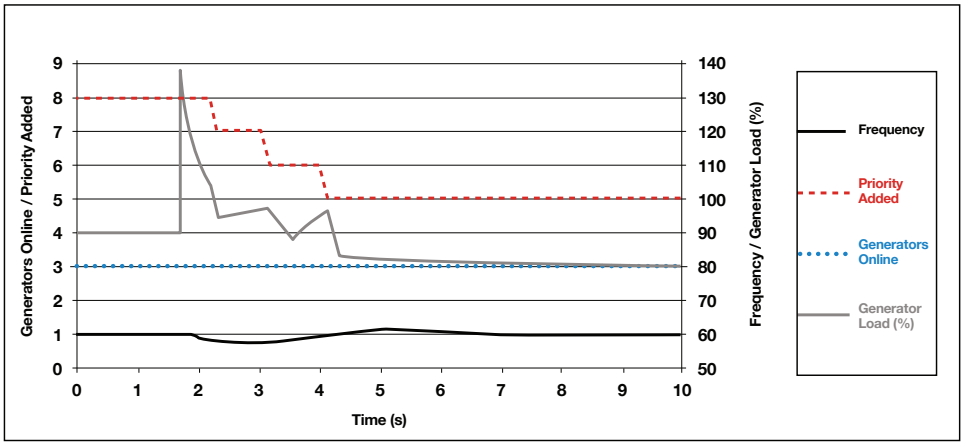


Figure 12: Under Frequency Shed (threshold=59Hz, delay=1.0s)Hz

Setup

The underfrequency shed level is usually set low enough to protect the generator from shutting down due to underfrequency or undervoltage, but high enough to avoid nuisance trips.

The time delay is usually chosen such that all available priorities should shed before the under–frequency shutdown or protective relay for the generator acts, since those protective features may cause further degradation of the power quality or a total loss of power to the critical load.

Intermittent loads may not reduce the load power requirement when shed, as they may not be drawing power at the time they are shed. In this case, the system will typically shed multiple loads to maintain the power quality.

Advantages – Underfrequency shed is relatively consistent between various power generation systems. It provides an alternate line of defense for power quality in the event that load management is configured incorrectly or another condition limits generator capacity.

Disadvantages – Underfrequency shed utilizes a drop in frequency to detect an overload condition, by which time power quality may have already decreased, before load can be shed.

7. TIME–BASED LOAD STAGING

Time–based load staging is more commonly provided by an automatic transfer switch than by a full load–management system, but the operation is often not complicated, as load priorities are added in sequence according to a fixed time schedule without regard for load or generator capacity. Some systems use a fixed time step for all priorities, while some will allow the configuration of the delay between each priority. In either case, the priorities are generally added at a fixed time after the loads were connected to the power generation system.

Example

As shown in *Figure 13*, time–based load adding is typically used to stage high–inrush loads such as motors and transformers to avoid a severe voltage dip from a sudden application of the entire load.

Setup

The time delay should be short enough to allow the load to receive power within a reasonable time, but long enough to allow the generator speed and voltage to recover before the next load is added.

Advantages – Time–based load staging may be easily configured and generally does not require frequency or power metering on the generator.

Disadvantages – Time–based load staging does not usually utilize feedback to determine if the generator capacity is sufficient to add the load.

Properly configured load–management systems have the potential to decrease system downtime and power loss in overload conditions, while improving flexibility, versatility and power quality. Understanding the details of a properly implemented load–management system can mean the difference between a mild inconvenience and a full loss of system function.

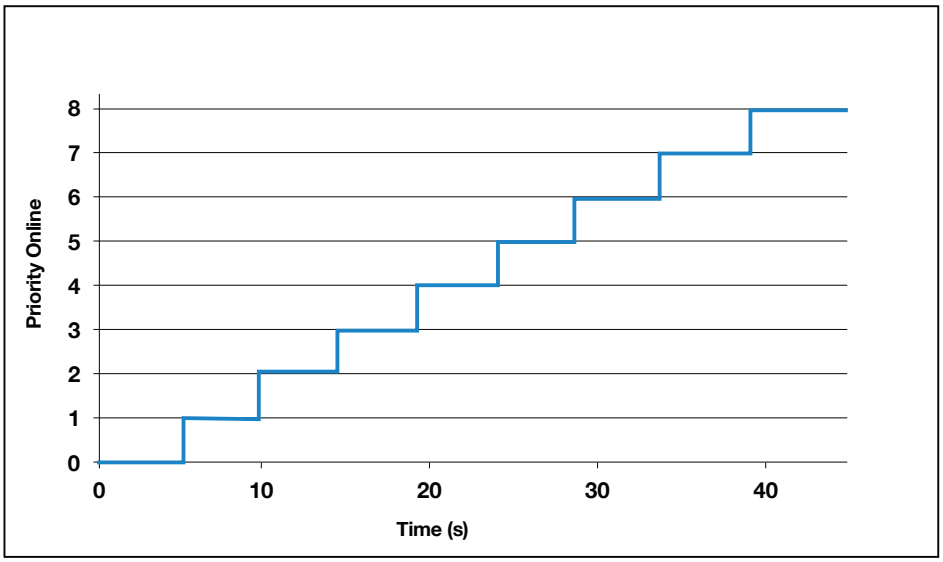


Figure 13: Time-Based Load Staging (delay=5.0s)



ABOUT THE AUTHOR

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