White Paper

PCS Load Management

ASCO Power Technologies®

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An Overview of Essential Load Control Capabilities

Power Control Systems (PCS) provide for sophisticated management of emergency power systems by managing the connection and disconnection of power sources and equipment loads. This paper focuses on load management controls and features, summarizes their operation, and describes their value. For a basic overview of PCS design and functions, see our prior whitepaper entitled **Power Control System Basics**.

Transferring Loads When Utility Power Fails

The most elementary function of a PCS system is to coordinate the connection of power sources and loads to a backup power system following the onset of a power outage. When a utility outage is sensed and/or engine-generators are called to supply building load, a PCS will annunciate the condition as Emergency mode. In this mode, Automatic Transfer Switches (ATSs) automatically issue start signals to all engine-generators. The PCS system connects the first generator to reach rated voltage and frequency to the main bus. After the bus is energized, synchronizers in the PCS automatically adjust the frequency of subsequent generators, and then connect them to the bus. For a facility with multiple generators, shown in Figure 1, the operation repeats until all generators are connected. Thereafter, the generators share load equally.

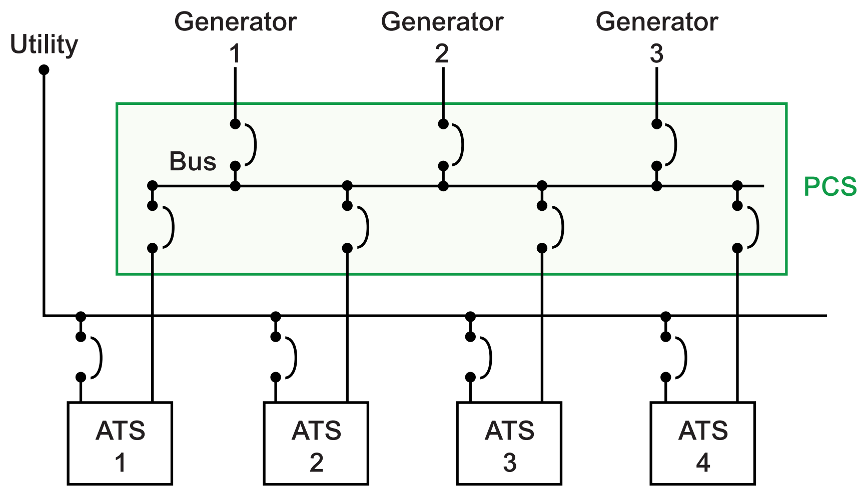

Figure 1: A PCS system serving three engine-generators and four automatic transfer switches

Prioritizing Loads

The narrative above describes a generic process for paralleling multiple engine-generators to an emergency power system when utility outages occur, and assumes that the system will provide sufficient power to operate all loads. However, it is unlikely that each generator will reach the rated voltage and frequency at the same moment. Even if the all of the generators reached acceptable voltage and frequency at the same instant, interlocks would prevent simultaneous connection to avoid affects from differences in phase angle between the power sources. In addition, the National Electrical Code (NEC) and industry standards may apply performance requirements for powering certain loads quickly when outages occur.[1] For example, NEC Articles 700 and 701 stipulate that regulated facilities supply backup power to life safety and critical loads within 10 and 60 seconds, respectively. Prioritizing loads as shown in Figure 2 assures that they will connect in the order necessary to meet both engine-generator specifications and regulatory requirements.

[1] *National Fire Protection Association, NFPA 70 - National Electrical Code, Fourteenth Edition, 2017. Quincy, Massachusetts, 2016.*

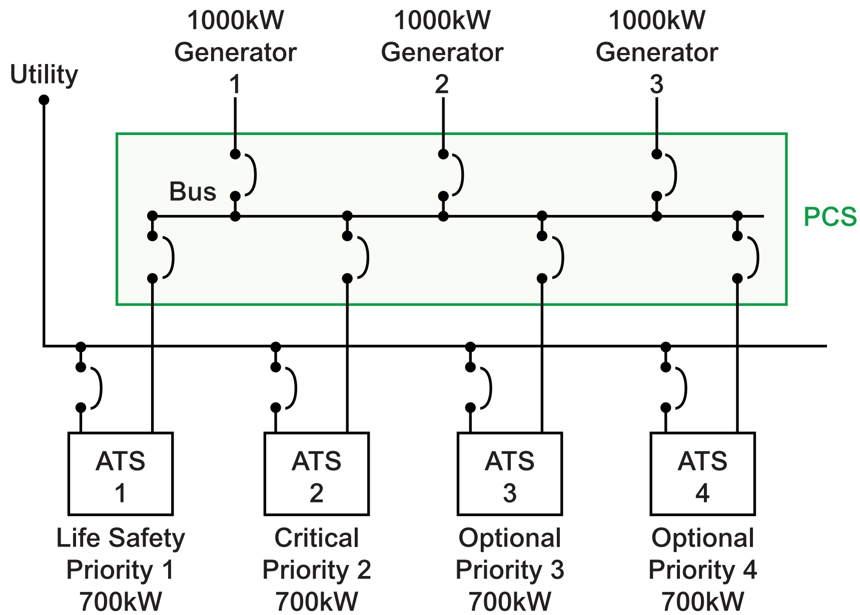

Figure 2: Prioritized loads

Providing the PCS controller with data regarding the maximum expected load for each ATS can enable the system to verify that sufficient generation capacity exists before load is added. Doing so for the system in Figure 2 would result in the following event sequence when utility power fails.

Table 1 - Event Sequence	
Event	**Description**
1	Utility power fails
2	ATSs issue engine-generator start signals
3	One generator produces acceptable frequency and voltage
4	The PCS connects the first generator to bus, bringing 1000kW of capacity online
5	The controller connects the Priority 1 ATS (700kW)
6	A second generator produces acceptable frequency and voltage
7	The PCS connects the second generator, bringing total online capacity to 2000kW
8	The controller connects the Priority 2 ATS (700kW), bringing total load to 1400kW
9	The third generator produces acceptable frequency and voltage
10	The PCS connects the third generator, bringing a total online capacity to 3000kW
11	The controller connects the Priority 3 ATS (700kW), bringing total load to 2100kW
12	The controller invokes a stabilization delay before checking whether Priority 4 loads can be added.
13	The PCS connects the Priority 4 ATS (700kW), bringing total load to 2800kW
14	The system continues to supply the Priority 1, Priority 2, Priority 3, and Priority 4 loads

Adding and Shedding Loads

After startup, emergency power systems respond to changing conditions by connecting and disconnecting power sources and loads to and from a facility's power system. As conditions change, it is possible to react quickly by automatically adding or shedding a prioritized group of loads in a single action. For the example in Figure 2, relatively large amounts of load are added when the each priority load block is connected to bus. These operations are referred to as a **block add**. As conditions continue to change, perhaps because of a generator failure causing an under-frequency condition, a group of loads can be removed in a single action known as a **block shed**. In elementary applications, each generator is associated with one load block. Additional load blocks can be managed if controllers are equipped with the bus optimization features described elsewhere in this document.

Loads can also be connected and disconnected in smaller discrete steps, operations known as **step add** and **step shed**. These functions enable sequential transfer of smaller loads, which can (1) avoid potential stresses of adding or shedding large block loads, and (2) allow PCS to increase the utilization of generation capacity.

Individual step add time delays can be assigned to each load. When step loading is employed, the PCS enables a device such as an ATS or circuit breaker to block add loads to the bus, following individually assigned time delays. The next load within the block is connected following its assigned time delay, and the process is repeated to bring the required loads online. Because the amounts of load are relatively small, step adding reduces mechanical and electrical stresses that can be associated with connecting large amounts of load in a single moment. Step shedding will only be initiated if an overload condition is detected, and will step shed loads in reverse priority order (last on - first off) at 1-second intervals. These features allow power control systems to mitigate overload conditions while still maintaining optimal load levels.

As noted above, step adding invokes individual time delays within a priority block, but step shedding is based on a fixed time delay with individual priority settings. In order to step shed, priority load blocks must be subdivided into smaller discrete loads and sub-priorities must then be assigned to each load. Sub-priorities are shown in Figure 3 together with their corresponding maximum expected load values. This information allows PCS controllers to be programmed with priority and time delay schedules for step-wise connection and disconnection of loads. Block load and step load results are illustrated in Figure 4.

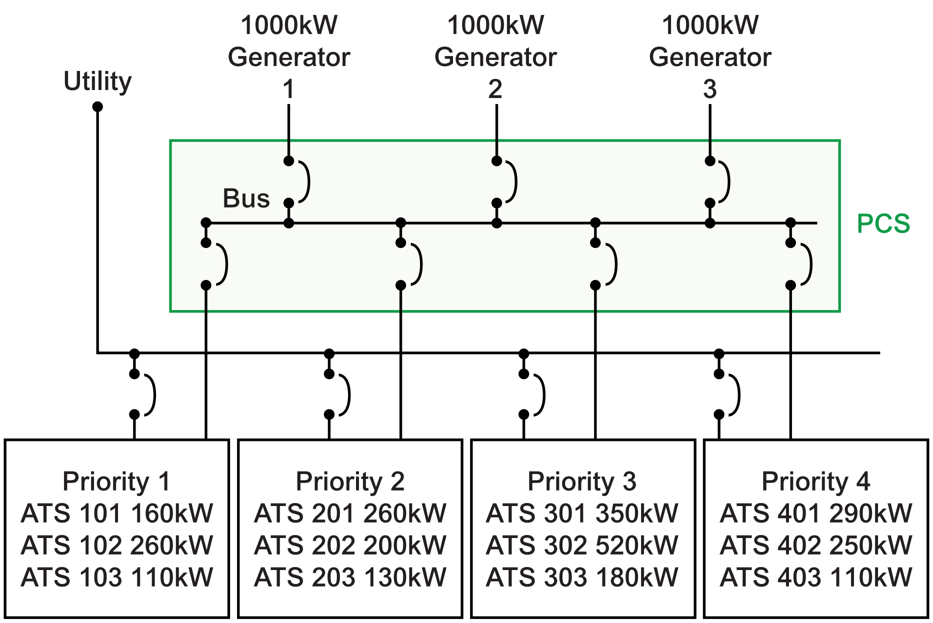

Figure 3: Sub-priorities assigned to discrete loads within priority blocks.[2]

[2] *Diagrams are provided for conceptual purposes only, and are not intended to reflect actual system configurations. For instance, while Figure 3 shows dedicated feeds for each load block, many configurations are possible, and dedicated feeds do not need to be provided when using the connection strategies described in this paper.*

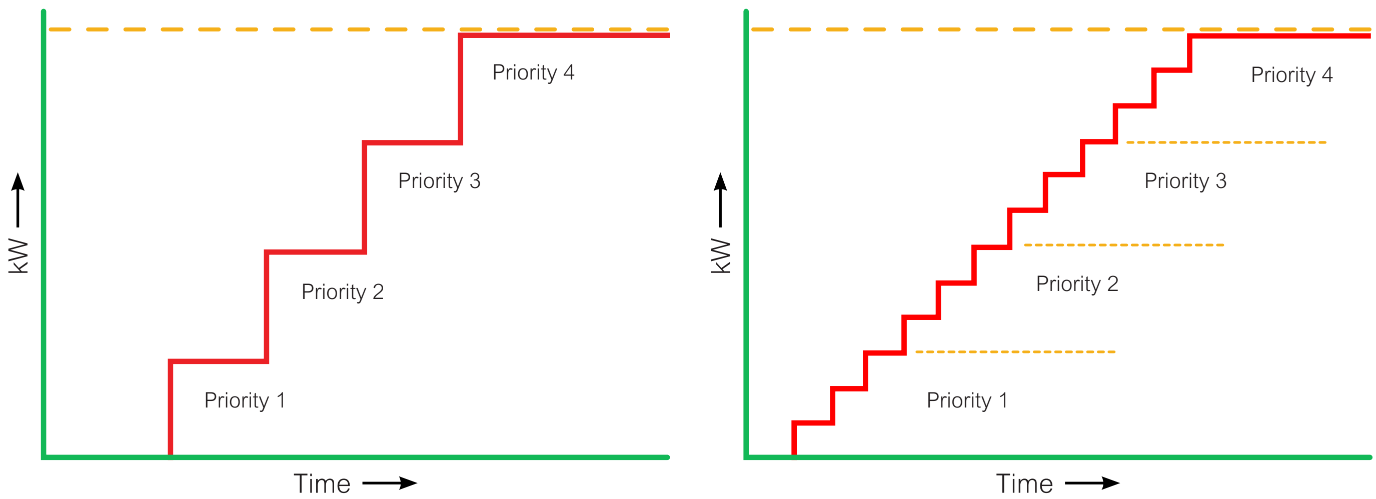

Figure 4: Block loading is shown at left, step loading at right

Standard Bus Optimization

If the amount of load in a priority block exceeds the available generation capacity, then **Bus Load Optimization** can increase the efficient use of that capacity by step loading sub-prioritized loads. To do so, a PCS controller compares real-time generator capacity to the load associated with next ATS. If there is sufficient generation capacity, the PCS can connect the ATS to the emergency power system. This capability becomes especially important if a generator fails to connect to the bus.

For example, an outage occurs on the system in Figure 5 at a time when the Priority 1 and Priority 2 loads total 1120kW. If one generator fails to connect to the bus, the remaining generators could carry these loads. However, this would leave only 880kW available for the next priority block, which presents an anticipated load of 1050kW. If the system employs only block loading, the PCS controller will not add the Priority 3 block to avoid overloading the generator, and the facility's 300- and 400-series ATSs would remain unpowered.

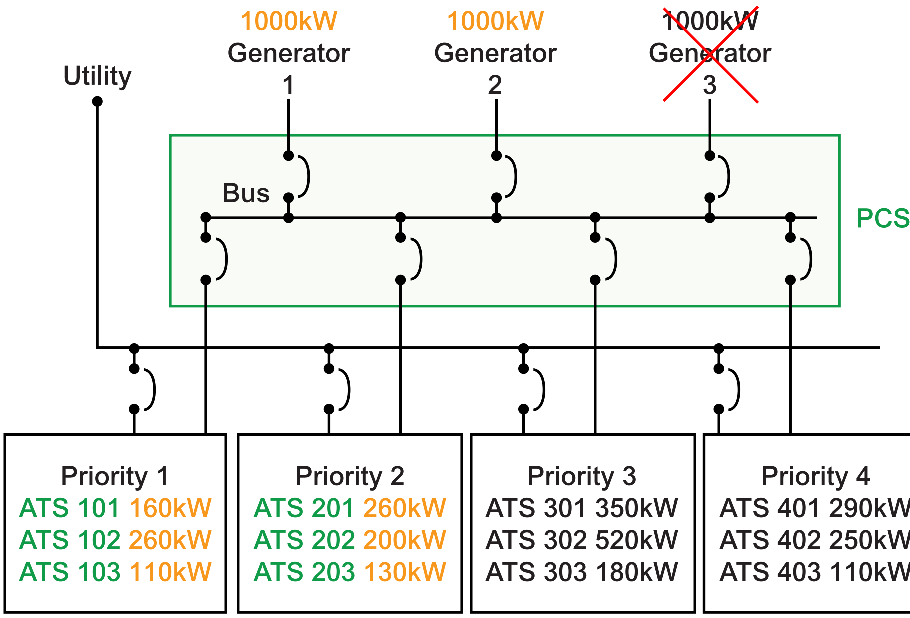

Figure 5: Block loading could leave a large amount of load offline when an engine-generator fails

If, however, the system employs **standard bus optimization** techniques, discrete loads within a load block may be brought online to better utilize available capacity. To do so, the PCS controller must be programmed with the maximum expected kW value for each load. During operation, the controller compares the remaining generation capacity with the maximum expected value of the next prioritized load. If sufficient generation capacity exists, that load is added, and the next load is evaluated. Extending this capability to the system in Figure 5 shows that the next scheduled loads are ATS 301 and ATS 302, which have a combined maximum demand of 870kW. Because 880kW of generation capacity is available, ATSs 301 and 302 can be sequentially added to the bus to power additional equipment, as shown in Figure 6.

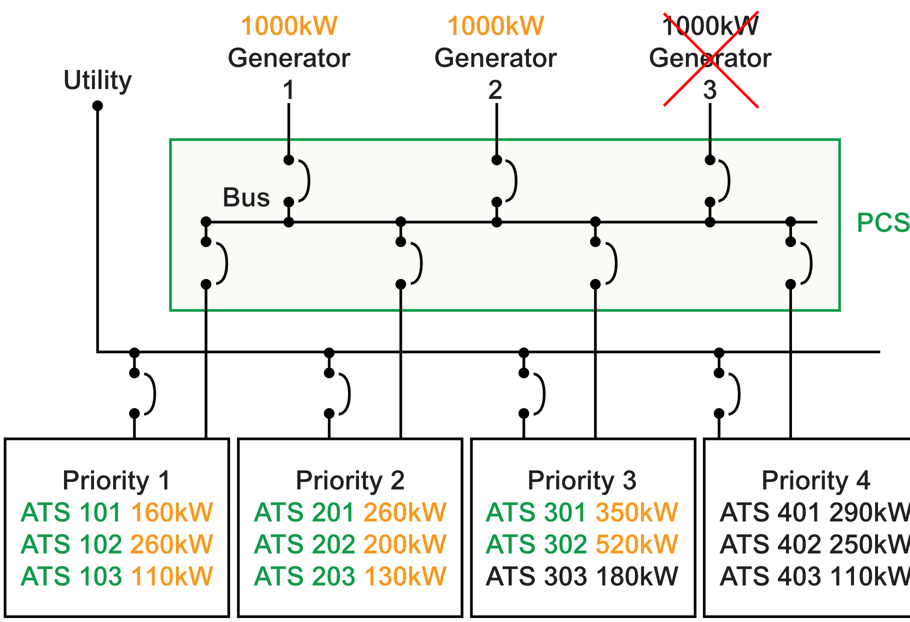

Figure 6: Standard bus optimization enables sub-prioritized loads to be connected to bus to increase capacity utilization

Dynamic Bus Optimization

While standard bus optimization can put more loads online for a given generation capacity, its protocols reference the expected maximum power that could be required by every sub-prioritized load. Nevertheless, because demand can change over time, a given circuit will typically require less power, often significantly less, than the maximum expected amount of power. If power meters are used to monitor the real-time demand of each sub-prioritized load, then the PCS controller can compare excess online capacity to actual (not anticipated) load for the next ATS in sequence. In practice, ASCO dynamic bus optimization compares excess online capacity to the total of the maximum demand recorded for each ATS during the prior 24 hours.

Monitoring real-time load usually reveals capacity that cannot be detected using standard bus optimization. Table 2 lists real-time load values for the example system at a specific point in time, and shows a total of 830kW for the Priority 1 and Priority 2 loads. This value is lower than the maximum value of 1120kW anticipated for the loads by standard bus optimization in Figure 5.

Table 2 - Measured Loads			
Priority 1	Priority 2	Priority 3	Priority 4
ATS 101 120kW	ATS 201 200kW	ATS 301 170kW	ATS 401 210kW
ATS 102 190kW	ATS 202 150kW	ATS 302 370kW	ATS 402 170kW
ATS 103 80kW	ATS 203 90kW	ATS 303 120kW	ATS 403 90kW

In Figure 6, with one engine-generator offline, 1170kW (2000kW minus 830kW) of generation capacity remains on the system. However, in Table 2, the measured real-time Priority Block 3 loads are lower than the expected maximum values shown in Figure 6. Because the total demand equals 1130kW, all of the Priority 3 and Priority 4 loads can be step-added to the energized bus as shown in Figure 7. Using dynamic bus optimization, power can thus be provided to all of the facility's systems, even without the offline generator.

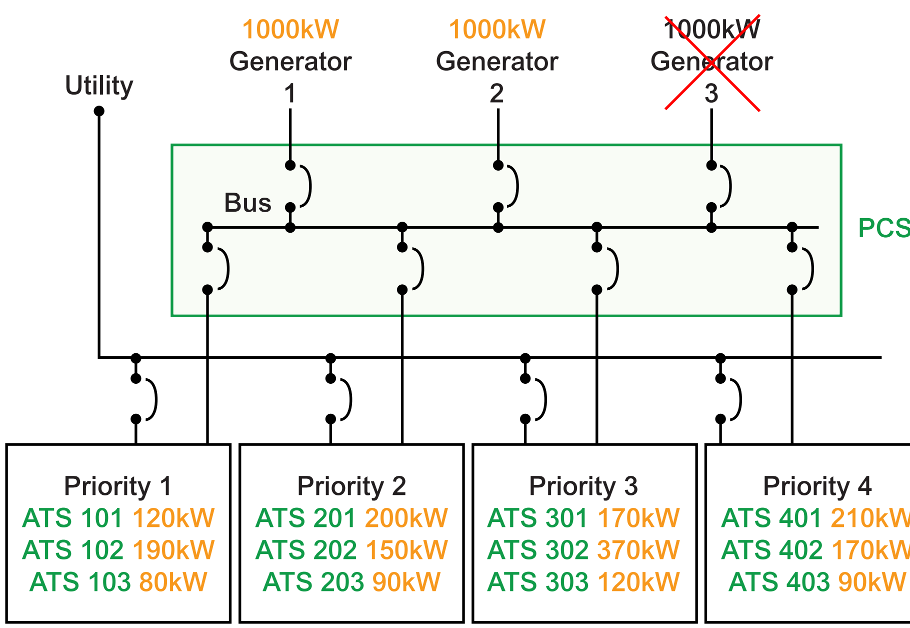

Figure 7: By using more of a system's real-time generation capacity, dynamic bus optimization connects the greatest amount of load to an emergency power system

Load Latch

Regardless of whether standard or dynamic bus optimization is used, it is important to consider how loads may be shed from a power distribution system. Figure 8 presents a system that is supplying backup power in steady-state operation.

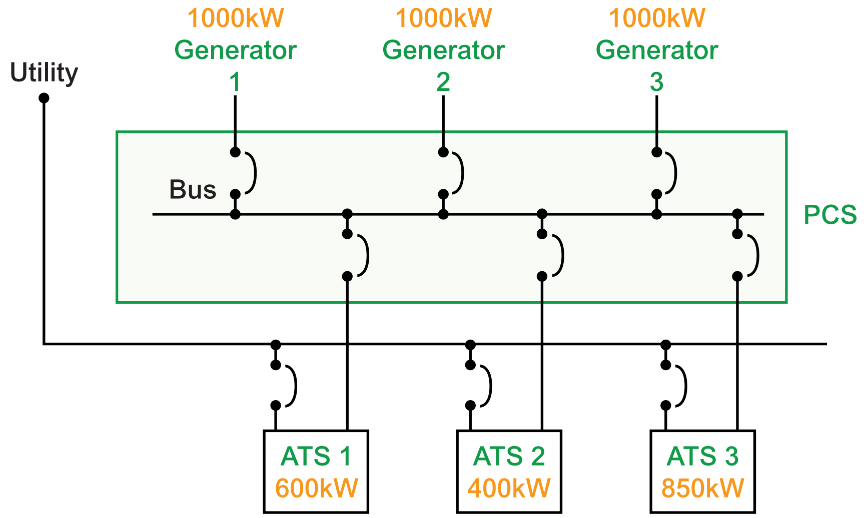

Figure 8: A backup power system supplying continuous power using three engine-generators

If one of the engine-generators fails, the online loads can be managed in two different ways. Without specific provisions, loss of a generator may result in the automatic shedding of that generator's entire corresponding load block. However, ASCO PCS systems provide **load latch** functionality that first compares the total capacity of the remaining online generators with the real-time demand of the online loads. If sufficient capacity remains, load latch ensures that the loads will remain online and prevents unnecessary disconnection and re-connection of loads.

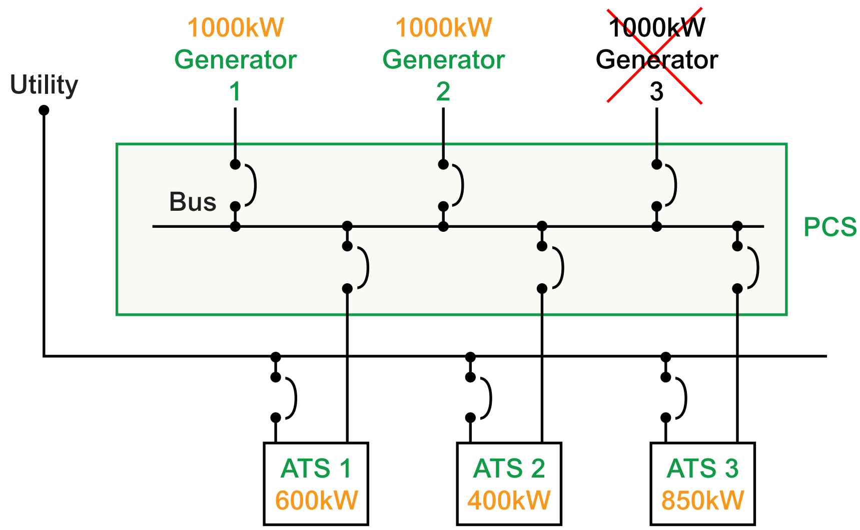

Figure 9: When sufficient capacity exists, load latch keeps entire load blocks online even when a corresponding engine-generator is unavailable

Manual Load Control Features

The functions outlined in this paper offer important reliability benefits including automatic operation, quick response to changing conditions, and reduction of human errors. Nevertheless, unanticipated or emergency conditions may require facility operators to manually connect and disconnect loads from energized bus. To support this capability, PCS systems should provide for manual control. ASCO PCS systems provide for **Load Shed Bypass/Reset**, which enables operators to manually add and/or re-shed priority load blocks when necessary. Likewise, **Hand-Off-Auto** allows operators to manually add or shed individual discrete loads.

Summary

Prioritization enables a PCS to connect loads in the order necessary to meet both engine-generator specifications and regulatory requirements. Connecting and disconnecting prioritized blocks of load provides quick response to changing conditions. Adding and shedding loads in a step-wise fashion reduces associated stresses, and allows for close regulation of loading to maximize utilization.

Standard bus optimization techniques compare available capacity to anticipated demand to evaluate whether discrete loads should be connected. Using power meters to measure loads is a prerequisite to providing dynamic bus optimization, where discrete loads are connected and disconnected to optimize efficiency based on real-time load measurements.

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