Practical Ideas to Facilitate Battery Maintenance and Testing in Power Plants

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Abstract

Power plant DC systems are essential for personnel safety and to allow reliable shutdown of equipment in case of a power outage. And with the recent passage of PRC-005-2 there are now regulatory obligations to ensure these systems remain continuously functional. But, as with any system, individual components must occasionally be taken out of service for maintenance and repair. It is important to recognize that taking a battery out of service can compromise the reliability of the plant protection system. This paper will describe the risks of taking a battery out of service, and will present examples of field modifications which have been implemented at several power plants to ensure continued reliability and make battery maintenance and testing easier.

Introduction

Emergency DC systems at generating stations supply power for a variety of critical loads including protective relays, circuit breaker trip and close functions, lube oil pumps, uninterruptible power supplies (UPS) for plant controls, emergency lighting, and fire protection. Each of these systems is extremely important to ensure personnel safety, and to allow reliable shutdown of equipment in case of a loss of power at the plant. If a system fails to operate, results can be catastrophic and can lead to expensive, lengthy repairs.

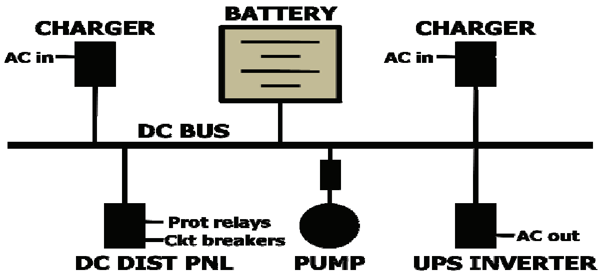

Figure 1 - Simplified Power Plant DC System

It will be obvious to the experienced engineer, that when opening contacts to clear a fault, most large circuit breakers rely on an external power source, typically the DC system. In addition, the protective relays which monitor conditions and issue the trip command require continuous power. If the external power supply is not available the breaker will not trip, and damaging fault current will flow until components disintegrate. It is also true that, although infrequent, total loss of AC power does occasionally occur at generating stations. Backup oil pumps must have an emergency power supply to start and run, to supply lubrication for the large rotating masses. Without lubrication, intense heat from friction has been known to ignite the hydrogen used for generator cooling, resulting in fires and explosions in the equipment. Repairs have taken many months and cost millions of dollars.

Potential for Compromising the Plant Protection System

Emergency DC systems in power plants always include a battery, and as will be demonstrated, for good reason. It is occasionally necessary to remove the battery from service, for example to repair a faulty intercell connector or to bypass a bad cell. It may also be desirable to disconnect the battery during an equalize charge, or during discharge and subsequent recharge when conducting a capacity test. During these times it can be tempting to rely on a battery charger as the sole source of DC power, but this can have very undesirable results if an electrical fault should happen to occur on the system.

Electrical faults on power systems are often characterized by extremely high short circuit currents. An example of this can be seen in Figure 2, which shows actual three phase current and voltage waveforms recorded by a microprocessor-based relay on a medium voltage plant auxiliary bus. Prior to the fault, current and voltage are observed to be stable and balanced (although current waveforms are difficult to discern due to the automatic scaling feature of the relay). At approximately the 3.5-cycle mark on the time scale, an electrical fault occurred on the feeder. Current magnitude began to increase immediately and the immense draw caused system voltage to decay. At the 4.0-cycle mark the relay trigger actuated to begin the process of clearing the fault. Note that within the first cycle, system voltage had collapsed to less than 20% of original strength.

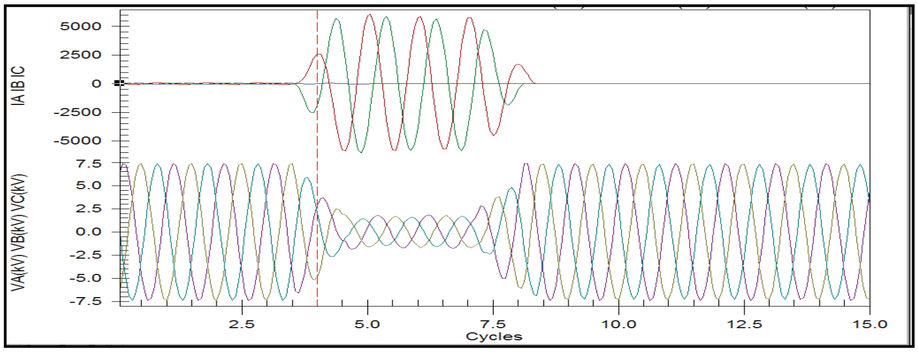

Figure 2 - Voltage Collapse during Electrical Fault

Motor-driven DC Generators were once the standard for DC supply and battery charging.[1] Due to their inherent rotating inertia these chargers were able to "ride through" AC system voltage sags approaching 30 cycles in duration. But due to the level of attention required to maintain DC output voltage and the high degree of maintenance, these systems have given way to "static" chargers which utilize diodes and SCRs. Static chargers rely on continuous rectification during each electrical cycle to maintain voltage output. To make matters worse, some chargers are designed with a shunt trip to open the AC input circuit breaker if low voltage is detected.[2] During a fault condition as described above, insufficient input voltage will render static chargers unable to sustain output, with no way to clear the fault. Fortunately in the case depicted in Figure 2, the battery was able to maintain power to the protective relay and circuit breaker, so the fault was cleared in about 4.5 cycles.

Beyond the functional risks and potential catastrophic consequences, there are also regulatory considerations[3] when removing a battery from service. NERC PRC-005 requires that Bulk Electric System (BES) protection system components are maintained "in such a manner that the protective systems operate to fulfill their function", and PRC-001 requires problems to be corrected as soon as possible. It would then be fair to say that Generator Owners/Operators must not knowingly remove from service any battery which provides essential protection for the BES.

So, it has been demonstrated that to ensure reliability of the emergency power system, there must be a battery connected at all times. Battery chargers alone will not sustain power in the event of a fault or a power failure.

Safety Considerations

It is occasionally necessary to bypass a cell. And the proactive approach would be to remove the bad cell from service before it is completely dead. Given the critical nature of DC systems it may be tempting to try this with the battery in service, but this can be a risky proposition. There will likely be a fair amount of stored energy remaining in the cell. If a jumper were to be applied on line, the overall string would see a reduction in total voltage by the magnitude of voltage in the weak cell, say 2 volts. But from a localized perspective, a smaller separate circuit would be created with a 2 volt source (the weak cell) and near zero impedance (the jumper). This effective short circuit condition would expose personnel to considerable risk, and could also have an adverse affect on the battery string. So to bypass a cell the string should always be taken off line, and the individual cell should be disconnected before the jumper is applied.

Whether to bypass a cell, or for any number of other reasons, manually disconnecting a battery cable can expose personnel to a high degree of risk if there is no way to first open the battery circuit. When an electrical circuit is interrupted in air, an arc is generated across the opening contacts as the electric field ionizes air molecules. The arc generates intense heat and causes damage to contact surfaces. Current will continue to flow through the ionized air and small amounts of vaporized metal until the energy in the field is suppressed by the impedance of the air gap. AC circuit interrupters can take advantage of the inherent zero-potential of the reversing sine wave. But DC circuits have no zero crossing and must interrupt the full magnitude of the current.

In a DC system, each battery cell is an uninterruptible source of power. As long as there is complete connection there is the potential for current to flow. Standby power system loads can be unpredictable, therefore the current flowing in the battery string is also unpredictable. Battery circuit breakers and disconnect switches are specifically designed to open quickly and to deflect and suppress the arc, allowing risks to be managed and mitigated.

Ideal Design

Ideal design of a power plant DC system includes alternate sources of supply. Such an example is shown in Figure 3, and this particular configuration offers a number of desirable features. It can be seen that there are three separate DC buses: Unit 1 Bus and Unit 2 Bus serve loads associated with their respective generating units, while the Station Bus serves common loads. Under normal conditions, each DC bus is operated independently for maximum reliability. In the event of problems with one of the batteries, a bus tie breaker can be closed to temporarily parallel two systems together, at which point the problematic battery can be isolated by opening its breaker. It would generally be undesirable to operate the generating units in this configuration, and careful evaluation of the risks would be prudent before doing so. The ideal design also includes a standby battery charger, either dedicated or shared. In this case the standby charger could be connected to any one of the three buses.

Finally, and perhaps the key advantage to this configuration, not only does each battery have a dedicated disconnecting means, but there is also a battery charger connected on the battery-side of the disconnect. The value of this arrangement cannot be overstated, as it facilitates charging the battery independent of the DC system. Following a repair, or especially following a capacity discharge test, charge voltage can be elevated (beyond the rating of isolated downstream equipment) to increase the recharge rate and reduce time, or voltage can be lowered if necessary to minimize heating of smaller cells. The arrangement can also come in handy when an equalizing charge is required.

Unfortunately, many power plants fall victim to budget constraints and install something less than the ideal design. But, as will be demonstrated, it is possible to implement field modifications to incorporate some of the beneficial aspects.

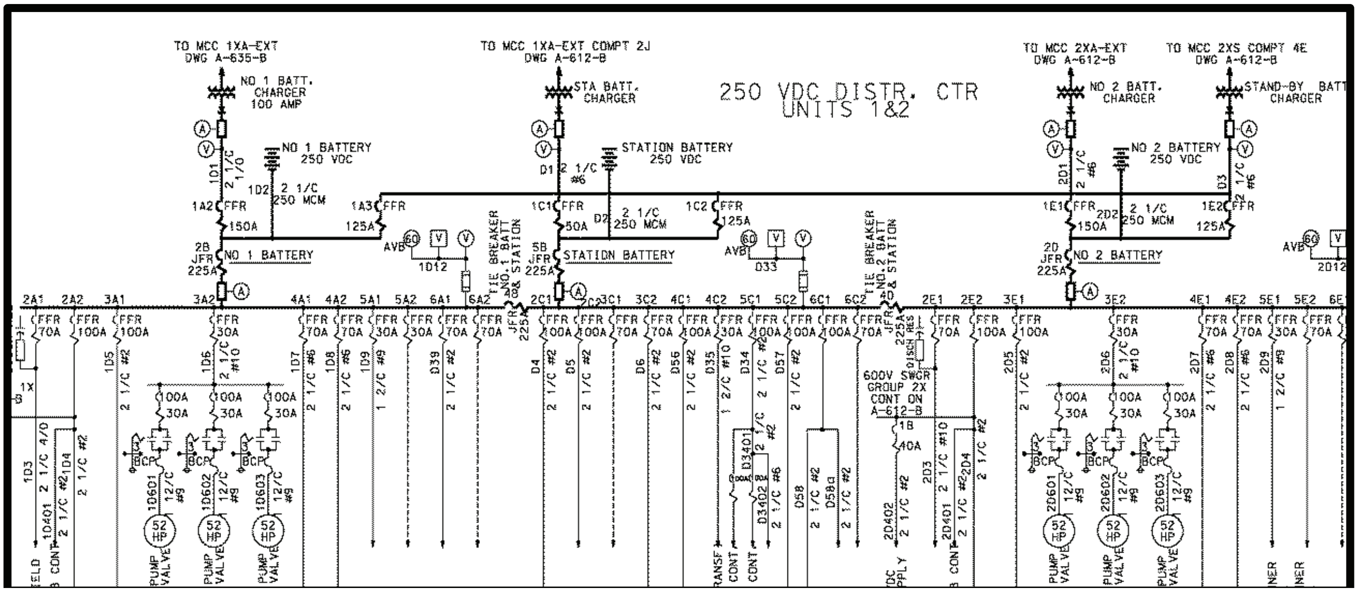

Figure 3 - Ideal Design for Power Plant DC System

Example #1: Addition of Alternate (Maintenance) Feeder for Single-Battery System

Figure 4 illustrates the original design of a vintage coal-fired plant DC system, which employed a single station battery to serve all loads including switchyard protection. Breakers in the DC switchgear provided the ability to isolate the battery and chargers, but there was no backup source. Any time battery maintenance was required the plant had two choices: either take a total plant blackout, or bring in a temporary battery along with a temporary charger.

Many years after initial commissioning, during a revitalization project, a second set of batteries was installed in a remote building to serve new equipment. So recently it was decided to install a maintenance feeder between the main plant DC bus and the new Balance-of-Plant (BOP) DC bus. There were a few minor challenges. First, available spare breakers in the main plant switchgear were of relatively small size (50A), so the feeder was designated as an "emergency" feeder, for use only during station outages and with minimal equipment in operation. Another challenge was distance; the run between DC buses was about 350 feet, so voltage drop was the driving factor in sizing the cable. Existing raceway was available for most of the run, but new raceway was required for several segments. Finally, procedures were required to ensure successful switching operations, summarized as follows: Downstream connections are utilized to tie together main plant Bus 1 and Bus 2. Then after matching voltages, the emergency tie is closed to connect the BOP bus with main plant Bus 1. Finally, main plant battery and chargers are isolated via DC panel main breakers. In this mode, work can be performed on the main plant battery while the BOP battery provides critical backup power for the main plant bus. The reverse can also be true to facilitate work on the BOP battery.

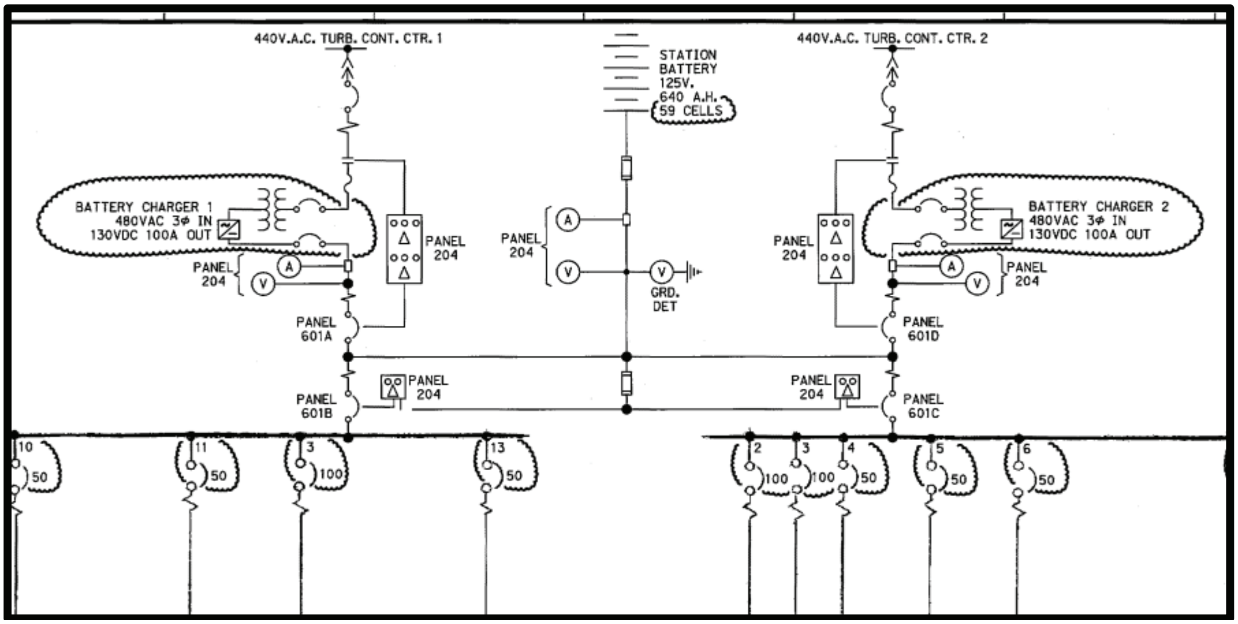

Figure 4 - Vintage Single Battery Design

In the first two years following installation, the feeder was utilized at least three times - once to correct a battery charger issue, and twice for load testing (main plant battery and BOP battery). Considering the avoided cost of temporary equipment and down time, the investment has already been paid off several times over.

Example #2: Parallel Banks to Replace Single Bank

During the natural gas boon of the late 1990s-2000s, many new Simple Cycle and Combined Cycle plants came on line. Common plant designs were utilized, few of which included backup DC systems. This became an issue recently for the Combined Cycle (CC) facilities, as all of the main station batteries were approaching end-of-life. Station batteries provide critical power for plant auxiliary controls and switchyard protection, so DC system outages are difficult to arrange, even during unit outages. The original DC systems comprised a single set of 2400AH VRLA batteries connected in a series-parallel cell configuration as required for capacity. Batteries were wired directly to the DC bus. Each system did at least include redundant battery chargers.

Figure 5 - Single Bank Converted to Parallel Banks

Looking forward, it was obvious that the station batteries would require frequent outages over the lives of the facilities, for testing and maintenance as well as regular replacement. So a common design (Figure 6) was developed for modifications that could be applied at all of the CC sites. The new design incorporates two separate battery banks operated in parallel, each associated with one of the battery chargers. In normal operation both sets of batteries must remain in service for full capacity. During station outages, one bank can be taken out of service without compromising the reliability of the DC system, and the isolated bank can be recharged if necessary before reconnecting to the system. Modifications were successfully implemented at all of the Combined Cycle facilities at the time the original station batteries were replaced.

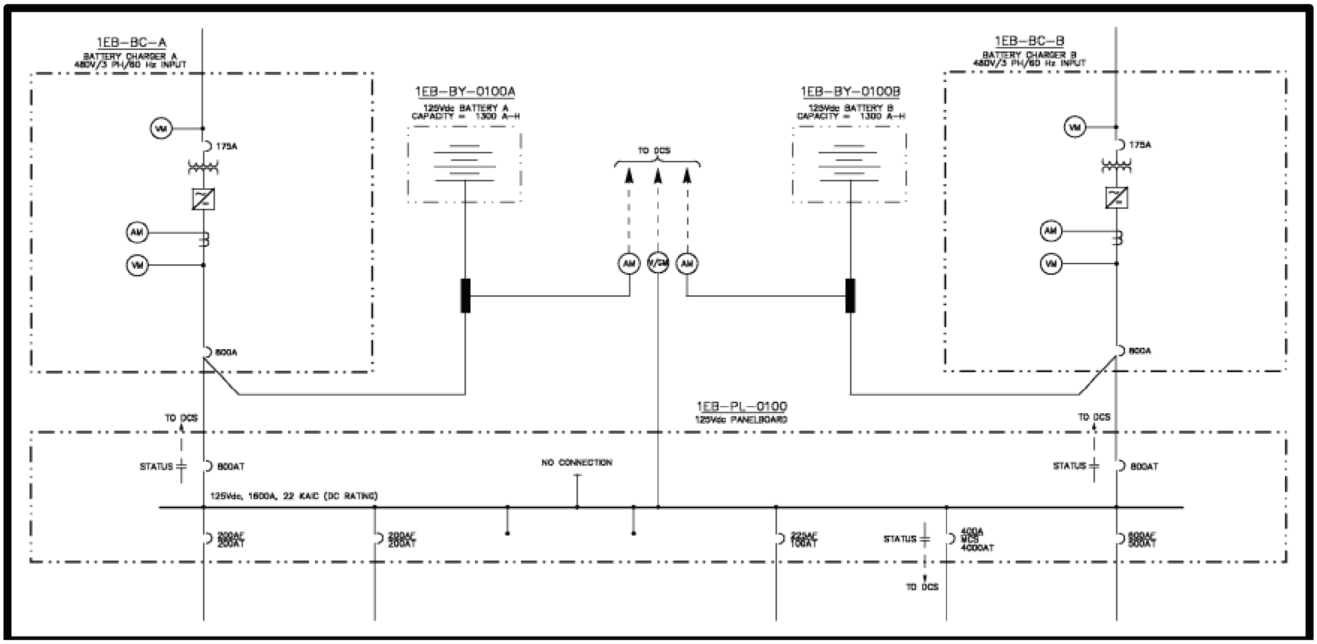

Figure 6 - Redesigned Parallel Bank Configuration

Incorporated in the design are several features to improve operability and reliability. Since main DC panel circuit breakers (for each battery/charger) are now critical links in the system, auxiliary contacts were added to breakers to monitor status. If a breaker trips or is manually opened, operators receive an alarm in the control room.

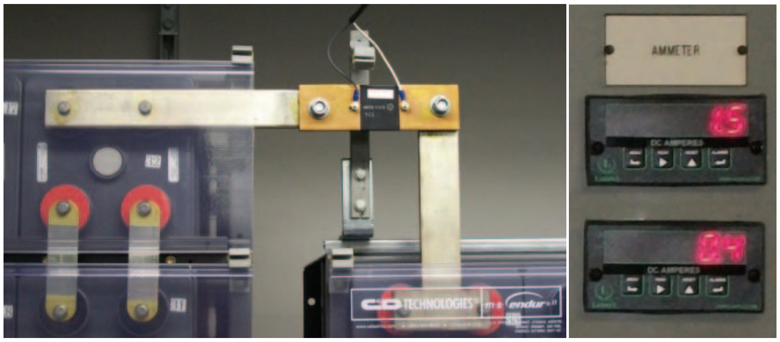

Figure 7 - Metering Shunt and Panel Meter

As a supplemental feature, current monitoring devices were installed for each bank (Figure 7). Due to space limitations in the DC distribution panel, shunts were installed at the batteries in place of intercell row connectors; customized bus connectors were specially designed for this purpose. Sizing of the shunts was important. Since battery current is very low the vast majority of the time, a smaller shunt would provide the best resolution at low range. However the shunt must be able to handle the highest anticipated emergency current without failing. Both of these factors were considered in selecting an 800A, 50mV shunt. Shunt secondary wiring was connected to a digital millivolt meter, scaled to display "amps", and which includes an analog output for connection to the plant DCS.

Example #3: Simple Cycle DC System Cross-Tie

In the Simple Cycle (SC) fleet, a typical standard design is for a pair of gas turbine generators to feed into a common Generator Step-Up Transformer (GSU), which connects to the power grid. Each generator has its own protection system, but the pair is interrelated because each system provides a portion of the protection for the common GSU and switchyard elements. The protection scheme relies on both segments to be powered and operational, so unless there is a complete power block outage (de-energized transformer) neither battery can be removed from service without compromising the system. Generator DC systems also supply power for critical generator functions including excitation, fire protection, and turbine/governor control.

Installation of an alternate DC source might, at first thought, be considered a quick and easy remedy. However typical SC DC systems are furnished in a relatively crude configuration (Figure 8A) with batteries and chargers wired directly to the DC bus (no disconnecting means). So even with an alternate source, removing a battery from service can place maintenance personnel at risk.

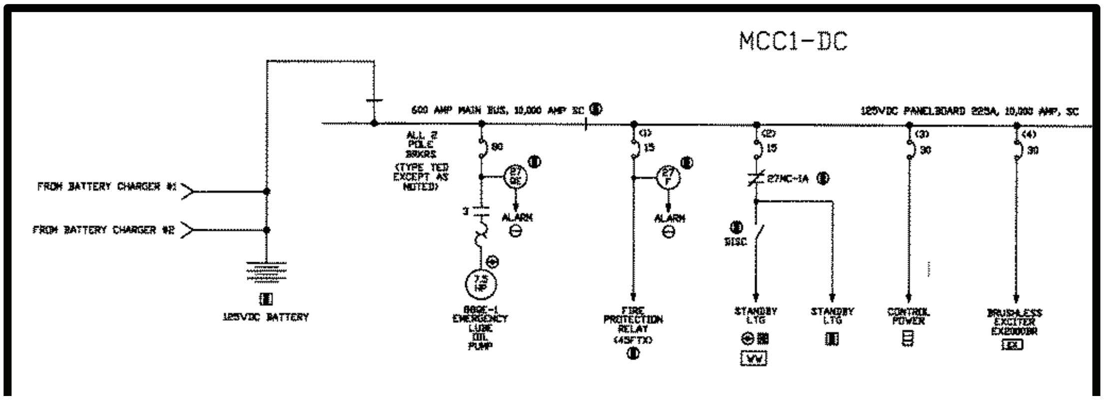

Figure 8A - Simple Cycle DC System - Original

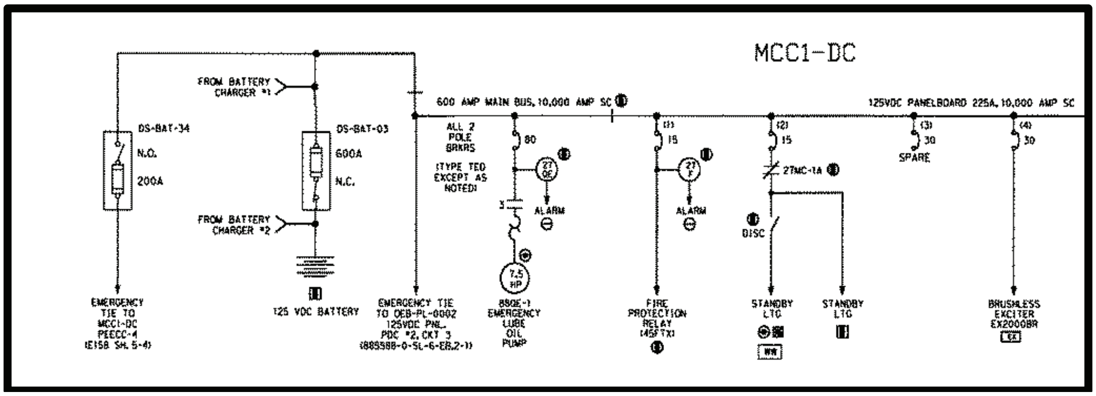

Figure 8B - Simple Cycle DC System - Modified

The cross-tie modification shown in Figure 8B provides improvements on multiple fronts. The concept first allows the battery of one gas turbine to be used as an alternate supply for its paired mate, and vice versa. Secondly, the design incorporates a disconnecting means for each battery, and relocates the connection point of one charger to the battery-side of the new battery disconnect switch.

Addition of the battery disconnecting means is arguably enough to justify the project based on the safety improvement alone. Among the other benefits of this configuration is a huge time savings in lock-out-tag-out operations, especially if only minor battery repairs are required. Confining switching operations to the DC system limits the number of power cycles on the large, expensive GSU transformer. It also eliminates the need to power down protective relays, fire protection, excitation systems, and turbine/governor controls; those familiar with these systems know how temperamental (and prone to failure) they can be any time power is cycled.

The most significant hardware cost items in the project were the new battery disconnect switches, sized for maximum current to match the rating of the existing DC bus. These switches are fairly large, so physical location can be a challenge. As for the cross-tie (alternate feed) disconnect switches, economics dictated that these should be smaller. It was not intended that a generating unit would operate with the cross-tie in use since a single battery lacks the capacity to safely shut down two generators. A significant advantage common to most sites is existing raceway between paired generating units, often via duct bank, trenches, and vaults. Significant cost savings can be realized if exiting infrastructure can be utilized. Conversely, lack of existing infrastructure can be cost prohibitive since installation labor is one of the biggest cost items and, by far, the most variable.

To date, prototype installations have been successfully completed on several units at one Simple Cycle site, and the concept has been studied for installation at several similar facilities elsewhere in the fleet.

References

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3. NERC Protection System Maintenance, A Technical Reference, September 13, 2007, Prepared by the System Protection and Controls Task Force of the NERC Planning Committee