WHITE PAPER
by Hassan Obeid

Design Considerations for Generator Set Mounted Paralleling Breakers

Cummins Power Systems has been delivering simple paralleling solutions since the introduction of PowerCommand® digital paralleling in the early 1990s. The typical paralleling system included generator set paralleling breakers commonly located in a switchgear lineup remote from the generator sets. Some markets are now driving for an option to mount the generator set paralleling breaker on the generator set itself. There are challenges associated with this type of design. The objective of this paper is to outline and address these challenges in an effort to provide an understanding of how to apply the advantages of this design and still maintain design integrity and system reliability.

Exhibit-01: Paralleling switchgear

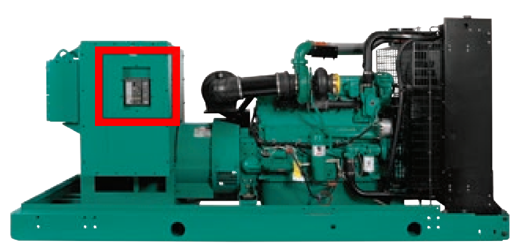

Exhibit-02: Generator set mounted paralleling breaker

Paralleling of generator sets is enabled by using electrically operated circuit breakers which are typically mounted in switchgear. Switchgear is defined as a metal-enclosed structure which contains bus bars, insulating material, connecting means, either stationary or drawout, manually or electrically operated circuit breakers in individual metal compartments, Exhibit-01. The switchgear may also contain controls, instruments, metering and protective equipment. Traditionally, the switchgear also included all discrete components needed for paralleling generator sets. Components such as speed governors, voltage regulators, reactive and real power load share controls, fuel ramping controls and protection for reverse power (anti-motoring) and loss of field (under excitation).

To improve the overall power system reliability, some Original Equipment Manufacturers such as Cummins design their paralleling scheme using what is called distributed logic architecture. Cummins accomplishes this type of architecture with PowerCommand Control, which is an autonomous microprocessor-based control for protection and paralleling functions. Therefore, the paralleling scheme is redundant on every generator set. In certain applications, the paralleling breaker can be mounted on the generator set, Exhibit-02, thereby eliminating the need for the switchgear described above. The physical paralleling point in this situation can be either a collector bus or a switchboard, Exhibit-03.

The point of common connection of paralleled generator sets with set-mounted paralleling breakers is either at a distribution board or a collector bus, as opposed to traditional paralleling, where it takes place in the paralleling switchgear. Exhibit-04 shows a systems configuration with generator set-mounted paralleling breakers. In this example, two generator sets with set mounted paralleling breakers are connected to a distribution board feeding downstream loads through two transfer switches. Exhibit-05 shows a transfer-pair application with single generator set/single utility connected to a collector bus feeding downstream loads. The Cummins PowerCommand Control has the capability to control the utility main breaker and also has built-in protection to isolate the generator set in the event of a fault.

Exhibit-03: Collector bus

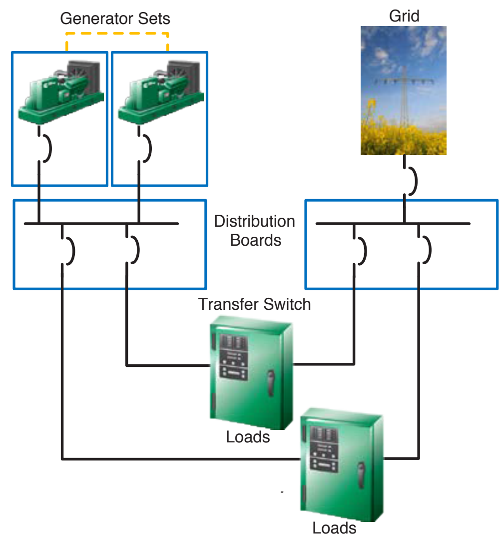

Exhibit-04: Typical isolated-bus configuration

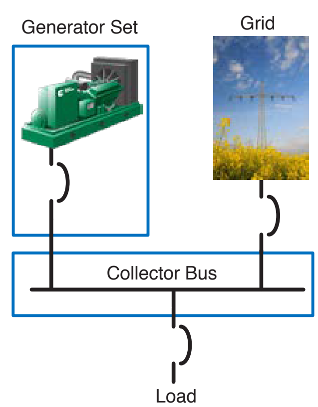

Exhibit-05: Typical infinite bus transfer-pair system configuration

In paralleling applications, the system requirements, overall physical layout, size and one-line configuration all influence the switchgear design. Also, there are rules and guidelines which are outlined in the NEC, UL and NFPA that need to be considered, as well as the Authority Having Jurisdiction (AHJ), when designing a paralleling system and in particular as it relates to the common point of connection of the paralleled sources. The following are some design considerations associated with paralleling and the common point of connection:

- **Maximum Available Fault Current –** The point of common connection must withstand the physical and thermal stresses caused by fault currents from all sources. The power cables between the generator sets and the point of common connection must be braced to handle fault currents.
- **Load Flow Analysis –** The ampacity of the point of common connection must handle the current contribution from all generator sets.
- **Ground Fault –** Isolate and properly detect a ground fault without causing nuisance tripping; the neutral and ground are bonded in one place in four-wire systems.
- **Generator Set Isolation –** Concurrently maintain generator sets and isolate faults.

MAXIMUM AVAILABLE FAULT CURRENT

An essential factor in paralleling system design is the maximum available fault current (Imafc), peak and RMS. Imafc is the sum of the available fault current from all generator sets (Iafc), motor loads (Imlfc) and utility distribution transformers (Iutfc) that can be simultaneously connected to the system. The value of Imafc is used to determine the physical construction and mechanical bracing required to safely sustain a fault at that level without danger of mechanical or electrical failure.

When a short circuit occurs in a power distribution system, very high levels of current will be drawn to the fault. These high magnitude currents rise quickly and develop strong magnetic fields which tend to force apart bus bars and power cables.

If the electrical distribution equipment is not properly designed and installed, the bus structure or other power conductors can mechanically fail, causing a catastrophic failure of the power system.

It is critical that the system designer verifies the level of available fault current in the system, and specifies equipment that will be suitable for the application. All of the supply side (utility or generator set)circuit breakers in the paralleling system require an interrupt rating that is $\geq I_{mafc}$.

I_{mafc} = Maximum Available Fault Current = $I_{afc1} + I_{afc2} + ... + I_{mlfc1} + I_{mlfc2} + ... + I_{utfc1} + I_{utfc2} + ...$

I_{afc} = Generator Set Available Fault Current = (kW*1,000)/(√3*V*p.f.*X”d)

Where:

kW: kilowatt output rating of the generator set

p.f.: generator set rated power factor

V: generator set rated output voltage

X”d: alternator per unit subtransient reactance based on the generator set rating

I_{mlfc} = Motor Load Fault Current ≊ Locked Rotor Starting Current

I_{utfc} = Utility Fault Current ≊ transformer steady state rating divided by the transformer impedance

The maximum available fault current, Imafc, must be less than or equal to the equipment bracing level design. In the event of a fault, the power cables must withstand the fault current thermal effects and might move or jump due to the high levels of magnetic forces. Therefore, the system design engineer should take into account the physical bracing of the power cables and apply appropriate strain reliefs. Also, the capacity and temp rise of the power cable are of high importance for the same reasons. And the impedance of the cables should also be considered in the full evaluation of the system. For example, if there are multiple power sources connected together and a fault takes place, the lugs and power cables must be able to withstand all the available fault current.

See Exhibit-06, which shows a fault in the power cables between generator set 1 and the distribution board. The cable and lugs at point 'A' must withstand the fault current contributions from the two motors and generator sets 2 and 3. The paralleling circuit breaker must have the proper interrupt rating to open the circuit under a fault without being damaged or causing an arc flash.

LOAD FLOW ANALYSIS

The system design engineer needs to perform a system load flow analysis, which can be done by knowing the generator set size and quantity, calculating the generator supply current (Igsc), and total supply current (Itgsc). Also, the maximum available fault current as described in the previous section should be taken into consideration. Igsc is used to determine the paralleling circuit breaker frame size and trip level. Improper design can jeopardize the system reliability and integrity.

I_{gsc} = Generator Supply Current = kW/(√3*V*p.f.)

I_{tgsc} = Total Generator Supply Current = $I_{gsc1} + I_{gsc2} + I_{gsc3} + \ldots\ldots + I_{gscn}$

If the total supply current of the generators is greater than the paralleling bus ampacity, then the loads can be spread out along the paralleling distribution panel to overcome this issue. The current flow at any point on the bus cannot exceed the continuous rating of the system main bus selected. Exhibit-07 shows that the capacity of the bus is exceeded at point 'A', since the contribution from all three generator sets is 6,000 amps. By applying load flow analysis and reconfiguring the bus, Exhibit-08, the continuous rating of the bus is no longer exceeded. Another way to overcome this challenge is to use a 6,000-amp distribution board or collector bus, Exhibit-09.

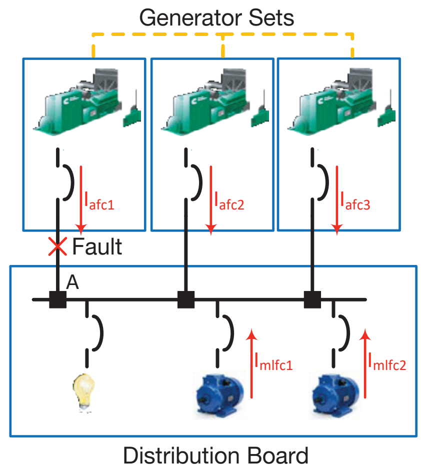

Exhibit-06: System fault

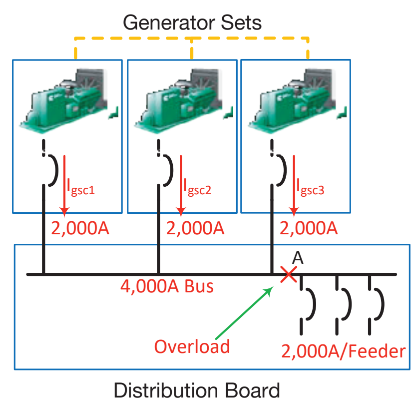

Exhibit-07: Exceeding bus capacity

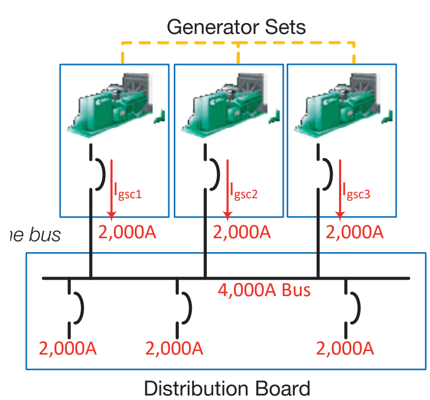

Exhibit-08: Re-configuring the bus

GROUNDING

For optimum continuity of power for critical loads and for the safety of personnel, careful consideration of the grounding arrangements of generator sets used in emergency and standby power systems is essential. Specific considerations for emergency and standby systems include selection of a system grounding method for the generators, requirements for indication only of a ground fault on the generator, and the methods used in transfer equipment for switching the neutral pole.

The National Electric Code (NEC) 2014-230.95 requires Ground Fault Protection (GFP) at the service disconnect (utility breaker) for systems with: solidly grounded wye, more than 150 volts to ground (277/480 or 347/600VAC) and over current device rating of 1,000A or more. Ground Fault Indication (GFI), not protection, is required at the emergency source (NEC 700.6 (D).

Adequate equipment and system grounding are necessary for creating an effective path for ground fault current to return to the source. One of the aspects for properly detecting ground fault current is to appropriately select and place current transformers (CTs) in a power system. Detecting ground current can be done using the residual method, zero-sequence or source ground return method. The source ground return method is typically what is used in paralleled systems where CTs must be placed on the neutral to ground bond. In four-wire systems, the bonding takes place in the distribution panel/collector bus, Exhibit-10. In three-wire systems, the neutrals can be bonded at the generator sets, given the generator sets are identical. Neutrals of dissimilar generator sets should not be interconnected to prevent circulating currents. The system designer needs to be aware of the space constraints when the paralleling gear is a riser collection bus or a small switchboard and all of CT wires need to be possibly brought back to the paralleling breaker trip units.

Ground fault schemes require further evaluation when interfacing a generator set mounted circuit breaker with another switchboard that includes generator set(s), a utility, or other alternative energy source connection.

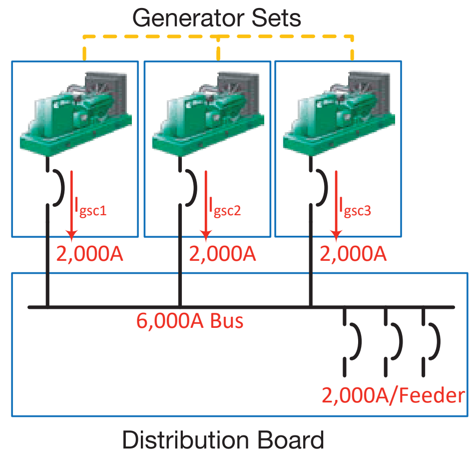

Exhibit-09: Using a 6,000-amp bus

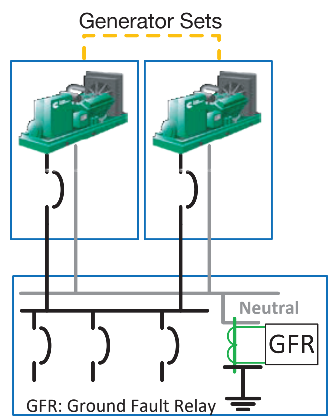

Exhibit-10: Four-wire system

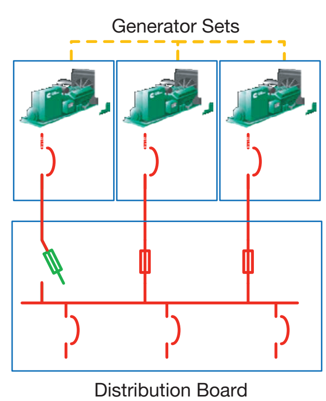

Exhibit-11: Fused disconnects

GENERATOR SET ISOLATION

Considerations should be given to generator set isolation for maintenance. To perform maintenance on a generator set, there must be means to individually disconnect each generator from the paralleling distribution bus. This can be accomplished at the paralleling switchboard by using fused disconnects. It can also be accomplished by using the generator set mounted paralleling breaker. However, if there are no disconnects at the distribution board, the load side of the breaker will be energized if other generator sets are online. In this case, performing maintenance on an individual generator set requires taking all sets offline. This reduces reliability because the system is no longer concurrently maintainable. Refer to Exhibit-11.

Another important factor to note is when a downstream disconnect switch is used, without proper design and protection there is a high risk factor of closing out of phase if an operator opens the disconnect switch and then closes it again while the bus is energized while the generator set is running; see Exhibit-11. An interlocking scheme between the paralleling breaker and its respective disconnect switch can be employed, which may prevent this type of occurrence.

Furthermore, isolation at the point of common connection improves reliability by preventing that connection from being a single point of failure. Without isolation, the occurrence of a cable fault between any generator set and the point of common connection will result in all generator sets disconnecting and shutting down. Isolation for each unit at the point of common connection will isolate the fault from the other generator sets and allow them to continue to supply power to the loads.

ADDITIONAL METHODS FOR POINT OF COMMON CONNECTION

Utilizing the lugs on an ATS as a paralleling point, Exhibit-12, or daisy-chain the power cables from one generator set to another and then go to a collector bus or switchboard. Exhibit-13 some additional options. However, achieving generator set isolation with these methods as shown in Exhibits-12 and 13, will be challenging. Other design considerations noted above, e.g., load flow analysis, maximum available fault current and physical bracing will need to be addressed as well.

CONCLUSION

Paralleling with generator set mounted paralleling breakers can be used in a variety of applications such as oil and gas, mining, commercial and municipal buildings, and healthcare clinics. This type of paralleling equipment may offer multiple attractive advantages, such as cost-reduction, smaller footprint, and ease of wiring and integration. However, the apparent advantages should be viewed alongside the design challenges and carefully considered to ensure maximum system reliability and adequate design.

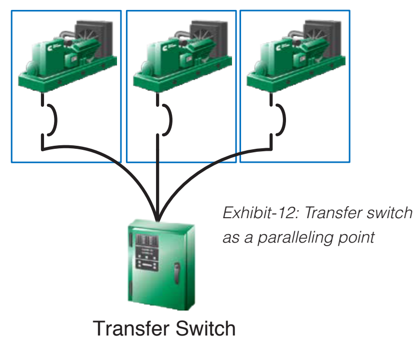

Exhibit-12: Transfer switch as a paralleling point

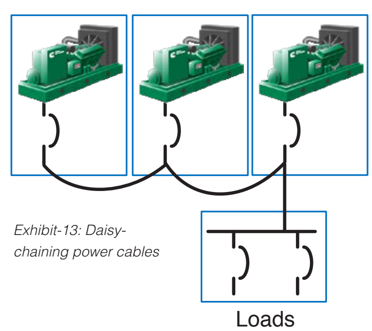

Exhibit-13: Transfer switch as a paralleling point

About the author

Hassan Obeid
Sr. Global Technical Advisor

Hassan Obeid is a Sr. Global Technical Advisor for Systems and Controls – Critical Protection at Cummins Power Generation focusing on technical vision, business strategy, and solving a wide range of complex problems. Hassan has been with Cummins since 2007 in a variety of roles: power systems design engineering, project engineering and application engineering.

Hassan has designed power systems involving switchgear, controls, paralleling, transfer switches, microgrids, generator sets and digital solutions. He has developed and conducted numerous technical power seminars to consultant engineers across the globe on several topics and products involving paralleling, grounding, power systems, microgrids, and controls. Hassan led the switchgear design for the BEAR 800kW Mobile Power Unit for the Air Force. Hassan received his bachelor's degree in Computer Science and master's degree in Electrical Engineering from Minnesota State University, Mankato.

Cummins Inc.
Box 3005
Columbus, IN 47202-3005
U.S.A.

cummins.com

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