Multiple Line-to-Ground Fault Characterization and Mitigation in MVDC Shipboard Electrical Systems

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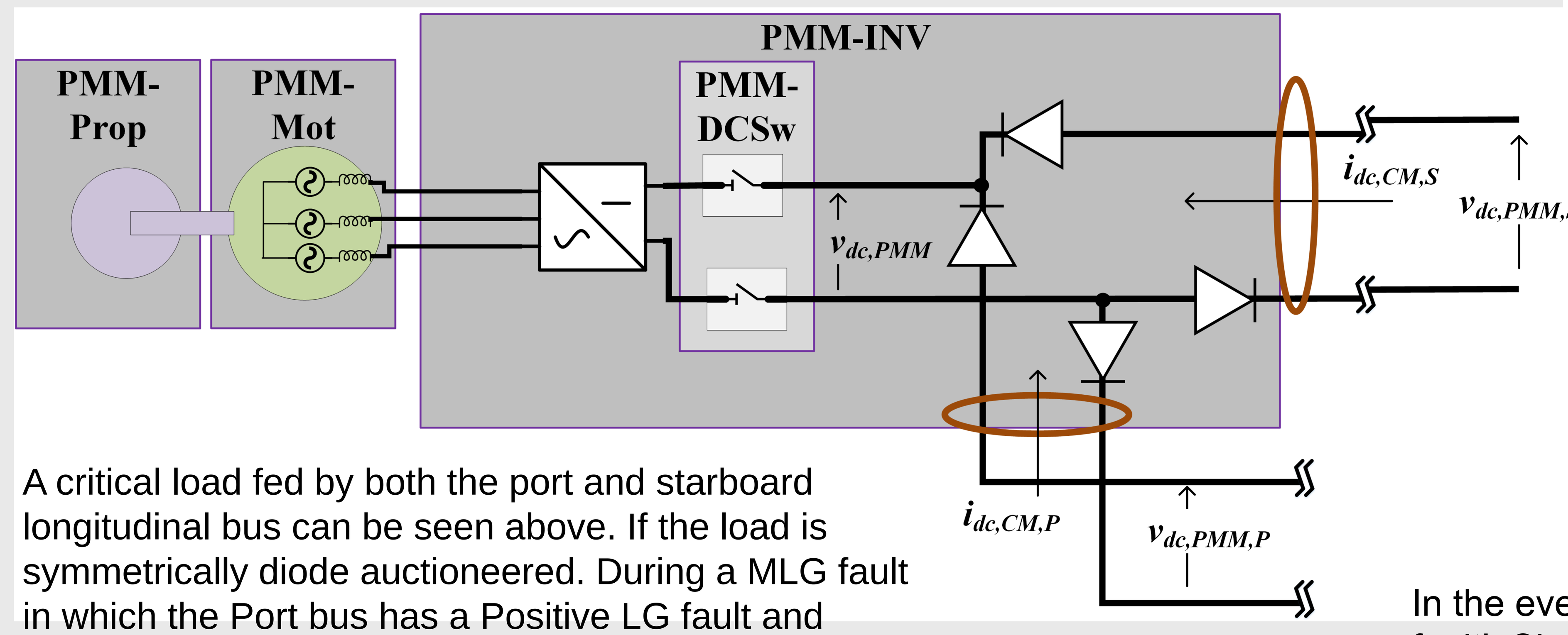
Introduction

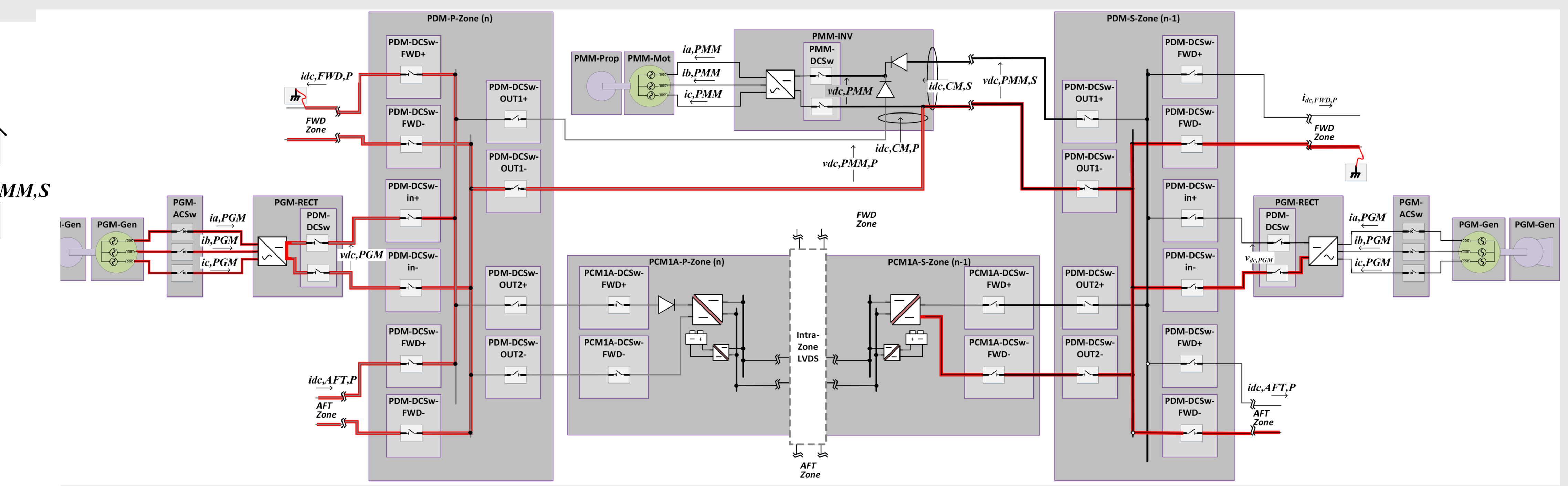
Future shipboard electrical systems utilizing zonal Medium Voltage dc (MVdc) distribution, face conflicting design objectives. The system must be simultaneously power dense, cost effective, and survivable. Shipboard electrical distribution systems can utilize a floating ground design to increase survivability in single line-to-ground (SLG) fault scenarios. However, this could decrease the survivability of the upon the incidence of a second line-to-ground (LG) fault. This work characterizes the most problematic Multi-Line-to-Ground (MLG) fault scenarios and analyzes mitigation approaches.

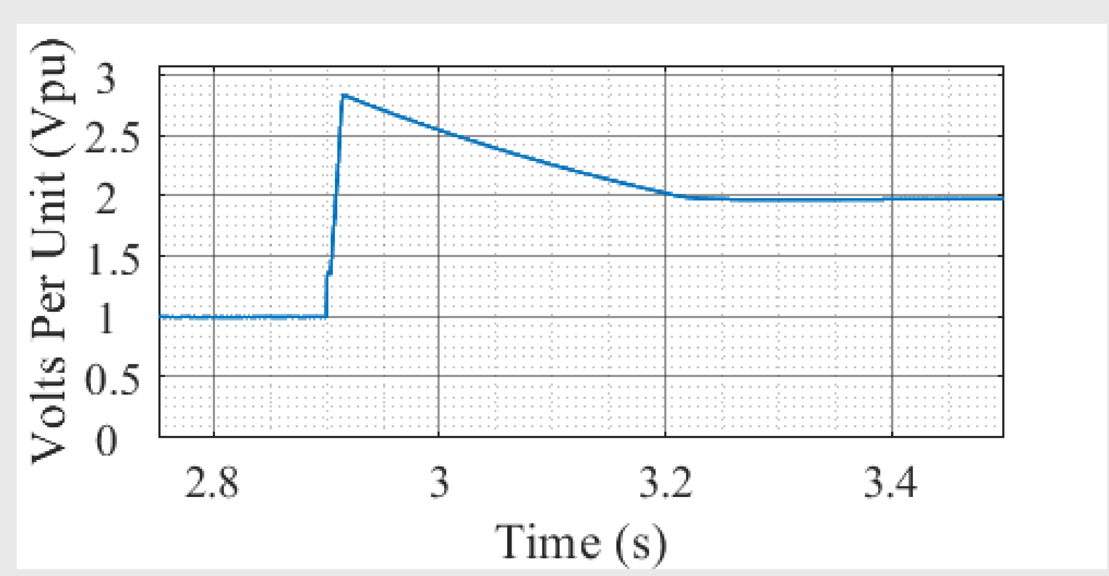
Architectural and Topological Impacts on Fault Behavior

Critical loads are fed from multiple non-isolated buses. To insure operability during a Line-to-Line fault, critical loads are diode auctioneered. However, depending on implementation this can cause problems during MLG fault scenarios



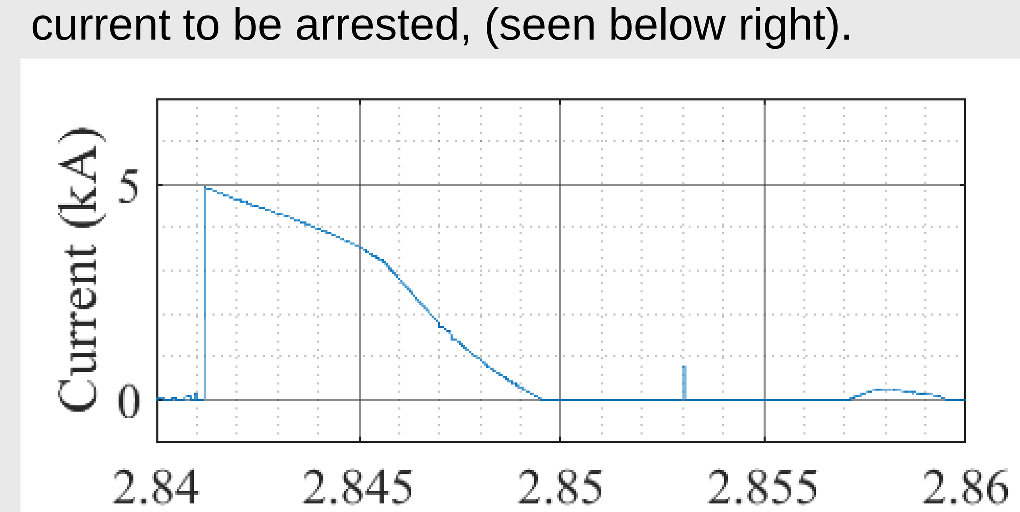
A critical load fed by both the port and starboard longitudinal bus can be seen above. If the load is symmetrically diode auctioneered. During a MLG fault in which the Port bus has a Positive LG fault and Starboard Bus has a Negative LG fault a voltage doubling effect occurs (Seen Below).

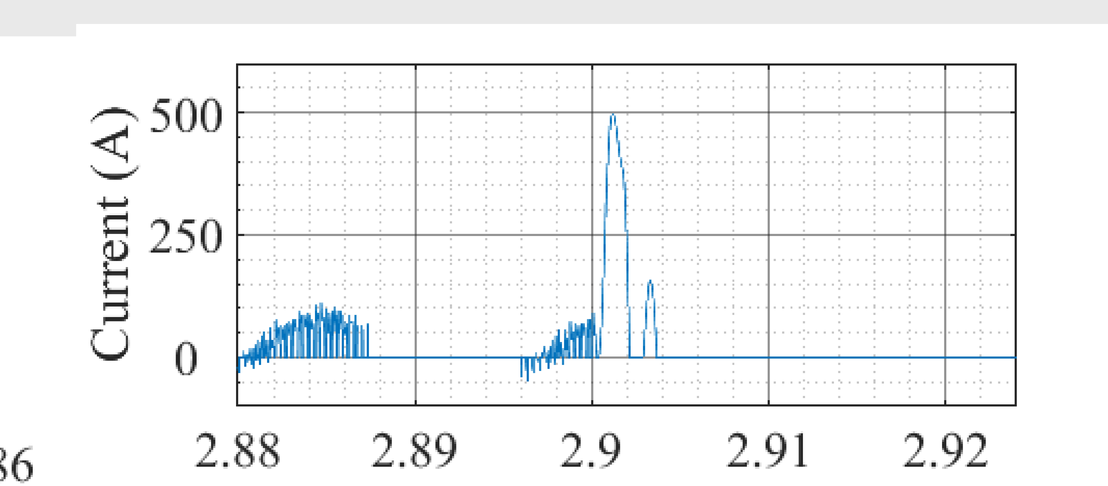


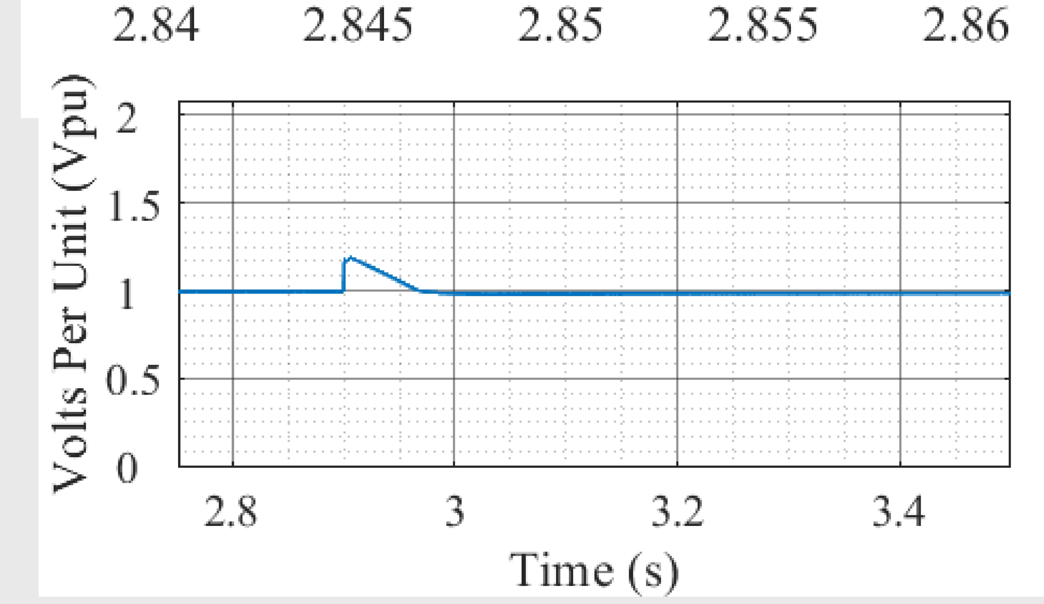


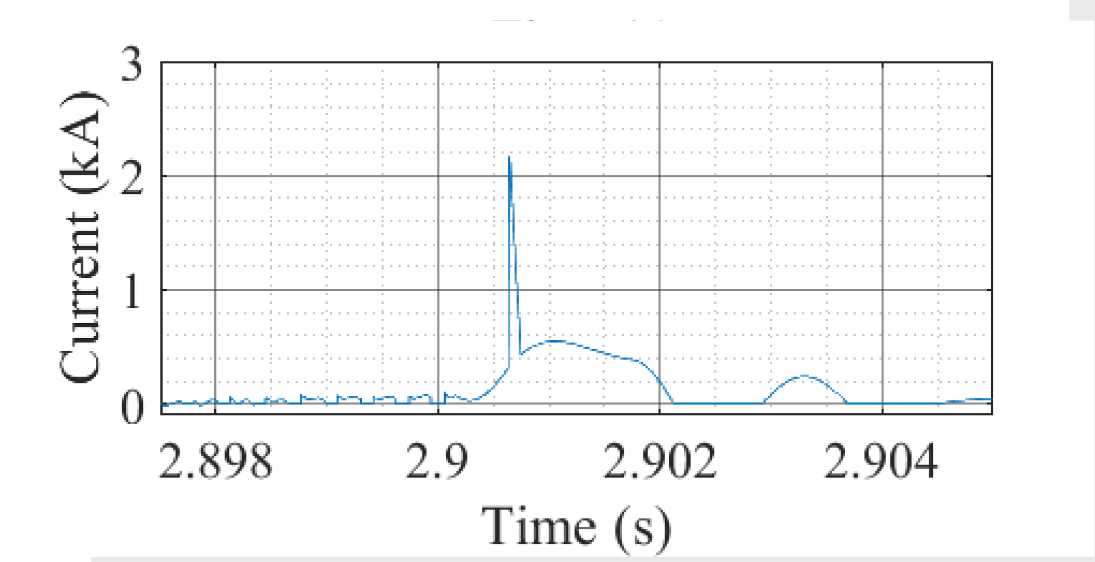
If a negative leg Solid State Circuit Breaker is added in place of the symmetric diode. This voltage doubling could be arrested by a sufficiently fast acting protection system (seen right). However, the active rectifier will still experience a large current transient. Which would be damaging to devices (seen far right).

In the event that Asymmetric Diode auctioneering is used, the system experiences a 'distributed LL fault'. Shown above is the distributed LL fault current path. Due to the topological behavior of a neutral point clamp (NPC) active rectifier, this distributed LL fault will result in high current in the diodes of the NPC (seen below left). The addition of Solid State Circuit Breakers to the output of the NPC allows this current to be arrested, (seen below right).









Further information

This work will be published at Electric Ship Technology Symposium 2021, for further information or a copy of the conference paper, email jdgudex@uwm.edu

Conclusions

MLG fault scenarios present the potential for several possible extreme fault scenarios which could result in over voltage or over current damage to power semiconductors, within the system. The potential for distributed LL faults, potential for charge pumps, and potential for voltage doubling, also presents a serious threat to survivability of ungrounded shipboard power systems. Several routes to solutions are possible in a PEC-based Unit-based protection architecture depending on the topologies in play. If the goal is to simultaneously have a power dense system and survivable system, a combination of NPC1-based PGM-Rectifier (or similar VSC-based topologies) and SSCBs yield a potentially viable result. This viability is contingent on the operating speed of the SSCB relative to the rate of rise of fault current or voltage doubling effect. When designing a future system, judicious placement of SSCBs in combination with VSC topology could result in a more power dense system than using alternative FB-MMC based PEC topologies for the PGM-Rectifier and other potentially fault feeding PECs in the system. Future work in this area will perform full characterization of MLG fault scenarios in shipboard IPES and derive the requirements for sensing, fault discrimination and FDIR algorithms.