Shipboard power system limiting load flow and load flow analysis

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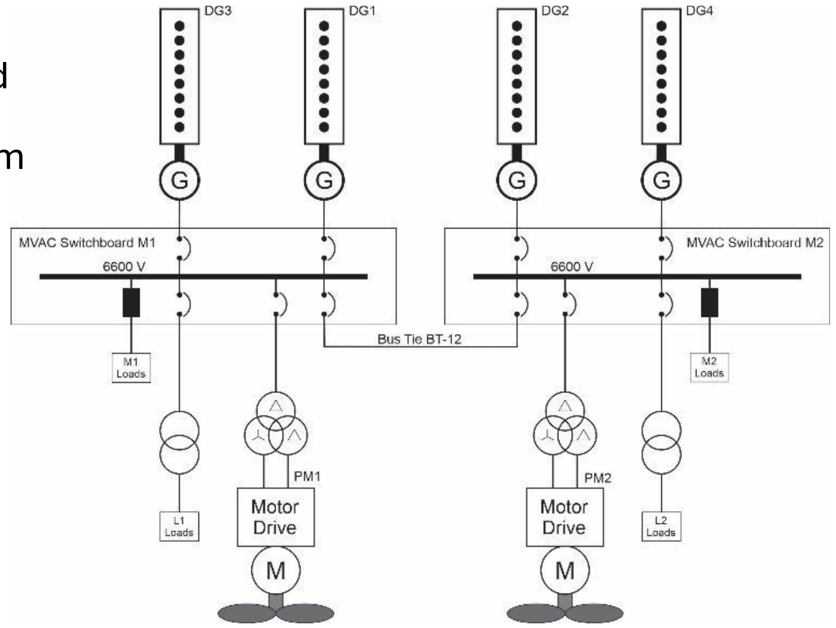
ESTS 2025
Alexandria VA

August 2025

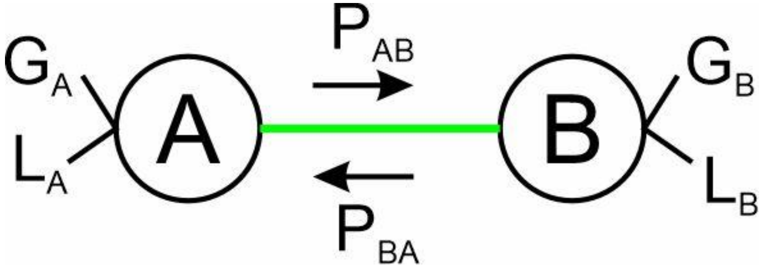
Load Flow Analysis in Shipboard Power Systems

- Purpose
  - Determine the potential for overloading cables and other distribution system equipment
  - Possibly support Voltage Drop calculations
- Traditional Load Flow Analysis
  - Calculate voltages and currents at all points in the system for all configurations and operating conditions
  - Use worst case current flow to determine adequacy of cable and distribution system equipment current rating
- Differences between shipboard systems and terrestrial systems that impact load flow analysis
  - Load Sharing vice Power Scheduling
  - Short Electrical Distances
  - Greater Centralized Control
- Identifying the worst case (highest current) condition for a given cable or distribution system equipment may be challenging
  - Different configurations of online generators
  - Different configurations of online loads
  - Electric Power Load Analysis (EPLA) may be immature
    - Detailed information may not be available
  - Ring buses, mesh topologies, and zonal systems are especially challenging



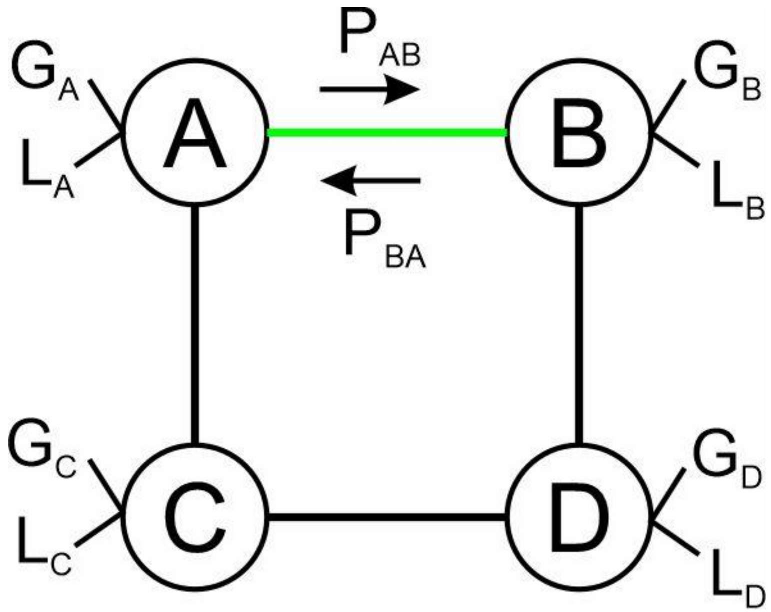
Limiting Load Flow (Cables)

- During early stages of design, do not have sufficient information to conduct a detailed load flow analysis.
- Can, however, estimate an upper bound of current (power) flow.
- In any cable segment the power flow through a cable in one direction is limited by the lower of the total generation capacity on one end of the cable and of the total load on the other end of the cable. (Capacity can be current or power)
- Limiting Load Flow estimates
  - Most Conservative: Ignore loads – Sum the capacity of all online generation connected to the cable.
  - Less Conservative: Ignore loads – compare generation capacity on each end of cable and use the larger.
  - Least Conservative: Compare the loads connected on one end of the cable and compare to generation on the other end, use the smaller as the limiting load flow in that direction. Use the larger of the limiting load flows of the two directions.



Limiting Load Flow nuances (Cables)

- Loads that may be switched via a bus transfer to either end of the cable should be counted on both ends of the cable.
- Loads should have margins and service life allowance applied
- Multi-path networks (where the two ends of the cable are connected within the network) require special treatment.
  - Must calculate limiting load flow for all possible cases where sufficient other cables are removed to eliminate the connection between the two ends of the cable – use the worst case.
- Program for calculating limiting load flow for cables is available
  - http://doerry.org/norbert/MarineElectricalPowerSystems/Software/C_LLF/

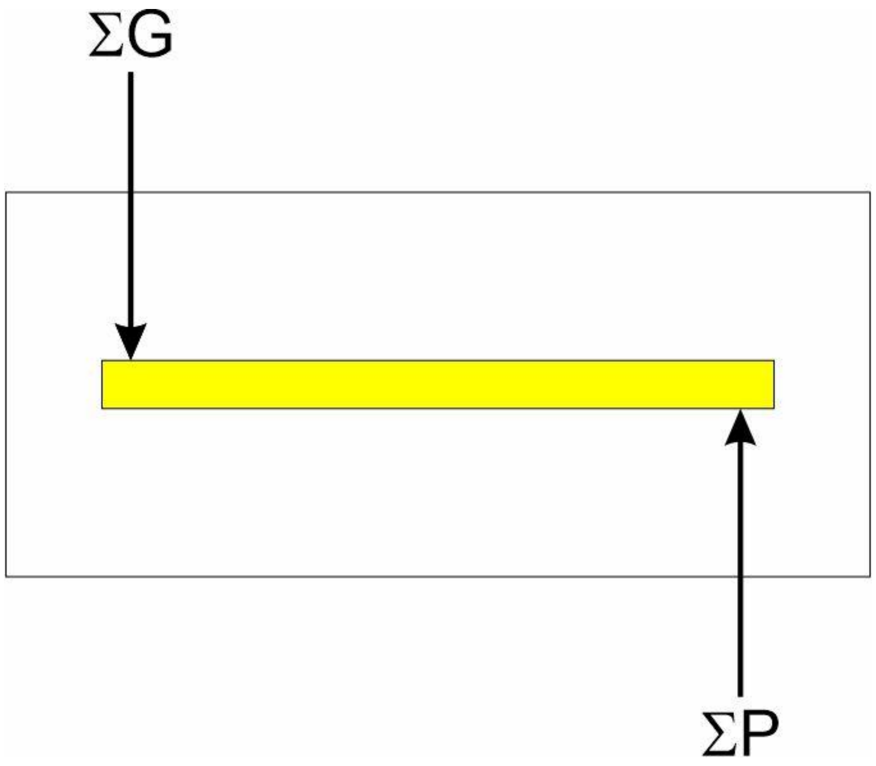


Load Flow (Cables and Switchboards)

- Load Flow Analysis is appropriate once the EPLA is mature and system concepts of operation (CONOPS) exist.
  - Generator set scheduling table
  - Propulsion motor scheduling table (for Integrated Power Systems (IPS))
- Typically employs a steady-state modeling and simulation tool such as S3D to find the worst case current (power) flow.
  - If the power distribution system incorporates a multi-path network, then details of the cable impedance of the bus ties are needed to accurately estimate power flows.
  - Worst case power flow often occurs where there is a lot of asymmetry of loads and sources on the ends of the cable (or switchboard connections)

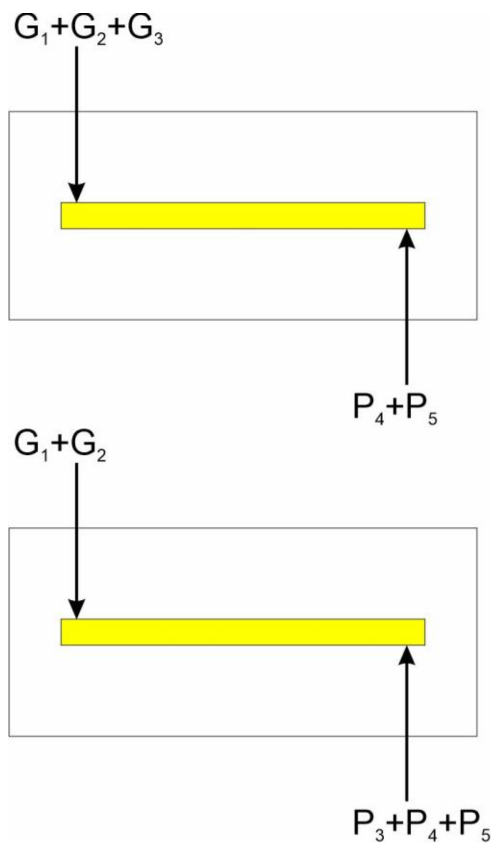
Limiting Load Flow (Switchboards)

- Goal: Determine maximum current flow in the bus bars of the switchboards
- Assume
  - All Generation connections are on one end of the bus bar
  - All Load connections are on the other end of the bus bar
- Limiting Load Flow
  - Most Conservative: Ignore loads – Sum the capacity of all online generation connected to the switchboard.
  - Least Conservative: Compare the loads connected to the switchboard and compare to generation connected to the switchboard. Use the smaller of the total generation and total load.



Limiting Load Flow nuances (Switchboards)

- Some connections have both sources and loads on the same interface.
  - For the set of connections that have both sources and loads, need to check for all combinations where one considers separately the connection to be generation or load.
- Loads should have margins and service life allowance applied
- Multi-path networks (where two connections to the switchboard are connected outside of the switchboard).
  - Must calculate limiting load flow for all possible cases where sufficient other cables are removed to eliminate the external connection between the switchboard connections – use the worst case.



Limiting Load Flow Example

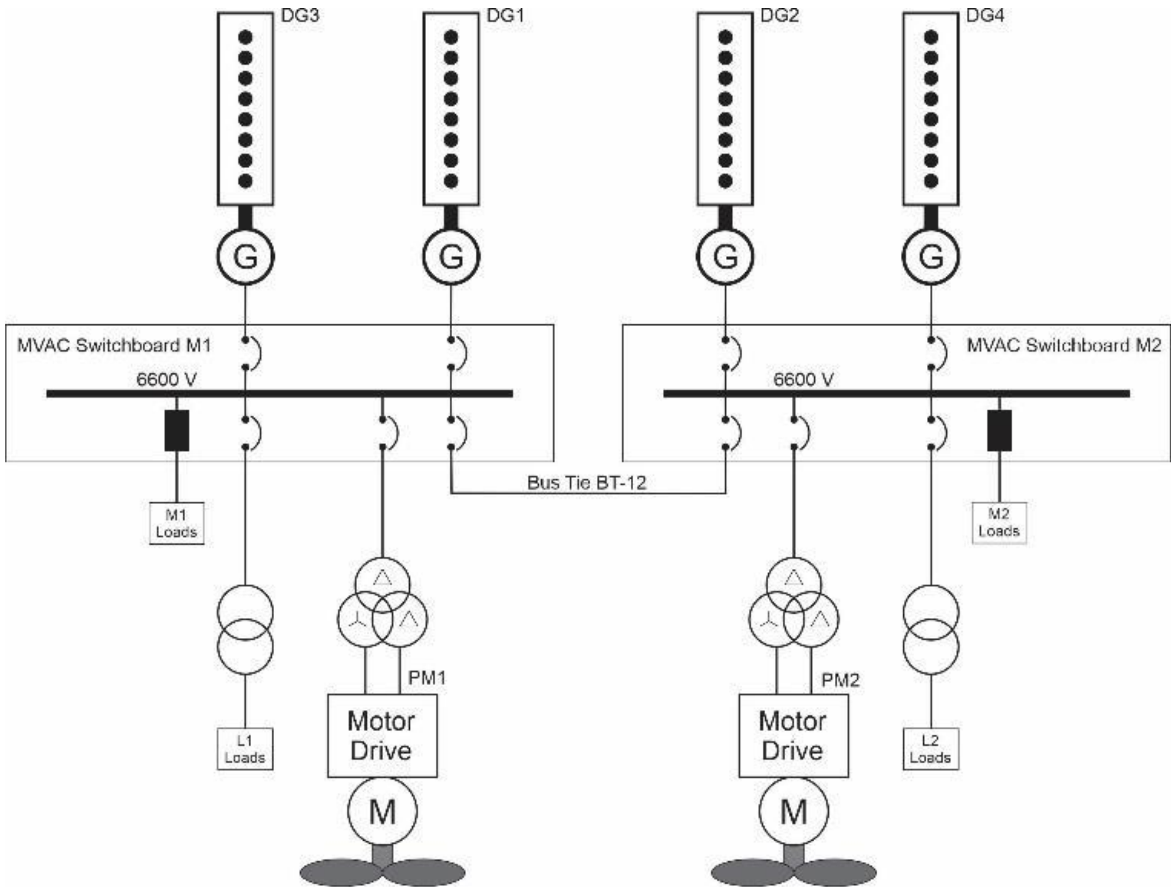


TABLE I: EQUIPMENT POWER RATING

Equipment	Power Rating (MW)
DG1, DG2, DG3, and DG4	10
PM1 and PM2	15

TABLE II: LOAD POWER RATINGS

Operational Condition	M1 Loads (MW)	M2 Loads (MW)	L1 Loads (MW)	L2 Loads (MW)
Inport Summer	2.0	2.3	1.8 + 0.3	1.6 + 0.3
Inport Winter	1.9	2.3	2.5+ 0.3	2.8 + 0.3
Cruise Summer	1.1	1.1	2.1 + 0.2	1.9 + 0.2
Cruise Winter	1.0	1.1	3.5 + 0.2	3.3 + 0.2
Functional Summer	1.5	1.2	2.1 + 0.4	1.9 + 0.4
Functional Winter	1.5	1.0	3.5 + 0.4	3.0 + 0.4

Limiting Load Flow Example (BT-12)

- Most Conservative: Ignore loads – Sum the capacity of all online generation connected to the cable.
  - 4 x 10 MW = 40 MW
- Less Conservative: Ignore loads – compare generation capacity on each end of cable and use the larger.
  - 2 x 10 MW = 20 MW
- Least Conservative: Compare the loads connected on one end of the cable and compare to generation on the other end, use the smaller as the limiting load flow in that direction. Use the larger of the limiting load flows of the two directions.
- Compare to Load Flow Analysis for 24 different simulations
  - Maximum power flow of 16 MW

TABLE III: LIMITEING LOAD FLOW BUS TIE BT-12 CALCULATIONS

	M1 to M2 (MW)	M2 to M1 (MW)
Sources	10 + 10 = 20	10 + 10 = 20
Propulsion	15	15
Worst Case Loads Operational Condition	Cruise Winter	Functional Winter
MVAC Loads	1.1	1.5
LVAC Loads	3.3 + 0.2 =3.5	3.5 + 0.4 = 3.9
Total Loads	15 + 1.1 + 3.5 = 19.6	15 + 1.5 + 3.9 = 20.4
Smaller of Sources and Total Loads	19.6	20
Limiting Load Flow		20

Summary

- Limiting Load Flow method useful in early stages of design when sufficient detail for a detailed load flow analysis does not exist.
- Load Flow method useful in later stages of design when sufficient detail about the power system, loads, and concepts of operation exist.