MVDC Grounding and Common Mode Current Control

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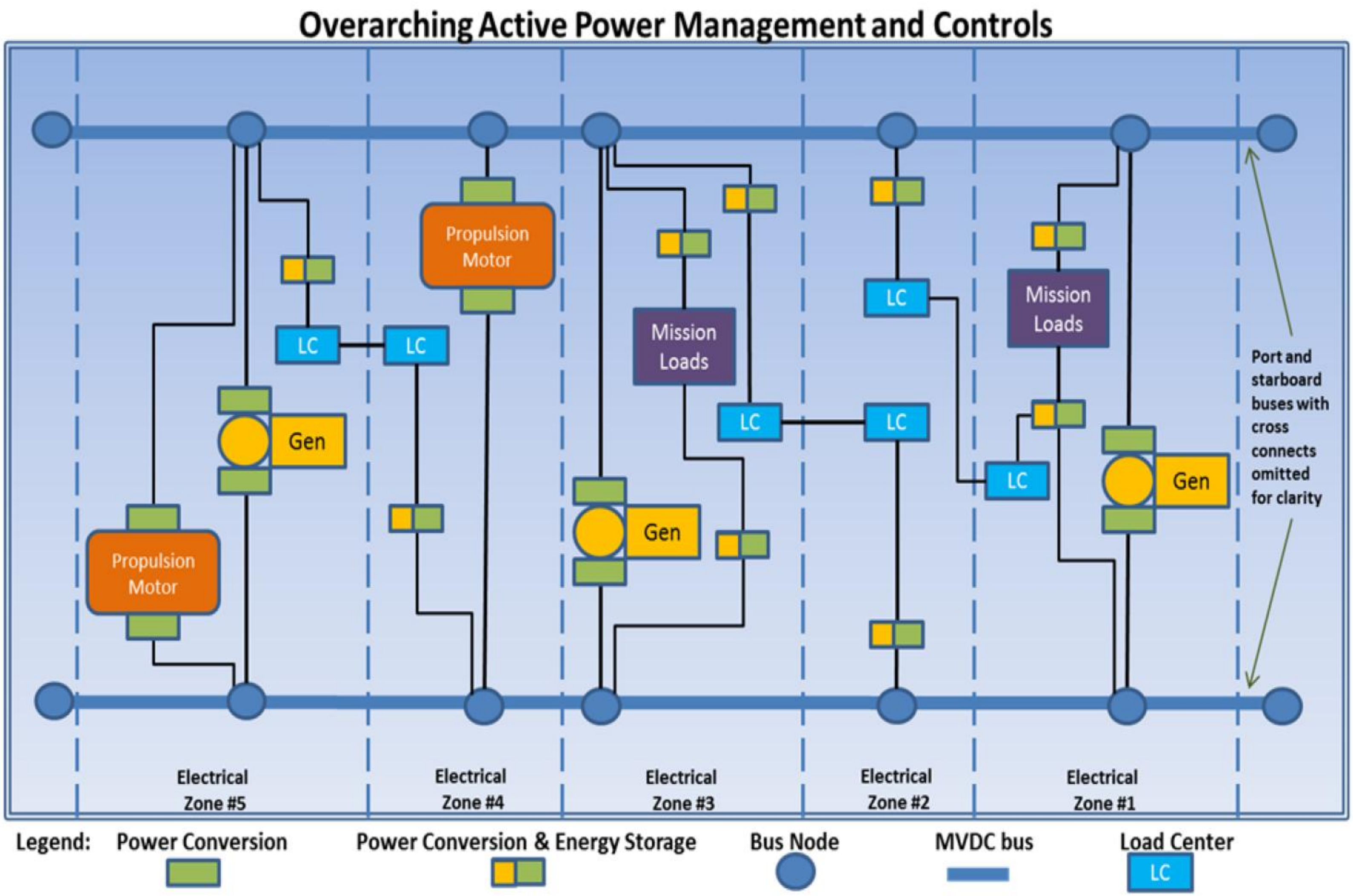
MVDC Reference Architecture



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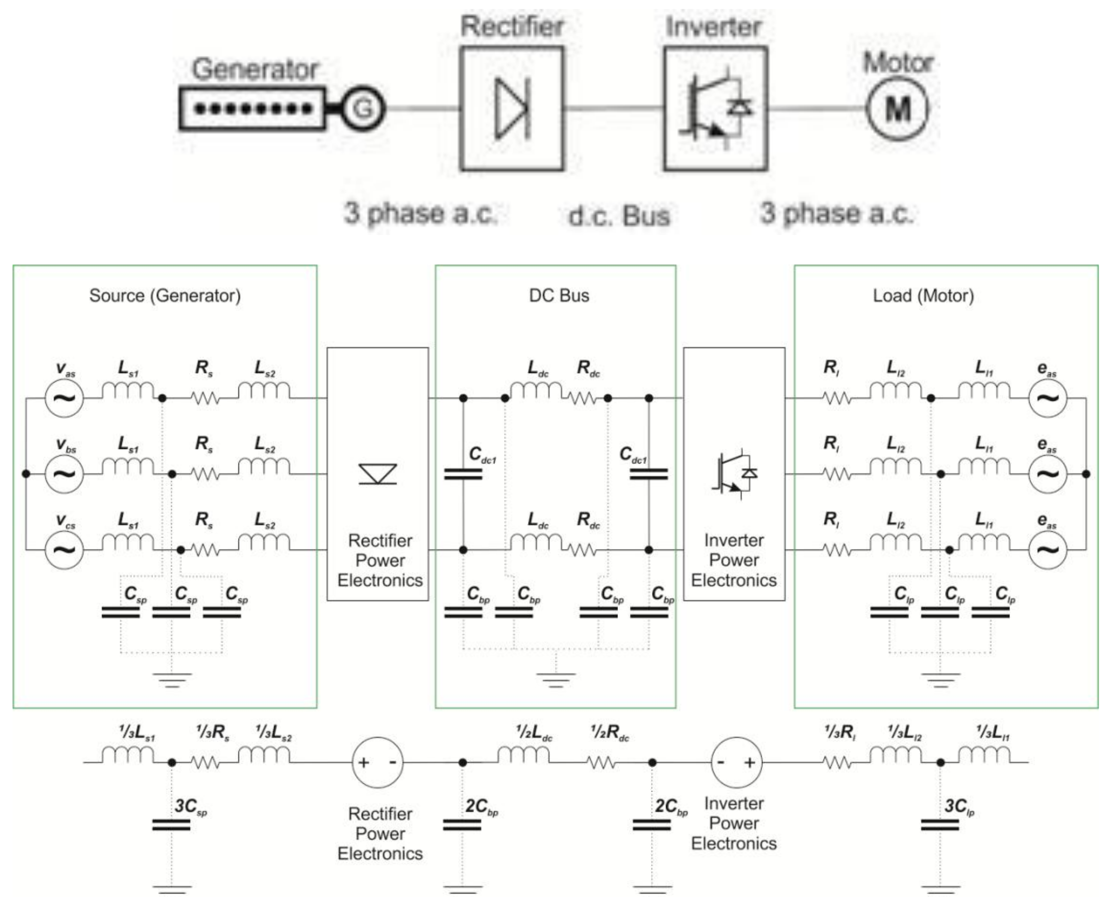
Introduction to Common Mode

- Common mode currents are also called leakage current: the return path of common mode currents is typically through the ship's hull.
- Common mode currents flow through the hull due to a.c. voltages of a power systems neutral with respect to the hull potential interacting with parasitic capacitances.
  - The neutral voltage with respect to ground is the instantaneous average of all the power system conductor voltages with respect to ground.
- The difference in power system neutral voltages between the input and the output of a power electronics based converter is the dominant source of common mode current.
- Common mode impedances are a function of frequency.
- Common mode currents can result in safety hazards and corrosion.
- Common mode currents can be a source of Electromagnetic Interference (EMI)
- Common mode currents are impacted by the grounding method.

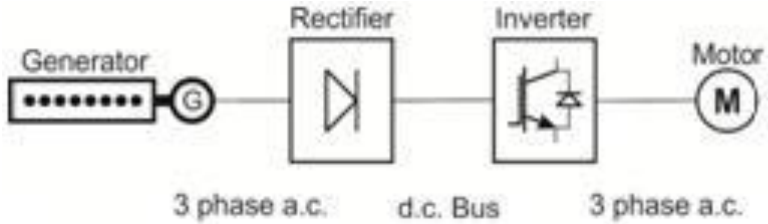
Simplified Model

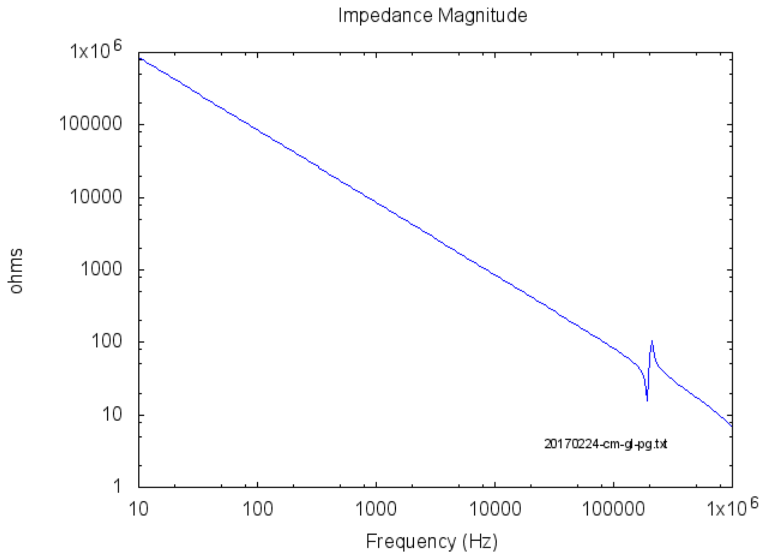
- Common Mode model derived from 3 phase model
- Eliminates components that only impact normal “Differential Mode”
- Combines paralleled components.
- Based on method described by Brovont and Pekarek presented at ESTS 2015

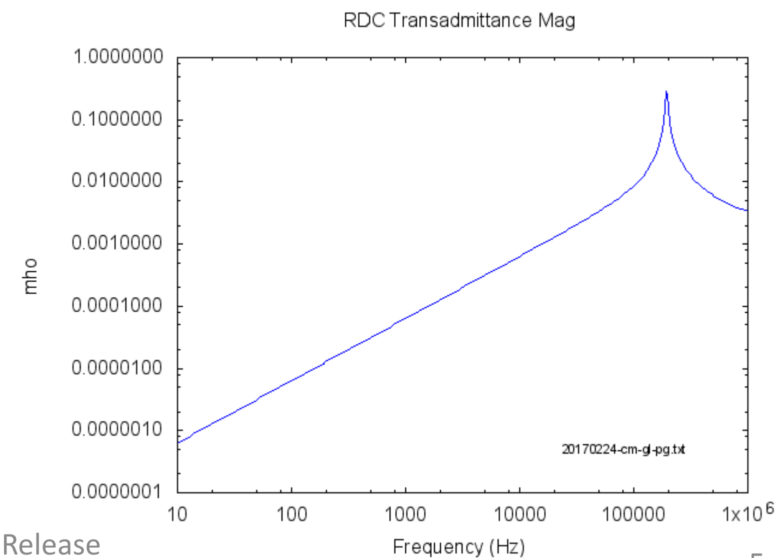


Metrics of Interest

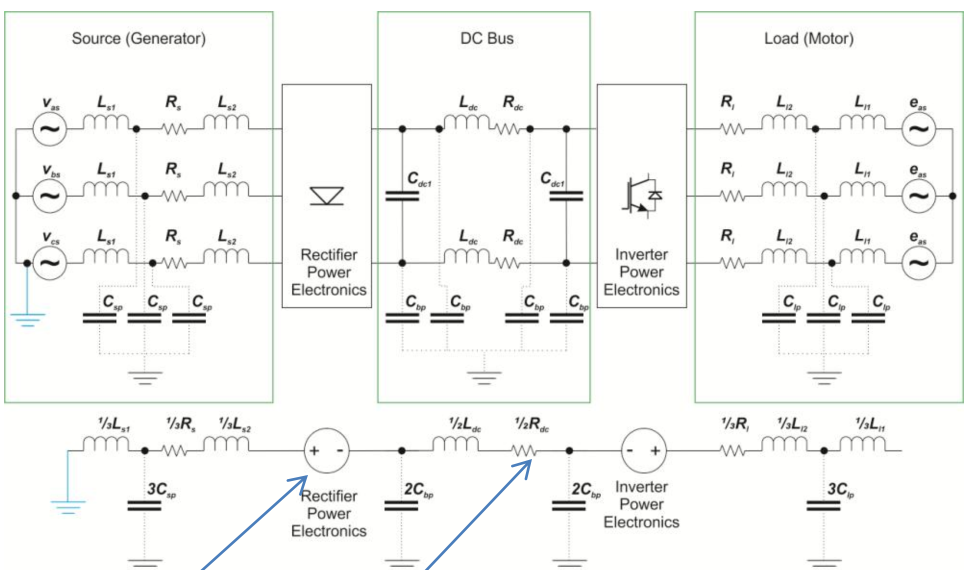
- Magnitude of common mode impedance seen by a common mode source as a function of frequency
  - Indicator of common mode currents local to equipment
- Magnitude of common mode “transadmittance” as a function of frequency
  - Ratio of common mode current in the distribution feeder (d.c. bus) to the common mode voltage
  - Measures how well common mode current is contained to the vicinity of the equipment.
- Design Objectives:
  - Prefer to have common mode currents depend on design variables and not hard to predict parasitic values
  - Minimizing transadmittance at frequencies of interest is of higher priority than maximizing common mode impedance
  - Need to keep common mode impedance high enough to limit common mode current local to the equipment.

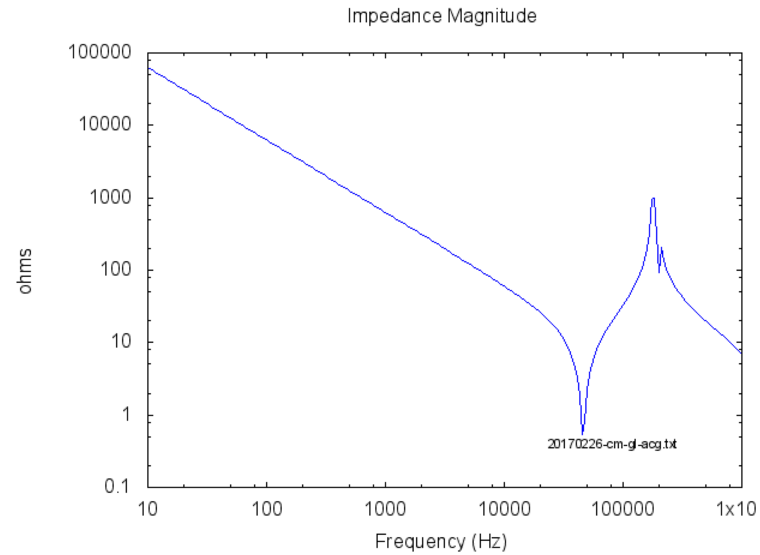


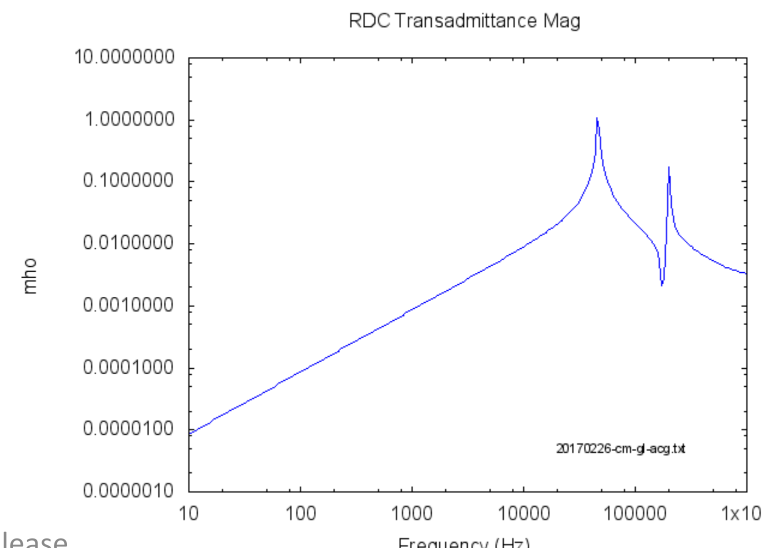




A.C. Side Hard Grounding



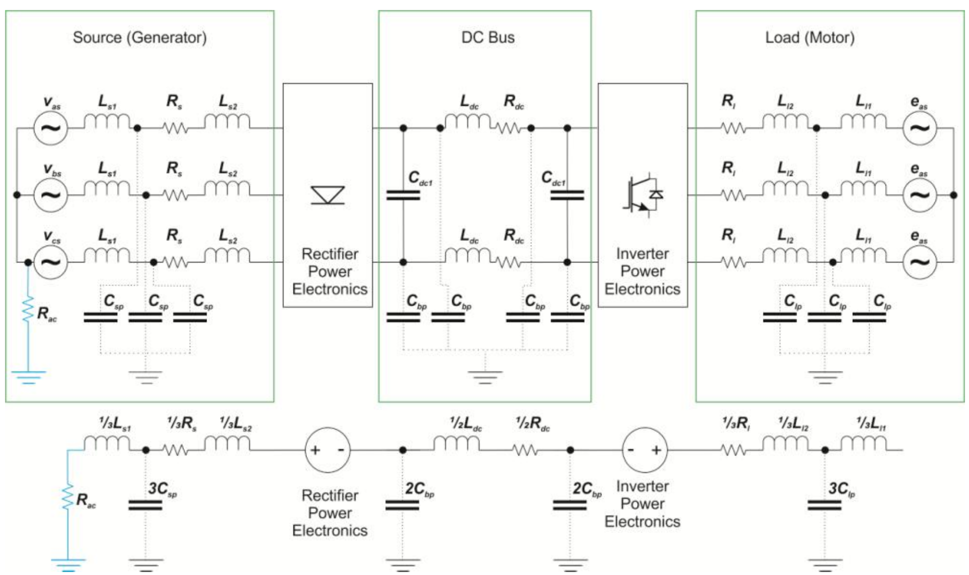


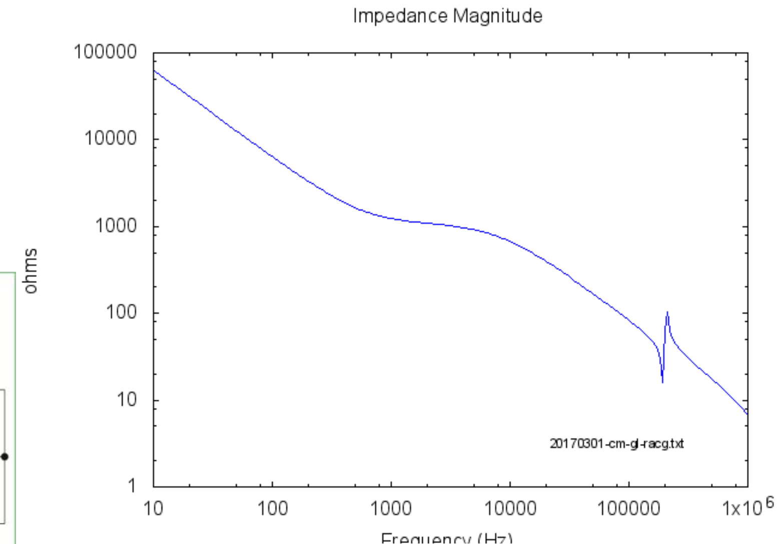


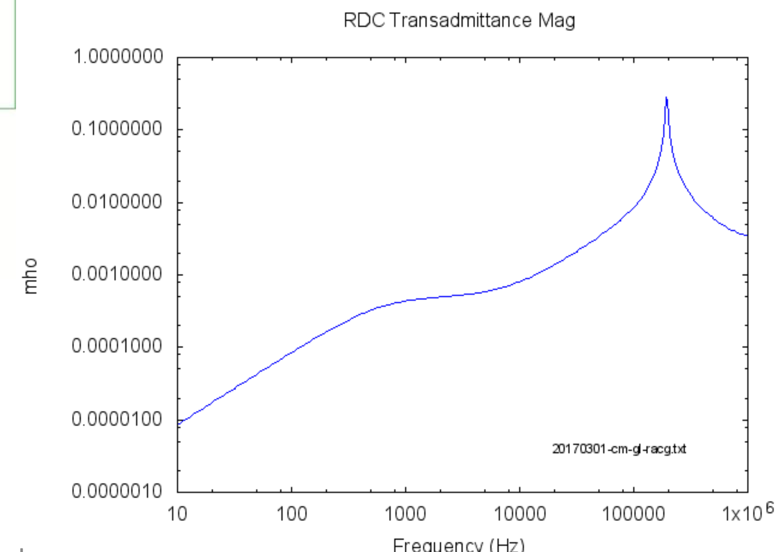
Impedance: common mode voltage associated with Rectifier Power Electronics divided by the common mode current through the Rectifier Power Electronics.

Transadmittance: common mode current through the DC bus divided by the common mode voltage associated with Rectifier Power Electronics.

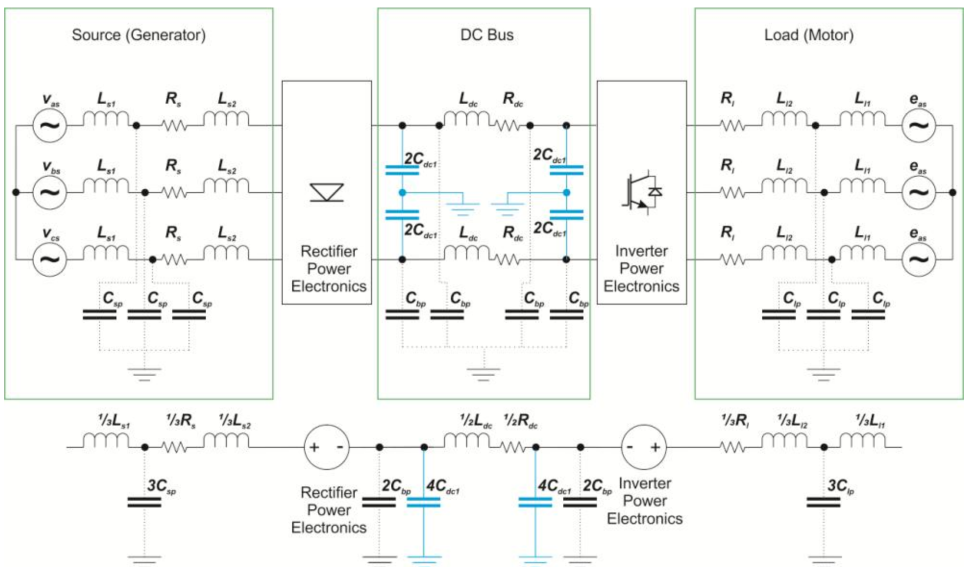
A.C. Side High Resistance Grounding

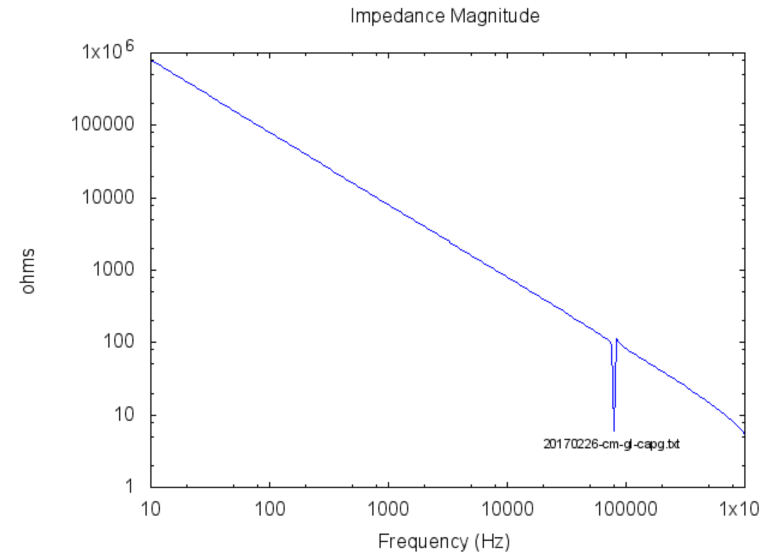


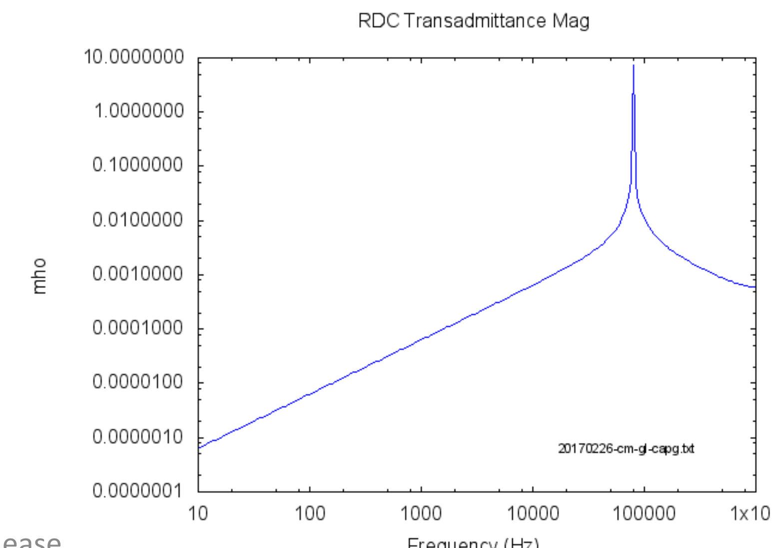




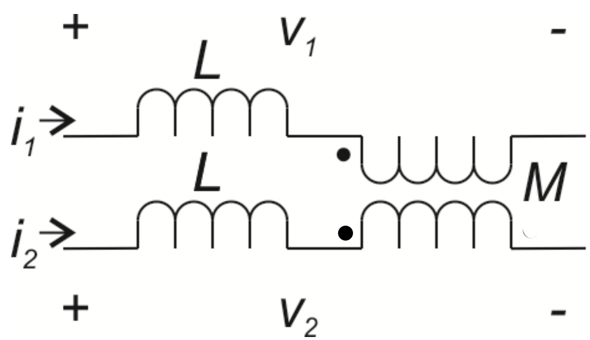
D.C. Side shunt capacitors







D.C. Side Choke



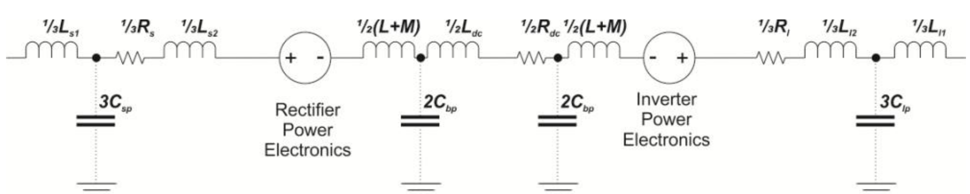
$L \approx M$

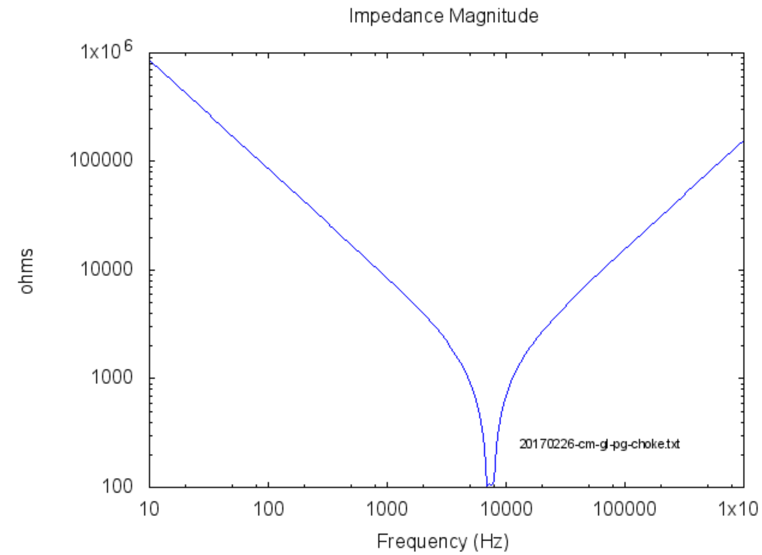
$i_{1cm} = i_{2cm}$

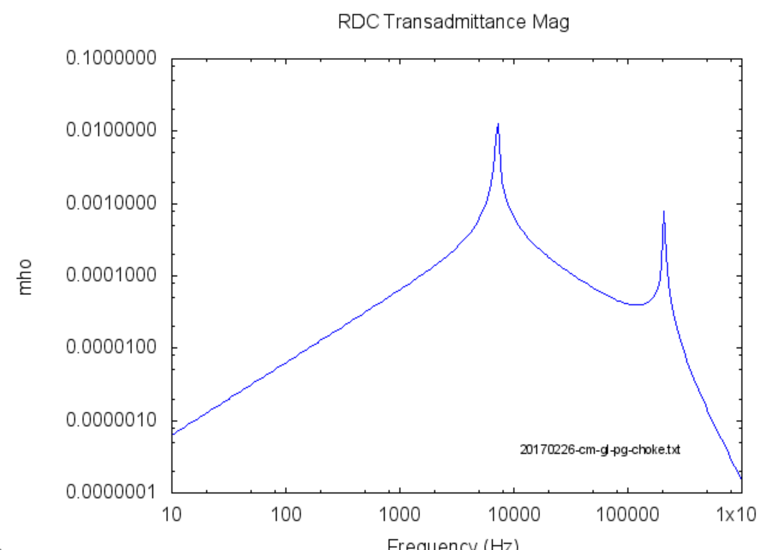
$i_{1dm} = -i_{2dm}$

$$v_1 = L\frac{di_1}{dt} + M\frac{di_2}{dt}$$

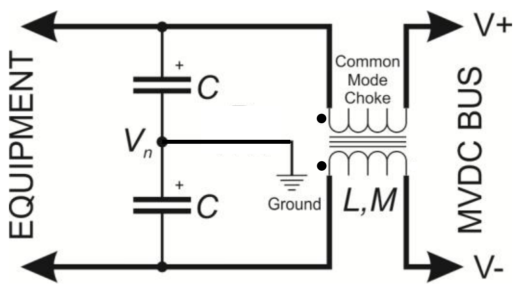
$$v_2 = L\frac{di_2}{dt} + M\frac{di_1}{dt}$$

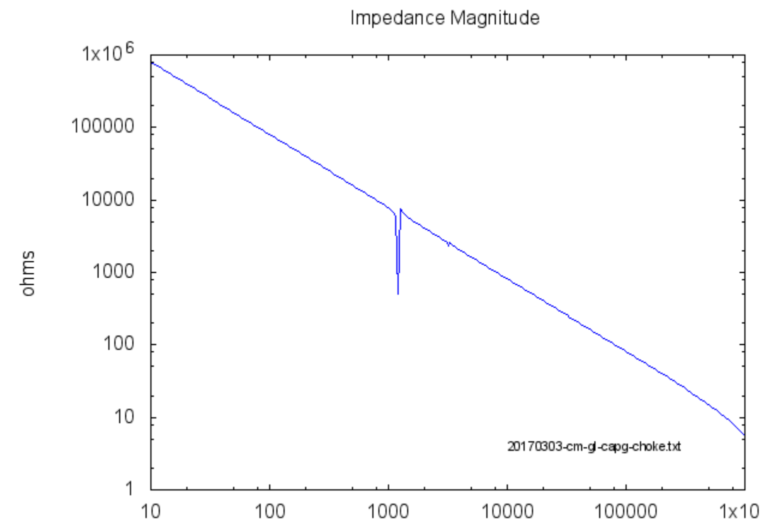


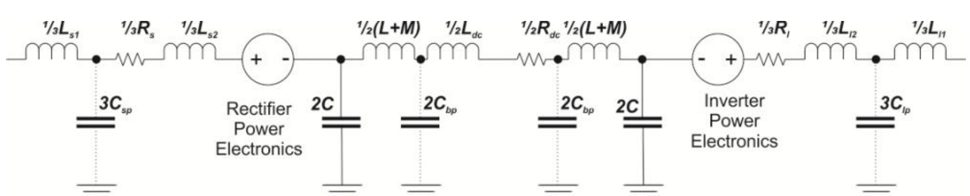


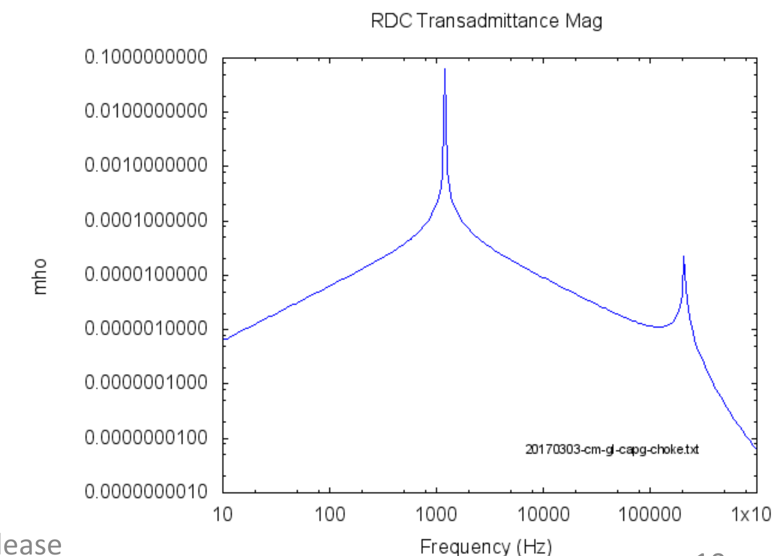


Choke and Shunt Capacitors

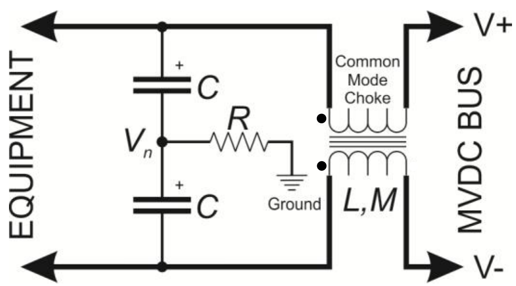


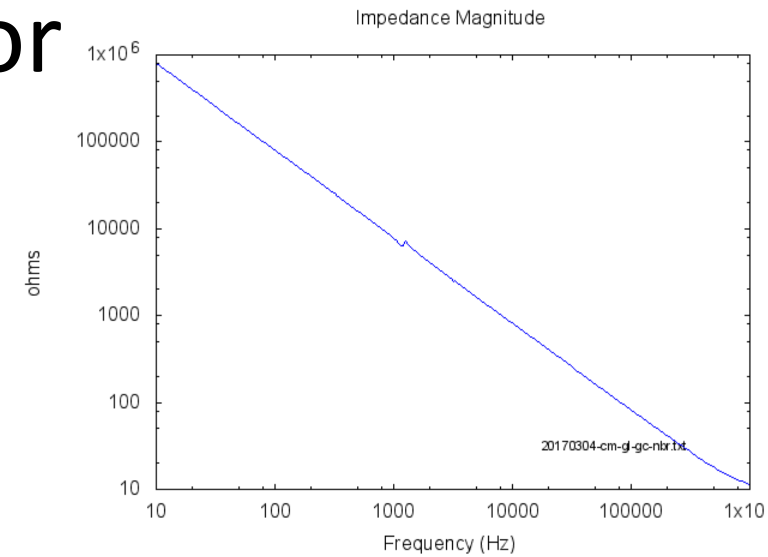


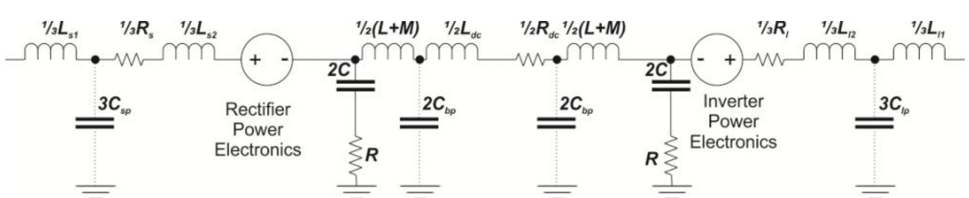


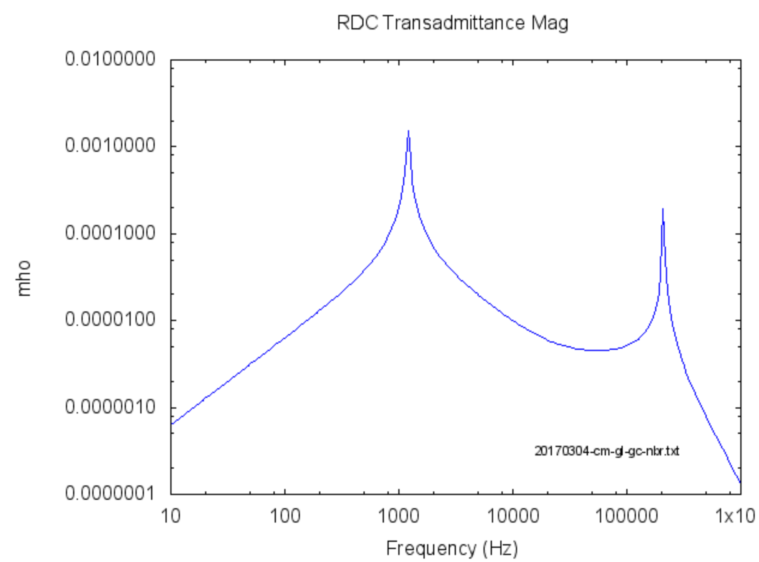


Choke, Shunt Capacitors, and Damping Resistor

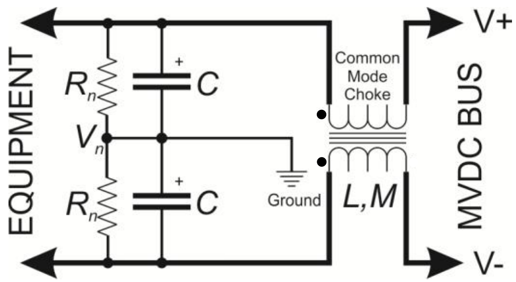


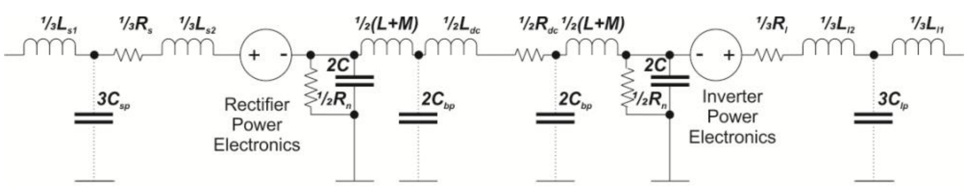


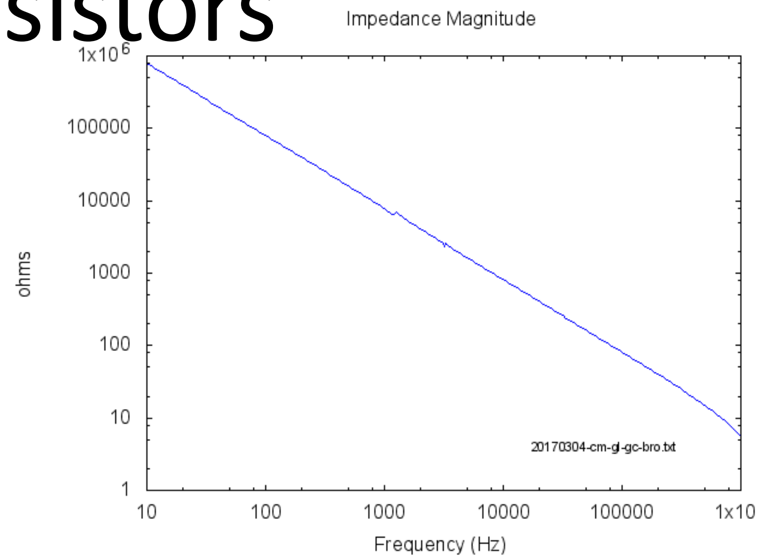


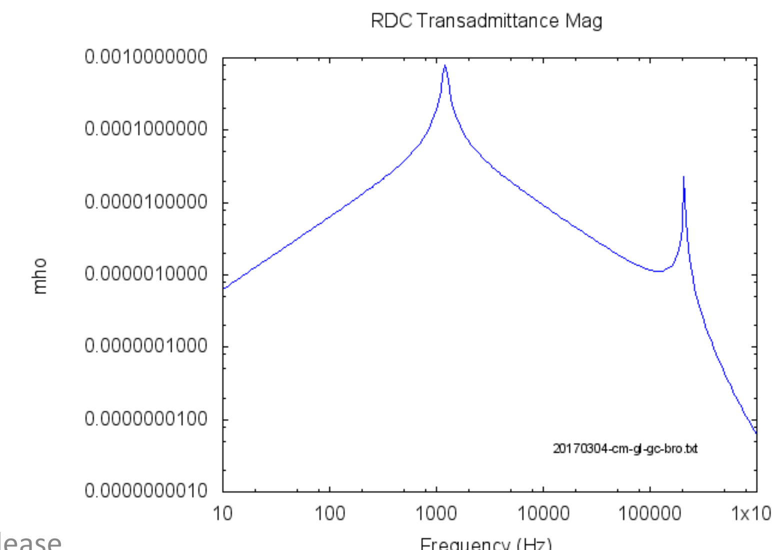


Choke, Shunt Capacitors, and Balancing Resistors

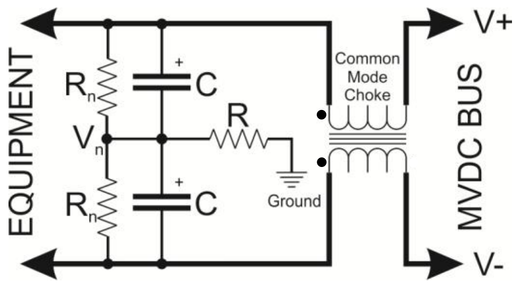


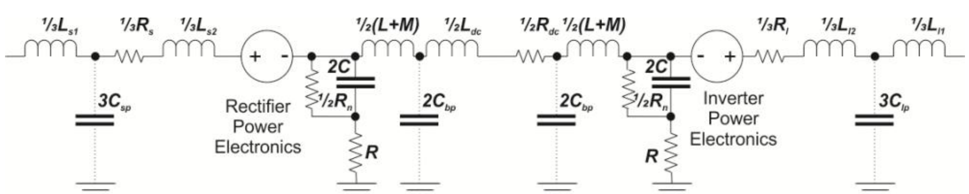


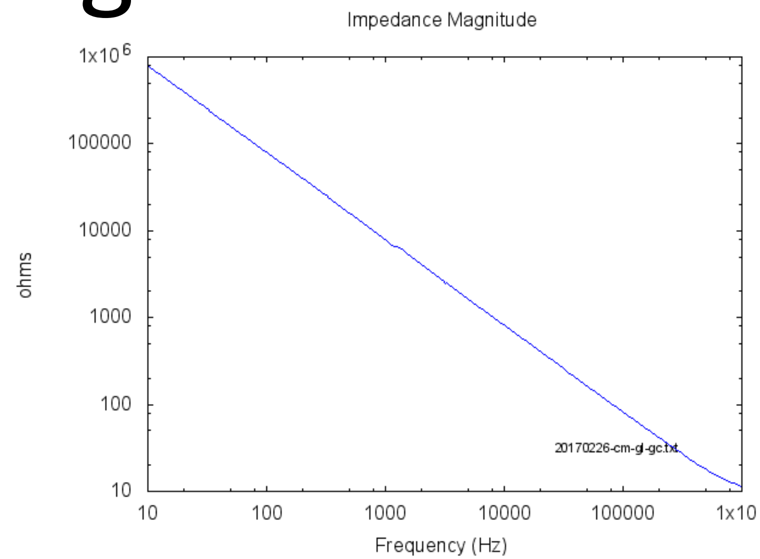


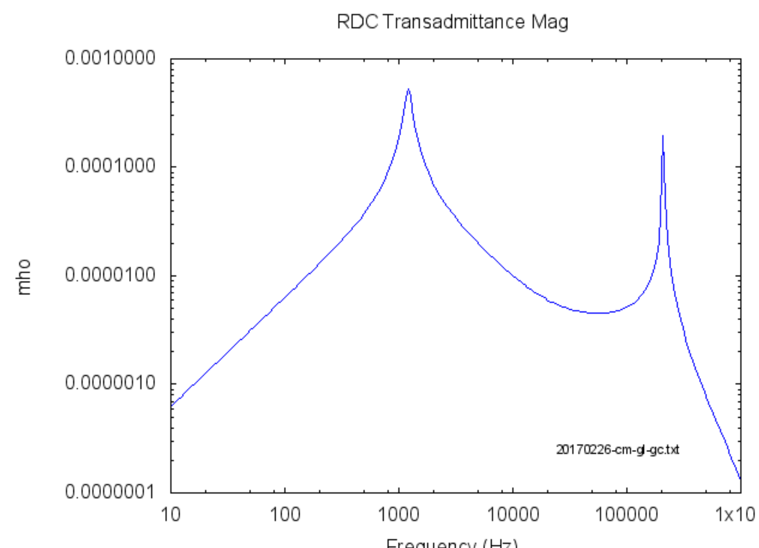


Everything

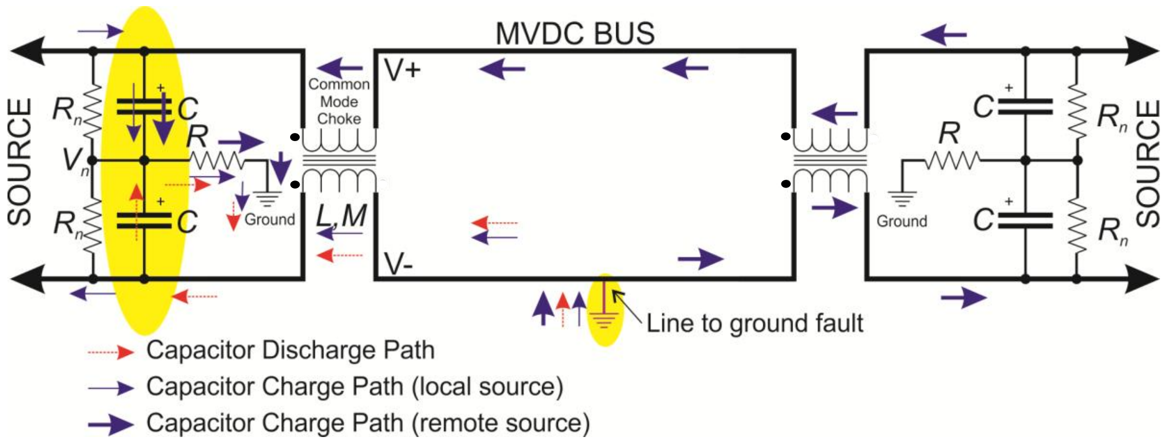

EQUIPMENT
R n
V n
R n
C
C
R
Ground
Common
Mode
Choke
MVDC BUS
V+
V-

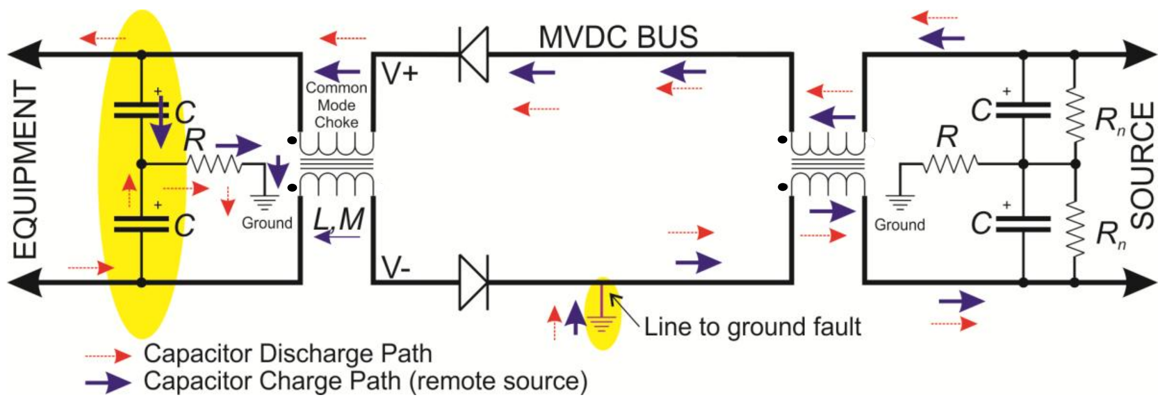

⅓L s1
⅓R s
⅓L s2
Rectifier
Power
Electronics
2C
½R n
R
3C sp
½(L+M)
½L dc
2C bp
½R dc
½(L+M)
2C bp
2C
½R n
R
Inverter
Power
Electronics
⅓R i
⅓L i2
⅓L i1
3C ip


Impedance Magnitude
ohms
1x10^6
100000
10000
1000
100
10
10
100
1000
10000
100000
1x10^6
Frequency (Hz)
20170226-cm-gl-gc.txt


RDC Transadmittance Mag
mho
0.0010000
0.0001000
0.0000100
0.0000010
0.0000001
10
100
1000
10000
100000
1x10^6
Frequency (Hz)
20170226-cm-gl-gc.txt

Impact of Line to Ground Fault on Common Mode Current





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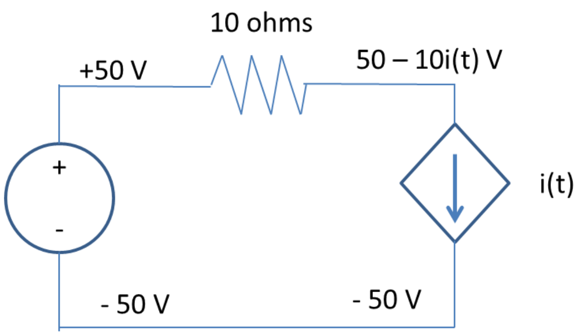
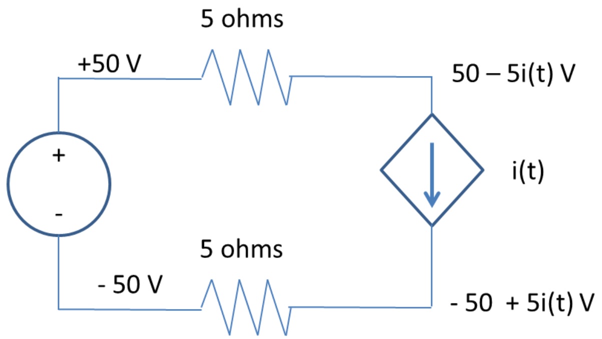
Reduce Common Mode Voltage

- Provide Symmetry
- Design power electronic gating algorithms to minimize common mode voltages
- Design rotating machines and associated power electronics synergistically to minimize common mode voltages
  - Consider two 3-phase systems 180 electrical degrees apart
  - Independently drive windings





Summary

- Control of Common Mode Currents must be accomplished both at the total system level and at the module level.
- Need to develop common mode models
- Common mode impedance and transadmittance are good metrics to help characterize common mode performance
- Need to consider impact of ground faults
- Need to consider methods of reducing common mode voltages