MVDC Distribution Systems

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Setting the Scene

"In FY2030, the DON plans to start building an affordable follow-on, multi-mission, mid-sized future surface combatant to replace the Flight IIA DDG 51s that will begin reaching their ESLs [Estimated Service Life] in FY2040."

Report to Congress on the Annual Long-Range Plan for Construction of Naval Vessels for FY2015

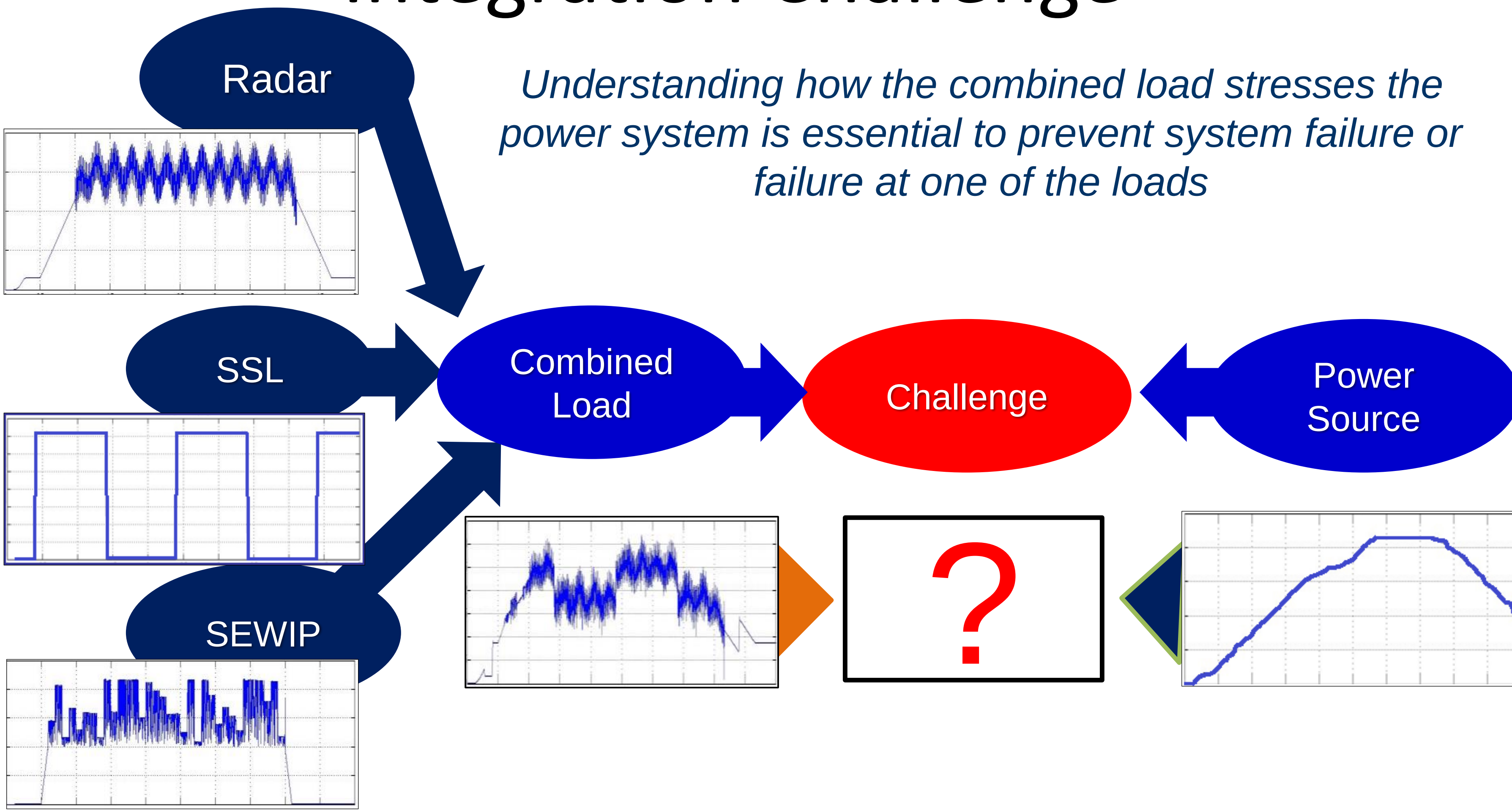
Big differences from DDG 51:

- High-energy weapons and sensors
- Flexibility for affordable capability updates

Photo by CAPT Robert Lang, USN (Ret), from site http://www.public.navy.mil/surfor/swmag/Pages/2014-SNA-Photo-Contest-Winners.aspx

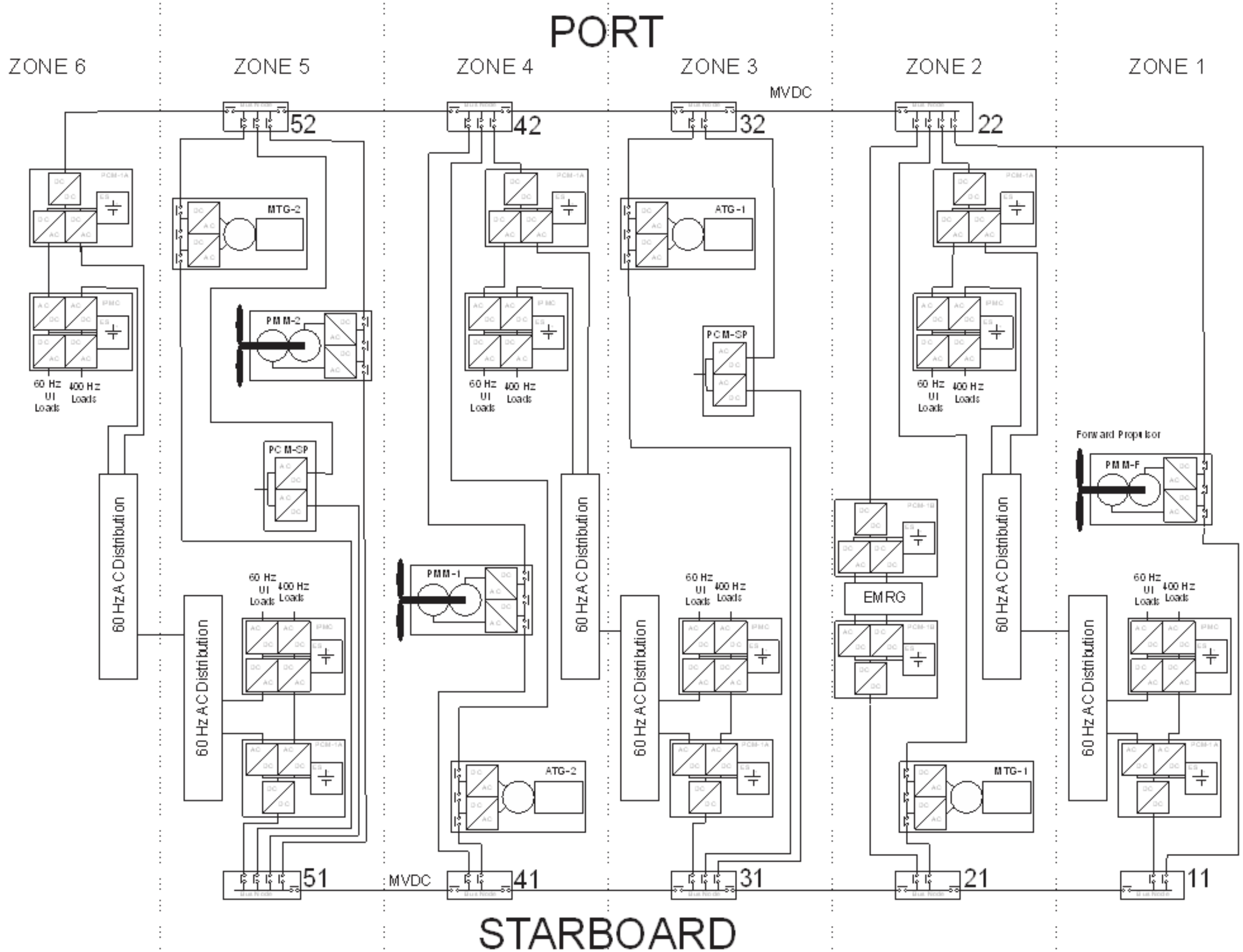
High Energy Mission Systems Integration Challenge

Understanding how the combined load stresses the power system is essential to prevent system failure or failure at one of the loads



Ships cannot support High Power Systems without modifications to the ship's Electric Power System and other ship systems

MVDC Reference Architecture



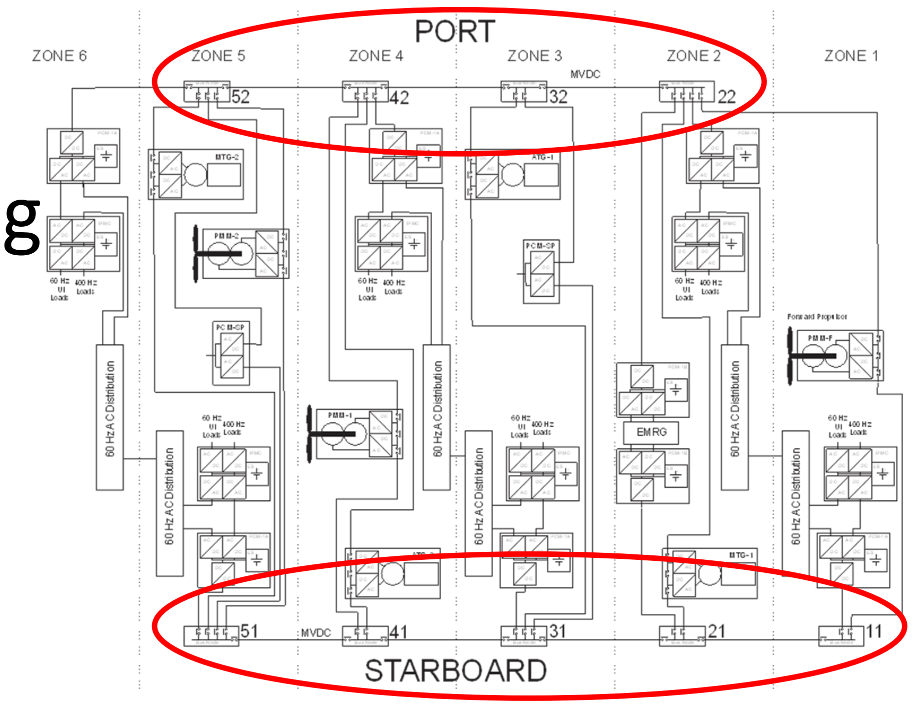
Topics

- Electrical Power System Concept of Operations (*)
- **MVDC Bus Capacity**
- **Cable and Bus Duct**
- **Cable Shielding**
- Voltage Regulation and Bus Stability (*)
- Dual Output Generators (*)
- **Creepage and Clearance**

(*) Discussed in paper, but not in this presentation

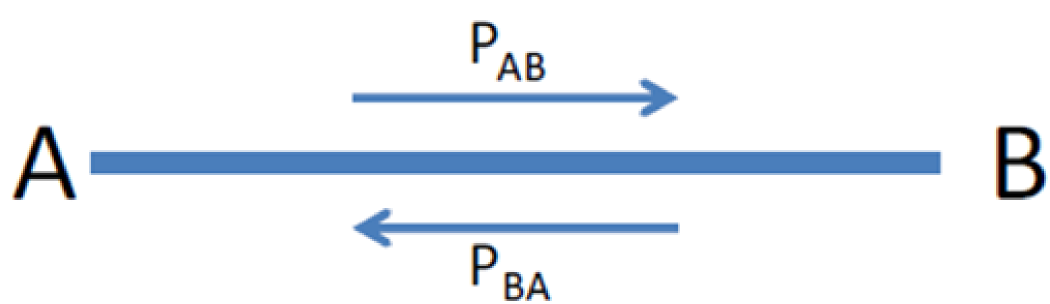
MVDC Bus Capacity

- Determining bus segment required capacity is challenging
  - Depends on source and load configurations
- Details Generally not available in early stage design



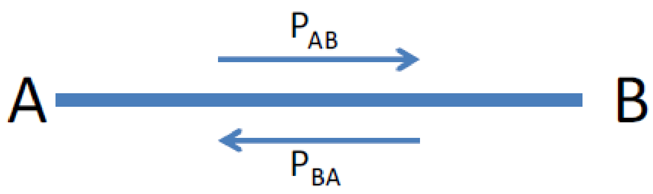
Determining MVDC bus capacity

- Total Generation
  - Sum of rated current of all PGMs that can connect to the bus
  - Very conservative
  - Very easy to calculate
  - No information on loads required
- Longitudinal Distribution of Generation
  - For each segment, the larger of the sum of generation on each end of the segment
  - Still conservative
  - Very conservative in end zones
  - No information on loads required



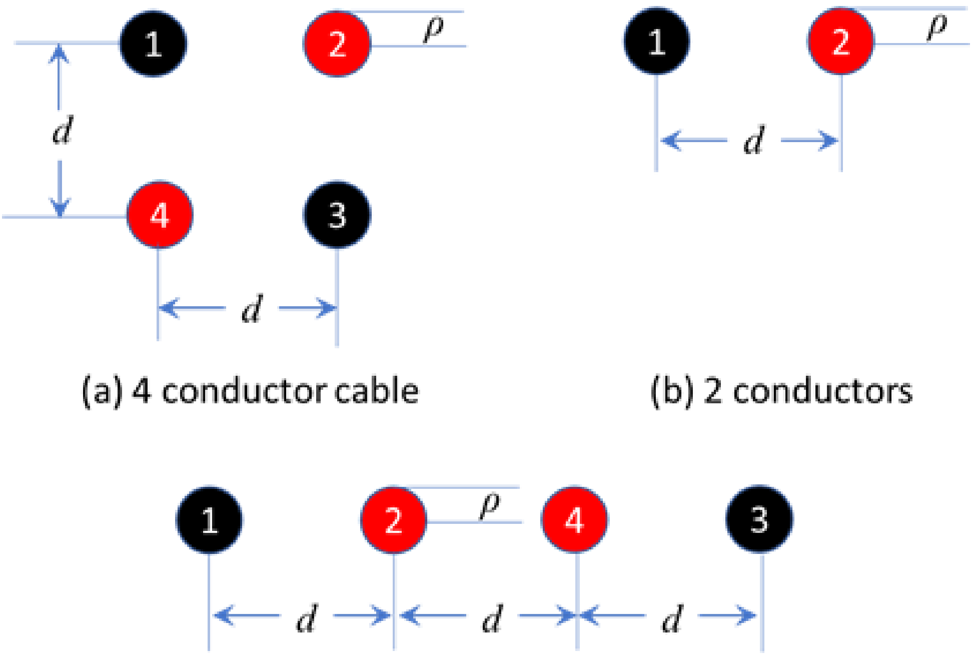
Determining MVDC bus capacity (continued)

- Limiting Load Flow
  - For each segment, calculate the maximum current flow that could occur in each direction, then use the bigger.
    - Take smaller of Generation forward and Load Aft
    - Take smaller of Generation aft and load Forward
    - Take the larger of the two
  - Load values should be the maximum value of the load aggregation for sizing the power system equipment (zonal load factors for example)
  - Still conservative, but does not require detailed knowledge of loads
- Load Flow
  - For each segment, calculate the maximum current flow for all possible load and generation configurations.
  - Very computational sensitive – worst case configuration rarely obvious.
  - Requires considerable modeling of correlated loads
  - Provides least conservative results.



Cables and Bus Duct

- Need to control magnetic fields
  - Magnetic Signature
  - Residual Fields

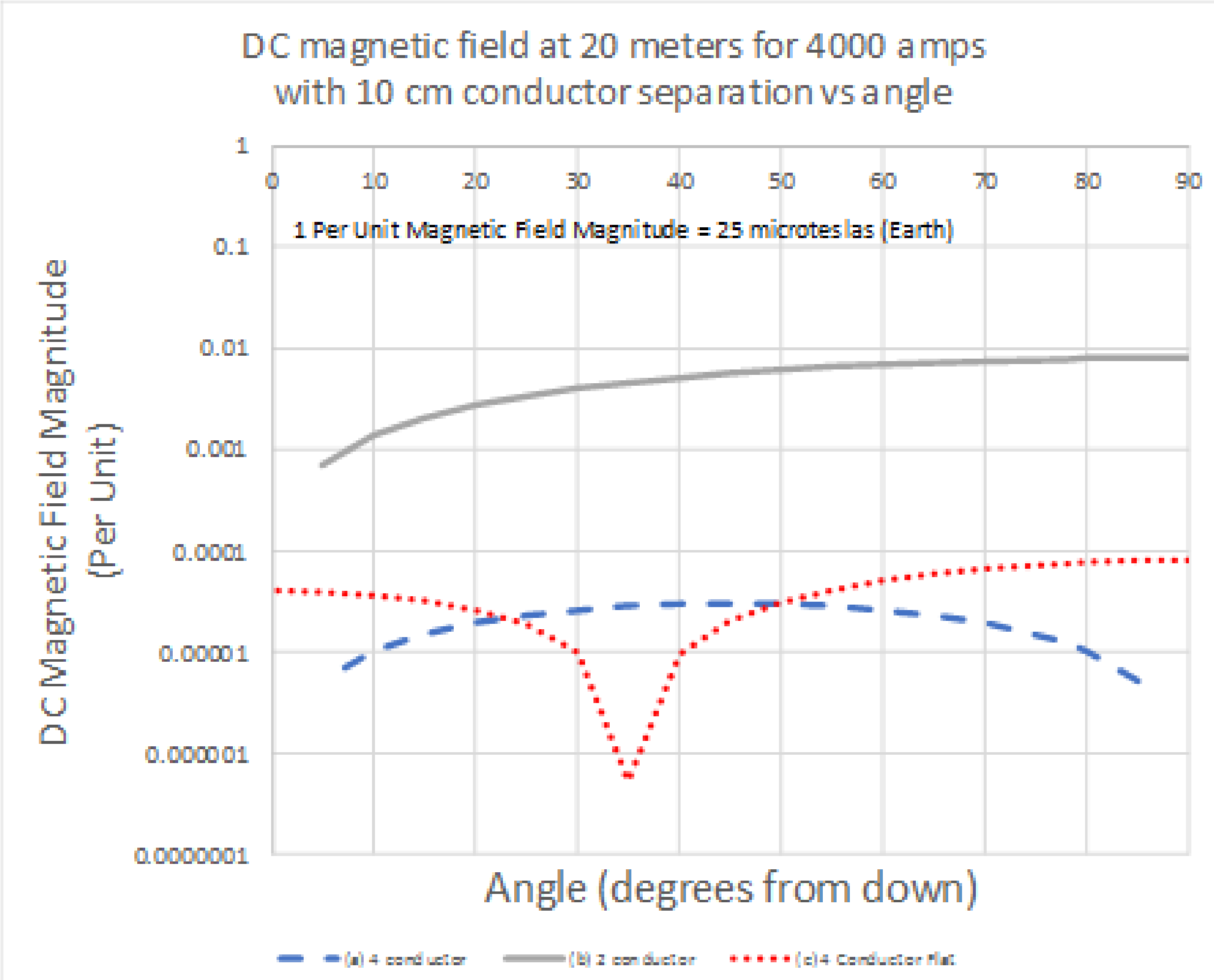


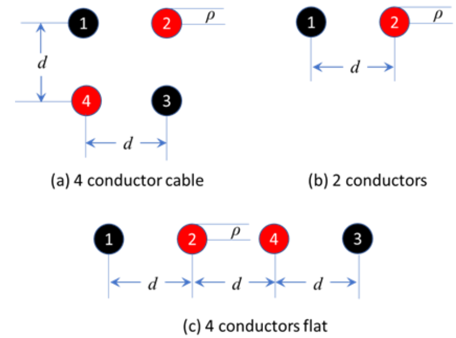
(a) 4 conductor cable

(b) 2 conductors

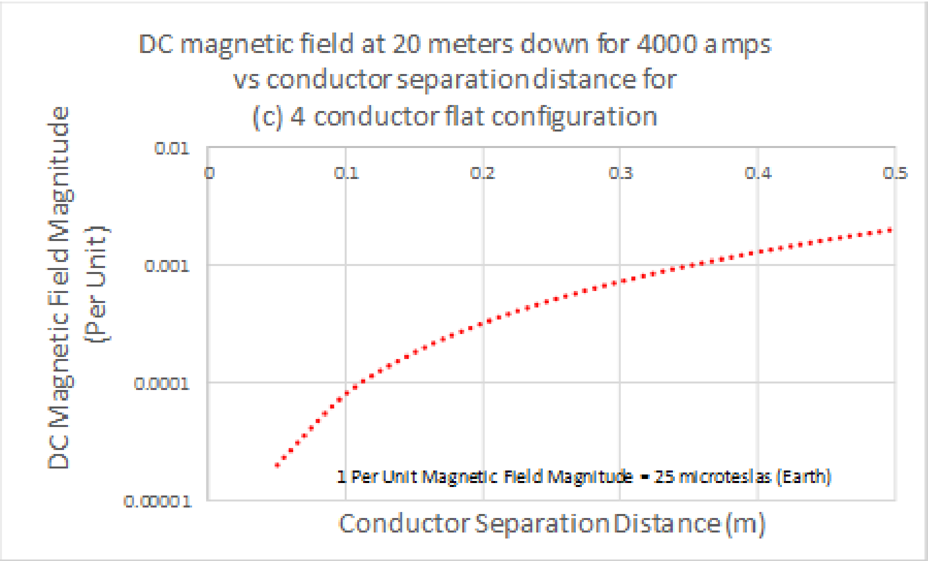
(c) 4 conductors flat

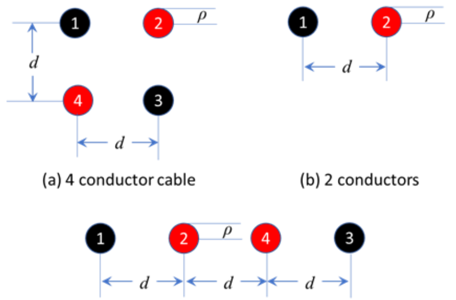
Magnetic Signature

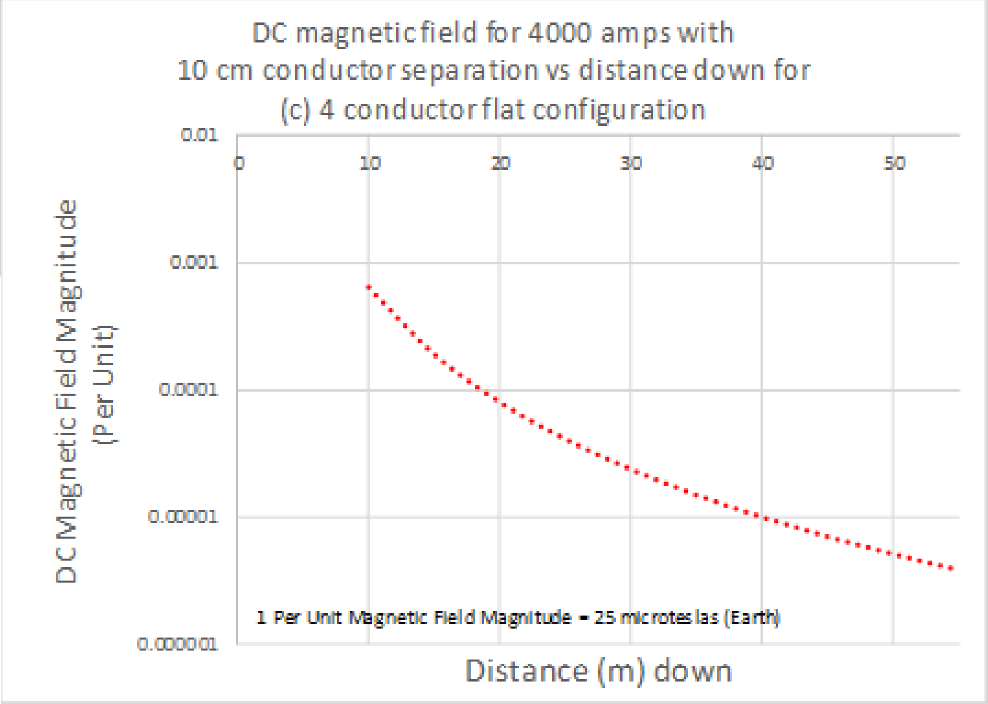




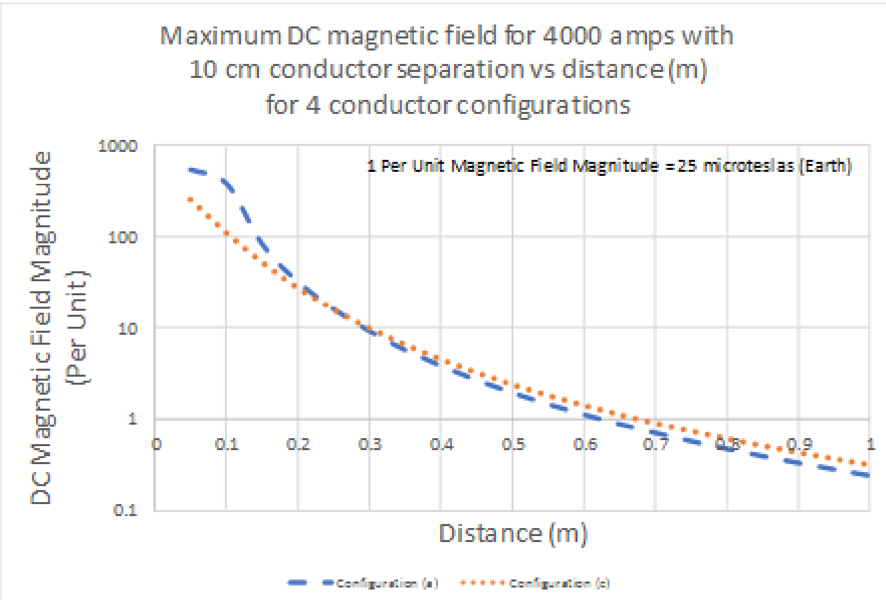
Magnetic Signature (Continued)

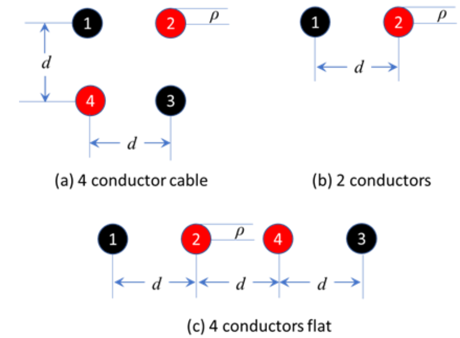


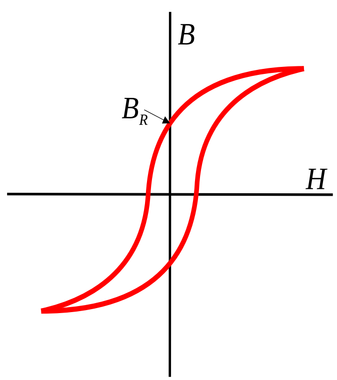


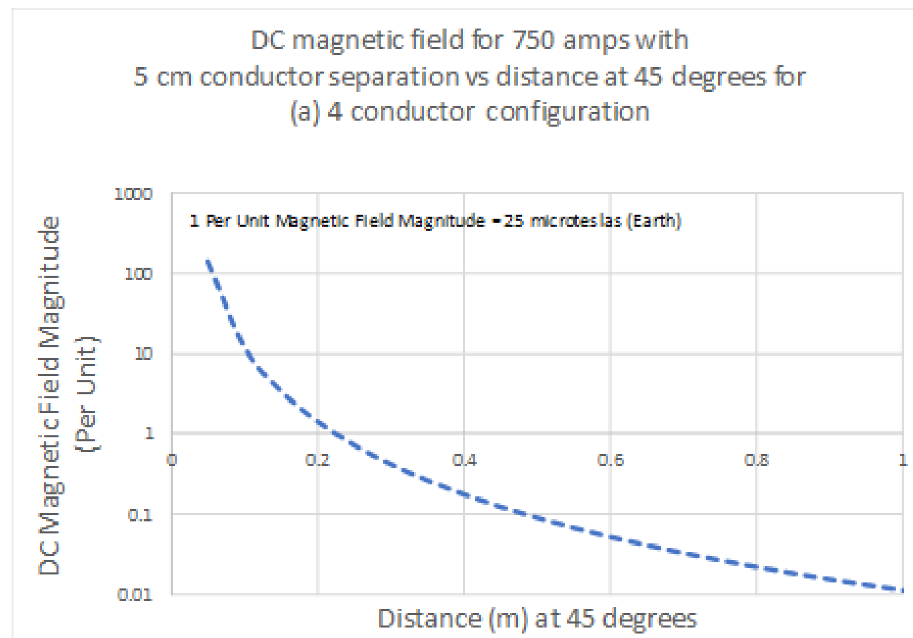


Residual Magnetism

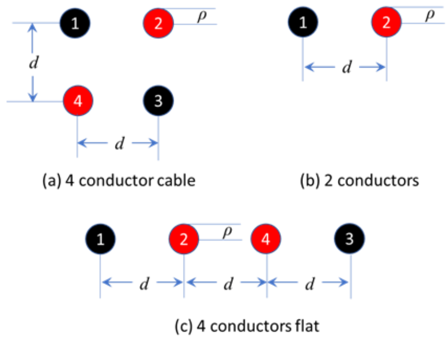


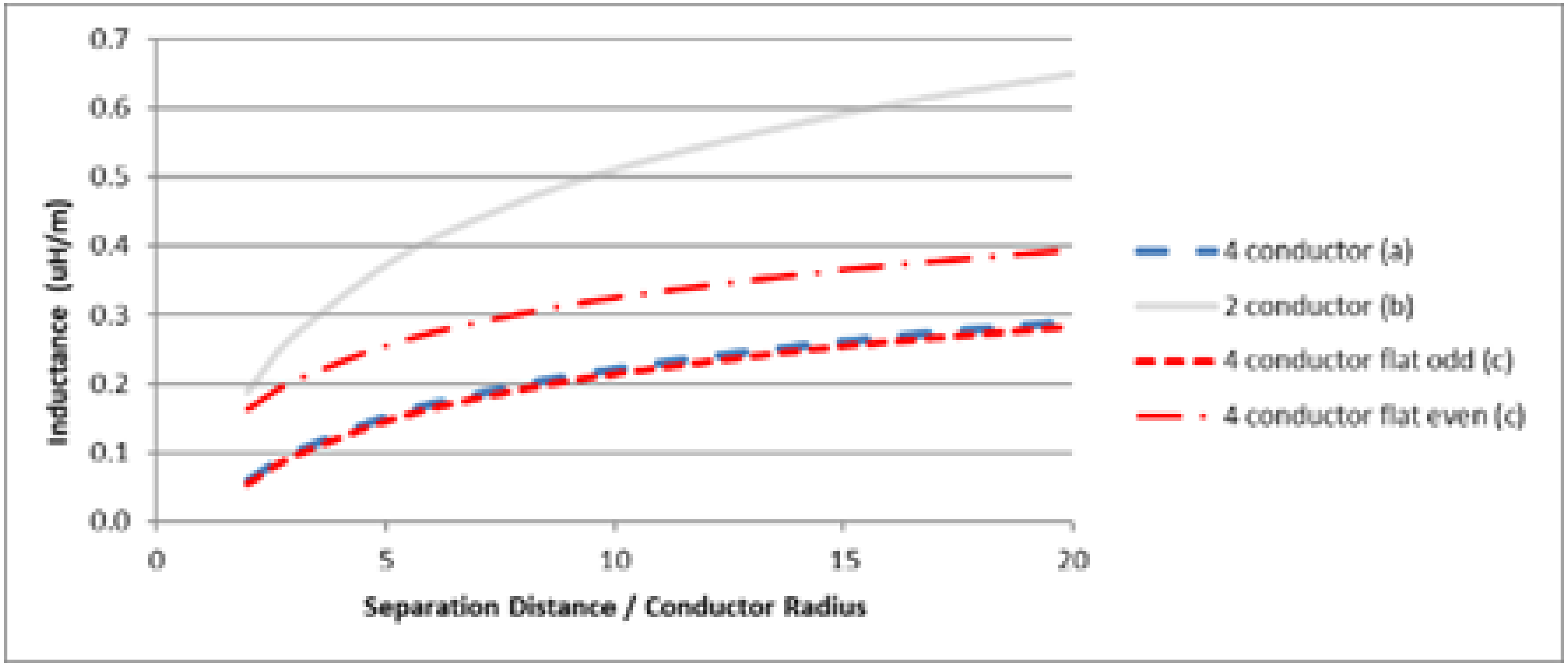






Cable Inductance





Cable Shielding

- Individual conductor shields
  - Ground at one end
  - Electric Field Control
- Overall Cable conductor
  - Ground at both ends
  - Path for common-mode current

Creepage and Clearance Definitions

- Creepage distance along the surface of an insulating material is the shortest distance between uninsulated energized parts or between an uninsulated energized part and ground.
- Clearance distance is the shortest point-to-point distance in air between uninsulated energized parts or between an uninsulated energized part and ground.

Creepage and Clearance Issue

- Dielectric strength of air is about 3 kV/mm.
  - Cannot use 3 kV/mm directly
    - Voltage spikes
    - Humidity
    - Contamination
    - Non-uniform electric fields
- AC guidance based on empirical data
  - Safety factors on the order of 20 to 45
- DC guidance does not exist
  - Physical phenomena are different
  - Electrical environment is different

BEST SOLUTION IS TO INSULATE ALL ENERGIZED PARTS

Creepage and Clearance Interim Guidance

CLEARANCE

6 kV	72 mm
12 kV	112 mm
18 kV	153 mm

Based on AC Guidance

CREEPAGE

Main Switchboards and Generators

Voltage	Creepage Distance (mm) for CTI			
	300 V	375 V	500 V	>600 V
6 kV	113	108	99	90
12 kV	220	210	194	180
18 kV	330	315	292	270

Other high voltage equipment

Voltage	Creepage Distance (mm) for CTI			
	300 V	375 V	500 V	>600 V
6 kV	83	80	75	70
12 kV	166	160	150	140
18 kV	249	240	225	210

CTI = Comparative tracking index as defined in IEC 60112

RECOMMENDED ONLY UNTIL BETTER DATA BECOMES AVAILABLE

Summary

- Electrical Power System Concept of Operations
- **MVDC Bus Capacity**
  - **4 different methods of calculating**
- **Cable and Bus Duct**
  - **Magnet Signature**
  - **Residual Magnetic Field**
  - **Inductance**
- **Cable Shielding**
  - **Conductor shields – single end ground**
  - **Cable shield – both end grounded**
- Voltage Regulation and Bus Stability
- Dual Output Generators
- **Creepage and Clearance**
  - **Insulate as much as possible**
  - **Need better data to establish good MVDC guidance**
  - **Provided MVDC Guidance, based on AC guidance**