Functional Decomposition of a Medium Voltage DC Integrated Power System

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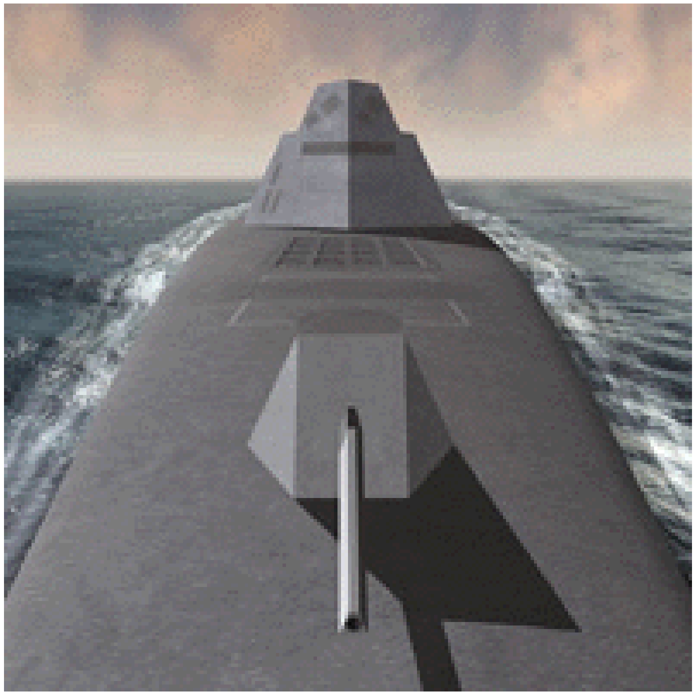
Approved for Public Release

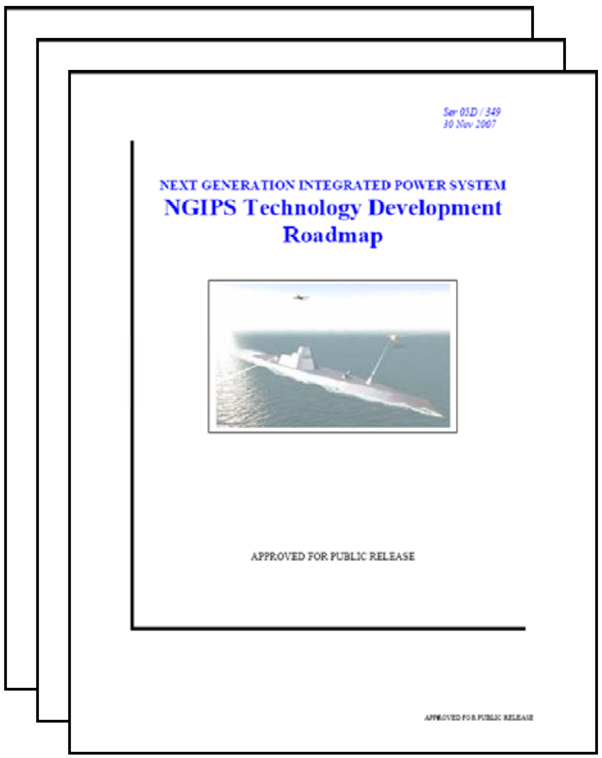
Agenda

- NGIPS Technology Development Roadmap
- Notional MVDC Architecture
- Functional Requirements
  - Power Management – Normal Conditions
  - Power Management – Quality of Service
  - Power Management – Survivability
  - System Stability
  - Fault Response
  - Power Quality
  - Maintenance Support
  - System Grounding
- Conclusions



NGIPS Technology Development Roadmap

<u>Vision</u>: To produce affordable power solutions for future surface combatants, submarines, expeditionary warfare ships, combat logistic ships, maritime prepositioning force ships, and support vessels.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NEXT GENERATION INTEGRATED POWER SYSTEM
NGIPS Technology Development Roadmap

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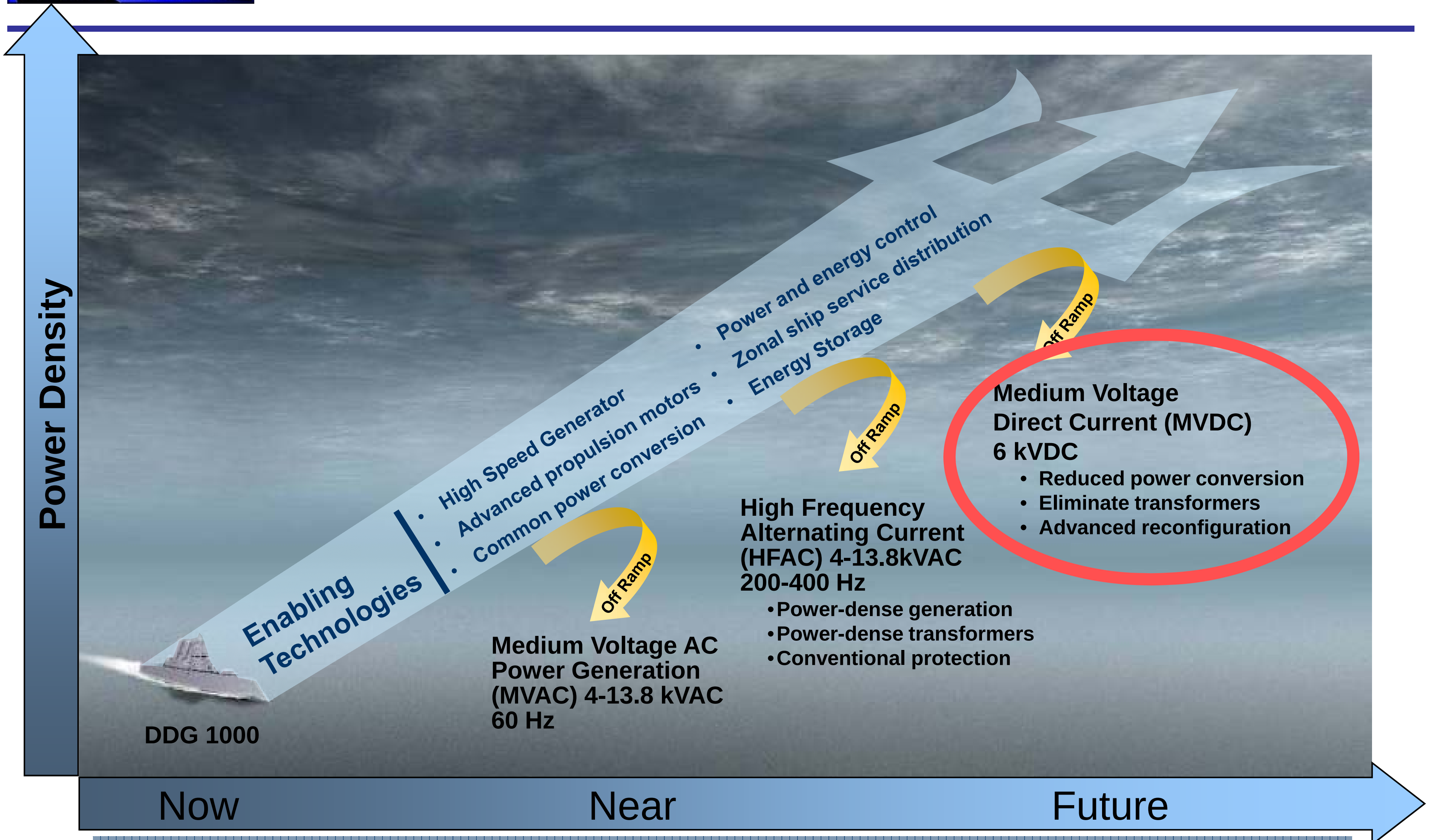
<u>The NGIPS enterprise approach will</u>:

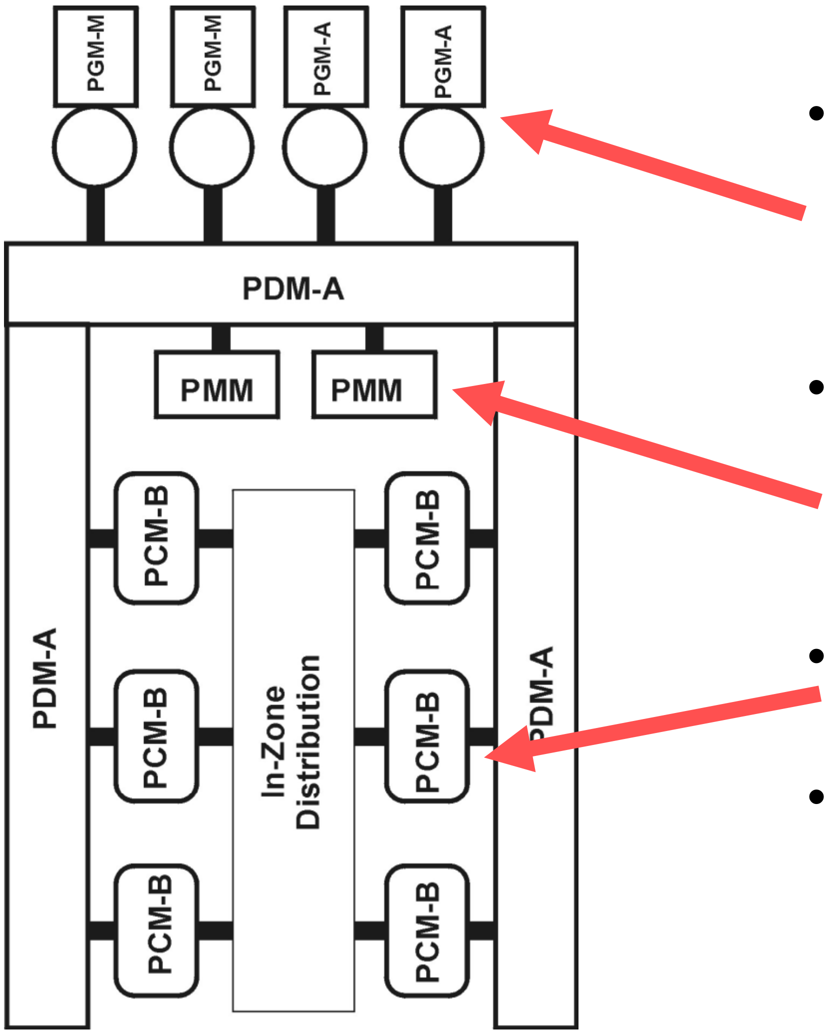
- Improve the power density and affordability of Navy power systems
- Deploy appropriate architectures, systems, and components as they are ready into ship acquisition programs
- Use common elements such as:
  - Zonal Electrical Distribution Systems (ZEDS)
  - Power conversion modules
  - Electric power control modules
- Implement an Open Architecture Business and Technical Model
- Acknowledge MVDC power generation with ZEDS as the Navy's primary challenge for future combatants

NGIPS Technology Development Roadmap



"Directing the Future of Ship's Power"

Notional MVDC Architecture



- Power Generation Modules produce Medium Voltage DC Power
  - Between 6 and 10 kV
- Large Loads (such as Propulsion Motor Modules) interface directly to the MVDC bus
- PCM-B is interface to in-zone distribution system
- Control provided by PCON

Location of Energy Storage within Architecture still an open issue

Power System Functions

- Power Management – Normal Conditions
- Power Management – Quality of Service
- Power Management – Survivability
- System Stability
- Fault Response
- Power Quality
- Maintenance Support
- System Grounding

Power Management – Normal Conditions

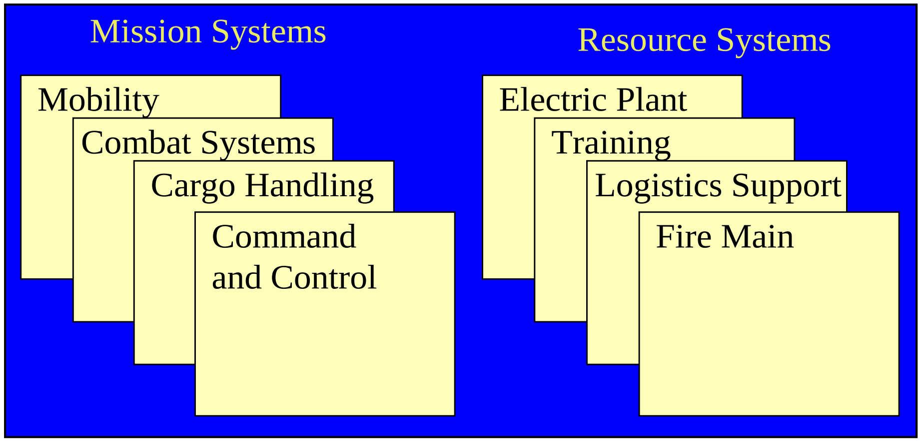
- Provide sufficient power to all loads while providing sufficient rolling reserve
- LOAD DEPENDENT POWER MANAGEMENT MODEL
  - Base rolling reserve on the total amount of load and the current operating condition
- RESOURCE MANAGEMENT MODEL
  - Calculate Rolling Reserve based on negotiations between Resource Managers

Number of generators connected	Generator load	Available power (Power reserve)	Time delay to initiate the starting sequence
2	70 %	2 x 30% = **60 %**	10 min.
3	75 %	3 x 25% = 75 %	10 min.
4	80 %	4 x 20 % = 80 %	10 min.
5	84 %	5 x 16 % = **80 %**	10 min.

Number of generators connected	Generator load	Available power (Power reserve)	Time delay to initiate the starting sequence
2	85 %	2 x 15% = **30 %**	10 sec
3	87 %	3 x 13% = 39 %	10 sec
4	89 %	4 x 11 % = 44 %	10 sec
5	91 %	5 x 9 % = **45 %**	10 sec

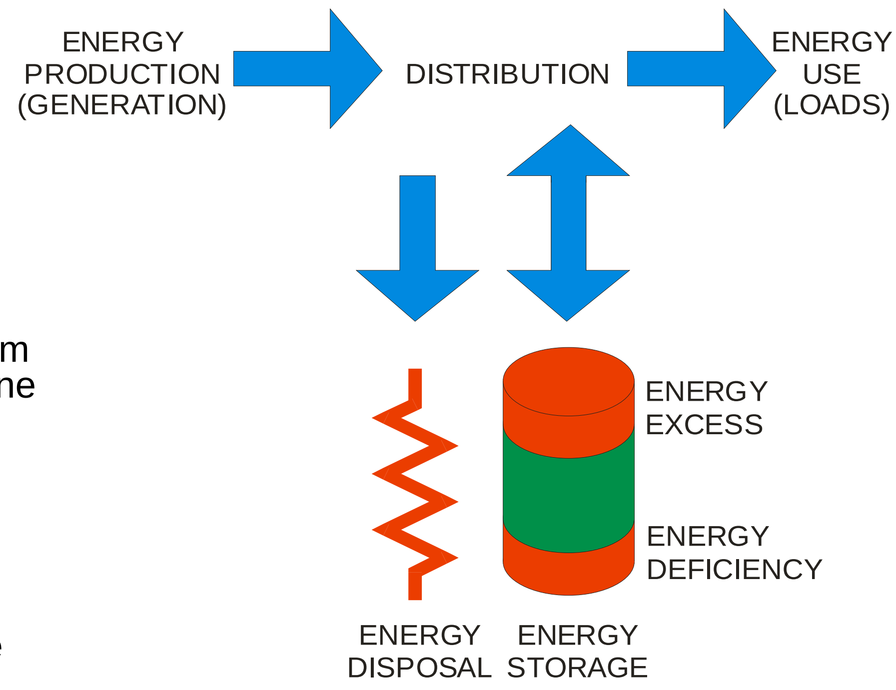
Number of generators connected	Generator load	Available power (Power reserve)	Time delay to initiate the starting sequence
2	105 %	0 %	Immediately
3	105 %	0 %	Immediately
4	105 %	0 %	Immediately
5	105 %	0 %	Immediately

Radan 2004



Power Management – Quality of Service

- Provide Power Continuity to the degree needed by the loads
  - Un-interruptible
  - Short term interruptible
  - Long term interruptible
- ROLLING RESERVE MODEL
  - Respond to a shortage in power generation capacity by shedding long-term interrupt loads.
  - Keep sufficient power generation capacity online to power uninterruptible and short-term interruptible loads on loss of the largest online generator.
  - Restore Long term interrupt loads are when sufficient power generation capacity is restored.
- ENERGY STORAGE MODEL
  - Use energy storage to power uninterruptible and short-term interruptible loads until sufficient power generation is restored to power all loads.

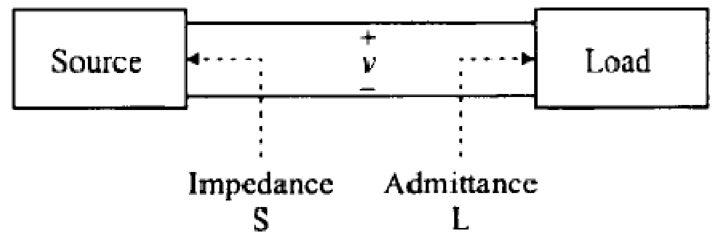


Power Management – Survivability

- Zonal Survivability is assumed. Issues become
  - Which power system components are safe to energize?
  - Which loads are safe to energize?
  - What is the priority ranking of loads to re-energize?
- OPERATOR-BASED RESPONSE MODEL
  - System reports the condition of power system equipment and loads.
  - Operator makes decisions.
- AGENT BASED RESPONSE MODEL
  - Resource Managers (computer agents) determine health of equipment and make decisions.

System Stability

- Stability of DC Power Systems complicated by negative incremental resistance of constant power loads.
- LINEAR STABILITY METHODS
  - Generally based on Gain and Phase margins.
  - Measure of Small Signal Stability only.
  - Need to address all operating conditions to assess stability.
- NONLINEAR STABILITY METHODS
  - Accurately model the time-varying, non-linear power system including initial conditions, system parameters and inputs.
  - Determine equilibrium points.
  - Determine perturbations about each equilibrium.
  - For each perturbation about each equilibrium, determine the dynamic response of the system and whether it is acceptable



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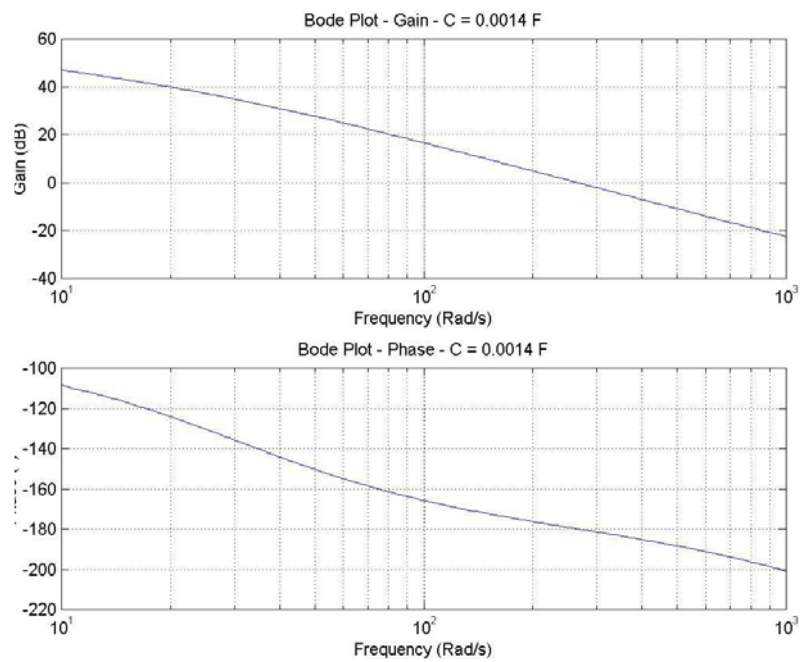
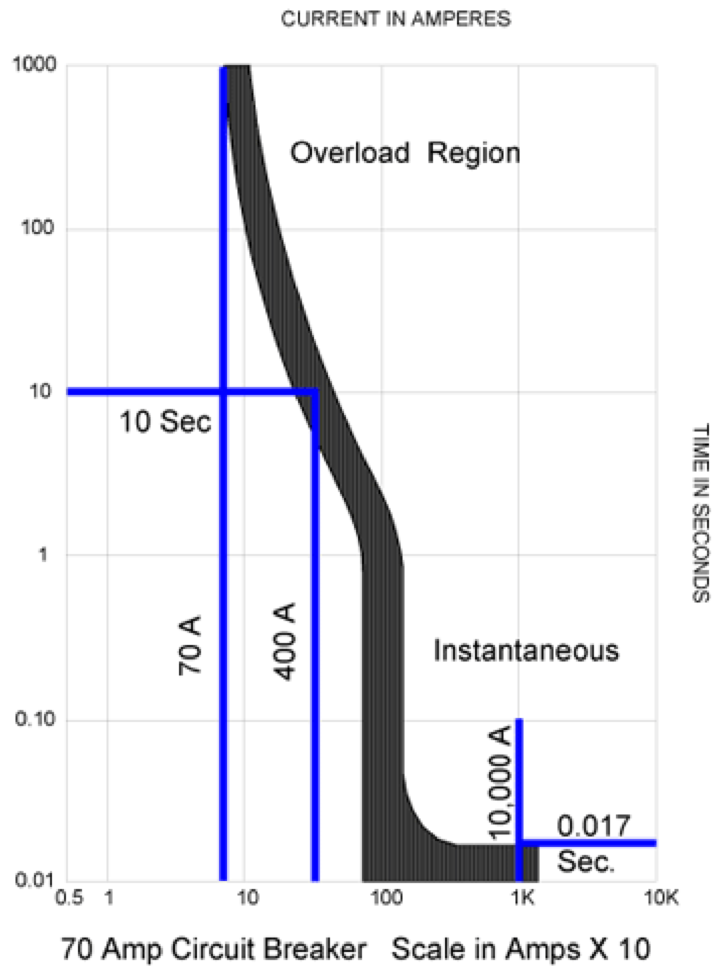


(Flower and Hodge 2005)

Fault Response

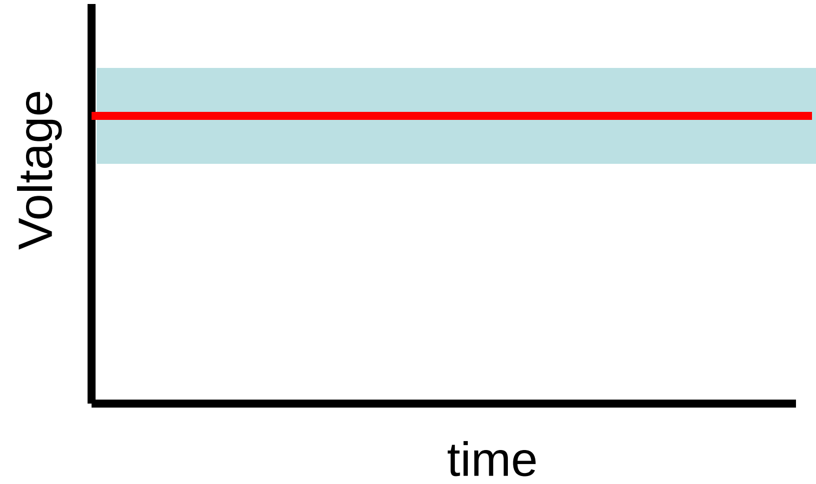
- Fault Response Actions
  - Identifies that a fault has occurred
  - Reconfigures the power system
  - Protects equipment and cables
- CIRCUIT BREAKER MODEL
  - Fault currents coordinate the tripping of breakers.
  - Affordability Concerns
    - DC Breakers
    - Power electronics sized to provide sufficient fault current
- POWER ELECTRONICS MODEL
  - Sensors and controls detect and localize faults.
  - Use QOS to enable taking bus down to isolate fault with zero-current switches.
    - Provide un-interruptible loads with alternate power source.
  - Requires an architecture and a design methodology.

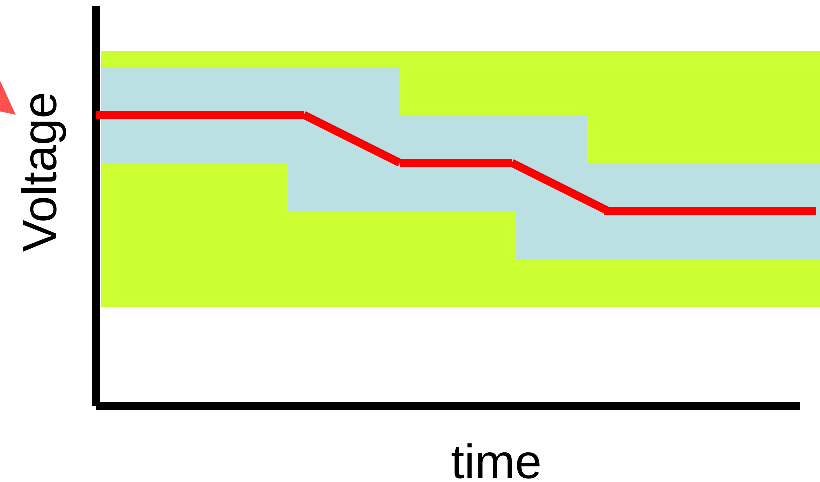


(Phillips 2006)

Power Quality

- MVDC bus has a limited diversity of sources and loads.
  - Ideal voltage range and degree of regulation is not obvious.
- TIGHT TOLERANCE MODEL
  - Voltages regulated within a relatively narrow band to a set nominal voltage.
  - Simplifies interface design
- LOOSE TOLERANCE MODEL
  - PCON sets nominal voltage over a wide range.
  - Regulate voltage within a band around the nominal voltage.
  - Optimize system efficiency.
  - Increase complexity of sources and loads.
  - Increase cable size to enable operation at the lower voltage limit.



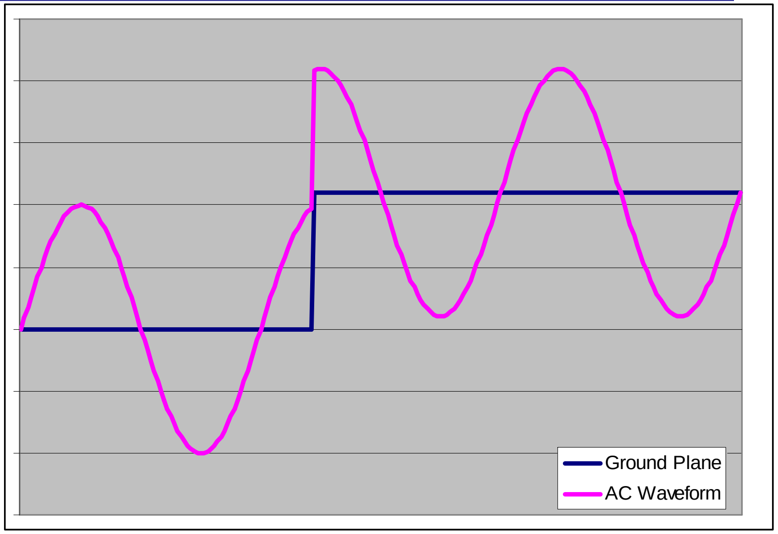


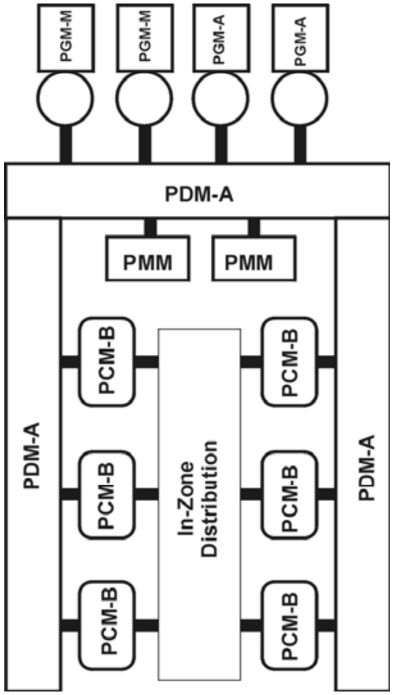
Maintenance Support

- Electrically isolate equipment in a safe and verifiable manner to support Maintenance.
- PHYSICAL DISCONNECT MODEL
  - Isolate equipment with switches, circuit breakers, removable links, removable fuses, etc.
  - Use of Danger Tags
- CONTROL SYSTEM, POWER ELECTRONICS DISCONNECT MODEL
  - Use power electronics to electrically isolate loads
    - Isolate gate drive circuits?
  - Automate “Danger Tags” through control system and component design.
  - Trades cost of hardware with complexity and cost of control system.

System Grounding

- Should PCM-B provide galvanic isolation between the MVDC Bus (PDM-A) and the In-Zone Distribution?
- PCM-B WITH GALVANIC ISOLATION
  - Prevents DC Offsets from ground faults on MVDC bus from propagating into the In-Zone Distribution
  - Weight of isolation transformers can be reduced by using high-frequency transformers.
- PCM-B WITHOUT GALVANIC ISOLATION
  - Potentially lighter, smaller, and cheaper.
  - May require fast removal of ground faults on the MVDC Bus to prevent insulation system failure in the In-Zone Distribution.





Summary

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