Power Electronics Capacity Sizing

Electric Power Load Analysis (EPLA)

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Essential Questions

How do the overload capabilities of power electronic converters differ from electromagnetic based generators?	Understand
What are the implications of the overload capabilities of power electronic converters?	Understand
What are the requirements for power electronic converter capacity?	Understand
What other considerations are there for selecting the capacity of power electronic converters?	Understand

Introduction

- Power electronic converters may be employed to connect two power systems having different power quality attributes (voltage, frequency, etc.)
- Power electronic converters may have multiple inputs and multiple outputs
  - IPMC (MIL-PRF-32272)
- Power electronic converters generally have limited overload capability as compared to transformers and synchronous generators
  - Commercial inverter
    - 2 x current rating for 3 seconds
    - 1.6 x current rating for 10 seconds
  - MIL-DTL-3124 synchronous generator
    - $I^2t \geq 180$ (7.75 x current rating for 3 seconds, 4.24 x current rating for 10 seconds)
    - Overload rating: 1.5 times rated current for 2 minutes.

ABS Rules for Building and Classing Marine Vessels

- “Where transformers and/or converters form a part of the vessel’s electrical system supplying to essential services and services necessary for minimum comfortable conditions of habitability, as defined in 4-8-1/7.3.3 and 4-8-1/7.3.4, the number and capacity of the transformers and/or converters is to be such that, with any one transformer or converter, or any one single phase of a transformer, out of service, the remaining transformers and/or converters or remaining phases of the transformer are capable of supplying power to these loads under normal seagoing conditions.”
- “Semiconductor converters are to be rated for continuous load conditions and if required by the application, are to have specified overload capabilities.”

Load analysis

- Traditional load analysis
  - Assumes many loads where variation of the total load around the mean is small.
  - Usually applicable at the total ship level
  - Power electronic converters usually only serve a subset of the total load
    - The variation of the total load around the mean is relatively larger
    - Limited overload capability of power electronic converters may result in converters shutting down due to large cycling loads
- Zonal load factor method (DPC 310-1)
  - Zonal load factors account for variability in the total load due to having non-constant power loads
  - Almost always results in a larger operating load as compared to the traditional load analysis
  - Reduces risk of converters shutting down due to large cycling loads.

Margin and service life allowance

- Margin accounts for uncertainty in the operating load estimate during design and construction
  - IEEE Std 45.1 recommendation
    - Detail Design Margin: 5% for existing follow-on designs to 20% for new first-time designs
    - Construction Margin: 5% for existing follow-on designs to 20% for new first-time designs
- Service life allowance (SLA) accounts for growth in load while the ship is in-service
  - IEEE Std 45.1 recommendation
    - 20% (1% per year for 20 years)

Quality of service and survivability

- Failure rates of power electronic converters are likely to be high enough to require redundancy
  - Redundancy at the total converter level
    - Requires one additional converter and system connectivity so all loads can be supplied with any one converter out of service.
  - Redundancy of modules within the converter
    - Requires being able to serve all loads with one module out of service
    - Single points of failure must be sufficiently reliable
    - Hot swapping capability is desirable
- Power electronic converter ratings should be sufficient for both normal operation and cases where load is transferred from other power electronic converters
  - May require load shedding
  - Must have adequate overload capability for period of time it takes to shed loads

In-rush current

- Power electronic converters should be capable of providing sufficient in-rush current to connected loads.
  - Electromagnetic-based loads such as transformers, motors, solenoids, and relays.
  - Input capacitors
- If power electronic converter unable to provide sufficient in-rush current, several mitigation strategies are possible
  - Use starting resistor to limit the in-rush current; bypass resistor when in-rush transient is complete
  - Soft start the converter (ramp up voltage slowly)
  - Use low-voltage protection (LVP) controllers for non-vital loads.
    - Requires manual restart after a loss of power
  - For loads with input contactors, use a random delay between when power is applied to the load when the input contactors are closed.
  - Use pre-charge circuitry
  - Use power electronic converters with sufficient capacity to supply in-rush current

Fault protection

- Power electronic converters may not provide sufficient fault current to enable traditional coordination of circuit breakers
- Alternate strategies
  - Flatten the distribution system by using multiple output converters
    - Output converter acts as one layer of circuit protection
    - Only one circuit breaker between load and converter
  - Use differential protection relay
    - Subdivide distribution into protection zones
    - Measure currents on all conductors at the boundary of the protection zones
    - Use Kirchhoff's current law (sum of currents should be zero) to determine which protection zone is zero
  - Increase power rating of the power electronic converter until it has sufficient fault current capability to selectively trip circuit breakers

Efficiency

- Power electronic converter losses typically have a constant, no-load component and a component proportional to the load current squared.
- If multiple modules are used to achieve power rating consider having the control system turn off modules when the load is low.
  - Eliminate no-load component of losses
  - Losses due to load current may rise

Black start

- Black start is energizing an electrical system after loss of power.
  - Dark ship – All generator sets are offline, but energy storage is available for control systems and to enable startup.
  - Dead ship – All generator sets are offline, and all energy storage is depleted (except for dedicated energy storage for emergency generator starting).
- Starting a power electronic converter from either dark ship or dead ship may be impeded if the converter depends on cooling water that is powered by the converter.
  - Consider employing a power electronic converter that has a reduced power rating when the cooling water is not available.
  - Goal is for rating without cooling water to be sufficient to enable startup.