HVDC planning, technology selection and specification

Presented By Bruno Bisewski on behalf of SC B4

Paris – 27 August 2018

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1. Planning
2. Technology Selection Considerations
3. Specifications

Planning

Owner’s Studies

- Feasibility studies
- Load flow
  - ✓ **AC System Upgrade requirements**
- Transient stability
  - ✓ **Overload requirements**
  - ✓ **Supplementary controls and modulations**
    - Power Oscillation damping
    - Frequency limiter,
    - Fast power transfer between poles
    - Runback, Runback, coordination with generator tripping and underfrequency load shedding
- Short circuit
  - ✓ **ESCR**
  - ✓ **UIF to determine susceptibility to SSTI**
- Harmonic Impedance Studies
- Reliability Assessment (to asses the need for Major Spares)
- Equivalents for Performance Demonstrations

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Owner’s Investigations

- Site Selection
- Environmental Planning and Permitting
- Preliminary Soils Investigation
- Background Harmonic Measurements
- Telephone Interference Assessment
- Line and/or Cable Routing
- Electrode Site Selection (if applicable)

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Technology Selection

Technology Selection

- Available Technology
- Factors that dictate one option
- Performance
- Cost and other factors

Available Technology

LCC Technology

Switching Devices

- ✓ ETT Thyristor
- ✓ LTT Thyristor
- ✓ Up to 8.5kV, 4000A

Converter Configurations

- ✓ 6-Pulse (rare)
- ✓ 12-Pulse

Switching for circuit reconfiguration

- ✓ HS commutating Switches
- ✓ Disconnectors

VSC Technology

Switching Devices

- ✓ IGBT with Freewheeling Diode
- ✓ Up to 4.5 kV, 2500A (in use)
- ✓ 6.5 kV on the horizon

Converter Configurations

- ✓ MMC Converters
  - Half bridge (HB)
  - Full Bridge (FB)
  - Hybrid (HyB) FB & HB submodules
- ✓ Cascaded Two Level Converters
  - Half bridge

Switching for circuit reconfiguration

- ✓ HS Commutating Switches
- ✓ Disconnectors
- ✓ DC breakers (Electronic & Hybrid)

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Circuit Configurations

Circuit Configurations	LCC	VSC	Comment
Bipole with Ground Return (GR)	yes	yes	
Bipolar with DMR	yes	yes	
Symmetric Monopole	yes	yes	
Rigid Bipole	yes	yes	
Asymmetric Monopole DMR	yes	yes	
Asymmetric Monopole GR	yes	yes	
Multi-terminal	yes	yes	
Paralleled converters	yes	yes	
Series converters	yes	*	* more difficult

Factors that may Drive Selection of one Option

LCC Converters

- Lowest Cost
- Minimum Losses
- Very High Power (>2500MW)
- Very High Voltage DC Cables
- High Short Time Overload
- Isolation of DC/AC faults
- Very Fast Recovery from DC Line Faults
- Repeated fault clearing/ overload

VSC Converters

- Very Long Land Cables
- Overhead Line is Not Possible
  - ✓ Limited Right of Way
  - ✓ Severe Pollution
  - ✓ Environmental Opposition
  - ✓ Regulatory Requirements
- Limited Space for Stations
- Immunity to Commutation Fail
- System Restoration (Black Start)

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Selection - Applicability Matrix

Application	LCC	VSC	Comment
Back-to-Back	Yes	Yes	
Long Distance Transmission	Yes	Yes	
Connecting Isolated systems	Yes	Yes	VSC has advantage for weak isolated systems
Connecting Offshore Wind	Less Suitable	Yes	
Frequency Changer	Yes	Yes	
Overhead Lines	Yes	Yes	VSC requires FB, HyB, DC Breaker for fast fault clearing
Cable systems	Yes (MI, MIPPL, OF)	Yes (as LCC+ Extruded)	
Multi-terminal Operation	Yes	Yes	More difficult with LCC
Very High Power	Yes	No	VSC is under development
System Recovery Services	No	Yes	Black Start

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Selection – Performance Matrix

Performance Characteristics	LCC	MMC HB AC breaker	MMC HyB	MMC FB	MMC HB electronic DC breaker	MMC HB Hybrid DC Breaker
DC fault current interruption	****	*	****	****	****	****
Decoupling of DC faults from ac system (di/dt)	****	0	***	***	***	***
DC line fault recovery fast recovery sequences	****	0	****	****	***	***
Repetitive Recovery Sequences	****	0	****	****	***	***
Reactive power support during dc fault clearing	*	0	***	***	***	**
DOV Limiting During Fault Recovery	0	0	**	**	**	**
Reduced DC Voltage Operation Due to Pollution	****	0	***	****	0	0
Demonstrated service history	****	***	*	**	*	*
Increases Short Circuit Level	0	*	*	*	*	*

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Technical Specification

" The greatest source of contract disputes, change orders and cost increase claims is an inadequate specification…"

Contents

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Purpose and Description of DC Link

- Generally the need is for **Energy Transfer** rather than **Capacity**
- If the HVdc must also provide capacity the reliability and availability targets may need to be higher and partial capability and overload capability is more important
- This may affect the configuration and redundancy provided

  For example it may mean a bipole or two monopoles are provided rather than a monopole symmetric monopole.

- Provide a description of the proposed HVDC link

Scope and Interfaces

The Contractor cannot be aware of the scope unless he is informed

- ✓ **Insofar as possible list all facilities, studies and services to be provided by Contractor.**
- ✓ **You can provide a catch all clause later such as "…including all necessary items for a fully functional installation."**
- ✓ **List and describe facilities and services to be provided by Owner.**

Define the interfaces between Contractor and Owner to as much detail as possible.

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Contracting Strategy

- Type of Contract
  - ✓ **Turnkey with minimal oversight**
  - ✓ **Turnkey with Owner review and Approval (most common)**

- Contract Conditions
  - ✓ **Owners usual conditions for large contracts**
  - ✓ **FIDIC Conditions (similar to Silver Book)**

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General requirements

- Equipment Lifetime
- Choice of Standards
  - ✓ **IEC**
  - ✓ **IEEE**
  - ✓ **Cigré Guides**
- Testing Requirements
- Contract Terms
- Contract Guarantees - (to be provided in the Special Conditions)
  - ✓ **Failure to achieve schedule or ratings**
  - ✓ **Failure rate of switching devices**
  - ✓ **Failure rate of capacitors**
  - ✓ **Reliability and availability**
  - ✓ **Losses**

General Information Requirements

- System Description, Location and Access
- Scope and Interfaces
- Site Ambient Weather Conditions
- Site Electrical Conditions
- Performance Requirements
- Equipment and Testing requirements
- Control and Protection Requirements
- Documentation and Training
- Required Guarantees and Warranties
- Proposed Contractual Conditions
- Information to be provided with the Bid

Site Information

- Site ambient climatic characteristics
  - ✓ **Location and Access**
  - ✓ **Transportation limitations**
- Temperature range
  - ✓ **Temperature for Power Rating Guarantee**
  - ✓ **Maximum 24 hour average temperature**
- Rainfall and snowfall amounts (icing if applicable)
- Insulation pollution levels
- Seismic withstand requirements
- Other environmental conditions or hazards

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DC Configurations

Operation Configurations

Assuming point to point transmission without paralleling

Owner should specify all required configurations

- Symmetric Monopole – only one configuration
- Bipole Ground Return (via electrodes)
- Bipole with Dedicated Metallic Return
- Rigid Bipole (no electrode, no DMR)
  - ✓ **Requires Stop and Fast Switch to monopolar metallic return on other pole conductor)**
- Monopole ground return (via electrodes)
- Monopole with DMR return
- Monopole with metallic return on other pole conductor

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Operating Modes

- Most usual Operating modes
  - ✓ **Bipole power control**
  - ✓ **Pole synchronous current**
  - ✓ **Pole reduced voltage mode**
  - ✓ **Pole open line test**
- Less common operating modes
  - ✓ **Round power mode**

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Ratings

Ratings

What ratings for an LCC System?

- Nominal Continuous Rating
  - ✓ **Basic continuous rating without redundant cooling**
- Inherent Continuous Rating
  - ✓ **Basic continuous rating with redundant cooling**
- Transient Overload Rating
- Nominal Short-time Overload Rating
- Inherent Short-time Overload Rating
- Minimum Power Transfer (~ 10% of nominal current)

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Ratings

What ratings for an VSC System?

- Nominal Continuous Rating
  - ✓ **Basic continuous rating without redundant cooling**
- Inherent Continuous Rating
  - ✓ **Basic continuous rating with redundant cooling**
- Very little transient and short time rating
- Minimum Power Transfer = 0 MW

Factors that Affect Rating

- Ambient Temperature
  - ✓ Rating is normally defined at maximum ambient temperature
  - ✓ Greater rating may be available at lower ambient temperature (not for cables)
- Redundant Cooling (Heat Exchangers and Fans)
  - ✓ Provide increased inherent continuous overload and inherent short-time overload capability
  - ✓ Generally not useful to increase transient overload capability
  - ✓ Avoids loss of capacity as cooler efficiency declines over time
  - ✓ Allows operation to full capacity in event of pump, fan or cooler maintenance
  - ✓ Typical Redundancy Specified
    - Cooling Water Pumps – 2x100% capacity
    - Outdoor coolers - 3x50% capacity or 4x33% capacity for liquid-air cooling
    - Fans – one extra fan per cooler
    - Plate heat exchangers (two loop or water-water cooling) - 2x100% capacity
    - Deionizer resin tanks 2x100%

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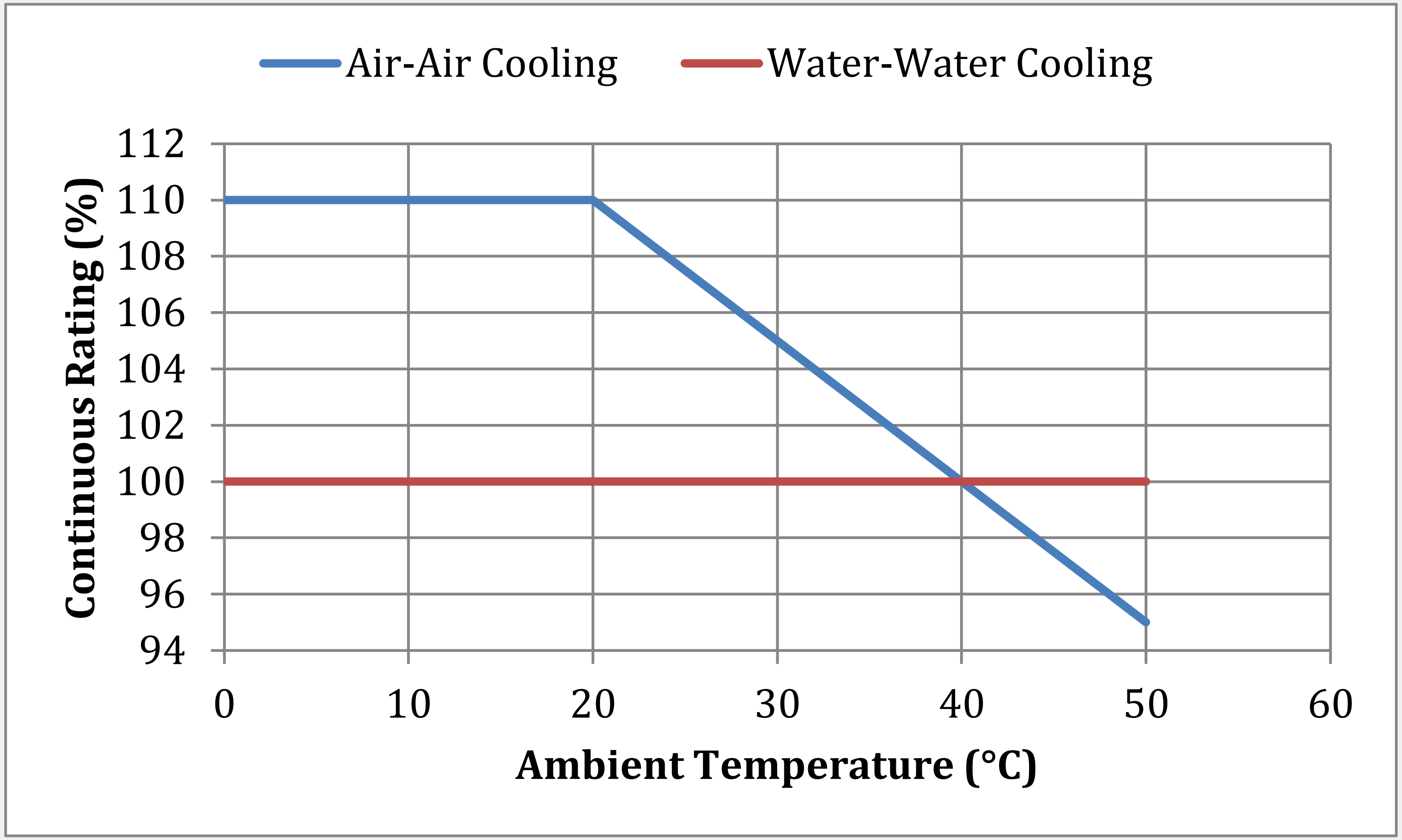
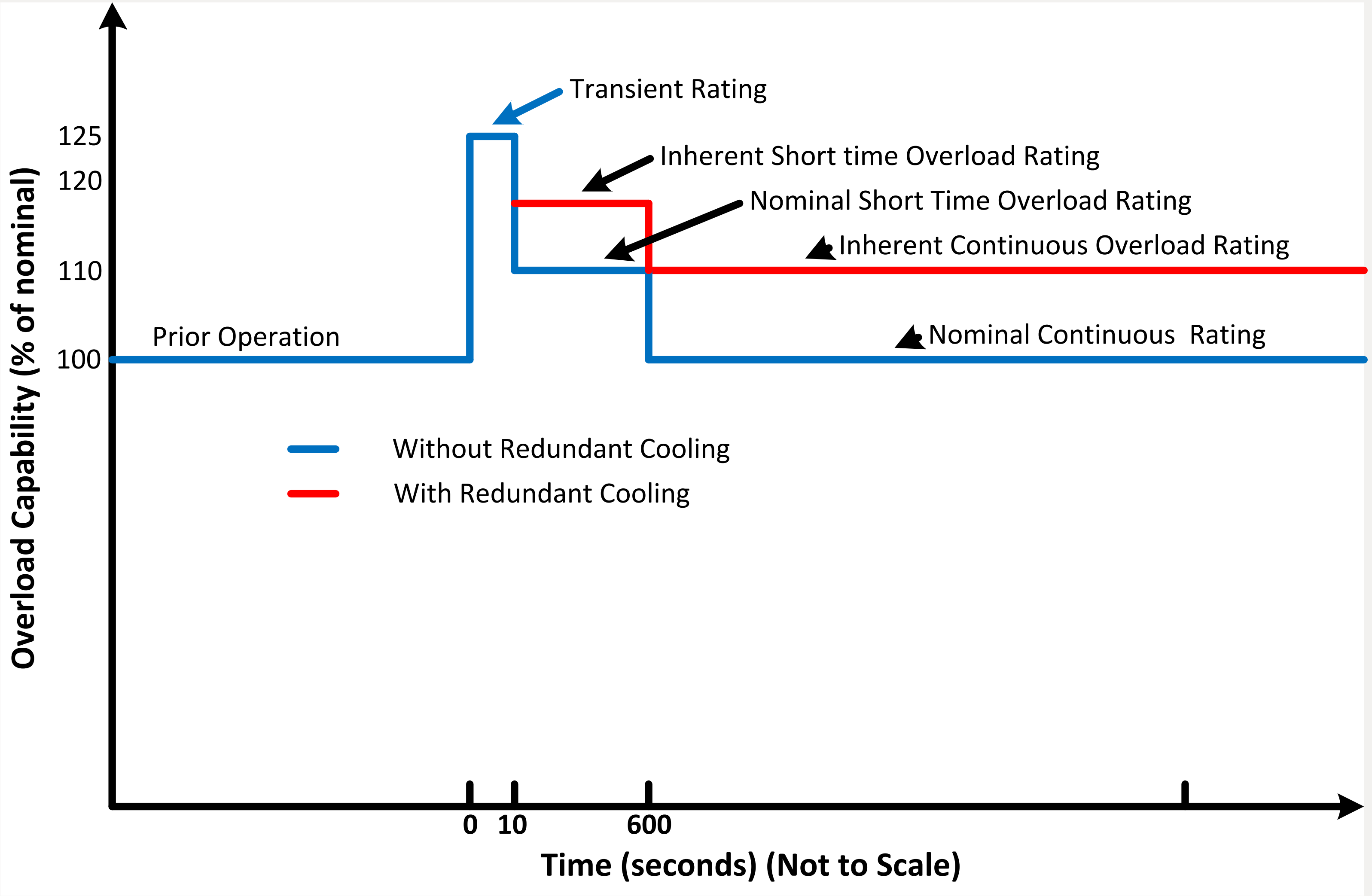
Impact on Rating

Low Ambient Temperature



Impact on Rating

Redundant Cooling Equipment (LCC with Air-Air Cooling)



Overload Rating

Factors to Consider

- Short time and transient ratings are design dependent
  - ✓ **need to be confirmed by designer (may have cost impact)**
  - ✓ **may cause temperature increase above acceptable long duration permitted values**
- Continuous overload requires some margin in cooling capacity
- Overload is dependent on the most limiting component
- Don’t overlook the smaller components
  - ✓ **Bushings**
  - ✓ **Instrument transformers**
  - ✓ **Air cooled reactors**
  - ✓ **Buswork**
- Can increase Dynamic Overvoltages (on load rejection)
- Overload cycles may need to be repeated within a short time
  - ✓ **Repeated DC line faults due to pollution or lightning**

Repeatability of Overload Cycle

- User must specify required repeatability (if needed)
- Repeatability is desirable when multiple faults can occur in a short time
  - ✓ Reclosing on to a permanent ac line fault
  - ✓ Short time between dc line faults due to lightning or pollution
- Repeatability depends on temperature rise of components during a cycle
- Different components have different thermal “mass” and time constants
  - ✓ Seconds for power electronic components
  - ✓ Tens of minutes for air-cooled reactors
  - ✓ Hours for transformers
- Cooling time constants are generally longer than heating time constants
- To fully exploit short-time overload capability on repeated basis it is necessary to use thermal image models of the most limiting components
  - ✓ **Full OL-time capability may not be used on previous cycle**
  - ✓ **With open-loop control (time based) the inherent OL capability cannot be fully used**

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Performance Requirements

Performance

Steady-State Operating Requirements

- ✓ Bus voltage range
- ✓ Short circuit level variation
- ✓ Voltage unbalance
- ✓ Preexisting background harmonics

Dynamic performance

- ✓ Performance Demonstration during Bid Phase
- ✓ Performance Demonstration at Contract Phase
- ✓ Response Times

Extreme condition ride-through

- ✓ Overvoltage withstand
- ✓ Low voltage ride through
- ✓ Off-frequency operation

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Dynamic Performance

Performance Demonstrations During Bid

- To some extent performance demonstration studies during Bid are optional – It depends on whether there are critical performance aspects to be demonstrated
- Serves to test that Suppliers understand the specification
- Normally performed on simplified network
  - ✓ **Typically 3 buses per side – may have a parallel ac tie if interaction between the two ends is needed**
  - ✓ **Can be dynamic or static depending on the objectives**
- A limited set of cases would be performed (< 20 cases) with Owner defined initial conditions
- Contractor uses his preliminary models of the dc converters

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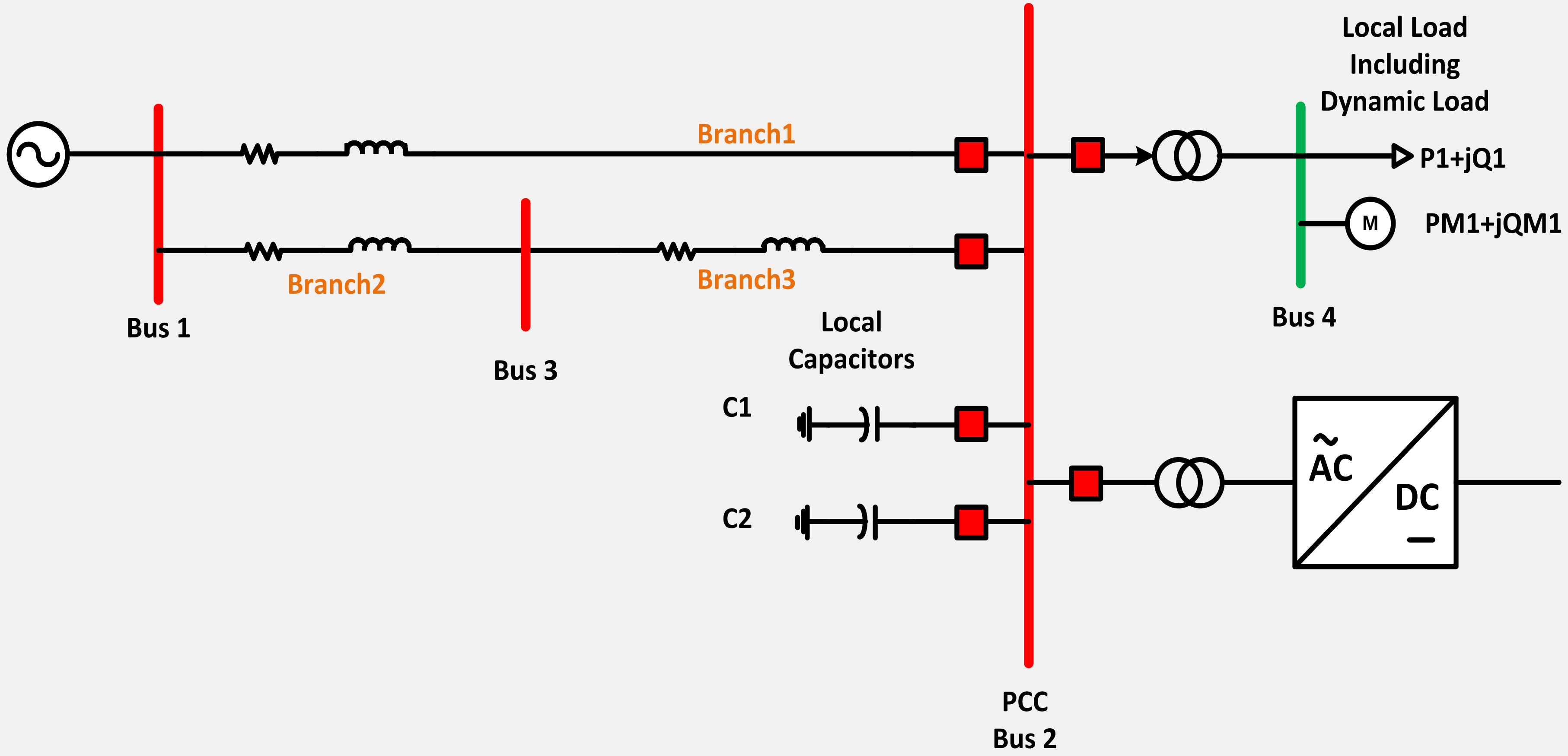
Simple Equivalent for Bid Studies

Add AC interconnection to other system if needed



Performance Demonstration During Contract

- Generally a larger system equivalent is used for performance demonstrations (typically 20 to 40 buses at each end)
- Can include sensitive installations and other fast acting controllers to enable control interaction studies
- May include generators that that have been identified as potentially sensitive to SSTI
- Usually includes a larger number of cases (again with Owner defined initial conditions)
- Contractor provides DC models and optimizes the performance prior to delivering the models to Owner

Models

- Models are required for Owners studies and for exchange with TSO
- Should be specified for the system study programs being used by Owner and TSO
- TSO generally wants generic models available in commercial software such as PSS/E and DigSilent
- Owner may want detailed custom models which include better control representation and special features of the link for his own studies. Generally this will require source code so that can be recompile when program updates are made.
- Single phase and three phase (PSCAD or similar) Models are needed

Performance Requirements

- Steady State System Variation
  - ✓ **Ac bus voltage magnitude range (normal and extreme)**
  - ✓ **Bus frequency range**
  - ✓ **Steady state unbalance (for performance and rating)**
- Withstand Requirements
  - ✓ **Over and undervoltage ride-through**
  - ✓ **Over and under-frequency**
- Response requirements –small and large signal
- Losses
- Reliability

Withstand & Ride Through Requirements

Principle is that Transmission Systems Should not Trip Before Generation

- DC system must meet Grid Code minimum requirements
- Where the HVdc may represent a major source or load in the ac system the Owner's requirements may be higher than required in the grid code for the following
  - ✓ **Low voltage ride through**
  - ✓ **Transient and Temporary Overvoltage Withstand**
  - ✓ **Off-frequency withstand**
  - ✓ **Negative sequence voltage (voltage unbalance)**
  - ✓ **High and Voltage Operational Extremes**
    - Can affect arrester ratings and tap range requirement
- Owner should define the requirements in his system studies

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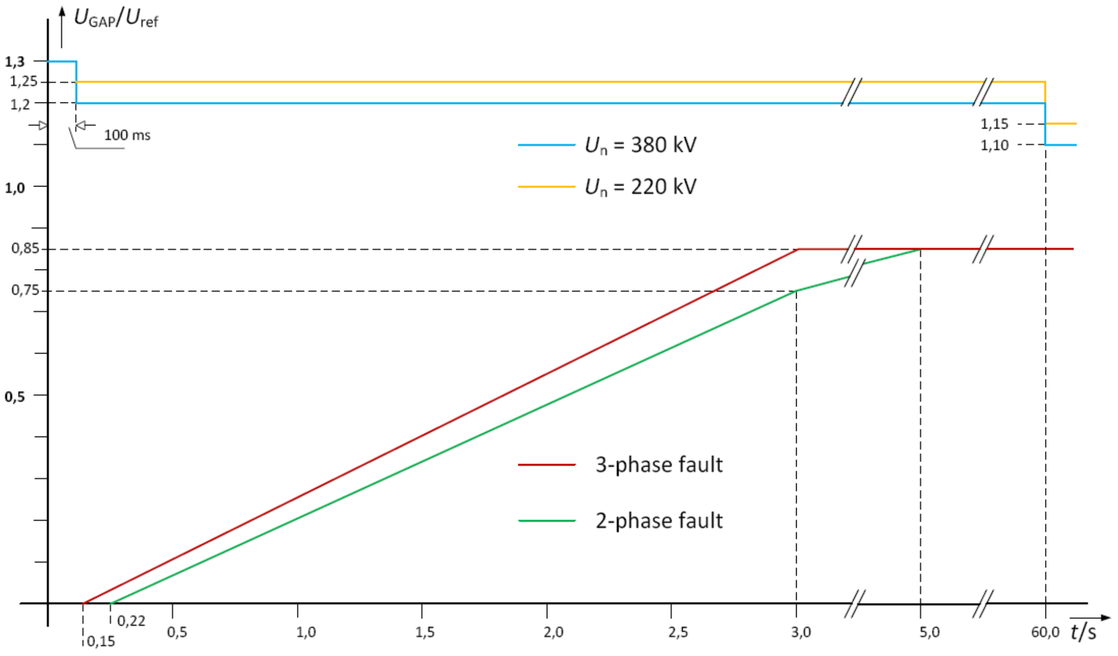
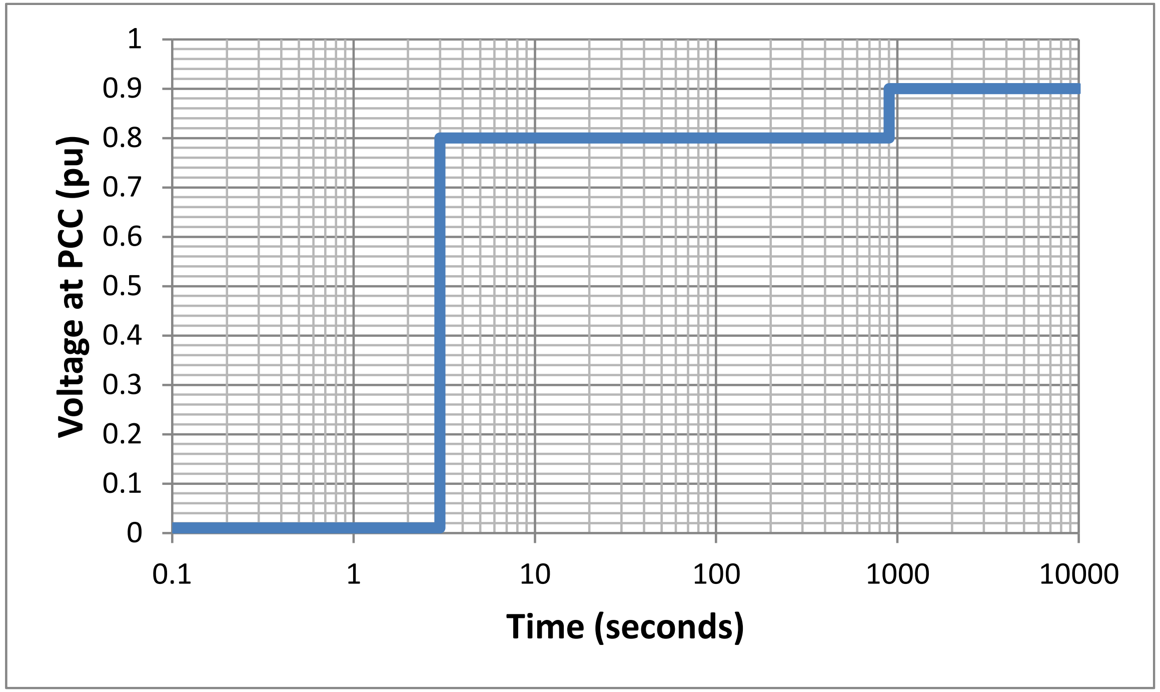
Low Voltage Ride-Through Examples

Grid Codes in Europe



Low voltage Ridethrough



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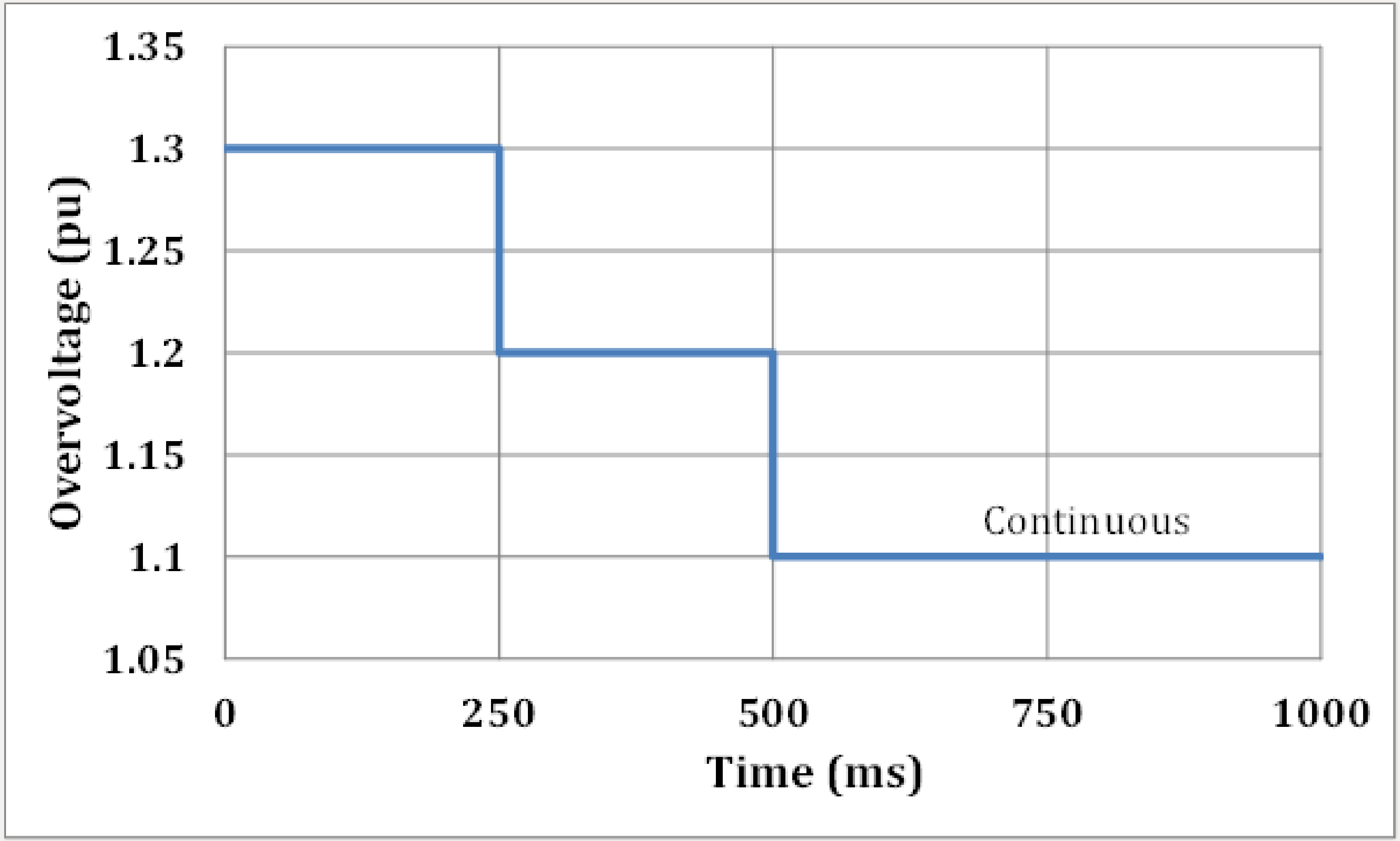
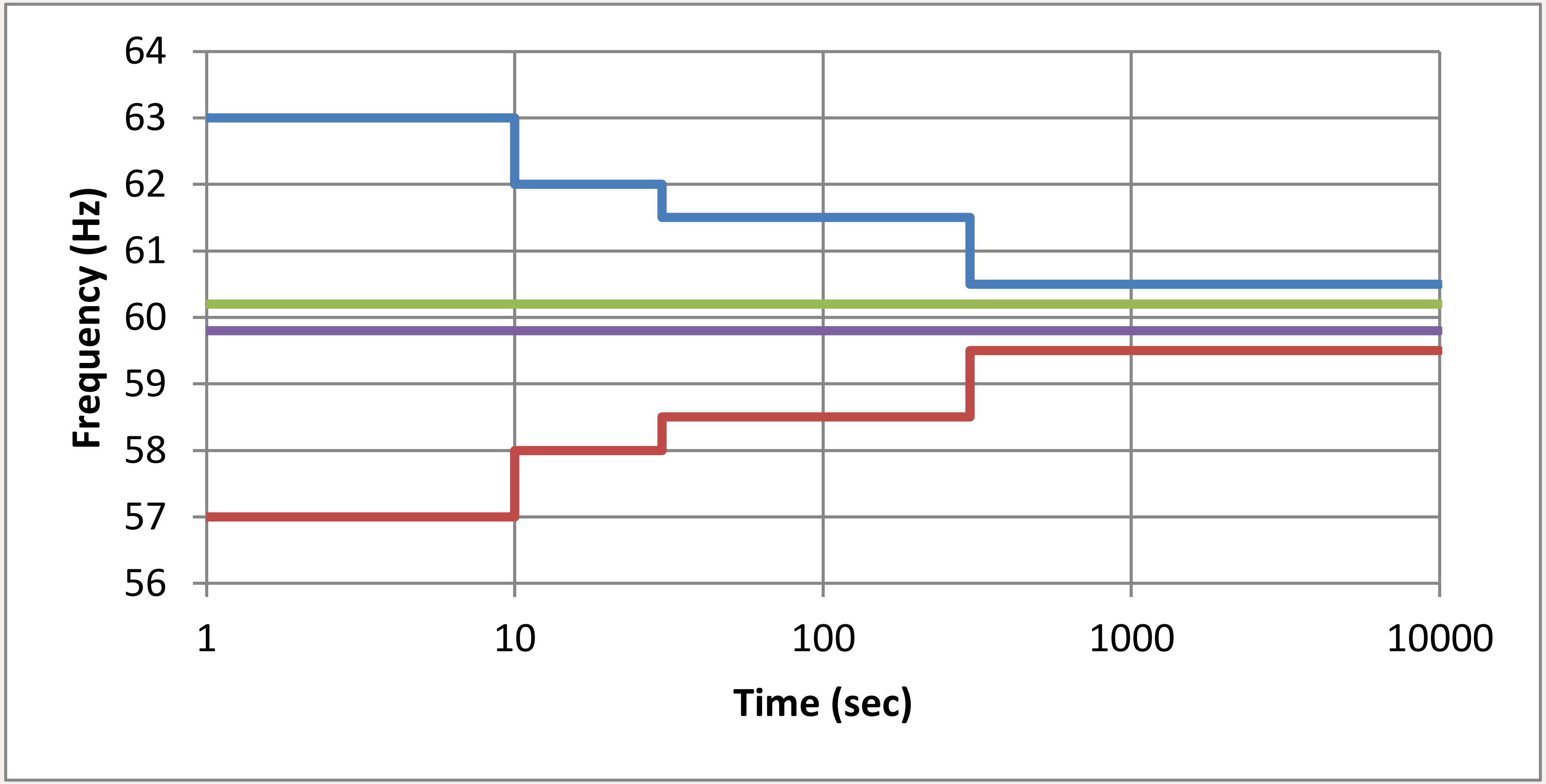
Overvoltage Withstand Capability

Define as the Cumulative OV/time Requirement



Short Time Off-frequency Variation

Define as the cumulative duration



Specification of Response Time

Small Signal and large Signal Response

- Response time generally refers to small signal step change
  - (step size 1-2% of nominal)
- Full power recovery following faults is a large-signal response
- LCC system
  - only Active Power recovery is specified
- VSC system
  - both Active and Reactive power (or ac voltage control) recovery can be specified
  - Converter power balance and active power recovery take precedence over reactive or ac voltage recovery
  - May not be possible to provide overvoltage suppression together with rapid active power recovery

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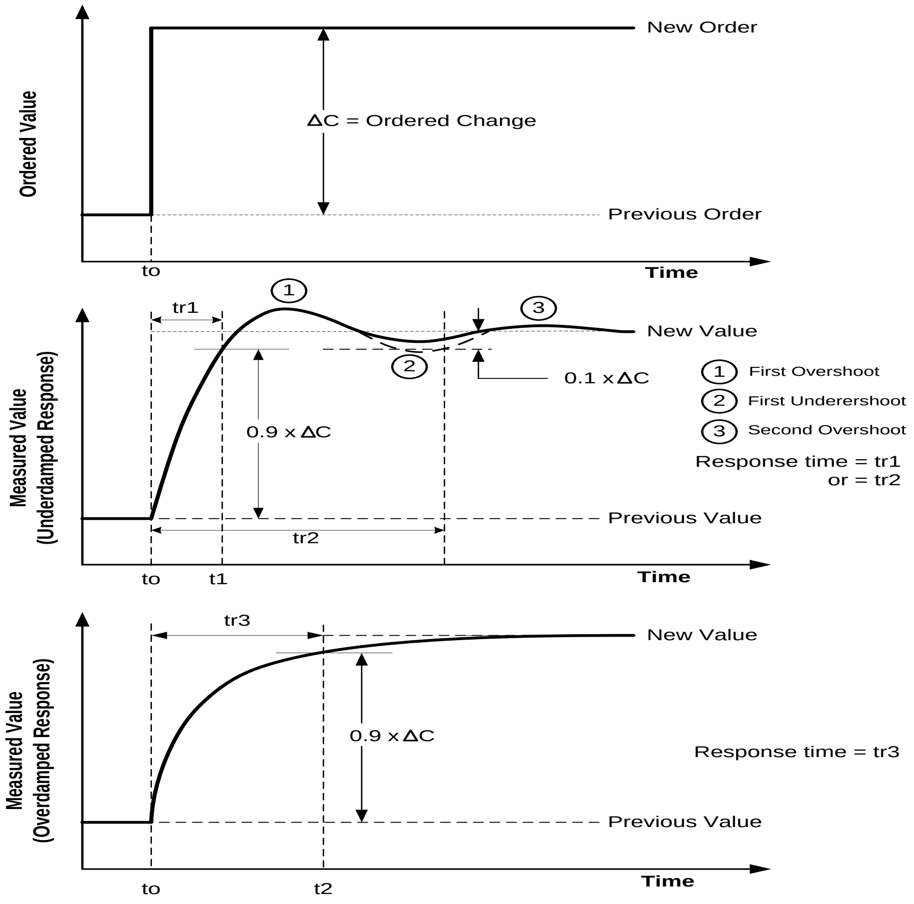
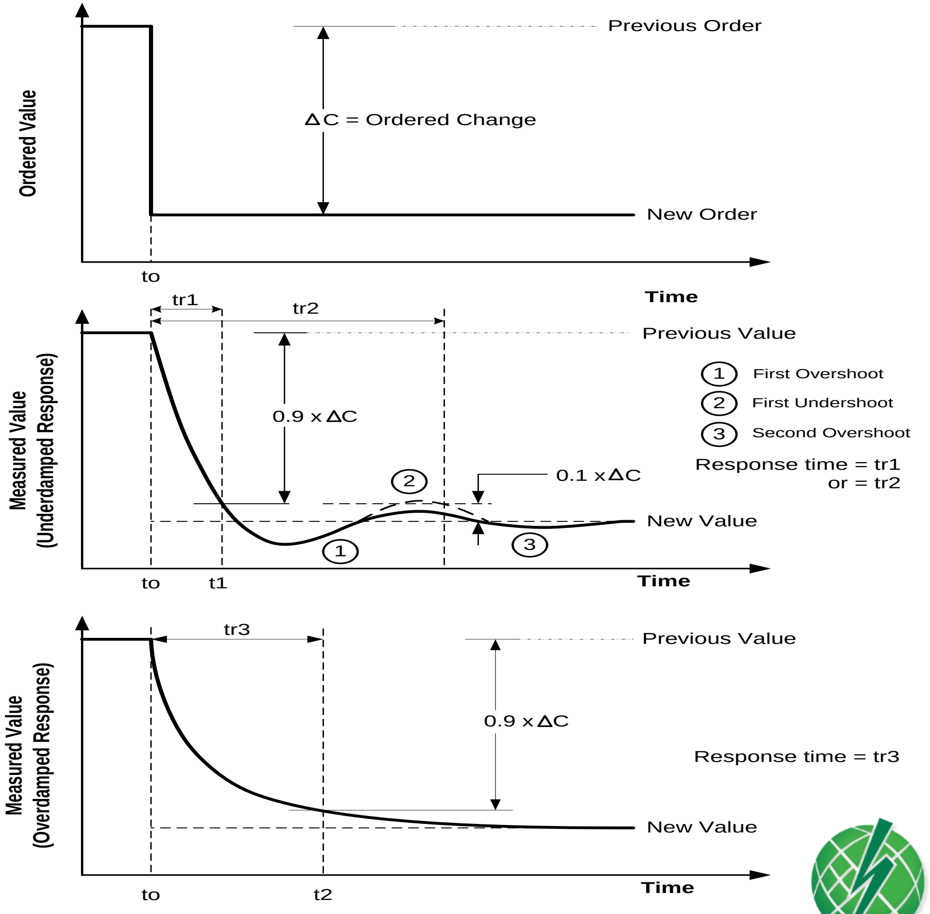
Specification of Step Response

Step Increase



Step Decrease



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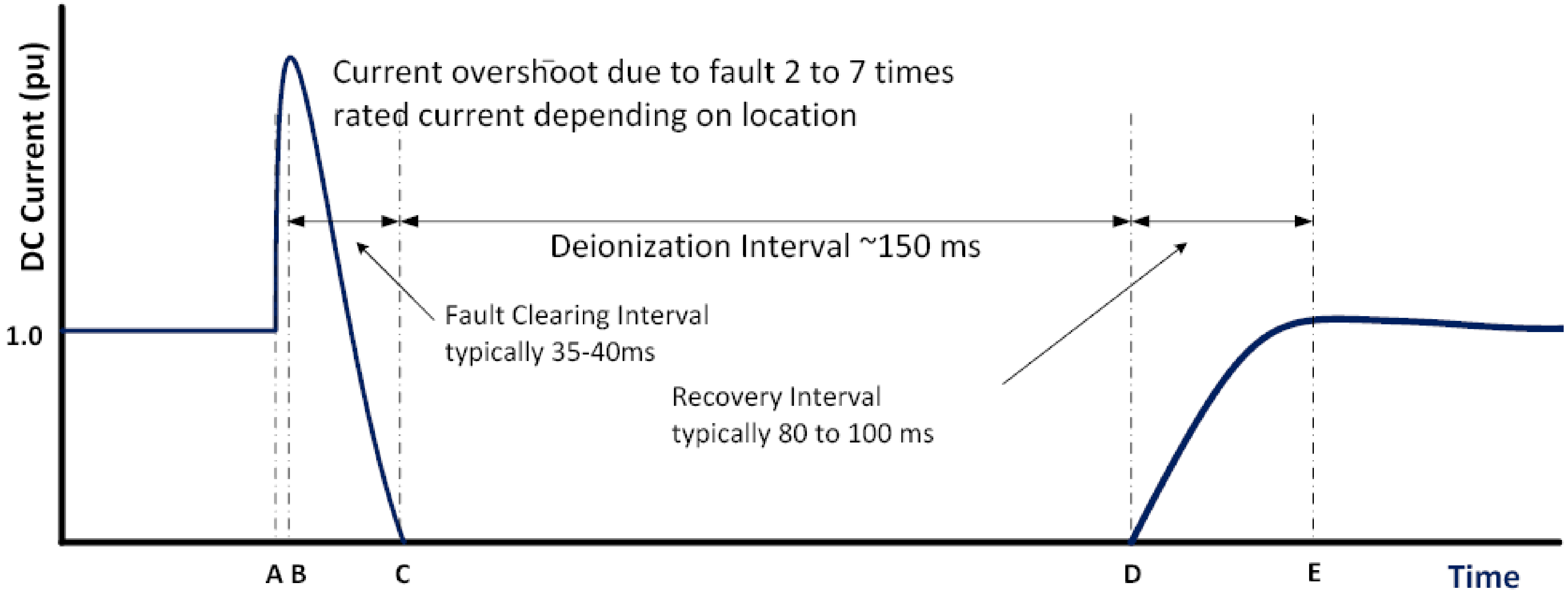
DC line Fault Recovery (LCC)



<u>Typical Times</u>

A. t=0 fault occurs
B. t=1ms fault detected Force retard applied
C. t= 35 ms fault current extinguished deionization begins
D. t= 185ms -deionization complete, recovery starts
E. t= 285ms Dc current and power recovery complete

Total time can extend to 500 to 600ms depending on deionization time

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Contractors Studies

Contractor’s Studies

Associated with DC Equipment and Substation (not usually AC system Performance)

- DC Equipment Design Studies
  - ✓ **Main Circuit**
  - ✓ **Valve Cooling**
  - ✓ **Breaker and Switch Duty**
  - ✓ **Insulation Coordination and Arrester Duty**
  - ✓ **Protection Algorithms and Settings**
  - ✓ **SSTI Investigations**
  - ✓ **Supplementary Modulation Design**
  - ✓ **AC, DC and PLC Filter Performance and Rating Studies**
  - ✓ **AC/DC coupling studies and Mitigation**
  - ✓ **Losses Calculations and Measurements**
- Dynamic Performance Studies
- Reliability and Availability Studies
- Audible Sound Studies

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Contractor’s Studies/Design Activities (cont’d)

Substation Design Studies

- ✓ **Grounding**
- ✓ **Lightning Protection**
- ✓ **Seismic Design**
- ✓ **Buswork Design, Sag, and Tension**
- ✓ **Cabling, trenches, trays**
- ✓ **Structures**
- ✓ **Foundations**
- ✓ **Buildings and Associated Mechanical Systems**
- ✓ **Transmission Line and Inter-station Communications (if applicable)**

Losses

Cost of Losses (COL)

- COL should be specified to encourage optimization by the HVdc supplier
- For transmission projects the main component is the present value of difference between the buying price and the selling price of energy for the design life of the project.
- The capacity cost portion is less applicable to transmission projects.
- Realistic interest and inflation rates should be used in the calculation
- Load factor should be considered
- COL is useful for defining liquidated damages (LDs) for failure to achieve unavailability targets which are equivalent to losses
- COL can be used to assess the total potential value of the project if applied to the total expected energy transfer

Cost of Losses (Example)

Ignoring Incremental Capacity Cost

Financial factors		
Interest rate	6.0	%/yr..
Inflation rate	2.5	%/yr..
Hours per year	8766	hr/yr.
Differential cost of energy	0.040	$USD/kW-hr
Annual cost of diff energy	350.64	$USD/kW-hr
Load factor	0.900	pu
	25 years	40 years
Cost of Energy Losses $USD/kW-hr	**5429**	**7062**

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Effect of Load Factor

- Load factor for a dc system can be considered to be equal to the duty cycle for which it is expected to operate.
- For example if the dc power transfer and % of the time operating at that power 50% of the time at 0.50pu and 50% of the time at 100% power the duty cycle would 0.25 +0.5 = 0.75
- The time duration at different power levels could be split up in to many different power levels and time durations as necessary. Losses should be requested in Bid at each level.
- This calculated duty cycle factor would be used to adjust calculated value of 100% duty cycle COL to reflect actual expected usage of the HVDC system. This would avoid placing too high a value on COL.

Reliability

Reliability and Availability

Major Target Performance Indices for HVdc

- Number of forced outages
  - Pole < 5 per converter pole or symmetric monopole/year
  - Bipolar or simultaneous monopole outages < 1 in 10 years
- Forced Unavailability < 0.5% /year
- Scheduled Unavailability < 1.4% /year /pole
- Interval Between Scheduled Outages ~ 1 year (up to 2 years)

Redundancy in equipment allows some maintenance to be performed on-line reducing the workload in annual outage

Factors which Affect Reliability and Availability

- Quality of Equipment and Design
- Redundancy of Equipment
- Overload Capability
- Capability to Operate in Degraded Modes (partial capability)
  - ✓ e.g. one pole out, one ac or dc filter out, 1 of 2 smoothing reactors out, etc.)
  - ✓ May require extra switches
- Availability of Spares on Site especially Major Spares
- Mobilization/Response Time of Repair Teams

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Quality of Equipment and Design

- Not all equipment or factories have the same quality
- High quality requires
  - ✓ Careful specification of requirements by Owner
  - ✓ Prequalification of factories by Owner
  - ✓ Development and Adherence to Quality Plan by Supplier
  - ✓ Monitoring of Supplier's Designs & Design Reviews by Owner
  - ✓ Witnessing of type tests and some routine tests by Owner
    - A significant commitment of manpower by Owner, but provides training opportunity
- New type tests are not free, they will increase cost
- Inclusion of penalty clauses in Special Conditions for failure to meet performance targets does not compensate for Owner participation in the design review and tests

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Redundancy of Equipment

To provide greater availability

Redundancy can be specified as follows:

- Duplicated auxiliary supply systems
- Extra outdoor valve air-air cooler(s) or water cooler
- Extra fans on valve coolers and transformer radiators
- Duplicated pumps on valve cooling and converter transformers
- Redundant valve cooling controls
- Redundant control and protection systems
- Redundant AC filters and Reactive Compensation Sub-banks

Major Spares

- The presence of major spares can have major impact on availability. Although failure rate may be low the time to repair may be high (e.g. transformer repair or replacement could take up to 9 months)
- Owner should review failure statistics (MTBF and MTTR) published by Cigré and other organizations to asses the value of having major spares.
- Cost of undelivered energy is the same as the cost of losses.

Emissions

Emissions

- Audible Sound (Noise)
- Harmonic Currents and Voltage
- PLC Frequency Interference
- Radio Frequency Interference
- Waste water (from evaporative cooling if applicable)

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Harmonic Emissions

- Generally in accordance with latest version of
  - ✓ **Grid Code applicable to the location**
  - ✓ **IEC Std. 61001-3-6**
  - ✓ **IEEE 519**
  - ✓ **National Standard (if applicable)**
- Typical performance limits
  - ✓ **Dn <1%**
  - ✓ **Deff 2% to 3%**
  - ✓ **THFF = 1**
- Current based limits (TDD or IT) are not often applied for HVDC especially in meshed ac systems where measurement is difficult
- Current based criterion is (Equivalent Disturbing Current) is universally applied for the HVdc line

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Audible Sound (Noise)

- Need to meet local ordinances which may get tighter over time
- Many Jurisdictions follow WHO noise guidelines
  - ✓ **Night Noise Guidelines for Europe**

- Typical levels (measured at receptors location)
  - ✓ **Day time (8am to 9pm) 60 dBA**
  - ✓ **Night time 40 dBA**
- Night time levels are very difficult to achieve
  - ✓ **Site selection with buffer zones**
  - ✓ **Low noise equipment (slow speed fans, reduced noise transformers)**
  - ✓ **Mitigation is a last resort**

Power Line Carrier (PLC)Frequency Noise

- PLC frequency covers the band from (30 kHz to 500 kHz)
  - ✓ **Use is declining due to low bandwidth and relatively high cost**
  - ✓ **Is most often used as a backup to primary communications**
- Converter noise
  - ✓ **highest at low end of the band**
  - ✓ **falls with increasing frequency**
  - ✓ **Filtering is easier at higher frequencies**
- Typical PLC Filter Performance Requirement
  - ✓ **0 dBm at 30 kHz,**
  - ✓ **decreasing linearly to -10 dBm at 50 kHz**
  - ✓ **decreasing linearly to -20 dBm at 100 kHz**
  - ✓ **remain at -20 dBm from 100kHz up to 500 kHz**

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Waste Water

- If evaporative valve cooling is used
  - ✓ **Water must be treated to remove minerals (reverse osmosis)**
  - ✓ **Chemical treatment is needed to avoid mould growth**
  - ✓ **Significant volumes of polluted backwash water may be produced**
  - ✓ **Generally maintenance is higher than with dry coolers**
  - ✓ **Water requirements can be significant.**
- Dry coolers are more frequently used to avoid these problems
  - ✓ **They are fully adequate and preferred in temperate climates**
  - ✓ **In hot climates**
    - They are less efficient than evaporative coolers
    - may result in higher device junction temperatures
  - ✓ **May produce more noise due to larger air volumes needed**

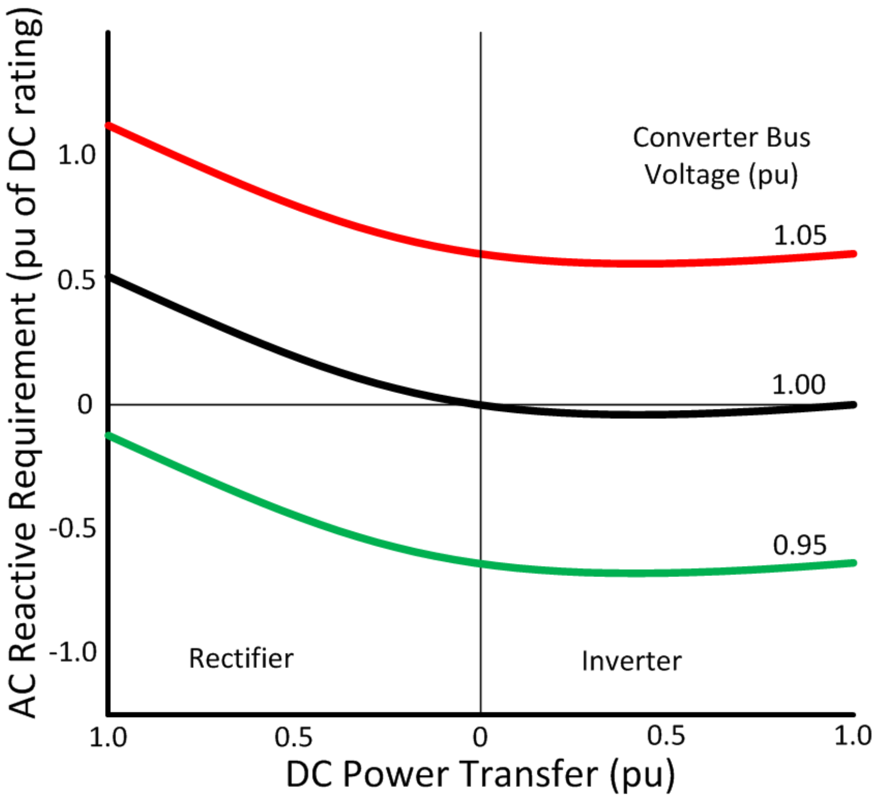
Reactive Power
Supply and Absorption

Reactive Power/ AC Voltage Control

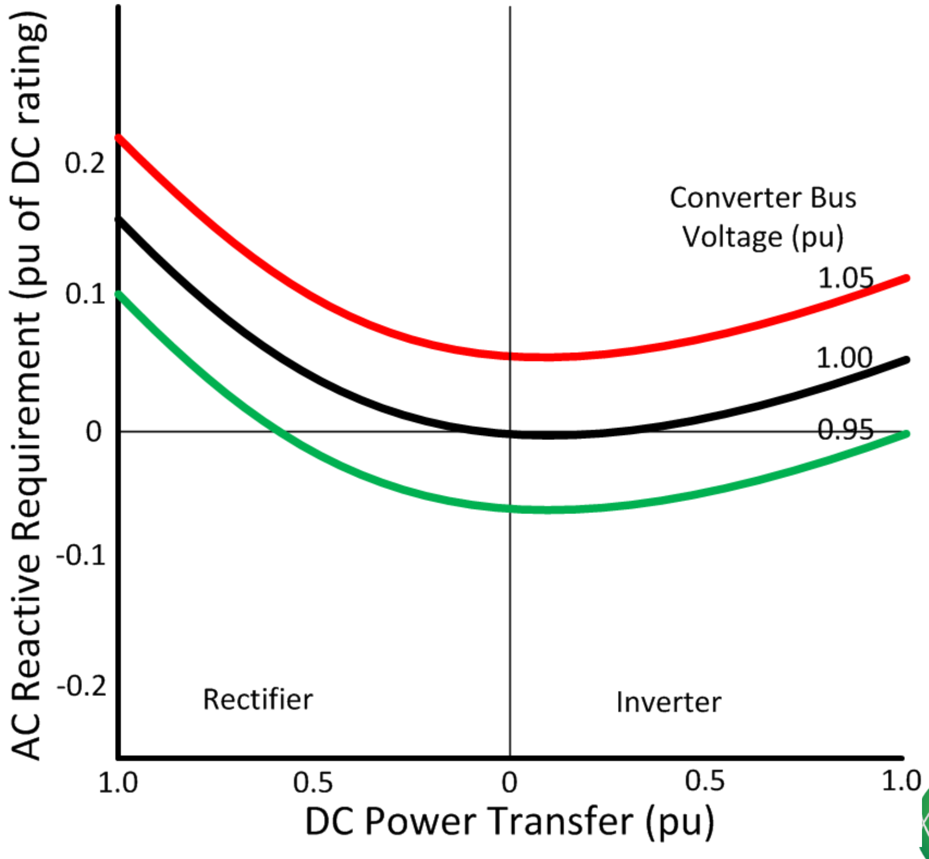
- Reactive power requirements are the sum of ac system requirements plus dc system requirement
- For LCC the HVdc requirement for reactive power is always positive and must be supplied from the system or from AC filters and capacitors
- For VSC the HVdc system can supply or absorb reactive power and extra capacitors are typically not needed.

AC System Reactive Power Requirement

Strong AC system



Weak AC System



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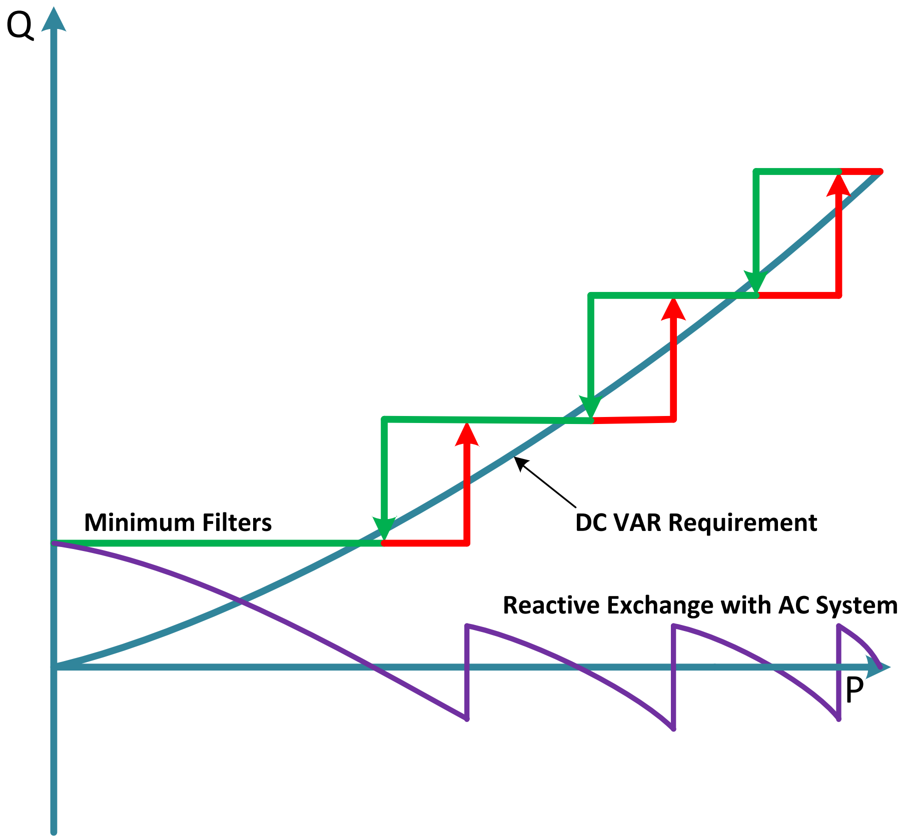
Reactive Requirement/Capability of HVdc System

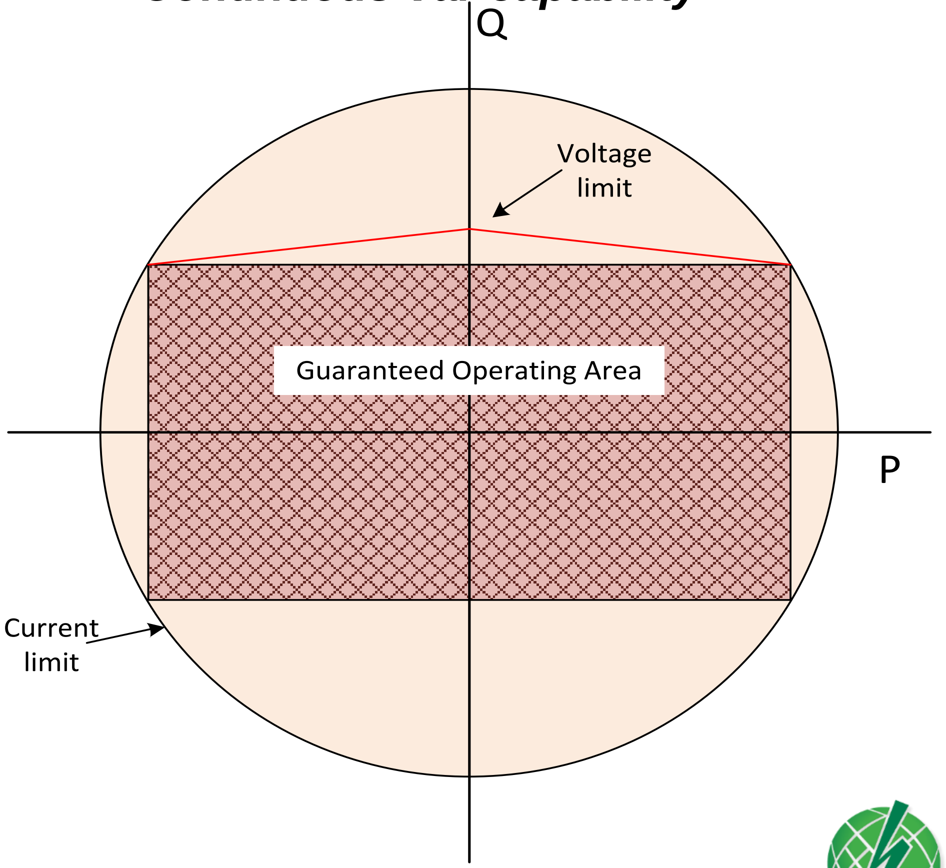
LCC System

(switched reactive Banks)



VSC System

Continuous Var capability



Observations

- With LCC a large number of switched banks may be needed if the dc system is large and the ac system reactive demand is high.
- This can result in high temporary overvoltage on load rejection (dc block) as well as high maintenance on breakers
- These disadvantages can to a large extent be avoided with A VSC system which can provide relatively high levels of supply and absorption in steady state. Exploitation of high levels of capacitive reactive support at low power transfer levels may require increased tap range.

Commissioning, Trial Operation and Performance Verification

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Commissioning

- Should generally follow existing Standards/Guides with possible supplemental tests defined by Owner or Contractor to reflect Project specific requirements (if any).
  - ✓ **TB 097 1995 SC 14 WG 14.12 System tests for HVDC installations**
  - ✓ **TB 697 2017 B4-63 Testing and commissioning of VSC HVDC systems**
  - ✓ **IEEE SA 1378 - Guide for Commissioning High-Voltage Direct-Current (HVDC) Converter Stations and Associated Transmission Systems**
- Any special DC/AC integrated system performance tests during commissioning should be defined by Owner at time of Contract and system configurations should be arranged by the Owner.

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Trial Operation

- Trial Operation should not have unrealistically long duration – durations of 2-6 weeks are considered realistic.
- Conditions for pass/fail and requirement for restart/repeat should be clearly defined in the contract.
- Schedule needs to allow for Trial operation with some possibility of at least 1 restart.
- Should ideally precede start of commercial operation to avoid questions of LD for failure to meet reliability and availability.

Verification of Reliability/Availability Performance

And Mitigation of Performance Issues

- Monitoring should be defined in the specification
  - ✓ **Should generally follow Cigré Protocol definitions**
- It is useful and recommended to have a burn-in period of 3-6 months prior to start of monitoring. (to avoid the early failure portion of bathtub curve)
- Should be monitored on an annual basis
- Remediation procedure for failure to perform should also be defined with a further monitoring period after remediation
- Requires a minimum of 3-year monitoring to allow one remediation plus continued monitoring for an additional 2 years
- The extended monitoring period beyond the commercial operation date generally requires a Performance Bond since full payment is usually made by that time
- Objective is to end up with a working system not liquidated damages

Thank you for your attention

Any Questions?

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