AC- DC Interaction
AC-DC Interaction

- AC/DC System interactions are concerned with
  - Voltage stability
  - Over voltages
  - Resonances
  - Recovery from disturbances
AC/DC System Strength

- Voltage stability conditions determine the type of voltage control and the type of reactive power supply.

- The level of Temporary Overvoltage influences station design, including thyristor valve and surge arrester ratings.

- The larger the ratio of shunt capacitor Mvar to ac system short circuit MVA, the lower is the resonance frequency.
An AC System Can Be Defined As “Weak” From Two Aspects...

- AC system impedance may be high relative to dc power at the point of connection.

- AC system mechanical inertia may be inadequate relative to the dc power infeed.
Short Circuit Ratio (SCR)

- SCR is an indicator used to characterize the strength of the power system.
  
  \[
  \text{SCR} = \frac{S}{P_d}
  \]

  Where 'S' is AC system three phase short circuit level in MVA at the Converter Terminal AC Bus with 1.0 pu AC Terminal Voltage, and \( P_d \) is the rated DC power in MW.

- The minimum value of 'S' at which the rated power \( P_d \) is transmitted is used when examining limiting operating conditions.
Short Circuit Ratio (SCR)

- A High SCR AC/DC System – SCR>3
- A Low SCR AC/DC System - 2<SCR<3
- A Very Low SCR AC/DC System – SCR<2

A scheme may be operating with High SCR for most of the time, but it may appear as Low or Very Low SCR scheme during emergency, at ac system outage conditions.

In such cases the scheme must be designed to operate for those conditions, unless DC power reduction is acceptable.
**Effective Short Circuit Ratio (ESCR)**

Shunt capacitors including ac filters connected at the ac terminal of a DC link can significantly increase the effective AC system impedance.

$$\text{ESCR} = \frac{(S-Qc)}{Pd}$$

Where $Qc$ is the value of three phase fundamental Mvar in per unit of $Pd$ at per unit AC Voltage of Shunt Capacitors connected to the Converter AC Bus Bar.
Inadequate and Zero Mechanical Inertia

- Turbine – generators in an ac system represent a large rotating mass. Their inertia ensures that an ac system does not collapse due to system fault.

- If all the power is brought into a system by DC and there is no local generator, then that system will have no mechanical inertia.

- To avoid frequency reduction by more than 5% due to a system fault, the effective DC Inertia Constant, Hdc should be greater than 2s.
Harmonic Transfer

- A DC Convertor appears substantially a source of harmonic current. It act as a constant current source on ac side and constant voltage source on dc side.

- The effective impedance in which this harmonic current flows is that of the complete system.

- Weak system may cause Core saturation Instability in the Convertor Transformer and Complementary Resonances.

- Back-to-back schemes are probably most at risk than long DC Transmission lines and Cable Systems.
Temporary Overvoltages

Larger disturbances result in temporary overvoltages and if resonance conditions in the ac network are close to one of the lower order harmonics, the overvoltage can be amplified. This is often the case with weak system.

Temporary overvoltages influence the design of arresters connected to ac and dc side.

Shunt capacitors and AC filters in DC station decrease the SCR on the bus bar and influencing TOV. TOV can be reduced by using Metal oxide gapless arrester and by switching of capacitors banks and ac filters.
Effect of AC System strength on Commutation failures

- Due to weak ac system connected to inverter, Commutation failure may occur on inverter side.

- Recovery after faults is usually easier with a high SCR than a very Low SCR system.

- Post fault system swings and voltage instability at the inverter bus of certain weak system may cause subsequent commutation failures. In these cases, slow rate of dc recovery is desirable and must be optimized.
Subsynchronous Torsional Interaction Between DC Convertors And Nearby Turbine Generators

Torsional Interaction:
- All phenomena related to interactions between the electrical power system and turbine/generator torsional mechanical modes of oscillation.
Torsional Interaction phenomena can be split into three main categories:

1. SSR = Subsynchronous Resonance:
   Resonance condition between torsional mode(s) of Turbine /Generator shaft and a natural frequency of the electrical power system.
   SSR can occur when series compensation is used the power system.

2. SSO = Subsynchronous Oscillations:
   (also known as DDSO = Device dependent subsynchronous Oscillations)
   Category of interaction between generator torsional system and power system components and power control system.
Torsional Interaction phenomena can be split into three main categories:

3. SSTI = Subsynchronous Torsional Interaction:

Type of DDSO which occurs between thermal generators and controls of large power Electronic Devices (e.g. HVDC) in the power system.
Mechanism of SSR

The network has a resonance frequency at $f_{el}$ with:

$$f_{el} = f_0 \times \sqrt{\frac{X_c}{X_N}}$$

with $f_0 = \text{frequency of power system}$

$X_c = \text{series capacitor reactance}$

$X_N = \text{total network reactance}$

$X_c$ is a percentage of the transmission line reactance $XL$ therefore the resonance frequency is always less than the nominal system frequency (subsynchronous)
Mechanism of SSR

- There exists a resonance in the ac system at \( f_{el} < f_0 \) (for example as a result of a series capacitor) and a mechanical resonance of the shaft at \((f_0 - f_{el} = f_{mech})\).
- Excitation of the system.
- Currents of the frequency \( f_{el} \) in the AC system are excited.
- In the rotor currents of the frequency \( f_0 \pm f_{el} \) are induced \((f_0-f_{el}=f_{mech})\). These currents lead to an oscillation of the generator/turbine shaft.
- The terminal voltage contains the frequencies \( f_0\pm f_{mech}(f_0-f_{mec}=f_{el})\)
- There exists a feedback loop. If the phase shift is unfavorable positive feedback can occur instability of the torsional oscillation.
Mechanism of SSTI

- If generator rotor is perturbed slightly from its steady state operating speed the ac bus voltage is changed. The ac voltage, having been both amplitude and phase modulated at natural torsional frequency contain side band frequency components.

- The ac-dc conversion process act as a demodulator in transposing fundamental frequency to dc on which torsional frequency is superimposed.
Mechanism of SSTI

- In current control mode, torsional frequency component on DC current appears as a control error in DC current regulator feedback loop and produces corresponding change in firing angle and hence AC current at the same frequency.

- This change in current produces a change in generator electrical torque. The increasing speed perturbations cause torsional vibrations in the shaft structure of the generator leading to torsional stresses and fatigue of the shaft.
Mechanism of SSTI

- Steam turbine generator shafts are more susceptible to torsional interaction than hydro generator shafts because:
  - Steam turbine generator have several torsional frequencies in the subsynchronous frequency range whereas hydro generator have typically only one torsional frequency in this range.
  - Hydro generator have considerably higher mechanical damping.
Factors Affecting Torsional Stresses

- It has found that generating units near a rectifier terminal are vulnerable to torsional interactions.

- The units near an inverter terminal do not experience much disturbances.

- The transfer of harmonics from one end of the dc link to other end may possibly result in steady state oscillations that could excite torsional modes nearby turbine-generators.
Factors Affecting Torsional Stresses

- The current and power control of an HVDC link is the main reason for negative electrical damping.

- Negative damping can increase when the firing angle of the HVDC link increases.

- The interaction between a generator and HVDC convertor depends on electrical distance between them.
Based on the results of the EPRI research project, the influence of dc control on torsional damping of a particular generator can be quantified by Unit Interaction Factor (UIF) as:

\[
UIF_i = \frac{MVA_{HVDC}}{MVA_i} \left(1 - \frac{SC_i}{SC_{TOT}}\right)^2
\]
Method of Investigation...

Where:
\( UIFi \) = Unit Interaction factor of the generator

\( MVA_{HVDC} \) = Rating of DC system

\( MVA_i \) = Rating of generator

\( SC_i \) = Short circuit capacity at the dc commutating bus excluding the generator

\( SC_{Tot} \) = Short circuit capacity at the dc commutating bus including the generator

\[
UIFi = \frac{MVA_{HVDC}}{MVA_i} \left(1 - \frac{SC_i}{SC_{Tot}}\right)^2
\]
Method of Investigation...

- For unit interaction factor less than 0.1, there is very little interaction between the dc controls and the turbine generator torsional oscillations.

- Larger values of UIF may need detailed studies an corrective action in the HVDC system.
Solutions to prevent Torsional Stresses

- HVDC control system implemented with supplementary stabilizing control called Sub synchronous Supplementary damping Control (SSDC), which is sensitive to shaft motion of electrically close generators and which adds sufficient damping to permit operation in a system condition which would otherwise be unstable.

- Generators that have any risk of torsional interactions, with HVDC links or other devices, equipped with protections (alarm and trip)
THANK YOU