Agenda

- What is reactive power?
- Uncompensated cable links – critical length
- Tuned compensation – perfect balance
- The Icelandic story – an example from a pre-study done by ABB
- Some conclusions
What, in fact, is reactive power….

Basic truths:
1. No macroscopic change in energy can be instantaneous
2. Electrical power can only be transmitted with interacting electric and magnetic fields (EM-fields)
3. Electrical active power is created with voltage (electrical field) and current (magnetic field) in phase with each other

If U and I not in phase, we introduce:
1. Inductance (L) → a constant related to magnetic energy
2. Capacitance (C) → a constant related to electrical energy

The reactive power is a mathematical (engineering) way to take into account the time lags between voltage and current in a transmission system!

- If U and I in phase: Active Power
- If U and I not in phase: Reactive Power
... and which are the consequences for the network, using cables?

- Voltage support during high load conditions
- Too high voltage during low load conditions
- Normally lower losses but for long uncompensated links, higher losses
- Higher short circuit power in the network
- May improve transient stability
- May prevent voltage collapse
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Typically, the capacitance increases with the rating, i.e. the larger conductor cross-section the higher capacitance ($C'$):

- 132 kV: 0.13 to 0.34 $\mu$F
- 220 kV: 0.13 to 0.27 $\mu$F
- 400 kV: 0.13 to 0.23 $\mu$F

The critical length ($L$) can be estimated using the simplified formula:

$$L \approx \frac{P_{tot}}{n \omega \cdot C' U_0^2}$$

where $P_{tot}$ is the total power rating, $n$ is the number of phases, $\omega$ is the angular frequency, $C'$ is the mutual capacitance per phase, and $U_0$ is the phase voltage. 

![Graph showing critical lengths for different power ratings and conductor sizes]
Uncompensated Cable Links – Critical lengths (2)

<table>
<thead>
<tr>
<th>U [kV]</th>
<th>132 kV</th>
<th>220 kV</th>
<th>400 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q [MVAr/km, and phase]</td>
<td>0,2 – 0,7</td>
<td>0,7 – 1,4</td>
<td>2,2 – 4,2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>U [kV]</th>
<th>132 kV</th>
<th>220 kV</th>
<th>400 kV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical length [km]</td>
<td>130-150</td>
<td>120-140</td>
<td>60-90</td>
</tr>
</tbody>
</table>

There may be either technical or economical reasons for compensation with 10-20% reduction in current or 40-60% of $L_c$!
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Tuned Shunt Compensated Cable Links

- **Voltage limitation at 66 kV/100 km**

- **Indicates normal range of critical length**

- **Indicates possible approximate border between AC and DC**

At 75 km:
- Power (P): 1020 MW (-5%)
- Reactive Power (Q): 335 MVAR in each end

At 220 kV/120 km:
- Power (P): 300 MW (-11%)
- Reactive Power (Q): 180 MVAR in each end

- **400 kV**
- **220 kV**
- **132 kV**
- **66 kV**

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Cost example for fixed inductive compensation 220 kV/400 MW

- Needed power consumption for 120 km: 2x180=360 MVAr
- Cost for the cable for 60 km (0,5 Lc): 1 curr/MVA
- Cost for fixed shunt compensation: 0,15 curr/MVAr
- 10% (=40 MW) decrease in rating: 40 curr
  - ⇒ Available MVAr's is 40/0,15=267 MVAr < 360 MVAr
- 20% (=80 MW) decrease in rating: 80 curr
  - ⇒ Available MVAr's is 80/0,15=533 MVAr > 360 MVAr

**Conclusion:** It may be economical justified with fixed inductive shunt compensation when the derating is between 10-20%.
Typical voltage and current profiles for a tuned system

Current profile

Voltage profile
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Severe weather conditions implied a lot of faults on the OH-line ring.

This implied problems with transient stability in the system.

Solution: A purpose-built 200 km long XLPE cable crossing the island.
The solution...

1x300, Al
Ins. thickness: 12 mm
Cu-wires/Al-laminate
HDPE-sheath

18 reactors, 10 MVAR each
10 MVAR Reactor
132 kV XLPE Cable
500 mm² Al

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... and the benefits of using the cable here

- The cable links is preventing post fault voltage collapse and improves transient stability for the whole network!
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Optimum reactive power control - Conclusion

- Degree of compensation changes with the characteristics of the network and the reactive power loads.

- If the cable link is operating "far from" the loads (inductive machines etc), the higher degree of compensation you need. Remote synchronous generators has a $\cos(\phi)$ close to 1.

- In EHV networks it may be sufficient with fixed compensation with a high degree of compensation. For long lengths, a huge amount of reactive power is needed, though.

- In HV networks (which are closer to the loads) a lower degree of compensation may be needed. Additionally, SVC-Classic or SVC-Light control may be needed.

- Voltage limitations (5-10%) are mainly present in HV networks below (100 kV/50-100 km) for tuned systems. For higher voltages/lengths, the charging current, losses etc set the limitations.

- 40-60% of the critical length (10-20% decrease in rating)— take a look if inductive shunt compensation may be cost efficient!

- There is no extra "MW-loss" for HVDC-Light systems. It is always interesting to look at the extra advantages, which are offered with DC-control as well as the other known benefits from extruded cable systems in general.
Thank You!

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