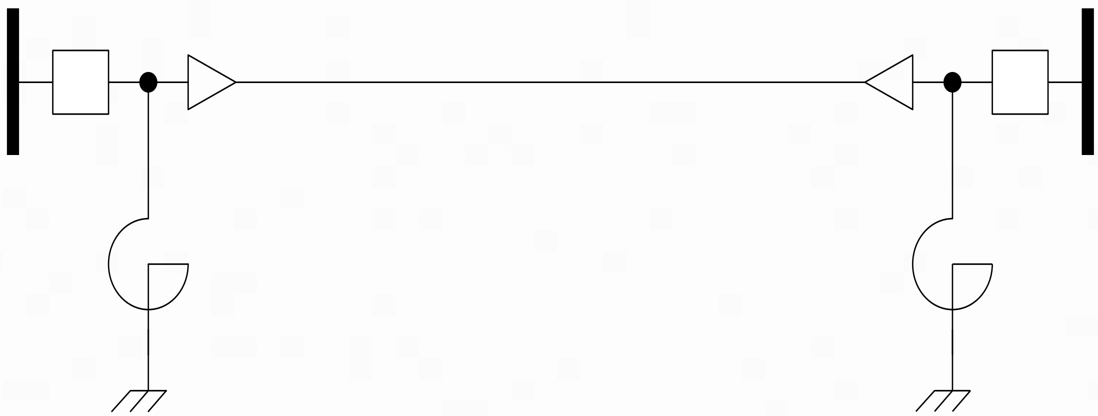
Technical (electrical) issues regarding the integration of a long distance underground or submarine cable in the network

Luigi COLLA

Terna

SAPIENZA
Università di Roma

Cable line with line-connected shunt compensation at both terminals



Cable length reduces maximum transmissible active power
DC offset of no-load energization current in highly shunt compensated cables
Risk of low order harmonic resonance

Uneven loading when cables are paralleled with overhead lines
Short circuit level increases in the network

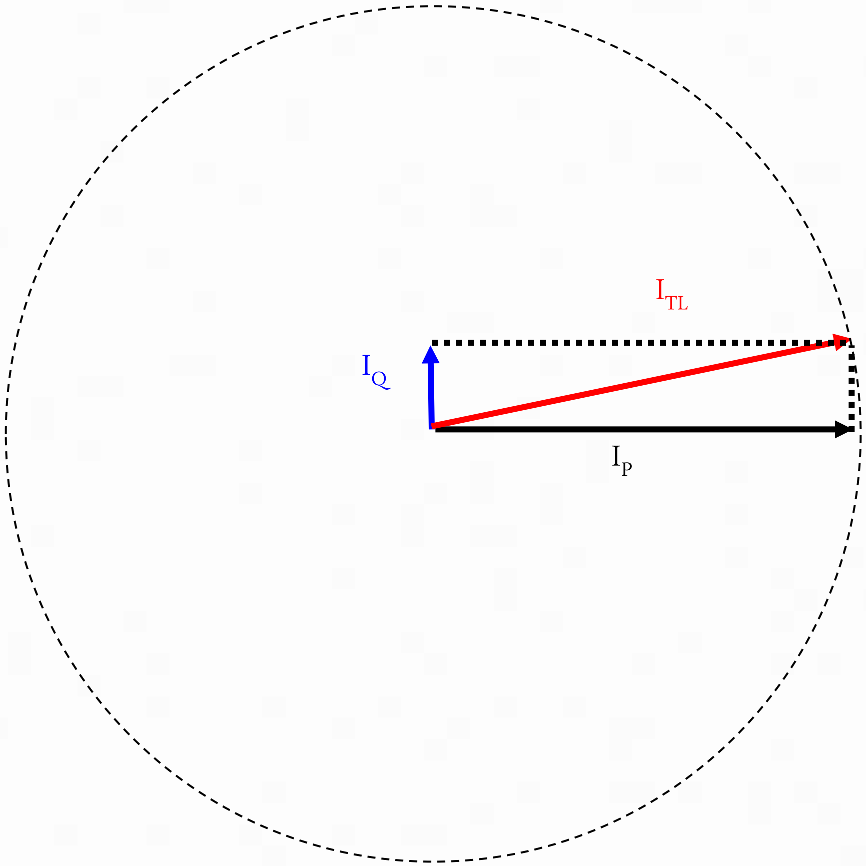
Temporary overvoltages
Self-excitation of synchronous generators
Capacitive switching
Lightning protection

Blue: specific issues of long cable lines
Black: issues that are normally dealt with by ordinary grid planning analyses
Green: issues that can be mitigated by proper shunt compensation design

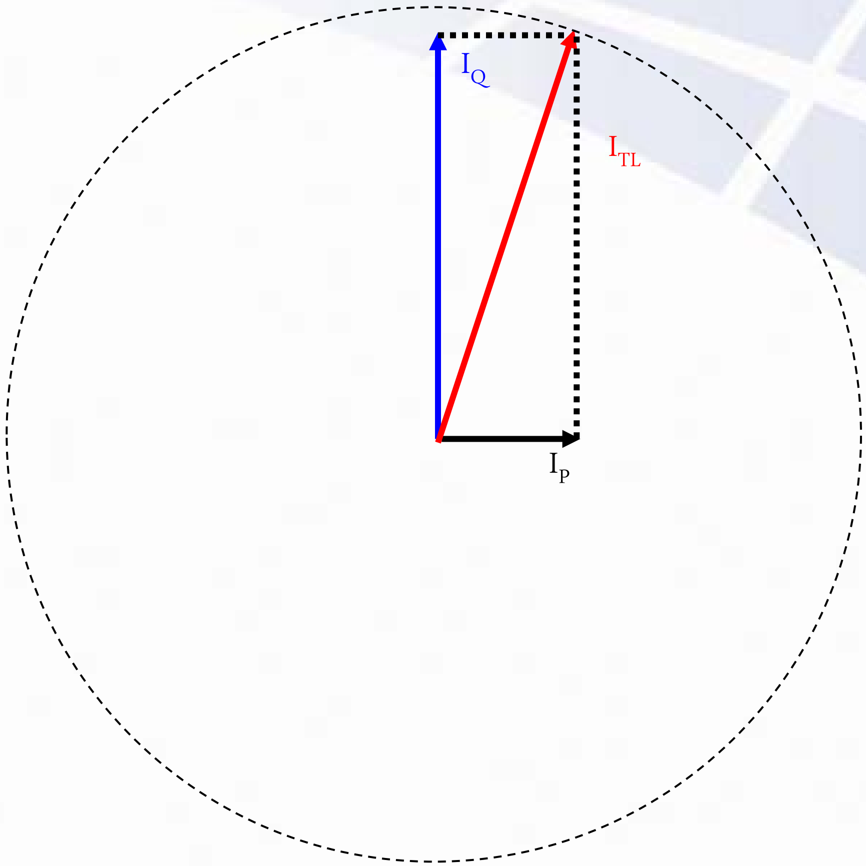
Cable length reduces maximum transmissible active power

Ampacity is still the fundamental limiting factor for the length of cable between compensating stations. Active and **charging current** load the cable; maximum active power transmission is attained when the same reactive power is evacuated at both ends of the CL. Neglecting losses, this corresponds to having **equal terminal voltages**.

Short cable



Too long cable

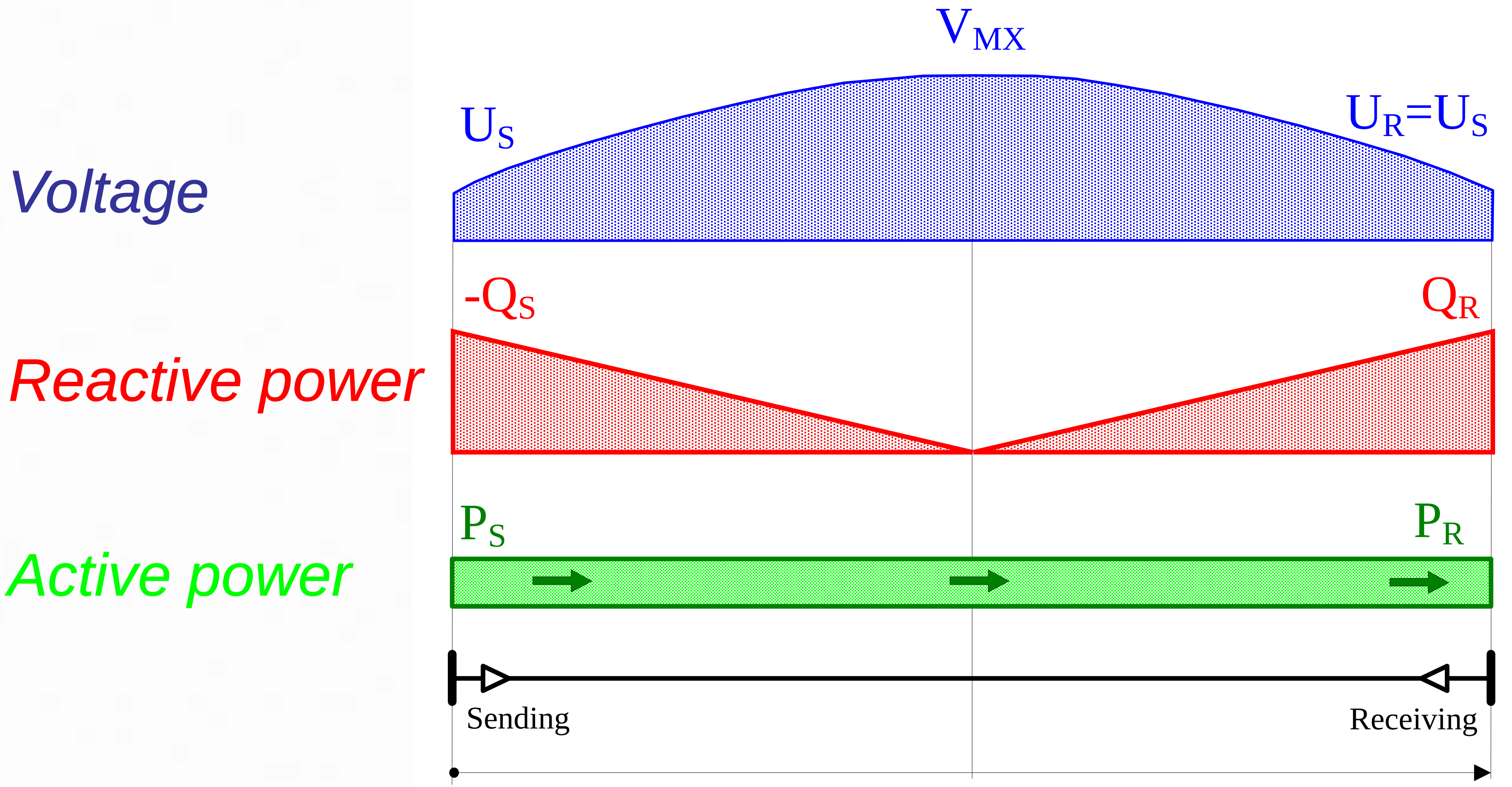


I_{TL} = Maximum current at thermal limit

I_Q = "Capacitive" current

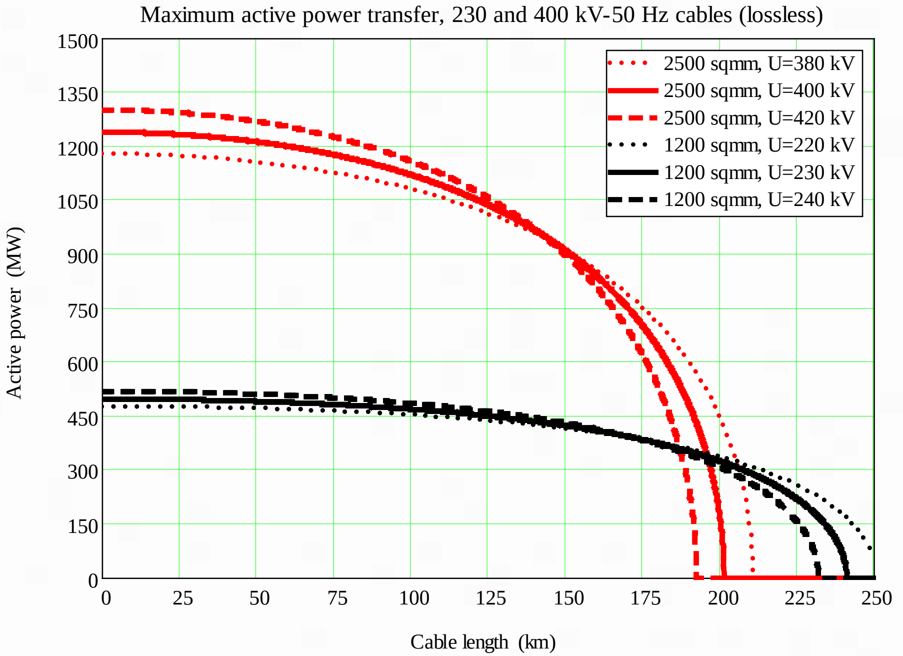
I_P = "Active" current

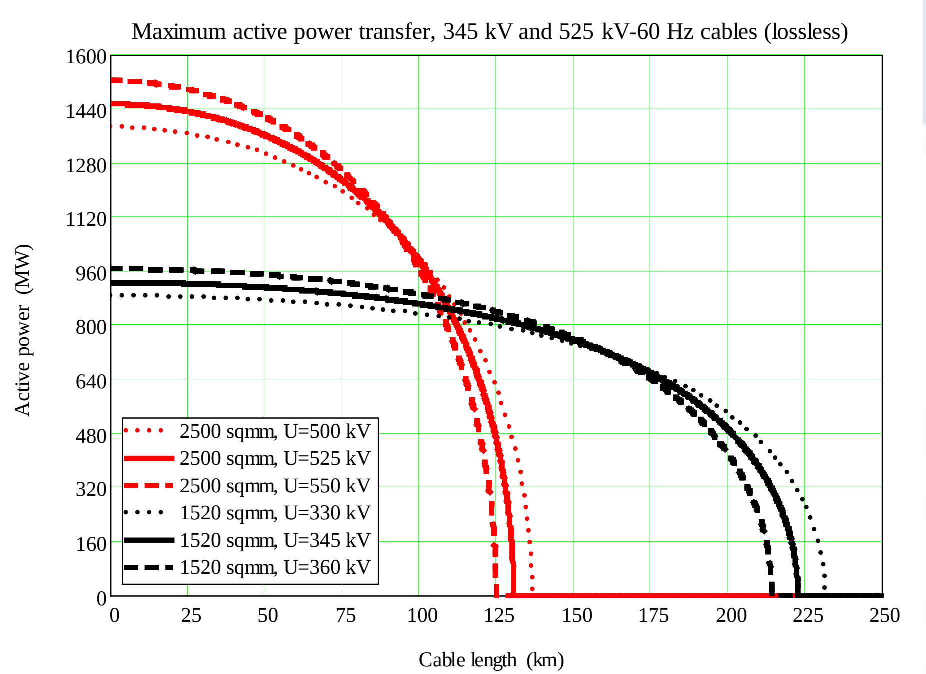
Optimal operation of a long cable line



Maximum length of AC cables

- P_{Max} *vs. L* plots





- Approximately:
- Cable lines long $\mathbf{0.75 \cdot} L_{Max}$ retain $P_{Max} \cong \mathbf{0.75 \cdot} S_Z$

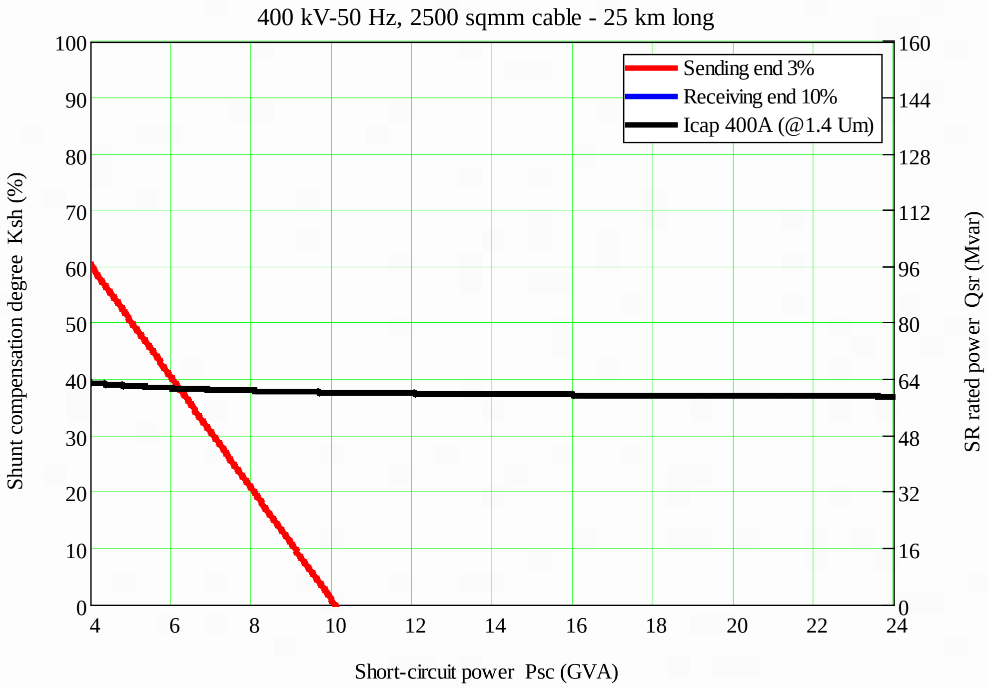
Shunt compensation

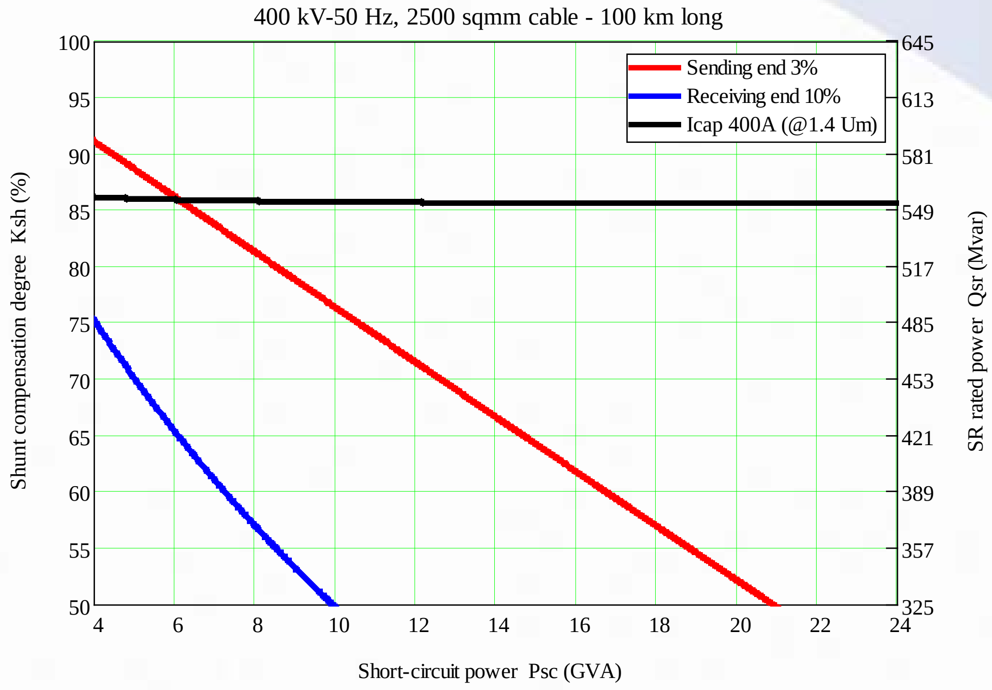
Shunt compensation design was based on open-ended operation. Figures for 400kV-50 Hz CLs are:

- **Energizing bus** voltage variation: $\Delta U_S \leq 3\%$
- **Receiving** (open) **end** overvoltage: $\Delta U_R \leq 10\%$
  - For slow reclosure it should be $U \leq 1.2 U_M$
  - TERNA 400 kV MOSAs have U_c=265 kV
- **Cable-charging current**: $I_c \leq 400$ A (U=1.4U_M)
  - Rated cable-charging breaking current of TERNA 400 kV CBs is 400 A (IEC 62271-100)

Shunt compensation

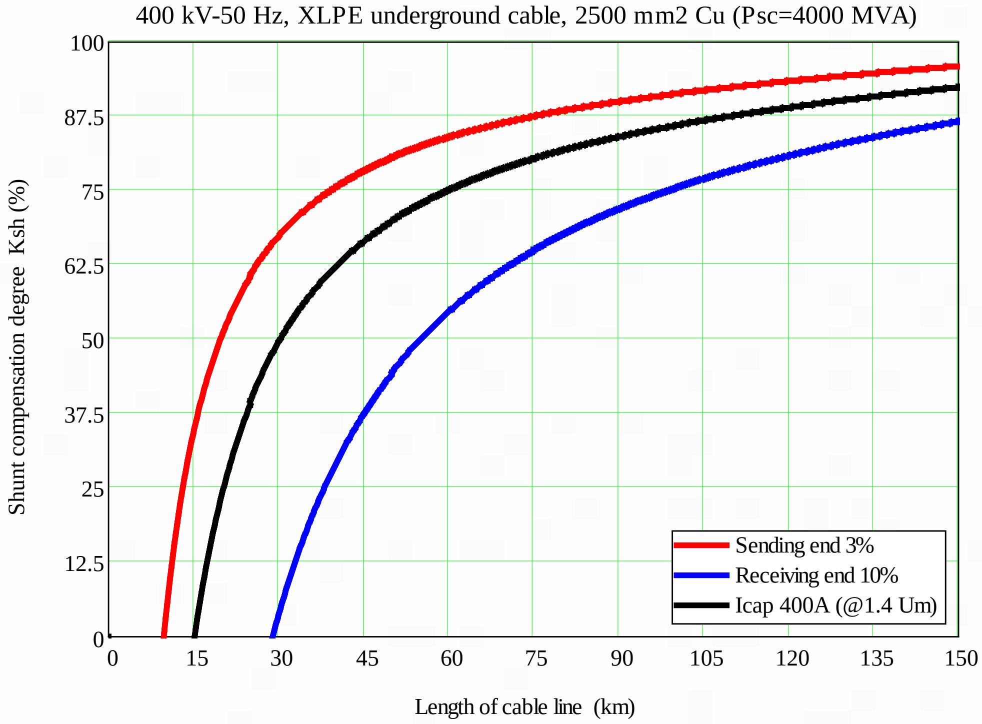
Examples of shunt compensation degree of n.2 400kV cable lines vs. short circuit power

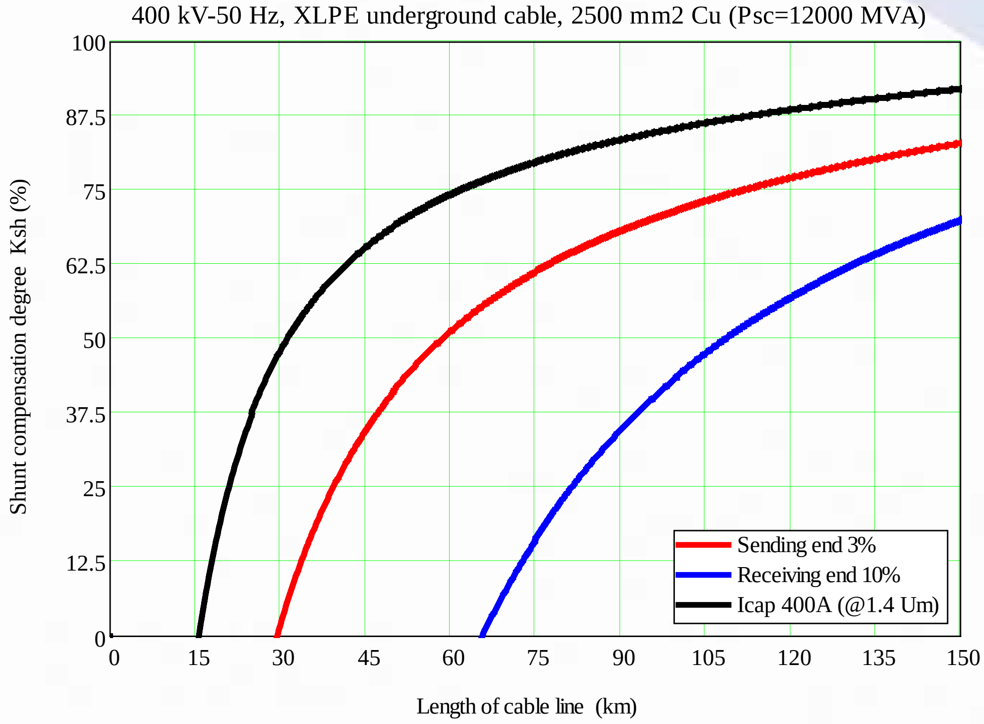




Shunt compensation

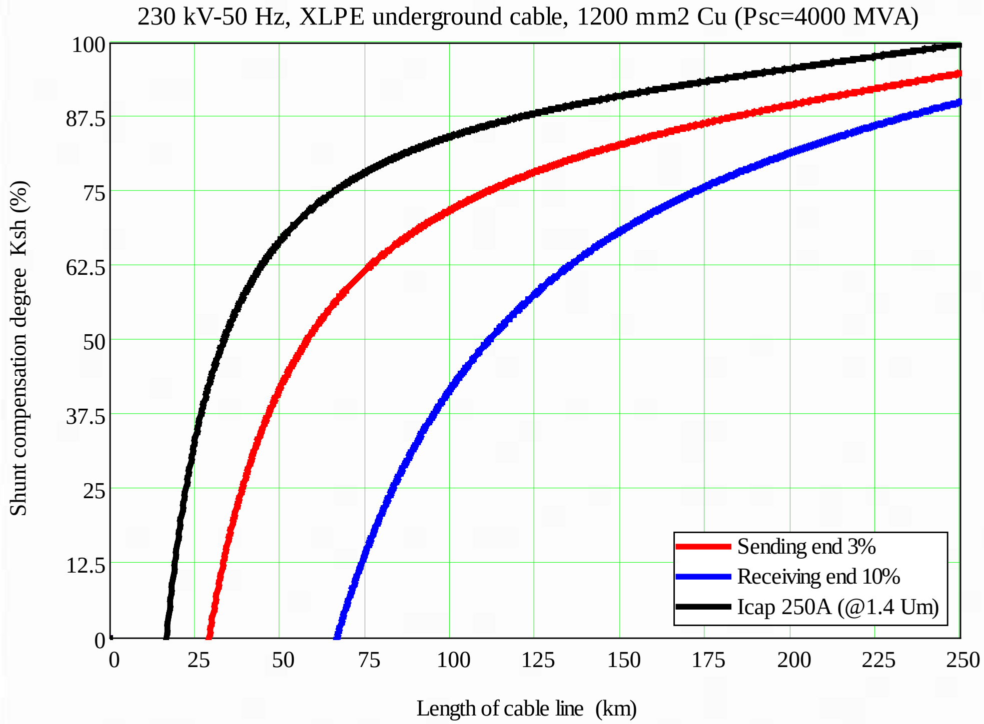
Examples of shunt compensation degree vs. 400kV cable line length. 2 short circuit power values

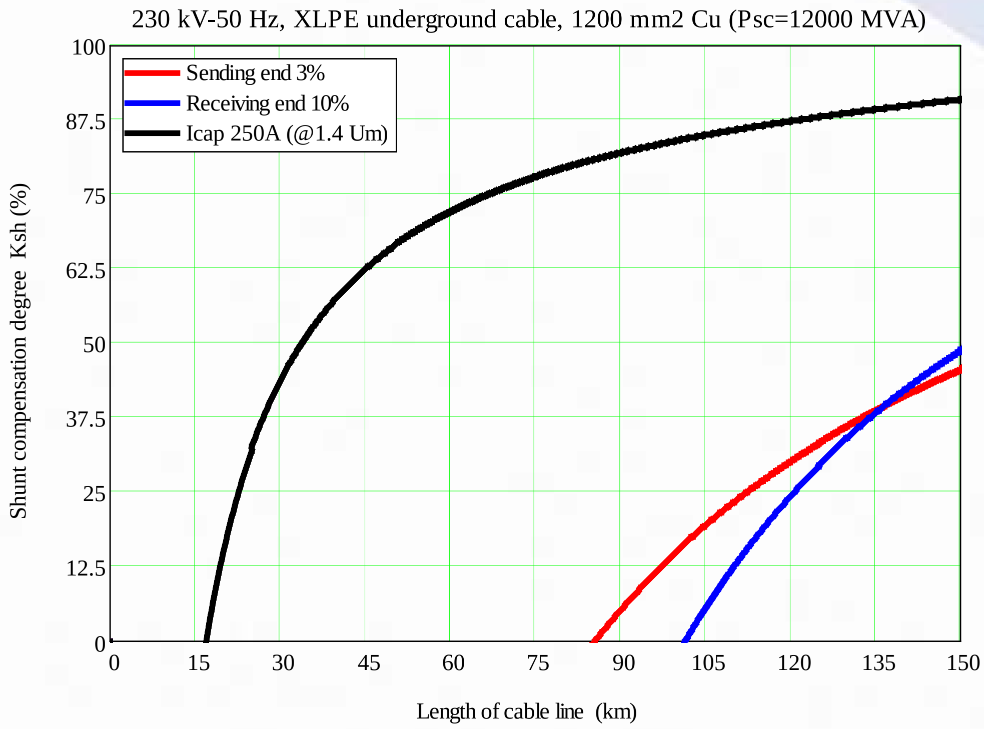




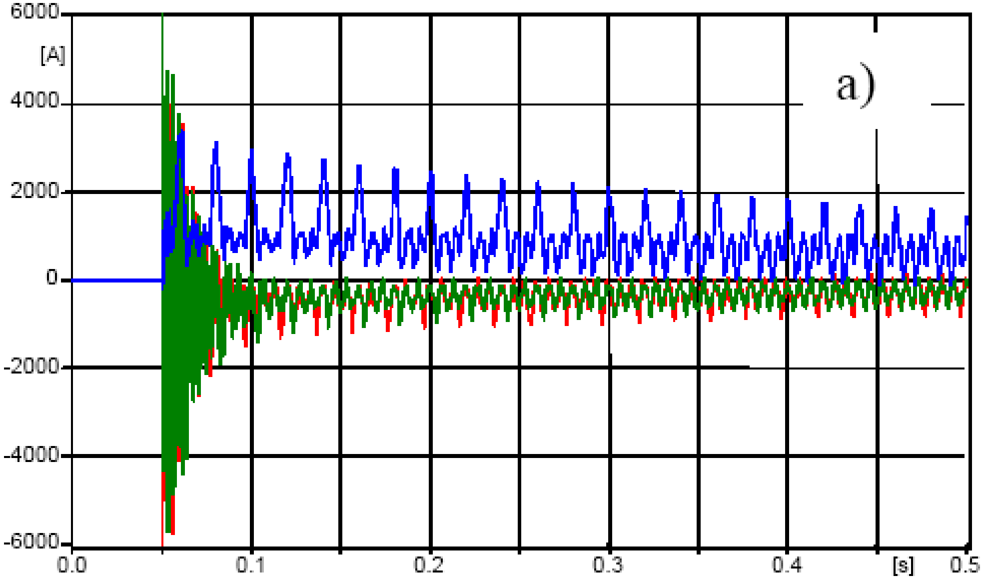
Shunt compensation

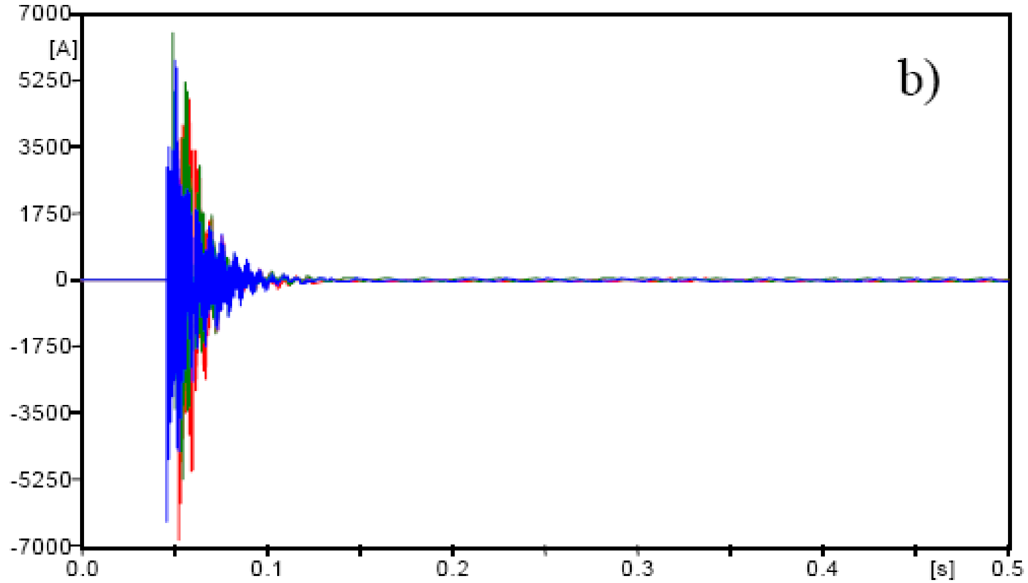
Examples of shunt compensation degree vs. 230kV cable line length. 2 short circuit power values





DC offset of no-load energization current





Phase currents in case of no-load energization of a 43 km long 400kV submarine cable line.

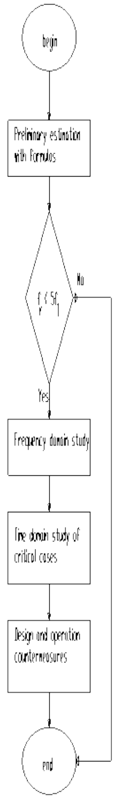
a) Synchronized switching not simulated

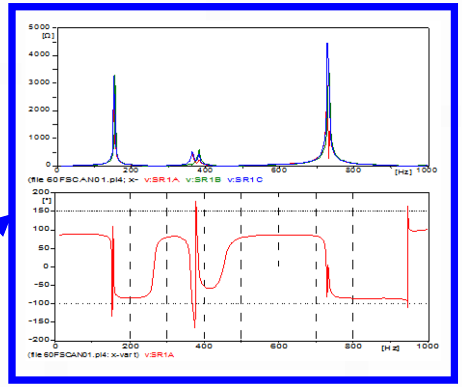
b) Synchronized switching simulated

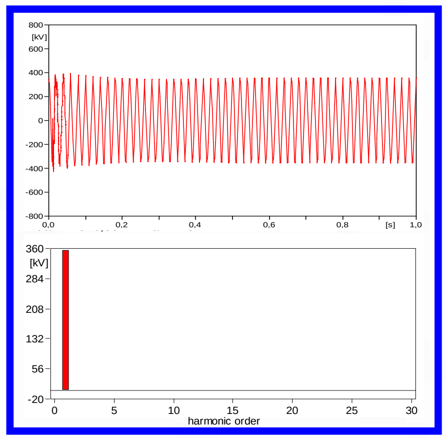
Circuit breakers ability to force the current zero crossing has to be verified/tested

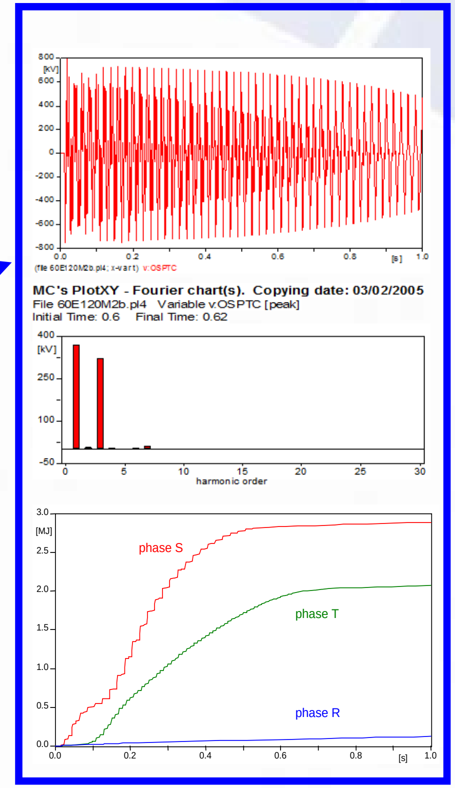
Risk of low order harmonic resonance

$$f_r = f_1 \sqrt{\frac{S_{sc}}{Q_{cap}}}$$









Risk of low order harmonic resonance

Design and operation countermeasures could include:

- Use of synchronized switching
- Proper specification of shunt reactors saturation characteristics
- Limit to the specification value of cable capacitance
- Restrictions to the allowed grid configurations (to be avoided if possible)

Conclusions

- Transmitting power over long lengths with HV and EHV cable lines **is feasible**
- Projects including long cables require an **ad hoc system design**
- The longer is the cable length the higher is the expected interaction with the network and therefore **the design horizon has to be extended to the network** (f.i. risk of resonances)
- To ensure the feasibility of a project including a long cable is therefore necessary to focus also on the network and on the expected **system operating conditions**

Some references

- M. Rebolini, L. Colla, F. Iliceto "400 kV AC new submarine cable links between Sicily and the Italian mainland. Outline of project and special electrical studies" CIGRE 2008 conference
- L.Colla et alii “HVAC submarine cable links between Italy and Malta. Feasibility of the project and system electrical design studies” CIGRE 2010 conference
- L. Colla, F. M. Gatta, F. Iliceto, S. Lauria “Design and operation of EHV transmission lines including long insulated cable and overhead sections” IPEC 2005 Singapore, November 2005
- L. Colla, F. M. Gatta, S. Lauria. “No-load energization of a long 380 kV cable: temporary overvoltages”. EEUG-Meeting 2006. Dresda, September 2006
- S. Lauria, F. M. Gatta, L. Colla. "Shunt compensation of EHV Cables and Mixed Overhead-Cable Lines" IEEE Power Tech Conference 2007
- L. Colla, S. Lauria, F. M. Gatta "Temporary Overvoltages due to Harmonic Resonance in Long EHV Cables" in Proc. International Conference on Power System Transients (IPST 2007), Lyon 2007
- L. Colla, S. Lauria, F. M. Gatta "Lightning Overvoltages in HV-EHV “Mixed” Overhead-Cable Lines" in Proc. International Conference on Power System Transients (IPST 2007), Lyon 2007