Project reality I: the Netherlands: 20 km AC-cabling 380 kV in the Randstad Area Study and monitoring

Dr. M. Popov, dipl-ing, TU Delft

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This Presentation

- Why applying HV cables?
- Facts
- Research activities at TU Delft and TU Eindhoven
- Conclusions

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I. Why cables?

- Provide better environment and landscape (90 % of the distribution network in the Netherlands consist of cables)

- Sometimes it is inevitable to apply cables:
  - densely-populated areas - Randstad (NL) , Tokyo (J),
  - Interconnection of islands, crossing natural reserve
  - Interconnection with offshore windparks

- There is no big experience with long HVAC hence

  Cigre WG C4.502 on "Technical Performance

  Issues Related to the Application of Long HVAC Cables" was launched

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Randstad380 total cable length 20km

4000A/2 cables per phase ca. 1000 Mvar at 400kV

Compensation at 380kV transformers 11x100 Mvar

10km in Zuidring Wtr-Bwk (ca. 2012 in operation)

10km in Noordring Bwk-Vhz-Bvw (ca. 2014 in operation)

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Related 400 kV cable Projects

Example	Function	Number of Circuit	Capacity [MW]	Cable length / circuit [km]	Total cable length [km]
Danish cable	core	1	975[1]	22	66
Berlin cable	core	2	1150[1]	12	72
Japanese cable	core	2	1200[1]	40	240
Spanish cable	core	2	1720[2]	13	156
Dutch Cable	artery	2	2640[2]	20	240
Sicily-Italian mainland	core	2	2000[1]	38	228

1) 1 cable per phase
2) 2 cables per phase

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II. Facts: Cable vs OHL (Data)

- Capacitance per unit length 20 times larger
- Reactive power generation ~24 Mvar/km vs<1MVar/km
  (based on a TU Delft study)

→ Much greater Level of shunt compensation

- Series inductance 5 times smaller
- Surge impedance is about 10 times smaller
- Wave propagation speed is √e smaller

→ Lower resonance frequencies

Cross-bonding and grounding

→ Difficulties to obtain parameters

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III. Research assignment TU Delft and TU/e

Goals:

- to provide information about the behavior of the 380 kV cable within a short- and a long-time operating scale with respect to some transient and steady-state phenomena which might occur
- to show its influence on the rest of the Dutch Power System when it is in/(out of) operation
- to provide on-line monitoring in order to increase the cable and system reliability

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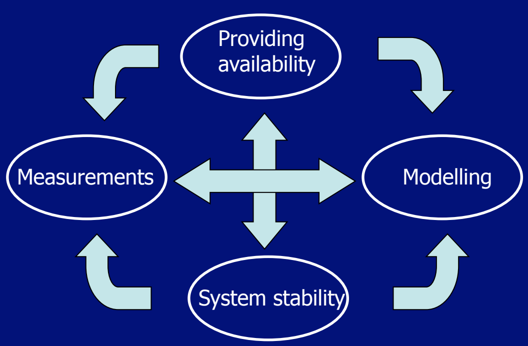
Research in Randstand 380 kV

- Due to the identified problems, TenneT wants to investigate:
  - Steady-state phenomena
  - Transient phenomena
  - Resonance phenomena
  - Monitoring possibilities
  - Providing availability



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Steady-state and Transient phenomena in Line-cable Systems

Contribution TU Delft (G. Hoogendorp, M. Popov, L. van der Sluis)

- Research on the amount of compensation needed for this project and its influence on the voltage levels in the system
- Switching phenomena and reflections in the system line-cable-line
- Measurements of the switching responses and cable modeling in a broad frequency range
- Investigation of the effect of lightning overvoltages in the system
- Modeling and measurements of the switching phenomena
- Investigation of the switching overvoltages during 1-phase fault current

Analysis by

Simulation on "Randstad 380 kV" and also including other circuits
Experimental verification and frequency-dependent impedance (if possible)

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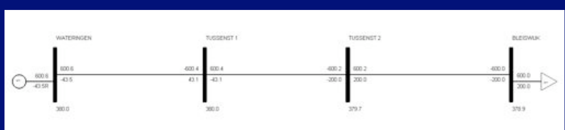
Steady-state and Transient phenomena in Line-cable Systems

Contribution TU Delft (G. Hoogendorp, M. Popov, L. van der Sluis)

Circuit Wateringen-Bleiswijk

only line



line–cable-line

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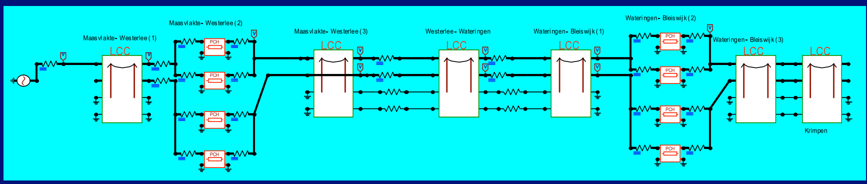
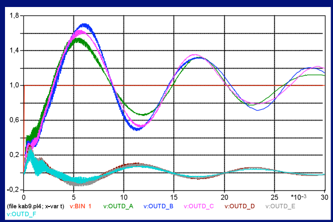
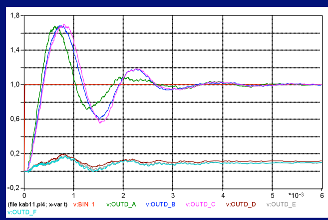
An example of simulated energisation of the Randstad 380 kV





Voltage response at Wateringen with line-cable-line Wateringen - Bleiswijk



Voltage response at Wateringen with line-line-line Wateringen - Bleiswijk

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Resonances in Combined HV Line-Cable

Contribution TU/e (Lei Wu, Peter Wouters, Fred Steennis)

Reported resonance related over-voltages include:

- Harmonic resonance over-voltages
- Overvoltage due to no-load energising / disconnection
- Superimposed frequencies due to load shedding
- Slow decaying DC component due to heavy shunt compensation
- Fault clearing over-voltages
- Effects on other systems when switching cables

Analysis by

- Simulation on "Randstad 380 kV" and also including other circuits
- Experimental verification (if possible)

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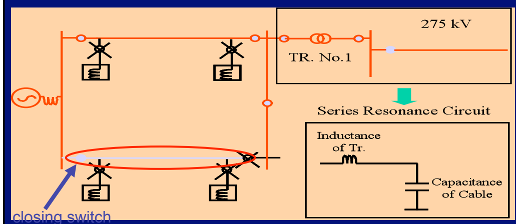
Resonances in Combined HV Line-Cable

Examples from literature (L. Colla et al & Tokyo Electric Power Company)

- **400 kV AC cable to Sicily – Italy mainland (about 40 km oil-filled cable)**

Estimate lowest resonance: $f_{res} = f_{pow}\sqrt{\frac{S_{cs}}{Q_{cap}}}$

with S_{cs} short circuit power at cable connection
and Q_{cap} charging reactive power of cables
Resonance system close to 3[rd] harmonics (150 Hz)



- **Coupling 500 kV Shin – Toyosu line by 275 kV network (Japan)**

Energizing 500 kV line resulted in switching over-voltage propagating in 275 kV network with frequency matching its series resonance
Result: transformer failure

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Failure investigation and analysis of 380kV cable circuit

Contribution by TUD (X. Chen, J.J. Smit)

Investigation including:

- Survey on 380kV XLPE cable service experience to interview several TSO's
- Survey on typical failures and repairing activities in 380kV cables
- Analysis of typical failures
  - Critical factors of operation related to failures
  - Quality control of cable system related to failures
  - Online monitoring techniques to lower possible failures
  - Current and voltage measurements (compare modeling and practice)
- Maintenance and special considerations for Randstad cable system

Challenges:
Limited existing service experience of 380kV cables

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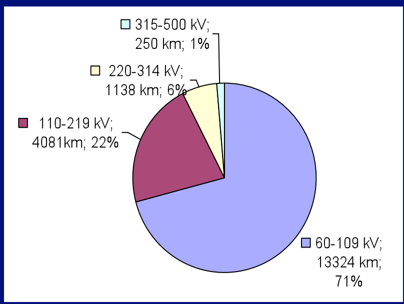
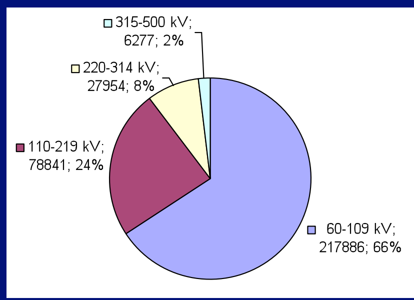
Service Experience of XLPE cables

Data source: CIGRE brochure 379, WG B1.10



XLPE cable circuit length in service



Quantities of accessories in cable circuit

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IV. Conclusions

- 380 kV cable systems of the length and power requirements as used in Randstad 380 project are not state of art
- Main identified problems are:
  - ❑ Steady-state phenomena
  - ❑ Transient phenomena
  - ❑ Resonance phenomena
  - ❑ Availability
  - ❑ Monitoring
- TenneT started an intensive investigation for the coming 8 years together with the TU Delft and TU Eindhoven
- A new Cigre WG C4.502 has been launched to investigate these problems among others; TenneT and TU Delft are actively involved

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