Optimal Transmission Voltage for Very Long HVAC Cables

Til Kristian Vrana

Olve Mo

Outline

- **Introduction**
- Approach
- Results
- Conclusion

Introduction

Definition

- What is *optimal*?

  Transmission voltage is optimal,…

  …when it enables for maximal power transfer capability

- What is *very long*?

  A HVAC cable can be considered very long,…

  …when the optimal transmission voltage is LOWER than rated voltage

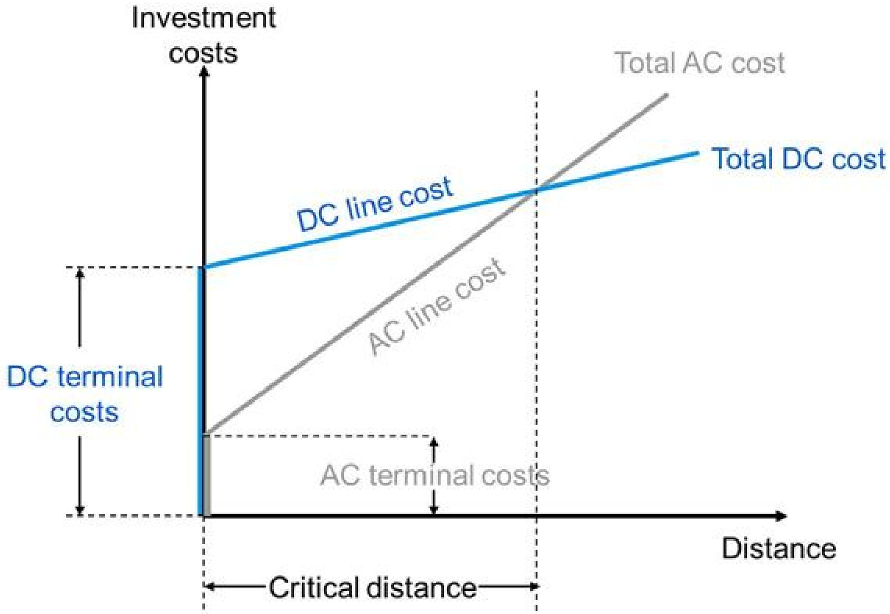
  (This is usually for lengths beyond 100-200 km)

  (depending on cable type)

Introduction

Motivation

- Why considering very long HVAC cables?
  - Used to be seen as economically inferior to HVDC solutions
    - Economic Break-Even-Length (usually referred as 50-100 km)



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Introduction
Motivation

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    - Economic Break-Even-Length (usually referred as 50-100 km)

- Offshore HVDC has proven to be more expensive than expected (German Bight)
- L>100 km becoming interesting

Introduction

State of the Art

Introduction

Background

- HVAC cables are operated at rated voltage
- Longest HVAC cables are around 100km (Malta, Ibiza,…)
- European standard voltage (400 kV) not applied for long cables.
- Applied: 220 kV, 155 kV, 132 kV, 110 kV
- Cable capacitance setting the limits.

Soon to come: Martin Linge Cable (162km, 55MW)

Introduction
Today's Approach

- See what cables are available
- Check which cable fits best for the purpose
- Aways operate at rated voltage

Operation voltage (for a given cable)
is taken as given and not as parameter

Introduction
New Systematic Approach

Rated voltage is NOT the operating voltage

Rated voltage is the upper boundary for operating voltage

Introduction
Justification 1

- Why not use a cable with lower voltage rating?
  (instead of lowering the operating voltage)

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1. Optimal voltage might lay between available voltage levels

Introduction
Justification 1

- Why not use a cable with lower voltage rating?

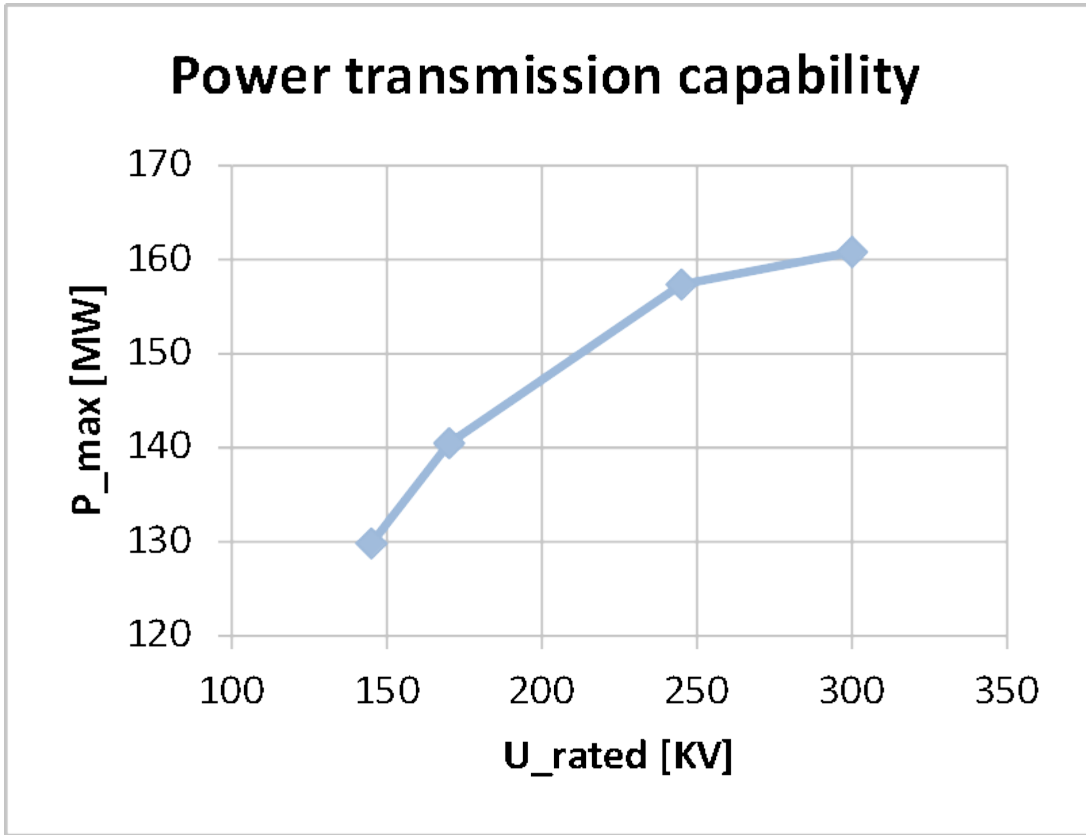
  (instead of lowering the operating voltage)

1. Optimal voltage might lay between available voltage levels
2. Power transfer capability is not the same!
   - Lower rated cables have thinner insulation.
   - Thinner insulation gives more capacitance.
   - Power transmission length limited by capacitance.

     -> degrades long distance transmission capability

Introduction
Justification 2

- Comparison of 4 cables
  - l = 200 km
  - U = 132 kV



Insulation thickness influences power transfer capability

Introduction
New Systematic Approach

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Introduction

New Systematic Approach

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Rated voltage is the upper boundary for operating voltage

Great, but…

…how to we make the choice?

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Approach
Calculation

- Purely analytical approach was chosen
- Focus: Deriving the basic equations
  - Cable length
  - Cable parameters
  - Power transmission capability
  - Operation voltage
  - Losses
  - Efficiency

Approach
Degree of Detail

- Lumped model
  - Resistive losses
  - Capacitance

heavily simplified approach!

- Only a starting point / first step
- Focus: Solvable equations

Approach
Simplification issues

- Voltage profile - Higher midpoint voltage
  - Using lower U_{max}
- Current profile - Lower current in the middle / higher in the ends
  - Ok for losses
  - Problematic for current limit
- Resistive voltage drop
  - Lower charging current @ receiving end
- Losses of reactive compensation equipment
  - Efficiency for cable only
  - Optimum efficiency voltage too high

Approach
Cable Type Example

- Three-core cable
- Copper conductor
- $A = 1000\ mm^2$
- XLPE insulation
- With armour
- 50 % reactive compensation on each end

    (symmetric compensation is also a simplification)

Approach
Cable Data Example

- Data taken from manufacturer brochures:

  (ABB, NKT, (Prysmian))
- Data used for calculations here:
  - $C' = 0{,}18\ \mu F/km$
  - $R' = 0{,}0275\ \Omega/km$
  - $I_{max} = 825\ kV$
  - $U_{max} = 275\ kV$

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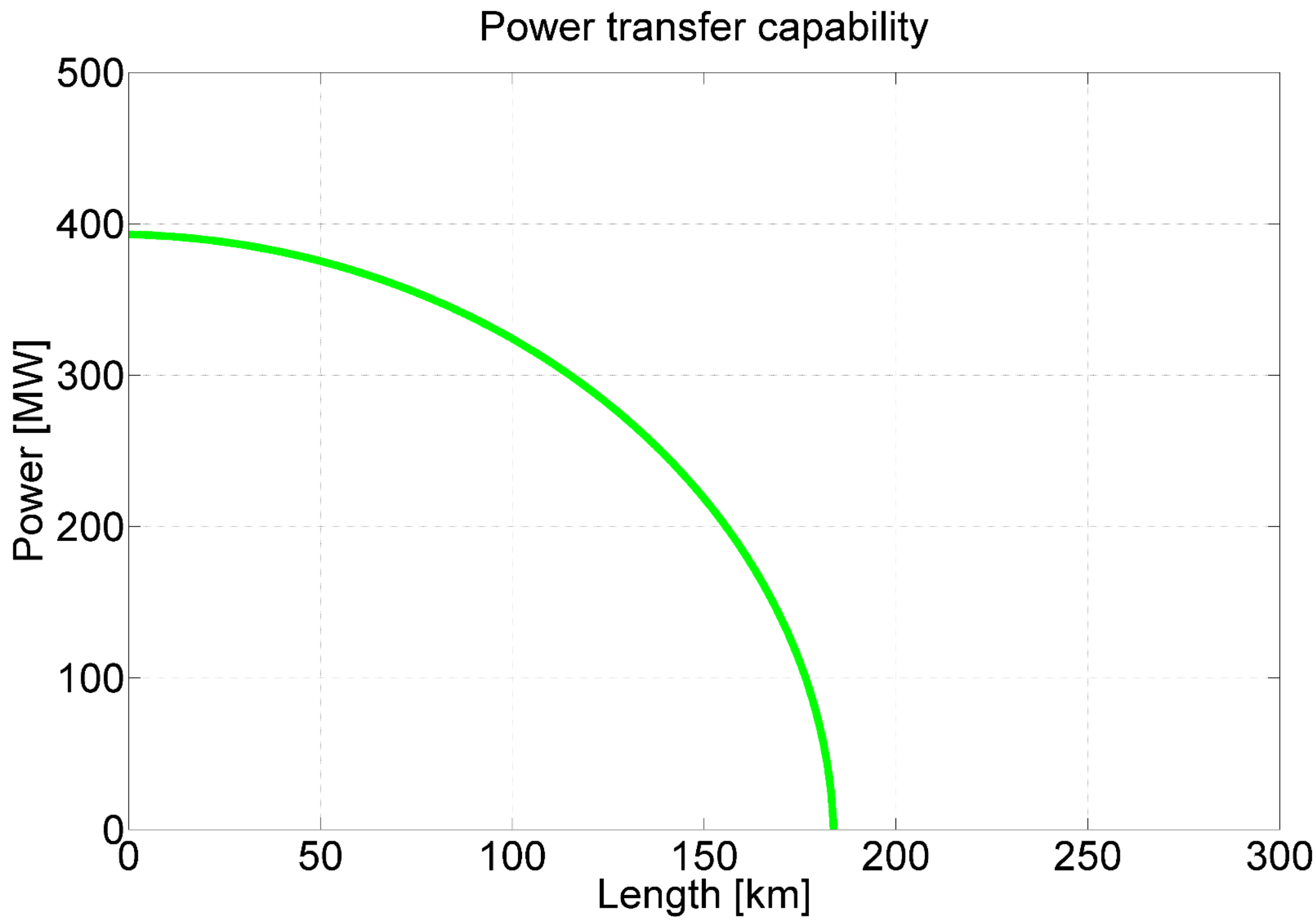
Results
Equations 1

- Power Transmission Capability

- Maximum Length at Rated Voltage

Results

Graphic Visualisation 1



Results

Equations 2 – Optimal Voltage

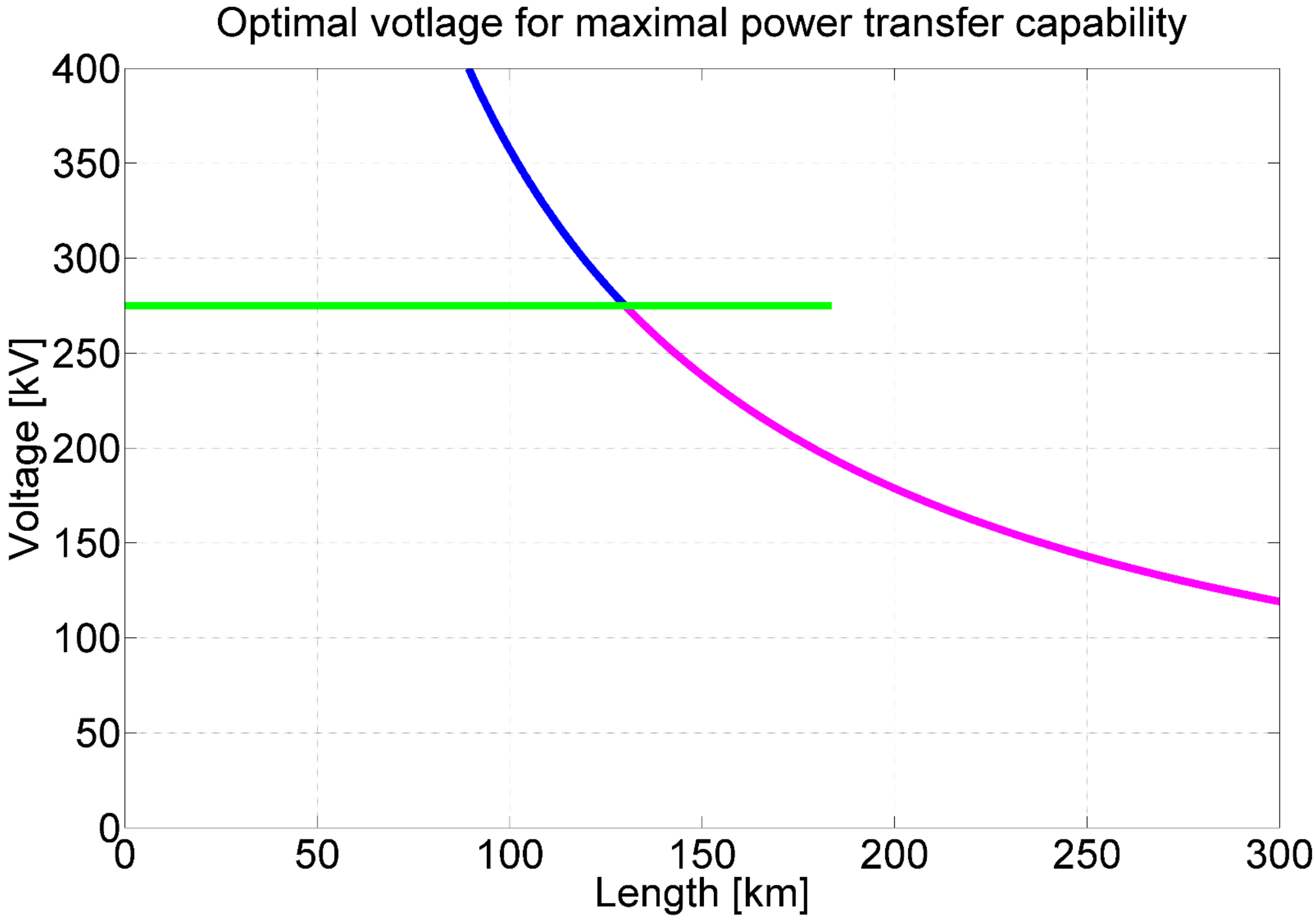
- Optimal operating voltage

- Technical Break-Even-Length

- Optimal operating voltage

Results

Graphic Visualisation 2 – Optimal Voltage



Results

Equations 3 – Maximal Power Transfer

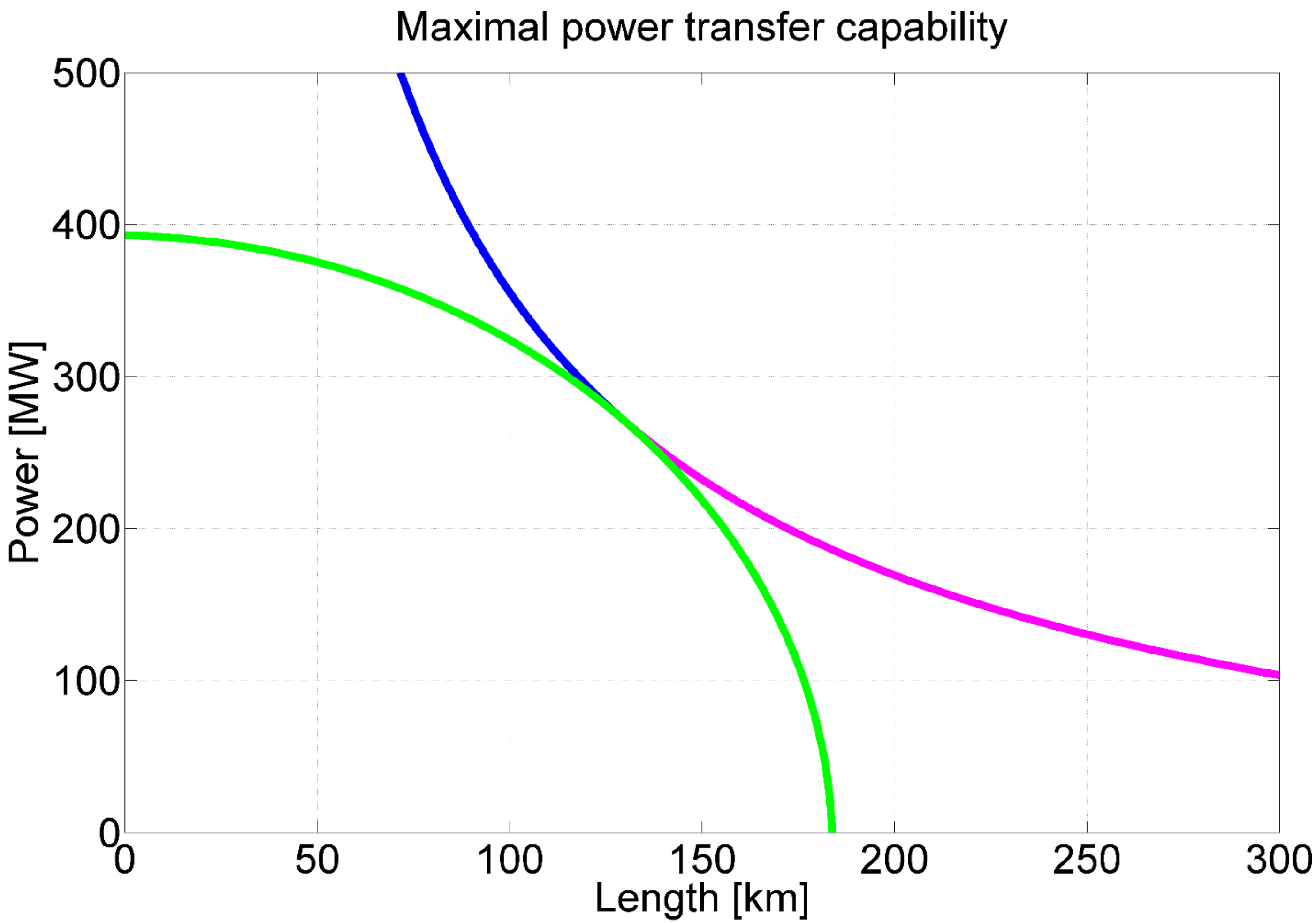
- Maximal power transfer

- Maximal length and resistance

- Maximal power transfer

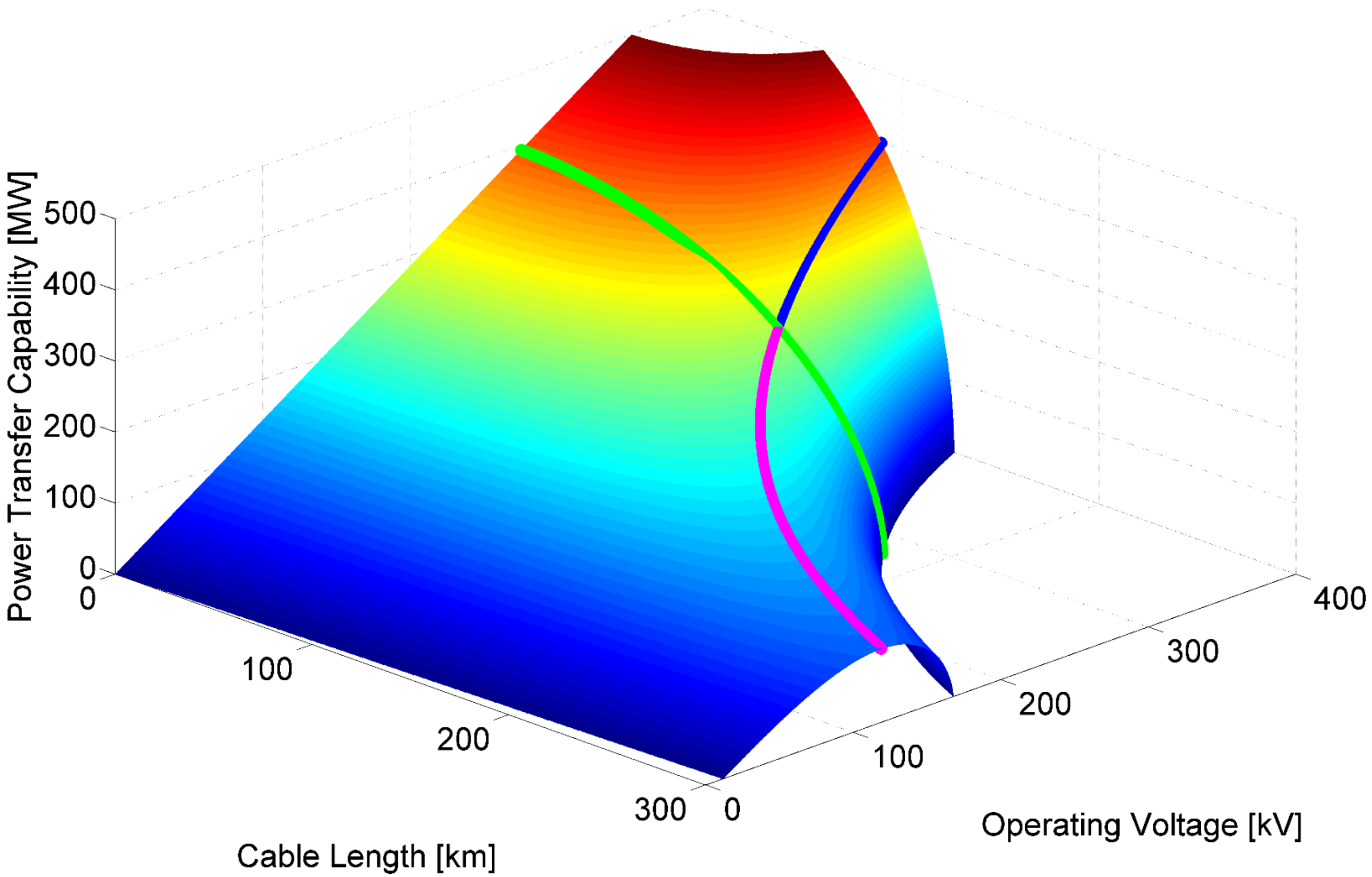
Results

Graphic Visualisation 3 – Maximal Power Transfer



Results

Graphic Visualisation 1+2+3 in 3D



Results

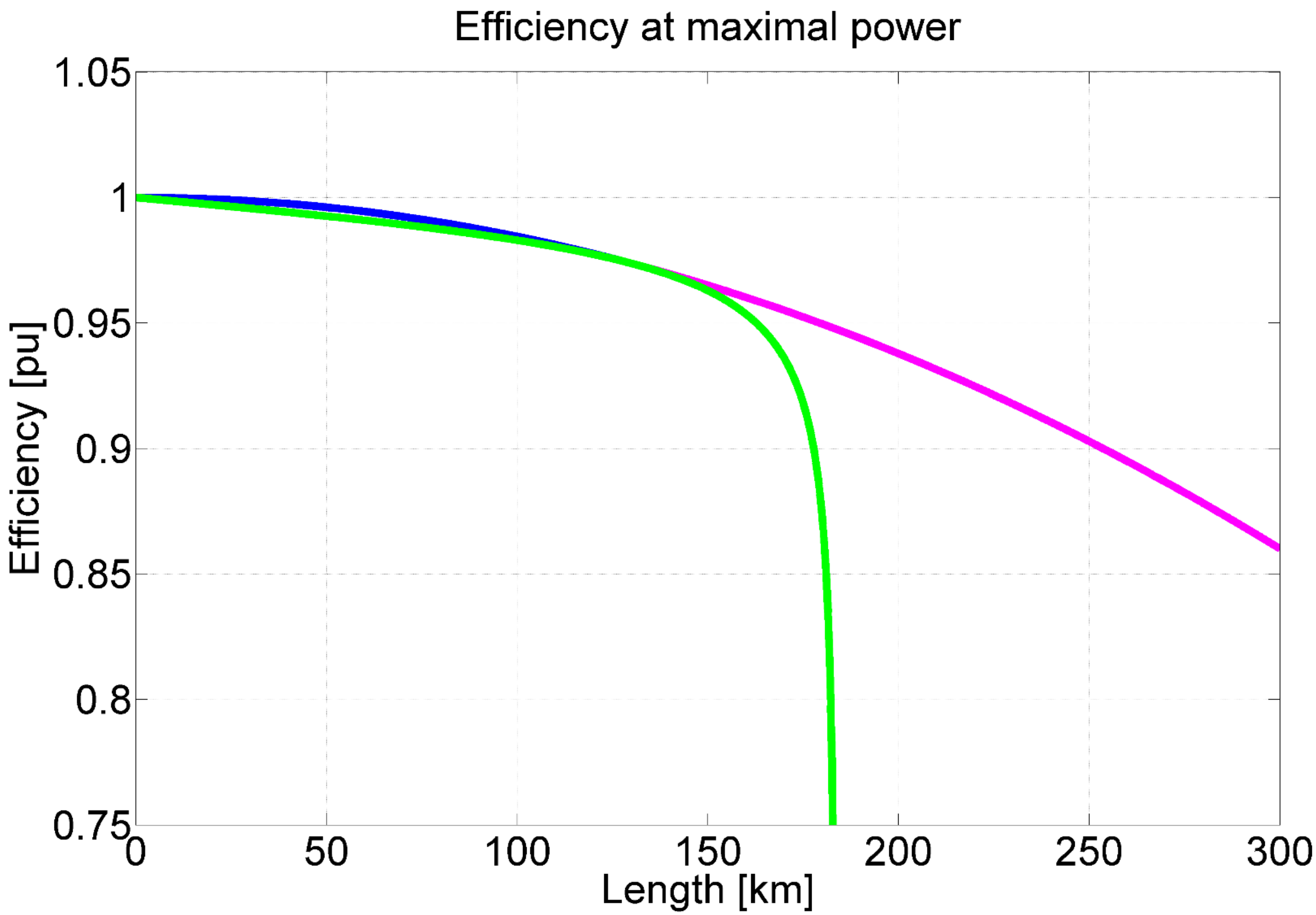
Equations 4 - Efficiency

- Fixed voltage

- Optimal voltage

Results

Graphic Visualisation 4 - Efficiency



Results

Implications 1

Maximal power transer capability (for all HVAC cables)

Results

Implications 1

Maximal power transer capability (for all HVAC cables)

(Would require unfeasibly high voltage for non-very-long cables)

Results

Implications 2

- l < 130 km
  - Business as usual
- 130 km < l < 184 km
  - Voltage reduction increases power transfer capability
- 184 km < l
  - Voltage reduction inevitable ($P(U_{rated}) = 0$)

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Conclusion
Summary 1

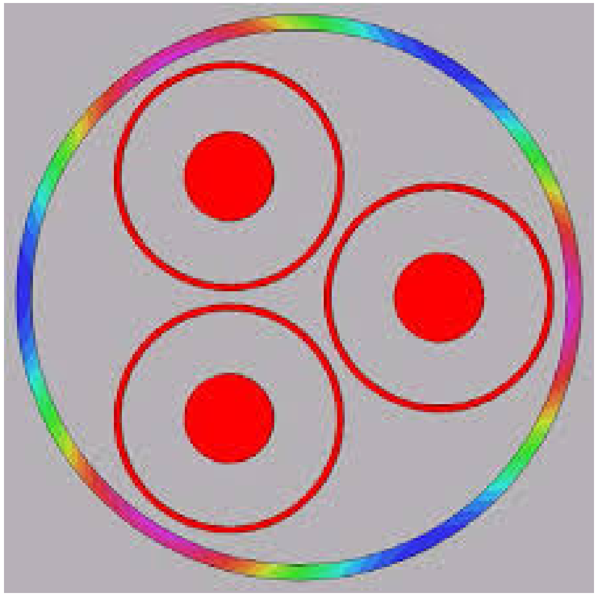
- Very long HVAC cables have received very little attention
  - Operating at rated voltage always made sense (until now…)
  - Trend goes towards longer and longer HVAC cables
  - Break-Even-Length is in reach
- Operating voltage becomes a constrained parameter

Conclusion
Summary 2

- Analytical equations help to understand phenomena
- Matlab tool gives quick look on long-distance properties
  - Get cable data
  - Calculate:
    - Break-even length
    - Maximal length at rated voltage
    - Maximal length (at optimal voltage)
    - Maximal resistance and maximal length
  - Get a first impression

Conclusion
Outlook 1

- Use of generic cable model

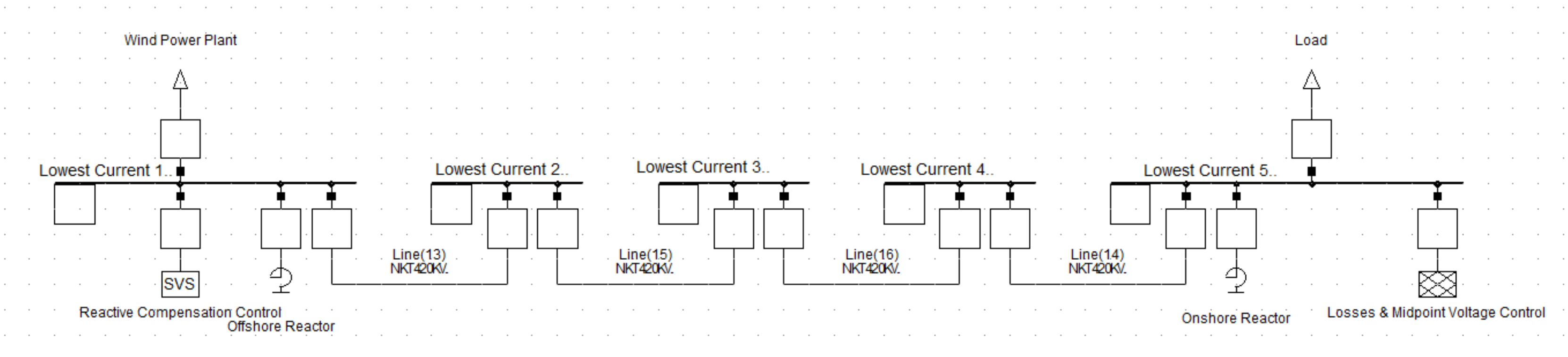


Conclusion
Outlook 2

- More advanced analytical calculations
  - Inductance
  - Distributed parameters

Conclusion
Outlook 3

- Numerical calculations for verification
  - First step indicated valididy of approach
  - Detailed study neccessary



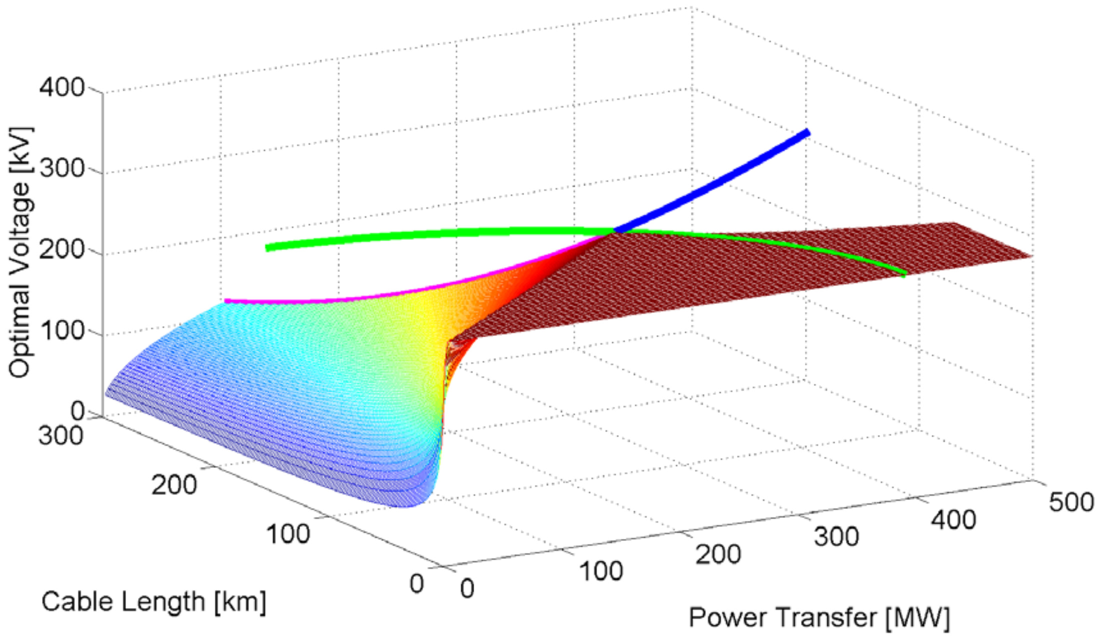
Conclusion

Outlook 4

- Loss-optimal operation with variable power transfer

  (variable voltage / constant cos(ϕ))

Olve Mo presenting soon



The End