DETERMINATION OF LOADING CAPABILITIES
OF POWER CABLES

EUREKA project E16799 POWEROPT "Mathematical modelling and optimization of electrical power cables for an improvement of their design rules"

Varikonta / Dr. Ilgevicius
AGENDA

1. Motivation and goals of the project
2. IEC 60287 Standard for power cable rating and its limitations
3. Application of analytical and numerical methods for cable calculations
4. Case examples of MV and HV cable installation projects
5. Conclusions
VARIKONTA SOLUTIONS FOR POWER UTILITIES

Project Management, Design & Engineering, Commissioning and Consulting
1. MOTIVATION AND GOALS OF THE PROJECT

Motivation / Problem:
- Existing standard methods (e.g. Neher-McGrath, IEC 60287 or by G. Anders) are based on analytical 1D formulations
- Determination of the hot spots under unfavorable thermal conditions
- Moisture migration
- Short time overload
- Induced voltage in the cable screen

Goals of the EUREKA “Poweropt”:
- Algorithm for steady-state and dynamic current rating for single-core and three-core cables under following thermal conditions:
  - Cable in air
  - cable in ground
  - Cable in duct / pipe
- Algorithm for economical optimization of cable cross section
- Validation of simulation results and recommendations to LST/IEC standards
## 1. MOTIVATION AND GOALS OF THE PROJECT

### Project schedule and milestones:

<table>
<thead>
<tr>
<th>ID</th>
<th>Task name</th>
<th>Duration</th>
<th>Start</th>
<th>End</th>
<th>Cost</th>
<th>Resource Names</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Project start date</td>
<td>0 days</td>
<td>2012.01.02</td>
<td>2012.01.02</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Project stage No. 1 (First Year of the Project)</td>
<td>230 days</td>
<td>2012.01.02</td>
<td>2012.11.16</td>
<td>70,000.00 €</td>
<td>VGTU[13%]; Varikonta[7%]; UniEp[8%]</td>
</tr>
<tr>
<td>3</td>
<td>2.1 Development of a module for simulation of continuous current rating for single-core and three-core cables</td>
<td>115 days</td>
<td>2012.01.02</td>
<td>2012.06.08</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.1.1 Development of a mathematical model (cable in air, directly buried and in cable duct)</td>
<td>60 days</td>
<td>2012.01.02</td>
<td>2012.03.23</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>5</td>
<td>2.1.2 Elaboration of the model coefficients</td>
<td>50 days</td>
<td>2012.03.26</td>
<td>2012.06.08</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>6</td>
<td>2.1.3 Presentation: temperature distribution in single-core and three-core cables</td>
<td>5 days</td>
<td>2012.06.04</td>
<td>2012.06.08</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>7</td>
<td>2.2 Development of a module for simulation of short-time overload regime (cycling loads)</td>
<td>115 days</td>
<td>2012.06.11</td>
<td>2012.11.16</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>2.2.1 Development of a mathematical model (short-time thermal overload (1-2s) and cycling loads (up 24h))</td>
<td>60 days</td>
<td>2012.06.11</td>
<td>2012.08.31</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>9</td>
<td>2.2.2 Elaboration of the model coefficients (e.g. cycling rating factors)</td>
<td>50 days</td>
<td>2012.06.30</td>
<td>2012.11.09</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>10</td>
<td>2.2.3 Presentation: temperature distribution in single-core and three-core cables</td>
<td>5 days</td>
<td>2012.11.12</td>
<td>2012.11.16</td>
<td>0.00 €</td>
<td>VGTU, Varikonta, UniEp</td>
</tr>
<tr>
<td>11</td>
<td>Project stage No. 2 (Second and the Third Year)</td>
<td>415 days</td>
<td>2012.11.19</td>
<td>2014.06.20</td>
<td>90,000.00 €</td>
<td>VGTU[13%]; Varikonta[7%]; UniEp[16%]</td>
</tr>
<tr>
<td>12</td>
<td>3.1 Development of a module for economical optimization of cable cross section</td>
<td>75 days</td>
<td>2012.11.19</td>
<td>2013.03.01</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>3.1.1 Elaboration of the parameters to be considered: financial, load and cable parameters</td>
<td>40 days</td>
<td>2013.03.01</td>
<td>2013.03.01</td>
<td>0.00 €</td>
<td>UniEp, VGTU, Varikonta</td>
</tr>
<tr>
<td>14</td>
<td>3.1.2 Analysis of estimation methods economical optimization</td>
<td>30 days</td>
<td>2013.03.01</td>
<td>2013.03.01</td>
<td>0.00 €</td>
<td>UniEp, VGTU, Varikonta</td>
</tr>
<tr>
<td>15</td>
<td>3.1.3 Presentation: calculation of single-core and three-core cables</td>
<td>5 days</td>
<td>2013.02.25</td>
<td>2013.03.01</td>
<td>0.00 €</td>
<td>UniEp, VGTU, Varikonta</td>
</tr>
<tr>
<td>16</td>
<td>3.2 Development of software package</td>
<td>340 days</td>
<td>2013.03.04</td>
<td>2014.06.20</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>3.2.1 Development of the numerical algorithms and coding: input and output GUI, databases, reporting and error handling</td>
<td>180 days</td>
<td>2013.03.04</td>
<td>2013.11.08</td>
<td>0.00 €</td>
<td>VGTU, UniEp</td>
</tr>
<tr>
<td>18</td>
<td>3.2.2 Database programming and filling up with the cable data</td>
<td>40 days</td>
<td>2013.11.11</td>
<td>2014.01.03</td>
<td>0.00 €</td>
<td>VGTU</td>
</tr>
<tr>
<td>19</td>
<td>3.2.3 Debugging and testing of the software and optimizing its performance</td>
<td>120 days</td>
<td>2014.01.06</td>
<td>2014.06.20</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Project stage No. 3 (Third Year)</td>
<td>135 days</td>
<td>2014.06.23</td>
<td>2014.12.26</td>
<td>90,000.00 €</td>
<td>VGTU[13%]; Varikonta[7%]; UniEp[16%]</td>
</tr>
<tr>
<td>21</td>
<td>4.1 Validation of the calculation programmes by the experimental data</td>
<td>75 days</td>
<td>2014.06.23</td>
<td>2014.10.03</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>4.1.1 Validation of the calculation programmes</td>
<td>60 days</td>
<td>2014.06.23</td>
<td>2014.09.12</td>
<td>0.00 €</td>
<td>VGTU</td>
</tr>
<tr>
<td>23</td>
<td>4.1.2 Presentation: Calculation of the cables for continuous current rating</td>
<td>5 days</td>
<td>2014.09.15</td>
<td>2014.09.15</td>
<td>0.00 €</td>
<td>VGTU</td>
</tr>
<tr>
<td>24</td>
<td>4.1.3 Presentation: Calculation of the cables for cycling loads</td>
<td>5 days</td>
<td>2014.09.22</td>
<td>2014.09.28</td>
<td>0.00 €</td>
<td>VGTU</td>
</tr>
<tr>
<td>25</td>
<td>4.1.4 Presentation: Calculation of the cables considering economical data</td>
<td>5 days</td>
<td>2014.09.29</td>
<td>2014.10.03</td>
<td>0.00 €</td>
<td>VGTU</td>
</tr>
<tr>
<td>26</td>
<td>4.2 Final report and recommendations for LST/IEC norms</td>
<td>60 days</td>
<td>2014.10.06</td>
<td>2014.12.26</td>
<td>0.00 €</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>4.2.1 Final report</td>
<td>30 days</td>
<td>2014.10.06</td>
<td>2014.11.14</td>
<td>0.00 €</td>
<td>UniEp, VGTU, Varikonta</td>
</tr>
<tr>
<td>28</td>
<td>4.2.2 Recommendations for LST/IEC norms</td>
<td>30 days</td>
<td>2014.10.06</td>
<td>2014.12.26</td>
<td>0.00 €</td>
<td>UniEp, VGTU</td>
</tr>
</tbody>
</table>
1. MOTIVATION AND GOALS OF THE PROJECT

Project Partners:

**UAB Varikonta** – Project Coordinator/ Dr. A. Ilgevicius

**Vilnius Gediminas Technical University** – Project Partner/ Prof. R. Ciegis

**Universität der Bundeswehr München** – Project Partner/ Prof. H.D. Liess
The Neher-McGrath (IEC 60287) method is based on a thermal-electrical analogy method. The basic idea is to subdivide the area in layers, where the heat sources are substituted by current sources, thermal resistances by electrical resistances and thermal capacitances by electrical capacitances.

The total Joule loss $W_{total}$ in a cable can be expressed as:

$$W_{total} = W_C + W_S + W_a = W_C (1 + \lambda_1 + \lambda_2)^3$$

The conductor temperature $\Delta T$ rise above the ambient temperature and rated current is given by:

$$\Delta T = \left( \frac{\rho_{AC} I}{A} \right)^2 + 0.5W_d R_{th1} + \left[ \frac{\rho_{AC} I}{A} \right]^2 (1 + \lambda_1) + W_d \right] nR_{th2} + \left[ \frac{\rho_{AC} I}{A} \right]^2 (1 + \lambda_1 + \lambda_2) + W_d \right] n(R_{th3} + R_{th4})$$

$$I_{rated} = \sqrt{ \frac{\Delta T - W_d \left[ (0.5R_{th1} + n(R_{th2} + R_{th3} + R_{th4})) \right]}{R_{AC} R_{th1} + n R_{AC} (1 + \lambda_1) R_{th2} + n R_{AC} (1 + \lambda_1 + \lambda_2) (R_{th3} + R_{th4})} }$$
Curren adjustment factors:

\[ I' = FI \]

with:

- \( I' \) is the permissible current under actual installation conditions,
- \( F \) overall adjustment factor,
- \( I \) is the base permissible current

The overall adjustment factor is:

\[ F = F_t F_{th} F_g \]

where:

- \( F_t \) is the adjustment factor to account the differences in ambient and conductor temperatures from the base temperature,
- \( F_{th} \) is the adjustment factor to account the differences in the soil thermal resistivity from the base value,
- \( F_g \) is the adjustment factor to account for cable grouping
Limitations of the IEC 60287:

- Modeling of **ground thermal properties**
- Modeling of the heat transfer in **air gap** between cable and duct
- **Dynamic loadability** of cables
Comparision of IEC 60287 vs. numerical Simulation

300mm2 XLPE copper cable direct buried in the ground:

Max permissible current acc. IEC 60287:

\[ I' = IF_t F_{th} F_g = 626A \cdot 1 \cdot 0.93 \cdot 0.89 = 518A \]
Three different time scales are relevant:

- Real time operation (minutes) – Analytical approach
- Day-ahead planning (hours) – Analytical approach
- Grid planning (years) – Numerical approach

A simulation tool should cover all three time scales

1. Real time operation/monitoring systems

\[ \Delta T_m = \Delta \hat{T}_n + \left[ \Delta T_{n-1} - \Delta \hat{T}_n \right] \exp \left( -\frac{t_{mn}}{\tau} \right) \]

\[ t_{mn} = -\tau \ln \frac{\Delta \hat{T}_n - \Delta T_{n-1}}{\Delta \hat{T}_n - \Delta T_m} \]

\[ t_{mn} = \tau \ln \frac{I_n^2 - I_{n-1}^2}{I_n^2 - I_m^2} \]
2. Day – ahead planning

- Predicted currents in each of three systems

- Predicted current in System 3 when System 1 is out of order and System 2 fails
4. ANALYTICAL AND NUMMERICAL METHODS FOR CABLE CALCULATIONS

3. Grid planning

\[ \lambda \frac{\partial T}{\partial n} = \mu(T - T_0) \]

\[ T = T_r(x, \nu) \]

Wind [1-10 m/s]
Air [\theta_0]
Soil

Dr. A. Ilgevičius
UAB Varikonta

Date: 28.05.2014
4. ANALYTICAL AND NUMERICAL METHODS FOR CABLE CALCULATIONS

-Cables in ducts

- Induced voltage into the screen by magnetic field from conductor
5. REFERENCE PROJECTS

-HVDC Nordbalt Project:
-Total cable length: ca. 450 km,
Rated Power: 700 MW
System Voltage: 400 kV DC
The longest cable route of such power rating so far.

Reference: ABB/Nordbalt
5. REFERENCE PROJECTS

-110 kV cable in Klaipeda, Lypkiai

Base rated current

- Calculated max. permissible current:

\[ I_{SK} = 650 \times 1 \times 0.85 \times 1.04 \times 0.93 \times 0.9 \times 0.94 = 452.08 \text{ A} \]
5. REFERENCE PROJECTS

-Fortum Waste-to-Energy Plant in Klaipeda
-10 and 6 kV cable installations in ground and air
9 single core cables of 500mm²
from generator to the step up transformer
6. CONCLUSIONS

AT THE END OF THE DAY, IT IS ALL ABOUT MONEY.
6. QUESTIONS

www.varikonta.lt