Handling of magnetic field-related risks during live-line maintenance

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Barehand method

Electric field
- Voltage level
- Geometry

Magnetic field
- Current
- Geometry

Source: http://fab.cba.mit.edu/classes/MIT/862.06/students/alki/GA.html
Magnetic field

- High current circuit in the HVL of BUTE
  - Current peak of 2 kA
- High current, high magnetic field
- Inspection of different conductive clothing
  - Different manufacturers
  - Different shielding efficiencies
Magnetic field – results 1
Magnetic field – results 2
Magnetic field – results 3
Magnetic field – summary of results

Ratio of measured magnetic flux density values

<table>
<thead>
<tr>
<th>Ratio [%]</th>
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<tbody>
<tr>
<td>120</td>
</tr>
</tbody>
</table>

- A-B | A-C | A-R | B-C | B-R | C-R |

- Head  | Back  | Front  |

- -2 m  | -1 m  | -0.5 m  |

- 0 m  | 0.5 m  | 1 m  | 2 m  |
Magnetic field – results 3.

- Shielding effect of conventional conductive clothing on magnetic fields is negligible
  - *Is it a problem?*

<table>
<thead>
<tr>
<th></th>
<th>Electric field strength, until 2010 [kV/m]</th>
<th>Electric field strength, since 2010 [kV/m]</th>
<th>Magnetic flux density, until 2010 [µT]</th>
<th>Magnetic flux density, since 2010 [µT]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public</td>
<td>5</td>
<td>5</td>
<td>100</td>
<td>200</td>
</tr>
<tr>
<td>Occupational (8 hours/day)</td>
<td>10</td>
<td>10</td>
<td>500</td>
<td>1000</td>
</tr>
</tbody>
</table>

Source: ICNIRP
A Hungarian example

- High transmission: international power line
- Nominal voltage level: 400 kV
- Real power (P): average is above 1000 MW often reaches 1200 MW
- Reactive power (Q): 50-80 Mvar
- Geometry: 2 conductor / phase (bundled)
Magnetic field – practical case

$I = 1732 \text{ A} / \text{phase}$

$I = 866 \text{ A} / \text{conductor}$
Exposure during LLM

• „For a very localized source with a distance of a few centimeters from the body, the only realistic option for the exposure assessment is to determine dosimetrically the induced electric field, case by case.”


Human body model according to IEC 62 233
Induced current density

Limit: 10 mA/m²

- 3D CAD model of human body (IEC 62 233)
- Induced current density in the human body
- Current density values in the head
Simulation results

Induced current density [mA/m$^2$]

Phase current [A]  vs  Distance [mm]
Magnetic field – issues

Two important points according to the measurements and calculations:

• none of conventional conductive clothing is effective from the aspect of shielding ELF magnetic fields
• during normal operational conditions induced current density in the human body model exceeds the limits
Ways of magnetic shielding

<table>
<thead>
<tr>
<th>Technique</th>
<th>Limit of application during HV LLM</th>
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</table>
| Eddy currents                | • Extra-low frequency (50/60 Hz)  
|                              | • Slow induction, high losses  
|                              | • Conductive threads divide the unity of the material (example: laminated transformer core)          |
| Ferromagnetic materials      | • Required thickness and mass  
|                              | • Only effective if the direction of source is covered                                               |
| „Active“ shielding           | • Same magnitude of power is required as the source                                                  |
Parallel current paths – principle

- The current \((I)\) which generates magnetic field around a conductor can be decreased \((I/n)\) by ensuring parallel branches \((n)\)
  - a geometry-dependent protected area \((P)\) appears between the distributed current-carrying conductors which could guarantee the safety of the worker

the magnetic flux density decreases around the conductors
# Laboratory measurement results

<table>
<thead>
<tr>
<th></th>
<th>$I_{\text{total}}$ [A]</th>
<th>$I_{\text{shunt}1}$ [A]</th>
<th>$I_{\text{shunt}2}$ [A]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>2 parallel branches</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>46,1</td>
<td>75,2</td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>34,1</td>
<td>55,7</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>22,8</td>
<td>37</td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>12,8</td>
<td>20,8</td>
<td></td>
</tr>
<tr>
<td><strong>1 parallel branch</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>200</td>
<td>75,9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>150</td>
<td>55,9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>37,2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>50</td>
<td>18,2</td>
<td></td>
<td></td>
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<tr>
<td><strong>Single conductor</strong></td>
<td></td>
<td></td>
<td></td>
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<td>200</td>
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<td>100</td>
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<tr>
<td>50</td>
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Simulation results based on laboratory measurements

- 1 conductor, no parallel branches
- 1 conductor, 1 parallel branch
- 1 conductor, 2 parallel branches
Magnetic flux density - measurements

Current: 50A, 100A, 150A, 200A
Average accuracy: 96.37%
Summary

- According to ICNIRP, magnetic fields near a localized source shall be calculated dosimetrically.
- During different high voltage live-line methods, induced current density may exceed its limits, which is unacceptable.
- Conductive clothing worn by the workers during “barehand” method shield the electric field effectively, but they do not have any significant effect on the shielding of magnetic fields.
- Method of parallel currents paths is an effective and practically applicable method to cancel B/H fields during HV LLM.
  - Theory has been proved by laboratory measurement results.
  - Development of an expert system for practical applicability is currently in progress.
Thank you for your attention!

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