## APPENDIX A:
**SKETCHES AND DRAWINGS FOR SUSPENSION TOWER**

<table>
<thead>
<tr>
<th>Item</th>
<th>Title</th>
<th>Drawing Nos</th>
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<tbody>
<tr>
<td>1</td>
<td>220 kV – Single Circuit Tower Outline, Type « A » - Suspension 0º - 2º</td>
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<tr>
<td></td>
<td>220 kV – Épuré du pylône simple circuit, Type “A” – Suspension 0º - 2º</td>
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<tr>
<td>2</td>
<td>220 kV – Double Circuit Tower Outline, Type « A » - Suspension 0º - 2º</td>
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<tr>
<td></td>
<td>220 kV – Épuré du pylône double circuit, Type “A” – Suspension 0º - 2º</td>
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</table>
**APPENDIX B: LOAD FLOW DIAGRAMS**

### Load Flow Case No.1 for 2015

<table>
<thead>
<tr>
<th>Item</th>
<th>Power Systems</th>
<th>Diagram No.</th>
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<tbody>
<tr>
<td>1</td>
<td>Rusumo-Falls for 2015&lt;br&gt;Case No. 1: EGL Power Grid&lt;br&gt;Configuration No.1: Réseau d’EGL</td>
<td>BRC-2015-SC-1</td>
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<td>2</td>
<td>Rusumo-Falls for 2015&lt;br&gt;Case No.1: Ugandan and Kenyan Power Grid&lt;br&gt;Configuration No.1: Réseau de l’Ouganda et du Kénya</td>
<td>UK-2015-SC-1</td>
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<td>3</td>
<td>Rusumo-Falls for 2015&lt;br&gt;Case No. 1: Tanzanian Power Grid&lt;br&gt;Configuration No. 1: Réseau de la Tanzanie</td>
<td>T-2015-SC-1</td>
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### Load Flow Case No.1 for 2025

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<td>Rusumo-Falls for 2025&lt;br&gt;Case No. 1: EGL Power Grid&lt;br&gt;Configuration No.1: Réseau d’EGL</td>
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</tr>
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<td>5</td>
<td>Rusumo-Falls for 2025&lt;br&gt;Case No.1: Ugandan and Kenyan Power Grid&lt;br&gt;Configuration No.1: Réseau de l’Ouganda et du Kénya</td>
<td>UK-2025-SC-1</td>
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<td>6</td>
<td>Rusumo-Falls for 2025&lt;br&gt;Case No. 1: Tanzanian Power Grid&lt;br&gt;Configuration No. 1: Réseau de la Tanzanie</td>
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### Load Flow Case No.2 for 2025

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<td>9</td>
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### Load Flow Case No. 3 for 2025

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<th>Diagram No.</th>
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<td>Rusumo-Falls for 2025&lt;br&gt;Case No. 3: EGL Power Grid&lt;br&gt;Configuration No. 3: Réseau d’EGL</td>
<td>BRC-2025-SC-3</td>
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<tr>
<td>From/De Tanzania to/vers Ouganda :</td>
<td>0.0 MW</td>
<td></td>
</tr>
<tr>
<td>From/De Tanzania to/vers Kenya :</td>
<td>63.8 MW</td>
<td></td>
</tr>
<tr>
<td>From/De Rusumo-Falls to/vers Nyakanazi :</td>
<td>67.3 MW</td>
<td></td>
</tr>
<tr>
<td>From/Burundi to/vers Tanzania :</td>
<td>0.0 MW</td>
<td></td>
</tr>
<tr>
<td>From Zambie / de la Zambie :</td>
<td>34.9 MW</td>
<td></td>
</tr>
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</table>

**RUSUMO-FALLS INTERCONNECTION LINES FOR 2015, CASE 1**

**TANZANIAN SYSTEM / RÉSEAU DE LA TANZANIE**

**Bus - VOLTAGE (kV):**
- 10.50 kV
- 0.950 kV

**Branch - MW/Mvar**

**Equipment - MW/Mvar**

**100.0% RATEA**

**FEASIBILITY REPORT / RAPPORT DE FAIBILITÉ**

**RUSUMO-FALLS FOR 2015**
**CASE No. 1 : TANZANIAN POWER GRID**
**CONFIGURATION No. 1 : RÉSEAU DE LA TANZANIE**

**T-2015-SC-1**

Data: November / Novembre 2008
## Appendix C: Results of Lightning Performance

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<tr>
<th>Item</th>
<th>Calculation Report</th>
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<tr>
<td>1</td>
<td>220 kV Single Circuit Line</td>
</tr>
<tr>
<td>2</td>
<td>220 kV Double Circuit Line</td>
</tr>
</tbody>
</table>
SIMPLE TERNE 220 KV (18 isolateurs -178 MM)x 0.95 = 2.327 meter 146 mm ANGLE >0

SIMPLE TERNES, 220 KV,
NIVEAU KÉRAUNIQUE: 110
ALTITUDE: 1750 m, Ka = 0.95
PYLONE DU RWANDA, 18 ISOLATEURS,
Angle >0
HAUTEUR MAXIMALE DU PYLONE: 38,5 m
Flèche: 10,00 m
PORTÉE: 350 m
CONDUCTEUR: Un ASTER 570

<------------------ SHIELDING CALCULATION ------------------>
Value of BETA used = 0.899999761581421
THE SHIELD ANGLE REQUIRED FOR CONDUCTOR 1 IS = 15.77 DEGREES
THE ACTUAL SHIELD ANGLE FOR CONDUCTOR 1 IS = 10.20 DEGREES
THE SHIELD ANGLE REQUIRED FOR CONDUCTOR 2 IS = 19.81 DEGREES
THE ACTUAL SHIELD ANGLE FOR CONDUCTOR 2 IS = 6.84 DEGREES

<------------------ BACKFLASH CALCULATION ------------------>
Footing RESISTANCE = 20.50 Ohms
Tower WAVE IMPEDANCE = 52.16 Ohms

Cond. Coupling Flashover Insulator Flashover Insulator Critical
No. Factor Voltage Voltage Voltage Voltage Current
   at 2 us at 2 us at 6 us at 6 us
   (kv)   (kv/kA)   (kv)   (kv/kA)   (ka)
1  0.4079  1739  13.38  1361  8.49  129.94
2  0.3296  1739  14.51  1361  9.61  119.81
3  0.2618  1739  15.38  1361 10.58  113.07

The PROBABILITY of BACKFLASHOVER by each PHASE is:
Cond. No. Probability (%) Average Critical Current(kA)
   1           11.1               116.79
   2           38.9               111.57
   3           50.0               105.76

Footing RESISTANCE = 20.00 Ohms
Tower WAVE IMPEDANCE = 52.48 Ohms

Cond. Coupling Flashover Insulator Flashover Insulator Critical
No. Factor Voltage Voltage Voltage Voltage Current
   at 2 us at 2 us at 6 us at 6 us
   (kv)   (kv/kA)   (kv)   (kv/kA)   (ka)
1  0.4079  1739  13.18  1361  8.34  131.93
2  0.3296  1739  14.28  1361  9.44  121.77
3  0.2618  1739  15.12  1361 10.40  115.03

The PROBABILITY of BACKFLASHOVER by each PHASE is:
Cond. No. Probability (%) Average Critical Current(kA)
   1           11.1               118.59
   2           38.9               113.40
   3           50.0               107.58

Footing RESISTANCE = 19.50 Ohms
Tower WAVE IMPEDANCE = 52.80 Ohms

Cond. Coupling Flashover Insulator Flashover Insulator Critical
<table>
<thead>
<tr>
<th>No.</th>
<th>Factor</th>
<th>Voltage at 2 us (kV)</th>
<th>Voltage at 2 us (kV/kA)</th>
<th>Voltage at 6 us (kV)</th>
<th>Voltage at 6 us (kV/kA)</th>
<th>Current (ka)</th>
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<tbody>
<tr>
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<td>8.19</td>
<td>134.00</td>
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<td>1739</td>
<td>14.04</td>
<td>1361</td>
<td>9.28</td>
<td>123.81</td>
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<tr>
<td>3</td>
<td>0.2618</td>
<td>1739</td>
<td>14.85</td>
<td>1361</td>
<td>10.22</td>
<td>117.06</td>
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</tbody>
</table>

The PROBABILITY of BACKFLASHOVER by each PHASE is:

<table>
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<tr>
<th>Cond. No.</th>
<th>Probability (%)</th>
<th>Average Critical Current (ka)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>16.7</td>
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<td>2</td>
<td>33.3</td>
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<td>3</td>
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Footing RESISTANCE = 19.00 Ohms  
Tower WAVE IMPEDANCE = 53.12 Ohms

<table>
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<th>Cond. No.</th>
<th>Coupling Factor</th>
<th>Flashover Voltage at 2 us (kV)</th>
<th>Flashover Voltage at 2 us (kV/kA)</th>
<th>Flashover Voltage at 6 us (kV)</th>
<th>Flashover Voltage at 6 us (kV/kA)</th>
<th>Critical Current (ka)</th>
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</thead>
<tbody>
<tr>
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<td>1739</td>
<td>12.77</td>
<td>1361</td>
<td>8.05</td>
<td>136.15</td>
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<tr>
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<td>14.59</td>
<td>1361</td>
<td>10.03</td>
<td>119.18</td>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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<th>Probability (%)</th>
<th>Average Critical Current (ka)</th>
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</thead>
<tbody>
<tr>
<td>1</td>
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<td>2</td>
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Footing RESISTANCE = 18.50 Ohms  
Tower WAVE IMPEDANCE = 53.45 Ohms

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<th>Coupling Factor</th>
<th>Flashover Voltage at 2 us (kV)</th>
<th>Flashover Voltage at 2 us (kV/kA)</th>
<th>Flashover Voltage at 6 us (kV)</th>
<th>Flashover Voltage at 6 us (kV/kA)</th>
<th>Critical Current (ka)</th>
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<tr>
<td>1</td>
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<td>9.84</td>
<td>121.40</td>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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<th>Cond. No.</th>
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Footing RESISTANCE = 18.00 Ohms  
Tower WAVE IMPEDANCE = 53.77 Ohms

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<th>Flashover Voltage at 6 us (kV)</th>
<th>Flashover Voltage at 6 us (kV/kA)</th>
<th>Critical Current (ka)</th>
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<td>123.71</td>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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<th>Probability (%)</th>
<th>Average Critical Current (ka)</th>
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<td>117.85</td>
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<tr>
<td>Cond. No.</td>
<td>Coupling Factor</td>
<td>Flashover Voltage at 2 us (kV)</td>
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<td>----------------</td>
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The probability of backflashover by each phase is:

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<th>Cond. No.</th>
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<th>Average Critical Current (kA)</th>
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<th>Flashover Voltage at 2 us (kV)</th>
<th>Flashover Voltage at 6 us (kV)</th>
<th>Insulator Voltage at 2 us (kV/kA)</th>
<th>Insulator Voltage at 6 us (kV/kA)</th>
<th>Critical Current at 2 us (kA)</th>
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The probability of backflashover by each phase is:

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<th>Flashover Voltage at 6 us (kV)</th>
<th>Insulator Voltage at 2 us (kV/kA)</th>
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<th>Critical Current at 2 us (kA)</th>
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The probability of backflashover by each phase is:

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<th>Flashover Voltage at 6 us (kV)</th>
<th>Insulator Voltage at 2 us (kV/kA)</th>
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<th>Critical Current at 2 us (kA)</th>
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The probability of backflashover by each phase is:

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<th>Probability (%)</th>
<th>Average Critical Current (kA)</th>
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<td>1</td>
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</tr>
<tr>
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<td>33.3</td>
<td>139.83</td>
</tr>
<tr>
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<td>50.0</td>
<td>135.02</td>
</tr>
<tr>
<td>No.</td>
<td>Factor</td>
<td>Voltage at 2 us (kV)</td>
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<tr>
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<td>--------</td>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

<table>
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<td>140.79</td>
</tr>
<tr>
<td>3</td>
<td>47.2</td>
<td>136.60</td>
</tr>
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</table>

--------------------------- F I N A L   R E S U L T S --------------------------

THE BACKFLASHOVER RATE = 5.764 FLASHOVERS/100 KM
= 9.280 FLASHOVERS/100 MI

THE SHIELDING FAILURE FLASHOVER RATE = 0.000 FLASHOVERS/100 KM
= 0.000 FLASHOVERS/100 MI

TOTAL FLASHOVER RATE = 5.764 FLASHOVERS/100 KM
= 9.280 FLASHOVERS/100 MI
SIMPLE TERNE 220 KV (18 isolateurs -178 MM) x 0.95 = 2.327 meter 146 mm ANGLE >0

---

**SHIELDING CALCULATION**

Value of BETA used = 0.899999761581421

The shield angle required for conductor 1 is = 20.10 DEGREES

The actual shield angle for conductor 1 is = 7.45 DEGREES

The shield angle required for conductor 2 is = 23.94 DEGREES

The actual shield angle for conductor 2 is = 4.83 DEGREES

---

**BACKFLASH CALCULATION**

Footing RESISTANCE = 20.50 Ohms

Tower WAVE IMPEDANCE = 51.36 Ohms

<table>
<thead>
<tr>
<th>Cond. No.</th>
<th>Factor</th>
<th>Flashover Voltage at 2 us (kV)</th>
<th>Flashover Voltage at 2 us (kV/kA)</th>
<th>Insulator Voltage at 6 us (kV)</th>
<th>Insulator Voltage at 6 us (kV/kA)</th>
<th>Critical Current (kA)</th>
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<tr>
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<td>1739</td>
<td>12.92</td>
<td>1361</td>
<td>8.26</td>
<td>134.56</td>
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<td>1739</td>
<td>14.18</td>
<td>1361</td>
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<td>0.2683</td>
<td>1739</td>
<td>15.12</td>
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<td>114.97</td>
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The probability of BACKFLASHOVER by each PHASE is:

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<th>Cond. No.</th>
<th>Probability (%)</th>
<th>Average Critical Current (kA)</th>
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Footing RESISTANCE = 20.00 Ohms

Tower WAVE IMPEDANCE = 51.70 Ohms

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<th>Insulator Voltage at 6 us (kV/kA)</th>
<th>Critical Current (kA)</th>
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The probability of BACKFLASHOVER by each PHASE is:

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<th>Average Critical Current (kA)</th>
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<td>55.6</td>
<td>110.58</td>
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Footing RESISTANCE = 19.50 Ohms

Tower WAVE IMPEDANCE = 52.03 Ohms

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<th>Critical Current (kA)</th>
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The probability of BACKFLASHOVER by each PHASE is:

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<th>Average Critical Current (kA)</th>
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<td>116.06</td>
</tr>
<tr>
<td>3</td>
<td>55.6</td>
<td>110.58</td>
</tr>
</tbody>
</table>
### Backflashover Probabilities

#### Cond. No. 1
- **Probability (%):** 5.6
- **Average Critical Current:** 124.78 kA

#### Cond. No. 2
- **Probability (%):** 38.9
- **Average Critical Current:** 118.03 kA

#### Cond. No. 3
- **Probability (%):** 55.6
- **Average Critical Current:** 112.56 kA

---

**Footing Resistance:** 19.00 Ohms

**Tower Wave Impedance:** 52.37 Ohms

---

### Coupling Factors

<table>
<thead>
<tr>
<th>Cond. No.</th>
<th>Coupling Factor</th>
<th>Flashover Voltage at 2us (kV)</th>
<th>Insulator Voltage at 2us (kV/kA)</th>
<th>Flashover Voltage at 6us (kV)</th>
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<th>Critical Current (kA)</th>
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<td>119.07</td>
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</table>

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### Backflashover Probabilities

#### Cond. No. 1
- **Probability (%):** 5.6
- **Average Critical Current:** 126.81 kA

#### Cond. No. 2
- **Probability (%):** 38.9
- **Average Critical Current:** 122.20 kA

#### Cond. No. 3
- **Probability (%):** 50.0
- **Average Critical Current:** 115.54 kA

---

**Footing Resistance:** 18.50 Ohms

**Tower Wave Impedance:** 52.70 Ohms

---

### Coupling Factors

<table>
<thead>
<tr>
<th>Cond. No.</th>
<th>Coupling Factor</th>
<th>Flashover Voltage at 2us (kV)</th>
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### Backflashover Probabilities

#### Cond. No. 1
- **Probability (%):** 11.1
- **Average Critical Current:** 131.11 kA

---

**Footing Resistance:** 18.00 Ohms

**Tower Wave Impedance:** 53.04 Ohms

---

### Coupling Factors

<table>
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<th>Cond. No.</th>
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<th>Critical Current (kA)</th>
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### Backflashover Probabilities

#### Cond. No. 1
- **Probability (%):** 11.1
- **Average Critical Current:** 131.11 kA

---

**Footing Resistance:** 18.00 Ohms

**Tower Wave Impedance:** 53.04 Ohms

---

### Notes

- The backflashover probabilities and critical current values are calculated based on the coupling factors and voltages at different time intervals.
- The footing resistance and tower wave impedance are given for each set of conditions.

---

Page 2
<table>
<thead>
<tr>
<th>No.</th>
<th>Cond.</th>
<th>Factor</th>
<th>Flashover Voltage at 2μs (kV)</th>
<th>Coupling Voltage at 2μs (kV/kA)</th>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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<th>Probability (%)</th>
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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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The PROBABILITY of BACKFLASHOVER by each PHASE is:

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<td>2</td>
<td>33.3</td>
<td>144.54</td>
</tr>
<tr>
<td>3</td>
<td>50.0</td>
<td>139.98</td>
</tr>
</tbody>
</table>

--------------------------------------------------------------------------------

--------------------------- F I N A L   R E S U L T S --------------------------

THE BACKFLASHOVER RATE = 5.406 FLASHOVERS/100 KM
                          = 8.700 FLASHOVERS/100 MI

THE SHIELDING FAILURE FLASHOVER RATE = 0.000 FLASHOVERS/100 KM
                                      = 0.000 FLASHOVERS/100 MI

TOTAL FLASHOVER RATE = 5.406 FLASHOVERS/100 KM
                      = 8.700 FLASHOVERS/100 MI

*******************************************************************************
## APPENDIX D: RESULTS OF ENVIRONMENTAL STUDIES

<table>
<thead>
<tr>
<th>Item</th>
<th>Calculation Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rusumo Falls 220 kV Single Circuit Design at Elevation 1500 m</td>
</tr>
<tr>
<td>2</td>
<td>Rusumo Falls 220 kV Single Circuit Design at Elevation 1750 m</td>
</tr>
<tr>
<td>3</td>
<td>Rusumo Falls 220 kV Double Circuit Design at Elevation 1500 m</td>
</tr>
<tr>
<td>4</td>
<td>Rusumo Falls 220 kV Double Circuit Design at Elevation 1750 m</td>
</tr>
</tbody>
</table>
STUDY ON THE INTERCONNECTION OF THE ELECTRICITY NETWORK OF THE NILE EQUATORIAL LAKES COUNTRIES

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m

1) TOWER CONFIGURATION

<table>
<thead>
<tr>
<th>Conductor number</th>
<th>At Tower X (m)</th>
<th>At Tower Y (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-5.05</td>
<td>25.1</td>
</tr>
<tr>
<td>2</td>
<td>5.05</td>
<td>21.55</td>
</tr>
<tr>
<td>3</td>
<td>-5.35</td>
<td>18</td>
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<tr>
<td>4</td>
<td>-</td>
<td>-</td>
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<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2) GENERAL

Rated voltage: 245 kV
Elevation: 1500 meter
Conductors sag: 10 meter
Frequency: 50 Hz
Ambient temperature: 20 °C

3) CASE DESCRIPTION

Case No.1: ONE ACSR CANARY
Case No.2: ONE ACSR CARDINAL
Case No.3: ONE AAAC T570AG
Case No.4: TWO ACSR OSTRICH
Case No.5: TWO AAAC T182AG

4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
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<tbody>
<tr>
<td>Number of circuits</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of subconductors</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Distance between subconductors (cm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>45.8</td>
<td>45.8</td>
</tr>
<tr>
<td>Subconductor type</td>
<td>ACSR</td>
<td>ACSR</td>
<td>AAAC6201</td>
<td>ACSR</td>
<td>AAAC6201</td>
</tr>
<tr>
<td>Subconductor name</td>
<td>CANARY</td>
<td>CARDINAL</td>
<td>T570AG</td>
<td>OSTRICH</td>
<td>T182AG</td>
</tr>
<tr>
<td>Subconductor area Al (kcmil)</td>
<td>900.0</td>
<td>954.0</td>
<td>1125.3</td>
<td>300.0</td>
<td>358.4</td>
</tr>
<tr>
<td>Subconductor total area (sq mm)</td>
<td>515.10</td>
<td>545.93</td>
<td>570.19</td>
<td>177.03</td>
<td>181.61</td>
</tr>
<tr>
<td>Subconductor diameter (cm)</td>
<td>2.95</td>
<td>3.04</td>
<td>3.10</td>
<td>1.73</td>
<td>1.75</td>
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<tr>
<td>CORONA INCEPTION</td>
<td></td>
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<tr>
<td>Surface roughness factor (m)</td>
<td>0.8</td>
<td>0.8</td>
<td>0.8</td>
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<td>0.8</td>
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<td>ABC</td>
<td>ABC</td>
<td>ABC</td>
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<tr>
<td>Ec</td>
<td>15.79</td>
<td>15.41</td>
<td>15.13</td>
<td>18.32</td>
<td>18.11</td>
</tr>
<tr>
<td>Ec/E0</td>
<td>26.57</td>
<td>26.49</td>
<td>26.43</td>
<td>28.28</td>
<td>28.23</td>
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<tr>
<td>Atmospheric correction factor type</td>
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<td>Ka</td>
<td>Ka</td>
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<td>Atmospheric correction factor</td>
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### STUDY ON THE INTERCONNECTION OF THE ELECTRICITY NETWORK OF THE NILE EQUATORIAL LAKES COUNTRIES

#### 4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
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<tr>
<td><strong>ELECTRIC FIELD</strong></td>
<td></td>
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<tr>
<td>Height above ground (m)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<tr>
<td>Horizontal scale of graphic (m)</td>
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<td>Width of right-of-way (m)</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Phase current (A)</td>
<td>660</td>
<td>660</td>
<td>660</td>
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<tr>
<td>Electric field outside right-of-way (-XN); (m)</td>
<td>1.161</td>
<td>1.166</td>
<td>1.170</td>
<td>1.492</td>
<td>1.494</td>
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<tr>
<td>Electric field outside right-of-way (XN); (m)</td>
<td>1.311</td>
<td>1.317</td>
<td>1.321</td>
<td>1.686</td>
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<td>Type of vehicle for induced short-circuit current</td>
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<td>Short-circuit current (mA)</td>
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<td>1.165</td>
<td>1.169</td>
<td>1.522</td>
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<td>56.0</td>
<td>56.0</td>
<td>56.0</td>
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<tr>
<td>Magnetic field outside right-of-way (XN); (mG)</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
<td>45.0</td>
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<tr>
<td>Conductor height selection</td>
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<td>Height above ground for RI (H1), (m)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
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<td>Height above ground for TVI (H2), (m)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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<tr>
<td>TV Channel</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
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<td>FCC Television service grade</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
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<tr>
<td>RI (L50-Rain), dB above 1 µV/m</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
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<tr>
<td>TVI (L50-Rain), dB above 1 µV/m</td>
<td>16.13</td>
<td>15.38</td>
<td>14.81</td>
<td>14.58</td>
<td>14.22</td>
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<td>TV interference SNR (L50-Rain) dB</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
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<tr>
<td>RI (L50-Fair), dB above 1 µV/m</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
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<td>TVI (L50-Fair), dB above 1 µV/m</td>
<td>-8.87</td>
<td>-9.62</td>
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<td>-10.42</td>
<td>-10.78</td>
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<tr>
<td>TV interference SNR (L50-Fair), (dB)</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
</tr>
<tr>
<td><strong>AUDIBLE NOISE CALCULATION</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductor height selection</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PTOTAL (L50-RAIN) (EPRI), dB (A)</td>
<td>57.35</td>
<td>56.85</td>
<td>56.45</td>
<td>53.99</td>
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<td>PTOTAL (L50-RAIN) (EPRI), db (A)</td>
<td>48.23</td>
<td>47.43</td>
<td>46.81</td>
<td>45.16</td>
<td>44.85</td>
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<tr>
<td>PTOTAL (L50-RAIN) (BPA), db (A)</td>
<td>48.82</td>
<td>48.25</td>
<td>47.82</td>
<td>43.54</td>
<td>43.27</td>
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Result_220 kV Line_Rusumo-Birembo_En_1500_1C.xls 2 November 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level

Result_220 kV Line_Rusumo-Birembo_En_1500_1C.xls 3 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
ELECTRIC FIELD CURVE

E (kV/m)

XN (m)

Electric field at ground level
Electric field at 1 meter above ground level

Result_220 kV Line_Rusumo-Birembo_En_1500_1C.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.4 - TWO ACSR OSTRICH

ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
MAGNETIC FIELD CURVE

Field at specified level

C1-A  C2-B  ▲C3  ▲C4-  ▲C5-  ▲C6

XN (m)  B (mG)

STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
MAGNETIC FIELD CURVE

1000.00
100.00
10.00
1.00
-1.00
-10 -5 0 5 10

B (mG)

-10 -5 0 5 10

XN (m)

Field at specified level

Result_220 kV Line_Rusumo-Birembo_Elevation 1500 m_1C.xls
November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.4 - TWO ACSR OSTRICH
MAGNETIC FIELD CURVE

Field at specified level

-XN (m)
B (mG)
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
MAGNETIC FIELD CURVE
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

Result_220 kV Line_Rusumo-Birembo_En_1500_1C.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

Result_220 kV Line_Rusumo-Birembo_Ed_1500_1C.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.3 - ONE AAAC T570AG
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

Result_220 kV Line_Rusumo-Birembo_En_1500_1C.xls
November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

C1-A
C2-B
C3-C
C4-
C5-
C6-

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)
RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.4 - TWO ACSR OSTRICH
AUDIBLE NOISE CURVE
RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m

1) TOWER CONFIGURATION

<table>
<thead>
<tr>
<th>Conductor number</th>
<th>At Tower X (m)</th>
<th>At Tower Y (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-5.05</td>
<td>25.1</td>
</tr>
<tr>
<td>2</td>
<td>5.05</td>
<td>21.55</td>
</tr>
<tr>
<td>3</td>
<td>-5.35</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>5</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>6</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

2) GENERAL

Rated voltage: 245 kV
Elevation: 1750 meter
Conductors sag: 10 meter
Frequency: 50 Hz
Ambient temperature: 20 °C

3) CASE DESCRIPTION

Case No.1: ONE ACSR CANARY
Case No.2: ONE ACSR CARDINAL
Case No.3: ONE AAAC T570 AG
Case No.4: TWO ACSR OSTRICH
Case No.5: TWO AAAC T182AG

4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
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<td>Number of circuits</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Number of subconductors</td>
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<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Distance between subconductors (cm)</td>
<td>-</td>
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<td>-</td>
<td>45.8</td>
<td>45.8</td>
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<tr>
<td>Subconductor type</td>
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<td>ACSR</td>
<td>AAAC6201</td>
<td>ACSR</td>
<td>AAAC6201</td>
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<tr>
<td>Subconductor name</td>
<td>CANARY</td>
<td>CARDINAL</td>
<td>T570AG</td>
<td>OSTRICH</td>
<td>T182AG</td>
</tr>
<tr>
<td>Subconductor area Al (kcmil)</td>
<td>900.0</td>
<td>954.0</td>
<td>1125.3</td>
<td>300.0</td>
<td>358.4</td>
</tr>
<tr>
<td>Subconductor total area (sq mm)</td>
<td>515.10</td>
<td>545.93</td>
<td>570.19</td>
<td>177.03</td>
<td>181.61</td>
</tr>
<tr>
<td>Subconductor diameter (cm)</td>
<td>2.95</td>
<td>3.04</td>
<td>3.10</td>
<td>1.73</td>
<td>1.75</td>
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CORONA INCEPTION

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<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
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<td>Surface roughness factor (m)</td>
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<td>ABC</td>
<td>ABC</td>
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<td>ABC</td>
<td>ABC</td>
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<td>E0</td>
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<td>Ka</td>
<td>Ka</td>
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<tr>
<td>Atmospheric correction factor</td>
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<td>0.854</td>
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</table>
### 4) CASE DETAILS

<table>
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<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
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</table>
### ELECTRIC FIELD

<table>
<thead>
<tr>
<th></th>
<th>Height above ground (m)</th>
<th>Horizontal scale of graphic (m)</th>
<th>Width of right-of-way (m)</th>
<th>Phase current (A)</th>
<th>Electric field outside right-of-way (-XN); (m)</th>
<th>Electric field outside right-of-way (XN); (m)</th>
<th>Type of vehicle for induced short-circuit current</th>
</tr>
</thead>
<tbody>
<tr>
<td>Case No.1</td>
<td>1</td>
<td>100</td>
<td>30</td>
<td>660</td>
<td>1.161</td>
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<td>30</td>
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<td>1.166</td>
<td>1.317</td>
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<td>Case No.3</td>
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<td>30</td>
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<td>1.170</td>
<td>1.321</td>
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<td>1.492</td>
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<td>1.494</td>
<td>1.688</td>
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### RADIO AND TELEVISION NOISE CALCULATION

<table>
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<tr>
<th>Conductors height selection</th>
<th>Average Height</th>
<th>Average Height</th>
<th>Average Height</th>
<th>Average Height</th>
<th>Average Height</th>
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</thead>
<tbody>
<tr>
<td>TVI Channel</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
</tr>
<tr>
<td>FCC Television service grade</td>
<td>B</td>
<td>B</td>
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<td>B</td>
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</table>

### Audible Noise Calculation

<table>
<thead>
<tr>
<th>Conductors height selection</th>
<th>Lowest Height</th>
<th>Lowest Height</th>
<th>Lowest Height</th>
<th>Lowest Height</th>
<th>Lowest Height</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height above ground (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>TVI (L50-Fair) dB above 1 µV/m</td>
<td>34.34</td>
<td>33.59</td>
<td>33.02</td>
<td>32.79</td>
<td>32.43</td>
</tr>
<tr>
<td>TVI (L50-Fair) dB above 1 µV/m</td>
<td>-8.04</td>
<td>-8.79</td>
<td>-9.36</td>
<td>-9.59</td>
<td>-9.94</td>
</tr>
<tr>
<td>TVI interference SNR (L50-Fair) dB</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
</tr>
<tr>
<td>Audible noise outside right-of-way (m)</td>
<td>49.66</td>
<td>49.09</td>
<td>48.66</td>
<td>44.37</td>
<td>44.10</td>
</tr>
</tbody>
</table>
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m

CASE No.1 - ONE ACSR CANARY

ELECTRIC FIELD CURVE

Electric field at ground level

Electric field at 1 meter above ground level

XN (m)

E (kV/m)
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.3 - ONE AAAC T570 AG

ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRICH
ELECTRIC FIELD CURVE

Result_220 kV Line_Rusumo-Birembo_EN_1750_1C.xls
November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.5 - TWO AAAC T182AG
ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m

CASE No.2 - ONE ACSR CARDINAL

MAGNETIC FIELD CURVE

Field at specified level

Result_220 kV Line_Rusumo-Birembo_Elevation_1750_1C.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRICH

MAGNETIC FIELD CURVE

Field at specified level

Result_220 kV Line_Rusumo-Birembo_Elevation 1750 m.xls

November, 2009
FIGURE 2: MAGNETIC FIELD CURVE FOR THE RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m

CASE No.5 - TWO AAAC T182AG

Field at specified level

XN (m) | B (mG)
---|---
-45.833 | -45.833
-41.667 | -41.667
-37.500 | -37.500
-33.333 | -33.333
-29.167 | -29.167
-25.000 | -25.000
-20.833 | -20.833
-16.667 | -16.667
-12.500 | -12.500
-8.333 | -8.333
-4.167 | -4.167
0.000 | 0.000
4.167 | 4.167
8.333 | 8.333
12.500 | 12.500
16.667 | 16.667
20.833 | 20.833
25.000 | 25.000
29.167 | 29.167
33.333 | 33.333
37.500 | 37.500
41.667 | 41.667
45.833 | 45.833
50.000 | 50.000
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.1 - ONE ACSR CANARY
RI, TVI NOISE CURVE

RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRICH
RI, TVI NOISE CURVE

Result_220 kV Line_Rusumo-Birembo En_1750_1C.xls 16 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m

CASE No.5 - TWO AAAC T182AG

RI, TVI NOISE CURVE

- E (kV/m)
  - XN (m)

E4 Average Fair
E4 Average Measurable Rain
TVI/Phase
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

Result_220 kV Line_Rusumo-Birembo_Elevation_1750_1C.xls
19 November, 2009

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.3 - ONE AAAC T570 AG

AUDIBLE NOISE CURVE

Result_220 kV Line_Rusumo-Birembo_En_1750_1C.xls 20 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV SINGLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.5 - TWO AAAC T182AG
AUDIBLE NOISE CURVE

<table>
<thead>
<tr>
<th>P dB(A)</th>
<th>XN (m)</th>
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<tbody>
<tr>
<td>-50.00</td>
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</tr>
<tr>
<td>-45.83</td>
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<td>33.33</td>
<td>95.00</td>
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<tr>
<td>37.50</td>
<td>100.00</td>
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</table>

- Ptotal (L5 Rain) (EPRI)
- Ptotal (L50 Rain) (EPRI)
- Ptotal (L50 Rain) (BPA)
# STUDY ON THE ELECTRICITY TRANSMISSION LINES
## LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

## RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m

### 1) TOWER CONFIGURATION

<table>
<thead>
<tr>
<th>Conductor number</th>
<th>Tower X (m)</th>
<th>Tower Y (m)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>-5.05</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>-5.05</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>-5.35</td>
<td>18</td>
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<tr>
<td>4</td>
<td>5.05</td>
<td>32</td>
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<tr>
<td>5</td>
<td>5.05</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>5.35</td>
<td>18</td>
</tr>
</tbody>
</table>

### 2) GENERAL

- Rated voltage: 245 kV
- Elevation: 1500 meter
- Conductors sag: 10 meter
- Frequency: 50 Hz
- Ambient temperature: 20 °C

### 3) CASE DESCRIPTION

- Case No.1: ONE ACSR CANARY
- Case No.2: ONE ACSR CARDINAL
- Case No.3: ONE AAAC T570AG
- Case No.4: TWO ACSR OSTRICH
- Case No.5: TWO AAAC T182AG

### 4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>BUNDLE AND SUBCONDUCTORS SPECIFICATIONS</th>
<th>CORONA INCEPTION</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Number of circuits</td>
<td>Number of subconductors</td>
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<tr>
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</table>

- Atmospheric correction factor type: Ka
- Atmospheric correction factor: 0.875

---

Result_220 kV Line_Rusumo-Birembo En_1500.xls  
November, 2009
4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
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<tbody>
<tr>
<td><strong>ELECTRIC FIELD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height above ground (m)</td>
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<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Horizontal scale of graphic (m)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Width of right-of-way (m)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Phase current (A)</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>Electric field outside right-of-way (-XN); (m)</td>
<td>0.855</td>
<td>0.859</td>
<td>0.862</td>
<td>1.122</td>
<td>1.124</td>
</tr>
<tr>
<td>Electric field outside right-of-way (+XN); (m)</td>
<td>0.855</td>
<td>0.859</td>
<td>0.862</td>
<td>1.122</td>
<td>1.124</td>
</tr>
<tr>
<td>Type of vehicle for induced short-circuit current</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
</tr>
<tr>
<td>Short-circuit current (mA)</td>
<td>1.118</td>
<td>1.123</td>
<td>1.127</td>
<td>1.472</td>
<td>1.474</td>
</tr>
<tr>
<td>Magnetic field outside right-of-way (-XN); (mG)</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
</tr>
<tr>
<td>Magnetic field outside right-of-way (+XN); (mG)</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
</tr>
<tr>
<td><strong>RADIO AND TELEVISION NOISE CALCULATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductor height selection</td>
<td>Average Height</td>
<td>Average Height</td>
<td>Average Height</td>
<td>Average Height</td>
<td>Average Height</td>
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<tr>
<td>Height above ground for RI (H1), (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Height above ground for TVI (H2), (m)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
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</tr>
<tr>
<td>TV Channel</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
</tr>
<tr>
<td>FCC Television service grade</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>RI (L_{\text{50}} \text{- Rain}), dB above 1 \mu V/m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td></td>
</tr>
<tr>
<td>TVI (L_{\text{50}} \text{- Rain}), dB above 1 \mu V/m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18.99</td>
<td>18.24</td>
<td>17.67</td>
<td>17.54</td>
<td>17.18</td>
<td></td>
</tr>
<tr>
<td>TVI interference SNR (L_{\text{50}} \text{- Rain}) dB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td></td>
</tr>
<tr>
<td>RI (L_{\text{50}} \text{- Fair}), dB above 1 \mu V/m</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td>OK at 30 m from outside conductor</td>
<td></td>
</tr>
<tr>
<td>TVI (L_{\text{50}} \text{- Fair}), dB above 1 \mu V/m</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>-6.01</td>
<td>-6.76</td>
<td>-7.33</td>
<td>-7.46</td>
<td>-7.82</td>
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<tr>
<td>TVI interference SNR (L_{\text{50}} \text{- Fair}) dB</td>
<td></td>
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</tr>
<tr>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td></td>
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<tr>
<td><strong>AUDIBLE NOISE CALCULATION</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Conductor height selection</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
<td>Lowest Height</td>
</tr>
<tr>
<td>Audible noise outside right-of-way (m)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<tr>
<td>Height above ground (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PTOTAL (L_{\text{P}} \text{- RAIN}) (EPRI), dB (A)</td>
<td>60.52</td>
<td>60.04</td>
<td>59.66</td>
<td>57.29</td>
<td>57.13</td>
</tr>
<tr>
<td>PTOTAL (L_{\text{P}} \text{- RAIN}) (EPRI), db (A)</td>
<td>51.72</td>
<td>50.95</td>
<td>50.34</td>
<td>48.85</td>
<td>48.55</td>
</tr>
<tr>
<td>PTOTAL (L_{\text{P}} \text{- RAIN}) (BPA), db (A)</td>
<td>52.09</td>
<td>51.53</td>
<td>51.10</td>
<td>47.10</td>
<td>46.83</td>
</tr>
</tbody>
</table>
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
ELECTRIC FIELD CURVE

Electic field at ground level

Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.3 - ONE AAAC T570AG
ELECTRIC FIELD CURVE

Result_220 kV Line_Rusumo-Birembo En_1500.xls 5 November, 2009

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.4 - TWO ACSR OSTRICH

ELECTRIC FIELD CURVE

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY

MAGNETIC FIELD CURVE

Field at specified level

C1-A C2-B C3-C C4-C C5-B C6-A

Result_220 kV Line_Rusumo-Birembo_En_1500.xls 8 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
MAGNETIC FIELD CURVE

Field at specified level

Result_220 kV Line_Rusumo-Birembo_En_1500.xls 9 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.3 - ONE AAAC T570AG
MAGNETIC FIELD CURVE

[Graph showing magnetic field curve with specified levels and coordinates]
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
MAGNETIC FIELD CURVE

Result_220 kV Line_Rusumo-Birembo_En_1500.xls 12 November, 2009

Field at specified level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

XN (m)

156 116 76 36 96 156

E (kV/m)

0.00 4.17 8.33 12.50 16.67 20.83 25.00 29.17 33.33 37.50 41.67 45.83 50.00

0.00 4.17 8.33 12.50 16.67 20.83 25.00 29.17 33.33 37.50 41.67 45.83 50.00

0.00 4.17 8.33 12.50 16.67 20.83 25.00 29.17 33.33 37.50 41.67 45.83 50.00

-10 -5 0 5 10

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35

C1-A C2-B C3-C C4-C C5-B C6-A

Result_220 kV Line_Rusumo-Birembo_Eng_1500.xls

November, 2009
## STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
RI, TVI NOISE CURVE

### Table: EMI Average Fair and Measurable Rain

<table>
<thead>
<tr>
<th>XN (m)</th>
<th>E (kV/m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>50</td>
</tr>
<tr>
<td>5</td>
<td>45.83</td>
</tr>
<tr>
<td>10</td>
<td>41.67</td>
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<tr>
<td>15</td>
<td>37.50</td>
</tr>
<tr>
<td>20</td>
<td>33.33</td>
</tr>
<tr>
<td>25</td>
<td>29.17</td>
</tr>
<tr>
<td>30</td>
<td>25.00</td>
</tr>
<tr>
<td>35</td>
<td>20.83</td>
</tr>
<tr>
<td>40</td>
<td>16.67</td>
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<tr>
<td>45</td>
<td>12.50</td>
</tr>
<tr>
<td>50</td>
<td>8.33</td>
</tr>
<tr>
<td>55</td>
<td>4.17</td>
</tr>
</tbody>
</table>

### Diagram: RI, TVI Noise Curve

- EMI Average Fair
- EMI Average Measurable Rain
- TVI/Phase

---

*Result_220 kV Line_Rusumo-Birembo_En_1500.xls*  
*November, 2009*
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.3 - ONE AAAC T570AG
RI, TVI NOISE CURVE

E (kV/m)

XN (m)

Result_220 kV Line_Rusumo-Birembo En_1500.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

Result_220 kV Line_Rusumo-Birembo_En_1500.xls 17 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.1 - ONE ACSR CANARY
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)

Result_220 kV Line_Rusumo-Birembo_En_1500.xls
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.2 - ONE ACSR CARDINAL
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

Result_220 kV Line_Rusumo-Birembo_En_1500.xls 19 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.3 - ONE AAAC T570AG
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.4 - TWO ACSR OSTRICH
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1500 m
CASE No.5 - TWO AAAC T182AG
AUDIBLE NOISE CURVE

Result_220 kV Line_Rusumo-Birembo_Elev_1500.xls
22 November, 2009

XN (m)
P dB(A)

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)
C1-A C2-B C3-C C4-C C5-B C6-A
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m

1) TOWER CONFIGURATION

<table>
<thead>
<tr>
<th>Conductor number</th>
<th>At Tower X (m)</th>
<th>At Tower Y (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-5.05</td>
<td>32</td>
</tr>
<tr>
<td>2</td>
<td>-5.05</td>
<td>25</td>
</tr>
<tr>
<td>3</td>
<td>-5.35</td>
<td>18</td>
</tr>
<tr>
<td>4</td>
<td>5.05</td>
<td>32</td>
</tr>
<tr>
<td>5</td>
<td>5.05</td>
<td>25</td>
</tr>
<tr>
<td>6</td>
<td>5.35</td>
<td>18</td>
</tr>
</tbody>
</table>

2) GENERAL

- Rated voltage: 245 kV
- Elevation: 1750 meter
- Conductors sag: 10 meter
- Frequency: 50 Hz
- Ambient temperature: 20 °C

3) CASE DESCRIPTION

- Case No.1: ONE ACSR CANARY
- Case No.2: ONE ACSR CARDINAL
- Case No.3: ONE AAAC T570NG
- Case No.4: TWO ACSR OSTRICH
- Case No.5: TWO AAAC T182AG

4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of circuits</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Number of subconductors</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Distance between subconductors (cm)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>45.8</td>
<td>45.8</td>
</tr>
<tr>
<td>Subconductor type</td>
<td>ACSR</td>
<td>ACSR</td>
<td>AAAC6201</td>
<td>ACSR</td>
<td>AAAC6201</td>
</tr>
<tr>
<td>Subconductor name</td>
<td>CANARY</td>
<td>CARDINAL</td>
<td>T570AG</td>
<td>OSTRICH</td>
<td>T182AG</td>
</tr>
<tr>
<td>Subconductor area Al (kcmil)</td>
<td>900.0</td>
<td>954.0</td>
<td>1125.3</td>
<td>300.0</td>
<td>358.4</td>
</tr>
<tr>
<td>Subconductor total area (sq mm)</td>
<td>515.10</td>
<td>545.93</td>
<td>570.19</td>
<td>177.03</td>
<td>181.61</td>
</tr>
<tr>
<td>Subconductor diameter (cm)</td>
<td>2.95</td>
<td>3.04</td>
<td>3.10</td>
<td>1.73</td>
<td>1.75</td>
</tr>
</tbody>
</table>

CORONA INCEPTION

| Surface roughness factor (m) | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 |
| Phasing | ABC-CBA | ABC-CBA | ABC-CBA | ABC-CBA | ABC-CBA |
| E_0 | 15.91 | 15.53 | 15.25 | 18.50 | 18.29 |
| E_0 | 26.00 | 25.92 | 25.86 | 27.69 | 27.64 |
| Ec/E0 | 0.87 | 0.85 | 0.83 | 0.94 | 0.94 |
| Atmospheric correction factor type | Ka | Ka | Ka | Ka | Ka |
| Atmospheric correction factor | 0.854 | 0.854 | 0.854 | 0.854 | 0.854 |

November 2009
### 4) CASE DETAILS

<table>
<thead>
<tr>
<th>CASE</th>
<th>Case No.1</th>
<th>Case No.2</th>
<th>Case No.3</th>
<th>Case No.4</th>
<th>Case No.5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ELECTRIC FIELD</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height above ground (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Horizontal scale of graphic (m)</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Width of right-of-way (m)</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
<td>30</td>
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<tr>
<td>Phase current (A)</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>660</td>
<td>660</td>
</tr>
<tr>
<td>Electric field outside right-of-way (-XN); (m)</td>
<td>0.855</td>
<td>0.859</td>
<td>0.862</td>
<td>1.122</td>
<td>1.124</td>
</tr>
<tr>
<td>Electric field outside right-of-way (+XN); (m)</td>
<td>0.855</td>
<td>0.859</td>
<td>0.862</td>
<td>1.122</td>
<td>1.124</td>
</tr>
<tr>
<td>Type of vehicle for induced short-circuit current</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
<td>School Bus</td>
</tr>
<tr>
<td>Short-circuit current (mA)</td>
<td>1.118</td>
<td>1.123</td>
<td>1.127</td>
<td>1.472</td>
<td>1.474</td>
</tr>
<tr>
<td>Magnetic field outside right-of-way (-XN); (mG)</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
</tr>
<tr>
<td>Magnetic field outside right-of-way (+XN); (mG)</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
<td>43.6</td>
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<tr>
<td><strong>RADIO AND TELEVISION NOISE CALCULATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductor height selection</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height above ground for RI (H1), (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Height above ground for TVI (H2), (m)</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>TV Channel</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
<td>2-6</td>
</tr>
<tr>
<td>FCC Television service grade</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
<td>B</td>
</tr>
<tr>
<td>RI (L&lt;sub&gt;50&lt;/sub&gt;-Rain), dB above 1 µV/m</td>
<td>62.75</td>
<td>62.00</td>
<td>61.42</td>
<td>61.00</td>
<td>60.64</td>
</tr>
<tr>
<td>TVI (L&lt;sub&gt;50&lt;/sub&gt;-Rain), dB above 1 µV/m</td>
<td>19.83</td>
<td>19.08</td>
<td>18.51</td>
<td>18.37</td>
<td>18.01</td>
</tr>
<tr>
<td>TV interference SNR (L&lt;sub&gt;50&lt;/sub&gt;-Rain) dB</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVI interference SNR (L&lt;sub&gt;50&lt;/sub&gt;-Rain) dB</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
</tr>
<tr>
<td>RI (L&lt;sub&gt;50&lt;/sub&gt;-Fair), dB above 1 µV/m</td>
<td>37.75</td>
<td>37.00</td>
<td>36.42</td>
<td>36.00</td>
<td>35.64</td>
</tr>
<tr>
<td>TVI (L&lt;sub&gt;50&lt;/sub&gt;-Fair), dB above 1 µV/m</td>
<td>-5.17</td>
<td>-5.92</td>
<td>-6.49</td>
<td>-6.63</td>
<td>-6.99</td>
</tr>
<tr>
<td>TVI interference SNR (L&lt;sub&gt;50&lt;/sub&gt;-Fair), (dB)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TVI interference SNR (L&lt;sub&gt;50&lt;/sub&gt;-Fair), (dB)</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
<td>Perceptible not annoying</td>
</tr>
<tr>
<td><strong>AUDIBLE NOISE CALCULATION</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conductor height selection</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Audible noise outside right-of-way (m)</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>15</td>
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<tr>
<td>Height above ground (m)</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>PTOTAL (L&lt;sub&gt;50&lt;/sub&gt;-RAIN) (EPRI), dB (A)</td>
<td>61.35</td>
<td>60.87</td>
<td>60.49</td>
<td>58.12</td>
<td>57.96</td>
</tr>
<tr>
<td>PTOTAL (L&lt;sub&gt;50&lt;/sub&gt;-RAIN) (EPRI), db (A)</td>
<td>52.55</td>
<td>51.78</td>
<td>51.18</td>
<td>49.68</td>
<td>49.38</td>
</tr>
<tr>
<td>PTOTAL (L&lt;sub&gt;50&lt;/sub&gt;-RAIN) (BPA), db (A)</td>
<td>52.92</td>
<td>52.36</td>
<td>51.93</td>
<td>47.94</td>
<td>47.67</td>
</tr>
</tbody>
</table>

*Result_220 kV Line_Rusumo-Birembo_En_1750.xls*  
November 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
ELECTRIC FIELD CURVE

Result_220 kV Line_Rusumo-Birembo_En_1750.xls
4 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.5 - TWO AAAC T182AG
ELECTRIC FIELD CURVE

Result_220 kV Line_Rusumo-Birembo_En_1750.xls 7 November, 2009

Electric field at ground level
Electric field at 1 meter above ground level
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.1 - ONE ACSR CANARY
MAGNETIC FIELD CURVE

Field at specified level

C1-A C2-B C3-C C4-C C5-B C6-A

XN (m)

B (mG)

0 5 10 15 20 25 30 35

-10 -5 0 5 10

Result_220 kV Line_Rusumo-Birembo_En_1750.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES 
LINKED TO THE RUSUMO-FALLS 
HYDRO-ELECTRIC GENERATION PLANT 

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m 
CASE No.2 - ONE ACSR CARDINAL 
MAGNETIC FIELD CURVE 

![Magnetic Field Curve Graph](result_220_kv_line_rusumo-birembo_en_1750.xls)
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.3 - ONE AAAC T570NG
MAGNETIC FIELD CURVE
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRICH
MAGNETIC FIELD CURVE

Field at specified level

Result_220 kV Line_Rusumo-Birembo_En_1750.xls

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.1 - ONE ACSR CANARY

RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

Result_220 kV Line_Rusumo-Birembo_En_1750.xls
November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

XN (m)
-50 0 5 10 15 20 25 30 35 40 45 50

E (kV/m)
0 5 10 15 20 25 30 35
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRIC
RI, TVI NOISE CURVE

Result_220 kV Line_Rusumo-Birembo En_1750.xls
16 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.5 - TWO AAAC T182AG
RI, TVI NOISE CURVE

EMI Average Fair
EMI Average Measurable Rain
TVI/Phase

XN (m)

E (kV/m)

Result_220 kV Line_Rusumo-Birembo_En_1750.xls 17 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.1 - ONE ACSR CANARY
AUDIBLE NOISE CURVE

Result_220 kV Line_Rusumo-Birembo_En_1750.xls 18 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.2 - ONE ACSR CARDINAL
AUDIBLE NOISE CURVE

![Graph showing audible noise curve with various markers and noise levels.](Result_220_kV_Line_Rusumo-Birembo_En_1750.xls)

- $P_{total}$ (L5 Rain) (EPRI)
- $P_{total}$ (L50 Rain) (EPRI)
- $P_{total}$ (L5 Rain) (BPA)
- Markers for different cases and locations.
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.3 - ONE AAAC T570NG
AUDIBLE NOISE CURVE

- $P_{dB(A)}$
- $XN$ (m)

![Graph](Result_220_kV_Line_Rusumo-Birembo_En_1750.xls)

November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.4 - TWO ACSR OSTRICH AUDIBLE NOISE CURVE

Result_220 kV Line_Rusumo-Birembo_En_1750.xls 21 November, 2009
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

RUSUMO FALLS 220 KV DOUBLE CIRCUIT DESIGN AT ELEVATION 1750 m
CASE No.5 - TWO AAAC T182AG
AUDIBLE NOISE CURVE

P dB(A)

XN (m)

-50.00 -45.83 -41.67 -37.50 -33.33 -29.17 -25.00 -20.83 -16.67 -12.50 -8.33 -4.17 0.00 4.17 8.33 12.50 16.67 20.83 25.00 29.17 33.33 37.50 41.67 45.83 50.00

0.00 5.00 10.00 15.00 20.00 25.00 30.00 35.00

C1-A C2-B C3-C C4-C C5-B C6-A

Ptotal (L5 Rain) (EPRI)
Ptotal (L50 Rain) (EPRI)
Ptotal (L50 Rain) (BPA)

Result_220 kV Line_Rusumo-Birembo_Em_1750.xls
November, 2009
# APPENDIX E: CALCULATION OF THE DISTANCE BETWEEN LIVES PARTS AND OBSTACLES

<table>
<thead>
<tr>
<th>Item</th>
<th>Calculation Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>New Single and Double Circuit 220 kV Line Calculation Distance Between Live Parts and Obstacles.</td>
</tr>
</tbody>
</table>
STUDY ON THE ELECTRICITY TRANSMISSION LINES
LINKED TO THE RUSUMO-FALLS
HYDRO-ELECTRIC GENERATION PLANT

Design brief
New single and double circuits 220 kV line
Calculation of distance between live parts and obstacles

Prepared by: ____________________________

Approved by: ____________________________
1. DESCRIPTION OF INPUT DATA USED IN CALCULATION OF THE ELECTRICAL DISTANCE

<table>
<thead>
<tr>
<th><strong>Symbol</strong></th>
<th><strong>Value</strong></th>
<th><strong>Description</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>$U_S$</td>
<td>245 kV</td>
<td>Maximum operating voltage of the system</td>
</tr>
<tr>
<td>$\text{TOCC}$</td>
<td>1</td>
<td>Occupancy at electrical distance</td>
</tr>
<tr>
<td>$k_g$ 1</td>
<td>1,2</td>
<td>First gap factor</td>
</tr>
<tr>
<td>$k_g$ 2</td>
<td>1,4</td>
<td>Second gap factor</td>
</tr>
<tr>
<td>$k_{mSF}$</td>
<td>0,4</td>
<td>Mitigation correction factor for slow-front surges</td>
</tr>
<tr>
<td>$k_{mFF}$</td>
<td>1,0</td>
<td>Mitigation correction for temporary overvoltages surges and fast-front surges</td>
</tr>
<tr>
<td>$k_{SSF}$</td>
<td>1,13</td>
<td>Statistical factor or the ratio of $U_{90\text{SF}}$ to $U_{2\text{SF}}$ due to switching operations</td>
</tr>
<tr>
<td>$k_{SSFR}$</td>
<td>1,11</td>
<td>Statistical factor or the ratio $U_{90\text{SFR}}$ to $U_{2\text{SFR}}$ for slow-front due to reclosing operations</td>
</tr>
<tr>
<td>$k_{SFF}$</td>
<td>1,13</td>
<td>Statistical factor or the ratio of $U_{90\text{FF}}$ to $U_{2\text{FF}}$ for fast-front overvoltages</td>
</tr>
<tr>
<td>Elev.</td>
<td>1750 m</td>
<td>Elevation</td>
</tr>
<tr>
<td>$k_a$</td>
<td>0,850</td>
<td>Atmospheric correction factor for temporary overvoltage</td>
</tr>
<tr>
<td>$k_a$</td>
<td>0,880</td>
<td>Atmospheric correction factor for slow-front surges</td>
</tr>
<tr>
<td>$k_a$</td>
<td>0,950</td>
<td>Atmospheric correction factor for fast-front surges</td>
</tr>
<tr>
<td>Length</td>
<td>182,0 km</td>
<td>Length of the line</td>
</tr>
<tr>
<td>$D_{LT}$</td>
<td>2,45 m</td>
<td>Gap between conductor and tower</td>
</tr>
<tr>
<td>$n_{SF}$</td>
<td>20 (Year$^{-1}$)</td>
<td>Number of slow-front overvoltages due to switching operations per year</td>
</tr>
<tr>
<td>$n_{SFR}$</td>
<td>15 (Year$^{-1}$)</td>
<td>Number of slow-front overvoltages due to reclosing operations per year</td>
</tr>
<tr>
<td>$n_{FF}$</td>
<td>15 (Year$^{-1}$)</td>
<td>Number of fast-front overvoltages per year</td>
</tr>
<tr>
<td>$N$</td>
<td>8760</td>
<td>Number of hours in a year</td>
</tr>
<tr>
<td>$R_a$</td>
<td>1,00E-7</td>
<td>Annual probability of breakdown of air gap due to temporary overvoltages</td>
</tr>
<tr>
<td>$R_{aSF}$</td>
<td>1,00E-7</td>
<td>Annual probability of breakdown of air gap due to slow-front surges</td>
</tr>
<tr>
<td>$R_{aFF}$</td>
<td>1,00E-7</td>
<td>Annual probability of breakdown of air gap due to fast-front surges</td>
</tr>
<tr>
<td>$S_A$</td>
<td>0,04</td>
<td>Coefficient of variation of the distribution of temporary overvoltages $U_{2A}$</td>
</tr>
<tr>
<td>$S_{SF}$</td>
<td>0,05</td>
<td>Coefficient of variation of the distribution of sparkover voltages for slow-front waves</td>
</tr>
<tr>
<td>$S_{FF}$</td>
<td>0,03</td>
<td>Coefficient of variation of the distribution of sparkover voltages for fast-front waves</td>
</tr>
<tr>
<td>$u_{2A}$</td>
<td>1,20 p.u.</td>
<td>Temporary overvoltage having a 2% probability of being exceeded in p.u.</td>
</tr>
<tr>
<td>$u_{2SF}$</td>
<td>2,60 p.u.</td>
<td>Slow-front overvoltage having a 2% probability of being exceeded in p.u.</td>
</tr>
<tr>
<td>$u_{2SFR}$</td>
<td>3,20 p.u.</td>
<td>Fast-front overvoltages having a 2% probability of being exceeded in p.u.</td>
</tr>
</tbody>
</table>
2. GENERAL

The maximum operating voltage $U_S$ for the new 220 kV lines will be 245 kV.

$T_{occ} = 1$ h; occupancy at electrical distance.

$K_g$ is the slow-front gap factor. The slow-front gap factor is taken to be 1.4 and to be 1.2 for this calculation.

*NOTE: The value to be used depends upon the configuration of the object and the line. Further information is given in CIGRE Guide 72 and IEC 60071-2. A gap factor of 1.4 is taken to be typical of the gap between a line and the outstretched hand of an individual and 1.1 for a gap between a line and the top of a flat object such as the line to the top of a vehicle.*

$k_a = 0.850$, is the altitude correction factor for the temporary overvoltage at an altitude of 1950 m, an ambient temperature of 20°C and a moisture content of 11 g ⋅ m$^{-3}$. The corresponding atmospheric correction factors for slow-front and fast-front surges are 0.880 and 0.935 respectively.

$K_m = 0.4$ is the selected value of the mitigation factor for switching and reclosing slow-front waveforms, but 1.0 is the selected value for temporary and lightning overvoltages.

It is presumed that there are 20 switching operations per year ($n_{SF} = 20$) with $U_2 = 2.60$ p.u. (i.e. $2.60 \times 245 \times \frac{\sqrt{2}}{\sqrt{3}} = 520.1$ kV

and 10 reclosing operation per year ($n_{SFR} = 10$) with :

$U_2 = 3.20$ p.u. (i.e. $3.20 \times 245 \times \frac{\sqrt{2}}{\sqrt{3}} = 640.1$ kV

A value of 10 fast-front overvoltages per year per 100 km is taken.

(i.e. 27.3 ) fast-front overvoltage per year of relevance for calculating individual probability of sparkover and of amplitude $U_{90}$ of the gap between conductor and tower).

The gap between conductor and tower is 2.45 m.

The temporary overvoltages can be up to 1.20 p.u. but its duration is not known with certainty.
3. DETERMINATION OF $D_{EL}$ FOR SWITCHING OPERATIONS

From sub clause 6 of IEC 61865 standard, the annual probability, $R_{aSF}$ has to be less than 1,00E-7. and so the probability of sparkover of the gap, $R_s$, can be calculated:

$$R_s = R_{aSF} (D_{el}) = \frac{R_{aSF}}{nT \frac{k}{m} \frac{\mu}{N}}$$

$$R_s (D_{el}) = 0,0001095$$

$K_S = 1,13$ from figure 8 of IEC 60071-2 standard for case-peak method.

According to sub clauses 6.2 of IEC 61865 standard, $U_{90}$ and $U_{50}$ statistical withstand voltage of the air gap can be determined by the following equations:

$$U_{90SF} = k_s U_{2SF} = 587,7 \text{kV}$$

and

$$U_{50SF} = \frac{U_{90SF}}{(1 - 1,3 S_{SF})} = 628,6 \text{kV}$$

Calculation of the reference electrical distance $D_{el}$ is as per the following:

$$D_{elSF} = 2,17 \left\{ EXP \left( \frac{U_{50SF}}{1080 k a} \frac{k}{gSF} \right) - 1 \right\}$$

Hence $D_{el} = 1,31 \text{ m}$ for $k_g = 1,4$ (and $D_{el} = 1,60 \text{ m}$ for $k_g = 1,2$)
4. DETERMINATION OF $D_{EL}$ FOR RECLOSED OPERATIONS

From clause 6, the annual probability, $R_{aSF}$, has to be less than 1,00E-7 and so the probability of sparkover of the gap, $R_{S}$, can be calculated:

$$
R_{S} = \frac{R_{aSF}}{SFR} = \left( D_{el} \right) \left( \frac{R_{aSF}}{n_{SFR} T_{ooc} k_{m} N} \right)
$$

With $R_{S} (D_{el}) = 0,000146$

$K_{S} = 1,11$ from figure 8 of IEC 60071-2 standard for case-peak method.

According to sub clauses 6.2 of IEC 61865 standard, $U_{90}$ and $U_{50}$ statistical withstand voltage of the air gap can be determined by the following equations:

$$
U_{90SFR} = k_{S} \frac{U_{2SFR}}{2} = 710,5 \text{kV}
$$

and

$$
U_{50SFR} = \frac{U_{90SFR}}{1 - 1,3 S_{SFR}} = 759,9 \text{kV}
$$

Calculation of the reference electrical distance $D_{el}$ is as per the following:

$$
D_{elSFR} = 2,17 \left\{ EXP \left( \frac{U_{50SFR}}{1080 \ kg \ k_{a}^{SFR}} \right) - 1 \right\}
$$

Hence $D_{el} = 1,67 \text{ m}$ for $k_{g} = 1,4$ (and $D_{el} = 2,05 \text{ m}$ for $k_{g} = 1,2$)
5. LIGHTNING

The fast-front $U_{50}$ of the insulator string, $U_{50FF}$ is calculated from its dimension $D_{LT}$ (2.45m) and the assumed gap factor of the insulator string conductor-to-tower gap (1.4 for slow-front waves) and the altitude correction factor $k_a$ is estimated at 0.935 for this line.

$$U_{50FF} = 530 \frac{D}{L_T} \left(0.74 + 0.26 \, kg_{SF}\right) k_a = 1361.9 \, kV$$  \hspace{1cm} (7)

and next $U_{90FF}$ is derived;

$$U_{90FF} = U_{50FF} \left(1 - 1.3 \, S_{FF}\right) = 1308.8 \, kV$$  \hspace{1cm} (8)

The probability of sparkover of the gap $R_S$ is given by the following equation:

$$R_S \left(\frac{D}{el}\right) = \frac{R_{aFF}}{N} \left(n_{SFF} T_{OOC} k_m \right)$$  \hspace{1cm} (9)

$$R_S \left(\frac{D}{el}\right) = 0.00003209$$

$$K_S = 1.13$$ from figure 8 of IEC 60071-2 standard for case-peak method;

The fast front overvoltage $U_{90}$ must be calculated as per the following for the gap to an object:

$$U_{90} = U_{90FF} \frac{k}{S} = 1478.9 \, kV$$

$$U_{50} = \frac{U_{90}}{\left(1 - 1.3 \, S_{FF}\right)} = 1538.9 \, kV$$

and as per item A.3 of IEC 61865 standard.
\[ D_{elFF} = \frac{U_{50FF}}{530 \left( 0.74 + 0.26 \, kg_{SF} \right) k_a} \]  

(10)

for \( K = 1.4 \); \( D_{el} = 2.77 \) m

and for \( K = 1.2 \); \( D_{el} = 2.91 \) m

6. TEMPORARY OVERVOLTAGES

The overvoltage \( U_{50} \) of the gap is taken to be four standards deviations above the peak value of the maximum amplitude of the temporary overvoltage (1.5 p.u. for this line) and the coefficient of variation \( S_A \) is taken to be 0.04.

\[ U_{50} = \left( 1 + 4 S_a \right) u_2 U \frac{\sqrt{2}}{S \sqrt{3}} = 278.5 \text{ kV} \]

The electrical distance \( D_{el} \) must be calculated with the following equations:

\[ D_{el} = 1.65 \exp \left( \frac{U_{50}}{X} \right) - 1 \]

\[ X = 750 k_{a} \left( 1.35 \, kg_{SF} - 0.35 \, kg_{SF}^2 \right) \]

A value of 767.55 is for \( K_g = 1.4 \) and a value of 711.45 for \( K_g = 1.2 \).

\( D_{el} = 0.83 \) m for \( K_g = 1.4 \)

and \( D_{el} = 0.89 \) m for \( K_g = 1.2 \)

7. SUMMARY OF THE RESULTS

The summary of the results is included in the following table:
The electrical distance $D_{el}$ will be the greatest of the component for each wave type, i.e. $2,77 \text{ m}$ for a gap factor of 1,4 and $2,91 \text{ m}$ for a gap factor of 1,2. A gap factor of 1,4 is taken to be the typical of the gap between a line and the outstretch hand of an individual. While the electrical distance $D_{el}$ for the lightning overvoltage is close to the electrical distance for the reclosing overvoltage, it is necessary to check that the overall probability of sparkover does not exceed $10^{-7}$. If such a condition exist, it is necessary to increase the value of the electrical distance $D_{el}$ until the overall probability of sparkover is at an acceptable level. For the studied it is not necessary.
APPENDIX F : TRANSIENT STABILITY
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

Transient Stability Curves
## Appendix F - Table of contents

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<td>4</td>
</tr>
<tr>
<td>1, Item 2</td>
<td>Permanent three phase fault at 220 KV Rusumo-Falls bus for 5 cycles, fault cleared by tripping of the two circuits of the 220 KV double circuit line from Kigali's airport to Rusumo-Falls</td>
<td>7</td>
</tr>
<tr>
<td>1, Item 3</td>
<td>Permanent three phase fault at 220 KV Rusumo-Falls bus for 5 cycles, fault cleared by tripping of the two circuits of the 220 KV double circuit line from Rusumo-Falls to Nyakanazi</td>
<td>10</td>
</tr>
<tr>
<td>1, Item 4</td>
<td>Permanent three phase fault at 220 KV Kigoma bus for 5 cycles, fault cleared by tripping of the 220 KV single circuit line from Kibuye to Kigoma</td>
<td>13</td>
</tr>
<tr>
<td>1, Item 5</td>
<td>Permanent three phase fault at 220 KV Kigoma bus for 5 cycles, fault cleared by tripping of the 220 KV single circuit line from Kigoma to Bubanza</td>
<td>16</td>
</tr>
<tr>
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<td>Permanent three phase fault at 220 KV Ruzizi 3 bus for 5 cycles, fault cleared by tripping of the 220 KV single circuit line from Ruzizi 3 to Bubanza</td>
<td>19</td>
</tr>
<tr>
<td>2, Item 1</td>
<td>Permanent three phase fault at 220 KV Birembo bus for 5 cycles, fault cleared by tripping of the two circuits of the 220 KV double circuit line from Kigali's airport to Birembo</td>
<td>22</td>
</tr>
<tr>
<td>2, Item 2</td>
<td>Permanent three phase fault at 220 KV Rusumo-Falls bus for 5 cycles, fault cleared by tripping of the two circuits of the 220 KV double circuit line from Kigali's airport to Rusumo-Falls</td>
<td>25</td>
</tr>
</tbody>
</table>
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PERMANENT THREE PHASE FAULT AT 220 KV NYAKANAZI
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PERMANENT THREE PHASE FAULT AT 220 KV BIREMBO BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM KIGALI’S AIRPORT TO BIREMBO
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP 2 CIRCUITS FROM BIREMBO TO AIRPORT

Time (seconds)
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP 2 CIRCUITS FROM BIREMBO TO AIRPORT

Time (seconds)
CASE N° 1, ITEM 2
PERMANENT THREE PHASE FAULT AT 220 KV RUSUMO-FALLS BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM KIGALI’S AIRPORT TO RUSUMO-FALLS
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP 2 CIRCUITS FROM AIRPORT TO RUSUMO
CASE N° 1, ITEM 3
PERMANENT THREE PHASE FAULT AT 220 KV RUSUMO-FALLS BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM RUSUMO-FALLS TO NYAKANAZI
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP TWO CIRCUITS FROM RUSUMO TO NYAKANAZI

![Graph showing voltage response over time]

- 232 - VOLT 5590 [NYAKAN_220KV220.00] : SVC_Case1_2L_Rusumo_Nyakanazi_2C
- 234 - VOLT 5592 [GEITA 220.00] : SVC_Case1_2L_Rusumo_Nyakanazi_2C
- 235 - VOLT 6051 [MASAKA-W 220.00] : SVC_Case1_2L_Rusumo_Nyakanazi_2C
- 233 - VOLT 5591 [RUSUMO 220.00] : SVC_Case1_2L_Rusumo_Nyakanazi_2C
RUSUMO FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP TWO CIRCUITS FROM RUSUMO TO NYAKANAZI

- 243 - POWR Airport 205 to Birembo 203 CKT '1': SVC_Case1_Rusumo_Nyakanazi_2C
- 275 - POWR Nyakanazi 5590 to Karagwe 11402 CKT '1': SVC_Case1_Rusumo_Nyakanazi_2C
- 285 - POWR Gelta 5592 to Nyakanazi 5590 CKT '1': SVC_Case1_Rusumo_Nyakanazi_2C
- 291 - POWR Masaka 6051 to Mbarara 6322 CKT '2': SVC_Case1_Rusumo_Nyakanazi_2C
CASE N° 1, ITEM 4
PERMANENT THREE PHASE FAULT AT 220 KV KIGOMA BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM KIBUYE TO KIGOMA
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP ONE CIRCUIT FROM KIBUYE TO KIGOMA

Time (seconds)

0 0,2 0,4 0,6 0,8 1 1,2 1,4 1,6 1,8 2 2,2 2,4

0 0,1 0,2 0,3 0,4 0,5 0,6 0,7 0,8 0,9 1 1,1

✓ 229 - VOLT 206 [KIGOMA_220K 220.00] : SVC_Case1_Kibuye_Kigoma_1C
✓ 230 - VOLT 207 [BUBANZA_220K220.00] : SVC_Case1_Kibuye_Kigoma_1C
✓ 231 - VOLT 208 [KIBUYE_220K 220.00] : SVC_Case1_Kibuye_Kigoma_1C
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP ONE CIRCUIT FROM KIBUYE TO KIGOMA

Time (seconds)

260
240
220
200
180
160
140
120
100
80
60
40
20
0
-20

0 0,5 1 1,5 2 2,5 3 3,5 4

263 - POWR BUBANZA 207 TO KIGOMA 206 CKT '1': SVC_Case1_Kibuye_Kigoma_1C
255 - POWR KIGOMA 206 TO AIRPORT 205 CKT '1': SVC_Case1_Kibuye_Kigoma_1C
243 - POWR AIRPORT 205 TO BIREMBO 203 CKT '1': SVC_Case1_Kibuye_Kigoma_1C
CASE N° 1, ITEM 5
PERMANENT THREE PHASE FAULT AT 220 KV KIGOMA BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM KIGOMA TO BUBANZA
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO. 1
TRIP ONE CIRCUIT FROM KIGOMA TO BUBANZA

Time (seconds)

0 0,2 0,4 0,6 0,8 1 1,2 1,4 1,6 1,8 2 2,2

1,1 1 0,9 0,8 0,7 0,6 0,5 0,4 0,3 0,2 0,1

166 - VOLT  209 [RUZIZI3 220 210.00] : SVC_Case1_Kigoma_Bubanza
229 - VOLT  206 [KIGOMA_220K 220.00] : SVC_Case1_Kigoma_Bubanza
230 - VOLT  207 [BUBANZA_220K220.00] : SVC_Case1_Kigoma_Bubanza
231 - VOLT  208 [KIBUYE_220K 220.00] : SVC_Case1_Kigoma_Bubanza
RUSUMO-FALLS FOR 2025

CASE NO.1 / CAS NO.1

TRIP ONE CIRCUIT FROM KIGOMA TO BUBANZA

Time (seconds)

0 0.5 1 1.5 2 2.5 3 3.5 4

0 20 40 60 80 100 120 140 160 180 200 220 240 260

- 255 - POWR KIGOMA 206 TO AIRPORT 205 CKT '1' : SVC_Case1_Kigoma_Bubanza
- 265 - POWR KIBUYE 208 TO KIGOMA 206 CKT '1' : SVC_Case1_Kigoma_Bubanza
- 243 - POWR AIRPORT 205 TO BIREMBO 203 CKT '1' : SVC_Case1_Kigoma_Bubanza
CASE N° 1, ITEM 6
PERMANENT THREE PHASE FAULT AT 220 KV RUZIZI 3 BUS FOR 5 CYCLES,
FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM
RUZIZI 3 TO BUBANZA
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP 1 CIRCUIT FROM RUZIZI 3 TO BUBANZA

Time (seconds)
RUSUMO-FALLS FOR 2025
CASE NO.1 / CAS NO.1
TRIP 1 CIRCUIT FROM RUZIZI 3 TO BUBANZA

Time (seconds)
CASE N° 2, ITEM 1
PERMANENT THREE PHASE FAULT AT 220 KV BIREMBO BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM KIGALI’S AIRPORT TO BIREMBO
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM BIREMBO TO AIRPORT

<table>
<thead>
<tr>
<th>Voltage</th>
<th>Terminal</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>227 V</td>
<td>BIREMBO</td>
<td>220K220.00</td>
</tr>
<tr>
<td>228 V</td>
<td>AÉROPOR</td>
<td>220K220.00</td>
</tr>
<tr>
<td>5592 V</td>
<td>GEITA</td>
<td>220.00</td>
</tr>
<tr>
<td>5590 V</td>
<td>NYAKAN</td>
<td>220KV220.00</td>
</tr>
</tbody>
</table>

Time (seconds)
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM BIREMBO TO

- 251 - POWR 205 TO 5591 CKT '1' : Case2_Airport_Birembo_2C-r1
- 267 - POWR 5590 TO 5591 CKT '1' : Case2_Airport_Birembo_2C-r1
- 275 - POWR 5590 TO 11402 CKT '1' : Case2_Airport_Birembo_2C-r1
- 305 - POWR 11402 TO 11401 CKT '1' : Case2_Airport_Birembo_2C-r1
CASE N° 2, ITEM 2
PERMANENT THREE PHASE FAULT AT 220 KV RUSUMO-FALLS BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM KIGALI’S AIRPORT TO RUSUMO-FALLS
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM AIRPORT TO RUSUMO

Time (seconds)

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1 1.2 1.3 1.4
0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

- 228 - VOLT 205 [AÉROPOR_220K220.00] : Case2_Airport_Rusumo_2C
- 233 - VOLT 5591 [RUSUMO 220.00] : Case2_Airport_Rusumo_2C
- 234 - VOLT 5592 [GEITA 220.00] : Case2_Airport_Rusumo_2C
- 227 - VOLT 203 [BIREMBO_220K220.00] : Case2_Airport_Rusumo_2C
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM AIRPORT TO RUSUMO

Time (seconds)

243 - POWR 205 TO 203 CKT '1' : Case2_Airport_Rusumo_2C
267 - POWR 5590 TO 5591 CKT '1' : Case2_Airport_Rusumo_2C
287 - POWR 5592 TO 5590 CKT '2' : Case2_Airport_Rusumo_2C
289 - POWR 6051 TO 6322 CKT '1' : Case2_Airport_Rusumo_2C
CASE N° 2, ITEM 3
PERMANENT THREE PHASE FAULT AT 220 KV NYAKANAZI BUS FOR 5 CYCLES, FAULT CLEARED BY TRIPPING OF THE TWO CIRCUITS OF THE 220 KV DOUBLE CIRCUIT LINE FROM RUSUMO-FALLS TO NYAKANAZI
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM RUSUMO TO NYAKANAZI

![Graph showing transient stability analysis](image)

- 227 - VOLT 203 [BIREMBO_220KV220.00] : Case2_Rusumo_Nyakanazi_2C
- 232 - VOLT 5590 [NYAKAN_220KV220.00] : Case2_Rusumo_Nyakanazi_2C
- 234 - VOLT 5592 [GEITA 220.00] : Case2_Rusumo_Nyakanazi_2C
- 235 - VOLT 6051 [MASAKA-W 220.00] : Case2_Rusumo_Nyakanazi_2C
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP TWO CIRCUITS FROM RUSUMO TO NYAKANAZI

Time (seconds)

- 243 - POWR 205 TO 203 CKT '1' : Case2_Rusumo_Nyakanazi_2C
- 275 - POWR 5590 TO 11402 CKT '1' : Case2_Rusumo_Nyakanazi_2C
- 285 - POWR 5592 TO 5590 CKT '1' : Case2_Rusumo_Nyakanazi_2C
- 291 - POWR 6051 TO 6322 CKT '2' : Case2_Rusumo_Nyakanazi_2C
CASE N° 2, ITEM 4
PERMANENT THREE PHASE FAULT AT 220 KV KIGOMA BUS FOR 5 CYCLES,
FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM
KIBUYE TO KIGOMA
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM KIBUYE TO KIGOMA

Time (seconds)

0 0.5 1 1.5 2 2.5 3 3.5 4

0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1

- 229 - VOLT 206 [KIGOMA_220K 220.00] : Case2_Kibuye-Kigoma_1C_r1
- 230 - VOLT 207 [BUBANZA_220K220.00] : Case2_Kibuye-Kigoma_1C_r1
- 231 - VOLT 208 [KIBUYE_220K 220.00] : Case2_Kibuye-Kigoma_1C_r1
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM KIBUYE TO KIGOMA

Time (seconds)

0 0.5 1 1.5 2 2.5 3 3.5 4
-60 -40 -20 0 20 40 60 80 100 120

247 - POWR 205 TO 206 CKT '1' : Case2_Kibuay-Kigoma_1C_r1
243 - POWR 205 TO 203 CKT '1' : Case2_Kibuay-Kigoma_1C_r1
267 - POWR 5590 TO 5591 CKT '1' : Case2_Kibuay-Kigoma_1C_r1
CASE N° 2, ITEM 5
PERMANENT THREE PHASE FAULT AT 220 KV KIGOMA BUS FOR 5 CYCLES,
FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM
KIGOMA TO KIGALI’S AIRPORT
RUSUMO FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM KIGOMA TO AIRPORT

Time (seconds)

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2

1,1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0

166 - VOLT 209 [RUZIZI 220 210.00] : Case2_Kigoma-Airport_1C
229 - VOLT 206 [KIGOMA_220K 220.00] : Case2_Kigoma-Airport_1C
230 - VOLT 207 [BUBANZA_220K220.00] : Case2_Kigoma-Airport_1C
228 - VOLT 205 [AÉROPOR_220K220.00] : Case2_Kigoma-Airport_1C
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM KIGOMA TO AIRPORT

Time (seconds)
CASE N° 2, ITEM 6
PERMANENT THREE PHASE FAULT AT 220 KV RUIZI 3 BUS FOR 5 CYCLES,
FAULT CLEARED BY TRIPPING OF THE 220 KV SINGLE CIRCUIT LINE FROM
RUZI 3 TO BUBANZA
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM RUZIZI 3 TO BUBANZA

![Graph showing transient stability analysis for RUSUMO falls for 2025.](image)

- **229 - VOLT 206 [KIGOMA_220K 220.00] : Case2_Ruzizi3-Bubanza_1C**
- **230 - VOLT 207 [BUBANZA_220K 220.00] : Case2_Ruzizi3-Bubanza_1C**
- **231 - VOLT 208 [KBUYE_220K 220.00] : Case2_Ruzizi3-Bubanza_1C**
- **166 - VOLT 209 [RUZIZI 220 210.00] : Case2_Ruzizi3-Bubanza_1C**
RUSUMO-FALLS FOR 2025
CASE NO.2 / CAS NO.2
TRIP ONE CIRCUIT FROM RUIZI 3 TO BUBANZA

Time (seconds)

0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4 3.6 3.8

0 50 100 150 200 250 300 350 400 450

265 - POWR 208 TO 206 CKT '1' : Case2_Ruzizi3-Bubanza_1C
255 - POWR 206 TO 205 CKT '1' : Case2_Ruzizi3-Bubanza_1C
245 - POWR 205 TO 203 CKT '2' : Case2_Ruzizi3-Bubanza_1C
## APPENDIX G: INSULATION COORDINATION

<table>
<thead>
<tr>
<th>Item</th>
<th>Calculation Report</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Birembo 220 kV Substation Insulation Coordination</td>
</tr>
<tr>
<td>2</td>
<td>Rusumo-Falls and Kigali’s Airport 220 kV Substations Insulation coordination</td>
</tr>
<tr>
<td>3</td>
<td>Nyakanazi 220 kV Substation Insulation Coordination</td>
</tr>
<tr>
<td>4</td>
<td>Muyinga and Gitega 220 kV Substation Insulation Coordination</td>
</tr>
</tbody>
</table>
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

Design brief
Birembo 220 kV substation
Insulation coordination

Prepared by: __________________________

Approved by: ________________________
1. **INTRODUCTION**

The 220 kV double circuit line from Kigoma’s airport substation to Birembo substation will always be operated at its rated voltage of 220 kV. The present coordination study provides the requirements for the 220 kV equipments installed at Birembo substation. Additional detailed insulation coordination studies, which are not part of our scope of works, will be required while additional reactive compensation will be added to the network for controlling its line voltage.

The characteristics of the future 220 kV network for interconnection of Rwanda with Uganda are as per the following:

- Maximum operating voltage $U_s$ equal to 245 kV;
- Pollution level equal to light and corresponds to level 1 for a creepage distance of 16 mm/kV;
- Maximum altitude $H$ at either substation equal to 1500 m.

2. **STEP 1 – DETERMINATION OF THE REPRESENTATIVE OVERVOLTAGES - VALUES OF $U_{RP}$**

2.1 **POWER-FREQUENCY VOLTAGE**

The maximum operating voltage $U_S$ is the most important reference voltage to complete co-ordination procedure. For the line under the scope of this report, the maximum value of $U_S$ is confirmed to be 245 kV while the nominal voltage is 220 kV. The network including compensation must be design to operate at or below this limit. Obviously, the equipment to be installed in either substation should have a rated voltage $U_m$ equal or greater than $U_S$. 
2.2 TEMPORARY OVERVOLTAGES

Temporary overvoltage can happen during phase-to-earth faults and during load rejection.

2.3 TEMPORARY OVERVOLTAGES DURING PHASE-TO-EARTH FAULTS

The 220 kV network will always be operated as an effectively grounded system. During the feasibility study, temporary overvoltage due to earth faults was analyzed and the 220 kV network maximum earth-faults factor was estimated to 1,3 at either substation. The corresponding phase-to-earth representative overvoltage is 183,9 kV.

2.3.1 Temporary Overvoltages During Load Rejection

Phase-to-earth and phase-to-phase temporary overvoltages due to load rejection are estimated to 1,35 P.U which results in phase-to-earth and phase-to-phase representative overvoltages of $U_{rp}=191$ kV and $U_{rp} = 330,8$ kV.

2.3.2 Maximum Temporary Overvoltages

The overvoltages due to a combination of an earth fault with a load rejection are not considered in this study. It is also assumed that ferroresonance are very unlikely for this network since all power transformer high voltage neutral bushings are effectively grounded.

The representative temporary overvoltages are the highest obtained considering all possible sources:

- Phase-to-earth : $U_{rp} = 191$ kV
- Phase-to-phase : $U_{rp} = 330,8$ kV

2.4 SLOW-FRONT OVERVOLTAGES

The slow-front overvoltages are mainly due to line energization and re-energisation switching operations and to improve the reliability of the studied network only two type of switching operations are allowed, The first one to clear phase-to-earth faults consists of single pole auto reclose operation SPAR. The second one to clear three-phase faults consists of three-poles tripping without any auto reclosure operations. The slow-front overvoltages are estimated to the following values for the different modes of operation.
2.4.1 Switching Overvoltages due to the closing of an Inductive Line

During normal operation of the network, a 220 kV line can be energized either from local substation or from all remote substations that are connected to this line. To confirm energisation of the line, the closing of the high voltage circuit breakers must always be supervised by synchro-check relays.

The 2 % overvoltage values are estimated from figure 1 of IEC Standard 60071-2, considering the energisation of a 220 kV line, from a network with low short circuit current and while the shunt compensation of the line capacitive reactance is greater than 50%. These overvoltage values provide an indication of whether or not detailed studies would be required and are valid for both local and receiving substations. Circuit breakers with closing resistance were not considered.

The 2 % overvoltage between phase and earth without limitation at either substation is estimated at 2,9 p.u. The 2 % phase-to-phase overvoltage based on figure 2 of IEC Standard 60071-2 is estimated at 4,3 p.u. The representative overvoltages, before applying surge arresters are the truncation values of these overvoltages distribution.

- \( U_{et} = 1.25 \times U_{e2} - 0.25 \quad U_{et} = 675.1 \text{kV} \)
- \( U_{pt} = 1.25 \times U_{p2} - 0.43 \quad U_{pt} = 989.2 \text{kV} \)

2.4.2 Switching Overvoltages due to Single Pole Auto Reclosure

During single pole auto reclosure, when the faulted phase circuit breakers open to clear the fault, the faulted phase remains mutually coupled to the healthy phases. This results in a coupled voltage on the faulty phase following secondary arc extension just prior to the reclosing of the previously faulted phase circuit breakers. It is unlikely that both line end circuit breakers would close at the same time and therefore the closing of one phase circuit breaker before the other is equivalent to energization of that phase with some level of trapped charge, and might lead to higher switching overvoltages. Yet with a conservative value taken from figure 1 of IEC standard 60071-2 for the 2% overvoltages due to the energization of a line from a weak network and with the addition of neutral reactors to limit the trapped charge, such an event should not be of any concern.
For this reason the 2% overvoltages during SPAR operation are estimated from figure 1 of the IEC Standard 60071-2 with the same criteria that were used for the energization of the line described in 2.3.1. The 2% phase-to-phase overvoltages are also based from figure 2 of IEC standard 60071-2. The 2% overvoltage between phase and earth without limitation at either station is estimated at 2.9 p.u. while the 2% phase-to-phase overvoltage is estimated at 4.3 p.u.

Further studies might be required later to confirm all assumptions included in this report.

### 2.4.3 Representative Slow-Front Overvoltages

The representatives slow-front overvoltages are the maximum obtained values considering all possible sources.
- \( U_{et} \) (Phase-to-earth) = 675.1 kV;
- \( U_{\phi pt} \) (phase-to-phase) = 989.2 kV.

### 2.4.4 Selection of Surge Arresters

To control the possible severe overvoltages resulting either from energization of a line or fault clearing on isolated network, metal-oxide surge arresters are installed at the line entrances and near power transformers. The rating of these arresters is selected to withstand the worst temporary overvoltage cycle (amplitude and duration). The arresters on equipment and line terminals are selected from ABB, IEC class 3, type PEXLIM Q, with a nominal voltage of 192 kV for a maximum continuous operating voltage of 154 kV and a 10 s temporary overvoltage of 211 kV.

The protective characteristics for these 192 kV surge arresters are:
- Switching impulse protective level : \( U_{ps} = 381 \) kV;
- Lightning impulse protective level : \( U_{pl} = 452 \) kV.

The slow-front representative overvoltages can be directly given by \( U_{ps} \) (phase-to-earth) or \( 2 \times U_{ps} \) (phase-to-phase) if these protective values are lower than the maximum slow-front overvoltage stresses (\( U_{et} \) and \( U_{\phi pt} \)) values. This is the case for any stresses values found above, so that the representative slow-front overvoltages are:
- Phase-to-earth : \( U_{rp} = 381 \) kV;
- Phase-to-phase : \( U_{rp} = 762 \) kV.
2.5 **FAST-FRONT OVERVOLTAGES**

Only fast-front overvoltages from lightning have to be considered. A simplified statistical approach will be used which leads directly to the co-ordination withstand voltage on Step 2 below.

3. **STEP 2 : DETERMINATION OF THE CO-ORDINATION WITHSTAND VOLTAGES - VALUES OF UCW**

3.1 **TEMPORARY OVERVOLTAGES**

For this class of overvoltages, the co-ordination withstand voltage is equal to the representative temporary overvoltage. Therefore, $U_{cw}$ values are:

- Phase-to-earth: $U_{cw} = 191 \text{ kV}$;
- Phase-to-phase: $U_{cw} = 330.8 \text{ kV}$.

3.2 **SLOW-FRONT OVERVOLTAGE**

The deterministic approach will be used. With such an approach, one must take into account that surge limitation by an arrester distorts the statistical distribution of these surges, creating a significant bulge in the probability distribution of surges at about the arrester protective level. Therefore, small uncertainties related to the arrester protective characteristics or to equipment strength could lead to an abnormally high increase in the failure rate. Figure 6 of IEC Standard 60071-2 takes this into account by applying a deterministic co-ordination factor $K_{cd}$ to the arrester protective level to obtain the $U_{cw}$ values.

For all equipment line terminal the $K_{cd}$ values are:

- Phase-to-earth: $U_{ps}/U_{c2} = 381 / 580.1 = 0.657$ $\rightarrow$ $K_{cd} = 1.1$;
- Phase-to-phase: $2 \times U_{ps}/U_{c2} = 762 / 580.1 = 0.886$ $\rightarrow$ $K_{cd} = 1.0$.

The resulting co-ordination withstand voltages are $K_{cd} U_{rp}$.

For all equipment line terminal:

- Phase-to-earth: $U_{cw} = 1.10 \times 381 = 419.1 \text{ kV}$;
- Phase-to-phase: $U_{cw} = 1.00 \times 762 = 764.7 \text{ kV}$.
3.3 **FAST-FRONT OVERVOLTAGE**

For equipment protected by surge arresters, the maximum fast-front overvoltage (and thus the fast-front representative overvoltage) is equal to the lightning-impulse protective level of the surge arrester, namely 452 kV.

However, to this value of 452 kV, one must add a voltage equal to $A \times L / (n \times (L_{sp} + L_a))$ to take into account the separation distance between the surge arrester and the protected equipment.

The parameters of this expression are obtained as per the following:

- $A$: (For an assumed single conductor transmission line) is 4500 according to IEC Standard 60071-2;
- $n$: The minimum number of in-service overhead line connected to the station assume to be equal to one;
- $L$: Equal to $a_1 + a_2 + a_3 + a_3$ according to figure 3 of IEC Standard 60071-2. This parameter is limited to 30 m for external insulation and 30 m for internal insulation;
- $L_{sp}$: The span length of the overhead lines is estimated to 350 m;
- $R_a$: Acceptable failure rate for equipment;
- $R_{km}$: Overhead line outage rate per year for a design corresponding to the first kilometer in front of the station;
- $L_a$: $L_a$ is the length of overhead line section with flashover rate equal to acceptable failure rate. The acceptable failure rate is selected to be $(1/400 \text{ years})$ or 0.0025 year$^{-1}$ and the line lightning flashover rate is estimated to be 10 per 100 km per year. Then for these selected values $L_a$ is equal to 25 m.

The resulting correction valued for separation are equal to:

Internal insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$

External insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$

Then, the resulting co-ordination withstand voltage are:

Internal insulation:
4. **STEP 3 – DETERMINATION OF THE REQUIRED WITHSTAND VOLTAGES – VALUES OF URW**

The required withstand voltages are obtained by applying to the coordination withstand voltages two correction factors: factor $K_a$ which takes into account the altitude of the installation and a safety factor $K_s$.

4.1 **SAFETY FACTOR**

- For internal insulation: $K_s = 1,15$
- For external insulation: $K_s = 1,05$

4.2 **ATMOSPHERIC CORRECTION FACTOR**

The altitude correction factor $K_a$ is applicable to external insulation only and its value is calculated from the following expression:

$$K_a = e^{m \left( \frac{H}{8150} \right)}$$

Where:

- $H$: $H$ is the altitude above sea level (1500 m);
- $m = 1,00$: For short duration test with light pollution insulation;
- $m = 0,96$: For phase-to-earth switching impulse withstand with $U_{cw} = 419,1$ kV;
- $m = 1,00$: For phase-to-phase switching impulse withstand with $U_{cw} = 764,7$ kV;
- $m = 1,00$: For lightning impulse withstand.
The corresponding values of $K_a$ are:

- For power-frequency withstand:
  (Phase-to-earth and phase-to-phase) $K_a = 1,202$;

- For switching impulse withstand:
  (Phase-to-earth) $K_a = 1,192$;

- For switching impulse withstand:
  (Phase-to-phase) $K_a = 1,202$;

- For lightning impulse withstand:
  (Phase-to-earth and phase-to-phase) $K_a = 1,202$.

### 4.3 Required Withstand Voltage

The values for the required withstand voltage are obtained from:

$$U_{rw} = U_{cw} K_a K_s$$

with $U_{cw}$ values found in Step 2.

#### 4.3.1 For Temporary Overvoltage

External insulation:

- Phase-to-earth: $U_{rw} = 191 \times 1,05 \times 1,202 = 241$ kV;
- Phase-to-phase: $U_{rw} = 330,8 \times 1,05 \times 1,202 = 417,5$ kV.

Internal insulation:

- Phase-to-earth: $U_{rw} = 191 \times 1,15 = 219,6$ kV;
- Phase-to-phase: $U_{rw} = 330,8 \times 1,15 = 380,4$ kV.

#### 4.3.2 For Slow-Front Overvoltages

External insulation:

- Phase-to-earth: $U_{rw} = 419,1 \times 1,05 \times 1,192 = 524,6$ kV;
- Phase-to-phase: $U_{rw} = 764,7 \times 1,05 \times 1,202 = 965,2$ kV.
Internal insulation:

- Phase-to-earth: $U_{rw} = 419,1 \times 1,15 = 482$ kV;
- Phase-to-phase: $U_{rw} = 764,7 \times 1,15 = 879,4$ kV.

4.3.3 **For Fast-Front Overvoltage**

External insulation:

- Phase-to-earth: $U_{rw} = 812 \times 1,05 \times 1,202 = 1024,9$ kV;
- Phase-to-phase: $U_{rw} = 812 \times 1,05 \times 1,202 = 1024,9$ kV.

Internal insulation:

- Phase-to-earth: $U_{rw} = 812 \times 1,15 = 933,8$ kV;
- Phase-to-phase: $U_{rw} = 812 \times 1,15 = 933,8$ kV.

### 5. **STEP 4 – CONVERSION TO WITHSTAND VOLTAGES NORMALIZED FOR RANGE 1**

In Range 1, the insulation level is normally described by a set of two values as shown in table 2 of IEC Standard 60071-1: a short-duration power-frequency withstand voltage and a lightning impulse withstand voltage. Table 2 of IEC Standard 60071-2 provides the test conversion factor to be applied to the required withstands voltage for slow-front overvoltage to get such an equivalent set of values.

#### 5.1 **CONVERSION TO SHORT-DURATION POWER-FREQUENCY WITHSTAND VOLTAGE (SDW)**

External insulation:

- Phase-to-earth: $SDW = 524,6 \times (0,6 + 524,6 / 8,500) = 347,2$ kV;
• Phase-to-phase : SDW = 965,2 x (0,6 + 965,2 / 12,700) = 652,5 kV.

Internal insulation :

• Phase-to-earth : SDW = 482 x 0,5 = 241 kV;
• Phase-to-phase : SDW = 879,4 x 0,5 = 439,7 kV.

5.2 CONVERSION TO LIGHTNING IMPULSE WITHSTAND VOLTAGE (LIW)

External insulation :

• Phase-to-earth : LIW = 524,6 x 1,3 = 682 kV;
• Phase-to-phase : LIW = 965,2 x (1,05 + 965,2 / 9,000) = 1116,9 kV.

Internal insulation :

• Phase-to-earth : LIW = 482 x 1,1 = 530,2 kV;
• Phase-to-phase : LIW = 879,4 x 1,1 = 967,3 kV.

6. STEP 5 : SELECTION OF STANDARD WITHSTAND VOLTAGE VALUES

Table 1 below summarizes values $U_{rw(s)}$ of minimum required voltage obtained from system studies in step 3 which become minimum test values to be applied to verify these withstands in terms of short-duration power-frequency, switching impulse and lightning impulse tests. In range 1, the required switching impulse withstand voltage is normally covered by a standard short-duration power-frequency test or by a standard lightning impulse test. In table 1 below, values obtained after such conversions in Step 3 are indicated under $U_{rw(c)}$. In this project, converted values for a lightning impulse test are retained so that converted values for short-duration power-frequency test need no more consideration.
Table 1 – SUMMARY OF MINIMUM REQUIRED VOLTAGES

| Values of $U_{rw}$: |  |  |  |
|---------------------|---------------------|---------------------|
| - in kV r.m.s. for short duration power frequency |  |  |  |
| External Insulation | Internal Insulation |  |  |
| Switchyard | Equipment | Main Transformer |  |
| $U_{rw(s)}$ | $U_{rw(C)}$ | $U_{rw(s)}$ | $U_{rw(C)}$ |  |
| Short-duration Power Frequency |  |  |  |
| Phase-to-earth | 241 | 347 | 220 | 241 |
| Phase-to-phase | 418 | 653 | 380 | 440 |
| Switching impulse |  |  |  |
| Phase-to-earth | 525 | - | 482 | - |
| Phase-to-phase | 965 | - | 879 | - |
| Lightning impulse |  |  |  |
| Phase-to-earth | 1025 | 682 | 934 | 530 |
| Phase-to-phase | 1025 | 1117 | 934 | 967 |

Standard voltages to be defined for the purpose of the short-duration power-frequency and lightning impulse tests have to be selected taking into account results shown in bold characters in table 1 (highest value of minimum withstand required $U_{rw(s)}$ or converted value $U_{rw(C)}$) and standard values included in table 2 of IEC Standard 60071-1.

For the external insulation a standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to the maximum available standardized insulation level for a system voltage $U_m$ equal to 245 kV. These values will cover all of the insulations requirements for phase-to-earth and phase-to-phase except the phase-to-phase external insulation due to the conversion of the switching overvoltages into lightning impulse withstand voltage, which require a standard value of 1127 kV. With the studies carried out so far it is impossible to define if this requirement is valid only on line entrance equipment or if it is valid for all 220 kV equipment installed in this substation. Increasing the distance between phases can easily accommodate this requirement. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
For internal insulation standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to such a standard available insulation level with a system voltage $U_m$ equal to 245 kV. is selected for phase-to-earth and phase-phase insulation of all switchyard equipment. These values will cover all the requirements for phase-to-phase and phase-to-earth insulation. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

Design brief
Rusumo-Falls and Kigali's Airport 220 kV substation Insulation coordination

Prepared by: __________________________

Approved by: __________________________
1. **INTRODUCTION**

There will be a minimum of two 220 kV double circuit lines at Rusumo-Falls hydropower plant. The first will be from Rusumo-Falls hydropower plant to Nyakanazi substation and the second will be from Rusumo-Falls hydropower plant to Kigali’s airport substation. It is also possible that a 220 kV single circuit line from Rusumo-Falls hydropower plant to Muyinga substation will be added in the future to this substation if the second load flow case is selected. At Kigali’s airport substation there will be a minimum of two double circuit lines, the first from Birembo substation and the second from Rusumo-Falls hydropower plant. In addition there will be either one or two single circuit lines from Kigoma substation depending of which load flow case will be selected. The present coordination study provides the requirements for the 220 kV equipments installed at Rusumo-Falls and Kigali’s airport substations.

The characteristics of the future 220 kV network for interconnection of Rwanda with Uganda are as per the following:

- Maximum operating voltage $U_s$ equal to 245 kV;
- Pollution level equal to light and corresponds to level 1 for a creepage distance of 16 mm/kV;
- Maximum altitude $H$ at either substation equal to 1600 m.

2. **STEP 1 – DETERMINATION OF THE REPRESENTATIVE OVERVOLTAGES - VALUES OF $U_{RP}$**

2.1 **Power-frequency voltage**

The maximum operating voltage $U_s$ is the most important reference voltage to complete co-ordination procedure. For the line under the scope of this report, the maximum value of $U_s$ is confirmed to be 245 kV while the nominal voltage is 220 kV. The network including compensation must be design to operate at or below this limit. Obviously, the equipment to be installed in either substation should have a rated voltage $U_m$ equal or greater than $U_s$. 


2.2 **TEMPORARY OVERVOLTAGES**

Temporary overvoltage can happen during phase-to-earth faults and during load rejection.

2.3 **TEMPORARY OVERVOLTAGES DURING PHASE-TO-EARTH FAULTS**

The 220 kV network will always be operated as an effectively grounded system. During the feasibility study, temporary overvoltage due to earth faults was analyzed and the 220 kV network maximum earth-faults factor was estimated to 1.3 at either substation. The corresponding phase-to-earth representative overvoltage is 183.9 kV.

2.3.1 **Temporary Overvoltages During Load Rejection**

Phase-to-earth and phase-to-phase temporary overvoltages due to load rejection are estimated to 1.35 P.U which results in phase-to-earth and phase-to-phase representative overvoltages of \( U_{rp} = 191 \) kV and \( U_{rp} = 330.8 \) kV.

2.3.2 **Maximum Temporary Overvoltages**

The overvoltages due to a combination of an earth fault with a load rejection are not considered in this study. It is also assumed that ferroresonance are very unlikely for this network since all power transformer high voltage neutral bushings are effectively grounded.

The representative temporary overvoltages are the highest obtained considering all possible sources:

- Phase-to-earth : \( U_{rp} = 191 \) kV
- Phase-to-phase : \( U_{rp} = 330.8 \) kV

2.4 **SLOW-FRONT OVERVOLTAGES**

The slow-front overvoltages are mainly due to line energization and re-energization switching operations and to improve the reliability of the studied network only two type of switching operations are allowed. The first one to clear phase-to-earth faults consists of single pole auto reclose operation SPAR. The second one to clear three-phase faults consists of three-poles tripping without any auto reclosure operations. The slow-front overvoltages are estimated to the following values for the different modes of operation.
2.4.1 **Switching Overvoltages due to the closing of an Inductive Line**

During normal operation of the network, a 220 kV line can be energized either from local substation or from all remote substations that are connected to this line. To confirm energization of the line, the closing of the high voltage circuit breakers must always be supervised by synchro-check relays.

The 2% overvoltage values are estimated from figure 1 of IEC Standard 60071-2, considering the energization of a 220 kV line, from a network with low short circuit current and while the shunt compensation of the line capacitive reactance is greater than 50%. These overvoltage values provide an indication of whether or not detailed studies would be required and are valid for both local and receiving substations. Circuit breakers with closing resistance were not considered.

The 2% overvoltage between phase and earth without limitation at either substation is estimated at 2,9 p.u. The 2% phase-to-phase overvoltage based on figure 2 of IEC Standard 60071-2 is estimated at 4,3 p.u. The representative overvoltages, before applying surge arresters are the truncation values of these overvoltages distribution.

- \[ U_{et} = 1,25 \times U_{e2} - 0,25 \quad \rightarrow \quad U_{et} = 675,1 \text{ kV} \]
- \[ U_{pt} = 1,25 \times U_{p2} - 0,43 \quad \rightarrow \quad U_{pt} = 989,2 \text{ kV} \]

2.4.2 **Switching Overvoltages due to Single Pole Auto Reclosure**

During single pole auto reclosure, when the faulted phase circuit breakers open to clear the fault, the faulted phase remains mutually coupled to the healthy phases. This results in a coupled voltage on the faulty phase following secondary arc extension just prior to the reclosing of the previously faulted phase circuit breakers. It is unlikely that both line end circuit breakers would close at the same time and therefore the closing of one phase circuit breaker before the other is equivalent to energization of that phase with some level of trapped charge, and might lead to higher switching overvoltages. Yet with a conservative value taken from figure 1 of IEC standard 60071-2 for the 2% overvoltages due to the energization of a line from a weak network and with the addition of neutral reactors to limit the trapped charge, such an event should not be of any concern.
For this reason the 2% overvoltages during SPAR operation are estimated from figure 1 of the IEC Standard 60071-2 with the same criteria that were used for the energization of the line described in 2.3.1. The 2% phase-to-phase overvoltages are also based on figure 2 of IEC standard 60071-2. The 2% overvoltage between phase and earth without limitation at either station is estimated at 2.9 p.u. while the 2% phase-to-phase overvoltage is estimated at 4.3 p.u.

Further studies might be required later to confirm all assumptions included in this report.

2.4.3 Representative Slow-Front Overvoltages

The representatives slow-front overvoltages are the maximum obtained values considering all possible sources.

- $U_{et}$ (Phase-to-earth) = 675.1 kV;
- $U_{φpt}$ (phase-to-phase) = 989.2 kV.

2.4.4 Selection of Surge Arresters

To control the possible severe overvoltages resulting either from energization of a line or fault clearing on isolated network, metal-oxide surge arresters are installed at the line entrances and near power transformers. The rating of these arresters is selected to withstand the worst temporary overvoltage cycle (amplitude and duration). The arresters on equipment and line terminals are selected from ABB, IEC class 3, type PEXLIM Q, with a nominal voltage of 192 kV for a maximum continuous operating voltage of 154 kV and a 10 s temporary overvoltage of 211 kV.

The protective characteristics for these 192 kV surge arresters are:

- Switching impulse protective level : $U_{ps} = 381$ kV;
- Lightning impulse protective level : $U_{pl} = 452$ kV.

The slow-front representative overvoltages can be directly given by $U_{ps}$ (phase-to-earth) or 2 x $U_{ps}$ (phase-to-phase) if these protective values are lower than the maximum slow-front overvoltage stresses ($U_{et}$ and $U_{φpt}$) values. This is the case for any stresses values found above, so that the representative slow-front overvoltages are:

- Phase-to-earth : $U_{rp} = 381$ kV;
- Phase-to-phase : $U_{rp} = 762$ kV.
2.5 **Fast-Front Overvoltages**

Only fast-front overvoltages from lightning have to be considered. A simplified statistical approach will be used which leads directly to the coordination withstand voltage on Step 2 below.

3. **Step 2: Determination of the Co-ordination Withstand Voltages - Values of UCW**

3.1 **Temporary Overvoltages**

For this class of overvoltages, the co-ordination withstand voltage is equal to the representative temporary overvoltage. Therefore, $U_{cw}$ values are:

- Phase-to-earth: $U_{cw} = 191 \text{kV}$;
- Phase-to-phase: $U_{cw} = 330.8 \text{kV}$.

3.2 **Slow-Front Overvoltage**

The deterministic approach will be used. With such an approach, one must take into account that surge limitation by an arrester distorts the statistical distribution of these surges, creating a significant bulge in the probability distribution of surges at about the arrester protective level. Therefore, small uncertainties related to the arrester protective characteristics or to equipment strength could lead to an abnormally high increase in the failure rate. Figure 6 of IEC Standard 60071-2 takes this into account by applying a deterministic co-ordination factor $K_{cd}$ to the arrester protective level to obtain the $U_{cw}$ values.

For all equipment line terminal the $K_{cd}$ values are:

- Phase-to-earth: $U_{pw}/U_{e2} = 381 / 580.1 = 0.657$  \(\rightarrow\)  $K_{cd} = 1.1$;
- Phase-to-phase: $2 \times U_{pw}/U_{e2} = 762 / 580.1 = 0.886$  \(\rightarrow\)  $K_{cd} = 1.0$.

The resulting co-ordination withstand voltages are $K_{cd} U_{rp}$.

For all equipment line terminal:

- Phase-to-earth: $U_{cw} = 1.10 \times 381 = 419.1 \text{kV}$;
- Phase-to-phase: $U_{cw} = 1.00 \times 762 = 764.7 \text{kV}$.

3.3 **Fast-Front Overvoltage**

For equipment protected by surge arresters, the maximum fast-front overvoltage (and thus the fast-front representative overvoltage) is equal to the lightning-impulse protective level of the surge arrester, namely 452 kV.
However, to this value of 452 kV, one must add a voltage equal to 
\( A \times \frac{L}{(n \times (L_{sp} + L_a))} \) to take into account the separation distance between 
the surge arrester and the protected equipment.

The parameters of this expression are obtained as per the following:

- **A** : (For an assumed single conductor transmission line) is 4500 
  according to IEC Standard 60071-2;
- **n** : The minimum number of in-service overhead line connected 
  to the station assume to be equal to one;
- **L** : Equal to \( a_1 + a_2 + a_3 + a_3 \) according to figure 3 of 
  IEC Standard 60071-2. This parameter is limited to 60 m for 
  external insulation and 60 m for internal insulation;
- **L_{sp}** : The span length of the overhead lines is estimated to 350 m;
- **R_a** : Acceptable failure rate for equipment;
- **R_{km}** : Overhead line outage rate per year for a design corresponding 
  to the first kilometer in front of the station;
- **L_a** : \( L_a \) is the length of overhead line section with flashover rate 
  equal to acceptable failure rate. The acceptable failure rate is 
  selected to be \((1/400 \text{ years})\) or 0.0025 year\(^{-1}\) and the line 
  lightning flashover rate is estimated to be 10 per 100 km per 
  year. Then for these selected values \( L_a \) is equal to 25 m.

The resulting correction valued for separation are equal to:

**Internal insulation**:

\[
4500 \times 60 / (2 \times (300 + 25)) = 812 \text{ kV}
\]

**External insulation**:

\[
4500 \times 60 / (2 \times (300 + 25)) = 812 \text{ kV}
\]

Then, the resulting co-ordination withstand voltage are:

**Internal insulation**:

\[
U_{cw} = 452 + 360 = 812 \text{ kV}
\]

**External insulation**:

\[
U_{cw} = 452 + 360 = 812 \text{ kV}
\]
4. STEP 3 – DETERMINATION OF THE REQUIRED WITHSTAND VOLTAGES – VALUES OF URW

The required withstand voltages are obtained by applying to the co-ordination withstand voltages two correction factors: factor $K_a$ which takes into account the altitude of the installation and a safety factor $K_s$.

4.1 SAFETY FACTOR

- For internal insulation: $K_s = 1.15$
- For external insulation: $K_s = 1.05$

4.2 ATMOSPHERIC CORRECTION FACTOR

The altitude correction factor $K_a$ is applicable to external insulation only and its value is calculated from the following expression:

$$K_a = e^{m \left( \frac{H}{8150} \right)}$$

Where:

- $H$: $H$ is the altitude above sea level (1600 m);
- $m = 1.00$: For short duration test with light pollution insulation;
- $m = 0.96$: For phase-to-earth switching impulse withstand with $U_{cw} = 419.1$ kV;
- $m = 1.00$: For phase-to-phase switching impulse withstand with $U_{cw} = 764.7$ kV;
- $m = 1.00$: For lightning impulse withstand.
The corresponding values of $K_a$ are:

- For power-frequency withstand:
  (Phase-to-earth and phase-to-phase) $K_a = 1,217$;

- For switching impulse withstand:
  (Phase-to-earth); $K_a = 1,206$;

- For switching impulse withstand:
  (Phase-to-phase); $K_a = 1,217$;

- For lightning impulse withstand:
  (Phase-to-earth and phase-to-phase); $K_a = 1,217$.

4.3 **REQUIRED WITHSTAND VOLTAGE**

The values for the required withstand voltage are obtained from:

$$U_{rw} = U_{cw} K_a K_a, \text{ with } U_{cw} \text{ values found in Step 2.}$$

4.3.1 **For Temporary Overvoltage**

External insulation:

- Phase-to-earth: $U_{rw} = 191 \times 1,05 \times 1,217 = 244 \text{ kV}$;

- Phase-to-phase: $U_{rw} = 330,8 \times 1,05 \times 1,217 = 422,6 \text{ kV}$.

Internal insulation:

- Phase-to-earth: $U_{rw} = 191 \times 1,15 = 219,6 \text{ kV}$;

- Phase-to-phase: $U_{rw} = 330,8 \times 1,15 = 380,4 \text{ kV}$.

4.3.2 **For Slow-Front Overvoltages**

External insulation:

- Phase-to-earth: $U_{rw} = 419,1 \times 1,05 \times 1,206 = 530,8 \text{ kV}$;

- Phase-to-phase: $U_{rw} = 764,7 \times 1,05 \times 1,217 = 977,1 \text{ kV}$.
Internal insulation:

- Phase-to-earth: $U_{rw} = 419.1 \times 1.15 = 482$ kV;
- Phase-to-phase: $U_{rw} = 764.7 \times 1.15 = 879.4$ kV.

### 4.3.3 For Fast-Front Overvoltage

External insulation:

- Phase-to-earth: $U_{rw} = 812 \times 1.05 \times 1.217 = 1037.5$ kV;
- Phase-to-phase: $U_{rw} = 812 \times 1.05 \times 1.217 = 1037.5$ kV.

Internal insulation:

- Phase-to-earth: $U_{rw} = 812 \times 1.15 = 933.8$ kV;
- Phase-to-phase: $U_{rw} = 812 \times 1.15 = 933.8$ kV.

### 5. STEP 4 – CONVERSION TO WITHSTAND VOLTAGES NORMALIZED FOR RANGE 1

In Range 1, the insulation level is normally described by a set of two values as shown in Table 2 of IEC Standard 60071-1: a short-duration power-frequency withstand voltage and a lightning impulse withstand voltage. Table 2 of IEC Standard 60071-2 provides the test conversion factor to be applied to the required withstands voltage for slow-front overvoltage to get such an equivalent set of values.

#### 5.1 Conversion to Short-Duration Power-Frequency Withstand Voltage (SDW)

External insulation:

- Phase-to-earth: $\text{SDW} = 530.8 \times (0.6 + 530.8 / 8.500) = 351.6$ kV;
- Phase-to-phase: $\text{SDW} = 977.1 \times (0.6 + 977.1 / 12.700) = 661.4$ kV.
Internal insulation:

- Phase-to-earth: $SDW = 482 \times 0.5 = 241\, \text{kV}$;
- Phase-to-phase: $SDW = 879.4 \times 0.5 = 439.7\, \text{kV}$.

### 5.2 Conversion to Lightning Impulse Withstand Voltage (LIW)

External insulation:

- Phase-to-earth: $LIW = 530.8 \times 1.3 = 690.1\, \text{kV}$;
- Phase-to-phase: $LIW = 977.1 \times (1.05 + 977.1 / 9,000) = 1132\, \text{kV}$.

Internal insulation:

- Phase-to-earth: $LIW = 482 \times 1.1 = 530.2\, \text{kV}$;
- Phase-to-phase: $LIW = 879.4 \times 1.1 = 967.3\, \text{kV}$.

### 6. Step 5: Selection of Standard Withstand Voltage Values

Table 1 below summarizes values $U_{rv(s)}$ of minimum required voltage obtained from system studies in step 3 which become minimum test values to be applied to verify these withstands in terms of short-duration power-frequency, switching impulse and lightning impulse tests. In range 1, the required switching impulse withstand voltage is normally covered by a standard short-duration power-frequency test or by a standard lightning impulse test. In table 1 below, values obtained after such conversions in Step 3 are indicated under $U_{rv(c)}$. In this project, converted values for a lightning impulse test are retained so that converted values for short-duration power-frequency test need no more consideration.
Table 1 – SUMMARY OF MINIMUM REQUIRED VOLTAGES

<table>
<thead>
<tr>
<th></th>
<th>External Insulation</th>
<th>Internal Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Switchyard Equipment</td>
<td>Main Transformer</td>
</tr>
<tr>
<td></td>
<td>U_{rw(s)}</td>
<td>U_{rw(C)}</td>
</tr>
<tr>
<td>Short-duration Power Frequency</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase-to-earth</td>
<td>244</td>
<td>352</td>
</tr>
<tr>
<td>Phase-to-phase</td>
<td>423</td>
<td>661</td>
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<tr>
<td>Switching impulse</td>
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<td>Phase-to-earth</td>
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<tr>
<td>Phase-to-phase</td>
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<td>Lightning impulse</td>
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<td>Phase-to-earth</td>
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<td>Phase-to-phase</td>
<td>1038</td>
<td>1132</td>
</tr>
</tbody>
</table>

Standard voltages to be defined for the purpose of the short-duration power-frequency and lightning impulse tests have to be selected taking into account results shown in bold characters in table 1 (highest value of minimum withstand required U_{rw(s)} or converted value U_{rw(C)}) and standard values included in table 2 of IEC Standard 60071-1.

For the external insulation a standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to the maximum available standardized insulation level for a system voltage U_m equal to 245 kV. These values will cover all of the insulations requirements for phase-to-earth and phase-to-phase except the phase-to-phase external insulation due to the conversion of the switching overvoltages into lightning impulse withstand voltage, which require a standard value of 1127 kV. With the studies carried out so far it is impossible to define if this requirement is valid only on line entrance equipment or if it is valid for all 220 kV equipment installed in this substation. Increasing the distance between phases can easily accommodate this requirement. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 60 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
For internal insulation standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to such a standard available insulation level with a system voltage $U_m$ equal to 245 kV. is selected for phase-to-earth and phase-phase insulation of all switchyard equipment. These values will cover all the requirements for phase-to-phase and phase-to-earth insulation. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 60 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO THE RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

Design brief
Nyakanazi 220 kV substation
Insulation coordination

Prepared by: 

Approved by: 
1. INTRODUCTION

The 220 kV double circuit line from Rusumo-Falls hydropower plant to Nyakanazi substation will always be operated at its rated voltage of 220 kV. The present coordination study provides the requirements for the 220 kV equipments installed at Nyakanazi substation. Additional detailed insulation coordination studies, which are not part of our scope of works, will be required while additional reactive compensation will be added to the network for controlling its line voltage.

The characteristics of the future 220 kV network for interconnection of Rwanda with Uganda are as per the following:

- Maximum operating voltage $U_s$ equal to 245 kV;
- Pollution level equal to light and corresponds to level 1 for a creepage distance of 16 mm/kV;
- Maximum altitude $H$ at either substation equal to 1300 m.

2. STEP 1 – DETERMINATION OF THE REPRESENTATIVE OVERVOLTAGES - VALUES OF $U_{RP}$

2.1 POWER-FREQUENCY VOLTAGE

The maximum operating voltage $U_S$ is the most important reference voltage to complete co-ordination procedure. For the line under the scope of this report, the maximum value of $U_S$ is confirmed to be 245 kV while the nominal voltage is 220 kV. The network including compensation must be design to operate at or below this limit. Obviously, the equipment to be installed in either substation should have a rated voltage $U_m$ equal or greater than $U_S$. 
2.2 **TEMPORARY OVERVOLTAGES**

Temporary overvoltage can happen during phase-to-earth faults and during load rejection.

2.3 **TEMPORARY OVERVOLTAGES DURING PHASE-TO-EARTH FAULTS**

The 220 kV network will always be operated as an effectively grounded system. During the feasibility study, temporary overvoltage due to earth faults was analyzed and the 220 kV network maximum earth-faults factor was estimated to 1.3 at either substation. The corresponding phase-to-earth representative overvoltage is 183.9 kV.

### 2.3.1 Temporary Overvoltages during Load Rejection

Phase-to-earth and phase-to-phase temporary overvoltages due to load rejection are estimated to 1.52 P.U which results in phase-to-earth and phase-to-phase representative overvoltages of \( U_{rp} = 215 \text{ kV} \) and \( U_{rp} = 372.4 \text{ kV} \).

### 2.3.2 Maximum Temporary Overvoltages

The overvoltages due to a combination of an earth fault with a load rejection are not considered in this study. It is also assumed that ferroresonance are very unlikely for this network since all power transformer high voltage neutral bushings are effectively grounded.

The representative temporary overvoltages are the highest obtained considering all possible sources:

- Phase-to-earth : \( U_{rp} = 215 \text{ kV} \)
- Phase-to-phase : \( U_{rp} = 372.4 \text{ kV} \)

2.4 **SLOW-FRONT OVERVOLTAGES**

The slow-front overvoltages are mainly due to line energization and re-energisation switching operations and to improve the reliability of the studied network only two type of switching operations are allowed. The first one to clear phase-to-earth faults consists of single pole auto reclose operation SPAR. The second one to clear three-phase faults consists of three-poles tripping without any auto reclosure operations. The slow-front overvoltages are estimated to the following values for the different modes of operation.
2.4.1  **Switching Overvoltages due to the closing of an Inductive Line**

During normal operation of the network, a 220 kV line can be energized either from local substation or from all remote substations that are connected to this line. To confirm energisation of the line, the closing of the high voltage circuit breakers must always be supervised by synchro-check relays.

The 2% overvoltage values are estimated from figure 1 of IEC Standard 60071-2, considering the energisation of a 220 kV line, from a network with low short circuit current and while the shunt compensation of the line capacitive reactance is greater than 50%. These overvoltage values provide an indication of whether or not detailed studies would be required and are valid for both local and receiving substations. Circuit breakers with closing resistance were not considered.

The 2% overvoltage between phase and earth without limitation at either substation is estimated at 2,9 p.u. The 2% phase-to-phase overvoltage based on figure 2 of IEC Standard 60071-2 is estimated at 4,3 p.u. The representative overvoltages, before applying surge arresters are the truncation values of these overvoltages distribution.

\[ U_{ct} = 1,25 \times U_{e2} - 0,25 \quad \Rightarrow \quad U_{ct} = 675,1 \text{ kV} \]

\[ U_{pt} = 1,25 \times U_{p2} - 0,43 \quad \Rightarrow \quad U_{pt} = 989,2 \text{ kV} \]

2.4.2  **Switching Overvoltages due to Single Pole Auto Reclosure**

During single pole auto reclosure, when the faulted phase circuit breakers open to clear the fault, the faulted phase remains mutually coupled to the healthy phases. This results in a coupled voltage on the faulty phase following secondary arc extension just prior to the reclosing of the previously faulted phase circuit breakers. It is unlikely that both line end circuit breakers would close at the same time and therefore the closing of one phase circuit breaker before the other is equivalent to energization of that phase with some level of trapped charge, and might lead to higher switching overvoltages. Yet with a conservative value taken from figure 1 of IEC standard 60071-2 for the 2% overvoltages due to the energization of a line from a weak network and with the addition of neutral reactors to limit the trapped charge, such an event should not be of any concern.
For this reason the 2\% overvoltages during SPAR operation are estimated from figure 1 of the IEC Standard 60071-2 with the same criteria that were used for the energization of the line described in 2.3.1. The 2\% phase-to-phase overvoltages are also based from figure 2 of IEC standard 60071-2. The 2\% overvoltage between phase and earth without limitation at either station is estimated at 2.9 p.u. while the 2\% phase-to-phase overvoltage is estimated at 4.3 p.u.

Further studies might be required later to confirm all assumptions included in this report.

2.4.3 Representative Slow-Front Overvoltages

The representatives slow-front overvoltages are the maximum obtained values considering all possible sources.

- \( U_{et} \) (Phase-to-earth) = 675.1 kV;
- \( U_{\phi pt} \) (phase-to-phase) = 989.2 kV.

2.4.4 Selection of Surge Arresters

To control the possible severe overvoltages resulting either from energization of a line or fault clearing on isolated network, metal-oxide surge arresters are installed at the line entrances and near power transformers. The rating of these arresters is selected to withstand the worst temporary overvoltage cycle (amplitude and duration). The arresters on equipment and line terminals are selected from ABB, IEC class 3, type PEXLIM Q, with a nominal voltage of 192 kV for a maximum continuous operating voltage of 154 kV and a 10 s temporary overvoltage of 211 kV.

The protective characteristics for these 192 kV surge arresters are:

- Switching impulse protective level : \( U_{ps} = 381 \) kV;
- Lightning impulse protective level : \( U_{pl} = 452 \) kV.

The slow-front representative overvoltages can be directly given by \( U_{ps} \) (phase-to-earth) or 2 x \( U_{ps} \) (phase-to-phase) if these protective values are lower than the maximum slow-front overvoltage stresses (\( U_{et} \) and \( U_{\phi pt} \)) values. This is the case for any stresses values found above, so that the representative slow-front overvoltages are:

- Phase-to-earth : \( U_{rp} = 381 \) kV;
- Phase-to-phase : \( U_{rp} = 762 \) kV.
2.5 **FAST-FRONT OVERVOLTAGES**

Only fast-front overvoltages from lightning have to be considered. A simplified statistical approach will be used which leads directly to the co-ordination withstand voltage on Step 2 below.

3. **STEP 2 : DETERMINATION OF THE CO-ORDINATION WITHSTAND VOLTAGES - VALUES OF UCW**

3.1 **TEMPORARY OVERVOLTAGES**

For this class of overvoltages, the co-ordination withstand voltage is equal to the representative temporary overvoltage. Therefore, $U_{cw}$ values are:

- Phase-to-earth: $U_{cw} = 215$ kV;
- Phase-to-phase: $U_{cw} = 372,4$ kV.

3.2 **SLOW-FRONT OVERVOLTAGE**

The deterministic approach will be used. With such an approach, one must take into account that surge limitation by an arrester distorts the statistical distribution of these surges, creating a significant bulge in the probability distribution of surges at about the arrester protective level. Therefore, small uncertainties related to the arrester protective characteristics or to equipment strength could lead to an abnormally high increase in the failure rate. Figure 6 of IEC Standard 60071-2 takes this into account by applying a deterministic co-ordination factor $K_{cd}$ to the arrester protective level to obtain the $U_{cw}$ values.

For all equipment line terminal the $K_{cd}$ values are:

- Phase-to-earth: $U_{p2}/U_{e2} = 381 / 580,1 = 0,657$ → $K_{cd} = 1,1$;
- Phase-to-phase: $2 \times U_{p2}/U_{e2} = 762 / 580,1 = 0,886$ → $K_{cd} = 1,0$.

The resulting co-ordination withstand voltages are $K_{cd} U_{rp}$.

For all equipment line terminal:

- Phase-to-earth: $U_{cw} = 1,10 \times 381 = 419,1$ kV;
- Phase-to-phase: $U_{cw} = 1,00 \times 762 = 764,7$ kV.
3.3 **Fast-Front Overvoltage**

For equipment protected by surge arresters, the maximum fast-front overvoltage (and thus the fast-front representative overvoltage) is equal to the lightning-impulse protective level of the surge arrester, namely 452 kV.

However, to this value of 452 kV, one must add a voltage equal to $A \times \frac{L}{n \times (L_{sp} + L_{a})}$ to take into account the separation distance between the surge arrester and the protected equipment.

The parameters of this expression are obtained as per the following:

- **$A$** : (For an assumed single conductor transmission line) is 4500 according to IEC Standard 60071-2;
- **$n$** : The minimum number of in-service overhead line connected to the station assume to be equal to one;
- **$L$** : Equal to $a_1 + a_2 + a_3$ according to figure 3 of IEC Standard 60071-2. This parameter is limited to 30 m for external insulation and 30 m for internal insulation;
- **$L_{sp}$** : The span length of the overhead lines is estimated to 350 m;
- **$R_a$** : Acceptable failure rate for equipment;
- **$R_{km}$** : Overhead line outage rate per year for a design corresponding to the first kilometer in front of the station;
- **$L_a$** : $L_a$ is the length of overhead line section with flashover rate equal to acceptable failure rate. The acceptable failure rate is selected to be $(1/400 \text{ years})$ or $0.0025 \text{ year}^{-1}$ and the line lightning flashover rate is estimated to be $10 \text{ per 100 km per year}$. Then for these selected values $L_a$ is equal to $25 \text{ m}$.

The resulting correction valued for separation are equal to:

Internal insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$

External insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$
Then, the resulting co-ordination withstand voltage are:

Internal insulation:

\[ U_{cw} = 452 + 360 = 812 \text{ kV} \]

External insulation:

\[ U_{cw} = 452 + 360 = 812 \text{ kV} \]

4. **STEP 3 – DETERMINATION OF THE REQUIRED WITHSTAND VOLTAGES – VALUES OF URW**

The required withstand voltages are obtained by applying to the co-ordination withstand voltages two correction factors: factor \( K_a \) which takes into account the altitude of the installation and a safety factor \( K_s \).

4.1 **SAFETY FACTOR**

- For internal insulation: \( K_s = 1,15 \)
- For external insulation: \( K_s = 1,05 \)

4.2 **ATMOSPHERIC CORRECTION FACTOR**

The altitude correction factor \( K_a \) is applicable to external insulation only and its value is calculated from the following expression:

\[ K_a = e^{m \left( \frac{H}{8150} \right)} \]

Where:

- \( H \): H is the altitude above sea level (1300 m);
- \( m = 1,00 \): For short duration test with light pollution insulation;
- \( m = 0,96 \): For phase-to-earth switching impulse withstand with \( U_{cw} = 419,1 \text{ kV} \);
- \( m = 1,00 \): For phase-to-phase switching impulse withstand with \( U_{cw} = 764,7 \text{ kV} \);
- \( m = 1,00 \): For lightning impulse withstand.
The corresponding values of $K_a$ are:

- For power-frequency withstand:
  
  \[ K_a = 1,173; \]  
  
  (Phase-to-earth and phase-to-phase)

- For switching impulse withstand:
  
  \[ K_a = 1,165; \]  
  
  (Phase-to-earth)

- For switching impulse withstand:
  
  \[ K_a = 1,173; \]  
  
  (Phase-to-phase)

- For lightning impulse withstand:
  
  \[ K_a = 1,173; \]  
  
  (Phase-to-earth and phase-to-phase)

### 4.3 Required Withstand Voltage

The values for the required withstand voltage are obtained from:

\[ U_{rw} = U_{cw} K_a K_s, \text{ with } U_{cw} \text{ values found in Step 2.} \]

#### 4.3.1 For Temporary Overvoltage

**External insulation:**

- Phase-to-earth: $U_{rw} = 215 \times 1.05 \times 1.173 = 264.8$ kV;

- Phase-to-phase: $U_{rw} = 372.4 \times 1.05 \times 1.173 = 458.6$ kV.

**Internal insulation:**

- Phase-to-earth: $U_{rw} = 215 \times 1.15 = 247.3$ kV;

- Phase-to-phase: $U_{rw} = 372.4 \times 1.15 = 428.3$ kV.

#### 4.3.2 For Slow-Front Overvoltages

**External insulation:**

- Phase-to-earth: $U_{rw} = 419.1 \times 1.05 \times 1.165 = 512.5$ kV;

- Phase-to-phase: $U_{rw} = 764.7 \times 1.05 \times 1.173 = 941.8$ kV.
4.3.3 **For Fast-Front Overvoltage**

**External insulation:**

- Phase-to-earth: \( U_{\text{rw}} = 812 \times 1,05 \times 1,173 = 1000 \) kV;
- Phase-to-phase: \( U_{\text{rw}} = 812 \times 1,05 \times 1,173 = 1000 \) kV.

**Internal insulation:**

- Phase-to-earth: \( U_{\text{rw}} = 812 \times 1,15 = 933,8 \) kV;
- Phase-to-phase: \( U_{\text{rw}} = 812 \times 1,15 = 933,8 \) kV.

5. **STEP 4 – CONVERSION TO WITHSTAND VOLTAGES NORMALIZED FOR RANGE 1**

In Range 1, the insulation level is normally described by a set of two values as shown in table 2 of IEC Standard 60071-1: a short-duration power-frequency withstand voltage and a lightning impulse withstand voltage. Table 2 of IEC Standard 60071-2 provides the test conversion factor to be applied to the required withstands voltage for slow-front overvoltage to get such an equivalent set of values.

5.1 **Conversion to Short-Duration Power-Frequency Withstand Voltage (SDW)**

**External insulation:**

- Phase-to-earth: \( \text{SDW} = 512,5 \times (0,6 + 512,5 / 8,500) = 338,4 \) kV;
- Phase-to-phase: \( \text{SDW} = 941,8 \times (0,6 + 941,8 / 12,700) = 634,9 \) kV.
Internal insulation:

- Phase-to-earth: \( \text{SDW} = 482 \times 0.5 = 241 \text{ kV} \);
- Phase-to-phase: \( \text{SDW} = 879.4 \times 0.5 = 439.7 \text{ kV} \).

5.2 **Conversion to Lightning Impulse Withstand Voltage (LIW)**

External insulation:

- Phase-to-earth: \( \text{LIW} = 512.5 \times 1.3 = 666.2 \text{ kV} \);
- Phase-to-phase: \( \text{LIW} = 941.8 \times (1.05 + 941.8 / 9,000) = 1087.4 \text{ kV} \).

Internal insulation:

- Phase-to-earth: \( \text{LIW} = 482 \times 1.1 = 530.2 \text{ kV} \);
- Phase-to-phase: \( \text{LIW} = 879.4 \times 1.1 = 967.3 \text{ kV} \).

6. **Step 5: Selection of Standard Withstand Voltage Values**

Table 1 below summarizes values \( U_{rw(s)} \) of minimum required voltage obtained from system studies in step 3 which become minimum test values to be applied to verify these withstands in terms of short-duration power-frequency, switching impulse and lightning impulse tests. In range 1, the required switching impulse withstand voltage is normally covered by a standard short-duration power-frequency test or by a standard lightning impulse test. In table 1 below, values obtained after such conversions in Step 3 are indicated under \( U_{rw(c)} \). In this project, converted values for a lightning impulse test are retained so that converted values for short-duration power-frequency test need no more consideration.
Table 1 – SUMMARY OF MINIMUM REQUIRED VOLTAGES

<table>
<thead>
<tr>
<th></th>
<th>External Insulation</th>
<th>Internal Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Switchyard Equipment</td>
<td>Main Transformer</td>
</tr>
<tr>
<td></td>
<td>( U_{rw(s)} )</td>
<td>( U_{rw(C)} )</td>
</tr>
<tr>
<td><strong>Short-duration Power Frequency</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase-to-earth</td>
<td>265</td>
<td>247</td>
</tr>
<tr>
<td>Phase-to-phase</td>
<td>459</td>
<td>428</td>
</tr>
<tr>
<td><strong>Switching impulse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase-to-earth</td>
<td>513</td>
<td>482</td>
</tr>
<tr>
<td>Phase-to-phase</td>
<td>942</td>
<td>879</td>
</tr>
<tr>
<td><strong>Lightning impulse</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Phase-to-earth</td>
<td>1000</td>
<td>934</td>
</tr>
<tr>
<td>Phase-to-phase</td>
<td>1000</td>
<td>934</td>
</tr>
</tbody>
</table>

Standard voltages to be defined for the purpose of the short-duration power-frequency and lightning impulse tests have to be selected taking into account results shown in bold characters in table 1 (highest value of minimum withstand required \( U_{rw(s)} \) or converted value \( U_{rw(C)} \)) and standard values included in table 2 of IEC Standard 60071-1.

For the external insulation a standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to the maximum available standardized insulation level for a system voltage \( U_m \) equal to 245 kV. These values will cover all of the insulations requirements for phase-to-earth and phase-to-phase except the phase-to-phase external insulation due to the conversion of the switching overvoltages into lightning impulse withstand voltage, which require a standard value of 1127 kV. With the studies carried out so far it is impossible to define if this requirement is valid only on line entrance equipment or if it is valid for all 220 kV equipment installed in this substation. Increasing the distance between phases can easily accommodate this requirement. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
For internal insulation standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to such a standard available insulation level with a system voltage $U_m$ equal to 245 kV. is selected for phase-to-earth and phase-phase insulation of all switchyard equipment. These values will cover all the requirements for phase-to-phase and phase-to-earth insulation. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
STUDY ON THE ELECTRICITY TRANSMISSION LINES LINKED TO RUSUMO-FALLS HYDRO-ELECTRIC GENERATION PLANT

Design brief
Gitega and Muyinga 220 kV substations Insulation coordination

Prepared by: _______________________

Approved by: _______________________

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1. **INTRODUCTION**

The two 220 kV single circuit line from Rusumo-Falls hydro power plant to Muyinga substation and from Muyinga substation to Gitega substation and will always be operated at its rated voltage of 220 kV if constructed. The three substations mentioned above are required to interconnect these two 220 kV line. A tap connection to the 220 kV line for interconnecting the Muyinga substation is not recommended, hence single pole auto reclosing will not be guaranteed. The present coordination study provides the requirements for the 220 kV equipments installed at Gitega and Muyinga substations.

The characteristics of the future 220 kV network for interconnection of Rwanda with Uganda are as per the following:

- Maximum operating voltage $U_s$ equal to 245 kV;
- Pollution level equal to light and corresponds to level 1 for a creepage distance of 16 mm/kV;
- Maximum altitude $H$ at either substation equal to 1650 m.

2. **STEP 1 – DETERMINATION OF THE REPRESENTATIVE OVERVOLTAGES - VALUES OF $U_{RP}$**

2.1 **POWER-FREQUENCY VOLTAGE**

The maximum operating voltage $U_s$ is the most important reference voltage to complete co-ordination procedure. For the line under the scope of this report, the maximum value of $U_s$ is confirmed to be 245 kV while the nominal voltage is 220 kV. The network including compensation must be design to operate at or below this limit. Obviously, the equipment to be installed in either substation should have a rated voltage $U_m$ equal or greater than $U_s$. 
2.2  **TEMPORARY OVERVOLTAGES**

Temporary overvoltage can happen during phase-to-earth faults and during load rejection.

2.3  **TEMPORARY OVERVOLTAGES DURING PHASE-TO-EARTH FAULTS**

The 220 kV network will always be operated as an effectively grounded system. During the feasibility study, temporary overvoltage due to earth faults was analyzed and the 220 kV network maximum earth-faults factor was estimated to 1.3 at either substation. The corresponding phase-to-earth representative overvoltage is 183.9 kV.

2.3.1  **Temporary Overvoltages During Load Rejection**

Phase-to-earth and phase-to-phase temporary overvoltages due to load rejection are estimated to 1.35 P.U which results in phase-to-earth and phase-to-phase representative overvoltages of $U_{rp} = 191$ kV and $U_{rp} = 330.8$ kV.

2.3.2  **Maximum Temporary Overvoltages**

The overvoltages due to a combination of an earth fault with a load rejection are not considered in this study. It is also assumed that ferroresonance are very unlikely for this network since all power transformer high voltage neutral bushings are effectively grounded.

The representative temporary overvoltages are the highest obtained considering all possible sources:

- Phase-to-earth : $U_{rp} = 191$ kV
- Phase-to-phase : $U_{rp} = 330.8$ kV

2.4  **SLOW-FRONT OVERVOLTAGES**

The slow-front overvoltages are mainly due to line energization and re-energisation switching operations and to improve the reliability of the studied network only two type of switching operations are allowed. The first one to clear phase-to-earth faults consists of single pole auto reclose operation SPAR. The second one to clear three-phase faults consists of three-poles tripping without any auto reclosure operations. The slow-front overvoltages are estimated to the following values for the different modes of operation.
2.4.1 **Switching Overvoltages due to the closing of an Inductive Line**

During normal operation of the network, a 220 kV line can be energized either from local substation or from all remote substations that are connected to this line. To confirm energization of the line, the closing of the high voltage circuit breakers must always be supervised by synchro-check relays.

The 2% overvoltage values are estimated from figure 1 of IEC Standard 60071-2, considering the energization of a 220 kV line, from a network with low short circuit current and while the shunt compensation of the line capacitive reactance is greater than 50%. These overvoltage values provide an indication of whether or not detailed studies would be required and are valid for both local and receiving substations. Circuit breakers with closing resistance were not considered.

The 2% overvoltage between phase and earth without limitation at either substation is estimated at 2.9 p.u. The 2% phase-to-phase overvoltage based on figure 2 of IEC Standard 60071-2 is estimated at 4.3 p.u. The representative overvoltages, before applying surge arresters are the truncation values of these overvoltages distribution.

\[
\begin{align*}
\text{U}_{et} &= 1.25 \times \text{U}_{e2} - 0.25 \\
&= 675.1 \text{ kV} \\
\text{U}_{pt} &= 1.25 \times \text{U}_{p2} - 0.43 \\
&= 989.2 \text{ kV}
\end{align*}
\]

2.4.2 **Switching Overvoltages due to Single Pole Auto Reclosure**

During single pole auto reclosure, when the faulted phase circuit breaker opens to clear the fault, the faulted phase remains mutually coupled to the healthy phases. This results in a coupled voltage on the faulty phase following secondary arc extension just prior to the reclosing of the previously faulted phase circuit breaker. It is unlikely that both line end circuit breakers would close at the same time and therefore the closing of one phase circuit breaker before the other is equivalent to energisation of that phase with some level of trapped charge, and might lead to higher switching overvoltages. Yet when a conservative value taken from figure 1 of IEC standard 60071-2 for the 2% overvoltages, the energisation of a line from a weak network and with the addition of neutral reactors to limit the trapped charge, such an event should not be of any concern.
For this reason the 2% overvoltages during SPAR operation are estimated from figure 1 of the IEC Standard 60071-2 with the same criteria that were used for the energization of the line described in 2.3.1. The 2% phase-to-phase overvoltages are also based from figure 2 of IEC standard 60071-2. The 2% overvoltage between phase and earth without limitation at either station is estimated at 2,9 p.u. while the 2% phase-to-phase overvoltage is estimated at 4,3 p.u.

Further studies might be required later to confirm all assumptions included in this report.

### 2.4.3 Representative Slow-Front Overvoltages

The representatives slow-front overvoltages are the maximum obtained values considering all possible sources.
- \( U_{et} \) (Phase-to-earth) = 675,1 kV;
- \( U_{\phi pt} \) (phase-to-phase) = 989,2 kV.

### 2.4.4 Selection of Surge Arresters

To control the possible severe overvoltages resulting either from energization of a line or fault clearing on isolated network, metal-oxide surge arresters are installed at the line entrances and near power transformers. The rating of these arresters is selected to withstand the worst temporary overvoltage cycle (amplitude and duration). The arresters on equipment and line terminals are selected from ABB, IEC class 3, type PEXLIM Q, with a nominal voltage of 192 kV for a maximum continuous operating voltage of 154 kV and a 10 s temporary overvoltage of 211 kV.

The protective characteristics for these 192 kV surge arresters are:
- Switching impulse protective level: \( U_{ps} = 381 \) kV;
- Lightning impulse protective level: \( U_{pl} = 452 \) kV.

The slow-front representative overvoltages can be directly given by \( U_{ps} \) (phase-to-earth) or 2 x \( U_{ps} \) (phase-to-phase) if these protective values are lower than the maximum slow-front overvoltage stresses (\( U_{et} \) and \( U_{\phi pt} \)) values. This is the case for any stresses values found above, so that the representative slow-front overvoltages are:
- Phase-to-earth: \( U_{et} = 381 \) kV;
- Phase-to-phase: \( U_{\phi pt} = 762 \) kV.
2.5 **Fast-Front Overvoltages**

Only fast-front overvoltages from lightning have to be considered. A simplified statistical approach will be used which leads directly to the co-ordination withstand voltage on Step 2 below.

3. **Step 2: Determination of the Co-ordination Withstand Voltages - Values of UCW**

3.1 **Temporary Overvoltages**

For this class of overvoltages, the co-ordination withstand voltage is equal to the representative temporary overvoltage. Therefore, $U_{cw}$ values are:

- Phase-to-earth: $U_{cw} = 191$ kV;
- Phase-to-phase: $U_{cw} = 330,8$ kV.

3.2 **Slow-Front Overvoltage**

The deterministic approach will be used. With such an approach, one must take into account that surge limitation by an arrester distorts the statistical distribution of these surges, creating a significant bulge in the probability distribution of surges at about the arrester protective level. Therefore, small uncertainties related to the arrester protective characteristics or to equipment strength could lead to an abnormally high increase in the failure rate. Figure 6 of IEC Standard 60071-2 takes this into account by applying a deterministic co-ordination factor $K_{cd}$ to the arrester protective level to obtain the $U_{cw}$ values.

For all equipment line terminal the $K_{cd}$ values are:

- Phase-to-earth: $U_{pw}/U_{e2} = 381 / 580,1 = 0,657$ → $K_{cd} = 1,1$;
- Phase-to-phase: $2 \times U_{pw}/U_{e2} = 762 / 580,1 = 0,886$ → $K_{cd} = 1,0$.

The resulting co-ordination withstand voltages are $K_{cd} U_{rp}$.

For all equipment line terminal:

- Phase-to-earth: $U_{cw} = 1,10 \times 381 = 419,1$ kV;
- Phase-to-phase: $U_{cw} = 1,00 \times 762 = 764,7$ kV.

3.3 **Fast-Front Overvoltage**

For equipment protected by surge arresters, the maximum fast-front overvoltage (and thus the fast-front representative overvoltage) is equal to the lightning-impulse protective level of the surge arrester, namely 452 kV.
However, to this value of 452 kV, one must add a voltage equal to $A \times \frac{L}{(n \times (L_{sp} + L_{a}))}$ to take into account the separation distance between the surge arrester and the protected equipment.

The parameters of this expression are obtained as per the following:

- $A$: (For an assumed single conductor transmission line) is 4500 according to IEC Standard 60071-2;
- $n$: The minimum number of in-service overhead line connected to the station assume to be equal to one;
- $L$: Equal to $a_1 + a_2 + a_3 + a_3$ according to figure 3 of IEC Standard 60071-2. This parameter is limited to 30 m for external insulation and 30 m for internal insulation;
- $L_{sp}$: The span length of the overhead lines is estimated to 350 m;
- $R_a$: Acceptable failure rate for equipment;
- $R_{km}$: Overhead line outage rate per year for a design corresponding to the first kilometer in front of the station;
- $L_{a}$: $L_a$ is the length of overhead line section with flashover rate equal to acceptable failure rate. The acceptable failure rate is selected to be $(1/400$ years) or $0.0025 \text{ year}^{-1}$ and the line lightning flashover rate is estimated to be 10 per 100 km per year. Then for these selected values $L_a$ is equal to 25 m.

The resulting correction valued for separation are equal to:

Internal insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$

External insulation:

$$4500 \times 30 / (1 \times (300 + 25)) = 812 \text{ kV}$$

Then, the resulting co-ordination withstand voltage are:

Internal insulation:

$$U_{cw} = 452 + 360 = 812 \text{ kV}$$
External insulation:

\[ U_{cw} = 452 + 360 = 812 \text{ kV} \]

4. **STEP 3 – DETERMINATION OF THE REQUIRED WITHSTAND VOLTAGES – VALUES OF URW**

The required withstand voltages are obtained by applying to the co-ordination withstand voltages two correction factors: factor \( K_a \) which takes into account the altitude of the installation and a safety factor \( K_s \).

4.1 **SAFETY FACTOR**

- For internal insulation: \( K_s = 1,15 \)
- For external insulation: \( K_s = 1,05 \)

4.2 **ATMOSPHERIC CORRECTION FACTOR**

The altitude correction factor \( K_a \) is applicable to external insulation only and its value is calculated from the following expression:

\[
K_a = e^{m \left( \frac{H}{8150} \right)}
\]

Where:

- \( m = 1,00 \) : For short duration test with light pollution insulation;
- \( m = 0,96 \) : For phase-to-earth switching impulse withstand with \( U_{cw} = 419,1 \text{ kV} \);
- \( m = 1,00 \) : For phase-to-phase switching impulse withstand with \( U_{cw} = 764,7 \text{ kV} \);
- \( m = 1,00 \) : For lightning impulse withstand.
The corresponding values of $K_a$ are:

- For power-frequency withstand:
  (Phase-to-earth and phase-to-phase)
  \[ K_a = 1,224; \]

- For switching impulse withstand:
  (Phase-to-earth);
  \[ K_a = 1,213; \]

- For switching impulse withstand:
  (Phase-to-phase);
  \[ K_a = 1,224; \]

- For lightning impulse withstand:
  (Phase-to-earth and phase-to-phase);
  \[ K_a = 1,224. \]

### 4.3 REQUIRED WITHSTAND VOLTAGE

The values for the required withstand voltage are obtained from:

\[ U_{rw} = U_{cw} K_a K_s, \]

with $U_{cw}$ values found in Step 2.

#### 4.3.1 For Temporary Overvoltage

External insulation:

- Phase-to-earth: \[ U_{rw} = 191 \times 1,05 \times 1,224 = 245,5 \text{ kV}; \]
- Phase-to-phase: \[ U_{rw} = 330,8 \times 1,05 \times 1,224 = 425,2 \text{ kV}. \]

Internal insulation:

- Phase-to-earth: \[ U_{rw} = 191 \times 1,15 = 219,6 \text{ kV}; \]
- Phase-to-phase: \[ U_{rw} = 330,8 \times 1,15 = 380,4 \text{ kV}. \]

#### 4.3.2 For Slow-Front Overvoltages

External insulation:

- Phase-to-earth: \[ U_{rw} = 419,1 \times 1,05 \times 1,213 = 533,9 \text{ kV}; \]
- Phase-to-phase: \[ U_{rw} = 764,7 \times 1,05 \times 1,224 = 983,1 \text{ kV}. \]
Internal insulation:

- Phase-to-earth: \( U_{rw} = 419,1 \times 1,15 = 482 \text{ kV} \);
- Phase-to-phase: \( U_{rw} = 764,7 \times 1,15 = 879,4 \text{ kV} \).

4.3.3 For Fast-Front Overvoltage

External insulation:

- Phase-to-earth: \( U_{rw} = 812 \times 1,05 \times 1,224 = 1043,9 \text{ kV} \);
- Phase-to-phase: \( U_{rw} = 812 \times 1,05 \times 1,224 = 1043,9 \text{ kV} \).

Internal insulation:

- Phase-to-earth: \( U_{rw} = 812 \times 1,15 = 933,8 \text{ kV} \);
- Phase-to-phase: \( U_{rw} = 812 \times 1,15 = 933,8 \text{ kV} \).

5. STEP 4 – CONVERSION TO WITHSTAND VOLTAGES NORMALIZED FOR RANGE 1

In Range 1, the insulation level is normally described by a set of two values as shown in table 2 of IEC Standard 60071-1: a short-duration power-frequency withstand voltage and a lightning impulse withstand voltage. Table 2 of IEC Standard 60071-2 provides the test conversion factor to be applied to the required withstands voltage for slow-front overvoltage to get such an equivalent set of values.

5.1 Conversion to Short-Duration Power-Frequency Withstand Voltage (SDW)

External insulation:

- Phase-to-earth: \( \text{SDW} = 533,9 \times (0,6 + 533,9 / 8,500) = 353,9 \text{ kV} \);
- Phase-to-phase: \( \text{SDW} = 983,1 \times (0,6 + 983,1 / 12,700) = 666 \text{ kV} \).
Internal insulation:

- Phase-to-earth: $SDW = 482 \times 0.5 = 241 \text{ kV}$;
- Phase-to-phase: $SDW = 879.4 \times 0.5 = 439.7 \text{ kV}$.

5.2 Conversion to Lightning Impulse Withstand Voltage (LIW)

External insulation:

- Phase-to-earth: $LIW = 533.9 \times 1.3 = 694.1 \text{ kV}$;
- Phase-to-phase: $LIW = 983.1 \times (1.05 + 983.1 / 9.000) = 1139.7 \text{ kV}$.

Internal insulation:

- Phase-to-earth: $LIW = 482 \times 1.1 = 530.2 \text{ kV}$;
- Phase-to-phase: $LIW = 879.4 \times 1.1 = 967.3 \text{ kV}$.

6. Step 5: Selection of Standard Withstand Voltage Values

Table 1 below summarizes values $U_{rw(s)}$ of minimum required voltage obtained from system studies in step 3 which become minimum test values to be applied to verify these withstands in terms of short-duration power-frequency, switching impulse and lightning impulse tests. In range 1, the required switching impulse withstand voltage is normally covered by a standard short-duration power-frequency test or by a standard lightning impulse test. In table 1 below, values obtained after such conversions in Step 3 are indicated under $U_{rw(c)}$. In this project, converted values for a lightning impulse test are retained so that converted values for short-duration power-frequency test need no more consideration.
### Table 1 – SUMMARY OF MINIMUM REQUIRED VOLTAGES

<table>
<thead>
<tr>
<th>Values of $U_{rw}$:</th>
<th>External Insulation</th>
<th>Internal Insulation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- in kV r.m.s. for short duration power frequency</td>
<td>Switchyard Equipment</td>
<td>Main Transformer</td>
</tr>
<tr>
<td></td>
<td>$U_{rw(s)}$</td>
<td>$U_{rw(C)}$</td>
</tr>
<tr>
<td>Short-duration Power Frequency</td>
<td>Phase-to-earth</td>
<td>246</td>
</tr>
<tr>
<td></td>
<td>Phase-to-phase</td>
<td>425</td>
</tr>
<tr>
<td>Switching impulse</td>
<td>Phase-to-earth</td>
<td>534</td>
</tr>
<tr>
<td></td>
<td>Phase-to-phase</td>
<td>983</td>
</tr>
<tr>
<td>Lightning impulse</td>
<td>Phase-to-earth</td>
<td>1044</td>
</tr>
<tr>
<td></td>
<td>Phase-to-phase</td>
<td>1044</td>
</tr>
</tbody>
</table>

Standard voltages to be defined for the purpose of the short-duration power-frequency and lightning impulse tests have to be selected taking into account results shown in bold characters in table 1 (highest value of minimum withstand required $U_{rw(s)}$ or converted value $U_{rw(C)}$) and standard values included in table 2 of IEC Standard 60071-1.

For the external insulation a standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to the maximum available standardized insulation level for a system voltage $U_m$ equal to 245 kV. These values will cover all of the insulations requirements for phase-to-earth and phase-to-phase except the phase-to-phase external insulation due to the conversion of the switching overvoltages into lightning impulse withstand voltage, which require a standard value of 1127 kV or more. With the studies carried out so far it is impossible to define if this requirement is valid only on line entrance equipment or if it is valid for all 220 kV equipment installed in this substation. Increasing the distance between phases can easily accommodate this requirement. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.
For internal insulation standardized values of 460 kV (for short-duration power-frequency) and 1050 kV (for lightning impulse) correspond to such a standard available insulation level with a system voltage $U_m$ equal to 245 kV. is selected for phase-to-earth and phase-phase insulation of all switchyard equipment. These values will cover all the requirements for phase-to-phase and phase-to-earth insulation. The define acceptable failure rate of 1 per 400 years can only be guaranteed if separation distance from surge arresters is always equal or smaller than 30 m. The length of the active part of the surge arresters as well as the length of the leads connecting the surge arresters to the line and to the earth must be considered when measuring the separation distance.