Remote Radio Unit (RRU) DC Feed protection
Abstract: Distributed Base Stations (DBS) split the traditional Radio Base Station (RBS) antenna tower base equipment into two locations; a Base Band Unit (BBU) at the tower base and a Remote Radio Unit (RRU) mounted on the top of the tower. Normally the BBU and the RRU would be connected by a fibre optic cable to carry the signals and a DC feed to power the RRU. Towers are likely to be struck with lightning and so some form of protection is necessary to prevent damage to the DC powering feed and connected equipment. Several example protection methods and a worked example are given. Feed cable currents and protection stress levels are calculated for negative and positive lightning flashes.

Clause 1 describes the DBS configuration with term definitions in clause 2. Clause 3 shows three possible protection configurations and clause 4 determines the circuit parameters. Clauses 5 through to 7 calculate DC feed cable currents and the Surge Protective Device (SPD) energy for four variants of lightning stroke. Clause 8 outlines two other forms of DC feed protection. Finally clause 9 summarises and comments on the results.

Keywords: DBS, RRU, RRH, BBU, SPD, DC powering feed, protection, lightning stroke, positive lightning, negative lightning
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1. Introduction

1.1 RRH Configuration

Traditionally Radio Base Stations (RBS) had the bulk of the equipment at the base of the antenna tower or mast. Distributed Base Stations (DBS) split the equipment into two sections; a Base Band Unit (BBU) at the tower or mast base and a Remote Radio Unit (RRU) mounted at the top of the tower or mast. Normally the BBU and the RRU would be connected by a fibre optic cable to carry the signals and a DC feed to power the RRU, see Figure 1. The RRU is also called a Remote Radio Head (RRH). To harmonize with [B3] the acronym RRU will be used in this document.

Where a tower exists, such as power distribution pylons, the RRU may be mounted at an intermediate level rather than at the tower top.
1.2 History

RRU DC feed protection has been under discussion in the ITU-T since the submission of [B1] in 2011. The 2012 presentation [B2] gave details the unexpected DC feed protection surge waveshape and the reasons for it. In 2014 the ITU-T published a Recommendation [B3] giving a more comprehensive explanation of the DC feed surge protection.

2. Definitions and abbreviations

2.1 Definitions

For the purposes of this document, the following terms and definitions apply.

**Radio Base Station (RBS):** Installation intended to provide access to the telecommunication system by means of radio waves. [B3]

**Distributed Base Station (DBS):** One kind of Radio Base Station, where the Remote Radio Unit (RRU) and Base Band Unit (BBU) can be installed separated. [B3]
Remote Radio Unit (RRU): The radio frequency module of Radio Base Station which can be installed separately. Optical fibre is commonly used to connect radio frequency module and base band unit of Radio Base Station. [B3]

Base Band Unit (BBU): The base band module of Radio Base Station which can be installed separately. Optical fibre is commonly used to connect base band module and radio frequency module. [B3]

surge reference equalizer: A surge protective device used for connecting equipment to external systems whereby all conductors connected to the protected load are routed, physically and electrically, through a single enclosure with a shared reference point between the input and output ports of each system. [B4]

2.2 Abbreviations

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BBU</td>
<td>Base Band Unit</td>
</tr>
<tr>
<td>DBS</td>
<td>Distributed Base Station</td>
</tr>
<tr>
<td>RBS</td>
<td>Radio Base Station</td>
</tr>
<tr>
<td>RRU</td>
<td>Remote Radio Unit</td>
</tr>
<tr>
<td>RRH</td>
<td>Remote Radio Head</td>
</tr>
<tr>
<td>RTN</td>
<td>Return</td>
</tr>
<tr>
<td>SPC</td>
<td>Surge Protective Component</td>
</tr>
<tr>
<td>SPD</td>
<td>Surge Protective Device</td>
</tr>
</tbody>
</table>

3. Protection configurations

Figure 2 shows the common arrangement where the floating DC feed has protection applied at the RRU and the BBU. During lightning stroke events the protection, the red block in Figure 2, becomes a surge reference equalizer, lightning event bonding the DC feed to the local tower structure via the black connection line from the protection block to the tower.
Figure 2 — Protection (red block) applied to DC powering feed at tower base and top

Figure 3 through to Figure 5 shows some protection configurations for a -48 V DC feed, assuming the lightning stroke current flows from tower top to bottom. The lightning stroke current, $I_s$, divides between the tower, $I_T$, and DC feed, $I_R$ and $I_F$. Because of the values of tower and DC feed impedances, most of the stroke current will flow in the tower. In the Figures, the tower impedances are $R_T$ and $L_T$ and the DC feed impedances are $R_R$ and $L_R$ for the return and $R_F$ and $L_F$ for the -48 V. The mutual inductance between the tower and DC feed is represented by $M_{TRF}$.

Figure 3 — 2 SPD Protection of DC powering feed

In Figure 3, SPD1 and SPD2 at the tower top and SPD3 and SPD4 at the base reference equalize the DC feed voltage to the local tower voltage during a lightning stroke.
Figure 4 — 3 SPD Protection of DC powering feed

Figure 4 is similar to Figure 3, but has the addition of an extra SPD, SPD 2 and SPD5, across the DC feed at the tower top and base to limit the differential feed surge voltage.

Figure 5 — Single SPD for reference equalization

Figure 5 uses a single SPD for reference equalization, SPD1 and SPD3, and another SPD, SPD2 and SPD4, across the DC feed at the tower top and base to limit the differential feed surge voltage.

4. Circuit component values

Reference [B1] measured a three leg, 5 cm square tube, folded 24 m tower in a laboratory environment fitted with a 6 mm² DC feed cable.

4.1 Resistances

The three mild steel tower legs had 2 mm walls, making the total cross-sectional area, \( A \), 3 x \((50^2 - 46^2)\) = 1152 mm². The calculated tower resistance will be:
\[ R_t = \rho \frac{l}{A} = 1.5 \times 10^{-7} \times \frac{24}{1152 \times 10^{-6}} = 3.1 \text{ m} \Omega \]

Where:

\( l = 24 \text{ m} \)
\( A = 1152 \times 10^{-6} \text{ m}^2 \)
\( \rho = 1.5 \times 10^{-7} \text{ } \Omega \text{m} \) (mild steel)

The actual measured tower resistance was 2.2 m\( \Omega \) equivalent to 6.6 m\( \Omega \) per leg.

Similarly the 6 mm\( ^2 \) DC feed cable resistance calculates to 68 m\( \Omega \) using \( \rho = 0.17 \times 10^{-7} \text{ } \Omega \text{m} \) (copper).

### 4.2 Inductances

To enable short connection leads to the surge generator, the tower was bent back on itself to form a “U” or hairpin shaped structure. Had the tower been straight, the equation for a straight conductor inductance,

\[ L = 0.2l(\ln(2l/r)-0.75) \text{ } \mu \text{H} \]

based on [B5] could have been used. This equation results in an inductance value of 32 \( \mu \text{H} \) per tower leg or 11 \( \mu \text{H} \) with three in parallel. A tower inductance relationship is given in [B6], which gives a rule of thumb of 0.84 \( \mu \text{H} \) for every metre of tower height, giving an inductance value of 20 \( \mu \text{H} \) for a 24 m tower.

The inductance of a hairpin shaped tower can be treated as rectangle with sides of length \( l \) and width \( d \) formed by a conductor of radius \( r \). The inductance equation [B9] for a rectangle is:

\[ L = 0.4 \left[ -2(l + d) + 2\sqrt{l^2 + d^2} - d \ln \left( \frac{d}{l} + \frac{\sqrt{l^2 + d^2}}{l} \right) - l \ln \left( \frac{l}{d} + \frac{\sqrt{l^2 + d^2}}{d} \right) + d \ln \left( \frac{2d}{r} \right) + l \ln \left( \frac{2l}{r} \right) \right] \mu \text{H} \]

This equation results in an inductance value of 17 \( \mu \text{H} \) per tower leg or 5.8 \( \mu \text{H} \) with three in parallel.

Using the equation for the 6 mm\( ^2 \) DC feed cable gives a value of 32 \( \mu \text{H} \). Bending the tower round in a hairpin to apply the surge generator reduces the tower and cable inductance.

The mutual inductance between the tower and cable is neglected as the recorded current waveforms did not show any major mutual inductive effects.

### 4.3 Equivalent experimental tower circuit

Figure 6 shows the simplified circuit for [B1] using the values from previous clauses showing currents and component voltages.
The tower path is lower in impedance than the cable path so most of the current flows in the tower path. As most of the current is in the tower path the tower acts like a voltage generator to drive current through the cable path. The voltage across the parallel arms must have the same value, giving:

\[ V_{LT} + V_{RT} = V_{LC} + V_{SPD} + V_{RC} \]

Rearranging in terms of \( V_{LC} \)

\[ V_{LC} = V_{LT} + V_{RT} - V_{SPD} - V_{RC} \]

Integrating this equation with time will result in the voltseconds applied to the cable inductance, \( L_C \), which, when divided by the cable inductance will give the cable current, \( I_C \). This approach is used to determine the cable current in the following clauses.

5. Tower voltage during a negative lightning flash

The median stroke values from [B7] will be used to emulate a negative lightning flash. The parameter values are:

- First stroke: 30 kA, 5.5/75 and 5.2 C
Subsequent strokes: 12 kA, 1.1/32 and 1.4 C

Inter-stroke interval: 60 ms

Subsequent stroke number: 3 to 5

5.1 First stroke

Figure 7 shows the simulated first stroke tower current. The slow start to current rise is to model more accurately the naturally occurring stroke initial current rise. A double exponential lightning equation gives a rapid initial rate of rise and overestimates the inductive voltage levels. The alternative equation given in [B8] was used to emulate the current waveform slow initial rise.

![Figure 7 — First stroke tower waveform](image-url)
Figure 8 shows the tower inductive ($V_{LT}$) and resistive ($V_{RT}$) voltage components as a result of the first stroke current.

The stroke current rate of rise develops a substantial tower inductive voltage (40 kV red line) and this determines the voltage applied to the cable and the consequent current in the cable. The tower resistive voltage developed in this case is negligible (green line). Until the combined voltage thresholds ($V_{SPD}$) of the two SPDs, SPD1 and SPD2, is exceeded, substantive current cannot flow in the cable. If, for example the combine threshold voltage was 200 V only the portion of the tower voltage exceeding 200 V will build up a current in the cable.

Figure 9 shows the portion of the inductive voltage that exceeds 200 V in red and that below 200 V in black. The fill represents the volt-seconds (172 mVs) applied to the cable inductance, $L_C$.

Figure 10 integrates the red portion (>200 V) volt-seconds of Figure 9 and shows the cumulative millivolt-seconds applied to the cable inductance $L_C$. As the volt-seconds divided by the cable inductance is the value of current, the cumulative waveshape is also the cable current rise waveshape. The total volt-seconds
applied is 172 mVs and that would give a peak inductive current of $172 \times 32 \mu = 5380$ A. The inductive cable energy stored is $0.5 \times 32 \mu \times 5380^2 = 460$ J.

![Cumulative millivolt-seconds applied to the cable inductance $L_C$](image)

**Figure 10** — Cumulative millivolt-seconds applied to the cable inductance $L_C$

Figure 11 shows the simplified circuit elements just after the cable current peak.

![Simplified circuit elements for cable current decay](image)

**Figure 11** — Simplified circuit elements for cable current decay

After the cable current has peaked, the cable stored inductive energy discharges. The voltage polarity across the cable inductance ($V_{LC}$) and tower ($V_{LT}$) reverses after the current peak as the stroke $di/dt$
becomes negative. The voltage across the cable inductance will essentially be the combined SPD clamping voltages of SPD1 and SPD2 (200 V) and the tower voltage. The previous voltage equation becomes

\[ V_{LC} = -V_{LT} + V_{RT} - V_{SPD} - V_{RC} \]

The modified equation shows that the combined SPD voltage now adds to the tower voltage instead of subtracting from it, so reducing the time for the cable inductive energy to discharge.

![Diagram](image)

**Figure 12 — Tower voltage after current peak**

The tower voltage plus the voltages of the SPD1 and SPD2 is applied to the cable inductance. Figure 12 shows the combined tower and SPD voltage after the stroke current peak. By integrating the total voltage with time, the time at which the volt-second product reaches 172 mVs can be found. The 172 mVs value is reached at 168 µs. At 168 µs the induced current in the cable will be zero.

Figure 13 shows the tower and cable currents. The cable current drops to zero at 168 µs or 151 µs after the current peak.

The SPD energy deposited can be found from integrating the cable current and multiplying by the SPD voltage (200 V). The total SPD energy deposited was found to be 68 J comprised of 5 J in the current rise and 63 J in the current decay. The total energy deposited in each SPD is 34 J. This is less than 10 % of the energy (460 J) that was stored in the cable inductance.
In summary, the significant first stroke parameters were:

- Peak tower current 30 kA (stroke current 35 A)
- Peak cable current 5.38 kA
- Cable volt-second integral during current rise 172 mVs
- Cable stored energy 460 J
- Cable current time from peak to zero 161 µs
- SPD energy 68 J (about 34 J each SPD)

5.2 Subsequent strokes

Subsequent strokes are typically lower in amplitude, faster rate of current rise and shorter decay times, but they occur in multiples of 3 to 5. Figure 14 shows the simulated subsequent stroke tower current.
Figure 14 — Subsequent stroke tower current

Figure 15 shows the tower inductive and resistive voltage components as a result of the subsequent stroke current.

Figure 15 — Subsequent stroke tower voltages

The fast rate of current rise causes a peak tower voltage of over 80 kV. The treatment of these values followed the same procedure as the first stroke clause. Significant parameters were:

- Peak tower current 12 kA (stroke current 14 kA)
- Peak cable current 2.17 kA
- Cable volt-second integral during current rise 69 mVs
- Cable stored energy 75 J
- Cable current time from peak to zero 70 µs
- SPD energy 13 J (about 7 J each SPD)

Figure 16 shows the tower and cable currents. If there were 5 subsequent strokes the total energy deposited in a single SPD (SPD 1 or SPD2) would be 5*7 + 34 = 69 J.

![Figure 16 — Tower and cable currents](image)

6. Tower voltage during a positive lightning stroke

The median stroke values from [B7] will be used to emulate a positive lightning stroke. The parameter values are:

- 35 kA, 22/230 and 16 C

6.1 Positive stroke

Figure 17 shows the simulated positive stroke tower current. The slow start to current rise is to model more accurately the naturally occurring stroke initial current rise.
Figure 17 — Positive stroke tower current

Figure 15 shows the tower inductive and resistive voltage components as a result of the subsequent stroke current.

Figure 18 — Positive stroke tower voltages

The rate of current rise causes a peak tower voltage of 12 kV. The treatment of these values follows the same procedure as the first stroke clause. Significant parameters were:

- Peak tower current 35 kA (stroke current 41 kA)
- Peak cable current 6.1 kA
- Cable volt-second integral during current rise 196 mVs
- Cable stored energy 595 J
223  • Cable current time from peak to zero 343 µs

224  • SPD energy 210 J (about 105 J each SPD)

225  Figure 16 shows the tower and cable currents. This figure shows that, with the 35 kA stroke current, when
226  the stroke current time to half value is 250 µs or longer the cable current decay waveshape tends to a linear
227  ramp. This was noticed on the oscilloscope shots of [B1] where the surge generator used had a time to half
228  value of 400 µs to 440 µs.

229

230  Figure 19 — Positive stroke tower and cable currents

231  7. Tower voltage during an extreme positive lightning stroke

232  The recommended extreme (1 % population) stroke values from [B11] were used to emulate an extreme
233  positive lightning stroke. The positive stroke parameter values given are:

234  • 350 kA peak current, 11 µs time to current peak, 40 µs time to half value and 500 kA/µs di/dt
235  maximum

236  For reference the extreme negative stroke parameter values given are:

237  • 160 kA peak current, 6 µs time to current peak, 80 µs time to half value and 500 kA/µs di/dt
238  maximum

239  Both waveforms have a 500 kA/µs maximum rate of rise and will generate the same value of peak
240  inductive voltage.
7.1 Extreme positive stroke

Figure 20 shows the simulated extreme positive stroke tower current. This simulation only achieves a maximum di/dt of 100 kA/µs and not the recommended 500 kA/µs.

![Extreme positive stroke tower current](image1.png)

**Figure 20 — Extreme positive stroke tower current**

Figure 21 shows the tower inductive and resistive voltage components as a result of the extreme positive stroke current.

![Extreme positive stroke tower voltages](image2.png)

**Figure 21 — Extreme positive stroke tower voltages**

The rate of current rise (105 kA/µs) causes a peak tower voltage of 620 kV. The treatment of these values follows the same procedure as the first stroke clause. Significant parameters were:

- Peak tower current 350 kA (stroke current 406 kA)
- Peak cable current 55.9 kA
- Cable volt-second integral during current rise 1.79 Vs
- Cable stored energy 50 kJ
- Cable current time from peak to zero 112 µs
- SPD energy 464 J (about 232 J each SPD)

Figure 22 shows the tower and cable currents. The tower inductive voltage dominates making the cable current waveshape similar to the stroke current waveshape.

8. Alternative protection arrangements

8.1 Gas Discharge Tube (GDT) reference bonding

Clause B.5 “Series connected GDTs for DC power applications” in [B10] shows how a series combination of GDTs can develop a combined arc voltage higher than the protected DC supply voltage. This series arrangement avoids the possibility of the GDTs continuing to conduct after a lightning surge.

The previous Figure 5 circuit can be used with single GDTs for SPD1 and SPD3.
When the tower stroke voltage causes the sparkover of the GDTs, the return, RTN, cable is bonded to the tower top and base. As a result a portion of the stroke current will flow in the cable RTN for the stroke duration. SPDs SPD2 and SPD4 should be clamping type voltage limiters to avoid shorting the DC supply. The feed (-48 V) cable current will be similar to that of the clause 4.3 circuit.

### 8.2 Shielded DC feed

The Appendix I, Isolated protection solution: example of [B3] shows how a cable shield and a power feed isolation barrier in the RRU could be used to remove the need of SPD elements. The withstand voltage of the isolation barrier needs careful consideration to comprehend the maximum stroke voltages. In this document peak values of 80 kV have been calculated just for nominal conditions on the 24 m tower.

### 9. Lightning stroke results and comments

#### Table 1—Lightning stroke values and results

<table>
<thead>
<tr>
<th>Stroke (clause #)</th>
<th>Peak tower current kA</th>
<th>Cable peak current kA</th>
<th>Stroke waveshape</th>
<th>Cable current time to 0 µs</th>
<th>Vs integral peak mVs</th>
<th>Tower energy J</th>
<th>Cable energy J</th>
<th>Total SPD energy J</th>
</tr>
</thead>
<tbody>
<tr>
<td>Negative first (5.1)</td>
<td>30 (100 %)</td>
<td>5.4 (18 %)</td>
<td>5.5/75</td>
<td>160</td>
<td>170</td>
<td>2610 (100 %)</td>
<td>460 (18 %)</td>
<td>68 (2.6 %)</td>
</tr>
<tr>
<td>Negative subsequent (5.2)</td>
<td>12 (100 %)</td>
<td>2.2 (18 %)</td>
<td>1.1/32</td>
<td>70</td>
<td>69</td>
<td>418 (100 %)</td>
<td>75 (18 %)</td>
<td>13 (3.1 %)</td>
</tr>
<tr>
<td>Positive (6.1)</td>
<td>35 (100 %)</td>
<td>6.1 (17 %)</td>
<td>22/230</td>
<td>340</td>
<td>200</td>
<td>3550 (100 %)</td>
<td>600 (17 %)</td>
<td>210 (5.9 %)</td>
</tr>
<tr>
<td>Extreme positive (7.1)</td>
<td>350 (100 %)</td>
<td>56 (16 %)</td>
<td>4.5/40</td>
<td>110</td>
<td>1800</td>
<td>355000 (100 %)</td>
<td>50000 (14 %)</td>
<td>460 (0.13 %)</td>
</tr>
</tbody>
</table>

Percentage values shown are relative the tower current peak or tower energy.
Table 1 results were obtained by the following procedure:

1) Estimate the inductive and resistive components of the tower and DC feed cable.
2) Define the lightning stroke waveform applied to the model.
3) Assume most of the stroke current flows in the tower
4) Calculate the tower voltage from the stroke current and the tower inductance and resistance.
   (in this example the resistive voltage was negligible)
5) Subtract the nominal SPD voltage from the result of 4).
6) Integrate the result of 5) with time to give a cumulative Vs waveform.
7) Divide the result of 6) by the cable inductance to give the SPD current versus time waveform.
8) Multiply the result of 7) by the nominal SPD voltage to give the SPD power versus time waveform.
9) Integrate the result of 8) for the cable current duration time to give the SPD cumulative energy.

Only a nominal value of SPD clamping voltage was used. A further refinement of this procedure would be
   to incorporate a model for the SPD clamping voltage versus current.

The lightning parameters used for analysis of the first three table data rows were median stroke values from
[B7]. The forth extreme positive stroke row used recommendations from [B11], which represents the more
stressful values occurring in the field. For a given amplitude of stroke current, the energy deposited into the
SPD increases with increasing time to half value of the stroke. Longer times, over about 250 µs, to half
value cause the SPD current decay waveshape to approach a linear ramp.

The transition from a truncated stroke waveshape to a linear ramp warrants further investigation. The
following (simplistic) approach provides some indication of the transition region. The actual tower current,
$i_T$, can be approximated to:

$$i_T = i_S \left( \frac{L_C}{L_C + L_T} \right)$$

Where:

- $i_s$ = Peak stroke current
- $L_T$ = Tower inductance
- $L_C$ = Cable inductance

In Figure 24 the tower current is approximated to a triangular waveform. The waveform rises in time $T_F$ to
a peak of current of $i_{T_{MAX}}$ and then linearly decays to 50 % of $i_{T_{MAX}}$ in time $T_{DT}$, measured from the current
peak. The cable current reaches zero in time $2_{T_{DT}}$. 

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Figure 24 — Simple analysis of cable current decay time to zero

In the time to peak current, the tower current rate of rise generates an inductive voltage, $V_{T\text{MAX}}$, of $L_T \cdot i_{T\text{MAX}} / T_F$. The voltage applied to the cable inductance, $L_C$, will be reduced by the SPD clamping voltage $V_{SPD}$. The peak cable current, $i_{CMAX}$, will be:

$$ i_{CMAX} = T_F \left( L_T \cdot i_{T\text{MAX}} / T_F - V_{SPD} \right) / L_C $$

Simplifying to

$$ i_{CMAX} = L_T \cdot i_{T\text{MAX}} / L_C - T_F V_{SPD} / L_C $$

Generally the $T_F V_{SPD} / L_C$ factor will be small making
During the tower current decay time the cable inductive voltage, $v_{CD}$, will be

$$v_{CD} = -(L_T i_{TMAX}/(2T_{DT}) + V_{SPD})$$

or

$$v_{CD} = -(L_T i_{TMAX} + 2T_{DT} V_{SPD}) / 2T_{DT}$$

The time, $2T_{DC}$, for the cable current to decay to zero is given by

$$2T_{DC} = L_c i_{CMAX} / v_{CD}$$

Simplifying

$$2T_{DC} = 2T_{DT} L_T i_{TMAX} / (L_T i_{TMAX} + 2T_{DT} V_{SPD})$$

$$2T_{DC} = 2T_{DT} / (1 + 2T_{DT} V_{SPD} / (L_T i_{TMAX}))$$

The equation above indicates that the cable current decay linearizes when the $2T_{DT} V_{SPD} / (L_T i_{TMAX})$ factor becomes significant compared to unity. Inserting the example values gives $400T_{DT} / (5.8 i_{CMAX}) = 69T_{DT} / i_{TMAX}$, where $T_{DT}$ is in microseconds. In clause 6.1 with $i_{TMAX} = 35$ kA and $T_{DT} = 200$ µs a linear ramp is noticeable. The factor for this condition is $69*200/35000 = 0.39$, making $2T_{DC} = 2*200/1.39 = 290$ µs. The actual calculated value using exponential decays was 340 µs.

Further the approximate SPD energy, $E_{SPD}$ can be calculated with

$$E_{SPD} = V_{SPD} i_{TMAX} T_{DC} L_T / L_C$$

Using previous values $E_{SPD} = 200*35000*100 \, \mu s*5.8/32 = 20*35*5.8/32 = 126$ J. The actual calculated value using exponential decays was 210 J. Thus the simplistic linear approach can be used to establish orders of magnitude but not to any level of accuracy.

The analyzed tower was 24 m and folded. Higher towers will result in proportionally larger values of stress as the inductances will be proportional to the tower height.
Annex A

(informative)

Bibliography

These bibliographical references provide background information, but do not need to be consulted to understand this document.

[B1] Mr Politis Zafiris, Lightning current through MOV based SPDs in RRH applications, Raycap SA


