DC SURGE PROTECTION OF REMOTE RADIO UNITS RRU or REMOTE RADIO HEAD RRH

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ABSTRACT

Traditionally, cellular radio antennae were connected to base station radio equipment using coaxial feeders. Microwave radio antennae were either connected with waveguides or coaxial cables, which will collectively be called feeders herein. The feeders would carry the baseband frequency and the RF signal. RF feeders have served the industry extremely well. However as the frequency and the bandwidth transmitted increased, the losses in the feeder and connectors became more significant. There is a limitation on the length of the RF feeder before losses become intolerable and the error rate significant.

The next generation of radio equipment utilized remote radio units close to the antennae which would convert the frequencies to an intermediate frequency and this could be transmitted more efficiently on smaller coax feeders with losses being less of a problem. This method is more common, with microwave radio than cellular.

Modern cellular and microwave equipment utilize remote radio unit RRU or remote radio head RRH which is fed from the base station via optical fiber. This eliminates the loss issues on feeders and allows transmission to occur at much higher frequencies with larger bandwidth. Power to the RRU cannot be transferred from the base station to RRU or RRH via the optical fiber. Hence, power is fed separately as DC on copper cables. The copper cables are either separate from the fiber or are a composite fiber-copper cable.

The DC feed acts as a source of lightning surges back into the equipment room. More precaution needs to be taken on how to control these surges, than ever before.

In traditional radio, damage to equipment would normally be limited to the radio equipment. In the modern scenario damage can occur to the rectifiers or the whole DC power system, which would jeopardize other equipment installed at the site.

1) Location of SPD The simple solution to this may seem like installing Transient Voltage Surge Suppressors (TVSS) or Surge Protective Devices (SPD) on the DC feeds. However, there are intricacies that involve ground loops & voltage drops associated with cable lengths that need to be understood before choosing the correct location of TVSS. This paper will discuss the possible location of the SPD and the benefit and disadvantages with each location presented.

2) Sizing of SPD There is guidance on the sizing of AC SPD in various standards, including IEEE C61.42, IEC61643 & ITU K56. There is some guidance on the sizing of SPD’s for coaxial feeders and tower lights in ITU K56.
guidelines. However the application of DC SPD on RRU is a relatively new concept and standards for sizing of these may not exist. The paper will look at methods of sizing AC SPD’s and SPD’s for traditional feeders and tower lights as a benchmark and propose suitable values for DC SPD for RRU.

3) **Testing of SPD** Finally, the application of SPD’s in DC applications poses some unique challenges that are not present in AC applications. One such challenge is ensuring that the DC voltage present does not cause the SPD to get into continuous conduction at any time. In AC systems there are many voltage crossing and hence there is opportunity for SPD to get out of conduction. This paper will look at a test setup that simulates the DC application and demonstrate examples of results obtained.

### 1. LOCATION OF TVSS (SPD)

**Scenario 1**

In this scenario the SPD is connected at each end of the power supply, typically near the remote radio and near the base station equipment. There is no direct grounding of SPD’s to the ground bar but it is grounded via the base station equipment and racks. The diagram depicts in a single point or star grounding arrangement installed in accordance with ITU K27 recommendations in ITU Handbook, Grounding & Bonding.
If the radio rack is very close to the ground bar then this may be an effective location for installing the SPD. The red dotted lines in the diagram below show the unwanted path of the currents or the partial currents to the ground if the rack is some physical distance away from the ground bar. The surges would be forced to go via base station equipment, the DC power system and possibly other load down to the ground. This would potentially cause damage to equipment as PCB tracks and components that the surge travels through will not be designed to carry surge currents. Scenario 1 is undesirable if the radio rack is some distance from the ground bar, and demonstrates that the simple case of installing SPD on both ends of the DC feed may not eliminate potential damage from lightning surges.

![Diagram showing the flow of currents](image)

**Figure 2**: Scenario 1 Flow of Currents if Distance Between Rack and Ground Bar is Large.
**Scenario 2**

In this scenario the SPD is connected at each end of the power supply, near the remote radio and near the base station equipment. The SPD’s is directly connected to the ground bar.

There are two main problems with this installation.

1) While some or even most of the lightning surge may travel to ground as shown by the red dotted line, additional paths exist as shown by the yellow dotted line. These paths can be catastrophic and will cause damage to base station equipment, the DC power system and possibly other load down to the ground.

2) The length of the path shown by the red arrow can potentially be a long path. The voltage drop across the cable during the conduction of a lightning surge will be in the order of magnitude of 1-5V per mm. If the cable length in total was 15ft then the total voltage drop could be in the order of 1000-5000V. This means that the voltage protection level at the SPD would be this voltage plus the voltage that the SPD protects to, say 500V. This would mean that there is insufficient voltage control at the base station equipment and damage may still occur.
**Scenario 3**

In this scenario, the SPD is mounted very close to the ground bar and connected to ground via a small piece of cable. The feed to the antennae is directly from the rectifier distribution past the shunt connected SPD mounted close to the ground bar.

The short distance from the ground bar allows the control of the voltage at the SPD. The non existence of paths via equipment eliminates risk of damage via ground loops.

The risk of damage to rectifier, base station equipment and other equipment is greatly minimized. There will be more than one antennae at a site. The next section will demonstrate a modern distribution block that can be used to provide distributed power to several antennae, protection by a single SPD.

This is the best DC surge protection scenario for protecting equipment in telecom building or cabinet from potential lightning surges induced on to the DC feeds.

![Figure 4: Scenario 3, SPD Near Ground Bar and near RRU](image-url)
Method of Distributing Surge Protected DC Supply to Antennae

A distribution method shown below is designed to provide DC feeds via circuit breakers to 6 segments of a cellular 4G antennae. The DC feeds are surge protected using single surge protective device. This SPD has built in alarm contacts, visual indication for end of life and thermal protection. The negative feeds are supplied distribution blocks, which replace bus-bars traditionally used for similar applications. This can be mounted next to the main ground bar.

Figure 5 : A Method of Distributing Power with SPD Mounted Close to Main Ground Bar
2. Sizing of SPD

A standard for the application, sizing and testing of a DC SPD for protecting RRU’s, does not exist. The ITU (International Telecommunications Union) has a comprehensive guide for protection against interference against interference at radio base stations, K56. However this does not contain any guidance on the use of DC SPD on RRU either.

The sizes and the reasoning behind the sizing of SPD’s for AC application and for tower lights, recommended by various international standards and guidelines, is discussed here. The aim of this discussion is to set a benchmark and start a thought process on what the appropriate ratings of these DC SPD’s should be.

Figure 7 below shows the locations at which consideration needs to be given to the sizing of the SPD. It should be noted that the magnitude of lightning currents used in IEC standards are a lot larger and with a longer tail than in IEEE Standards.

In reality this may be an academic exercise as often is the case when we try to use mathematical methods to predicts and model a random phenomenon like lightning. Nevertheless, looking at industry accepted values is a good starting point.

Analysis referred to in IEEE C62.41.1 demonstrates that the highest possible surge entering a building is 30 kA across all the wires. Of course this would split across the wires and depending on the number of phases, the typical peak current expected on a phase is 10 kA. This standard uses an assumption that a 100 kA lightning strike on wave-shape (8/20us) has struck the power-line immediately outside the building. Hence there is a strong argument to say that this is indeed a rare and potentially worse case scenarios. We will later analyze the application of similar currents to a telecom tower and use a current split analysis done in an experiment by Barbosa to decide what the rating of a SPD on tower should be if we used the IEEE reasoning as a guide.

Source: Martzloff and Crouch 1978 [B117]

*Figure 8: Magnitude & Distribution of Lightning Currents Based on IEEE C62.41*
The IEC62305 set of standards define the maximum peak current of lightning based on protection level. The protection level is determined using a risk assessment calculator. While this calculator may not be ideal for a telecommunication radio site it can be used within the limits of its constraints.

The worst case peak current of 200kA is at protection level I, but it should be noted that the wave-shape used here is the longer tail 10/350µs wave-shape as opposed to 8/20 in IEEE standards. The table below from IEC62305-1 shows the lightning maximum peak currents at other protection levels.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum peak current</td>
<td>kA</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Maximum current rate of rise</td>
<td>kA/µs</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>100</td>
</tr>
<tr>
<td>Radius of electro-geometric sphere</td>
<td>m</td>
<td>20</td>
<td>30</td>
<td>45</td>
<td>60</td>
</tr>
<tr>
<td>Probability of flash</td>
<td>%</td>
<td>99</td>
<td>98</td>
<td>95</td>
<td>90</td>
</tr>
</tbody>
</table>

Looking at table E.2 of Annex E of IEC62305 (copied in next page) we find that the expected value of the surge due to coupling for a line directly exposed to a partial direct lightning current, which is the case of the RRU line mounted along the tower leg. This value is 5kA (10/350 µs) for protection levels III and IV and 10 kA (10/350 µs) for protection level 1 and II, if there is a direct flash to the service.

In the case of multiple feeders and multiple DC Feed going up the telecommunication tower, this value would get divided by the number of physical conductors.

For example, if there was just one DC feed, which is unlikely but just an example to simulate the worst case, the 10kA for PL 1 and II would divide by 2 to equal 5 kA (10/350 µs). There is no easy way to correlate this wave-shape to the 8/20 µs, however if one was to take an estimate based on energy levels under the curve, this would equate to approximately 40-50kA 8/20 µs.

As this is a reasonable value and not far from 30kA 8/20us worst case value under the IEEE C62.41, it may be possible to align future standards to both IEEE standards and IEC standards.
E.2.1 Surges due to flashes to services (source of damage S3)

For direct lightning flashes to connected services, partitioning of the lightning current in both directions of the service and the breakdown of insulation must be taken into account.

The selection of the \( I_{\text{imp}} \) value can be based on values given in Table E.2 where the preferred values of \( I_{\text{imp}} \) are associated with the lightning protection level (LPL).

Table E.2 – Expected surge overcurrents due to lightning flashes

<table>
<thead>
<tr>
<th>LPL</th>
<th>Low voltage systems</th>
<th>Telecommunication lines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flash to the service</td>
<td>Flash near the service</td>
</tr>
<tr>
<td></td>
<td>Source of damage S3</td>
<td>Source of damage S4</td>
</tr>
<tr>
<td></td>
<td>(direct flash)</td>
<td>(indirect flash)</td>
</tr>
<tr>
<td></td>
<td>Wavform: 10/350 μs</td>
<td>Wavform: 8/20 μs (kA)</td>
</tr>
<tr>
<td>III-IV</td>
<td>5</td>
<td>2.5</td>
</tr>
<tr>
<td>I-II</td>
<td>10</td>
<td>5</td>
</tr>
</tbody>
</table>

For shielded lines, the values of the overcurrents given in Table E.2 can be reduced by a factor of 0,5.

NOTE: It is assumed that the resistance of the shield is approximately equal to the resistance of all service conductors in parallel.

Figure 9: Expected Surge Overcurrent as Predicted in IEC62305 - Table E.2 of Annex E of

**ITU K56 PROTECTION AGAINSTS INTERFERENCE: Protection of radio base stations against lightning discharges**

In the APPENDIX, ITU K56 takes into consideration the outcomes of the study & paper by C.F. Barbosa, FE Nallin, S. Person & A. Zeddam. Titled Current Distribution in a Telecommunication Tower Struck by Rocket Triggered Lightning.
This paper presents the results of the measurement of currents carried out on an experimental radio base station struck by rocket triggered lightning. The test site is based on the installation of a rocket platform on the top of a metallic tower and the placement of current probes at strategic locations. The study measures the lightning stroke currents. It measures the currents recorded in coaxial feeders that run along the tower where their waveforms are compared with the waveform of corresponding stroke current, the results allow an assessment of the fraction of the stroke current that I carried out by coaxial feeder.

It was not clear if the experiment had one or more feeders but this knowledge will not change the decision of sizing of SPD greatly.

The magnitudes of lightning stroke current are lower in rocket triggered lightning. In this experiment the median was around 12 kA.

The results showed that about 2% of the lightning stroke current flow in the feeder. This percentage is remarkably low due to the of the shielding effect of the tower and the cable trays.

At the worst case current at Protection Level 1, of 200kA, the current flowing in feeders would be expected to be 4kA or less. This would split across multiple feeds. This value is consistent with the values predicted in IEC62305-1 Standard and again stated are based on 10/350 µs waveform. The energy levels would equate roughly to that contained in a 40 kA 8/20 µs wave-form.

This is consistent with ITU K56 approximation of surge currents in feeders given by

\[
\text{Surge Current} = I_{LPL} \alpha_T \alpha_F
\]

Where:

\(I_{LPL}\) = Maximum Peak Current at a particular LPL (Lightning Protection Level) and worst case is 200kA at LPL

\(\alpha_T\) = Shielding factor provided by tower (0.20 for 3 legged tower)

\(\alpha_F\) = Shielding factor provided by cable trays (0.15 for Cable Tray)

Hence Surge Current at Highest Possible Peak Current = 200 x 0.20 x 0.15 = 6kA.

This would equate to 3 kA (10/350µs) per DC Cable if only one unshielded DC cable existed. This would have similar energy levels to 30-40kA 8/20 µs wave-shape.
As a different point of comparison, ITU K56 recommends very similar values for protecting unshielded tower lights. The extract below from ITU K56 shows the values recommended for various protection levels. This table shows a rating of 40 kA at PL I.

<table>
<thead>
<tr>
<th>LPL</th>
<th>I</th>
<th>II</th>
<th>III–IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Current (kA)</td>
<td>40</td>
<td>30</td>
<td>20</td>
</tr>
</tbody>
</table>

### 3. Testing of TVSS (SPD)

The added challenge in the use of SPD in DC power systems is that of ensuring the devices recover or quench after the application of the surge. A good method of testing for this is by simulating surges superimposed on a DC voltages created with aid of batteries.

![Figure 10: Test Set Up for DC SPD](image)
A test case study below is courtesy of ERICO® Labs, Greg Martinjak

The test setup in Figure 11 was designed to investigate if these triggered spark gap or the MOV based SPD’s would recover from conduction, after a single or multiple surges are superimposed on to a DC voltage of 65VDC continuously present across the devices.

Furthermore, the test was carried out to see if there would be good coordination between the triggered spark gap and the MOV based SPD. And to see if using these two devices used in parallel would significantly reduce the voltage protection level or the let through voltage.

The preliminary results of these tests show that triggered spark gaps are proven to be able to self-extinguish internal arcs created during a surge event while a 65VDC voltage is applied to the device.

The tests also showed that significant reduction of the Voltage Protection Level Vpl or Up can be achieved by paralleling suitable triggered spark gap and MOV based devices correctly. Figure 12 below shows the summary of results of part of the testing.
The requirement to take a DC power feed up to a RRU or a RRH in feeder-less cellular base stations introduces a new problem of needing surge protection. The purpose of this surge protection is to protect the radio equipment inside the shelter as well as protecting the rectifiers and other loads.

The selection and the location of surge protection device may at first seem a trivial design consideration. However, upon closer examination it becomes clear that the SPD must be installed close to the main ground bar and ground loops via equipment need to be minimized.

After examining Standard IEEE C62.41, Standard IEC62305-1 and Guideline ITU K56, the author feels that a surge rating Imax of around 40kA 8/20 µs would be adequate for DC Surge Protection of RRU. Higher ratings than this is may be opted for in future North American standards to provide longevity to the devices. One purpose of this paper is to commence discussions on this subject.

The test method for DC SPD used to simulate real life existence of continuous voltage is proposed in this paper. Triggered spark gaps which have previously been dismissed in DC SPD applications may be a viable device in future. Significant reduction in voltage protection level can be gained by parallel use of appropriate triggered spark gaps with MOV based devices.

| TSG1103S2  | 3 kA | 2.91 kA | 1.380 kV |
| TSG1103S2  | 20 kA | 20.6 kA | 0.920 kV |
| DSD1401S-75 | 3 kA | 2.91 kA | 0.292 kV |
| DSD1401S-75 | 20 kA | 20.4 kA | 0.560 kV |
| DSD1402BR24/48 (+ to -) | 3 kA | 19.1 kA | 1.470 kV |
| DSD1402BR24/48 (+ to -) | 20 kA | 20.9 kA | 0.730 kV |
| DSD1402BR24/48 (+ to G) | 3 kA | 19.1 kA | 0.870 kV |
| DSD1402BR24/48 (+ to G) | 20 kA | 20.4 kA | 0.810 kV |
| DSD1402BR24/48 (- to G) | 3 kA | 19.1 kA | 1.740 kV |
| DSD1402BR24/48 (- to G) | 20 kA | 20.9 kA | 1.800 kV |
| TSG & DSD1401S-75 | 20 kA | 20.6 kA | 0.540 kV |
| TSG & DSD1402BR24/48 (+ to -) | 20 kA | 20.6 kA | 0.440 kV |

Figure 12 : Test Results, ERICO Labs
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