A SIMPLE METHOD FOR LIGHTNING PROTECTION OF PV-SYSTEMS

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ABSTRACT
PV-modules are often integrated into roofs or walls of buildings. Therefore they are exposed to lightning strokes. In a paper presented at the last conference, damage caused by lightning currents in the frames of PV-modules was examined [1]. The tests showed that framed modules are quite rugged and damages caused by lightning currents flowing very close to the solar cells are relatively moderate. A complete protection seems to be feasible. Increasing distance between the lightning current and solar cells to a few centimeters (cm) completely eliminates damage to the cells due to the electromagnetic field. Tests have shown that lightning strokes can be captured with small rods of about 30cm mounted on top of the PV-arrays. Thus lightning currents can be injected in a defined way into a conductor (preferably part of the supporting structure) far enough from the solar cells. It seems that with these measures, proper wiring with low mutual inductance to the lightning current path and adequate use of surge arresters PV-systems can be fully protected against lightning strokes.

1. Increasing Immunity against Lightning Currents

High impulse currents delivered by ISB's generator (see fig. 1 and 2) injected directly into the frame of a PV-module caused some damages [1, 2], especially a change in I-V-characteristic (loss of some MPP-power and therefore a decrease of fill factor FF, see fig. 3). Repeated tests with high impulse currents (I_{peak} up to 111kA and di/dt up to 56kA/µs) injected into an aluminium U-profile 50mm·40mm·4mm with a new PV-module Siemens Solar M65 mounted directly to it (see fig. 4) showed no damage to the I-V-characteristics of this module (see Fig. 5) [4]. Earlier tests with similar currents injected directly into the frame of such a module had also shown slight damages [5]. Increasing the distance between the lightning currents and the solar cells to a few cm seems to be enough to avoid any damage by a lightning current. The only problem that remains is to ensure this minimum distance under all conditions, i.e. to avoid direct lightning strokes into the frame or into the cells. This can be done easily by the lightning current capturing rods described in chapter 2.

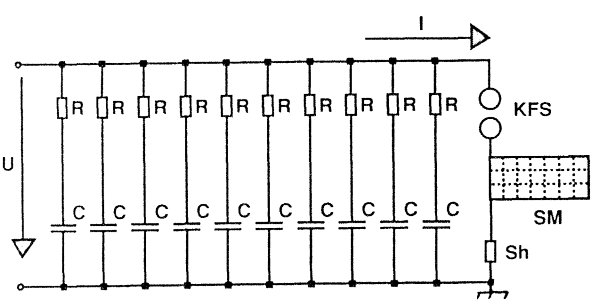

Fig. 1: Schematic diagram of ISB's high impulse current generator.

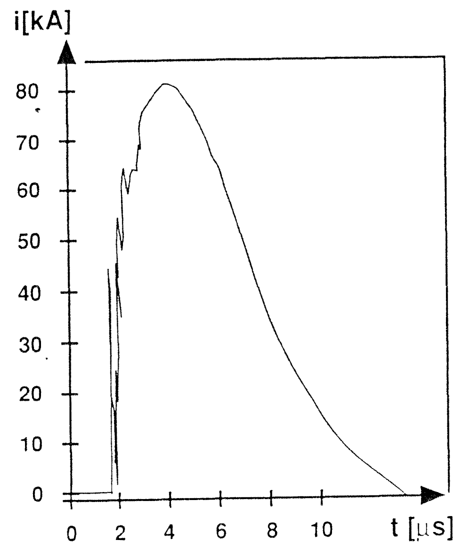

Fig. 2: Typical high impulse current produced by ISB's generator (I_{peak} = 80kA, di/dt = 53kA/µs).

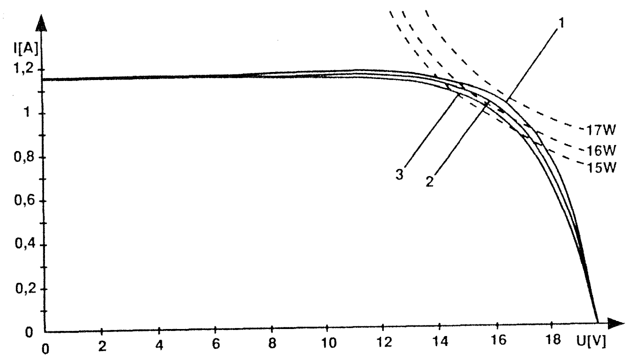

Fig. 3: Change in I-V-characteristic at G' = 300W/m² caused by high impulse currents flowing in the frame of a module SOLAREX MSX60 (shorted while subjected to impulse).
1: Initial characteristic
2: After impulse current with I_{peak} = 53kA, di/dt = 33kA/µs
3: After another impulse with I_{peak} = 80kA, di/dt = 53kA/µs

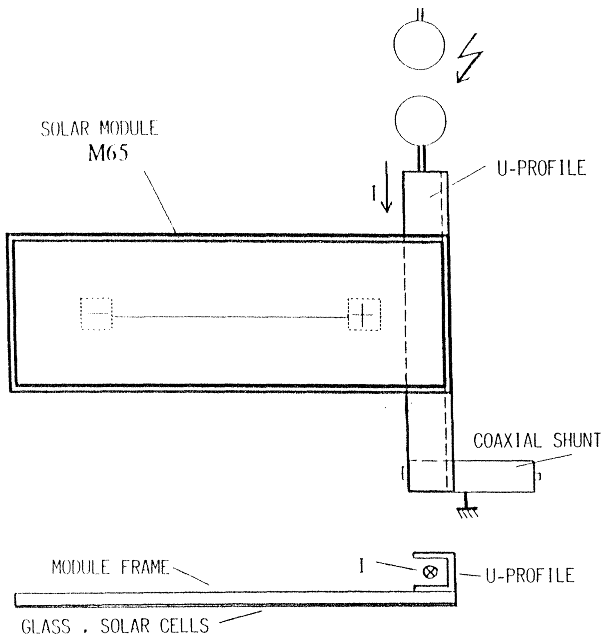

Fig. 4: Test arrangement with increased distance (about 60mm) between current path and solar cells. The high impulse current is injected into an aluminium U-profile 50mm·40mm·4mm with a PV-module Siemens Solar M65 mounted directly to it.
No damage encountered even with the highest impulse currents (see fig. 5). Drawing not to scale.

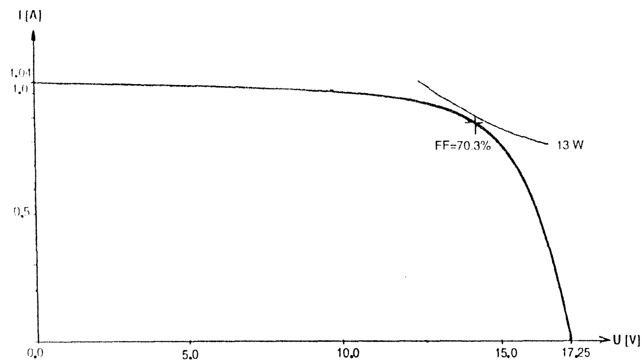

Fig. 5: I-V-characteristic of module Siemens Solar M65 at G' = 295W/m². No measurable difference between I-V-characteristic before and after exposure to magnetic field of high impulse current (at a distance of about 60mm in test arrangement according to fig. 4) with I_{peak} up to 111kA and di/dt up to 56kA/µs.

A word of caution: *Complete protection was only possible using modules with a metallic frame.* It is possible that an induced current in the frame contributes to attenuate the harmful effects of the high impulse current (see also [3]). I-V-characteristics of frameless modules (laminates) were still deteriorated considerably even when the impulse current was injected into a U-profile right under the laminate instead of a flat profile used in earlier tests [1, 2, 4].

2. Capturing Lightning Currents with small Metallic Rods

Earlier attempts to avoid direct lightning strokes used large vertical rods or horizontal metallic ropes. Such structures have shadows that may influence the production of the PV-field and are not feasible for every application (e.g. on buildings). The fact that only a few cm of separation between lightning current and module is enough to avoid any damage permits the use of much smaller structures. A small lightning capturing rod with a length of only 30cm was developed for ISB's new PV-generator (60kWp) on the new building of the electrical engineering department. Extended tests in the high voltage laboratories at the Swiss Federal Institute of Technology in Lausanne (EPFL) and at Emil Haefely AG in Basel with lightning strokes of a length of up to 3m and impulse voltages (1,2µs/50µs) up to 2MV (see fig. 6) showed that these rods were a very efficient protection when mounted on both sides of a module Siemens M55 (more than 40 tests with no hits into the frame but only into the rods). As these rods have a diameter of only 1cm, shadowing of neighbouring modules in larger arrays can nearly be neglected. Therefore the PV-generator of 60kWp on the roof of ISB's new building for the department of electrical engineering was equipped with these lightning capturing rods (see Fig. 7).

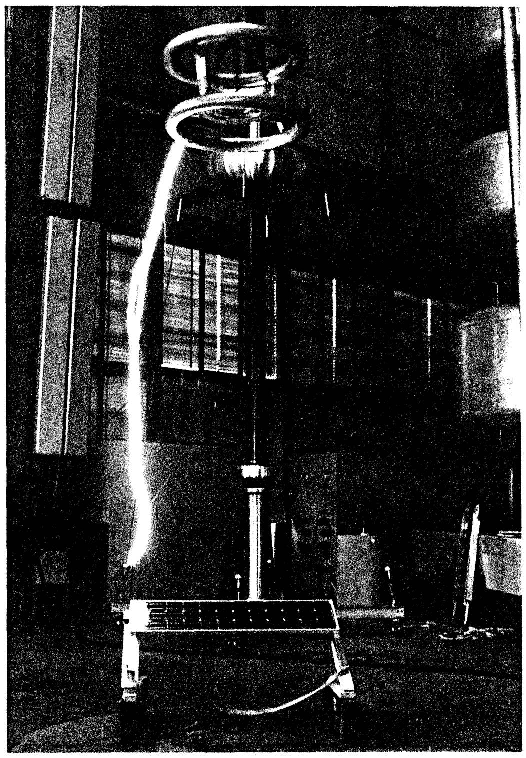

Fig. 6: Lightning stroke with a length of about 3m and 2MV peak impulse voltage into module protecting rods developed at ISB. Tests were performed with both positive and negative impulse voltages. The module (Siemens Solar M55) was completely undamaged after these tests. Photo taken in the high voltage laboratory of Emil Haefely AG, Basel.

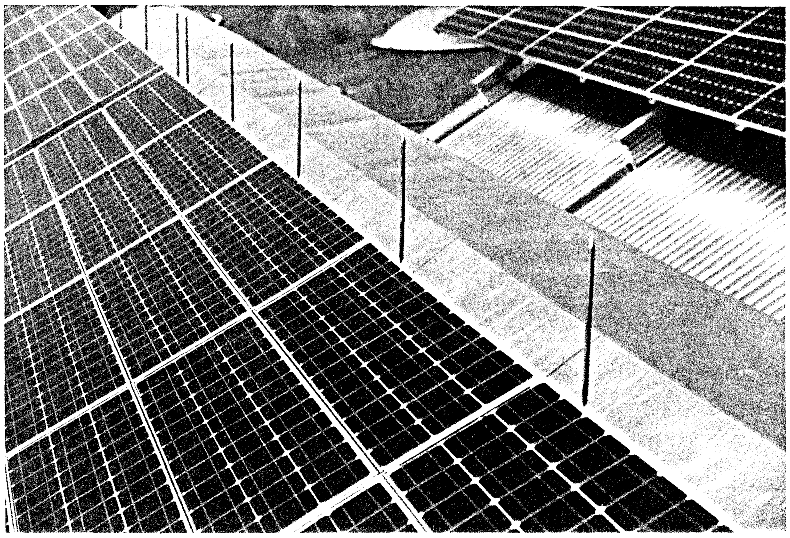

Fig. 7: Partial view of the PV-generator (60kWp) on ISB's new building for the department of electrical engineering . Top modules (Siemens Solar M55HO with about 57Wp each) are protected with new developed lightning capturing rods. Lightning current is injected into supporting structure a few centimeters below module frame, thus avoiding any damage to module and wiring.

3. Mutual Inductance between Lightning Current Path and Wiring

In order to calculate induced voltages in the wiring of the PV-array, it is useful to know the mutual inductance between the lightning current and the wiring. For a model of a PV-array with the geometric arrangement used above that avoids damages to the modules, a layout with low mutual inductance was developed (see fig. 8). To simplify calculation of induced voltage in the solar module itself, it is assumed that there is an equivalent wire connecting the center of gravity of each cell (thick lines). In ISB's high impulse current generator, the magnetic field is cancelled for a distance greater than about 0.4m from the impulse current due to the coaxial layout of the generator (picture in [1]). This fact has to be considered when the mutual inductance of the test arrangement is calculated. Therefore mutual inductance of a real lightning current is somewhat higher than in the model used for the tests. However, when measured and calculated mutual inductances are close together, it is relatively easy to calculate the approximate value of the mutual inductance, as the principal correctness of the model used has been demonstrated.

Using a auxiliary plane as shown in fig. 9, total mutual inductance M can be calculated as about 21nH, when it is assumed that the lightning current path has infinite length. In the test arrangement of fig. 8, induced differential voltage is

$$U = U_2 - U_1 = -M \cdot di/dt. \quad (1)$$

This value could be confirmed in the test arrangement of fig. 8, when a lightning current according to fig. 10. was injected into the U-profile connected directly to a solar module. Using capacitive voltage dividers matched to two double shielded triaxial lines, the induced differential voltage $U = U_2 - U_1$ was measured (see fig. 11). As the induced voltage is disturbed a little bit in the front of the impulse current, the values at t = 8µs were used (U = 150V and di/dt = -7.5kA/µs). Using these values and formula (1), M can be determined as about 20nH, a very good correspondance with the value calculated earlier.

Based on these results, it is possible to calculate M for an actual lightning current with a magnetic field also beyond 0.4m. For one module M55 in the wiring layout of fig. 8, mutual inductance M is about 46nH, for a series string of 6 modules M55 with the same wiring scheme about 79nH. These values are quite low, therefore it should be possible to handle the remaining overvoltages with suitable surge arresters.

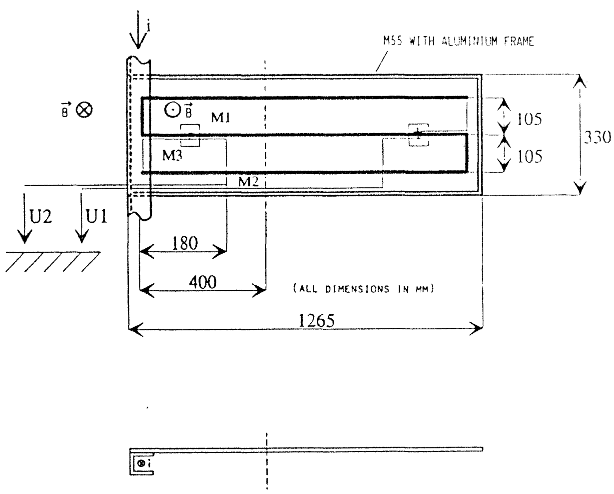

Fig. 8: Test arrangement used to measure induced voltage in wiring of PV-module in order to calculate mutual inductance M. Distance between center of impulse current path and solar cells about 6 cm (like in fig. 4) to avoid any damage.

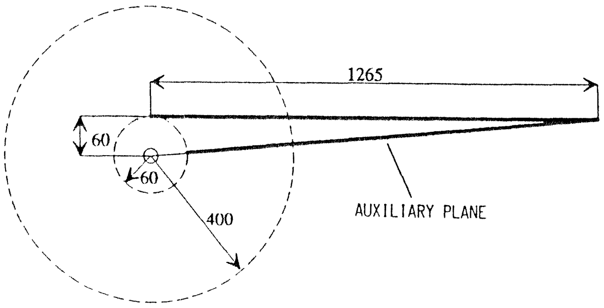

Fig. 9: Auxiliary plane used to calculate mutual inductance M.

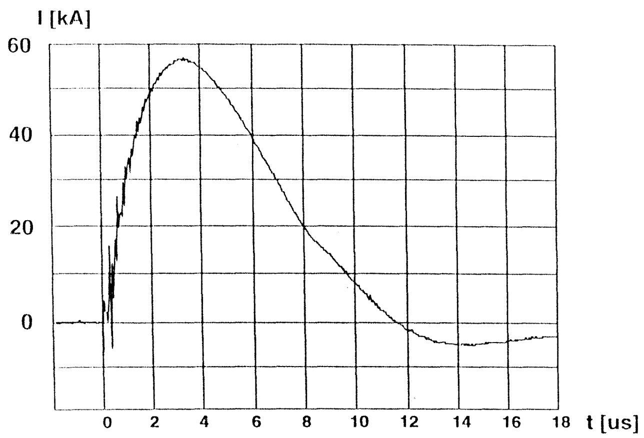

Fig. 10 : Impulse current I applied to test arrangement in fig. 8 in order to measure induced voltage $U = U_2 - U_1$ for determination of M.

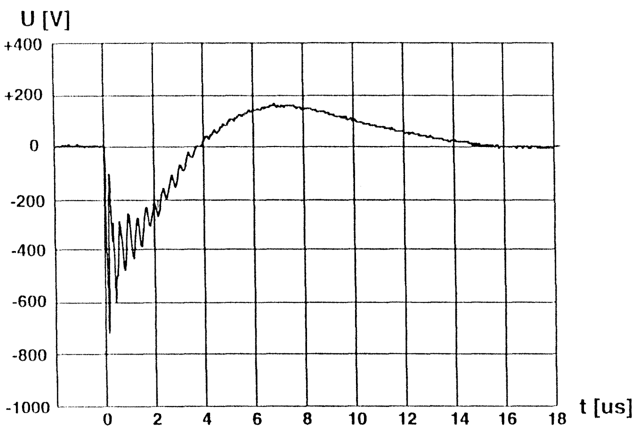

Fig . 11: Induced voltage U in test arrangement according to fig. 8, when an impulse current according to fig. 10 is injected into the U-profile.

4. Conclusion

Capturing direct lightning strokes with small rods and injecting the lightning current into a metallic conductor a few cm away from the cells, together with proper wiring and use of surge arresters seems to be a possibility to avoid any damage to PV-generators at relatively low cost without loosing much energy production due to shadowing.

Acknowlegements

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Important Notice

Information contained in this paper is believed to be accurate. However, as errors can never be completely excluded, we disclaim any liability in a legal sense for correctness or completeness of the information or for any damage that might result from its use.

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