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Lightning Protection Design Of A Renewable Energy Hybrid-System Without Power Mains Connection

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ABSTRACT

In the year 2000 a direct lightning strike to the hybrid-system without power mains connection VATALI on the Greek island Crete results in the destruction and damage of some mechanical and electrical components. The hybrid-system VATALI was not lightning protected at that time. The hardware damage costs are approx. 60,000 €. The exposed site of the hybrid-system on top of a mountain was and still is the reason for a high risk of lightning strikes. Also in the future further lightning strikes have to be taken into consideration.

In the paper a fundamental lightning protection design concept for renewable energy hybrid-systems without power mains connection and protection measures against direct strikes and overvoltages are shown in detail. The design concept was realized exemplarily for the hybrid-system VATALI. The hardware costs for the protection measures were about 15,000 €. About 50% of the costs are due to protection measures against direct strikes, 50% are due to overvoltage protection. Future extensions, new installations, or modifications have to be included into the lightning protection design concept of the hybrid-system.

INTRODUCTION

Independent renewable energy systems without power mains connection generally consist of one or more photovoltaic (PV-) systems, one or more wind turbine generator (WTG-) systems, and recently solarthermic (ST-) systems too. Those hybrid-systems are installed especially in regions with non-existent or low quality public energy supply, i.e. in regions with a low population density and in developing countries. Lightning protection of independent hybrid-systems is a subject actually not widely investigated. For large WTG-systems in the past some R&D-projects were conducted showing existing problems in the WTG-design. Measures were determined to protect the entire WTG (here especially the rotor blades) against the mechanical destructions and the electrical / electronic systems against overvoltages (e.g. [1, 2, 3]). The relevant state-of-standard is fixed in draft IEC 61400-24 „Wind turbine generator systems; Part 24: Lightning protection“ [4]. The measures described herein, however, are useful especially for larger WTG-systems. For smaller WTG-systems their realization is hardly possible. Nevertheless, smaller WTG-systems are also strongly endangered to lightning strikes, if they are located on mountaintops. For those WTG-systems, usually used for hybrid-systems, the lightning protection measures described in draft IEC 61400-24 have to be modified in part.

For PV-systems a lightning protection standard does not exist. Often protection against direct lightning strikes is not sufficiently taken into account: e.g. air-terminations are not planned. Usually their lightning protection is focused only on a strike in a far away distance leading to comparatively low-energy induced overvoltages. Those overvoltages are limited by weak surge protective devices, like return-current diodes, bypass diodes or small varistors, being overstressed and therefore destroyed in case of direct and nearby strikes. In addition, both direct and nearby strikes may also lead to a weakening of the electrical strength of the PV-module isolation causing a locally, extremely high, heat development, up to the melting of glass (secondary long-term effect).

Protection against lightning strikes must be taken into serious consideration, if it is highly probable that a strike can occur. Firstly, the entire hybrid-system VATALI, being a year 2000-victim of a direct lightning strike and therefore serving as an exemplary system, was inspected. Then requirements regarding lightning protection were defined and finally protection measures were derived, which can be realised with acceptable expenses.

The investigation conducted for the independent hybrid-system VATALI leads to some ideas regarding general recommendations about lightning protection measures for other hybrid-systems.

Finally those measures are described in general as some rules for a lightning protection concept taking into account different types of hybrid-systems (components, power, site, etc.).

DESCRIPTION OF THE INDEPENDENT HYBRID-SYSTEM VATALI

The center C.A.R.E. (Centre for the Application of Renewable Energies) in VATALI with the University of Applied Sciences of Aachen (ACUAS), the Community Prasses, the Technological Educational Institute of Crete and the ITC-CIEA from Gran Canaria, promote the development of the local agricultural community. These projects are promoted by the European Union (EU), the German state Nordrhein-Westfalen and some other partners. The first project was the establishment of a PV-operated cooling-house in the year 1994. On 6th July 1997 the Center was initiated by the Ministry of Science and Research (MWF, today MSWWF) of the German state Nordrhein-Westfalen along with the Greek ministry of agriculture (fig. 1)

Figure 1: Top view of the hybrid-system VATALI location

The essential characteristics of the center are:

- International and interdisciplinary research and postgraduate centers;
- Research, demonstration and distribution of technologies to the local community;
- Technologies for renewable energy production and their benefits (photovoltaic (PV), wind, biogas, water);
- Hybrid-systems for the decentralization of energy supply;
- Storage and processing of agricultural products;
- Water and waste technology;
- Building the network with cooperation partners in the Mediterranean area;
- Integral solutions for financial development of local resources (energy, water, agriculture, protection of the environment, nature balance restoration).

In the systems of VATALI as well as in other projects in the surrounding area (e.g. the installations for desalination of sea water, waste-technologies) lies the concept of C.A.R.E. The center offers in eastern Mediterranean region the capability for research, development, demonstration and distribution of renewable energy technologies and their applications. It sets up the infrastructure for subsequent projects with local and European partners from universities and enterprises. In cooperation with the local partners, C.A.R.E. enables numerous students of the Aachen University of Applied Sciences (ACUAS) to fulfil their practice-semester or their graduate-work. A total of 135 students worked in C.A.R.E. during the past seven years.

The collaboration with small and medium-sized companies in Germany, Greece, and Spain is also important, because of the experience that is earned, along with the opportunity to enhance their own performance and to spread the projects of renewable energies. The development of new products on renewable energies is a big advantage for the collaborating companies. Educational and further education courses contribute the transfer of technology from the R&D-area to business. Local companies became able to install and monitor renewable technologies in order to have successful venture in commercial applications.

The energy needed for the operation of a cheese-dairy and the total lighting of the installation comes from a hybrid installation that consists of a photovoltaic generator, two wind generators, one biogas generator and one diesel generator set. The disparate generators are connected to each other (fig. 2). The consumer with a voltage of 230 V must be supplied with an AC power source. The generated energy will be directed either directly to the cheese-dairy or the battery system with 1200 Ah capacity. The diesel generator only operates in the case of a power shortage. The energy consumption of the cheese-dairy is covered by the scant solar reserves and then it is preserved. The capacity of the battery can cover the energy consumption of the area for 2,6 days without recharging. One biogas tank exists as an additional reserve of biogas for the biogas generator to operate when the batteries are empty.

A photovoltaic generator of 3,8 kW exists for the electrical energy of the ice-storage (fig. 3). The module operates at a voltage level of 48 V.

The generated energy will be stored in a 800 Ah battery or will be directed to the compressors to convert the electrical energy into turning water to ice for the cold-storage.The battery will power up the compressors and the rest of electrical consumption (pumps, regulators) only during the night.

The cold-storage house has a photovoltaic generator installed with an output of 4,5 kW (fig. 4). The generators operate in groups at a voltage level of 48 V. In order to cover cooling at nights and in sunless days, a 800 Ah battery has been installed. This capacity ensures the autonomy of the system for 15 days. For the compressors to work at the 230 V AC there must be an converter, that transforms the generated 48 V DC into AC.

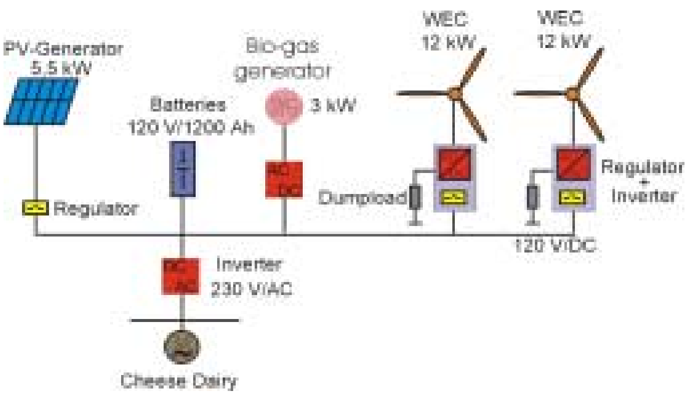

Figure 2: Schematic diagram of the hybrid installation

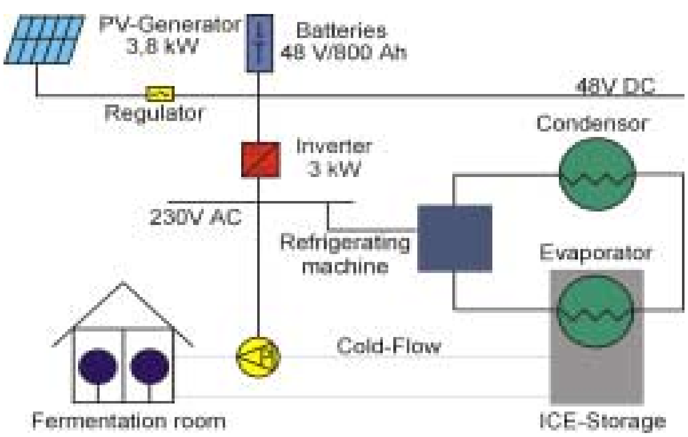

Figure 3: Schematic diagram of the energy provided ice-storage room

Concept And Requirements Of Lightning Protection

The lightning protection concept for a hybrid-system has to cover two different applications:

- Protection against the effects of direct lightning strikes to the system's components or to the system's buildings;
- Protection against the lightning induced overvoltages at the system's components being caused by direct as well as by indirect (nearby) lightning strikes.

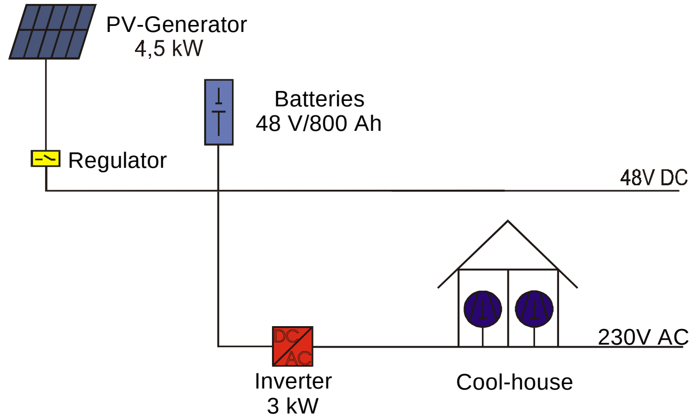

Figure 4: Schematic diagram of the cold storage house

Protection against the effects of direct strikes is the main subject of the European prestandard ENV 61024-1 [8]. This prestandard is actually in the so-called maintenance cycle. New items are to be found in the draft [9]. Furthermore application examples are documented in [10]. The content of these standards and drafts was taken into consideration for the concept described herein. Additional requirements for the protection against lightning electromagnetic fields and induced overvoltages (protection against LEMP) are given by IEC 61312-1 [11]. This standard was also taken into account for this concept.

At the time, when this concept was worked out, the system VATALI had no effective lightning protection. Only some earthing measures were realized. Therefore this concept deals with an improvement or a basic installation, resp. of a lightning protection system for an existing system. In this case the existing conditions (buildings, installations, components, cabling, etc.) have to be considered. Due to that not all of the measures, required in the standards and drafts mentioned above, can be realized with tolerable effort. Then equivalent measures have to be taken to fulfil the relevant protective aims.

The following protective aims are covered by the lightning protection concept for the hybrid-system VATALI:

- Wind turbine generators (WTG) and photovoltaic (PV-) modules will be protected by isolated lightning protection systems (LPS) against direct lightning strikes.
- The buildings of the hybrid-system (electrical station, appartement house/cold-storage house) will be equipped with complete lightning protection systems.
- The electrical cables from the WTGs and the biogas-system to the electrical station will be protected at both ends by surge protective devices (SPD) with a sufficient lightning impulse current carrying capability: lightning current arresters.

- The electrical cables between electrical station and appartement house/cold-storage house and within the two buildings will be protected by surge protective devices, which must not be able to conduct partial lightning currents: overvoltage arresters.
- The electrical cables from the electrical station to the PV-modules are already protected by overvoltage arresters.

PROTECTION AGAINST DIRECT LIGHTNING STRIKES

WIND TURBINE GENERATOR SYSTEMS - Both WTGs (fig. 5) will be protected by isolated lightning protection systems (fig. 6). This is necessary because the WTGs are not planned to withstand the effects of a direct lightning strike. Such a direct strike may lead to not-acceptable mechanical destructions. For each WTG an air-termination rod with a height of approx. 25 m will be installed in a distance of approx. 5 m. These rods exceed the WTGs by approx. 8 m (see fig. 5). The air-termination rods and the metal fixing wires will be connected to small FEEs (Foundation Earth Electrode) to conduct the lightning current to earth safely. A copper cable will be routed between the base points of each rod and the protected WTG for equipotentialization. With that the WTGs will be protected against direct strikes with lightning current amplitudes of i_{max} > 10 kA [9]. For an even better protection each WTG would need to be protected by two air-termination rods with a connecting air-termination wire. This seemed to be a not-acceptable expense in this case.

Figure 5: Wind turbine generator system

PHOTOVOLTAIC SYSTEMS - The three PV-system modules will be protected by four air-termination rods (fig. 7, 8 and 9). The four rods will be connected to the (ring) earth electrodes of electrical station and appartement house/cold-storage house via two new earthing wires. Air-termination rods and earthing wires must ensure a minimum distance to the PV-

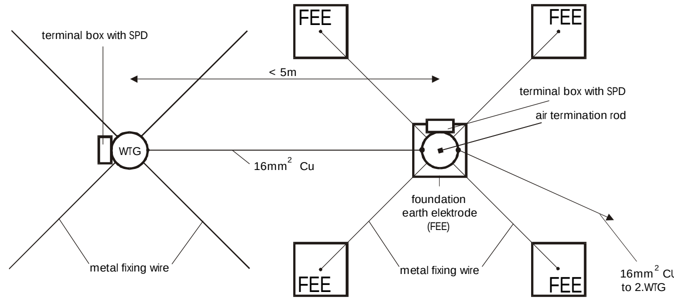

Figure 6: Lightning protection measures at the WTG (shown for only one WTG)

module constructions of 2 m. In addition the vertical earth electrodes of the three PV-module constructions will be removed and replaced by new bonding wires to the ring earth electrode of the electrical station. These bonding wires will be isolated against the soil to prevent the electrical cables to the PV-modules against galvanic coupling. Due to that, the protective diodes existing at the PV-modules and the SPDs already installed at the components of the PV-systems 1 and 2 inside the electrical station (DEHNguard 75) may not be changed.

Figure 7: PV – system modules 1 and 3 in front of the electrical station

ELECTRICAL STATION - For the electrical station a complete lightning protection system will be installed (fig. 10 and 11). At the roof edge an air-termination wire will be laid connected via four down-conductors to the existing ring earth electrode. The existing metal roof covering a part of the roof will be considered. The temperature sensor at the roof will be protected by a small rod against direct strikes. The ring earth electrode is connected via a short bonding wire to a new equipotential bonding bar (EBB) in the system room. Only the lightning current arresters (SPDs which have to carry lightning impulse currents) installed in the system room will be connected to this new EBB.

Figure 8: PV – system module 2 with appartement house

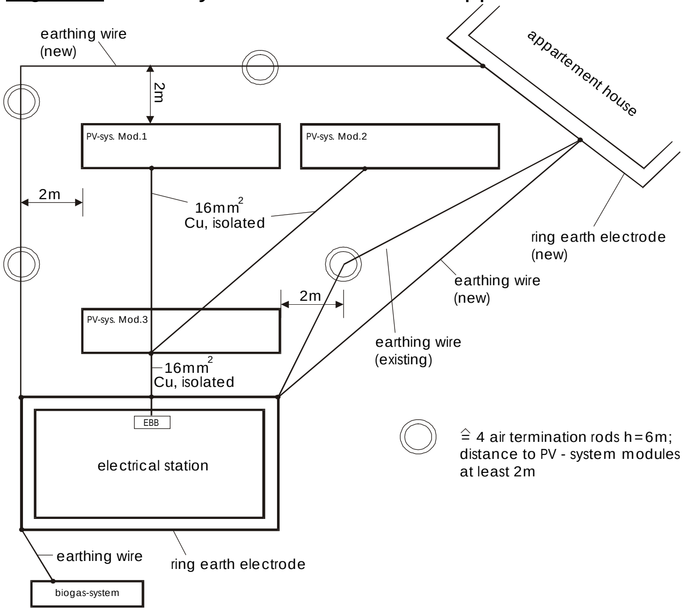

Figure 9: Lightning protection measures at the PV – system modules

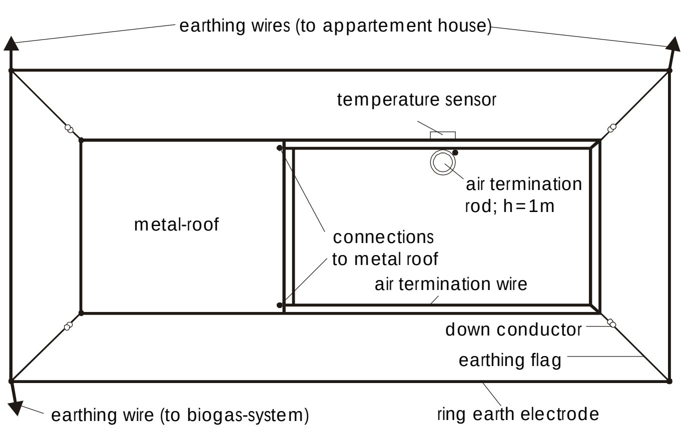

Figure 10: Lightning measures at the electrical station

Figure 11: Electrical station (backside) with entrance of cables and wires

APPARTEMENT HOUSE/COLD-STORAGE HOUSE - For the appartement house/cold-storage house also a complete lightning protection system will be installed (fig. 12). New air-termination wires will be installed on the roof; existing metal roof parts will be connected. Nine down-conductors will connect the air-termination system with the new ring earth electrode.

The depth of the ring earth electrode should be at least 50 cm. Roof installations are not planned actually; if necessary in the future they should be protected against direct strikes by air-termination rods. A restaurant is planned for the future. Thus the down-conductors should be equipped with a PVC-isolation up to a height of 2,5 m above the corresponding ground level to avoid touch voltages. Inside the building four equipotential bonding bars (EBBs) will be installed (distribution appartement house, heating room, distribution cold-storage house, ice-storage room).

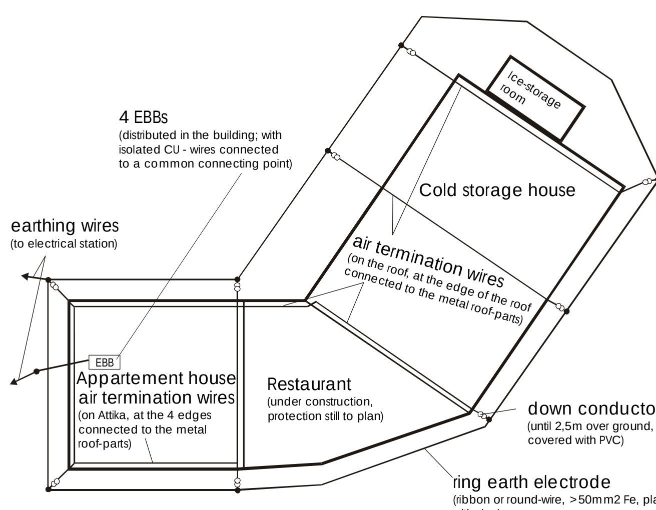

Figure 12: Lightning measures at the appartement house/cold-storage house

The four EBBs will be connected via (isolated) bonding wires to a common connecting point to the ring earth electrode (external wall of appartement house; see fig. 12). With that compensating currents inside the building are avoided in case of a direct strike. However, this measure requires sufficient isolation between the electrical installations inside the building and the lightning protection system outside. A safety distance of 25 cm, valid in the entire building, seems to be acceptable.

INSTALLATION OF SURGE PROTECTIVE DEVICES

WIND TURBINE GENERATOR SYSTEMS - The electrical cables of both WTGs will be protected at both ends (at the WTGs and in the electrical station) by surge protective devices (SPDs) having a sufficient impulse current withstand capability (SPDs class I: DEHNbloc/3) [12, 13]. At the WTGs the SPDs will be installed in the terminal box (fig. 13). The PE (protective earth) will be connected directly to the metal mast construction. The positioning lights will be mounted on top of an air-termination rod (approx. 8 m taller than the WTG) in the future. The power cable for the positioning lights will be protected by SPDs class I (DEHNbloc/1) in a terminal box at the base of the rod. The PE will be connected directly to the metal rod construction. The WTG belong to the overvoltage category IV (6 kV impulse voltage), so that a further protection with SPDs class II, eventually in combination with decoupling inductances, is not necessary.

Figure 13: Terminal box at the WTG

PHOTOVOLTAIC SYSTEMS - At the PV-modules no further protection measures will be conducted The already existing protective diodes will not be changed. Due to the new lightning protection concept and especially due to the earthing concept of the PV-module constructions a galvanic coupling of partial lightning currents to the PV-system cabling is avoided. Future lightning strikes may show, if the protective diodes at the PV-modules are still overloaded by inductive coupling. If so, they will have to be changed. The SPDs class II for the cabling from the PV-modules installed in the cabinets in the electrical station (DEHNguard 75) are also sufficient for the latter case (fig. 14).

The electrical measurements at the PV-modules seem to be sufficiently protected by the new lightning protection and earthing concept. Therefore additional measures will not be realized, for the moment. Future lightning strikes may show, if overvoltages still occur at the measurement circuits; then further protection measures (SPDs) will be necessary.

Figure 14: Available SPDs for the PV–systems 1 and 2

ELECTRICAL STATION - The SPDs class I (DEHNbloc/3 and DEHNbloc/1) for the electrical cables from the WTGs will be installed directly at the entrance to the electrical station in a separated and new terminal box (fig. 15). This is also valid for the power cable to the biogas-system, which has to be protected by SPDs class I (DEHNbloc), too. This terminal box containing SPDs class I is bonded only to the ring earth electrode of the electrical station via a separated and short bonding wire. Furthermore both power cables from the WTGs will be protected at the entrance to the AC/DC converter by SPDs class II (DEHNguard T275), which are installed also in separated terminal boxes. Because the cables between the SPDs class I and class II have a length of a few meters only, a decoupling by inductances is necessary (DEHNbridge 63A).

At the cable entrance from the appartement house/cold-storage house (fig. 16) another terminal box will be installed: four cables will be protected by SPDs class II (DEHNguard T275 and DEHNguard T150). Two further cables run directly in the main distribution of the DC/AC-converter: the necessary SPDs class II (DEHNguard T275) will be installed there. With that, no additional measures are necessary at the cable entrance.

The last cable entering the electrical station here (measuring cable 0 ... 20 mA from the ice-storage room) will be protected just by bonding the cable shield (the cable shield will be bonded at both ends, i.e. also in the ice-storage room). The terminal box with the SPDs class II mentioned above will be connected to the existing bonding bar via a short bonding wire.

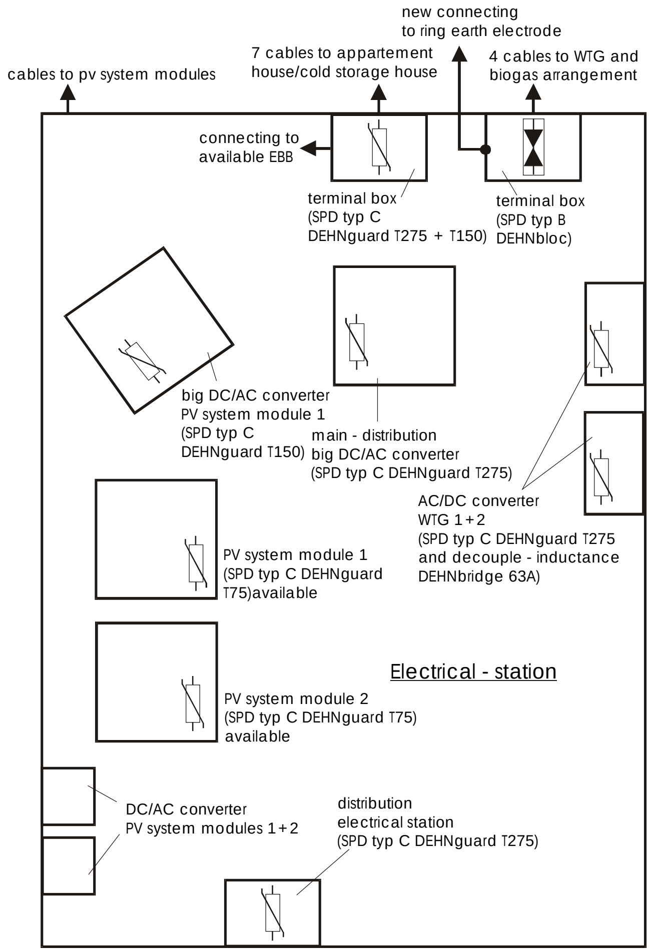

Figure 15: SPDs in the electrical station

Figure 16: Entrance of the cables and wires in the electrical station (left: PV-systems; middle: appartement house/cold–storage house; right: WTGs and biogas-system)

Additional SPDs class II are necessary in the following equipment and distributions: DEHNguard T150 in the DC/AC-converter (fig. 17), DEHNguard T275 in the sub-distribution for the electrical station (fig. 18) and DEHNguard T275 in the switching box for the diesel generator (not shown in fig. 14). The selection and installation of the SPDs class I and II depends on the configuration of the power network and the voltage level. The WTG-grids are IT three-phase 400 V, behind the AC/DC-converters DC-grids +120 V, the grids of the PV-systems are DC +60 V (System 1 and 2) and +120 V (System 3), the power-grid for the entire station is configured in the DC/AC-converters as a TN-C-S three-phase 400 V. Due to that, in the main distribution only three DEHNguard T275 are necessary (L1/L2/L3 against PEN), in the sub-distributions, however, four DEHNguard T275 (L1/L2/L3/N against PE).

Figure 17: Cable – entrance to the DC/AC- converter (PV system module 1)

Figure 18: Sub-distribution for the electrical station

APPARTEMENT HOUSE/COLD-STORAGE HOUSE - At the biogas-system only the power cable from the electrical station will be protected by SPDs class I (DEHNbloc) installed in a new terminal box. The terminal box will be mounted directly at the metal construction of the biogas-system. From there a bonding wire to the ring earth electrode of the electrical station already exists.

SPDs class II will be installed in the appartement house/cold-storage house in the following sub-distributions or equipment, resp. (see fig.12): DEHNguard T275 in the sub-distribution appartement house, DEHNguard T275 in the sub-distribution cold-storage house, DEHNguard T150 in the heating room (heating device +/- against PE) installed in a separated terminal box, DEHNguard T275 in the ice-storage room (two DC/AC converter cables) either in separated housings or in existing terminal boxes. Wires of the cables to the ice-storage room being not in use will be bonded directly (not via SPDs) to the PE. To protect the measuring cable (0 ... 20 mA) from the electrical station only the cable shield will be bonded to the PE.

All SPDs installed in the sub-distributions or equipment mentioned above will be bonded to the equipotential bonding bars (EBB: see chapter 4) via short bonding wires.

The protection of the cabling between electrical station and appartement house/cold-storage house based on SPDs class II is sufficient for usual lightning effects, including direct strikes with not extreme values of the lightning current. In the latter case, i.e. for direct strikes with very high values of lightning current, the SPDs class II might be overloaded. Due to the terrain structure and the arrangement of the buildings this case seems to be very improbable. Nevertheless this deficiency shall be closed in a long-term solution. Here two alternatives are possible: Protection of all cables between electrical station and appartement house/cold-storage house by SPDs class I (being able to handle also partial lightning currents) or covering of the entire cabling with an upgrading shield [11]. The first alternative is expensive due to costs of the SPDs class I, for the second one earth works are only necessary. Therefore it seems to be useful to cover the cable way along its entire length with a flexible cable protection shield, if earth works are necessary due to other reasons (therefore long-term solution). This is also possible for existing cable ways with special material [14]. The cable protection shield is interconnected over its entire length and connected at both ends to the ring earth electrodes and the equipotential bonding bars directly at the cable entrance to both buildings.

GENERAL DESIGN CONCEPT FOR LIGHTNING PROTECTION OF INDEPENDENT HYBRID-SYSTEMS

Based on the experiences mentioned above further considerations can be summarized as a „general design concept“ for lightning protection of independent hybrid-systems comparable to the VATALI system.

RISK ANALYSIS - The first step regarding lightning protection of an independent hybrid-system is the decision, whether such protection is necessary, and if so, which kind of protection. Parameters which have to be taken into account are for example:

- the area covered by the hybrid-system;
- the lightning flash density at the area;
- the components of the hybrid-system (WTGs, PV-systems; ST-systems, diesel generators, etc.) and their exposition;
- the costs of the hybrid-system;
- the necessity of the supplied consumers for an uninterrupted or only shortly interrupted power supply;
- the possibility of a quick repair of damaged or disturbed components in case of a strike.

The list, of course, can not be complete due to the very special conditions of the individual independent hybrid-systems. A risk analysis going very deeply into detail is possible by using the new draft IEC 61662 Edition 2: „Management of risk due to lightning“ [15]. By using this, a very detailed calculation of the risk, individually for a special hybrid-system, is possible. The risk analysis also leads directly to necessary protective measures.

In case of the hybrid-system VATALI a risk analysis was not necessary due to the existing damages caused by the direct strike in the year 2000. Therefore the decision was clear to install a complete lightning protection system according to the concept and the requirements given in chapter 3.

In general, however, two different main concepts can be distinguished, based on the need to handle direct strikes and/or to protect against overvoltages.

An alternative to protection measures is to have spare parts available within some hours. Then any damage (or disturbance) may be repaired within an acceptable time. This alternative „concept“ may be useful in cases, where the damaged (or disturbed) components of the hybrid-system can be foreseen with a high safety and where the costs of the lightning protection measures related to the costs of the entire hybrid-system are comparatively high.

This is a strategy probably for low-cost hybrid-systems like planned or even installed especially in developing countries. Of course, this strategy can not be counted as a real lightning protection concept. Therefore it is neglected in the further considerations.

PROTECTION AGAINST DIRECT LIGHTNING STRIKES - If the risk analysis leads to the result, that the hybrid-system has to be protected against direct strikes, the following items have to be investigated:

- Are the WTGs able to withstand a direct strike, i.e. do they fulfil the requirements of IEC 88/117/CD (Draft IEC 61400-24):1999-10 [4] ?
- Are the PV-modules (and ST-systems) able to withstand a direct lightning strike ? Here especially at the possible points of strike small air termination rods are useful to prevent the metal frames of the PV-modules from damage [16].
- Are there any buildings or housings which have to withstand a direct strike ?
- Are there any additional installations (diesel generator, TV-tower, mobile phone-tower, etc.) which can be struck by lightning directly ?

If the installations mentioned above are able to withstand a direct strike due to their construction, there is no more need for additional air-terminations (fig. 19). However, the down-conductor system may have to be planned. In addition to that, the equipotentialization has to be carefully taken into consideration, so that no potential differences may occur between the individual components. Finally the earthing system has to be planned, including all possible earth terminations of the individual components and their interconnections.

If the installations mentioned above are not able to withstand a direct strike, and if an upgrading of the installations themselves also is not possible or does not seem to be meaningful, then a isolated lightning protection system has to be installed [8, 9]. This concept was realized for the hybrid-system VATALI, both for the WTGs and the PV-modules (see fig. 6 and 9).

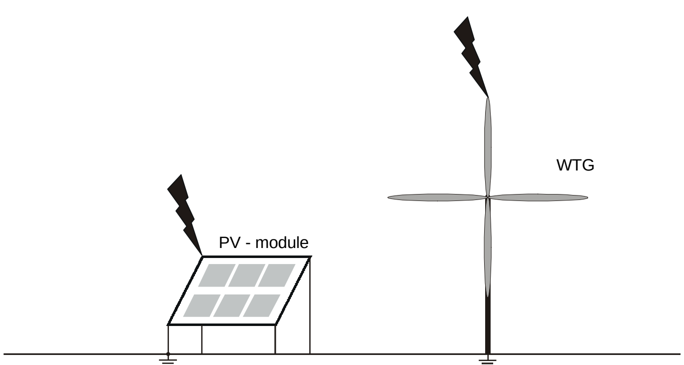

Figure 19: Integrated lightning protection system with direct strikes to the components

Air-termination rods and wires and down-conductors have to be planned in such a way, that the lightning current can not affect the hybrid-system components (fig. 20). The most important items here are:

- the zones of protection given by the air-termination rods and wires are sufficient for all components which need to be protected;
- the necessary safety distances have to be ensured between the air-termination and down-conductor arrangement and the components of the hybrid-system.

Additional care has to be taken about the partial lightning currents distributed into the earth. Any galvanic coupling to equipotential wires and to system cables has to be avoided, i.e. the requirements of a "safety distance" have to be considered also at the earth surface (see fig. 9). If buildings have to be protected by a common lightning protection system, the typical requirements are given in the relevant and well-known standards [8, 9]. Therefore in this paper no additional considerations are necessary.

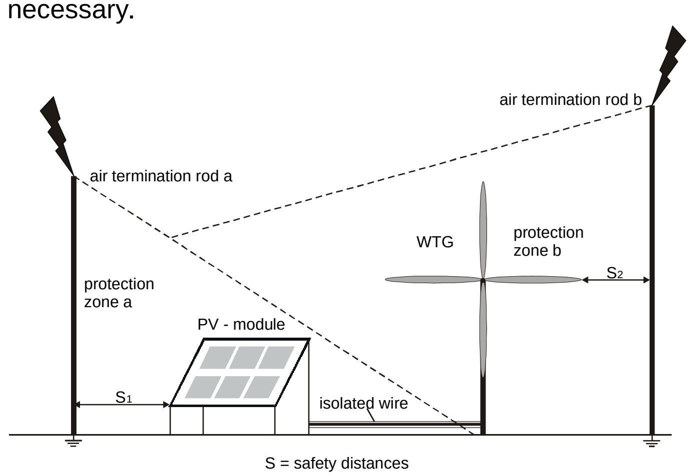

Figure 20: Isolated lightning protection system preventing the components from direct strikes

PROTECTION AGAINST OVERVOLTAGES - If the risk analysis leads to the result, that the hybrid-system components have to be protected against overvoltages (in addition to or without a protection against direct strikes according to chapter 6.2), the following items have to be investigated:

- Are there any existing surge protective devices at the components ?
- Are there shielded cables running between the components ?
- Is the hybrid-system exposed to direct strikes ? If so, can the cables between the components be affected by partial lightning currents ?

In general, there are three main protection measures against overvoltages for the interconnecting cabling (fig. 21, see also fig. 15):

- In case of unshielded cables, and in case of direct strikes and with that the possibility of partial lightning currents along the interconnecting cables, the components can be protected by lightning current arresters SPDs class I [12, 13].

- Shielding of the interconnecting cabling by cable shields for each single cable or by metal ducts, metal covers, etc. for a number of parallel cables. Shielding is possible for both the case of direct strikes as well as for overvoltage protection only. In case of direct strikes and with that the possibility of partial lightning currents along the shield, a sufficient current carrying capability of the shield has to be ensured.
- In case of unshielded cables but with the need only to limit overvoltages, i.e. no partial lightning currents along the interconnecting cables have to be considered, the components can be protected by overvoltage arresters SPDs class II [12, 13].

All overvoltage protection measures have to be planned in detail. However, the recommendation can be given, that the passive measure of shielding should be used preferably, especially if partial lightning currents have to be considered. This is absolutely necessary for DC-cables (e.g. from the PV-modules to the converter), because here SPDs class I are usually not applicable. So the protection philosophy should be applied as follows:

- Firstly use proper shields where necessary and where possible;
- Secondly install SPDs class I where necessary (it is recommended to limit those SPDs class I to an absolute minimum);
- Finally install SPDs class II where necessary.

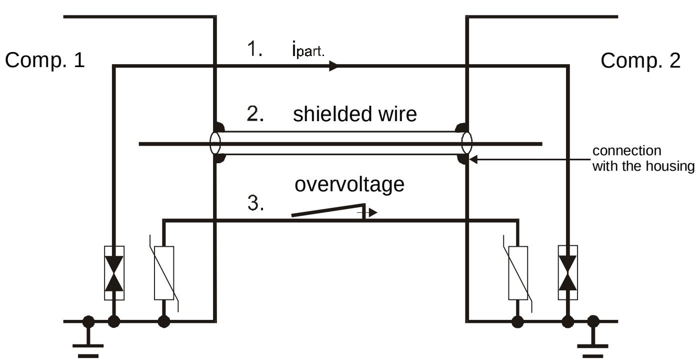

Figure 21: General measures for the protection against overvoltages.

PROTECTION INSTALLATION, MAINTENANCE AND INSPECTION - All lightning protection measures, especially the SPDs as active protection measures, should be installed or realized professionally, taking into account the relevant installation guidelines. After completion of all measures a final inspection should be carried out by an independent expert.

Hybrid-systems like VATALI may be used as a station for research and development expansions, i.e. new installations and modifications take place permanently, which have to be included in the lightning protection concept. To ensure this, an inspection of those hybrid-system once a year seems to be useful. If necessary, the lightning protection measures should be maintained.

CONCLUSIONS

Due to the increasing number of renewable energy hybrid-systems without power mains connection worldwide and due to their exposed locations, the number of lightning strikes to those hybrid-systems and their components will increase also. If the hybrid-systems have no protection measures against lightning effects, more and more damages and destructions of important components will occur resulting in long fault times, because the repair is costly and needs specialized man-power. In some cases the hybrid-system may be lost totally. In addition the power supply of the consumers connected to the hybrid-systems is lost, sometimes for longer time periods. This may lead to serious consequences depending on the kind of consumers (waste of food, standstill of production processes, loss of infrastructure like computers, telecommunications, decreasing acceptance of renewable energy hybrid-systems).

For the hybrid-system VATALI at Crete, a victim of a direct lightning strike in year 2000, it could be shown exemplarily, that a technically/economically balanced protection against lightning strikes is possible with still acceptable costs and efforts. The hardware costs for the protection measures are about 15,000 €. About 50% of the costs are due to protection measures against direct strikes, 50% are due to overvoltage protection.

Of course, an upgrading or new installation, resp. of a lightning protection system in case of an existing system is always more expensive than an earlier consideration of the relevant requirements during the installation of the whole system. Therefore the costs of the measures related to lightning protection will decrease in case of their installation for new hybrid-systems.

Finally it can be stated, that lightning protection of independent renewable energy hybrid-systems will become more important in the future. Therefore it is necessary to take into consideration technically /economically balanced protection measures. The installer, owner or user of such a hybrid-system has to decide whether it needs protection or not. The help of a lightning protection expert and the analysis of the relevant risks can be useful.

The authors of this paper are involved in some projects dealing with lightning protection of renewable energy systems (independent hybrid-systems, mains connected WTGs and PV-systems). Aim is the further development of simple design concepts which can be realized easily, worldwide and with limited costs for those systems.

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