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Integrating the Loss of Economic Value in Lightning-Related Risk Assessments of Large Scale Photovoltaic Systems Participating in Regulated and Competitive Energy Markets

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***Abstract*— Large-scale Photovoltaic (PV) systems can be vulnerable to lightning due to the large areas their installation occupies and because of the volume of their constituent electrical and electronic equipment. Thus, the need for installing appropriate Lightning Protection Systems (LPS) is increasingly acknowledged, especially in PV plants that will be participating in regulated and liberalised energy markets. To this aim, the selection of adequate lightning protection measures should be determined by utilizing methods that are also able to assess the risk of equipment damage that may lead in subsequent loss of revenue. However, no specific standardized methods, for managing the lightning-related risk in large scale PV systems, currently exists. Therefore, the first objective of this paper is to assimilate existing standardized risk assessment methods to conform to large PV systems' explicit features. The second and most important objective is to propose a method for integrating the loss of revenue in risk management endeavors associated with lightning protection.**

***Index Terms*—Photovoltaic, Lightning Protection, Risk Assessment, Economic Losses**

I. INTRODUCTION

LARGE scale Photovoltaic (PV) plants fulfill an integral role in promoting the penetration of fossil-free energy in the generation mix of a system. Many PV plants of such size are owned by Independent Power Producers (IPP) and are operated in regulated or competitive energy markets. One important pylon for safely dispatching solar energy rests with installing appropriate grounding and lightning protection systems [1]-[2]. These should act to limit any physical damage to the plants as well as life hazards. However, in today's competitive and dynamic energy markets, it may be beneficial to appraise the economic benefits of installing protection measures in order to reduce the economic loss that may arise when lightning/surge related damages will prohibit delivering the required PV energy output to the grid. To this extent, the selection of adequate lightning protection measures should be determined by utilizing methods that are able to assess the risk of equipment damage that may lead in subsequent loss of revenue. However, no specific standardized methods, for managing the lightning-related risk in large scale PV systems, currently exists. (Note: The lightning protection of roof-top PV installations is addressed in CLC/TS 50539-12: 2013 [3]). Some risk management related work - associated with PV plants' lightning protection, is reported in literature [2]-[4]. The work reported partially relies on existing standardized risk assessment methods such as IEC 62305-2: 2010 [5] and experience acquired in the field. It should be noted that the IEC 62305-2 standard [5] describes a generic risk assessment method the result of which determines if protection is required and if so, the specifications of the external and internal lightning protection systems to be installed [6].

However, the standardized risk assessment method [5] for lightning protection conforms to complex-structured buildings. This entails that its clauses may be subjectively interpreted when it comes to evaluating structures other than buildings (e.g. large scale Renewable Energy plants). This gap has forced stakeholders to define an international standard [7], which explicitly applies to lightning protection of wind turbine generators and wind power farms. In particular, this standard defines the lightning protection requirements and application of risk assessment for wind turbines/farms. It is based on normative references that are made through utilizing generic standards for lightning protection, low and high voltage systems for machinery and installations as well as electromagnetic compatibility. Finally, within the standard's (lightning protection of wind turbines) clauses it is verbally acknowledged that the risk assessment method for protection against lightning should also embrace the economic losses due to loss of revenue. However, no specific methodology or example is provided to this end. Therefore, the first objective of this paper is to constructively espouse and subsequently fine-tune the standardized risk assessment method described in IEC 62305-2 [5] to conform to the explicit features of large PV systems. This fine-tuning process will act as a benchmark to facilitate the second and most important objective of the paper. That is to propose and numerically evaluate a method for integrating the loss of economic value - attributed to loss of revenue- in risk management endeavors associated with lightning protection of large scale PV plants. The latter should be perceived as being part of the universal efforts for integrating risk and cost-based decision making processes in today's competitive and dynamic energy markets.

II. PROPOSED METHODOLOGY

Large-scale Photovoltaic (PV) systems can be vulnerable to lightning due to the large areas their installation occupies and because of the volume of their constituent electrical and electronic equipment. Thus, the design of Lightning Protection Systems (LPS) should take into account the risk of lightning damaging PV plants. For an unprotected PV plant the damage may be to the PV modules, general PV equipment, inverters, monitoring devices and inverters' house. Furthermore, people in and around the PV plant can be subject to hazards that may arise from touch/step voltages or fires caused by lightning strikes.

A. Reference to General IEC Risk Management Method

The objective of LPS is to reduce the risk R from all possible hazards to a tolerable level R_T. The risk R is explicitly defined in IEC 62305-2 [5] as the probability of having an annual loss in the structure or its contents. Table I embraces the four types of risks (R_1-R_4) identified in IEC 62305-2 [5] and associates them to their corresponding loss element (L_1-L_4). The tolerable level of risk R_T is also marked in Table I.

TABLE I
GENERAL DESCRIPTION OF RISKS AND ASSOCIATED LOSSES [5]

R_1 - L_1	Risk of Loss of a Human Life (permanent injury included)	$R_T = 10^{-5}$/year
R_2 – L_2	Risk of Loss of Service to the Public	$R_T = 10^{-3}$/year
R_3 – L_3	Risk of Loss of Cultural Heritage	$R_T = 10^{-4}$/year
R_4 – L_4	Risk of Loss of Economic Value	**Cost/Benefit Analysis**

Each risk (R_1-R_4) is evaluated by adding a series of risk components. These are defined in IEC 62305-2 [5] and are reproduced in Table II. The risk components are classified based on their source and the type of damage and can be individually evaluated through the formula shown in (1).

$$R_X = N_X \times P_X \times L_X \qquad (1)$$

Where N_X is the number of dangerous events per year, P_X is the probability of damage to a structure and L_X is the consequent loss.

TABLE II
DESCRIPTION OF INDIVIDUAL RISK COMPONENTS [5]

X	***Risk Components (R_X)***	**Source and Type of Damage**
A,B,C	R_A, R_B, R_C	Risk components to the structure due to *S1 - flashes to the structure*
M	R_M	Risk component for a structure due to *S2 - flashes near the structure*
U,V,W	R_U, R_V, R_W	Risk components for a structure due to *S3 - flashes to a line connected to the structure*
Z	R_Z	Risk component for a structure due to *S4 - flashes near a line connected to the structure*

B. Assimilating General IEC Method to Large-scale PV Plants

Field experience suggests that the risk factors most applicable in the case of protecting large PV plants against lightning are: a) those associated with loss of human life (R_1-L_1) and b) those associated with economic losses (R_4-L_4). This implies that the loss of service to the public (L_2) and the loss of cultural heritage (L_3) are considered less relevant for large scale PV plants. It is worth noting that the same risk factors (i.e. R_1 & R_4) are reported relevant in the case of large wind farms [7]. To facilitate an appropriate risk assessment, the PV plant can be divided into certain independent structures. A realistic as well as practical approach would be to divide the PV plant into three single zone-structures as follows: a) Str_1 – structure that embraces the PV generators, b) Str_2 – structure that embraces the central inverter and control house and c) Str_3 – the substation (if it exists) that will interface to the grid. For each structure a separate risk assessment should be performed. (Note: In case where the PV plant benefits from an outdoor MV substation, an alternative risk assessment with specific protection measures [8]-[9] may be applied). For each of the three structures, Table III summarizes the potential sources of damage (S_x), the type of damage (D_x) and type of loss (L_x) according to point of lightning strike. It should be noted that Table III is a reformed version of Table 1 in IEC 62305-2 [5], in an attempt to account for the PV plants' specific features.

Table III discloses that the type of loss considered most relevant for large PV plants is the loss of economic value (L_4) associated with the three structures (Str_1, Str_2, Str_3). Further, the loss of human life (L_1) may be considered for Str_2 in case where people are present in it, during a thunderstorm. Thus, the associated relevant risks are the risk of loss of human life (R_1) and the risk of loss of economic value (R_4). The evaluation of R_1 can be achieved by summing the individual risk components identified in Table II, as shown in (2) i.e. according to the method described in IEC 62305-2 [5].

$$R_1 = R_{A(1)} + R_{B(1)} + R_{C(1)} + R_{M(1)} + R_{U(1)} + R_{V(1)} + R_{W(1)} + R_{Z(1)} \qquad (2)$$

TABLE III
SOURCES OF DAMAGE, TYPES OF DAMAGE AND TYPES OF LOSS ACCORDING TO POINT OF STRIKE ON PV PLANT

		Structures			
		Str_1: PV – Generators **Str_3:** Substation		**Str_2:** Inverter/Control House	
Point of Strike	**Source of Damage**	**Type of Damage**	**Type of Loss**	**Type of Damage**	**Type of Loss**
Striking On structure	S_1	$*D_2$ $*D_3$	L_4 L_4	$*D_1$ $*D_2$ $*D_3$	L_1 L_4 L_4
Striking	S_2	$*D_3$	L_4	$*D_3$	L_4

near structure					
Striking Service Line	S_3	*D_2 *D_3	L_4 L_4	*D_1 *D_2 *D_3	L_1 L_4 L_4
Striking Near Service Line	S_4	*D_3	L_4	*D_3	L_4
Relevant Risk		R_4		R_1 & R_4	

** IEC 62305-2 [5] Definitions*
D_1: Injury to living beings by electric shock
D_2: Physical Damage
D_3: Failure of Electrical/Electronic Equipment

1) Proposed Methodology for Evaluating Loss of Economic Value - R_4

According to Annex D in IEC 62305-2 [5], the evaluation of R_4 pertains to the assessment of the cost effectiveness offered by lightning protection by comparison to the costs of the total economic loss with and without proposed protection measures. Thus, the cost of the total economic loss (C_L) can be evaluated through the use of (3). Where, (c_t) is the total economic value of the structure, embracing the individual economic values of c_a -animals, c_b -building, c_c -content and c_s-internal systems including their activities.

$$C_L = R_4 \times c_t \qquad (3)$$

According to the generic methodology reported in [5] the total economic value of: a) internal systems and b) their activities are tallied together as a single variable c_s. However, as far as large-scale PV plants are concerned the calculation of economic value pertaining to the activity of the internal systems (i.e. PV arrays, inverter, etc.) is more complex. This is particularly applicable both in regulated and dynamic energy markets, where PV plants are obliged to deliver a certain amount of energy to the grid. That is a failure of internal system may result in revenue loss to the owners. To this extent, in the proposed methodology of this paper the variable (c_s) would explicitly refer to the economic value of internal systems and therefore a new variable (c_e) is introduced that refers to the value of revenue associated with the activity of internal systems (i.e. $c_t = c_b + c_c + c_s + c_e$). . (Note: it is assumed that no animals are present in a PV plant thus c_a is omitted.)

Therefore, the risk of economic loss R_4 for each structure of a PV plant can be calculated as the sum of the individual risk components, according to their source and type of damage. The proposed evaluation method is thoroughly described in Table IV

TABLE IV
CALCULATION OF RISK FACTORS FOR EVALUATING THE TOTAL ECONOMIC LOSS

Risk of loss of economic value R_4	
$R_4 = \sum_X R_{X(4)}$ (4)	
Where, X= B,C,M,V,W,Z (See Table II)	
and R_X	
$R_{B(4)} = N_D \times P_B \times L_{B(4)}$	$R_{C(4)} = N_D \times P_C \times L_{C(4)}$
$R_{M(4)} = N_M \times P_M \times L_{M(4)}$	$R_{V(4)} = (N_L + N_{DJ}) \times P_V \times L_{V(4)}$
$R_{W(4)} = (N_L + N_{DJ}) \times P_W \times L_{W(4)}$	$R_{Z(4)} = N_I \times P_Z \times L_{Z(4)}$

***N_D, N_M, N_L, N_{DJ}, N_I*:** *Number of dangerous events per annum for each risk component as evaluated in IEC 62305-2 Annex A[5].*
***P_B, P_C, P_M, P_V, P_W, P_Z*:** *Probability of damage relevant to PV Plant for each risk component as evaluated in IEC 62305-2 Annex B[5].*
***$L_{B(4)}$, $L_{C(4)}$, $L_{M(4)}$, $L_{V(4)}$, $L_{W(4)}$, $L_{Z(4)}$* :** *Mean amount of economic loss consequent on a specified type of damage due to a dangerous event, relative to the value of the structure to be protected as evaluated in IEC 62305-2 Annex C[5].*

With reference to Table IV, the mean values of the economic losses ($L_{B(4)}$, $L_{C(4)}$, $L_{M(4)}$, $L_{V(4)}$, $L_{W(4)}$, $L_{Z(4)}$) consequent to a specified type of damage due to a dangerous event, relative to the value of the structure to be protected, can be calculated from (5) and (6) in Table V.

Comparing the formulations given in (5) and (6) with the formulation described in the IEC62305-2 [5], for explicitly calculating the value of economic losses, the following remarks should be noted. In the proposed formulation applicable for PV plants, two new factors i.e. k and c_e are introduced. That is to facilitate the integration of the revenue loss element in the process.

Firstly, the factor k should be related to the expected loss of PV generation capacity due to one dangerous lightning event. It should be noted that the consequence of a lightning strike on a PV plant may range from partial to total loss of PV energy production. To reflect on this the value of k may, in principle, take values between 0 (for maintaining full PV capacity and energy production) and 1 (for totally losing PV capacity and energy production). However, estimating the value of k can be very complex, bearing in mind: a) the topological arrangement of the PV modules and how these are connected in strings and arrays in Str_1 b) the electrical/electronic equipment (e.g. inverters, distribution boards) in Str_2 and c) the MV transformer in Str_3. It should be noted that lightning related damages in Str_2 and Str_3 would result in higher and perhaps total loss of PV generation capacity. Damage in Str_1, on the contrary, may result in partial loss of PV energy delivered to the grid, as the damage may only occur in certain strings of the PV array.

However, to simplify the process, a conservative approach for estimating the maximum PV capacity loss anticipated from a lightning related damage would be to set k factor equal to 1 (i.e. total loss of PV capacity and energy production) for all structures (i.e. Str_1 –Str_3) associated with the PV plant.

TABLE V
CALCULATION OF LOSS VALUES

Type of Damage	**Type of Loss**
D_2	$L_{B(4)} = L_{V(4)} = r_p \times r_f \times L_f \times (c_b + c_c + c_s)/c_t$ $+ r_p \times r_f \times k \times c_e / c_t$ (5)
D_3	$L_{C(4)} = L_{M(4)} = L_{W(4)} = L_{Z(4)} = L_O \times c_s / c_t$ $+ k \times c_e / c_t$ (6)

L_f: is the typical mean percentage of economic value of all goods damaged by physical damage (D2) due to one dangerous event.
L_o: is the typical mean percentage of economic value of all goods damaged by failure of internal systems (D3) due to one dangerous event.
k: is the expected loss of PV generation capacity due to one dangerous lightning event. A conservative approach would be to set k=1
r_p:is a factor reducing the loss due to physical damage depending on provisions taken to reduce the consequences of fire.
r_f: is a factor reducing the loss due to physical damage depending on the risk of fire or on the risk of explosion of the structures.
c_b: is the value of building-structure
c_c: is the value of content
c_s: is the value of internal systems
c_e: is the value of revenue
c_t: is the total value of the structure (c_t=c_b+c_c+c_s+c_e)
*parameter's values can be found in [5]

Subsequently, the c_e factor is defined as the total economic value that correlates to the revenue that will be lost when the PV system experiences a lightning related damage. The fundamental logic is that at the event of a lightning related damage, exporting PV energy to the grid will be prohibited (partially or fully (i.e. k=1)), as determined by the factor *k* in (6) for a certain time period (*t*) required to restore full PV energy production. The respective formulation of c_e is provided in (7).

$$c_e = P_m \times C_{pr} \times t \quad (7)$$

Within (7), P_m is the average daily energy production in kWh/day, C_{pr} is a levelized value of the PV energy price over the life cycle of the PV plant in currency (€/kWh). Finally, *t* reflects on the number of days required to repair the lightning related damage that may occur in the PV plant. This factor, i.e. *t*, can be approximately estimated based on the following annotations:

1. Time required to be informed about the damage (this time would be dependent on whether any personnel are present in the PV plant on a daily basis, or whether any remote condition monitoring devices are in operation).
2. Time required to locate the fault/damage occurred.
3. Time required for replacing the damaged equipment (stock availability etc.)
4. Insurance time requirements for inspection/ autopsy procedures (if applicable).
5. Time required for recommissioning PV plant.

Moreover, particular attention in the formulation shown in (7) should be given when evaluating C_{pr}. It is proposed that this factor should be evaluated depending on whether the PV plant (to be protected from lightning) is operated in regulated or competitive energy markets as detailed in Table VI Specifically, if the PV plant participates in a regulated energy market, it is proposed that C_{pr} should be the Power Purchase Agreement (PPA). The PPA is the price at which the PV plant owner has agreed to sell its generated energy over a long time-horizon. It embraces both a revenue margin as well as the credit quality of a renewable generating project throughout the plant's lifetime. In fact, PPA may reflect on feed-in-tariff policies (i.e. a long-term contractual basis) that usually apply in regulated energy systems/markets.

TABLE VI
EVALUATION OF LEVELIZED PV ENERGY SELLING PRICES FOR REGULATED AND FREE ENERGY MARKETS

	Regulated Market	**Liberalized Energy Market**
C_{pr}	Power Purchase Agreement (P.P.A) or Feed in Tariff Contract	$f\left(MP;\overline{\mu_{LE}},\sigma_E^2\right)$ (8) Where, • *MP:* Historical Wholesale Market Prices (1-2 Years) • μ_{LE} **:** The mean value of inflated *MP* over a future evaluation period *n*. • σ_E^2 **:** The standard deviation of *MP* as results from the statistical treatment of historical data.

In liberalized/dynamic energy markets however, the picture is more complex since feed-in-tariff policies are no longer preferred. Thus, in the case where the PV plant participates in a dynamic energy market the statistical formulation shown in (8) can be used. The fundamental logic in (8) arises from the fact that the revenue of a PV plant (i.e. PV energy selling price) will be dependent on the wholesale energy Market Prices (*MP*), which may vary significantly within a specified period (e.g. a year). The variation of *MP* can therefore take the form of a probability density function - $f\left(MP;\overline{\mu_{LE}},\sigma_E^2\right)$ with a levelized mean value μ_{LE} and a standard deviation σ_E. The derivation, levelization over a future time and the evaluation of (8) are comprehensively described in [10] and are therefore not reproduced in this paper.

III. NUMERICAL EVALUATION

The method thoroughly described in Section II, is numerically evaluated for a rural 528 kWp PV plant, which is graphically illustrated in Fig.1.

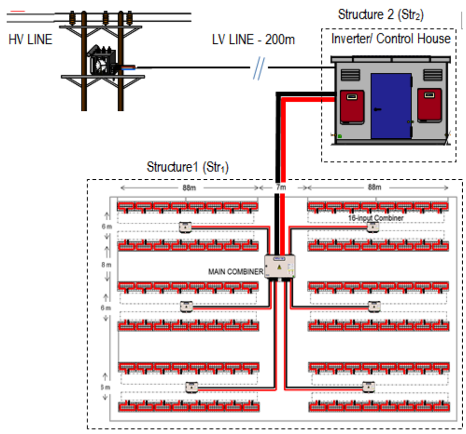


Fig.1. Layout of the PV Plant to be protected from Lightning

We highlight that evaluation pertains to an example where only two structures (Str_1 and Str_2) are applicable (i.e. there is no substation and therefore no need to define Str_3). Moreover, in the interest of space only the significant results of the evaluation pertaining to the cost of loss (C_L) in structure 2 (Str_2_inverter/control house) are presented. The principal aim of this example is therefore to indicate the impact of the loss of revenue in a PV plant's (lightning) risk assessment.

Briefly the 528kWp PV plant is assumed to be located in a rural area and is connected to a MV network via an overhead three phase distribution HV/LV transformer. In this particular example, the Str_2 is a structure that occupies an area of $64m^2$ with height of 4m. The ground flash density in the region is 4 events/km^2/year. The underground cables of PV array run in metallic conduit leading to the central inverter/control house (i.e. Str_2). The structure (Str_2) is powered by a LV three phase aerial unshielded power lines. The adopted lighting protection measures include external and internal lighting protection system (LPS) class I [6].

To highlight the effect of loss of revenue, the value of k is selected to be equal to 1. This value corresponds to the worst case scenario (i.e. full loss of PV energy production). This assumption is realistic because the failure of the central inverter may result in total loss of production (i.e. not supplying energy to the grid).

To justify the need for a LPS the cost and benefit analysis results should reflect on the annual saving (S_M) in money that will occur if the annuitized cost of protection measures (C_{PM}) and the value of residual losses (C_{RL}) are subtracted from the total estimated economic value of losses (C_L) (i.e. when no protection measures are installed) [6].

The formulation for evaluating S_M is shown in (9). Protection will be thus justified if the annual saving S_M is positive (i.e. S_M>0).

$$S_M = C_L - (C_{PM} + C_{RL}) \qquad (9)$$

The procedure to perform a cost and benefit analysis regarding the lightning protection measures enforced is conveniently shown in Fig.2 and comprises 5 explicit steps.

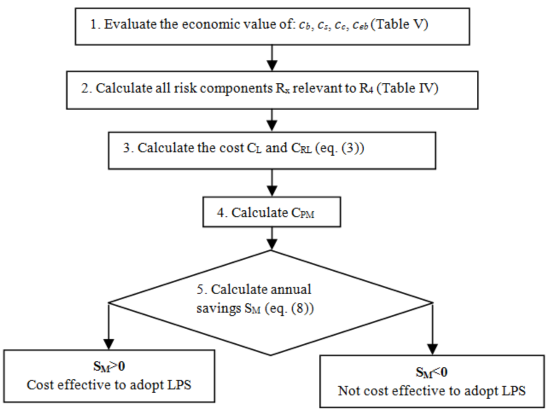
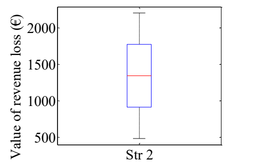


Fig.2. Procedure to evaluate the cost-effectiveness of protection measures.

A. Numerical Evaluation of Total economic Values

By means of an example, Table VII illustrates some assumed values for c_b, c_s and a numerical evaluation of the total value of revenue (c_e) that is performed separately for regulated and dynamic energy markets.

TABLE VII
ECONOMIC VALUES OF A STRUCTURE

Element	**Value (€)**
Building-c_b	7000
Internal systems-c_s	63000
Content-c_c	-
*Revenue Loss-c_e Regulated Energy Market $C_e = P_m \times C_{pr} \times t$	1052
*Revenue Loss-c_e Independent Energy Market	 Value of Revenue (C_e) for Str_2 in a Competitive Energy Market Environment
* P_m=1754 kwh/day, t=3 days, C_{pr}=0,2 €/kw (PPA)	

With reference to Table VII, the value of c_e in a competitive energy market can be given in a box-plot format. This results from a specific probability density function $f\left(MP;\overline{\mu_{LE}},\sigma_E^2\right)$ provided by means of an example in Fig. 3, as per the particulars described in Table VI and (8). The box-plot shown in Table VII can be interpreted as follows: If the PV plant participates, in a dynamic market, the value of revenue loss attributed to Str_2 damages (under the conditions assumed in (Table VII – i.e. P_M and t as well as Fig.3), has a 50% probability to lie in the range of 911-1771 € with a median value of €1340.

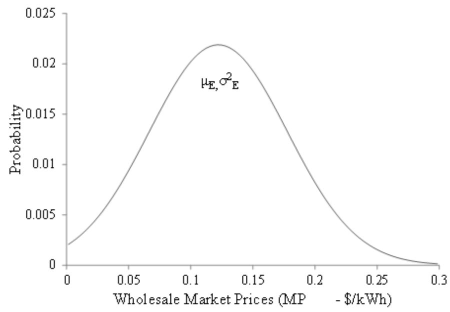


Fig.3. Levelized Probability Density Function – Wholesale Market Price (MP)

B. Calculation of risk components R_x and total risk R_4.

With reference to Table IV and (4) the total risk of loss of economic value R_4 is calculated as a sum of individual risk components R_x. To this extent, Table VII illustrates R_4 with and without protection measures for: a) the case where the loss of revenue is considered and b) the case where the loss of revenue is excluded.

TABLE VIII
VALUES OF RISK OF LOSS OF ECONOMIC VALUE R_4

R4- revenue loss considered		**R4- revenue loss excluded**	
NO LPS	LPS Class I	NO LPS	LPS Class I
2,056	3,125E-03	1,839E-02	2,811E-05

C. Impact Integrating the Loss of Economic Value in Lightning-Related Risk Assessments

The calculation of the cost of economic loss *(C_L)* for each case is performed by using the formulation shown in (3). It is noted that in case where protection measures are adopted, the new calculated value of (C_L) equals to residual losses (C_{RL}) [5]. Thus, if we assume that the installation of an LPS has an annual cost (C_{PM}) of about 1500 €/year, a cost/benefit analysis can be performed (as shown in Fig.2) to justify whether LPS installation is justified.

Table IX effectively benchmarks the cost and benefit analysis results that have occurred for this particular example with and without considering the loss of revenue, under the particulars of a regulated energy market.

TABLE IX

COST AND BENEFIT ANALYSIS UNDER REGULATED ENERGY MARKET

Cost and Benefit Analysis			
		Loss of revenue considered	**Loss of revenue excluded**
Loss for the unprotected structure	C_L	3449	1306
Residual loss for protected structure	C_{RL}	5	2
Annual cost of protection	C_{PM}	1500	1500
Annual Savings €	S_M	1944	-196

More specifically the results tabulated in IX show that, when the loss of revenue is considered, the economic cost of loss for an unprotected structure may is significant higher. Furthermore the introduction of this special consideration may justify the investment for a LPS with positive annual savings.

The same conclusion can be drawn when performing a cost and benefit analysis for a PV plant participating in a dynamic energy market as illustrated in Fig. 4. It should be noted that in such a case, S_M will change only as far as the cost of the loss revenue is concerned. Thus, S_M will be probabilistically evaluated and presented (see Fig. 4) as per the market price characteristics shown in Table VII.

Nevertheless, the results shown in Table IX and Fig. 4 should be interpreted with care as these are very dependent on the actual facts and figures that apply in the particular example modeled. However, they clearly show that when integrating the loss of revenue in lightning related risk assessment, the installation of a LPS may be beneficially justified.

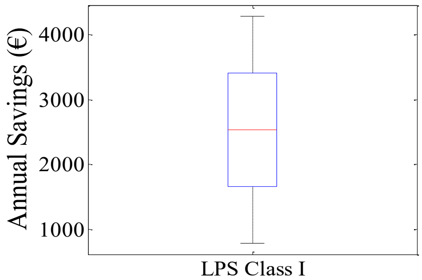


Fig.4. Cost and Benefit Analysis for Evaluating S_M Under Dynamic Energy Market Conditions

IV. CONCLUSION

A holistic top-down approach to integrate both the direct and indirect elements that affect the loss of economic values in lightning related risk assessments for large scale PV plants is presented. The method proposed is applicable to PV plants participating in regulated and competitive energy markets. The cost and benefit analysis presented in the paper constitute itself more realistic and complete as it integrates the impact of loss of revenue. It is shown that LPS can be well justified if the loss of revenue from lightning related damages is appropriately integrated in risk management procedures. As a conclusive message, we wish to highlight that large scale PV plants are increasing in number and complexity. Their installation and operation are dictated by a variety of design specifications, codes of practice and international standards. Hence, the development of standards for describing realistic risk management endeavors against the effect of lightning may be also necessary to assist PV plant owners to minimize their equipment and financial losses.

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