A Power Line Lightning Protection Method for Television and Radio Stations

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Abstract-The existing research on lightning protection focuses on risk assessment or equipment selection. There has not been any thorough research about lightning protection including risk assessment for a building in order to identify the risks when selecting lightning protection equipment according to technical requirements and cost optimization. The objective of the current paper is to propose a new risk computational method of damages by lightning for a Television and Radio Station (TRS). The new computational method consists of nine steps for identifying two risk indices, human life loss (R_1) and service loss (R_2). If the value of R_1 is higher than the regulatory limit value R_{T1} and the value of R_2 is higher than the regulatory limit value R_{T2}, the damage risks due to lightning are very serious. Therefore, the TRS is necessary to select lightning protection solutions to reduce these risks. In addition, the paper proposes a six-step procedure for selecting and testing surge protective devices. The proposed calculations are then applied to a real TRS in Vietnam, and some testing results are simulated in Matlab-Simulink.

Keywords-risk of damage by lightning; Lightning Protection System (LPS); Surge Protection Measures (SPM); Television and Radio Station (TRS)

I.   INTRODUCTION

Power system development can cause many problems. The issue of maintaining and stabilizing the power system when there is a problem is always a topic of interest [1, 2]. There have been many studies regarding the assessment of the risk of damages by lightning to buildings [3, 5-7] and the guidelines for selecting and installing lightning protection equipment [4, 8, 9]. Based on the above, we propose an overall protection method for surge protective devices on power lines connected to the TRS including risk assessment, equipment selection, and installation for reducing the risks of damages caused by lightning. This overall method is proposed for applying Surge Protective Devices (SPDs) on power lines for a TRS in Vietnam. Based on the computation of the damage values of the TRS, the paper provides a solution for selecting SPDs suitable to the characteristics of the TRS. This research focuses on the risk values about the human life loss (R_1) and service loss (R_2). When these two indices are higher than the regulatory limit values, TRS must be installed with SPDs to reduce the risk of damage by lightning. Besides, the estimation of lightning protection level is performed by simulations in Matlab/Simulink. With the simulation results, it is possible to select the SPDs that satisfy with the real requirements of the TRS with a reasonable investment funding.

II.   A NEW COMPUTATION METHOD FOR SELECTING LIGHTNING SURGE PROTECTIVE DEVICES ON POWER LINES

A.   The Procedure for Assessing Risk Values for the TRS

This section proposes a new computational method for identifying risk values R_1 and R_2 for a TRS. The method includes nine steps as shown in Figure 1.
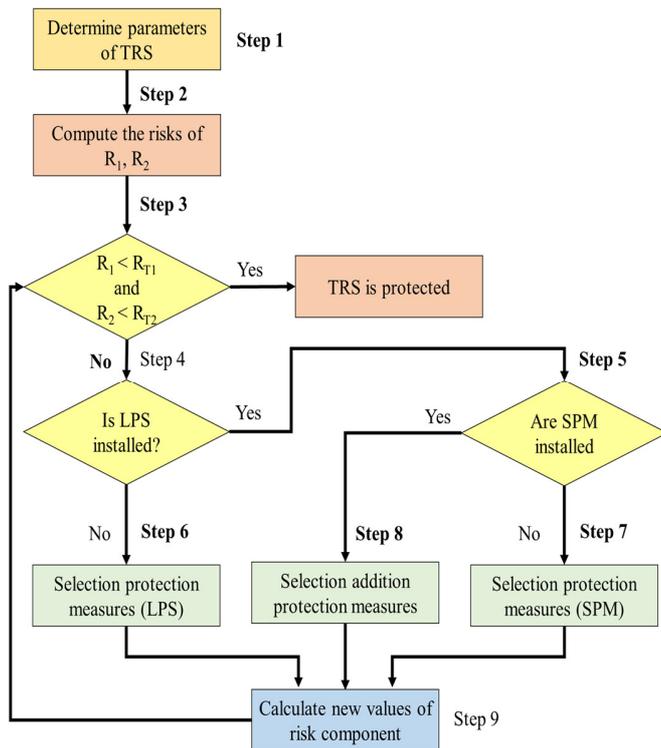
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Fig. 1.   Procedure for assessing the risk values for the TRS.

- Step 1: Determine the parameters of the TRS encompassing height, length, width; height of antenna tower, degree of shielding by the structures around, density of lightning, measures of fire protection, installation method, and length of the power and service lines directly connected to the TRS, and the current lightning protection equipment.

- Step 2: Compute the risk components by the lightning strikes direct and indirect to the TRS. Then, identify risk values R_1 and R_2.

- Step 3: Collate risk values of the R_1 and R_2 with the R_{T1} and R_{T2} (regulatory limit values R_{T1} and R_{T2} are referenced to IEC 62305-2 [5]). If these risk values are bigger than R_{T1} and R_{T2}, move to the step 4.

- Step 4: Check if the TRS has been installed with Lightning Protection System (LPS) or not. If the TRS has not been installed with LPS, transfer to step 6. If the TRS has been installed with LPS, transfer to Step 5.

- Step 5: Check if the TRS has been installed with Surge Protection Measures (SPM) on the power lines or not. If the TRS has been installed with LPS and SPM but the risk values of the R_1 and R_2 are still higher than R_{T1} and R_{T2} risk values, go to Step 8. If the TRS has not been installed with SPM, go to Step 7.

- Step 6: Select a suitable LPS for installation and go to Step 9.

- Step 7: Select a suitable SPM equipment on the power line for reducing the risk values and go to Step 9.

- Step 8: Select additional SPM equipment and go to Step 9.

- Step 9: Recompute R_1 and R_2 and go back to Step 3.

TABLE I.   RECOMMEND MAXIMUM LIGHTNING CURRENT

	Exposure level		
	Low	**Medium**	**High**
Environment of building	The building is located in an urban/ suburban area.	The building is located in plain.	The building is located in areas where there is high lightning risk by the surrounding environment (pylons or mountainous regions, trees, wet areas, ponds, etc.)
Recommended maximum lightning current (kA)	20	40	65

B. The Procedure for Testing and Installing SPDs

Based the calculated values of R1 and R2, the procedure for selecting and testing SPDs is implemented in 6 steps, shown in Figure 2.
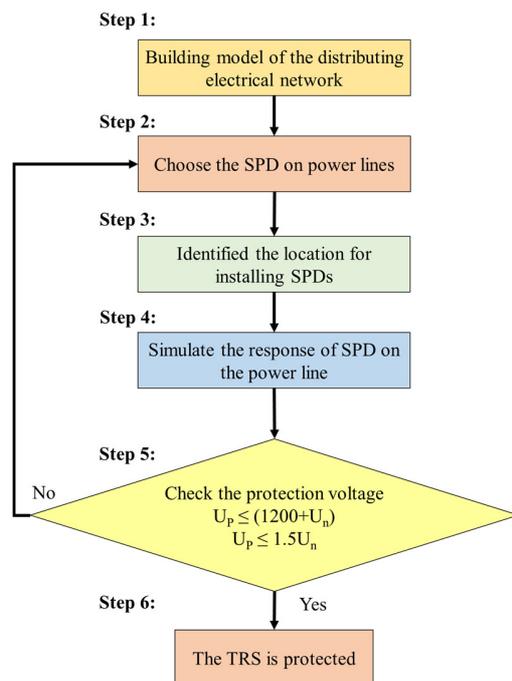

Fig. 2.   Procedure for testing and installing SPDs.

- Step 1: Relying on the single-line diagram of power lines connected to the TRS, build a model of the electrical network in Matlab/Simulink including surge currents.

- Step 2: Choose the SPDs for installing on the power lines.

- Step 3: Identify the locations for installing the SPDs on the power lines for Essential Main Switchboard (EMSB) and Main Switchboard (MSB).

- Step 4: Simulate for checking the withstanding of the SPDs on the power lines with wave impulse 8/20μs.

- Step 5: Check the protection voltage value (UP). The UP has to satisfy the requirements in (1) for electrical equipment [9] and in (2) for electronic devices [6]. If these requirements are not satisfied, the procedure goes back to Step 2. If these requirements are satisfied, go to Step 6.

$$U_P \leq (1200 + U_n) \quad (1)$$

$$U_P \leq 1.5 U_N \quad (2)$$

- Step 6: The TRS is protected.

III. COMPUTATION FOR A REAL TRS

A. Characteristics of the Real TRS

The studied TRS was built by reinforced concrete in an area with the lightning flash density of 13.7 strikes/km^2/year without nearby higher buildings. The distance from the antenna tower to the station is 4m, and the height of the antenna tower is 55m. The length of the power lines connected to the station is 550m, and the telecom line is 960m. LPS is already installed, and the telecom lines are designed with SPM. However, the power lines are not protected by SPM. The TRS needs to calculate the R_1 and R_2 and then select for the SPD to be installed on the power lines

B. Assessing the Damage Risk due to Lightning for the Studied TRS

The followed steps of the proposed method are:

- Step 1: Define the parameters of the TRS.

- Step 2: Compute the risk values of R_1 and R_2. The results are shown in Table III.

- Step 3: The risk value R_2 is higher than the regulatory limit RT2 [5].

- Step 4: Class I LPS is installed in the TRS.

- Step 5: The TRS is not yet installed with SPM on power lines.

- Step 7: Select SPD with LPS class II.

- Step 9: Recomputation of the risk values after installing the SPD. The results are shown in Table IV.

After the SPD installation, the R_1 and R_2 risk values were less than the regulatory limit values [5]. Therefore, the TRS is protected and the risk of damages by lightning is limited. In addition, the effective protection of SPD on the power lines is implemented below.

C. Implementing the Selection and Testing the Protection Level of SPD on the Power Lines

The followed steps of the proposed method are:

- Step 1: Based on the single-line diagram of the power lines connected to the TRS and the electric devices used in the TRS, the distribution network model is built in the Matlab as shown in Figure 3.

TABLE II.   TRS PARAMETERS

Parameter		Notation	Value
Density of ground flash (flashes/km^2/year)		N_g	13.7
Structure dimensions (m)		$L \times W \times H$	12×8×10
Heigher of antenna tower t (m)		H_{anten}	55
Location factor		C_D	1
Measures for protection		p_B	0.02
Coordinated SPDs		P_{EB}	0.01
Shield at external structure boundary		K_{S1}	1
Type of floor		r_t	10^{-3}
Probability of a dangerous discharge based on structure type		P_s	0.2
Probability that lightning will cause a shock to animal or human being outside the structure due to touch and step voltage		P_h	0.01
Measures of protection		P_{TA}	10^{-2}
Protection against touch voltages		P_{TU}	10^{-2}
Risk of fire		r_f	10^{-3}
Fire protection		r_p	0.2
Shield at internal structure boundary		K_{S2}	1
Hazard		H_Z	2
Loss of human life	Due to touch and step voltage	L_T	10^{-2}
	Due to physical damage	L_F	10^{-2}
	Due to failure of the internal system	L_O	-
Loss of service	Due to physical damage	L_F	10^{-2}
	Due to failure of the internal system	L_O	10^{-2}

TABLE III.   RISK VALUES BEFORE SPD INSTALLING

Computed risk values	Regulatory limit risk values	Comparison
$R_1 = 4.69 \times 10^{-6}$	$R_{T1} = 10^{-5}$	$R_1 < R_{T1}$
$R_2 = 0.034$	$R_{T2} = 10^{-3}$	$R_2 > R_{T2}$

TABLE IV.   RISK VALUES AFTER SPD INSTALLATION

Computed risk values	Regulatory limit risk values	Comparison
$R_1 = 7.753 \times 10^{-8}$	$R_{T1} = 10^{-5}$	$R_1 < R_{T1}$
$R_2 = 0.00022$	$R_{T2} = 10^{-3}$	$R_2 < R_{T2}$

- Step 2: The SPD class I is selected to be installed at the Essential Main Switchboard (EMSB) with 275V rated voltage and 40kA rated current. Besides, SPD class II is chosen to be installed at the AC Main Switch Board (MSB) with 275V rated voltage and 25kA rated current.

- Step 3: Define the location for installing SPD on the power lines at EMSB and MSB.

- Step 4: Simulate and test the withstanding capacity of the SPD on power lines and the protection voltage of the load. The location of TRS has a lightning density of 13.7 strikes/km^2/year, a surge current of 8/20μs and 40kA which is considered before installing the SPD. The protection voltages at the loads are presented in Table V, and their waveforms are presented in Figures 4-5.

- Step 5: From the results (Table V), there are some critical points. The protection voltage value across the AC load is 385.000V and across the DC load is 458V. These voltage values are higher than the tolerable voltage values of 1430V and 72V respectively. These tolerable voltage values are calculated using (1) and (2) with the nominal voltage of the system being 230V for AC load and 48V for DC load. Therefore, TRS needs to install SPD for protecting the electronic devices against the surges on the power lines.

- Step 2: Select the SPD of class I with rated voltage of 275V and rated current of 40kA for installation at the EMSB, the SPD of class II with rated voltage of 275V and rated current of 25kA for installation at the MSB.

- Step 3: The selected SPDs are installed on the power lines at the EMSB and MSB, and their models are added in the simulation network.

- Step 4: Simulate for SPD class I with waveform of 8/20μs, surge current of 40kA and SPD class II with waveform of 8/20μs, surge current of 25kA. The simulation result with AC load is shown in Table VI and with DC load in Table VII.
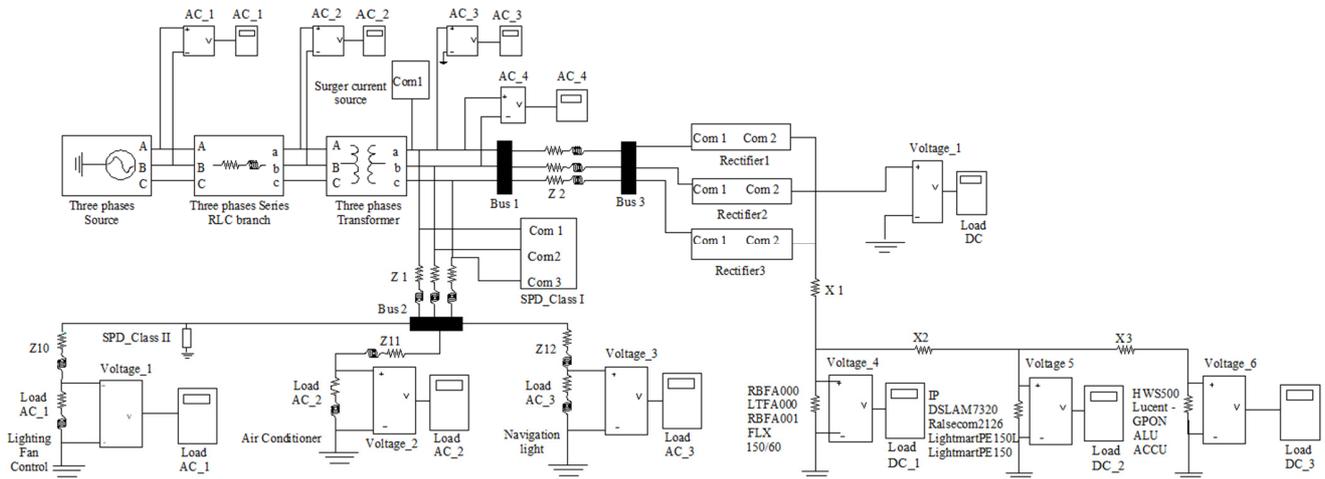
Fig. 3.   Model of the distribution network in Matlab-Simulink.

TABLE V.   SIMULATION RESULTS OF THE PROTECTION VOLTAGE AT LOADS WITHOUT SPD INSTALLED

Amplitude of rated current 8/20μs (kA)	Peak of protection voltage across the AC load (V)	Peak of protection voltage across the DC load (V)
40	386.000	459

TABLE VI.   PROTECTION VOLTAGE VALUES AT THE AC LOAD AFTER SPD INSTALLATION AT THE EMSB AND MSB

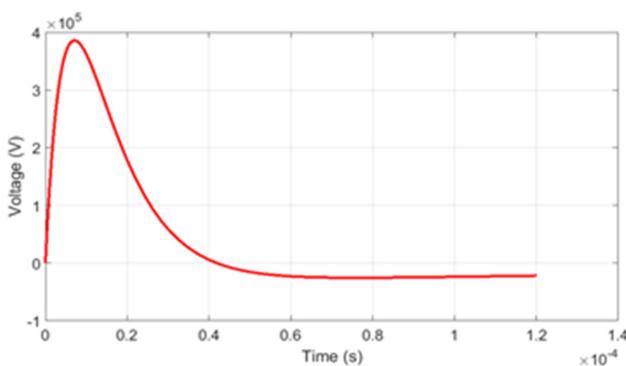| Surge current 8/20μs (kA)	Voltage tolerance (%)	SPD class I			SPD class II		
		Rated voltage (V)	Rated current (kA)	Protection voltage across the load (V)	Rated voltage (V)	Rated current (kA)	Protection voltage across the load (V)
40	10	275	40	1779	275	25	1118

Fig. 4.   Waveform of protection voltage across the AC load when SPD is not installed.
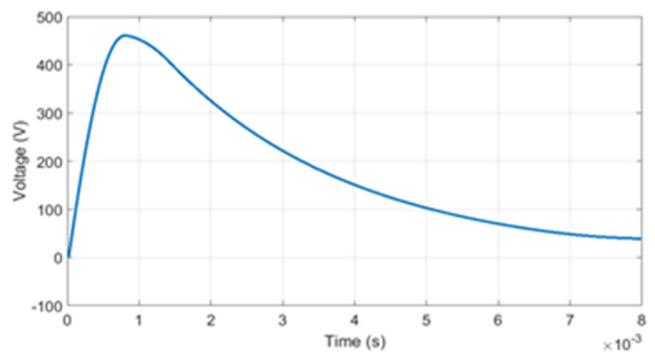
Fig. 5.   Waveform Protection voltage across DC load after SPD installation.

The conclusion after the simulation results with AC load about the protection capacity of SPDs is that the TRS needs to select and install SPD class I with surge current 40kA and SPD class II with surge current 25kA.

After installing the SPD class I, the protection voltage across the DC load is 64V. This voltage value is lower than the limit of 72V. Therefore, the TRS needs to select and install SPD class I with surge current of 40kA.

- Step 5: The final solution is installed with SPD class I with rated voltage of 275V and rated current of 40kA and SPD class II with rated voltage of 275V and rated current of 25kA.

- Step 6: The structure is fully protected from surges on the power line.
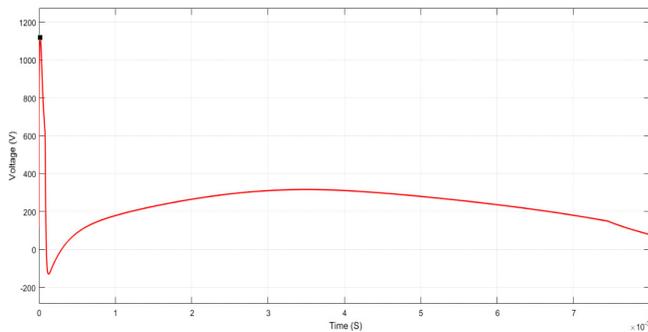

Fig. 6.   Waveform of the protection voltage across the AC load after the installation of class I and II SPDs.

TABLE VII.   PROTECTION VOLTAGE VALUES AT THE DC LOAD AFTER INSTALLING SPDS AT THE EMSB

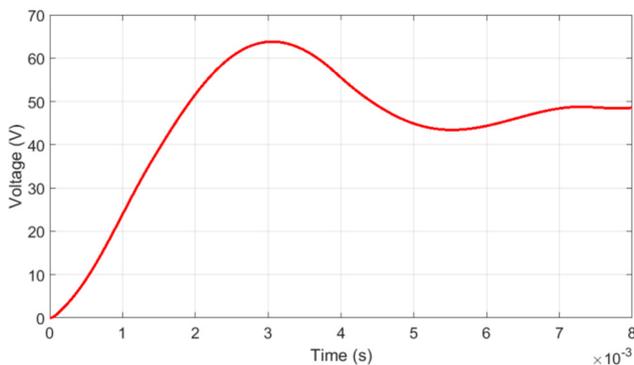| Rated voltage of SPD class I	Rated current (kA)	Voltage tolerance (%)	Surge current 8/20µs (kA)	Protection voltage across the load (V)
275	40	10	40	64

Fig. 7.   Waveform of protection voltage across the DC load after the SPD installation.

IV.   CONCLUSION

This paper proposes a new computation method for protecting from lightning propagation on the power lines of a TRS. It involves nine steps for calculating the risk values of human life loss (R1) and service loss (R2) and six steps for selecting and testing the protection level of SPD on the power lines. The effectiveness of this method is tested on a real TRS in Vietnam.

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