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Performance of the Line Surge Arresters of the 110 kV Overhead Lines on the island Brač

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SUMMARY

One and a half year after the installation of the line surge arresters (LSAs) to 110 kV overhead lines (OHL) on the island Brač it is possible to obtain representative statistical analysis results.
The correlation of the relay protection tripping data and lightning locating system (LLS) data proved the impact of the lightning on the operation reliability of the overhead lines. Number of outages was analysed in relation to the lightning statistics for the observed area.
Case by case analyses of the outages were performed in order to identify which towers of the overhead lines are endangered due to their exposure to the lightning discharges. Conclusions on line surge arresters lightning performance and possible improvements of their configuration will be considered.

KEYWORDS

110 kV overhead line, outage, lightning performance, line surge arrester, lightning location system.

1. INTRODUCTION

Since lightning is the most usual cause of the overhead lines (OHL) outages, lightning induced overvoltage protection is one of the most important tasks in safeguarding of the transmission lines and whole electric power system. The protection of OHL is usually achieved using shield wires which intercept lightning strokes so they cannot strike directly to phase conductors. In order to avoid backflashover, low tower footing resistance is demanded. Multiple studies have proved that surge arresters' installation improves the lightning performance of OHL reducing the outage rate. Operational experience of the OHL 110 kV Ston-Komolac equipped with line surge arresters (LSA) has been described in recent papers showing the effectiveness of the arresters on improvement of the line reliability, i.e. decrease in the number of the line outages caused by the lightning [1], [2].

The 110 kV transmission network on island Brač was exposed to significant lightning activity due to its specific geographical location and soil characteristics.

After performed analyses of the 110 kV transmission network in the observed area have shown that the most line outages were caused by lightning, decision has been made to implement LSAs to protect 110 kV OHLs on the island Brač.

The configuration of the LSAs installation on the OHLs was obtained by computer software simulation [3]. LSAs were installed to the OHLs during the year 2014 and already within the six months of the installation it was possible to conclude about the improvement of the 110 kV OHLs performance [4]. The correlation of the relay protection tripping data and lightning location system (LLS) data proved the decreased lightning impact to the operation reliability of the OHLs i.e. decreased number of the OHL outages in relation to the total number of the lightning activity detected by the LLS in the observed area. In addition, simulations of the lightning strokes hitting a tower were performed for the case without LSAs installed at the respective tower and for the cases with LSA installed in the bottom phase and with LSAs installed in bottom and middle phases. Simulations have confirmed the compatibility of the relay protection tripping and LLS performance [4].

One and a half year after the installation of the LSAs it is possible to obtain more representative statistical results. Operational reports indicate that the influence of lightning on the OHL operation decreased after the LSAs installation. While the lightning is still the main cause of outages for the first OHL, it is not the case with the second. As described in [3] installation of LSAs on OHLs on island Brač included the counters which registers surge of arresters. Due to some difficulties data collected by counters are not yet available in appropriate data format and this paper presents the analysis of the LSAs performance using data obtained from the relay protection system and LLS. Relay tripping data are correlated with LLS data to show the performance of OHLs. Lightning statistics for the observed area are obtained from LLS database. Spatial correlation was performed in order to identify the towers of the OHL which are particularly exposed to lightning strokes. Further analysis will take in account data from the counters for the observed period and conclusions on LSA configuration and its possible improvements will be considered.

2. OUTAGES OF THE 110 kV OVERHEAD LINES DUE TO THE LIGHTNING

For the purpose of this paper the outages of the 110 kV OHL 1 and OHL 2 of the island Brač transmission network were analysed using relay protection operation reports and LLS data during the time period from year 2009 to now on. The lengths of the overhead line sections are 5.929 km and 8.228 km for the OHL 1 and OHL 2, respectively.

The LSA application was applied to the lines in the mid of the year 2014, so the outages after LSAs installation was of the particular interest.

The data on line outages for the period of 2009-2015 are available from the relay protection operational report. During the observed period the protection relays registered 94 outages on the observed OHLs including automatic reclosures and definite disclosures of the circuit breakers. The correlation between the events registered by the protection relays and the LLS showed that in 56 cases

LLS registered a lightning stroke within the alarm zones of the respective overhead line in the time close to the time of the outages registered by the relay. This means that 60 % of all outages were caused by lightning.

In [5] and [6], for the case where the protection relays have been GPS synchronized and had fault distance calculation function implemented, it was shown that time-spatial correlation can be used for identifying the cause of OHL outage. The protection relays of the observed OHLs were not GPS synchronized and had no fault distance calculation function implemented, but time correlation between the events registered by the protection relays and LLS data registered within the alarm zones of the observed OHLs was performed to determine which outages were caused by lightning.

The results of this analysis are influenced by the error of both of the systems, the relay protection and the LLS. The accuracy of the distant protection function of the relay is affected by several factors. Such are, for example, errors in current and voltage transformers, uncertainties of the line constants, effects of untransposed transmission lines or changing network configuration. The observed OHLs and the respective sensors of LLS are located in the coastal area. Since the sensors measure the magnetic flux directly as function of time, the results of a lightning stroke location are influenced by the different conductivity (of land and sea) and, therefore, different field propagation effects [7].

Fig. 1 shows the yearly distribution of total number of outages and those caused by lightning on the observed OHLs.

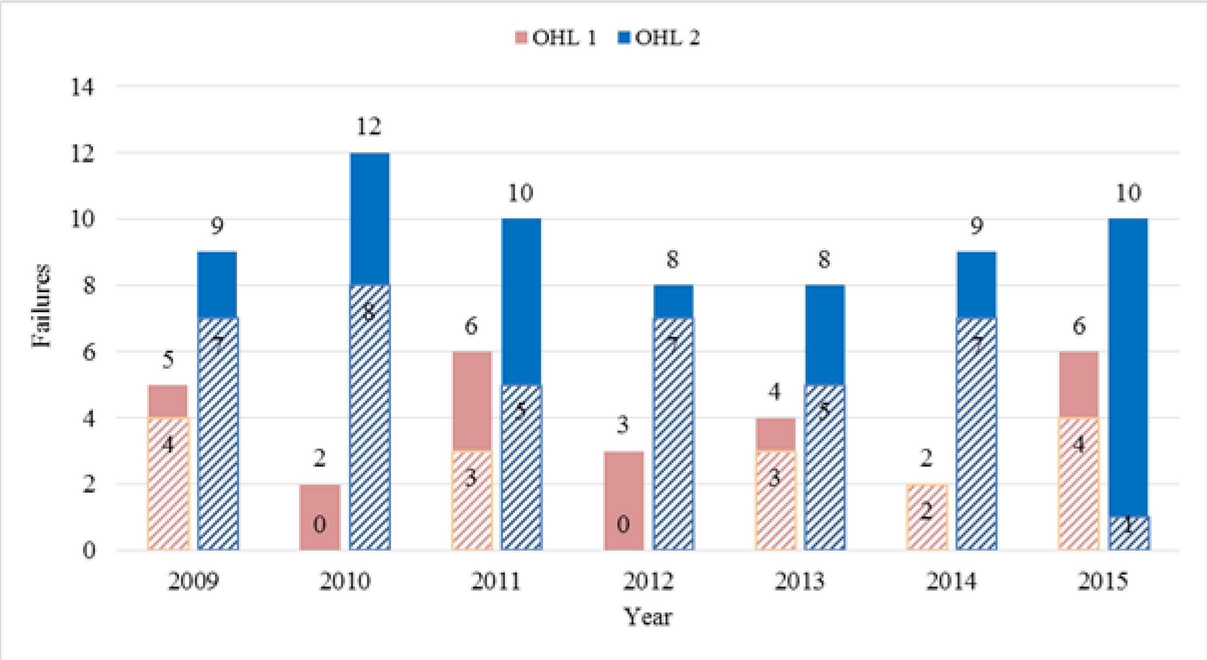

Fig. 1. Number of outages caused by the lightning (2009-2015)

In [4] it has been shown that all of the outages caused by lightning in 2014 occurred after LSAs installation. The analysis of the lightning activities in the observed area showed that the 2014 was extremely lightning active and provided reasonable explanation for increased number of outages caused by lightning.

In 2015 there was increased number of the outages of the OHL 1 and decreased number of the outages of the OHL 2. In order to determine the cause of such outages distribution on the OHLs, analysis of lightning activities during 2015 was performed.

3. LIGHTNING ACTIVITY IN THE OBSERVED AREA

LLS has been established in Croatia at the end of 2008 as a part of LINET network. Application of LLS in power system control of Croatian Transmission System Operator enables lightning activity tracking and time-spatial correlation with incidences (faults, automatic reclosures, outages) registered by the relay protection system [5]. Also, it is possible to obtain the lightning statistics from LLS database.

For calculation of lightning statistics, LLS data for the last seven years (2009 – 2015) were available. Fig. 2 represents the lightning stroke distribution registered by the LLS within the alarm zones around the observed overhead lines for the period 2009-2015, while Fig. 3 shows the lightning stroke distribution within the alarm zones for the year 2015.

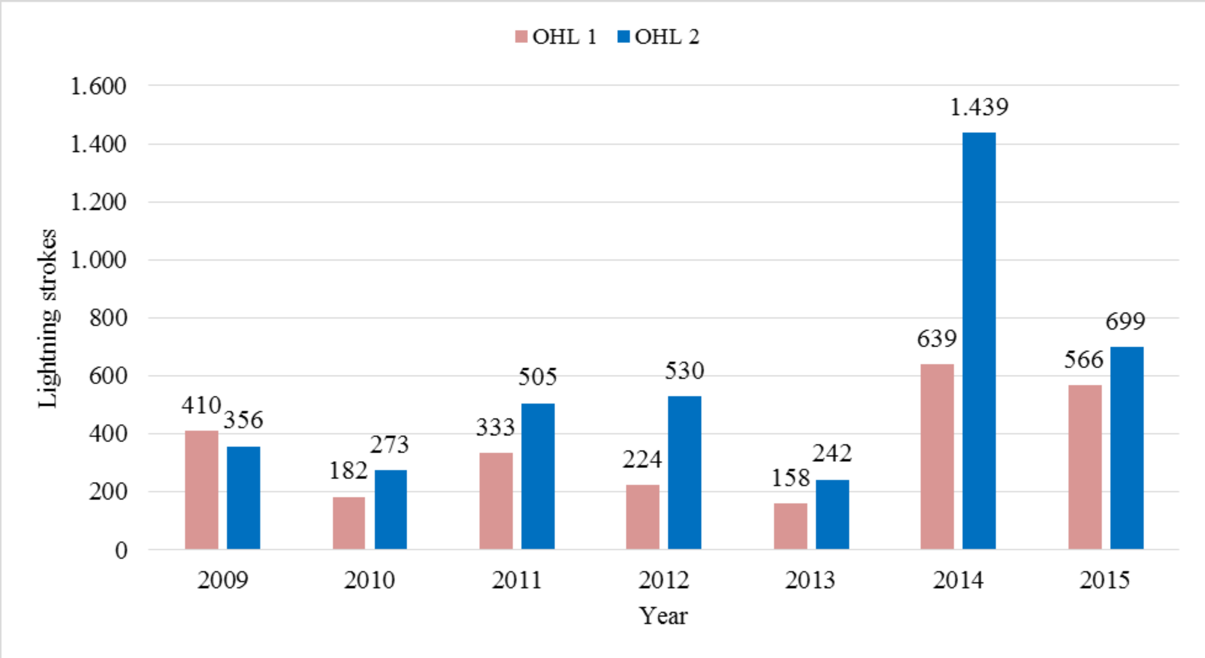

Fig. 2. Number of the lightning strokes within the OHL alarm zones (2009-2015)

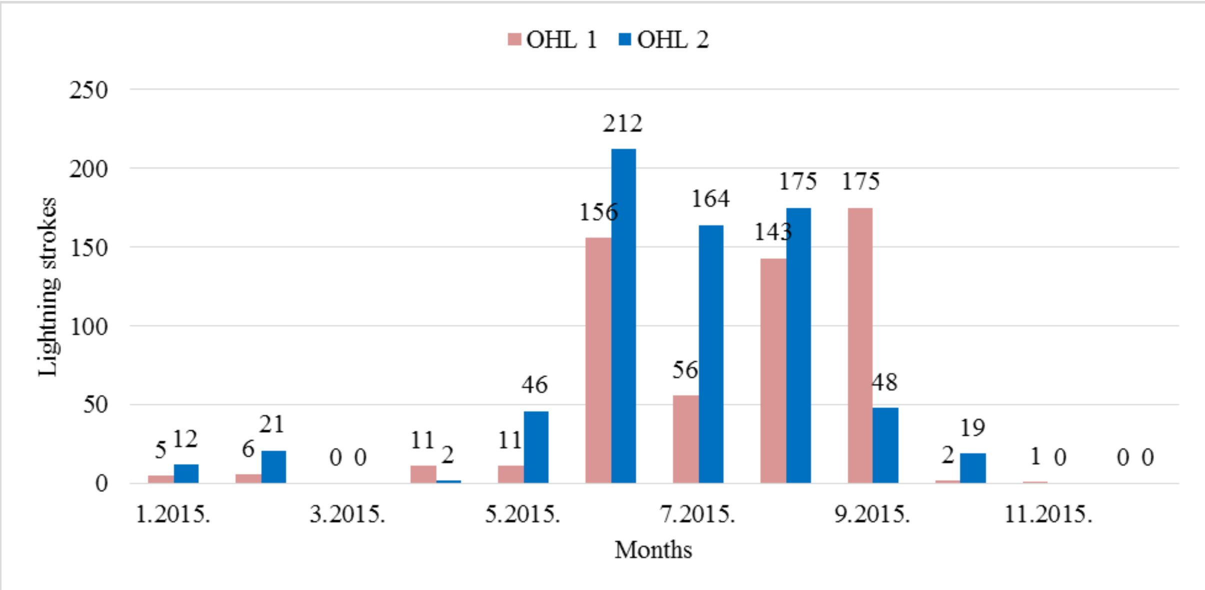

Fig. 3. Number of the lightning strokes within the alarm zones (2015)

According to the distributions of the lightning strokes represented in the Figures 2 and 3 conclusions about the influence of lightning to the operation of the OHLs are possible. During the 2015 there was less lightning than in year 2014 in the observed area, but still above the yearly average (based on the seven year measured period).

In order to be able to bring some conclusions on the performance of the LSA application installed on the observed lines, case by case correlations between LLS and relay protection data were made.

For the OHL 2, despite the recorded lightning activities during the year 2015 were above the average, only one outage occurred due to lightning and, as the further analysis showed, the outage occurred on one of the highest and most exposed towers without LSAs. In addition, the outage occurred during the summer period when the lightning activities are significantly enhanced as it can be seen on Fig. 3. As described in operational reports the majority of the outages of OHL 2, other than the one due to the lightning, occurred due to the salt pollution of the insulators in combination with the strong north wind which is very common for the coastal area.

For the OHL 1, the increased lightning activity during the year 2015 resulted with the increased number of outages in comparison to previous years. Moreover, the some of the towers within the affected line section are equipped with the LSAs in the bottom phase. Analyses showed that all of the outages of the OHL 2 occurred due to the lightning during the summer period which corresponds with the increased lightning activities in the same period (Fig. 3).

As regards the general lightning statistics of the observed area, it is possible to obtain different data from LLS.

Fig. 4 shows the low resolution map of cloud to ground stroke density for the observed area. The values on the map correspond to the values of 4.23 – 5.36 flashes/km^2/year. The majority of lightning flashes comprises multiple strokes which strike a few milliseconds from each other. According to the LLS data, the observed area had an average stroke multiplicity of 1.508 strokes per flash. The ground stroke density varies between 6.38 – 8.08 strokes/km^2/year.

By comparing these statistical values with the ones from previous years [3], [4], it is possible to conclude that after seven years statistics are not influenced by the climatologically extreme year [4] anymore and that the statistical values started to converge, unlike it is the case with the outages of the overhead lines.

Fig. 4. Low resolution Ground stroke density [stroke/km^2/year] map of the observed area (2009-2015)

For the purpose of detailed analysis of the causes of OHL outages due to lightning high resolution ground stroke density [stroke/km^2/year] map of the observed area was obtained from the LLS database as represented in the Fig. 5. In addition the locations of OHL towers were added to the map in order to be able to identify the level of their exposure to the lightning.

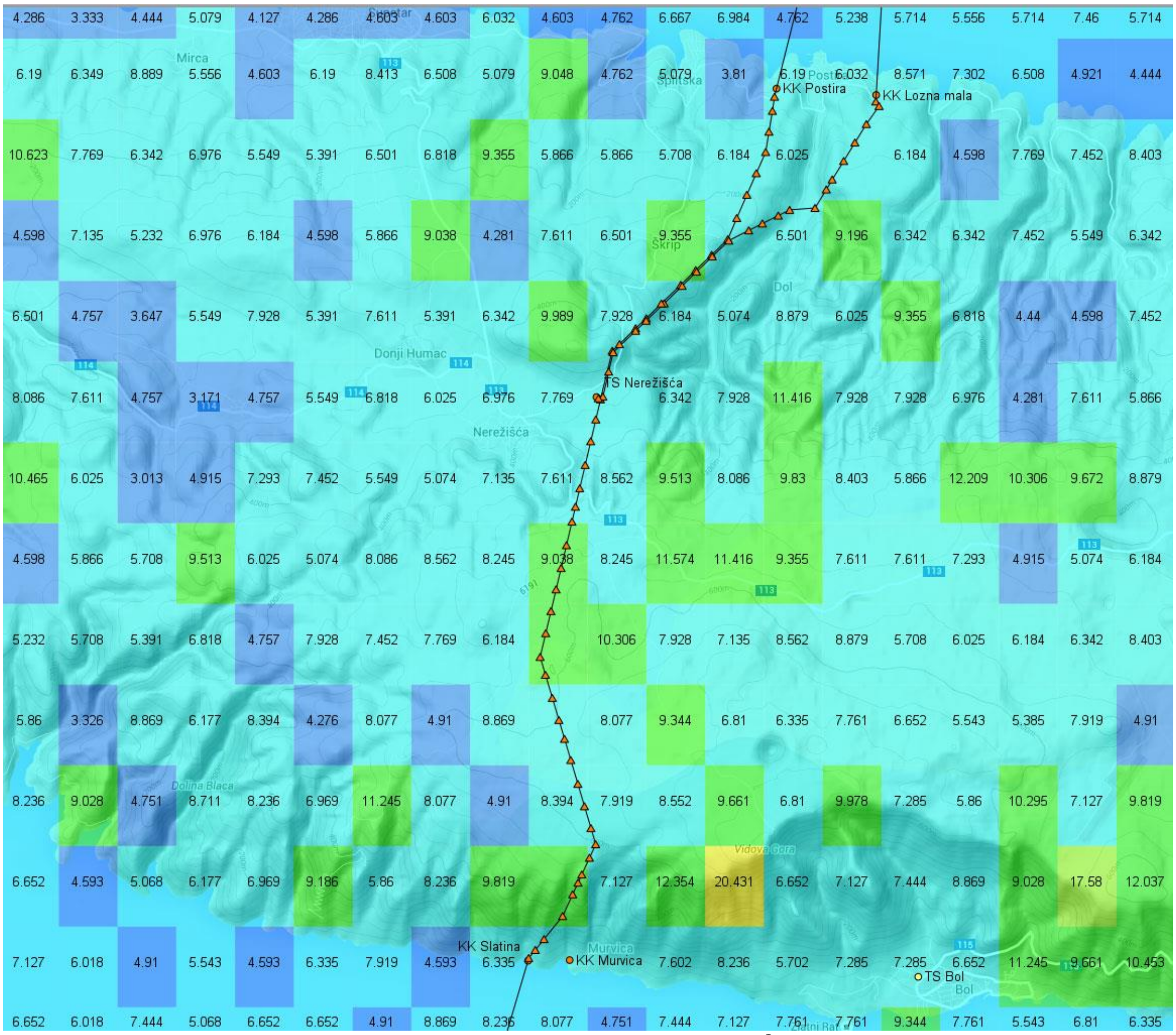

Fig. 5. High resolution ground stroke density [stroke/km^2/year] map of the observed area (2009-2015)

4. TIME AND SPATIAL CORRELATION OF OHL OUTAGES AND LIGHTNING STROKES

In order to indicate which outages of the observed cases were caused by lightning, time and spatial correlations between the outages data obtained by relay protection system and LLS data were performed. In order to check the correlation results and to prove the relay protection system and LLS performance, simulations were performed using EMTP/ATP software as written in [4]. Simulations of two real cases of line outages showed that the faults recorded by relay protection system could be caused by lightning induced overvoltage.

Time and spatial correlation were performed for all of the outages due to the lightning after the LSAs installation. Two cases of time and spatial correlations for outages on the overhead are presented in the continuation of the paper.

A. Case1 – Lightning stroke to the shielding wire of OHL 2

The first case is the correlation of the only outage which occurred due to the lightning on the OHL 2. The relay protection system and corresponding LLS data for the Case 1 are given in Table I, while the time- spatial correlation between relay protection system and LLS data are shown on the Fig. 6.

Table I. Relay protection system and LLS data for the fault event, Case 1

110 kV overhead line 2			
Relay protection system data:			
Tripping time	23.07.2015. 10:43:05.682		
Fault type	Definite disclosure		
LLS data:			
Lightning stroke time	23.07.2015. 10:43:05.553		
Lightning current (kA)	-34.0	Distance (km)	7.286

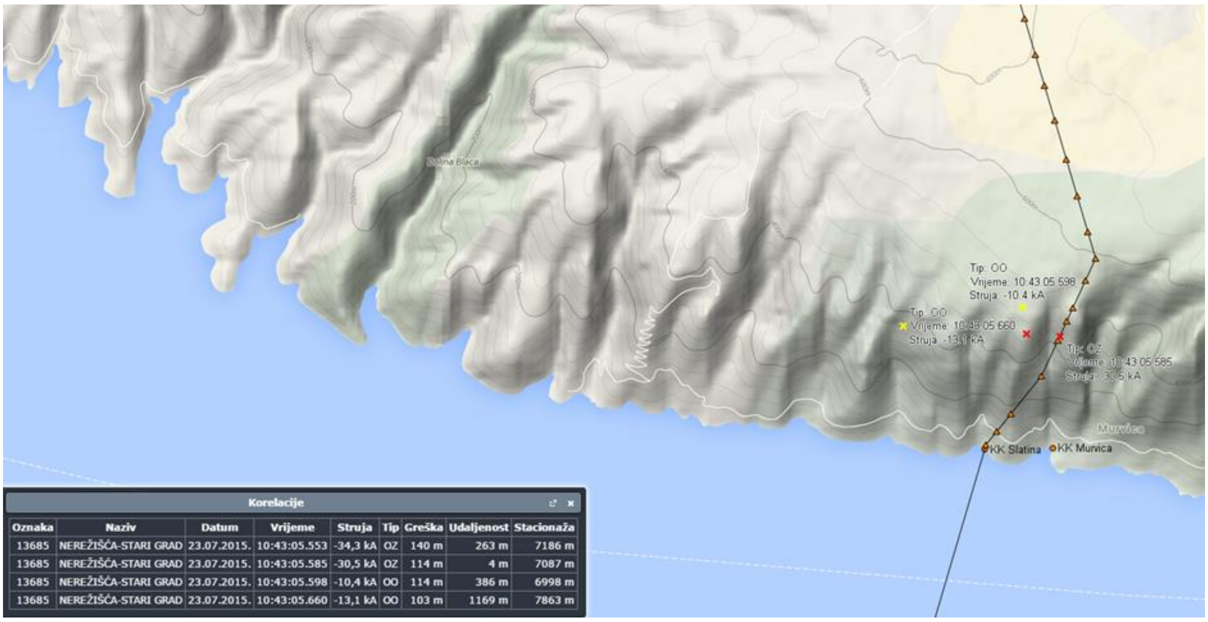

Fig. 6. Time and spatial correlation between relay protection system and LLS data, Case 1

In Fig. 6 it is shown that a multiple stroke flash with two ground strokes of lightning current of 34.3 kA and 30.5 kA was detected by LLS near the tower number 26. Measured tower's footing resistance was 21.3 Ω. No LSAs were installed to the observed tower.

As shown in the Fig. 6 a flashover occurred on the tower located on the highest and most exposed part of the transmission line corridor extending over mountain area on the south side of the island towards the sea. This corresponds to the results of correlation performed in [4] where all outages registered in the period after the LSAs installation occurred on the highest and most exposed towers without LSAs. High resolution ground stroke density map of the observed overhead lines obtained by the LLS (Fig. 5) shows that this line section was extremely exposed to the lightning discharges in the observed period. According to the data obtained from LLS database ground flash density for the tower number 26 is 8.945 [flash/km^2/year] which indicates that this particular tower is the most exposed to the lightning activities among all of the towers of the observed overhead lines.

Critical current i.e. maximal lightning current which could strike the phase conductor according to electro-geometric model was calculated for the highest conductor of the suspension towers of the overhead line 2 (Fig. 7). Calculation showed that critical current value for the towers of the OHL 2 is from 6.0 kA to 14.8 kA. For the tower number 26 the calculated critical current is 13.5 kA which is lower than the lightning current of the analysed case. This indicates that the lighting strike could be to the shielding wire.

Moreover, the high resolution ground stroke density map of the overhead line (Fig. 5.) shows that there is a part of the overhead line 2 which was also significantly exposed to the lightning activities in the same period and no outages due to the lightning were registered on this particular line section. There were LSAs installed on towers of this OHL section as described in [4].

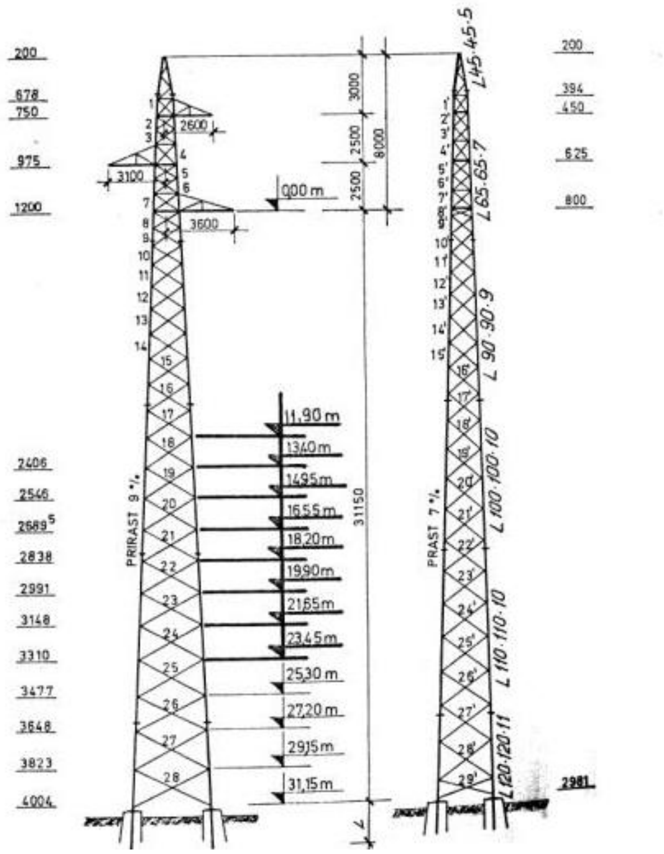

Fig. 7. Suspension tower Nc7-T

Regardless of the increased lightning activities all of the outages due to the lightning of the OHL 2 occurred on the towers without the LSAs and no outages occurred on the towers with the LSAs. The total number of the outages significantly decreased after the LSAs installation. It is possible to conclude that the efficiency of the LSAs configuration implemented to this overhead line has been confirmed.

It has been identified that there is a line section of the OHL 2 without LSAs which is exposed to the lightning influence due to its specific location. In the continuation analysis will be exceeded with data coming from the counters and possible installation of additional LSAs to the towers of this line section might be considered. Because of their location and terrain surrounding these suspension towers the access to them is difficult and LSAs installation could require significant costs. Since the number of outages of this overhead line due to the lightning has decreased significantly, the decision about LSAs reconfiguration will be postponed.

B. Case 2 – Shielding failure on OHL 1

The relay protection system and corresponding LLS data for the Case 2 are given in the Table II and the time and spatial correlation between relay protection system and LLS data are shown in the Fig. 8.

Table II. Relay protection system and LLS data for the fault event, Case 2

110 kV overhead line 1			
Relay protection system data:			
Tripping time	4.09.2015. 19:59		
Fault type	Definite disclosure		
LLS data:			
Lightning stroke time	24.09.2015. 19:59:56.908		
Lightning current (kA)	-9.7	Distance (km)	2.194

In Fig. 8 it is shown that the tower number 15 was the closest one to the location of the lightning stroke detected by the LLS. Measured tower's footing resistance was 20.8 Ω.

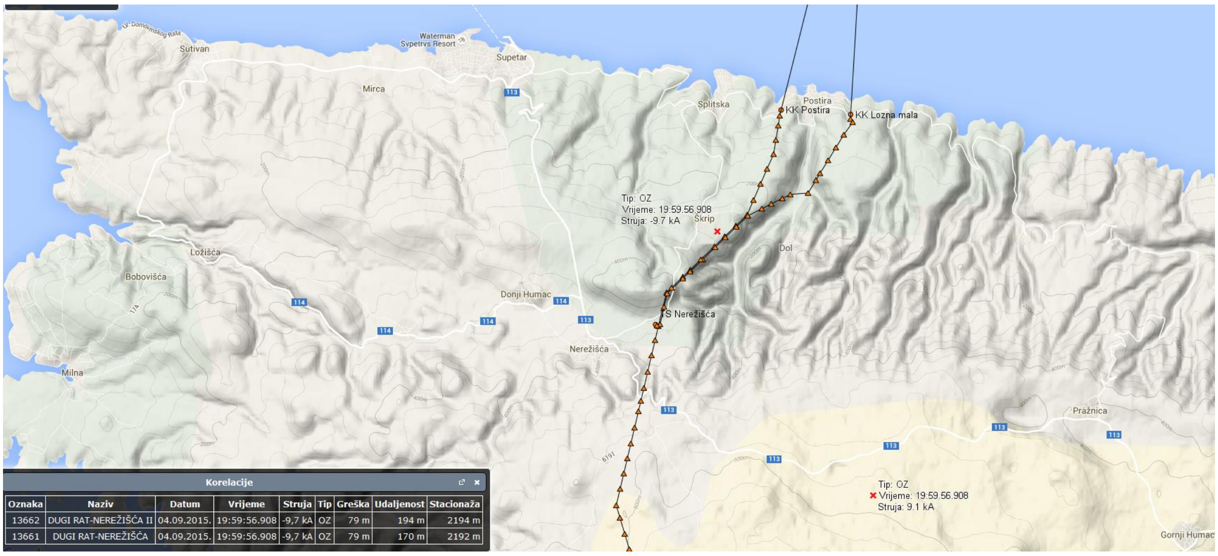

Fig. 8. Time and spatial correlation between relay protection system and LLS data, Case 2

High resolution ground stroke density map of the observed overhead lines obtained by the LLS (Fig. 5) indicates that the area around tower number 5 was significantly exposed to the lightning strokes in the observed period. According to the data obtained from LLS database ground flash density value for the tower number 15 is 3.049 flashes/ km2/year.

According to the relay protection report data and correlations with LLS data it is visible that two outages occurred on the tower number 15 in the period after the LSAs installation to the OHL 1. Tower number 15 is located on the highest and most exposed part of the overhead line and no LSA is installed to it. Similarly, correlations showed that in the period after the LSAs installation to the OHL 1 two outages occurred on the tower number 13 and one outage occurred on the tower number 5 with LSA installed to the bottom phase of both towers. It is important to stress that both of the towers, number 13 and number 5, are exposed to the lightning influence due to their location.

For most of the correlations of the outages of the OHL 1 data on the lightning strokes obtained from the LLS indicates the low value of the lightning current.

Calculation showed that critical current value for the towers of the OHL 1 is from 7.6 kA to 19.3 kA. For the analysed outages that occurred on the tower number 15 the lighting current was 9.7 kA while the calculated critical current for the tower number 15 is 11.6 kA. This indicates that the lighting strike could be to the phase conductor.

As for the extremely increased lightning activity on the area where observed OHL 1 is located, the number of line outages after the LSAs installation remained the same in comparison with period before installation, the LSAs reconfiguration might be considered as effective.

Similarly as for the OHL 2, there is a line section of the OHL 1 without LSAs installed which is exposed to the increased lightning influence. In addition some outages occurred to the tower with LSA. This would indicate a reconfiguration of LSAs might be advisable, but the further analyses including data from the counters are needed.

5. CONCLUSION

Lightning protection performance of the LSAs applications on the 110 kV overhead lines on island Brač was analysed during the one year and a half after the installation.

Time and spatial correlation of the relay protection system data and LLS data was performed to determine the number of outages which occurred due to lightning. Lightning statistics were used in order to evaluate the efficiency of the LSA configuration in relation to the lightning activities in the observed area.

In general, number of outages of the observed overhead lines in the relation to the recorded lightning activities decreased after the LSAs application was installed.

Possible improvements of the LSAs configurations have been identified and for the final decision on LSA reconfiguration further analyses including data from the counters will be performed.

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