Application of Line Surge Arresters on Transmission Lines in Croatian Power System

G. Levačić, M. Mesić, S. Piliškić, L. Ćurin, D. Škarica

***Abstract* - A brief overview of a ten-year experience related to application of the line surge arresters on overhead transmission lines in Croatian power system has been given in this paper. The line surge arresters are mainly used for transmission line lightning performance improvement, for the reduction of overhead lines outages and for increasing reliability of the entire transmission system. The first part of this paper describes the pilot project of line surge arresters installation on the 110 kV overhead line Ston - Komolac from its beginning and reports about conducted measurements and application of gained knowledge on other 110 kV overhead lines in the Croatian transmission system. The second part of the paper points out the main challenges and further perspective of the project.**

***Keywords:* line surge arrester, overhead line, pilot project, line lightning performance, measurement system, lightning location system.**

I. Introduction

THE main task of a transmission system operator is establishment of an energy supply infrastructure in order to maintain security of supply with minimal costs and care for environmental protection. A transmission of energy is performed through overhead lines that are exposed to various factors that may lead to the occurrence of issues, which then can cause outages and interruptions of electricity supply. Such issues can be caused by a natural “transient” phenomenon, also known as the lightning stroke, which is often the main reason for outages of transmission and distribution lines. Therefore, it is important to improve performance of transmission lines that are exposed to lightning. That can be achieved using different solutions, such as reduction of the tower footing resistance, increasement of line insulation level (critical flashover voltage), installation of shielding wires [1][2] and application of line surge arresters (LSAs). LSAs are mainly used for transmission line lightning performance improvement, for the reduction of outages on single and double circuit lines reducing the risk of insulator flashover during surge events and improving the overall security of electricity supply.

In Croatian transmission network, the standard protection of overhead transmission lines against lightning is a shield wire. Although shield wire intercepts lightning strokes so they cannot strike directly to a phase conductors, a relatively low crest current of lightning can affect a phase conductor and shielding failure can occur. Back flashover occurs when lightning stroke terminates on the overhead ground wire or tower. A stroke that thus terminates, is forcing currents to flow down the tower and out on the ground wires. In order to avoid back flashovers, low tower grounding resistance is demanded.

The 110 kV transmission line Ston - Komolac plays a key role in the electricity supply of the wide area of the city of Dubrovnik and southern part of the Croatian power system. From the early 2000’s, a large number of outages have been registered on the 110 kV transmission line Ston - Komolac, mainly due to its specific location in the area with high ground flash density. In addition, due to the specific mountain area of the southern part of the Croatia, it is very hard to have impact on the tower grounding resistance. Since the outages have significantly diminished the reliability and security of the operation of that part of the Croatian transmission network, it was concluded that the most technically and economically feasible solution for improving the protection of this transmission line against lightning is application of LSAs.

II. Pilot Project of Installation of Line Surge Arresters and Counters

The 110 kV overhead transmission line Ston - Komolac is 44 km long single circuit shielded line, located in a specific terrain area within the region, with a high lightning activity (keraunic level is about 70 thunder days in the year). Since it was considered that this line had a poor lightning performance [1], Croatian Transmission System Operator (HOPS) has started with the pilot project for application of line surge arresters (LSA) in 2007, which main goal was to improve the overvoltage protection and lightning performance of the line. The substation for the connection of the wind power plant Rudine (installed capacity 34,2 MW) has been connected to the 110 kV transmission line Ston - Komolac in 2015, but in the analysis the initial configuration of the network (Ston - Komolac) was considered.

Fig. 1. Location of the110 kV transmission line Ston - (Rudine) - Komolac.

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Initially, two types of polymer housed line surge arresters were selected for this pilot project [2]: gapless LSAs (108 kV, 10 kA, class II) and LSA's with a series gap (108 kV, 10 kA, class II). The configuration of the surge arresters' installation was obtained by the computer software simulation [3], using the overhead line parameters data and tower grounding resistance data as the input for the calculations. In July 2007 the initial configuration of 110 LSAs was applied to the 110 kV overhead line Ston - Komolac.

The current configuration consists of 104 LSAs, as follows: 50 towers with 1 LSA installed in bottom phase, 24 towers with 2 LSAs installed, one in lower and one in the middle phase, and 2 towers with 3 LSAs installed, one in each of the bottom, middle and top phase.

After a few years of the LSAs implementation, based on the monitoring and analysis of the outages data, it was found that application of LSAs significantly improved the line lightning performance and decreased number of outages. Fig. 1 and 2 show the yearly number of outages of 110 kV overhead line Ston - Komolac for the period before and after the LSAs installation.

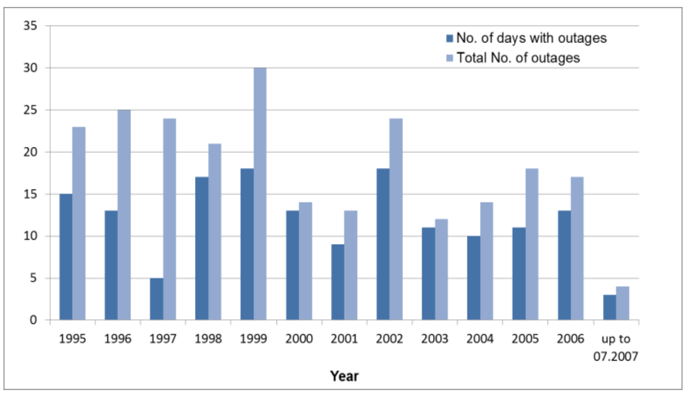

Fig. 2. Number of outages before installation of LSAs on transmission line 110 kV Ston - Komolac (1995-2007).

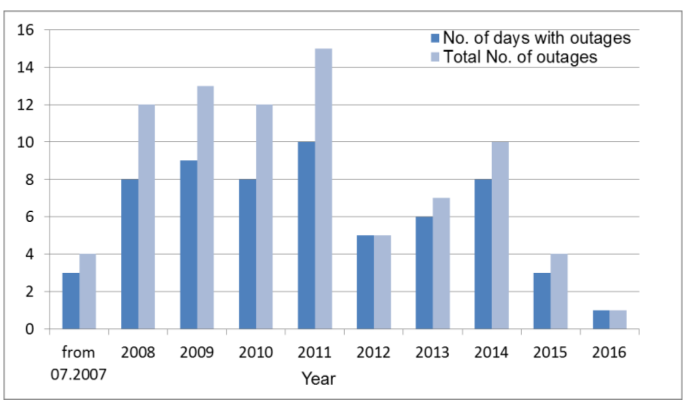

Fig. 3. Number of outages after installation of LSAs on transmission line 110 kV Ston-Komolac (2007-2016).

The initial configuration of installed LSAs was modified twice during the six years of the operation on the transmission line 110 kV Ston - Komolac. In addition, it is important to emphasize that during the period of ten years, 6 LSAs were dismantled due to mechanical damages [3].

Together with LSAs, 47 EXCOUNT-II type of surge monitors were installed (on 13 towers with one monitor in lower phase, on 14 towers with two monitors in both lower and middle phases and on 2 towers with monitors in all three phases). EXCOUNT-II shown on Fig. 4 [4] is a complete surge arrester monitoring system that permits recording of the number of discharges seen by the arrester as well as their amplitude (10-99 A; 100-999 A; 1000-4999 A; 5000-9999 A; over 10000 A), with time-stamp, together with measurement of the total leakage current and resistive current through the arrester [5].

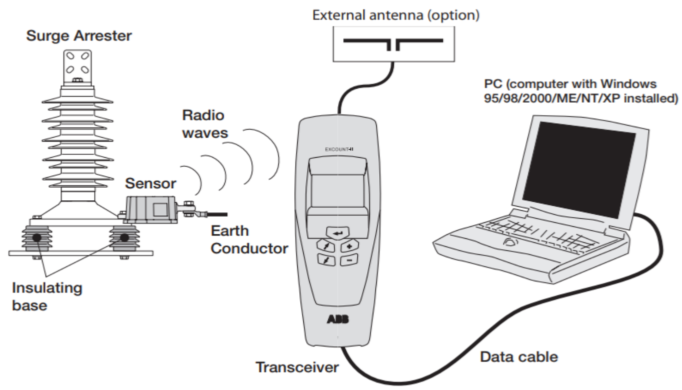

Fig. 4. EXCOUNT-II type of monitoring system [4].

According to the distribution of the discharge current, amplitudes that were recorded by the installed surge monitors, as shown on Fig. 5, the majority (70%) of all discharged currents were shown in amplitude range of 10-99 A. The discharges with the current amplitude within ranges from 10-99 A and 100-999 A, could be a result of the switching overvoltages or overvoltages induced by the cloud to cloud or cloud to ground discharges. The discharges with the current amplitude higher than 1000 A were probably a result of the lighting activities [3].

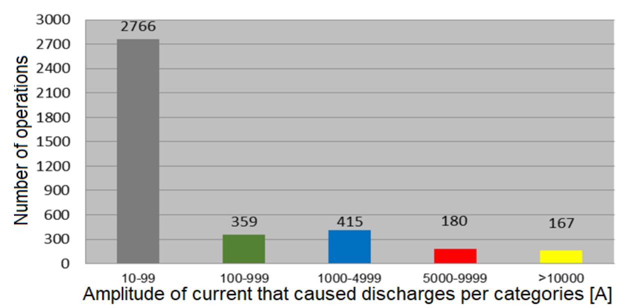

Fig. 5. Number of LSA discharge operations recorded by the surge monitors per different current categories for the period 2007-2017.

Fig. 6 shows that the highest number of discharge operations was recorded on towers with installed LSAs in top phase (A). The majority of the discharge operations (with LSAs installed in phases B and C) were a result of the following discharge current category: 1000-4999 A. Only on towers number 119 (phase B) and 122 (phase C) more discharge operations by discharge current category over 10000 A were recorded.

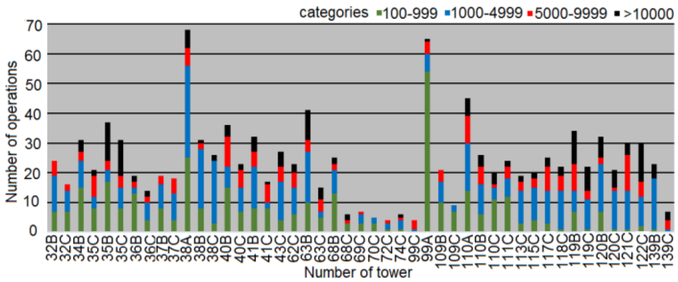

Fig. 6. Number of LSA discharge operations in values of each category per different phases for period 2007-2017.

Fig. 7 and 8, show number of LSA discharge operations on towers 38 and 110 with installed surge monitors in all three phases and on tower 99 with installed surge monitors in two phases. It can be seen as the highest number of operations was recorded in top phases (A), followed by middle phases (B) and then by lower phases (C).

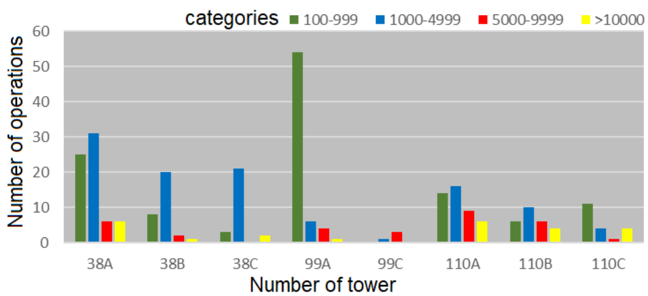

Fig. 7. Number of LSA discharge operations per phases on towers.

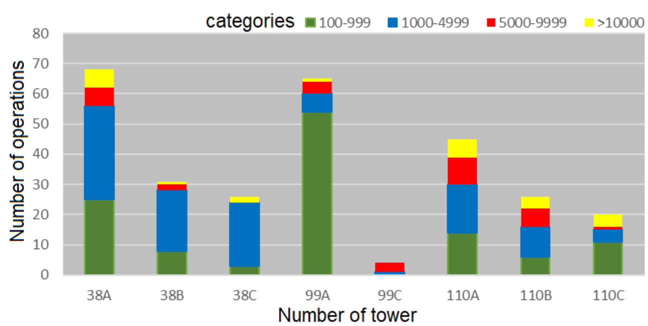

Fig. 8. Total number of LSA discharge operations per towers.

Fig. 9 shows grounding resistances (measured in March 2017 [3]) in correlation with the location altitude for all the towers of the 110 kV overhead line Ston - Komolac.

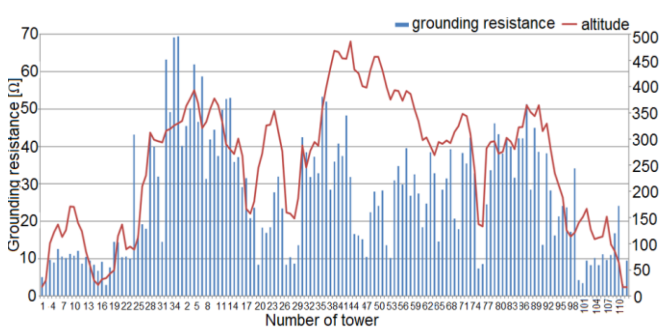

Fig. 9. Grounding resistances correlated with tower altitudes.

The grounding resistance values are higher for the towers located at higher altitudes, because at higher altitudes the soil is mostly rocky with the higher value of the specific soil resistance. Consequently, with the higher values of tower grounding resistances, the back flashovers occurred more often on the overhead line sections with towers located at higher altitudes.

Fig. 10 and 11 show analysis of LSA discharge operations per season and monthly period of the year, for discharge current category >5000 A. It can be considered that the higher number of LSA discharge operations was recorded in summer and autumn period of the year, particularly in June, and it is in accordance with typical weather and climate conditions for this location.

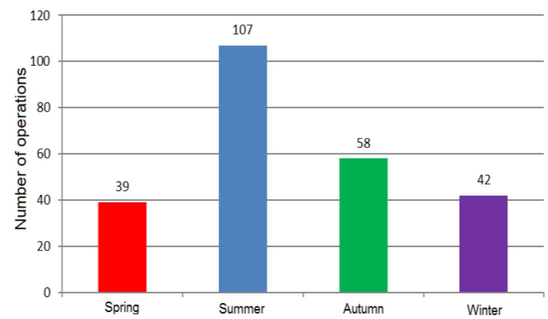

Fig. 10. Seasonal distribution of LSAs discharge operations.

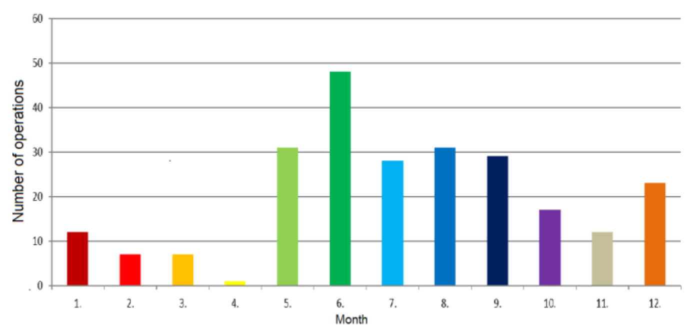

Fig. 11. Montly distribution of LSAs discharge operations.

III. Application of Measurement Systems and Other Devices to the Pilot Project

In 2008, several measurements and monitoring devices were installed to the 110 kV overhead line Ston - Komolac. The real-time measurement system (RMS) was installed on transmission line towers no. 38 and 110 in 2009. The RMS, in Fig. 12 consists of the following components:

- a solar power supply (2 solar panels);
- a controller;
- an acquisition unit;
- a communication system.

The RMS contains the sensors for monitoring of the transient current flowing through the ground conductor of the top phase LSA and the specifically developed Rogowski coil that was installed around the tower in order to measure the total lightning current flowing through it (up to 50 kA) [6].

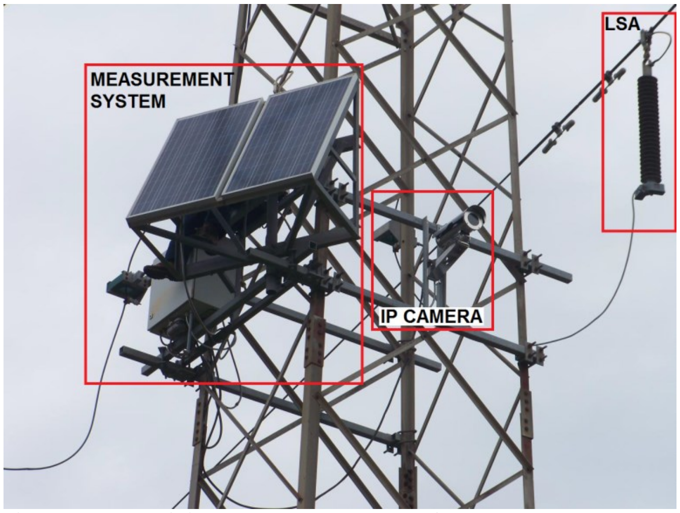

Fig. 12. LSA, real-time measurement system and IP camera on tower no. 38.

In 2017, two Internet Protocol cameras for visual monitoring of lightning strikes were installed on towers no. 38 and 110 [7] [8]. Both cameras are directed on the side of substation Komolac, in order to gain greater visibility of transmission line and neighbouring towers.

Fig. 13. View from the IP camera installed on tower no. 38.

In addition to the above described RMS and IP cameras installed on towers no. 38 and 110 [6], the two additional systems were installed for recording transients on the line remote ends. They consist of the system for monitoring of the same type of transient currents through the surge arresters in the relevant line bays, including the measurements on the secondary side of the voltage and current transformers (in both substations, Ston and Komolac).

IV. Lightning Location System

The lightning location system (LLS) [9] was established in Croatia at the end of 2008. LLS data comes from LINET system, provided by nowcast GmbH, Germany, which has round 125 sensors all across Europe. LINET system provides the following data for each component of a lightning stroke [10]:

- GPS Date and Time with 100 ns resolution;
- Latitude and Longitude coordinates of the stroke, with location error;
- Current amplitude of the stroke;
- Current polarity of the stroke;
- Type of discharge: Cloud to Ground (CG) or Cloud to Cloud (CC).

The data of this system can easily be correlated with data of transmission line outages and faults in network, which improves the network monitoring, detection of causes and locations of faults, as well as minimizes the time and expenses needed to eliminate the fault. The LLS allows extracting the lightning statistics, real-time lightning tracking, extracting the lightning history data and interconnection with other systems, such as GIS, SCADA, EMS etc.

V. Application of Gained Experience on Other Transmission Lines

In the first part of this paper was presented the 110 kV transmission line Ston - Komolac, on which LSAs and surge monitoring devices were installed within the scope of the pilot project. In addition, two real-time measurement systems and IP cameras were installed on the transmission lines towers (no. 38 and 110). Moreover, two systems for monitoring transient currents in the station surge arresters for recording transients on line remote ends are installed. A set of data gained from the measurements in correlation with LLS make the basis of the data used for analysis and reconfiguration of installed LSAs. The data together with the measurements of tower grounding resistances allow obtaining of representative statistical analysis results and performing detail investigations, through modelling and simulations in different software tools for calculation of transients, e.g. EMTP-RV, ATP, etc. Ten years' experience gained through this pilot project has enabled the application of LSAs on other 110 kV transmission lines with poor lightning performance in Croatia. The 110 kV transmission network on the island Brač is exposed to significant lightning activity due to its specific geographical location and soil characteristics [11][12]. In total, 45 LSAs were installed on the island Brač to the overhead sections of the 110 kV overhead line Dugi Rat - Nerežišća 2 and 110 kV overhead line Nerežišća - Stari Grad, during 2014 [13].

Application of LSAs to the overhead lines in Croatian transmission network has continued during the period from 2015 to 2017. LSAs have been installed to the following 110 kV overhead lines located in the coastal area and exposed to significant lightning activities: Ston - Ponikve, Ponikve - Blato and Blato - Stari Grad.

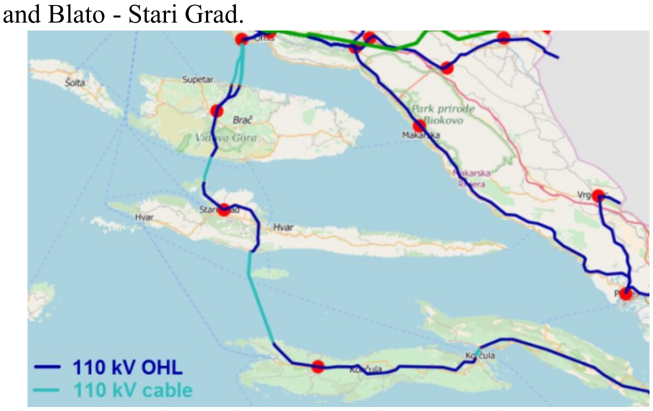

Fig. 14. Part of coastal area of Croatian transmission network that is exposed to significant lightning activities.

VI. Further Steps and Challenges of the Pilot Project

In the following period HOPS plans to install additional 70 LSAs on 110 kV transmission lines in the coastal area of the Croatian transmission network (110 kV transmission lines on island Hvar, 110 kV transmission lines on island Korčula and 110 kV transmission line Konjsko - Kaštela).

Moreover, for resilience improvement of the regional power system, HOPS is currently considering application of LSAs on 220 kV voltage level, particularly on double circuit transmission line 220 kV Plomin - Pehlin, which connects the thermal power plant Plomin to the power system. For this purpose, several initial studies have been conducted and reported in [14][15].

Further challenges will be addressed on application of the performed measurements and gained knowledge for:

- better understanding of the thermal stress of the line equipped by arresters due to lightning,
- reconfiguration of existing LSAs location that are installed on certain overhead lines with purpose of further reduction of the number of outages,
- identification of the new overhead lines with bad lightning performance,
- installation of LSAs on the new overhead lines with an initial optimal configuration,
- monitoring and analysis of the data measured and gained from different sources,
- improvement of the knowledge of lightning current and providing a valuable information for the calculations in transient software tools (e.g. EMTP, ATP etc.).

The pilot project will continue through monitoring and improvement of the existing configuration of LSAs on the transmission lines, extension of the pilot project to other 110 kV and 220 kV transmission lines endangered by lightning, correlation of different measured data with lightning location system, testing of monitoring devices, counters and LSAs in lab, and detailed modelling of the transmission line for analysis of power system transients in EMTP-type software.

VII. Discussion of the Results

From the yearly distribution of total number of outages presented in [3], it is evident that the majority of outages on overhead line Ston - Komolac were caused by lightning. Furthermore, from Fig. 2 and 3, it can be concluded that the total number of outages after the installation of LSAs on observed transmission line significantly reduced.

Key conclusions made from the measured results are as follows:

- the majority of the discharge operations occur during the summer, during which thunderstorms occur more often than in other seasons with regards to the specific climate of the observed area.
- Fig. 6 shows that some sections of the overhead line are more exposed to lightning activities due to the geographical configuration of the terrain combined with the specific climatic configuration in these areas.
- Fig. 9 shows that grounding resistance is important factor in relation to the lightning discharge. The tower grounding resistance of this overhead line is quite high because of the high resistive terrain (specific terrain configuration), often correlated with higher altitude.
- Fig. 3 shows that number of outages have reduced but also that the number of the outages of the overhead line is in correlation with the lightning activities in the observed area, having in mind that lightning activities are not equally distributed during the years.
- Data in Fig. 7 indicate that number of discharge operations is more frequent in upper phases, which points out that more shielding failures could occur than expected.

Considering the reported results and lightning statistics it is possible to evaluate the efficiency of the LSA configuration in relation to the lightning activities in the observed area. Installation of LSAs on higher voltage level (220 kV) and implementation of steps mentioned in previous chapter, together with correlation of measured data from different sources with lightning location system could bring new experiences in defining technical guidelines or methodology for optimal installation of LSAs on particular transmission line. Such experience, together with the achieved results and observations from this pilot project might facilitate easier application of LSAs on transmission lines in other power systems.

VIII. Conclusion

The paper describes the ten years' experience from the operation of the line surge arresters on the 110 kV overhead lines of the Croatian transmission network.

After the installation of the LSAs on the overhead line Ston - Komolac, the number of outages caused by the lightnings significantly decreased. Based on the gained experience, it was decided to install LSAs on other overhead lines with poor lightning performance too, mainly located in southern part of Croatia and on some islands.

The data obtained from different monitoring systems and measured tower-grounding resistances, present a set of important information that enable better understanding of the lightning phenomena and possible LSA reconfiguration for improvement of the line overvoltage performance and to decrease the number of outages caused by lightning.

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