On Site Operation of a Real Time Measurement System for Monitoring Transient Currents Through Line Surge Arresters

S. Grebović, I. Uglešić, A. Xémard, L. Diaz, S. Sinčić

***Abstract*--A precise knowledge of the transient lightning current which circulates in towers and arresters is of great importance for the specification of line surge arrester's energy duty.**

This paper presents a measurement campaign of lightning current transient which takes place on a single-circuit transmission line equipped with line arresters located in Croatia. A measurement system which measures the transient current circulating through the body of a tower and its arresters is presented. It is able to record precisely the shape of the transient currents and to transmit the information to a concentrator. The last part of the paper is devoted to the presentation of 2 measurements recorded in 2024. The first one is related to a lightning stroke and the second one to a slow-front overvoltage due to a switching on the electrical system. Both measurements are analyzed.

***Keywords*: Lightning current, arresters, transient current measurement .** [1]

I. Introduction

LIGHTNING remains one of the main causes of outages on transmission lines even though it has been studied extensively since the beginnings of power transmission [1]. The use of line surge arresters (LSA) constitutes a very efficient solution to reduce the number of lightning outages and consequently the number of disturbances to customers and to improve power supply availability. LSAs' specification remains challenging because of a lack of precise knowledge regarding lightning current, in particular the charge transferred through the arresters in case of lightning stroke [2]. Typically, lightning current's parameters are estimated based on guidelines and recommendations available in various guidelines [3] which were established several decades ago at a time when measurement techniques were less efficient than today. Although it has been recognized that most of the information contained within is relevant and applicable, it is still possible to improve knowledge using the latest information obtained by the modern lightning location systems installed worldwide. The goal of the experiment presented in this paper is to contribute help remedy this situation by measuring the lightning current which circulates though the line arresters and the body of a transmission tower located in a Croatian region of high lightning activity.

The current waveforms captured by the developed measurement system will offer critical data necessary for assessing the energy stress experienced by the line surge arrester.

Additionally, the measurement results from the proposed system will shed light on how the lightning current is distributed among the surge arresters installed across the three phases of the transmission line.

The literature does not provide a clear methodology for measuring the current waveform using existing methods and no commercial equipment is specifically designed for recording lightning current through line surge arresters. Lightning measurement systems rely on specific developments. Therefore, a specific measurement system was developed for this experiment. It is presented in the first part of the paper. Its main principles are recalled as well as its testing and its expected accuracy. Then 2 measurements records captured by the system are presented and analyzed.

II. Real Time Transient Currents Monitoring

A. *Main Purpose*

The most important basic parameters of lightning currents are the peak value and the waveform. Existing systems for measuring lightning current peak value and waveforms are mostly installed on high towers [4]- [9].

The main purpose of the system presented in this paper is to measure the waveforms of the lightning current which circulates through the surge arresters and the tower of a 110 kV single-circuit transmission line equipped with a sky wire (see Fig. 1).

It cannot be found in the literature how to measure the current waveform by using existing methods and commercial equipment for measurement of the lightning current through line surge arresters, therefore a specific measurement system was developed. The measurement of lightning current

S. Grebović is with University of Sarajevo, Faculty of Electrical Engineering, Sarajevo, Bosnia and Herzegovina (e-mail: sgrebovic@etf.unsa.ba).
I. Uglešić is with University of Zagreb, Faculty of Electrical Engineering and Computing (FER), Zagreb, Croatia (e-mail: Ivo.Uglesic@fer.hr).
A. Xémard is with Electricite de France, Paris, France (e-mail: alain.xemard@edf.fr).
L. Diaz is with Réseau de Transport d'Electricité, Paris, France (e-mail: luis.diaz@rte-france.com).
S. Sinčić is with Croatian Transmission System Operator (HOPS), Zagreb, Croatia (e-mail: Silvia.Sincic@hops.hr).

Paper submitted to the International Conference on Power Systems Transients (IPST2025) in Guadalajara, Mexico, June 8-12, 2025.

Fig. 1. Single-circuit.110 kV transmission line equipped with a sky wire

circulating in line surge arresters and through the tower could be used to improve knowledge on specification of the lightning impulse discharge capabilities of arresters [2]. Communication of the monitoring system over the mobile network with a telecom base station in the future could possibly enable its interaction with other systems like weather monitoring system, lightning location system and SCADA. This could allow for the fast detection of faults' locations and minimizing the outage time of the overhead lines due to the lightning.

The measurement results of the proposed system can also provide insights into how the lightning current is divided between the gapless LSAs installed on the three phases of a transmission line.

It is essential to note that while the number of installed devices may be limited, their strategic placement enhances their ability to record crucial data, contributing to the development of smarter control systems for improved power infrastructure management.

In addition, the obtained results can be useful for the development of a general method for selection and determination of the location of LSAs with the purpose of improving the efficiency of overvoltage protection.

B. Development and Laboratory Testing of the System

The experimental system was designed, developed and tested at the high voltage laboratory of University of Zagreb

Faculty of Electrical Engineering and Computing. The experimental system and the laboratory testing results are described in [10].

B.1. Development of the System

Up-to-date state-of-the-art in measuring sensors, communication and information technologies are implemented in the developed experimental system for real time measurement of the lightning currents which circulate through the line surge arresters and through the tower of an overhead transmission line [11].

The developed experimental measurement system consists of the following parts (see Fig. 2):

- Sensor unit;
- Recording unit;
- Power supply unit;
- Communication and storage;
- Software;
- User interface.

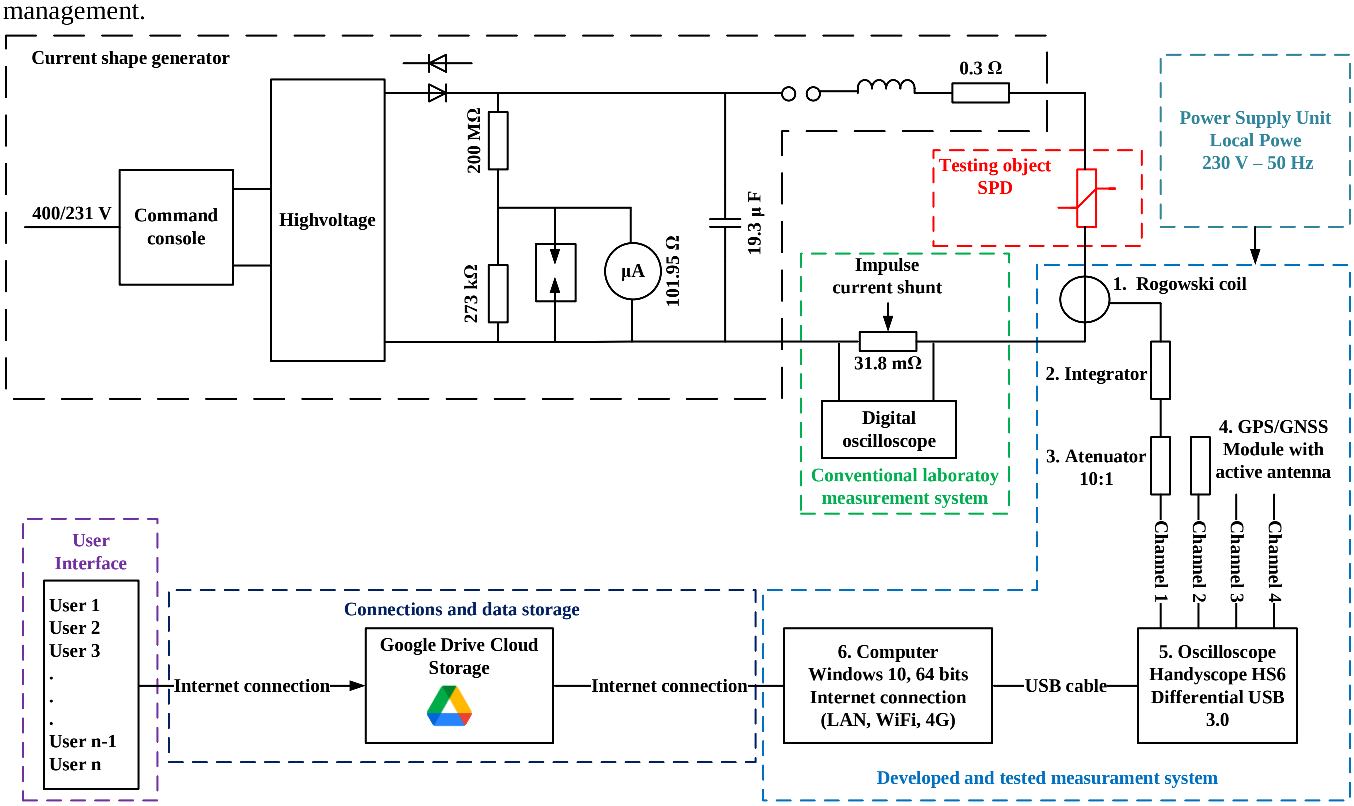

Fig. 2. Description of the experimental system in a high voltage laboratory.

A Rogowski coil (number 1 in Fig. 2) is used as a sensor unit to measure the current that passes through the surge protective device (SPD). A specific Rogowski coil was designed for this purpose, along with the accompanying integrator (number 2 in Fig. 1).

As a unit for recording the lightning current waveshape and its parameters, a differential oscilloscope (number 5 in Fig. 2) that contains differential dividers and probes is used. It has a maximum sampling rate of 1 GSa/s, which is suitable for recording fast front transients, and a resolution of 8, 12, 14 or 16 bits. The oscilloscope uses an internal A/D converter with a very precise clock (with accuracy ± 0.0001 %, stability ± 1 ppm and with time base aging ±1 ppm/year) that determines the moments at which sampling needs to be performed. The measuring range of input voltages is between ± 200 mV and ± 80 V, and the connection to the instrument is made via a USB 3.0 cable.

Due to the synchronization of measurements on different channels (in this case two channels: channel for measuring discharge current and channel for Pulse Per Second/PPS signal) it is very important that the data acquisition card has a very precise internal timer.

A 10:1 voltage divider (number 3 in Fig. 2), which is necessary to protect the oscilloscope from damage during the tests, is placed between the integrator of the Rogowski coil and one of the inputs of the data download card (e.g., as in Fig. 2 Channel 1). The voltage attenuator has the following characteristics: voltage ratio 10:1, midband accuracy ±1%, input and output resistance of 50 Ω, useable rise time 5 ns, frequency range: DC – 3 GHz.

A precise GPS/GNSS (Global Positioning System/Global Navigation Satellite System) module with active antenna (number 4 in Fig. 2) is connected to the recording unit.

A computer (number 6 in Fig. 2) is used for storage and transfer of the measured data from the acquisition unit to the cloud. Data are transferred from the acquisition unit to the computer via Super Speed USB 3.0.

B.2. Laboratory Testing of the System

The laboratory setup (Fig. 2) in addition to the developed experimental measurement system consisted of the impulse current generator, SPD as the testing object, conventional laboratory measurement system, local power connection as a power supply for the developed system and 4G internet connection which is used for data transferring to the cloud storage. Data which are stored in the cloud are available to the authorized users.

Lightning First Stroke Test is performed to check that the laboratory set-up was operational, and that the equipment met the desired requirements. It consists of the single 8/20 µs current impulse. The low current amplitude of the first impulse is used to check the accuracy of the selected thresholds.

The second experiment consists of the generation of several current shapes with different peaks to ensure that the monitoring system acquire all of the impulses and send them to the server over the mobile network. All generated lightning current shapes (standard waveform 8/20 µs) were successfully recorded. The results of the laboratory tests have shown excellent matching in amplitude and shape of impulse current through the SPD, i.e. matching of current shape recorded by tested system and recorded on impulse current shunt and conventional laboratory oscilloscope (see Fig. 3 – 5).

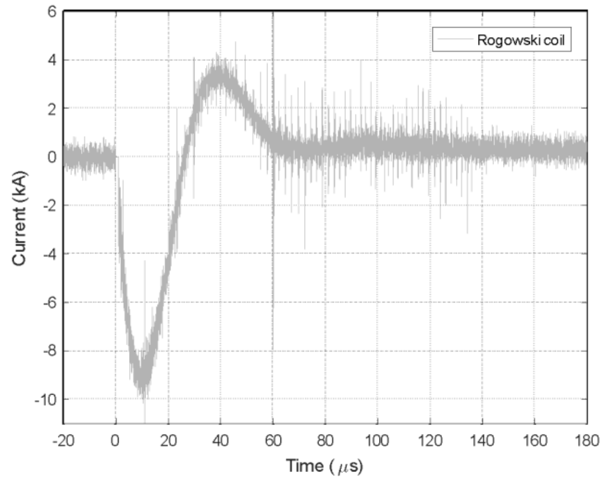

Fig. 3. Current measured with the experimental system, the peak value I ≈ 8,3 kA

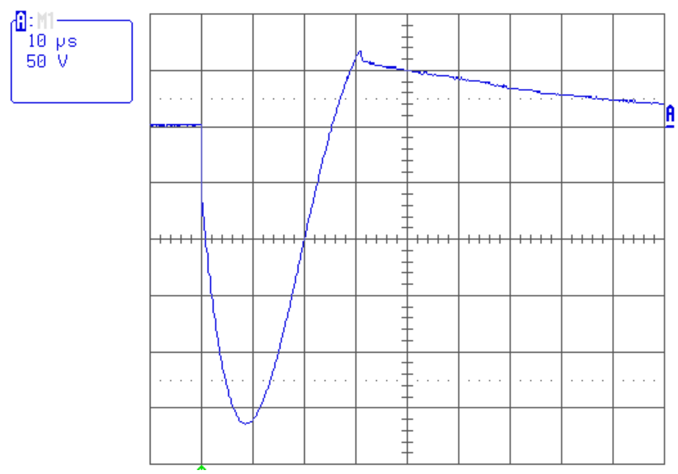

Fig. 4. Current measured directly with the conventional measurement system, the peak value I ≈ 8,3 kA

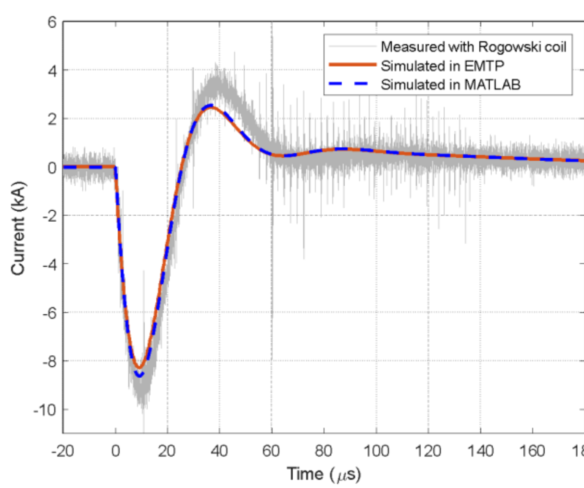

Fig. 5. Comparison of measured current with current simulated in EMTP and MATLAB, the peak value I ≈ 8,3 kA

Numerical simulations were conducted in EMTP and MATLAB in order to compare simulated results with the results of measurement system. Communication tests and tests for data transfer to cloud and storage were also successful. Results of the testing showed that the real time measurement system could also operate properly on the site installed on transmission line tower.

C. Installation

Due to the substantial cost associated with these monitoring systems, widespread installation across all main transmission lines may not be economically feasible. A strategic approach has been adopted to install these systems at selected locations, prioritizing areas prone to high lightning activity or those crucial for system resilience. The criteria for the site selection is inherently tied to optimizing the system's impact and utility within budgetary constraints. The strategic placement of the measurement devices on site enhances the ability to record crucial data, contributing to the development of smarter control systems for improved power infrastructure management.

Developed real time measurement system for monitoring transient currents through line surge arresters was implemented to the tower of the 110 kV transmission line equipped with the LSAs in all of the three phases. The overhead section of the line is located in the area with high ground stroke density where it is expected that the sufficient number of lightning events could occur during the operation of the line (Fig. 6). A keraunic level of 40 lightning days per year is commonly used when performing computations of lightning performance in the observed area.

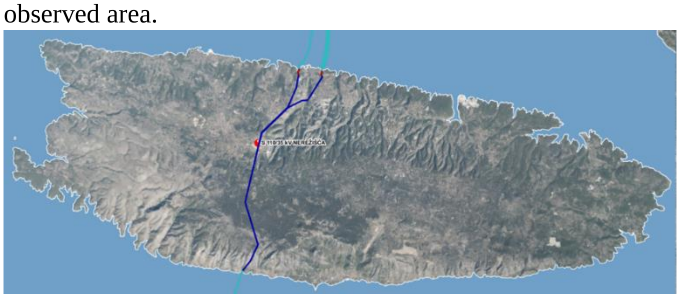

Fig. 6. Geographical location of the 110 kV transmission line

The analyzed transmission line is a 110 kV line with a maximum equipment voltage of 123 kV and it connects the substation on the island with the substation on the mainland. The total length of the line is approximately 14,200 meters. It consists of 22 towers along an overhead route of 5,900 meters on the island and an undersea cable section of 8,300 meters (Fig. 6). Electrical scheme of the 110 kV line transmission line is represented on Fig. 7.

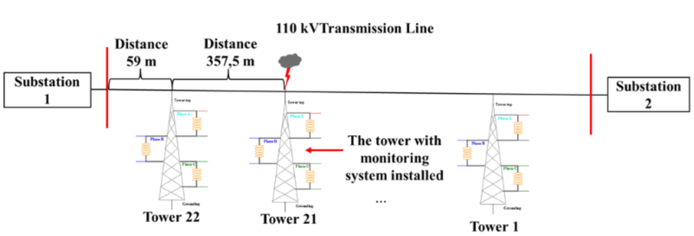

Fig. 7. Electrical scheme of the 110 kV line transmission line

In order to improve the line's operational reliability and protection against lightning the line was equipped with the 20 LSAs in total as follows: 15 towers with the one LSA in bottom phase, 1 tower (close to the undersea cable section) with two LSAs in bottom and middle phases and 1 tower (closest to the substation) with three LSAs in all of the phases. The configuration of the LSAs installation on the overhead lines was obtained by computer software simulation [12]. After LSAs were installed to the overhead line, the outages recorded by the relay protection system were monitored in order to obtain the conclusions on the performance of the overvoltage protection of the lines equipped with the LSAs. In the period after the LSAs installation, operational reports indicated a significantly decreased number of outages of the observed overhead lines due to lightning. The correlation of the relay protection tripping data and lightning location system (LLS) data were performed. The analyses proved the decreased impact of lightning on the operation reliability of the overhead lines i.e. decreased number of outages in correlation to the total lightning activity detected by the LLS in the observed area [13].

At the tower where the monitoring system was installed, instead of the one LSA, which was initially installed in the bottom phase, three new surge arresters were simultaneously mounted in all the phases to enhance the protection and ensure accurate data collection. The arresters' characteristics are given in Table 1.

TABLE I
THE CHARACTERISTICS OF THE LINE SURGE ARRESTERS

Rated Voltage (U_r)	108 kV
Continuous Operating Voltage (Uc)	86 kV
Nominal Discharge Current (8/20 µs)	20 kA
High-Current Withstand (4/10 µs)	100 kA
Discharge Class	2
Type	Silicone-housed

The installation of the measurement system on transmission line towers presented significant challenges, requiring a carefully designed approach to ensure precise positioning and structural integrity. Given the tower's intricate structure and the need for accurate sensor placement, a thorough planning phase was essential. Additionally, the tower's mechanical strength was evaluated to confirm its ability to withstand the particularly severe wind conditions. Ultimately, integrating innovative design with systematic planning proved essential to overcome the deployment challenges. Considering that the tower is located in a coastal area with possible extreme wind, the wind load of the tower with the measurement system installed has been checked. The electronic equipment is conceived to work in the range -20 to +60 °C. This range was considered adequate considering the area. The implementation of a monitoring system, detailing considerations, analyses, and the thoughtful design devised for the effective deployment of measurement systems on transmission line towers is described in [14]. The left part of the Fig. 8 represents the location of the tower along the transmission line, the middle part represents the location of the tower in the environment and the right part shows the tower with the installed measurement system.

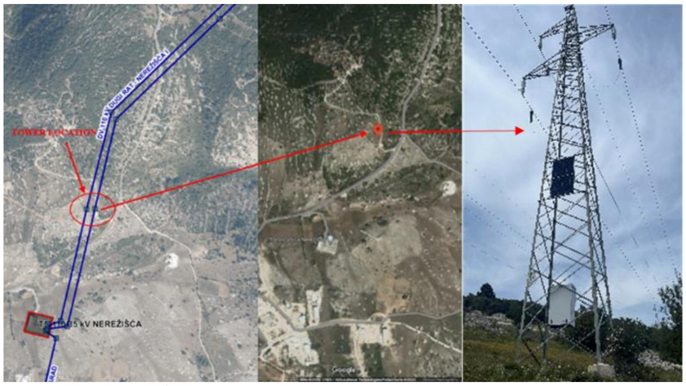

Fig. 8. Location of the tower with installed measurement system

The connection scheme of the measurement system installed to the overhead line tower is represented in Fig. 9. There are four Rogowski coils, three of which serve as sensors for measuring currents through the line surge arresters and the one is used as sensor to measure currents through the transmission line tower. Each of the coils is connected to the respective wide bandwidth integrator via a cable, and then the integrators are connected to the A/D converter (oscilloscope) with cables with BNC connectors.

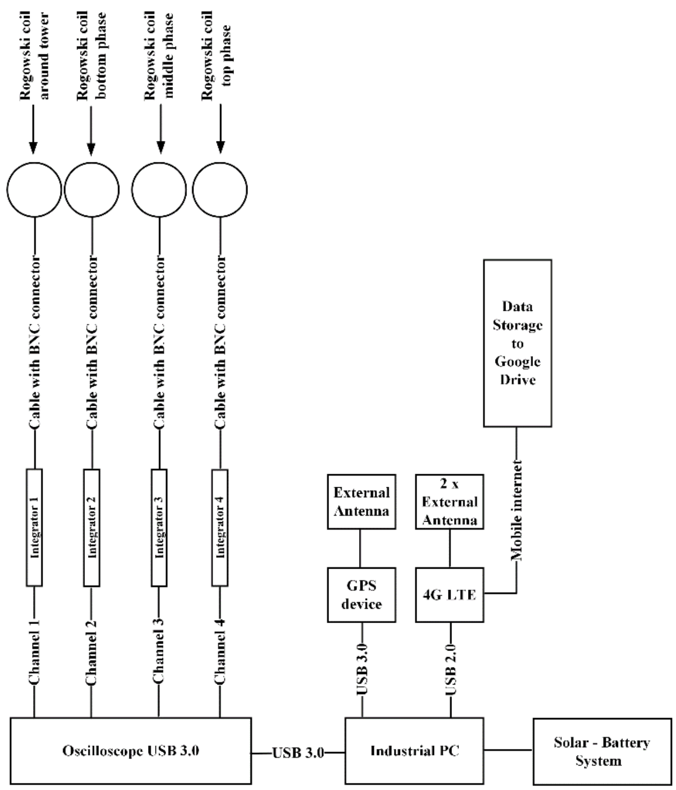

Fig. 9. The transient current measurement system connection scheme

Rogowski coils are installed on the tower, while the integrators are placed in a cabinet together with the A/D converter (USB oscilloscope), computer, GPS device, and communication module. The entire system set up within the cabinet is isolated.

The A/D converter is connected to an industrial computer via a USB 3.0 cable. The GPS device with an external antenna is also connected to the computer, with the external antenna positioned outside the cabinet.

The communication and data transfer module (4G LTE module) is connected to the computer via a USB 3.0 port. A SIM card is inserted into the 4G LTE module, and two external 4G LTE antennas are connected to it via TS9 to SMA cables, antennas are positioned outside the cabinet.

The measurement system is powered by a solar-battery system, carefully designed to maximize solar energy utilization and efficiency.

III. Transient Currents Measurement Results

The system was installed in May 2024 and has been operating continuously since then. Two events are described in the following section of this paper.

Since the installation of the measurement system, there have been no disruptions or operational issues reported. The system has operated stably and reliably, with the solar-battery power supply proving highly effective in ensuring uninterrupted performance. No communication issues have been encountered, and remote access to the system has consistently worked without any failures, allowing for seamless monitoring and control from a distance.

Moreover, the mobile internet connection has provided continuous and reliable service, maintaining an impressive speed that supports the transmission of data. This stable network performance has been crucial for the real-time operation and monitoring of the system, further contributing to its overall reliability and effectiveness.

A. Lightning Current Recording

A lightning event was recorded by the measurement system on July 20, 2024, at 11:27:08.918147. The current was measured using a Rogowski coil placed around the tower, along with three additional Rogowski coils measuring the currents through the surge arresters installed on the bottom, middle, and top phases of the 110 kV transmission line tower.

The current measured through the tower is shown in the diagram in Fig. 10, while the currents measured through the surge arresters are presented in the diagram in Fig. 11.

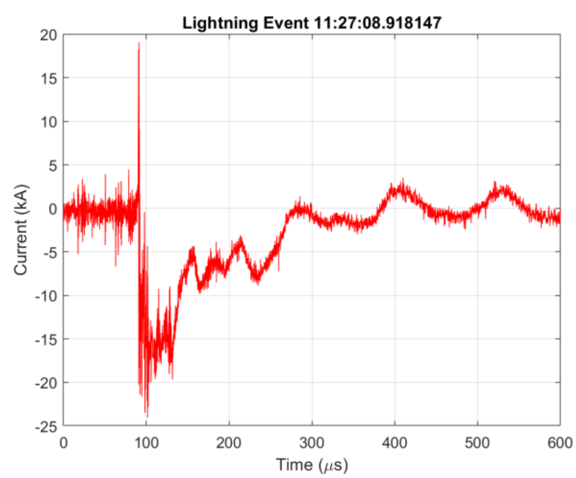

Fig. 10. The current measured through the tower (Event on July 20, 2024, at 11:27:08.918147)

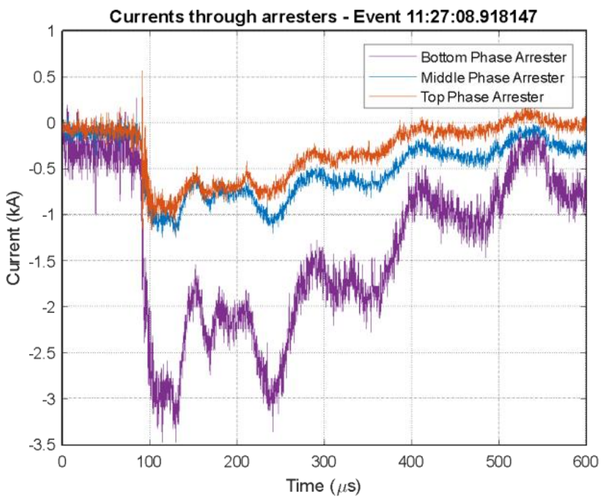

Fig. 11. Currents measured through the surge arresters (Event on July 20, 2024, at 11:27:08.918147)

The amplitude of the voltage across the insulator string can be affected by several parameters such as the tower surge impedance, the tower footing resistance, the influence of electromagnetic coupling and the value of the phase voltage at the time of the lightning strike.

The electromagnetic coupling factor takes into account the influence of the voltage induced on the phase conductor due to electric and magnetic coupling, which acts to reduce the voltage on the insulation. The electromagnetic coupling factor depends on the mutual distance between the phase and the shield wire, i.e. it is smaller the greater the mutual distance between the phase and the shield wire. Therefore, the overvoltage amplitude is highest on the insulator chain in the bottom phase, which is farthest from the shield wire.

The recorded signals present noise, which could be minimized in future work through the application of advanced filtering techniques.

A comparison was made between the recorded event captured by the developed measurement system and the data from the Lightning Location System (LLS). LLS software provides with the data on time and date of the lightning stroke, GPS coordinates (2D), lightning current amplitude, lightning type (inter-cloud /IC or cloud-to-ground/CG), height (for inter-cloud lightning), and 2D statistical error. The developed system recorded the event on July 20, 2024, at 11:27:08.918147, with a current amplitude of -17.8 kA. Meanwhile, the LLS registered a negative stroke with a current of -18.2 kA, occurring on July 20, 2024, at 11:27:08.860. It can be easily concluded that both systems recorded the same event, as the time and amplitude match remarkably well. Table II represents the list of the lightning strokes recorded by LLS which spatially correlate with the overhead line's corridor while Fig. 12 shows LLS software's geographical representation of the lightning strokes recorded on June 20, 2024.

The event was not registered by the relay protection system of the overhead line. Therefore, it could be concluded that the stroke did not cause the outage of the line since the LSAs performed their function correctly.

TABLE II

EXTRACT OF THE EVENTS RECORDED BY THE LLS ON JULY 20, 2024 (ADAPTED FROM THE LLS SOFTWARE OUTPUT)

Object Type	Time	Strike Offset [m]	Fault Distance [m]	Current	Error [m]	Strike Height [m]	Lat / Lon
Substation	20.07.2024. 11:27:09.354	579	1654	-3.9	177	0	43.3524° 16.6001°
Substation	20.07.2024. 11:27:09.302	638	1555	-25.1	54	0	43.3523° 16.5989°
Substation	20.07.2024. 11:27:08.860	763	209	-18.2	100	0	43.3403° 16.5844°
Line	20.07.2024. 11:26:33.696	377		10.9	32	8600	43.3365° 16.5881°
Substation	20.07.2024. 11:26:01.281	991		4.2	434	0	43.3273° 16.5968°
Line	20.07.2024. 11:20:17.882	936	8599	-3.6	11	5900	43.3977° 16.6295°

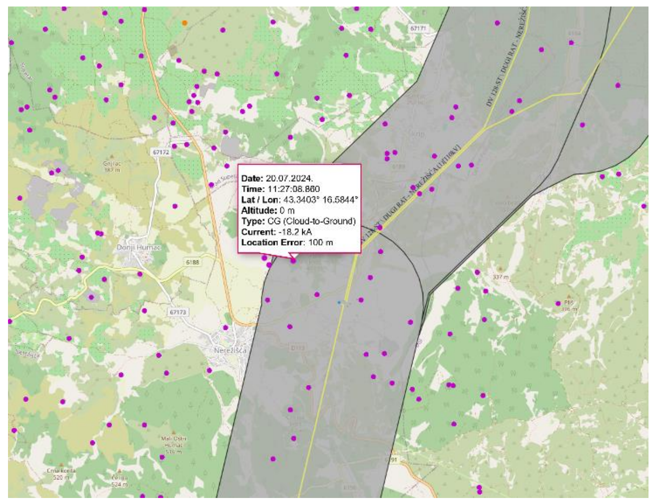

Fig. 12. Geographical representation of the events recorded by the LLS on July 20, 2024 (snapshot of the LLS software)

B. Switching Transient Current Recording

Since the system became operational, it has recorded one more event. On June 21, 2024, a major power outage occurred in Bosnia and Herzegovina, Montenegro, Croatia, and Albania. During the process of restoring the grid, the SCADA system logged the reactivation of the transmission line where the developed measurement system is installed, at 14:53:41 on June 21, 2024 (Fig. 13). At the same time, the measurement system recorded the activation of the surge arrester installed on the top phase of the tower at 14:53:40 on the same day (Fig. 14). From this, it can be concluded that both systems registered the same event, as there is excellent time correlation.

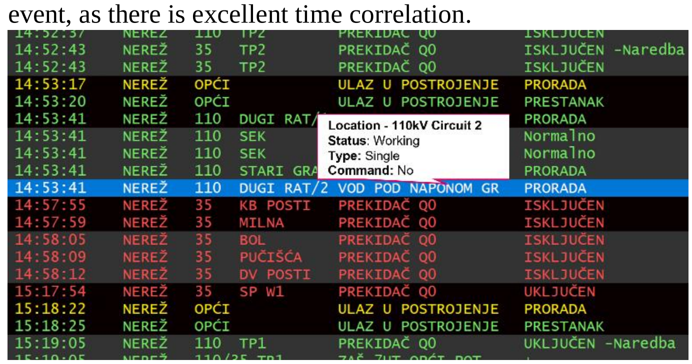

Fig. 13. Switching Event recorded in SCADA on 21.06.2024. 14:53:41

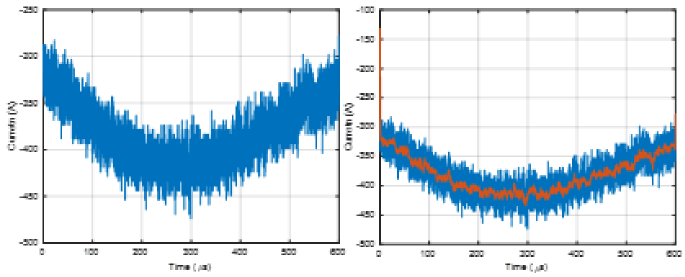

Fig. 14. Current in the Top Phase Arrester recorded by Measurement System on 21.06.2024. 14:53:40

The measurement system, although specifically designed for recording lightning events (e.g., the event on July 20, 2024, shown in Fig. 10 and Fig. 11), demonstrated its robustness and effectiveness by successfully capturing a switching transient during the grid restoration process on June 21, 2024 (Fig. 14). These results highlight the system's versatility in detecting various types of transient phenomena.

IV. Future Research and System Development

Further research will focus on a comprehensive analysis of the recorded data from the lightning monitoring system. This includes processing and interpreting large datasets to refine our understanding of lightning current waveforms and their impact on transmission infrastructure. Advanced signal processing techniques could be applied to extract more detailed insights from the raw data, potentially revealing patterns in lightning behavior and its interaction with the power system. This data will also serve as a foundation for validating and improving simulation models.

The CIGRE brochure 955 published in 2025 provides the development status of advanced lightning transient voltage and current sensors for power systems [15]. The literature does not provide a clear methodology for measuring the current waveform using existing methods and no commercial equipment is specifically designed for recording lightning current through line surge arresters. The laboratory testing results show the good agreement of the proposed system measuring result with the measurement results of the conventional laboratory setup [11].

An important step in future research is the development of an Electromagnetic Transient (EMT) model of the lightning protection system. This model will simulate the transient behavior of lightning currents and their impact on surge arresters and the transmission network. By integrating the recorded data into the EMT model, we will be able to simulate different lightning strike scenarios and predict the system's response under varying conditions. This will assist in optimizing the design of lightning protection strategies and improving overall system resilience.

The real-time measurement system for monitoring transient currents could be enhanced in the future by integrating additional functionalities, such as battery status monitoring, alarms for critical events and power interruptions, and ambient condition monitoring. Special attention should be given to the installation of a high-speed camera aimed at capturing the tower where the measurement system is installed. This addition would provide valuable insights into whether the recorded event was caused by upward or downward lightning and confirm whether the strike occurred at the top of the tower or along the transmission line.

The proposed methodology is adaptable for capturing a wide range of transient events. However, achieving optimal accuracy requires tailoring the system hardware to the specific characteristics of each transient type—i.e., adjusting parameters such as the sampling rate and measurement range.

V. Conclusions

Nowadays energy utilities increasingly deploy real time measurements to monitor the conditions of the different equipment in order to minimize the interruption of operation, the time and costs of the maintenance and damage repair, but at the same time prolonging the life cycle of the assets. Development of real time measurement system for monitoring transient currents through line surge arresters is part of this contemporary trend. The most state-of-the-art in measuring sensors, communication and information technologies are implemented to monitor the operation of line surge arresters installed to the overhead line tower but also to measure the distribution of the lightning currents through the overhead line tower and phase conductors.

This paper analyses measurements that were obtained by the system installed on the site on the overhead line tower. While the measurement system was specifically designed for recording lightning events such is the one of the analyzed event, it has also successfully captured a switching transient during the grid restoration process. Both measurements demonstrated the functionality and effectiveness of the developed system.

VI. References

[1] Cigre WG C4.23 TB 839 - Procedures for Estimating the Lightning Performance of Transmission Lines – New Aspects, June 2021

[2] IEC 60099-4:2014 Surge arresters - Part 4: metal-oxide surge arresters without gaps for a.c. systems, June 2014

[3] CIGRE SC 33 WG 01, "Guide to Procedures for Estimating the Lightning Performance of Transmission Lines", CIGRE Technical Brochure 63, October 1991, 2021 Edition

[4] N. Watanabe, A. Nag, G. Diendorfer, H. Pichler, W. Schulz, V. A. Rakov, and H. K. Rassoul, "Characteristics of Currents in Upward Lightning Flashes Initiated from the Gaisberg Tower," IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 3, pp. 705-718, June 2019.

[5] F. H. Heidler, and C. Paul, "High-Speed Video Observation, Currents, and EM-Fields from Four Negative Upward Lightning to the Peissenberg Tower, Germany," IEEE Transactions on Electromagnetic Compatibility, vol. 63, no. 3, pp. 803-810, June 2021.

[6] M. Azadifar, M. Rubinstein, F. Rachidi, V. A. Rakov, G. Diendorfer, W. Schulz, and D. Pavanell, "A Study of a Large Bipolar Lightning Event Observed at the Säntis Tower," IEEE Transactions on Electromagnetic Compatibility, vol. 61, no. 3, pp. 796-806, June 2019.

[7] S. Kazazi, A. M. Hussein, and P. Liatos, "Evaluation of the performance characteristics of the North American Lightning Detection Network based on recent CN Tower lightning data," in *Proc.* 2015 International Symposium on Lightning Protection (XIII SIPDA), pp. 327-333, Sept. 2015.

[8] https://www.aldis.at/en/lightning-research/lightning-research-at-gaisberg/general/?ADMCMD_view=542

[9] C. Romero, A. Rubinstein, M. Paolone, F. Rachidi, M. Rubinstein, P. Zweiacker and B. Daout, "Instrumentation of the Säntis Tower in Switzerland for Lightning Current Measurements," International Journal of Plasma Environmental Science & Technology, vol.4, No.1, 2010.

[10] S. Grebović, I. Uglešić, A. Xémard, L. Diaz, S. Sinčić and L. Ćurin, "Line Surge Arresters' Monitoring System," in *Proc.* 2023 International Symposium on Lightning Protection (XVII SIPDA), Suzhou, China, 2023.

[11] S. Grebović, I. Uglešić, A. Xémard, V. Milardić, S. Sinčić and L. Diaz, "The principles of a new line surge arrester's transient current measurement system," Electric Power Systems Research, vol.223, 109633, Oct. 2023.

[12] M. Puharić, M. Mesić, S. Piliškić and M. Mijoč, "The Overvoltage Protection of the 110 kV Overhead Lines of the Island of Brač by the Line Surge Arresters Application," in *Proc.* CIGRE Colloquium on Lightning and Power Systems, Lyon, France, 2014.

[13] M. Mesić, S. Piliškić, I. Uglešić, B. Filipović-Grčić and B. Franc, "Performance of the Line Surge Arresters of the 110 kV Overhead Lines on the island Brač," in *Proc.* ICLPS, Bologna, Italy, 2016.

[14] S. Sinčić, S. Grebović, I. Uglešić and A. Župan, "Measurement of lightning current circulating in line arresters and through the transmission line tower," in *Proc*. 2024 CIGRE Paris Session, Paris, France,2024

[15] Cigre WG C4.61 TB 955 - Lightning Transient Sensing, Monitoring and Application in Electric Power Systems, January 2025