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# Automatic lightning stroke location on transmission lines using data mining and synchronized initial travelling

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ABSTRACT

The automatic location of lightning stroke impact point on transmission lines is one of the most crucial factors related to the behavior of Electric Power Systems, which can improve the swift recovery of electric power. The usual location of this phenomenon has been based on distance protection relays, which requires operation times of approximately one cycle. This paper presents a high-speed protection approach for the lightning-caused transient automated location on transmission lines or on ground. This work is based on the synchronized initial voltage-travelling waves at both ends of high voltage transmission lines. Lightning strikes at different sections along the 220 kV transmission line are detected at both protection relays by using an algorithm based on the ellipsoidal pattern previously presented in another research project. That methodology uses the projection of original signals. Thus, if these signals are located along the ellipsoidal pattern, the electric power system is operated under normal conditions. Unlike the aforementioned case, if the projected signals are located outside of the ellipsoidal pattern, it represents the presence of lightning strokes. After those signals are detected, initial voltage traveling waves measured by protection relays located at both ends of the transmission line are used in order to localize the lighting stroke impact point. At the instant that a lightning stroke hits either on the phase conductor or the ground, travelling waves propagate along the transmission line. Later on, depending on the impact point of atmospheric discharges, different time instances, which the travelling waves require to arrive at their respective ends, are determined. These times are used to calculate the distance from the impact point to both protection relays. Therefore, this paper presents a concise simple methodology for lightning stroke location on transmission lines or ground based in data mining to perform the signal detection and travelling wave times to determine the location along the transmission line. Simulations of lightning stroke signals on a 220 kV transmission line are carried out in the Alternative Transients Program (ATP). The results show that the behavior of the work is swift and effective in order to locate the impact point, especially in situations where flash current values, inception angles, distances from the impact point to protection relays, direct and indirect lightning and other factors, are considered, since it is immune to flash currents and other features. Finally, the proposed work could be considered as an alternative routine for protection relay algorithms



## 1. Introduction

Electric Power Systems (EPS) constitute a crucial element for the development of a region. Transmission Lines (TLs) allow electric power supply to thousands of consumers such as hospitals, school, factories and others. Currently, EPS are modern, but must be more secure and reliable in order to guarantee adequate electric power service under outages caused by external or internal causes. TLs supply electric power to customers that generally are in an exterior environment. These elements are highly exposed to different conditions and phenomenon that can produce outages. Within this context, weather can cause damage to TL systems, producing service interruptions and possible outages, where system parameters such as voltage, current, frequency, must be regulated and controlled [1]. Thus, lightning strokes on TLs are manifested in two ways. First, when lightning hits directly on the transmission tower and the second when the lightning hits the ground and induces an overvoltage on the insulator strings. EPS are most vulnerable to

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weather conditions. In this context, it is highly desirable to improve the TL reliability. Thus, the device known as Protection Relay is crucial for the proper behavior of these devices. The main roles of relay are to induce the secure detection, classification, location of faults or disturbances produced by different causes.

Lightning strokes are the main cause of power line outages, imposing a crucial impact on the quality of the electric power supplied. Based on data analyzed from a regional worldwide bibliographical review, it allows authors to conclude that LS exert great influence on outages. For instance, from 1984 to 2006 in United States, more than 933 outages were reported, of which, lighting stroke represents the third major cause in outages produced [2]. See Fig. 1. Moreover, several countries have suffered serious consequences. One example is Austria, where by using a lightning location system (LLS), operators determined that lightning strokes directly affect overhead lines [3]. Analyzing the outages of 25 TLs of 220 kV and 440 kV, revealed that more than 205 outages were related to the lightning discharges [4]. Other cases demonstrating that electric power is susceptible to lightning phenomenon occurred in the southeastern Amazonia in the state of Pará, where frequent outages have been attributed to this phenomenon. Thus, different outages have been produced in the Brazilian network [5,6]. This zone has the highest flash peak current magnitude compared to anywhere else worldwide [7,8]. In addition, based on the report regarding the ten severest blackout events that affected the population, in Brazil, a lightning stroke on a substation in the state of Bauru–Sao Paulo caused several 440 kV circuits to trip. More than 65% of population suffers effects of this blackout [9].

On the contrary, atmospheric discharges were the most important cause in the blackout produced in New York City and Ontario in July 1997 and June 1998, respectively [10]. Several cases of outages where the lightning stroke have been the cause are presented in Refs. [11–18]. Corresponding to protection relays, one of the ten most severe blackout events was produced in Brazil in 02-April-2011. The cause was a failure in an element corresponding to part of protection system, affecting approximately fifty-three million people [19].

Therefore, lightning is clearly a significant influence on EPS behavior, which has been seriously considered by different countries in order to search for strategies and ideas that could incorporate smart grids, automatization and other measures that allow for increasing the reliability and reducing the outages of EPSs caused by hazardous weather [20]. In this context, international suggestions have been directional for reducing weather-related outages such as Tree-Trimming Schedules [21], Undergrounding of Distribution/Transmission Lines [22], Implementing Smart Grid Improvements [23,24] among others.

In addition, studies have estimated that weather effects have a big cost on the EPS, being cost around of billion dollars. Thus, it is crucial develop or propose new policies, plans, actions and others for reducing the impact of this phenomenon. On the other hand, it is important to make plans, methodologies and other measures in order to strengthen and improve everything related to the electrical system. Therefore, increase power flow capacity and provide the best control over power system could increase the performance of EPS, providing the first step to increase the system flexibility and robustness, which can reduce the risk of outages. In this context, energy management system researches in order to control monitor and conserving energy has been proposed, which are crucial to reduce line power wastage and improve the reliability of electric power [25–32].

An EPS operates in steady-state when the variables describing voltages, currents, and others are periodical functions of time. However, it can be in a transient-state when the variables are suddenly changed by any disturbance. It changes from one steady-state to another [33]. Usually, the transient process in TL is produced by lightning, switching operation, and other variables. After transient disturbances on TL are produced, these changes are followed by traveling waves, which at first approximation can be treated as step front waves. For instance, when a LS hits a TL wire conductor, the induced overvoltage wave tends to divide into two halves, each going in opposite directions. When a voltage wave arrives at any element, such as an insulator string, it can cause a stress distribution, which is not uniform and may lead to the breakdown of the insulator [34]. Thus, LSs can cause permanent or temporary faults on TLs, independently if it is direct or induced LS. Currently, the TL isolation level is highly affected by atmospheric discharges, where localizing the impact point of this phenomena is crucial to the proper behavior of EPS. This argument alone would caveat the importance of developing methodologies related to LS impact point location.

Based on research review, traditional protection schemes and also those based on travelling waves, have usually been proposed to determine the common fault direction, omitting LS signals, which are crucial to the performance of EPS. Additionally, due to advances of ultra-high frequency bandwidth equipment, microprocessors and other technology, research has led to proposing schemes based on traveling waves.

In the instances when a lightning bolt hits on a TL or the ground, the protection relay must localize the impact point of this phenomenon. However, at the moment those techniques could suffer from drawbacks due to lightning strokes, which are indicated as follows:

The basic principle of the protection relays is based on Fourier, which uses the movement of a sampling window to analyze and extract information of input signals. However, it is well known, that operation time of Fourier filters is dependent on the length of the sampling window. Its operation time is usually 1 cycle. Moreover, when high frequency transient signals caused by lightning strokes are present; sampling windows longer than 1 cycle could be necessary to remove those unwanted components. However, longer sampling windows delay the operation time of protection relays. Therefore, transmission line protection relays based on phasor estimation, such as the distance protection, cannot always operate correctly due to lightning stroke effects on transmission lines. At the moment, the operating time of these relays often reaches 50–70 ms for lightning strokes impact point location. Conversely, in order effect proper behavior of this relay like speed, security and other variables, adequate settings must be established.

The impedance protective relay determines the distance from the lightning impact point to location of installation of protection relay based on the calculated impedance. Of course, these devices must fix settings based on the recommendations by the manufacturer of protective devices.

In Ref. [35], an analysis of lightning location on real transmission lines belonging to the CEMIG (Brazilian Energy Utility), using distance protection relays is presented. The analysis was done by using Real Time Digital Simulations (RTDS$^{TM}$) at SIEMENS AG's facilities (Erlangen–Germany). In this analysis, different lightning stroke cases were used to analyze the behavior of the protection relays, specifically its operation time. In this context, the protection relay behavior regarding the operation time and location error is one on one short line (23.9 km) and one long line (148.6 km), constructed around the city of Belo Horizonte. 134 simulations of lightning strokes with different conditions were realized and testing with the RTDS. Table 1 presents some results of simulations on work presented in Ref. [35].

Based on the 134 simulation, it can be determined that the operation time range of protection relay in order to localize the lightning stroke is about 13.8 ms–45.7 ms, respectively.

Based on the work presented in Ref. [35], it is clear that operation time of distance protection relays in order to analyze and localize