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# A specific modeling of ground protection system for wind power plants

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**Abstract**

This paper presents specific combined protection of grounding systems that can be applied for wind power plants. The proposed prototype design is a combination of the ferrite ring technique, surge arrester models, as well as voltage surge protector, which impacts dampen tension more effectively by building a dedicated line with a separate model. The proposed model is 100 m in width with a depth of 2 m from the soil which is based on the IEC-61643-12 study. The transmission line approach model is used to obtain a description of the behavior of lightning occurring in the soil. The simulation results show the proposed design can be applied effectively.


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*Keywords:* Wind power plants; Wind turbine; Transmission line; Voltage surge protection; Surge arrester; System grounding; Ground potential rise

## 1. Introduction

Wind energy is clean and renewable energy that is ideal for reducing the use of fossil fuels in electricity generation, which plays a very important role in life in this modern era [1]. One of the problems faced by this renewable energy generation is a natural phenomenon that cannot be predicted such as lightning strikes. By taking into consideration the condition of wind power plants (WPPs) that are usually located up in the mountains, high earth resistance and an open location that makes it very vulnerable to be hit by a direct lightning strike and may further cause system instability. In addition, if the system is currently working on its stability limit, more attention should be given to avoid potential transmission congestion [2].

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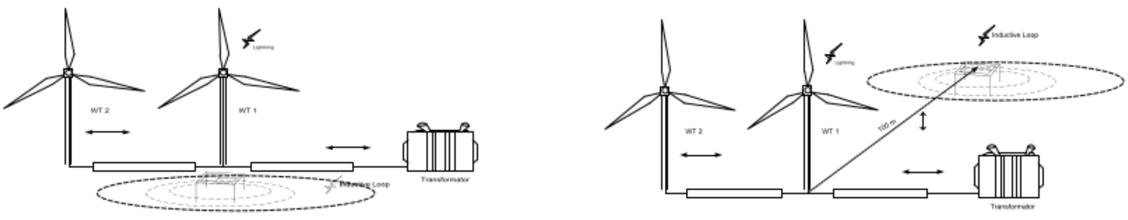
Generally, when a wind turbine is hit by a direct transient current that passes through each part of the turbine, it propagates throughout the equipment with a high voltage and current capacity. These events can aggravate the energy distribution system and cause total damage to WPP equipment [3]. Therefore it is necessary to design superior protection.

Another problem that arises is when the high current passes through the blade and tower. Voltages and currents accumulated beneath the feet of the wind turbine (WT) tower propagate in a direction and can infect other adjacent WTs. Induction produced by lightning with a very large capacity leads to an increase in the soil potential that can trigger a backflow. This situation can be worsened since the surge arrester (SA) that is earthed around the WT can operate in a reverse direction. To avoid this, the protection system should be designed effectively by prioritizing the separate ground, dampening the voltage surge protector (VSP) feedback as well as the proper use of the arrester model. In the literature, many authors have been discussing the risk of direct strikes on WPPs and the evaluation of grounding systems [4,5]. In this research, the transient behavior with the incorporation of various methods of transmission line (TL) approach, Ferrite ring, Pinceti model, and VSP is assumed. The purpose of this research is to design the combination of ferrite ring, Pinceti model, VSP to reduce equipment failure due to direct strike of lightning, dampen over-voltage and limit backflow with separated grounding method.

## 2. Problem formulations

This simulation is performed on 1 wind generator distributed on the final substation shown in Fig. 1(a), with a ground value of 10 $\Omega$, and 100 $\Omega$ and WPP placements are assumed in mountainous and rocky locations. All WPPs are connected with a 6.6 kV/ 66 kV grid transformer [6], with SAs inserted between the primary and secondary sides. Fig. 1(b) shows a specially constructed (proposed) route method to remove more voltage when a direct strike occurs by lightning. This method is proposed because of the magnitude of the light current at lightning which can induce a large induction of the WPP grounding system beneath the foot of the tower.




(a) (b)

**Fig. 1.** (a) The lightning direct strike lightning causes more stress on the basic foundation of WPP [7] (b) Implementation of separated land from WT [7].

As an approach to strengthening the lightning phenomenon protection in the case of strikes, for the first case usually more tension can be absorbed without much damage, in the second case after the occurrence of an over-voltage strike which is reversed due to the integrated grounding system around the WT and the more discharged high voltage this can be expressed in the equation.

$$U = M \times \frac{di}{dt} \tag{1}$$

### 2.1. Voltage surge protector (VSP) for WPP

This equipment is used as part of WPP protection, for additional special grounding combinations that are proposed as protection methods. Usually, this tool is used to provide installation protection on high buildings. Because of its ability to work as a breaker circuit (CB), hence this tool serves as an over-voltage breaker when there is a lightning strike [8]. The performance of VSP can be seen in Fig. 2.

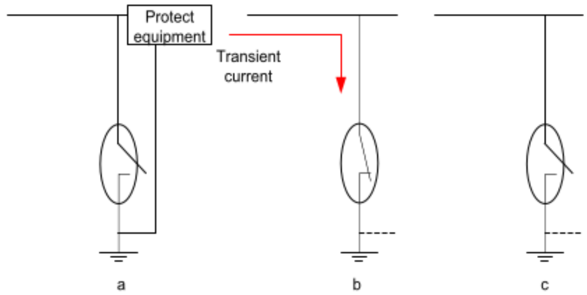



**Fig. 2.** VSP working system. (a) before transient overvoltage (b) during overvoltage (c) after overvoltage [8].

### 2.2. The arrester model

The arrester's selection to be used is based on its maximum operating voltage which can be seen in the electrical data of the ASEA Brown Boveri (ABB) [9]. Is expected to work continuously to protect the transformer from over-voltage [10]. The modified Pinceti et al. model of the IEEE is employed in the form of an equivalent circuit consisting of 2 non-linear resistances $A_0$ and $A_1$, separated by 2 inductances arranged in series with $L_1$ and $L_0$ [11]. Parallel resistance is added as a function of avoiding numerical errors in the circuit system, where R is 1 M$\Omega$ [12]. To calculate the value of $L_1$ and $L_0$, we use the following equations.

$$L_1 = \frac{1}{4}\frac{V_{r(\frac{1}{T2})} - V_{r(\frac{8}{20})}}{V_{r(\frac{8}{20})}} V_n \mu H \tag{2}$$

$$L_0 = \frac{1}{4}\frac{V_{r(\frac{1}{T2})} - V_{r(\frac{8}{20})}}{V_{r(\frac{8}{20})}} V_n \mu H \tag{3}$$

Where is $V_n$ is the voltage of the arrester in kV, $V_{r(\frac{1}{T2})}$ is the 10 kA fast front current surge $\left(\frac{1}{T2}\right)$ residual voltage. $V_{r(\frac{8}{20})}$ is the residual voltage at 10 kA current surge with 8/20 $\mu$s time referring to $V_{r(\frac{8}{20})}$ selected based on electrical data of the ASEA Brown Boveri (ABB) [9].

### 2.3. WPP grounding model system

The main basis of the WPP grounding system consists of conductors buried in the ground with a very strong concrete foundation. The outline of the conductor is connected to the electrical system in WPP as the grounding system [13]. The simplified transmission line (TL) approach used is shown in Fig. 3.

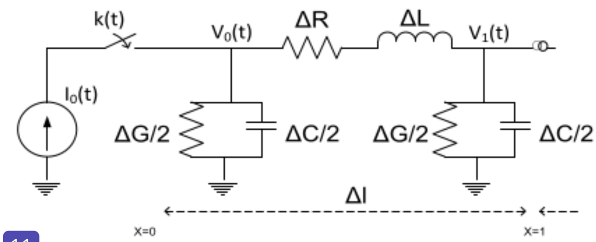


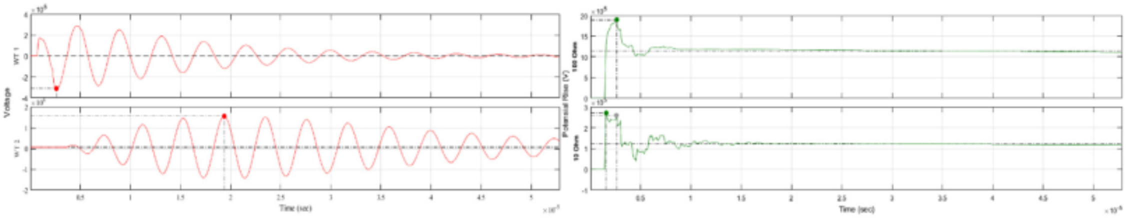

**Fig. 3.** Equivalent circuit of each conductor segment of $\Delta l$ length [4].

Where $\Delta$R is horizontal resistance in per-unit, $\Delta$L is horizontal the inductance in per-unit, $\Delta$G and $\Delta$C is the conductance with capacitance in per-unit. The distributions of the parameter are based on the state of the location and space. More details of the expression of the distributed parameters can be seen in [4] and the cable parameters are referring to [14].

## 3. Results and discussions

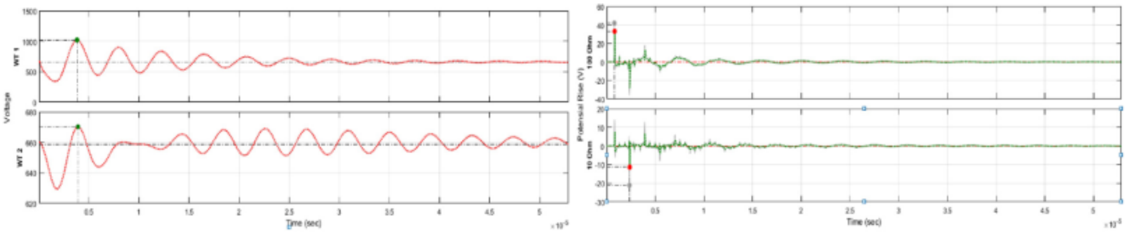
This study compares the simulation results between the conventional design and the proposed design method. The simulated response is a 51 kA direct lightning strike hit the transformer between WT 1 and WT 2, then observing the ground potential response after the strike by assuming the soil resistance of 10 $\Omega$ and 100 $\Omega$.

The simulation results showed a very significant difference by using the combination of protection, as can be seen in Figs. 4 and 5. Fig. 4(a) and (b) show the simulation results using the conventional design with a combination of protection, which only uses SA and VSP. The voltage on the recorded equipment system for WT 1 reaches up to 300 kV and for WT 2 reaches 17 kV. With earthing-centered at the foot of the tower, the potential value of soil caused by lightning recorded reaches 1.9 MV at 100 $\Omega$ and 270 kV soil resistance values at soil resistance value 10 $\Omega$. This may trigger a backflow for the grounding case between WT protections in one segment.



(a) (b)

**Fig. 4.** (a) lightning strike reaction to turbine control equipment (b) ground potential rises stricken around WPP.




(a) (b)

**Fig. 5.** (a) lightning strike reaction to WT's control equipment by using protection combination (b) Response GPR using a combination of protection.

Fig. 5 (a) and (b) show the recorded over-voltage on WT 1 that reaches only 1.1 kV and for WT 2 to 670 V. The soil potential drops from 1.9 MV to 40 V in case of the soil resistance value of 100 $\Omega$ and 270 kV to 15 V at resistance 10 $\Omega$. The results achieved are based on the combination of protection capabilities consisting of ferrite, VSP, SA's, and separate grounding systems. The interesting result is that the failure of each protection to cover each other and serve according to the capabilities of each separate earth system is expected as the main point to overcome the effects of backflow caused by lightning.

## 4. Conclusions

This combination of protection is designed to protect all existing equipment in WPP against overcurrent voltage and current well as the lightning reverse currents from the soil. The proposed soil resistance role leads to a soil resistivity response and refers to a high voltage wave peak increase with some fluctuations in the grounding system that may cause transient radiation effects to some nearby point. Restricting this separate earth path in line with VSP based on Eq. (1) can reduce the 99% radiation effects of transients. Other planned protection such as ferrite rings and SAs can reduce the voltage and current by about 98%. With this combination technique the performance of the protection is not emphasized on the SA's alone but rather centered to a more effective transient disposal line.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

The data that has been used is confidential.

## Acknowledgment

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