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A Surge Absorber for the Sri Lankan Distribution Substation to Mitigate Lightning Damage

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***Abstract* - Due to high grounding resistance and soil conditions surge arrester performance decreases. Even though in installation the standard earthing resistance is achieved with time the earthing resistance would be at a high value. When a high voltage arrives at the surge arrestor it discharges the excess voltage by providing low impedance shunt path to ground and providing protection for the transformer. Because of high impedance path the voltage would not divert to the ground and carry on its original path and damage the transformer. Therefore, for areas with high earthing resistances protection must be improved for distribution substations. Throughout this research method of reducing the peak and the rate of rise of surge was analyzed for providing extra protection for the transformer. The selected substation was AV047 it was selected because of lightning occurrence in the selected area, Replacement of the transformer due to damages cause by overvoltage surges and high earthing resistance of the installed substation. Usage of the surge absorber for additional protection was investigated throughout the research. By this method proposed by the research group it was able to provide the sufficient protection for the transformer during surge conditions and reduce the peak and the rate of rise of the surge. Losses of the surge absorber were also analyzed at different conditions. Further an algorithm was developed so that the surge absorber could be implemented to any MV and HV networks for protection of the transformer.**

Keywords: Surge absorber, Earthing Resistance, Transformer, Surge.

I. INTRODUCTION

Lightning over voltages is one of the main reasons for transformer failures and, sometimes it can result in damages to consumer electronic equipment connected to the power distribution network. It is known that lightning strikes on overhead lines are the main cause of failure in medium voltage distribution system [1]. According to the studies that have been done, distribution transformers can be damaged by direct strokes and indirect strokes [2]. To study the behavior and results of lightning over voltages, high frequency transformer models can be used.

Due to lower basic insulation levels in the electrical distribution systems, low voltage networks are often affected by lightning surges that enter from transmission and distribution networks through distribution transformers. Surges can enter the power system by various coupling mechanisms, like from direct strikes to the systems or from induced voltages from a nearby strikes [3,4]. The distribution network consists of a step-down transformer and radial networks towards the consumers. Over time, people have expanded their work, and triggered lightning has been used to apply practical lightning circumstances to the power system, and the surge propagation in the MV system has been achieved [5]. In Sri Lanka, reliability of distribution network mainly depends on transformer protection. The magnitude, and the frequency of the surges at the transformer secondary to the final consumer service point depends on the circuit model of the distribution transformer.

Oscillatory shape of the surge is created by the coupling of winding inductance and capacitances, and to understand the phenomena, different circuit models are proposed [6,7]. But analyzing with complicated models can be troublesome since it can be unvarying and takes a lot of time. A three phase transformer model has been used to investigate the influence of mutual coupling of LC components, with analysis conducted in both the time and frequency domains [6,7].

The three-phase transformer model provides a clear picture of the surge's consequence when applied to a distribution network with many power transformers. During the rainy seasons (April/May and November/December), lightning strikes often in Sri Lanka, inflicting significant damage to the MV and LV systems. Surges can ruin energy meters, residual current devices, and electrical equipment at the consumer level. We must ensure that the main side's protection fulfills our expectations because the secondary side of the distribution transformer is not normally shielded against lightning surges.

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In Sri Lanka, each year considerable number of distribution transformers is damaged due to lightning surges. The existing surge protection system of distribution substation mainly has surge arrestors which divert the excess voltage to the earth, to protect the transformer. But in many areas, it is hard to achieve and keep the earthing resistance at the standard value of less than 10 ohms due to soil conditions, climate and seasonal changes, temperature etc. Higher earthing resistance affects the performance of the earthing system of distribution substation which leads the transformer to be vulnerable against overvoltage transients. Therefore, the need for an improvement of surge protection in distribution substation, is emerged.

In this research, the aim is to mitigate lightning damages to distribution substation transformers, which is discussed to be achieved by mainly introducing an inductive element before the surge arrestors in distribution substation. Since Sri Lankan power distribution network yearly suffers a substantial amount of loss of transformers due to lightning surges, it is deliberated to gather information about substations that are repeatedly damaged due to lightning and the parameters of those existing distribution substations, using the CEB database.

Therefore, using those parameters, such distribution substation is modelled with its existing surge protection method, to analyze the performance and effectiveness of the current surge protection method, against a modelled surge. To reach the main goal of protecting distribution substation against lightning surges by using an inductive element before the arresters, it is essential to determine an inductive element which is capable of reducing the peak of the overvoltage caused due to lightning surge, so that surge arrester can easily normalize the voltage by diverting the remaining excess voltage to the earth. Therefore, mainly the possibility of using a surge absorber which consists of an inductance and a resistance is investigated, through this research, in an effective manner. After choosing a proper inductive element that fits to the requirements, it is intended to model a substation with the protection of both surge arresters and the inductive element and observe its ability of reducing the peak of the over voltage transient and ultimately compare it with the competence of reducing the same over voltage transient by the previously modelled existing substation with just the protection of surge arrester. Advantages and disadvantages of using an inductive element before the arresters is proposed to talk through, since adding a whole new element to a distribution network can affect its performance in so many ways, both in positive and negative ways. Although if using an inductive element helps to mitigate lightning damages, it is important to learn and explore the effects of such element on other elements of the distribution network, power distribution, transformer life span, and economic efficiency which is considered as a main objective to be achieved in order to complete the research successfully. Further it is expected to design and develop the simulated surge absorber which fits to the requirements and implement it in high voltage laboratory to imply its capability of reducing the peak of the surge, in a convincing manner.

Ultimately, through this research project it is expected to observe and determine the protection provided by the surge protection system in distribution substations which suffers lots of damage due to lightning, after using an inductive element (surge absorber) before the arresters, as a support to the arresters to normalize the overvoltage transient immediately without causing severe damages and develop and design the said element for physical demonstration to emphasize its usability in the current distribution network.

II. METHODOLOGY

According to CEB data gathered Avissawella region (DD3-CEB) in Sri Lanka has a high lightning damage occurrence rate to transformers. From the Avissawella region the selected substation was the AV047.According to the data gathered it was found out that the particular substation AV047 is constantly getting damaged due to lightning. And the relevant data of the substation was found which are the kVA rating, fault levels, zero sequence impedance, positive sequence impedance, 33kv transmission line data and the source details.

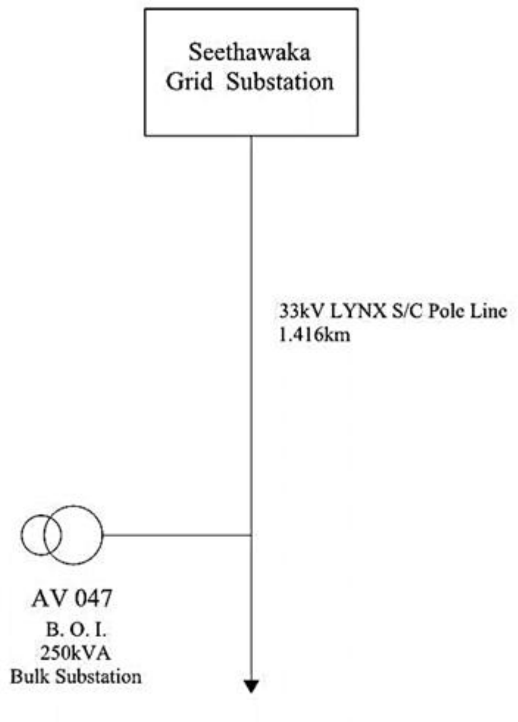

Figure 1: AV047 Substation

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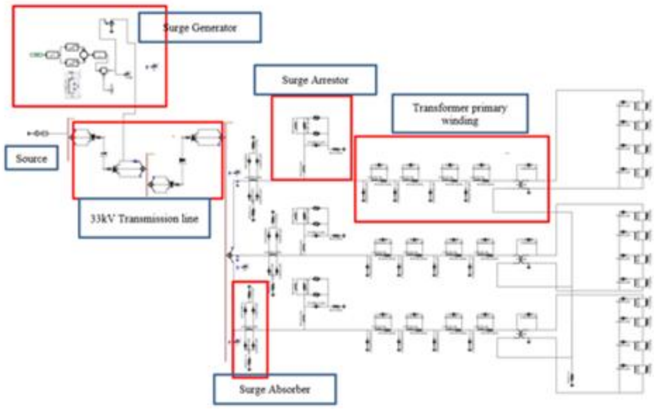

Figure 2: AV047 Substation

This distribution substation is modelled in PSCAD, and it is shown in figure 2.

Table I: Inductance, Capacitance and Resistance Value of the Surge Absorber

Inductance	0.4555 mH
Capacitance	29.3 pF
Resistance	0.13 ohm

The derivation of surge absorber model is required as for a method to mitigate the lightning damages caused to the distribution substation. It has an air cored inductor which can be connected with the line in series and a metal cylindrical dissipator surrounding it. The metal cylinder is connected to the earth, so it is also known as the earth metallic dissipator. Using the Ferranti surge absorber, we can minimize the sharpness of the travelling wave. When the surge wave reaches the Ferranti surge absorber energy is transmitted from the coil to the dissipator the energy is being absorbed. After being expanded to the dissipator it is then expanded as heat. Using Solution Setups in Ansys Maxwell software simulations and theoretical methods we found the resistance capacitance and inductance values of the said inductor and the number of capacitances of the Ferranti surge absorber.

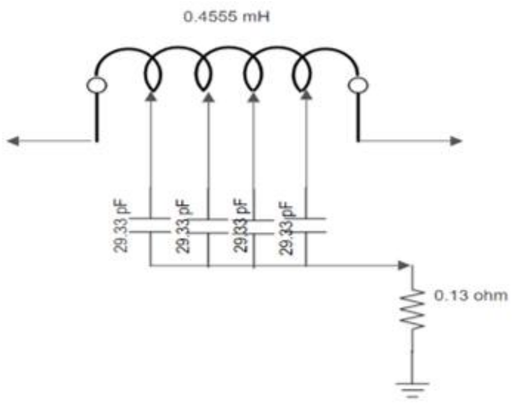

Figure 3: Derived Equivalent Circuit of Surge Absorber

III. RESULTS AND SIMULATIONS

Basic Insulation Level (BIL) of the distribution transformer = 170 kV. However, peak value of all voltage waveforms without the surge absorber is greater than 170 kV, in both scenarios, (i.e., when voltage surge and current surge is introduced) causing damages to the distribution transformer during lightning.

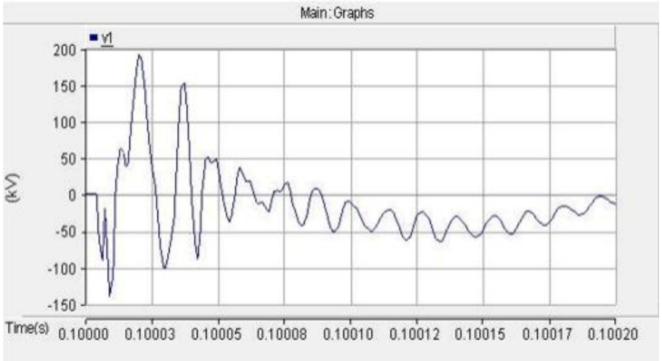

Figure 4: Voltage Waveform before Surge Arrester without the Surge Absorber when a current surge is introduced

Hence, usage of the surge absorber has drastically reduced the peak value as shown in figure 5, figure 7, figure 9, and figure 11.

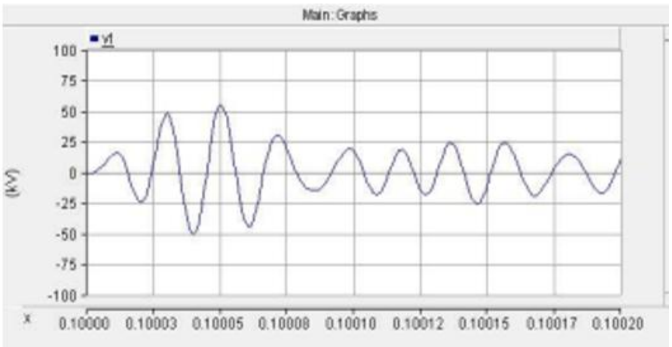

Figure 5: Voltage Waveform before Surge Arrester with the Surge Absorber when a current surge is introduced

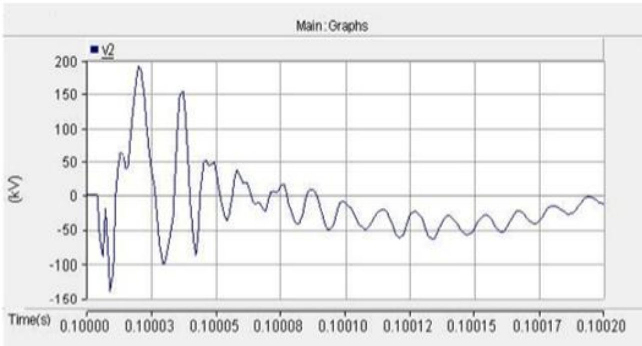

Figure 6: Voltage Waveform of the Start of the Outermost Layer of the HV Winding of the Transformer without the Surge Absorber when a Current Surge is introduced

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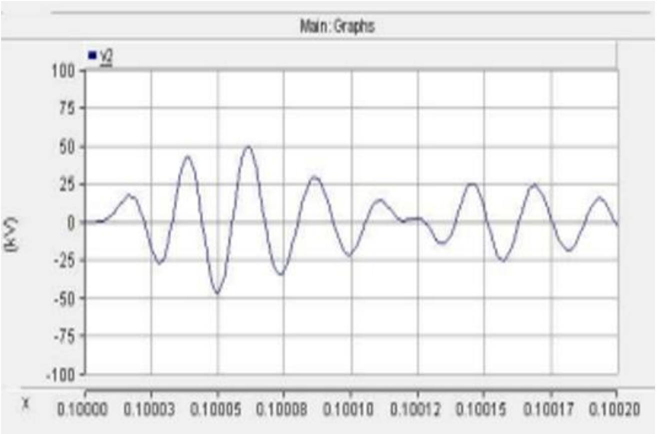

Figure 7: Voltage Waveform of the Start of the Outermost Layer of the HV Winding of the Transformer with the Surge Absorber when a Current Surge is introduced

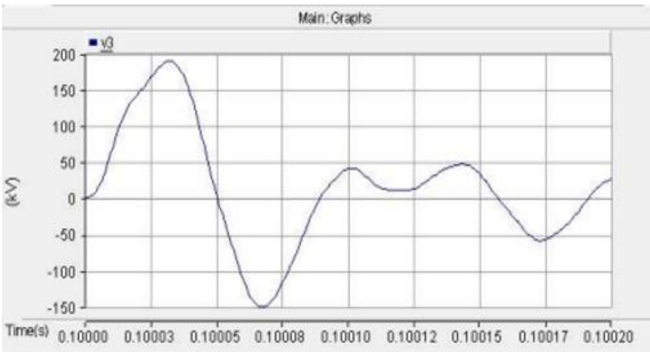

Figure 8: Voltage Waveform before Surge Arrester without the Surge Absorber when a Voltage Surge is introduced

Figure 9: Voltage Waveform before Surge Arrester with the Surge Absorber when a Voltage Surge is introduced

Analysis of the eddy current losses was done to investigate whether the surge absorber is possible to be used during steady state condition and during a surge.

IV. CONCLUSION

It was observed that in Sri Lanka more than 28 per cent of transformer failures occur due to lightning damages. The existing surge protection system at a distribution substation mainly consists of the surge arrestor. Surge arrestor is used to discharge the excess voltage by a low impedance current path. By that it provides the required protection for the transformer. It was identified that in Sri Lanka it is hard to achieve the standard earthing resistance of 10 ohm or less for the grounding of the surge arrestor earth electrode because of soil conditions, climate and seasonal changes and temperature.

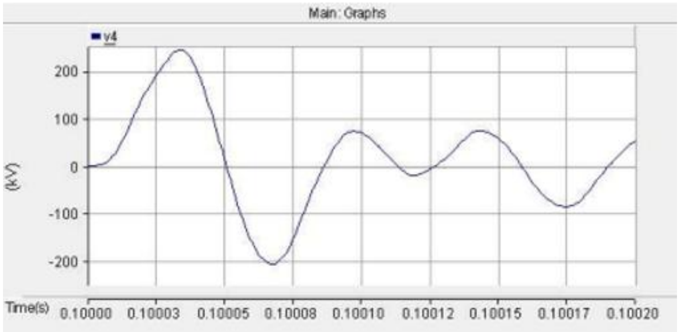

Figure 10: Voltage Waveform of the Start of the Outermost Layer of the HV Winding of the Transformer without the Surge Absorber when a Voltage Surge is introduced

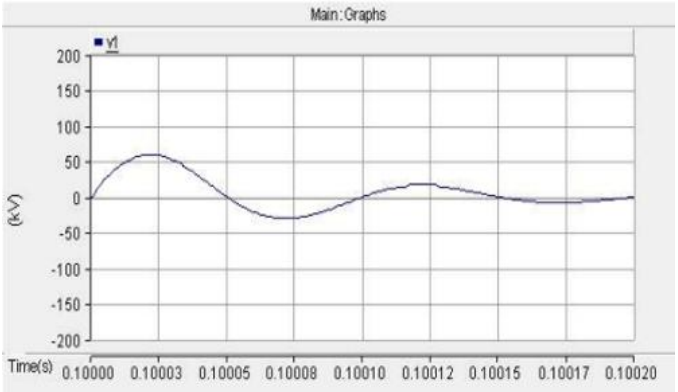

Figure 11: Voltage Waveform of the Start of the Outermost Layer of the HV Winding of the Transformer with the Surge Absorber when a Voltage Surge is introduced

Higher earthing resistance affects the performance of the surge arrestors thus improvement for the current surge protection is required. Throughout the research firstly current existing substation (Avissawella AV047) was modelled and its current surge protection systems capability of mitigation surges was analyzed. It was identified under the current grounding resistance at 50.5 ohm the substation is at risk of getting damaged by surges. Further it was also identified that the consumer side is also at risk of surge damages since about 600V of peak can be observed at the secondary side of the transformer. Firstly, as a solution the feasibility of using an inductor and the reduction of the peak and rate of rise was analyzed and it was identified that reduction of the peak is low but a steady state power loss can be seen. So, using of the surge absorber as the protection method was analyzed. Throughout the literature review it was identified that no equivalent circuit of the Ferranti surge absorber was yet to be

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derived. So, a main focus of this research was to derive the equivalent circuit of the surge absorber. Using Ansys maxwell software the surge absorber was modelled according to the standards of coils and the metal sheet. Solution setups Magnetostatic, Electrostatic and DC conduction was used to derive the equivalent circuit of the surge absorber. It was verified that the surge absorber has an inductance, four capacitances and a resistance. Using the model, the parameters for the surge absorber equivalent circuit was derived for the 33kV line substation protection. Using the equivalent circuit, the improvement of protection was analyzed using the PSCAD model and it can be said that the protection of the substation has been improved drastically. It can be clearly observed that the peak is reduced, and the rate of rise is also reduced by the derived surge absorber. The surge absorber was modelled to reduce eddy current effects by modeling the steel sheet thin and by doing that making the effective resistance of the sheet high. Using Ansys maxwell losses in the surge absorber model was analyzed and it was identified that during the surge phenomena low hysteresis losses and ohmic losses are occurred. It was also identified that steady state losses are at a minimum. Further a multiple run was implemented to analyze the performance of the surge absorber with various grounding resistances, voltages and frequency. As stated previously no equivalent circuit was derived until now of the surge absorber so an algorithm was developed to derive the parameters of the surge absorber using that required parameters can be easily obtained for any system voltages. So, this can be implemented for protection of 11kV, 132kV and 220kV systems. Further by analyzing the results it can be concluded by saying that the surge absorber is a suitable application for 33kV substations with high surge damaging occurrence to mitigate lighting damages.

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