SSRG International Journal of Electronics and Communication Engineering Volume 7 Issue 3, 22-28, March 2020
ISSN: 2348 – 8549 /doi:10.14445/23488549/IJECE-V7I3P104

Design an Automatic Switching of Lightning Arrester to Control Both Sides of Transformer

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Received Date: 18 February 2020
Revised Date: 25 March 2020
Accepted Date: 31 March 2020

Abstract: *This study focuses on protecting electrical distribution line equipment against lightning strikes in the Mbeya region. The distribution line equipment of the Mbeya region has been suffered from lightning strikes. This equipment includes distribution transformers, reactors, switchgear, and line insulators. The study aimed to review the existing lightning protection system in the Mbeya region and suggest possible ways of improving them. The study was conducted in five major areas of the Mbeya Region: Mbeya town, Iyunga, Igurusi, Songwe, and Chimala. Data were collected through site visitation as well as field measurements. It was revealed that in the Mbeya region, the percentage of the transformer without lightning arrestors ranges from 12.5% to 25%. About 66.7% of distribution lines of 33kV have got no overhead ground wire for protection against lightning. Not only that but also earthing resistance at distribution transformers was unfulfilling the standards for protection against lightning strikes. The study found that almost all distribution transformers in the Mbeya region are protected by surge arrestors on the primary side, leaving the secondary side unprotected. It is recommended that the transformer must be protected from lightning strikes and traveling waves by surge arrestors on both the primary and secondary sides. The primary distribution lines should be protected with overhead ground wire since they are most likely to be stroked by direct lightning strikes. The grounding system should be improved to meet the recommended standards for the protection of the substation.*

Keywords: *Distribution transformer, surge arresters, and lightning strikes*

I. INTRODUCTION

Transient overvoltages can be generated at high frequency (load switching and lightning). When a lightning surge travels along the power line to the transformer, the current surge is diverted through the arrester. In the case of overhead distribution lines, a stroke doesn't need to contact the line to produce dangerous equipment overvoltages. This is so because "induced voltages" caused by the electrostatic field's collapse with a nearby stroke may reach values as high as 300 kV [1]. When powerful lightning or surge reaches or strikes a particular electrical system, it damages the whole system and any electrical devices connected to the system. Electrical devices work at a certain voltage range. When these devices receive a voltage higher than the specified, they blow up or get damaged[2]. During lightning, a surge current is produced, which continues to flow until the system is damaged. After this situation, the feeder is de-energized from the system. Lightning affects all transformers within the feeder as they are connected in parallel. Transformers will not operate, and it becomes difficult to know where the problem or fault occurs to carry out repair and maintenance. The study's main objective was to design a circuit for automatic switching of lightning arresters to control both primary and secondary sides of the transformer after the powerful lightning. To accomplish the main objective, the following are the specific objectives:

- To identify various types of lightning arresters.
- Designing the circuit that can protect both sides of the transformer against lightning

II. LITERATURE REVIEW

Electrical systems protected by a Lightning arrester do not get damaged because the arrester ensures that the high voltage does not get into the electrical system [3]. Lightning is the main reason for outages in transmission and distribution lines [4]. When lightning strikes a power line, it is like closing a "big switch" between a large current source and the power line circuit. The sudden closing of this "big switch" causes an abrupt change in the circuit conditions, creating a transient. The research work has been done designing and developing a novel Distribution Automation System (DAS) in an open-loop customer-side distribution system [5]. The lightning arrester does not absorb all of the high voltage that passes through it. It simply diverts it to the ground, the voltage that passes through it. This operation's reality remains that arrester's success in diverting lightning or high electrical surges through the Metal Oxide Varistor (MOV). MOV is a semiconductor that is highly sensitive to voltage. At normal voltages, the MOV works as an insulator and does not allow current to pass through. At high voltages, the MOV acts as a conductor. It works as a switch that is opened when there are a standard AC voltage and a closed switch when lightning or high voltage is present. The amplitude of this voltage is higher than its normal level, but the frequency is the same as it was in normal condition. According to [6], provide overexcitation protection for power transformers through a Volts/Hz element that calculates the ratio of the measured voltage to the frequency per unit of the nominal quantities. Overvoltage in the system causes an increase in stress on the insulation of the transformer. When the AC line frequency reduces in a power system network, then the magnetic flux in the core increases the effect are more or less similar to that of the overvoltage.

A. Lightning Arresters

The typical lightning arrester has a phase (high-voltage) terminal and a ground terminal. Lightning arrester diverts the abnormal high voltage to the ground without affecting the continuity of supply. It is connected between the line and Earth in parallel with the equipment to be protected at the substation. The arrester should be connected to the ground to a low resistance for effective discharge of the surge current. The arrester should be mounted close to the equipment to be protected and connected with the shortest possible lead on both the line and ground side to reduce the leads' inductive effects while discharging large surge current. The equipment's insulation can be protected if the shape of the voltage and current at the diverter terminal is similar to the shape shown in figures 1 and 2, respectively.

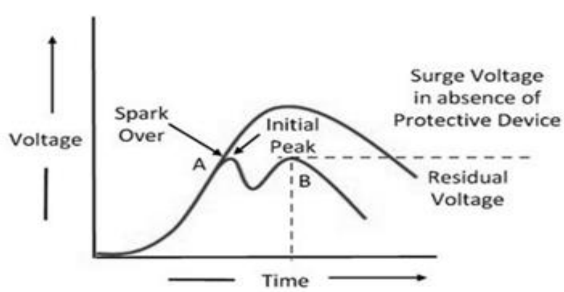

Figure 1:Voltage Characteristics

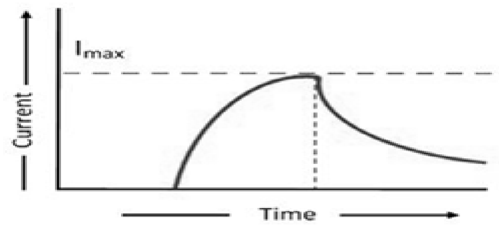

Figure 2: Current characteristics

The lightning stroke duration is usually less than a couple of hundred microseconds, as shown in Figure3. The industry-accepted 8 ×20 current wave is shown in figure 3 as a reasonable approximation of a lightning surge [7].

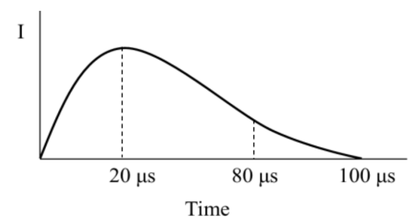

Figure3: Time Duration of a Typical Lightning Surge.

B. Rod Gap Arrester

It is a very simple type of diverter and consists of two 1.5 cm rods bent at right angles with a gap in between. One rod is connected to the line circuit, and the other rod is connected to Earth. The distance between the gap and insulator must not be less than one-third of the gap length so that the arc may not reach the insulator and damage it. Under normal operating conditions, the gap remains non-conducting. On the occurrence of a high voltage surge on the line, the gap sparks over, and the surge current is conducted to Earth. In this way, an excess charge on the line due to the surge is harmlessly conducted to Earth. Figure 4 shows the rod gap across the bushing of a transformer.

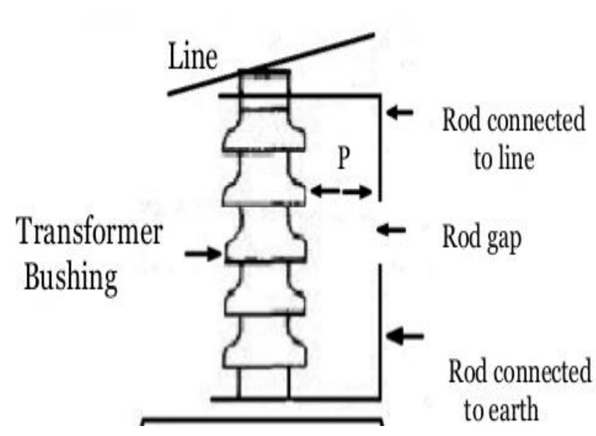

Figure 4 Rod Gap Arrester

C. Metal Oxide Arrester

The MOV arrester is the arrester usually installed nowadays. The metal oxide arresters are without gaps; this “gap-less” design eliminates the high heat associated with the arcing discharges. The MOV arrester has a two-voltage rating, duty cycle, and maximum continuous operating voltage, unlike the silicon carbide that just has the duty cycle rating. A metal-oxide surge arrester utilizing zinc-oxide blocks provides the best performance, as surge voltage conduction starts and stops promptly at a precise voltage level, thereby improving system protection. Typically, the residual voltage for an impulse current having a front time equal to 1 µs is 8{12 %} higher than that predicted for an impulse current having a front time equal to 8 µs. The residual voltage for longer time-to-crests between 45 µs and 60 µs is 2{4 %} lower than that of 8µs current impulse [8]. To reproduce the Metal Oxide (MO) surge arrester dynamic characteristics mentioned previously, many pieces of research have been done on modeling and simulation of MO surge arresters [8]. Failure is reduced, as there is no air gap contamination possibility, but there is always a small value of leakage current at the operating frequency. Duty cycle testing of an arrester is performed by subjecting an arrester to an AC rms voltage equal to its rating for 24 minutes. During which the arrester must be able to withstand lightning surges at 1-minute intervals. The maximum continuous operating voltage (MCOV)rating is usually 80 to 90% of the duty cycle rating [9]. The metal oxide arrester is indicated in figure 5.

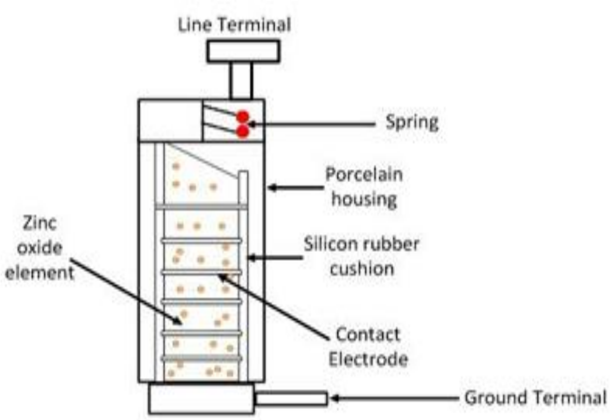

Figure 5:Metal Oxide Arrester

D. Valve Type Arrester

Valve type arresters incorporate non-linear resistors and are extensively used on systems operating at high voltages. It consists of two assemblies’ series spark gaps and non-linear resistor discs in series. The non-linear elements are connected in series with the spark gaps and Earth. Under normal conditions, the normal system voltage is insufficient to cause the breakdown of air gap assembly. On the occurrence of an overvoltage, the breakdown of the series spark gap occurs, and the surge current is conducted to Earth via the non-linear resistors. Since the magnitude of surge current is very large, the non-linear elements will offer very low resistance to the surge passage. The result is that the surge will rapidly go to Earth instead of being sent back over the line. When the surge is over, the non-linear resistors assume high resistance to stop the flow of current. The valve type arrester is shown in figure 6

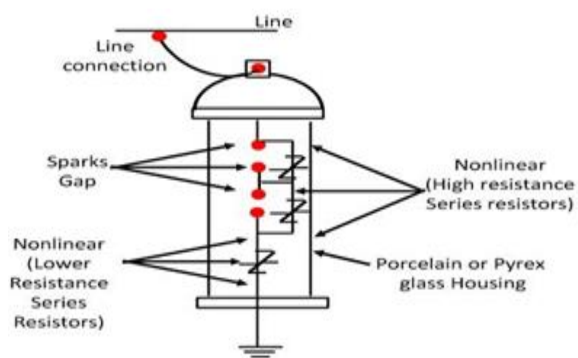

Figure 6: The Valve Type Arrester

E. Types of Lightning

Although lightning is thought of as a bolt that crashes to the Earth from the sky, most lightning happens inside a cloud, but sometimes it happens between the cloud and the ground. Lightning can strike the ground or hit inside clouds or the air. According to the United States National Severe Storm Laboratory, there are five to ten times as many lightning flashes inside clouds as there are cloud-to-ground strikes. Types of lightning include Cloud to Ground Lightning, Intra-Cloud Lightning, Cloud-to-Air Lightning, Ground-to-Cloud Lightning, and Inter-Cloud Lightning [10].

F. Cloud to Ground Lightning

Lightning occurs between the cloud and the ground. As the negative charge grows inside a thunderstorm’s base, positive charge begins pooling within the Earth’s surface below, shadowing the storm wherever it goes. Almost any grounded object or organism under a thunderstorm may attract a stepped leader, but lightning is lazy, so the closer, the better. Trees, tall buildings, towers, and antennas are favorite targets, and contrary to folk wisdom, lightning can strike twice. This is responsible for nearly all cloud-to-ground lightning, shown in figure 7

Figure 7:Cloud to Ground Lightning

G. Intra-Cloud Lightning

The most common type of lightning happens completely inside the cloud, jumping between different charge regions in the cloud. Intra-cloud lightning is sometimes called sheet lightning because it lights up the sky with a ‘sheet’ of light. All or parts of the actual channel may be obscured inside the cloud and may or may not be visible to an observer on the ground. Intra-Cloud lightning is shown in figure 8.

Figure 8: Intra-Cloud Lightning

H. Cloud-to-Air Lightning

Lightning occurs when the air around a positively charged cloud top reaches out to the negatively charged air around it. All cloud-to-ground lightning strikes contain ‘cloud-to-air’ components in the many branches that extend away from the main channel and terminate abruptly in mid-air. Cloud to Air Lighting is indicated in figure 9

Figure 9: Cloud to Air Lighting

I. Ground-to-Cloud Lightning

Ground-to-Cloud lightning (sometimes called Upward-moving lightning) is a discharge between cloud and ground initiated by an upward-moving leader originating from an object on the ground. Ground-to-Cloud lightning (GCL) strikes are common on tall towers and skyscrapers. GCL can also be either positive or negative in polarity. Lightning that demonstrates branching upward indicates a ground-to-cloud flash, though some upward-moving lightning is branchless below the cloud base. Ground-to-Cloud Lightning is shown in figure 10

Figure10: Ground-to-Cloud Lightning

J. Inter-Cloud Lightning

Lightning occurs between two or more separate clouds. Also known as Cloud to Cloud lightning

III. METHODOLOGY

This part describes the methodology adopted in the study. It describes the study area’s location, data collection, and other necessary information from the field and transformer with both primary and secondary lightning protection. Lightning Arrester (LA)and

Distance of Lightning Arrester (DLA) from the protected transformer.

A. Data collection

The study was conducted in the TANESCO Mbeya region. This area was selected because it is one of the regions most affected by lightning strokes in Tanzania. During data collection, the researcher was involved in obtaining several defective Lightning Arresters and Transformer burnt by lightning yearly, earth resistance at the different substation (Distribution substation), and general observation of protection schemes of distribution Transformer.

B. Data Analysis.

The data collected was subjected to editing, classification in terms of each specific objective's needs, tabulation, and computation to enhance analysis and interpretation.

IV. DATA PRESENTATION, ANALYSIS, AND DISCUSSION OF THE RESULTS

This part describes in detail all the mathematical analysis of the components together with circuit design and appropriate circuit components values for the entire system

A. Transformers Burnt by Lightning

The transformers burnt by lightning for five years under study were 40. The distribution of these burnt transformers yearly from 2015 to 2019 is shown in table 1. From table 1, it was revealed that large numbers of transformers were burnt in 2017 (25%).

Table 1: Number of Transformer Burnt by Lightning from 2015 to 2019

Year	Number of transformers	Percentage
2015	9	22.5 %
2016	7	17.5 %
2017	10	25 %
2018	9	22.5 %
2019	5	12.5 %
Total	40	100%

Source: TANESCO MBEYA, 2019

B. Number of Defective Lightning Arrester by Lightning.

Data covering five years from 2015 to 2019 of defective Lightning Arresterby lightning was analyzed to find the percentage of defective Lightning Arrester yearly from the total number of defective Lightning Arresters. The total number of defective lightning arresters for five years was 30. Percentage of defective Lightning Arrester was given by

$$\% = \frac{\text{Defective Lightning Arrester yearly}}{\text{Defective Lightning Arrester for five years}} \times 100\%$$

The analysis in percentage is as indicated in table 2. The analysis indicates that the highest percentage of defective lightning arresters occurred in 2015, which is (30%).

Table 2:Number of Defective Lightning Arrester.

Year	Number of Lightning Arrester	Percentage
2015	9	30 %
2016	6	20 %
2017	4	13.3 %
2018	8	26.7 %
2019	3	10 %
Total	30	100%

C. Protection of Primary Distribution Line

The study conducted on the primary distribution line, which is connected to the distribution transformer's primary side, revealed that most of the lines are not protected by overhead ground wire. Table 3 shows protected and unprotected feeder.

Table 3: Primary Distribution Line Protected by Overhead Ground Wire

S/N.	Name of the line (Feeder).	Rating.	Observation.
1.	Tukuyu feeder.	33kV.	Not protected
2.	Makete feeder.	33kV.	Not protected
3.	Chunya feeder.	33kV.	Not protected
4.	Mbalali feeder.	33kV.	Not protected
5.	Sae feeder.	33kV.	Protected
6.	Inter-connector feeder.	33kV.	Protected

From table 3, there are four (4) feeders out of six (6) observed to be unprotected, and only two feeders are protected. The unprotected feeders are equal to 66.7% of the total feeders investigated.

D. Designed Circuit Diagram of the Proposed System

The designed circuit diagram consists of two transformers; one distribution transformer is connected with the lightning arrester, and the second transformer is for supplying power to the rectifier circuit. The circuit has a control unit comprising a microcontroller, voltage/current sensor, and switching circuit for controlling the lightning arrester in case of transient voltage caused by lightning, as indicated in figure 11.

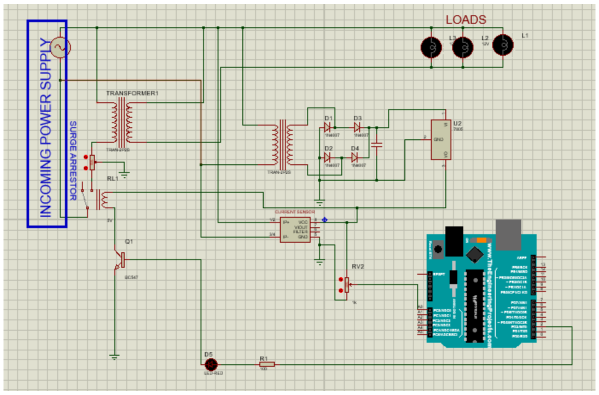

Figure 11: Designed Circuit Diagram of the Proposed System

E. The Operation of Designed Circuit Diagram of the Proposed System

This circuit is used to protect the transformer against lightning. The circuit is connected to the incoming power supply through arresters which is for grounding the excessive voltage. The signal flows to the current sensor direct for transient voltage or over voltage, and it will send that signal to the microcontroller. Here, the microcontroller will give the output. If there is over current, it produces a high signal that will go directly to the transistor, which is a switch, and hence activates the magnetic circuit that opens the arrester. If there is no signal, the transistor and relay are off; hence the arrester will operate normally. The operation of the designed circuit diagram is as shown in figure 12

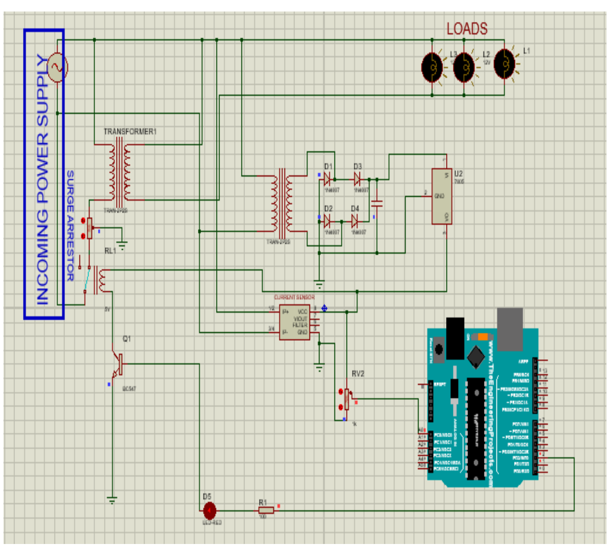

Figure 12: The Operation of Designed Circuit Diagram of the Proposed System

CONCLUSION

In this paper, the designed system for protecting the transformer on both sides against lightning is based on a microcontroller. The simulation result shows that when lightning arresters act as an insulator, the three lightings are ON. When the lightning arrester acts as a conductor, the lightings are OFF. The assessment observed that there was a violation of the standards of protection and absence of protective equipment. The findings revealed that in the Mbeya region, the percentage of transformer with no arrestors ranges from 12.5% to 25%. About 66.7% of distribution lines of 33kV have got no overhead ground wire for protection against lightning. This leads to failure when there are transient voltages on the transformers and hence causes burn of the transformer and outages to the concerned feeder's customers. Therefore, the protection made reduce the outages and time consumed by TANESCO to carry out maintenance.

ACKNOWLEDGEMENT

This work would not have been the same without endurance, encouragement and continuous consultations, and valuable contributions from TANESCO-Mbeya.

LIST OF ABBREVIATIONS AND ACRONYMS

DAS	Distribution Automation System
GCL	Ground-to-Cloud Lightning
IEEE	Institution of Electrical and Electronics Engineers
LA	Lightning Arrester
DLA	Distance of Lightning Arrester
MCOV	Maximum Continuous Operating Voltage
MO	Metal Oxide
MOV	Metal Oxide Varistor
TANESCO	Tanzania Electrical Supply Company

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