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# A Novel Method to Improve the Residual Life of Switchgear by Reducing the Impact Caused by Thermal and Mechanical Stresses Produced Due to SLG Cable Faults in Electrical Substations

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**ABSTRACT**

From the studies carried out in the field of power systems, it is found that the single line to ground fault is more common and produces severe electro-mechanical and thermal stress on the connected equipment. In urban areas, power utilities are replacing the overhead conductors with underground cables due to low availability of space for new lines or ROW issues. With the increase in the number of power cables, it is becoming difficult for the utilities to maintain and test the healthiness of the cables. On the other side, due to advances in computational capabilities, the manufacturers are providing an optimized solution which is reducing the fault feeding capability of the equipment and equipment are failed frequently. In this paper, a new advanced method of protecting the power transformers from SLG faults using both conventional and automated techniques is proposed. A combined solution using conventional and automation provides a redundant and robust approach to improve the residual life of equipment. To limit the fault current due to SLG faults neutral grounding reactor (NGR) is proposed, and GOOSE technique is used to isolate the equipment from the fault as soon as possible. The proposed method is simulated using MATLAB/SIMULINK and results obtained are satisfactory.

## 1. Introduction

Due to rapid urbanization and low availability of space, utilities are using, showing more interest on using cables for power transmission in place of bare conductors [1]. To provide stable and reliable operation, the condition of cables needs to be observed. Grid operators are often assessed on customer-minutes-lost and frequency of outages [2]. Since the impact of these parameters is larger with increasing voltage level of failing component, most efforts have been put in maintaining the health of medium and high voltage connections. However, compared to overhead lines, underground power cable installation and maintenance costs are higher.

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Polyethylene (PE), a thermoplastic semi-crystalline polymer, is used to make cables today. It is created by polymerizing ethylene ($C_2H_4$), and ethylene's cross-linking creates cross-linked polyethylene (XLPE). Cables can resist high temperatures of up to $125^o C$ because to this cross-linking (Figure 1). Its dielectric qualities are comparable to normal PE, but it is more resistant to cold flow and abrasion. Cross-linking enables filler to be loaded heavily without suffering considerable physical property loss. For this reason, in the medium voltage range, XLPE cable has nearly fully surpassed compound filled cables. The main issues with PE and XLPE insulation, however, are their sensitivity to partial discharge and the ensuing lifespan issue. Cavities between 1 to 30 micrometers in diameter are inevitable throughout the production process and might be a source of the frequently seen partial discharge activity.

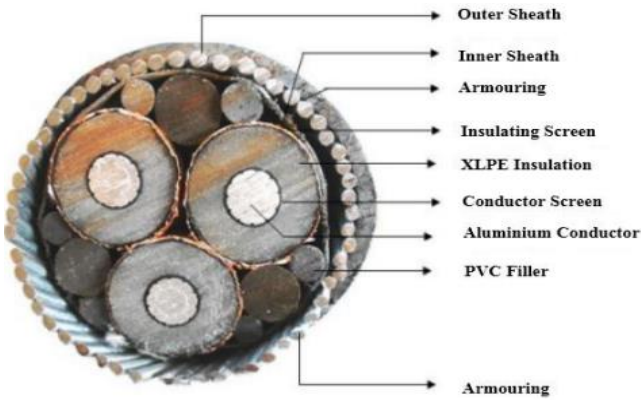


**Fig. 1.** Cross section of XLPE 3-core cable

Most significantly, the cable failure has a negative influence on the network health of the cable system and maintenance needs. Other causes of rapid breakdown in cable terminations include harmonics, weather conditions for outdoor terminations, partial discharge, cavities, and contamination under layers [3]. Most of the books that have been published have explored material qualities and the reasons cables break [4-11]. Phase failures can happen during the second, useful life for a number of reasons, including external damage, component wear, environmental stress, and more. As the third phase of the process unfolds, the bulk dielectric strength deteriorates and local stress increases as a result of artifacts caused by things like water intrusion and detachments at material interfaces. Ageing is the final result of these reactions, and its rate is affected by a variety of variables, including voltage, thermal stressors, maintenance, system age, cable system technology, and environment [12]. The most dangerous type of degradation and the one that harms solids the most severely is electrical degradation. Partial discharge is the mechanism underlying the electrical treeing process. Electrical treeing affects a specific area of the insulator and is a random process. The total breakdown of insulation is associated with a specific localised region. Cable is used to transfer power to nearer substations and cable end kits fail due to poor workmanship and poor maintenance. Utilities should follow partial discharge test for cables to avoid the failure. Most of the cable faults are SLG faults, sometimes instead of 3-core cable power distribution companies are using 3 single core cable with the usage of this type of cables would increase the probability of the SLG faults. From Figure 2 and Figure 3, it can be observed that SLG faults produce severe stress on the connected equipment and causing damage to the equipment.

Consciously placed between the system ground and the neutral of the substation transformer is an inductor known as an NGR [13,14]. The NGR's impedance is added to the grounding system's impedance, increasing the total impedance that ground currents must cross. Because the amount of a fault current is determined by dividing the system voltage by the impedance of the path it flows through (I=V/Z), the additional impedance reduces the fault current's size. Always keep in mind that an NGR only impacts ground faults. Understanding how the NGR raises the impedance of the fault channel for ground faulty requires taking into account the fact that all currents, whether load or fault, must flow in a loop and must return to their source. When current from the transformer winding passes through the phase conductor and into the earth, a line to ground fault is created. The current will split as it travels back to the transformer and pass through the neutral conductor and the earth. The current is sent back to the transformer winding through the neutral bushing. All currents returning to the transformer windings via the neutral and the earth are forced to pass through the NGR once it has been added. Line-to-line fault currents, for instance, are unaffected by the NGR since they do not have to pass through it in order to return to the transformer windings.

**Fig. 2.** Circuit Breaker limb flashover

**Fig. 3.** Flashover from limb to mechanism

In recent times, the conventional substations are converted to automated substations using substation protocols like IEC61850, Modbus and others. There are many advantages of converting the non-automated substation to automated substation. IEC61850 is used predominately for faster and reliable communications in the substations [15-23]. By assessing the variables impacting the difficulties encountered by water utilities in reducing NRW rates, the study examines the impact of magnetic field, Joule heating, and temperature profiles, as well as the reduction solutions [24-28]. GOOSE is used for lateral communication between the IEDs inside the substations. Currently, GOOSE is only used in low priority functions like interlocks, circuit breaker failure protection and etc. 0The solution proposed is implemented in the substation and it is tested using secondary injection and found that GOOSE publishing and subscribing occurred within 10milliseconds as per the requirement. Advanced options instead of copper wiring like GOOSE will reduce the fault feeding time and thereby improve the life of transformers.

The objective of this study is to present research on power transformer failures caused by power cables and fault currents in substations. In order to achieve these goals, a novel technique that combines the traditional way of positioning the ideal NGR with automated features of detecting the SLG defect and publishing the GOOSE to trip the associated power transformer is provided. This technique aims to decrease failure and increase residual life.

## 2. Research Objective

In this paper, a detailed study was made on failure of power transformers due to power cable faults. It was observed that fault currents which are nearer to the short-circuit capability of the transformers are producing severe mechanical and thermal stresses on the power transformers and leading to the failure of the power transformers. Transformers connected directly to low voltage substations like 33KV and below are failed frequently due to the low and improper maintenance of the power cables which are causing SLG faults.

A detailed study was done by studying the magnitude of the fault currents due to faults occurring in the substation, it was found that when the fault currents are beyond 7K Amps it is causing severe thermal and mechanical stress on the equipment and leading to failures. Power transformers being the costliest equipment in the substation, a new method combining the conventional solution of placing the optimal NGR and automation feature of detecting the SLG fault and publishing the GOOSE to trip the connected power transformer is proposed to reduce the failure and increase the residual life. Optimal placement of NGR with GOOSE technique will improve the residual life of the transformer.

In section 3.1 the short circuit capability of the 132/33KV 80MVA PTR is calculated for understanding the maximum fault current that a PTR can feed. In section 3.2 the NGR sizing is calculated to limit the fault current to its safe limit. In fourth section MATLAB/SIMULINK simulation is carried out to test the proposed NGR sizing. Voltages and currents graphs are plotted to see the limits of currents and voltages are within the limits.

## 3. Analysis and Discussions

In this study, fault on 33KV feeder connected to 80MVA PTR in 132/33KV voltage rating substation is considered. Out of connected 33kV feeders, a SLG fault has occurred on one of the feeders. It was observed that the one phase of the feeder was punctured due to moisture leading to a SLG fault. After the event of fault, disturbance records are extracted from the Intelligent Electronic Devices (IEDs) connected to the feeders. Disturbance record is advanced feature present in the IEDs which provides the snapshot of voltages and currents mostly from 1 second to 5 second depending on the provision provided in the IEDs will be recorded during any fault. Analysis of disturbance record will provide protection engineers more insight into the nature of the fault and action on the protective elements present inside the relays.

### *3.1 Pressure Distribution Short Circuit Capability of 80MVA PTR for SLG Fault and Comparison with Real Time Fault Current*

As per the name plate details: % impedance at tap 5 is 12.39 and Single Phase to Ground short circuit current is shown in Table 1.

As per the calculation given Table 1, the short circuit current for a SLG fault would be 13.96kA, but due to effect of system impedance, fault impedance and other real time conditions the fault magnitude will be less than calculated above. The disturbance record shown in the Figure 4 shows the fault current due to a real time fault is 9.7kAmps which occurred on the 33KV feeder due to a puncture of cable end kit. From the disturbance record, it can be seen that the due to the SLG fault current on the R-Phase is increased but other two healthy phases are feeding the load current only.

**Table 1**
SLG fault and comparison with real time fault current

| Single Phase to Ground short circuit current | | Due to a short circuit nearer to PTR | |
|---|---|---|---|
| $I$ | $I_{actual}$ | $I_{HV}$ (actual) | $I_{LV}$ (actual) |
| 3.33 pu | 3499 Amps | 3499 Amps | 13.96kA Amps |

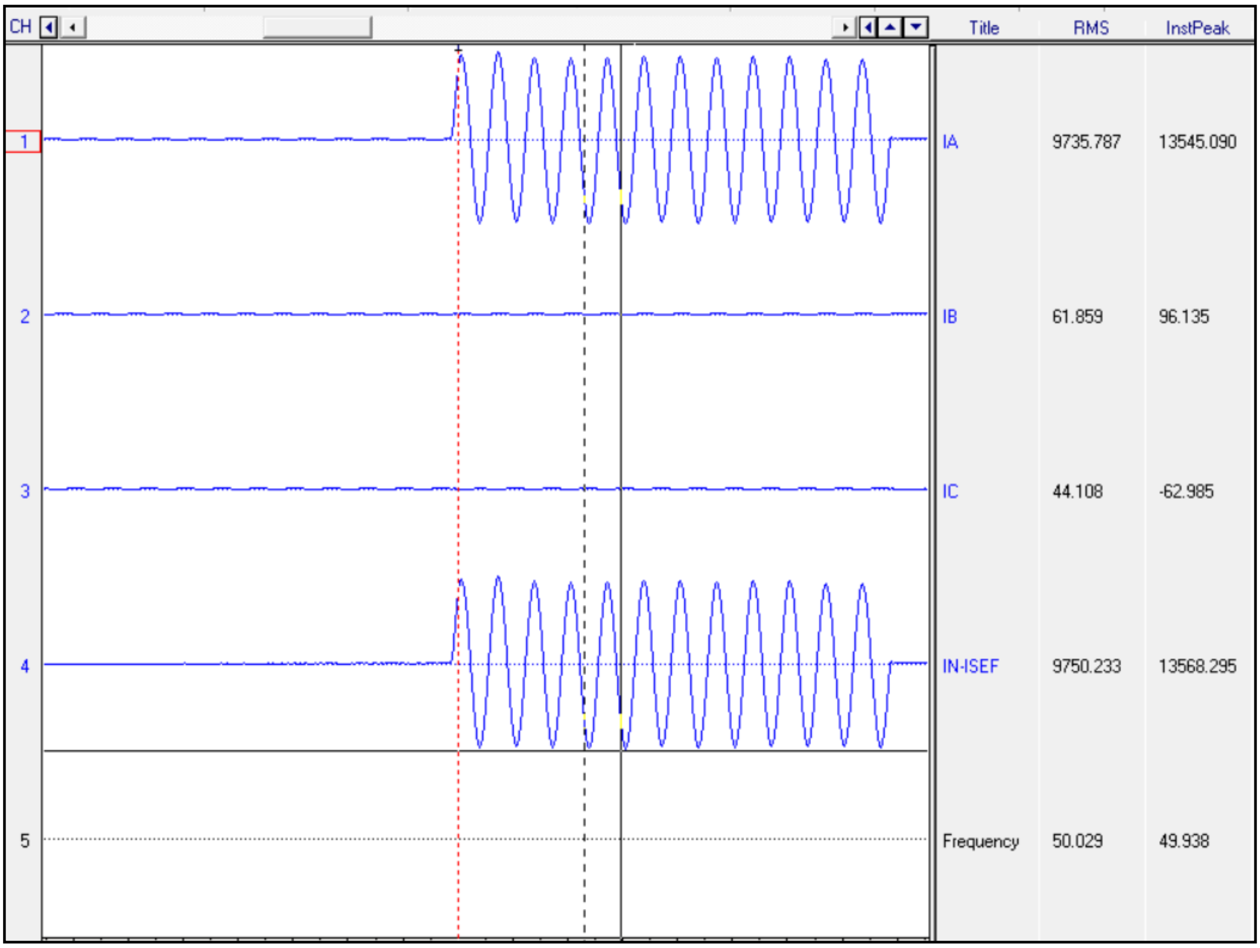


**Fig. 4.** Disturbance record showing the fault currents of magnitude 9.734KAmps on 33kV feeder due to SLG fault on R-Phase

### *3.2 Derivation of Sizing of NGR*

In this section, the size of NGR is derived to limit the fault current to 6000 Amps. As mentioned in section 2 it is found from the practical study in various substations that the currents above 7000 Amps are producing severe thermal and mechanical stresses on the equipment and leading to failure of the equipment. If the SLG fault current is limited to 6000Amps, then the residual life of the equipment will be improved. Sequence currents due to SLG faults is

$$I_0 = I_1 = I_2 = \frac{E_{pu}}{Z_1+Z_2+Z_0+(3*Z_n)} \tag{1}$$

$where\ Z_n is\ the\ impedance\ of\ the\ neutral\ reactor.$

$I\ actual\ in\ pu = 3 * I\ (sequence\ currents)$

I actual = $Iactualpu * \frac{MVA}{1.732*KV}$ (2)

On solving the above algebraic equation for $Z_n$ we get the value of neutral reactor will be 10.9pu.

Ratio of $\frac{X_0}{X_1} = 2.7 \ \leq 3$ which is effective grounding requirement.

## 4. Simulation and Results

In this section, a simplified circuit is taken in which a power transformer with the impedances given in section 3.1 is connected to a circuit breaker and to a cable of length 5KM as shown in Figure 5. This simulation circuit resembles the real time circuit existing in the substations. The voltage rating of the power transformer is 132/33KV, power rating of the power transformer is 80MVA. In this simulation, a SLG fault is created on one of the phases at time $t_1$=1sec and the fault is cleared at $t_2$=1.5sec. From Figure 6, it can be seen that during the faulted period the fault current is approximately 10000Amps which is a simulation of the real time fault current shown in Figure 4 during a SLG fault which occurred on a 33KV feeder.

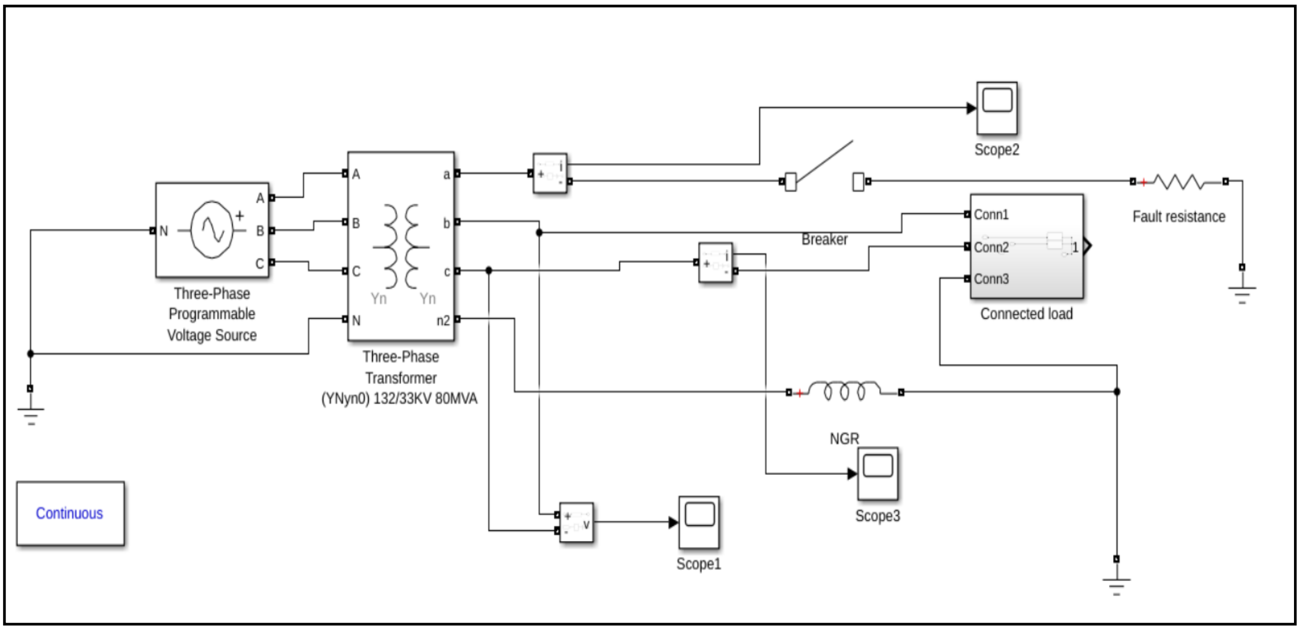


**Fig. 5.** Circuit showing an 80MVA PTR connected to a load and feeding fault on R-Phase

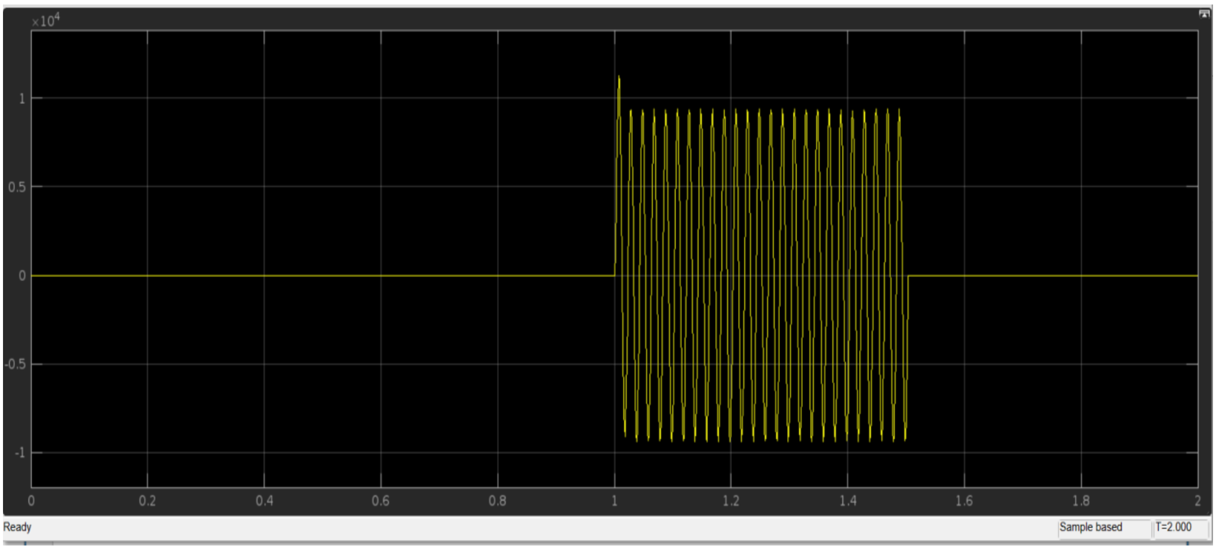


**Fig. 6.** Graph showing fault current from $t_1$ = 1sec to $t_2$ = 1.5sec is approximately 10KAmps

From Figure 8, it is shown that after placement of NGR the fault current has reduced to 6KAmps. A reduction in fault current would reduce the stresses on the equipment. It can also be seen from Figure 7 and Figure 9 that the line-to-line voltage of the healthy phases is the same and voltage transients are absent. From the figures, it can be observed that the proposed NGR is capable of reducing the fault currents to the required level.

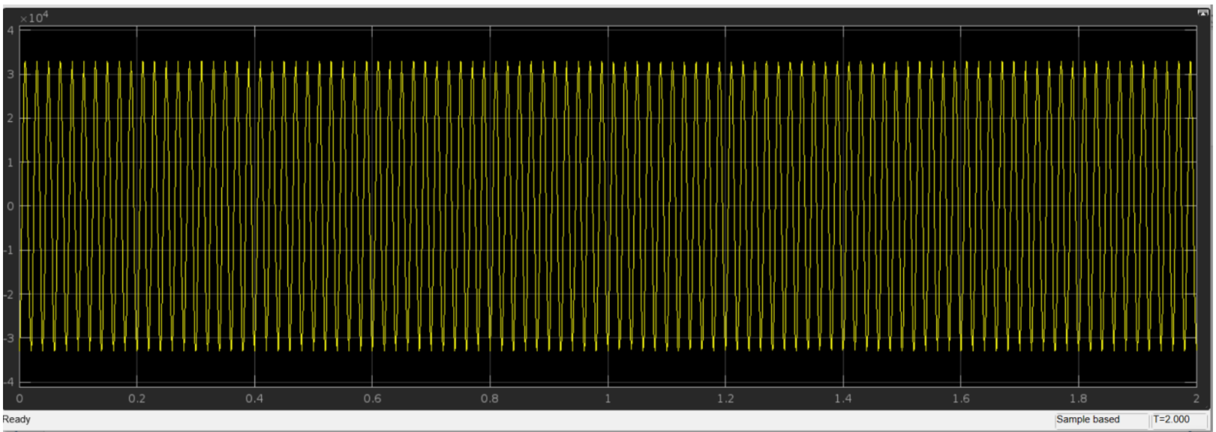


**Fig. 7.** Graph showing voltage of the healthy phases (V-YB) before fault

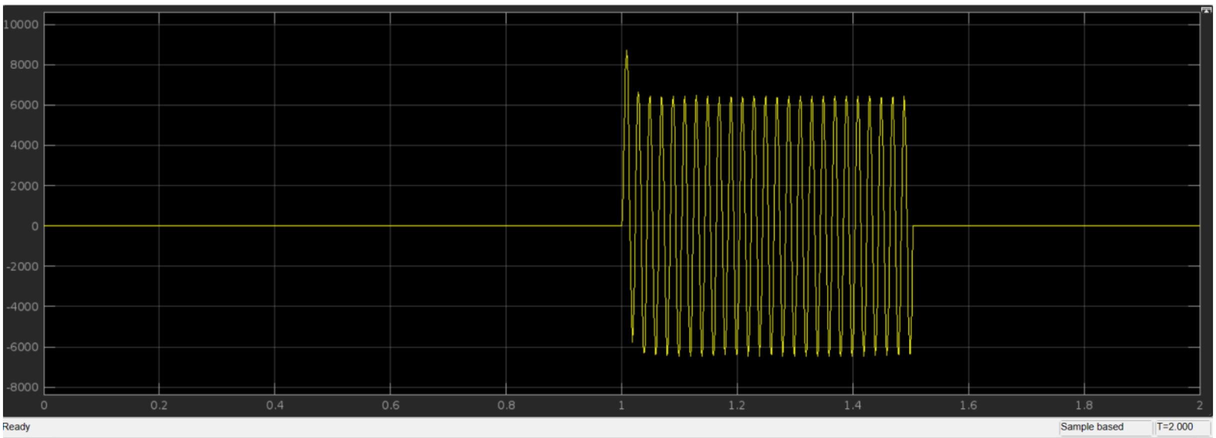


**Fig. 8.** Graph showing fault current from $t_1$ = 1sec to $t_2$ = 1.5sec is approximately 6KAmps after placement of NGR

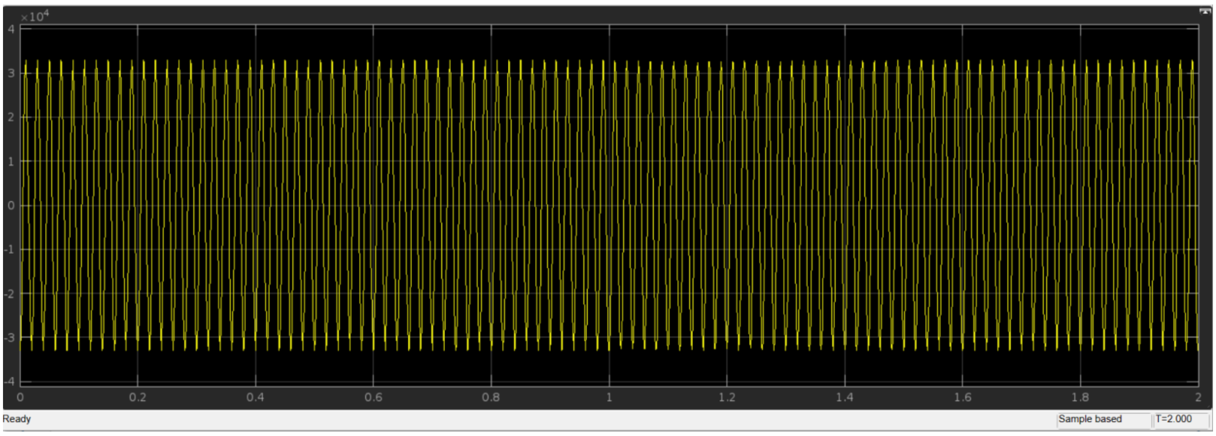

**Fig. 9.** Graph showing voltage of the healthy phases (V-YB) after fault

Using an IEC61850-GOOSE technique the following programmable logic can be implemented in the feeders connected to PTRs. In the event of a SLG fault, the following logic shown in Figure 10 will send a GOOSE command to the relays of PTR. On receiving the GOOSE command, the relay connected to the PTR will trip both the HV&LV circuit breakers and the fault is isolated. Isolation of the SLG fault quickly will reduce the stress on the PTR.

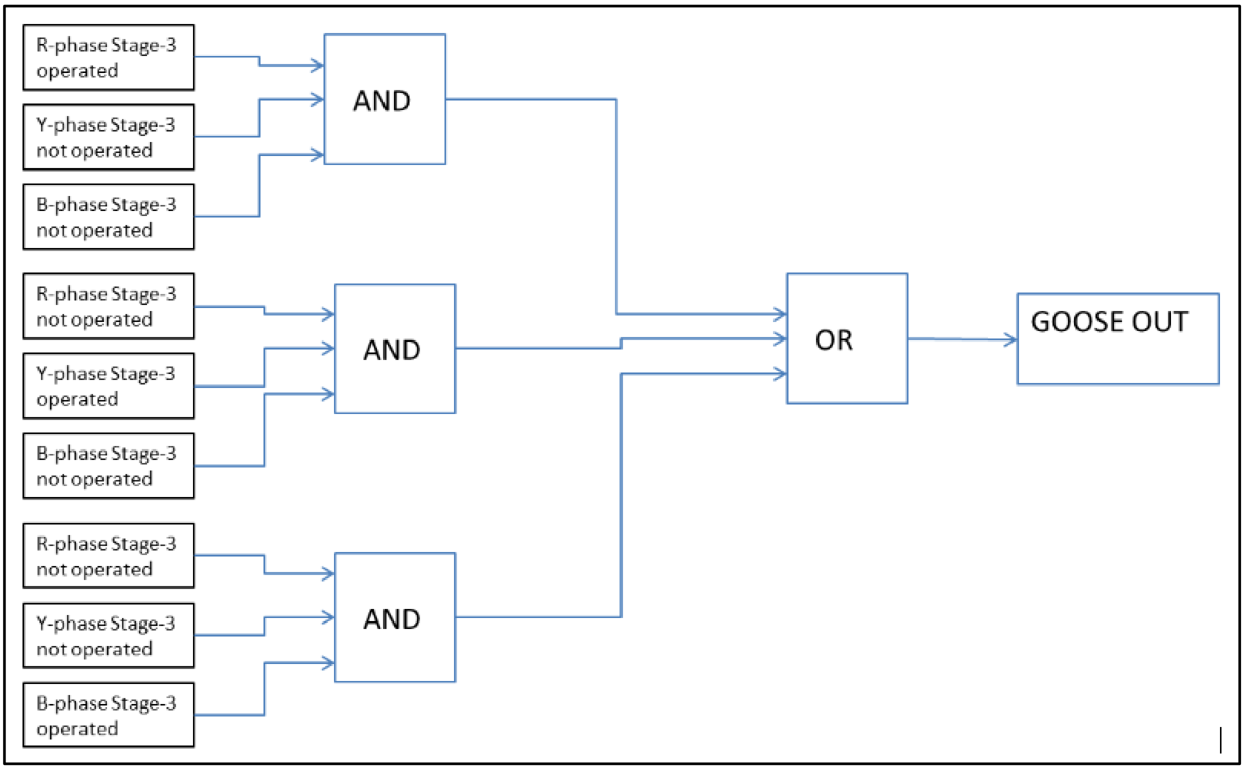


**Fig. 10.** Programmable logic for detecting SLG fault and publishing a GOOSE command to trip the connected PTRs

## 5. Conclusion

It can be concluded that, SLG cable faults are unavoidable in the substations. Due to increase in usage of the cables and majority of faults occurring in the cables are SLG faults, it is the need to protect the expensive equipment in the substations. The technique proposed in this paper will help in protecting the equipment failures. Optimal placement of NGR would reduce the magnitude of the fault currents. GOOSE technique would aid the existing primary protection system present in the PTRs and would provide additional protection. It can be concluded from the simulation studies that the optimal placement of NGR would reduce the fault current to the safe limit.

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