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Transient Fault Analysis in 63/20 KV Substation

Behrooz Taheri[1], Farzad Razavi[1*] and Mehdi Mohammadi Ghalesefidi[2]

[1]Department of Electrical Engineering, Islamic Azad University of Qazvin, Qazvin, Iran; behrooztaheri1372@gmail.com, farzad.razavi@gmail.com

[2]Technical and Engineering Faculty, Imam Khomeini International University, Qazvin, Iran; mehdimohamadi.gh@gmail.com

Abstract

Objectives: An important field of study concerning power grids is the analysis of different incidents that are taking place in the grid. There are various reasons for such incidents. Realizing the cause of failures and finding solutions to prevent their recurrence can be of great help in grid development planning and also for reducing damages caused by such failures. **Methods/Analysis:** This paper addresses an incident that took place in a 63/20 KV substation. First we overview the substation and its installed equipment in order to have a comprehensive investigation on the failure and its cause. In the following, simulation process based on available data is described. **Findings:** We address the failure and how it happened, focusing on the factors intensifying it. **Novelty/Improvement:** A method is proposed to prevent the recurrence of such failures.

Keywords: Power System, Protection, Recovery Voltage, Substation, Transient

1. Introduction

Short circuit current in power systems are constantly increasing, which is due to increasing usage of electric energy[1]. A common method for overcoming this problem is using power equipment and switches that have a higher voltage range. In such cases, a larger investment would be inflicted on the system for updating the power grid[1]. Another less expensive solution is investigation and analysis of incidents in the power grid in order to find low cost solutions. Accurate analysis of these incidents can be of great help when planning for development and expansion of the grid and also for prevention of a similar incident in other parts of the grid. Different factors can affect transient failures in power systems, leading to an increase or a reduction of damages to power system.

Generally speaking, capacitor equipment can be notably effective on transient conditions of the power system. This impact can be affected by hidden capacitors of the equipment. These capacitors can affect break properties of a circuit breaker[2]. Similar to the case of the 63/20 KV substation-addressed here in this paper-which resulted in a chain of continuous transient states, making it difficult to find the reason for the incident.

2. A Description of the Incident

When a feeder output experienced phase-to-phase-to-earth short circuit, current relays identified the failure and disrupted feeder outputs. A very short while after feeder output was disrupted (few milliseconds) the end busbar switch went through an incident and due to activation of busbar protection relay, some of the healthy lines in the second half of the busbar were disconnected as well.

Initial investigations showed the end busbar switch to be healthy as for the circuit breaker.

Failure was caused by end busbar power switch overvoltage.

Substation insulation level is 40 KV, which switch voltage, as shown by initial investigations, would not exceed. Insulation tests verified the good insulation conditions of the substation Figure 1.

** Author for correspondence*

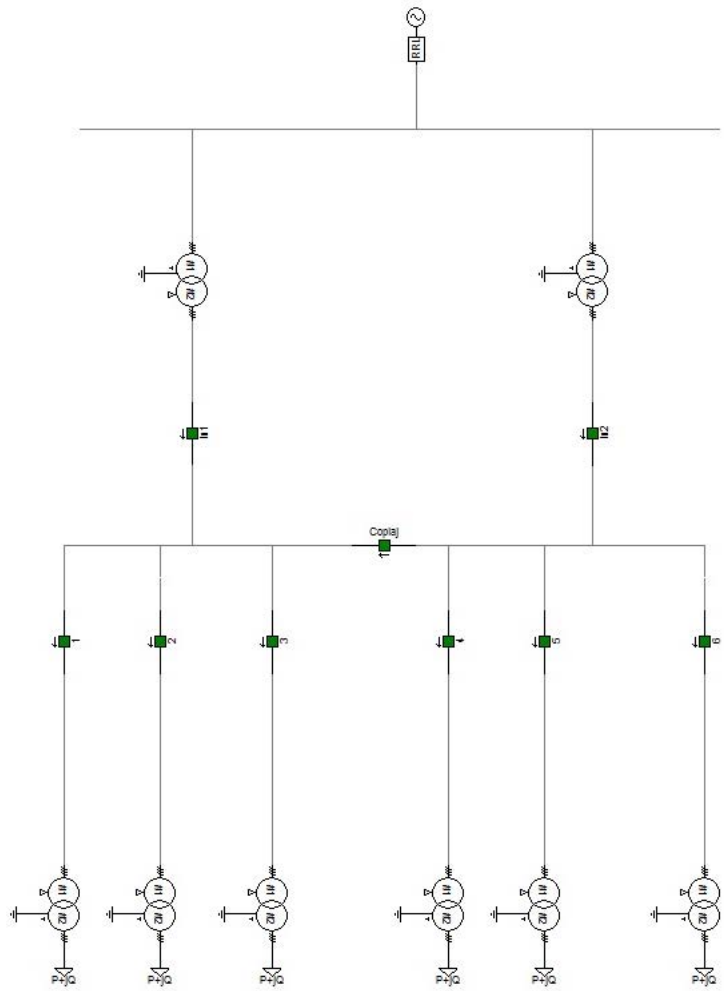

Figure 1. View substation simulation PSCAD/EMTDC.

3. COMTRADE Analysis

To analyze the incidents, it is better to first refer to wave shapes recorded by relays. This helps us a lot in understanding the incident. Moreover, we extensively use this information for simulation purposes.

Figure 2 shows waves and triggers recorded by Line 2 relay. Considering the shape of the waves it can be deduced that a phase-to-phase-to-earth failure had happened. This short circuit was a result of high winds that broke phase a cable which then touched phase C. The recorded triggers show that the relay picked up immediately after the failure and signaled breaker after 120 milliseconds.

The wave shape in Figure 3, corresponding to high-current coupling relay, verifies a phase-to-phase-to-earth failure and opens the coupling power switch after 147 milliseconds. Then, a failure takes place in the end busbar power switch. This failure activates Input 2 relay, disconnecting all outputs from the circuit.

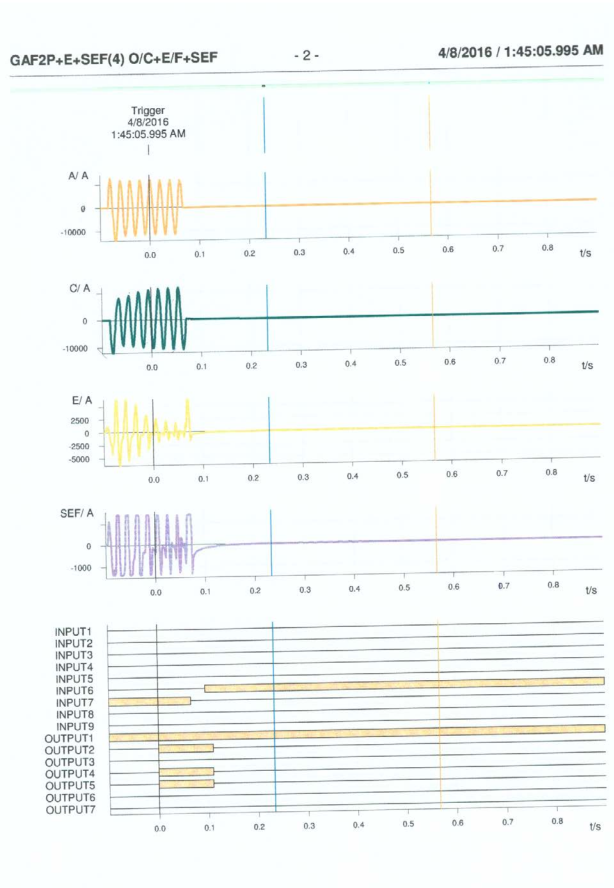

Figure 2. COMTRADE from line 2.

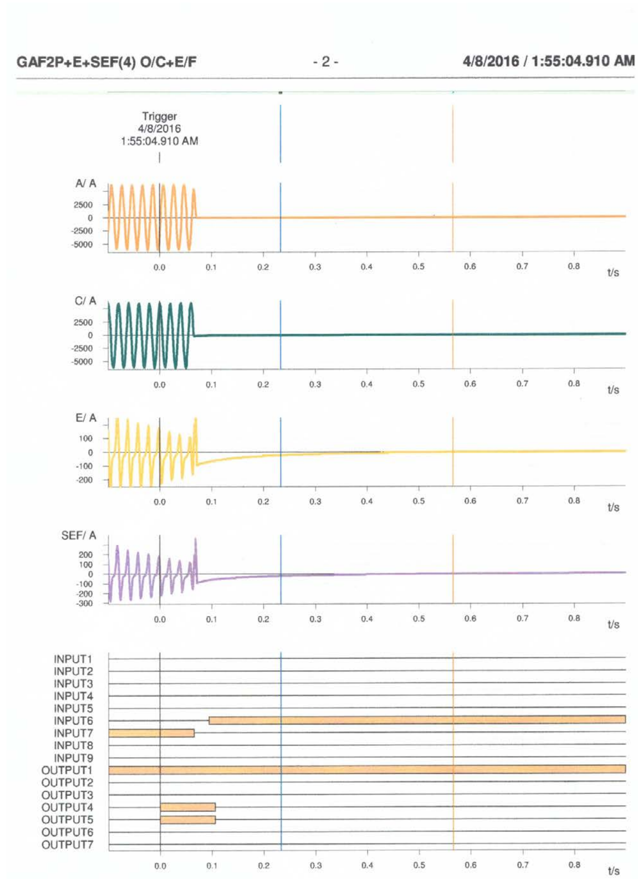

Figure 3. COMTRADE from coupling.

It was first speculated that a current returning from the line resulted in these wave shapes, but given that no incident was recorded by the relay on the other side of the line and also the fact that relay had not picked up, this theory was rejected. A second theory discussed relay impairment and its error which was also put aside after testing the transient state of the relay and verifying COMTRADE results to be correct. Signs of arc were observed on the switch during inspection. Considering the signs of arc on the power switch, the wave shapes recorded in this relay were attributed to sparks in the switch. The switch was shown to be in good condition and the substation to be insulation resistant by examination and insulation testing Figure 4.

4. Simulation

4.1 Circuit Breaker Simulation

Pscad was employed to simulate the incident. First, a capacitor equal to the total capacitance of the breaker circuit was paralleled to it for a realistic power switch simulation. The capacitance was assumed 0.5 μf [1].

4.2 Busbar Simulation

Busbar systems are extensively used in industries today. Busbars are used for electric energy distribution purposes in industries. Easy and quick installation and utilization, easy modification of development program, and simple maintenance can be named as the main advantages offered by busbars. Accurate modelling methods are required for the same reasons[3].

When modelling busbars, magnetic field impact limitations[4-6] and the need for reducing the volume of busbar are goals that need to be addressed[3]. Numerical methods based on partial derivatives of differential equations have always been complex[3], but numerical methods allow evaluation of flow density distribution[6] Busbar model often uses a D-2 model which plays a key

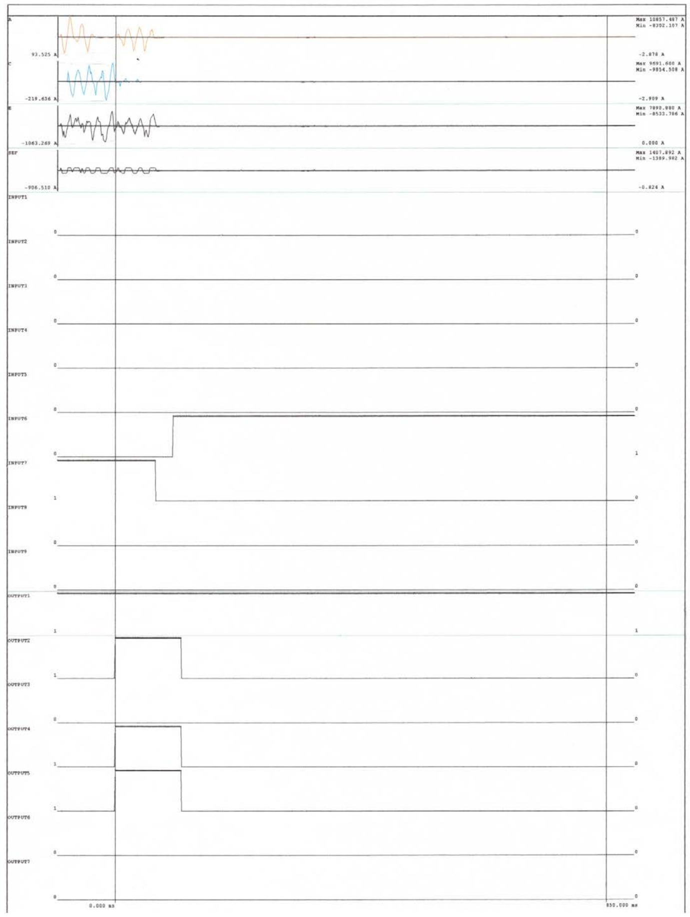

Figure 4. COMTRADE from end line.

role in busbar system analysis, since it is simple and quick and does not require a numerical code[3]. In MC model, every phase of busbar is assumed to be composed of thin conductive elements[4-5].

In this paper, busbar is modelled based on P Line model for an accurate, simple simulation. P model equations can be expressed as follows[7]:

$$Z = R + jX \quad (1)$$

$$Y = G + jB \quad (2)$$

Furthermore, voltage and current equations are[7]:

$$V_s = Z(I_R + V_R \frac{Y}{2}) + V_R = V_R(1 + \frac{ZY}{2}) + ZI_R \quad (3)$$

$$I_s = I_R + V_R \frac{Y}{2} + V_S \frac{Y}{2} \quad (4)$$

Substituting Equation (3) in Equation (4) we have[7]:

$$I_S = V_R Y(1 + \frac{ZY}{4}) + I_R(1 + \frac{ZY}{2}) \quad (5)$$

If the equations are solved using the characteristics of the busbar, it is observed that the end busbar voltage would not exceed 40 KV which is the insulation level of the substation. That is the reason for which the system is examined using Pscad and in transient state.

The other lines of output are ignored in order to simplify the system, hence only the incident line and the end busbar line were simulated (Figure 5).

A parallel capacitor was put before the line model. This is a capacitor bank which is installed on the bus in order to control reactive power.

Figure 6 shows the voltages of the two ends of line 1 power switch after the switch is opened. It is evident that a voltage recovery has taken place in the switch. We extract the existing harmonics using Formula 6 or 7 for a more thorough analysis.

$$X[m] = \sum_{n=0}^{N-1} x[n] e^{-j\frac{2\pi}{N}nm} \quad (6)$$

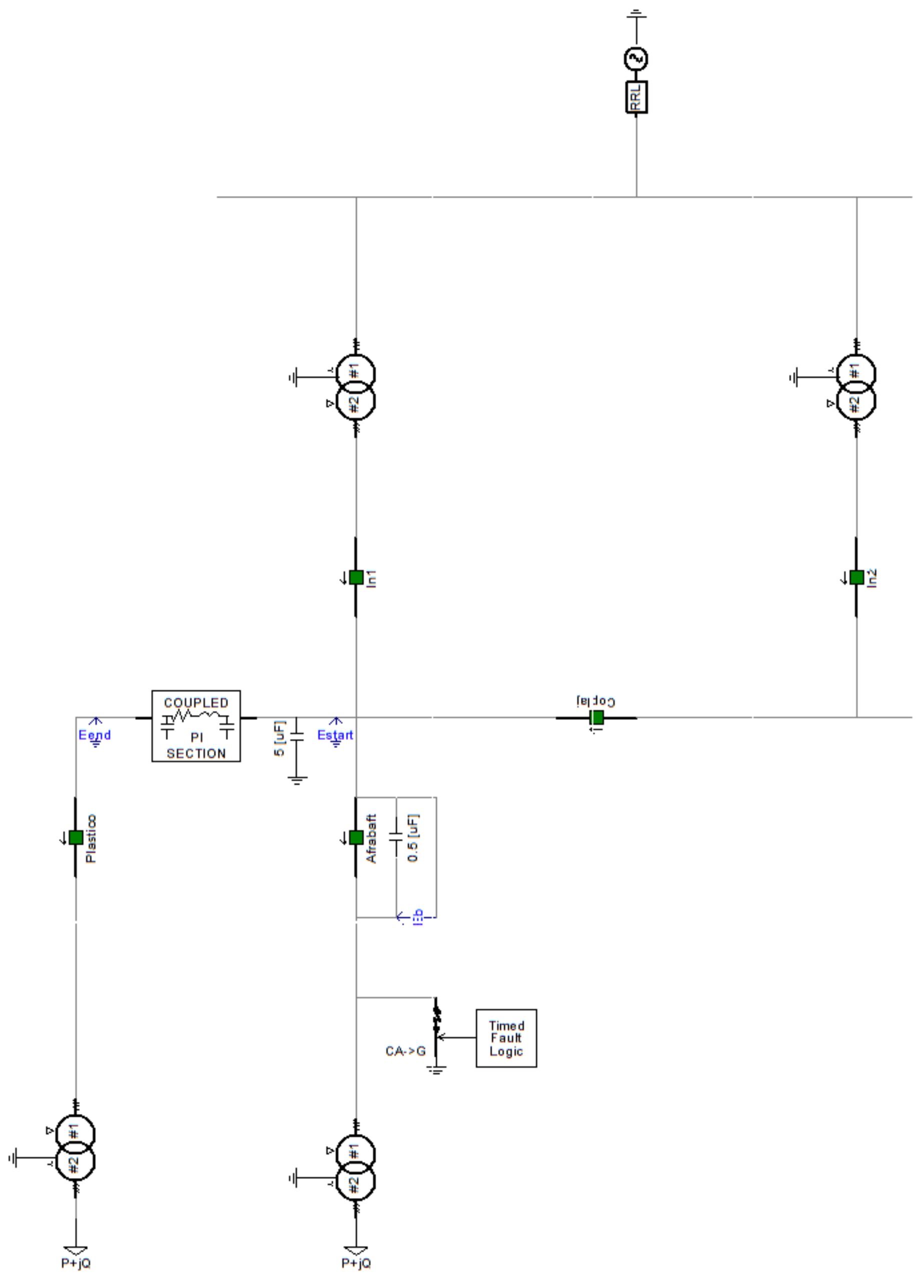

Figure 5. Simulation substation in PSCAD/EMTDC.

$$X[m] = \sum_{n=0}^{N-1} x[n](\cos\frac{2\pi}{N}nm - j\sin\frac{2\pi}{N}nm) \quad (7)$$

This is done so the incident could be better analyzed.

Considering Figure 7, it can be deduced that at the moment line 1 power switch is closed, a highly harmonic voltage takes up in a short time.

Waves sweep under two conditions:

- Low frequency and long transmission line
- High frequency and short transmission line

During the first few microseconds after the failure, any of the above cases result in a flow of voltage and current in busbar that is governed by different equations from those mentioned earlier.

In the busbar which was modelled using P model, after voltage recovery, a signal with high frequency and amplitude takes place flowing along the short busbar. The equations below can be written for sweeping waves:

$$dV_x = r.ix + L\frac{dix}{dt} \quad (8)$$

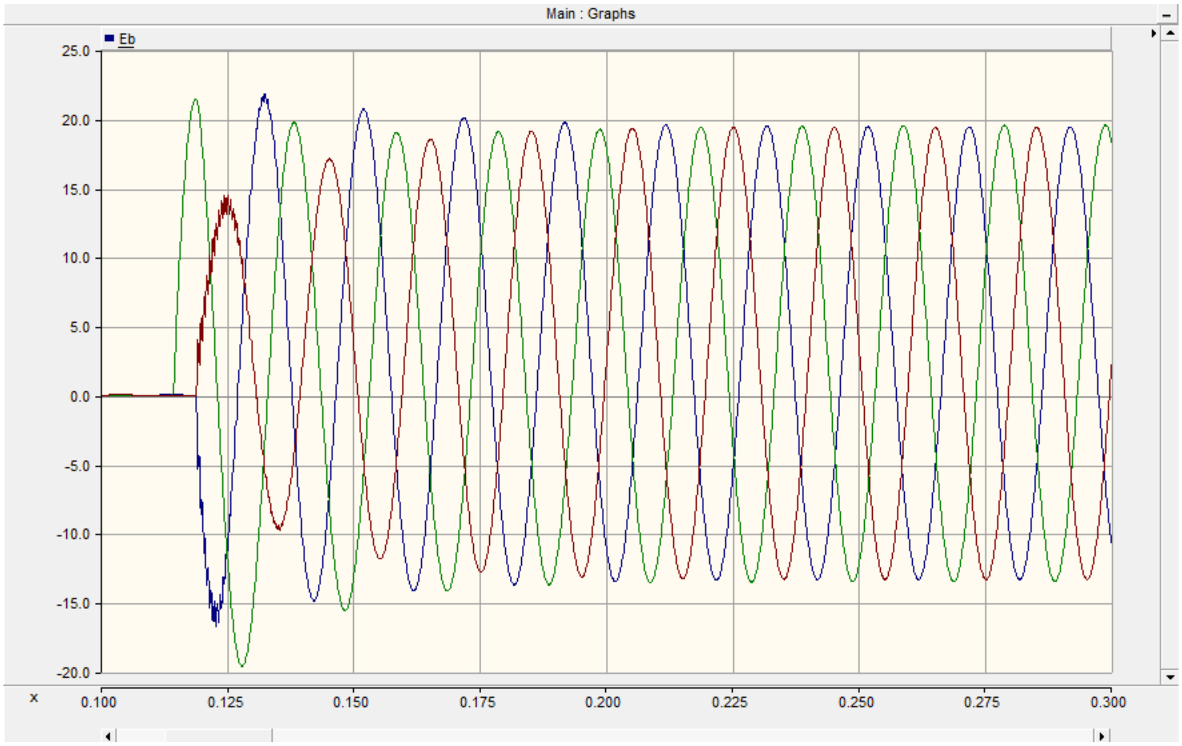

Figure 6. Circuit breaker voltage.

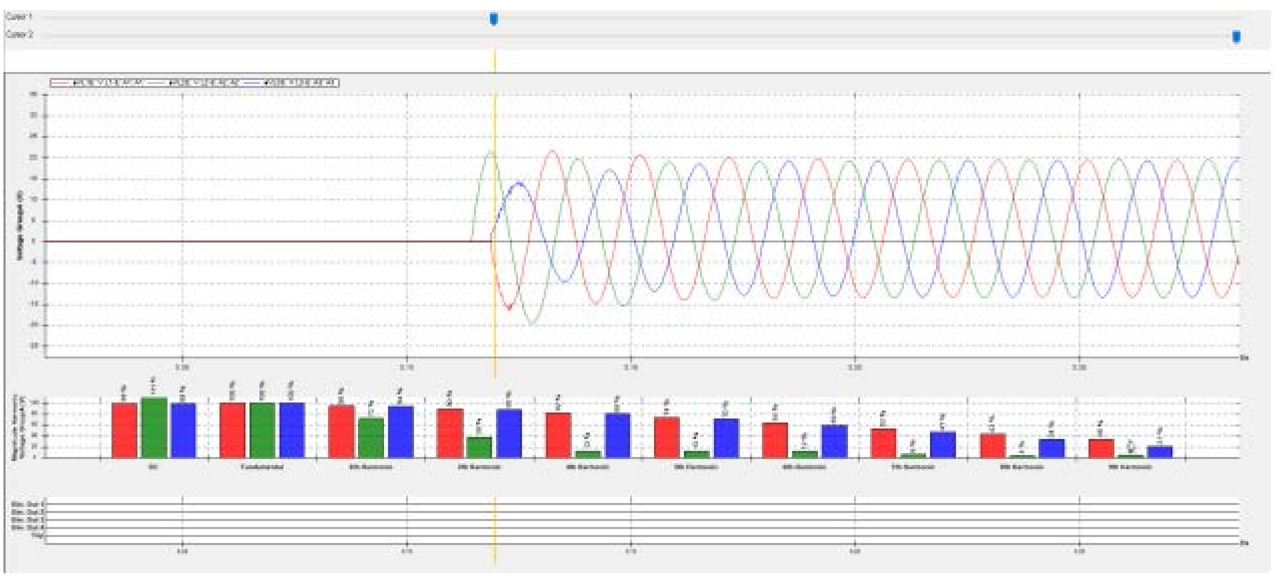

Figure 7. Harmonic for circuit breaker.

And for current we have:

$$dI_x = -C\frac{dV_x}{dt} \quad (9)$$

Resistance can be ignored due to the short busbar length.

$$dV_x = L\frac{dix}{dt} \quad (10)$$

$$dI_x = -C\frac{dV_x}{dt} \quad (11)$$

Substituting Ix equation in Vx equation, this can be written:

$$dV_x = -LC\frac{dV_x^2}{dt^2} \tag{12}$$

$$\frac{dV_x^2}{dt^2} + \frac{1}{L.C}dV_x = 0 \tag{13}$$

Solving the differential equation above, the following is obtained:

$$y = c_1\cos(at) + c_2\sin(at) \tag{14}$$

In Equation 14, is $\frac{1}{\sqrt{L.C}}$.Solving these equations, it can be deduced that end busbar voltage rises very high in a few milliseconds.

5. Solving the Problem

It is proposed to install an impedance equal to characteristic impedance of busbar at its end after the damaged power switch is changed, so to solve this problem and prevent its recurrence.

$$Z = \sqrt{\frac{X_L}{X_C}} = \sqrt{\frac{L}{C}} \tag{15}$$

This prevents waves from sweeping along busbar and also results in equal voltage rms throughout busbar in steady state.

6. Conclusion

After analyzing simulation outputs and equations that are written, it can be deduced that the error was due to a problem in line 1 switch which resulted in voltage recovery. The voltage recovery generates a high frequency with high amplitude which moves along the busbar, resulting in a voltage sweep. By the time voltage has reached the end of busbar, it has a high peak and since the end of busbar is open, voltage uses the end busbar power switch as arrester on its return, resulting in generation of arc in the power switch.

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