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Fault Analysis of Injection Substation Using Symmetrical Component Method and Validation of Results Using MATLAB: a Case Study of Mofor Injection Substation, Delta State, Nigeria

Oladimeji JA[*]

Afe Babalola University, Ado-Ekiti, Nigeria

Abstract: This study centers on the fault analysis of 15MVA Mofor Injection Substation, which is an Injection Substation located in Warri, Delta state which gets its source from PTI transmission station. Mofor Injection substation has two outgoing feeders which are Orhuwhorun feeder and Ekete feeder. The analysis was carried out and deductions were made considering the various faults which occurred during the period of assessment and their associated fault current was calculated using symmetrical Component method of Fault analysis. A model of the distribution network was made using Electrical Transient Analyzer Program [ETAP]; the value of real and reactive powers and voltage magnitudes in the whole network was observed. From data obtained from the injection substation indicates that Orhuwhorun feeder has a higher frequency of fault and from results obtained from Symmetrical method of fault analysis revealed that double Line to ground fault has the highest fault current and could cause adverse damages to equipment's and as such must be avoided. The fault current calculated from Symmetrical component method of Fault analysis was validated with computer program MATLAB as results agreed closely since error was below 0.1%. This paper covers the transient stability analysis of 33/11 kV Substation of Mofor Injection Substation and the results are based on actual data received from the substation.

Keywords: Mofor injection substation, Fault analysis, Fault current.

I. INTRODUCTION

One of the major problems industries in Nigeria face is to counter the sudden voltage fluctuations in the system which results in the deterioration of power quality and damages to equipment. The consequences of power incidents show that industrial and digital firms are losing revenue per year due to power interruptions. The cost to replace equipment damaged because of voltage spikes is very high as these results to reduction in production. Electricity supply is also very important as it affects all sphere of life both social and economic development of any nation. Power supply to consumer must be reliable, adequate and of acceptable quality at a minimum cost, but this is not easily achievable as the reliability of supply and adequacy is being truncated by incessant faults along the line, which reduces the efficiency of the system [1].

The Manufacturers Association of Nigeria (MAN) and the National Association of Small Scale Industries (NASSI) estimated that their members spend an average of about N2billion (about $12 million) per week on self-power generation [2].

A series of power sector polls conducted by NOI Polls Ltd for the second quarter of 2013 revealed that about 130 million, representing 81 per cent, out of the 160 million Nigerians generated their own electricity through alternative sources to make up for irregular power supply. Study also showed a combined average of 69 percent or 110 million of Nigerians experienced greater spending on alternative electricity supply [3].

Nigeria's electricity consumption on a per capita basis was among the lowest in the world when compared with the average per capita electricity usage in Libya which is 4,270 KWH; India, 616 KWH; China, 2,944 KWH; South Africa, 4,803 KWH; Singapore, 8,307 KWH; and the United States, 13,394 KWH [1-3]. By Journal of Sustainable Development Studies, South Africa with a population of just 50 million, has an installed electricity generation capacity of over 52,000 MW [4].

The Electrical system is sub divided into generation, transmission and distribution sections. The subsystem that generates electrical energy is called generation subsystem or generating plants (stations). It consists of generating units (consisting of turbine alternator Sets) including the necessary accessories. Speed governors for the prime Movers (turbines; exciters and voltage regulators for generators, and step-up transformers also form part of the generating plants. The subsystem that transmits the electrical energy over long distances (from generating Plants to main load centers) is called transmission subsystem. It consists of transmission Lines, regulating transformers and static/rotating VAR units (which are used to control Active/reactive powers).

The sub system that distributes energy from load centers to individual consumer points along with end energy converting devices such as motors, resistances etc. is called Distribution Subsystems. It consists of feeders, step-down transformers, and individual Consumer connections along with the terminal energy converting electrical equipment Such as motors, resistors etc.

The electricity distribution network starts at the Injection substation, where power is delivered by overhead transmission lines and stepped down by Power transformer (15 MVA) from 33 KV to 11 KV. But sadly, at each of these stages of power system, a vital obstacle called FAULT is encountered. A Fault in an electrical equipment is a defect in the electrical circuit due to which current is diverted from the intended path [5]. This fault is subdivided into Transient and permanent faults.

Transient faults are faults, which do not damage the insulation permanently and allow the circuit to be safely re-energized after a short period, such as sudden loss of generation or an interconnecting line, or the sudden connection of additional load. The duration of the transient period is in the order of a second. System behavior in this interval is crucial in the design of power systems. Transient overvoltage occurring in our power system can cause operational breakdown and also cause failure in industrial and household equipment. These types of problems have been given serious consideration by engineers since most of the equipment that are used in the substation have a specific Basic Insulation Level (BIL) and if the overvoltage exceeds the safety or defined limit, insulation breaks down and failure of equipment occur. For that reason, several protective devices and schemes are applied to reduce the effect of transient overvoltage to control damage caused to the utility system and to avoid poor power quality.

Transient over voltages in power systems may be caused due to several reasons of which those occurring due to lightning strikes or switching operations of inductive or capacitive are the commonest [6].

Permanent faults result in permanent damage to the insulation. In this case, the equipment has to be repaired.

II. METHODOLOGY

The following analysis will be carried out for this research purpose:

1. Data collection from the Injection Substation.
2. Simulation of the Mofor injection Substation using ETAP.
3. Calculation of Fault Current and Line Impedance using symmetrical method for fault analysis.
4. Validation of Fault current using Matlab.
5. Determination of the bus voltage, Real and reactive power from the load flow analysis.

2.1 Data Collected From 33 KV Current Transformer

Product of C.T=ABB

C.T Ratio=400:1

RHSV 36KV

Type =outdoor

Frequency =50 Hz

Burden =50VA core

Core 1=400/1A=10P10

Core 2=10P10 400-1A

Core 3=10P10 400-1A

2.2 CT Ratio on the Secondary Side of 15 MVA Transformer

Product Of C.T=Abb

C.T ratio=400:5

CALCULATION OF LOAD CURRENT

The 15MVA transformer is connected in Delta/Star.

Primary Full Load current=$\frac{15\text{x}10^6}{\sqrt{3}*33*10\text{\^{}}3} = 262.4\text{A}$

C.T Ratio for the H.V side of the Transformer 400:1A

Secondary full load current=$\frac{15X10^6}{\sqrt{3}\,\text{X}11\text{X}10^3} = 787.3\text{A}$

Name plate reading=780A

Secondary full load current in primary CT $\frac{262.4X1}{400} = 0.656A$

Secondary full load in secondary C.T=$\frac{787.3X5}{400} = 9.841A$

On the low voltage side of the main transformer winding are connected in star,so

Phase voltage $= \text{line voltage} / \sqrt{3} = \frac{11}{\sqrt{3}} = 6.351\text{KV}$

On the high voltage side of the transformer, the main transformer windings are connected in Delta,so

$Phase\ voltage\ = line\ voltage\ = 33KV$

Turn ratio of main transformer $= 33/6.351 = 5.2 \approx 5\text{turns}$

Current transformer on 11KV side are connected in delta and the turn ratio =400/5=80

Apparent Power =Vrms Irms $= \text{I}^2\text{rms Z} = \frac{\text{Vrms}^2}{\text{Z}}$

Reactive Power=Vrms Irms $= \text{Irms}^2\ \text{X} = \frac{\text{Vrms}^2}{\text{X}}$

Active Power=√3 VI COS ø

Instantaneous power is defined as:

Pinst (t)=V(t)I(t)

Where V(t) and I(t) are the time varying voltage and current waveforms (Tables 1 and 2).

Substation	Apparent Power (kva)	Reactive Power (kvar)	Real Power kw	Rated capacity (kva)	Power factor	Frequency (Hz)	Route Length (Km)
Maternity substation	443	266.6	353.8	500	0.798	50	0.7
Catholic Substation	429	258.2	342.6	500	0.794	50	0.8

Express Junction Substation	431	259.4	344.2	500	0.793	50	0.9
Cross and stop substation	408	245.5	325.8	500		50	1.1
Old Ekete Road Substation	421.8	253.8	336.9	500	0.794	50	1.4

Table 1: Loading distributions on ekete feeder.

Substation	**Power (kva)**	**Power (kvar)**	**Power (kw)**	**Power factor**	**Frequency (Hz)**	**Route length (km)**	**Rated capacity (kVA)**
1st orhuwhorun Road sub station	453	272.6	361.8	0.795	50	0.6	500
Oboh street substation	433	260.6	345.8	0.792	50	0.8	500
Udu market Substation	451	271.4	360.2	0.793	50	1.1	500
kotokoto substation	431	259.4	344.2	0.794	50	1.4	500
Newyork Substation	421.7	253.8	336.8	0.797	50	1.5	500

Table 2: Loading distributions on orhuwhorun feeder.

2.3 Calculation of Line Parameters for Mofor Injection Substation

For short transmission line:For short length, the shunt capacitance of this type of line is neglected and other parameters like Electrical resistance and inductor of these short lines are lumped [7]. Hence the vector diagram is given Figure 1.

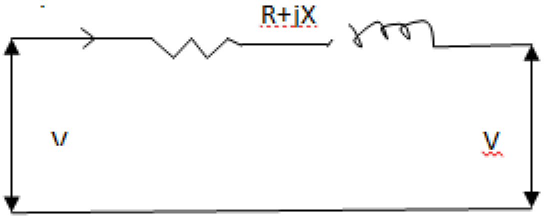

Figure 1: Representing a short transmission line.

RESISTANCE $= R = PL/A$ Where P is the resistivity of the conductor material (Tables 3 and 4).

F=50Hz

$Z = \sqrt{R^2 + (\omega L)^2}$

$w_L = 2\prod fL$

Node	*P* (Ω/km)	Inductance (mH)	Length (km)	Area (mm^2)	R(Ω)	X(Ω)	Z(Ω)	Y
Node 3	0.00001	11.26	20	100	2	3.5	4.03	0.25
Node 5	0.00004	4.78	0.5	70	0.3	1.5	1.5	0.67
Node 8	0.00004	4.78	0.7	70	0.4	1.5	1.5	0.67
Node 11	0.00003	4.78	0.8	70	0.3	1.5	1.5	0.67
Node 12	0.00002	4.78	1.1	70	0.3	1.5	1.5	0.67
Node 13	0.00002	6.37	1.4	70	0.4	2	2	0.5
Node 19	0.00002	6.37	0.6	70	0.2	2	2	0.5
Node 20	0.00004	6.37	0.8	70	0.45	2	2	0.5
Node 21	0.00004	3.18	1.1	70	0.6	1	1	1
Node 22	0.00002	3.18	1.4	70	0.4	1	1	1
Node 23	0.00001	3.18	1.5	70	0.2	1	1	1

Table 3: Shows the impedance of the various node in the injection substation.

Fault	SLG	LL	DLG	3-phase fault	Miscellaneous	Total	Monthly Total
January 2015							
Ekete feeder	14 times	10 times	2 times	Nil	Nil	26 times	44 times
Orhuwhorun feeder	9 times	7 times	1 time	1 time	1time	18 times	
February 2015							
Ekete feeder	13 times	5 times	4 times	Nil	Nil	22 times	49 times
Orhuwhorun feeder	12 times	10 times	5 times	Nil	Nil	27 times	
March 2015							
Ekete feeder	15 times	10 times	3 times	Nil		28 times	48 times
Orhuwhorun feeder	9 times	8 times	5 times	Nil	1time	23times	
April 2015							
Ekete feeder	13 times	7 times	5 times	1time	Nil	26 times	44 times
Orhuwhorun Feeder	7 times	6 times	4 times	1time	Nil	18 times	
May 2015							
Ekete feeder	9 times	7 times	6 times	Nil	Nil	22 times	41 times
Orhuwhorun feeder	8 times	6 times	5 times	Nil	Nil	19 times	
June 2015							
Ekete feeder	11 times	9 times	2 times	Nil	Nil	22 times	48 times

Orhuwhorun feeder	10 times	7 times	3 times	Nil	Nil	23 times	
July 2015							
Ekete feeder	17 times	11 times	4 times	Nil	Nil	32 times	57 times
Orhuwhorun feeder	11 times	9 times	5 times	Nil	Nil	25 times	
August 2015							
Ekete feeder	10 times	8 times	5 times	Nil	Nil	23 times	44 times
Orhuwhorun feeder	10 times	7 times	4 times	Nil	Nil	21 times	
September 2015							
Ekete feeder	16 times	8 times	7 times	2times	1time	34 times	61 times
Orhuwhorun feeder	15 times	6 times	5 times	1time	Nil	27 times	
October 2015							
Ekete feeder	13 times	7 times	7 times	Nil	Nil	27times	50 times
Orhuwhorun feeder	14 times	6 times	3 times	Nil	Nil	23 times	
November 2015							
Ekete feeder	17 times	11 times	3 times	Nil	Nil	31 times	63 times
Orhuwhorun feeder	19 times	5 times	7 times	Nil	1time	32 times	
December 2015							
Ekete feeder	14 times	6 times	4 times	1 time	Nil	25	50 times
Orhuwhorun feeder	13 times	5 times	5 times	Nil	2 times	25	
Total	299	181	104	7 times	6times	597	
Total fault on Ekete feeder	296						
Total fault on Orhuwhorun feeder	301						

Table 4: Fault analysis of mofor injection substation feeders for 2015 [4].

2.4 Analysis of Typical Single Line to Ground Fault on the 11 kv Line with Fault at Phase A

Fault currents through bus M are independent of fault distances and fault resistances [6,7].

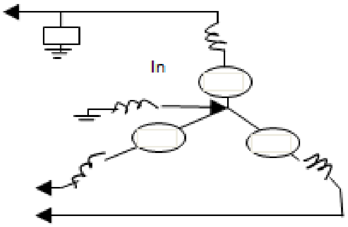

Figure 2: Representation of the line to ground fault.

Base Current=$\frac{15X10^6}{\sqrt{3}\,X11X10^3} = 787.3\text{A}$

Base Impedance=$\frac{(11*10^3)^2}{15*10^6}$=8.07Ω

Line to Line Voltage= 11kV

Base Voltage=11kV/√3

Let fault occur between terminal “a” and ground.

Fault impedance Zf =o.

Let the induced voltage of phase “a” be 1 per unit and be taken as reference phasor. So $Ea = 1.0\angle 0\circ pu$

Neglecting the resistance since the reactance is much larger we have,

$\text{Z1} = \text{2j}, \text{Z2} = 1.5\text{j}, \text{Z0} = 1\text{j}\ \text{Zf} = 0$

Converting to per unit

$Z_1 = \frac{actual\ impedance}{base\ impedance} = \frac{2j}{8.07} = 0.25j$

$Z_2 = \frac{actual\ impedance}{base\ impedance} = \frac{1.5j}{8.07} = 0.2j$

$Z_0 = \frac{actual\ impedance}{base\ impedance} = \frac{1j}{8.07} = 0.125j$

We have $\text{Ia0} = \text{Ia1} = \text{Ia2} = \frac{\text{Ea}}{\text{Z1+Z2+Z0+3Zf}}$

$$= \frac{1.0\angle 0\circ}{j0.25 + j0.2 + 0.125j + 0}$$

=1.0∠0∘/0.575j= -j1.739p.u

$\text{Fault Current}, \text{If} = \text{Ia} = 3\text{Ia1} = -3 * \text{j1.739p.u} = -\text{j5.217p.u}$

$= 5.217 * 787.3 = 4107.3A$

$Ib = 0\ and\ Ic = 0$

Symmetrical components of voltages from terminals “a” to ground

$\text{Va1} = \text{Ea} - \text{Ia1Z1} = (1 + \text{j0}) - (-\text{j1.739}) * \text{j0.25} = 0.5653\text{p.u}$

$\text{Va2} = -\text{Ia2Z2} = -(-\text{j1.739}) * \text{j0.2} = -0.3478\text{pu}$

$\mathrm{Va0} = -\mathrm{Ia0Z0} = -(-\mathrm{j}1.739) * \mathrm{j}0.125 = -0.2174\mathrm{pu}$

Line to ground Voltages,

$\mathrm{Va} = \mathrm{Va1} + \mathrm{Va2} + \mathrm{Va0} = 0.5653 - 0.3478 - 0.2174 = 0$

$\mathrm{Vb} = \mathrm{a}^2\mathrm{Va1} + \mathrm{aVa2} + \mathrm{Va0}$ Where a=-0.5+j0.866

$= 0.5653(-0.5 - \mathrm{j}0.866) - 0.3478(-0.5 + \mathrm{j}0.866) - 0.2174$

$= -0.3262 - \mathrm{j}0.7907\mathrm{pu}$

$\mathrm{Vc} = \mathrm{aVa1} + \mathrm{a}^2\mathrm{Va2} + \mathrm{Va0}$ where a=-0.5+j0.866

$= 0.5653(-0.5 + \mathrm{j}0.866) - 0.3478(-0.5 - \mathrm{j}0.866) - 0.2174$

$= -0.3262 + \mathrm{j}0.7907\ \mathrm{pu}$

Line to line voltages at fault points

$\mathrm{Vab} = \mathrm{Va} - \mathrm{Vb} = 0 - (-0.3262 - \mathrm{j}0.7907) = 0.3262 + \mathrm{j}0.7907$

$=\frac{11}{\sqrt{3}} * 0.8553\angle 67.6 = 5.43\angle 67.6 \circ \mathrm{KV}$

$\mathrm{Vbc} = \mathrm{Vb} - \mathrm{Vc} = (-0.3262 - \mathrm{j}0.7907) - (-0.3262 + \mathrm{j}0.7907) = -\mathrm{j}1.5814$

$= 1.5814\angle 270 \circ\ \mathrm{pu} = 11/\sqrt{3} * 1.5814\angle 270 \circ \mathrm{KV} = 10.04\angle 270 \circ$

$\mathrm{Vca} = \mathrm{Vc} - \mathrm{Va} = (-0.3262 + \mathrm{j}0.7907) - 0 = -0.3262 + \mathrm{j}0.7907$

$= 0.8553\angle 112.4\mathrm{pu} = 11/\sqrt{3} * 0.8553\angle 112.4 = 5.43\angle 112.4 \circ \mathrm{KV}$

It can be seen that when a fault occurs the post fault voltages and current are different from pre-fault voltage and current. While the voltage on the affected phase is reduced the current rises tremendously. Fault current = 4107.3 A.

The secondary current in CTs on LV side will be 4107.3*5/400=51.35 A.

The current in the pilot wires =51.35√3=88.93 A since the CT on LV side is delta connected (Figure 2).

2.5 Line to Line Fault Analysis

Considering a line to line that occurred between phase b and c.

Base Current=$\frac{15X10^6}{\sqrt{3}\,X11X10^3} = 787.3\mathrm{A}$

Base Impedance=$\frac{(11*10^3)^2}{15*10^6}$=8.07Ω

Base Voltage= 11KV

Let fault occur between terminal "b " and c.

Fault impedance Zf =j0.01

Z1= j0.2 , Z2= j0.2 Z0= j0.125

The induced voltage of phase "a" line to neutral voltage be 1 per unit.

So, $\mathrm{Ea} = (1 + \mathrm{j}0)\mathrm{pu}$

Vb-Vc=IbZf; Ia=-Ic;

Ia1=Ea/Z1+Z2+Zf= 1+jo/j0.20+j0.2+j0.01= -j2.44p.u

Ia2=-Ia1=j2.44p.u

Iao=0

Ia=Ia1+Ia2+Ia0= -j2.44+j2.44+0=0

$\mathrm{Ib} = \mathrm{a}^2\mathrm{Ia1} + \mathrm{aIa2} + \mathrm{Ia0}$

$= -\mathrm{j}2.44(-0.5 - \mathrm{j}0.866) + j2.44(-0.5 + \mathrm{j}0.866) + 0 = -4.23\ \mathrm{pu}$

$\mathrm{Ic} = \mathrm{aIa1} + \mathrm{a}^2\mathrm{Ia2} + \mathrm{Ia0}$

$= -\mathrm{j}2.44(-0.5 + \mathrm{j}0.866) + j2.44(-0.5 - \mathrm{j}0.866) + 0 = 4.23\mathrm{pu}$

Therefore Ia=0

$\mathrm{Ib} = -4.23 * 787.3 = -3330.3\mathrm{A}$

$\mathrm{Ic} = 4.23 * 787.3 = 3330.3\mathrm{A}$

Symmetrical component of the voltages from terminal a to ground

$\mathrm{Va1} = \mathrm{Ea} - \mathrm{Ia1Z1} = (1.0 + \mathrm{j}0) - (-\mathrm{j}2.44) * \mathrm{j}0.20 = 0.512\mathrm{pu}$

$\mathrm{Va2} = -\mathrm{Ia2Z2} = -\mathrm{j}2.44 * \mathrm{j}0.20 = 0.488\mathrm{pu}$

Va0 =0 since the transformer is grounded

Line to ground Voltages,

Va=Va1+Va2+Va0=0.512+0.488=1pu

$\mathrm{Vb} = \mathrm{a}^2\mathrm{Va1} + \mathrm{aVa2} + \mathrm{Va0}$

$= 0.512(-0.5 - \mathrm{j}0.866) + 0.488(-0.5 + \mathrm{j}0.866) + 0 = -0.5 - \mathrm{j}0.021\mathrm{pu}$

$\mathrm{Vc} = \mathrm{aVa1} + \mathrm{a}^2\mathrm{Va2} + \mathrm{Va0}$

$= 0.512(-0.5 + \mathrm{j}0.866) + 0.488(-0.5 - \mathrm{j}0.866) + 0 = -0.5 + \mathrm{j}0.021\mathrm{pu}$

$\mathrm{Vb} - \mathrm{Vc} = \mathrm{IbZf} = -4.23 * \mathrm{j}0.01 = -\mathrm{j}0.0423$

Line to line Voltages,

$\mathrm{Vab} = \mathrm{Va} - \mathrm{Vb} = 1 - (-0.5 - \mathrm{j}0.021) = 1.5 + \mathrm{j}0.021 = 1.5\measuredangle 0.8\circ\ \mathrm{pu}$

$$= \frac{11}{\sqrt{3}} * 1.5\measuredangle 0.8\circ = 9.53\measuredangle 0.8\circ\ \mathrm{KV}$$

$\mathrm{Vbc} = \mathrm{Vb} - \mathrm{Vc} = -0.5 - \mathrm{j}0.021 - (-0.5 + \mathrm{j}0.021) = -\mathrm{j}0.042\mathrm{pu} = 0.042\measuredangle 90\mathrm{pu}$

$$= \frac{11}{\sqrt{3}} * 0.042\measuredangle 90\circ = 266.7\measuredangle 90\circ\ \mathrm{V}$$

$\mathrm{Vca} = \mathrm{Vc} - \mathrm{Va} = -0.5 + \mathrm{j}0.021 - 1$

$= -1.5 + \mathrm{j}0.021 = 1.5\measuredangle 0.8\circ\ \mathrm{pu}$

$$= \frac{11}{\sqrt{3}} * 1.5\angle 0.8 \circ = 9.53\angle 0.8 \circ \text{KV}$$

It can be seen that when a fault occurs the post fault voltages and current are different from pre-fault voltage and current, while the voltage on the affected phase is reduced the current rises tremendously. For fault current = 3330.3 A.
The secondary current in CTs on LV side will be 3330.3*5/400=41.6 A.
The current in the pilot wires =51.35√3=72 A since the CT on LV side is delta connected.

2.6 Double Line to Ground Fault Analysis

Considering a double line to ground fault which occurred between terminal b and c to ground (Figure 3).

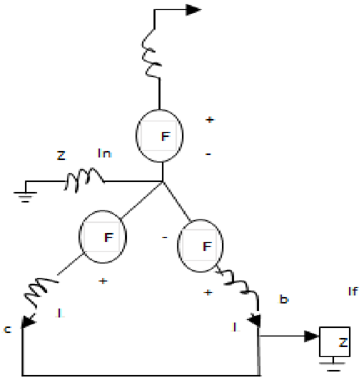

Figure 3: Double line to ground fault.

Base Current=$\frac{15X10^6}{\sqrt{3}\,\text{X}11\text{X}10^3} = 787.3\text{A}$

Base Impedance=$\frac{(11*10^3)^2}{15*10^6}$=8.07Ω

Base Voltage= 11KV

Let fault occur between terminal “b,c” and ground.

Fault impedance Zf=0

Z1=0.25pu ,Z2=j0.20,Z0=j0.125

The induced voltage of phase “a” line to neutral voltage is 1 per unit.

So, $\text{Ea} = (1 + \text{j}0)\text{p.u}$

$\text{Ia1} = \frac{\text{Ea}}{\text{Z1}+\frac{\text{Z2Z0}}{\text{Z2+Z0}}} = \frac{1+\text{jo}}{\text{j}0.25+\frac{\text{j}0.20*\text{j}0.125}{\text{j}0.20+\text{j}0.125}}$ = -j3.06 pu

Va1=Va2=Va0

Va1=Ea-Ia1Z1

$\text{Va0} = \text{Va2} = \text{Va1} = \text{Ea} - \text{Ia1Z1} = (1 + \text{jo}) - (-\text{j}3.06) * \text{j}0.25 \ = 0.235\text{pu}$

Ia2= -Va2/Z2 = -0.235/j0.2=j1.175pu

And Ia0=Va0/Z0= -0.235/j0.125=j1.88pu

And Iao +Iai+Ia2=j1.88-j3.06+j1.175=0

$\mathrm{Ib} = \mathrm{a}^2\mathrm{Ia1} + \mathrm{aIa2} + \mathrm{Ia0}$

$= -\mathrm{j3.06}(-0.5 - \mathrm{j0.866}) + j1.175(-0.5 + \mathrm{j0.866}) + \mathrm{j1.88} = -3.67 + \mathrm{j2.82pu}$

$= 4.63\measuredangle 142.4 \circ \mathrm{pu} = 3645.2\mathrm{A}\measuredangle 142.4 \circ$

$\mathrm{Ic} = \mathrm{aIa1} + \mathrm{a}^2\mathrm{Ia2} + \mathrm{Ia0}$

$= -\mathrm{j3.06}(-0.5 + \mathrm{j0.866}) + j1.175(-0.5 - \mathrm{j0.866}) + \mathrm{j1.88} = 3.67 + \mathrm{j2.82pu}$

$= 4.63\measuredangle 37.6 \circ \mathrm{pu} = 3645.2\mathrm{A}\measuredangle 37.6 \circ$

$\text{Fault current} = \mathrm{If} = \mathrm{Ib} + \mathrm{Ic} = \mathrm{j5.64pu} = 5.64\measuredangle 90 \circ * 787.3 = 4440.4\measuredangle 90 \circ \mathrm{A}$

Va0=Va1=Va2=0.235pu and Zf=0

Vb=Vc=0

Va=Va0+Va1+Va2=3*0.235=0.705pu

Line to line voltages in pu ,

Vab=Va-Vb=0.705-0=0.705∠0∘ pu

Vbc=Vb-Vc=0

Vca=Vc-Va=0-0.705=0.705∠180∘ pu

Line to line voltage in KV,

$$\mathrm{Vab} = 0.705\measuredangle 0 \circ * \frac{11}{\sqrt{3}}\,\mathrm{KV} = 4.48\measuredangle 0 \circ \mathrm{KV}$$

Vbc=0

$$\mathrm{Vca} = 0.705\measuredangle 0 \circ * \frac{11}{\sqrt{3}}\,\mathrm{KV} = 4.48\measuredangle 180 \circ \mathrm{KV}$$

It can be seen that when a fault occurs the post fault voltages and current are different from pre-fault voltage and current, while the voltage on the affected phase is reduced the current rises tremendously.
For fault current = 4440.4 A.
The secondary current in CTs on LV side will be 4440.4*5/400=55.5 A
The current in the pilot wires =55.5√3=96.1 A since the CT on LV side is delta connected.

2.7 Fault Analysis for a 3 Phase Fault on the 11 KV Line

$\mathrm{Ea} - \mathrm{Ia1Z1} = 0 \text{ or } \mathrm{Ia1} = \mathrm{Ea/Z1}$
$\text{Line current } = 1.0 \circ/\mathrm{j0.25} = 4\measuredangle - 90 \circ \mathrm{pu}$
$\text{Actual value of the line current } = 4 * 787.3\measuredangle - 90 \circ = 3149.2\measuredangle - 90 \circ$
For fault current = 3149.2A,
The secondary current in CTs on LV side will be 3149.2*5/400=39.4A
The current in the pilot wires =68.2*√3=68.2A since the CT on LV side is delta connected.

2.8 **Modeling of the Power Network Load**

Flow studies are used to ensure that electrical power transfer from generators to consumers through the grid system is stable, reliable and economic [8] (Table 5 and Figure 4).

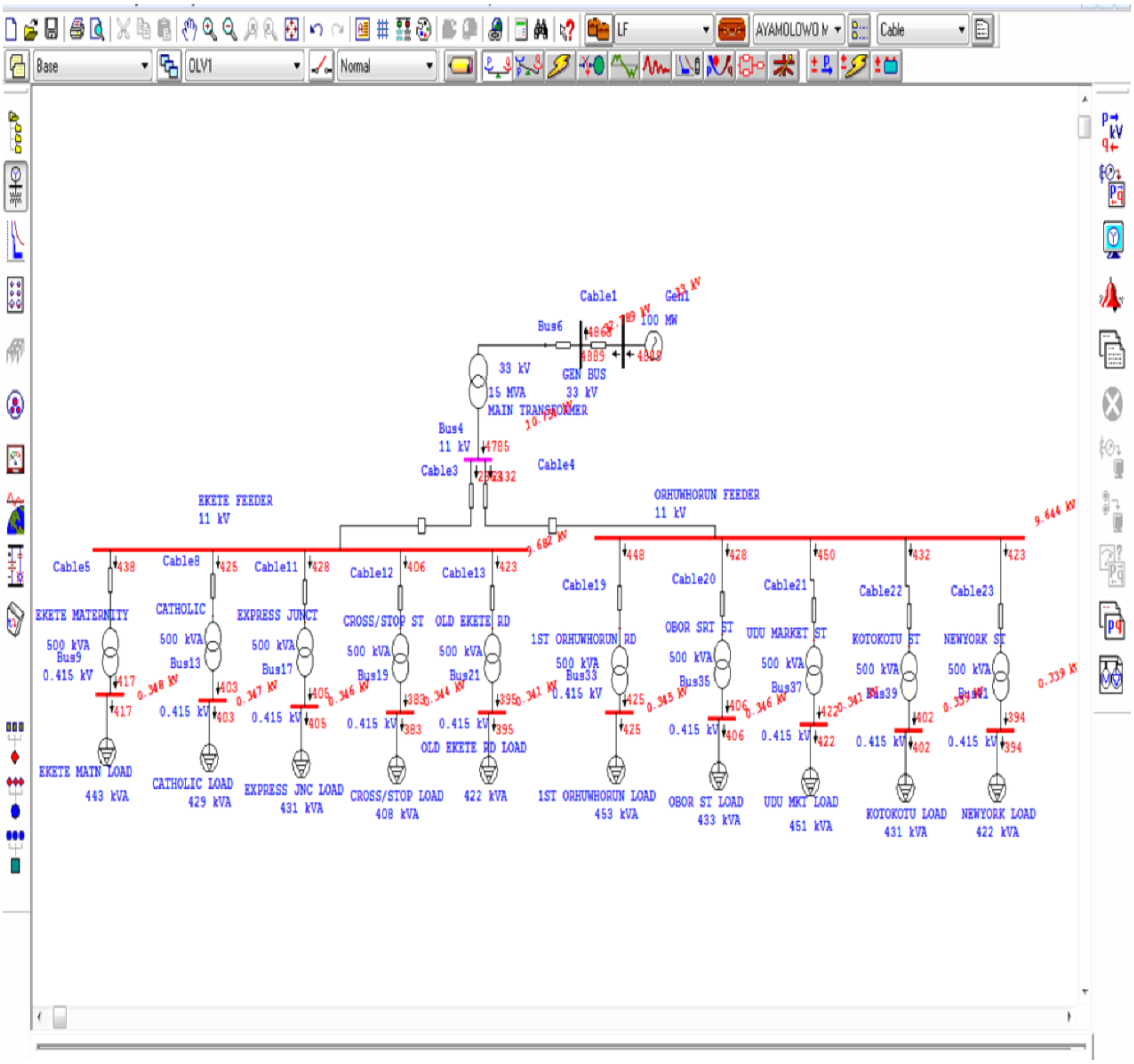

Figure 4: Simulated power network using ETAP 7.0.

Faults	Fault current(A)	Voltage Magnitude(KV) of line voltage Vab	Voltage Magnitude(KV) of line voltage Vbc	Voltage Magnitude(KV) of line voltage Vca
Single line to Ground	4107.3	5.43	10.04	5.43
Line to Line fault with fault at phase b,c	3330.3	9.53	0.227	9.53
Double Line to ground With fault at phase b,c to ground	4440.4	4.48	0	4.48
3 Phase fault	3149.2	0	0	0

Table 5: Shows the summary of fault analysis of various faults in mofor injection substation with 11 KV as base voltage and Base power MVA 15 MVA.

III. RESULTS AND DISCUSSION

Simulated and calculated results obtained from 15 MVA Mofor Injection Sub-station are analyzed. The study was carried out considering various faults in the Substation (Tables 6 and 7).

3.1. Input Data for Simulation of the Various Faults using MATLAB

FAULTS	R0(Ω)	X0(H)	Zo(P.U)	R1(Ω)	X1(H)	Z1(P.U)	R2(Ω)	X2(H)	Z2(P.U)	Zf(P.U)
SLG	0	1	j0.125	0	2	j0.25	0	1.5	j0.2	0
LL	0	1	j0.125	0	1.5	j0.2	0	1.5	j0.2	0.01
DLG	0	1	J0.125	0	2	J0.25	0	1.5	J0.2	0
3PHASE	0	1	j0.125	0	2	j0.25	0	1.5	j0.2	0
BASE VOLTAGE=11/√3 KV										
BASE POWER (KVA=15MVA										
BASE IMPEDANCE=8.07Ω										

Table 6: Shows the input parameter for simulation using MATLAB.

Fault	Line Voltage	Hand Calculations	Matlab
Single Line to Ground at phase A Line to Line fault with fault at phase b,c	Vca (KV)	5.43	5.4
	Fault Current(A)	4107.3	4107.1
	Vab (KV)	9.53	9.49
	Vbc (KV)	0.227	0.225
	Vca (KV)	9.53	9.49
	Fault Current (A)	3330.3	3330.1
Double Line to ground With fault at phase b,c to ground	Vab (KV)	4.48	4.45
	Vbc (KV)	0	0
	Vca (KV)	4.48	4.45
	Fault Current(A)	4440.4	4440.1

3 Phase fault	Vab (KV)	0	0
	Vbc (KV)	0	0
	Vca (KV)	0	0
	Fault Current(A)	3149.2	3149

Table 7: Comparing the calculate and the simulated results.

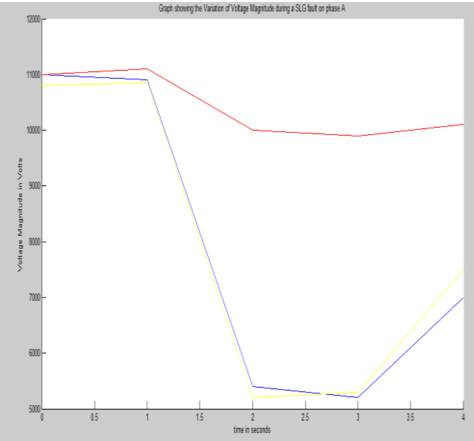

Figure 5: Graphical illustration of line to line voltage variation during a single line to ground fault using Matlab.

The Figure 5 shows the sharp decline in the Line to line voltage of Vab and Vca during a single line to ground fault at Phase A, while line voltage Vbc remains simply un affected.

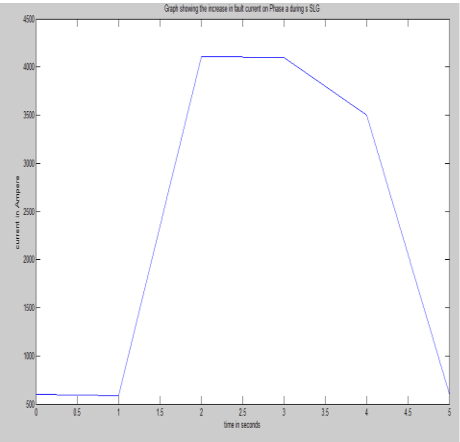

Figure 6: Graphical illustration of sharp increase in current during a single line to ground fault using Matlab.
The Figure 6 shows the increase in fault current due to the single line to ground fault at Phase A, this fault current is the second highest Fault current in power system and could cause severe damages if no proper protective device is in place.

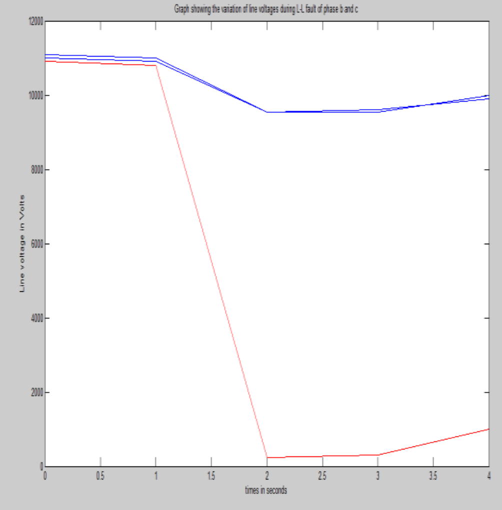

Figure 7: Graphical illustration of sharp decrease in phase voltage Vbc during a line to line fault between phase b and c using Matlab.

The Figure 7 shows the decrease in line voltage Vbc due to the Line line fault between phase b and c, while line Vab and Vca have fairly steady voltages.

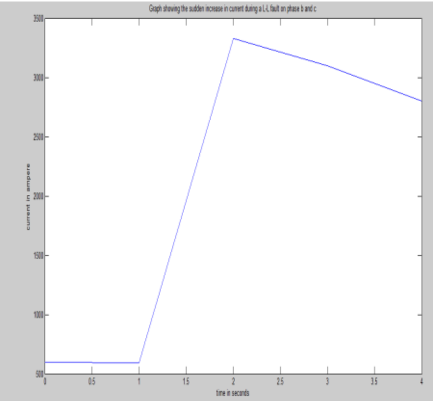

Figure 8: Graphical illustration of sharp increase in current during a line to line fault using Matlab.

The Figure 8 shows the increase in fault current due to the line to line fault at Phase b and c , the fault current could cause severe damages if no proper protective device in place.

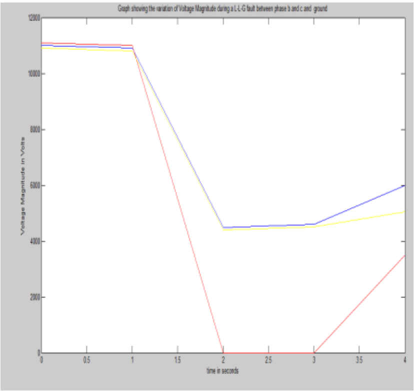

Figure 9: Graphical illustration of voltage magnitude variation during a DLG fault between phase b and c using Matlab.

The Figure 9 shows the sharp decline in the Line to line voltage as Vbc drops to zero while Vab,Vca suffered a decline in voltage during the period of the fault.

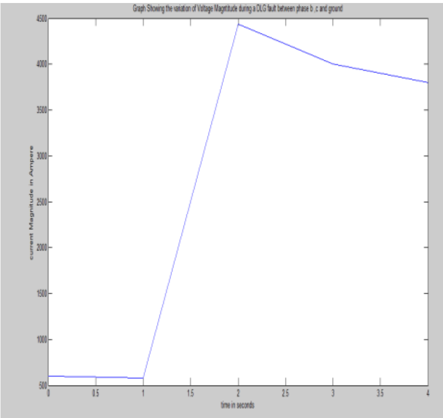

Figure 10: Graphical illustration of sharp increase in fault current during a double line to ground fault using Matlab.

The Figure 10 shows the increase in fault current due to the Double line to ground fault between phase b,c and ground, the fault current in the type of fault is the largest in power system and must be avoided. It was observed that this type of fault most times in Mofor Injection Substation causes the 33 KV line to open.

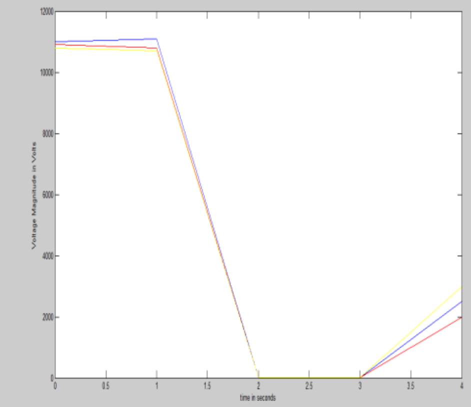

Figure 11: Graphical illustration of voltage magnitude variation during a 3 phase fault between phase a, b and c using Matlab.

The Figure 11 shows the sharp decline in the Line to line voltage as Vbc, Vca, Vab all dropped to zero. The type of fault has the least possibility of occurrence in power system.

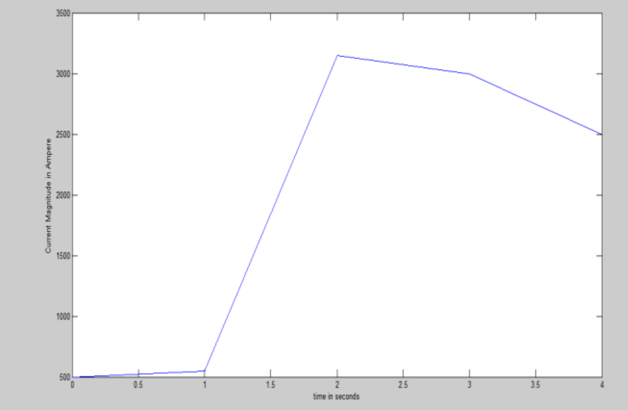

Figure 12: Graphical illustration of sharp increase in current during 3 phase using Matlab.

The Figure 12 shows the increase in fault current due to the short circuit involving all three phase. This fault current can cause severe damages in power system.

IV. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

In this project, fault analysis was carried out on Mofor Injection Substation. The analysis was carried manually using symmetrical components method. The results were compared with software solutions 'MATLAB' to validate the hand calculations' accuracy. The error was acceptable and below 0.1% for all type of fault. The following observations have been made based on the results obtained from the analysis.

1. In three phase fault, the voltages at faulted bus phases dropped to zero during the fault. In the faulted bus, Phase, A, B and C has a zero-voltage potential.

2. In the single line to ground fault However, only voltage at Phase A is equal to zero in. In addition, only Phase A has fault current since it is the faulted phase. The fault current in this is the second highest fault currents of in the system in consideration.
3. In line to line fault Phase B and Phase C are in contact, the voltages at both phases are equal. The fault current passes from B to C. In Phase A, the current is equal to zero compared to the fault current.
4. In double line to ground fault, Phase B and C voltages are equal to zero. The faulted current is flowing through both phases only. In addition, this type of fault is the most severe fault on the system which can be seen from its current value has it has the highest value of fault current.

The analysis was carried out on Mofor Injection Sub-station a 15 MVA network reveals that electrical power transfer from the Substation to consumers through the grid system is stable, reliable and the system is stable however, and it was also observed that the Substation was been under-utilized as it is operating less than its rated capacity.

4.2 Recommendation

To improve on the power availability of Mofor Injection Substation the following are recommended.

1. Use of High Speed Circuit Breaker. The best method of improving Mofor Injection Substation stability is the use of high speed circuit breakers. The quicker a breaker operates, the faster the fault is removed from the system and better is the tendency of the system to restore to normal operating conditions.
2. A dual supply of 33 KV to the injection substation will prevent incident of total power outage.
3. The use of digital system in tracking fault will reduce the time clearing time of fault.
4. Expansion of the Substation, as it presently under-utilized, it has capacity for two 15 MVA transformer but only one has been currently installed. The inclusion of the other will aid in expansion to other areas and improve efficiency of the Substation.

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