ANALYSIS OF ALTERNATING CURRENT INFLUENCE ON PIPELINES

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A thesis submitted in partial fulfillment of the requirements for the Degree of

Master of Technology

(Pipeline Engineering)

By

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Under the guidance of

A.Aravind Kumar

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CERTIFICATE

This is to certify that the work contained in this thesis titled "**ANALYSIS OF ALTERNATING CURRENT INFLUENCE ON PIPELINES**" has been carried out by **K.MANIKANDAN** under my supervision and has not been submitted elsewhere for a degree.

A.ARAVIND KUMAR 05/05/10

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Date :

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ABSTRACT:

Interference is one of the major challenges that the pipeline cathodic protection industry facing now a days. Interference is due to AC&DC transmission lines, DC transit system and foreign pipelines. Due to the recent increase in the number of industries, HVAC transmission lines are increasing in great number. There might be a situation arises when the pipeline and power line shares the same corridor. Project focuses primarily on the alternating current influence on the pipelines. In India HVAC overhead lines are available in the range of 66KV, 132KV, 220KV, & 400KV and their corresponding maximum operating current varies between 200 to 200 Amperes. Based on the current influenced corresponding mitigation methods will be carried out. Alternating current influenced on the pipelines is due to electromagnetic or inductive coupling, resistive or conductive coupling, and electrostatic or capacitive. Practical data are considered and the amount of current that will influence on the pipelines is identified and their corresponding plots are made. Based on the current influenced corresponding mitigation methods will be carried out.

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INTRODUCTION

Introduction:

Transfer of electrical energy between the pipeline and power line takes place due to electrostatic coupling, electromagnetic coupling and conductive coupling. Electrostatic coupling is because of the aboveground pipelines in the vicinity of overhead AC transmission lines, this primarily happens during the early construction stage when the pipelines are placed above the sand bags. Primary focus of the project is on Electromagnetic coupling or inductive coupling, which arises because of the steady state operating current of the transmission lines and conductive coupling which arises mainly due to the single phase to earth fault operating current.

Type of circuit:

Single circuit

Triangular circuit

Double circuits with vertical and horizontal configurations

Electrostatic coupling:

Electrostatic coupling which is also referred to as conductive coupling arises due to the transfer of electrical energy between the power line and aboveground pipelines. Mitigation of the electrostatic coupling can be carried out by proper grounding of power line and pipeline. Electrostatic coupling does not play a major role in the interference of onshore pipelines, because all the onshore pipeline are of buried.

Electromagnetic coupling:

Electromagnetic coupling which is also referred to as inductive coupling arises due to the transfer of energy between steady state operating current of the transmission lines and pipelines. Pipeline is considered as separate lossy conductor and there will be mutual impedance between the each phase of the transmission line and the pipelines, followed by the mutual impedance between the earth and each phase of the transmission lines. Based on the mutual impedance available corresponding EMF induced on the pipeline during steady state operating current is identified.

Conductive coupling:

Conductive coupling which is also referred to as resistive coupling arises due to the transfer of energy between the single phase to earth fault operating current of transmission lines and pipelines. Fault in the transmission line arises mainly due to the lightning stroke, conductor failure, and insulators failure. Conductive coupling also referred to as short term interference because the fault happens for short duration of time which varies from 0.2 to 0.5 sec. Analysis of conductive coupling can be made based on fault current and fault duration.

TOLERANCE LIMIT

2.1 Step, Touch Potentials:

Step potential is the potential difference between the two points on the earth surface and the distance between the two points is assumed to be 1m apart

Touch potential is the potential difference between a metallic structure and the point on the earth's surface separated by a distance equal to the normal maximum horizontal reach of the human (approximately 1m)

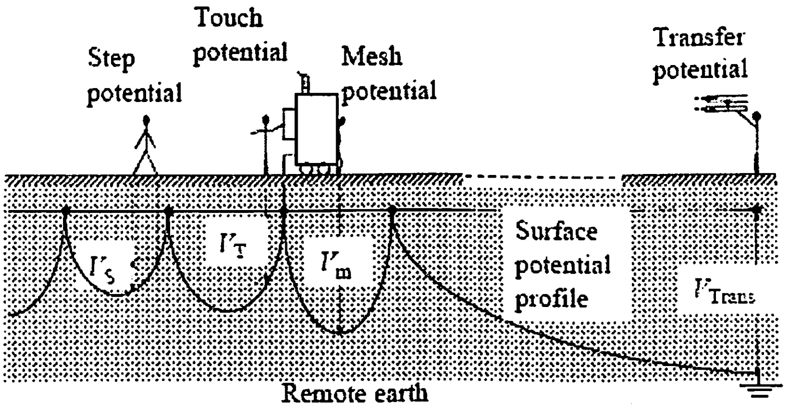

Figure no: 1 step, touch, and mesh potential

2.2 Electric current influence on the human body:

CURRENT	REACTION
< 1 milliamperes	Safe range
1 milliamperes	Faint consciousness
5 milliamperes	Shock might be slight, not painful but a sensation is felt
6-25 milliamperes – women	Painful shock – muscular control loss
9-30 milliamperes – men	Let go current (range)
50-150 milliamperes	Pain is severe with an extreme shock and death may be possible
1000-4300 milliamperes	Muscular contraction and damage of nerves
10000 milliamperes	Cardiac arrest, probability of death is high

Table no 1: Current influence on human body

2.3 Touch voltage criteria for metal – metal contact:

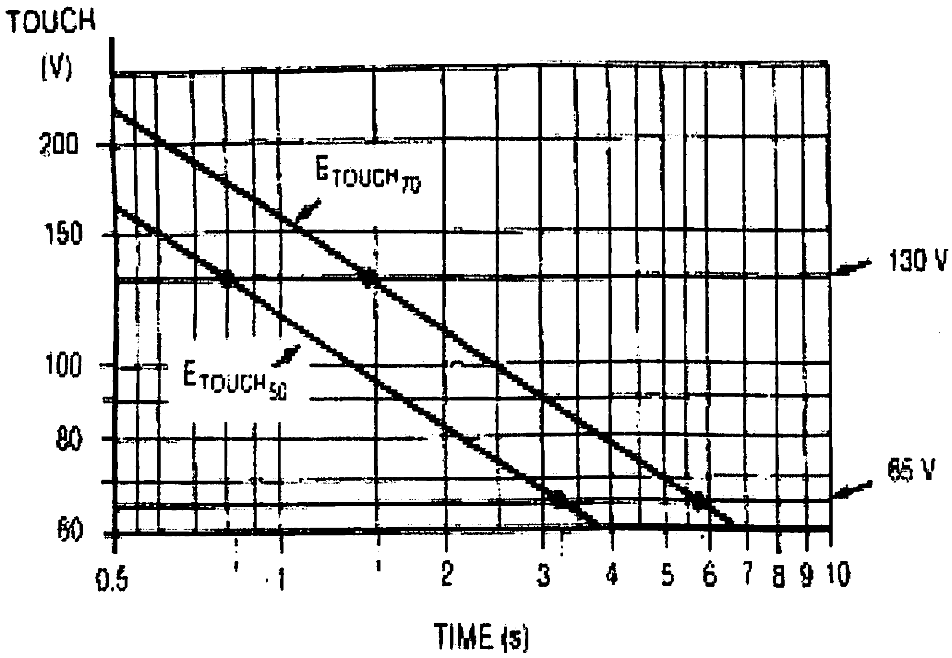

Figure no 2: Touch voltage limit for 70 and 50kg person

As per IEEE standard 80:2000 the permissible touch & step potential for 50Kg person is

V step50kg = (1000 + 6Cs * ρ) Ib Volts

V touch50kg = (1000 + 1.5Cs * ρ) Ib Volts

Whereas Ib is given by

Ib = 0.116 / √ts Amperes and ts should be between 0.03 seconds and 3 seconds

As per IEEE standard 80:2000 the permissible touch & step potential for 70Kg person is

V step70kg = (1000 + 6Cs * ρ) Ib Volts

V touch70kg = (1000 + 1.5Cs * ρ) Ib Volts

Ib = 0.157/ √ts Amperes and ts should be between 0.03 seconds and 3 seconds

2.4 Step, touch potential of SA-SS pipeline section:

pipeline	fault duration	fault current - 50kg	fault current - 70kg	Vstep 50	Vtouch 50	Vstep 70	Vtouch 70
SA-01	0.5	0.164048773	0.222031529	183.735	168.97	248.675	228.692
SA-02	0.5	0.164048773	0.222031529	183.735	168.97	248.675	228.692
SS-01	0.5	0.164048773	0.222031529	183.735	168.97	248.675	228.692
SS-02	0.5	0.164048773	0.222031529	183.735	168.97	248.675	228.692
SS-03	0.5	0.164048773	0.222031529	183.735	168.97	248.675	228.692
resistivity	20	ohm-m					

Table no 2: Step, touch potentials of SA-SS section

Fault duration in seconds

Fault current in amperes

Step and touch potentials in volts

2.5 Reference:

IEEE Std 80-1986 IEEE Guide for safety in AC substation grounding, page no: 43 - 47

W.B.Kouwenhoven " Human safety and electrical shock", Electrical safetypractices,monograph,112, instrument society of America page no:93,NOV 1968

NACE RP-0177 mitigation of alternating current and lightning effects on metallic structure, page no: 2, 3

SECTION - 01 STEADY STATE OPERATING CONDITION

3.1 Pipeline and Powerline specification : SA-01

Length of parallelism : 9.30 KM

Distance of the tower from pipeline : 100m

Depth at which pipeline layed : 2m

Phase to phase distance : 7.5 m

KV rating : 380 KV

Type of circuit : Double circuit

Maximum operating current : 1200 Amperes

Coating thickness : 3.2mm

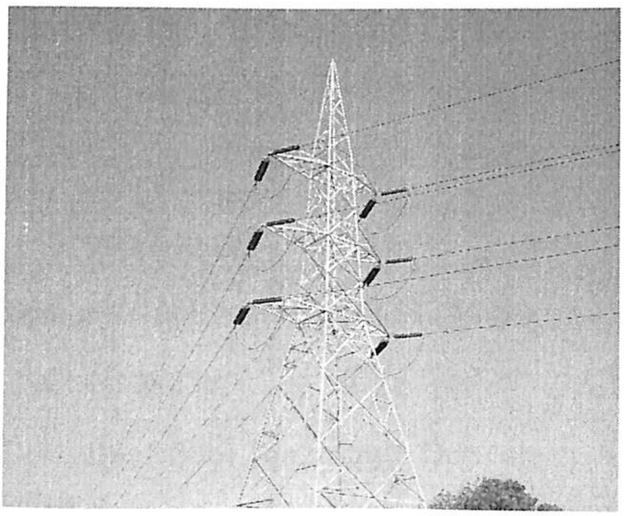

Figure no 3: Typical double circuit tower with one earth wire

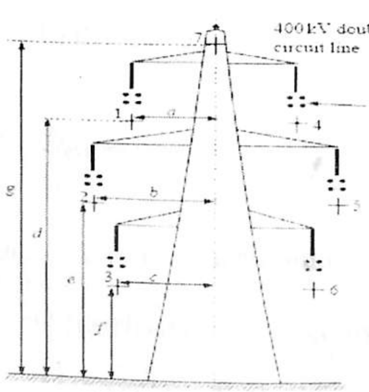

Figure no 4: Double circuit line considered

From the figure above f =13m, a=6.93m, b=10.16m, c=8.33m

$Dpr1 = \sqrt{(100 - 6.93)^2 + (13+2)^2}$

$= 92.88m$

$Dpy1 = \sqrt{(100 - 10.16)^2 + (13+7.5+2)^2}$

$= 92.61m$

$Dpb1 = \sqrt{(100 - 8.33)^2 + (13+7.5+7.5+2)^2}$

$= 96.45m$

$Dpr2 = \sqrt{(100 + 6.93)^2 + (13+2)^2}$

$= 109.3\ m$

$Dpy2 = \sqrt{(100 + 10.16)^2 + (13+7.5+2)^2}$

$= 112.43\ m$

$Dpb2 = \sqrt{(100 + 8.33)^2 + (13+7.5+7.5+2)^2}$

$= 112.40\ m$

$Dpe = \sqrt{(100)^2 + (13+7.5+7.5+7.5+2)^2}$

$= 106.8\ m$

Dpr1, Dpy1,Dpb1,Dpr2, Dpy2, Dpb2 are the distance the R,Y,B phases of the tower line and the pipeline

Dpe is the distance between the pipeline and the earth line

3.2 Depth of Earth Return Current:

$$D_{erc} = 658.87 \times \sqrt{\frac{\rho_e}{f}}\ \text{m}$$

Derc = depth of earth return current

Earth resistivity is denoted by $\rho e = 200$ ohm-m

Frequency f is in hertz ; f = 60 HZ

Derc = 658.87 x $\sqrt{(200/60)}$ = 1202 m

3.3 Mutual impedance between the power line and pipeline:

$$Z_{pj} = \pi^2 10^{-4} f + j4\pi f\, 10^{-4} \sqrt{\frac{\left[\log_e\left(1 + 1.382\frac{D_{erc}^2}{d_{pj}^2}\right)\right]^2}{4} - \frac{\pi^2}{16}}\ \Omega/\text{km}$$

Zpj = mutual impedance between the conductors

F is the frequency = 60 HZ

Derc = depth of earth return current = 1202 m

Dpj = distance between the pipeline and powerline phases

Mutual impedances	Values
Zpr1	0.059+j0.1920
Zpy1	0.059+j0.1922
Zpb1	0.059+j0.1892
Zpr2	0.059+j0.1798
Zpy2	0.059+j0.1777
Zpb2	0.059+j0.1772
Zpe	0.059+j0.1815

Table no 3:Mutual impedance between power line and pipeline

Distance between the earth and phases of the transmission line

Distance	Values in m
Der1	23.99
Dey1	18.11
Deb1	10.21

Table no 4: distance between the earth and phases

Mutual impedance between the earth and phases of transmission line

Mutual impedance	Values
Zer1	0.059+j0.2935
Zey1	0.059+j0.1314
Zeb1	0.059+j0.3576
Zee	0.1136+j0.6988

Table no 5: Mutual impedance between the earth and phases of transmission line

Mutual impedances are represented in ohms/KM

3.4 EMF induced on the pipeline without earth:

$$-\mathrm{EMF_p} = Z_{\mathrm{pR}} I_{\mathrm{R}} + Z_{\mathrm{pY}} I_{\mathrm{Y}} + Z_{\mathrm{pB}} I_{\mathrm{B}} \ \mathrm{V/km}$$

-EMFp = -3.63720000000001+J4.38000000000002 Volts/Km

EMFp = 3.63720000000001-J4.38000000000002

Absolute value = 5.693 volts/km

3.5 EMF induced on the pipeline with earth:

$$-\mathrm{EMF_p} = (Z_{\mathrm{pR}} I_{\mathrm{R}} + Z_{\mathrm{pY}} I_{\mathrm{Y}} + Z_{\mathrm{pB}} I_{\mathrm{B}}) - \frac{Z_{\mathrm{pE}}}{Z_{\mathrm{EE}}}(Z_{\mathrm{ER}} I_{\mathrm{R}} + Z_{\mathrm{EY}} I_{\mathrm{Y}} + Z_{\mathrm{EB}} I_{\mathrm{B}}) \ \mathrm{V/km}$$

EMFp = 23.6047476293827-J35.1528144666602

Absolute value = 42.03 volts/km

3.6 Electrical characteristics of the pipeline:

3.6.1 Pipeline shunt admittance:

$$y_c = \frac{2000\pi r_p}{\rho_c t_c} + j\frac{\pi r_p f \varepsilon_c 10^{-6}}{9 t_c} \ \mathrm{S/km}$$

Radius of the pipeline = rp = 0.5588m

Resistivity of the pipeline coating = ρc = 25x10^6

Thickness of the coating = tc = 3.2mm

Frequency = f = 60 HZ

Coating relative permittivity = εc = 5 x 10^-6

Yc = 0.043+j0.0182 S/Km

3.6.2 Pipeline series impedance:

$$z = \frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + \pi^2 10^{-4} f + j\left[\frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + 4\pi 10^{-4} f \log_e\left(\frac{D_{erc}}{r_p}\right)\right] \ \Omega/\mathrm{km}$$

Radius of the pipeline = rp = 0.5588m

Derc = depth of earth return current = 1202 m

Relative permeability of the metal = μ = 300

Z = 0.0874 + j 0.6061 ohms/Km

3.6.3 Propagation constant:

Propagation constant γ = √(z * y) /km

And γ = √(0.0874 + j 0.6061) x (0.043+j0.0182) = 0.10324 + j0.1339

3.6.4 Characteristic impedance:

Z = √(z / y) ohms

Z = √(0.0874 + j 0.6061) / (0.043+j0.0182) = 3.152 + j1.77925 ohms

3.7 Distribution of voltage along the pipeline and powerline parallelism:

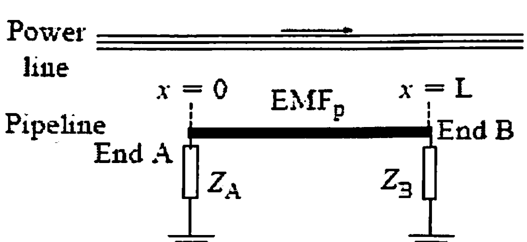

Figure no 5: shows the portion of pipeline parallel to powerline

$$V(x) = \frac{E_0}{2\gamma}[(2e^{-\gamma L} - e^{-2\gamma L})e^{\gamma x} - e^{-\gamma x}]\ \mathrm{V}$$

Propagation constant is denoted by γ

L is the overall length of parallelism = 9.30m

X which varies from 0 to 9.30 Km

Eo is the EMF induced on the pipeline

V(x) shows the variation of voltages along the various length of parallelism

3.8 Voltage to earth along the pipeline is tabulated as:

X	Eo	γ	L	voltage-abs
0	23.604-35.1528i	0.10324+0.1339i	9.3	112.9054539
1.5	23.604-35.1528i	0.10324+0.1339i	9.3	68.69681144
2	23.604-35.1528i	0.10324+0.1339i	9.3	56.02277349
2.5	23.604-35.1528i	0.10324+0.1339i	9.3	46.48552339
3	23.604-35.1528i	0.10324+0.1339i	9.3	42.59342909
3.5	23.604-35.1528i	0.10324+0.1339i	9.3	46.06710699
4	23.604-35.1528i	0.10324+0.1339i	9.3	55.71522923
4.5	23.604-35.1528i	0.10324+0.1339i	9.3	69.10211984
5	23.604-35.1528i	0.10324+0.1339i	9.3	84.53054714
5.5	23.604-35.1528i	0.10324+0.1339i	9.3	101.1012203
6	23.604-35.1528i	0.10324+0.1339i	9.3	118.3462324
6.5	23.604-35.1528i	0.10324+0.1339i	9.3	136.0072086
7	23.604-35.1528i	0.10324+0.1339i	9.3	153.9312411
7.5	23.604-35.1528i	0.10324+0.1339i	9.3	172.0228004
8	23.604-35.1528i	0.10324+0.1339i	9.3	190.2206242
8.5	23.604-35.1528i	0.10324+0.1339i	9.3	208.4860931
9	23.604-35.1528i	0.10324+0.1339i	9.3	226.7971609
9.3	23.604-35.1528i	0.10324+0.1339i	9.3	237.8015682

Table no 6: Voltage influenced along various sections of parallelism

3.9 Plot of voltage versus length of parallelism at various distance:

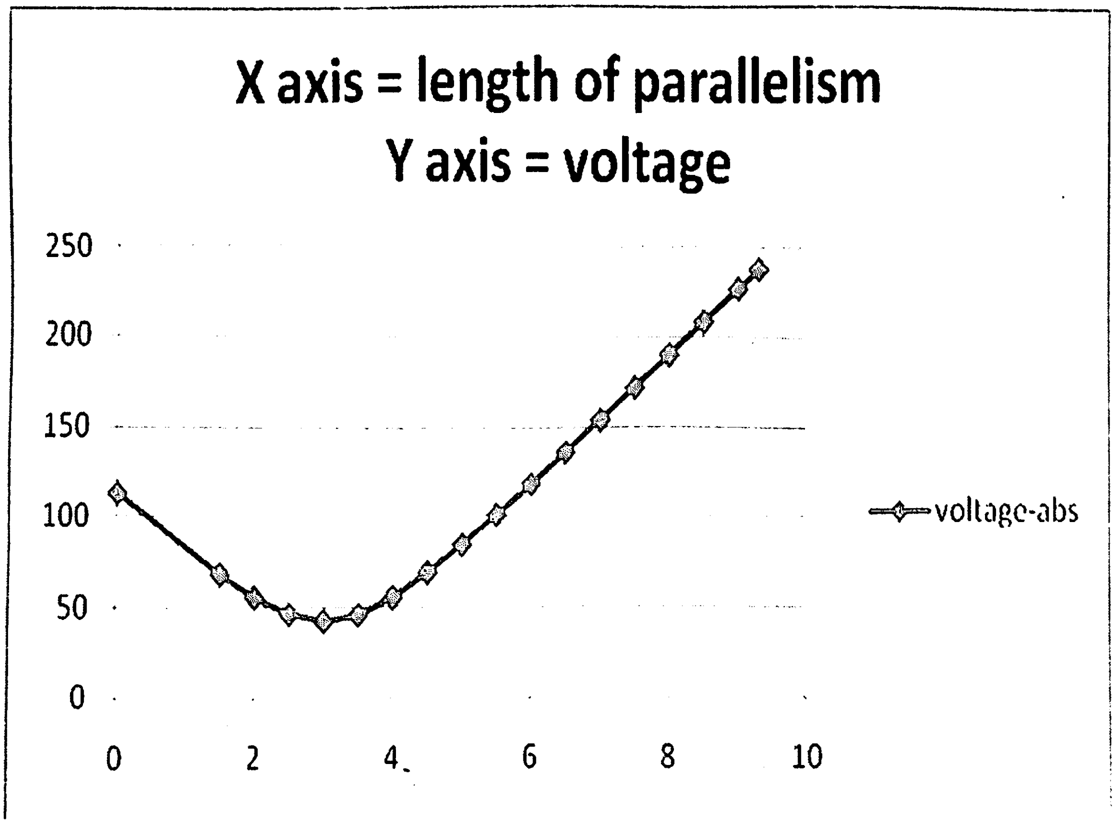

Figure no 6:Voltage versus Length of parallelism

3.10 Distribution of Current along the pipeline and powerline parallelism:

$$I(x) = \frac{E_0}{2\gamma Z_0}[2 + (e^{-2\gamma L} - 2e^{-\gamma L})e^{\gamma x} - e^{-\gamma x}]\ \mathrm{A}$$

L is the overall length of parallelism = 9.30m

X which varies from 0 to 9.30 Km

Eo is the EMF induced on the pipeline

Zo is the characteristic impedance

3.11 Representation of current distribution along various section:

X	Eo	Γ	L	I(xabs)
0	23.60476-35.15281i	0.10324+0.1339i	9.3	31.1776
0.5	23.60476-35.15281i	0.10324+0.1339i	10.3	32.69179
1	23.60476-35.15281i	0.10324+0.1339i	11.3	33.97301
1.5	23.60476-35.15281i	0.10324+0.1339i	12.3	34.97087
2	23.60476-35.15281i	0.10324+0.1339i	13.3	35.64841
2.5	23.60476-35.15281i	0.10324+0.1339i	14.3	35.97796
3	23.60476-35.15281i	0.10324+0.1339i	15.3	35.93847
3.5	23.60476-35.15281i	0.10324+0.1339i	16.3	35.51372
4	23.60476-35.15281i	0.10324+0.1339i	17.3	34.69107
4.5	23.60476-35.15281i	0.10324+0.1339i	18.3	33.46067
5	23.60476-35.15281i	0.10324+0.1339i	19.3	31.81488
5.5	23.60476-35.15281i	0.10324+0.1339i	20.3	29.74785
6	23.60476-35.15281i	0.10324+0.1339i	21.3	27.2552
6.5	23.60476-35.15281i	0.10324+0.1339i	22.3	24.33383
7	23.60476-35.15281i	0.10324+0.1339i	23.3	20.98169
7.5	23.60476-35.15281i	0.10324+0.1339i	24.3	17.19766
8	23.60476-35.15281i	0.10324+0.1339i	25.3	12.98142
8.5	23.60476-35.15281i	0.10324+0.1339i	26.3	8.333356
9	23.60476-35.15281i	0.10324+0.1339i	27.3	3.254407
9.3	23.60476-35.15281i	0.10324+0.1339i	28.3	0.000809

Table no 7: Current distribution

3.12 Plot for current distribution along the various section:

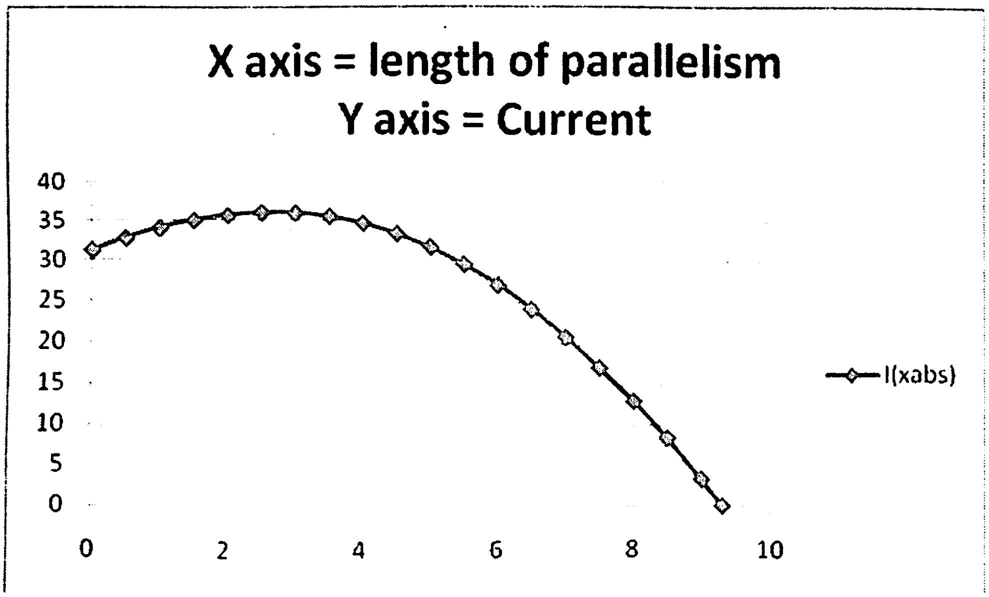

Figure no 7: current distribution plot

3.13 Reference:

Power Systems Modelling and Fault Analysis,Theory and Practice-Nasser Tleis page number: 588 - 601

SECTION - 02 STEADY STATE OPERATING CONDITION

4.1 Pipeline and Powerline specification : SA-02

Length of parallelism : 13.50 KM

Distance of the tower from pipeline : 100m

Depth at which pipeline layed : 2m

Phase to phase distance : 7.5 m

KV rating : 110 KV

Type of circuit : Double circuit

Maximum operating current : 800 Amperes

Coating thickness : 3.2mm

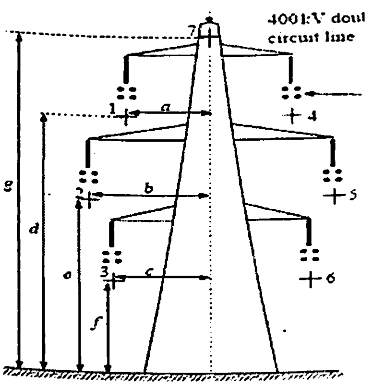

Figure no 8: Double circuit line considered

From the figure above f =13m, a=6.93m, b=10.16m, c=8.33m

$$Dpr1 = \sqrt{(100 - 6.93)^2 + (13+2)^2}$$

$$= 92.88m$$

$$Dpy1 = \sqrt{(100 - 10.16)^2 + (13+7.5+2)^2}$$

$$= 92.61m$$

$$Dpb1 = \sqrt{(100 - 8.33)^2 + (13+7.5+7.5+2)^2}$$

$$= 96.45m$$

$$Dpr2 = \sqrt{(100 + 6.93)^2 + (13+2)^2} = 109.3 \text{ m}$$

Dpy2 = √(100 + 10.16)² + (13+7.5+2)²

= 112.43 m

Dpb2 = √(100 + 8.33)² + (13+7.5+7.5+2)²

= 112.40 m

Dpe = √(100)² + (13+7.5+7.5+7.5+2)²

= 106.8 m

Dpr1, Dpy1,Dpb1,Dpr2, Dpy2, Dpb2 are the distance the R,Y,B phases of the tower line and the pipeline

Dpe is the distance between the pipeline and the earth line

4.2 Depth of Earth Return Current:

$$D_{erc} = 658.87 \times \sqrt{\frac{\rho_e}{f}}\ \mathrm{m}$$

Derc = depth of earth return current

Earth resistivity is denoted by ρe = 200 ohm-m

Frequency f is in hertz ; f = 60 HZ

Derc = 658.87 x √(200/60) = 1202 m

4.3 Mutual impedance between the power line and pipeline:

$$Z_{pj} = \pi^2 10^{-4} f + j4\pi f\, 10^{-4} \sqrt{\frac{\left[\log_e\left(1 + 1.382\frac{D_{erc}^2}{d_{pj}^2}\right)\right]^2}{4} - \frac{\pi^2}{16}}\ \Omega/\mathrm{km}$$

Zpj = mutual impedance between the conductors

F is the frequency = 60 HZ

Derc = depth of earth return current = 1202 m

Dpj = distance between the pipeline and powerline phases

Mutual impedances	Values
Zpr1	0.059+j0.1920
Zpy1	0.059+j0.1922
Zpb1	0.059+j0.1892
Zpr2	0.059+j0.1798
Zpy2	0.059+j0.1777
Zpb2	0.059+j0.1772
Zpe	0.059+j0.1815

Table no 8:Mutual impedance between power line and pipeline

Distance between the earth and phases of the transmission line

Distance	Values in m
Der1	23.99
Dey1	18.11
Deb1	10.21

Table no 9:Distance between the earth and the phases

Mutual impedance between the earth and phases of transmission line

Mutual impedance	Values
Zer1	0.059+j0.2935
Zey1	0.059+j0.1314
Zeb1	0.059+j0.3576
Zee	0.1136+j0.6988

Table no 10: Mutual impedance between earth and phases

Mutual impedances are represented in ohms/KM

4.4 EMF induced on the pipeline without earth:

$$-\mathrm{EMF_p} = Z_{pR}I_R + Z_{pY}I_Y + Z_{pB}I_B \text{ V/km}$$

Ir = 800 Amperes

Iy=-400+692.8i Amperes

Ib=-400-692.8i Amperes

-EMFp = -2.42479999999998+2.91999999999999i Volts/Km

EMFp = 2.42479999999998-2.91999999999999i Volts/Km

Absolute value = 3.79 volts/km

4.5 EMF induced on the pipeline with earth:

$$-\mathrm{EMF_p} = (Z_{pR}I_R + Z_{pY}I_Y + Z_{pB}I_B) - \frac{Z_{pE}}{Z_{EE}}(Z_{ER}I_R + Z_{EY}I_Y + Z_{EB}I_B)\ \mathrm{V/km}$$

EMFp = 15.7364984195884-23.4352096444401i volts/Km

Absolute value = 28.228 volts/km

4.6 Electrical characteristics of the pipeline:

4.6.1 Pipeline shunt admittance:

$$y_c = \frac{2000\pi r_p}{\rho_c t_c} + j\frac{\pi r_p f \varepsilon_c 10^{-6}}{9 t_c}\ \mathrm{S/km}$$

Radius of the pipeline = rp = 0.5588m

Resistivity of the pipeline coating = ρc = 25x10^6

Thickness of the coating = tc = 3.2mm

Frequency = f = 60 HZ

Coating relative permittivity = εc = 5 x 10^-6

Yc = 0.043+j0.0182 S/Km

4.6.2 Pipeline series impedance:

$$z = \frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + \pi^2 10^{-4} f + j\left[\frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + 4\pi 10^{-4} f \log_e\left(\frac{D_{erc}}{r_p}\right)\right]\ \Omega/\mathrm{km}$$

Radius of the pipeline = rp = 0.5588m

Derc = depth of earth return current = 1202 m

Relative permeability of the metal = μ = 300

Z = 0.0874 + j 0.6061 ohms/Km

4.6.3 Propagation constant:

Propagation constant γ = √(z * y) /km

And γ = √(0.0874 + j 0.6061) x (0.043+j0.0182) = 0.10324 + j0.1339

4.6.4 Characteristic impedance:

Z = √(z / y) ohms

Z = √(0.0874 + j 0.6061) / (0.043+j0.0182) = 3.152 + j1.77925 ohms

4.7 Distribution of voltage along the pipeline and powerline parallelism:

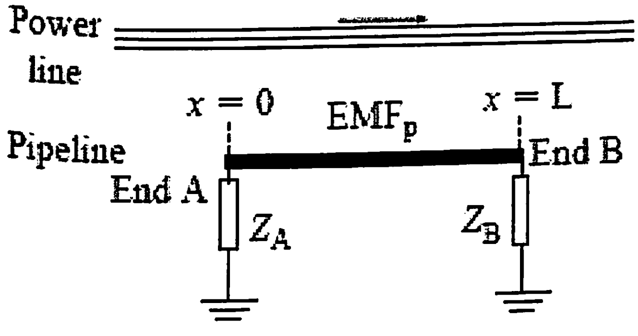

Figure no 9: shows the portion of pipeline parallel to powerline

$$V(x) = \frac{E_0}{2\gamma}[(2e^{-\gamma L} - e^{-2\gamma L})e^{\gamma x} - e^{-\gamma x}]\ V$$

Propagation constant is denoted by γ

L is the overall length of parallelism = 13.50m

X which varies from 0 to 13.50 Km

Eo is the EMF induced on the pipeline

V(x) shows the variation of voltages along the various length of parallelism

4.8 Voltage to earth along the pipeline is tabulated as:

X	Eo	Γ	L	voltage-abs
0	15.7364-23.4352i	0.10324+0.1339i	13.5	98.33825614
1.5	15.7364-23.4352i	0.10324+0.1339i	13.5	75.05391432
2	15.7364-23.4352i	0.10324+0.1339i	13.5	67.10810759
2.5	15.7364-23.4352i	0.10324+0.1339i	13.5	59.19951698
3	15.7364-23.4352i	0.10324+0.1339i	13.5	51.47774799
3.5	15.7364-23.4352i	0.10324+0.1339i	13.5	44.19123326
4	15.7364-23.4352i	0.10324+0.1339i	13.5	37.76120685
4.5	15.7364-23.4352i	0.10324+0.1339i	13.5	32.87609832
5	15.7364-23.4352i	0.10324+0.1339i	13.5	30.4689553
5.5	15.7364-23.4352i	0.10324+0.1339i	13.5	31.27275027
6	15.7364-23.4352i	0.10324+0.1339i	13.5	35.18457034
6.5	15.7364-23.4352i	0.10324+0.1339i	13.5	41.41452256
7	15.7364-23.4352i	0.10324+0.1339i	13.5	49.14441974
7.5	15.7364-23.4352i	0.10324+0.1339i	13.5	57.81233997
8	15.7364-23.4352i	0.10324+0.1339i	13.5	67.07859439
8.5	15.7364-23.4352i	0.10324+0.1339i	13.5	76.7401966
9	15.7364-23.4352i	0.10324+0.1339i	13.5	86.67223254
9.5	15.7364-23.4352i	0.10324+0.1339i	13.5	96.79502599
10	15.7364-23.4352i	0.10324+0.1339i	13.5	107.0564646
10.5	15.7364-23.4352i	0.10324+0.1339i	13.5	117.4224086
11	15.7364-23.4352i	0.10324+0.1339i	13.5	127.8713753
11.5	15.7364-23.4352i	0.10324+0.1339i	13.5	138.391534
12	15.7364-23.4352i	0.10324+0.1339i	13.5	148.978982
12.5	15.7364-23.4352i	0.10324+0.1339i	13.5	159.6367501
13	15.7364-23.4352i	0.10324+0.1339i	13.5	170.3742298
13.5	15.7364-23.4352i	0.10324+0.1339i	13.5	181.2068417

Table no 11 : Voltage influenced along various sections of parallelism

4.9 Distribution of Current along the pipeline and powerline parallelism:

$$I(x) = \frac{E_0}{2\gamma Z_0}[2 + (e^{-2\gamma L} - 2e^{-\gamma L})e^{\gamma x} - e^{-\gamma x}]\ A$$

L is the overall length of parallelism = 9.30m

X which varies from 0 to 9.30 Km

Eo is the EMF induced on the pipeline & Zo is the characteristic impedance

4.10 Representation of current distribution along various section:

X	Eo	Γ	L	I(xabs)
0	15.73649-23.4352i	0.10324+0.1339i	13.5	27.15449
0.5	15.73649-23.4352i	0.10324+0.1339i	13.5	28.55152
1	15.73649-23.4352i	0.10324+0.1339i	13.5	29.90543
1.5	15.73649-23.4352i	0.10324+0.1339i	13.5	31.17443
2	15.73649-23.4352i	0.10324+0.1339i	13.5	32.3261
2.5	15.73649-23.4352i	0.10324+0.1339i	13.5	33.3351
3	15.73649-23.4352i	0.10324+0.1339i	13.5	34.18132
3.5	15.73649-23.4352i	0.10324+0.1339i	13.5	34.84856
4	15.73649-23.4352i	0.10324+0.1339i	13.5	35.32364
4.5	15.73649-23.4352i	0.10324+0.1339i	13.5	35.59571
5	15.73649-23.4352i	0.10324+0.1339i	13.5	35.6557
5.5	15.73649-23.4352i	0.10324+0.1339i	13.5	35.49604
6	15.73649-23.4352i	0.10324+0.1339i	13.5	35.11034
6.5	15.73649-23.4352i	0.10324+0.1339i	13.5	34.4932
7	15.73649-23.4352i	0.10324+0.1339i	13.5	33.64009
7.5	15.73649-23.4352i	0.10324+0.1339i	13.5	32.54717
8	15.73649-23.4352i	0.10324+0.1339i	13.5	31.21127
8.5	15.73649-23.4352i	0.10324+0.1339i	13.5	29.62972
9	15.73649-23.4352i.	0.10324+0.1339i	13.5	27.80038
9.5	15.73649-23.4352i	0.10324+0.1339i	13.5	25.72151
10	15.73649-23.4352i	0.10324+0.1339i	13.5	23.39175
10.5	15.73649-23.4352i	0.10324+0.1339i	13.5	20.81005
11	15.73649-23.4352i	0.10324+0.1339i	13.5	17.97565
11.5	15.73649-23.4352i	0.10324+0.1339i	13.5	14.888
12	15.73649-23.4352i	0.10324+0.1339i	13.5	11.54675
12.5	15.73649-23.4352i	0.10324+0.1339i	13.5	7.951662
13	15.73649-23.4352i	0.10324+0.1339i	13.5	4.102614
13.5	15.73649-23.4352i	0.10324+0.1339i	13.5	0.000626

Table no 12: Current distribution

4.11 Plot for voltage variation along the various section:

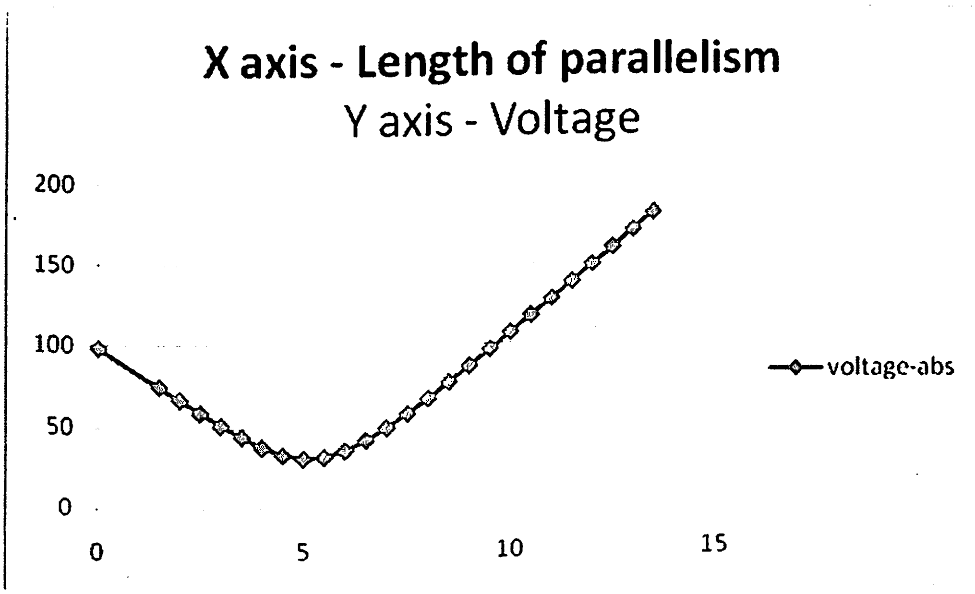

Figure no 10: Voltage variation along the section

4.12 Current distribution plot along the section:

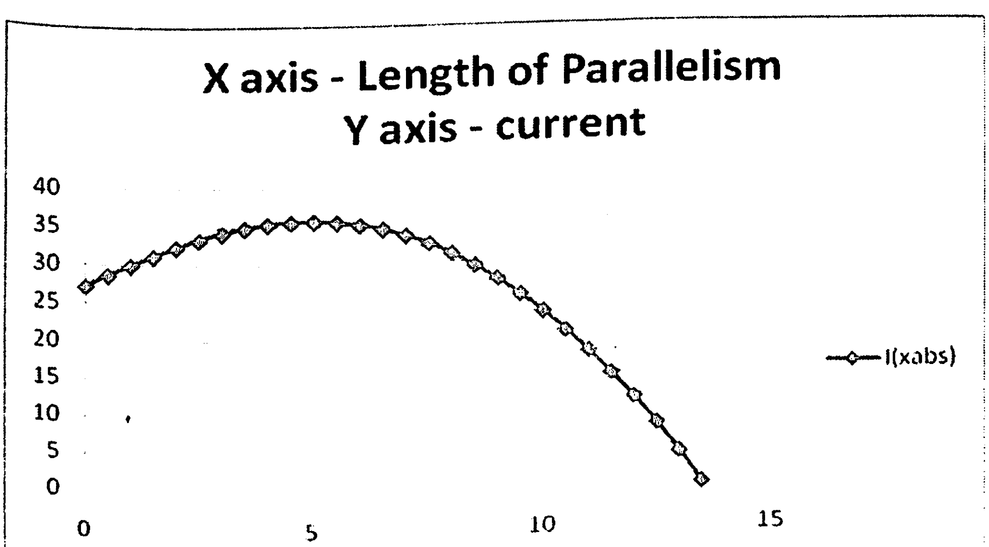

Figure no 11: Current distribution plot

4.13 Reference:

Power Systems Modelling and Fault Analysis,Theory and Practice-Nasser Tleis page number: 588 – 601

SECTION -03 STEADY STATE OPERATING CONDITION

5.1 Pipeline and Powerline specification : S-03

Length of parallelism : 23.00 KM

Distance of the tower from pipeline : 50m

Depth at which pipeline layed : 2m

Phase to phase distance : 7.5 m

KV rating : 380 KV

Type of circuit : Double circuit

Maximum operating current : 1200 Amperes

Coating thickness : 3.2mm

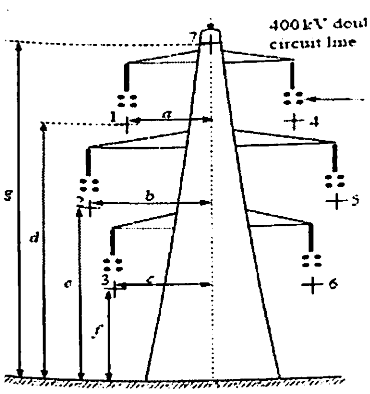

Figure no 12: Double circuit line considered

From the figure above f =13m, a=6.93m, b=10.16m, c=8.33m

$$Dpr1 = \sqrt{(50 - 6.93)^2 + (13+2)^2}$$

$$= 45.60m$$

$$Dpy1 = \sqrt{(50 - 10.16)^2 + (13+7.5+2)^2}$$

$$= 45.75m$$

$$Dpb1 = \sqrt{(50 - 8.33)^2 + (13+7.5+7.5+2)^2}$$

$$= 51.34m$$

$$Dpr2 = \sqrt{(50 + 6.93)^2 + (13+2)^2} = 58.873 \text{ m}$$

Dpy2 = $\sqrt{(50 + 10.16)^2 + (13+7.5+2)^2}$

= 64.22 m

Dpb2 = $\sqrt{(50 + 8.33)^2 + (13+7.5+7.5+2)^2}$

= 65.59 m

Dpe = $\sqrt{(50)^2 + (13+7.5+7.5+7.5+2)^2}$

= 62.5 m

Dpr1, Dpy1,Dpb1,Dpr2, Dpy2, Dpb2 are the distance the R,Y,B phases of the tower line and the pipeline

Dpe is the distance between the pipeline and the earth line

5.2 Depth of Earth Return Current:

$$D_{erc} = 658.87 \times \sqrt{\frac{\rho_e}{f}}\ \mathrm{m}$$

Derc = depth of earth return current

Earth resistivity is denoted by ρe = 200 ohm-m

Frequency f is in hertz ; f = 60 HZ

Derc = 658.87 x √(200/60) = 1202 m

5.3 Mutual impedance between the power line and pipeline:

$$Z_{pj} = \pi^2 10^{-4} f + j4\pi f\, 10^{-4} \sqrt{\frac{\left[\log_e\left(1 + 1.382\frac{D_{erc}^2}{d_{pj}^2}\right)\right]^2}{4} - \frac{\pi^2}{16}}\ \Omega/\mathrm{km}$$

Zpj = mutual impedance between the conductors

F is the frequency = 60 HZ

Derc = depth of earth return current = 1202 m

Dpj = distance between the pipeline and powerline phases

Mutual impedances	Values
Zpr1	0.059+j0.245
Zpy1	0.059+j0.244
Zpb1	0.059+j0.236
Zpr2	0.059+j0.226
Zpy2	0.059+j0.219
Zpb2	0.059+j0.218
Zpe	0.059+j0.221

Table no 13: Mutual impedance between pipeline and power line

Distance between the earth and phases of the transmission line

Distance	Values in m
Der1	23.99
Dey1	18.11
Deb1	10.21

Table no 14: Distance between earth and phases

Mutual impedance between the earth and phases of transmission line

Mutual impedance	Values
Zer1	0.059+j0.2935
Zey1	0.059+j0.1314
Zeb1	0.059+j0.3576
Zee	0.1136+j0.6988

Table no 15: Mutual impedance between earth and phases

Mutual impedances are represented in ohms/KM

5.4 EMF induced on the pipeline without earth:

$$-\mathrm{EMF_p} = Z_{\mathrm{pR}} I_{\mathrm{R}} + Z_{\mathrm{pY}} I_{\mathrm{Y}} + Z_{\mathrm{pB}} I_{\mathrm{B}} \text{ V/km}$$

Ir = 1200 Amperes

Iy=-600+1039.2i Amperes

Ib=-600-1039.2i Amperes

-EMFp = -9.24888000000001+14.94i Volts/Km

EMFp = 9.24888000000001-14.94i Volts/Km

Absolute value = 17.57 volts/km

5.5 EMF induced on the pipeline with earth:

$$-EMF_p = (Z_{pR}I_R + Z_{pY}I_Y + Z_{pB}I_B) - \frac{Z_{pE}}{Z_{EE}}(Z_{ER}I_R + Z_{EY}I_Y + Z_{EB}I_B)\ \text{V/km}$$

EMFp = 35.2201801533966-50.5769783379711i volts/Km

Absolute value = 61.631 volts/km

5.6 Electrical characteristics of the pipeline:

5.6.1 Pipeline shunt admittance:

$$y_c = \frac{2000\pi r_p}{\rho_c t_c} + j\frac{\pi r_p f \varepsilon_c 10^{-6}}{9 t_c}\ \text{S/km}$$

Radius of the pipeline = rp = 0.5588m

Resistivity of the pipeline coating = ρc = 25x10^6

Thickness of the coating = tc = 3.2mm

Frequency = f = 60 HZ

Coating relative permittivity = εc = 5 x 10^-6

Yc = 0.043+j0.0182 S/Km

5.6.2 Pipeline series impedance:

$$z = \frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + \pi^2 10^{-4} f + j\left[\frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + 4\pi 10^{-4} f \log_e\left(\frac{D_{erc}}{r_p}\right)\right]\ \Omega/\text{km}$$

Radius of the pipeline = rp = 0.5588m

Derc = depth of earth return current = 1202 m

Relative permeability of the metal = μ = 300

Z = 0.0874 + j 0.6061 ohms/Km

5.6.3 Propagation constant:

Propagation constant γ = √(z * y) /km

And γ = √(0.0874 + j 0.6061) x (0.043+j0.0182) = 0.10324 + j0.1339

5.6.4 Characteristic impedance:

$Z = \sqrt{(z / y)}$ ohms

$Z = \sqrt{(0.0874 + j\,0.6061) / (0.043+j0.0182)} = 3.152 + j1.77925$ ohms

5.7 Distribution of voltage along the pipeline and powerline parallelism:

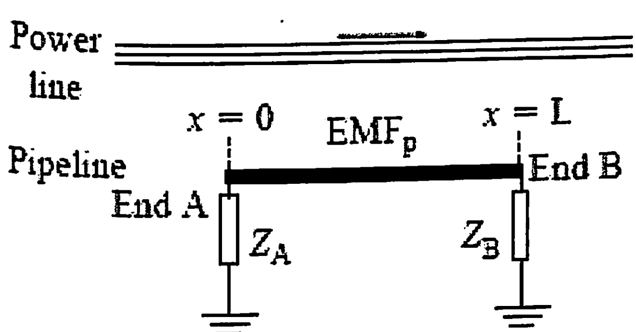

Figure no 13: shows the portion of pipeline parallel to powerline

$$V(x) = \frac{E_0}{2\gamma}[(2e^{-\gamma L} - e^{-2\gamma L})e^{\gamma x} - e^{-\gamma x}]\,V$$

Propagation constant is denoted by γ

L is the overall length of parallelism = 23Km

X which varies from 0 to 23Km

Eo is the EMF induced on the pipeline

V(x) shows the variation of voltages along the various length of parallelism

5.8 Voltage to earth along the pipeline is tabulated as:

X	Eo	γ	L	Voltage
0	35.22018-50.576i	0.10324+0.1339i	23	217.6898
1	35.22018-50.576i	0.10324+0.1339i	23	201.9889
2	35.22018-50.576i	0.10324+0.1339i	23	185.905
3	35.22018-50.576i	0.10324+0.1339i	23	169.0636
4	35.22018-50.576i	0.10324+0.1339i	23	151.2392
5	35.22018-50.576i	0.10324+0.1339i	23	132.3662
6	35.22018-50.576i	0.10324+0.1339i	23	112.5718
7	35.22018-50.576i	0.10324+0.1339i	23	92.27395
8	35.22018-50.576i	0.10324+0.1339i	23	72.4739
9	35.22018-50.576i	0.10324+0.1339i	23	55.60746
10	35.22018-50.576i	0.10324+0.1339i	23	47.16045
11	35.22018-50.576i	0.10324+0.1339i	23	53.02146
12	35.22018-50.576i	0.10324+0.1339i	23	70.58361
13	35.22018-50.576i	0.10324+0.1339i	23	93.9586
14	35.22018-50.576i	0.10324+0.1339i	23	120.0376
15	35.22018-50.576i	0.10324+0.1339i	23	147.5167
16	35.22018-50.576i	0.10324+0.1339i	23	175.8263
17	35.22018-50.576i	0.10324+0.1339i	23	204.7323
18	35.22018-50.576i	0.10324+0.1339i	23	234.1994
19	35.22018-50.576i	0.10324+0.1339i	23	264.3418
20	35.22018-50.576i	0.10324+0.1339i	23	295.4052
21	35.22018-50.576i	0.10324+0.1339i	23	327.7581
22	35.22018-50.576i	0.10324+0.1339i	23	361.8843
23	35.22018-50.576i	0.10324+0.1339i	23	398.3723

Table no 16: Voltage influenced along various sections of parallelism

5.9 Distribution of Current along the pipeline and powerline parallelism:

$$I(x) = \frac{E_0}{2\gamma Z_0}[2 + (e^{-2\gamma L} - 2e^{-\gamma L})e^{\gamma x} - e^{-\gamma x}]\,A$$

L is the overall length of parallelism = 9.30m

X which varies from 0 to 9.30 Km

Eo is the EMF induced on the pipeline

Zo is the characteristic impedance

5.10 Representation of current distribution along various section:

X	Eo	γ	L	I(xabs)
1	35.22018-50.5769i	0.10324+0.1339i	23	66.83003
2	35.22018-50.5769i	0.10324+0.1339i	23	74.05259
3	35.22018-50.5769i	0.10324+0.1339i	23	81.21975
4	35.22018-50.5769i	0.10324+0.1339i	23	87.97628
5	35.22018-50.5769i	0.10324+0.1339i	23	94.08882
6	35.22018-50.5769i	0.10324+0.1339i	23	99.39518
7	35.22018-50.5769i	0.10324+0.1339i	23	103.7756
8	35.22018-50.5769i	0.10324+0.1339i	23	107.1366
9	35.22018-50.5769i	0.10324+0.1339i	23	109.4022
10	35.22018-50.5769i	0.10324+0.1339i	23	110.5084
11	35.22018-50.5769i	0.10324+0.1339i	23	110.4001
12	35.22018-50.5769i	0.10324+0.1339i	23	109.0294
13	35.22018-50.5769i	0.10324+0.1339i	23	106.3539
14	35.22018-50.5769i	0.10324+0.1339i	23	102.3355
15	35.22018-50.5769i	0.10324+0.1339i	23	96.93933
16	35.22018-50.5769i	0.10324+0.1339i	23	90.13237
17	35.22018-50.5769i	0.10324+0.1339i	23	81.88238
18	35.22018-50.5769i	0.10324+0.1339i	23	72.15643
19	35.22018-50.5769i	0.10324+0.1339i	23	60.91945
20	35.22018-50.5769i	0.10324+0.1339i	23	48.13273
21	35.22018-50.5769i	0.10324+0.1339i	23	33.75247
22	35.22018-50.5769i	0.10324+0.1339i	23	17.72828
23	35.22018-50.5769i	0.10324+0.1339i	23	0.003068

Table no 17: Current distribution

5.11 Plot for voltage variation along the various section:

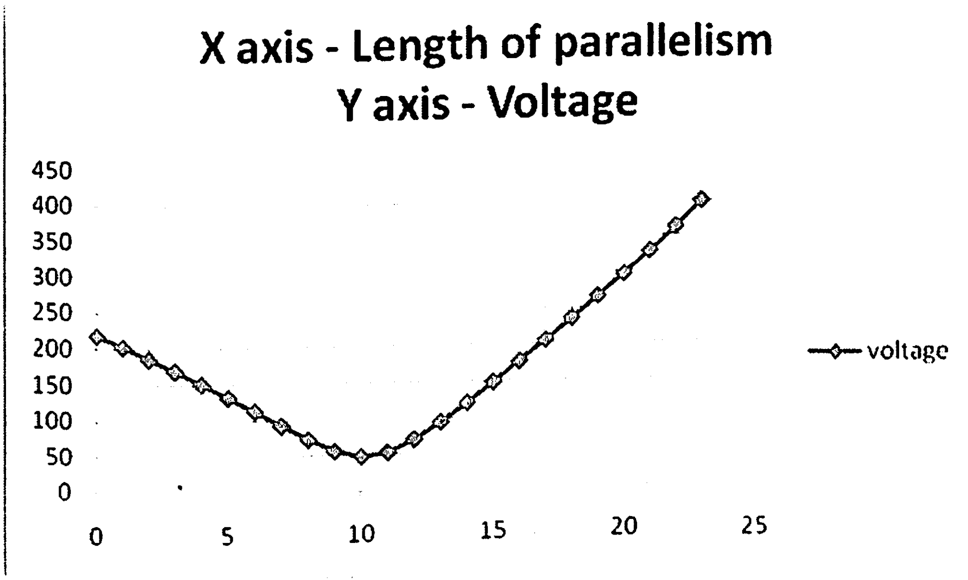

Figure no 14: Voltage variation along the section

5.12 Current distribution plot along the section:

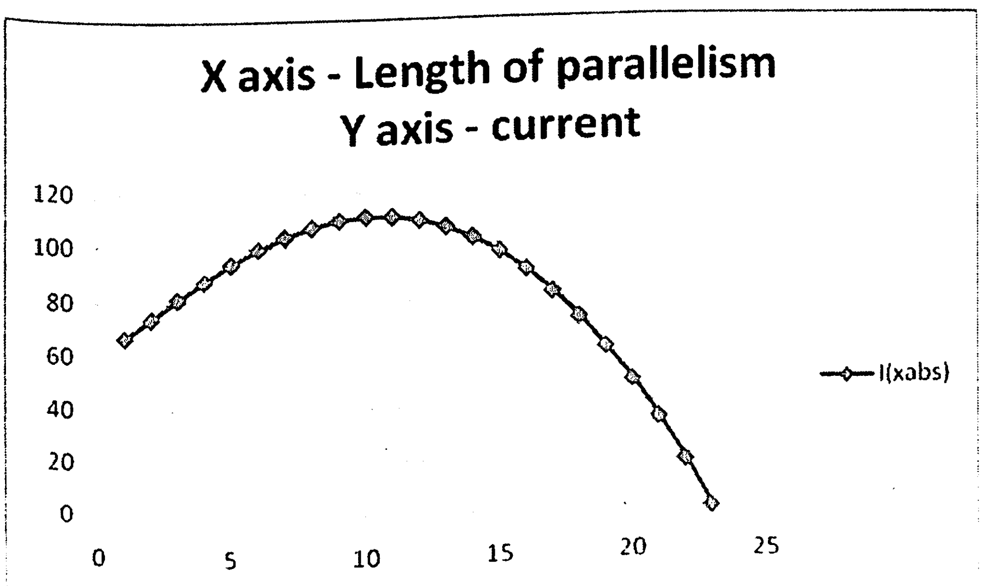

Figure no 15: Current distribution plot

5.13 Reference:

Power Systems Modelling and Fault Analysis,Theory and Practice-Nasser Tleis page number: 588 - 601

SECTION - 04 STEADY STATE OPERATING CONDITION

6.1 Pipeline and Powerline specification : S-04

Length of parallelism : 0.90 KM

Distance of the tower from pipeline : 50m

Depth at which pipeline layed : 2m

Phase to phase distance : 7.5 m

KV rating : 380 KV

Type of circuit : Double circuit

Maximum operating current : 1200 Amperes

Coating thickness : 3.2mm

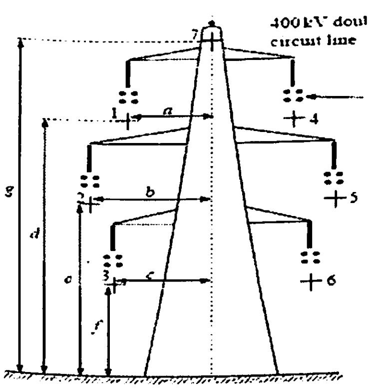

Figure no 16: Double circuit line considered

From the figure above f =13m, a=6.93m, b=10.16m, c=8.33m

$Dpr1 = \sqrt{(50 - 6.93)^2 + (13+2)^2}$

$= 45.60m$

$Dpy1 = \sqrt{(50 - 10.16)^2 + (13+7.5+2)^2}$

$= 45.75m$

$Dpb1 = \sqrt{(50 - 8.33)^2 + (13+7.5+7.5+2)^2}$

$= 51.34m$

$Dpr2 = \sqrt{(50 + 6.93)^2 + (13+2)^2} = 58.873$ m

Dpy2 = $\sqrt{(50 + 10.16)^2 + (13+7.5+2)^2}$

= 64.22 m

Dpb2 = $\sqrt{(50 + 8.33)^2 + (13+7.5+7.5+2)^2}$

= 65.59 m

Dpe = $\sqrt{(50)^2 + (13+7.5+7.5+7.5+2)^2}$

= 62.5 m

Dpr1, Dpy1,Dpb1,Dpr2, Dpy2, Dpb2 are the distance the R,Y,B phases of the tower line and the pipeline

Dpe is the distance between the pipeline and the earth line

6.2 Depth of Earth Return Current:

$$D_{erc} = 658.87 \times \sqrt{\frac{\rho_e}{f}}\ \text{m}$$

Derc = depth of earth return current

Earth resistivity is denoted by ρe = 200 ohm-m

Frequency f is in hertz ; f = 60 HZ

Derc = 658.87 x $\sqrt{(200/60)}$ = 1202 m

6.3 Mutual impedance between the power line and pipeline:

$$Z_{pj} = \pi^2 10^{-4} f + j4\pi f\, 10^{-4} \sqrt{\frac{\left[\log_e\left(1 + 1.382\frac{D_{erc}^2}{d_{pi}^2}\right)\right]^2}{4} - \frac{\pi^2}{16}}\ \Omega/\text{km}$$

Zpj = mutual impedance between the conductors

F is the frequency = 60 HZ

Derc = depth of earth return current = 1202 m

Dpj = distance between the pipeline and powerline phases

Mutual impedances	Values
Zpr1	0.059+j0.245
Zpy1	0.059+j0.244
Zpb1	0.059+j0.236
Zpr2	0.059+j0.226
Zpy2	0.059+j0.219
Zpb2	0.059+j0.218
Zpe	0.059+j0.221

Table no 18: mutual impedance between power line and pipeline

Distance between the earth and phases of the transmission line

Distance	Values in m
Der1	23.99
Dey1	18.11
Deb1	10.21

Table no 19: distance between earth and phases

Mutual impedance between the earth and phases of transmission line

Mutual impedance	Values
Zer1	0.059+j0.2935
Zey1	0.059+j0.1314
Zeb1	0.059+j0.3576
Zee	0.1136+j0.6988

Table no 20: mutual impedance between earth and the phases

Mutual impedances are represented in ohms/KM

6.4 EMF induced on the pipeline without earth:

$$-\mathrm{EMF_p} = Z_{pR} I_R + Z_{pY} I_Y + Z_{pB} I_B \text{ V/km}$$

Ir = 1200 Amperes

Iy=-600+1039.2i Amperes

Ib=-600-1039.2i Amperes

-EMFp = -9.24888000000001+14.94i Volts/Km

EMFp = 9.24888000000001-14.94i Volts/Km

Absolute value = 17.57 volts/km

6.5 EMF induced on the pipeline with earth:

$$-\mathrm{EMF_p} = (Z_{pR}I_R + Z_{pY}I_Y + Z_{pB}I_B) - \frac{Z_{pE}}{Z_{EE}}(Z_{ER}I_R + Z_{EY}I_Y + Z_{EB}I_B)\ \mathrm{V/km}$$

EMFp = 35.2201801533966-50.576978337971 1i volts/Km

Absolute value = 61.631 volts/km

6.6 Electrical characteristics of the pipeline:

6.6.1 Pipeline shunt admittance:

$$y_c = \frac{2000\pi r_p}{\rho_c t_c} + j\frac{\pi r_p f \varepsilon_c 10^{-6}}{9 r_c}\ \mathrm{S/km}$$

Radius of the pipeline = rp = 0.5588m

Resistivity of the pipeline coating = ρc = 25x10^6

Thickness of the coating = tc = 3.2mm

Frequency = f = 60 HZ

Coating relative permittivity = εc = 5 x 10^-6

Yc = 0.043+j0.0182 S/Km

6.6.2 Pipeline series impedance:

$$z = \frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + \pi^2 10^{-4} f + j\left[\frac{\sqrt{\rho_p \mu_p f}}{3.163 r_p} + 4\pi 10^{-4} f \log_e\left(\frac{D_{erc}}{r_p}\right)\right]\ \Omega/\mathrm{km}$$

Radius of the pipeline = rp = 0.5588m

Derc = depth of earth return current = 1202 m

Relative permeability of the metal = μ = 300

Z = 0.0874 + j 0.6061 ohms/Km

6.6.3 Propagation constant:

Propagation constant γ = √(z * y) /km

And γ = √(0.0874 + j 0.6061) x (0.043+j0.0182) = 0.10324 + j0.1339 .

6.6.4 Characteristic impedance:

Z = √(z / y) ohms

Z = √(0.0874 + j 0.6061) / (0.043+j0.0182) = 3.152 + j1.77925 ohms

6.7 Distribution of voltage along the pipeline and powerline parallelism:

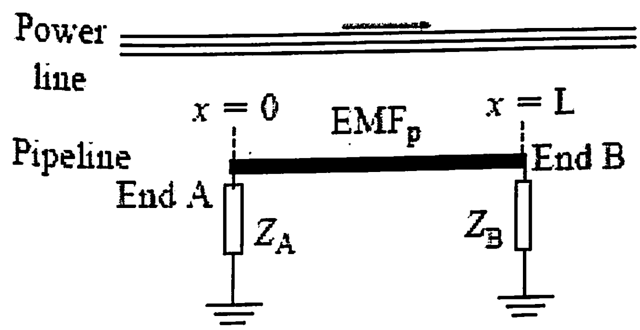

Figure no 17: shows the portion of pipeline parallel to powerline

$$V(x) = \frac{E_0}{2\gamma}[(2e^{-\gamma L} - e^{-2\gamma L})e^{\gamma x} - e^{-\gamma x}]\,\mathrm{V}$$

Propagation constant is denoted by γ

L is the overall length of parallelism = 0.90Km

X which varies from 0 to 0.90Km

Eo is the EMF induced on the pipeline

V(x) shows the variation of voltages along the various length of parallelism

6.8 Voltage to earth along the pipeline is tabulated as:

X	Eo	Γ	L	voltage
0	35.22018-50.576i	0.10324+0.1339i	0.9	3.843959
0.1	35.22018-50.576i	0.10324+0.1339i	0.9	4.473626
0.2	35.22018-50.576i	0.10324+0.1339i	0.9	10.07281
0.3	35.22018-50.576i	0.10324+0.1339i	0.9	16.09708
0.4	35.22018-50.576i	0.10324+0.1339i	0.9	22.20247
0.5	35.22018-50.576i	0.10324+0.1339i	0.9	28.33573
0.6	35.22018-50.576i	0.10324+0.1339i	0.9	34.48097
0.7	35.22018-50.576i	0.10324+0.1339i	0.9	40.63161
0.8	35.22018-50.576i	0.10324+0.1339i	0.9	46.78429
0.9	35.22018-50.576i	0.10324+0.1339i	0.9	52.93702

Table no 21: Voltage influenced along various sections of parallelism

6.9 Distribution of Current along the pipeline and powerline parallelism:

$$I(x) = \frac{E_0}{2\gamma Z_0}[2 + (e^{-2\gamma L} - 2e^{-\gamma L})e^{\gamma x} - e^{-\gamma x}]\ A$$

L is the overall length of parallelism = 9.30m

X which varies from 0 to 9.30 Km

Eo is the EMF induced on the pipeline

Zo is the characteristic impedance

6.10 Representation of current distribution along various section:

X	Eo	γ	L	I(xabs)
0	35.22018-50.5769i	0.10324+0.1339i	0.9	1.060927
0.1	35.22018-50.5769i	0.10324+0.1339i	0.9	1.057631
0.2	35.22018-50.5769i	0.10324+0.1339i	0.9	1.025772
0.3	35.22018-50.5769i	0.10324+0.1339i	0.9	0.96528
0.4	35.22018-50.5769i	0.10324+0.1339i	0.9	0.876111
0.5	35.22018-50.5769i	0.10324+0.1339i	0.9	0.758235
0.6	35.22018-50.5769i	0.10324+0.1339i	0.9	0.611637
0.7	35.22018-50.5769i	0.10324+0.1339i	0.9	0.436308
0.8	35.22018-50.5769i	0.10324+0.1339i	0.9	0.232245
0.9	35.22018-50.5769i	0.10324+0.1339i	0.9	0.000831

Table no 22: Current distribution

6.11 Plot for voltage variation along the various section:

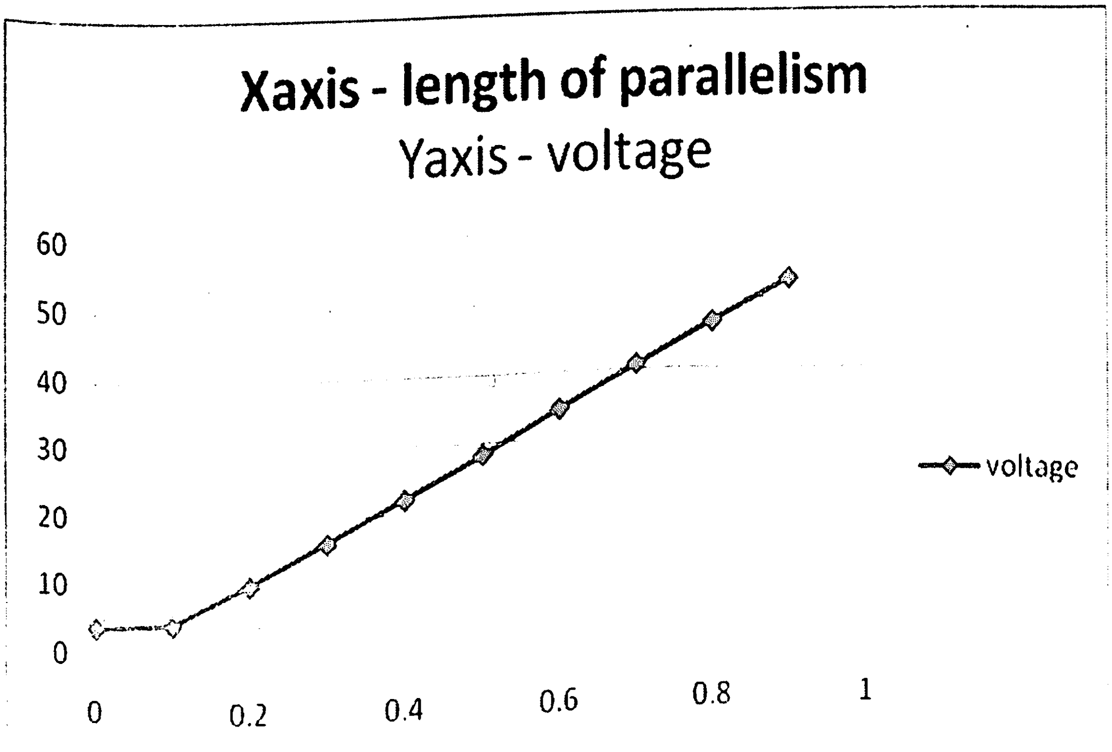

Figure no 18: Voltage variation along the section

6.12 Current distribution plot along the section:

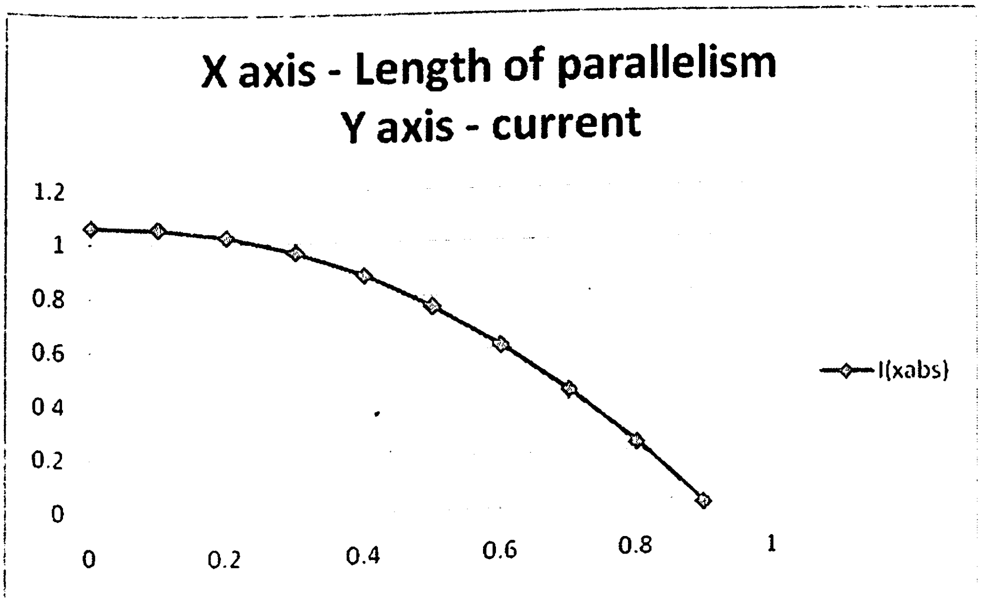

Figure no 19: Current distribution plot

6.13 Reference:

Power Systems Modeling and Fault Analysis, Theory and Practice-Nasser Tleis page number: 588 - 601

EMF INDUCED - FAULT OPERATING CONDITION

7.1 S-01 single phase to earth faulted operating condition:

$$k = 1 - \frac{Z_{ER}}{Z_{EE}} \times \frac{Z_{pE}}{Z_{pR}}$$

Mutual impedances	Values
Zpr1	0.059+j0.1920
Zpr2	0.059+j0.1798
Zer	0.059+j0.2935
Zee	0.1136+j0.6988

Table no 23: mutual impedances

K = 0.586629738976518+0.0182819790463379i

Induced EMF on the pipeline is given by

-EMFp = Zpr*If*K volts/Km

If is the fault current = 25.5 KA

-EMFp = 1591.83926943992+5616.7883672129i volts/Km

Absolute value = 5832 Volts/Km

7.2 S-02 Single phase to earth faulted operated condition:

Mutual impedances	Values
Zpr1	0.059+j0.1920
Zpr2	0.059+j0.1798
Zer	0.059+j0.2935
Zee	0.1136+j0.6988

Table no 24: mutual impedances

K = 0.586629738976518+0.0182819790463379i

Induced EMF on the pipeline is given by

-EMFp = Zpr*If*K volts/Km

If is the fault current = 31.5 KA

-EMFp = 1966.38968577872+6938.38563008652i volts/Km

Absolute value = 7211.649 Volts/Km

7.3 S-03 single phase to earth faulted operating condition:

Mutual impedances	Values
Zpr1	0.059+j0.245
Zpr2	0.059+j0.226
Zer	0.059+j0.2935
Zee	0.1136+j0.6988

Table no 25: mutual impedances

K = 0.602145633416682+0.0209581886481039i

Induced EMF on the pipeline is given by

-EMFp = Zpr*If*K volts/Km

If is the fault current = 25.5 KA

-EMFp = 1560.13788619274+7295.1333197932i volts/Km

Absolute value = 7460.094 Volts/Km

S-04 single phase to earth faulted operating condition:

Mutual impedances	Values
Zpr1	0.059+j0.245
Zpr2	0.059+j0.226
Zer	0.059+j0.2935
Zee	0.1136+j0.6988

Table no 26: mutual impedances

K = 0.602145633416682+0.0209581886481039i

Induced EMF on the pipeline is given by

-EMFp = Zpr*If*K volts/Km

If is the fault current = 31.5 KA

-EMFp = 1927.22915353221+9011.6352773916i volts/Km

Absolute value = 9215.41 Volts/Km

7.4 S-04 single phase to earth faulted operating condition:

Mutual impedances	Values
Zpr1	0.059+j0.245
Zpr2	0.059+j0.226
Zer	0.059+j0.2935

Table no 27: mutual impedances

K = 0.602145633416682+0.0209581886481039i

Induced EMF on the pipeline is given by

-EMFp = Zpr*If*K volts/Km

If is the fault current = 25.5 KA

-EMFp = 1560.13788619274+7295.1333197932i volts/Km

Absolute value = 7460.094 Volts/Km

7.5 Reference:

Power Systems Modeling and Fault Analysis, Theory and Practice-Nasser Tleis page number: 588 - 601

CONCLUSION & SUGGESTIONS

8.1 Conclusion:

Analysis of the alternating current (HVAC) transmission lines influenced on the pipelines are made. Voltage distribution and current distribution plot for the various sections of the pipelines are plotted.

EMF induced on the pipelines including earth wire and without earth wires are identified. Mutual impedances between the power line and pipelines serves as the inputs in identifying EMF induced on the pipelines.

Analysis is made for both steady state operating condition and also for fault operating condition. EMF induced on the pipeline when the fault arises on the pipelines are also identified based on the practical fault duration and fault current data.

8.2 Suggestions:

Better use of GPS coordinates & the photographs of each section of the transmission lines should be available for proper analysis. Better mapping of the pipeline by the use of Google earth can be carried out to make analysis faster and quicker.

8.3 Further Developments:

Effective software will be developed based on various tools like simulink, & Wavelet techniques in order to make the analysis more effective and efficient.

8.4 Reference:

IEEE Std 80-1986 IEEE Guide for safety in AC substation grounding, page no: 43 - 47

W.B.Kouwenhoven " Human safety and electrical shock", Electrical safetypractices,monograph,112, instrument society of America page no:93,NOV 1968

NACE RP-0177 mitigation of alternating current and lightning effects on metallic structure, page no: 2, 3

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