Impedance Estimation Method Using Phasors Under Dynamic Condition

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Abstract : This paper presents an application of dynamic phasor model (DPM) for the impedance measurement of the transmission line in transient condition. Sinusoidal steady state measurement is a simple subset of the same. This model gives simulation results which are in line with conventional DFT result.

***IndexTerms* -** Phasor, Dynamic Phasor Model (DPM), Single phase to ground fault, Direct Line Parameter Estimation Method (Integration) i.e DLI method, R-X Trajectory.

I. Introduction

The first paper to identify the importance of positive sequence voltage and current Phasor measurement and some of the applications of these measurements was published in 1983. This can be viewed as the starting point of modern Synchronized Phasor Measurement technology. The basic fundamentals of Synchronized Phasor Measurement and their applications are given in detail. During off-nominal frequency, Phasors give errors in the measurement. [1]

The concept of DPM is first introduced in 1991 as Generalized Averaging Method [2]. The formula given in this paper gives the good approximation for slowly varying w_s . This paper also puts the application of this method to state-space model of switched power electronic circuits in which Dynamic Phasors are state variables. Application of dynamic phasor modeling technique to unbalanced polyphase power system is given in [3]. Slowly time varying Fourier coefficients describes the waveform of interest. Hence simulation in terms of DPM allow larger integration steps than the standard time domain formulations for revealing dynamical couplings between higher frequency transients and electromechanical transients.

Dynamic phasor analysis is applied to understand the effect of phase imbalance on subsynchronous resonance (SSR)[4]. As explained and analyzed in this paper, DPM of unbalanced system yields a linearized and time-invariant model which facilitates eigen-analysis. The equations derived are complex and they can be separated into real and imaginary and linearized around an operating point for eigen-analysis.

[5]This paper is about impedance estimation method for distance relaying based on DPM. A simple single phase two source system is considered. Single phase to ground fault is considered. Then, based on DPM, direct and indirect impedance (R and X) estimation methods are derived at different fault locations and different fault resistance. Then all newly estimated methods are compared with conventional dft method giving superior results. [6] is the standard for Phasor Measurement Unit (application and communication).

In this paper, DPM is used to estimate impedance of Transmission Line with and without fault. Single phase to ground fault is considered. These results are compared with R and X estimated by conventional DFT algorithm.

This paper is organised as follows. Section II describes the Dynamic Phasor concept. Single phase to ground fault on transmission line is modelled in MATLAB/ simulink in section III. Section IV includes the simulation results for the fault at two different locations on transmission line. This section also includes the comparison of proposed method with conventional algorithm. This paper concludes in section V.

II. Introduction to Dynamic Phasor Model (DPM)

Any periodic waveform can be approximated on the interval [t-T, t] to arbitrary accuracy with a Fourier series representation of the form

$$x(\tau) = \sum_{k=-\infty}^{\infty} X_k(t) e^{jk\omega_s \tau} \qquad \text{. . . eq(1)}$$

$w_s = 2\pi/T$ and X_k are the complex Fourier Coefficients i.e Phasors. These Fourier Coefficients are functions of time since the interval under consideration slides as a function of time. A few coefficients provide a good approximation of the original waveform and these coefficients vary slowly with respect to time. The k-th coefficients (or k-th phasor) at time t is determined by the following averaging operation.

$$X_k(t) = \frac{1}{T}\int_{t-T}^{T} x(\tau)e^{-jk\omega_s\tau}d\tau = \langle x\rangle_k(t) \quad ...\ eq(2)$$

This analysis provides a dynamic model for the dominant Fourier series coefficients as the window of length T slides over the waveforms of interest. Thus, the coefficients in above equation are the state variables in state-space model.

The following are properties of Dynamic Phasor of the instantaneous signal x(t)

1. The derivative of the Dynamic Phasor is given by

$$\langle \dot{x}\rangle_k = \frac{d\langle x\rangle_k}{dt} = \left\langle \frac{dx}{dt}\right\rangle_k - jk\omega_s\langle x\rangle_k \quad ...\ eq(3)$$

For slowly varying w_s , it is a good approximation[2].

2. The Dynamic Phasor of the product of two signals u(t) and v(t) can be obtained by the discrete convolution of the corresponding Dynamic Phasors.

$$\langle uv\rangle_k = \sum_{l=-\infty}^{\infty}\langle u\rangle_{k-l}\langle v\rangle_l \quad ...\ eq(4)$$

3. When x(t) is real

$$\langle x\rangle_k = \langle x\rangle_{-k}^{*} \quad ...\ eq(5)$$

when $x(t) = y(t)^*$

$$\langle x\rangle_k = \langle y\rangle_{-k}^{*} \quad ...eq(6)$$

where ``*" represents the complex conjugate.

If x(t) is periodic with a period of T, then Dynamic Phasor is a constant. The Dynamic Phasor Analysis of the unbalanced system yields a linearized and time invariant model which facilitates the Eigen analysis [4].

III. TRANSMISSION LINE MODEL

A. System Description

Single phase 110kV, 50Hz and 80km Transmission Line is considered for simulation in MATLAB/ Simulink. System parameter as per [5]. All the parameters are recalculated in per unit quantities for SIMULINK, considering 110kV as base voltage and 45+j9 MVA as base MVA. Load at bus 2 is calculated from transmitted power and line parameters. It is 0.8738 + j0.0228 PU.

Sampling Frequency: 2 kHz (i.e. N=40 samples per cycle)
Algorithm used for Phasor calculation: Full cycle Recursive DFT

B. Simulink Model and Algorithm (DLI Method)

As we are interested in behaviour of fundamental component of voltage and current, we develop DPM using significant Phasor by keeping k=1. Direct Line Parameter Estimation Method (Integration) [5] is used to estimate R and X (i.e. Resistance and Reactance) of transmission line.

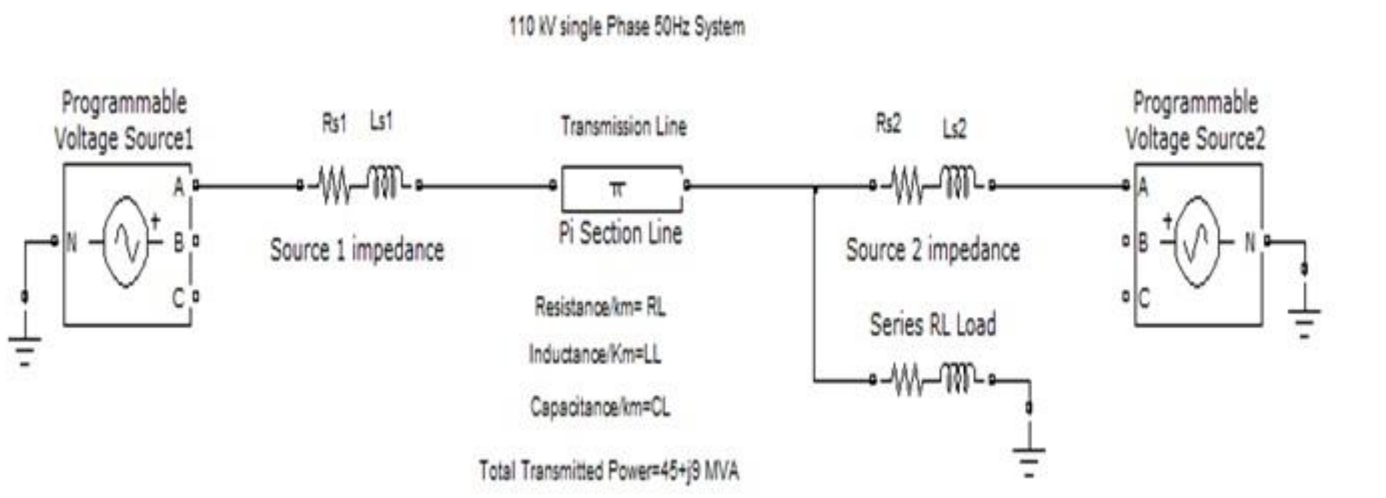

Fig.1 System considered for simulation

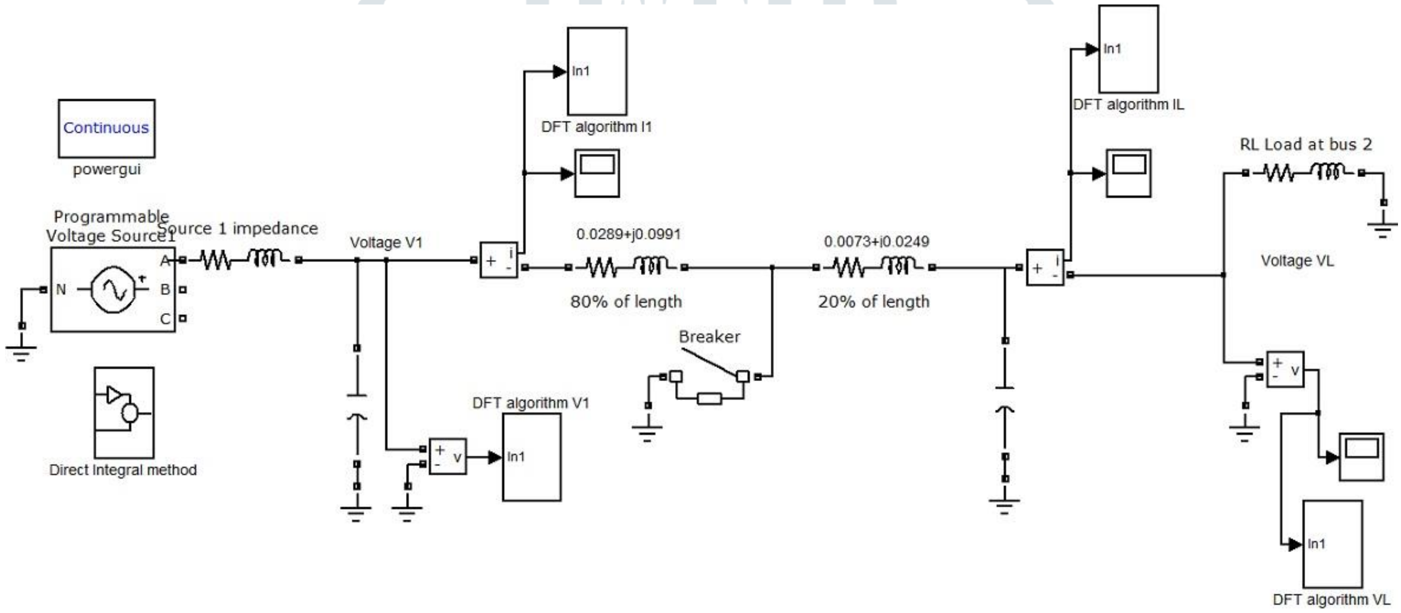

Fig.2 Single phase to ground fault created by using circuit breaker at 80% of transmission line

Simulation parameter	Actual value	Per unit value
Rs1	0.5 Ohm	0.0019
XLs1	3.98 Ohm	0.0151
Rs2	2.1 Ohm	0.0080
XLs2	62.8 Ohm	0.2382
RL	0.119 Ohm/Km	0.00045132
LL	0.0013 H/Km	4.930e-6

CL	8.6 pF/Km	0.0022e-6

Table 1. Actual and Per Unit values of system parameters

The derivative of Dynamic Phasor is given by

$$\langle \dot{x} \rangle_k = \frac{d\langle x \rangle_k}{dt} = \left\langle \frac{dx}{dt} \right\rangle_k - jk\omega_s \langle x \rangle_k \qquad ...eq(7)$$

As per the state space equation

$$\underline{\dot{\mathrm{X}}} = \frac{dX(t)}{dt} = AX(t) + BU(t) \qquad ...eq(8)$$

Therefore the equation formed is

$$\underline{\dot{\mathrm{X}}}(t)_k = (A - h\omega_0 \Im)\underline{X}_k(t) + B\underline{U}_k(t); \underline{X}_k(0) \qquad ...eq(9)$$

For the considered transmission line, state space equation becomes

$$\begin{bmatrix} \dot{I}_{\mathrm{Re}}(t)_h \\ \dot{I}_{\mathrm{Im}}(t)_h \end{bmatrix} = \begin{bmatrix} \frac{-R}{L} & \omega_0 \\ -\omega_0 & \frac{-R}{L} \end{bmatrix} \begin{bmatrix} I_{\mathrm{Re}}(t) \\ I_{\mathrm{Im}}(t) \end{bmatrix} + \frac{1}{L} \begin{bmatrix} U_{\mathrm{Re}}(t) \\ U_{\mathrm{Im}}(t) \end{bmatrix} \qquad ...eq(10)$$

The vector of parameter is $\hat{\theta} = [\hat{R}, \hat{X}]$ ...eq(11)

Two successive samples are considered and trapezoidal integration method is used.

$$\underline{I}_s = {T_s}/{2}\,(\underline{I}_k + \underline{I}_{k-1}) \qquad \underline{U}_s = {T_s}/{2}\,(\underline{U}_k + \underline{U}_{k-1}) \qquad \underline{I}_\delta = (\underline{I}_k - \underline{I}_{k-1})$$

$$\begin{bmatrix} I_{\mathrm{Re}}(t) & \frac{1}{\omega_0}\dot{I}_{\mathrm{Re}}(t) - I_{\mathrm{Im}}(t) \\ I_{\mathrm{Im}}(t) & \frac{1}{\omega_0}\dot{I}_{\mathrm{Im}}(t) + I_{\mathrm{Re}}(t) \end{bmatrix} \hat{\theta} = \begin{bmatrix} U_{\mathrm{Re}}(t) \\ U_{\mathrm{Im}}(t) \end{bmatrix} \qquad ...eq(12)$$

$$R\int_{t_0}^{t} \underline{I}(\tau)d\tau + L(\underline{I}(t) - \underline{I}(t_0)) + L\Im\omega_0 \int_{t_0}^{t} \underline{I}(\tau)d\tau = \int_{t_0}^{t} \underline{U}(\tau)d\tau \qquad ...eq(13)$$

$$\underline{I}(t)=\begin{bmatrix}-\int I_{\mathrm{Re}} & \int U_{\mathrm{Re}}\\ -\int I_{\mathrm{Im}} & \int U_{Im}\end{bmatrix}\begin{bmatrix}\frac{R}{L}\\ \frac{1}{L}\end{bmatrix}+\omega_0\begin{bmatrix}\int I_{\mathrm{Im}}\\ -\int I_{\mathrm{Re}}\end{bmatrix} \qquad ...eq(14)$$

$$+\begin{bmatrix}I_{\mathrm{Re}}(t_o)\\ I_{\mathrm{Im}}(t_o)\end{bmatrix}=\int_{t_0}^{t}\psi(\underline{I},\underline{U})\theta+\Im\omega_0\int_{t_0}^{t}\underline{I}(\tau)d\tau+\underline{I}(t_0)$$

$$\hat{\theta}=\psi_s^{-1}(\underline{I},\underline{U})+(\underline{I}_S+\Im\omega_0\underline{I}_S-\underline{I}_{k-1}) \qquad ...eq(15)$$

$$\hat{\theta}=\frac{\begin{bmatrix}U_{S\,\mathrm{Re}}(I_{\delta\,\mathrm{Im}}+I_{S\,\mathrm{Re}}\omega_0)-U_{S\,\mathrm{Im}}(I_{\delta\,\mathrm{Re}}-I_{S\,\mathrm{Im}}\omega_0)\\ \omega_0(U_{S\,\mathrm{Im}}I_{S\,\mathrm{Re}}-U_{S\,\mathrm{Re}}I_{S\,\mathrm{Im}})\end{bmatrix}}{\omega_0(I^2_{S\,\mathrm{Re}}+I^2_{S\,\mathrm{Im}})+I_{S\,\mathrm{Re}}I\delta_{\mathrm{Im}}-I_{S\,\mathrm{Im}}I\delta_{\mathrm{Re}}} \qquad ...eq(16)$$

IV. SIMULATION RESULTS

Single phase to ground fault is created using circuit breaker for time period of 100ms (i.e. from 2 sec to 2.1 sec). Results are taken for the fault at 50% and 80% of total transmission line. Resistance vs time plot, reactance vs time plot and R-X trajectory are as follows. The percentage error in the measurement is calculated based on formula (calculated- actual)/actual*100 and it is mentioned in table for both the cases.

Case-I Fault at 50% of transmission line (i.e at 40km).

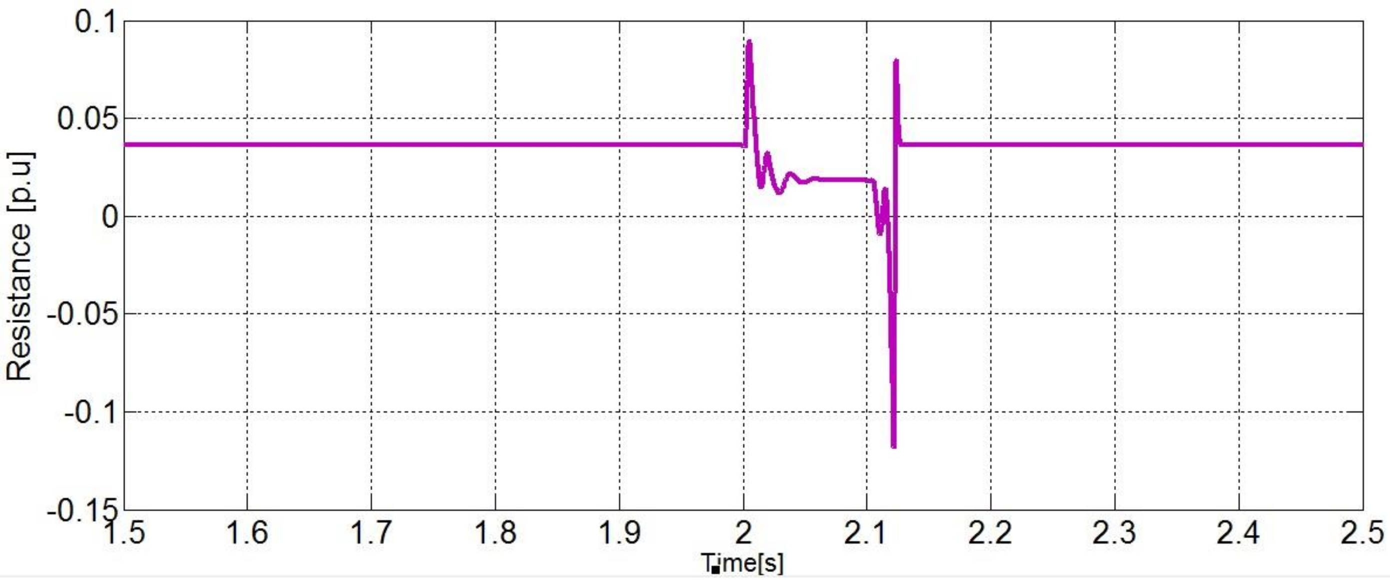

Fig. 3. RESISTANCE CALCULATED BY DLI METHOD (FAULT AT 50% OF LINE LENGTH).

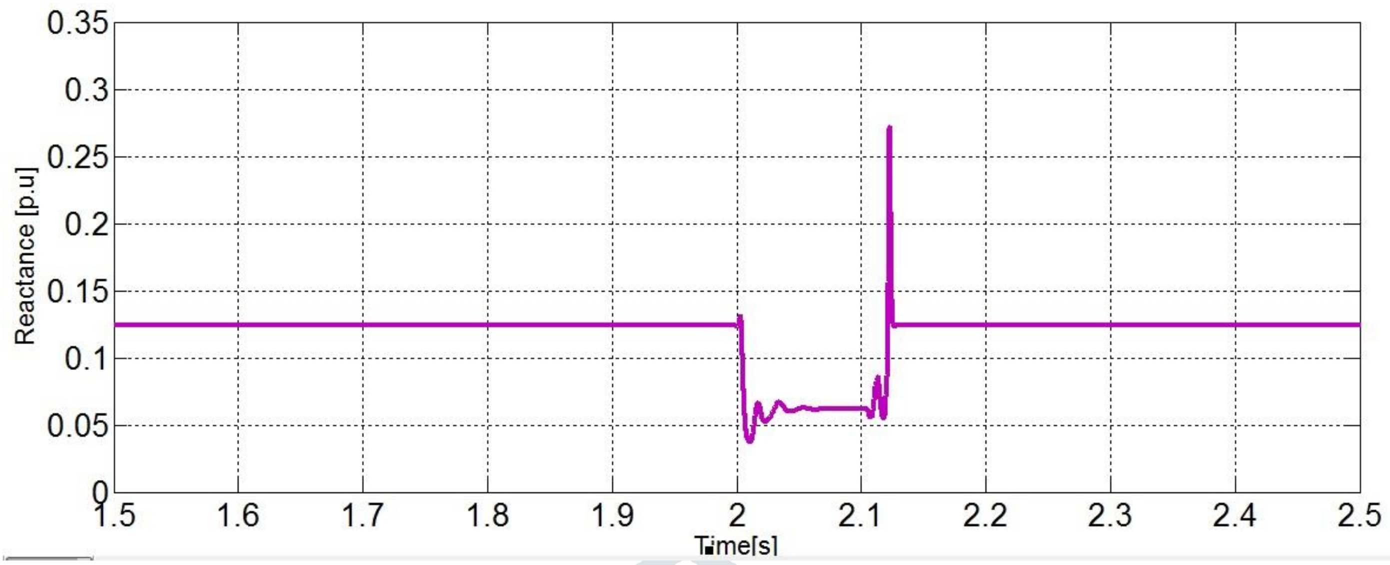

Fig. 4. REACTANCE CALCULATED BY DLI METHOD (FAULT AT 50%)

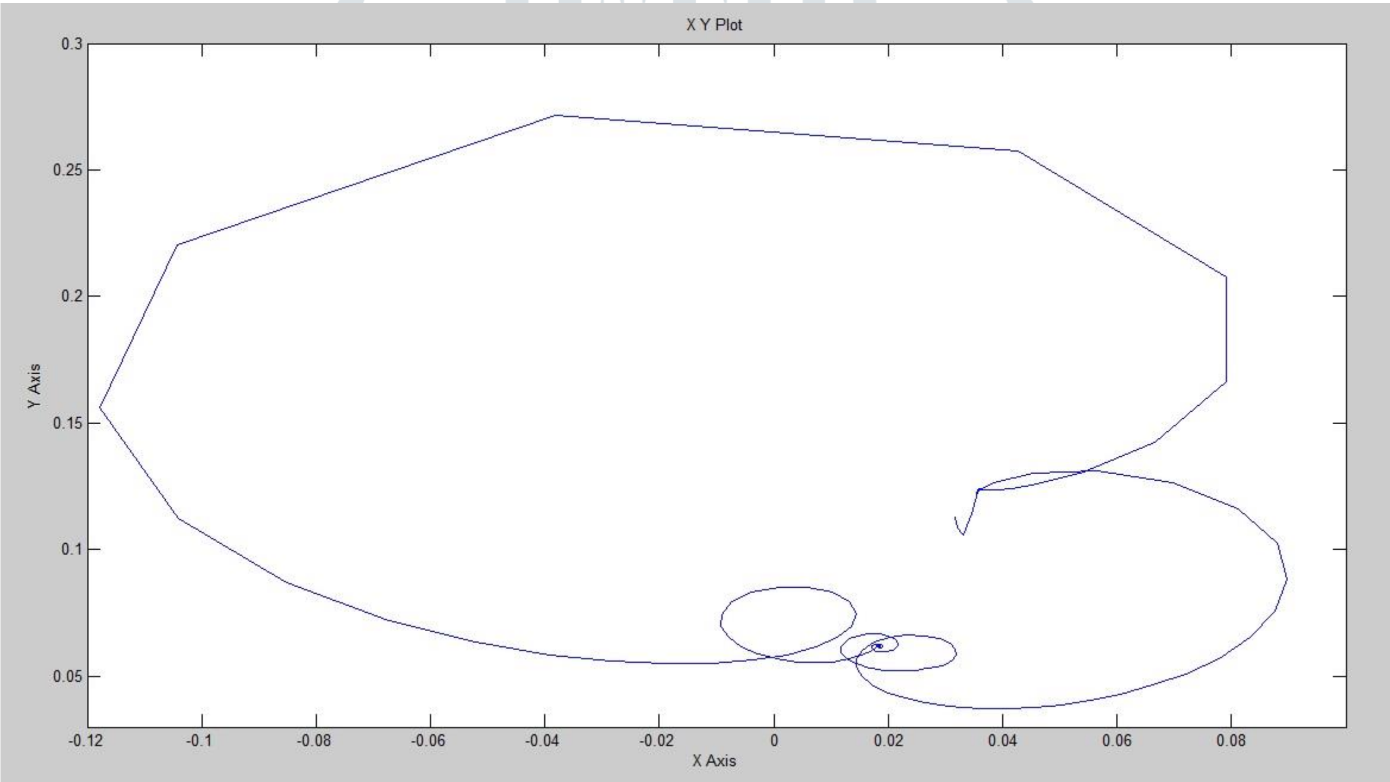

Fig. 5. R-X TRAJECTORY BY DLI METHOD(FAULT AT 50% OF LINE LENGTH).

Case-II Fault at 80% of transmission line (i.e at 64km).

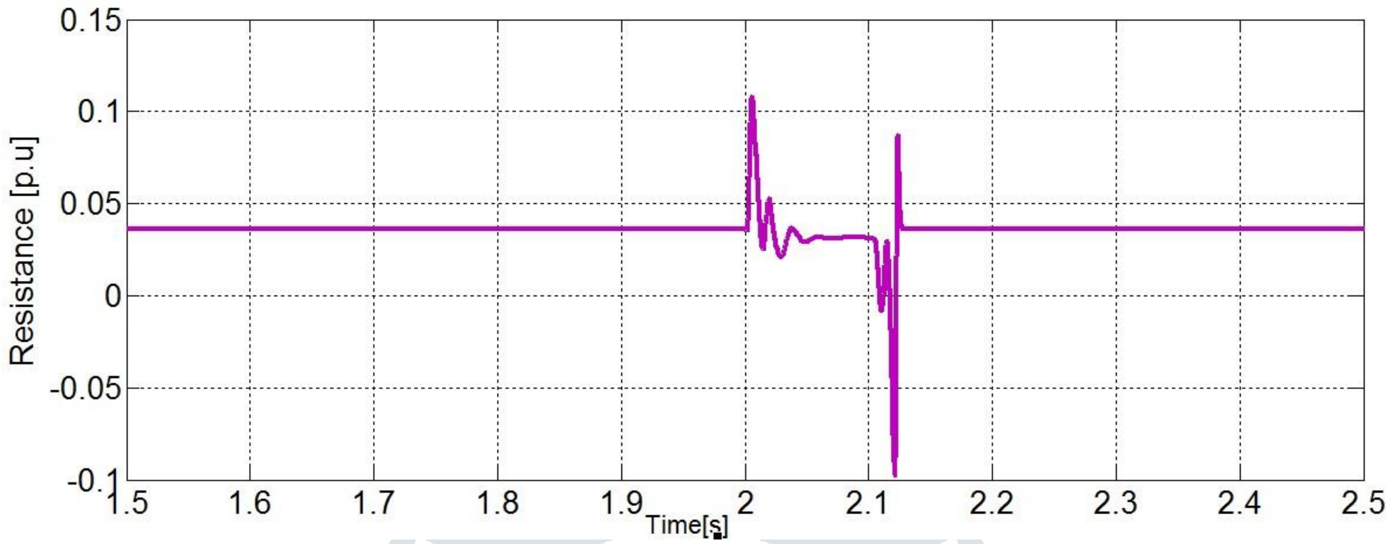

Fig. 6. RESISTANCE CALCULATED BY DLI METHOD (FAULT AT 80% OF LINE LENGTH).

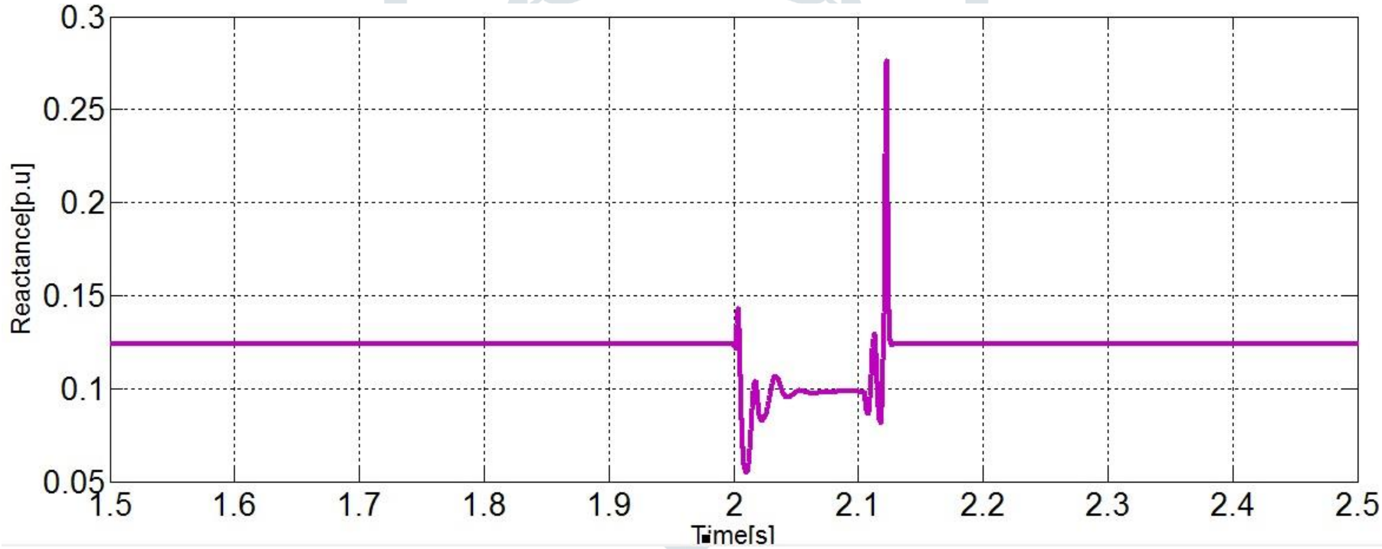

Fig. 7. REACTANCE CALCULATED BY DLI METHOD (FAULT AT 80% OF LINE LENGTH).

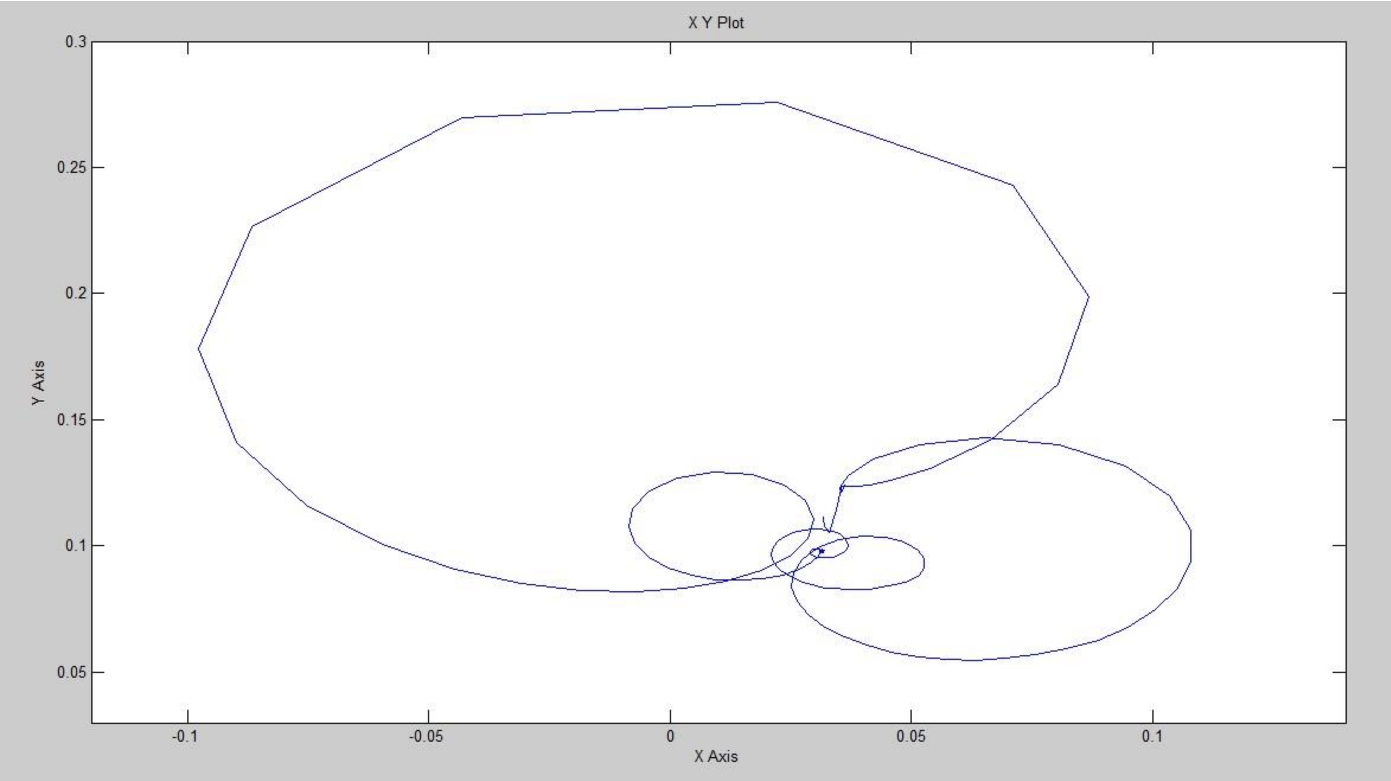

Fig. 8. R-X TRAJECTORY BY DLI METHOD (FAULT AT 80% OF LINE LENGTH).

Parameter	Fault Location	Actual value in Ohm	Calculated value in Ohm	Percentage Error
R	50%	0.0181	0.0184	1.6574%
X	50%	0.0620	0.0619	-0.1613%
R	80%	0.0289	0.0294	1.73%
X	80%	0.0991	0.0980	-1.109%

TABLE II. PERCENTAGE ERROR IN CALCULATION OF R AND X BY DLI METHOD DURING FAULT

Results of DLI method are compared with conventional DFT method. DLI method gives results in transient/ dynamic condition which are in line with conventional DFT results.

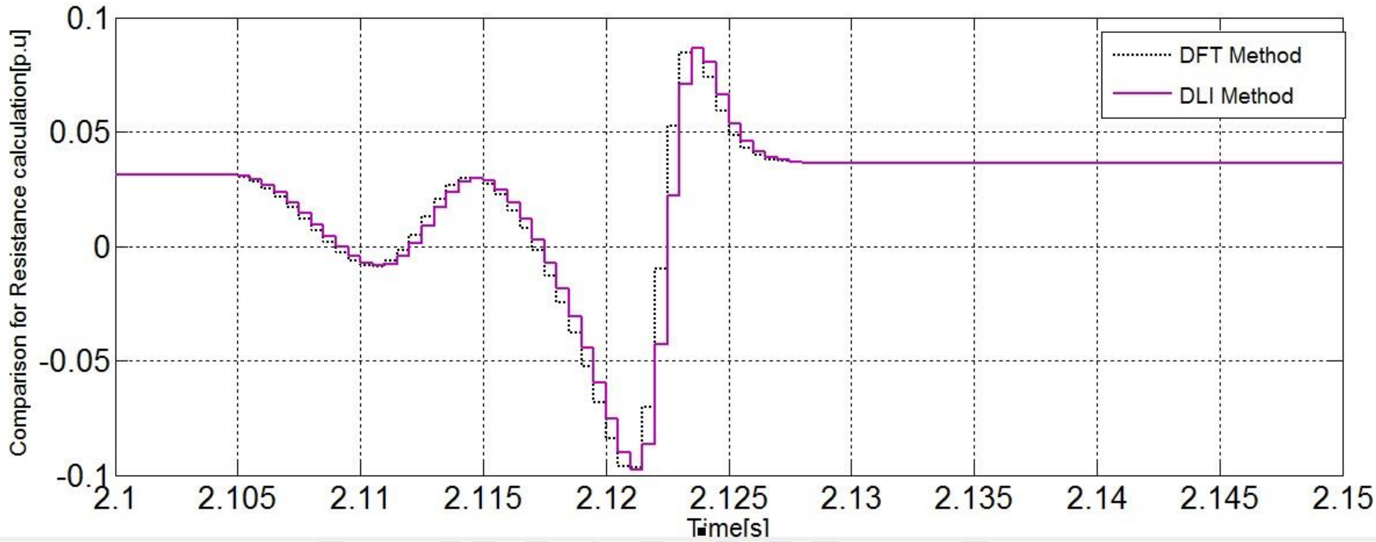

FIG. 9. COMPARISON FOR RESISTANCE CALCULATION (FAULT AT 80% OF LINE LENGTH

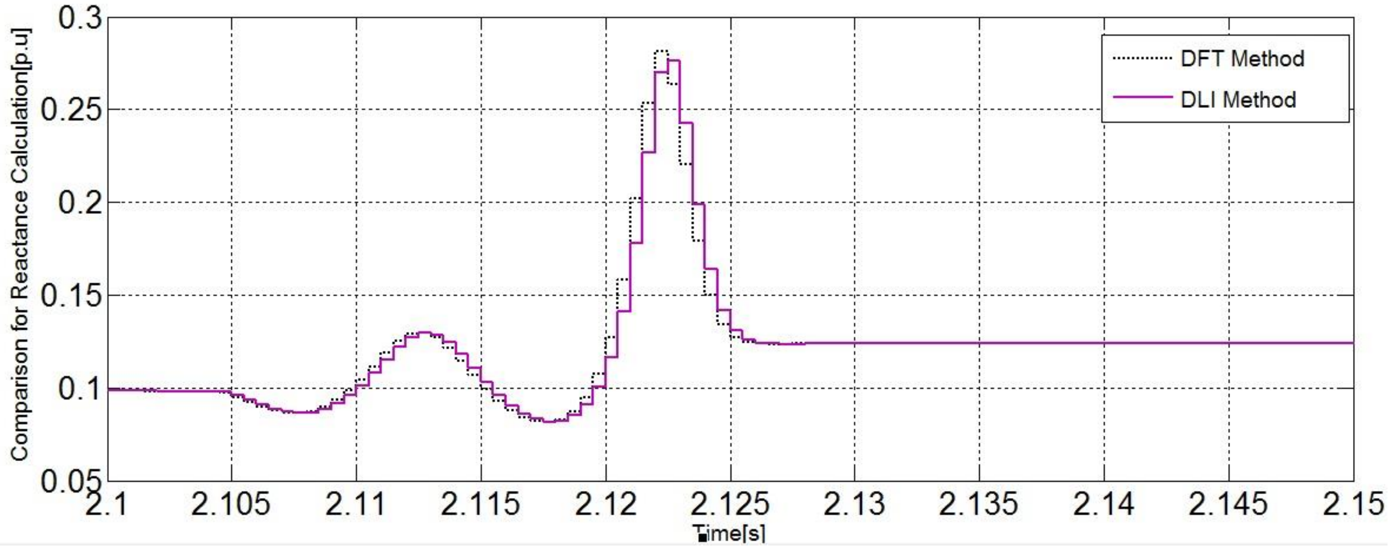

FIG. 10. COMPARISON FOR REACTANCE CALCULATION (FAULT AT 80% OF LINE LENGTH

V. CONCLUSION

This paper presents the Impedance Estimation of transmission line using Phasors under Dynamic conditions. Single phase to ground fault is considered at different locations on line. Proposed method gives results which are in line with conventional DFT method. Different challenges in digital distance protection can be evaluated using Dynamic Phasor Model. This is the scope of further research work.

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