Hardware Implementation of Transmission Line and Its Study Using MATLAB

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Abstract

Transmission lines happen to be one of the important subjects in Electrical Power System curriculum. Unfortunately, the theoretical concepts learned in the class room can not be verified in a laboratory. The development of laboratory model to perform experiments is very much essential. This paper discusses the steps involved in the design and development of laboratory model of transmission line. Moreover, the MATLAB based simulation of the designed line is also presented.

Keywords:Transmission line; laboratory model;fabricaton; & testing; MATLAB simulation ;experiments .

I. INTRODUCTION

An electric power system consists of three principle divisions: the generating station, the transmission line and the distribution systems. Transmissions lines are the connecting links between the generating stations and the distribution systems and lead to other power systems over interconnections. Though, the transmission lines can be used both for transmission of electrical energy at power frequency and for sending communication signals at high frequency, here a power transmission line transferring electrical power from one end to other is modeled. A transmission line is an electrically conductive medium delivering electrical energy among various circuits in an electric power system. For the purpose of analysis, a transmission line is said to have a sending end and a receiving end. The power frequency transmission lines usually carry higher voltages and currents at power frequency (50Hz or 60Hz). This paper highlights design, fabrication and testing of transmission line.

II. CHARACTERIZATION OF TRANSMISSION LINE

The transmission line is generally characterized by a few parameters like *R* (series resistance), *L* (series inductance), *C* (shunt capacitance), *G* (shunt conductance), measured per unit length and Z_0 (characteristic or surge impedance) and γ (propagation constant). Conventionally, *R*, *L*, *G* and *C* are bunched to be named as primary constants while Z_0 and γ are classified as secondary constants.

A transmission line may electrically be represented as a circuit consisting of series resistance *R* and series inductance *L* along with shunt capacitance *C* and leakage conductance *G*. When the circuit elements are assumed to be lumped with impedance *Z* in series and admittance *Y* in shunt having lumped single parameters like resistance, inductance, capacitance etc., then this equivalent representation is called lumped parameter representation Though, the transmission line parameters are distributed throughout the entire line, the lumped parameter representation can be used to get clearer understanding of the concepts involved. Fig.1 shows a π section representation of transmission line.

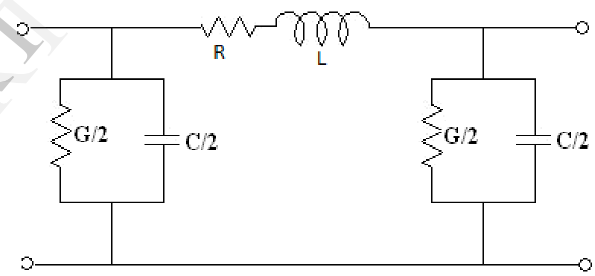

Fig.1: Circuit representation of a transmission line using π section

In fig (1),

$$Z = R + j\omega L$$

$$Y = G + j\omega C$$

The relationships between the primary and secondary constants of the transmission line are as follows;

$$Z_o = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R + i\omega L}{G + j\omega C}}\Omega / km$$

$$\gamma = \sqrt{ZY} = \sqrt{(R + i\omega L)(G + j\omega C)}$$

In analysis, frequently lines are treated as lossless (i.e. neglecting $r = 0$, $g = 0$), making

$$Z_o = \sqrt{\frac{L}{C}}$$

$$\gamma = j\omega\sqrt{LC}$$

Here, Z_0 is independent of line length. For the lossless line, Z_0 is a real quantity and is often called natural impedance of the line. It is also called as a characteristic impedance or surge impedance of the line. Power frequency transmission lines transmit bulk electrical power with a balanced three phase load. The analysis can conveniently be made on per phase basis and the line on per phase basis can be regarded as a two port network, wherein the sending end voltage V_S and current I_S are related to the receiving end voltage V_R and current I_R through *ABCD* (transmission) parameters as:

$$\begin{bmatrix} V_S \\ I_S \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_R \\ I_S \end{bmatrix}$$

III. DESIGN OF TRANSMISSION LINE MODEL:

This work includes developing a scaled down laboratory model of transmission line. This transmission line model is now put in practice to perform different power system experiments. To develop the laboratory scales down model of three phase line from the actual transmission line of 400 Km, 173 MVA (SIL), and 289 kV is scaled down to 8.66 KVA and 400 Volts. For developing this model the transmission line parameters such as series resistance and inductance, shunt capacitance given in per kilometer length are used. Then the Load bank with RLC load is designed and fabricated.

It is decided to represent entire length of 400 Km using eight π sections consisting of resistance, inductance and shunt capacitances. Thus, each π section is representing 50 Km line. By using the following data the various quantities related to transmission line model and load bank are calculated.

A. *Transmission line model ratings-:*

The ratings of actual transmission line are as follows:
Surge impedance loading of the line: - 173MVA
Voltage rating of the line: 289KV
Resistance: 0.073Ω/Km
Inductive Reactance: 0.4794Ω/Km
Shunt Admittance: 3.36μmho/Km
Frequency: 50Hz

1) The current in the line is calculated as:

Current (*I*), $I = \frac{P}{\sqrt{2}V}$

Giving, *I* = 345.61Amp

2) Base Impedance (*Z*)- $Z = \frac{V}{I}$

Base impedance *Z*=836.20Ω

3) Series Inductance $X_L = 2\pi f L$

Giving:, *L*=1.525mH
Series Inductance *L*=1.525mH

4) Shunt Admittance $Y = \omega C$

Giving: Shunt Capacitance *C*=10.70×10^{-9}F

5) Propagation Constant (*γ*) $\gamma = \sqrt{LC}$

Giving: *γ* =4.03×10^{-6}

B. *Per unit values-:*

Per unit values of Resistance

$$R_{pu} = R\left(\frac{Base\ MVA}{(Base\ KV)^2}\right)$$
$$= 0.073\left(\frac{173}{(289)^2}\right)$$
$$= 1.5120 \times 10^{-4}\Omega$$

Per unit values of Reactance

$$X_{Lpu} = X_L\left(\frac{Base\ MVA}{(Base\ KV)^2}\right)$$
$$= 0.4794\left(\frac{173}{(289)^2}\right)$$
$$= 9.929 \times 10^{-4}\Omega$$

C. *Scaled down model for 8.66 KVA and 400 Volt*

Current (*I*) =

$$I = \frac{P}{\sqrt{3}\,V}$$
$$I = \frac{8660}{\sqrt{3} \times 400}$$

I =12.5 Amp

Base impedance (*Z*) =

$$Z = \frac{V}{I}$$

Z =32Ω

D. *The actual values of Resistances & Reactance's in the scaled down model*

(The subscript SD stands for scale down)

1) $R_{SD} = R_{pu} \times Z_{pu}$

$$= 1.5120 \times 10^{-4} \times 32$$
$$= 0.0048\ \Omega/\text{km}$$

2) $X_{LSD} = X_{pu} \times Z_{pu}$

$$= 9.929 \times 10^{-4} \times 32$$
$$= 0.0317\ \Omega/\text{km}$$

$$L_{SD} = \frac{X_{LSD}}{2\pi f}$$
$$L_{SD} = 0.1009\,\frac{\text{mH}}{\text{km}}$$

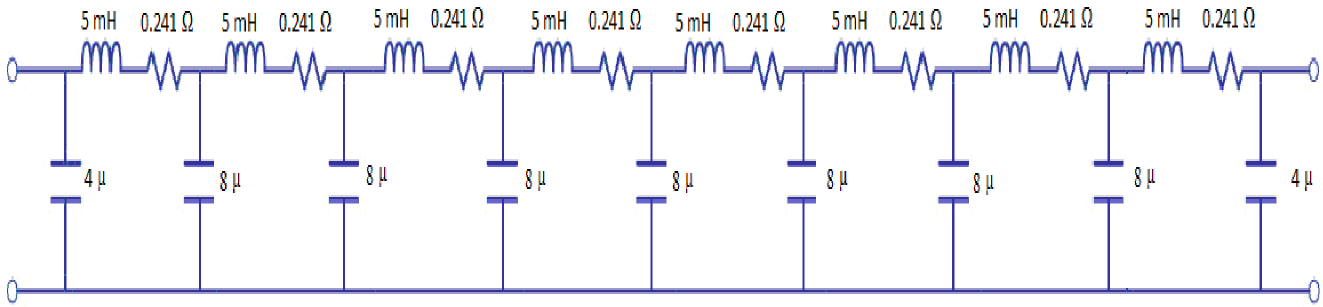

Fig. 2 Model transmission line

3) $C_{SD} = \frac{\gamma^2}{L_{SD}}$

$C_{SD} = \frac{(4.03 \times 10^{-6})^2}{0.1009 \times 10^{-3}}$

$C_{SD} = 0.1609\ \mu F/km$

E. Line parameters for 50Km Line Mode

The line parameters for each π section are then calculated as follows:

Resistance

$R_L = R_{SD} \times 50$

=0.24 Ω

Inductance

$L_L = L_{SD} \times 50$

$L_L = 0.1009 \times 10^{-3} \times 50$

$L_L = 5.045$ mH

Capacitance

$C_L = C_{SD} \times 50$

$= 0.1609 \times 10^{-6} \times 50$

$= 8.045$ ⍰F

F Design of Load Bank

A three phase load bank as fabricated which can supply a resistive inductive and capacitive current of 7.5A (maximum) in step of 0.5A. Thus any combination of phasor relation can be obtained between receiving end voltage and current.

IV. PERFORMANCE TESTING

The performance of a transmission line model was then tested and a laboratory manal is then prepared for conduct of many following is the list of few experiments:

- Voltage regulation on short, medium and long transmission line
- Voltage profile on transmission line
- Ferranti effect
- ABCD parameters of transmission line
- Circle diagram
- Reactive power exchange
- Effect of line parameters on power flow
- Additionally, a SIMULIK model of the line was developed to supprort the experimental results.

V. SIMULATION OF TRANSMISSION LINE

In order to verify the performance of transmission line the SIMULINK model of transmission line is developed as shown in Fig. 3.

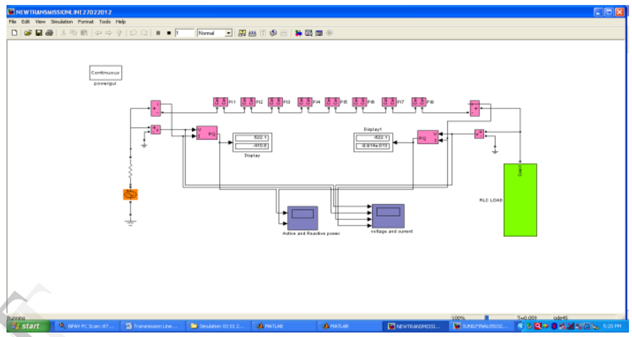

Fig. 3 - Simulation of transmission line

The simulation of transmission line is designed same as hardware rating. Simulink of transmission line consists of 8 pi sections as shown in Figure 4

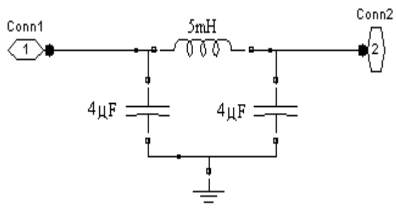

Fig. 4: Pi section of Line

The simulation of transmission line is designed with the help of values of inductor, capacitor & resistor obtained from the calculation of transmission line model. The values are L=5.045mH, C=8.045µF & R=0.24Ω for 50Km transmission line. Simulation of transmission line consists of 8 pi sections each having 50Km length as shown in Figure 2. The SIMULINK model of the load bank is also developed to study active power, reactive power, voltage and current variations for different loading conditions. The experimental transmission line model build in laboratory is as shown in

Figure 5. This gives an opportunity to study the performance of a transmission line.

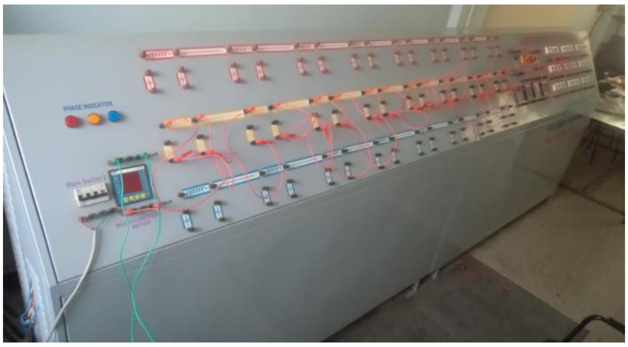

Fig. 5 – Experimental Transmission line Model

The foregoing discussion has elaborated the steps involved in understanding the idea of design, fabrication and simulation of transmission line. The simulation results were compared with practical results on the model transmission line. This line is further compensated by using developed laboratory models of STATCOM which help to practically understand line compensation.

VI. CONCLUSIONS

This paper explains development of laboratory model of transmission line and also steps involved in design, fabrication and testing of transmission line. The reactive power exchange cannot seen because of the limitations of the metering facilities. However, the effect can be seen by measuring the voltage at the receiving end. The developed laboratory model of transmission line is used for performing the experiments related to transmission line for undergraduate and postgraduate students. Further, the same model will be used to develop the laboratory setup for demonstration of different series and shunt FACTS devices.

VII. REFERENCES

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