LABORATORY SETUP FOR LONG TRANSMISSION LINE

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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 cannot be verified in a laboratory. The development of laboratory model to perform experiments is very much essential. So in this regard the designing and development of laboratory model for transmission line is carried out. Moreover, the MATLAB based simulation of the designed line and online monitoring of model is also presented. This in-house made demo model will be helpful for finding out voltage regulation as well as to observe voltage profile on transmission line. This model will not only be used to observe Ferranti effect but also to do online monitoring of parameters. In future work, this model will be helpful for designing protection system and various other applications such as development of FACTS controllers.*

***Key Words*: Transmission line, laboratory model, fabrication & testing, MATLAB simulation; experiments**

1. INTRODUCTION

Transmission line is one of the major parts of power system. Electrical power system is vast subject having various theoretical concepts. These concepts of power system cannot be cleared therefore experiments should be perform on laboratory basis to conceptualize this knowledge. This project is a laboratory setup to perform various power system experiments on demonstration level. The main objective of this project is to study Ferranti effect and to find various parameters regarding transmission line.

This in-house made demo model will be used to find out voltage regulation as well as to observe voltage profile on transmission line. This project also highlights the design, fabrication, online monitoring/automation and testing of transmission line.

We have done design, fabrication and testing of transmission line and explain the performance of long transmission line with an experimental study on demo model. In this scaled down laboratory model of transmission line the real line parameters of KORADI-BHUSAVAL line are used. The parameters of the actual transmission line are 351 km; 375MVA & 400kV are scaled down to 415 volts and 10 Amp. For developing these model parameters, positive sequence components of transmission line which is given in per kilometer length are used. It is decided to represent

entire length of 351 km using seven π sections consisting of calculated lumped parameters i.e. R, L & C. Thus each π section represents 50 km long length. In order to verify the performance of transmission line the SIMULINK model of transmission line is developed. The performance of transmission line model was then tested & a laboratory panel is then prepared for performing various experiments related to transmission line.

The idea about this model was taken from [5] which discuss the steps involved in the design & development of a laboratory model of transmission line. Moreover, the MATLAB based simulation of the designed line is also presented.

2. Design of transmission line model

This work includes developing a scaled down laboratory model of transmission line. This transmission line model will be put in practice to perform different power system experiments.

This scaled down model is developed from the actual parameters of KORADI-BHUSAWAL transmission line of 400kV and 351km long. These double circuit line having power handling capacity of 750 MVA. These parameters are scaled down to 7.188 KVA and 415 VOLTS in a single circuit design. For developing this model for transmission line parameters such as series resistance and inductance, shunt capacitance given in per km are used.

It is decided to represent entire length of 351km using 7 π sections consisting of resistance, inductance and shunt capacitances. Thus each π section is representing 50km line length. By using the following data the various quantities related to transmission line model is calculated.

A)   Actual Transmission Line Ratings

The ratings of actual transmission line are as follows:
MVA rating: - 375MVA
Voltage rating of the line: 400kV
Resistance: $0.027\Omega/Km$
Inductive Reactance: $0.334\Omega/Km$
Capacitive Reactance: $0.296\times10^6 \ \Omega/Km$
Frequency: 50Hz
1) The current in the line is calculated as:

Current (I), $I_{ph} = \frac{P}{\sqrt{3}\ V_{ph}}$

$= \frac{375 \times 10^6}{\sqrt{3} \times 400 \times 10^3}$

$= 541.26$ Amp

2) Base Impedance (Z)

$Z_{ph} = \frac{V_{ph}}{I_{ph}}$

$= \frac{\frac{400 \times 10^3}{\sqrt{3}}}{541.26}$

$Z_{ph} = 546.67\ \Omega/km$

3) Series Inductance

$X_L = 2\pi f L$

$L = \frac{1}{2\pi f} X_L$

$L = \frac{0.334}{2\pi f}$

$= 1.0631$ mH

4) Shunt Capacitance

$X_c = \frac{1}{2\pi f C}$

$C = \frac{1}{2\pi f X_c}$

$= \frac{1}{2\pi \times 50 \times 0.296 \times 10^6}$

$= 1.075 \times 10^{-8}$ F

5) Shunt Admittance

$Y = \omega C$

$= 2\pi \times 50 \times 1.075 \times 10^{-8}$

$= 3.37 \times 10^{-6}\ \mho/km$

6) Propagation Constant

$\gamma = \sqrt{LC}$

$\gamma = \sqrt{1.0631 10^{-3} \times 1.075 \times 10^{-8}}$

$= 3.38 \times 10^{-6}$

B) Per unit values:-

Per unit values of Resistance

$R_{PU} = R \times \frac{BASE\ MVA}{(BASE\ KV)^2}$

$= 0.027 \times \frac{375}{400^2}$

$= 6.32 \times 10^{-5}$

Per unit values of Reactance

$X_{LPU} = X_L \times \frac{BASE\ MVA}{(BASE\ KV)^2}$

$= 0.334 \times \frac{375}{400^2}$

$= 7.8281 \times 10^{-4}$

C) Scaled down model for 7.188 KVA and 415 Volt

Current (I) $= \frac{P}{\sqrt{3}\ V}$

$I = \frac{7188}{\sqrt{3} \times 415}$

$I = 10$ Amp

Base impedance (Z) :

$Z = \frac{V_{ph}}{I_{ph}} = \frac{\frac{415}{\sqrt{3}}}{10}$

$Z = 23.9$ Amp

D) The actual values of Resistances & Reactance's

In the scaled down model
(The subscript SD stands for scale down)

1) $R_{SD} = R_{PU} \times Z$

$= 6.32 \times 10^{-5} \times 23.9$

$= 1.51\ m\Omega/km$

2) $L_{SD} = X_{PU} \times Z$

$= 6.32 \times 10^{-5} \times 23.9$

$= 0.0186\ \Omega/km$

$L_{SD} = X_{LSD} \times \frac{1}{2\pi f}$

$= \frac{0.0186}{2 \times \pi \times 50}$

$= 5.92 \times 10^{-5}$

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

$= \frac{(3.38 \times 10^{-6})^2}{5.92 \times 10^{-5}}$

$= 0.192\ \mu F$

The Line Parameter for each π Section.

$R_L = R_{SD} \times 50$

$= 1.51 \times 10^{-3} \times 50$

$= 0.075\ \Omega$

$L_L = L_{SD} \times 50$

$= 5.92 \times 10^{-5} \times 50$

$= 2.99$ mH

$C_L = C_{SD} \times 50$

$= 0.192 \times 10^{-6} \times 50$

$= 9.64 \times 10^{-6}$

$C_L/2 = \frac{9.64 \times 10^{-6}}{2}$
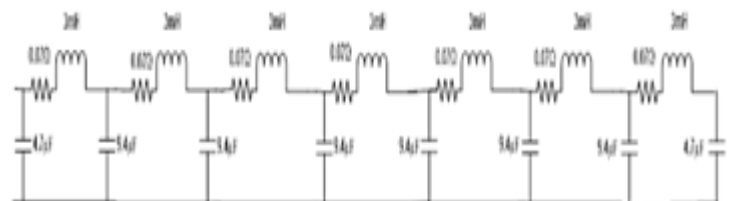
$= 4.82\ \mu F$

Fig1.Model of transmission line

3.HARDWARE IMPLEMENTATION:

3.1 Inductor

Type - Laminated Core

Construction of inductor:

The construction of inductor is done according to the rating required. The calculation for rating of the required inductor is done as follows:

As per the collected data:

The positive sequence inductive reactance (X_L) is found to be = 0.334 Ω/Km/phase
Since Inductance of a coil is given by;
$$L = \frac{xL}{2\pi f}$$
Where f is the supply frequency = 50 Hz
Therefore $L = \frac{0.334}{2\pi \times 50}$
          = 1.063 mH/km

Scaled Down Calculations for 415V, 10A, 7.188KVA

Z = V/I = 23.78 Ω/ph.
   X_{LSD} = Z×X_{Lpu} = 18.77mΩ/Km/ph.
$L_{SD} = \frac{Xl_{SD}}{2\pi f}$ = 0.0598mH/Km

**Line parameters for 50Km Line Model:
(Total line distance=351 km)**

L_L = 50×L_{SD}=2.99 MH/ph.
Thus finally the inductor having a value of 2.99 mH/ph is used in this model.

3.2 Capacitor

Type-Electrolyte Capacitor
The analysis of the requirement of capacitor for the laboratory setup for long transmission line is done as follows:
The positive sequence capacitive reactance (X_C) is found to be = 0.296×10^6 Ω/Km/phase
Since capacitance of a coil is given by;

$$C = \frac{1}{2\pi f \times X_C}$$

Where f is the supply frequency = 50 Hz

Therefore,
$$C = \frac{1}{2 \times 3.14 \times 50 \times 0.296 \times 106}$$

 C = 0.0107 µF/Km

Scaled Down Calculations for 415V, 10A, 7.188KVA

Z = = 23.78 Ω/ph.
   X_{LSD} = Z×X_{LPU} = 18.77mΩ/Km/ph.
   $L_{SD} = \frac{Xl_{SD}}{2\pi f}$ = 0.0598mH/Km
   γ = √LC =3.377×10^{-6}
   C_{SD} = $γ^2$/L_{SD} =0.191µF/Km/phase

**Line parameters for 50Km Line Model:
(Total line distance=351 km)**

Thus for a section of 50 km transmission line of a π model having two distributed capacitance value is found to be;

$$C_L = 50 \times \frac{C_{SD}}{2} = 4.784 \text{ µF/ph.}$$

Thus finally the capacitor having a value of 4.784**µF/ph** is used in this model.

3.3 Contactor

Rating of contactor used in laboratory setup of long transmission line is given as follows:

MNX 18 contactor manufactured by L &T,
Ue: 415 V (Ac voltage), AC-3,
Power rating: 9.3 kW
Ith10 A
Temperature rating: suitable for 55˚c

Auxiliary Contact:

Ie: 4 A, AC -15
50 Hz/60 Hz

3.4 Miniature circuit Breaker (MCB):

Rating of Miniature circuit breaker used in The Laboratory Setup for Long Transmission Line:
Current Rating: The breaking current rating of a MCB is 15 kA
Voltage rating: 415 Volts (AC)
Class used – C 10

3.5 Current Transformer (CT):

CT Ratio – 20A/5A

3.6 NOVA Meter:

Manufactured by L&T

This panel meter measures voltage, current and kWh energy in a 3 phase 4 wire system. The meter has an LCD display with backlight, thus enabling ease of reading.

Fig.2 NOVA Meter

Features*:*

- Class 1 accuracy
- AC/DC auxiliary supply
- RS 485 communication
- Password protected CT/PT value programming

Table 1:-Nova Meter Technical Specification

Dimension	96X96 mm X105 mm(HXWXD)
Connection	3P 4W
Display	Backlit LCD
Type	kWh Meter
Measurements	kWh/kW/Frequency/voltage/current
Starting Current	0.2% of rated current(5A)
Class of Accuracy	Class 1.0
Current	5A (rated),10A (max)
Voltage (P-N)	3 X 240 V (-30% to +20% of Vref)
Frequency	50 Hz ± 5%
Auxiliary Supply	88V TO 300V AC/DC

DISPLAY PARAMETERS:

- Cumulative energy
- Total active power
- Frequency
- R phase voltage
- Y phase voltage
- B phase voltage
- R phase current
- Y phase current
- B Phase current
- R phase active power
- Y phase active power
- B phase active power

3.7 PLC

COMPONENTS USED IN PLC:

- SMPS (SWITCH MODE POWER SUPPLY)

Voltage rating: 12 V DC (Regulated supply)

- PLC (ALLEN BRADLEY):
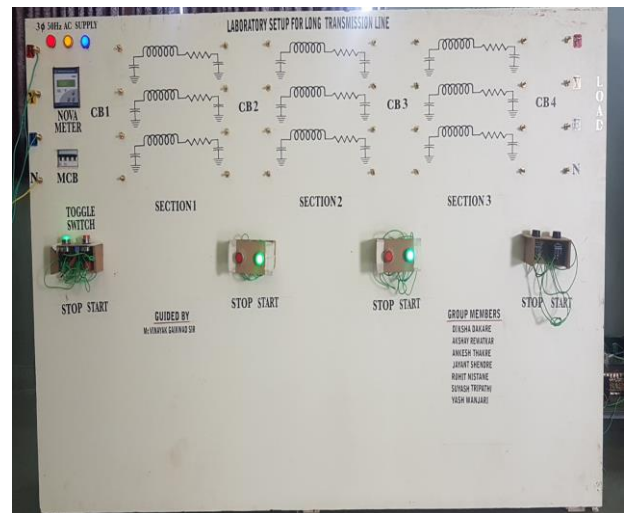
MICROLOGIX 1100

- RELAY :

Type- 8 Channel Relay

Fig 3. Photograph of Front View of Prototype

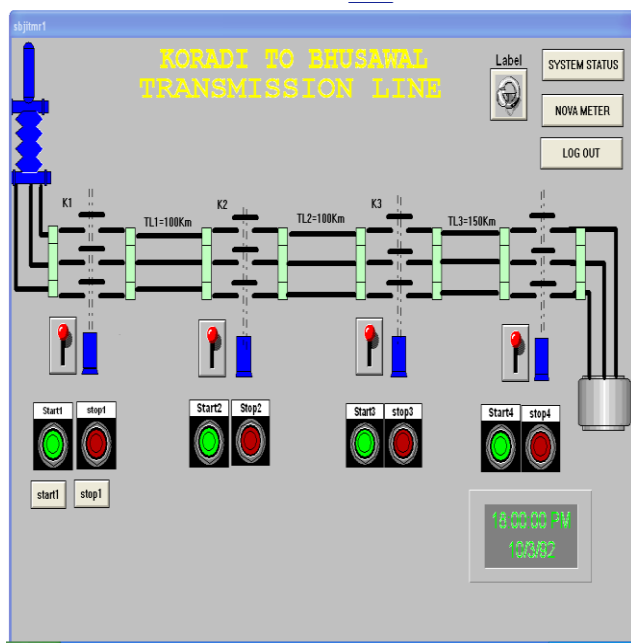**Fig 4:- Photograph of Back View of Pane**

Fig 5:- Graphical user interface of SCADA

4. AUTOMATION

4.1 Advanced Transmission line Automation

The real need for advance transmission line automation is associated with the growing demand for reliability of power supply and desire for optimized network condition in normal and emergency operations, one of the most important aspects of transmission automation system is featured by the electric utility dispatcher's ability to remotely monitor, coordinate and operate transmission line components.

Transmission automation ensures power system stability, fast load restoration, advance fault notification and fault analysis. In addition, condition monitoring can be implemented, reducing maintenance costs while improving reliability.

In this model, automation has been done using PLC-SCADA. NOVA meter is used for data acquisition. RS485 port has been used for communication between PLC and NOVA meter. After data acquisition by NOVA meter, data has been sent to PLC which sends data to SCADA system. This system helps to online monitoring of parameters.

For controlling transmission line, the equipment's should be connected as per control diagram and power diagram. Following software are used to access online monitoring of Laboratory setup for long transmission line model.

Table2:- list of software

SR NO	SOFTWARE	VERSION	QUANTITY
1	Rockwell Automation software		
a)	Boot-Dhcp Server	2.3	1
b)	Rs linx	CLASSIC	1
c)	Rs Logix Micro Starter Lite	8.30.00	1
2	Wonderware Intouch 7.0		
a)	Window Maker	7.0	1
b)	Window viewer	7.0	1

5.RESULT

The calculated scaled down values were used for MATLAB simulation. The simulation has been carried out for results are as tabulated below.

Testing on the In-house laboratory based model is conducted.

The hardware results are given below:

- **Ferranti Effect**

Table3:-Simulation Results

Sending end voltage (volts)	Receiving end voltage (volts)	Load
415	461	NO LOAD

Table 4:-Hardware Results

Sending end voltage(volts)	Receiving end voltage(volts)	Load
392.4(3-ϕ Supply)	438	NO LOAD

Table5:-Simulation Result of 1- φ De-scaled Model

INPUT VOLTAGE(Vph)	240	240	240	240	240	240	240	240
LOAD (kVA)	2.38	NO LOAD	2.38	2.38	2.38	2.38	1.195	1.76
POWER FACTOR	1	-	0.8(lag)	0.85(lag)	0.9(lag)	0.95(lag)	1	1
OUTPUT VOLTAGE(Vph)	242.2	257.6	212.7	215.7	219.5	225.2	252	247.5
RECEIVING CURRENT(amp)	10.7	0	8.85	8.97	9.132	9.368	5.241	7.222
EFFICIENCY	97.75	0	97.97	98	98	97.97	98.59	98.2
REGULATION (%)	5.97	-	17.43	16.26	14.79	12.57	2.17	3.92

6. CONCLUSION

Using the actual transmission line parameters a laboratory based de-scaled model can be fabricated. This model helps the students/research scholars to design various laboratory experiments for enriching the theoretical concepts.

In this project work the Ferranti effect demonstration, calculation of regulation of transmission line has been conducted. The de-scaled model gives approximately same results as that of the original transmission line.

By using the PLC-SCADA the automation can be implemented in the laboratory based panel which helps the students to understand the remote control & operation of the power system.

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