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Performance Study of Transmission Line Ferranti Effect and Fault Simulation Model Using MATLAB

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Abstract: In this paper, performance analysis of transmission line has been carried out and Ferranti effect and short circuit fault have been studied. The proposed study has been done using MATALB/Simulink and has been experimentally verified on hardware. In open circuit or light loaded condition, it has been observed that receiving end voltage is slightly greater than sending end voltage in both, simulation as well as in hardware. During short circuit condition a relay has been used to trip the fault condition and line is isolated from the grid. Experimental and simulation results have been presented in this paper.

Keywords: Transmission line, Ferranti effect, rises in voltage, MATLAB software.

I. INTRODUCTION

The factors are causing to sudden over voltage may be considered in insulation. The phenomenon of Ferranti effect in the uncompensated transmission line gives result as remote end voltage is always higher than that of source voltage. It is the effect of capacitive charging current as it flows through the inductance of line and resulting that as length of line increases over voltage also increases. [1]

Traditionally transmission line have been designed most accurate method of a constant transformation matrix with frequency dependent modes. For the high frequency transients this kind of model may give satisfactory results, but accuracy of the model gets deteriorates while considering low frequency transients due to frequency dependency of the transformation matrix. [2]

In ling transmission line, length of the line and the degree of shunt compensation these are the most important factors. And these factors affect the power frequency voltage on the line during normal working and the rise in voltage during a fault. [3]

The Ferranti effect describes the strong phenomenon that certain conditions on length of line and frequency, a rise in voltage is found at an open ended transmission line as source voltage is relatively sinusoidal in nature. This effect of phenomenon was discovered at the end of 19^{th} century in the Great Britain during the ac based distribution system. In the UK it was Sebastian Sinai de Ferranti, who as an ardent defender of an ac system which installed an ac system along with intermediate levels of different voltage and remote step-down transformers. Ferranti observed on one ac transmission system an altered by his installers that by increasing length of line i.e. by adding an extra section of distribution line, the rise in voltage various remote ends. In fact they observed firstly on Deptford-London line that the increased in the luminosity of some lamps, when those were attached to extra added distribution section. Under this case it should be noted that they had a load of just couple of low power lamps while having an effective generator power exceeding slightly 935 kW. Thus he had in fact approximately open ended line. Now-a-days, at relatively low frequencies Ferranti effect is well known and considered in the power transmission system for a long distance. [4]

In electric power system reactive power plays very important role as it affects the efficiency of these systems. Over voltage can produced due to capacitive loads in electric transformers by this phenomenon which generates very deficient power quality, hence it is necessary to measure reactive power as correctly as possible.

II. MODEL OF TRANSMISSION LINE

Generally, transmission line is modelled by a few parameters like R (series resistance), L (series inductance), C (shunt capacitance), all are measured per unit length of line and Zo (surge or characteristic impedance) and γ (propagation constant). Formerly, R, L, C and G are named as primary constant while Zo and γ are named as secondary constant. A transmission line is represented as electrically circuit which consists of series resistance R and series inductor L, shunt capacitance C and leakage conductance G. lumped parameters representation of transmission line is as shown in below fig.1.

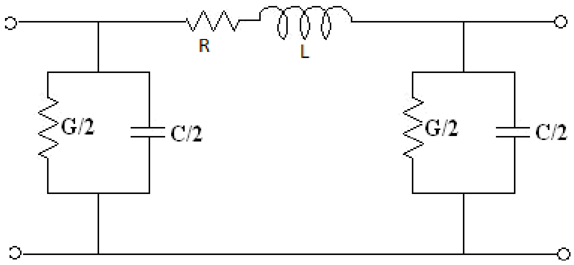

Fig.1.Transmission line model represents π section.

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As fig.1.represents the electrical circuit of π-section transmission line. It consists of series impedance Z, shunt admittance Yare lumped to get proper concept involved in it.

From fig.1, $Z = R + jwL$,

$$Y = G + jwC.$$

Relationships between primary and secondary constants are as follows:

$$Zo = \sqrt{\frac{Z}{Y}} = \sqrt{\frac{R+jwL}{G+jwC}}\,\Omega/km.$$

$$\gamma = \sqrt{ZY} = \sqrt{(R + jwL)(G + jwC)}.$$

In general analysis, R and G are neglected. So, Zo is given by,

$$Zo = \sqrt{\frac{L}{C}}\,\Omega/km.$$

And $\gamma = \sqrt{LC}$.

Here, Zo is called as the impedance of the transmission line. For lossless transmission line, it is also known as a surge impedance or characteristic impedance. It is a real quantity therefore considered as the natural impedance of the line.

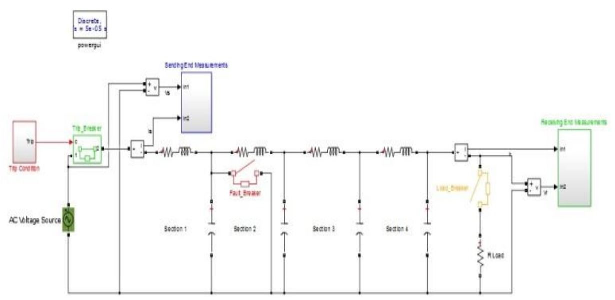

Fig.2.MATLAB Simulink block diagram of long transmission line.

The bulk electrical power being transmitted by using power frequency transmission line with balanced three phase system. The analysis can comfortably be studied on per phase basis and per phase basis can be put down as the two port network, wherein sending end quantities (sending end voltage, Vs and current Is) are given by the receiving end quantities (receiving end voltage Vr and current Ir) along with ABCD or transmission parameters.

It is given by

$$Vs = AVr + BIr$$
$$Is = CVr + DIr.$$

III. FERRANTI EFFECT

In the power system, long transmission line draws considerable quantity of charging current and under goes the phenomenon of Ferranti effect while lightly loaded or open circuited at remote end, in which the receiving end voltage becomes considerably more than steady source voltage.

In the transmission line, voltage drop is due to the inductive nature of all electrical loads as they are consume the reactive power from the line. While capacitors are acts as the source of the reactive power and connected parallel to the line at the load side to compensate the effect of inductive loads. Reactive power consumed by the inductive loads is supplied by the capacitors and simultaneously these capacitors compensate the reactive power consumption from transmission line. However the inductive loads are switch off or acting as inactive, capacitors may still be in operation. In this case capacitors aids the reactive power on the transmission line due to which the consumers or remote end voltage increases resulting in greater in magnitude than the source voltage. Due to the charging current voltage drop across the inductance gets align with the sending end voltage. Therefore both inductance and capacitance of the transmission line are responsible for the Ferranti effect.

Consider the figure given below shows phasor diagram of Ferranti effect of transmission line. Receiving end voltage as reference phasor we have,

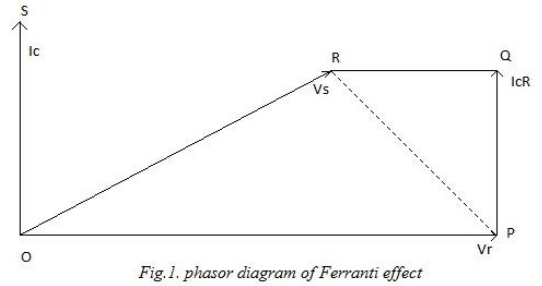

Fig.3.Phasor diagram of Ferranti effect in long transmission line

Then,

OP= Receiving end voltage, Vr

OR= Sending end voltage, Vs

PQ= Resistive drop,

QR= Inductive reactance drop,

OS= Current drawn by the capacitor $=Ic$.

From figure it is easily observed that sending end voltage (Vs) is less than receiving end voltage(Vr).

Since, resistance is very small as compared to the reactance. Hence, neglected in Ferranti effect in medium and long transmission line.

$Vr = Vr(1 + j0)$, represented by the phasor OP.

Charging current,$Ic = jeCVr$, represented by phasor OS.

Voltage at sending end,

$Vs = Vr + resistive\ drop + reactive\ drop\ in\ line = Vr + IcR + IcX$,

$$Vs = Vr + Ic(R + jX) = Vr + jwCVr(R + jX)$$

Or,

$Vs = Vr - w^2CLVr + jwCRVr$, represented by phasor OR.

Noticeably the overhead transmission line of long length brings the effect as reactance is fairly large than resistance, and by considering the magnitude of the effect easily derived.

By neglecting resistive drop IcR we get,

Voltage rise = OP-OR = inductive drop in line.

For a transmission line per km length values of capacitance and inductance are Co and Lo respectively, length is l in km. capacitive reactance, $Xc = \frac{1}{wlCo}$.

The capacitance is uniformly distributed along the length of line, Therefore, average current flowing throughout line is given by

$$Ic = \left(\frac{1}{2}\right)\left(\frac{Vr}{Xc}\right) = \frac{1}{2}VrCowl.$$

The transmission line reactance, $X = wlLo.$

Voltage rise= $IcXc = \frac{1}{2}w^2l^2VrCoLo$ volts.

Velocity of propagation $=\frac{1}{\sqrt{LoCo}}$ is always constant for all overhead lines and its value is nearly equals to the speed of light i.e. $3 * 10^5$ km/s.

So the voltage rise at receiving end is

$$= \frac{1}{2}w^2l^2Vr\frac{1}{(3*10^5)^2} = \frac{w^2l^2 10^{-10}}{18} \ldots(1)$$

From the equation it is easily perceived that $Vs - Vr$ is negative. From above it is cleared that Ferranti effect depends on the frequency and square of length of the line.

In general for line, $\mathrm{Vs} = \mathrm{AVr} + \mathrm{BIr}$

At no load, $\mathrm{Ir} = 0, \mathrm{Vr} = \mathrm{Vrnl}.$

$$\mathrm{Vs} = \mathrm{AVrnl}, \qquad |\mathrm{Vrnl}| = \frac{|\mathrm{Vs}|}{\mathrm{A}}.$$

Where, A is inversely proportional to the length of line. As length increases, A becomes smaller and smaller.

Hence $\mathrm{Vrnl} > Vs.$ As the line length increases voltage rise at receiving end at no load becomes more prevailing.[4]

IV. RESEARCH METHOD

In this paper the research work has done in the software as well as hardware.

A. MATLAB Simulation

The name MATLAB stands for the Matrix Laboratory. MATLAB is a very fast performing language in technical fields. It integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are demonstrated in intimate mathematical notation. In this paper we have consider the Ferranti effect in transmission line and the fault simulation by MATLAB software.

1. Ferranti effect in long transmission line:

• **CONSTRUCTION**

Fig.2 shows the model of long transmission line. It gives clear idea about the connections in the model line. It consists of four Pi-section of length of 100kms.

In this MATLAB software there are two switches are provided. First for the study of Ferranti effect with load C.B, while second to create the short circuit fault along with fault C.B.

Components/ parts:

1. Resistance, R=4.7Ω,
Inductance, L=$110 * 10^{-3}$ mH,
Capacitance, C=0.47μF, all values are for 100km.
2. Fault circuit breaker
3. Load circuit breaker
4. Trip breaker
5. Relay circuit
6. Load

In the demo model, provision for study of Ferranti effect and fault simulation is done. Afterwards, to analysis of fault switch is connected after the first Pi-section of 100kms. It consists of three circuit breakers (Trip C.B., fault C.B. and load C.B.) for the analysis purpose of Ferranti effect and the fault simulation process. Load circuit breaker is closed under the Ferranti effect analysis while fault circuit breaker for fault simulation. Trip breaker is provide for the protection against any failure condition off any one of the other two circuit breakers operation to isolate the whole system from considerable loss.

• **WORKING**

Ferranti effect is observed by closing the switch at load side. In this case output side is open circuited or light loaded to be assumed, hence resulting voltage at this remote terminals in more than sending end voltage.

For the study of Ferranti effect in the long line load breaker at load side should be closed while the fault circuit breaker kept as opened. Ferranti effect is observed for the time period at about 0.3 seconds out of 1 second time interval. That means for 0.3 sec this load breaker has been kept closed and after this interval it became as open circuited. Results are as shown below.

• **RESULTS OF THE FERRANTI EFFECT**

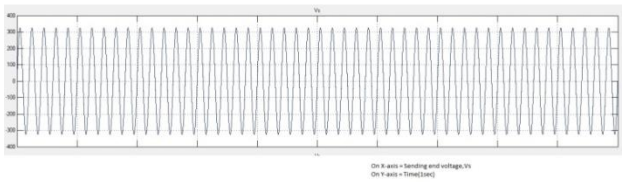

Fig.4.1. Sending end voltage, Vs.s

Sending end voltage = 325 volts.(peak), as shown in waveform in fig.4.1.

Therefore, RMS value of $\mathrm{Vs} = 230$ volts.

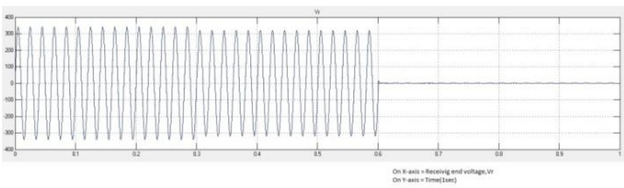

Fig.4.2. Receiving end voltage, Vr.

Ferranti effect is observed as shown in fig.4.2.

Receiving end voltage is greater than sending end and its magnitude is,

$$\mathrm{Vr} = 340 \text{ volts (peak)}$$

$\mathrm{Vr} = 240.416$ volts (rms).

From fig.4.2.it is completely observed that up to 0.3 seconds Ferranti effect is observed.

• **EQUATIONS**

As we know the performance of long transmission line, the sending end quantities are given as follows,

$$\mathrm{Vs} = \mathrm{AVr} + \mathrm{BIr}$$
$$\mathrm{Is} = \mathrm{CVr} + \mathrm{DIr}$$

Where ABCD are the transmission line generalized constants given as,

$$A = D = \sinh\sqrt{YZ} \quad \ldots.(2)$$
$$B = Zc * \sinh\sqrt{YZ} \quad \ldots.(3)$$
$$C = \frac{1}{ZC}\sinh\sqrt{YZ} \quad \ldots.(4)$$
$$Zc = \sqrt{\frac{Z}{Y}}.$$

1. FERRANTI EFFECT:
Observation table:

Sr. no	Sending end voltage (Vs) Volts	Receiving end voltage(Vr), Volts
1.	230	240.4163

From equation (2), (3), (4) we get the ABCD parameters of the long transmission line as

$\sqrt{YZ} = 0.0189 + j0.2787 = \boldsymbol{\alpha} + \mathbf{j}\boldsymbol{\beta}$.
$A = D = 1 + j9.19 \times 10^{-5} = 0.999\angle 0.005$;
$B = 9.73\angle 10.5775 = 9.56466 + j1.78609$
$C = 3.906 \times 10^{-5}\angle 22.195 = 3.61658 \times 10^{-5} + 1.47553 \times 10^{-5}$.

From the above results we have studied an analysis performance of long transmission line and Ferranti effect observed in the MATLAB software.

2. Fault simulation
Fault simulation is considered in single phase system as Simulink block diagram shows in fig.2.
Fault in the given long transmission line model is created manually by using the fault breaker. After the instant of 0.3 sec this breaker should be closed. And line being undergoes the short circuit fault between phase to neutral. It is depicted in the fig.2. Fromit is clear that fault breaker is used for the fault simulation purpose only.
Then the sending end current is increased as shown in the waveform of the current.

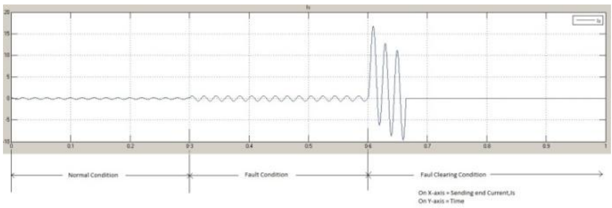

Fig.5. sending end current, Is.

1. Normal condition (t=0 sec to 0.3 sec)
From t=0 to 0.3 sec
Is= 0.2 amps.

2. Fault condition (t=0.3 sec to 0.6 sec)
At the instant of time t=0.3 sec, Fault switch has been closed.
Current increases upto, Is=0.6 amps.
This current flowing through the system for the given period until relay get energised.

3. Fault clearing condition (t > 0.6 sec)
At the instant of time, t=0.6 sec, relay operates.
And fault has been cleared.
Therefore from this operation consists of three time intervals. Fig.5.shows the sending end current and the different time intervals of operation.

V. CONCLUSION

This paper on the "Performance study of the long transmission line, Ferranti effect and fault simulation using MATLAB" has successfully studied. This paper explains the performance of long transmission line with an experimental study on demo model. From this model, Ferranti effect been studied which gives result as receiving end voltage greater the sending end voltagein the long transmission line about 400 kilometers. It is observed from the voltage rise equation the Ferranti effect been increased as the length of line increased. Also fault clearing process has been performed by using fault breaker along with relay circuit both, MATLAB/Simulink as well as on hardware.

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