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Ferranti Effect in Transmission Line

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ABSTRACT

A temporary over voltage is an oscillatory phase to ground or phase to phase over voltage that is relatively long duration and is undamped or only weakly damped. Temporary over voltages usually originate from faults, sudden charge of load, Ferranti effect, linear resonance, ferroresonance, open conductor, induced resonance from coupled circuits and so forth. The steady voltage at the open end of an uncompensated transmission line is always higher than the voltage at the sending end. This phenomenon is known as the Ferranti effect. This paper presents a study of Ferranti effect in electrical transmission line. The study is based on both software and hardware. The MATLAB program gives the locus of sending end voltage with line length which shows that receiving end voltage is greater than sending end voltage. From the experiment with transmission line simulator the values of three phase voltages at sending end and receiving end were found which proves the Ferranti effect. These two methods were used to give the idea about the Ferranti effect.

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1. INTRODUCTION

There are many factors affecting temporary over voltages that may be considered in insulation.The ferranti effect is an phenomenon where the steady voltage at the open end of an uncompensated transmission line is always higher than the voltage at the sending end.It occours as a result of the capacitive charging current flowing through the inductance of the line and resulting over voltage increases according to the increase in line length [1].

Traditionally the most accurate transmission line models have been based on a constant transformation matrix with frequency dependent modes.This type of model may give satisfactory results for situations involving high frequency transients, but the accuracy often deteriorates in the low frequency area due to frequency dependency of the transformation matrix [2].

In long transmission lines, the most important factors which affect the power frequency voltages on the line during normal operation and the increase in voltages during a fault are the length of the line and the degree of shunt compensation.Both parameters have a major indirect influence on the transient phenomena connected with the initiation or clearing of a fault, as well as with normal switching operations [3].

The ferranti effect descrives the strange phenomenon that under certain conditions of frequency and line length a voltage increase may be observed at an open ended transmission line relative to a sinusoidal input voltage.The effect was discovered at the end of the 19th century during the installation of an ac based distribution systems in Great Britain.In fact this was during the ‘ war of currents’ raging in the US between Westinghouse with Nikola Tesla as main driver and Thomas Edison.The former were the proponent of an ac system whereas Edison mainly commercially motivated proposed a dc system.In the UK it was Sebastian Ziani de Ferranti, who as an ardent defender of ac systems – installed an ac distribution system with intermediate voltage levels and remote step down transformers.This was basically the forerunner of the systems used to date.On one installation of an ac transmission system Ferranti observed alerted by his installers that by adding additional distribution sections, i.e by increasing the total length of the transmission line, the voltage on the line increased locally.In fact they observed first on the Deptford - london line that the luminosity of some carbon fibre lamps increased, when they attached an additional distribution section.In this case it should be noted that they had a load of only a couple of low power bulbs while having an effective generator power exceeding slightly 935 kW.Thus Ferranti had in fact approximately an open ended transmission line.As a result today the ferranti effect is well known in the field of power transmission over long distances at relatively low frequencies[4].

Reactive power is a very imporant quantity in electric power systems since it affects the efficiency of these systems.Also capacitive loads can produce over voltage in electric transformers by Ferranti effect which produces bad power quality, so it is necessary to measure the reactive power correctly [5].

Shunt inductive compensation is used either when charging the transmission line or when there is very low load at the receiving end.Due to very low or no load, very low current flows through the transmission line.Shunt capacitance in the transmission line causes voltage amplification (Ferranti effect).The receiving end voltage may become double the sending end voltage (generally in case of very long transmission lines).To compensate in the case of no loss line, voltage magnitude at receiving end is the same as voltage magnitude at sending end : Vs = Vr =V.Transmission results in a phase lag δ that depends on line reactance X. Shunt reactors are connected across the transmission lines [6].

This paper presents knowledge both from software and hardware point of view about the Ferranti effect. Matlab is very important in this case. From this knowledge some practical rules can be derived. The objective of this work is to give simple idea about the Ferranti effect which can cause over voltages in transmission line.

2. THEORY

A long transmission line draws a substantial quantity of charging current. If such a line is open circuited or very lightly loaded at the receiving end the voltage at receiving end may become greater than voltage at sending end. This is known as Ferranti Effect and is due to the voltage drop across the line inductance being in phase with the sending end voltages. Therefore both capacitane and inductance is responsible to produce this phenomenon.

The capacitance and charging current is negligible in short line but significant in medium line and appreciable in in long line by equivalent π model.

It is proportional to the square of lengths of lines, that is, $\Delta V \alpha kx^2$, where x is the length of line and k is a constant for all voltage levels [1].

Ferranti Effect can be explained by considering a nominal π model of the line. Figure 1(b) shows the phasor diagram of Figure 1(a).Here OE represents the receiving end voltage Vr.OH represents the current Ic1 through the capacitor C/2 at the receiving end.The voltage drop Ic1R across the resistance R is shown by EF.it is in phase with Ic1. The voltage drop across X is Ic1X.It is represented by the phasor FG which leads the phasor Ic1R by 90°.The phasor OG represents the sending end voltage Vs under no-load condition.It is seen from the phasor diagram that Vs<Vr.In other words, the voltage at the receiving end is greater than the voltage at the sending end when the line is at no load.

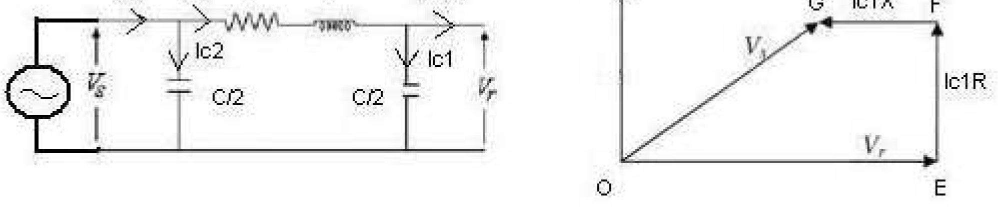

Figure 1. (a) Nominal π model of the line at no load (b) Phasor diagram

In practice, the capacitance of the line is not concentrated at some definite points.It is distributed uniformly along the whole length of the line.Therefore the voltage will increase from sending end to receiving end.At no load or light load the voltage at the receiving endis quite large as compared to the constant voltage at the sending end.

For a nominal π model of a line

$Vs = (1+ ZY/2)\, Vr + ZIr$

At no load, $Ir = 0$

$Vs = (1+ ZY/2)\, Vr$

$Vs - Vr = (ZY/2)\, Vr$

$Z = (r + j\omega l)S,\ Y = (j\omega c)S$

If the resistance of the line is neglected,

$Z = j\omega l\, S$

And $Vs - Vr = \frac{1}{2}(j\omega l\, S)\, (j\omega cS)\, Vr = -\frac{1}{2}\, (\omega^2 s^2)lc\, Vr$

For overhead lines

$1/ \sqrt{lc}$ = velocity of propagation of electromagnetic waves on the line = $3\text{x}\ 10^8$ m/s

$Vs - Vr = -\frac{1}{2}\, (2\, \pi\, f)^2\, S^2\ .\ 1/ (3\text{x}\ 10^8)^2\, Vr = -\, (4\, \pi^2/\, 18\ \text{x}\ 10^{16})\, f^2S^2Vr$

This equation shows that (Vs – Vr) is negative. That is, Vr > Vs. This equation also shows that Ferranti effect depends on frequency and electrical length of the line. The conductor diameter and spacing have no bearing on Ferranti effect.

In general, for any line

$V_s = AV_r + BI_r$

At no load,

$I_r = 0,\ V_r = V_{rnl}$

So, $V_s = AV_{rnl},\ |V_{rnl}\,| = |V_s|\, /\, |A|$

For a long line A is less than unity and it decreases with the increase in length of line. Hence $V_{rnl} > V_s$. As the line length increases the rise in the voltage at the receiving end at no load becomes more predominant [7].

3. RESEARCH METHOD

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

3.1. Programming in MATLAB

The name MATLAB stands for Matrix Laboratory. MATLAB is a high-performance language for technical computing.It integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

When a transmission line is unloaded, the ferranti effect will cause a rise in voltage from the sending end towards the remote end .When the open line is dropped at its sending end the voltage on each side of the circuit breaker will change in opposite ways : the source side voltage will adjust itself to a lower level by way of a transient oscillation whwreas on the line side the voltage will rise in the process of redistribution of the electrostatic charge that takes place along the line length as a result of the break of the line charging current.

The program given below illustrates the Ferranti effect.It simulates the effect by varying the length of line from zero(receiving end) to 5000 km in steps of 10 km and plots the sending end voltage phasor.

MATLAB program to show Ferranti effect:

```
clear
VR=220e3/sqrt(3);
alpha = 0.163e-3;
beta = 1.068e-3;
l=5000;
k=1;
for i=0:10:l,
VS=(VR/2)*exp(alpha*i)*exp(j*beta*i)+(VR/2)*exp(-alpha*i)*exp(j*beta*i);
x(k) = real(VS);
y(k) = imag (VS);
k=k+1;
end
plot(x,y);
```

3.2. Experiment by Transmission line simulator

The transmission line simulator is designed to have length adjustment facility (200,300, 400,500Km……) such that the study can be extended for short, medium and long lines. The simulator is fed at the sending end has using a three phase 400 V (L-L) variac equivalent to 1.0 pu at the sending end. The sending end is connected with different meters for measuring all line and phase quantities. A frequency meter is also provided at the sending end.

The sending end is connected to the line units housed in a steel enclosure. The line units are modeled as ‘pi’ circuits and have variable length facility.

The receiving end system serves as a major load center with variety of static impedance loads. The receiving end bus consists of bus, metering, loading and a variac for voltage control.

The auxiliary bus is connected with the receiving end through a 100 Km line. The auxiliary bus also has independent metering and external loads can be connected with the auxiliary bus.

Simulator rating:

Voltage	: 400 V (L-L)
Current	: 2A (Max 3A) continuous
Frequency	: 50 Hz
Power	: 1400 VA
Line Unit	: ‘pi’ equivalent with 400 KV, Single Circuit on H- tower (simulated) and having, l = 1 mH/ Km, c = 10 nF/ Km, r = 0.01/ Ω/ Km.

4. RESULTS AND ANALYSIS

The results obtained from MATLAB program and Transmission line simulator are discussed below:

4.1. Result from Software

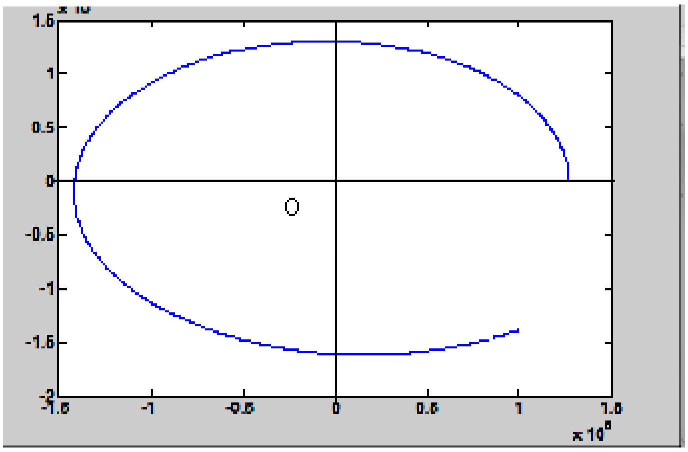

Figure 2. Locus of sending end voltage with line length

It is observed from this figure that as line length increases, the incident voltage wave increases exponentially while the reflected voltage wave decreases. It is apparent from the geometry of this figure that the resultant phasor voltage V_s is such that , $|V_R| > |V_s|$.

4.2. Result from Hardware

After proper connection the experiment was done with Transmission line simulator in no load condition.The results obtained from the experiment are tabulated below:

The experiment was carried out for line lengths of 200, 300, 400 and 500 Km.In each case the voltage of sending end and receiving end for three phases were observed.The values of $V_{RB,}$ V_{BY} and V_{RY} in sending end and receiving end were tabulated.In every case it is observed that the value of voltage increases from sending end side to receiving end side at no load condition.

Table 1. Sending End and Receiving End Voltage

Sl. No.	Line Length (Km)	Sending End Voltage (V)			Receiving End Voltage (V)		
		V_{RB}	V_{BY}	V_{RY}	V_{RB}	V_{BY}	V_{RY}
1	200	228	233	234	249	254	255
2	300	246	251	252	284	286	283
3	400	245	253	250	293	312	308
4	500	246	251	251	364	368	380

5. CONCLUSION

In this paper, the over voltage can be confirmed due to ferranti effect along the transmission line length.It occours when the line is energised but there is a very light load or the load is disconnected.The effect is due to the voltage drop across the line inductance being in phase with the sending end voltages.Therefore inductance is responsible for producing this phenomenon.The ferranti effect will be more pronounced the longer the line and the higher the voltage applied.From the knowledge of ferranti effect and by compensating this effect the temporary overvoltage in the transmission line can be reduced and thus the line can be protected.

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