Performance Comparison of Overhead Line Under Various Load Conditions

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Abstract — An overhead line is an electric power transmission line suspended by towers or poles. Since most of the insulation is in the air, overhead transmission lines are generally the lowest-cost method for transmitting large quantities of electric power over long distance. In this paper, the performance of overhead lines is studied under 3 different load conditions. The conditions are: no-load, matched-load and short-circuit loads. We focuses on the four parameters of voltage, current, real power and efficiency. The study is conducted using MATLAB/Simulink. According to simulation results, it has been shown that the performance of the transmission line under different load conditions is varied.

Keywords - component; MATLAB/Simulink, transmission line, Ferranti effect

I. INTRODUCTION

Practically, a transmission network is developed to supply electrical power from generating units to end users. In urban areas, since there is a lot of buildings and constructions taking place, overhead lines become more preferable than underground transmission lines. Other than that, the use of overhead lines can tremendously reduce the cost of delivering large power, and their maintenance cost and procedures are lower and easier than using underground lines. An overhead line is frequently used to supply power to trams, trolleybuses and trains at distance from the energy supply point. In Malaysia, the public supply of power is three-phase with frequency of 50Hz [1].

The knowledge of various load overhead lines is very important to maintain adequate clearance between energized conductors and the ground so as to prevent dangerous contact with the line. Building on the work of previous researchers in this field who used calculation and performed experiment to determine the performance of overhead line [2] using MATLAB/Simulink, our work extends and performs the simulation to the whole process.

The objective associated with this project is to observe the performance of overhead lines under various loads conditions. The conditions are no-load, matched-load and short-circuit loads. These 3 load conditions will be considered by constructing appropriate single-phase equivalent simulation circuits. In this work, the Delorenzo module with 380V peak voltage supply is used to perform the testing.

II. LOAD CONDITIONS

As mentioned, there are 3 types of load conditions to be considered. In this work, a single-phase equivalent circuit for each load condition will be utilized, for the study.

A. No-load

In this condition, only an equivalent total capacitance is being considered, for an easier study. It is because the parameter is directly proportional to the length of the transmission line. Theoretically, the value of transmission loss in this load condition is assumed to be zero. However, in real practice, the parameters (capacitance and resistance) of a transmission line are distributed, which is crossing the line resistors. Subsequently, the capacitive currents will provoke power losses even when the transmission line is in no-load condition. Fig. 1 shows a single-phase equivalent circuit for no-load condition.
According to the figure, $i_{out}$ is equal to zero; no current flows in no-load condition. Therefore, in this no-load condition, only charging current will flow. Hence, power that involves is called charging power. In some cases, voltages at the end of transmission line will increases to impermissible values because of the equivalent total capacitance.

This occurrence is called Ferranti effect, and it can cause a dangerous state in greater line length. In defective form, the Ferranti effect also occurs if the network is supplying weak loads, such as at night. In [3], Gagar Dea had mentioned that the effect is an occurrence in which the steady voltage at the open end of transmission line is often higher compare to the input voltage. It shows a strange phenomenon under some condition of frequency and transmission line length. A voltage increase may be seen at no-load condition transmission line. The following equations are applied in the Ferranti effect:

$$I_{21} = \frac{V_{out}}{2} \times C$$  

(1)

and

$$Q_e = \omega CV^2$$

(2)

**B. Matched-load**

If the load is similar to the line, therefore there is no backward propagating wave that will bring the reflection coefficient equals to 0. The sum of voltage drop across the two transmission lines is the same as the forward propagating wave. Thus, the total voltage is a pure travelling wave. Voltage and current envelopers of a pure travelling wave is constant no matter the meter is put along the line. Nevertheless, the phase will change. Fig. 2 shows a single-phase equivalent circuit for matched-load condition.

Based on the figure, the condition exists when the transmission line is terminated by an ohmic consumer resistance that is equivalent to the characteristic impedance. Power in this system is known as natural load. Also, in this system, power loss of the transmission line is very minimal and it is known as an optimum case. To supply fixed voltage to consumer, supply voltage must be regulated at the supplying transformer [4]. In this condition, (1) can also be applied.

**C. Short-Circuit Load**

In this condition, the consumer resistance is short-circuited by a fault. So that a very high line current will flow. When a short circuit occurs, the transmitted power is generally much greater than the thermal limit rating of the transmission line. Therefore, the protection device must able to recognize this occurrence and switched off the system within shortest possible time. Among all 3 load conditions, short-circuit load is the most dangerous. Fig. 3 shows equivalent circuit for three phase short circuit.

In this work, each single-phase equivalent circuit is simulated using MATLAB/ Simulink. The simulation uses discrete solver with sampling frequency 150 kHz. For each load condition, some related parameters are measured and studied.

**A. No-load**

As mentioned, in no-load operation, $I_{out}$ is equal to zero. Hence, other than supply voltage and current, this study is concentrated on measuring both charging current

$$P = I V \cos \theta$$  

or  

$$I^2R$$

(3)

$$P_{loss} = P_{send} - P_{consumed}$$

(4)

$$\eta = \frac{P_{consumed}}{P_{send}} \times 100$$

(5)
and reactive power. Table I and Fig. 4 presents all measured parameters during this load condition.

**TABLE I. MEASUREMENT OF VOLTAGES, CURRENTS AND REACTIVE POWER DURING NO-LOAD CONDITION**

<table>
<thead>
<tr>
<th>$V_s$ (V)</th>
<th>$I_1$ (A)</th>
<th>$V_{out}$ (V)</th>
<th>$I_{22}$ (A)</th>
<th>$Q_r$ (Var)</th>
</tr>
</thead>
<tbody>
<tr>
<td>380</td>
<td>0.62</td>
<td>409.3</td>
<td>0.32</td>
<td>113.4</td>
</tr>
</tbody>
</table>

Figure 4. Steady-state simulated voltage and current during no-load condition.

According to all results, it can be noticed that the Ferranti effect has occurred. In Table I, the value of $V_{out}$ is higher than $V_s$ by 8%, and it also shown in Fig. 4. It happens due to charging and discharging process of the equivalent capacitance [5]. During the charging process, the supply voltage requires to supply almost 50% of $I_1$ to the equivalent capacitance. Additionally, the charging reactive power equals to 113.4 Var.

**B. Matched-load**

In this load condition, the value of $R$ is varied. Then, the effect of using different value of $R$ on supply and output voltage and current is studied. Furthermore, the efficiency of the system is also measured. Table II, Fig. 5 and Fig. 6 present all measured parameters during matched-load condition.

**TABLE II. MEASURED VOLTAGES, CURRENTS, POWER AND EFFICIENCY DURING MATCHED-LOAD CONDITION**

<table>
<thead>
<tr>
<th>$R$ (Ω)</th>
<th>$V_s$ (V)</th>
<th>$I_1$ (A)</th>
<th>$V_{out}$ (V)</th>
<th>$I_{out}$ (A)</th>
<th>$P_{supplied}$ (W)</th>
<th>$P_{delivered}$ (W)</th>
<th>$P_{loss}$ (W)</th>
<th>$\eta$ (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>380</td>
<td>2.06</td>
<td>392.0</td>
<td>2.29</td>
<td>325.3</td>
<td>323.2</td>
<td>2.1</td>
<td>99.354</td>
</tr>
<tr>
<td>150</td>
<td>380</td>
<td>1.91</td>
<td>313.7</td>
<td>2.09</td>
<td>329.9</td>
<td>328.1</td>
<td>1.8</td>
<td>99.454</td>
</tr>
<tr>
<td>213</td>
<td>380</td>
<td>1.64</td>
<td>361.5</td>
<td>1.70</td>
<td>308.1</td>
<td>306.8</td>
<td>1.3</td>
<td>99.578</td>
</tr>
<tr>
<td>300</td>
<td>380</td>
<td>1.39</td>
<td>394.6</td>
<td>1.32</td>
<td>260.4</td>
<td>259.5</td>
<td>0.9</td>
<td>99.654</td>
</tr>
<tr>
<td>435</td>
<td>380</td>
<td>1.18</td>
<td>416.5</td>
<td>0.96</td>
<td>200.1</td>
<td>199.4</td>
<td>0.7</td>
<td>99.650</td>
</tr>
<tr>
<td>750</td>
<td>380</td>
<td>1.00</td>
<td>431.9</td>
<td>0.56</td>
<td>124.8</td>
<td>124.3</td>
<td>0.5</td>
<td>99.599</td>
</tr>
<tr>
<td>1050</td>
<td>380</td>
<td>0.96</td>
<td>436.0</td>
<td>0.42</td>
<td>91.0</td>
<td>90.5</td>
<td>0.5</td>
<td>99.451</td>
</tr>
</tbody>
</table>

Figure 5. Relationship between load resistance and (a) voltages and (b) currents.

Figure 6. Relationship between load resistance and (a) power loss and (b) efficiency.
Based on all values of parameters in Table II, it can be noticed that the performance of the system is varied. Clearly as shown in Fig. 5a that $V_{out}$ is directly proportional to $R$, and $I_{out}$ is inversely proportional to $R$. Other than that, it can be observed that the value of $V_{out}$ is lower than $V_s$ when the system is connected to light load; which is lower than 260 $\Omega$. Meanwhile, the value is higher than $V_s$ when the system is connected to heavy load; which is higher than 260 $\Omega$. Oppositely, in Fig. 5b, the value of $I_{out}$ is higher than $I_s$ when the system is connected to light load and vice versa.

Nevertheless, despite of different relationship between load resistances with $V_{out}$ and $I_{out}$, it can be seen in Table II that the value of $P_{send}$ is keep decreasing along with the value of $R$. Moreover, Fig. 6a has shown that $P_{loss}$ is also keep decreasing. In regard to the efficiency of the system, it can be noticed in Fig. 6b that the system reaches its optimum performance when it is connected to 300 $\Omega$ load. Moreover, it can be observed that the performance of the system with load greater than 260 $\Omega$ is better than using load lower than 260 $\Omega$.

C. Short-circuit Load

In this load condition, the sending end is being shorted, and Table III shows all measured parameters.

<table>
<thead>
<tr>
<th>Table III.</th>
<th>Measured Voltages, Currents, Power and Efficiency During Short-Circuit Load Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>$V_s$ (V)</td>
<td>$I_s$ (A) $V_{out}$ (V) $I_{out}$ (A) $P_{send}$ (W) $P_{delivered}$ (W)</td>
</tr>
<tr>
<td>380</td>
<td>3.88 0 4.17 7.51 0</td>
</tr>
</tbody>
</table>

As compared to Table II, it can be noticed that $I_{out}$ of short-circuit load condition is approximately 50% higher than the $I_{out}$ of matched-load condition. It is due to the absent of the loads. This kind of behaviour can lead to damages of the system. Other than that, this load condition has resulted very low $P_{send}$.

IV. Conclusion

Based on all results, it has been proven that the Ferranti effect can occur during no-load condition due to the charging and discharging process of the equivalent capacitance. On the other hand, the performance of the system during matched-load condition is varied depending on the value of load. According to simulation results, it can be noticed that the relationship between load and voltage or current is inversely proportional to each other. Nevertheless, it can be concluded that the performance of the system is better when it is connected to a resistance load higher than 260 $\Omega$. Furthermore, the results have shown that the highest efficiency can be reached when the system is connected to 300 $\Omega$ load. For short-circuit load condition, the result has shown that the output current is very high, as compared to the output current of matched-load condition. Hence, it can damage the system.

REFERENCES