



Analysis of Measured Transmission Line Constants

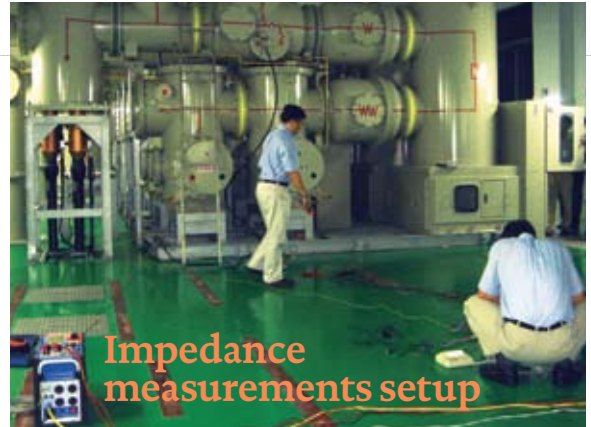
The accuracy of line impedance data has great impact on system analysis

The transmission line constants are the most important element of data needed for the operation of an electric power network. It comprises positive-sequence impedance (Z_1), zero-sequence impedance (Z_0) and admittance.

The parameters of line constants are conventionally computed by calculation programs, and the measured values of transmission line constants have been utilized as reference data when a newly built generating plant or substation undergoes a commissioning test.

Notwithstanding, it is known that the conventional method of reading voltage drop after applying voltage to the transmission would not work effectively in energized substations due to the influence of induction voltage.

However, the new type of measurement equipment introduced hereon is unique in terms of injecting electric



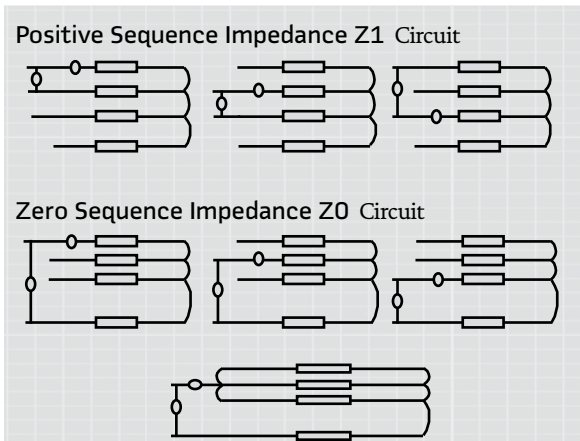
current through the circuits and measuring the voltage raised from the loaded test current. Because this new measurement device is equipped with an additional feature for selecting variable frequency for the source current, it could advantageously perform measurement of transmission constants without receiving any interference from induction voltage of the frequency in use.

The measurement of transmission constants as described below has been conducted with the help of the new sophisticated measurement equipment to verify and analyze the deviation between calculated and measured values of transmission constants.

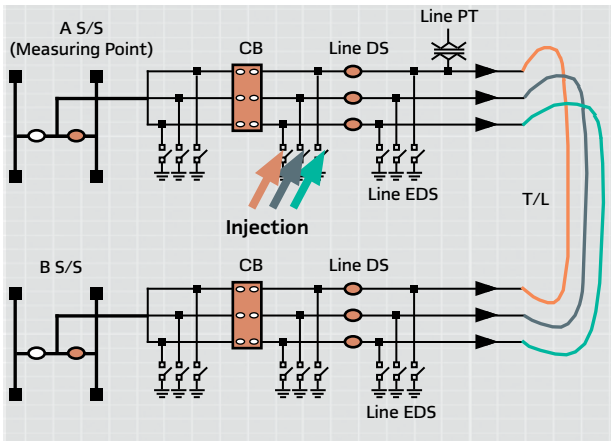
Representation of Line Constants Measurement

The transmission line constants are defined as the constants showing electrical impedance values between busbars of transmission lines in electric power networks. These data are crucial in the electrical interpretation of power networks. The transmission constants are also utilized in the construction or expansion of power facilities as basic data for areas such as the simulation review of load flow and fault

1 Line Constants Measuring Circuit



2 Measuring Schematic for Transmission Line Constants



Captured data was used to examine instantaneous phase angles between Rockport and Marysville



Biographies

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current, voltage stability and the protection relay settings. While the calculated values have been conventionally used in specifying transmission constants for the reasons of physical obstruction to the field measurement of transmission line constants, there has been growing support for adopting the new measuring equipment featured with a frequency-dependent device.

Therefore, we have responded by demonstrating measurement of transmission line constants with the new equipment as described in this article.

The new data obtained by this measurement will be utilized as basic materials for future management of and policies for transmission line constants by analyzing and comparing calculated and values measured.

Measurement of Transmission Line Constants

There are three methods of applying test voltage and current to transmission lines, i.e., phase-to-ground, line-to-line, and 3-phase combined-to-ground. The positive sequence impedance was measured by the line-to-line method, while zero sequence impedance was measured by 3-phase combined-to-ground method.

The impedance was computed by measuring the results of test voltage applied by the test equipment, and the admittance by measuring the transmission charging current at the time of initial energization.

Measurement Equipment

The measurement equipment used is as follows:

- A compact multifunctional primary test set capable of applying up to 2000V and 800 A, with a frequency range of 10-400 Hz

- Coupling unit

We need to highlight that measurement is impossible with induction voltage exceeding 500V (as is the case with 345kV overhead transmission lines.) See Figure 3.

Measurement Schematic for Line Constants

The transmission constants were measured, as shown in Figure 3, by connecting the measurement equipment to the EDS terminal behind the line DS at measuring end of Substation “A”, and grounding 3-phase combined via EDS at the other end of Substation “B”. See Figure 2.

Computation of Transmission Line Constants

The transmission line constants were computed, as shown in Figure 4, by using a frequency-dependent method at frequencies of 20, 40, 80 and 100 Hz, respectively to find corresponding R and X values, which were averaged to produce mean values.

However, the 60-Hz setting was excluded taking into account noticeable errors due to the surrounding electro-magnetic induction.

Figure 6 clearly shows that the resistance component remains almost constant with variation of frequency, while the reactance linearly increases as frequency rises.

Measurement of Transmission Line Constants

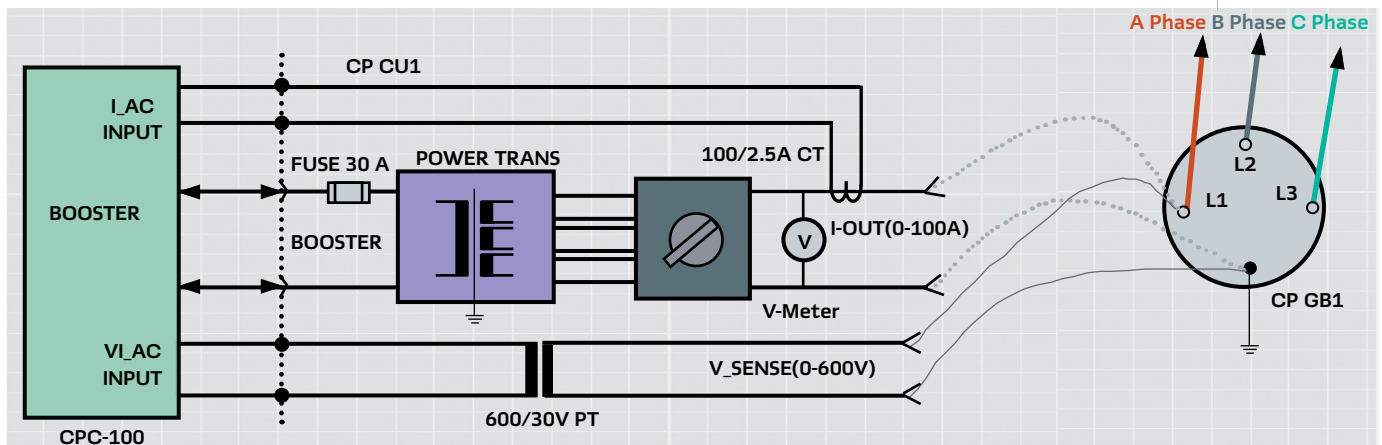
Approximately 5% of all transmission lines have been selected for measurement of transmission constants for analysis of deviation between calculated- and measured-values. These data will be used as basic material when management and policies are established for overall transmission constants in the future.

The transmission line circuits were tested during a 12 weeks period between 18 September and 15 December 2006 are as follows:

- A total of 86 circuits of 154 kV transmission lines under jurisdiction of 11 KEPSCO Power Transmission District Offices and Jeju Branch Office. (10 out of 96 circuits are not considered due to suspended power supply)

- 34 circuits of overhead transmission lines (cable types: ACSR 330, ACSR 410, and ACSR 410B)

3 Arrangement of Equipment for Measurement of T-line Constants





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- 46 circuits of underground transmission lines (Cable types: XLPE, OF, CV, and CNCV)
- 6 complex circuits

Analysis and Comparison of Calculated and Measured Values

The results for overhead and complex transmission lines are summarized in Figure 4.

For positive sequence impedance (Z1) transmission lines with error rates exceeding 5% included 4 out of 40 circuits with a maximum error rate of 18.4%.

Statistics by error range are shown in row 1 of Table 1 with an average X1/R1 value equal to 6.17.

As protection relay settings assume about 5% of error rate for transmission line constants values, the use of present calculated values seems not problematic.

For zero sequence impedance (Z0) transmission lines with error rates exceeding 5% included 14 out of 40 circuits with a maximum error rate of 18.9%.

Statistics by error range are shown in row 2 of Table 1 with an average X0/R0 value equal to 4.88.

For the positive sequence admittance (Y1) statistics by error range are shown in row 1 of Table 2.

The error seems to arise from calculation error as well as from change of the fringing field underneath transmission lines, such as change of ground altitudes (growth of bush and trees, etc.).

Positive effects from improving the accuracy of admittance measurements are that when formulating reactive power compensation plan, investment cost for phase modifying equipment may be reduced.

For the ratio of zero sequence (Z0) to positive sequence impedance (Z1) the following results were obtained:

- Average value of calculated Z0/Z1 = 2.69
- Average value of measured Z0/Z1 = 2.66



The results for underground transmission lines are summarized in Figure 5.

For positive sequence impedance (Z1) transmission lines with error rates exceeding 5% included 23 out of 46 circuits with a maximum error rate of 18.4%.

Statistics by error range are shown in row 3 of Table 1 with an average X1/R1 value equal to 6.21.

The calculated values are not suitable for application to protection relay settings as error rates are high (about 10%) and error ranges vary widely depending on the installation condition of underground transmission lines.

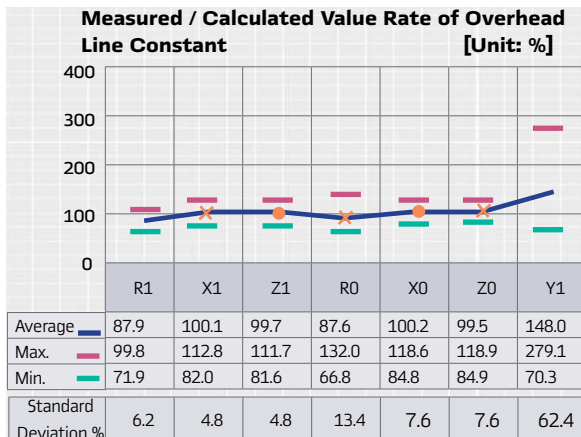
For zero sequence impedance (Z0) transmission lines with error rates exceeding 5% included all 46 circuits.

Statistics by error range are shown in row 4 of Table 1 with an average X0/R0 value equal to 1.90. 2) Zero sequence impedance (Z0)

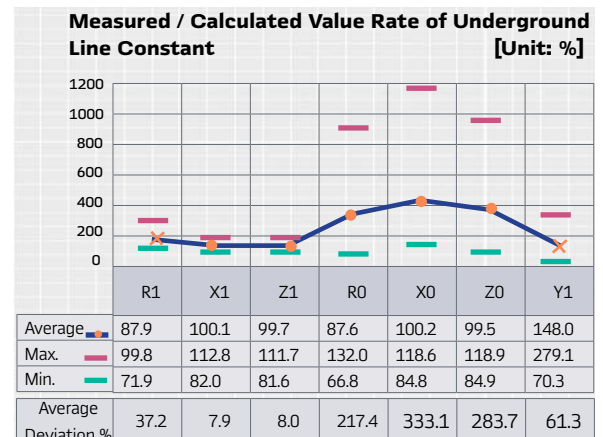
The transmission district offices having substantial length of underground transmission lines require procurement of new test equipment for physical measurement of transmission lines. Research needs to be tasked to raise accuracy of calculation program.

For the positive sequence admittance (Y1) statistics by error range are shown in row 2 of Table 2. The ratio of

4 Transmission Lines
Overhead Lines - Overhead & Complex Lines



5 Transmission Lines
Underground Transmission Lines





average to calculated values is $131.9 \pm 61.3\%$.

The measured values of admittance of underground transmission lines were found to be lower than those of overhead transmission lines.

For the ratio of zero sequence (Z_0) to positive sequence impedance (Z_1) the following results were obtained:

- Average value of calculated $Z_0/Z_1 = 0.48$
- Average value of measured $Z_0/Z_1 = 1.87$

Transmission line constants per unit length for different conductors for admittance are shown in Figure 7 and for positive and zero sequence impedance - in Figure 8.

The analysis of the measured data obtained in this research clearly shows that:

- The constants of overhead transmission lines are excellent as they stay well within acceptable error range.
- The constants of underground transmission lines are remarkably high, particularly in zero sequence impedance due to underground cable grounding system, such as whether the close bond grounding is provided at one end or at both ends of cable spans. Further research must be conducted to review the accuracy and application problem with the calculation program for constants of underground transmission lines.

Also, as the importance of transmission line constants is expected to be emphasized with the innovation of power network operations and techniques, measurement equipment will be broadly introduced to enable extensive measurement and analysis of transmission line constants, so that an expanded data base can be effectively utilized.

Building an accurate data base of transmission line constants will greatly improve the quality of interpretation of electric power networks, and will further contribute to stabilization and optimum operation of electric power systems.

7 Admittance

For different conductors

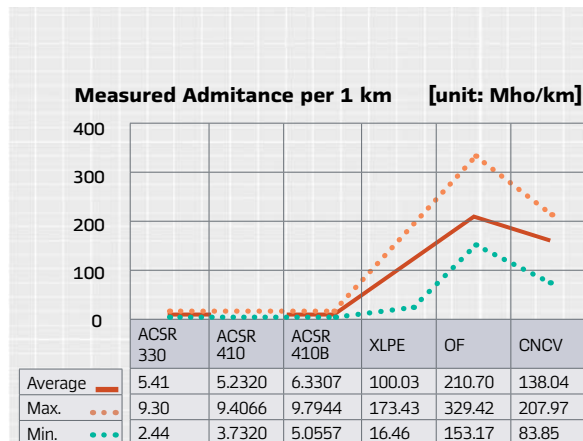


Table 1 Statistics by Error Range and by Average

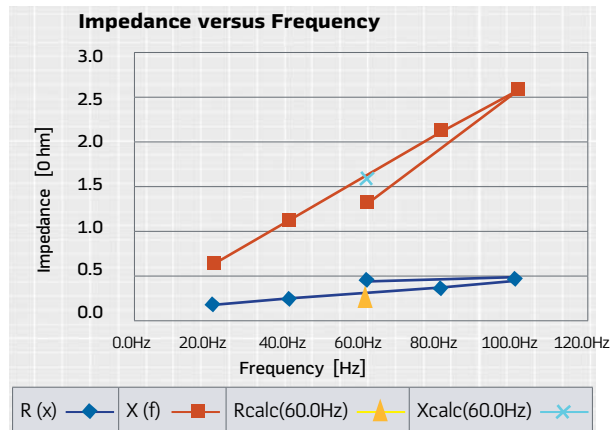
row	5%	5 10%	10 15%	15 29%	20 25%	Total
1	35	2	1	2	0	40
2	25	6	7	2	0	40
3	22	14	6	2	2	46
4	0	14	12	3	17	46

Table 2 Statistics by Error Range and by Average

row	10%	20 50%	50 100%	100 200%	200 300%	Total
1	17	9	5	9	0	46
2	5	28	9	2	2	46

6 T-line Constants

T-line Constants with Variable Sequences



8 Impedance

Positive Sequence and Zero Sequence Impedance

