Comparison between Measurement and ATP Computation on Traveling Wave Propagation Characteristics of Long Power Cable

S. Nishiwaki, T. Koshizuka, O. Hosokawa, K. Yamamoto

***Abstract*--We measured stepped wave propagation characteristics for a non-cross-bonded submarine power cable of 54 km in length. We attempted to reproduce the waveform obtained by measurement via computation using EMTP-ATP. We computed using 1) a distributed parameters without frequency-dependent characteristics and 2) the Semlyen Setup and the Noda Setup, both of which have frequency-dependent characteristics. The waveform obtained by computation using the Noda Setup most corresponded to the waveform obtained by actual measurement.**

***Keywords*: traveling wave, power cable, ATP**

I. Introduction

THE Matsushima Island and the Goto Archipelago in Nagasaki Prefecture, Japan, are connected with a long submarine power cable for a distance of 54 km. This 66-kV power cable is type CVT325mm^2, with cross-linked polyethylene insulation and lead sheath. We measured the stepped wave propagation characteristics of this submarine power cable. As the cable is not cross-bonded, measurement was available for the full interval of 54 km of the long coaxial power cable. We attempted to reproduce the waveform obtained by measurement via computation using EMTP-ATP. We computed via simulations using 1) a distributed parameters without frequency-dependent characteristics and 2) the Semlyen Setup and the Noda Setup, both of which have frequency-dependent characteristics. The computation waveform using the Noda Setup most corresponded to the waveform obtained by actual measurement.

According to Mr. Noda, the Semlyen Setup takes into account the frequency dependency regarding the modal propagation, whereas the Noda Setup additionally takes into account the frequency dependency regarding the modal transformation matrix in addition to the frequency dependency of the modal propagation [1, 2].

Comparison of overhead transmission line models in EMTP-ATP has been published by Orland P. Hevia [3].

II. Measurement Circuit

The 66-kV submarine power cable used by our measurements is composed of three single core cables and these are twisted each other into a single bundle. The peripheral circumference of the insulation for each phase is lead-sheathed. The three phases without cross-bonding are wholly protected by armor with steel wire. The cross section of the cable is shown in Fig.1 [4].

Fig. 2 shows the measurement circuit for the stepped wave propagation characteristics. A DC voltage power supply of approximately 20 V was serially connected with a 19.35 ohm resistor. A stepped wave was applied to a cable end by closing the mercury contact switch. The opposite end of the cable was

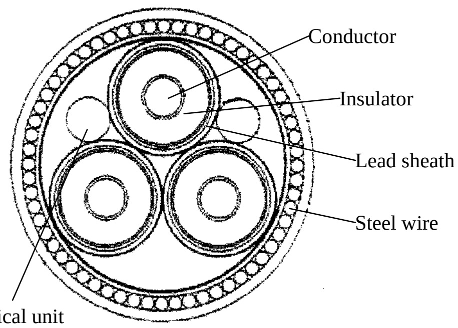

Fig. 1 Cross section of the cable [4].

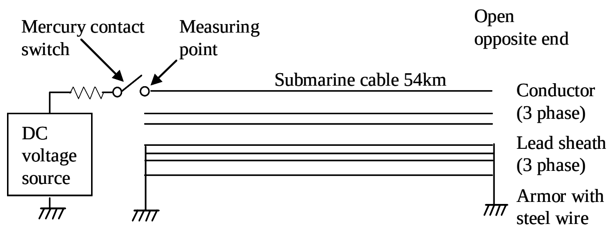

Fig. 2 Measurement circuit for step voltage propagation.

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set open. The measuring point is the cable terminal at which the step voltage was applied.

III. Waveform Obtained by Measurement

Fig. 3 shows the resulting waveform obtained by the measurement. The a, b, c, p and q in Fig. 3 have the following meanings:

a: Time point when the mercury contact switch was closed.

b: Time point when the first wave reflected at the open opposite end of the cable turns back to the measurement point.

c: Time point when the second wave reflected at the open opposite end of the cable turns back to the measurement point.

p, q: Round trip time of the traveling wave between the measurement end and the open opposite end of the cable.

We obtained a surge impedance of 29.5 ohm and a traveling propagation velocity of 169 m/μs for this cable based on data for the voltage value measured at the point a, serial resistance of 19.35 ohm and time for the interval p.

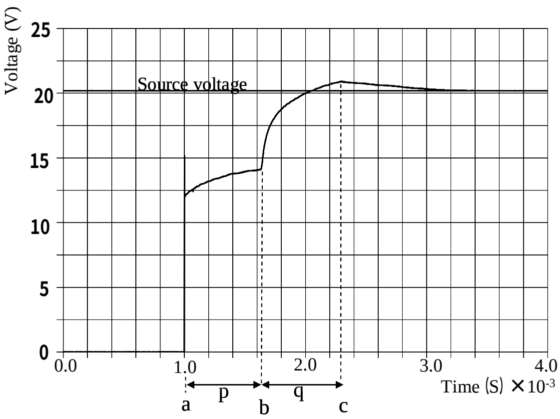


Fig. 3 Waveform obtained by measurement.

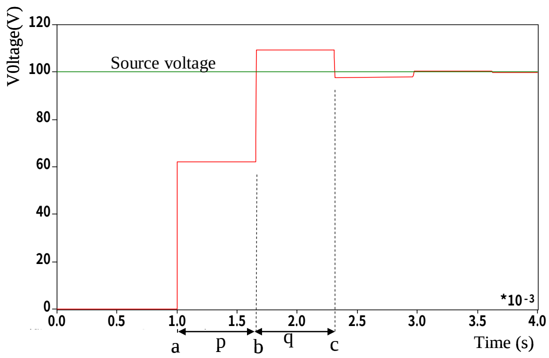
IV. Waveforms Obtained by Computation

To reproduce the waveform obtained by measurement, we conducted computation using EMTP-ATP. We computed with changing the simulation method for the submarine cable. The waveforms obtained by the computation are shown in Fig. 4 (a), (b), (c) and (d). The (a), (b), (c) and (d) in Fig. 4 are the result of the respective computations following the simulated methods below.

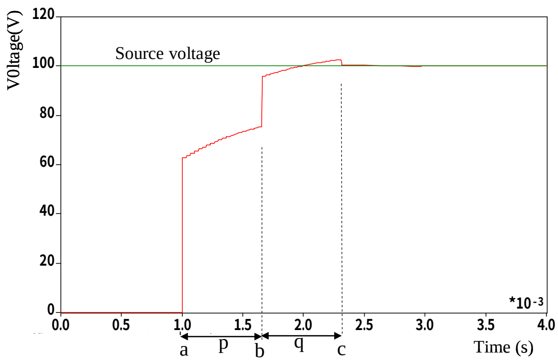
Fig.4(a):Simulation with basic surge impedance and propagation velocity without using the frequency-dependency, without line resistance

Fig.4(b):The same as Fig. 4 (a), but simulating the line resistance of 1 kHz

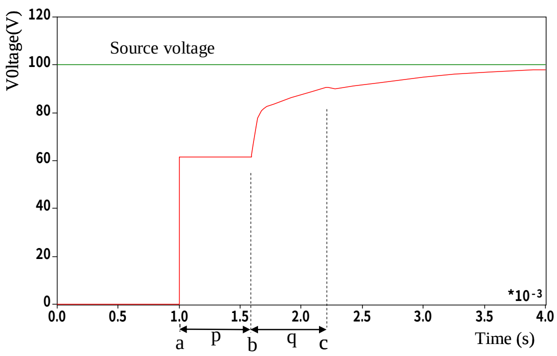
Fig.4(c):Simulation using the Semlyen Setup that takes into



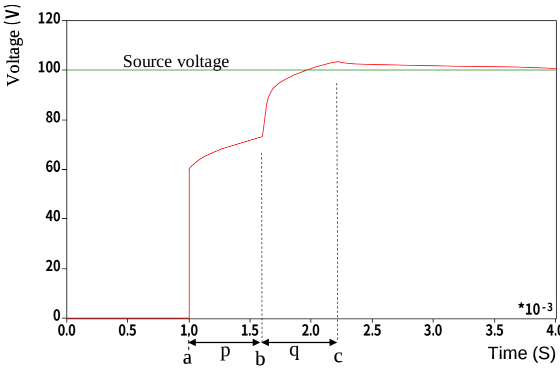
(a) Basic distributed parameters without frequency-dependency, without line resistance



(b) Basic distributed parameters without frequency-dependency, with line resistance



(c) Semlyen Setup



(d) Noda Setup

Fig. 4 Waveforms computed at cable terminal of step voltage application.

account the frequency dependency

Fig.4(d):Simulation using the Noda Setup that takes into account the frequency dependency

The a, b, c, p and q in the computation waveforms of Fig.4 respectively have the same meaning as the corresponding a, b, c, p and q in Fig. 3. Comparing the waveform obtained by the measurement in Fig. 3 with the computation waveforms in Fig. 4 (a), (b), (c) and (d) reveals that there are several features in the followings.

1. Steepness in the rise of the reflected wave at points b and c.
2. Change in voltage at intervals p and q.
3. Overshoot at point c.

These features are summarized in Table 1. In Table 1, the gray-colored boxes mean that the waveform features obtained by the measurement and those obtained by the computation correspond to each other. In particular, it reveals that the computation waveform in Fig. 4 (d) using the Noda Setup corresponds to the waveform that obtained by measurement in all the features. The overall wave shapes computed by the Noda Setup also well correspond to the measured wave form.

Computation of Noda Setup was numerically stable with using the parameters that were shown in “User Instruction of Noda Setup in ATP” [2].

Table 1 Comparison between measurement and computation waveforms.

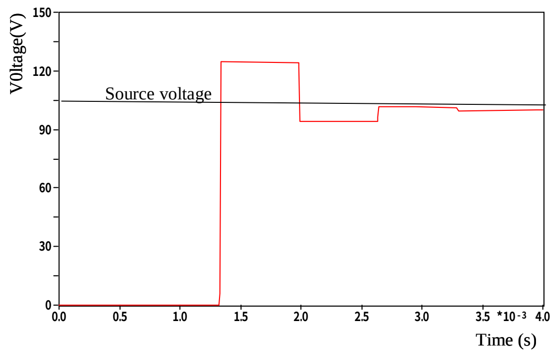
Items for comparison	Fig.2 Measured	Fig.3 (a) Basic	Fig.3 (b) Basic, Line resistance	Fig. 3 (c) Semlyen	Fig.3 (d) Noda
Rise of the reflected wave at point b	Slow	Vertical	Vertical	Slow	Slow
Rise of the reflected wave at point c	Slow	Vertical	Vertical	Slow	Slow
Voltage at interval p	Gradual increase	Constant	Gradual increase	Constant	Gradual increase
Voltage at interval q	Gradual increase	Constant	Gradual increase	Gradual increase	Gradual increase
Overshoot at point c	Yes	Yes	Yes	None	Yes

V. Discussion

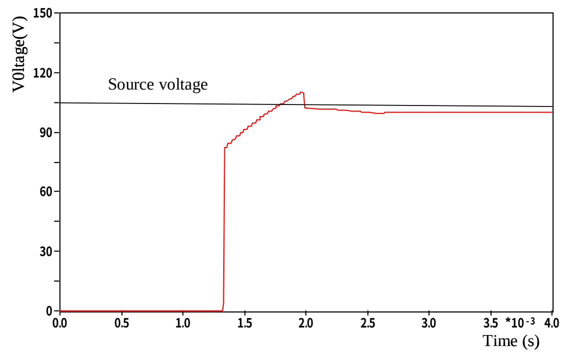
A. Comparison between Voltages at Opposite End of Cable

In the measurement of the aforementioned 54 km submarine power cable, we did not measure voltage at the cable opposite open end. As a result, we could not compare the waveform obtained by measurement and the waveform obtained by actual measurement as for the voltage at the opposite open end. We therefore compared only for the computation waveforms.

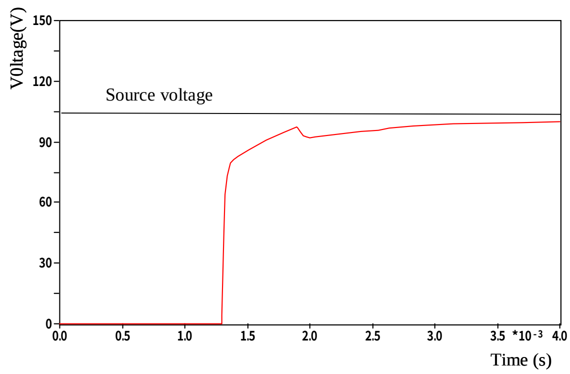
The waveforms in Fig. 4 (a), (b), (c) and (d) are voltage waveforms at the step voltage application end when the cable simulation method is changed. The voltage waveforms at the open opposite end of the cable obtained by these computations are shown in Fig. 5 (a), (b), (c) and (d). They show the difference in waveform depending on the cable simulation method.



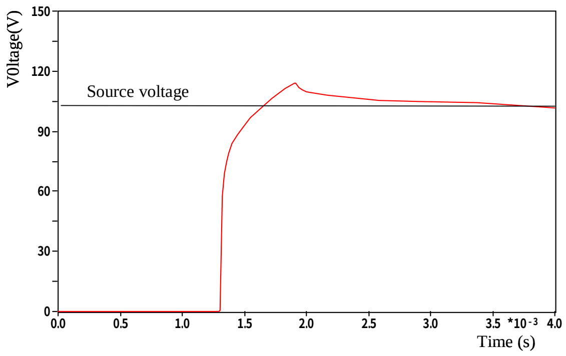
(a) Basic distributed parameters without frequency-dependency, without line resistance.



(b) Basic distributed parameters without frequency-dependency, with line resistance.



(c) Semlyen Setup



(d) Noda Setup

Fig. 5 Waveforms computed at the open opposite end of the cable

B. Computation Using Semlyen Setup Examples in the Atp Documents

In the computation for the Semlyen Setup case, there are many parameters to be determined by the user. Some concern remains in the computation of Fig.4 (c) as to whether the selection of parameters was appropriate. We therefore computed the stepped wave response by using Semlyen Setup examples of the power cable, which are described in the ATP-related documents. We computed for the following two examples.

1. An example presented in “Chapter XXII. SEMLYEN SETUP” of the ATP Rule Book; and
2. Case No. 2-2-6 in “EMTP Calculation Examples” published by Japanese EMTP Committee.

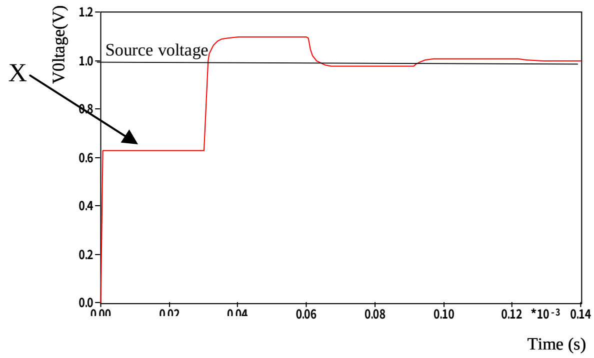
Example 1 is on a three-phase, single-core cable of 3 km in length, and Example 2 is on a three-phase, pipe-type cable of 1 km in length. In both cases, a step voltage of 1 V was applied through a 20 ohm resistor. Fig. 6 (a) and (b) show the waveforms that are derived from the computation. These waveforms are at the voltage application end. In Fig. 6 (a) and (b), X and Y represent voltage variation until the reflected wave turns back from the opposite end of the cable. It is found that the voltage is constant for both X and Y. On the other hand, in the computation waveform using the Semlyen Setup in Fig.4 (c), the interval p indicates voltage variation until the reflected wave turns back from the opposite end of the cable. Also for interval p, the voltage is constant, similarly to X and Y.

Consequently, for the waveform obtained by computation shown in Fig. 4 (c), we may conclude that the constant voltage for interval p is from a general characteristic of the Semlyen Setup.

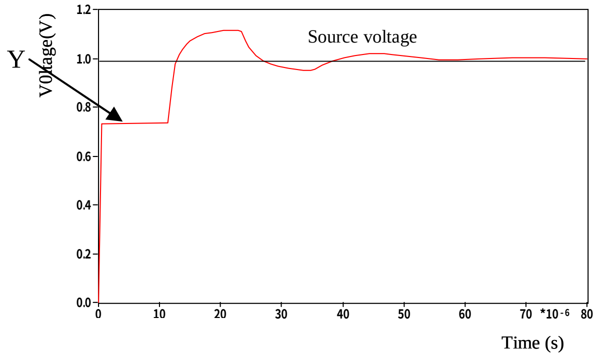
VI. Conclusions

We had the experimental opportunity to measure stepped wave propagation characteristics for a submarine power cable of 54 km in length without cross-bonded. We attempted to reproduce the waveform obtained by measurement via computation using EMTP-ATP. The waveform obtained by computation using the Noda Setup most corresponded to the waveform obtained by measurement. The computation waveform corresponded to the measurement waveform in characteristics such as:

1. the gradual increase in voltage until the reflected wave turns back, and
2. the slow steepness in the rise of the reflected wave component turning back from the opposite end.



(a) Computation results of the example 1.



(b) Computation results for example2.

Fig. 6 Computation using semlyen setup examples in the Atp documents.

VII. Acknowledgements

We appreciate the immeasurable cooperation of Kyushu Electric Power Co., Inc., for the traveling wave propagation measurements of the 54-km submarine power cable.

VIII. References

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