PROGNOSTIC FAILURE DETECTION ON OVERHEAD POWER DISTRIBUTION GRID UTILIZING TDR MEASUREMENT METHOD

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ABSTRACT

We attempt to apply new method for locating fault point by injecting high-frequency short pulse into overhead distribution line. This method, which is called as TDR (Time Domain Reflectometry) measurement, enables us to detect the fault point easily by measuring propagation time of the pulse reflected due to impedance change at the fault point. In our prior research, we confirmed that TDR measurement method can be applied in overhead power distribution system, and we clarified the propagation characteristics [1]. Because the pulse wave is reflected not only from the fault point but also from the branch point of the line, in order to sense reflected wave more precisely, we need to remove reflected waves other than fault point.
In this paper, we propose new method which utilizes waveforms measured before and after the distribution failure. Through experiments, we confirmed improvement of new method's sensing ability and verified the applicability of new method for prognostic failure detection.

INTRODUCTION

The Kansai Electric Power Company (KANSAI) has introduced Distribution Automation System (DAS) since 1989. DAS has the function to isolate the fault section and minimize outage area automatically when distribution failure occurs; nevertheless, field technicians have to be dispatched to the site and detect the fault point to restore the fault.
While this method has contributed to improving restoration efficiency, it requires a lot of labour force because the field technicians need to climb up utility poles and apply current detector at each of the branch lines.
For more restoration efficiency, we attempt to apply new method by observing reflected waveforms of high-frequency short pulse in overhead distribution lines. This method, which is called as TDR (Time Domain Refletometry) measurement, enables us to find the fault point easily by measuring propagation time of the pulse reflected due to impedance change at the fault point [1-3]. Because the pulse wave is reflected not only from the fault point but also from the branch point of the distribution line [4], in order to locate the fault point, we need to remove reflected waves other than fault point. In this paper, we propose to identify the fault point by comparing TDR measurement waveforms before and after the failure and verified by experimental results. We conducted experiments using distribution grid for simulation with 1 km length. In this experiment we clarified the effectiveness of the method of locating the fault points by subtracting the measured waveform before and after the failure.
There is a probability that constant monitoring of overhead power distribution line condition enables us to detect prognostic failure.

2. TDR MEASUREMENT

(1)Pulse injection and extraction method by current probe

For energized lines, measurement environments are different from power failure states, such as high voltage applied between the lines and load current flowing through the tracks, are measurement problems, so the measurement method was examined from the safety and technical aspects. In the TDR measurement in the energized state, a current probe that is sandwiched from the wire covering and that enables measurement in a non-contact state with the wire conductor was used. Fig.1 shows the TDR measurement method. The pulse waves of positive and negative opposite phases generated by a Pulse Generator (PG) are injected differentially into two wires via a current probe as shown in Fig.2. Measurement of reflected waveform was extracted with another current probe and measured with an oscilloscope.

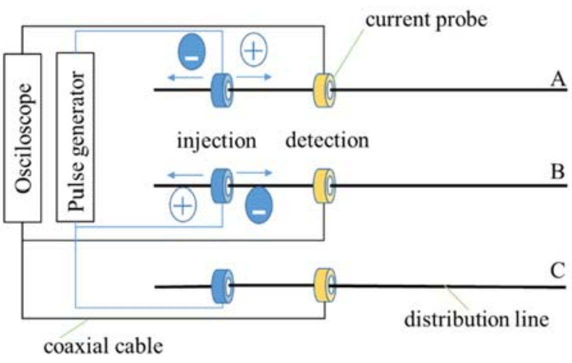


Fig.1 Measuring circuit

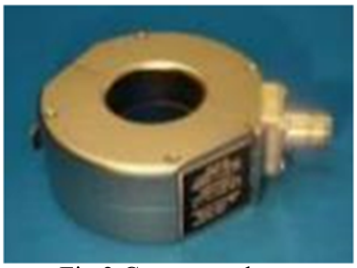


Fig.2 Current probe

3. PRINCIPLE OF PROGNOSTIC FAILURE DETECTION

The method proposed in this report is to extract the change of the parasitic capacitance on the line by subtracting the difference of TDR measurement waveform. Therefore, prior to accidents, we position and position the factors and try to by maintaining them. Explain the principle using a tree contact as a model.

(1) Equivalent circuit of tree contact

The equivalent circuit before and after tree contact is shown in Fig.3. When a pulse wave of a sufficiently short wavelength is injected to the distribution line, no reflected wave is generated unless there is a change point of the impedance. When trees straddle between two lines, it is equivalent to parasitic capacitance being inserted in parallel. Due to this parasitic capacitance, a reflected wave is generated.

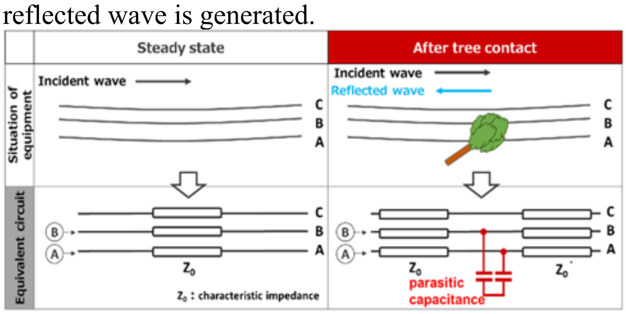


Fig.3 Equivalent circuit

(2) Derivation of reflected wave

The incident pulse wave is a trapezoidal wave as shown in Fig. 4, which can be expressed by combining positive and negative ramp function. (Eq.1)
Represent the reflection coefficient of current in the Laplace domain. (Eq.2)

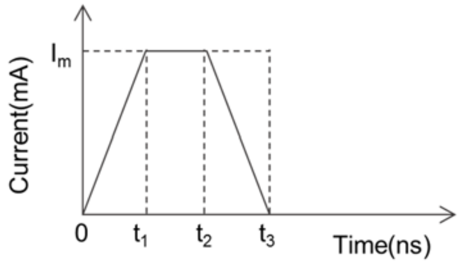


Fig.4 Incident pulse waveform

$$I_{i(s)} = \frac{I_m}{t_1 S^2} \times (1 - e^{-st_1} - e^{-st_2} + e^{-st_3}) \quad (1)$$

$$\Gamma_{i(s)} = \frac{I_{r(s)}}{I_{i(s)}} = \frac{sC + \frac{1}{Z'_0} - \frac{1}{Z_0}}{sC + \frac{1}{Z'_0} + \frac{1}{Z_0}} \quad (2)$$

When the expression of the reflected wave obtained by multiplying Equation 1 and Equation 2 is expressed in the time domain, the appearance of the reflected wave after inserting the parasitic capacitance is as shown in Fig.5. The parasitic capacitance C is 40 pF, the characteristic impedance Z_0=Z_0'=560Ω, the pulse height value I_m of the pulse current I_m=10mA, t_0=0ns、t_1=10ns、t_2=20ns、t_3=30ns ns, (Falling) time Δt_r=t_1-t_0=10ns

By inserting the parasitic capacitance into the line, a reflected wave is generated, so it can be understood that it can be extracted as an impedance change point.

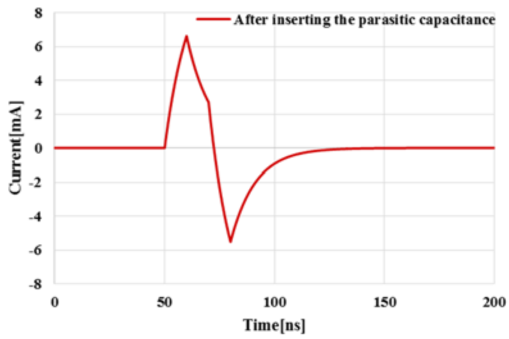


Fig.5 Waveform simulation after parasitic capacitance insertion

4.VERIFICATION OF APPLICABILTY FOR PROGNOSTIC FAILURE DETECTION

We experimented TDR measurement in real-scale distribution system to verify the applicability of the proposed method.

(1) Real-scale distribution system
As shown in Fig.6, the circuit is about 1km length. The fault point was set at the pole No.29(manual switchgear), and the measurment point was set to the automatic switchgear of the utility pole No.18. In the system before distribution failure, the effectibe value of the load current was set to 20A in the 6.6kV conduction.
The measurement was carried out by a differential measurement in which pulse waves of opposite phases are injected by a current probe attached to phase A and phase B.

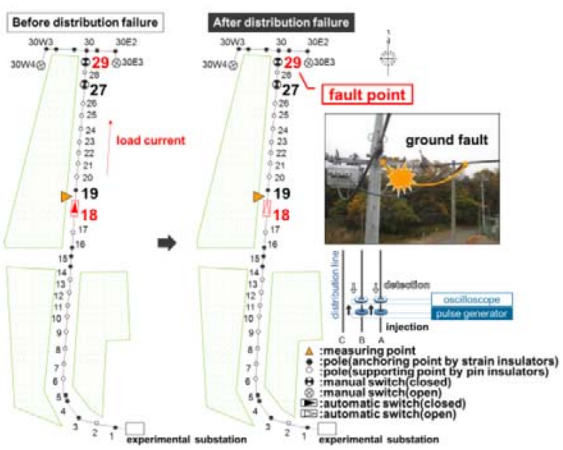
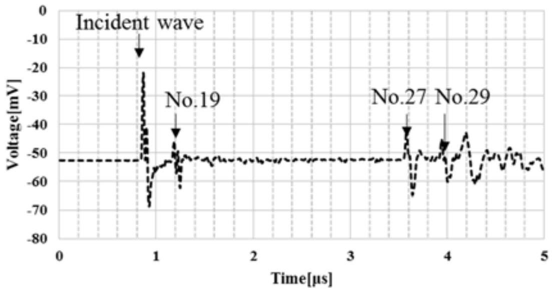


Fig.6 Real-scale distribution system

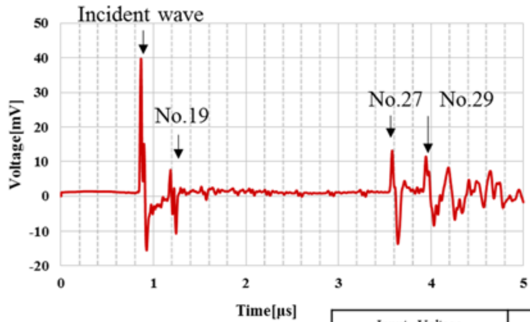
(2) TDR measurement result with “live distribution line”
As PG parameter, injected pulse width is set to 20ns, and input voltage is 10V. The TDR measurement result before failure is shown in Fig.7. After the incident wave appearing at the beginning, a lot of reflected waves are observed. Injected pulse wave appear at Time = 0.8μs. Reflected wave from anchoring point by strain insulators of utility pole No.19 at Time = 1.2μs, from manual switchgear part at the utility pole No. 27 at Time = 3.6μs, and from the automatic switchgear part at the utility pole No.29 at Time = 4.0μs. From this result, it was found that the pulse wave can be injected and the reflected wave can be observed even when the line is charged.



Input Voltage	10[V]
Pulse Width	20[ns]
Pulse rize and fall times	8.4[ns]

Fig.7 TDR measurement result with “live distribution line”

(3) TDR measurement result with “no live distribution line”
The TDR measurement result with “no live distribution line” is shown in Fig.8. Reflected waves from the fault point appear at about 4.0μs, but since the reflected waves before the fault point are large, the fault point cannot be specified as it is. TDR measurement waveform comparison before and after failure.



Input Voltage	10[V]
Pulse Width	20[ns]
Pulse rize and fall times	8.4[ns]

Fig.8 TDR measurement result with “no live distribution line”

(4) TDR measurement waveform comparison before and after failure
Fig.9 shows the superimposed measured waveforms before and after the fault obtained in (2) and (3), and the difference waveform is shown in Fig.10.
As a result of the verification, we confirmed that the difference of waveform with between “live distribution line” and “no live distribution line” before 4.0μs is small. And we also confirmed fault point were extracted at time about 4.0μs by subtracting before and after the failure.
Therefore, we are able to validate the effectiveness of the proposed method. The difference waveform before the fault point is thought to be due to the difference in the incident wave before and after the failure due to the influence of the load current.

Moreover, we calculate the fault point distance from the propagation time of reflected difference waveform and pulse velocity (2.93×10^8 m/s), and the result nearly correspond to actual setting. The calculated distance was 453.7m. The actual distance at setting point is 447m; the difference is 6.7m.

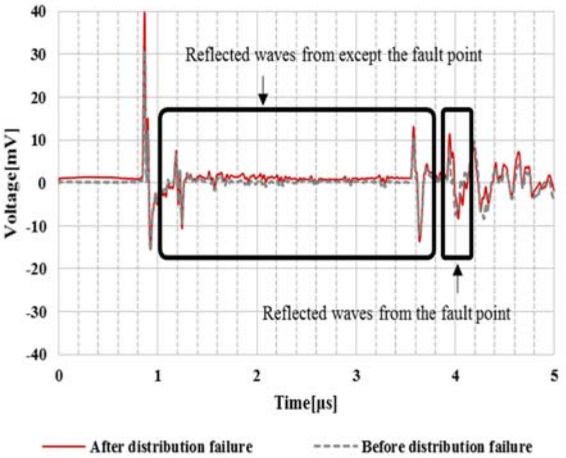


Fig.9 TDR measurement waveform comparison before and after failure

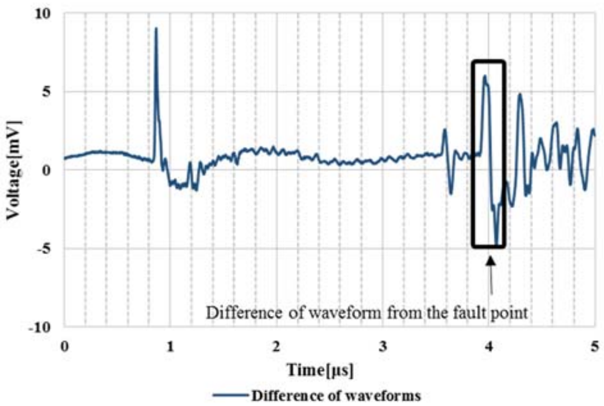


Fig.10 Difference of waveform

5. THE EFFECT OF CONSTANT MONITORING

In the above description, the effectiveness of the fault point identification was clarified by subtracting the TDR measured waveform by the pulse wave before and after the failure. It is necessary to inject a pulse wave into the line before the failure and measure it. There is a possibility that further effects can be expected by constantly performing TDR measurement by a pulse wave on a line in a normal state before the failure.

Conventionally, the failure point locating technique in the distribution line is mostly to locate the position after the occurrence of the failure. Therefore, in addition to not only locating the fault point after the failure by TDR measurement, we were also oriented to be able to locate the position before fault occurred. We constantly tried monitoring the line while measuring the TDR, suggesting to locate the position by grasping a small change in the reflection waveform of the event which does not lead to a distribution line fault at once but can be a fault factor. We report the verified results.

6. VERIFICATION OF EFFECTIVENESS BY EXPERIMENT

(1)The measurement method and real-scale distribution system.

The measurement method is the same as the measurement method in section 2. We experimented TDR measurement in real-scale distribution system as shown in Fig.11 to clarify the effectiveness of the proposed method. The event simulation before the fault was a tree contact. The measurment point was set at the utility pole No.24, and the tree contact point was set at between the utility pole No.21 to No.22. The distance from the measuring point to the position where tree contact was made was 87 m. The effective value of the load current was set to 20A in the 6.6kV conduction.

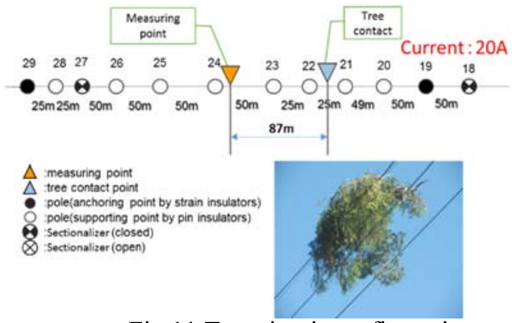


Fig.11 Test circuit configuration

(2) TDR measurement waveform comparison before and after tree contact.

The TDR measurement result is shown in Fig.12. It shows the superimposed measured waveforms before and after tree contact. Injected pulse wave appear at Time=0μs. Reflected wave from supporting point by pin insulators of utility pole No.23 and No.25 at time about 380ns, No.22 at Time=500ns, and No.21 and No.26 at time about 700ns. Reflected wave from tree contact point at Time=600ns. By this alone, it is impossible to distinguish between reflected waves from tree contact point and other reflected waves. Fig.13 shows the result of subtracting measured waveforms before and after tree contact. By subtracting, it can be seen that only the change due to tree contact can be extracted at time about 500ns.

Moreover, we calculate the tree contact point distance from the propagation time of reflected difference waveform and pulse velocity (2.93×10^8 m/s), and the result nearly correspond to actual setting. The distance that we calculated the tree contact point was 86.4m. The actual distance at setting point is about 87m, and the difference is within 1m.

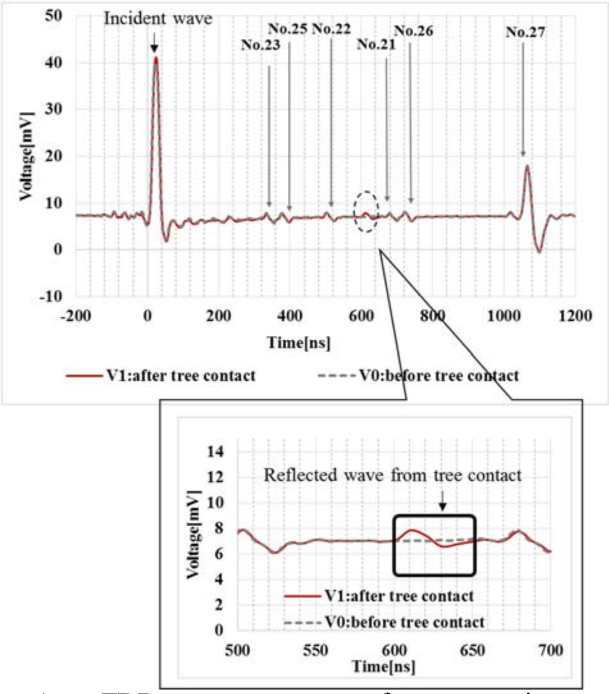


Fig.12 TDR measurement waveform comparison before and after tree contact

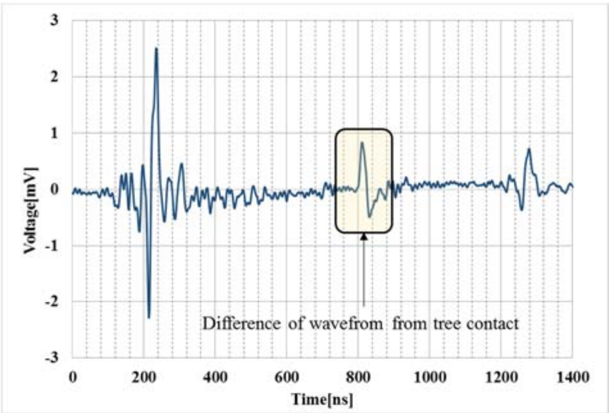


Fig.13 Difference of waveform

7.CONCLUSION

In this paper, we verified the effectiveness of TDR measurement by pulse waves for the purpose of locating failure point in overhead power distribution system. In the overhead power distribution system, it is necessary to remove reflected waves from points other than the failure point, and proposed a method of subtracting the TDR measurement waveform before and after the failure as a method of identifying the failure point. In addition, by constantly monitoring the line while measuring the TDR, we could identify the position by grasping minute changes in the reflected waveform of the event that did not result in the failure but caused a failure of the distribution line. In this verification, pulse injection and detection were carried out using a current probe. Although the current probe can be attached in a non-contact manner, there is a problem that it is affected by magnetic saturation due to the load current. In the future, we will study methods that can inject pulse waves without being affected by magnetic saturation.

REFERENCES

For a Conference citation:

[1] Shweta Gajbhiye, 2013, "Cable Fault Monitoring and Indication: A Review", IJCSN, Vol.2, Issue 4, 20-24

[2] Martin Hartebrodt, 2014, "Fault Detection in Fieldbuses with Time Domain Reflectometry", IEEE AFRICON2014, 391-396

[3] Francesco de Paulis, 2016, "Detectability of Degraded Joint Discontinuities in HV Power Lines Through TDR-Like", IEEE Transactions on Instrumentation and Measurement, Vol.65, No.12, 2725-2733

[4] Shinpei Oe, 2017, "TDRmeasurement with utility-pole-interval resoulution of real-scale distribution system",CIRED2017