13th European Conference on Applied Superconductivity 4LP2-07

Monitoring Method for an Unbalanced Three-Phase HTS Cable System via Time-Frequency Domain Reflectometry

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Abstract

In this paper, we propose a new time-frequency based analysis method that monitors the state of the high temperature superconducting (HTS) cable system in a real-time manner and detects the current imbalance of HTS cable system. The new time-frequency based method utilizes the cross Wigner-Ville distribution (XWVD) to analyze the time-frequency localized phase difference (TFLPD) of the reflected signal, which varies depending on the insulation characteristics of the HTS cable system. Also, a real-world AC 22.9 kV 50 MVA HTS cable system and current source are used to validate the performance of the new monitoring method in order to detect current imbalance phenomenon.

Introduction

Needs for HTS Cable Diagnosis

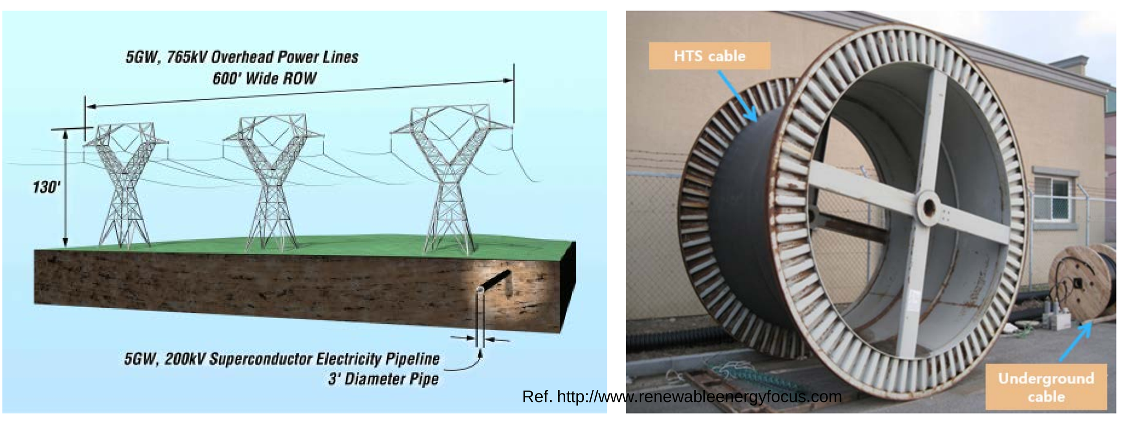

Fig. 1. The comparison of HTS cables to conventional cables

- Limitations for long-distance transmission
  - The **brittleness** of the HTS cable material
  - **Critical points** of superconductivity
- A great increase in resistance when a **quench** occurs
  - **Power shortages** due to failures of power system

Background

Reflectometry

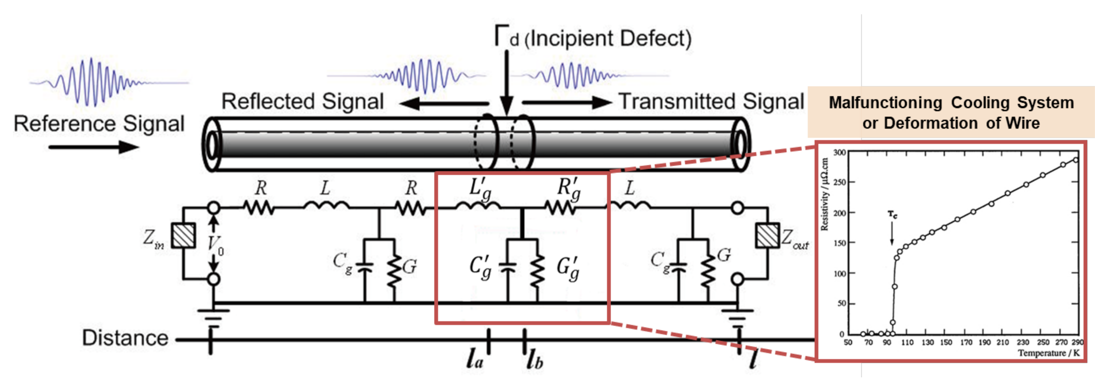

Fig. 2. Reflectometry based on Transmission theory

- The localized **impedance change**
  - Defects from segments of HTS cable
  - **Cryogenic failures**
- Detection technique based on **the reflection of waves** at the impedance discontinuity

Time-Frequency Domain Reflectometry (TFDR)

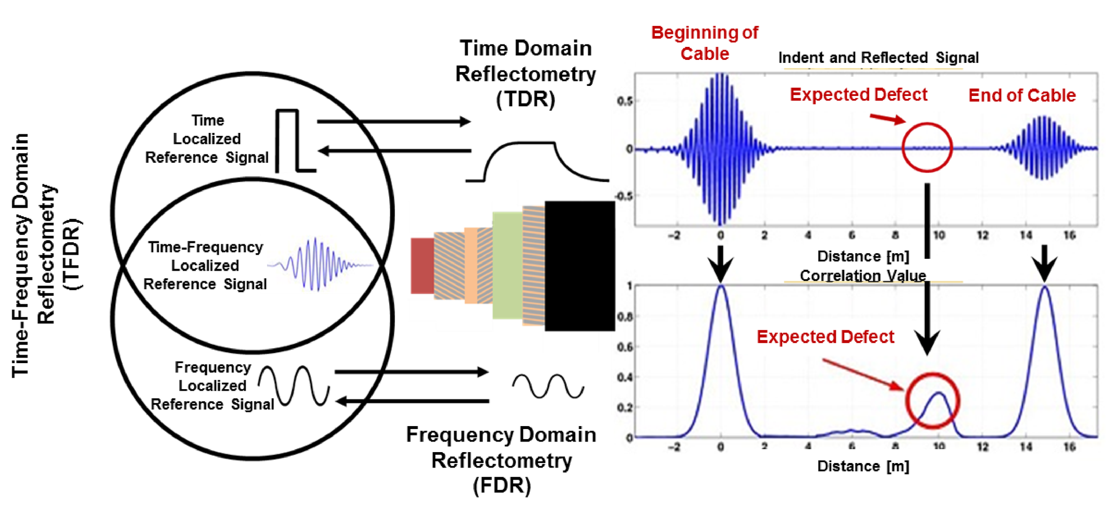

Fig. 3. Time-frequency reflectometry (TFDR)

- The new methodology which has advantages of **both TDR and FDR**
  - Analysis on both time domain and frequency domain
  - **Time-frequency cross-correlation value**
- The methodology considering physical characteristics of HTS cable
  - Optimization of the reference signal
  - Gaussian envelope chirp signal

TFDR System

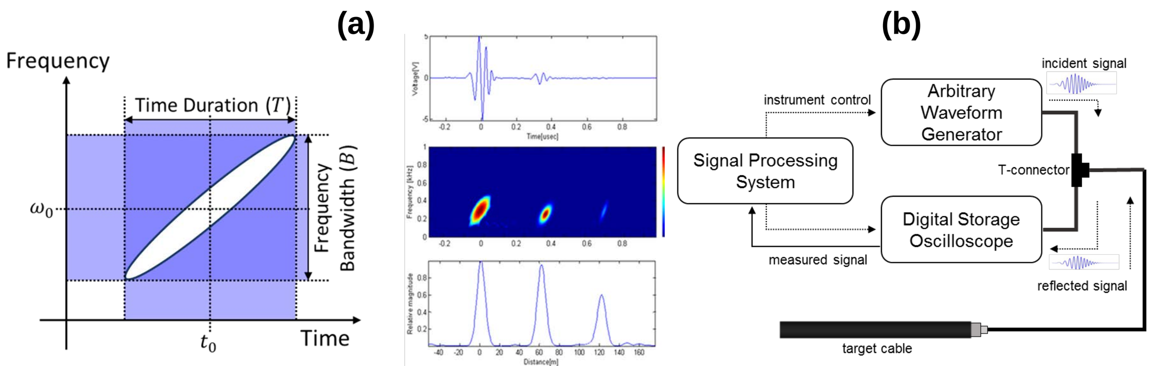

Fig. 4. (a) Wigner-Ville distribution and (b) the diagram of TFDR system

- Time-frequency analysis: Wigner Ville distribution
  - Up-chirp signal / Down-chirp signal
  - **Attenuation and dispersion of propagated signal**
- TFDR system: AWG, DPO and signal processing system

Previous Research

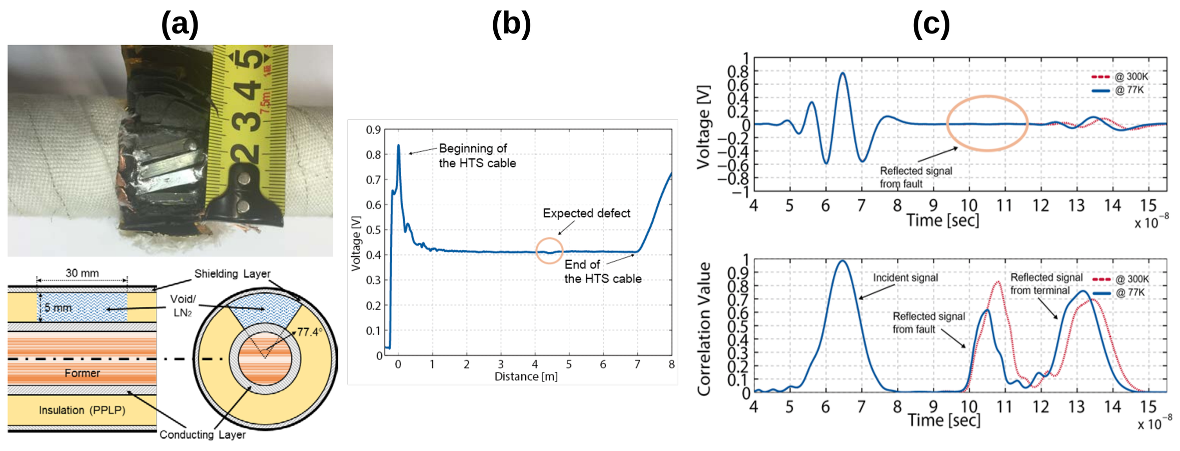

Fig. 5. (a) HTS cable's insulation fault, (b) TDR result, and (c) TFDR result [7]

- In order to provide a location to test the capability to detect and locate failure, on the HTS cable, the PPLP is cut.
- As shown in Fig. 5(b), the terminal of the HTS cable is easily detected at approximately 7 m, whereas the magnitude of the reflected signal at the fault location is so small that the point of expected fault is difficult to detect.
- Note that **the value of the time-frequency cross-correlation has the local peak point at the reflected point.**
- The performance of the diagnostic method needs to be tested and evaluated **using a real-world HTS cable system.**

Experimental Setup

Unbalanced Three-Phase Current

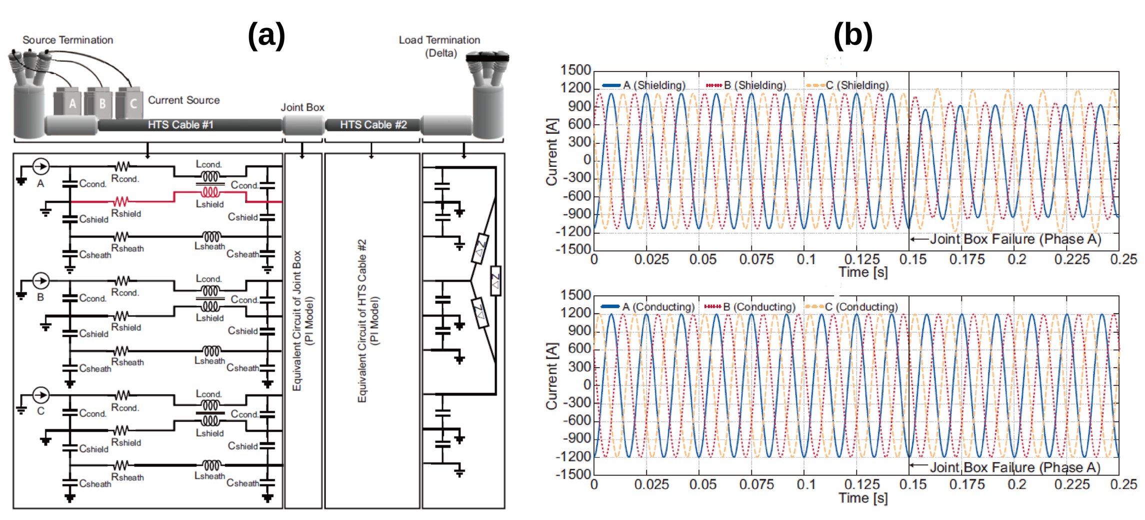

Fig. 6. (a) The diagram of the HTS cable system and the PI model for EMTP, (b) EMTP simulation current data when joint box failure occurs

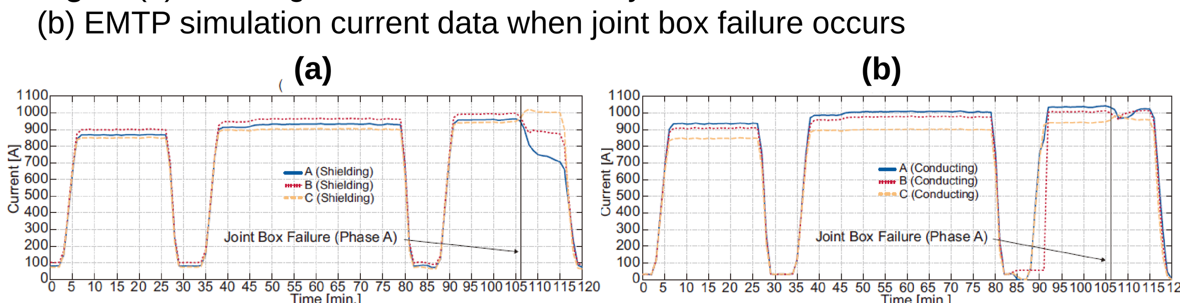

Fig. 7. Real current data when joint box failure occurs: (a) shielding layer and (b) conducting layer

- A real-world 22.9 kV HTS cable system consists of two cables of different lengths (270 m and 150 m), a joint box to connect two cables, and two terminations.
- The fault is formed **in the shielding layer at the front of the phase-A joint box**.
  - The **current imbalance** phenomenon

Monitoring Methods: conventional TFDR&TFLPD

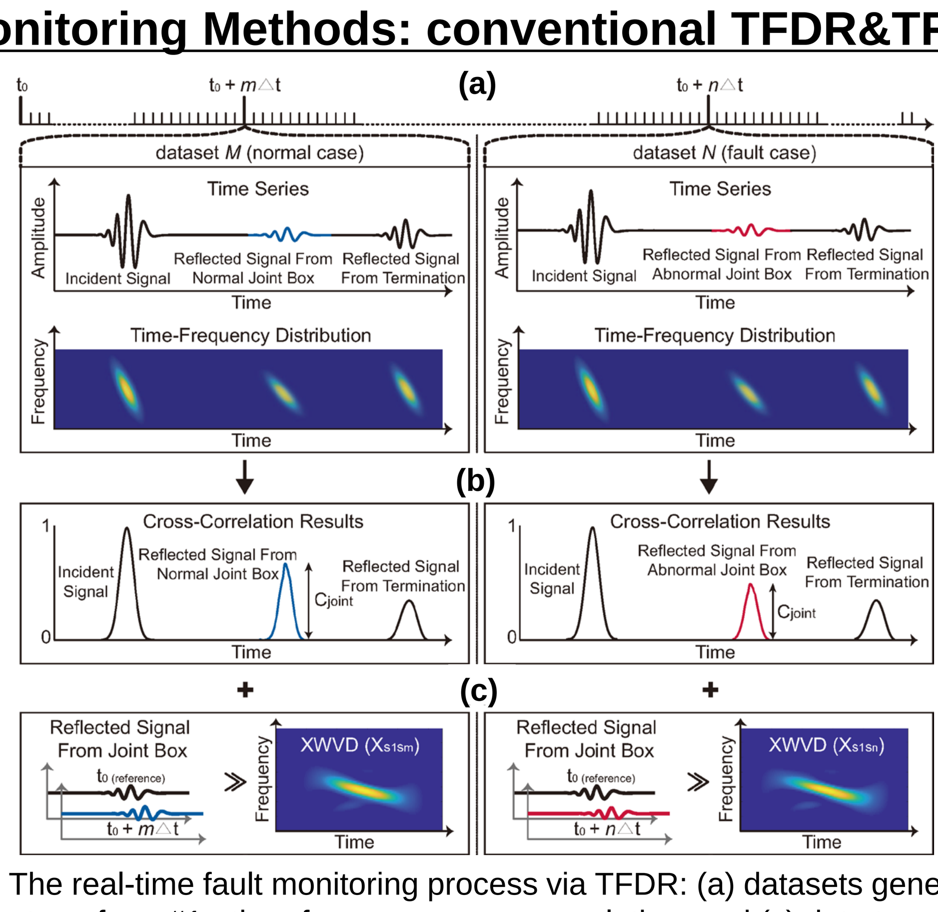

Fig. 8. The real-time fault monitoring process via TFDR: (a) datasets generation, (b) data transform #1 - time-frequency cross-correlation, and (c) data transform #2 - XWVD

Results & Discussion

TFDR Monitoring Results and Discussion

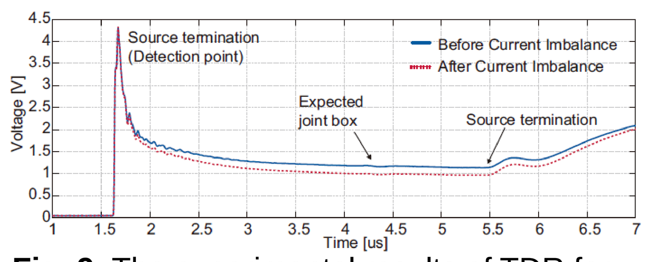

Fig. 9. The experimental results of TDR for the phase-A cable.

- The voltage of TDR rises overall.
- It is still difficult to identify the cause and the location of the failure / current imbalance.

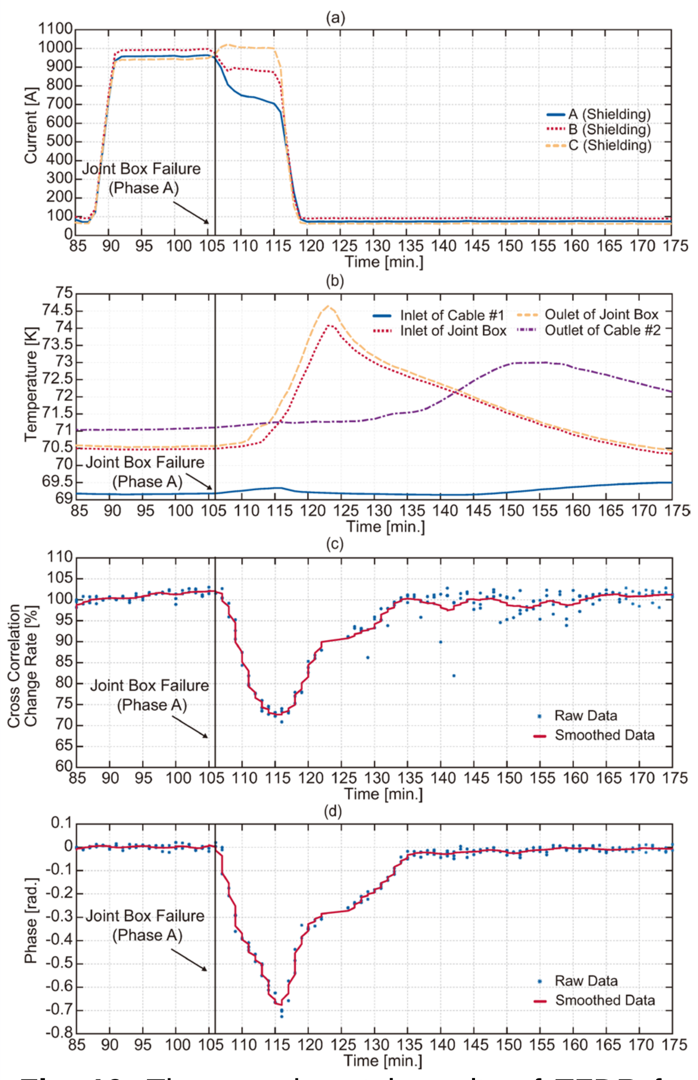

Fig. 10. The experimental results of TFDR for the phase-A cable: shielding layer current profile in (a), temperature profile in (b), the monitoring result of time-frequency cross-correlation in (c), and the monitoring result of time-frequency localized phase difference in (d).

- The heat of the joint box is measured first by the temperature sensor on the rear side of the joint box according to the flow of the liquid nitrogen.
- After that, the heat due to the change of the current path of the cable #1 is observed by the temperature sensor on the front part of the joint box.
- Temperature sensor: **more than 5 minute delay**
- Both **the cross-correlation change rate** and **the TFLPD react immediately.**

- The cross-correlation change and the TFLPD are varied **only in the result of the phase-A cable**, not in the result of other two phases.
- TFLPD improves the conventional TFDR and is less susceptible to noise.
  - The monitoring technology of the HTS cable system

Conclusion

We propose a **monitoring method to select the problematic power cable and localize the fault within the cable in a real-time manner.** In order to validate the efficacy of the method, 22.9 kV three-phase HTS cable system with the emulation of malfunction on the joint box is utilized. As a result, the temperature sensor and the conventional diagnostic methodologies detect an accident after a delay of about 1 to 5 minute, **while TFLPD can immediately detect the problematic cable and find the cause of the fault.**

It is expected that the TFLPD analysis can be used as a monitoring method to check the state of the HTS cable system and prevent the quench phenomenon in a real power system with the conventional TFDR methodology. Furthermore, the diagnostic method as a smart grid technology will enable the HTS cable system to carry out self-diagnosis and advanced protection of connected power systems.

Acknowledgment

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Ministry of Science, ICT & Future Planning, #NRF-2017R1A2A1A05001022. Also, this research was supported by Korea Electric Power Corporation Research Institute.

Reference

[1] S.-H. Sohn *et al.*, *IEEE Trans. App. Supercond.*, vol. 22, no. 3, Jun. 2012, Art. ID. 5800804.
[2] Y.-J. Shin *et al.*, *IEEE Trans. Instrum. Meas.*, vol. 54, no. 6, pp. 2493–2500, Dec. 2005.
[3] J. Wang *et al.*, *IET Signal Process.*, vol. 4, no. 4, pp. 395–405, Aug. 2010.
[4] J. Li *et al.*, *IEEE Trans. App. Supercond.*, vol. 24, no. 5, Oct. 2014, Art. ID. 4803205.
[5] J. G. Kim *et al.*, *IEEE Trans. App. Supercond.*, vol. 19, no. 3, pp. 1785–1788, Jun. 2009.
[6] G. S. Lee *et al.*, *IEEE Trans. App. Supercond.*, vol. 27, no. 4, Jun. 2017, Art. ID. 9000605.
[7] G. S. Lee *et al.*, *IEEE Trans. App. Supercond.*, vol. 26, no. 4, Jun. 2016, Art. ID. 5401005.
[8] Y.-J. Shin *et al.*, Proc. SPIE-Advanced Signal Processing Algorithms, Architectures, Implementations X, San Diego, CA, 2000, pp. 9–16.