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**
  - 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**
  - 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)**
  - 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**
  - 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

- **Experimental Setup**
  - Unbalanced Three-Phase Current
    - 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

- **Previous Research**
  - 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.

- **Results & Discussion**
  - The voltage of TFDL varied overall.
  - It is still difficult to identify the cause and the location of the failure / current imbalance.
  - 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.
  - 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 is expected to be used as a diagnostic tool to detect and localize the fault in a real-time manner.

- **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.

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**Reference**