ABSTRAK

Sistem DC multi-terminal berbasis *Voltage Source Converter* (VSC) memiliki tantangan proteksi yang signifikan akibat karakteristik gangguan yang cepat, ketiadaan *zero-crossing*, serta keterkaitan respon antar terminal. Metode proteksi berbasis indikator tunggal, seperti analisis waktu-frekuensi, turunan sinyal, atau impedansi, umumnya mampu mendeteksi gangguan, namun masih memiliki keterbatasan dalam penentuan lokasi gangguan, ketahanan terhadap noise, serta deteksi gangguan impedansi tinggi (*high impedance fault*).

Penelitian ini mengusulkan metode deteksi hybrid yang mengombinasikan indikator *Short-Time Fourier Transform* (STFT), derivative (turunan kedua arus), dan impedansi untuk meningkatkan keandalan deteksi dan analisis gangguan pada sistem VSC DC multi-terminal. STFT digunakan untuk menentukan waktu terjadinya gangguan, sedangkan indikator derivative dan impedansi dimanfaatkan sebagai bukti tambahan dalam penentuan lokasi terminal gangguan dan klasifikasi gangguan.

Metode yang diusulkan dievaluasi pada berbagai skenario gangguan, meliputi gangguan *pole-to-pole* (PP), *pole-to-ground* (PG), variasi tingkat noise, serta variasi resistansi gangguan untuk merepresentasikan kondisi HIF. Hasil pengujian menunjukkan bahwa perbedaan waktu deteksi antar metode relatif kecil, namun metode deteksi hybrid memberikan konsistensi penentuan lokasi terminal yang lebih baik dibandingkan metode individual. Selain itu, metode hybrid mampu melakukan klasifikasi gangguan HIF dan membedakan gangguan internal dan eksternal, yang tidak dapat dicapai oleh metode deteksi berbasis indikator tunggal.

Kata kunci—Deteksi DC, STFT, derivative, impedansi, high impedance fault, sistem DC multi-terminal.

ABSTRACT

VSC-based DC multi-terminal systems present significant protection challenges due to their fast fault dynamics, lack of natural zero-crossing, and coupled responses among terminals. Detection methods based on a single indicator, such as time–frequency analysis, signal derivatives, or impedance-based techniques, are generally capable of detecting faults but remain limited in fault location determination, noise robustness, and high impedance fault (HIF) detection.

This thesis proposes a hybrid detection method that combines *Short-Time Fourier Transform* (STFT), derivative (second-order current derivative), and impedance indicators to enhance fault detection and analysis in VSC DC multi-terminal systems. STFT is employed to determine the fault occurrence time, while derivative and impedance indicators provide complementary evidence for faulted terminal localization and fault classification.

The proposed method is evaluated under various fault scenarios, including pole-to-pole (PP) faults, pole-to-ground (PG) faults, noise variations, and different fault resistance levels to represent HIF conditions. The results demonstrate that while the detection time differences among methods are relatively small, the hybrid detection approach significantly improves the consistency of faulted terminal identification compared to individual methods. Furthermore, the hybrid method enables HIF classification and internal/external fault discrimination, which cannot be achieved by single-indicator-based protection schemes.

Keywords—DC detection, DC multi-terminal systems, derivative, impedance, high impedance fault, STFT.