

## Abstract

The focus of the thesis is to first identify the fault and then locate its position in DC distribution systems also known as DC microgrids. DC systems have a lower impedance to offer for a fault in comparison to their AC counterpart which results in high  $di/dt$  and high steady-state current. This causes the requirement of fast fault isolation which has been suggested to be within 5ms of fault inception. Since  $di/dt$  is very high upon fault inception, current limiting reactors (CLRs) can be used externally to limit the rate of increase of current. If used, CLR also serves as a local differentiator for fast, robust, and selective protection. Low voltage and medium voltage DC systems have short lines or cable lengths (<10km) for power distribution. DC fault transients have natural frequency of oscillation,  $f_n < 500\text{Hz}$ . Based on the wavelength of propagation,  $\lambda f = v$ , lumped R-L parameters can be used in the analysis. Different attributes like security, dependability, selectivity, sensitivity to high resistance faults, fault detection time, computational burden, degree of external modification, robustness to white Gaussian noise in measurement, etc are used to validate different proposed fault identification and location schemes for DC systems.

**Fault Identification:** A high rate of rising of current due to discharging converter capacitor can damage the interfacing converter switches in case of improper control logic. Even if the control is proper, the converter control is bypassed to limit the current affecting the power transfer in the system. Either way, there is an indispensable requirement for a fault identification scheme that can detect a fault and identify the faulty section in the system. This allows the operation of solid-state circuit breakers (SSBCs) and isolators to isolate the faulty line/cable in the microgrid.

- To address the issue of fault identification for DC microgrids without any external modification, a localized backup fault identification scheme is proposed. The scheme uses running autoregressive smoothing average of local current and voltage signals to identify the fault on the DC side up to  $5\Omega$ . Additionally, adaptive thresholds are derived for the wider application of the scheme. The proposed method is simple and does not require any external modifications like current limiting reactors. As a trade-off, the application of the method is limited to low resistance faults. Also, the method has selectivity issues where internal and forward external faults may not be differentiated between one another.
- Focussing on the shortcomings of previous work, the proposed work is aimed to improve the application of fault identification methods for low as well as high resistance faults. The method has good selectivity which means it is easily able to differentiate between internal and forward external DC faults. The algorithm detects faults with fault resistance as high as  $200\Omega$ . The method also introduces the concept of cyber resiliency of a protection scheme. The proposed fault identification scheme is validated to be robust against cyber attacks in the system. The analysis involves using current limiting reactors (CLR) as external modifications in the medium voltage microgrids. Using CLR in the system limits the rate of increase of fault current.

**Fault Location:** Once the faulty section is identified, location methods can accurately calculate the distance of the fault in the identified faulty segment. Locating the fault point accurately helps in clearing the fault in time, acting as the key to the rapid restoration of faulty distribution lines and cables.

- A single-terminal fault location method is proposed that is robust to variations of key parameters (e.g. sampling frequency, system parameters, etc.) and performs particularly well for low resistance faults in low voltage DC systems. The proposed method uses local measurements to estimate the current experienced by the other terminals affected by the contingency. This mimics the strategy followed by double terminal methods

that require communications and decouples the accuracy of the methodology from the fault resistance. The algorithm is based on an iterative approach that starts from an initial guess of the fault location. This is used to achieve faster convergence and better accuracy than other approaches in founding the literature. The method is however limited to low fault resistances up to  $5\Omega$  only.

- A double-terminal fault location method is proposed focussing on the shortcomings of the previous single-terminal fault location method. The proposed work is aimed to improve the application of fault location methods for low as well as high resistance faults. The algorithm accurately locates faults with fault resistance as high as  $200\Omega$ . Based on the availability of communication and sensors, different terminals can be used to increase the reliability of the proposed fault location method.