

Improved Protection Schemes for DC and Hybrid AC-DC Microgrids



Thesis submitted in partial fulfillment
for the award of degree

Doctor of Philosophy

by

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2025

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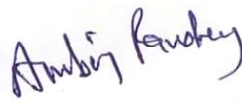
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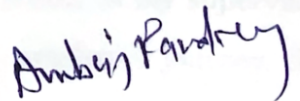
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Nomenclature

Abbreviations

| | |
|------|-----------------------------------|
| AC | Alternating Current |
| ADC | Analog to Digital Converter |
| AI | Artificial Intelligence |
| BESS | Battery Energy Storage System |
| BIC | Bidirectional Interlink Converter |
| CLR | Current Limiting Reactor |
| CM | Confusion Matrix |
| CHIL | Control Hardware-in-Loop |
| CNN | Convolutional Neural Network |
| CSS | Cascading Style Sheets |
| DApp | Decentralized Application |
| Dos | Denial of Service |
| DC | Direct Current |
| DG | Distributed Generation |
| DER | Distributed Energy Resources |
| DSP | Digital Signal Processing |

| | |
|------|-----------------------------------|
| DSO | Digital Storage Oscilloscope |
| DAC | Digital to Analog Converter |
| FCN | Fully Connected Network |
| FDI | False Data Injection |
| FN | False Negative |
| FP | False Positive |
| GPIO | General Purpose Input Output |
| GPS | Global Positioning System |
| GCN | Graph Convolutional Network |
| GFT | Graph Fourier Transform |
| GNN | Graph Neural Network |
| GTAI | Gigabit Transceiver Analog Input |
| GTAO | Gigabit Transceiver Analog Output |
| GTDI | Gigabit Transceiver Digital Input |
| HIL | Hardware-in-loop |
| LANs | Local Area Networks |
| LSTM | Long Short Term Memory |
| LG | Line-to-ground |
| LLG | Double Line-to-ground |
| LLLG | Triple Line-to-ground |
| IED | Intelligent Electronic Device |
| MPPT | Maximum Power Point Tracking |

| | |
|------|-------------------------------|
| MVDC | Medium Voltage Direct Current |
| NGF | Negative pole-to-ground Fault |
| OMS | Outage Management System |
| P2P | Peer to Peer |
| PCC | Point of common coupling |
| PGF | Positive pole-to-ground Fault |
| POC | Passive Oscillator Circuit |
| PPF | Pole-to-pole Fault |
| PV | Photovoltaic |
| PoW | Proof of Work |
| PoS | Proof of Stake |
| ReLu | Rectified Linear Unit |
| RES | Renewable Energy Source |
| RTDS | Real Time Digital Simulator |
| SOC | State of Charge |
| SNR | Signal-to-Noise Ratio |
| SVM | Support Vector Machine |
| TN | True Negative |
| TP | True Positive |
| TSA | Time Synchronization Attack |
| VSC | Voltage Source Converter |
| WECS | Wind energy conversion system |

Variables

| | |
|------------|------------------------------------|
| ξ | Disturbance Index |
| k | Threshold of ξ |
| ω_0 | Resonant Frequency |
| ω_d | Damped Resonant Frequency |
| α | Attenuation Constant |
| N | Total number of samples considered |

Superscripts

| | |
|-------|--------------------------------|
| F | Any parameter during fault |
| pre | Any parameter during pre-fault |

Subscripts

| | |
|------|------------------------|
| $+$ | Positive-pole quantity |
| $-$ | Negative-pole quantity |
| ab | From bus-a to bus-b |
| ba | From bus-b to bus-a |