Designing Ultra-Fast, High Performance DC Circuit Breaker for Distribution Systems with Renewable Energy Resources

Landon Mackey, Md Rifat Kaisar Rachi, Dr. Chang Peng and Dr. Iqbal Husain

FREEDM SYSTEMS CENTER

NC STATE UNIVERSITY

Motivation

With the increasing demand of efficient & smart loads and rapid growth in renewable energy resources in its various forms, DC power distribution has become a suitable solution for many application, as shown in Fig. 1.

- To ensure reliable and safe operation of such systems, DC protection equipment is a key component.

Fig. 1: DC distribution system with renewable energy resources

Background

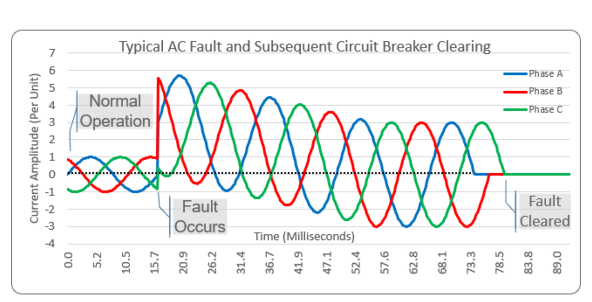

Fig. 2: AC fault with zero crossing

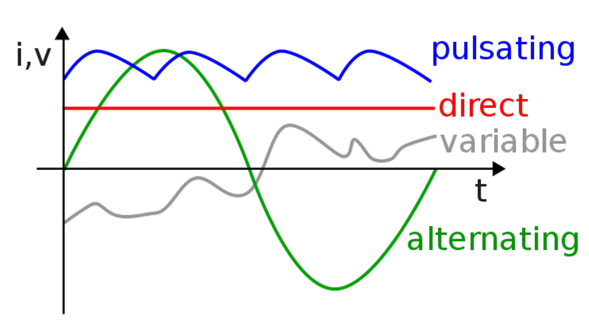

Fig. 3: Non synchronous wave forms

- AC has natural a zero-crossing that facilitates arc quenching during fault interruption.
- Lack of zero crossing in DC makes safe fault current interruption challenging.
- Lower system inductance leads to faster current rise during DC fault.
- Fast and reliable fault isolation is required to facilitate safe integration of distributed renewable energy resources (DRERs).

Actively Damped UFMS

- Thomson coil actuation (TCA) is utilized to develop a medium voltage ultra-fast mechanical switch (UFMS) (Fig. 4).
- The switch motion is actively damped to facilitate faster isolation from DC faults.

Fig. 4: Ultra-fast mechanical switch

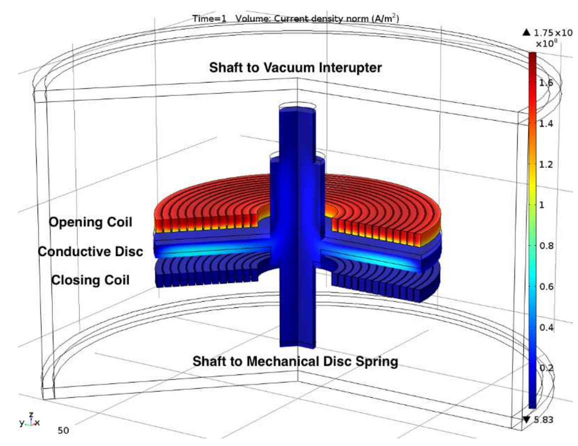

Fig. 5: FEA model of TCA

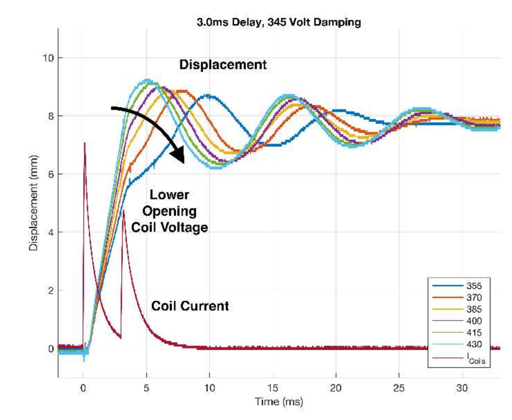

Fig. 6: Mechanical displacement of actively damped UFMS

Progressively Switched Solid State DCCB

- Voltage differential is built up in a progressive manner leading to a reduced peak fault current.
- Response during fault isolation is defined by number of stages used.

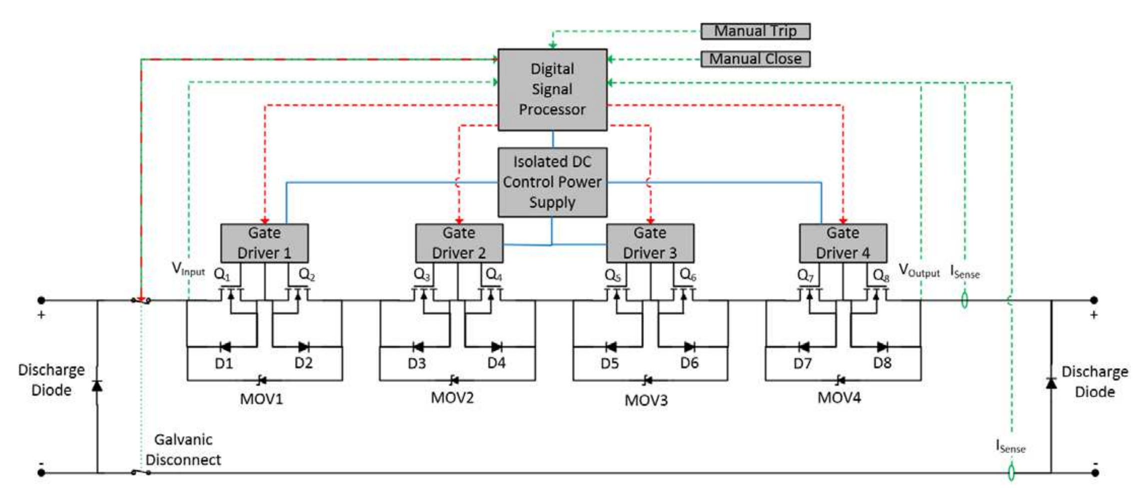

Fig. 7:Four-stage solid-state progressively switched DCCB

- Fig.8 illustrates the concept of differential voltage build up in progressive switching and fig.9 shows progressive switching for different step number.

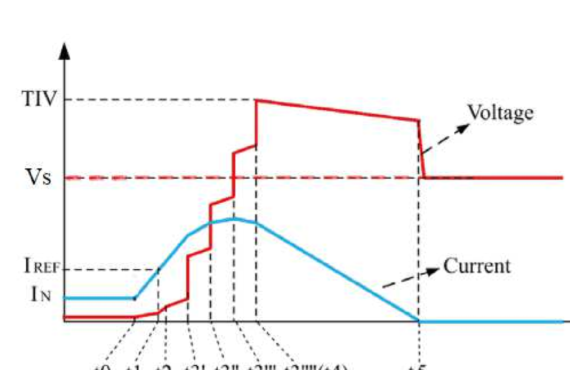

Fig. 8: Progressive Switching Concept

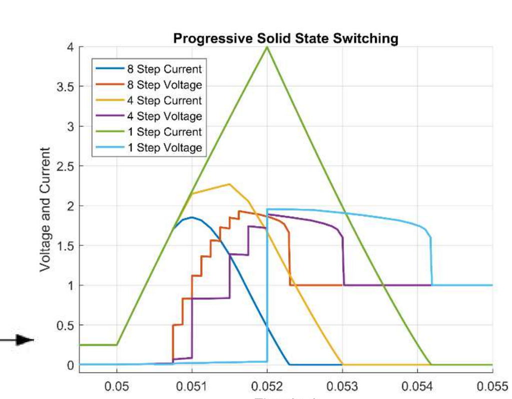

Fig. 9: PSCAD simulation of progressively switched DCCB

Current Sensing & Control

- Bi-directional current sensing.
- Provides ground fault protection.
- Incorporates manual control.

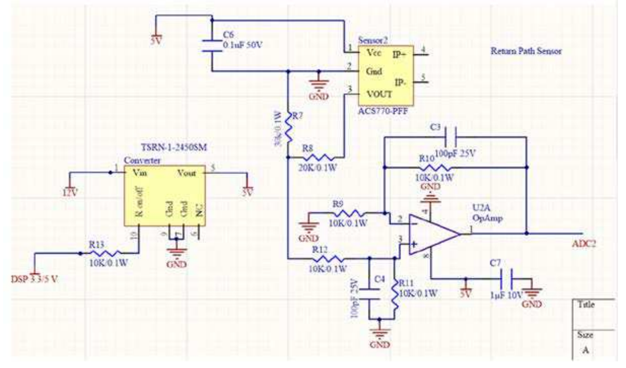

Fig. 10: Current sensing and buffering

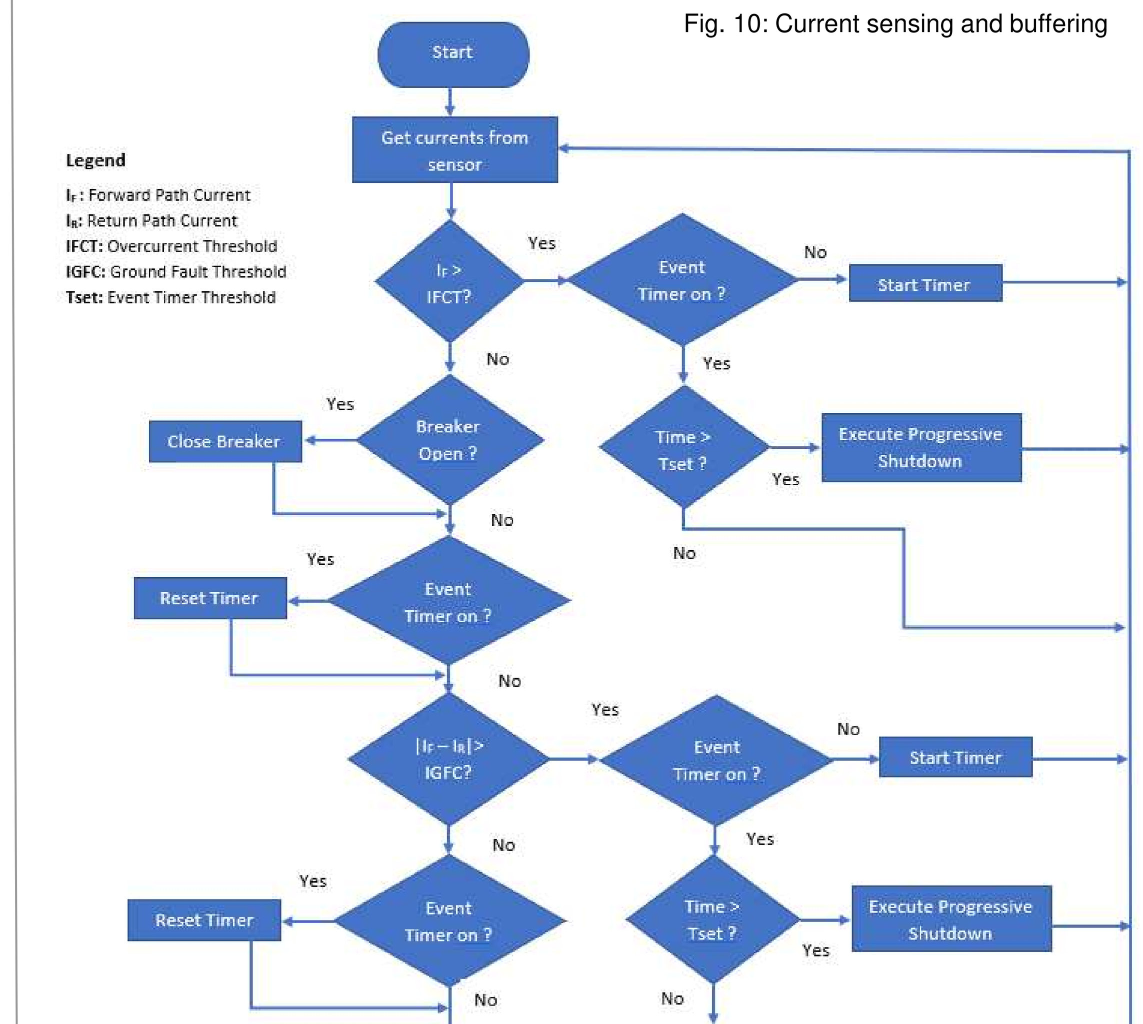

Fig. 11: DC circuit breaker control loop flowchart

Experimental Results

- A four-stage bidirectional progressively switched solid-state prototype has been built and tested in a 380 Volt / 25 Amp test-bench under load.

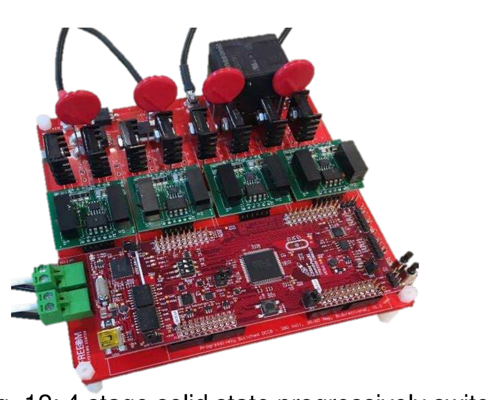

Fig. 12: 4 stage solid state progressively switched DCCB prototype

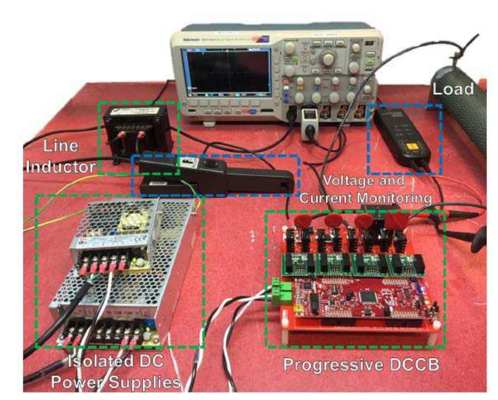

Fig. 13: Test-bench setup for 380V/25 Amp system

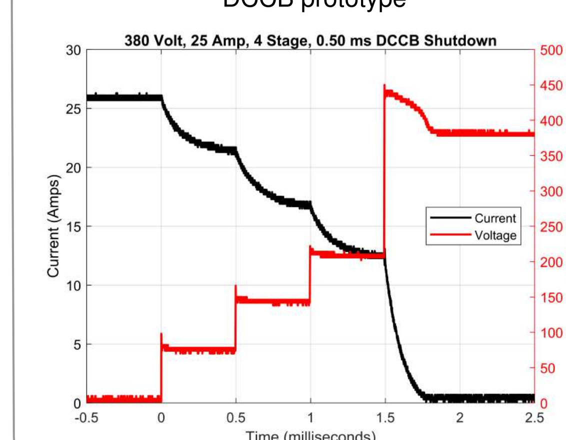

Fig. 14: Experimental waveforms of 4 stage progressively switched solid state DCCB

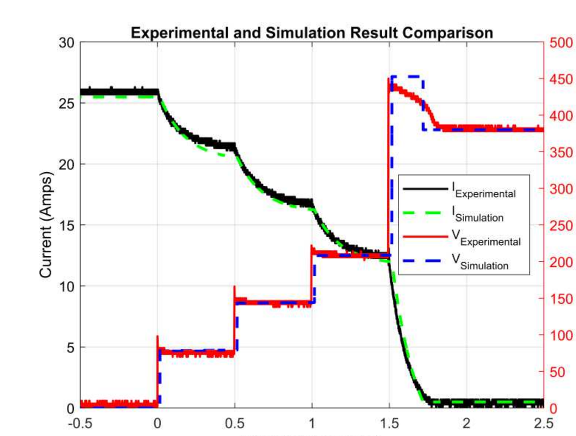

Fig. 15: Comparison between experimental and simulation waveforms

Potential Impacts

- Ultra-fast (< 2ms) and reliable fault isolation is provided in a DC distribution system.
- Reduction in peak fault current ensures reduced stress on protective devices and tied converters.
- Bi-directional nature of the protection element enables integration of DRERs in future smart grid designs to facilitate diverse energy capabilities.

Conclusion and Next Steps

- A silicon MOSFET based four-stage progressively switched bi-directional DCCB with necessary control is built and tested.
  - Silicon Carbide (SiC) based semiconductor devices will be utilized in the next generation.
- The proposed high performance DCCB is suitable for safe and reliable harvesting of ocean energy.
  - Advanced algorithm for fault detection and isolation for an islanded subsea micro-grid is necessary which can be extended to other micro-grid applications.

References

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[2] L. Mackey, C. Peng and I. Husain, "A Progressive Switching Scheme for Solid State DC Circuit Breakers," Abstract accepted for 2018 IEEE 9th International Symposium on Power Electronics for Distributed Generation Systems.

[3] L. Mackey, M. R. K. Rachi, C. Peng and I. Husain, "Progressive Switching of Hybrid DC Circuit Breakers for Faster Fault Isolation," Abstract accepted for IEEE *Energy Conversion Congress and Exposition (ECCE)*, Portland, OR, 2018.

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