Y9.ET4.3: Fault Isolation Device (FID) Development - BIL

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1. Project Goals

The FREEDM system is an example of the application of power electronic devices applied to the control, instrumentation, and switching in power distribution systems. Applications include solid state transformers and solid state fault interruption devices. Some of these devices may be connected directly to the distribution primaries (typically in the 15 kV class). This research addresses the concerns related to the direct galvanic (ohmic) connection of solid state components directly to the distribution primaries.

In distribution engineering, voltage, current, and power ratings vary, but it is common that the distribution primary voltage is in the 15 kV three-phase class (i.e., 8660 V phase to neutral). Residential distribution trans-formers are commonly in the 10 – 200 kVA class. These voltage and power levels seem to be suited for controls, interrupters, converters, and reactive power sources that are made up of solid state components. The FREEDM system is a power distribution system largely composed of solid state devices. A key such component is the solid state transformer (SST). Other solid state devices which may have valuable applications in distribution engineering include the solid state fault interruption device (FID). Many of these devices have a common attribute in that there could be applications in which it is desirable to connect the device directly to the distribution primary conductor. The advantages of such a connection are avoidance of an intervening transformer, reduction of cost, and reduction of circuit impedance. The disadvantages include the potential hazards of unexpected current flowing from the primary conductor to a distribution system load, and the possible harmful impact of lightning and switching voltage impulses.

2. Role in Support of Strategic Plan

In the distribution engineering configuration shown in Fig. 2, note that the electronic FID and SST are directly connected (ohmically) to the distribution primary conductor. This is the configuration used in the FREEDM system. For the FREEDM system configuration, it is evident that the FID and SST depicted must withstand the lightning impulse as indicated in Table I since the electronic components are directly connected to the distribution primaries. As an example, Fig. 3 shows a simplified FREEDM SST connected to a 3.6 kV phase-neutral. The ‘input’ (line) side of the SST will nominally be an LCL filter (with small parasitic resistance R) to block high frequency signals from the pulse width modulation (PWM) used in the SST. Typical unipolar PWM designs for the rectifier stage of the SST at residential distribution power levels have switching frequencies in the 3.0 to 15 kHz range. The frequency spectrum of the PWM signals contain components at $kf_s \pm mf_o$, where f_o is the baseband (‘power frequency’) and f_s is the PWM switching frequency, and k and m are even integers.

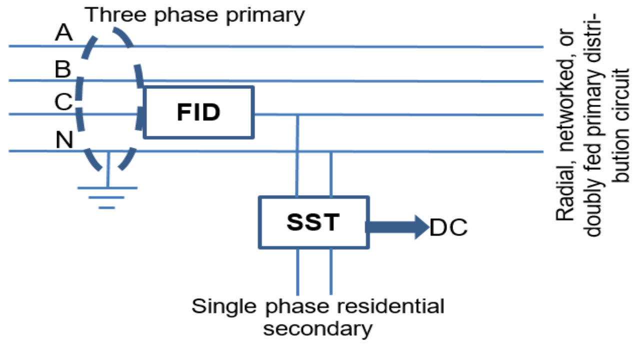

Figure 1: The connection of solid state components directly to the distribution primary conductor

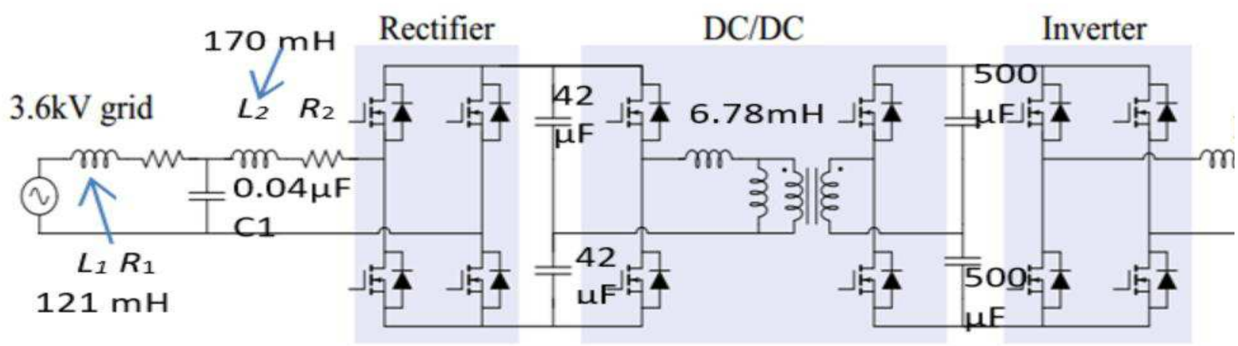

Figure 2: Simplified FREEDM SST model showing a low pass T-filter at the 'front end'

3. Fundamental Research, Technological Barriers and Methodologies

The basic impulse insulation requirements:

Power distribution system components are designed to withstand lightning and switching voltage impulses which may be grouped as the design to a basic impulse insulation level (BIL). The term 'BIL' has been in common use in North America for over 50 years, but newer documents are beginning to favor the term "Lightning Impulse Withstand Level (LIWL)". Perhaps the best discussion and identification of BIL requirements for electronic devices in distribution engineering applications appears in the International Electrotechnical Commission Standard 60071. The cited standard gives the method for specifying and checking compliance with BIL requirements as impulse testing. This testing entails the application of two types of impulse waveshapes as indicated in Fig. 1. Table I shows parameters of these tests for commonly used distribution primary voltages.

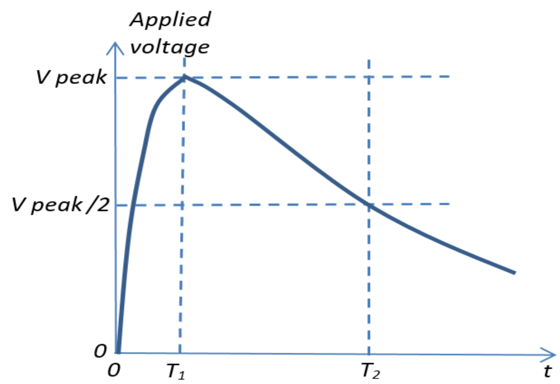

Figure 3: Waveshape used for testing com-pliance for BIL from IEC Standard 60071: (a) for switching impulses {T1,T2} = {250, 2500 µs and (b) for lightning impulses {T1,T2} = {1.2, 50 µs}

Table I Parameters used in BIL compliance tests for commonly used distribution primary voltages

Rated line-neutral voltage (rms, kV)	Rated line-neutral voltage (0-peak, kV)	*Applied BIL voltage*	
		Standard rated short duration* withstand (rms, kV)	Standard rated lightning impulse withstand (0-peak, kV)
3.6	5.1	10	40
7.2	10.2	20	60
12	17	28	95
17.5	24.7	38	95
24	33.9	50	145

*At the power frequency

BIL compliance through simulation tests:

A typical application of an SST interfacing with a 3.6 kV distribution primary is discussed here. In order to achieve compliance with IEC 60071 requirements, metal oxide varistors (MOVs) may be used to clamp volt-ages at the distribution primary port of the SST shown in Fig. 3. This approach requires separating the input side components into stages in order to obtain components that are commercially available at the required voltage ratings. For example, the 121 mH inductor and its associated parasitic resistance R1 may be resolved into two identical series stages (each 60.5 mH). These stages are protected by a parallel MOV which clamps the voltage, for example to 15 kV in a 7.2 kV single phase application. Similarly, the 0.04 µF capacitor C1 is replaced by two series 0.08 µF capacitors which are paralleled by 15 kV (maximum) MOVs. A typical response to the use of MOVs for the cited application is shown in Fig. 4. Calculation of dissipated energy in the four MOVs used indicates that commercially available units are readily available.

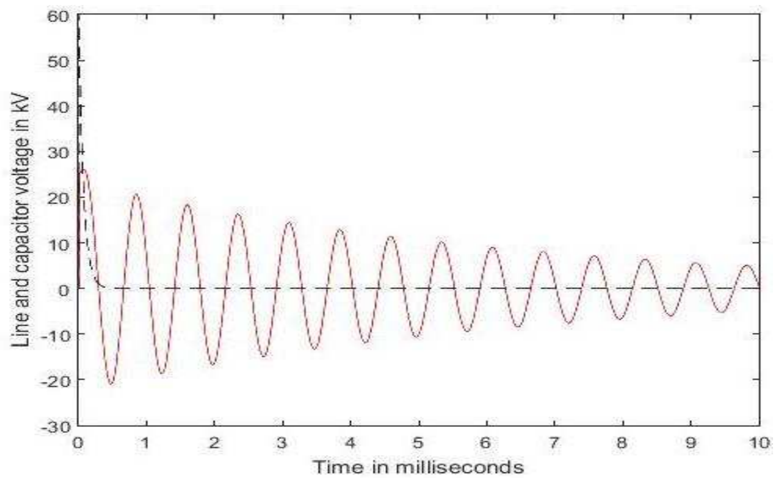

Figure 4: A typical response: 60 kV 1.2 / 50 μs impulse (dashed line) applied at the line side of an SST with a two stage input inductor and capacitor. The sum of the capacitor voltages is shown (solid). For this illustration, two 15 kV MOVs are used in parallel with the input inductor and the 0.04 μF capacitor.

A conclusion is that the IEC Standard 60071 provides the best available guidance for the connection of electronic components to distribution primary conductors. This, then, is the appropriate standard to use for the FREEDM system. In the application of a FREEDM solid state distribution transformer, a front-end filter is required. This filter must withstand most of impulse voltage required in BIL testing and compliance. This is accomplished by dividing the filter into stages some of which are shunted by MOVs to reduce the voltage stress on filter components. This design results in semiconductor voltage ratings that do not need to be exceedingly high and can be selected based on operating conditions rather than the primary distribution line BIL.

4. Achievements
(Including Previous Years, but with an Emphasis on the Current Year)

The previous year's achievements are:

- Identification of the appropriate standards for impulse testing of FREEDM components
- Simulation testing of alternative designs for the FREEDM SST

Present achievements are:

- Design of a 60 kV BIL impulse generator
- Identification of test requirements for the FREEDM FID
- Study of the impact of stray capacitance

5. Other Relevant Work Being Conducted Within and Outside of the ERC

The researchers have been in contact with manufacturers of static var compensators and similar FACTS controllers to assess the role of standards in solid state controller designs. Presently accepted testing has been identified among manufacturers.

6. Milestones and Deliverables

By December 2016: design impulse testing procedures for the SST based on IEC 60071

By February 2017: design the 60 kV impulse generator required for testing

By May 2017: construct and test the 60 kV impulse generator at the ASU high voltage laboratories

By August 2017: report results, make recommendations on SST design changes if needed, and document the project

7. Plans for Next Five Years

The planned work includes the design of a testing regimen for the FREEDM FID.

8. Member Company Benefits

Compliance with the IEC 60071 standard is mandatory for FREEDM components. The researchers note that the commercial manufacture of FREEDM components require this compliance.

9. References

Xuening Rong, G. G. Karady, D. Zhang, G. T. Heydt, “Insulation coordination of FREEDM solid state transformer,” CIGRÉ Grid of the Future Conference, Philadelphia, Oct. 30 – Nov. 1, 2016.