Y9.ET4.1: Fault Isolation Device (FID) Development – Fast Mechanical Switch

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1. Project Goals

The FMS needs to have a separation speed in the order of 1 ms in order to keep the overall interruption time smaller than 2 ms. The FMS also needs to have an ultra-low conduction loss. Our FMS concept is based on the patented idea of integrating a piezo-electric actuator and the mechanical contacts with a vacuum switching chamber. This concept has never been applied to high voltage and high current circuit breaker applications.

2. Role in Support of Strategic Plan

FREEDM System is a networked grid with current limiting capability. The FID is one of the key enabling technologies. In particular, it enables the ultra-fast protection philosophy pursued by FREEDM in order to maximize system availability by minimizing fault clearing time. FREEDM System is current limiting; hence the grid voltage will decrease quickly in the event of a fault. Ultra-fast fault isolation is therefore absolutely needed. In a DC grid, ultra-fast protection is also needed. Our work therefore will also have significant impact to medium voltage DC grid protection.

3. Fundamental Research, Technological Barriers and Methodologies

<u>Y9.ET4.1 FMS Dynamic Response in Air and DSP Controller Validation:</u> Prior to affixing the piezo electric actuator in vacuum, it is necessary to determine contact spacing throughout the current path during dynamic operation. The dynamic operation of the device is driven by a ramp in voltage across the piezo electric actuator. Mechanical compression testing shows the total force needed to create contact separation near 0.5 mm per contact is approximately 110 N, while the contact separation testing shows that 150 V applied to the piezo creates a total contact separation of 4x0.4 mm. The dynamic testing proved useful in multiple ways: 1. Determination of voltage ramp speed applied to the piezo, 2. impact of voltage ramp speed on physical structure and support switch elements, 3. to validate the DSP actuation of the piezo.

Figure 4 provides the test setup that consists of the RTDS to act as the signal from the power electronics side (NCSU) commanding the FMS to open/close, the FMS DSP, the Techron amplifier and the piezo switch. Through testing of various voltage ramp speeds, the contacts were visualized using a high-speed camera. A voltage ramp speed of 600 us (250 kV/s) was chosen, based on mechanical vibrations seen through the camera and voltage measurements. When the signal to open the FMS is sent, the contacts quickly and a damping mechanical oscillation occurs between the contacts. At higher ramp rates the oscillation is great enough to almost cause the contacts to bounce off each other after opening. Figure 5 shows a still image taken when the contacts are open from the high speed camera capture. Using the 250 kV/s ramp, Figure 6 shows the commanded voltage sent from the DSP, and the voltage response at the piezo switch. After 600 us, the contacts are separated by 0.25 mm, a small mechanical oscillation occurs then the switch is fully open with a contact separation of ~0.32 mm.

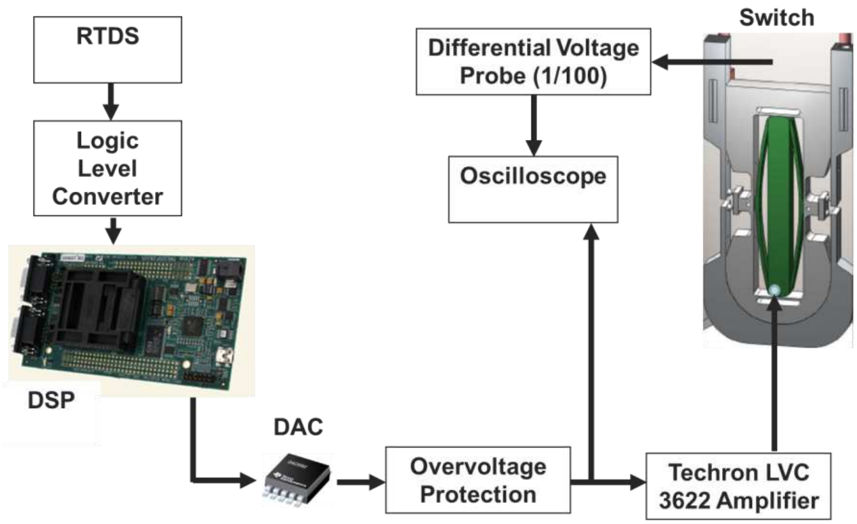

Figure 1: Dynamic Testing setup

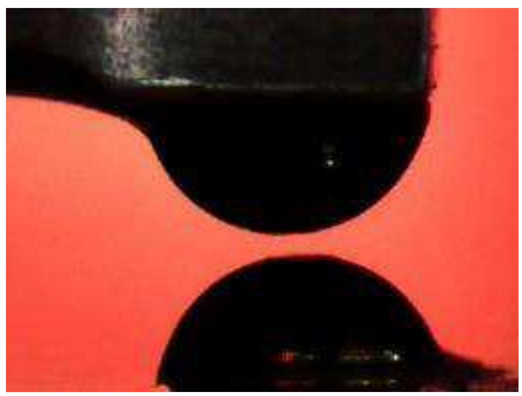

Figure 2: Still image from high speed camera when contacts are open

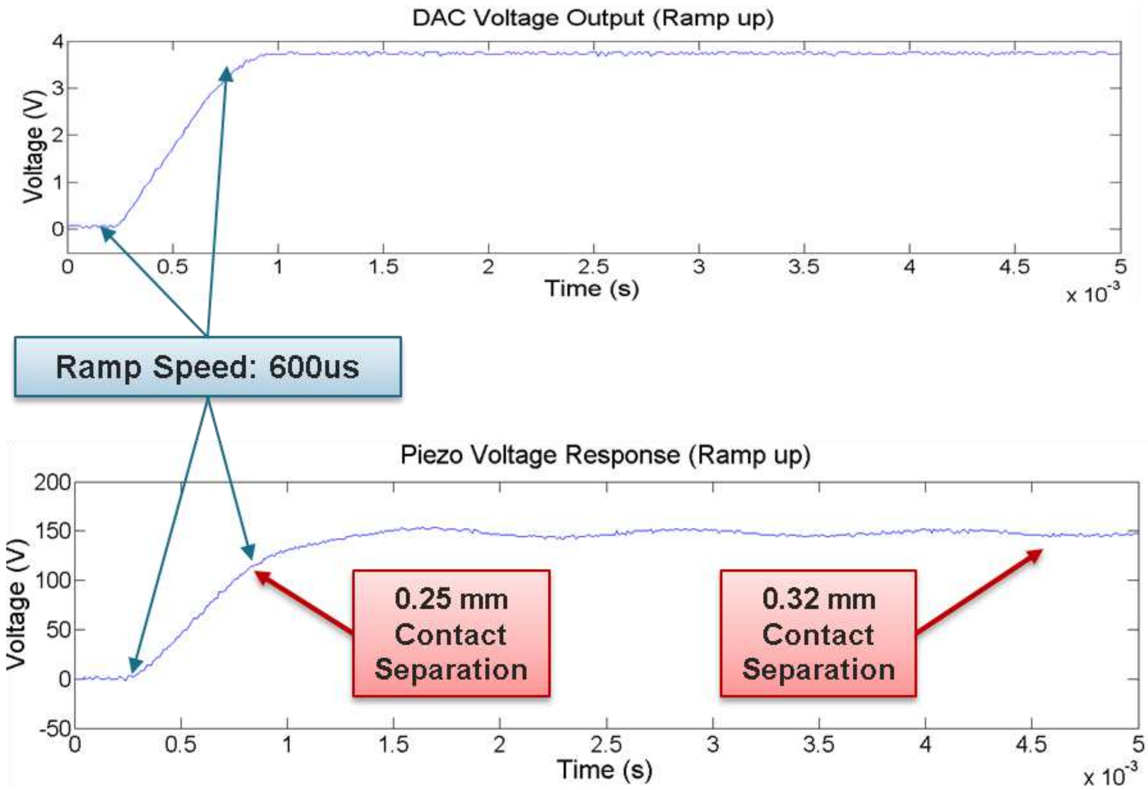

Figure 3: Graphs showing voltage command and measured piezo voltage response during opening.

<u>Y9.ET4.1 Piezo Actuator Voltage Withstand in 1 atm:</u>

Using the dynamic testing as a guide, next is the question of whether this ~0.32 mm separation can withstand voltages seen during the FID's turn-off sequence. The following tests also provide a means to rate the device. Prior to determining the FMS's voltage breakdown limits in vacuum, the team chose to test the voltage breakdown limit in open air (1 atm). This test is also useful to visualize the contact separation of the piezo and determine the proper feedback response to send to the master controller (NCSU) that the piezo is open. Once in vacuum the only feedback will be the voltage measurement across the piezo device. Figure 7 provides the experimental setup for these tests. The piezo opening and closing is controlled by an analog signal sent from the RTDS. This signal is then amplified by a Techron amplifier with a 15 Ω resistor in series with the piezo. The voltage across the piezo is measured. To provide an AC voltage pulse across the terminals of the FMS, a 1:100 Xfmr is used. Similarly, the RTDS sends a pulse that is 60 Hz, 10 cycles, starting at the peak of the AC waveform, with a 10 V/s down ramp in magnitude. This pulse is then amplified by a Techron amplifier and applied to the primary of the Xfmr. The secondary side of the Xfmr has a pair of 10 M Ω resistors connected to the terminals, to minimize the current flowing through the FMS terminals. The primary and secondary voltages and currents are measured. For these tests, the piezo is opened and held open with a contact separation of ~0.35 mm per contact, and the magnitude of the pulse is varied until breakdown is seen in the voltage measurement. Figure 8 provides the voltage waveforms measured across the terminals of the FMS at the breakdown threshold. The voltage breakdown threshold of the FMS in open air with one gap of ~0.35 mm is 1.68 kVrms, whereas with all 4 gaps in series it is 4.83 kV. This confirms that the applied ac voltage drops quite uniformly across the 4 contact gaps. With this promising threshold, it can be assumed that the required voltage withstand of at least 10 kV in vacuum can be achieved.

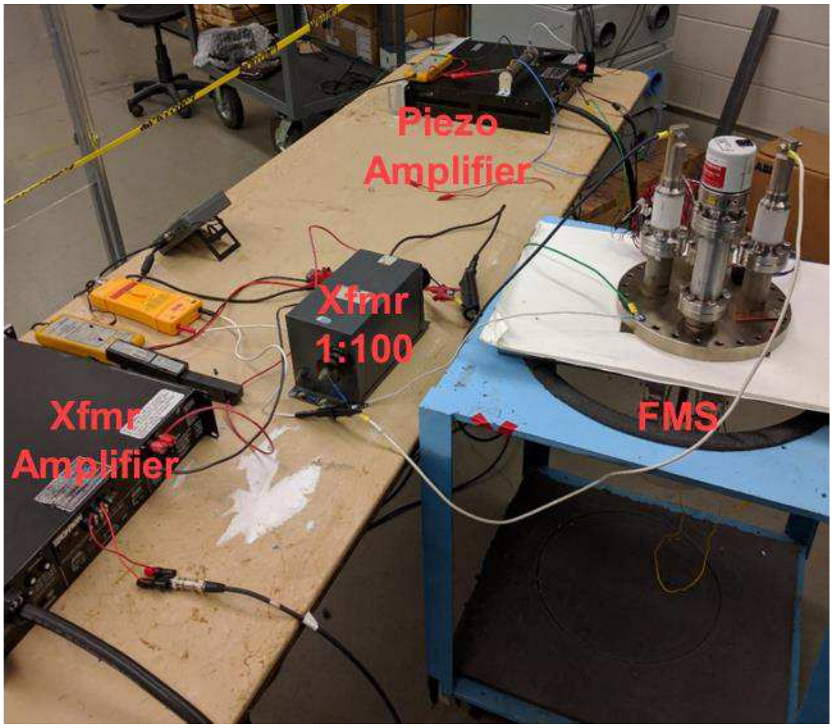

Figure 4: Experimental setup for voltage withstand testing

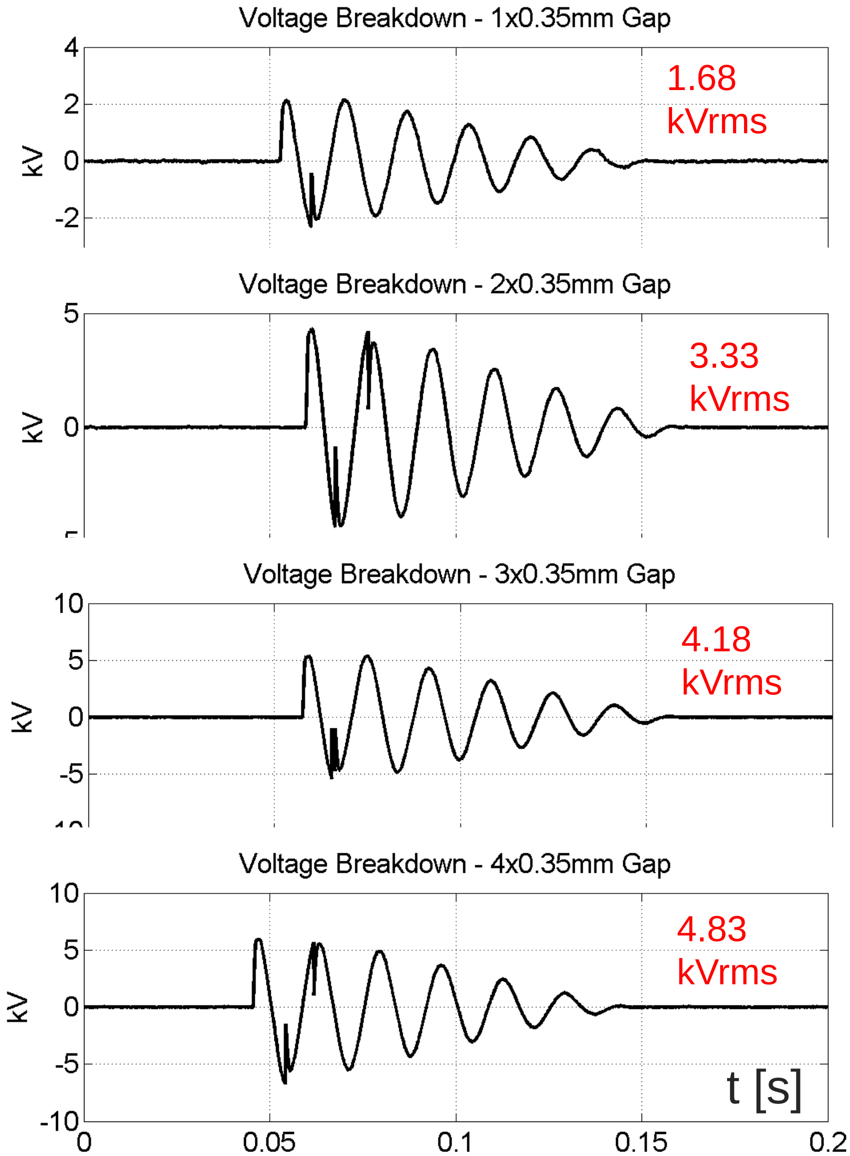

Figure 5: Voltage breakdown during full opening of piezo contacts

4. Achievements

- 200 A Heat Run in low vacuum, with use of Piezo reverse polarity shows stabilization of temperatures less than 70 °C
- Mechanical Compression and Contact Separation Static Testing provided total force needed for 0.5 mm contact separation of 110 N, and 150 V applied to piezo shows a total contact separation of 4 x 0.4 mm
- Development FMS DSP controller and Dynamic Testing validated DSP control of piezo actuator, provided proper voltage ramp speed for opening and closing of Piezo, thus minimizing mechanical oscillations, while providing true contact separation during opening sequence, 4 x 0.32 mm.
- Open Air (1 atm) voltage withstand testing shows a voltage breakdown around 4.83 kVrms with 4 x 0.32 mm contact separation.

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

6. Milestones and Deliverables

Gen-I, Gen-II FID have been developed in early years. In Year 9, Gen-III FID will be delivered. This is the second most important MV equipment that the center is developing for future AC and DC grids.
Deliverable for SV (04/2017):

- Full functionality of Gen-III FID tested
    - Integration of the MB, AB with FSU developed FMS
    - Testing of the Gen-III FID to reach rated voltage and current

Final Deliverable (08/2017):

- PHIL system demo with two FIDs

7. Plans for Next Year

Utilize the FIDs in the final system integration tests at FSU.

8. Member Company Benefits

None

9. References

None