UW IEC Group 2011: Continuing Preparations for 300 kV Operation – Device Switching

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Motivation for Using Greater Cathode Voltages

Improved access to $\text{He}^3$-He$^3$ Fusion

Spherical $\phi$, Maximum charge states

Source: J. F. Santarius

~500%

$\text{D-T}$

$\text{D-He}^{+2}$

$\text{D-D}$

$\text{p-}^{11}\text{B}^{+5}$

$\text{He}^{+2}$

$\text{He}^{+2}$

$\text{He}^{+2}$

$\text{He}^{+2}$

$\text{He}^{+2}$

$\text{He}^{+2}$

~55%
Motivation for Using Greater Cathode Voltages

- Neutron flux appears to be monotonically increasing with voltage (greater voltage ==> more neutrons)

\[
\text{Neutron Rate} = 2500(\text{Voltage}[kV])^2 + 34000(\text{Voltage}[kV])
\]

From 2008 Workshop Donovan presentation (WE-08)
Adaptations for 300 kVDC

Completed:
• Power Supply upgrade (done)
• Vacuum Feed-through assemblies
  (covered by Becerra during this workshop)

In Progress:
• Cabling
• Series Resistance assembly ("resistor barrel")
• Switching
Cabling

(New) 300 kVDC cable, left, and (current) 200 kVDC cable, right

_The new cable is much less flexible, and more subject to flexure-induced failures._
High Voltage Switch and Series Resistance Assembly

Specifications:

1. Cold-switch the high-voltage power supply between four different devices

2. Removing and replacing cables not to be required

3. Non-inductive series resistor of 50 kΩ able to carry 200 mA current in steady state

4. Resistor to be adjustable to higher resistances (though at a lower current), and completely bypassable

5. Pulsing capacitor and related equipment is to be in the same enclosure as the switch.
Switch Design Drivers

• 35 cm path length between 300 kV surface and ground (to prevent track arcing)

• 15 cm (oil filled) distance between 300 kV surface and ground (to prevent through-oil arcing)

• Electric field below ~5 MV/m

• Resistor System requires electrostatic shielding
• Capacitor system switched in parallel with power supply for pulsing
System Schematic

Switch Enclosure

resistance selector rods

1 MΩ
250 kΩ
250 kΩ
250 kΩ
250 kΩ

swing arm

2 kΩ

80 MΩ (cap. bleed-down)

400 nF, 100 kVDC
400 nF, 100 kVDC

2 Ω (current-sense resistor)

~1.5 Ω

HVPS 0-300 kV

~1.5 Ω

HOMER
HELIOS
SIGFE
MITE-E

University of Wisconsin -- Madison
Fusion Technology Institute
Inertial Electrostatic Confinement Group

Presented by Richard Bonomo, December 2011
Design & Construction methodology

Design/Redesign
Concept

Simulation (MAXWELL -3D)

Construct → Test → Modify
Final System Layout

Switching Electrodes

Power In

Power Out (4)

Output Electrode (4)

Bridge Electrode (4)

Resistor tube

Rotating Electrode
Manufacturing – Internal Components

Electrodes (5 types)

Series Resistor Strings

Support components (and electrodes)
Manufacturing – External Components (Tank)

Tank Body Volume
~ 1200 L

Removing scale

Leak Checking
(note red dye)

Plasma Cutting
Slot into Lid

Manufacturing – External Components (Tank)

Tank (~320 Gal)
Lids (2)
Electrodes (5 types)
Resistor boards (20)
Support structure (a lot)
Implementation: Electrode Assembly

Rotating Selector Electrode
Output Electrode 1 of 4
Vertically Translating Bridge Electrode 1 of 4

Power Input Contact
Resistor String Selector
Resistor Tube
Implementation: Pulsing

“Bleed-Down” Resistor (4 X 20 MΩ)  Current Sense Res. (2 Ω)

Swing Arm
Control Rod

Swing Arm

Discharge Resistor (2 kΩ)

Capacitors
Testing: Resistor Assembly

Initial Testing Failure: Internal Arc (corrected later)
Final Assembly

Installation of the pulsed system in the switch tank

Photo of main switch assembly being lowered into switch tank
Testing: Resistor Assembly

Initial Testing Failure: Insufficient Cooling (later corrected)
System Testing: High-Potential Test to 100 kV Without Dielectric Oil

Result: Unexpected, very short-time-scale arcs occurred in IEC devices when they were connected via the new switch, but not otherwise!

Vertical scale is 1 A / division: arc peak current is off scale!

Arc duration is approx. 100 µsec.
Testing Results Summary:

• **OK:** The resistor string assemblies, as modified, can withstand the anticipated voltages and currents that are expected in regular operation.

• **OK:** The resistor string assemblies, when immersed in oil, will not exceed their temperature limits.

• **OK:** The assembled switch has been tested to 100 kV DC in air, which implies that it will likely be able to work at 300 kV DC when immersed in oil.

• **FAIL:** When an IEC devices is connected through the new switch, arcing within the device occurs at 60 kV DC. **This does not occur when the device is connected via the present resistor barrel.**
Why are these “micro-arcs” in our IEC devices not seen when we use our present (designed for 200 kV DC) resistor barrel?

Present Resistor Barrel – internal components exposed
It is our “working assumption” that some electrical characteristic of the present resistor barrel prevents these arcs.

We are attempting to determine what this characteristic is in order that we might incorporate it into the new switch

Analytic procedure (in progress):

1. Make measurements of overall impedance characteristics, i.e., |Z| at various frequencies

2. Attempt to fit the observed characteristics with a lumped parameter model

3. If unsuccessful, adjust the model and attempt a fit again.
Summary of Current Status:

• Switch components have been built and successfully tested
• System-level testing of the assembled switch failed with a peculiar “micro-arcing” which occurs in our IEC devices when powered through the new switch, but not through the present resistor barrel.
• Analysis of the current resistor barrel is in progress
Questions?