Artificial Island Area Proposal 1

500 MVAR SVC plus Two Thyristor Controlled Series Compensation (TCSC) Devices

Dominion Virginia Power

June 26, 2013

Contact Information

For technical inquiries on the study please contact:

Solomon Yirga

Solomon.1.yirga@dom.com

804-771-4854

For technical inquiries on protection schemes please contact:

Mark Schroeder, P.E.

Mark.schroeder@dom.com

804-257-4750

Purpose of Proposal

This solution proposal is being made in response to PJM's Request For Proposal (RFP) on April 29, 2013 in which PJM seeks technical solution alternatives (hereinafter referred to as "Proposals") to improve PJM Operational Performance in the Artificial Island area under a range of anticipated system conditions and to eliminate potential planning criteria (PJM, NERC, RFC, and Local Transmission Owner criteria) violations in the Artificial Island area.

The objectives as stated in the RFP include

1. Generate maximum power (3818 MW total) from all AI Units (Salem1: 1253MW, Salem-2: 1245MW, Hope Creek: 1320MW) without a minimum MVAR requirement from the AI. Full maximum power must be maintained under both the baseline and all N-1 outage conditions of 500kV transmission lines in the AI area. For both the baseline and N-1 outage conditions, AI voltage must be maintained within operating limits and stable for all NERC Category B and C contingencies. NERC Category C3 contingencies "N-1-1 contingencies" do not need to be run on top of the N-1 outage condition.
2. Maximum MW output from AI should not be affected by the simultaneous outage of Power System Stabilizers (PSS) of Artificial Island units Hope Creek and Salem-2. The Salem-1 PSS is assumed to be on for all scenarios.
3. Reduce operational complexity.
4. Improve Artificial Island stability.
5. Maintain PJM System Operating Limits (SOLs).

Proposal

Dominion is submitting this proposal as the Entity to construct, own and operate should PJM select and approve as a baseline upgrade. As demonstrated in the Pre-Qualification package for Virginia Electric and Power Company (Dominion Virginia Power), Dominion has demonstrated its qualifications to construct, own, and operate electric facilities.

The proposal has the following major components:

- Install one 500 MVAR SVC plus Two Thyristor Controlled Series Compensation (TCSC) Devices and associated breakers, controls and protection at a new Substation near New Freedom
- Add two 500 kV breakers at East Windsor Substation
- Add two 500 kV breakers at Hope Creek Substation
- Add two 500 kV breakers at New Freedom Substation
- Add one 500 kV breaker at Red Lion

Description of the proposed solution

Dominion Virginia Power is proposing to construct a new eight breaker 500 kV Transmission Switching Station near the existing New Freedom Substation. This new 500 kV Switching Station will tie 500 kV Lines # 5023 and 5024 together. A new 500 kV SVC (+500 MVAr to -250 MVAr) will be installed at this new 500 kV Switching Station. On Line #5023 (New Station – Hope Creek) and Line #5024 (New Station – Salem) a TCSC will be installed respectively. The SVC and the two new TCSC will be installed inside the new proposed 500 kV Switching Station. Figure 2 provides a one-line of the new proposed transmission configuration in the Artificial Island area.

A TCSC is a static thyristor controlled reactor in parallel with conventional series capacitor for a fast adjustment of the line reactance. Because of this ability of the TCSC, the compensation level can be increased for a short duration immediately after a contingency to improve system stability. In this kind of application the steady state compensation level can be low.

For lines 5023 and 5024, the proposed steady state compensations are 40% and 45% respectively while the compensation is boosted to 90% compensation for both lines immediately (within 3 cycles) after fault, on lines in the Artificial Island area, is cleared. The controllers sense the change in power flow on the compensated lines (5023 and 5024) immediately after fault disturbances, on lines in the Artificial Island area, are cleared and boost the compensation level to 90% of the uncompensated line reactance for about 2.5 seconds.

The rush of power on the lines happens immediately after fault is cleared when the generators put out real power as a result of the voltage recovery and the generator rotor angle advance. This naturally - happening rush of power from the generators provides a synchronizing torque, which may or may not be enough to keep the units from going out of step.

The purpose of the boosted compensation is to reduce the impedance seen by the generators so that the power output from the generator provides large enough synchronizing torque to keep the generators transiently stable. A 500 MVAR SVC to be installed near New Freedom station where lines 5023 and 5024 are tied together shall also be part of the proposed solution. Because of the boosted series compensations on 5023 and 5024 lines, the SVC will be electrically very close to the generators in Artificial Island during the boosted compensation period. The SVC contributes to the synchronizing torque by holding the voltage high.

TCSC also provides important benefits in eliminating the risk of Sub Synchronous Resonance (SSR) and can have a power oscillations damper which could be more effective in damping inter-area mode of oscillations than a PSS. With this proposed solution, an auxiliary controller, to damp out inter-area oscillation, can be incorporated either with the TCSCs or the SVC . More information on the TCSC and SSR is provided in Appendix E.

Although not studied, Dominion believes an additional benefit to this solution is the increase of transfer capability to PJM East Reactive interface.

Appendix C addresses the protection of series compensated lines. The protection strategies that are being used for fixed series compensated lines apply for TCSC compensated lines as well. Dominion has two 500 kV series capacitors on the Bath to Lexington and Bath to Valley lines that have been in operation for several years.

Appendix D describes the capability of Dominion Real-Time Digital Simulator (RTDS). This real-time capability provides the ability to use the RTDS for testing of relaying schemes and equipment controllers among other things. The relay schemes that would be designed for the compensated lines or the adjacent lines can be tested using the RTDS.

Following devices are required for this solution

- One TCSC device on the 5023, 500 kV line (Hope Creek – New Freedom) with steady state compensation of 40%. The value of Xc (Figure 1) in this case is -10.5 ohms. With the line current rating of about 3000 Amp, The TCSC rating will be 283.5 MVAR. The steady state compensation of 40% is chosen so that the line loading will not exceed the emergency rating of the line with the loss of the 5024 and 5021 lines. This is studied using the 2011 series MMWG 2017 summer peak case. The temporary line current during the compensation level of 90% could be as high as 3900 Amps for the same power flow case. The duration of this temporary loading is about 2.5 seconds.

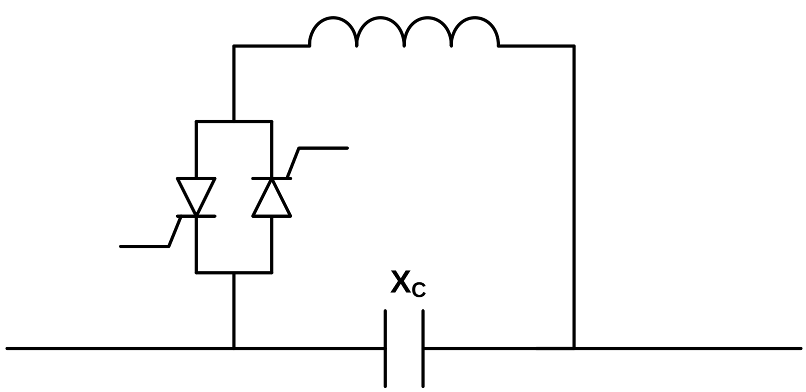

Figure 1 TCSC Device

- One TCSC device on the 5024, 500-kV line (Salem – New Freedom) with steady state compensation of 45%. The value of Xc in this case is -13.5 ohms. With the line current rating of about 3000 Amp, The TCSC rating will be 364.5 MVAR. The steady state compensation of 45% is chosen so that the line loading will not exceed the emergency rating of the line with the loss of the 5023 and 5021 lines. This is studied using the 2011 series MMWG 2017 summer peak case. The temporary line current during the compensation level of 90% could be as high as 3900 Amps for the same power flow case. The duration of this temporary loading is about 2.5 seconds.

- A 500 MVAR SVC shall be installed near New Freedom station where lines 5023 and 5024 are tied together. It is assumed that the SVC shall have 250 MVAR absorbing capability.

- Following line breakers, as identified in the (PJM provided) single line diagram, need to be doubled. The elimination of the delay for breaker failure cases is the main reason for this doubling of the breakers more than the avoidance of loss of additional circuit elements.

    - Breaker 505 @ Red Lion
    - Breaker B16 @ East Windsor for line 5022
    - Breaker B13 @ East Windsor for line 5022
    - Breaker 2-10 at New Freedom for line 5038
    - Breaker 9-10 at New Freedom for line 5038
    - Breaker 2-4 at Hope Creek for line 5037
    - Breaker 2-6 at Hope Creek for line 5037
    - Breaker 1-3 at Hope Creek for line 5015

- Following breaker failure fault clearing times should be changed to 8.75 cycles
    - 5023 SLG breaker 1- 5 stuck
    - 5037 SLG breaker 2-10 stuck
    - 5024 SLG breaker 2- 6 stuck

- Fault clearing time for the following normally cleared faults should not exceed 4.13 Cycles
    - Normally-cleared three phase fault on line 5038
    - Normally-cleared three phase fault on line 5037
    - Normally-cleared three phase fault on line 5015
    - Normally-cleared three phase fault on line 5021

Description of the Study

PJM provided a modified 2011 series MMWG 2017 light load power flow case and the corresponding dynamics data. PJM also specified twenty seven (27) normally cleared and stuck breaker contingencies to be applied on thirteen (13) line outage cases and the All-in case. The combination of the contingencies and the fourteen power flow cases resulted in 355 contingencies. All these contingencies are studied with the PSSs of Salem unit 2 and Hope Creek unit out of service.

Results of the Study without any Solution

Out of the 355 contingency cases 81 of them were found to be transiently unstable while the rest, 274 cases were transiently stable.

Results of the Study with Solution

- With the two TCSCs on lines 5023 and 5024 and the 500-MVAR SVC near the New Freedom station, All the contingencies were transiently stable and the damping of the modes associated with the three generators, Salem 1 & 2 and Hope Creek 1, are greater than 4%.
- Plots of the generator angles and terminal voltages and Artificial Island 500-kV voltages, for the simulation with the solution, are attached in Appendix A.
- The pre-fault and post-fault values of the generators' terminal voltages and Artificial Island 500-kV voltages are included in Appendix B.
- These results show that the pre-fault and the post fault voltages of the Artificial Island 500-kV buses are within the operating range of 1.0 – 1.1 PU. The post-fault steady state voltages are above 0.986 PU at the Salem and Hope Creek 500 kV buses.
- However, the terminal voltage of Salem G1 is 0.9497 PU for the outage of line 5015 and the post fault voltages are even lower. In order to keep the terminal voltage within above 0.95 PU pre trip and post trip, the unit terminal voltage should be held at about 0.965 PU with the outage of the 5015 line in pre-fault. This can be done either by letting the generator output more VAR(increase the Qmax value in the power flow) or install a switchable capacitor at the station. Doing so will eliminate the violation of the operating range. From the stability point of view, simulating the contingencies with low terminal voltage is more conservative and that is what is done here. Therefore, the proposed solution is more robust than it needs to be if the generator terminal voltage is greater than or equal to 0.95 PU.
- The voltage drop magnitude from pre-fault to post-fault steady state conditions do not exceed 2% and 2.5% respectively for Salem units and Hope Creek unit.
- The worst angle deviations of each of the contingency cases are included in Appendix A.
- The worst of the worst angle deviation is 64.12 degrees (Salem G1 unit) for contingency 2A_2017SLL_L5038_TCSC2 (contingency 2A, fault applied on line 5015 for the case with Line 5038 is out). This shows that there is a large stability margin. The study results show that the unit VAR absorption is not limited by stability constraints; it is limited rather by the generator terminal voltage being at the lower end of the operating voltage range. The out files including all the required monitored facilities and data channels for all required contingencies are included in the data package. The naming convention of the out files is as shown below.
- 2A_2017SLL_L5038_TCSC2
- 2A - Contingency name,
- 2017SLL_5038 - Power flow with line 5038 out
- TCSC2 – Associated with the solution

Right of Ways

Dominion has investigated and found multiple land parcels located along the existing corridor that would be suitable for constructing this new substation. This would require short line segments to be constructed from the existing lines that would terminate into this new substation or the construction of in-line dead-end structures. Installation of any line tapping facilities will require an outage to the corresponding 500kV line.

Dominion has procured a confidential report from a third party consultant that if requested can be provided to PJM on these potential substation sites.

Permitting and Construction Schedule

Depending on the parcel location, permits could be required from federal, state, and local jurisdictions.

- Examples of federal would be Corp of Engineers permits.
- Examples of both state and local permitting would be Erosion and Sediment Plan permits and site construction permits.
- There may be local rezoning requests and sound or screening permits as well.

It is estimated that 36 to 48 months after project approval will be required to complete this project. Included in this estimate are permitting, site development, delivery of long lead equipment and installation.

Cost Estimates

New Substation	
500 MVAR 500 kV SVC *	$70 Million
Two 500 kV TCSC Series Capacitors*	$25 Million
Substation Land and Development	$9 Million
Eight 500 kV 4000 amp breakers	$15 Million
Total	$119 Million

*Long lead items – built into construction time

East Windsor Substation – Existing	
Install two additional 500 kV 4000 amp breakers	$4 Million
Total	$4 Million

New Freedom – Existing	
Install two additional 500 kV 4000 amp breakers	$4 Million
Total	$4 Million

Hope Creek Substation – Existing	
Install two additional 500 kV 4000 amp breakers	$4 Million
Total	$4 Million

Red Lion Substation – Existing	
Install one additional 500 kV 4000 amp breakers	$2 Million
Total	$2 Million

** System protection costs are embedded in the figures above*

The total estimated cost for Option 1 Proposal = $133 Million

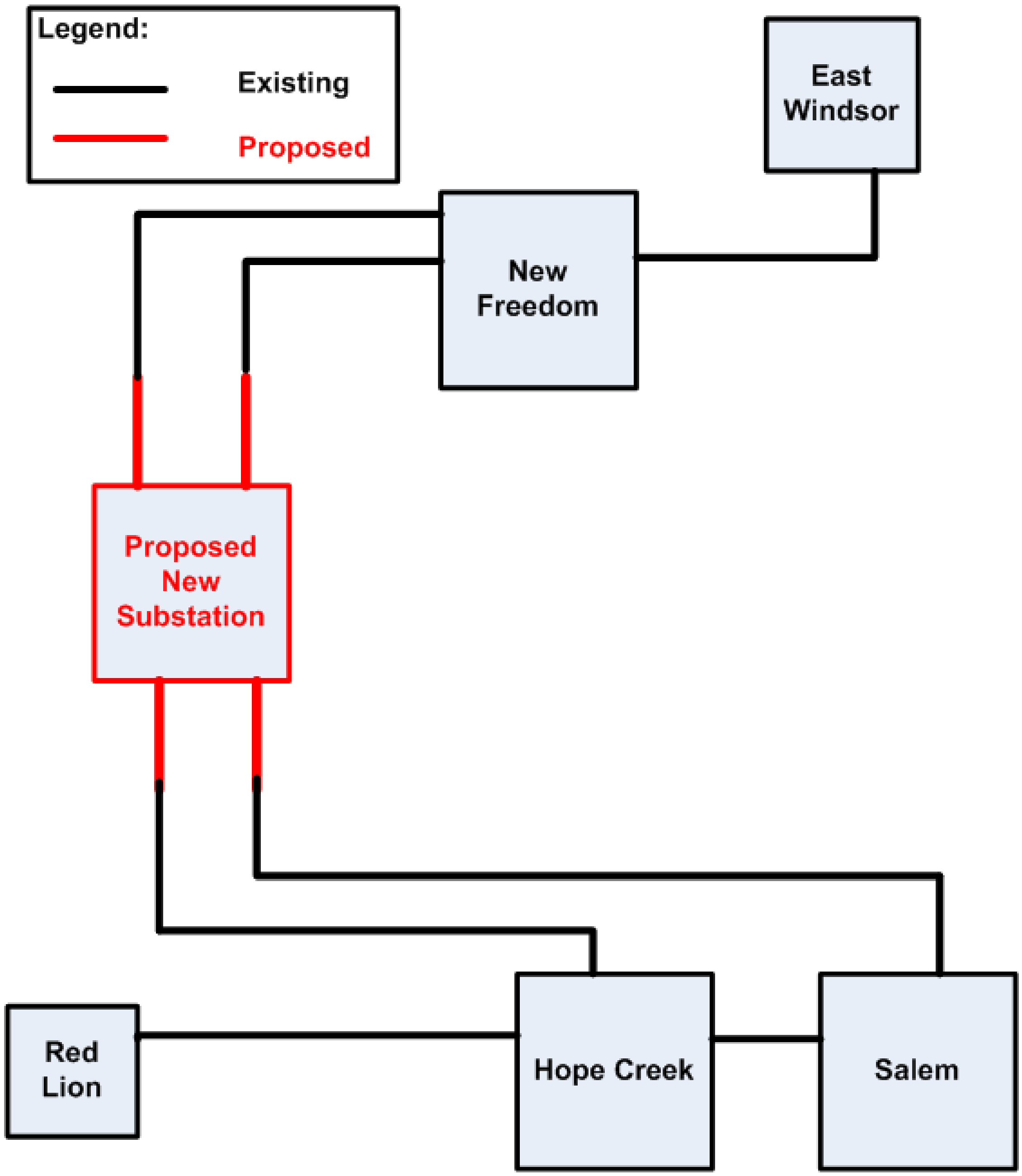

Figure 2 One Line Diagram for the Proposed TCSC/SVC Solution

APPENDIX A

Angle Deviations –Excel sheet is included with the electronic data package

APPENDIX B

Pre and Post Trip Voltages - Excel sheet is included with the electronic data package

APPENDIX C

Protection of Series Compensated Line

Dominion currently operates two 500 kV series capacitors on the Bath to Valley and Bath to Lexington lines. These series capacitors have been in services for several years and the protection philosophy described below has been successfully applied.

The protection strategy for the project lines that will be incorporating the variably compensating series capacitors seems to be almost identical to those with statically compensating series banks, like those on our Bath County lines to Lexington and Valley. This assessment is based on the knowledge that that these series banks will be bypassed (shorted out) very quickly (within a cycle) for faults occurring in their "electrical vicinity". "Electrical vicinity" refers the protection zone of the line for which the bank is compensating, as well as the zones of adjacent and other nearby lines. For these faults in the electrical vicinity of the bank, the understanding is that the "short period compensation boost", will not apply. As opposed to the application of the static series banks, where the high speed shorting action quickly results in the totally uncompensated line, the same action for the variably compensating series bank will introduce a small series inductance, which will increase the uncompensated inductive reactance of the line about 3%. This additional reactance will be of no consequence in protecting the line.

A few special considerations apply for the proper protection of series compensated lines for which the series compensating bank is both: 1) included as part of the line zone, and 2) quickly removed under an electrically nearby fault condition, as described above:

- "Underreaching Impedance Tripping" Functions (both phase & ground versions) [a.k.a. "Zone 1"] -Due to the very high speed response of this function, it is subject to possibly initiating a terminal trip before the series bank is effectively removed. One option would be setting Zone 1 to properly underreach for the fully (maximum) compensated condition of the line. Generally, however, this would not be preferred, since it would lead to a greatly underreaching Zone 1 coverage of the uncompensated line. Alternately, if it is set, as normal, for properly underreaching the uncompensated line impedance, a blocking of the Zone 1 response should be introduced until the series bank is removed before an undesirable over-trip would be initiated. The SEL-421, used in the standard protection scheme for DVP transmission lines, incorporates a "Series Compensation" protection feature that is enabled for the Bath County 500 kV lines. With this feature enabled, Zone 1 is set to underreach the uncompensated line. Given the capacitive reactance of the fully compensating series bank; the scheme's logic then makes a determination as to whether or not the series bank is in between relay and the fault. If it determines the bank's reactance to be in-line to the fault, a blocking of the Zone 1 tripping is introduced until the bank is by-passed, thereby, increasing the Zone 1 operating time by about a cycle. If the logic determines that the bank is not between the relay and fault, there is no block of Zone 1.

- "Underreaching Directional Ground Overcurrent Tripping" Functions –Concerns similar to those outlined above for "Zone 1" would apply.

- “Pilot Impedance Tripping” & “Time-delayed Impedance Tripping” Functions (both phase & ground versions) –No changes are required; the normal overreaching coverage of the uncompensated line impedance is applied.

- “Pilot Directional Ground Over current Tripping Functions -No changes are required; the normal overreaching coverage of the uncompensated line is applied.

- “Pilot Impedance Blocking” Function (both phase & ground versions) –For this function, a setting yielding greater coverage than normal will typically be required. To ensure that the blocking signal is started for every fault the remote terminal’s pilot tripping will see outside the line zone (behind the local terminal), this function must be set to properly cover the remote terminal’s pilot tripping zone’s overreach of its terminal. Due to the very high-speed response of this function, coupled with the fact that the series compensation should always be present upon fault incidence, its setting will need to cover the worst case overreach, which will exist before the series bank is removed.

- “Pilot Directional Over current Ground Blocking” Function –Concerns analogous to those outlined above for the impedance versions of this function will apply.

- “Microprocessor Relay Directional Control Elements” –Microprocessor packages typically have a series of “directional control” elements used for ascertaining the directionality for the various impedance and over current functions. Since the temporary presence of the series capacitor line compensation can adversely affect the generalities assumed for determining proper direction, settings other than the usual ones are typically recommended. For normal applications of the DVP standard package (SEL-421), the settings for all the directional control elements are automatically set for the “typical/standard” values by simply setting the global enable for the directional control to “AUTO”. For applications of series line compensation, the manufacturer (SEL) has specially recommended settings for a number of the directional control elements; in order the user to apply these “custom” settings, the directional control enable must be set to “Y” (instead of “AUTO”).

In addition to the series compensated lines, the directional determination for faults in line zones without compensation, that are electrically close to series banks in adjacent lines, can also be adversely affected by resulting voltage and current inversions. Special settings for the directional control elements of these lines may also apply.

APPENDIX D

RTDS and Studies Capability Statement

Electric Transmission

RTDS and Studies Capability Statement

June 13, 2013
R. Matthew Gardner, Ph.D., P.E.

Modeling and Simulation Capabilities

Dominion's modeling and simulation capabilities include a Real-Time Digital Simulator (RTDS). An RTDS is a real-time engine that simulates electric power system dynamics. Both electromechanical and electromagnetic dynamics are contemplated. Dominion's RTDS lab supports a six-rack RTDS that is capable of simulating a power system of up to 288 busses in real time. This comprehensive real-time capability provides the ability to use the RTDS for experimentation, design, and testing of relaying schemes, equipment controllers, operator interactions, and many other systems that require either closed-loop or operator-in-the-loop control. Unlike other non-real-time simulation software packages like PSCAD, EMTP, PSS/E, et al., the RTDS is a sophisticated combination of hardware, software, and amplifiers that generates real time point-on-wave data. This confection of technology allows for the incorporation of external components/hardware/variables into a real time simulation case just as if these external components were implemented in a live power system. Figure 2 shows Dominion's RTDS lab. Table 1 provides an overview of the RTDS specifications.

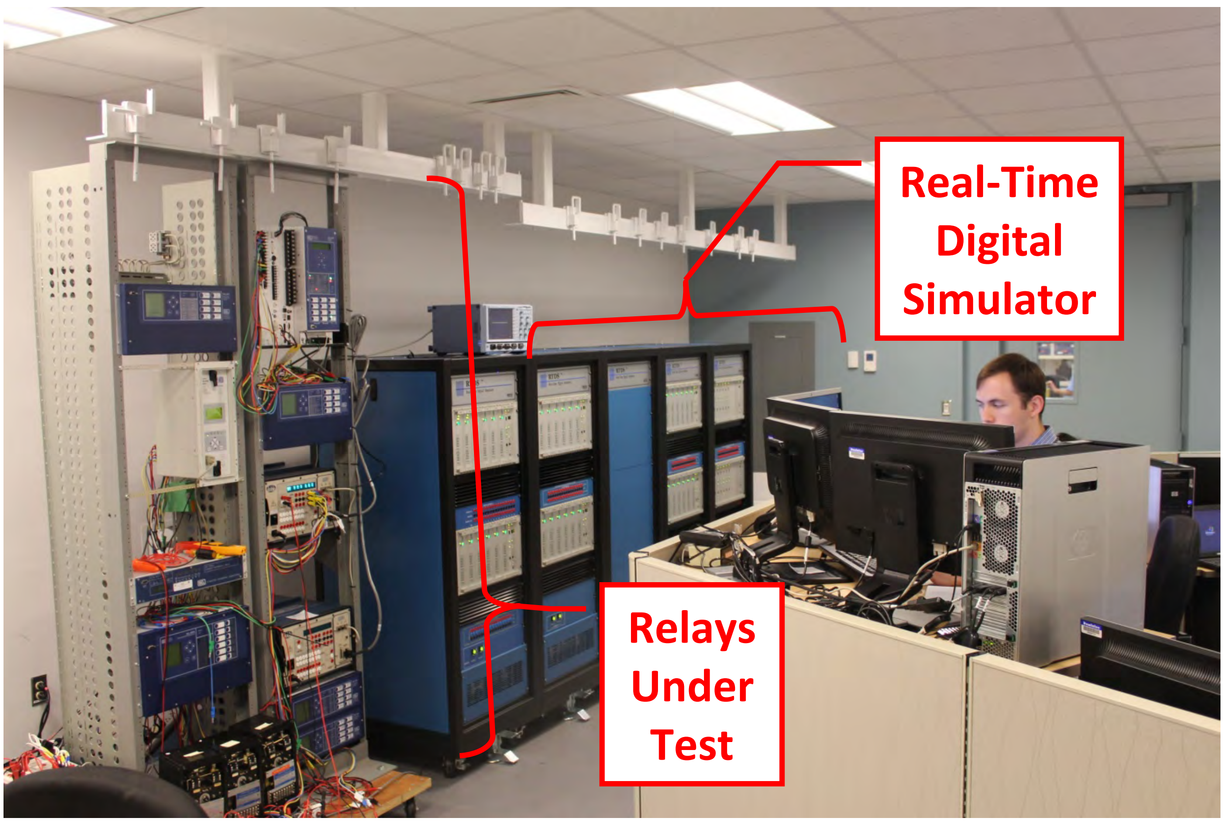

Figure 2: Dominion's RTDS Lab.

Table 1: Dominion's RTDS Specifications

Card Type	Description	Number
GTWIF	Parallel Processing Connections	8
PB5	Simulation Processor Card (Up to 288 simulated buses)	36
GTIRC	Inter-Rack Communication	6
GTSYNC	GPS Clock Synchronization	1

GTAO	12 Channel Analogue Output	9
GTDI	64 Channel Digital Input	2
GTFPI	16 Channel High Voltage (250 V) I/O	4
GTNET	External Device Communication (e.g. Physical Relay I/O)	16
GTAI	12 Channel Analog Input	1

Summary	Description	Number
Racks	Inter-Timestep Groups	6
Network Size	48 Buses per Rack Maximum	288

To date, Dominion has used or is using the RTDS to support a number of studies including:

- System restoration and blackstart simulation and testing
- Relay misoperation replication and investigation
- Synchrophasor Simulation and Operator Training
- SVC controller testing
- System protection design, evaluation, and testing addressing issues such as:
  - Open-phase detection
  - Transformer Inrush Studies
  - Distributed generation (wind/solar) impacts

Dominion's simulation capabilities also include PSS/E, MATLAB, ANSYS Maxwell 3D, ASPEN, and PSCAD, amongst others. Perhaps more importantly, Dominion has demonstrated the ability to leverage these tools to their maximum extent via the company's Dominion Technical Solutions, Inc. ("DTech") Engineering team. The DTech Engineering team comprises a diverse talent pool with responsibilities ranging from major electric transmission equipment specification to system analysis. This engineering consulting team both leads technical investigations and root cause analyses critical to utility operations, and serves as the "major asset owner" – advising on best practices for safe and reliable operation and maintenance over the asset's lifecycle. The team specifies major power systems equipment and ensures quality through factory inspections, equipment monitoring initiatives, and active industry involvement including participation in CIGRE, IEC, IEEE, and other associations. The team also includes a lettered doctoral staff with wide academic and industry involvement. This high-power group uses state of the art tools, including the aforementioned RTDS, to support root cause analysis investigations and address specialized engineering needs within the utilities sector as an engineering consulting clearinghouse. The group is widely published as authors and editors in texts including books, refereed journals, conference papers, industry standards, and trade magazines.

APPENDIX E

TCSC

For technical information on TCSC, please look up the following link to ABB product website.

http://www05.abb.com/global/scot/scot221.nsf/veritydisplay/fdf0b019e1fe08a48325771f002dbfc5/$file/a02-0158.pdf