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DC1020 - HVdc System Integration Study

Volume 4 - Multi-Terminal HVdc Link PSSE Stability Model

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Executive Summary

A custom user-written two-timestep PSSE transient stability model representing the Lower Churchill multi-terminal HVdc link has been developed for use in future PSSE studies. The model represents the dynamics of the HVdc overhead lines and cables, and includes simplified fast HVdc closed-loop controls that are directly based on the controls used in the PSCAD electromagnetic transients model.

PSSE model validation was performed against the same PSCAD model as was used in the WTO DC1020 transient stability studies. Validation testing showed excellent correlation between the PSSE and PSCAD dynamic performance for most faults during various powerflow and HVdc configurations. Any differences in results can be attributed to inherent differences between the three-phase switching solution used in an electromagnetic transient program, such as PSCAD, and the positive-sequence phasor-based solution of transient stability software, such as PSSE. Validation testing provided excellent comparability within the degree possible between two such different types of models.

The PSSE multi-terminal HVdc model was programmed to be capable of operating in bipolar or monopolar modes for the following HVdc configurations:

1. 3-terminal: Gull Island – rectifier, Soldiers Pond – inverter, Salisbury – inverter
2. 2-terminal: Soldiers Pond – rectifier, Salisbury – inverter
3. 2-terminal: Salisbury – rectifier, Soldiers Pond – inverter

Validation testing was performed on various powerflows to demonstrate the PSSE model performance of all three of the HVdc configurations listed above.

The validation testing was performed using the PSCAD version 4.2.1 software package and the PSSE version 30.2 software package.

Instructions on how to use the model are contained in the last section of this report.

1. Introduction

This report provides end-user instructions and validates the custom PSSE transient stability model of the multi-terminal high voltage direct current ("HVdc") link that was developed specifically for the Lower Churchill Project for work task order ("WTO") DC1020. This report discusses the results of the validation testing that was performed against the same PSCAD model that was developed and used for the transient-stability studies portion of WTO DC1020.

The multi-terminal HVdc PSSE stability model represents the three-terminal HVdc bipole connecting Gull Island (Station A) in Labrador, Soldiers Pond (Station B) in Newfoundland Island and Salisbury (Station C) in New Brunswick.

The standard PSSE library contains only a response-type model for a multi-terminal HVdc link. This response-type model does not include any of the DC line/cable dynamics, nor does it model any of the HVdc closed-loop controls. Such a model also requires that one of the inverters be operated in voltage-control mode, which is not consistent with the control scheme used by the PSCAD model in the transient stability analysis. Therefore, a custom model of the multi-terminal HVdc link was developed for use in future PSSE studies to represent the response of the multi-terminal HVdc system more accurately. This custom model is based on a two-timestep algorithm that allows for detailed controls and for HVdc overhead line and cable dynamics to be represented while still ensuring numerical stability. For more detailed information on response-type models compared to the two-timestep model, please refer to [1].

Validation testing was performed using the PSCAD version 4.2.1 software package and the PSSE version 30.2 software package.

1.1 Objectives

The objectives of the PSSE multi-terminal HVdc stability model development are to:

1. Develop a custom PSSE stability model of the multi-terminal HVdc link using simplified controls that are based on the PSCAD model used in the transient stability studies of WTO DC1020.
2. Develop a PSSE IPLAN program to provide a simple method for the end user to set up a desired powerflow on the HVdc link in the PSSE loadflow program so that the model will initialize properly for use with the custom PSSE stability model.
3. Validate the PSSE stability model against the PSCAD model for various loadflows and contingencies.

1.2 Procedure

The PSSE model was developed using the following procedure:

1. Create simplified controls based on the detailed PSCAD model for inclusion with the PSSE model.
2. Write the Fortran code to represent the multi-terminal HVdc overhead lines and cables and the DC controls for use in PSSE.

3. Validate the PSSE model by comparing dynamic performance of the PSSE model to the PSCAD model for various contingencies during various powerflow scenarios.
4. Provide instructions for the end user to implement and use the custom PSSE model.

2. PSSE Model – HVdc Configurations

The loadflow portion of the Lower Churchill multi-terminal HVdc model is set up using two PSSE multi-terminal DC line models (one for each pole of the bipole) and a series of filter shunt branches connected to the three existing system buses that will become the commutating buses of the HVdc link, namely Gull Island 230 kV bus, Soldiers Pond 230 kV bus, and Salisbury 345 kV bus. Appendix A shows this setup in an equivalent voltage-source test system, along with the PSSE bus numbers used in this test system.

As the electrode lines and ground resistances are of no impact in bipolar mode, ground resistances of each electrode and each electrode line are modeled only if the HVdc link is operating in monopolar mode. A provided IPLAN program (LCPDC.irf, as described in Section 6 herein) can be used to set up the desired HVdc configuration and powerflow, and will automatically insert the appropriate ground resistance and electrode line parameter values into the HVdc model if the user chooses to operate in monopolar mode.

The IPLAN program takes the zero impedance branches that connect each filter to the commutating bus in or out of service as needed.

The PSSE multi-terminal HVdc dynamic model was programmed to be capable of operating in bipolar or monopolar modes for the following HVdc configurations:

1. 3-terminal: Gull Island – rectifier, Soldiers Pond – inverter, Salisbury – inverter
2. 2-terminal: Soldiers Pond – rectifier, Salisbury – inverter
3. 2-terminal: Salisbury – rectifier, Soldiers Pond – inverter

Please note that the PSSE model has been programmed only to model monopolar operation in which all three terminals are operating in monopolar mode, i.e. an entire pole is out-of-service. Mixed mode operation where two terminals operate bipolar and the third terminal operates monopolar is not currently supported within the model.

While in reality it will be possible to operate any of the three terminals as rectifier or inverter, it was not possible to include all of the combinations of configurations in the PSSE model due to time constraints. The three HVdc configurations that are included in the PSSE model were chosen because they demonstrate the feasibility and worst case configurations of the multi-terminal link. Gull Island as inverter was not included as it is assumed this would be the least likely mode of operation of the Lower Churchill HVdc link.

3. PSCAD and PSSE Model Descriptions

This report compares results from two different models:

- PSSE Transient Stability Lower Churchill HVdc Model
- PSCAD (Electromagnetic Transient) Lower Churchill HVdc Model

PSSE Transient Stability is the main focus of this report. The PSSE transient stability solution is a fundamental frequency phasor-based solution, and does not represent switching harmonics or individual phase quantities. A typical timestep used in PSSE simulation is a half-cycle, or 8.33 ms, which is large relative to that used in PSCAD simulations. Accordingly, the user-written model alone is run at a smaller internal timestep in order to maintain numerical stability due to the small integration timesteps of the HVdc current, voltage, and gamma controllers, and to the differential equations associated with the line and cable capacitances and inductances. Since the PSSE model is a phasor-based solution and does not represent individual thyristors, commutation failures cannot be modeled accurately. In order to represent the response to a commutation failure of the HVdc link, the inverter is forced into "bypass" mode if the inverter extinction angle gamma falls below a certain internal model setpoint. This setpoint represents the minimum extinction angle below which the converter is assumed to fail commutation.

The PSCAD model is the actual project model used in the transient stability studies for WTO DC1020. It represents the details of all of the converter controls, including the DC converter current, voltage, and gamma controllers along with low level valve firing controls to produce firing pulses used to turn individual thyristors on and off. Filtering functions for signal measurement and conditioning are used to remove the harmonics generated by the converter. This model is the more accurate of the two, since it represents all parts of the control system and does not make any approximations. In electromagnetic transient simulation, network equations are solved at a series of discrete intervals (timesteps). A typical timestep used in a PSCAD simulation is 50 μs.

More accurate than the PSSE Transient Stability model, the PSCAD model includes all of the low-level firing controls, as well as the non-linear aspects of the electrical grid (such as transformer saturation). The application and removal of the fault are also point-on-wave dependent in the PSCAD solution (i.e. the fault can be applied at a peak voltage or at a zero point), which can affect the initial control response. The controls in the PSCAD model also respond to certain events, such as the detection of commutation failures and the sensing of individual phase voltages, which cannot be represented in the PSSE model. As such, more accurate results are expected with the PSCAD model. Transient stability programs, such as PSSE, produce only positive-sequence voltages.

4. Validation Testing – Description of Test Systems and Contingencies

4.1 Equivalent Test System

Validation of the PSSE model was first performed using an equivalent test system as shown in Appendix A. A test system with simple ac equivalents representing short-circuit levels of 8694 MVA at Gull Island (Station A), 2994 MVA at Soldiers Pond (Station B) and [redacted] MVA at Salisbury (Station C) were used. The Gull Island terminal was operated in a bipolar configuration as the rectifier, supplying rated power to the Soldiers Pond and Salisbury terminals, both operating as inverters.

For all dynamic simulations, loads were modeled with the real power portion as constant current loads and with the reactive power portion as constant impedance loads.

The frequency controller at Soldiers Pond was enabled for all simulations.

4.2 Reduced PSSE Model Test System

Validation testing was then performed using the reduced Newfoundland Island and Labrador ac systems PSSE model, the same model representation as was used to perform the transient stability studies in PSCAD. The New Brunswick ac system remained as an equivalent voltage source.

In each of the three possible HVdc configurations that can be simulated with the PSSE model (as described in Section 3) it is possible to run any of them in bipolar or monopolar operation, resulting in a total of six possible HVdc configurations. Monopolar operation was only tested on the three-terminal HVdc configuration as it can be assumed that this validation testing can be extended to both of the two-terminal configurations.

The two two-terminal HVdc configurations, one in which Soldiers Pond is the rectifier and the other in which Salisbury is the rectifier, were tested in bipolar operation using powerflow cases BC8-DC8 and BC1-DC7 respectively.

In order to test the four HVDC configurations described above, the following powerflows were used for validation testing (please refer to the report for the Transient Stability Studies of WTO DC1020 [2] for detailed descriptions of the powerflow cases):

BC1-DC1 - Rated bipolar operation with Gull Island as rectifier and Soldiers Pond and Salisbury as inverters (3-terminal)

BC2-DC3 - Monopolar operation with Gull Island as rectifier and Soldiers Pond at 1.5 pu and Salisbury at 1.1 pu overload as inverters (3-terminal)

BC8-DC8 - Bipolar operation with Soldiers Pond as rectifier supplying 175 MW to Salisbury (2-terminal)

BC1-DC7 - Bipolar operation with Salisbury as rectifier supplying rated power to Soldiers Pond (2-terminal)

4.3 Contingencies

The test cases that were simulated are listed in Table 1. Results for all cases comparing the PSCAD model and PSSE model are provided in Appendices 3-7. The PSSE model validation tests were run with the default PSSE timestep of 8.33 ms.

Table 1
Test Case Descriptions

Test No.	Contingency No. [2]	Power Flow Case	Power Flow Description	Test Description
T1.1	n/a	EQUIV	Equivalent Voltage Source System representing BC1-DC1. [See Appendix C]	**DC Voltage Reference Step at Station A.** 1.0 pu -> 0.95 pu -> 1.0 pu
T1.2	n/a	EQUIV		**DC Current Reference Step at Station B.** 1.0 pu -> 0.95 pu -> 1.0 pu
T1.3	n/a	EQUIV		**DC Current Reference Step at Station C.** 1.0 pu -> 0.95 pu -> 1.0 pu
T1.4	n/a	EQUIV		**3PF at Station A to 0% voltage for 100 ms.** No equipment tripping.
T1.5	n/a	EQUIV		**3PF at Station B to 0% voltage for 100 ms.** No equipment tripping.
T1.6	n/a	EQUIV		**3PF at Station C to 0% voltage for 100 ms.** No equipment tripping.
T1.7	n/a	EQUIV		**3PF at Station A to 50% voltage for 100 ms.** No equipment tripping.
T1.8	n/a	EQUIV		**3PF at Station B to 50% voltage for 100 ms.** No equipment tripping.
T1.9	n/a	EQUIV		**3PF at Station C to 50% voltage for 100 ms.** No equipment tripping.
T1.10	n/a	EQUIV		**3PF at Station A to 90% voltage for 100 ms.** No equipment tripping.
T1.11	n/a	EQUIV		**3PF at Station B to 90% voltage for 100 ms.** No equipment tripping.
T1.12	n/a	EQUIV		**3PF at Station C to 90% voltage for 100 ms.** No equipment tripping.
T2.1	C15	BC1-DC1	Bipolar three-terminal operation. Gull Island rectifier Soldiers Pond inverter – 1.0 pu Salisbury inverter – 1.0 pu 2016 winter peak Newfoundland Island load (1600 MW) [See Appendix D]	**3PF at Station B to 0% voltage for 100 ms.** No equipment tripping.
T2.2	C60	BC1-DC1		**3PF at Station A to 0% voltage for 100 ms.** No equipment tripping.
T2.3	C70	BC1-DC1		**3PF at Station C to 0% voltage for 100 ms.** No equipment tripping.
T2.4	C17	BC1-DC1		**3PF at Bay d'Espoir 230 kV bus.** Trip Bay d'Espoir – Pipers Hole line and refinery load.
T2.5	C18	BC1-DC1		**3PF at Pipers Hole 230 kV bus.** Trip Pipers Hole – Sunnyside line.
T2.6	C19	BC1-DC1		**3PF at Sunnyside 230 kV bus.** Trip Sunnyside – Western Avalon line.
T2.7	C20	BC1-DC1		**3PF at Western Avalon 230 kV bus.** Trip Western Avalon – Soldiers Pond line.
T2.8	C21	BC1-DC1		**3PF at Soldiers Pond 230 kV bus.** Trip Soldiers Pond – Hardwoods line.
T2.9	C22	BC1-DC1		**3PF at Oxen Pond 230 kV bus.** Trip Oxen Pond – Soldiers Pond line.

Test No.	Contingency No. [2]	Power Flow Case	Power Flow Description	Test Description
T2.10	C23	BC1-DC1		**3PF at Holyrood 230 kV bus.** Trip Holyrood – Soldiers Pond line.
T2.11	C72	BC1-DC1		**3PF at Pipers Hole 230 kV bus.** Trip Pipers Hole – Bay d'Espoir line.
T2.12	C26	BC1-DC1		**3PF at Pipers Hole 230 kV bus.** Trip Pipers Hole synchronous condenser.
T2.13	C28	BC1-DC1		**3PF at Soldiers Pond converter transformer 230 kV** Trip converter transformer and Pole 2.
T3.1	C15	BC2-DC3	Monopolar 3-terminal operation. Gull Island rectifier Soldiers Pond inverter – 1.5 pu overload Salisbury inverter – 1.1 pu overload Future winter peak Newfoundland Island load (1800MW) [See Appendix E]	**3PF at Station B to 0% voltage for 100 ms.** No equipment tripping.
T3.2	C60	BC2-DC3		**3PF at Station A to 0% voltage for 100 ms.** No equipment tripping.
T3.3	C70	BC2-DC3		**3PF at Station C to 0% voltage for 100 ms.** No equipment tripping.
T3.4	C17	BC2-DC3		**3PF at Bay d'Espoir 230 kV bus.** Trip Bay d'Espoir – Pipers Hole line and refinery load.
T3.5	C19	BC2-DC3		**3PF at Sunnyside 230 kV bus.** Trip Sunnyside – Western Avalon line.
T4.1	C15	BC8-DC8	Bipolar 2-terminal operation. Gull Island OFF Soldiers Pond rectifier Salisbury inverter – 175 MW Summer night Newfoundland Island load (625 MW) [See Appendix F]	**3PF at Station B to 0% voltage for 100 ms.** No equipment tripping.
T4.2	C70	BC8-DC8		**3PF at Station C to 0% voltage for 100 ms.** No equipment tripping.
T4.3	C17	BC8-DC8		**3PF at Bay d'Espoir 230 kV bus.** Trip Bay d'Espoir – Pipers Hole line and refinery load.
T4.4	C19	BC8-DC8		**3PF at Sunnyside 230 kV bus.** Trip Sunnyside – Western Avalon line.
T5.1	C15	BC1-DC7	Bipolar 2-terminal operation. Gull Island OFF Soldiers Pond inverter – 1.0 pu Salisbury rectifier 2016 winter peak Newfoundland Island load (1600 MW) [See Appendix G]	**3PF at Station B to 0% voltage for 100 ms.** No equipment tripping.
T5.2	C70	BC1-DC7		**3PF at Station C to 0% voltage for 100 ms.** No equipment tripping.
T5.3	C26	BC1-DC7		**3PF at Pipers Hole 230 kV bus.** Trip Pipers Hole synchronous condenser.

5. Validation Testing – Comparison of PSSE and PSCAD Models

The steady-state and dynamic performance of the PSSE model compares very well to the PSCAD model. Despite inherent differences between the models the comparability of results between the two models is excellent, and correlations are within the degree of accuracy possible given that PSCAD and PSSE use different main program solution methods.

The PSSE Transient Stability model compares very well to the PSCAD model; however, there are some slight differences evident in some cases. The controls for the converter are not represented in full detail in the PSSE model, and a simplified control system has been assumed to be sufficiently accurate and practical for the purposes of transient stability modeling.

Since the PSSE model is a phasor-based solution and does not represent individual thyristors, commutation failures cannot be modeled accurately. In order to represent the response of the HVdc link to a commutation failure, the inverter is forced into "bypass" mode if the inverter firing angle gamma falls below a certain internal model setpoint. Therefore, disturbances that result in a commutation failure in PSCAD may look slightly different in PSSE.

Another inherent difference between the PSCAD and PSSE models is the measurement of the voltages and real and reactive powerflows in these models. The PSCAD method of determining an RMS quantity uses instantaneous three-phase inputs; whereas in PSSE the RMS value is calculated directly.

The measurement of frequency is also different between the PSCAD and PSSE models. In the PSCAD model, the frequency measurement is based on a real-world algorithm in which instantaneous bus voltages are processed via an industry-accepted method used for measuring frequency. In the PSSE model, the frequency measurement is simply taken as the derivative of the bus angle. Due to fast changes in the current injected from the PSSE model, it was seen for certain faults in PSSE that numerical spikes in frequency were possible depending on the fault location. In order to remove or lessen these spikes in frequency, the time constant for the frequency filter used in PSSE was set to 100ms instead of the default 33.3ms. For the two-terminal mode of operation in which Salisbury is operating as the rectifier sending power to Soldiers Pond, frequency spikes at Salisbury that were caused by disturbances in the Newfoundland Island system that resulted in a commutation failure at Soldiers Pond require the frequency filter time constant to be set even higher, up to 200ms. The frequency filter is used to remove numerical issues associated with the PSSE frequency measurement. The time constant for this filter can be modified using the ALTR -> Solution Parameters command in the PSSE dynamics program.

To summarize, the most important issue is that the PSSE model injects the correct currents such that the real and reactive powers at the AC buses – and especially the AC bus voltages – look as close to those of the PSCAD model as possible. The AC bus voltage responses between PSCAD to PSSE compare very well. The upcoming section discusses the test results in more detail.

5.1 Results – Equivalent Test System

PSSE results for the validation testing performed on the equivalent test system provide a good comparison with PSCAD.

Some differences are notable in a few cases, particularly the 50% faults in which the HVdc system is on the verge of switching control modes on fault recovery. In some of the PSCAD cases this control mode switching occurs; whereas the PSSE model does not quite switch control modes. It is important to note that control mode switchover can have a noticeable impact on the overall response of the converter. Therefore, responses of the two models look slightly different.

In addition, some slight differences can be seen in current reference responses during fault cases. This is due to the fact that these current references are non-linear functions that are very dependent on the DC-voltage responses (due to voltage-dependent current limits). Any slight difference in DC-voltage response will cause a difference in DC current order.

Despite slight differences as described above, the overall trend of the responses between PSCAD and PSSE are very similar, and become nearly identical by several hundred milliseconds after fault clearing.

Please note that the PSCAD AC voltages are RMS measurements that have a smoothing time constant of 20ms, whereas the PSSE AC voltages are not smoothed, with the exception of the ac voltage measurements on the commutating buses that are coming from measurements inside the custom PSSE HVdc model; these three PSSE AC commutating bus voltages have a smoothing time constant of 8ms which is still not the same as PSCAD. Therefore the ac voltages look slightly different especially on fault application and clearing.

Results for the equivalent test system are provided in Appendix C.

5.2 Results – Reduced PSSE Model Test Systems

Results for the validation testing performed on the reduced PSSE model test systems provide a good comparison with PSCAD as well.

The same comments can be made for these cases as was described for the equivalent test system in Section 5.1.

In addition to these comments, it should be noted that the 300 MVAR synchronous condensers modeled at Pipers Hole and Soldiers Pond do not model the same exciters in PSSE and PSCAD. The PSCAD model includes a more detailed and better exciter model, which was not available in the PSSE library. Therefore, the differences in responses of the synchronous condensers in PSCAD and PSSE are sometimes cause for slight differences in voltage and reactive power quantities in the Newfoundland Island ac system, particularly for faults near to the synchronous condensers.

Also is should be noted that good correlation was seen between the frequency responses of the PSSE and PSCAD models, except during faults. This is because the PSCAD frequency measurement stops measuring during a fault whereas the PSSE model does not, therefore the frequency response during a fault cannot be fairly compared between the two models.

Results for the reduced PSSE model test systems are provided in Appendices D-G.

Please note that for the BC8-DC8 cases in which the Soldiers Pond terminal is exporting to the Salisbury terminal, the transient stability studies determined that the worst case Bay d'Espoir-Pipers Hole fault (contingency 17) requires a fast runback of the HVdc in order to maintain ac system stability on the Newfoundland Island. The custom PSSE model does not include this runback scheme and so this contingency is not shown in the validation testing.

6. Model Use Instructions for End User

6.1 Model Files Delivered

The following files were delivered in electronic format. All testing was performed on Windows XP platform, PSSE Version 30.2.

CLCPDC.obj	Lower Churchill HVdc dynamic controls and line/cable model compiled code
LCP_HVDC.dyr	HVdc model dynamic data input file
LCP_HVDC.raw	Powerflow raw data file corresponding to BC1-DC1 powerflow case, 1600 MW Gull Island rectifier, 800 MW Soldiers Pond Inverter, 800 MW Salisbury inverter (rated)
LCPDC.ipl	IPLAN program code for user to set up a valid powerflow operating point for the Lower Churchill HVdc link
LCPDC.irf	Compiled IPLAN program
LCP_input.dat	Input text file containing commutating bus and filter bus numbers, required by IPLAN program.
Test-System.raw*	Equivalent test system powerflow data file corresponding to powerflow BC1-DC1
Test-System.dyr	Equivalent test system dynamic data file corresponding to powerflow BC1-DC1

*If other test systems representing different HVdc powerflows are required, the provided IPLAN program can be used on the test system powerflow case provided to move to a different operation point. Please see Section 6.3 herein, describing the IPLAN program.

6.2 Notes for First Time Model Use

Prior to performing a dynamic simulation with the Lower Churchill HVdc link in PSSE, the following steps must be taken:

1. The HVdc link and associated equipment must be added to the existing large system loadflow SAV case, as shown in the provided LCP_HVdc.raw file. PLEASE NOTE: The bus numbers associated with the rectifier and inverter commutating buses, the filter buses, and the DC line numbers associated with both HVdc poles can be changed to whatever new bus/line numbers are desired; however, the DYR file must then be changed to match the loadflow configuration (step 3, below). The filters are connected to the ac commutating buses through zero impedance branches and are represented as bus shunts. All circuit IDs for these zero impedance branches should be “1”.

2. The provided HVdc controls and line/cable dynamics model file, titled "CLCPDC.obj", must be placed with other model object files.
3. The contents of the provided dynamic data file, titled "LCP_HVDC.dyr", must be added into the existing large system SNP snapshot file. PLEASE NOTE: The bus numbers associated with the rectifier and inverter commutating buses as well as the filter buses must be changed to match the loadflow configuration.

6.3 IPLAN Program to Move to a New HVdc Loadflow Operating Point

Once the model has been added to a powerflow case (as described in Section 7.2), the provided IPLAN program, LCPDC.irf, should be used to automatically set up the desired operating point of the HVdc link in the powerflow case.

The IPLAN program contains all of the filter-switching logic. It also ensures that a minimum number of filters are in service for harmonic performance requirements. The PSSE network solution will automatically determine the converter transformer tap-changer setpoints based on the firing angle limits as set in the provided loadflow HVdc data.

Before running the IPLAN program the user must ensure the text file titled "LCP_input.dat" contains the PSSE bus numbers of the commutating buses and the filter buses. An example text file has been included in the model files with bus numbers matching those used in the test system. These numbers should be modified to match the actual loadflow case being used.

The user will be asked to provide the following inputs to the IPLAN program:

----

1. Whether the HVdc link is to be operated in bipolar or monopolar mode.

```
-------------------------

SELECT THE NUMBER OF POLES IN OPERATION (NORMAL MODE IS BIPOLAR OPERATION):
1 = MONOPOLAR OPERATION
2 = BIPOLAR OPERATION
(IF MONOPOLAR OPERATION IS SELECTED, THEN THE NEGATIVE POLE WILL BE BLOCKED)
```

2. The user is allowed to select from the following HVdc configurations. The PSSE model is programmed to operate in one of only three configurations.

```
-------------------------
SELECT FROM THE FOLLOWING THREE HVdc CONFIGURATIONS (NORMAL CONFIGURATION IS NO 1):
 CONFIG NO   GULL ISLAND   SOLDIERS POND     SALISBURY
     1        RECTIFIER     INVERTER          INVERTER
     2        BLOCKED       RECTIFIER         INVERTER
     3        BLOCKED       INVERTER          RECTIFIER

 ENTER CONFIG NO?(1,2,3)
```

3. Depending on the HVdc configuration selected in Step 2 above, the user will be asked first if they would like to change the inverter power order, and, if so, what the desired power order is on a per-pole basis. The rated power at both Soldiers Pond and Salisbury during bipolar operation is 400 MW per pole. During monopolar operation the continuous overload rating at Soldier Pond is 1.5 pu and at Salisbury is 1.1 pu. Soldiers Pond can also operate at 2 pu overload for 10 minutes.

```
________________

  CURRENT SOLDIERS POND POWER ORDER (PER POLE)                      =   399.6(MW)
  CURRENT SOLDIERS POND INVERTER DC CURRENT MAGNITUDE               =   888.0(A)
  CURRENT MAGNITUDE OF DC POWER INFEED AT SOLDIERS POND (PER POLE) =   384.8(MW)
  CHANGE IT?(y/n)
  y
  ENTER SOLDIERS POND INVERTER OUTPUT POWER
  (MAGNITUDE OF SCHEDULED POWER IN MW, PER POLE)
    300.0 MW
 -------------------------
  CURRENT SALISBURY POWER ORDER (PER POLE)                        =   399.6(MW)
  CURRENT SALISBURY INVERTER DC CURRENT MAGNITUDE                 =   888.0(A)
  CURRENT MAGNITUDE OF DC POWER INFEED AT SALISBURY (PER POLE)   =   381.3(MW)
  CHANGE IT?(y/n)
  n
 -------------------------
```

4. Then the IPLAN will solve the powerflow using the PSSE activity FDNS (fast decoupled Newton solution) with input from the user as to the options for the solution.

```
-------------------------
  SETTING INITIAL FILTER STATUS
  ENTER OPTIONS FOR FDNS POWERFLOW SOLUTION

  TAP CODE IS 0 TO LOCK, 1 FOR STEPPING, 2 FOR DIRECT
  AREA INT CODE IS 0 TO DISABLE, 1 FOR TIE LINES ONLY, 2 FOR TIE LINES AND LOADS

  ENTER:
  [TAP] , [AREA INT] , [1 FOR PHASE] , [1 TO FLAT] , [1 TO LOCK] , [1 TO LOCK ]
  [CODE]   [ CODE ]    [ SHIFTERS  ]   [  START  ]   [D.C. TAPS]   [SWCH SHNTS]
   1   ,             ,     1         ,             ,             ,
```

5. Then the IPLAN will output a powerflow summary of the HVdc operating point and filter statues, and indicate whether or not the powerflow solution reached convergence.

```
 POWERFLOW SOLUTION REACHED CONVERGENCE TOLERANCE
  -------------------------
  GULL ISLAND FILTER ADJUSTMENT

  REACTIVE POWERFLOW ABSORBED BY CONVERTER          =   723.4 (MVAR)
  REACTIVE POWERFLOW SUPPLIED BY FILTERS            =   820.2 (MVAR)
  REACTIVE POWER EXCHANGE WITH THE AC SYSTEM        =    96.8 (MVAR)
  NO CHANGE FOR FILTER STATUS

  -------------------------
  SOLDIERS POND FILTER ADJUSTMENT

  REACTIVE POWERFLOW ABSORBED BY CONVERTER          =   445.7 (MVAR)
  REACTIVE POWERFLOW SUPPLIED BY FILTERS            =   423.0 (MVAR)
  REACTIVE POWER EXCHANGE WITH THE AC SYSTEM        =   -22.6 (MVAR)
```

```
        NO CHANGE FOR FILTER STATUS

        -------------------------
        SALISBURY FILTER ADJUSTMENT

        REACTIVE POWERFLOW ABSORBED BY CONVERTER          =   451.0 (MVAR)
        REACTIVE POWERFLOW SUPPLIED BY FILTERS            =   394.3 (MVAR)
        REACTIVE POWER EXCHANGE WITH THE AC SYSTEM        =   -56.7 (MVAR)
        NO CHANGE FOR FILTER STATUS

-------------------------

         ------------------------------------------------------------
         |              FINAL FILTER STATUS:                        |
         ------------------------------------------------------------
         |FILTER NO      | GULL ISLAND | SOLDIERS POND | SALISBURY   |
         ------------------------------------------------------------
         |      0        |      1      |       1       |      1      |
         |      1        |      1      |       1       |      1      |
         |      2        |      1      |       1       |      1      |
         |      3        |      1      |       1       |      1      |
         |      4        |      1      |       1       |      1      |
         |      5        |      1      |       1       |      1      |
         |      6        |      1      |       1       |      1      |
         |      7        |      1      |       1       |      1      |
         |      8        |      0      |       0       |      0      |
         |      9        |      0      |       0       |      0      |
         ------------------------------------------------------------

         ------------------------------------------------------------
         |              POWERFLOW SUMMARY:                          |
         ------------------------------------------------------------
         |ACTIVE POWER   |  779.6(MW)  |  385.0(MW)    |  363.2(MW)  |
         |REACTIVE POWER*|   96.8(MVAR)|  -22.6(MVAR)  |  -56.7(MVAR)|
         |  DC CURRENT   | 1732.4(A)   |  888.0(A)     |  844.4(A)   |
         |  DC VOLTAGE   |  450.0(kV)  |  433.6(kV)    |  430.1(kV)  |
         ------------------------------------------------------------
         * EXCHANGE WITH AC SYSTEM
         -------------------------
```

6.4 Dynamic Model User – Settable Parameters – CONs and ICONs

The model data sheet is contained in Appendix B. The CONs (real constants) and ICONs (integer constants) are described below.

6.4.1 CONs

PREFDC_A (J): Power reference at Gull Island (Station A) (pu). The dynamic model will automatically initialize this CON to match the steady-state conditions of the loadflow case. This CON can be used dynamically to change the DC power reference, but should be changed only if Station A is operating as the inverter. <u>However the PSSE model is not programmed to model Gull Island as an inverter in any of the HVdc configurations included in the PSSE model, therefore this CON should not be changed.</u> The filter-switching logic is included in the dynamic model; however, tap-changer control is not included (due to the very slow action of tap-changer control). Therefore, the simulation should be accurate to approximately 10 seconds, at which time tap changers would begin to act. The dynamic model should therefore not be used to move to a new steady-state operating point.

PREFDC_B (J+1): Power reference at Soldiers Pond (Station B) (pu). The dynamic model will automatically initialize this CON to match the steady-state conditions of the loadflow case. This CON can be used dynamically to change the DC power reference but should be changed only if Station B is operating as an inverter, i.e. only in HVdc configurations 1 and 3 [see Section 6.3 (2)]. The filter-switching logic is included in the dynamic model; however, tap-changer control is not included (due to the very slow action of tap-changer control). Therefore, the simulation should be accurate to approximately 10 seconds, at which time tap changers would begin to act. The dynamic model should therefore not be used to move to a new steady-state operating point.

PREFDC_C (J+2): Power reference at Salisbury (Station C) (pu). The dynamic model will automatically initialize this CON to match the steady-state conditions of the loadflow case. This CON can be used dynamically to change the DC power reference but should be changed only if Station C is operating as an inverter, i.e. only in HVdc configurations 1 and 2 [see Section 6.3 (2)]. The filter-switching logic is included in the dynamic model; however, tap-changer control is not included (due to the very slow action of tap-changer control). Therefore, the simulation should be accurate to approximately 10 seconds, at which time tap changers would begin to act. The dynamic model should therefore not be used to move to a new steady-state operating point.

Frequency Controller at B (J+3): 1 enables the frequency controller at Soldiers Pond (Station B); 0 disables it. Default 1.

Filter Switching (J+4): 1 enables the filter switching; 0 disables it. Default 0.
Filter switching was only enabled during validation testing when performing the power order ramping tests. Filter switching was disabled during fault testing.

HVdc Configuration (J+5): Default 1.
1. 3-terminal: Gull Island – rectifier, Soldiers Pond – inverter, Salisbury – inverter
2. 2-terminal: Soldiers Pond – rectifier, Salisbury – inverter
3. 2-terminal: Salisbury – rectifier, Soldiers Pond – inverter

6.4.2 ICONs

Please fill in the bus numbers as appropriate as described in the model data sheet contained in Appendix C.

*Please note the user is responsible to ensure the CONs and ICONs of the dynamic model match the loadflow setup [see Section 6.2].

6.5 Simulating a Power Ramp

In order to simulate a change in power reference at one or both inverters (depending on the HVdc configuration being studied), during the dynamic simulation the user must change the appropriate CON to the desired per unit value: CON (J + 1) for Soldiers Pond as inverter, and CON (J + 2) for Salisbury as inverter. The CON associated with the rectifier power reference should not be changed; the CON should be changed only at the inverter ends.

It is also important to note that the inverter power references should be changed for both DC lines (poles) to be the same value. The custom model has not been programmed to operate with unbalanced bipolar operation. The ground currents, and hence HVdc losses, will be incorrect if the user attempts to operate the HVdc link in this manner.

6.6 Simulating a Permanent Block of One Pole

In order to simulate a permanent block of one of the HVdc poles, the user must change the control mode of the **SECOND*** multi-terminal DC line loadflow model to "blocked" or "0" during a dynamic simulation. The dynamic model will then automatically perform a permanent DC block of this line. Please note that the PSSE model is not intended for simulating a restart from a DC block. If the DC line is blocked, the model assumes it is a permanent block. If Soldiers Pond is an inverter, the model will automatically go to the 2 pu monopolar operation; if Salisbury is an inverter, the model will automatically go to the 1.1 pu monopolar operation.

*It is very important that it is the second of the two multi-terminal DC lines that is blocked, as the custom PSSE dynamic model requires this to be so.

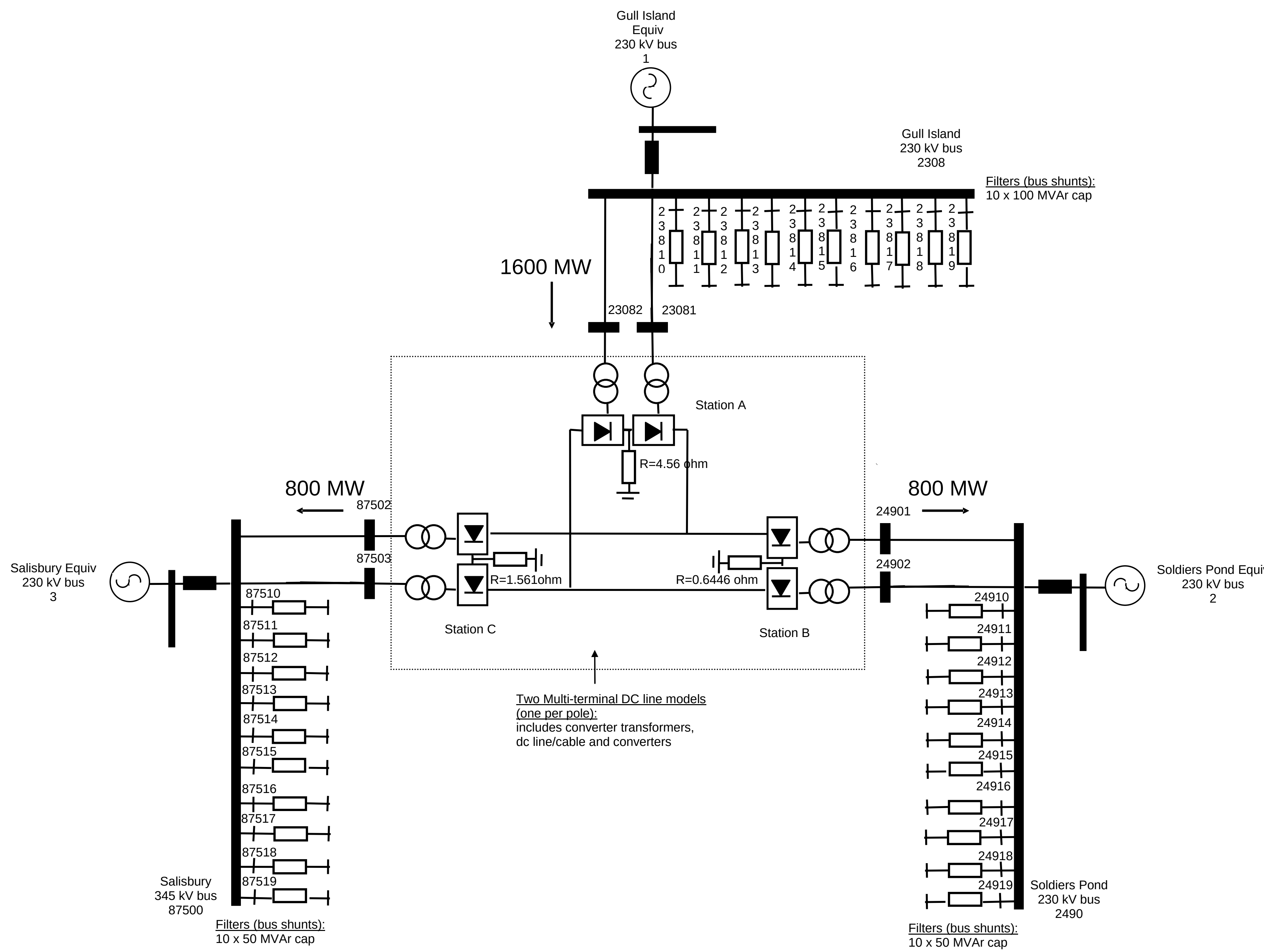
References

1. R.M. Brandt, U.D. Annakkage, D.P. Brandt, N. Kshatriya, "Validation of a Two-Time Step HVDC Transient Stability Model including Detailed HVDC Controls and DC Line L/R Dynamics," *Conference Proceedings,* IEEE Power Engineering Society General Meeting, Montreal, Canada, June 2006.

2. Newfoundland and Labrador Hydo Lower Churchill Project, "DC1020 – HVDC System Integration Study – Transient Stability Studies Report".

Appendix A

Diagram of Equivalent Test System


Gull Island Equiv 230 kV bus 1
Gull Island 230 kV bus 2308
Filters (bus shunts): 10 x 100 MVAr cap
23810
23811
23812
23813
23814
23815
23816
23817
23818
23819
1600 MW
23082
23081
Station A
R=4.56 ohm
800 MW
87502
87503
R=1.561ohm
Station C
R=0.6446 ohm
Station B
800 MW
24901
24902
Salisbury Equiv 230 kV bus 3
87510
87511
87512
87513
87514
87515
87516
87517
87518
87519
Salisbury 345 kV bus 87500
Filters (bus shunts): 10 x 50 MVAr cap
Soldiers Pond Equiv 230 kV bus 2
24910
24911
24912
24913
24914
24915
24916
24917
24918
24919
Soldiers Pond 230 kV bus 2490
Filters (bus shunts): 10 x 50 MVAr cap
Two Multi-terminal DC line models (one per pole): includes converter transformers, dc line/cable and converters

Appendix B

Lower Churchill HVdc PSSE Model Datasheet

TransGrid Solutions, Inc. User Model Data Sheet
CLCPDC

LOWER CHURCHILL PROJECT HVDC INTERCONNECTOR MODEL

DC Line	#_______I
This model uses CONs starting with	#_______J
and STATEs starting with	#_______K
and VARs starting with	#_______L
and ICONs starting with	#_______M

CONs *	#	Value	Description
J		1.0	PREFDC_A, Operator power reference at A (pu)
J+1		1.0	PREFDC_B, Operator power reference at B (pu)
J+2		1.0	PREFDC_C, Operator power reference at C (pu)
J+3		1	Frequency Controller at B Enable : 1, Disable : 0
J+4		0	Filter Switching Enable : 1, Disable : 0
J+5		1	HVDC Configuration 1 : A-Rec, B-Inv, C-Inv 2 : A-OFF, B-Rec, C-Inv 3 : A-OFF, B-Inv, C-Rec

STATEs	#	Description
K		IDC_A
K+1		IDC_B
K+2		VD
K+3		IDC_C
K+4		Not used
K+5		X_PI_A
K+6		X_PI_B
K+7		X_PI_C
K+8		KP_A
K+9		KP_B
K+10		KP_C
K+11		UREF_ADD1_A
K+12		UREF_ADD1_B
K+13		UREF_ADD1_C
K+14		UDMEAS_A
K+15		UDMEAS_B
K+16		UDMEAS_C
K+17		UDMEAS1_A
K+18		UDMEAS1_B
K+19		UDMEAS1_C
K+20		AMIN1_A
K+21		AMIN1_B
K+22		AMIN1_C
K+23		AMAX1_A
K+24		AMAX1_B
K+25		AMAX1_C
K+26		IMARG2_A
K+27		IMARG2_B
K+28		IMARG2_C
K+29		IMARG5_A
K+30		IMARG5_B
K+31		IMARG5_C
K+32		UVDCLI_A
K+33		UVDCLI_B
K+34		UVDCLI_C
K+35		UVDCLR_A
K+36		UVDCLR_B
K+37		UVDCLR_C
K+38		IREFCC2_A
K+39		IREFCC2_B
K+40		IREFCC2_C
K+41		UDAVG_A
K+42		UDAVG_B
K+43		UDAVG_C
K+44		IDCM_A
K+45		IDCM_B
K+46		IDCM_C
K+47		GMEAS_A
K+48		GMEAS_B
K+49		GMEAS_C
K+50		VACM_A
K+51		VACM_B
K+52		VACM_C
K+53		IAD
K+54		IDB
K+55		IDC
K+56		VA
K+57		VB
K+58		VC
K+59		IDAMP3_A
K+60		IDAMP3_B
K+61		IDAMP3_C
K+62		IDAMP1_A
K+63		IDAMP1_B
K+64		IDAMP1_C
K+65		X_UFC_B
K+66		X_LFC_B
K+67		IDREF_A
K+68		IDREF_B
K+69		IDREF_C
K+70		QACM_A
K+71		QACM_B
K+72		QACM_C
K+73		PCONVM_A
K+74		PCONVM_B
K+75		PCONVM_C
K+76		QCONVM_A
K+77		QCONVM_B
K+78		QCONVM_C

K+79		Not used

VARs	#	Description
L		PAC_A
L+1		PAC_B
L+2		PAC_C
L+3		QAC_A
L+4		QAC_B
L+5		QAC_C
L+6		IDC_A
L+7		IDC_B
L+8		IDC_C
L+9		VDC_A
L+10		VDC_B
L+11		VDC_C
L+12		ALFA_A
L+13		ALFA_B
L+14		ALFA_C
L+15		FA_A
L+16		FA_B
L+17		FA_C
L+18		VAC_A
L+19		VAC_B
L+20		VAC_C
L+21		PI_INPUT_A
L+22		PI_INPUT_B
L+23		PI_INPUT_C
L+24		PI_OUT_A
L+25		PI_OUT_B
L+26		PI_OUT_C
L+27		TN_A
L+28		TN_B
L+29		TN_C
L+30		PI_MAX_A
L+31		PI_MAX_B
L+32		PI_MAX_C
L+33		PI_MIN_A
L+34		PI_MIN_B
L+35		PI_MIN_C
L+36		KP1_A
L+37		KP1_B
L+38		KP1_C
L+39		AMIN_A
L+40		AMIN_B
L+41		AMIN_C
L+42		AMAX_A
L+43		AMAX_B
L+44		AMAX_C
L+45		ACUV_TIMER_A
L+46		ACUV_TIMER_B
L+47		ACUV_TIMER_C
L+48		AMAX_SWITCH_A
L+49		AMAX_SWITCH_B
L+50		AMAX_SWITCH_C
L+51		ID0_TIMER_A
L+52		ID0_TIMER_B
L+53		ID0_TIMER_C
L+54		ID0_TIMER1_A
L+55		ID0_TIMER1_B
L+56		ID0_TIMER1_C
L+57		HIGH_ALFA_A
L+58		HIGH_ALFA_B
L+59		HIGH_ALFA_C
L+60		ALFA_TIMER_A
L+61		ALFA_TIMER_B
L+62		ALFA_TIMER_C
L+63		UDMEAS_TIMER_A
L+64		UDMEAS_TIMER_B
L+65		UDMEAS_TIMER_C
L+66		TNSWITCH_A
L+67		TNSWITCH_B
L+68		TNSWITCH_C
L+69		UDR_ERR_A
L+70		UDR_ERR_B
L+71		UDR_ERR_C
L+72		UREF_ADD2_A
L+73		UREF_ADD2_B
L+74		UREF_ADD2_C
L+75		ID01_TIMER_A
L+76		ID01_TIMER_B
L+77		ID01_TIMER_C
L+78		UDI_ERR_A
L+79		UDI_ERR_B
L+80		UDI_ERR_C
L+81		GERR_A
L+82		GERR_B
L+83		GERR_C
L+84		ID_ERR_A
L+85		ID_ERR_B
L+86		ID_ERR_C
L+87		PI_CMODE_A
L+88		PI_CMODE_B
L+89		PI_CMODE_C
L+90		IREFCC_A
L+91		IREFCC_B
L+92		IREFCC_C
L+93		UVDCL_A
L+94		UVDCL_B
L+95		UVDCL_C
L+96		UVDCLR7_A
L+97		UVDCLR7_B
L+98		UVDCLR7_C
L+99		UVDCLR7_PREV_A
L+100		UVDCLR7_PREV_B
L+101		UVDCLR7_PREV_C
L+102		UVDCLR8_TIMER_A
L+103		UVDCLR8_TIMER_B
L+104		UVDCLR8_TIMER_C

L+105		UVDCLR7_TIMER_A
L+106		UVDCLR7_TIMER_B
L+107		UVDCLR7_TIMER_C
L+108		UVDCLR10_TIMER_A
L+109		UVDCLR10_TIMER_B
L+110		UVDCLR10_TIMER_C
L+111		UVDCLR10_A
L+112		UVDCLR10_B
L+113		UVDCLR10_C
L+114		IREF_TC4_A
L+115		IREF_TC4_B
L+116		IREF_TC4_C
L+117		IREF_TC4_TIMER_A
L+118		IREF_TC4_TIMER_B
L+119		IREF_TC4_TIMER_C
L+120		IREF_TC7_TIMER_A
L+121		IREF_TC7_TIMER_B
L+122		IREF_TC7_TIMER_C
L+123		IREF_A
L+124		IREF_B
L+125		IREF_C
L+126		UREF_A
L+127		UREF_B
L+128		UREF_C
L+129		IMARG_A
L+130		IMARG_B
L+131		IMARG_C
L+132		IMARG1_A
L+133		IMARG1_B
L+134		IMARG1_C
L+135		IMARG4_A
L+136		IMARG4_B
L+137		IMARG4_C
L+138		IREFDC_A
L+139		IREFDC_B
L+140		IREFDC_C
L+141		UDREF_A
L+142		UDREF_B
L+143		UDREF_C
L+144		ACUV_A
L+145		ACUV_B
L+146		ACUV_C
L+147		ID0_A
L+148		ID0_B
L+149		ID0_C
L+150		UDREC_A
L+151		UDREC_B
L+152		UDREC_C
L+153		IREF_TC8_A
L+154		IREF_TC8_B
L+155		IREF_TC8_C
L+156		IREF_CC1_A
L+157		IREF_CC1_B
L+158		IREF_CC1_C

L+159		GAMMA_A
L+160		GAMMA_B
L+161		GAMMA_C
L+162		ACUV_TIMER1_A
L+163		ACUV_TIMER1_B
L+164		ACUV_TIMER1_C
L+165		UDMEAS_HIGH_A
L+166		UDMEAS_HIGH_B
L+167		UDMEAS_HIGH_C
L+168		REAL IA_INJ
L+169		REAL IB_INJ
L+170		REAL IC_INJ
L+171		IMAG IA_INJ
L+172		IMAG IB_INJ
L+173		IMAG IC_INJ
L+174		CHECK_A
L+175		CHECK_B
L+176		CHECK_C
L+177		Not used
L+178		DCMODE_PREV
L+179		INV_RECOV_C
L+180		INV_TIMER_A
L+181		INV_TIMER_B
L+182		INV_TIMER_C
L+183		INVBYP_A
L+184		INVBYP_B
L+185		INVBYP_C
L+186		Not used
L+187		Not used
L+188		Not used
L+189		IDAMP2_A
L+190		IDAMP2_B
L+191		IDAMP2_C
L+192		IDAMP_A
L+193		IDAMP_B
L+194		IDAMP_C
L+195		LFC_OUT_B
L+196		UFC_IN_B
L+197		UFC_OUT_B
L+198		SEVERE_FAULT_C
L+199		SEVERE_FAULT_B
L+200		UDRECBP_A
L+201		UDRECBP_B
L+202		UDRECBP_C
L+203		PREF_A
L+204		PREF_B
L+205		PREF_C
L+206		ACUV_TIMER2_A
L+207		ACUV_TIMER2_B
L+208		ACUV_TIMER2_C
L+209		QACUP_A
L+210		QACUP_B
L+211		QACUP_C
L+212		QACUP_PREV_A

L+213		QACUP_PREV_B
L+214		QACUP_PREV_C
L+215		QACUP_TIMER_A
L+216		QACUP_TIMER_B
L+217		QACUP_TIMER_C
L+218		QACDOWN_A
L+219		QACDOWN_B
L+220		QACDOWN_C
L+221		QACDOWN_PREV_A
L+222		QACDOWN_PREV_B
L+223		QACDOWN_PREV_C
L+224		QACDOWN_TIMER_A
L+225		QACDOWN_TIMER_B
L+226		QACDOWN_TIMER_C
L+227		CTR_A
L+228		CTR_B
L+229		CTR_C
L+230		LFC_OUT_B
L+231		QEXCH_A
L+232		QEXCH_B
L+233		QEXCH_C
L+234		IREFAA_B
L+235		FCONT2_B
L+236		UFC_OUT_B
L+237		LFC_OUT_B
L+238		IREFPU_A
L+239		IREFPU_B
L+240		IREFPU_C
L+241		QAC_PREV_C
L+242		HOLD_QAC_B
L+243		QAC_PREV_B
L+244		HOLD_QAC_A
L+245		QAC_PREV_A
L+246		HOLD_QAC_C
L+247		QACDOWN_TIMER1_A
L+248		QACDOWN_TIMER1_B
L+249		QACDOWN_TIMER1_C
L+250		250 to 299 – 20ms TIME DELAY A
L+299		250 to 299 – 20ms TIME DELAY A
L+300		300 to 349 – 20ms TIME DELAY B
L+349		300 to 349 – 20ms TIME DELAY B
L+350		350 to 399 – 20ms TIME DELAY C
L+400		350 to 399 – 20ms TIME DELAY C

ICONs **	#	Value	Description
M		1	DC line number of Pole 1
M+1		2	DC line number of Pole 2
M+2		2308	230 kV bus number station A
M+3		23010	Station A filter 1
M+4		1	Ckt Id branch connecting A filter 1
M+5		2308	230 kV bus number station A
M+6		23011	Station A filter 2
M+7		1	Ckt Id branch connecting A filter 2
M+8		2308	230 kV bus number station A
M+9		23012	Station A filter 3
M+10		1	Ckt Id branch connecting A filter 3
M+11		2308	230 kV bus number station A
M+12		23013	Station A filter 4
M+13		1	Ckt Id branch connecting A filter 4
M+14		2308	230 kV bus number station A
M+15		23014	Station A filter 5
M+16		1	Ckt Id branch connecting A filter 5
M+17		2308	230 kV bus number station A
M+18		23015	Station A filter 6
M+19		1	Ckt Id branch connecting A filter 6
M+20		2308	230 kV bus number station A
M+21		23016	Station A filter 7
M+22		1	Ckt Id branch connecting A filter 7
M+23		2308	230 kV bus number station A
M+24		23017	Station A filter 8
M+25		1	Ckt Id branch connecting A filter 8
M+26		2308	230 kV bus number station A
M+27		23018	Station A filter 9
M+28		1	Ckt Id branch connecting A filter 9
M+29		2308	230 kV bus number station A
M+30		23019	Station A filter 10
M+31		1	Ckt Id branch connecting A filter 10
M+32		2490	230 kV bus number station B
M+33		24910	Station B filter 1
M+34		1	Ckt Id branch connecting B filter 1
M+35		2490	230 kV bus number station B
M+36		24911	Station B filter 2
M+37		1	Ckt Id branch connecting B filter 2
M+38		2490	230 kV bus number station B
M+39		24912	Station B filter 3
M+40		1	Ckt Id branch connecting B filter 3
M+41		2490	230 kV bus number station B
M+42		24913	Station B filter 4
M+43		1	Ckt Id branch connecting B filter 4
M+44		2490	230 kV bus number station B
M+45		24914	Station B filter 5
M+46		1	Ckt Id branch connecting B filter 5
M+47		2490	230 kV bus number station B

M+48		24915	Station B filter 6
M+49		1	Ckt Id branch connecting B filter 6
M+50		2490	230 kV bus number station B
M+51		24916	Station B filter 7
M+52		1	Ckt Id branch connecting B filter 7
M+53		2490	230 kV bus number station B
M+54		24917	Station B filter 8
M+55		1	Ckt Id branch connecting B filter 8
M+56		2490	230 kV bus number station B
M+57		24918	Station B filter 9
M+58		1	Ckt Id branch connecting B filter 9
M+59		2490	230 kV bus number station B
M+60		24919	Station B filter 10
M+61		1	Ckt Id branch connecting B filter 10
M+62		87501	230 kV bus number station C
M+63		87510	Station C filter 1
M+64		1	Ckt Id branch connecting C filter 1
M+65		87501	230 kV bus number station C
M+66		87511	Station C filter 2
M+67		1	Ckt Id branch connecting C filter 2
M+68		87501	230 kV bus number station C
M+69		87512	Station C filter 3
M+70		1	Ckt Id branch connecting C filter 3
M+71		87501	230 kV bus number station C
M+72		87513	Station C filter 4

M+73		1	Ckt Id branch connecting C filter 4
M+74		87501	230 kV bus number station C
M+75		87514	Station C filter 5
M+76		1	Ckt Id branch connecting C filter 5
M+77		87501	230 kV bus number station C
M+78		87515	Station C filter 6
M+79		1	Ckt Id branch connecting C filter 6
M+80		87501	230 kV bus number station C
M+81		87516	Station C filter 7
M+82		1	Ckt Id branch connecting C filter 7
M+83		87501	230 kV bus number station C
M+84		87517	Station C filter 8
M+85		1	Ckt Id branch connecting C filter 8
M+86		87501	230 kV bus number station C
M+87		87518	Station C filter 9
M+88		1	Ckt Id branch connecting C filter 9
M+89		87501	230 kV bus number station C
M+90		87519	Station C filter 10
M+91		1	Ckt Id branch connecting C filter 10

**The user must fill in the ICONs with the appropriate bus numbers.

```
 1 'USRMDL' 0 'CLCPDC' 7 1 92 6 80 400
      1     2
    2308 23010  1
    2308 23011  1
    2308 23012  1
    2308 23013  1
    2308 23014  1
    2308 23015  1
    2308 23016  1
    2308 23017  1
    2308 23018  1
    2308 23019  1
    2490 24910  1
    2490 24911  1
    2490 24912  1
    2490 24913  1
    2490 24914  1
    2490 24915  1
    2490 24916  1
    2490 24917  1
    2490 24918  1
    2490 24919  1
   87501 87510  1
   87501 87511  1
   87501 87512  1
   87501 87513  1
   87501 87514  1
   87501 87515  1
   87501 87516  1
   87501 87517  1
   87501 87518  1
   87501 87519  1
   0 0 0 0 0 0 0 0
        1.00000      1.00000      1.00000      1.00000      0.00000
        0.00000      1.00000      0.00000      0.00000      0.00000/
```

*CON(J), CON(J+1) and CON(J+2) are automatically initialized by the model to match the loadflow conditions. The other CONs should be set by the user. Please see Section 7.4 for more details.

Appendix C

Validation Test Results – Equivalent Source Model

Appendices C through G not filed