E.S. Cornwall Memorial Scholarship
April to June 2019

Electranix Corporation

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THE UNIVERSITY OF QUEENSLAND

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Contents

1.0 Executive summary

This report provides an overview of my learnings during my time at Electranix, and impressions made, from April to June 2019. I worked on three major dynamic performance benchmarking studies for large inverter connected generation in North America. This report includes an outline of my six-step study methodology for benchmarking PSS/E and PSCAD results which was applied to each of these studies, see below.

- PSS/E simulation;
- preliminary PSCAD model testing;
- fault automation;
- model implementation;
- PSCAD monitoring; and
- report preparation.

During this time, I gained experience in the following areas.

- Modeling different power system elements including solar farms, wind farms, High Voltage Direct Current (HVDC) converters, synchronous machines and voltage support elements.
- Further developed my PSS/E, PSCAD, E-TRAN, Python and technical communication skills.

Through my work I gained the following impressions.

1. **Dynamic performance studies are critical to ensure system security**

With my new skills and experience I am better prepared for the system study requirements of a national planner. It is an enhancement to AEMO's national planner role to have the experience I have gained at Electranix, to be able to share this experience with my team and to have developed profession relationships with the excellent study engineers at Electranix.

2. **There are important differences between PSCAD and PSS/E**

PSS/E and PSCAD are both valuable tools in assessing the dynamic performance of network elements. These tools have fewer limitations when used together, than when either is used on its own to run studies. It is important for study engineers to understand the differences between the tools and to be able to identify where these differences propagate in the results. Differences in response can be intrinsic and understanding this is an important enhancement to AEMO's role as the national planner.

Finally, as part of my next quarter I will focus on the following areas.

Next steps

- I have started my third international placement in the HVDC group at Siemens in Erlangen, Germany. While Siemens HVDC has representation internationally, the key manufacturing, engineering design and sales are conducted in Nuremberg and Erlangen.
- I will be here for 12 months and am working with my team to put together an expansive work program across transmission solutions such as synchronous condensers, submarine HVDC, AC to DC transmission conversion and HVDC PLUS (voltage source conversion, grid forming) technology.

2.0 Introduction

This report provides an overview of my work at Electranix Corporation (Electranix) from April to June 2019, my dynamic performance methodology and impressions gained. I was fortunate to continue working on generation dynamic performance studies in North America as part of the generation connection process, with a focus on weak conditions. I further developed my prowess in PSCAD, E-TRAN and PSS/E. These studies provided me an opportunity to become familiar with the individual and interdependent behaviour of grid connected devices. This report meets the requirements of a quarterly report as part of the 2018 – 2019 ES Cornwall Memorial Scholarship.

3.0 Scholarship theme

In June, 2017 Dr. Alan Finkel, Australia's Chief Scientist, and an Expert Panel published the Independent Review into the Future Security of the National Electricity Market. The report recommends a way forward to ensure a secure and reliable energy future as the energy industry experiences significant change[1]. Four key outcomes were identified for the National Electricity Market (NEM): increased security, future reliability, rewarding consumers and lower emissions. These outcomes are enabled by three key pillars: Orderly Transition, System Planning and Stronger Governance.

Chapter 5 delivered five key recommendations focused on improving System Planning. The first two recommendations focus on the delivery of an Integrated Grid Plan, conducted by the Australian Energy Market Operator (AEMO), which have since been addressed or are underway. The third recommendation (recommendation 5.3) is now coming into focus and states:

> *The COAG Energy Council, in consultation with the Energy Security Board, should review ways in which the Australian Energy Market Operator's role in national transmission planning can be enhanced.*

AEMO's national transmission planner functions include review and advice on the development of the transmission grid across the NEM; provide a national strategic perspective for transmission planning and coordination; and have regard to the National Electricity Objective. The underlying theme of my Scholarship proposal is to identify ways the national transmission planning role can be enhanced.

Transmission planning, in Australia and around the world, is becoming increasingly challenging due to the rapid increase in inverter connected devices and the decommitment of synchronous generation. AEMO is now required to monitor the fault level at nodes in the power system to ensure the reliable operation of the grid. AEMO's national planner role requires new power system study skills such as electromagnetic transient tools (PSCAD). My time at Electranix has enhanced my skills in PSCAD and E-TRAN, my understanding of the limitations of PSS/E and PSCAD, and the application of the results from each.

[1]Dr Alan Finkel, Ms Karen Moses, Ms Chloe Munro, Mr Terry Effeney, Professor Mary O'Kane. Independent Review into the Future Security of the National Electricity Market. 2017. Available here: https://www.energy.gov.au/sites/g/files/net3411/f/independent-review-future-nem-blueprint-for-the-future-2017.pdf

4.0 Background

A secure and reliable supply of low-cost electricity is a highly desirable input into a strong, prosperous and robust economy. The changing generation mix has introduced challenges for system operators to maintain power system security and reliability. A key challenge is the declining available fault level across the power system due to the retirement of synchronous generation and the connection of inverter connected generation. As a result, AEMO now monitors the impact of these changes as part of the national planner role.

These changes are seen elsewhere in the world, in regions like North America, Hawaii and Europe. Some system operators in these regions apply detailed power system analysis to ensure the secure operation of the power system. ISO New England (ISONE) in northeast US (Massachusetts, Connecticut, Maine, New Hampshire, Rhode Island and Vermont) and the Electric Reliability Coordinator of Texas (ERCOT) in Texas are examples of system operators who conduct these types of detailed studies.

4.1 Work completed

My second three months at Electranix has provided me with the opportunity to complete dynamic performance studies on three prospective inverter connected generation projects in North America. These studies assessed the performance of models provided to the system operator as part of the generation connection process. I had the opportunity to study the interaction of existing and future grid connected devices in the world's largest interconnected transmission network – the eastern interconnection.

These studies included the assessment of PSS/E and PSCAD models of synchronous machines, wind farms, photovoltaic (PV) farms, HVDC converter stations, STATCOMs, and Battery Energy Storage Systems (BESS). I also translated PSS/E cases to PSCAD with Electranix's E-TRAN package, which now comes as a standard add on with PSS/E.

This section provides an outline of the three major studies completed during my final three months at Electranix. Note that details (such as location, client, and associated manufacturers) of the studies are withheld to align with the non-disclosure agreement underlining the work. The focus of these studies is to first ensure the project can survive the faults, under the scenario conditions. Secondly, differences between PSS/E and PSCAD results are identified for the project and for existing nearby projects.

4.1.1 Project 1

Project 1's scope included a prospective 20 MW solar PV farm located near a 200 MW HVDC converter station and two larger wind farms (65 MW and 30 MW). The network studied taps a single 115 kV radial line parallel with the 345 kV bulk power system (BPS). Two faults were studied, one disconnecting the project from the east, and the other from the west. The faults were chosen due to their severity and the fault minimising potential.

For this study there were two scenarios and each fault was applied to each of these, resulting in four cases. The difference between the two scenarios were the HVDC

converter control settings, which can dramatically change the dynamic performance in this part of the system.

Initially, the prospective project was unable to ride through the first fault in either of the scenarios. This was due to tight overvoltage protection at the project. The vendor provided updated input files for the model with a relaxed over voltage protection threshold. The studies were re-run and the project was able to ride through all cases.

Other key areas of learning include:

- The 30 MW wind farm was connected to the same bus involved in fault 1. The inverter measured the local voltage and used this measurement to calculate the frequency. As a result of the severe transient response of the measured voltage, the frequency calculation was incorrect. This resulted in the plant tripping and so the frequency protection was disabled for this study.
- The 65 MW wind farm had a recurring mode switching characteristic. This caused the wind farm to go in and out of fault ride through and caused the other generators to behave similarly. This was reported to the client and was an existing issue unrelated to the project. Often models exhibit undesirable behaviour which were never identified in their connection studies process. This is because moderate fault conditions are applied, which were not studied. Typically, severe conditions are studied only.
- The HVDC converter station control settings required careful tuning to align with the PSS/E settings. The voltage set point, filter capacitor and power order were all carefully tuned to aligned. The performance of every nearby generator was sensitive to these settings.

4.1.2 Project 2

Project 2's scope included a prospective 50 MW solar PV farm located near another solar PV farm, a wind farm and an SVC. The study included network with voltages from 0.6 kV to 345 kV with the project embedded in the 115 kV network with strong links to the BPS. Four 3-phase faults were studied, the variety of fault characteristics are outlined below:

- Applied to busses in the 115 kV network.
- Fault site ranged from close to the prospective project to closer to the BPS.
- All faults included at least three line outages.

Three scenarios were included in this study, Light Load A, Light Load B and Peak Load. The large number of fault and scenarios resulted in a larger number of cases.

The key outcome of this study was that the PSCAD and PSS/E voltage response of the project do not align. During the fault, the response is comparable, however after the fault has cleared there are clear differences in voltage recovery. Figure 1 shows the simulation results for PSCAD (blue), PSSE (orange) and PSCAD with the project model replaced with a source (green). The top plot shows the reactive power injection comparison, while the bottom plot shows the resultant rms voltage. The PSCAD simulation results (beginning at 14.10 seconds) show the project injecting reactive power to support the voltage, while in the PSS/E simulation the project absorbs reactive power. The voltage

plot shows an approximate difference in voltage (between 14.15 and 14.30 seconds) of approximately 0.1 pu.

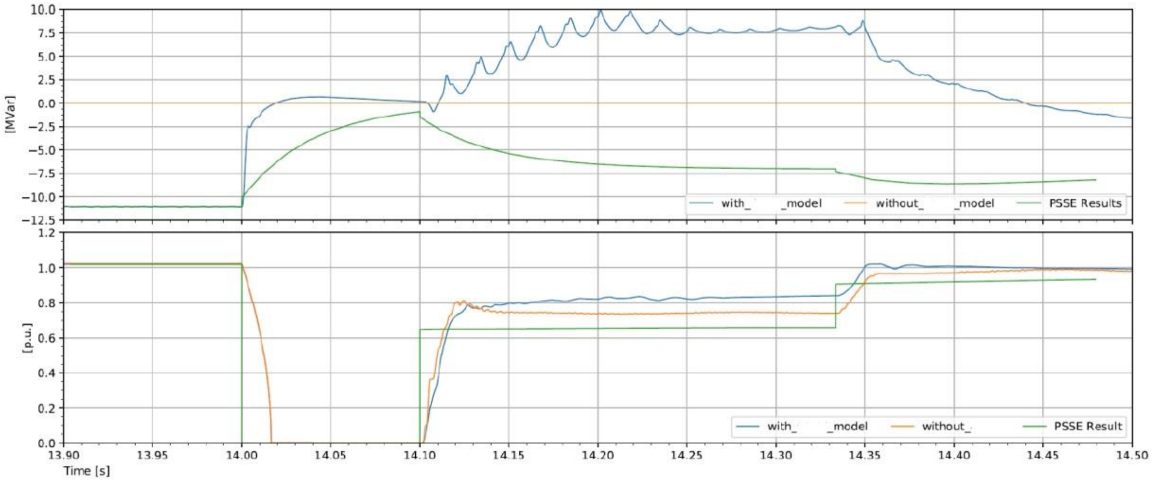

Figure 1 - Inconsistent voltage response between PSS/E (green) and PSCAD (blue) simulation

This was reported to the client however remediation will not be sort, instead the results will be provided to the project and this behaviour in future projects will not be tolerated. The reason for this is that this difference in the models does not propagate outside of the local network. However, it could do so as clusters of these projects exhibit the same behaviour and so future projects should not include this difference.

4.1.3 Project 3

Project 3's scope included a prospective 20 MW solar PV farm located near a major 1000 MW HVDC converter station, another solar PV farm and an SVC. The network includes voltages from 0.4 kV to 425 kV and is generally embedded in the 115 kV and 230 kV network with strong links to the BPS. Three 3-phase faults were studied, the variety of fault characteristics are outlined below:

- Applied to busses in the 46 kV and 115 kV network.
- The first fault included a prolonged (up to 70 cycles or 1.1667 seconds) protection delay and was located at the projects point of interconnection (POI).
- Fault site ranged from close to the project to close to the BPS.

Three scenarios were included in this study, Light Load A, Light Load B and Peak Load. The large number of faults and scenarios resulted in nine cases and nine sets of results.

Immediately after the fault is cleared (in all cases) the transient voltage reported in PSCAD spikes due to the projects reactive power injection. This fault clearing spike occurs when the phase lock loop in PSCAD re-synchronises, which does not occur (as its not modelled) in PSS/E. This is not seen in PSS/E because the simulation has a larger time step and limits the reaction time of the plant. The plant recovers after the fault is cleared, and does so for every fault and scenario.

4.2 PSS/E-PSCAD benchmarking methodology

This section outlines the methodology I implemented for conducting each benchmarking study. A typical PSS/E – PSCAD benchmarking study has six stages:

(1) PSS/E simulation;
(2) preliminary PSCAD model testing;
(3) fault automation;
(4) model implementation;
(5) PSCAD monitoring; and
(6) report preparation.

4.2.1 PSS/E simulation

The PSS/E studies were conducted and provided by the client. Therefore, this is considered as only a single step in this methodology. However, this step would include a range of intermediate steps not reported here. The PSS/E results were in a package and included the following:

- base cases: dispatch, network and generator information.
  - .sav
  - .raw
- dynamic data: PSS/E dynamic models are useful for parameters comparisons (where possible).
  - .snp
  - .dyr
- simulation results: PSS/E channel traces are required for comparing quantities such as active power, reactive power, frequency and voltage.
  - .out
- inputs files: fault progression and details for other assumptions (such as load modelling).
  - .idv
  - .conl

4.2.2 Preliminary PSCAD model testing

The purpose of this stage is to prepare the project model in a small system. The steps are outlined below:

1. PSS/E single line diagram: Provides the important contextual and topological information necessary for later work and helps to answer questions like what generation is nearby? How far away is the BPS? Is there any static and dynamic reactive support?
2. Simple circuit: E-TRAN is used to translate a free lunch[2] simple circuit, refer to Figure 2 which illustrates the components included in the translation. A typical

[2] *Free lunch* refers to the standard or default translation E-TRAN provides from PSS/E to PSCAD.

simple circuit includes the project generator, GSU transformer, collector, the POI bus and network equivalent. The forked network is useful for fault analysis beyond a simple ring down test[3] and typically connects the POI to the network equivalent. The free lunch translation provides an accurate representation of line and transformer parameters, as well as a simple source model for generators. Using the multi meter component in PSCAD, the steady state conditions are compared between the PSS/E power flow case and the PSCAD free lunch case to ensure they're the same.

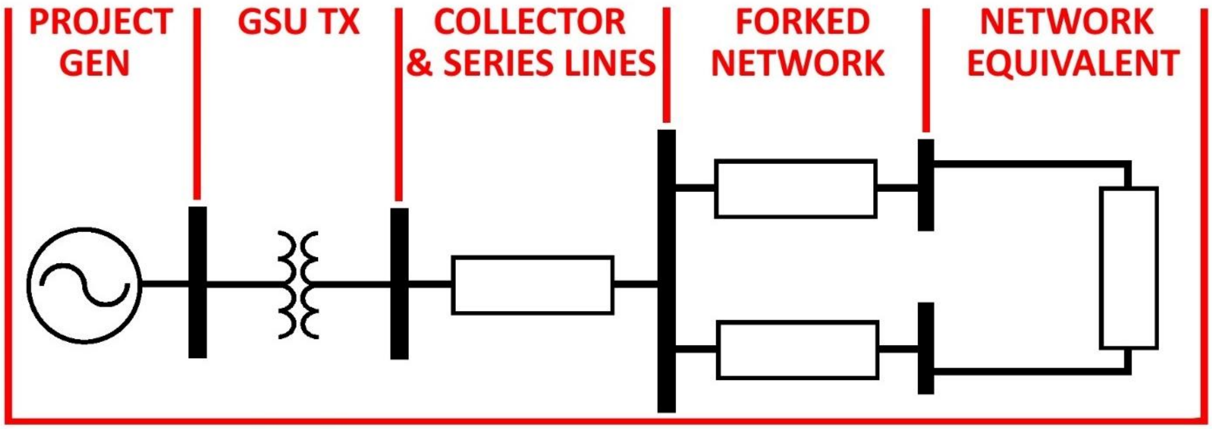

Figure 2 - Typical simple system which only includes the project up to the first instance of a node with three lines

3. Implement PSCAD model: Replace the project source with a 'copy transfer'[4] of the PSCAD model. Typically, the model is provided by the client in a simple system case used for model validation. Sometimes the model is tuned already, other times the model is not tuned and requires alignment with PSS/E. Model alignment includes voltage control bus, voltage set point, reactive power injection and active power injection. The model would include an external power plant controller (PPC) which requires voltage and reactive power inputs either from the POI or terminal. Older models may not include a PPC.

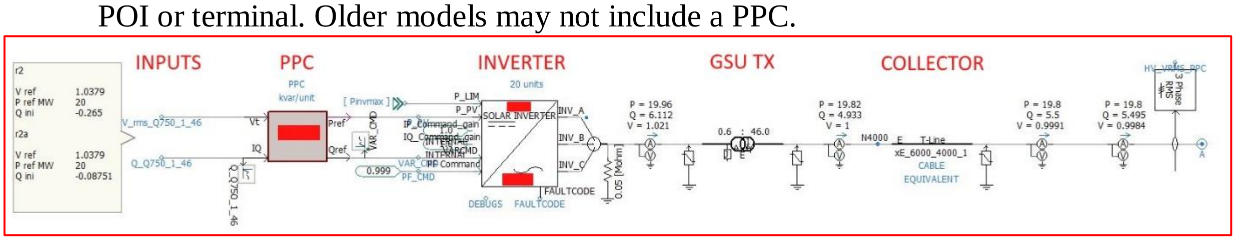

Figure 3 - Typical project model setup

4. Results: Implement monitoring in PSCAD and prepare python benchmarking script to compare PSS/E and PSCAD. PSCAD and PSS/E outputs files are accessed by the script and the comparable channels are plotted against each other. At this point no faults are applied, just the steady state conditions are checked to ensure they're consistent. One reason why the steady state conditions may differ

[3] Ring down refers to a 3 phase fault at the POI of the project generator.
[4] Copy transfer refers to the copying of the model and the model description from one PSCAD case to another.

is due to the imbedded model impedance which is not consistent between PSS/E and PSCAD.

4.2.3 Fault automation

5. Substitution library: E-TRAN has a useful capability to read from a substitution library. This library stores the desired models and network pages which are translated directly into the case in place of the less detailed free lunch components. The project model is also stored in the substation library.
6. Medium system: E-TRAN is used to translate the case again, except this time the busses included are expanded from the project to each of the busses involved in the study faults. In this medium system PSCAD case, the fault automation is built and stored in the substitution library. This preserves the work for use in later translations. Figure 4 illustrates the medium system with the generator project, lines associated with fault automation and the network equivalent.

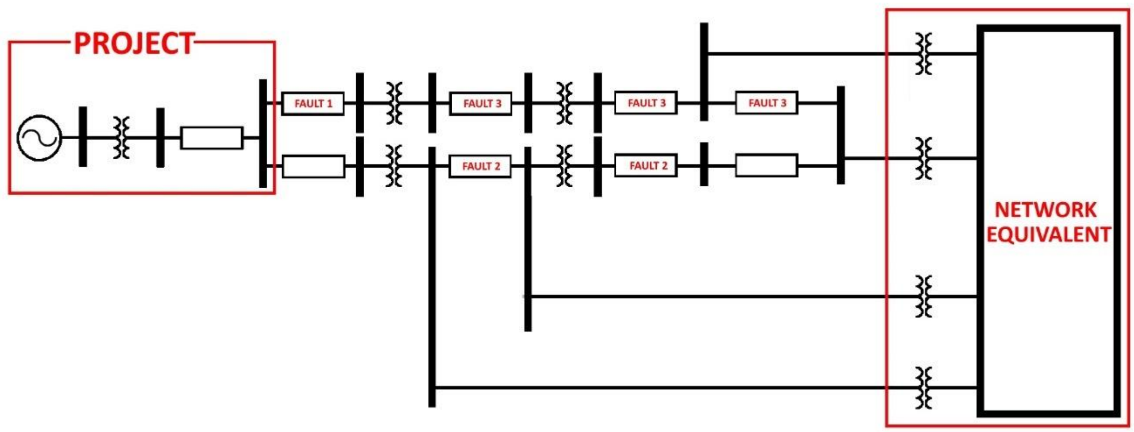

Figure 4 - Typical medium system with all busses associated with the fault automation included

7. Fault logic: Each fault is setup in the medium system case and the logic varies in complexity. Using the .idv files provided with the PSS/E package, the fault logic is implemented in PSCAD to ensure it is consistent with the PSS/E simulation.
8. Results: monitoring is implemented in each fault page and the python script for collecting the output file data is updated. This allows for system quantities to be monitored and can assist in understanding how the fault propagates throughout the system. It also serves the purpose of ensuring the fault logic is consistent with PSS/E.

4.2.4 Model implementation

9. Additional models: E-TRAN is then setup to translate many busses to ensure the inclusion of nearby network elements (generation, Flexible Alternating Current Transmission Systems (FACTS) devices) which are to be included in the PSCAD simulation. PSCAD models were typically included using substation libraries from previous studies and have the benefit of being prepared for study work. The first model is introduced into the PSCAD study, the simulation is run and then the results reviewed to identify undesirable operation of the system for each fault and scenario. This process is repeated for each model independently of the others and

then each model is included one at a time and reviewed. Figure 5 illustrates the inclusion of nearby generation and additional network elements.

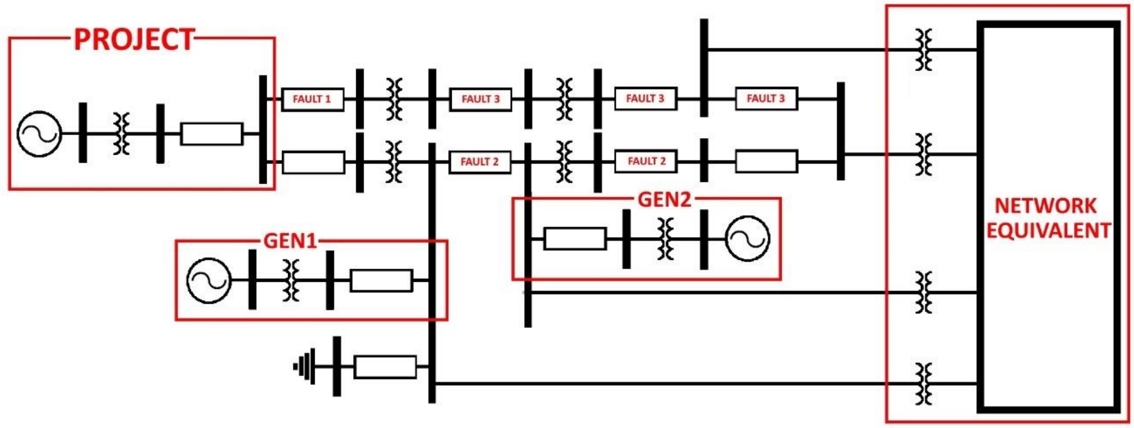

Figure 5 - Typical large system with additional generation included

10. Results: Once each model has been implemented into the case, they are transferred to the substitution library. The library serves as a collection of the power system elements.

4.2.5 Monitoring

Each model and network page has monitoring built in. This is the mechanism for PSCAD to store power system quantities for review. Python is used to read the PSS/E and PSCAD output files. The data is then plotted and compared against each other. The typical setup for the appendix of traces is as follows:

- Scenario 1
  - Fault 1
    - Project
    - System Quantities
    - HVDC 1
    - Generator/source 1
    - Generator/source 2
    - FACTs device 1
  - Fault 2
    - Project
    - System Quantities
    - HVDC 1
    - Generator/source 1
    - Generator/source 2
    - FACTs device 1
  - Fault 3
    - Project
    - System Quantities
    - HVDC 1
    - Generator/source 1
    - Generator/source 2

        - FACTs device 1
- Scenario 2
    - Fault 1
        - Project
        - System Quantities
        - HVDC 1
        - Generator/source 1
        - Generator/source 2
        - FACTs device 1
    - Fault 2
        - Project
        - System Quantities
        - HVDC 1
        - Generator/source 1
        - Generator/source 2
        - FACTs device 1
    - Fault 3
        - Project
        - System Quantities
        - HVDC 1
        - Generator/source 1
        - Generator/source 2
        - FACTs device 1

4.2.6 Report preparation

The reporting of the results followed a standard technical writing layout. There are often limitations around how much of the results can be discussed due to the volume. Typically, two sets of results are chosen which show evidence of all the observed dynamic behaviour.

4.3 Impressions gained

This section outlines the impressions gained during my time at Electranix from April to June 2019.

1. **Dynamic performance studies are critical to ensure system security**

With my new skills and experience I am better prepared for the system study requirements of a national planner. It is an enhancement to AEMO's national planner role to have the experience I have gained at Electranix, to be able to share this experience with my team and to have developed profession relationships with the excellent study engineers at Electranix.

2. **There are important differences between PSCAD and PSS/E**

PSS/E and PSCAD are both valuable tools in assessing the dynamic performance of network elements. These tools have fewer limitations when used together, than when either is used on its own to run studies. It is important for study engineers to understand the differences between the tools and to be able to identify where these differences propagate in the results. Differences in response can be intrinsic and understanding this is an important enhancement to AEMO's role as the national planner.

5.0 Next steps

This section outlines the planned next steps from July 2019 to June 2020. I have started my third international placement in the HVDC group at Siemens in Erlangen, Germany. While Siemens HVDC has representation internationally, the key manufacturing, engineering design and sales are conducted in Nuremberg and Erlangen.

I will be here for 12 months and am working with my team to put together an expansive work program across transmission solutions such as synchronous condensers, submarine HVDC, AC to DC transmission conversion and HVDC PLUS (voltage source conversion, grid forming) technology.

I will produce a quarterly report, in October 2019, of work completed and impressions gain in my first three months at Siemens.

6.0 Conclusion

This report provides an overview of my work at Electranix Corporation (Electranix) from April to June 2019, my dynamic performance methodology and impressions gained. I was fortunate to continue working on generation dynamic performance studies in North America as part of the generation connection process, with a focus on weak conditions. I further developed my prowess in PSCAD, E-TRAN and PSS/E. These studies provided me an opportunity to become familiar with the individual and interdependent behaviour of grid connected devices. This report meets the requirements of a quarterly report as part of the 2018 – 2019 ES Cornwall Memorial Scholarship.