CIGRE Australia APB5
SEAPAC 2015
Sydney 17-18 March

Faulting the System – The Ultimate Commissioning Test

[Subject]

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Keywords: Windfarm, Commissioning, Testing, Fault, Protection

Contents

1 Abstract

As part of a wind farm connection commissioning process, a staged fault test was conducted by TasNetworks at Derby Substation. This paper discuss about the preparation, challenges and result analysis of the test. The staged fault test was conducted as part of NER 5.8.1 requirement to demonstrate the fault ride through capability of the new wind farm. As the wind farm relies on multiple reactive support systems to ride through any system fault, the staged fault test also served as a performance check to the reactive support system.

Several protection modifications were required at multiple substations to provide the requirement for performance assessment. The modifications also provide additional protection in the unlikely event of any unplanned incident happening during the test. Additional fault recorders were also configured to provide high resolution data for the post testing analysis and assessment. The results from the fault records is later compared to any theoretical and simulation result.

2 Introduction

As Tasmania is located within the Roaring 40s, it is a very suitable location for wind generation. The latest wind farm that comes online within the Tasmania power system is located at Cape Portland, North Eastern of Tasmania. The wind farm is connected to the power system through a 110 kV connection point at Derby Substation which is then connected to the main power system through a long radial line back to Norwood Substation.

The wind farm is rated at 168 MW and is comprised of 56 Vestas V90 turbines. As it is connected to a weak portion of the power system, the wind farm is also installed with an auxiliary reactive plant. The reactive plant consists of two synchronous condenser and four switched capacitors banks.

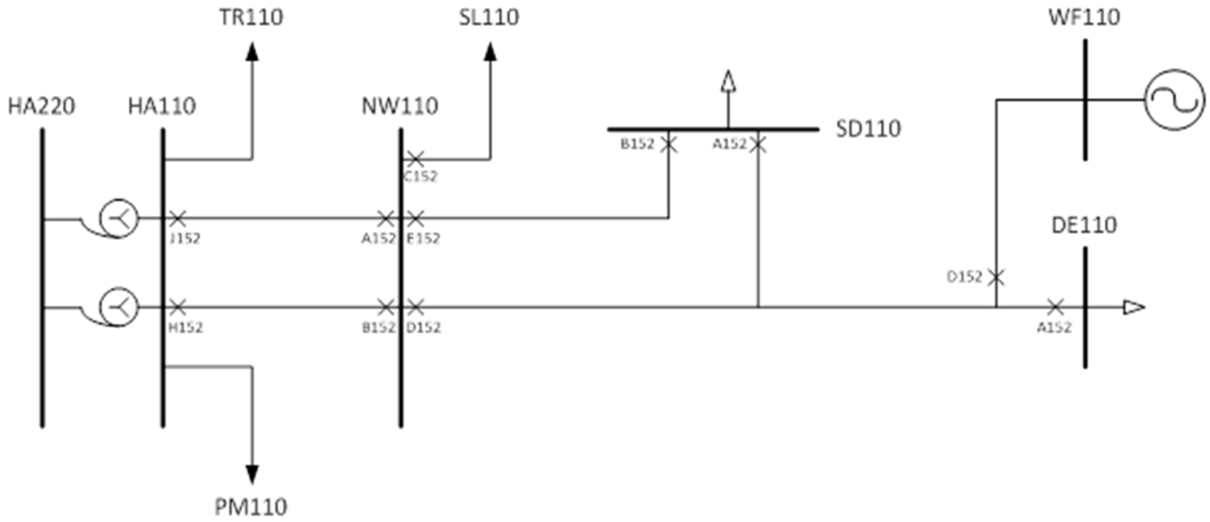

Figure 1 Single Line Diagram

Under the obligation of NER 5.8.1, a Transmission Network Services Provider (TNSP) is required to test and confirm the fault ride through capability of a newly connected generator. A TNSP is also required to check the performance of the generator against the modelling detail. The proof of performance could be checked by waiting for a naturally occurred fault within the system. However due to the dynamic nature of faults, it may only occur after a long time with the exact details of the fault occurrence uncontrollable by the TNSP. A staged fault test however allows for the TNSP to control the condition and variable of the fault introduce hence the result can be better compared against the modelling result.

With the configuration of the wind farm connection point at Derby Substation, it is fairly easy to perform a staged fault test without any major changes or impact to any other connected parties. The fault level at Derby substation is also relatively low with the maximum fault level of 3.8 kA with the wind farm contributing about one third to the fault level. All these condition provided the opportunity to conduct the staged fault test during the commissioning process of the wind farm.

3 Test Preparation

3.1 Primary Configuration

3.1.1 Basic Test Requirement

In order for the test to be meaningful in terms of system performance, a few conditions have been made in the very early stage of preparation. These conditions are:

1. The fault impedance should fixed and consistence
2. The fault duration should be known and controlled
3. The fault phases can be selected and controlled
4. The fault can be executed and terminated as required

3.1.2 Fault Delivery Mechanism

With the basic requirement of the test set, the fault delivery mechanism can then be chosen. A very common way in the electrical industrial for conducting staged fault test is to use a "piano wire" to connect the required faulted phases to earth. This method was considered but however rejected as it is hard to control the actual fault to meet the basic test requirements.

A "piano wire" would create a short circuit and then disintegrate through the fault current. As it disintegrates, an arc will be form until a wide enough air gap has been created in the disintegration process. The timing of the fault is therefore hard to control as the arc forming and extinguish period is dependent on the system and ambient condition at the time of test. It is also hard to establish the exact fault impedance in an arcing fault. Furthermore, there will be a risk while low that the arc could jump to nearby structure thereby damaging them.

The method that has been chosen after long consideration was to setup a "hard-wired short circuit" between a circuit breaker (CB) terminal and the station earth mat. The "hard-wired" in this case will be a conductor that is fully rated for the maximum expected fault current within the fault duration. The substation operation earth cable was thought to be suitable for this purpose as it is rated for fault condition. A standard TasNetworks operation earth cable comprise of:

- Aluminium conductor, 130 mm2
- PVC insulation with melting temperature of 1500C

Based on IEEE Std. 80, simulation result shows that the operation earth lead can withstand a fault current of 11.9 kA for one second duration. This is about three times above the maximum fault current at Derby Substation.

The primary yard configuration of Derby substation also presents a suitable connection point for applying the fault with a circuit breaker. The wind farm is connected on to the end of a four ended transmission line with a tapped supply transformer within the close proximity of the connection point. The maximum load of Derby during the autumn period can be supply through a parallel distribution feeder hence the possibility to disconnect the tapped supply transformer for the test. The final arrangement for the primary configuration is shown in Figure 2 below.

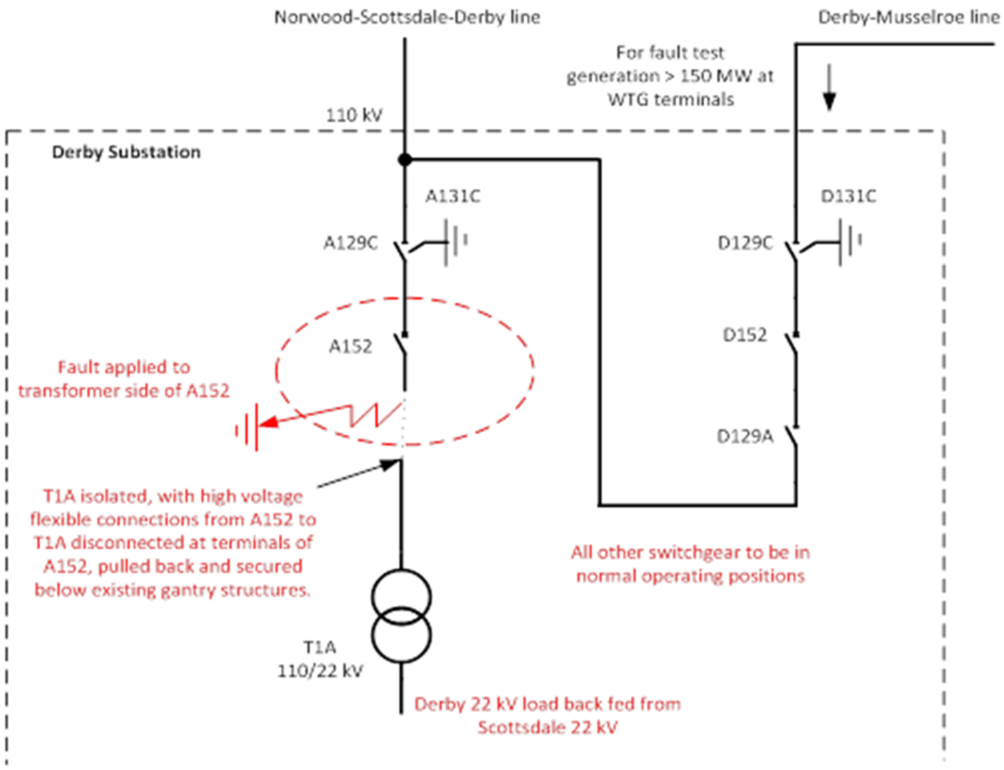

Figure 2 Primary Switchyard Configuration

With such an arrangement, the wind farm can then be connected to the Tasmanian power system prior to the application of the fault for pre-fault condition. The fault will then be applied by closing of the circuit breaker. The circuit breaker will then be control through the secondary system for the application and removal of the fault. Details of the secondary system setup will be discussed in Chapter 3.2.

3.1.3 Physical Arrangement

To avoid exposing the supply transformer to the test condition, the droppers connecting the supply transformer to the circuit breaker is disconnected and tie securely to a nearby structure. L-shaped aluminium adapter plate with brass stub fitted on will then be connected to the circuit breaker bushing. The brass stub allows robust connection of operational earth cable using conventional clamp fittings.

The other end of the operation earth will then be connected to the earthing bar located at the base of the CB stool. A trailing earth cable will then connect the earthing bar of the CB to the base of the disconnector A129C. This trailing earth cable provides a redundancy path to earth in the case where the CB earthing bar is faulty.

The earthing cable will also be selected with suitable length and the excess slack roll up and tied together at the base of the circuit breaker. This allows for the cable to move under the fault condition but not in excess where the whipping motion of the cable could damage the nearby structure. For multiple phases fault, the same earthing connection will be made to the required phase of the circuit breaker.

3.2 Secondary System Setup

3.2.1 Protection System

The circuit breaker where the fault will be applied is controlled by two set of protection scheme, transmission line and transformer protection. The transmission line protection scheme consists of duplicated current differential relay with backup under impedance protection. The transmission line protection is expected to see the fault as a through fault in the current differential zone and a reverse zone fault for the under impedance protection. It is therefore expected that the transmission line protection will only operate for fault after one second based on standard TasNetworks transmission line protection standard.

The transformer protection scheme consists of a current differential relay with a backup overcurrent relay. The transformer protection is expected to see the fault as an in zone fault and the backup overcurrent is expected to pick up on the fault. It is therefore expected that the transformer protection will operate for the fault with minimal delay pending on the exact system X/R ratio.

3.2.2 Circuit Breaker Control

As the circuit breaker is the main device to apply and remove the fault to the system, the circuit breaker control is very important for the test. All of TasNetworks Extra High Voltage (EHV) CB can be remotely controlled through station Supervisory Control And Data Acquisition (SCADA) system. Furthermore protection relay can also control the CB through protection and internal logic functions.

In order for the fault to be realistic, it was determine that the fault duration should be between 95 and 120 milliseconds. This timing was selected based on the Generator Performance Standard for the wind farm with consideration of possible error margins. If the wind farm can supply uninterrupted during this period, it would be deemed that the wind farm have met its obligation.

To better control the operating timing of the circuit breaker, it was decided not to rely on the protection function but to use the logic function on the transmission line protection relay. Using the logic function has a few advantages over the protection function for this test.

1. The operation does not rely on the fault current which may change due to the system condition. The fault current will also need to be measured through current transformer that can be susceptible to residue flux from previous faults.
2. There will be no need to modify any of the protection setting reducing the possibility of human error when restoring the protection schemes after the test.
3. The timing of the circuit breaker control can be tested and fine tune without exposing the power system to additional faults.
4. The logic used will ensure that all test logic shall be removed for the circuit breaker to remain closed. This reduce the risk of any residue test modification remain within the protection scheme after restoration.

3.2.3 Control Logic

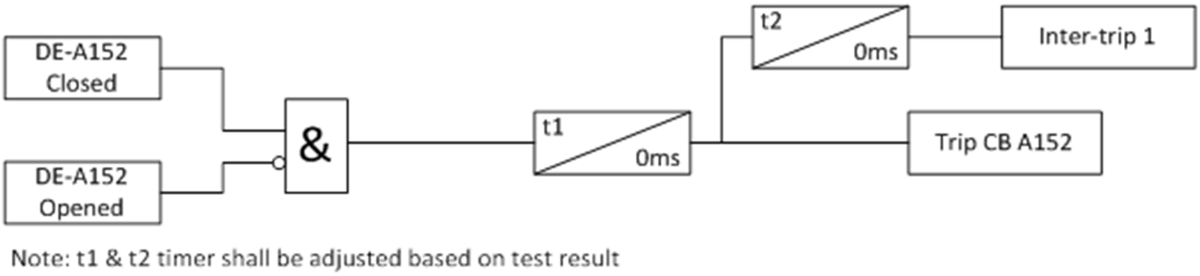

Figure 3 Control Logic Diagram

The control logic as shown in Figure 3 will check the breaker status using the 52a and 52b contact which have been provided to the transmission line relay as part of normal protection scheme requirements. Once the logic detect the circuit breaker has closed, it will start the timer t1. When timer t1 expired, it will send a trip signal to the circuit breaker and start timer t2. If timer t2 expired before the circuit breaker status changes from closed to open, it will then send an inter-trip signal to the remote end breaker to clear the fault. In effect, timer t2 acts as a backup breaker failure protection for the test.

Prior to the actual test, an initial "dry run" test will be conducted to determine the final timing for timer t1. Based on the time stamp of the 52a and 52b contacts in the protection relay, timer t1 will be tuned so that the circuit breaker remain closed for a period between 95 and 120 milliseconds. Timer t2 will be fixed to 120 milliseconds so that the fault will be cleared from the power system in the unfortunate event that the circuit breaker fails during the test.

As the fault will be seen by the transformer protection scheme as an in zone fault, the transformer protection will be isolated so as to not disturb the timing of the control.

3.2.4 Backup Protection

In the very unlikely event that the duplicated main control logic failed to remove the fault from the system, backup protection will be activated from the remote end substation to clear the fault. All remote end substations have backup distance protection on its transmission line protection scheme. The fault applied at Derby substation shall be detected as a Zone 2 fault by the remote end transmission line protection scheme. TasNetworks transmission line protection standard have Zone 2 timer set to 400 milliseconds.

For the comfort of the system operator, regulator and management, a third stage backup has been studied. In the event where backup protection is required and the remote end circuit breaker failed to operate, the circuit breaker fail protection within the remote end transmission line protection scheme will then clear the fault in 600 milliseconds by clearing the remote end buses. A simplified operating timing of each stage of the control and backup protection is shown below.

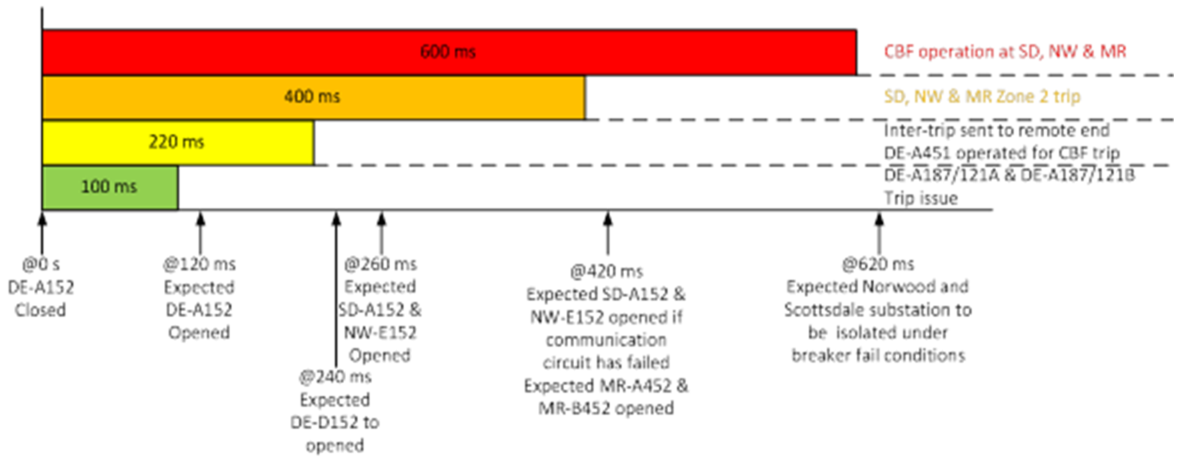

Figure 4 Protection Timing Diagram

3.2.5 Data Record

As the main aim of the test is to assess the performance of the wind farm, data record is the most important part of the test. As part of the wind farm requirement, a synchrophasor based anti-islanding scheme was installed at Derby Substation. The Phasor Measurement Unit (PMU) will be measurement both the current contribution from the wind farm and the EHV voltage at Derby Substation. The data will be streamed back to a central server for storage and analysis. The data will have 50 Hz resolution.

At the remote end substations, the transmission line protection scheme will be configured to record oscillography at the start of Zone 2 under impedance protection. Within Derby substation, the transformer backup overcurrent protection relay will be configured to record oscillography at the overcurrent pickup. These relay will record the system contribution into the fault. The data will have 2.4 kHz resolution.

Within the wind farm, semi-permanent power quality recorders have been installed as part of the commissioning and compliance process. These recorders are located from the EHV section of the wind farm substation to the low voltage terminal of the wind generators. The power quality recorder will record continuously and pushed its data to the wind farm local storage server. The data will have 12.8 kHz resolution.

Within most critical substations in Tasmania Power System, permanent disturbance recorders have also been installed. These recorders will record both the current flow and bus voltage on these substations when a system disturbance is sense.

For future reference and remote checking of the switchyard condition, an IP camera was also installed in the switchyard to monitor the fault application. For safety reason, all personnel are required to remain within the control building of Derby substation during the test. In the event where the circuit breaker did not operate as intended, a visual confirmation can be done with the IP camera before personnel approach the switchyard. The IP camera is also set to record the fault application process to check the reaction of the fault on the physical arrangement.

Figure 5 IP Camera Installation

4 Site Work

4.1 Coordination

As the test could have severe consequences if not handle properly, several groups have been setup to assess and conduct the test. A team will be working on site at Derby which is responsible for both primary and secondary system setup. A coordinator has also been selected to check and verify the setup as well as communicate with other groups.

Within the head office of TasNetworks, another team is setup within the control room to monitor the power system as well as coordinating with the system operator. Whenever a test is completed, the system will be checked to confirm that no unintended system operation has occurred within the system and all load and generation remain connected. The control room team is also in charge of communication with AEMO, major industrial and the wind farm control centre.

A third team will be at the wind farm substation where it will monitor the wind farm condition. Upon every test, they will report back to the coordinator at Derby on the wind farm condition. The team will manage the wind farm output and ensure that all control systems at the wind farm are put in the normal operating condition. They are also in charge of restarting the wind turbines in the events that a wind turbines tripping off during the test.

4.2 Primary and Secondary Modification

The primary connection to the Derby transformer was removed a day prior to the test. This allows for preparation work and checks to be conducted on the primary equipment to reduce the setup time on the day of the test. Prior to disconnection of the transformer, the 22 kV distribution feeder is parallel up to retain the supply to Derby substation. With the circuit breakers isolated, the adapter plate with brass stub is fitted onto the bushing palms of the circuit breaker.

Secondary setting modifications are also applied a day prior to the test. The circuit breaker control logic was applied and the transformer protection isolated. The circuit breaker was then remotely controlled closed while isolated from the system to test the control logic. With the event time stamp from the relays, the timer for the control logic was tweak to achieve the required timing. The test was then repeated to confirm that the modified timing provides the required fault application time. After the "dry run" test is completed, all primary equipment are then tagged and locked for the main test.

4.3 The Day of the Fault

On the day of the actual test, a quick check was conducted to all the modification to confirm that they remain intact. Once confirmed the earth cable is then applied to the left most phase of the circuit breaker. The connection is checked by the coordinator and the switchyard is cleared for the test. With conference communication between all parties, final check was performed to confirm that all systems are ready for the test. The disconnector is then closed by the control room back in head office to arm the fault. Once confirmed and ready, the circuit breaker is then closed by the control room to apply the fault.

With indication on the protection relays and SCADA back to the control room, the circuit breaker is confirmed to be opened by the control logic. The disconnector is then opened remotely by the control room to disarm the fault. A quick check is then done on all data collected to confirm the fault has been applied and the duration of it. Once confirm that all systems are good, the second earth cable is then applied to the middle phase of the circuit breaker with the same procedure repeated. Once the two phase fault is completed the same process is then repeated for three phase fault with earth cable applied to the right most phase of the circuit breaker.

Figure 6 Fault Setup – Earth Cable Connection

4.4 Restoration

Once all the tests have been completed, all the modifications are restored back to its normal state. All the data recorded are retrieved from the relative devices for result checking and comparison. The wind farm is also returned to the commissioning operating state.

5 Result and Conclusion

5.1 Result Discussion

The test was considered successful with all required result obtained. However for the wind farm, some wind turbines disconnected during the test. The manufacturer indicated that this was to do with some fine tuning of the control system and have since been rectified.

From the power system, the whole system withheld well during the test. Although this was to be expected, it was good to have a confirmation. The result is shown in the figure below.

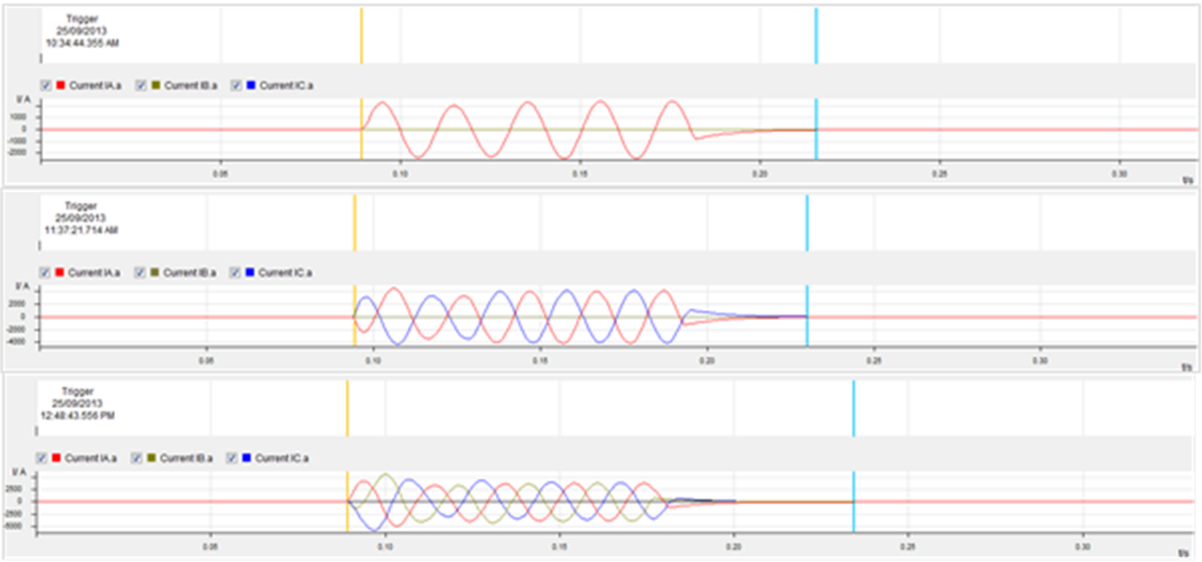

Figure 7 Oscillography Result

Table 1 below shows a comparison between the fault current measured during the test and the simulation result. The total fault current measured at the point of the fault is fairly close to the actual fault. However the fault contributions from various sources are not quite as close to the simulation result. This is likely due to the difference in steady state pre-fault voltage level and margin of errors in the simulation model.

Table 1 Comparison of Simulation and Actual Result

	L-G			2L-G			3L-G		
	Simulation	**Actual**	**Difference**	**Simulation**	**Actual**	**Difference**	**Simulation**	**Actual**	**Difference**
Point of fault	1836	1676.1	9.54%	3277	2943.8	11.32%	3648	3844.6	5.11%
NW	910	591.16	53.93%	1440	934.1	54.16%	1470	1019	44.26%
SD	682	454.71	49.99%	1105	765	44.44%	1142	801	42.57%
Wind farm	874	882.072	0.92%	1464	1431.1	2.30%	1325	1837.8	27.90%

5.2 Conclusion

With the test conducted, this type of testing has proofed to be very useful and should be conducted if possible as part the commissioning of a new generation source. It is definitely the ultimate commissioning test and provides a high degree of confidence for the commissioned equipment.

References

List any references here

1. National Electricity Rule, Version 68, Australia Energy market Commission
2. IEEE Std. 80-2000, IEEE

Biography: Jimmy (Yuan Long) Chong

Jimmy Chong is currently the Senior Protection and Control Engineer at TasNetworks. He graduated from University of Tasmania at 2007 with a Bachelor Degree in Electrical Power Engineering. He then started working in Hydro Tasmania Consulting as a graduate engineer working in Power System studies and Protection and Control team. He then moved to Transend Networks by 2010 and have stayed with the company since the merger with Aurora to become TasNetworks.