REPORT

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System Impact Assessment Report

Kruger
Wind Generation Station (WGS)

CONNECTION ASSESSMENT & APPROVAL PROCESS

CAA ID 2005-203

Applicant: Kruger Energy Port Alma Limited Partnership

Transmission Assessments & Performance Department

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System Impact Assessment Report

Kruger Wind Generation Project

Acknowledgement

The IESO wishes to acknowledge the assistance of Hydro One in completing this assessment.

Disclaimers

IESO

This report has been prepared solely for the purpose of assessing whether the connection applicant's proposed connection with the IESO-controlled grid would have an adverse impact on the reliability of the integrated power system and whether the IESO should issue a notice of approval or disapproval of the proposed connection under Chapter 4, section 6 of the Market Rules.

Approval of the proposed connection is based on information provided to the IESO by the connection applicant and the transmitter(s) at the time the assessment was carried out. The IESO assumes no responsibility for the accuracy or completeness of such information, including the results of studies carried out by the transmitter(s) at the request of the IESO. Furthermore, the connection approval is subject to further consideration due to changes to this information, or to additional information that may become available after the approval has been granted. Approval of the proposed connection means that there are no significant reliability issues or concerns that would prevent connection of the proposed facility to the IESO-controlled grid. However, connection approval does not ensure that a project will meet all connection requirements. In addition, further issues or concerns may be identified by the transmitter(s) during the detailed design phase that may require changes to equipment characteristics and/or configuration to ensure compliance with physical or equipment limitations, or with the Transmission System Code, before connection can be made.

This report has not been prepared for any other purpose and should not be used or relied upon by any person for another purpose. This report has been prepared solely for use by the connection applicant and the IESO in accordance with Chapter 4, section 6 of the Market Rules. The IESO assumes no responsibility to any third party for any use, which it makes of this report. Any liability which the IESO may have to the connection applicant in respect of this report is governed by Chapter 1, section 13 of the Market Rules. In the event that the IESO provides a draft of this report to the connection applicant, you must be aware that the IESO may revise drafts of this report at any time in its sole discretion without notice to you. Although the IESO will use its best efforts to advise you of any such changes, it is the responsibility of the connection applicant to ensure that it is using the most recent version of this report.

HYDRO ONE

Special Notes and Limitations of Study Results

The results reported in this study are based on the information available to Hydro One, at the time of the study, suitable for a preliminary assessment of a new generation or load connection proposal.

The short circuit and thermal loading levels have been computed based on the information available at the time of the study. These levels may be higher or lower if the connection information changes as a result of, but not limited to, subsequent design modifications or when more accurate test measurement data is available.

This study does not assess the short circuit or thermal loading impact of the proposed connection on facilities owned by other load and generation (including OPG) customers.

In this study, short circuit adequacy is assessed only for Hydro One breakers and does not include other Hydro One facilities. The short circuit results are only for the purpose of assessing the capabilities of existing Hydro One breakers and identifying upgrades required to incorporate the proposed connection. These results should not be used in the design and engineering of new facilities for the proposed connection. The necessary data will be provided by Hydro One and discussed with the connection proponent upon request.

The ampacity ratings of Hydro One facilities are established based on assumptions used in Hydro One for power system planning studies. The actual ampacity ratings during operations may be determined in real-time and are based on actual system conditions, including ambient temperature, wind speed and facility loading, and may be higher or lower than those stated in this study.

The additional facilities or upgrades which are required to incorporate the proposed connection have been identified to the extent permitted by a preliminary assessment under the current IESO Connection Assessment and Approval process. Additional facility studies may be necessary to confirm constructability and the time required for construction. Further studies at more advanced stages of the project development may identify additional facilities that need to be provided or that require upgrading.

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KRUGER WIND GENERATION PROJECT
IESO SYSTEM IMPACT ASSESSMENT

SIA Findings

The Kruger Energy Port Alma Ltd is developing a new 101.2 MW wind power generation farm in Port Alma. The project was awarded a contract under the government RFP II, and is expected to start commercial operation at the end of 2008.

Summary

This Assessment examined the impact of injecting 101 MW of wind power generation to the provincial gird via 230 kV circuit C23Z or C24Z south of Chatham on the reliability of the IESO-controlled grid.

Following conclusions and recommendations were made.

Conclusions and Recommendations

Conclusions:

The analysis concluded that:

(1) The proposed wind farm does not have a negative adverse impact to the reliability of the IESO-controlled grid.

(2) The post-contingency voltage declines are within IESO criteria.

(3) None of the recognized contingencies cause any material adverse impact to the transient performance of the IESO-controlled grid.

(4) Special protection schemes existing in Windsor area can be continued to use as specified in the IESO operational instructions.

(5) Siemens MK II generator which is used in this wind farm does not fully meet IESO Market Rules on reactive capability requirement. The connection impedance between the wind turbine generators and the IESO-controlled grid exceeds the required limit. Measures must be taken to mitigate both.

(6) The new wind farm is not required to be part of any special protection scheme.

(7) Under extreme weather conditions, the flow in J3E, J4E and Keith T12 could exceed their ratings by 2008. This situation has been identified in previous assessments, and is not caused by the Kruger wind farm. In fact, the presence of the Kruger wind farm results in a slight reduction in the power flow in above transmission equipment.

Recommendations:

(1) The proponent provides a copy of the functionalities of the Wind Farm Management System (WFMS) to the IESO.

(2) The transmitter changes the relay settings of C23Z/C24Z terminal stations to account for the effect on apparent impedance due to power injection from the wind farm.

IESO's Requirements for Connection

The following requirements for the incorporation of Kruger WGS to C23Z or C24Z have been identified.

(1) The generators must be operated at rated voltage of 673 V instead of 690 V. The generators should have a nominal operating range of 639 – 706 V in which entire range, the generators must be able to produce full MW output. All auxiliary systems including Low Voltage Ride Through (LVRT), protections and controls must operate reliably in this entire range. The tap ratio of each generator step-up transformer must be changed from 34.5 kV/690 V = 50 to 34.5 kV/673 V = 51.26 or the tap must be placed at 51.26/50 = 1.025 pu compared to nominal setting. Since the generator is operated at 673/690 = 0.975 pu, the first under-voltage trip setting of the generator must be reduced from standard 0.9 pu to 0.875 pu.

(2) The output of each generator must be limited to 2.23 MW when directed by the IESO control room. The proponent has agreed to comply with this requirement. The Wind Farm Management System must be able to implement this limit in a timely manner on each of all 44 generators.

(3) A static compensation of 36 MVAr must be connected to the collector bus. This must constitute 6 steps of 6 MVAr each. The capacitors will need to be auto-switched by the Wind Farm Management System via suitable over/under voltage settings.

(4) The generators and the capacitor bank must control the 34.5 kV collector bus voltage to a value to be determined by the IESO operating staff. The Wind Farm Management System must coordinate and direct the combine voltage control by generators and capacitors to avoid 'hunting'. Periodically, the IESO will revise the voltage set point as necessary.

(5) The generators should not trip for contingencies except for which the generators will be removed by configuration. If generators trip for contingencies for which they are not removed by configuration, the LVRT capability must be upgraded.

(6) The 34.5/230 kV transformer must have the manual tap changer facilities.

(7) During commissioning period, a set of IESO specified tests must be performed. The commissioning report must be submitted to the IESO within three months of the conclusion of commissioning. The field test results should be verifiable using the PSS/E models used for this SIA.

(8) All protection systems must be supplied from separate batteries and separate communication paths.

(9) The autoreclosure of the new 230 kV breaker at the connection point must be blocked. Upon its opening for a contingency, it must be closed only after the IESO approval is granted. The IESO will require reduction of power generation prior to the closure of the breaker followed by gradual increase of power to avoid a power surge.

(10) The generators should not trip for frequency variations that are above the curve in Figure 1.

(11) The applicant is responsible for providing real-time telemetering of following variables to the IESO.

- net active and reactive power measured either at 34.5 kV or 230 kV side of the transformer T1
- status of new 34.5 kV and 230 kV breakers and disconnect switches
- 230 kV and 34.5 kV voltages at the transformer station
- in service status of the Wind Farm Management System (WFMS)
- voltage controlling set point

Additional telemetry requirements may be identified if necessary by the IESO during facility registration process.

(12) If the Wind Farm Management System (WFMS) is unavailable, each generator must control its own terminal voltage while capacitors continue to control 34.5 kV voltage.

(13) A disturbance monitoring device must be installed. The applicant is required to provide these data to the IESO upon a request from the IESO.

(14) The registration of the new facilities will need to be completed through the IESO's facility registration process before any part of the facility can be placed in-service. If the data or assumptions supplied for the registration of the facilities materially differ from those that were used for the assessment, then some of the analysis might need to be repeated.

Notification of Conditional Approval

From the information provided, our review concludes that the proposed changes will not result in a material adverse effect on the reliability of the IESO-controlled grid. It is recommended that a Notification of Conditional Approval be issued for Kruger WGS subject to the IESO receiving written acknowledgement that the requirements listed in this report will be implemented.

1. Project Description

Kruger Energy Port Alma Limited Partnership was awarded a contract under the government RFP II, and in the process of developing a 101.2 MW Wind Generation Station (WGS) near the town of Merlin, south of Chatham.

The power generated at this new facility will be converted to 230 kV at a transformer station to be built by the proponent, transmitted 12 km by an overhead line and injected into provincial gird via 230 kV circuit C24Z or C23Z at about 24 km south of Chatham. The construction is scheduled to commence spring of 2007 with commercial operation expected at the end of 2008.

The generating facility will consist of forty four 2.55 MVA, 2.3 MW, 690 V, Siemens 2.3MK II, 60 Hz variable speed wind turbine generators that employ squirrel cage induction generators. Each of them has two AC/DC converters connected back-to-back interfacing the stator and the generator step-up transformer. Each converter has the capability to operate in all four quadrants, so they enable the two-way transfer of power. While these converters perform conversion of power from fluctuating frequency at stator to constant frequency at step-up transformer, the dc link provides added advantage of curtailing the propagation of disturbances between the generator and the grid. The harmonics generated by the dc link are attenuated by a filter and a series reactor connected to the generator terminals. During severe voltage drops occurring in the grid, the low voltage ride through capability gets activated by the grid side AC/DC converter producing more reactive current at the expense of active current to increase the terminal voltage.

Each tower will have a generator, two AC/DC converters, a step-up transformer and a breaker, and will be connected to a collector system that consists of four 34.5 kV circuits C1, C2, C3 and C4. Each circuit will have following number of generators.

Circuit	C1	C2	C3	C4	Total
Number of generators	10	10	12	12	44
Maximum MW	23.0	23.0	27.6	27.6	101

Each 0.690/34.5 kV transformer has reactance of 0.06 pu on 2.6 MVA base and has manual off-load tap changers on HV windings. They will have 2 equal steps above nominal and 2 equal steps below nominal giving a total of –5 % to +5 % tap variation. All four circuits will be connected to one collector bus which will be connected to a single 66/88/110 MVA, 34.5/230 kV transformer with reactance of 0.06 pu on 88 MVA base, then to a 12 km overhead line up to C23Z/C24Z tap point. The 34.5/230 kV transformer will have manual tap change facilities. It will have 8 equal steps above nominal and 8 equal steps below nominal on HV winding giving a total of –10 % to +10 % tap variation.

– End of Section –

2. General Requirements

Models & Data

1. The Connection Applicant must complete the IESO Facility Registration process before IESO final approval for connection is granted. Final models and data including any details of control systems that would be operational must be provided to the IESO prior to the first energisation of any equipment.

2. During commissioning, the Connection Applicant must provide evidence to the IESO that the equipment installed meets the Market Rules requirements and matches or exceeds the performance predicted. This evidence shall be either type tests done in a controlled environment or commissioning tests done on-site. In either case, the testing must be done accordance with widely recognized standards and to the satisfaction of the IESO. Until this evidence is provided, the Connection Applicant must accept any restrictions the IESO may impose upon their participation in IESO-administered market or connection to the IESO-controlled grid.

Generators

1. Each generator must satisfy the Generator Facility requirements in Appendix 4.2 of Market Rules.

The generators must have the capability to operate ± 5 % of the nominal terminal voltage.

The generators must have the dynamic reactive power capabilities to supply reactive power continuously at all active power outputs in the range of 0.9 lag to 0.95 lead power factor based on rated active power at its generator terminals for at least one constant 230 kV system voltage.

If necessary, shunt capacitors must be installed to offset the reactive power losses within the facility in excess of the maximum allowable losses. If generators do not have dynamic reactive power capabilities as described above, dynamic reactive compensation devices must be installed to make up the deficient reactive power.

2. The generators must be able to ride through recognized contingencies on the IESO-controlled grid that does not disconnect the facility by configuration.

3. The connection and disconnection of the generators must minimize any adverse effects on the IESO-controlled grid.

Connection Equipment (Breakers, Disconnects, Transformers, Buses)

1. The 230 kV equipment connected to terminal stations must be capable of continuously operating in the range between 220 kV and 250 kV as per Appendix 4.1 of Market Rules.

Some recognized contingencies (e.g. load shedding, open line end) can cause a temporary voltage increase above the maximum continuous limit of 250 kV. For these conditions, connection equipment may be exposed to voltages slightly above its maximum continuous rating for the short period of time that it takes the IESO to direct operations to restore a normal voltage and to prepare for the next contingency. This re-preparation period will be as short as possible, but it will not take longer than 30 minutes.

The 230 kV equipment must be able to interrupt rated fault current for voltages up to the maximum continuous rating. They must remain in service, and not automatically trip for voltages up to 5% above the maximum continuous rating for up to 30 minutes to allow the system to be re-dispatched to return voltages within their normal range.

2. The Transmission System Code states that 230 kV connection equipment should have a rated 3-phase symmetrical short circuit capability of 63 kA and a rated single line to ground short circuit capability of 80 kA (usually limited to 63 kA). It also requires that 230 kV breakers have a rated interrupting time of three cycles (50 ms) or less.

3. The connection equipment must be designed so that the adverse effects of failure on the IESO-controlled grid are mitigated.

4. The connection equipment must be designed so that it will be fully operational in all reasonably foreseeable ambient temperature conditions. This includes ensuring that SF6 breakers are equipped with heaters to prevent freezing.

IESO Monitoring and Telemetry Data

The Appendix 4.15 and Appendix 4.19 of Market Rules list the requirements with respect to the telemetry that must be provided to the IESO and to the standards that must be achieved on a continual basis by all generators.

In accordance with the requirements for a *major generation facility*, Connection Applicant must ensure that all the equipment needed to provide the telemetry data and meet the performance standards will be installed.

The IESO will finalize items to be telemetered during the IESO Market Entry Process.

Protection Systems

1. Faults within the facility must not trip 230 kV circuits C23Z/C24Z except for the failure of a Kruger 230 kV connection breaker. After the facility begins operation, if the tripping of C23Z or C24Z occurs due to events within Kruger facility, the facility may be required to be disconnected until the problem is solved.

2. Protection systems must be designed to meet all the requirements of the Transmission System Code and any additional requirements identified by Hydro One.

3. The facility must be capable of operating at full active power for a limited period of time for frequencies as low as 58.8 Hz. The wind turbine generators must not trip for under-frequency system conditions that are below 60 Hz but above 57.0 Hz and above the curve shown in Figure 1.

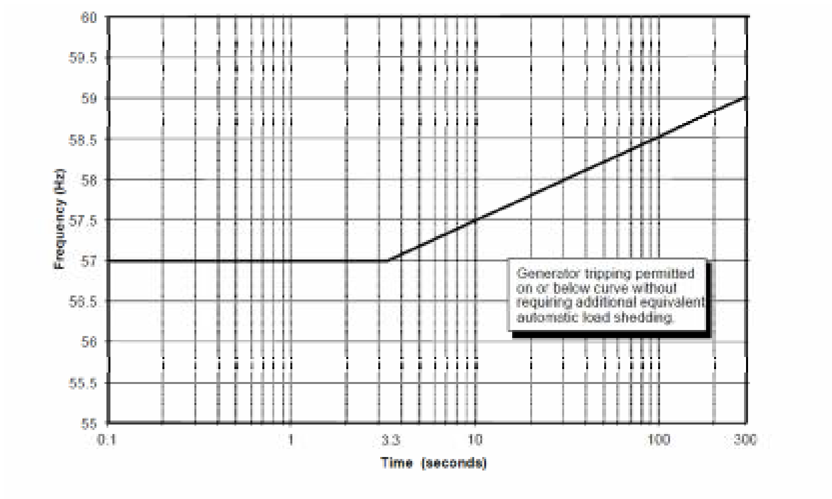


Figure 1: Standards for Setting Under-frequency Trip Protection for Generators

Miscellaneous

1. The generators must be capable of operating continuously in the range between 59.4 Hz and 60.6 Hz as specified in Appendix 4.1 of Market Rules.

2. The generators must operate in the voltage control mode. Operation of the facility in power factor control or reactive power control is not acceptable.

3. All plant auxiliaries must be capable of operating continuously within the voltage range of 220 kV to 250 kV.

4. Connection Applicant is required to install at the facility a disturbance recording device with clock synchronization that meets the technical specifications provided by Hydro One. The device will be used to monitor and record the response of the facility to disturbances on the 230 kV system in order to verify the dynamic response of generators. The quantities to be recorded, the sampling rate and the trigger settings will be provided by Hydro One.

– End of Section –

3. Review of Connection Proposal

3.1 Proposed Connection Arrangement

The proposed connection arrangement is shown in Figure 2.

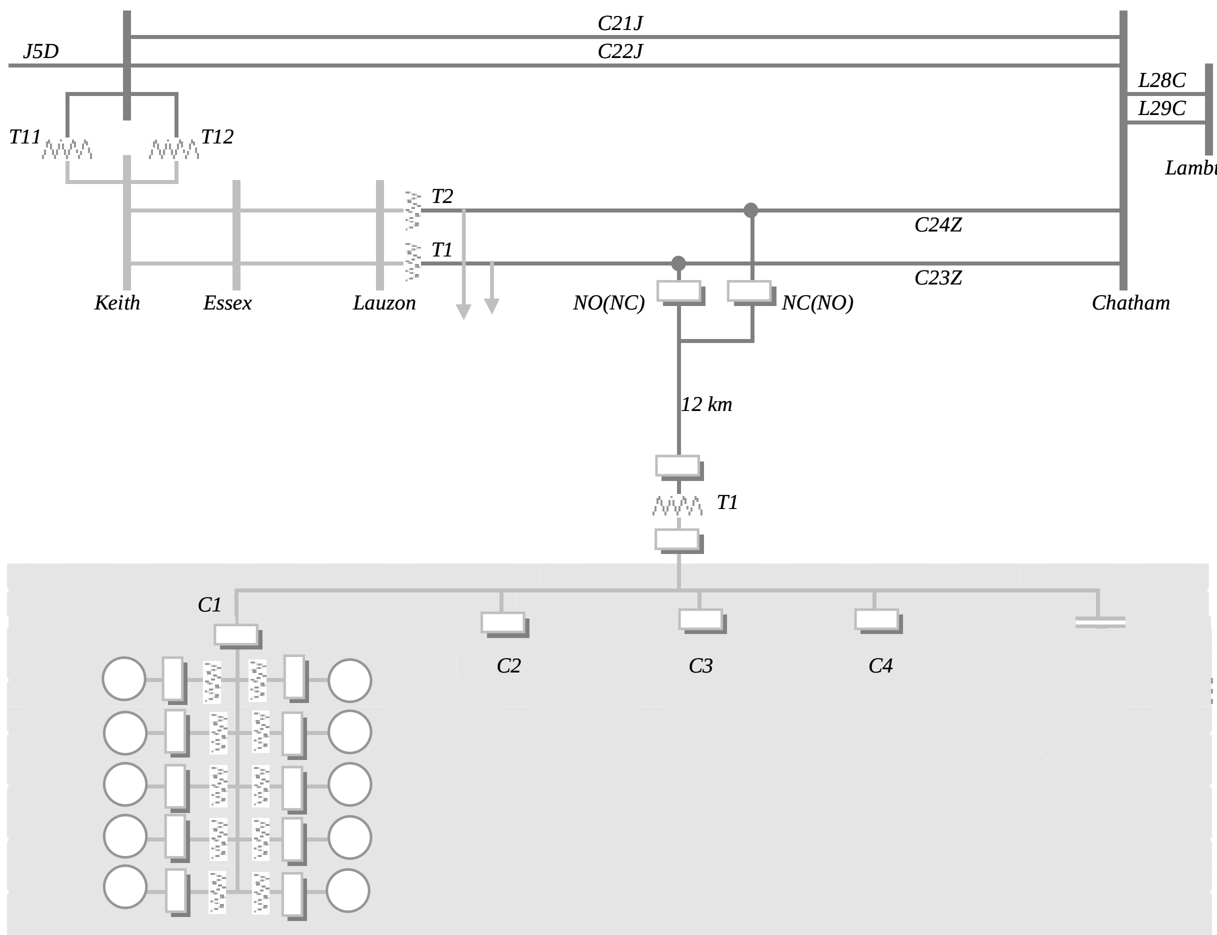


FIGURE 2 – PROPOSED CONNECTION ARRANGEMENT

The number of turbines N per circuit and MW injection into each circuit is summarized below.

Circuit	C1	C2	C3	C4	Total
N	10	10	12	12	44
MW	23.0	23.0	27.6	27.6	101

3.2 Existing System

The geographical area in which the new facility will be located is supplied by C23Z and C24Z at Chatham, Keith autotransformers T11 and T12 and three generating stations, i.e. West Windsor GS, Windsor Transalta GS and Brighton Beach GS. Figure 3A, 3B, 3C and 3D show the MW flow in C23Z and C24Z at Chatham, Keith autotransformers T11 and T12 in 1 Hr average samples during the period of Jan 1- Dec 31, 2005.

The Windsor 115 kV system which is a sub-system of above area is considered 'closed' when there is a continuous 115 kV transmission path between Lauzon TS and Keith TS. The Windsor 115 kV System is considered 'open' when the 115 kV transmission path between Lauzon TS and Keith TS is broken. Since the SIA is performed with all transmission elements in service, this assessment is limited to analysing the closed Windsor 115 kV system configuration.

Figure 3E and 3F show the 230 kV voltage at Chatham and Lauzon. Based on available data for 2005, Chatham voltage is shown from Jan 1 - Dec 31 and Lauzon voltage is shown from Aug 1 – Dec 31.

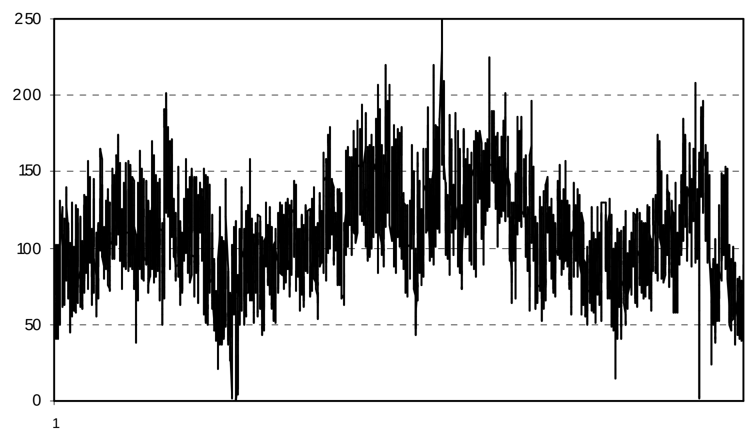


FIGURE 3A – MW FLOW IN C24Z @ C

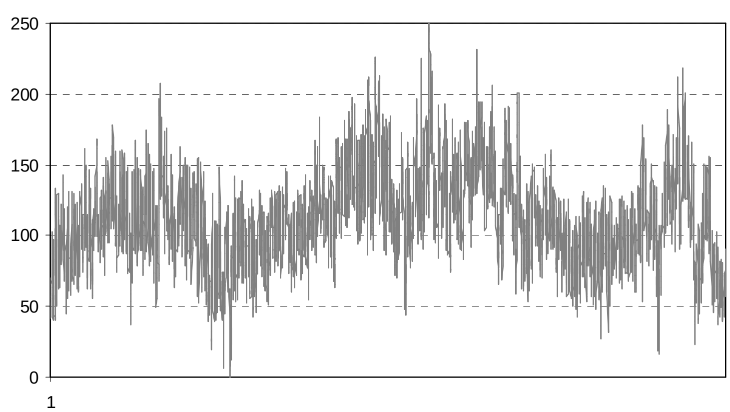


FIGURE 3B – MW FLOW IN C23Z @ C

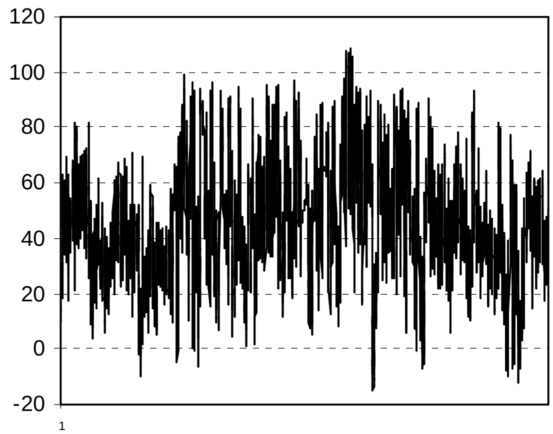


FIGURE 3C – MW FLOW IN KEITH T11

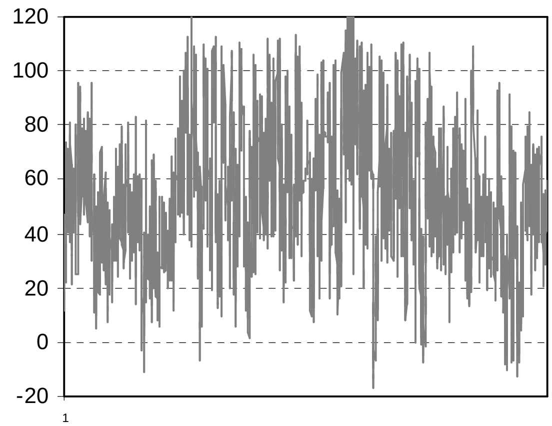


FIGURE 3D – MW FLOW IN KEITH T12

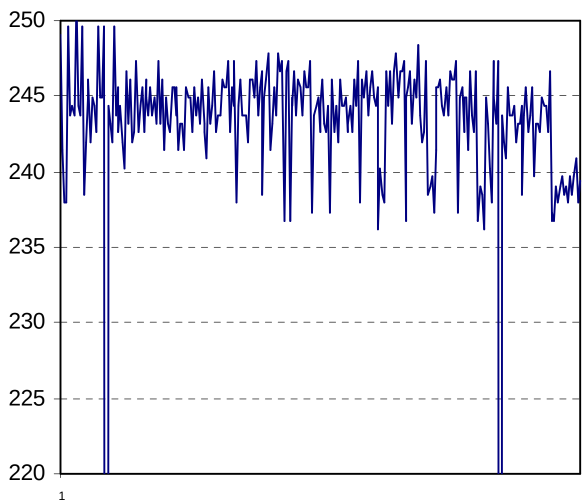


FIGURE 3E – CHATHAM 230 KV VOLTAGE

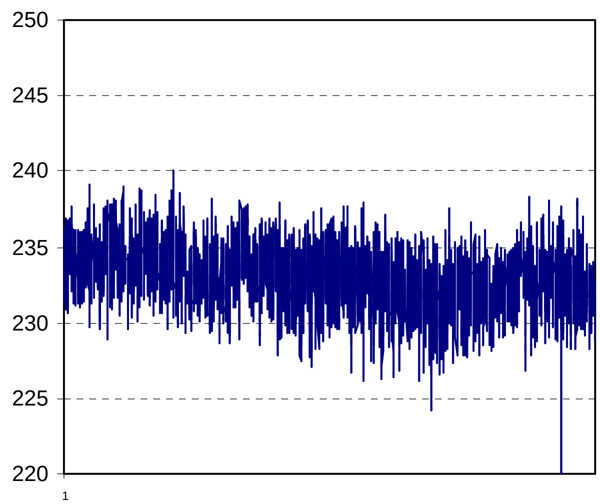


FIGURE 3F – LAUZON 230 KV VOLTAGE

The summation of power flows from Figure 3A+3B+3C+3D is shown in Figure 3G. This would give the net flow into the area enclosed by 230 kV busbars at Chatham and Keith. This is in effect the generation deficit in that area where the 2005 average is about 320 MW. The Kruger project will help to reduce this deficit.

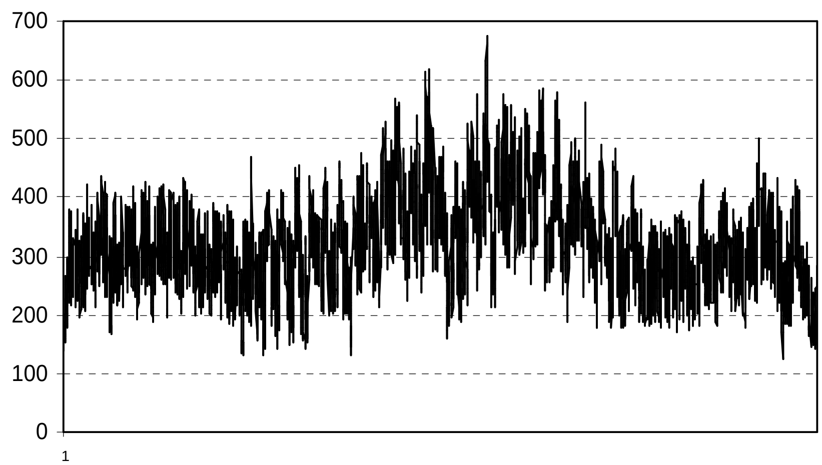


FIGURE 3G – NET MW FLOW IN FROM CHATHAM AND KEITH

4. Data Verification

4.1 Generator

A generator connecting to the IESO-controlled grid must have the capability to perform the following unless specified otherwise.

- Supply reactive power continuously at all active power outputs in the range of 0.9 lag to 0.95 lead power factor based on rated active power at its generator terminals for at least one constant 230 kV system voltage, and
- Supply full active power continuously while operating at a generator terminal voltage ranging from 0.95 pu to 1.05 pu of the generator's rated terminal voltage

The details of the generator data used in this assessment are given in Appendix A.

4.2 Transformer

Specifications for the 34.5/230 kV step-up transformer is listed below.

Transformation	240/34.5 kV
Rating	66/88/110 MVA ONAN/ONAF/ONAF
Impedance	0.06 pu based on 88 MVA
Configuration	3 phase, high side: wye, low side: delta
Tapping	on-load tap changers at HV (± 10% in 17 steps)

4.3 Circuit Breakers and Switches

Specifications of the isolation devices provided by the connection applicant are listed below. The incomplete data must be provided to the IESO.

Breakers	**LV**	**HV**
Rated line-to-line voltage	34.5 kV	230 kV
Interrupting time		3 cycles
Interrupting media		SF6
Rated continuous current		1200 A
Rated short circuit breaking current		63 kA
Switches		
Rated line-to-line voltage	34.5 kV	230 kV
Rated continuous current		1200 A

– End of Section –

5. Fault Level Assessment

Fault level studies were completed by Hydro One to examine the effects of the Kruger Wind Farm on fault levels at existing facilities in the area. Studies were performed to analyze the fault levels with and without Kruger and other proposed wind farms in the surrounding area. A summary of the study results is shown in Table below. The short circuit study was carried out with the following facilities and system assumptions:

Proposed wind farms to be studied:
- Kingsbridge II Phase 1 (B562L) 158.7 MW and Phase 2 (B563L) 140.3 MW
- Leader A & B (B4V) 99 MW
- Leader A & B (B5V) 100.65 MW
- Melancthon II (B4V) 33 MW
- Melancthon II (B5V) 99 MW
- Ripley (B22D/B23D) 76 MW
- Kruger (C23Z/C24Z) 101.2 MW

Generation facilities to be included:
- 6 Bruce units
- 6 Pickering units: Pic B G5-8, Pic A G1 & G4
- GTAA – 44 kV buses at Bramalea TS and Woodbridge TS = 117 MW
- TransAlta Douglas – 44 kV buses at Bramalea TS = 110 MW
- Expected RFP contracts:
  a) Erie Shores Wind Farm (W8T) 99 MW
  b) Blue Highlands Wind Farm (S2S) 49.5 MW
  c) Kingsbridge Wind Farm (Goderich TS) 39.6 MW
  d) Melancthon Grey Wind Farm (B4V) 67.5 MW
  e) Greenfield Energy Centre (Lambton SS connection as per SIA Report 0292, Diagram 7) 1,147 MW
  f) St. Clair Energy Centre (L25N & L27N, new connection point between Petrosar Junction & Sarnia-Scott) 638 MW
  g) Enbridge/Sithe Goreway (V72R/V73R) 900 MW
  h) Portlands (Hearn SS) 550 MW
- 4 Darlington units
- 8 Nanticoke units
- 4 Lennox units
- West Windsor Power – near Keith TS on J2N = 129 MW
- TransAlta Sarnia – on N6S and N7S from Scott TS = 580 MW
- Brighton Beach – near Keith TS on J20B (230 kV) & J1B (115 kV) = 680 MW
- Imperial Oil on N6S and N7S = 112 MVA

System Assumptions:
- Preston-Cambridge TS 230/115 kV autotransformer
- Parkway TS 500/230 kV autotransformers (2)
- All new capacitor banks in service: Essa TS, Burlington TS, John TS, Leaside TS, Richview TS, & Trafalgar TS
- Circuit B3N in service
- Claireville TS 230 kV bus needs to be closed
- Leaside TS 115 kV bus needs to be open

- Richview TS 230 kV bus needs to be open
- Cherrywood TS needs to be operated with separate north & south 230 kV switchyards, and the 230 kV buses at Cherrywood North TS & Cherrywood South TS need to be open
- Hearn SS 115 kV bus needs to be closed
- Cooksville TS 230 kV bus needs to be closed
- Mid-point of Claireville TS to Parkway TS 230 kV circuits V71RP and V75P is closed
- Middleport TS 230 kV bus needs to be open
- Ontario-Michigan phase shifters on neutral taps (minimum impedance taps)

Michigan Assumptions:
Hydro One to use short circuit equivalent (May 2005) provided by International Transmission Company.

Lambton SS & TGS Assumptions:

Case 1: Lambton SS 230 kV bus closed with 1 unit in service (worst case fault levels at Lambton with Greenfield & St. Clair in service).

Case 2: Lambton SS 230 kV bus open with 4 units in service (worst case fault levels away from Lambton with Greenfield & St. Clair in service).

Bus	All Wind Farms I/S Total Fault Current Symmetrical (kA)		All Wind Farms O/S Total Fault Current Symmetrical (kA)		Breaker Ratings Symmetrical (kA) (1)
	3-phase fault	L-G	3-phase fault	L-G	
	Lambton Closed				
Chatham 230 kV	20.8	15.2	20.0	13.2	32.8
Lambton 230 kV	60.5	66.8	60.3	63.7	65 / 70 (2)
Lambton A 230 kV	60.6	66.8	60.3	63.7	65 / 70 (2)
Keith 230 kV	16.4	18.6	16.3	18.5	43.3
Keith 115 kV	17.5	21.6	17.5	21.5	39.3
Lauzon 115 kV	15.6	18.3	15.5	18.2	40
	Lambton Open				
Chatham 230 kV	21.1	15.4	20.3	13.4	32.8
Lambton 230 kV	44.4	48.5	44.3	48.4	65 / 70 (2)
Lambton A 230 kV	47.6	51.3	47.5	51.2	65 / 70 (2)
Keith 230 kV	16.5	18.6	16.4	18.6	43.3
Keith 115 kV	17.6	21.6	17.5	21.5	39.3
Lauzon 115 kV	15.7	18.3	15.6	18.3	40

(1) Worst case rating
(2) The 65 kA rating applies to breakers PL4 & KL4; the 70kA rating to remaining 230 kV breakers at Lambton SS.

The results show that the fault levels in the surrounding area of the Kruger wind farm are below the symmetrical breaker ratings. At the Lambton 230 kV bus, the fault levels exceed the 65 kA rating when the Lambton Bus is closed. This issue is resolved when Lambton bus is operated ‘open’ and the fault level decreases to 51.3 kA.

Fault levels increase slightly when all the wind farms are in service with the highest increase at Lambton of 3.1 kA.

– End of Section –

6. System Impact Studies

This connection assessment was done to identify the effect of the proposed facility on thermal loading of transmission interfaces in the vicinity, the system voltages for pre/post contingencies, the ability of the facility to control voltage and the transient performance of the system.

6.1 Assumptions and Background

Following sections summarizes the study assumptions and the background information required for the analysis.

6.1.1 Pre-contingency conditions

- The study was performed for a system with all transmission elements in service.
- The loads used were 2008 summer coincident peaks under extreme weather conditions. The total Ontario demand is 27,500 MW and the zonal distribution is :

NW	NE	Essa	Ottawa	East	Toronto	Niagara	SW	Bruce	West
923	1169	1673	1916	1738	10149	1045	5391	57	3439

- All four Ontario-Michigan ties J5D, L4D, L51D and B3N were in service. However, only the J5D phase shifter was in service. The other phase shifters on B3N, L51D and L4D were by-passed.
- The pre-contingency had following MW flow levels without new facility in service. The C23Z, C24Z, Keith T11 and T2 flows are similar to the real-time flow data shown in Figure 3A, 3B, 3C and 3D. The total import from Michigan to Ontario is 1462 MW over four ties with J5D limited to 150 MW.

C23Z@C	C24Z@C	Keith T11	Keith T12	C21J@J	C22J@J	J5D@J	L4D@L	L51D@L	B3N@N
176.5	177.1	104.3	117.7	118.2	114.6	-150.1	-722.9	-567.3	-21.2

- For voltage decline studies, the MW loads were converted into constant current and admittance loads equally. The MVAr loads were converted only into constant admittance loads.
- The large power stations in the province had following number of units in service.

Darlington GS	Bruce GS	Nanticoke GS	Lennox GS	Pickering GS	Lambton GS
3	6	5	4	6	0

- The power stations in the vicinity of the proposed project had following MW outputs.

Sarnia Transalta	Brighton Beach 230 kV,115 kV	Windsor Transalta	West Windsor Power	Calpine	Invenergy
500	375,160	66	125	1150	592

6.1.2 Siemens MK II reactive power limits

The Siemens MK II wind turbine generator has a dc link between the stator and the grid. Therefore, the reactive capability of the MK II generator not only depends on the AC voltage at terminals, but also depends on the active power capability of the DC link, i.e. the DC voltage and the DC current. As a result, the ***reactive power capability*** curves of MK II are different to those of synchronous machines, and the Q_{max} and Q_{min} can no longer be assumed constants within ± 5% of rated voltage. Therefore, the variation of Q_{max} and Q_{min} in MK II with terminal voltage needs to be correctly modelled in the load flow simulation; if not, a conservative Q_{max} and Q_{min} corresponding to rated power within ± 5% of rated voltage need to be used instead of using Q_{max} and Q_{min} corresponding to rated power as well as rated voltage.

The Figure 4 shows the pu reactive power capability of MK II corresponding to rated power. Please note that the pu values are not based on machine MVA, but based on P_{max} of 2.3 MW as provided by Siemens.

The IESO requires that any generator including MK II must be able to continuously operate within ± 5 % of rated voltage. For that entire range, the MK II must have the capability to generate $2.55 \times \sin[\cos^{-1}(0.9)]/2.3 = 0.47$ pu reactive power and to absorb $2.55 \times \sin[\cos^{-1}(0.95)]/2.3 = 0.34$ pu reactive power on P_{max} base. The Figure 4 shows this required level of lag and lead reactive power.

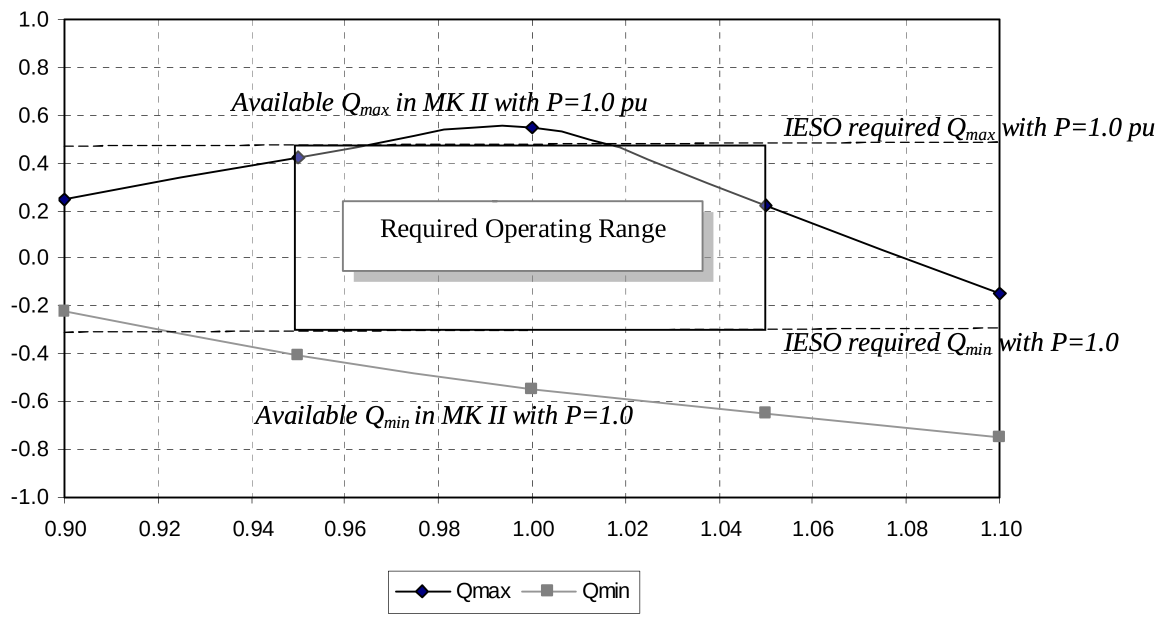


FIGURE 4 – VARIATION OF Q_{MAX} AND Q_{MIN} WITH WTG TERMINAL VOLTAGE

It can be seen that if the rated voltage is 1.0 pu, at the extremes of the ± 5% voltage range, the generator can deliver only $Q_{max} = 0.42$ pu (at 0.95 pu voltage) and $Q_{max} = 0.22$ pu (at 1.05 pu voltage). That would imply each MK II generator can be short of delivering 0.47 – 0.22 = 0.25 pu or 0.25×2.3 = 0.575 MVAr of required dynamic reactive power. As far as the entire wind farm is concerned, it can be short of delivering 0.575×44 = 25 MVAr of required dynamic reactive power. Conversely, the MK II can absorb $Q_{min} = 0.41$ pu at 0.95 pu terminal voltage and $Q_{min} = 0.65$ pu at 1.05 pu terminal voltage. That would mean each MK II has the capability to absorb excess reactive power than required by the IESO.

6.1.3 Review of special protection schemes in Windsor area

- *Windsor Area Overload Protection Scheme*

The Windsor Overload Protection Scheme protects against equipment overloading and over-voltages. The scheme is contingency-based, initiating for contingencies that occur on elements emanating from Essex and Keith TS. From the contingencies examined, the loss of C21J+C22J, C22J+T12, J3E+J4E, J5D and Z7E+Z1E are recognized by this scheme. The preferred selection is to arm Brighton Beach units and the rejection of Brighton Beach G1 was sufficient for contingencies which required the overload scheme.

- *Load Rejection Scheme (Contingency-Based)*

The connectivity-based L/R scheme protects the loads on circuits K2Z and K6Z from excessive voltage declines following the loss of C23Z+C24Z or the loss of C23Z or C24Z when the companion circuit is out of service. The L/R is achieved by opening K2Z and K6Z 115 kV circuits at Lauzon together with 115 kV capacitor SC12. From the contingencies examined, the loss of C23Z+C24Z is recognized by this scheme. For this SIA, there was no need to deploy this scheme.

- *Load Rejection Scheme (Voltage-Based)*

The voltage dependent L/R scheme is initiated if the voltage level at Kingsville TS declines to 106 kV or less. This scheme is triggered when Brighton Beach GS or J3E+J4E are lost.

6.1.4 Contingencies and control actions

	Loss of	Control Actions
C1	C21J+C22J	Brighton Beach G1 was tripped by the overload protection scheme as a preliminary thermal analysis indicated a possible overloading scenario.
C2	C22J+T12	Brighton Beach G1 was tripped by the overload protection scheme as a preliminary thermal analysis indicated a possible overloading scenario.
C3	C23Z+C24Z	50% of Kingsville load was rejected post ULTC by the voltage dependent L/R scheme as preliminary analysis indicated that K2Z and K6Z voltages at Kingsville TS were both less than 106 kV.
C4	J3E+J4E	50% of Kingsville load was tripped pre ULTC by voltage dependent L/R scheme as preliminary analysis indicated that K2Z and K6Z voltages at Kingsville TS were both less than 106 kV
C5	J5D	Brighton Beach G1 was tripped by the overload protection scheme as a preliminary analysis indicated a possible overloading scenario.
C6	W44LC+W45LC	No control actions were required
C7 (1)	Kruger WGS	No control actions were required
C8	Z7E+Z1E	No control actions were required
C9 (2)	Brighton Beach GS (230 kV+115 kV)	50% of Kingsville load was tripped pre ULTC by the voltage dependent L/R scheme as preliminary analysis indicated that K2Z and K6Z voltages at Kingsville TS were less than 106 kV
C10	C24Z	No control actions were required
C11	Chatham SC22+SC23	No control actions were required
C12	Lauzon SC12	No control actions were required
C13	J2N	No control actions were required

(1) For C7, the base case was modified such that the Kruger facility operates at 0.9 lag power factor.
(2) For C9, the base case was modified such that Brighton Beach was at full output at 0.9 lag power factor.

In Windsor Area, typically only single contingencies are respected for local area security. Of the contingencies listed above, the single contingencies are C2, C5, C7, C10, C11, C12, and C13. Double contingencies are used in order to examine their effect on the bulk power system. .

6.2 Thermal Analysis

The summer day-time continuous ratings of circuits near Kruger WGS under 35ºC and 5 km/h conditions are as follows.

Continuous Ratings						
J4E@ Keith	J3E@Keith	Keith T11	Keith T12	C24Z@ Z	C24Z@ C	J5D@ Keith
996 A	1209 A	115 MVA	115 MVA	1303 A	1017 A	1074 A
C23@ C	C23Z@Z	C21J@Keith	C22J@Keith	Z1E@ Z	Z7E @ Z	
1401 A	1401 A	877 A	877 A	1194 A	1194 A	

The following are the pre-contingency flows for various circuits in the local area *prior* to the connection of Kruger. The pre-contingency flows are expressed in Amperes for circuits while those for transformers are expressed in MVA.

Pre-contingency flow without Kruger													
Circuit	J4E@J	J3E@J	Keith T11	Keith T12	C24Z@C	C24Z@L	C23Z@C	C23Z@L	J5D@J	C21J@K	C22J@K	Z1E @L	Z7E @L
Flow	1207.6	1192.3	104.8	118.1	456.2	469.2	461.3	475.3	369.7	290.5	282.3	304.5	311.8
Flow/Cont. Rat.	1.21	0.99	0.91	1.03	0.45	0.36	0.33	0.34	0.34	0.33	0.32	0.26	0.26

The flows from the table above indicate that prior to the Kruger connection, J4E and Keith T12 are overloaded pre-contingency.

The following are the pre-contingency flows for various circuits in the local area *after* the connection of Kruger.

Pre-contingency flow with Kruger													
Circuit	J4E@J	J3E@J	Keith T11	Keith T12	C24Z@C	C24Z@L	C23Z@C	C23Z@L	J5D@J	C21J@K	C22J@K	Z1E @L	Z7E @L
Flow	1201.9	1184.5	102.3	115.3	445.9	459.5	420.5	494.5	372.3	296.5	288.3	271.7	281
Flow/Cont. Rat.	1.21	0.98	0.89	1.00	0.44	0.35	0.30	0.35	0.35	0.34	0.33	0.23	0.24

With the connection of Kruger, J4E and Keith T12 remain overloaded. The results of this pre-contingency analysis indicate that for peak load conditions, the thermal capability of the 115 kV lines from Keith to Essex is not adequate. This is an existing system problem, and it is not a result of the proposed wind generating station. Therefore, the subsequent analysis of this presentation was carried out with J4E overloaded pre-contingency.

The STR of the circuits depends on the level of the pre-contingency flow. The post-contingency flow was compared with STR obtained with pre-contingency loading of 95 % of the continuous rating. Such a high pre-flow was used to obtain a greater degree of confidence in results. The following table summarizes the STRs obtained with pre-flow of 95 % under 35ºC and 5 km/hr wind speed.

STR													
Circuit	J4E@J	J3E@J	Keith T11	Keith T12	C24Z@C	C24Z@L	C23Z@C	C23Z@L	J5D@J	C21J@K	C22J@K	Z1E @ L	Z7E @ L
STR	1070	1291	222	185	1091	1422	1524	1091	1146	937	937	1294	1294

Post-contingency analysis

The following are the post-contingency percentage loadings of the monitored circuits. Since lines J4E and J3E are above its 95 % preload value, their percentage loadings compared to STR are not calculated, instead their post contingency flows are expressed as a ratio to their pre-contingency flows. The descriptions of control actions initiated are detailed for each contingency in the Section (e) of this report.

Contingency	*Post-contingency flow/Pre-contingency flow*		*Post-contingency current flow×100 / STR*										
	J4E@J	J3E@J	Keith T11	Keith T12	C24Z@C	C24Z@L	C23Z@C	C23Z@L	J5D@J	C21J@K	C22J@K	Z1E @L	Z7E @L
C21J+C22J+T12	0.94	0.94	84.9	0	44.4	35.0	29.9	34.9	22.6	0	0	17.9	18.1
C22J+T12	0.87	0.86	66.3	0	48.0	37.7	31.3	37.7	50.0	43.9	0	12.5	12.0
C23Z+C24Z	1.10	1.10	57.1	77.2	-	-	-	-	29.2	26.9	25.8	26.6	27.8
J3E+J4E	0.00	0.00	60.8	82.2	81.5	63.2	51.4	62.5	13.2	69.8	68.5	62.9	60.7
J5D	0.83	0.82	26.3	35.6	49.8	39.0	31.5	39.1	-	4.7	5.1	9.3	8.1
W44LC+W45LC	0.93	0.93	39.3	53.2	45.6	36.0	31.3	35.8	2.8	19.4	18.5	18.3	18.2
Kruger facility	1.00	1.00	47.5	64.2	41.0	32.4	29.7	30.6	35.4	32.9	32.0	25.5	25.9
Z7E+Z1E	0.52	0.52	5.1	6.9	48.9	38.0	29.5	38.5	9.9	48.8	47.7	-	-
Brighton Beach	0.77	0.77	53.8	72.8	47.0	36.6	26.3	37.5	93.1	13.7	13.6	17.2	15.1
J2N	0.91	0.90	62.2	84.2	45.7	35.9	29.8	36.0	42.1	8.1	11.0	14.3	14.4
C24Z	1.16	1.15	59.3	80.2	-	-	42.8	49.0	36.1	8.9	12.0	30.2	32.2
Chatham SC22+SC23	1.02	1.01	45.0	60.8	38.2	29.9	21.7	31.0	32.9	32.1	31.5	18.2	19.8
Lauzon SC12	1.01	1.00	44.6	60.3	28.6	32.6	41.2	32.7	31.3	31.9	31.0	17.1	18.7

Ignoring the overloads of lines J4E and J3E, the results for 2008 extreme weather indicate that the post flows are within STR given that the sufficient control actions are initiated. It must be emphasized that these percentages are based on a rating obtained with 95 % pre-load value where in most cases the actual pre-load values are below this threshold. There does not appear to be instances of overloading other than on J4E and J3E.

From the (post contingency flow/pre-contingency flow) ratios for lines J4E and J3E, it can be seen that the loss of C24Z or the loss of C23Z+C24Z will cause the J4E and J3E to be overloaded even more than they are already in pre-contingency. Note that the loss of C23Z causes the loss of the Kruger facility.

6.3 Voltage Analysis

The voltage declines were performed with the Kruger facility connected to the circuit C23Z. The declines given below are the worst of pre-ULTC and post-ULTC values. For pre-ULTC and post-ULTC, the declines are calculated after MW loads are converted into constant current and admittance loads equally and the MVAr loads are converted fully into constant admittance loads.

The following table summarizes the post-contingency voltage declines for various buses in the vicinity of the Kruger facility. Note that the Kingsville 115 kV post-ULTC voltages are listed for K2Z and K6Z after the load rejection scheme was initiated. The descriptions of the control actions that were initiated are detailed for each contingency in the Section (e) of this report.

Contingency	Chatham 230 kV	Lauzon 230 kV	Lauzon 115 kV	Essex 115 kV	Kent 230 kV	Keith 230 kV	Keith 115 kV	Lauzon 27 kV	Wat/Mich 230 kV	Kruger 230 kV	Kruger 34 kV	Lambton 230 kV	K2Z@K 115 kV	K6Z@K 115 kV
C21J+C22J+T12	-0.67	-0.24	-0.16	-0.09	-0.60	0.32*	0.10	-0.25*	0.02	-0.50	-0.39	-0.06	111.54	108.90
C22J+T12	0.03	0.35	0.20	0.18	0.06	0.84	0.30	0.36	0.12	0.17	0.13	0.06	111.12	108.49
C23Z+C24Z	-3.57*	-	4.58*	3.65*	-3.40	-0.22*	1.70*	-	-0.02*	-	-	-0.77*	115.91	116.88
J3E+J4E	2.89*	8.19*	8.79*	9.15*	2.73	0.34*	-0.98*	8.37*	0.00	4.53*	3.15*	0.70*	116.64	113.95
J5D	0.88	0.96	0.56	0.44	0.95	0.73	0.40	0.99*	-0.08	0.94	0.68	0.52	110.71	108.09
W44LC+W45LC	-2.00*	-1.20*	-0.98*	-0.84*	-1.97	-0.50*	-0.52*	-1.22*	-0.09	-1.67*	-1.35*	-0.15	112.51	109.85
Wind Farm	0.40	0.48	0.36	0.30	0.39	0.13	0.18	0.45	0.02	0.83	-	0.12	113.61	110.93
Z7E+Z1E	-0.32*	-1.87*	-3.22*	-1.91*	-0.30	-0.42*	-0.90*	-1.22	-0.07*	-0.64*	-0.50*	-0.04*	116.34	113.56
Brighton Beach	2.06*	3.51*	3.59*	3.85*	2.01*	4.77*	4.63*	3.59*	0.99*	2.43*	1.65*	0.53*	116.67	114.36
J2N	0.19	0.38*	0.26*	0.24*	0.19	0.21	0.32*	0.39*	0.04	0.27*	0.21*	0.07	111.06	108.43
C24Z	-0.36	4.23	3.66	2.96	-0.35	0.34	1.50	7.47*	0.04	1.06	0.77	-0.11	106.64	104.11
Chatham SC22+SC23	4.67	3.09	2.35	1.95	4.40	1.24	1.23	3.03*	0.12	3.98	2.77	0.98	108.41	105.83
Lauzon SC12	0.35	1.26	1.78	1.41	0.33	0.23	0.72	1.28	0.02	0.58	0.44	0.07	109.28	106.69

* indicates a post contingency pre-ULTC voltage decline value. Voltage declines are otherwise given as a post-contingency post-ULTC value.

- Only the single contingencies are needed to be respected in Windsor 115 kV local area. However, the double contingencies are simulated to check any voltage concerns to the rest of the power system.
- It can be concluded that all the voltage declines are less than 10.0 % which meets the voltage decline criteria observed by the IESO.

6.4 Reactive Power Compensation

6.4.1 Dynamic Reactive Power Compensation

The Figure 5 shows the variation of available Q_{max} and Q_{min} of MK II if the power output is at rated level (1.0 pu or 2.3 MW) and 97 % of rated level (0.97 pu or 2.23 MW) and also the IESO requirement on Q_{max} and Q_{min}.

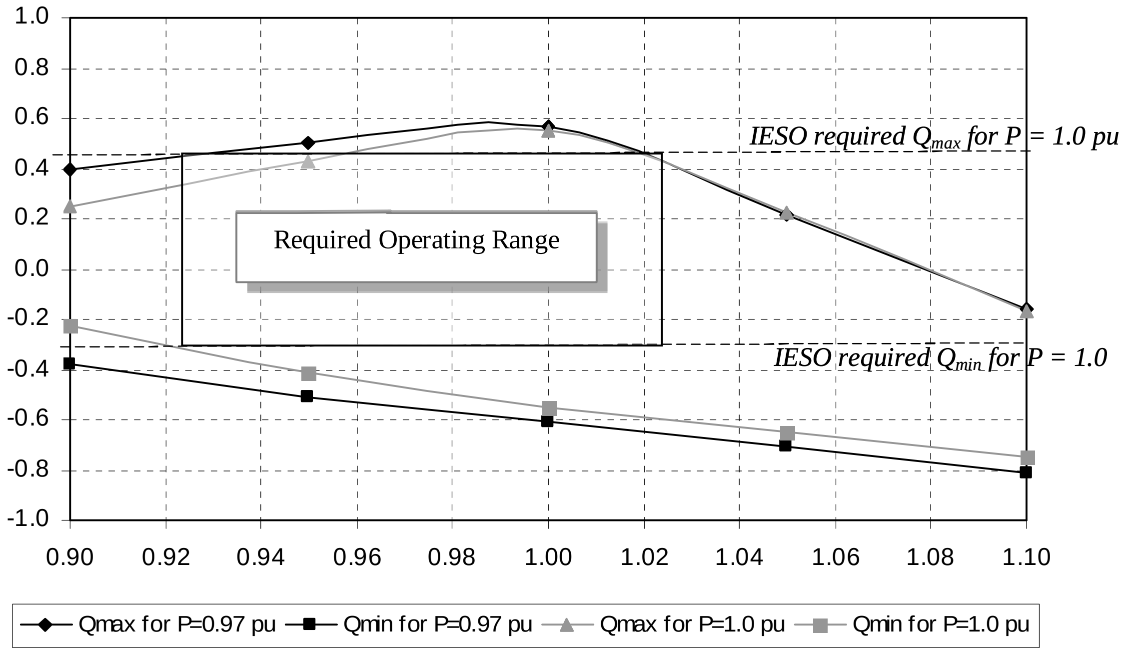


FIGURE 5 – VARIATION OF Q_{MAX} AND Q_{MIN} WITH WTG TERMINAL VOLTAGE

It was evident from the Figure 4 of the Section 6.1.2, that if the MK II is operated at 1.0 pu rated voltage, the generator is not able to supply the IESO required level of dynamic reactive power near the extremes of the ± 5% voltage range. This will impose a requirement to have an extra dynamic reactive power source to compensate for above deficiency. As an alternative solution, it can be seen from Figure 5 that if the rated operating voltage is reduced to 0.975 pu and the generator produces only up to 0.97 pu active power, the generator could largely meet the IESO requirement on reactive power capability without having any extra dynamic reactive power source.

This would mean,

(a) the generator must be nominally operated at 673 V
(b) the maximum power output should be 2.23 MW
(b) the generator must be able to continuously produce 2.23 MW within 639 - 706 V range

The IESO has been notified that the MK II will exceed producing 2.23 MW only when the wind speed exceeds 12.11 m/s. The proponent reviewed the wind farm model that was prepared using the data collected over last 20 months from Kruger wind farm site meteorological measurement towers and indicated that the hourly mean wind speed exceeded 12 m/s only for an annualized 1,053 hours or 12.02 % of the time of the year that mostly occurs during winter months. Therefore, the prediction is that the wind turbines in Kruger facility will generate in excess of 2.23 MW only for a relative short period of the year.

Therefore, the IESO has determined during that short period, it could allow generators at Kruger wind farm to make more than 2.23 MW when the wind speed exceeds of 12.11 m/s, but if the system conditions require, the proponent must limit the output of each turbine to 2.23 MW upon the request of the IESO control room. Having a lower requirement of this nature on reactive power for induction generation facilities is in accordance with Market Rules since the IESO has identified that the lower requirement does not adversely affect the reliability of the IESO-controlled grid. It must be noted that this is a mere 3 MW penalty on the entire wind farm output, but what is required is not a reduction of collective output of wind farm to 98 MW, but a reduction of each generator output to 2.23 MW. As this reduction must be performed in 44 separate generators, the WFMS must have the capability to perform this reduction in a rapid manner in order to maintain the security of the IESO-controlled grid.

In load flow and dynamic studies, the proposed Kruger project was modeled with four radial circuits with a single equivalent MK II generator connected to end of each circuit. For the analysis, it has been assumed that each generator is producing maximum output = 2.3 MW. The Q_{max} and Q_{min} used for the analysis correspond to 2.3 MW and the terminal voltage 0.925 pu since Q_{max} = 0.35 pu and Q_{min} = 0.32 pu that corresponds to 0.925 pu voltage are the minimums within 0.925 pu to 1.025 pu voltage range. The equivalent P_{max}, P_{min}, Q_{max} and Q_{min} are calculated by aggregating P_{max}, P_{min}, Q_{max} and Q_{min} for the number of generators connected to each circuit.

Circuit	Per Turbine	C1	C2	C3	C4	Total
Number of generators	-	10	10	12	12	44
Q_{max}	0.8 MVAr	8 MVAr	8 MVAr	9.6 MVAr	9.6 MVAr	35 MVAr
Q_{min}	0.73 MVAr	7.3 MVAr	7.3 MVAr	8.7 MVAr	8.7 MVAr	32 MVAr
P_{max}	2.3 MW	23 MW	23 MW	27.6 MW	27.6 MW	101 MW
P_{min}	0 MW	0 MW	0 MW	0 MW	0 MW	0 MW

6.4.2 Static Reactive Power Compensation

If any generator is operated within 1.05 – 0.95 pu voltage in a system where the reactance between generator terminals and the HT connection point is excess of 0.1313 pu on generator MVA base, the reactive power produced by the generator will not be sufficient to maintain the HT voltage to a single value. This will result the need to have a static reactive compensation. If the terminal voltage is reduced to 0.975 pu, the taps of each generator step-up transformer must be changed to 1.025 pu to obtain 1.0 pu voltage at the collector bus. This 0.025 pu tap change will increase the impedance of each step-up transformer by a factor of $(0.025)^2$. Thus, the static compensation must be further increased to accommodate this increase in impedance.

Equivalent impedance

With generator transformer taps changed to 1.025 pu, the followings are the equivalent impedances on 100 MVA base to represent the collector network and generator step-up transformers for each feeder.

	C1	C2	C3	C4
R_{Line}	0.027	0.017	0.046	0.079
X_{Line}	0.321	0.242	0.341	0.539
B_{Line}	0.0046	0.0071	0.0063	0.0061
$X_{Transformer}$	0.243	0.243	0.202	0.202

The equivalent impedance between generator terminals and the existing 230 kV connection point on 100 MVA base are calculated using followings.

Equivalent reactance for feeder C1, C2, C3, C4 and their generator transformers	=	0.1424	pu
Reactance of 34.5/230 kV transformer T1	=	0.0682	pu
Total reactance between generator terminals and the 230 kV terminal of T1	=	0.2106	pu
Total reactance of 230 kV cables from T1 to C23Z/C24Z tap point	=	0.0101	pu
Total reactance between generator terminals and existing 230 kV system	=	0.2207	pu

Capacitor requirement

The equivalent impedance between generator terminals and the existing 230 kV point is 0.2207 pu on 100 MVA base or 0.2477 on facility MVA base of 2.55 × 44 = 112 MVA. When the terminal voltage is reduced to 0.975 pu and the taps are changed to 1.025 pu, the system voltage can be controlled up to 1.0 pu only if the connection impedance is not more than 0.1306 pu. This would mean the losses occurring in excess impedance of 0.2477 – 0.1306 = 0.1171 pu must be compensated via a static reactive source.

The calculation of reactive compensation to account for the excess impedance is shown below.

	Acceptable conditions	*Actual conditions*
Rated WTG terminal voltage	673 V	673 V
WTG terminal voltage range	639 - 706 V	639 - 706 V
0.69/34.5 kV transformer tap	1.025 pu	1.025 pu
34.5/230 kV transformer tap	1.0 pu	1.0 pu
Lag power factor at generator terminal	0.9 lag	0.9 lag
Maximum reactive power generation	48 MVAr	48 MVAr
Total connection impedance on facility MVA base	0.1306 pu	0.2477 pu
230 kV voltage is controlled to	1.0 pu	0.97 pu
Reactive power injected into existing 230 kV system	36 MVAr	24 MVAr
Reactive power loss in the connection	12 MVAr	24 MVAr

The difference in losses between actual and acceptable condition is 12 MVAr. Due to this difference, the 230 kV voltage can be controlled only up to 0.97 pu. The 230 kV voltage can be regulated to 1.0 pu only if this loss of 12 MVAr is supplied to the 230 kV connection point in the form of a reactive compensation. Further, if the 230 kV voltage is to be controlled to 1.05 pu, an additional 24 MVAr must be required. Thus, the total requirement to control the 230 kV point to 1.05 pu is 36 MVAr to be supplied in 6 steps of 6 MVAr. The normal voltage in C23Z/C24Z connection point can be greater than 1.05 pu, thus further changes to the voltage can be obtained by changing the taps of the 34.5/230 kV transformer.

In order to avoid hunting, the capacitor switching must be done automatically by a local over/under voltage scheme with suitable settings by the Wind Farm Management System. Instead of controlling the 230 kV voltage, it is also acceptable to the IESO if the capacitor bank controls the collector bus voltage to a level that is determined by the IESO operating staff. In that case, the Wind Farm Management System must coordinate the capacitor switching and generators as both equipment controls the voltage at same busbar. The voltage set point could be asked to be changed by the IESO control room as system conditions change.

Voltage at post-capacitor switching

Followings are terminal voltages with and without a 36 MVAr capacitor bank in service while all generators are controlling the collector bus voltage to 1.0 pu. The 34.5/230 kV transformer tap has been set to 1.1 pu.

Capacitor bank	O/S				36 MVAr			
Generator ID	G1	G2	G3	G4	G1	G2	G3	G4
Q_{max} in MVAr	8.0	8.0	9.6	9.6	8.0	8.0	9.6	9.6
Q_{min} in MVAr	7.3	7.3	8.7	8.7	7.3	7.3	8.7	8.7
P_{Gen} in MW	23.0	23.0	27.6	27.6	23.0	23.0	27.6	27.6
Q_{Gen} in MVAr	1.3	1.3	1.3	1.3	-7	-7	-7	-7
Gen controls voltage at	34.5 kV	34.5 kV	34.5 kV	34.5 kV	34.5 kV	34.5 kV	34.5 kV	34.5 kV
Terminal voltage	0.98 pu	0.98 pu	0.99 pu	0.99 pu	0.94 pu	0.94 pu	0.94 pu	0.93 pu
Collector bus voltage	34.5 kV or 1.0 pu				34.5 kV or 1.0 pu			
Kruger 230 kV bus	243 kV or 1.1 pu				243 kV or 1.1 pu			

The results show that when the capacitor bank is placed in service, the generators can still operate within 0.925 – 1.025 pu voltage range and do not trip.

Voltage change due to capacitor switching

Following summarizes the change in voltage due to switching of a single capacitor of different sizes at the collector bus. All generators are made to operate at a fixed power factor to prevent their dynamic reactive power capability changes bus voltages, so that the ΔV is only due to capacitor switching. The ΔV has been tested when generators offer no voltage support and at the worst condition, i.e. the generators absorb maximum reactive power so that the ΔV due to cap switching is maximum. The 34.5/230 kV transformer tap has been set to 1.1 pu. The transformer ULTCs have been locked.

	Generator Qgen = 0.0			Generator Qgen = Qmin		
Size of capacitor switched	12 MVAr	30 MVAr	36 MVAr	12 MVAr	30 MVAr	36 MVAr
ΔV 34.5 kV collector bus	1.37	3.38	4.02	1.64	3.97	4.7
ΔV Kruger 230 kV bus	0.50	1.24	1.47	0.58	1.41	1.69
ΔV C24Z connection bus	0.40	0.98	1.16	0.46	1.12	1.33

The IESO allows ΔV on a single capacitor switching to be no more than 4 %. It appears switching of a single capacitor of 30 MVAr also produces less than 4 % voltage increase. However, it is necessary to supply the 36 MVAr in 6 steps to increase the operational flexibility.

6.5 Transient Analysis

Nine contingencies were tested. They include a permanent three-phase fault on a circuit cleared with normal fault clearing time (TSC1, TSC3, TSC7, TSC8), simultaneous permanent phase to ground faults on different phases of each of two adjacent circuits on a multiple circuit tower cleared with normal fault clearing times (TSC2, TSC4, TSC5, TSC6) and the loss of all Brighton Beach units (TSC9). It is assumed that 230, 115 and 44 kV breakers open in 3, 5 and 8 cycles respectively.

- TSC1 **Normally cleared 3ph fault at C22J @ C + loss of Keith T12**
  Brighton Beach G1 was tripped by Windsor area overload protection scheme as preliminary thermal analysis indicated overloading.
  Breaker Times (fault occurs at t = 0.1 s):
  Open local 230 kV breakers @ Chatham t = 0.183 s
  Open remote 230 kV breakers @ Keith t = 0.208 s
  Open remote 115 kV breakers @ Keith t = 0.241 s
  Open breakers at Brighton Beach G1 t = 0.408 s

- TSC2 **Normally cleared LG fault at C21J @ C + LG fault at C22J @ C**
  Brighton Beach G1 was tripped by Windsor area overload protection scheme as preliminary thermal analysis indicated overloading.
  Breaker Times(fault occurs at t = 0.1 s):
  Open local 230 kV breakers @ Chatham t = 0.183 s
  Open remote 230 kV breakers @ Keith t = 0.208 s
  Open remote 115 kV breakers @ Keith t = 0.241 s
  Open breakers at Brighton Beach G1 t = 0.408 s

- TSC3 **Normally cleared 3ph fault at C24Z @ C**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0. 1s):
  Open local 230 kV breakers @ Chatham t = 0.183 s
  Open remote 115 kV breakers @ Lauzon t = 0.241 s

- TSC4 **Normally cleared LG fault at W44LC @ C + LG fault at W45LC @ C**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1 s):
  Open local 230 kV breakers @ Chatham t = 0.183 s
  Open remote 230 kV breakers @ Buchn t = 0.208 s

- TSC5 **Normally cleared LG fault at L28C @ C + LG fault at L29C @ C**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1 s):
  Open local 230 kV breakers @ Chatham t = 0.183 s
  Open remote 230 kV breakers @ Lamb t = 0.208 s

- TSC6 **Normally cleared LG fault at L28C @ L + LG fault at L29C @ L**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1 s):
  Open local 230 kV breakers @ Lambton t = 0.183 s
  Open remote 230 kV breakers @ Chatham t = 0.208 s

- TSC7 **Normally cleared 3ph fault at Kruger T1**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1 s):
  Open remote 230 kV breakers @ Kruger t = 0.191 s
  Open local <50 kV breakers @ Kruger t = 0.266 s

- TSC8 **Normally cleared 3ph fault at Kruger 34.5 kV collector circuit # 4**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1 s):
  Open local <50 kV breakers @ Kruger t = 0.266 s
  Open remote <50 kV breakers @ Kruger t = 0.291 s

- TSC9 **Loss of Brighton Beach**
  No control actions were initiated
  Breaker Times (fault occurs at t = 0.1s):
  Open local 50 kV breakers @ BB t = 0.1 s

The Appendix B show the transient curves. None of the contingencies caused any adverse significant impact on IESO-controlled grid. This can be seen from machine angle plots for Brighton Beach and Calpine units as well as from voltage plots at key 230 kV buses in the vicinity. The results for TSC8, normally cleared 3ph fault at Kruger collector circuit 4 indicate that the WTGs on the feeder were tripped by the under-voltage relay 3; 0.046 sec after the feeder was tripped. As for the wind farm itself, the WTGs were most responsive to 3-phase faults i.e., TSC1, TSC3 and TSC7, but did not trip for any contingency other than TSC8 or showed any instability. Further, the wind farm was able to maintain connectivity to the system for the loss of all three Brighton Beach units (TSC9) despite loss of voltage support.

Islanding

When C23Z is tripped, the MK II generators in the wind farm will island with available capacitors at that instant. Subsequently, the capacitors may switch out by over-voltages and generators may trip by over-frequency. Upon the request of the proponent, the IESO attempted to simulate the transient performance of the over-generated island to investigate the resulting island voltages and turbine speeds. It did not appear that the MK II model is suitably developed to simulate wide variations of frequency and voltage occurring in islanding situations, as a result no predictions on voltage or speed could be made.

6.6 Low-voltage ride through capability

As any other generator, the MK II is expected to trip only for contingencies which removes the generator by configuration or abnormal conditions such as severe and sustained under-voltage, over-voltage, under-frequency, over-frequency etc. The severity of under-voltage seen by generator terminals is to be temporarily mitigated by the LVRT capability. The LVRT feature is implemented by injection of additional reactive current by the grid side AC/DC converter to maintain generator terminal voltage in the event of a disturbance in the power system that caused terminal voltage to drop.

The implementation of LVRT should not require any instant modification to under-voltage protection settings. In PSS/E model for MK II, the LVRT feature accompanies a change of under-voltage setting as shown below.

With No LVRT		*With LVRT*	
Voltage range	*Event*	*Voltage range*	*Event*
1.00 – 0.90 pu	No trip	1.00 – 0.90 pu	No trip
0.90 – 0.85 pu	Relay 1 trips in 3.1 sec	0.90 – 0.70 pu	Relay 1 trips in 3.1 sec
0.85 – 0.00 pu	Relay 3 trips in 0.075 sec	0.70 – 0.15 pu	Relay 2 trips in 2.5 sec
		0.15 – 0.00 pu	Relay 3 trips in 0.15 sec

In order to investigate the impact of LVRT, of the nine contingencies simulated for the transient study, the most severe contingency TSC3 (a norally cleared 3ph fault at C24Z @ C) was tested with and without LVRT. The under-voltage protection has been enabled to allow tripping in case the terminal voltage drops excessively.

Figures 6A and 6B show the variation of terminal voltage and the reactive power generation of WTG1 for TSC3 with and without LVRT. The simulation results showed that as a result of the severity and proximity to the fault location of TSC3, the generator did not stay connected without LVRT (the terminal voltage would drop below 0.85 pu longer than 75 ms resulting in the generators to be tripped by relay 3).

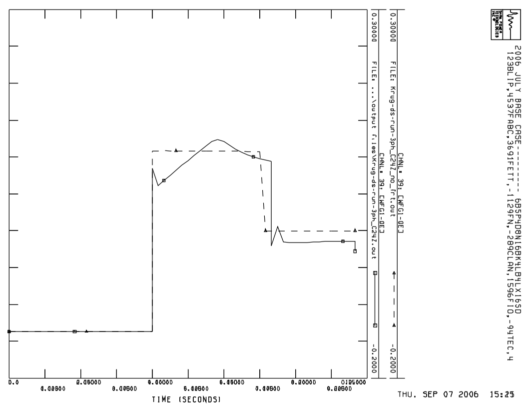


FIGURE 6A – REACTIVE POWER GENERATION

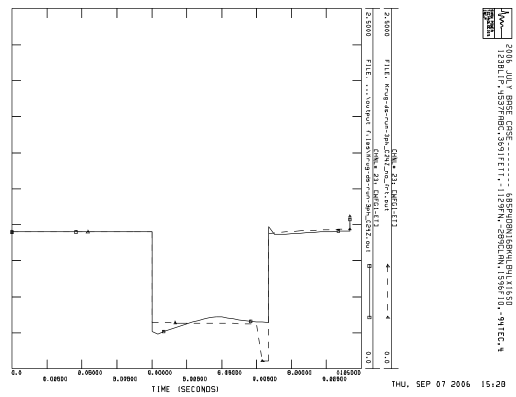


FIGURE 6B – TERMINAL VOLTAGE

LVRT enables the grid side converter to produce more reactive current if terminal voltage drops. With LVRT, the fault seems to be causing a deeper voltage decline than without LVRT. With an increase in terminal voltage and reactive current, the reactive power output with LVRT increases more than with no LVRT. However, the moments before the unit tripped, the reactive power with LVRT is less than the reactive power without LVRT even if the terminal voltage is higher.

The LVRT capability must be demonstrated during commissioning by monitoring several variables under a set of IESO specified field tests and the result should be verifiable using the PSS/E model.

6.7 Wind Farm Management System

The Wind Farm Management System (WFMS) must coordinate the voltage control process. The proponent must submit a description of the functionalities of the WFMS, including the coordination between the automatic capacitor switching and generator reactive power production to control the voltage at a desired point. This document also must contain the settings of the automatic capacitor switching scheme.

If the WFMS is unavailable, the IESO requires each generator controls its own terminal voltage.

– End of Section –

APPENDIX A

Generator Data

2.30	Machine Active Power Rating (MW)	MBASE
0.69	Stator Voltage Rating (kV)	
60	Rated network frequency (Hz)	FBASE
90200	Connection busbar number	
1	Generator Identifier	
0.0000	Generator Resistance in Loadflow (Rs, pu)	RSORCE
0.6415	Generator Reactance in Loadflow (Xd'', pu)	XSORCE
2.6	Unit Transformer Rating (MVA)	Note 1
0.0084	Unit Transformer Resistance (pu)	Note 1
0.0600	Unit Transformer Reactance (pu)	Note 1

Value	**Description**	**Ref:**
1	Model Version Number	
1	Reactive control mode (0=fixed, 1=voltage, 2 & 3 not in use)	
1	Fault Ride Through mode (0=disabled, 1=enabled)	
1	Enable Under-voltage relay 1	
1	Enable Under-voltage relay 2	
1	Enable Under-voltage relay 3	
1	Enable Over-voltage relay 1	
1	Enable Over-voltage relay 2	
1	Enable Under-frequency relay 1	
1	Enable Under-frequency relay 2	
1	Enable Over-frequency relay 1	

Value	**Description**	**Ref:**
54.62		
1.0927	Generator Inertia Constant (MW.s/MVA)	
14.3349	Rotor Inertia Constant (MW.s/MVA)	
0.1458	Shaft Damping	
138.49	Shaft Stiffness	
1.2471	Description N/A	
1.1432	Description N/A	
1.1109	Description N/A	
1.0003	Description N/A	
1.40	Description N/A	
1.10	Description N/A	
0.10	Description N/A	
22	Description N/A	
100000	Description N/A	
3.00	Description N/A	
100000	Description N/A	
2.00	Description N/A	
0.10	Voltage dip threshold for FRT activation (pu)	Normal
0.40	Voltage dip threshold for FRT activation (pu)	Post-Fault
0.090	Description N/A	
0.090	Description N/A	
0.160	Description N/A	
1.00	Description N/A	

3.2	Description N/A	
63.7	Description N/A	
0.90	Description N/A	
50.00	Description N/A	
10.00	Description N/A	
0.472	Description N/A	
66.0	Description N/A	
1.0878	Description N/A	
0.0022	Description N/A	
0.1348	Description N/A	
0.040	Description N/A	
2.10	Description N/A	
0.70	Description N/A	
1.20	Description N/A	
0.70	Description N/A	
1.89	Description N/A	
2.00	Description N/A	
0.82	Description N/A	
0.50	Description N/A	
0.40	Description N/A	
4.00	Description N/A	
1.225	Air density	
15.00	User defined wind speed for rated power operation (m/s)	
1.00	Description N/A	
0.1768	Description N/A	
0.6464	Description N/A	
1.0069	Description N/A	
13.05	Description N/A	
-94.25	Description N/A	
-52.36	Description N/A	
0.15	Description N/A	
7.0	Description N/A	
-8.0	Description N/A	
45.0	Maximum pitch angle	
-1.0	Minimum pitch angle	
2.0	Description N/A	
0.060	Description N/A	
0.9655	Description N/A	
-4.7283	Description N/A	
-0.6755	Description N/A	
0.2174	Description N/A	
-0.2174	Description N/A	
1.00	Description N/A	
0.90	Under Voltage Relay 1 - Voltage Setting (pu)	
3.000	Under Voltage Relay 1 - Time Setting (s)	
0.100	Under Voltage Relay 1 - Relay activation time (s)	
0.70	Under Voltage Relay 2 - Voltage Setting (pu)	
2.400	Under Voltage Relay 2 - Time Setting (s)	
0.100	Under Voltage Relay 2 - Relay activation time (s)	
0.15	Under Voltage Relay 3 - Voltage Setting (pu)	FRT Mode

0.100	Under Voltage Relay 3 - Time Setting (s)	FRT Mode
0.050	Under Voltage Relay 3 - Relay activation time (s)	FRT Mode
0.85	Under Voltage Relay 3 - Voltage Setting (pu)	
0.075	Under Voltage Relay 3 - Time Setting (s)	
0.000	Under Voltage Relay 3 - Relay activation time (s)	
1.10	Over Voltage Relay 1 - Voltage Setting (pu)	
1.000	Over Voltage Relay 1 - Time Setting (s)	
0.000	Over Voltage Relay 1 - Relay activation time (s)	
1.20	Over Voltage Relay 2 - Voltage Setting (pu)	
0.200	Over Voltage Relay 2 - Time Setting (s)	
0.000	Over Voltage Relay 2 - Relay activation time (s)	
0.95	Under Frequency Relay 1 - Frequency Setting (pu)	
10.000	Under Frequency Relay 1 - Time Setting (s)	
0.000	Under Frequency Relay 1 - Relay activation time (s)	
0.94	Under Frequency Relay 2 - Frequency Setting (pu)	
0.100	Under Frequency Relay 2 - Time Setting (s)	
0.000	Under Frequency Relay 2 - Relay activation time (s)	
1.04	Over Frequency Relay 1 - Frequency Setting (pu)	
0.100	Over Frequency Relay 1 - Time Setting (s)	
0.000	Over Frequency Relay 1 - Relay activation time (s)	
0.10	Description N/A	
11.47	Description N/A	
22.91	Description N/A	
2.522	Description N/A	

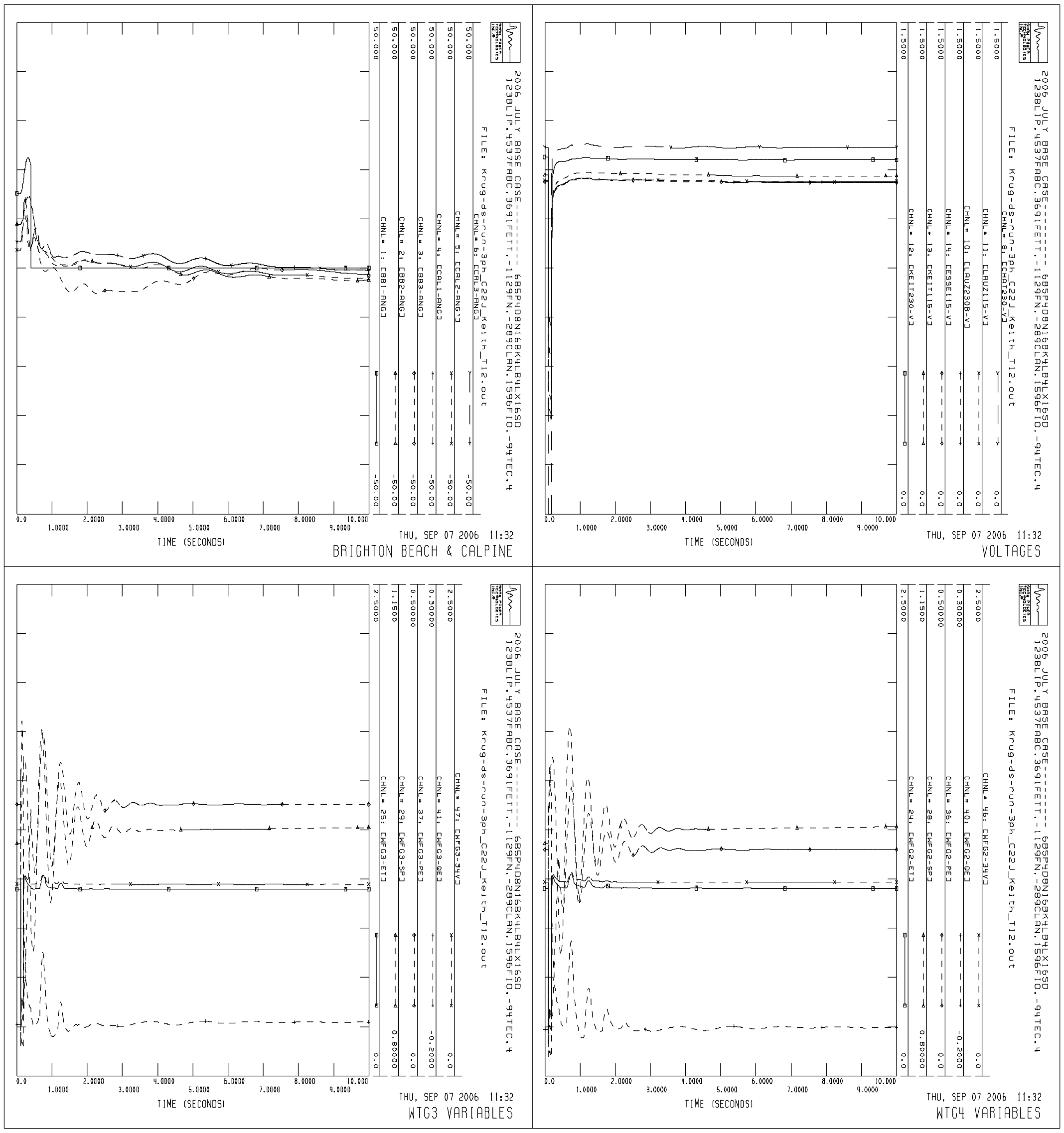
DYRE Data (auto-generated from datasheet information. Copy/paste into DYRE file.)

```
 / SMK203 V1.0, 2.3 MW Turbine Data
90200 'USRMDL' 1 'SMK203' 1 1    11 97 19 78
  1 1 1 1 1 1 1 1 1 1 1 54.62 1.0927 14.3349 0.1458 138.49 1.2471 1.1432 1.1109 1.0003 1.40 1.10 0.10 22 100000 3.00 100000
  2.00 0.10 0.40 0.090 0.090 0.160 1.00 3.2 63.7 0.90 50.00 10.00 0.472 66.0 1.0878 0.0022 0.1348 0.040 2.10 0.70 1.20
  0.70 1.89 2.00 0.82 0.50 0.40 4.00 1.225 15.00 1.00 0.1768 0.6464 1.0069 13.05 -94.25 -52.36 0.15 7.0 -8.0 45.0 -1.0 2.0 0.060
  0.9655 -4.7283 -0.6755 0.2174 -0.2174 1.00 0.90 3.000 0.100 0.70 2.400 0.100 0.15 0.100 0.050 0.85 0.075 0.000 1.10 1.000 0.000
  1.20 0.200 0.000 0.95 10.000 0.000 0.94 0.100 0.000 1.04 0.100 0.000 0.10 11.47 22.91 2.522 /
```

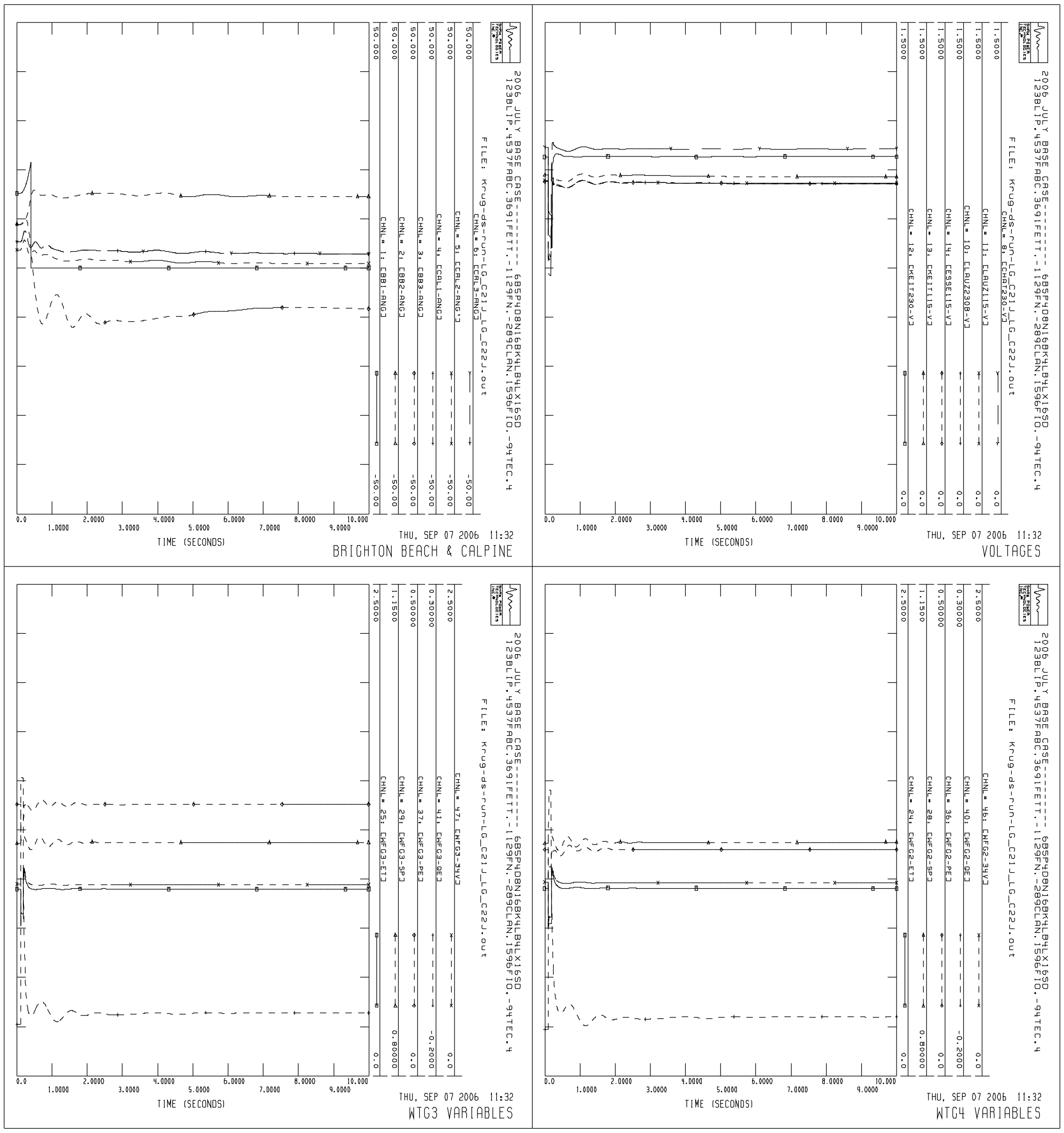
– End of Section –

APPENDIX B

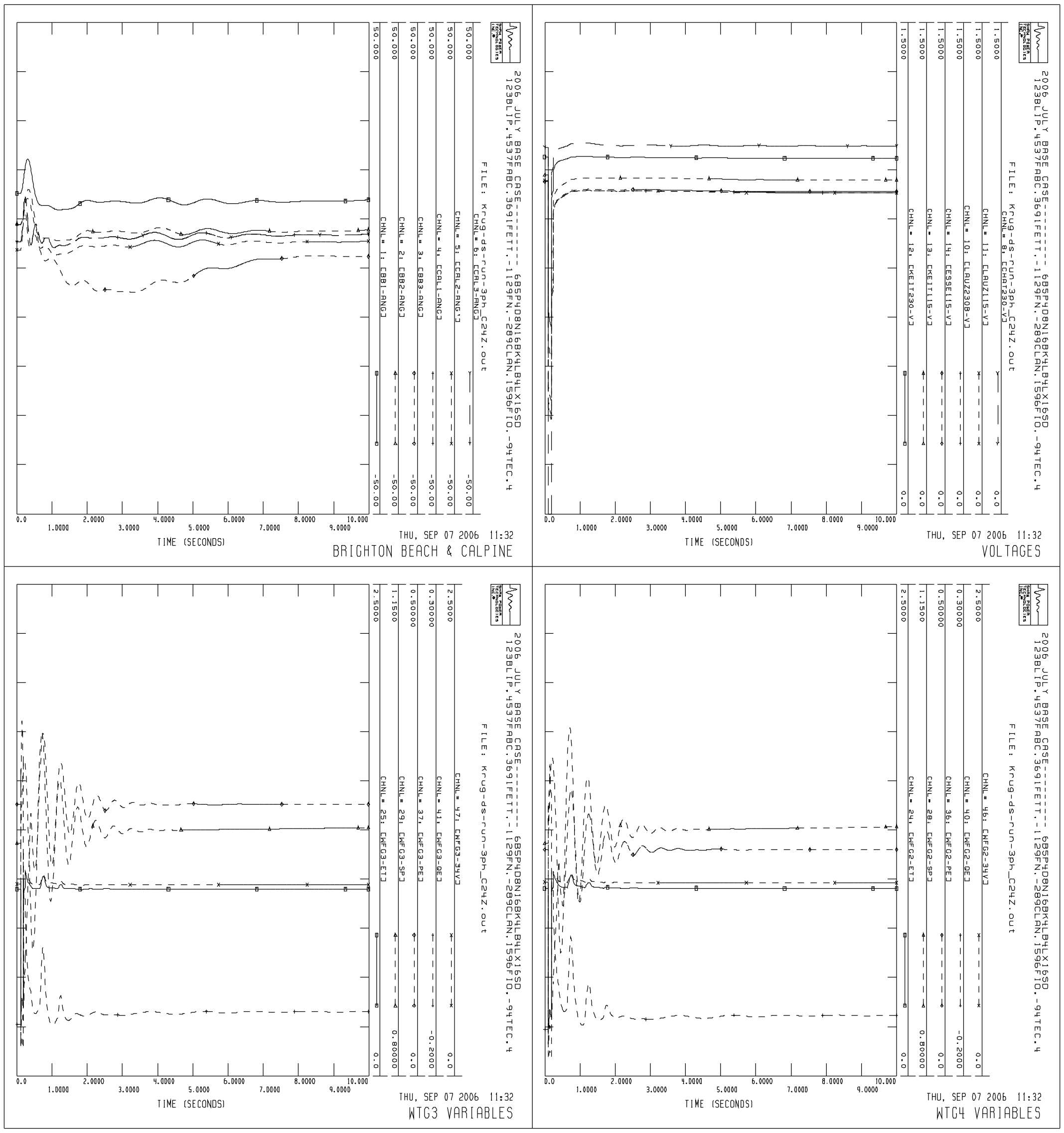
TSC1 – Normally cleared 3ph fault at C22J @ C + loss of Keith T12



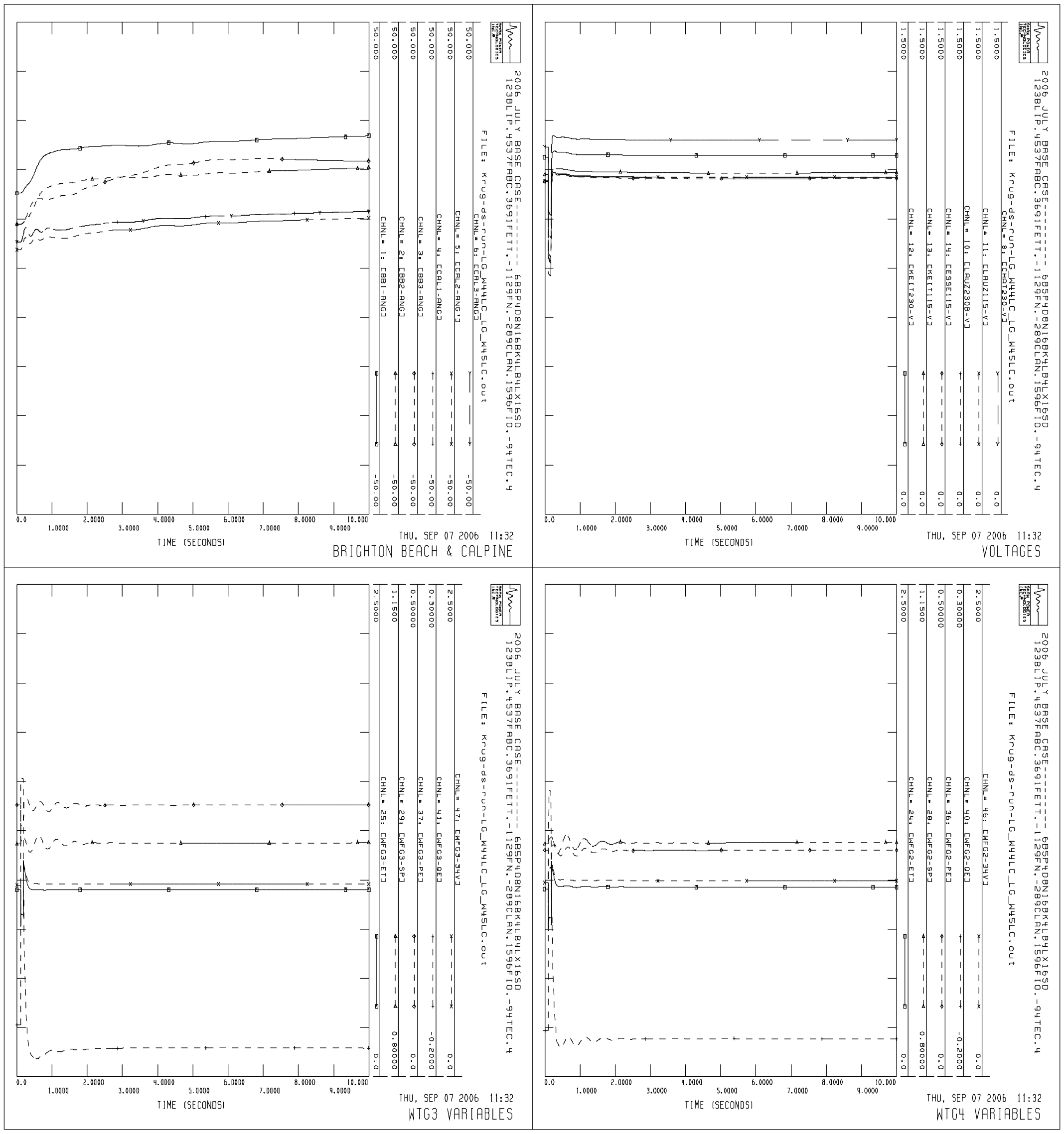
TSC2 - Normally cleared LG fault at C21J @ C + LG fault at C22J @ C



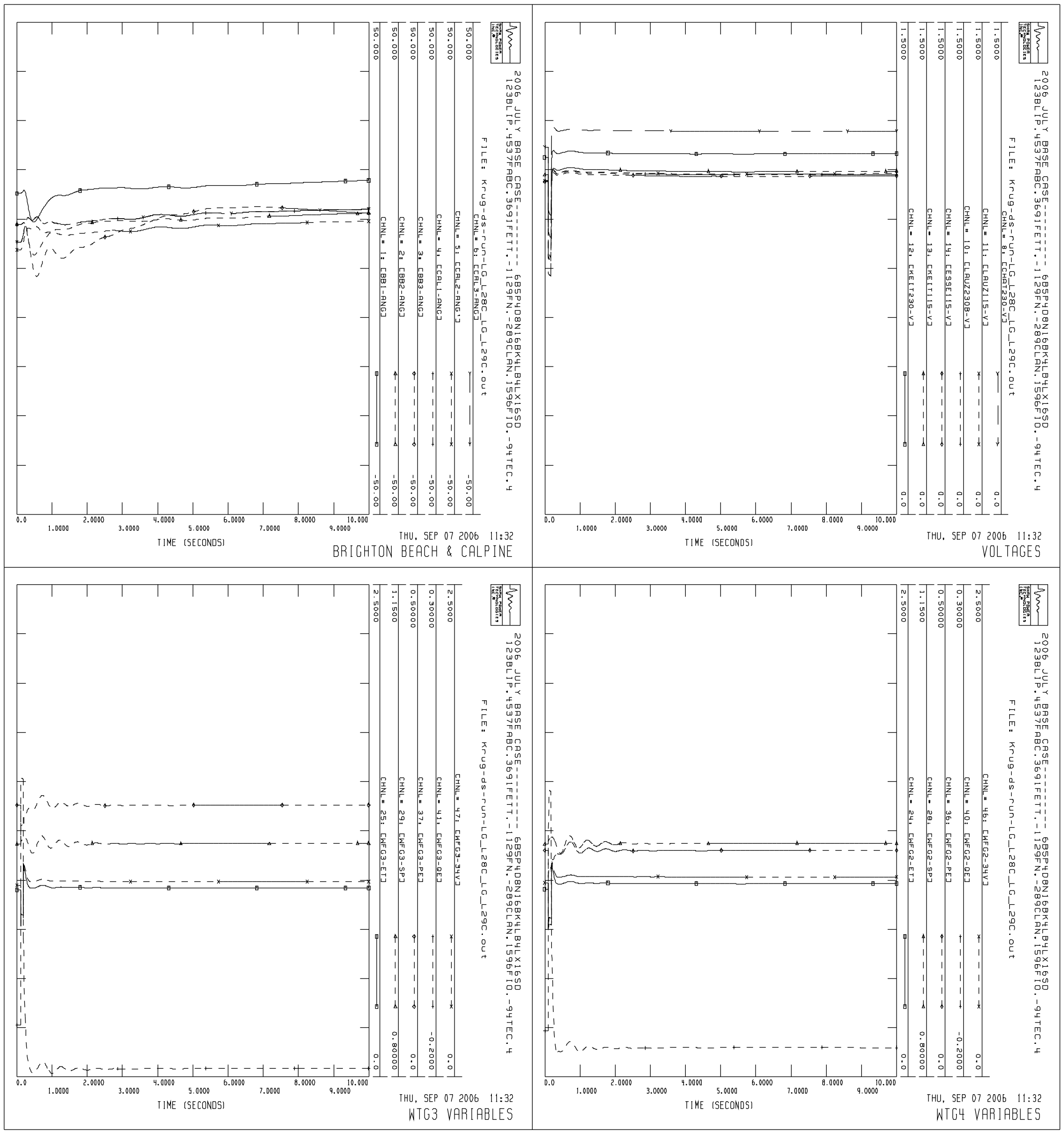
TSC3 - Normally Cleared 3ph fault at C24Z @C



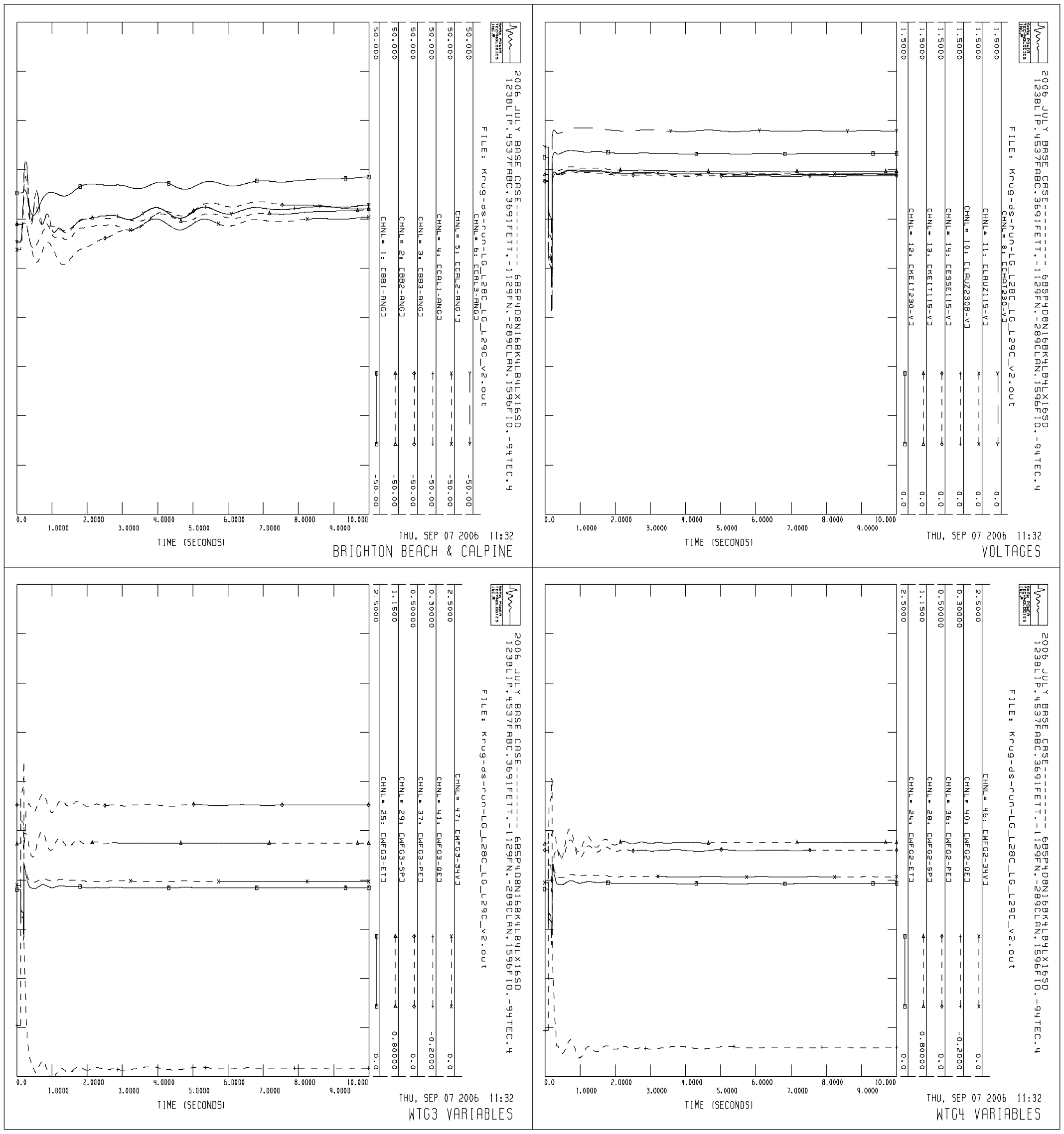
TSC4 - Normally cleared LG fault at W44LC @ C + LG fault at W45LC @ C



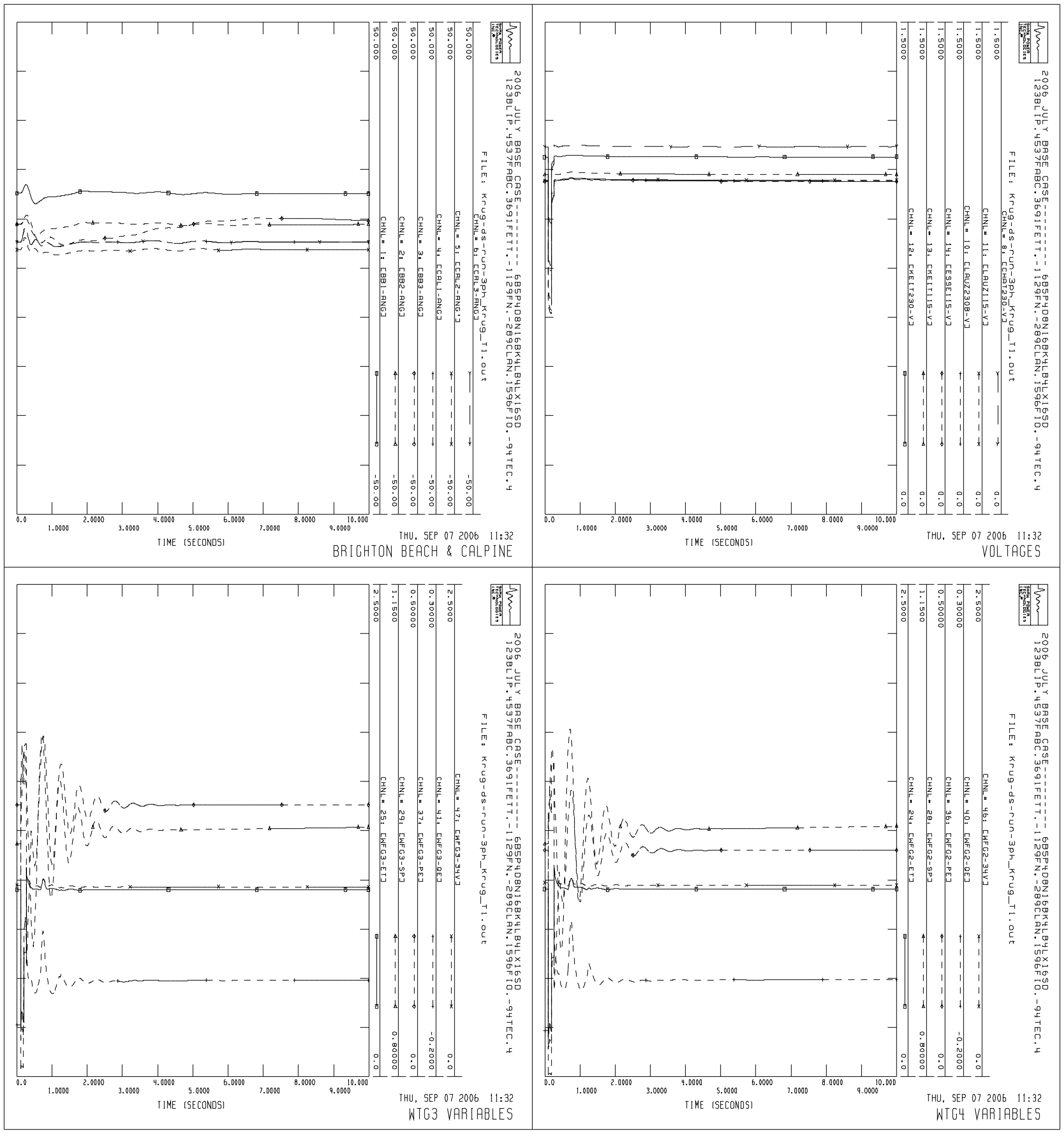
TSC5 - Normally cleared LG fault at L28C @ C + LG fault at L29C @ C



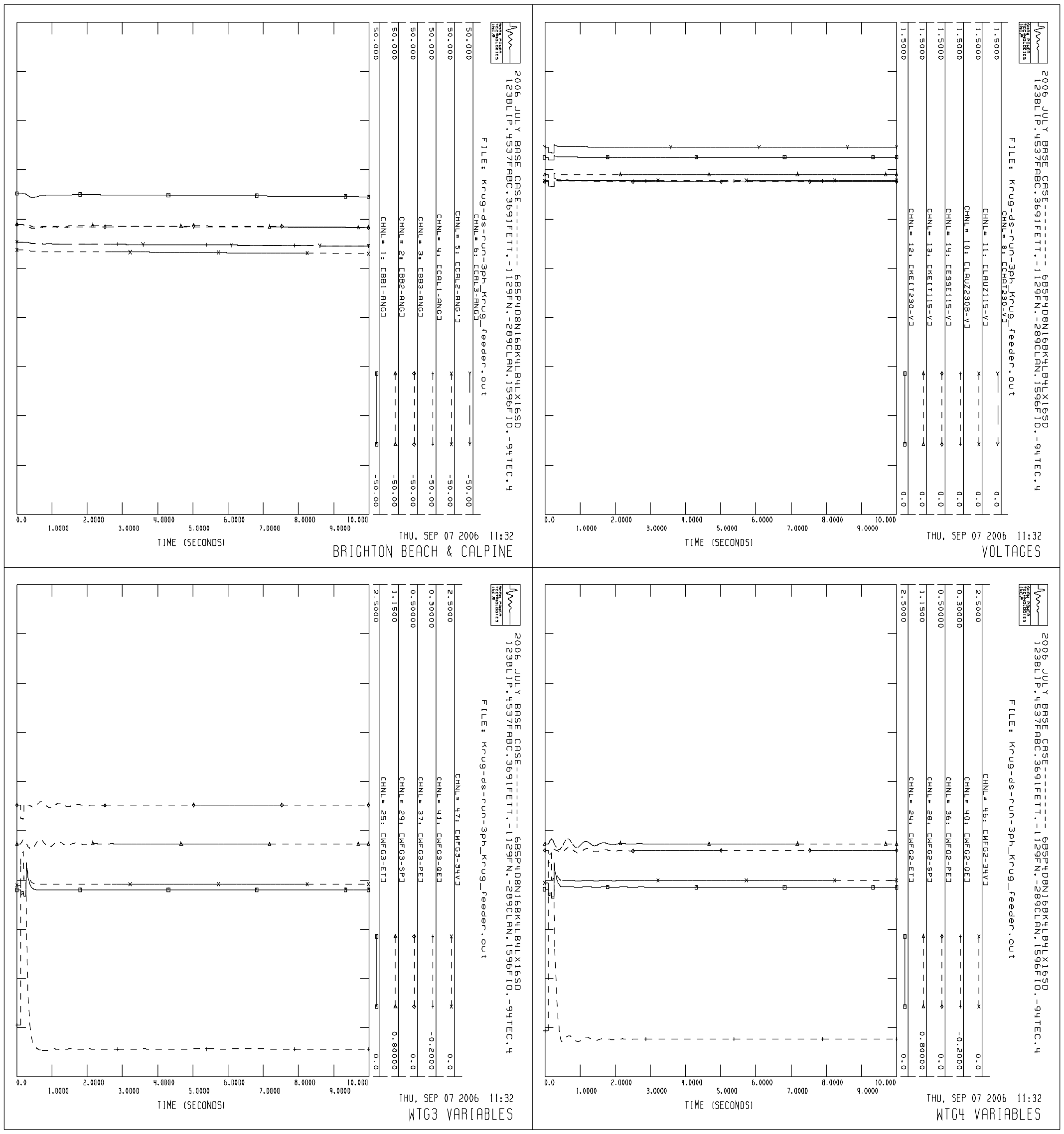
TSC6 - Normally cleared LG fault at L28C @ L + LG fault at L29C @ L



TSC7 - Normally cleared 3ph fault at Kruger T1



TSC8- Normally cleared 3ph fault at Kruger Feeder 4



TSC9- Loss of Brighton Beach