Wind Integration Project

Transmission Planning Study

Stage 1 Study Report

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System Planning and Performance Assessment
BC Transmission Corporation

DISCLAIMER OF WARRANTY, LIMITATION OF LIABILITY

This report is based on the best information available at the time of the study. The findings are based on high level review of the BCTC transmission system performed under a compressed time schedule. Accordingly, this report is suitable only for such purposes, and is subject to any changes arising after the date of this report when a detailed study is performed with adequate time resource.

Executive Summary

The BC Energy Plan: A Vision for Clean Energy Leadership directs BCTC and BC Hydro to ensure clean, renewable electricity generation continues to account for at least 90 per cent of the province's total generation.

There is a considerable interest in developing wind resources in BC. To further the understanding of the impact of integrating wind resources to the BCTC Transmission System, and as indicated in its 23 October 2007 bulletin, BCTC initiated a ***Wind Integration Project*** *to examine the impact of intermittent generation sources on the transmission system, as well as propose effective solutions for integrating wind power reliably and economically.*

The objective of this study is to produce a high level system planning assessment of the capabilities of the BC transmission system to integrate the potential wind generation resources in various parts of the province.

Five potential wind generation areas have been studied, including Peace, North Coast, Kelly Lake, Nicola and North Vancouver Island. Each interconnection is studied independent of the other. Each power injection to the system is offset by a corresponding generation reduction at Peace or South Interior, i.e. as a sink, to assess the wind generation impact to transmission system from a generation dispatch perspective. Two stages of system development relevant to wind development schedule have been studied, F2011 and F2014. Due to the nature of wind resource, generation shedding was considered as an acceptable mitigation measure in response to contingencies. Power flow, voltage stability and transient stability studies have been conducted for each of the potential wind interconnections by checking both steady state (pre-outage and post-outage) and transient performances.

In general, the study has found that considerable wind generation could be integrated at various parts of the BC transmission system in F2011 and F2014 based on the above study approach. The F2014 system can accommodate slightly more wind generations than the F2011 system due to improved transmissions. With reinforcements that require short lead time such as line upgrades for higher thermal rating, new transformer banks, series capacitor compensation of existing lines (existing compensation upgrade or new ones), switched shunt reactors for over-voltage relief, and dynamic shunt devices such as Static VAR Compensator (SVC) and Static Compensator (STATCOM), significant additional wind generation could be accommodated at North Coast and Peace regions. The reinforcement requirement of DC connection options is less than the AC option due to the assumed high dynamic VAR capability (0.9 lead and lag) provided by DC at the Point of Interconnection (POI). Preliminary Estimates of reinforcement costs are produced based on historical unit costs and estimates, and provided for reference only.

The following tables summarize the system capabilities for accommodating the potential wind generations at each location individually and the Preliminary Estimate of upgrade cost for increasing the capabilities based on the Generation Sink in Peace Region or South Interior. Other issues such as the combined effect, fast transient voltages, and *operational concerns will be covered by follow-up studies or system impact studies when detailed information becomes available.*

Summary of System Capability and Preliminary Estimate

Generation Sink in Peace Region

POI	F2011 System			F2014 System		
	Existing Limit (MW)	Reinforced System		Existing Limit (MW)	Reinforced System	
		Limit (MW)	Preliminary Estimate[1] ($M)		Limit (MW)	Preliminary Estimate[1] ($M)
1 SKA500 AC	700	1550	120	710	1570	120
1 SKA500 AC (Altn)[2]	700	2500	275	710	2500	268
2-I SKA287 DC[3]	400	800	18	420	800	18
2-II SKA287 AC	400	800	110	420	800	108
3-I RUP287 DC[3]	240	580	45	240	580	45
3-II RUP287 AC	240	580	80	240	580	78
4 GMS500 AC	1600	1600	not identified	1600	1600	not identified
5 GMS230 AC	160	1600	55	160	1600	55
6 SNK230 AC	160	460	30	160	460	30
7 KLY230 AC	350	350	not identified	350	350	not identified
8 NIC230 & NIC138 AC	260	300	0.5	260	300	0.5

[1] The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of costs and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.
[2] Alternative reinforcement option for a higher limit
[3] Due to high dynamic VAR capability assumed for the DC transmission option (0.9 lead – lag at the transmission POI), DC system reinforcement cost is significantly lower than the AC option.

Generation Sink in South Interior

POI	F2011 System			F2014 System		
	Existing Limit (MW)	Reinforced System		Existing Limit (MW)	Reinforced System	
		Limit (MW)	Preliminary Estimate[1] ($M)		Limit (MW)	Preliminary Estimate[1] ($M)
1 SKA500 AC	640	1550	165	650	1570	165
1 SKA500 AC (Altn)[2]	640	2000	270	650	2160	284
2-I SKA287 DC[3]	400	800	60	420	800	60
2-II SKA287 AC	400	800	115	420	800	115
3-I RUP287 DC[3]	240	580	45	240	580	45
3-II RUP287 AC	240	580	85	240	580	82
4 GMS500 AC	480	1600	80	620	1600	80
5 GMS230 AC	160	1600	135	160	1600	135
6 SNK230 AC	160	460	70	160	460	30
7 KLY230 AC	350	350	not identified	350	350	not identified
8 NIC230 & NIC138 AC	260	300	0.5	260	300	0.5
9 GLD230 AC	180	240	4	180	240	4
10 PML132 & JUL132 & PHY132 AC	140	140	not identified	140	140	not identified

[1] The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of costs and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

[2] Alternative reinforcement option for a higher limit

[3] Due to high dynamic VAR capability assumed for the DC transmission option (0.9 lead – lag at the transmission POI), DC system reinforcement cost is significantly lower than the AC option.

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1. Introduction

The BC Energy Plan: A Vision for Clean Energy Leadership directs BCTC and BC Hydro to ensure clean, renewable electricity generation continues to account for at least 90 per cent of the province's total generation.

There is a considerable interest in developing wind resources in BC. To further the understanding of the impact of integrating wind resources to the BCTC Transmission System, and as indicated in its 23 October 2007 bulletin, BCTC initiated a **Wind Integration Project** to examine the impact of intermittent generation sources on the transmission system, as well as propose effective solutions for integrating wind power reliably and economically.

The objective of this study is to produce a high level system planning assessment of the capabilities of the transmission system to integrate various levels of wind generation with a two-step approach:

Step 1: identify potential transmission capabilities as of F2011 and F2014 (the "F2011 Study" and "F2014 Study") to accommodate new wind generation in various regions in BC, with no additional reinforcements to the planned or existing transmission system beyond the Point of Interconnection (POI). The combined effect of this wind generation is not considered.

Step 2: identify potential feasible transmission system reinforcements, such as re-conductoring or upgrading existing lines, adding new transformers, line series compensation, and Flexible AC Transmission System (FACTS) Controllers, for F2011 and F2014, to allow the integration of higher levels of wind generation at the identified locations. Adding new transmission lines is excluded in this study. In addition, preliminary cost estimates (the "Preliminary Estimates") for potential reinforcements are provided. These Preliminary Estimates are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of costs. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

As a result, Powertech Labs, Inc. (PLI) was contracted to conduct the studies. Ten POI locations were studied as shown in Figure 1. For each location, voltage and transient security studies were performed using PLI's Voltage Security Assessment Tool (VSAT) and Transient Security Assessment Tool (TSAT). Voltage security (also referred to as static analysis) consists of voltage stability, voltage decline and rise, and branch overload assessments. Similarly, transient security (also known as dynamic analysis) includes transient stability, transient voltage dip and rise, and frequency dip assessments. Detailed analysis of fast transient voltage or resonance studies were not included in this high level purpose, as these types of studies would require detailed information of actual interconnection equipment.

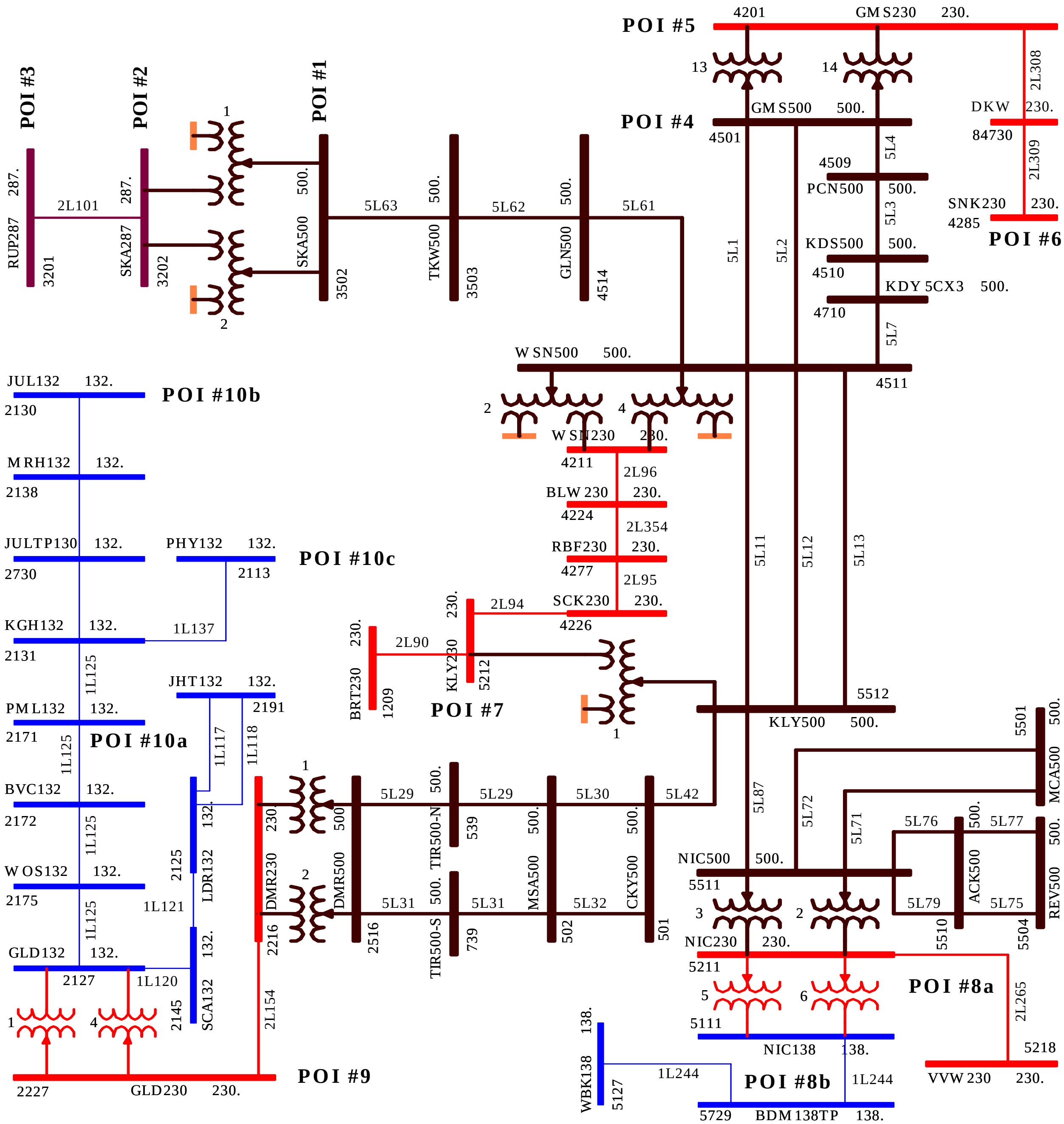

Figure 1: Points of Interconnection Studied

2. Assumptions and Special Models

2.1. Wind Generating Facilities Interconnection

Based on available information to BCTC on potential wind resources, the interconnection for the assumed Wind Generating Facilities (WGF) is summarized in Table 1. To integrate wind generation into the BCTC Transmission System, two alternative generation sinks (i.e., to offset the wind generation injection), which are GMS/PCN in the Peace Region (PR) and MCA/REV in the South Interior (SI), were considered for the wind resources located in North Coast (NC), PR and SI. For the North Vancouver Island (NVI) wind resources, however, only a MCA/REV sink was applied. For POI #8 and POI #10 which involve more than one WGF, the MW injections were assumed to be increased simultaneously in proportion to the potential WGF sizes.

Typical cable and overhead (O/H) line data were used for the AC interconnection circuits with appropriate shunt compensations. As an alternative to AC interconnection, a High Voltage Direct Current (HVDC) link with Voltage-Source Converters (VSC) was also considered for POI #2 and POI #3.

2.2. Model of Wind Turbine Generator

A Doubly Fed Induction Generator (DFIG) was assumed at the end of each AC interconnection circuit, using typical GE 1.5 MW Wind Turbine Generator (WTG) model and data, and 14% total transformer reactance (6% for pad-mounted transformer and 8% for station transformer). A shunt capacitor at the wind farm collector bus was assumed to supply any capacitive power demand to meet interconnection requirements in addition to the typical capability of the DFIG model–0.9 power factor lagging and 0.95 power factor leading.

Types of WTG technology can be ignored for DC alternatives as the WGF is isolated from the transmission grid by the converters. However, a User Defined Model (UDM) capable of supplying the required active power, as well as controlling the supplied reactive power, was used for the converters at the grid side with a rated power factor of 0.9 lead – lag (DC voltage was set at 300 kV). Sufficient shunt VAR compensation was assumed at the converter for near unity power factor operation at pre-contingency situations.

Table 1: Interconnection Information for BC Potential Wind Generation.

Region	POI #	POI Bus	WGF Interconnection	Generation Sink
North Coast	1	SKA 500 kV	One or two AC circuits (Cable and O/H lines), depending on the size of WGF	(1) GMS/PCN (2) MCA/REV
	2	SKA 287 kV	(I) One VSC DC link (II) One or two AC circuits (cables and O/H lines) depending on the size of WGF	(1) GMS/PCN (2) MCA/REV
	3	RUP 287 kV	(I) One VSC DC link (II) One AC circuit (cable and O/H line)	(1) GMS/PCN (2) MCA/REV
Peace	4	GMS 500 kV	One or two AC circuits (O/H lines) depending on the size of WGF	(1) GMS (2) MCA/REV
	5	GMS 230 kV	One or two AC circuits (O/H lines) depending on the size of WGF	(1) GMS (2) MCA/REV
	6	SNK 230 kV	One AC circuit (O/H line)	(1) GMS (2) MCA/REV
West of SI	7	KLY 230 kV	One AC circuit (O/H line)	(1) GMS/PCN (2) MCA/REV
	8	(a) Middle of 2L265 (NIC to VVW) (b) Middle of 1L244 (NIC-WBK)	(a) One AC circuit (O/H line) (b) One AC circuit (O/H line)	(1) GMS/PCN (2) MCA/REV
North VI	9	GLD 230 kV	One or two AC circuits (O/H lines) depending on the size of WGF	MCA/REV
	10	(a) PML 132 kV (b) JUL 132 kV (c) PHY 132 kV	(a) One AC circuit (O/H line) (b) One AC circuit (O/H line) (c) One AC circuit (O/H line)	MCA/REV

3. Description of Base Cases

Three modified summer base cases for F2011 were prepared and used in the study as follows:

1. ***W10HS-ND*** **–** Northern Division (ND) base case with the ND light load and high generation in the region.

2. ***W10HS-VI*** **–** Vancouver Island (VI) base case with the VI light load and high generation in Lower Mainland (LM) and VI to stress the transfer.

3. ***W10HS-SI*** **–** South Interior (SI) base case with the SI light load and high generation in the region to stress the transfer.

Similar base cases have been produced and used to study the F2014 system.

4. Applied Criteria and Contingencies

North-American Electric Reliability Corporation (NERC) and Western Electricity Coordinating Council (WECC) planning criteria, as well as applicable BCTC System Operating Orders (SOO) and Local Operating Orders (LOO), were applied in analyzing the acceptability of system performance in response to various contingencies.

The applicable voltage security criteria are as follows:

- ***Voltage Stability Margin:*** For single contingency; 5% margin on the transfer path level. For double contingency; 2.5% margin on the transfer path level.

- ***Voltage Deviation (Decline or Rise):*** For single contingency; not to exceed 5% at any bus. For double contingency; not to exceed 10% at any bus.

- ***Branch Overload:*** 100% of Rating A (continuous) for pre-contingency and 100% of rating B (emergency) for post-contingency.

The applicable transient security criteria are as follows:

- ***Transient Stability:*** System remains stable for the specified contingencies.

- ***Transient Voltage Dip:*** For single contingencies; not to exceed 20% for more than 20 cycles at load buses. For double contingencies; not to exceed 20% for more than 40 cycles at load buses.

- ***Over-Voltage Protection:*** To avoid sequential over-voltage tripping of relevant 500 kV lines, the transient voltages are to be less than the over-voltage protection settings specified in BCTC SOO 7T-22.

- ***Contingency and Generation Shedding Application:*** For each of the POIs, the relevant transmission system contingencies were applied to check the system performance after the subject WGF was connected to the transmission system. The contingencies include the loss of one system element (N-1) and applicable double contingencies (N-2). N-1 contingencies include single phase ground faults and three phase faults of transmission lines, or a transformer fault. Double contingencies include the loss of two circuits simultaneously. The partial or complete shedding of the subject WGF was allowed for the major single and double contingencies.

5. F2011 Study

5.1. F2011 Existing System Capabilities

The simulation results of the existing system capabilities in F2011 are summarized in Table 2 for the PR sink and in Table 3 for the SI sink. In these tables, the first column lists the ten POIs for wind resource; the second column indicates the type of limiting factor for wind MW injection; the third column gives the capability of how much wind generation can be injected at the POI without additional reinforcement; the fourth is the estimated capacitive VAR support at the collector bus to meet interconnection requirement in addition to the typical VAR capability of DFIG; the fifth column indicates the reasons whether a specific contingency or pre-disturbance condition causes the limit; the sixth column shows where the system performance is an issue or which element has been critically affected by the contingency.

The limits were found within a 20 MW resolution. In general, the most limiting factor of the existing system in 2011 is either branch overload or transient voltage dip. In case of a line overload, the limit corresponds to that occurring without any contingency, i.e., N-0. In case of a transformer overload, the limit corresponds to that occurring after one transformer is tripped out, i.e., N-1. The situations requiring wind generation shedding/runback are indicated in the notes of these tables.

The following details the capability and findings for each specific region on individual basis.

5.1.1. North Vancouver Island Region (POI #9 and POI #10)

In this region, the system from DMR to GLD is a 230-132 kV loop operated system, and the system from GLD to PHY is a 132 kV radial system. Any contingency causing the 230 kV connection (DMR to GLD) to be broken may require a generation runback/tripping Remedial Action Scheme (RAS) to resolve 132 kV line thermal overloads and/or significant bus voltage deviation.

For the wind generation POI at GLD230 (POI #9), generation shedding RAS was applied to resolve transient and post-transient performance issues including 132 kV line thermal overload for any contingency causing the loss of 230 kV connection (GLD to DMR). For contingencies in the 132 kV system, generation shedding was not applied unless the contingency disconnected the WGF. The study shows that for the given summer base case, the loss of ICG generation would overload 1L121 (SCA-LDR) when the WGF output is more than 180 MW. Therefore the capability for wind generation injection at GLD 230 kV is 180 MW.

For POI #10 (PML132, JUL132 and PHY132), generation shedding was also applied for any contingency causing the DMR-GLD connection to be broken. It has been found that the most limiting factor for wind generation injection is the conductor thermal rating (123 MVA at 30^{o} C summer) of 1L125 (GLD-WOS-PML-KGH) under system normal conditions. 140 MW is the maximum injection the NVI system can take at POI #10.

5.1.2. North Coast Region (POI #1, POI #2 and POI #3)

For the POI #1 at SKA500, a wind generation shedding RAS was applied for the contingencies resulting in a North Coast island such as loss of 5L61 (WSN to GLN), 5L62 (GLN to TKW), or 5L63 (TKW to SKA), and other major single and double contingences including:

- loss of 5L11 (WSN to KLY);
- loss of 5L12 (WSN to KLY);
- loss of 5L13 (WSN to KLY);
- loss of 5L11 & 5L12;
- loss of 5L11 & 5L13; and
- loss of 5L12 & 5L13.

It has been found that the most limiting contingency for wind injection is a 5L61 single phase ground fault which would cause a transient voltage dip violation at the HML 138 kV bus. The study shows that the existing capability is 700 MW with the generation sink in PR, and 640 MW for with the generation sink in SI.

For the POI at SKA287 DC or AC connection (POI #2-I and POI #2-II), the same generation shedding principle was applied as for the POI at SKA500. The most limiting contingency is the loss of one of the two SKA 500/287 kV transformers (T1 and T2), which would cause another transformer overload. The capability at SKA287 for AC or DC connection is about 400 MW whether the generation sink is in PR or in SI.

For the POI at RUP287 DC or AC connection (POI #3-I and POI #3-II), the same generation shedding principles were applied as at the POI at SKA500 or SKA287. The most limiting factor for wind generation injection at RUP287 is the 2L101 line thermal rating under system normal condition. The existing capability at RUP287 for AC or DC connection is about 240 MW whether the generation sink is in PR or in SI.

5.1.3. Peace Region (POI #4, POI #5 and POI #6)

For the POI #4 at GMS500, the wind generation shedding RAS was applied for single and double line contingencies in the bulk transmission system. The single contingences include the loss of any 500 kV line from GMS to KLY. The double contingencies include the loss of two 500 kV lines from GMS through WSN to KLY. The 500 kV lines from GMS through WSN to KLY are 5L1 (GMS to WSN), 5L2 (GMS to WSN), 5L3 (PCN to KDS), 5L4 (GMS to PCN), 5L7 (KDS to WSN), 5L11, 5L12, and 5L13 (WSN to KLY). Due to the application of generation shedding for loss of a transmission line, the line contingency is not the most limiting factor for wind generation injection. The study has found that, if the generation sink is in SI, the most limiting factor is GMS T14 or T13 contingency resulting in the BLW230 bus voltage dip violation. The limit for wind generation injection is 480 MW.

If the generation sink is in PR, the wind injection of up to 1600 MW is acceptable since the MW injection at GMS500 is basically the replacement of GMS generation reduction.

For POI #5 at GMS230, the most limiting contingency is the loss of one of GMS T13 and T14 that would result in another transformer overload. The maximum capability for injection at GMS230 is 160 MW whether the generation sink is in PR or SI.

For POI #6 at SNK230, the most limiting contingency and the capability are the same as for the POI at GMS230.

5.1.4. West of SI Region (POI #7 and POI #8)

For POI #7 at KLY230, wind generation injection up to 350 MW is acceptable for both sink locations for pre-contingency, transient, and post-transient performance for the applicable contingencies. Generation shedding is not required for applicable N-1 contingencies.

For POI #8 at NIC, there are two small potential wind resources identified in this area. One was assumed to connect to the system at the middle of line 2L265 (NIC to VVW) and another was assumed to connect at the middle of 1L244 (NIC to WBK). The study shows that both wind resources can inject up to a total of 260 MW (175 MW into 2L265 and 85 MW into 1L244) into the regional system without any extra transmission reinforcements. The limiting factor is the thermal rating of 1L244 under system normal condition.

5.1.5. Reactive Requirement

In addition to the typical DFIG reactive power capability (assumed at 0.9 pf lagging and 0.95 pf leading), to meet the reactive power requirement, the required shunt capacitive support at the collector bus of the WGF have been computed and provided in Table 2 and 3 (column 4). These estimates are for reference purpose only. Detailed dynamic vs. static VAR requirements will be determined in WGF interconnection system impact and facility studies based on specific type of WTG technology, interconnection scheme, and location.

Table 2: Summary of the F2011 Existing System Results with Generation Sink in Peace Region.

# & Name of POI & Type of Interconnection	Limit Type	Existing Limit (MW)	Shunt MVAR Estimate[6]	Limiting Contingency	Most Critical Element (Rating)
1 SKA500 AC[1]	Transient Voltage Dip	700	280	5L63 1Ph	HML138 (138 kV)
2-I SKA287 DC[2]	Branch Overload	400	N/A	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
2-II SKA287 AC[2]	Branch Overload	400	250	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
3-I RUP287 DC[3]	Branch Overload	240	N/A	Pre-cont.	2L101 (318 MVA)
3-II RUP287 AC[3]	Branch Overload	240	70	Pre-cont.	2L101 (318 MVA)
4 GMS500 AC[4]	Potential Wind MW	1600	440	-	-
5 GMS230 AC[4]	Branch Overload	160	60	GMS T14	GMS 500/230 T13 (300 MVA)
6 SNK230 AC[4]	Branch Overload	160	40	GMS T14	GMS 500/230 T13 (300 MVA)
7 KLY230 AC[5]	Potential Wind MW	350	170	-	-
8 NIC230 & NIC138 AC	Branch Overload	260	(a) 50 (b) 20	Pre-cont.	1L244 NIC-POI138 (86 MVA)

Notes:

1. For POI #1 wind generation shedding was required after NC islanding, or single contingencies involving 5L1, 5L2, 5L7, 5L11, 5L12, and 5L13, or double contingencies involving 5L1& 5L2, 5L11&5L12, and 5L11&5L13 for example.
2. For POI #2 wind generation shedding was required after NC islanding, or single contingencies involving 5L11, 5L12, and 5L13, or double contingencies involving 5L11&5L12, 5L12 &5L13, and 5L11&5L13.
3. For POI #3 wind generation shedding was required after NC islanding, or double contingencies involving 5L11& 5L12, 5L12 &5L13, and 5L11&5L13.
4. For POIs #4, 5, and 6, wind generation shedding was required after double contingencies involving lines between GMS/PCN-WSN-KLY, e.g. 5L1&5L2, 5L11&5L12, and 5L11&5L13.
5. For POI #7 slight wind generation re-dispatch was required after 5L41 outage.
6. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.

Table 3: Summary of the F2011 Existing System Results with Generation Sink in South Interior.

# & Name of POI & Type of Interconnection	Limit Type	Existing Limit MW	Shunt MVAR Estimate[7]	Limiting Contingency	Most Critical Element (Rating)
1 SKA500 AC[1]	Transient Voltage Dip	640	240	5L63 1Ph	HML138 (138 kV)
2-I SKA287 DC[2]	Branch Overload	400	N/A	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
2-II SKA287 AC[2]	Branch Overload	400	250	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
3-I RUP287 DC[3]	Branch Overload	240	N/A	Pre-cont.	2L101 (318 MVA)
3-II RUP287 AC[3]	Branch Overload	240	80	Pre-cont.	2L101 (318 MVA)
4 GMS500 AC[4]	Transient Voltage Dip	480	120	GMS T14	BLW230 (230 kV)
5 GMS230 AC[4]	Branch Overload	160	60	GMS T14	GMS 500/230 T13 (300 MVA)
6 SNK230 AC[4]	Branch Overload	160	40	GMS T14	GMS 500/230 T13 (300 MVA)
7 KLY230 AC[5]	Potential Wind MW	350	170	-	-
8 NIC230 & NIC138 AC	Branch Overload	260	(a) 50 (b) 20	Pre-cont.	1L244 NIC-POI138 (86 MVA)
9 GLD230 AC[6]	Branch Overload	180	90	ICG IPP	1L121 (151 MVA)
10 PML132 & JUL132 & PHY132 AC[6]	Branch Overload	140	(a) 20 (b) 10 (c) 10	Pre-cont.	1L125 (123 MVA)

Notes:
1. For POI #1 wind generation shedding was required after NC islanding, or single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, and 5L13, or double contingencies involving 5L1&5L2, 5L11&5L12, and 5L11&5L13 for example.
2. For POI #2 wind generation shedding was required after NC islanding, or single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, and 5L13, or double contingencies involving 5L11&5L12, 5L12&5L13, and 5L11&5L13.
3. For POI #3 wind generation shedding was required after NC islanding, or single contingencies involving 5L11, 5L12, and 5L13, or double contingencies involving 5L11&5L12, 5L12&5L13, and 5L11&5L13.
4. For POIs #4, 5, and 6, wind generation shedding was required after single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, and 5L13, or double contingencies involving 5L1&5L2, 5L11&5L12, and 5L11&5L13 for example.
5. For POI #7 slight wind generation re-dispatch was required after 5L41 outage.
6. For POIs #9 and 10 wind generation runback was required for loss of 2L154 radial line.
7. The estimate MVAR is the power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.

5.2. F2011 System with Reinforcements

The simulation results of the F2011 system with proposed reinforcements and the Preliminary Estimates are summarized in Table 4 for the PR generation sink and in Table 5 for the SI generation sink.

With reinforcements, such as re-conductoring or upgrading existing lines, adding new transformers, line series compensation, and Flexible AC Transmission System (FACTS) devices, the system capability in accepting power injection is increased and the amount of the increase depends on the proposed upgrades and the location of the POI.

The proposed reinforcements for each POI are discussed below in details. They are the minimum upgrade requirements for achieving the indicated capabilities; for a different amount of power injection, the required upgrades will have to be reassessed and adjusted accordingly. Please note that the proposed upgrades for each POI are based on a high level assessment. More detailed studies are required for the specific project proposed.

The principles for the application of generation shedding/runback RAS are the same as those used in Section 5.1 for applicable contingencies. Situations requiring wind generation shedding/runback are indicated in the notes of Table 4 and Table 5, which do not constitute an exhaustive list for this requirement.

The following assumptions were used in the simulation study:

- The series capacitor compensations were assumed to be increased in steps of 10%.
- The SVCs requirements were determined in steps of 10 MVAR and STATCOMs in steps of ±10 MVAR.
- For single line to ground fault clearing, it was assumed that the series compensations of un-faulted phases were not bypassed.

5.2.1. North Vancouver Island Region (POI #9 and POI #10)

For POI #9 at GLD230, by re-conductoring 1L121 (SCA to LDR) to a summer rating of 1055 amps (241 MVA) from the present rating of 660 amps, the capability at this POI would increase to about 240 MW.

The Preliminary Estimate for re-conductoring 1L121 is about $4M.

For the POI #10 (PML132, JUL132 and PHY132), the wind power injection limit cannot exceed the existing system injection limit even with the critically overloaded lines (i.e., lL125 and 1L121) upgraded to a higher thermal rating. This is due to the transient frequency dip violations in the vicinity of the DFIGs as the regional system is weak and has limited installed synchronous generation capacity.

5.2.2. North Coast Region (POI#1, POI #2 and POI #3)

For the POI #1 at SKA500, three power injection levels (1550 MW, 2000 MW and 2500 MW) were studied to identify required upgrades.

As indicated in Table 4 and Table 5, the 1550 MW wind power injection is limited by the acceptable transient performance for a single phase fault on 5L63. The upgrade requirements based on generation sinks in PR and in SI are listed below.

For a 1550 MW power injection with generation sink in PR, the required upgrades are:

- 50% series capacitor compensations to 5L61, 5L62, and 5L63 with a summer rating of 2000 amps (1732 MVA),
- A ±130 MVAR STATCOM at SKA 500 kV bus, and
- A 150 MVAR switched shunt reactor at GLN 138 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $120M.

For a 1550 MW power injection with generation sink in SI, the required upgrades are:

- 50% series capacitor compensations to 5L61, 5L62, and 5L63 with a summer rating of 2000 amps (1732 MVA),
- Increasing the series compensation of 5L11, 5L12, and 5L13 from 50% to 70%, The rating of the series compensation station remains unchanged,
- A ±190 MVAR STATCOM at SKA 500 kV bus, and
- A 110 MVAR switched shunt reactor at GLN 138 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $165M.

As indicated in Table 6, the maximum potential wind capacity of 2500 MW can only be achieved when generation sink is in PR. This high wind power injection would trigger 5L61, 5L62 and 5L63 thermal upgrade. The required upgrades include:

- High series capacitor compensation of 70% on 5L61, 5L62, and 5L63 with a summer rating of more than 3150 amps (2730 MVA),
- Thermal upgrade of 5L61, 5L62 and 5L63 to a summer rating of more than 3150 amps (2730 MVA),
- A ±240 MVAR STATCOM at SKA 500 bus, and
- A 130 MVAR switchable shunt reactor at GLN138 bus.

The total Preliminary Estimate for the proposed reinforcements is $275M.

For the generation sink in SI, the achievable limit is about 2000 MW. This capability is limited by the acceptable transient performance for the double contingency of 5L11 and 5L12. The required upgrades for a 2000 MW injection include:

- High series capacitor compensation of 70% on 5L61, 5L62, and 5L63 with a summer rating of more than 2540 amps (2200 MVA),
- Increased series compensations of 5L11, 5L12, and 5L13 from 50% to 70% with a summer rating of 2200 amps (1900 MVA),
- Thermal upgrade of 5L61, 5L62, and 5L63 to a summer rating of more than 2540 amps (2200 MVA), and
- A ±200 MVAR STATCOM at WSN 500 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $270M.

Please note that due to the limitations of a high level study, the full impact of high wind power injection of this magnitude has not been analyzed and needs to be studied in detail when the application is received.

For the POI at SKA287 DC or AC connection (POI #2-I and POI #2-II), 800 MW wind power injection could be achieved for both generation sinks in PR and SI.

For the DC connection with the generation sink in PR, the required upgrades are:

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor.

The total Preliminary Estimate for the proposed reinforcements is $18M.

For the AC connection with the generation sink in PR, the required upgrades are:

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor,
- 50% series capacitor compensations to 5L61 and 5L62 with a summer rating of 1200 amps (1040 MVA), and
- A ±180 MVAR STATCOM at SKA 500 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $110M.

The required upgrades for DC connection with the generation sink in SI are:

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor, and
- 50% series capacitor compensations to 5L61 and 5L62 with a summer rating of 1200 amps (1040 MVA).

The total Preliminary Estimate for proposed reinforcements is $60M.

The required upgrades for AC connection with the generation sink in SI are:

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor,
- 50% series capacitor compensation to 5L61 and 5L62 with a summer rating of 1200 amps (1040 MVA), and
- A ± 250 MVAR STATCOM at SKA 500 kV bus.

The total Preliminary Estimate for proposed reinforcements is $115M.

Please note that the 800 MW limit is assumed to be a practical wind power injection for the 287 kV connection. If more than 800 MW wind power injection is desired, a 500 kV connection option should be considered.

For the POI at RUP287 DC and AC connection (POI #3-I and POI #3-II), 580 MW could be achieved for both generation sink in PR and SI.

The required upgrades for DC connection with the generation sink in PR or SI are:

- Increasing the ground clearance of 2L101 (SKA to RUP) to a conductor temperature of 90 C (summer rating of 1270 amps or 631 MVA) from the existing 50 C (summer rating of 640 amps),
- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor, and
- 50% series capacitor compensation to 2L101 with a summer rating of 1270 amps.

The total Preliminary Estimate for the proposed reinforcements is $45M.

The required upgrades for AC connection with the generation sink in PR are:

- Increasing the ground clearance of 2L101 (SKA to RUP) to a conductor temperature of 90 C (summer rating of 1270 amps or 631 MVA) from the existing 50 C (summer rating of 640 amps),
- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor,
- 70% series capacitor compensation to 2L101 with a summer rating of 1270 amps (631 MVA), and
- A 90 MVAR SVC at SKA 500 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $80M.

The required upgrades for AC connection with the generation sink in SI are:

- Increasing the ground clearance of 2L101 (SKA to RUP) to a conductor temperature of 90 C (summer rating of 1270 amps or 631 MVA) from the existing 50 C (summer rating of 640 amps),

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor,

- 70% series capacitor compensation to 2L101 with a summer rating of 1270 amps (631 MVA), and

- A 150 MVAR SVC at SKA 500 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $85M.

5.2.3. Peace Region (POI #4, POI #5 and POI #6)

For the POI #4 at GMS500, the potential 1600 MW injection could be achieved by increasing the series capacitor compensation of 5L1, 5L2, 5L3-7, 5L11, 5L12, and 5L13 from the existing 50% to 70%, based on the generation sink in SI. For the generation sink in PR, 1600 MW injection at GMS500 could be achieved without requiring system upgrade since the power injection is correspondingly reduced at GMS generating station. The total Preliminary Estimate for the proposed reinforcements is $80M.

For the POI #5 at GMS230, the amount of maximum injection allowed would depend on the feasibility of GMS station expansion for additional equipment such as transformers, CBs, etc., in addition to other system reinforcements such as the increase of series compensation to the 500 kV lines from GMS down to KLY. The listed injection limits and the proposed reinforcements for POI #5 at GMS230 in Table 4 and 5 are for reference only.

For POI #6 at SNK230, a 460 MW injection could be accommodated for both generation sinks in PR and SI.

The required upgrades for the SNK230 AC connection with the generation sink in PR are:

- Re-conductoring and strengthening the towers to bring the 2L308 and 2L309 capacity to a summer rating of 1500 amps (598 MVA) from the current rating of 1054 amps (420 MVA), and

- A 300 MVA 500/230 kV transformer at GMS station.

The total Preliminary Estimate for the proposed reinforcements is $30M.

The required upgrades for SNK230 AC connection with the generation sink in SI are:

- Re-conductoring and strengthening the towers to bring the 2L308 and 2L309 capacity to a summer rating of 1500 amps (598 MVA) from the current rating of 1054 amps (420 MVA),

- A 300 MVA 500/230 kV transformer at GMS station, and

- A 170 MVAR SVC at WSN230 kV bus.

The total Preliminary Estimate for the proposed reinforcements is $70M.

5.2.4. West of SI Region (POI #7 and POI #8)

For POI #7 at KLY230, as indicated in the section 5.1.4, the existing wind generation injection capability at this POI can be up to 350 MW, which is the potential wind generation in the area. Thus, cost of reinforcement is considered negligible for this high-level assessment purpose.

For POI #8 at NIC, as described in the section 5.1.4, there are two small potential wind resources identified in this area. One was assumed to connect to the middle of line 2L265 (NIC to VVW) and another was assumed to connect at the middle of 1L244 (NIC to WBK).

By upgrading the line section from the interconnection point to NIC of the line 1L244 (NIC to WBK) to a higher summer rating of 415 amps from the current rating of 359 amps, the identified two potential wind power of 300 MW (200 MW into 2L265 and 100 MW into 1L244) could be accommodated. The Preliminary Estimate for upgrading 1L244 is $1M.

5.2.5. Reactive Requirement

In addition to the typical DFIG reactive power capability, the column 4 in Table 4 and Table 5 shows the estimates for the required capacitive support at the collector bus of the WGF to meet BCTC reactive power requirement at the POI. These estimates are for reference purpose only. Detailed dynamic vs. static VAR requirements will be determined in WGF interconnection studies based on the specific type of WTG technology, interconnection scheme, location, and etc.

Table 4: Summary of the F2011 Reinforced System Results with Generation Sink in Peace Region.

# & Name of POI & Type of Interconnection	Limit Type	Reinforced Limit (MW)	Shunt MVAR Estimate[10]	Proposed System Reinforcements	Preliminary Estimate[11] ($M)
1 SKA500 AC[1]	Transient Voltage Dip (5L63 1Ph)	1550[8]	635	o Add 50% series compensations to 5L61, 5L62, and 5L63. o Add a ±130 MVAR STATCOM at SKA500. o Add 150 MVAR switched shunt reactor at GLN138 bus.	120
2-I SKA287 DC[2]	Practical wind MW injection capacity at 287 kV SKA	800[9]	353	o Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor.	18
2-II SKA287 AC[2]	Practical wind MW injection capacity at 287 kV SKA	800[9]	500	o Add one 672-MVA SKA500/287/12.6 kV transformer with a 37.5 MVAR tertiary reactor. o Add 50% series comp to 5L61 and 5L62. o Add a ±180 MVAR STATCOM at SKA500.	110
3-I RUP287 DC[3]	Branch Overload, 2L101	580	120	o Upgrade 2L101 for higher thermal rating. o Add one 672-MVA SKA500/287/12.6 kV transformer with a 37.5 MVAR tertiary reactor. o Add 50% series compensation to 2L101.	45
3-II RUP287 AC[3]	Branch Overload, 2L101	580	194	o Upgrade 2L101 for higher thermal rating. o Add one 672-MVA SKA500/287/12.6 kV transformer with a 37.5 MVAR tertiary reactor. o Add 70% series compensation to 2L101. o Add a 90 MVAR SVC at SKA500.	80
4 GMS500 AC[4]	Potential Wind MW	1600	438	not identified	
5 GMS230 AC[4]	Potential Wind MW	1600	1282[5]	o Add five 300-MVA (or three 600-MVA) GMS500/230 kV transformers.	55
6 SNK230 AC[6]	Branch Overload, 2L308	460	119	o Add one 300-MVA GMS500/230 kV transformer. o Upgrade 2L308/2L309 for a higher summer rating of 1500 amps (598 MVA).	30
7 KLY230 AC[7]	Potential Wind MW	350	164	not identified	
8 NIC230 & NIC138 AC	Potential Wind MW	300	(a) 54 (b) 16	o Upgrade 1L244 for a higher summer rating of 415 amps (100 MVA).	0.5

Notes:

1. For POI # 1 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1& 5L2, 5L11& 5L12, or 5L11& 5L13.
2. For POI # 2 wind generation shedding was required at least after NC islanding, and double contingencies involving 5L11 & 5L12 or 5L11 & 5L13.
3. For POI # 3 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L11& 5L12 or 5L11& 5L13.
4. For POIs # 4 and 5 wind generation shedding was required at least after double contingencies involving 5L1 & 5L2, 5L11 & 5L12, or 5L11 & 5L13.
5. For POI # 4 some series compensation of the two wind interconnection lines was assumed (or more circuits).
6. For POI # 6 wind generation shedding was required for single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1 & 5L2, 5L11 & 5L12, or 5L11 & 5L13.
7. For POI # 7 slight wind generation re-dispatch was required after 5L41 outage.
8. The limit of 1550 MW was determined by acceptable transient performance for single phase fault of 5L63.
9. The 800 MW limit was assumed as the practical capacity at SKA287. If the application is more than this amount, it is prudent to consider 500 kV integration option. A detail assessment from technical and economical perspectives for 287 kV vs. 500 kV connections shall be required.
10. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.
11. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

Table 5: Summary of the F2011 Reinforced System Results with Generation Sink in South Interior.

# & Name of POI & Type of Interconnection	Limit Type	Reinforced Limit (MW)	Shunt MVAR Estimate[9]	Proposed System Reinforcements	Preliminary Estimate[10] ($M)
1 SKA500 AC[1]	Transient Voltage Dip (5L63 1Ph)	1550[7]	635	o Add 50% series compensations to 5L61, 5L62, and 5L63. o Increase 5L11, 5L12, and 5L13 series compensation from 50% to 70%. o Add a ±190 MVAR STATCOM at SKA500. o Add 110 MVAR switched shunt reactor at GLN138 bus.	165
2-I SKA287 DC[2]	Practical wind MW injection capability at 287 kV SKA	800[8]	316	o Add one 672-MVA SKA500/287/12.6 kV transformer with a 37.5 MVAR tertiary reactor. o Add 50% series comp to 5L61 and 5L62.	60
2-II SKA287 AC[2]	Practical wind MW injection capability at 287 kV SKA	800[8]	500	o Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary a reactor. o Add 50% series comp to 5L61 and 5L62. o Add a ±250 MVAR STATCOM at SKA500.	115
3-I RUP287 DC[2]	Branch Overload, 2L101	580	136	o Upgrade 2L101 for higher thermal rating. o Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary a reactor. o Add 50% series compensation to 2L101.	45
3-II RUP287 AC[2]	Branch Overload, 2L101	580	194	o Upgrade 2L101 for higher thermal rating. o Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. o Add 70% series compensation to 2L101. o Add a 150 MVAR SVC at SKA500.	85
4 GMS500 AC[3]	Potential Wind MW	1600	438	o Increase 5L1, 5L2, 5L3-5L7, 5L11, 5L12, and 5L13 series comp from 50% to 70%.	80
5 GMS230 AC[3]	Potential Wind MW	1600	765[4]	o Add five 300-MVA (or three 600-MVA) GMS500/230 kV transformers. o Increase 5L1, 5L2, 5L3-5L7, 5L11, 5L12, and 5L13 series comp from 50% to 70%.	135
6 SNK230 AC[3]	Branch Overload, 2L308	460	119	o Add one 300-MVA GMS500/230 kV transformer. o Upgrade 2L308/2L309 for higher thermal rating. o Add a 170 MVAR SVC at WSN230.	70

7 KLY230 AC[5]	Potential Wind MW	350	164	not identified	
8 NIC230 & NIC138 AC	Potential Wind MW	300	(a) 54 (b) 16	o Upgrade 1L244 for a higher summer rating of.	0.5
9 GLD230 AC[6]	Branch Overload, 2L154	240	134	o Upgrade 1L121 to a summer rating of 1055 amps (240 MVA)	4
10 PML132 & JUL132 & PHY132 AC[6]	Frequency Dip in vicinity of DFIGs	140	(a) 15 (b) 6 (c) 8	not identified	

Notes:

1. For POI #1 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1 & 5L2, 5L11 & 5L12, or 5L11 & 5L13.
2. For POIs #2, and 3 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L11 & 5L12 or 5L11 & 5L13.
3. For POIs #4, 5, and 6 wind generation shedding was required at least after single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1 & 5L2, 5L11 & 5L12, or 5L11 & 5L13.
4. For POI # 4 some series compensation of the two wind interconnection lines was assumed (or more circuits).
5. For POI #7 slight wind generation re-dispatch was required after 5L41 outage.
6. For POIs #9 and 10 wind generation runback was required for loss of 2L154 radial line.
7. The limit of 1550 MW was determined by acceptable transient performance for single phase fault of 5L63.
8. The 800 MW limit was assumed as the practical capacity at SKA287. If the application is more than this amount, it is prudent to consider 500 kV integration option. A detail assessment from technical and economical perspectives for 287 kV vs 500 kV connections shall be required.
9. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.
10. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

Table 6: Alternative Reinforcements for POI #1 Allowing 70% Series Compensation of NC 500 kV Lines.

Sink for POI #1 (SKA500 AC)	Limit Type	Reinforced Limit (MW)	Shunt MVAR Estimate	Proposed System Reinforcements	Preliminary Estimate[3] ($M)
GMS/PCN[1]	Potential Wind MW	2500	1413	Upgrade 5L61, 5L62, and 5L63 for higher thermal rating. Add 70% series compensations to 5L61, 5L62, and 5L63. Increase 5L11, 5L12, and 5L13 series compensations from 50% to 70%. Add a ±240 MVAR STATCOM at SKA500. Add 130 MVAR switched shunt reactor at GLN138 bus.	275
MCA/REV[2]	Transient Voltage Dip (5L11&5L12)	2000	966	Upgrade 5L11, 5L12, 5L13, 5L61, 5L62, and 5L63 for higher thermal rating. Add 70% series compensations to 5L61, 5L62, and 5L63. Increase 5L11, 5L12, and 5L13 series compensations from 50% to 70%. Add a ±200 MVAR STATCOM at WSN500.	270

Notes:

1. With the PR sink wind generation shedding was required at least for NC islanding, and double contingencies involving 5L11 & 5L12, or 5L11 & 5L13.
2. With the SI sink wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1 & 5L2, 5L11 & 5L12, or 5L11 & 5L13.
3. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

6. F2014 Study

6.1. F2014 Existing System Capabilities

Compared with the F2011 existing system, the major change in the planned F2014 system is the addition of NIC-MDN 500 kV line (5L83) including 50% series capacitor compensation of the line, in addition to some minor regional network upgrades.

The simulation results for the F2014 system capabilities are summarized in Table 7 for the PR generation sink, and in Table 8 for the SI generation sink.

For the generation sink in PR (Table 7), the system capabilities of integrating wind generation injection for all the listed POIs are almost the same as those for F2011 existing system; the differences are within the 20 MW calculation resolution.

For the generation sink in SI (Table 8), depending on the limiting contingency and nature of the problem, the system capabilities of integrating wind injection for some POIs in F2014 system may be different from the F2011 system mainly due to the Interior to Lower Mainland (ILM) reinforcement, NIC-MDN 500 kV line (5L83), and the increased area load.

For POI #4, the issue limiting wind MW injection is the 230 kV voltage dip violation for GMS T14 outage. With the new NIC-MDN 500 kV line (5L83) and the reduction in transfer from GMS/PCN to KLY due to load increase in the Peace area, the system capability of integrating wind generation increases to 620 MW, about 140 MW more than that of the F2011 system.

The system capabilities of integrating wind generation injection for the other POIs are almost the same as those of the F2011 system; the differences are within the 20 MW calculation resolution.

Table 7: Summary of the F2014 Existing System Results with Generation Sink in Peace Region

# & Name of POI & Type of Interconnection	Limit Type	Existing Limit (MW)	Shunt MVAR Estimate[5]	Limiting Contingency	Most Critical Element (Rating)
1 SKA500 AC[1]	Transient Voltage Dip	710	276	5L63 1Ph	HZN138 (138 kV)
2-I SKA287 DC[2]	Branch Overload	420	198	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
2-II SKA287 AC[2]	Branch Overload	420	272	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
3-I RUP287 DC[3]	Branch Overload	240	81	Pre-cont.	2L101 (318 MVA)
3-II RUP287 AC[3]	Branch Overload	240	60	Pre-cont.	2L101 (318 MVA)
4 GMS500 AC[4]	Potential Wind MW	1600	438	-	-
5 GMS230 AC[4]	Branch Overload	160	51	GMS T14	GMS 500/230 T13 (300 MVA)
6 SNK230 AC[4]	Branch Overload	160	45	GMS T14	GMS 500/230 T13 (300 MVA)
7 KLY230 AC	Potential Wind MW	350	164	-	-
8 NIC230 & NIC138 AC	Branch Overload	260	(a) 44 (b) 14	Pre-cont.	1L244 NIC-POI138 (86 MVA)

Notes:

1. For POI #1 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12, or 5L11&5L13.
2. For POI #2 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12 or 5L11&5L13.
3. For POI #3 wind generation shedding was required at least after NC islanding, and double contingencies involving 5L11&5L12 or 5L11&5L13.
4. For POIs #4, 5, and 6, wind generation shedding was required at least after double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
5. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.

Table 8: Summary of the F2014 Existing System Results with Generation Sink in South Interior.

# & Name of POI & Type of Interconnection	Limit Type	Existing Limit MW	Shunt MVAR Estimate[5]	Limiting Contingency	Most Critical Element (Rating)
1 SKA500 AC[1]	Transient Voltage Dip	650	240	5L63 1Ph	HZN138 (138 kV)
2-I SKA287 DC[1]	Branch Overload	420	223	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
2-II SKA287 AC[1]	Branch Overload	420	272	SKA T1	SKA500/287/12.6 T2 (672/672/150 MVA)
3-I RUP287 DC[1]	Branch Overload	240	72	Pre-cont.	2L101 (318 MVA)
3-II RUP287 AC[1]	Branch Overload	240	63	Pre-cont.	2L101 (318 MVA)
4 GMS500 AC[2]	Transient Voltage Dip	620	155	GMS T14	SVY (138 kV)
5 GMS230 AC[3]	Branch Overload	160	51	GMS T14	GMS 500/230 T13 (300 MVA)
6 SNK230 AC[3]	Branch Overload	160	46	GMS T14	GMS 500/230 T13 (300 MVA)
7 KLY230 AC	Potential Wind MW	350	164	-	-
8 NIC230 & NIC138 AC	Branch Overload	260	(a) 44 (b) 14	Pre-cont.	1L244 NIC-POI138 (86 MVA)
9 GLD230 AC[4]	Branch Overload	180	82	ICG IPP	1L121 (151 MVA)
10 PML132 & JUL132 & PHY132 AC[4]	Branch Overload	140	(a) 15 (b) 6 (c) 8	Pre-cont.	1L125 (123 MVA)

Notes:
1. For POIs #1, 2, and 3, wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12, or 5L11&5L13.
2. For POI #4 wind generation shedding was required at least after single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
3. For POIs #5, and 6 wind generation shedding was required at least after single contingencies involving 5L11, 5L12, or 5L13, and double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
4. For POIs #9 and 10 wind generation runback was required for loss of 2L154 radial line.
5. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.

6.2. F2014 System with Reinforcements

The study results of the F2014 system with proposed reinforcements are summarized in Table 9 for the PR generation sink and in Table 10 for the SI generation sink.

For the generation sink in PR, the capacities that the system could integrate at the various POIs are the same as the F2011 system. The proposed reinforcements for each POI are similar to those identified for the F2011 system. The required line series compensations, thermal upgrades, and transformer additions are the same except a small reduction (~30 MVAR) in VAR compensation (SVC) requirement for the F2014 system compared to the F2011 system.

For the generation sink in SI, depending on the limiting contingency and nature of the problem, the required reinforcements for some POIs in F2014 system may be different from the F2011 system reinforcements, mainly due to ILM reinforcement project and change in area load. The following lists are the major differences in capabilities and required reinforcements of the F2014 system.

For POI #2-I at SKA287 with a DC connection, the same 800 MW wind power injection could be integrated with the following upgrades:

- A 672 MVA 500/287/12.6 kV transformer at SKA and a 37.5 MVAR switchable tertiary reactor (the same requirement as for the F2011 system), and
- A 90 MVAR SVC at TKW500 (instead of the 50% series capacitor compensations to 5L61 and 5L62 required for the F2011 system).

For POI #6 at SNK230, the same 460 MW injection could be integrated with the following upgrades:

- Re-conductoring and strengthening the towers to bring 2L308 and 2L309 to a summer rating of 1500 amps (598 MVA) from the current rating of 1054 amps (420 MVA), and
- A 300 MVA 500/230 kV transformer at GMS station.

The above upgrades are the same as for the F2011 system except that SVC compensation is not required at WSN230 kV bus for the F2014 system.

To accommodate the potential wind resource of 2500 MW at POI #1 for the generation sink in PR, the required upgrades are:

- Thermal upgrade of 5L61, 5L62 and 5L63 to a summer rating of more than 3150 amps (2730 MVA) (i.e. the same as for the F2011 system),
- A ±200 MVAR STATCOM at SKA 500 bus (i.e. 40 MVAR lower than the F2011 system requirement), and
- A 80 MVAR switchable shunt reactor at GLN138 bus (i.e. 50 MVAR lower than the F2011 system requirement).

For the generation sink in SI, the achievable limit is about 2160 MW, which is 160 MW higher than the F2011 system capability. The required upgrades for a 2160 MW injection at POI #1 are similar to the F2011 case, which include:

- High series capacitor compensation of 70% on 5L61, 5L62, and 5L63 with a summer rating of more than 2800 amps (2400 MVA),
- Increased series compensations of 5L11, 5L12, and 5L13 from 50% to 70% with a summer rating of 2300 amps (2000 MVA),
- Thermal upgrade of 5L61, 5L62, and 5L63 to a summer rating of more than 2800 amps (2400 MVA),
- A ±200 MVAR STATCOM at WSN 500 kV bus, and
- A 100 MVAR switched shunt reactor at GLN138 bus. Without this shunt addition, the capability would be 2040 MW, a reduction of 120 MW.

Please note that due to the limitations of a high level study, the full impact of high wind power injection of this magnitude hasn't been analyzed and needs to be studied in detail when the application is received.

Table 9: Summary of the F2014 Reinforced System Results with Generation Sink in Peace Region.

# & Name of POI & Type of Interconnection	Limiting Cause	Reinforced Limit (MW)	Shunt MVAR Estimate[6]	Proposed System Reinforcements	Preliminary Estimate[7] ($M)
1 SKA500 AC[1]	Transient Voltage Dip (5L63 1Ph)	1570	648	Add 50% series compensations to 5L61, 5L62, and 5L63. Add a ±130 MVAR STATCOM at SKA500. Add 140 MVAR switched shunt reactor at GLN138 bus.	120
2-I SKA287 DC[2]	Potential Wind MW	800	341	Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor.	18
2-II SKA287 AC[2]	Potential Wind MW	800	500	Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 50% series comp to 5L61 and 5L62. Add a ±150 MVAR STATCOM at SKA500.	108
3-I RUP287 DC[3]	Branch Overload, 2L101 (630 MVA)	580	114	Upgrade 2L101 for higher thermal rating. Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 50% series compensation to 2L101.	45
3-II RUP287 AC[3]	Branch Overload, 2L101 (630 MVA)	580	194	Upgrade 2L101 for higher thermal rating. Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 70% series compensation to 2L101. Add a 60 MVAR SVC at SKA500.	78
4 GMS500 AC[4]	Potential Wind MW	1600	438	not identified	
5 GMS230 AC[4]	Potential Wind MW	1600	1282 [5]	Add five 300-MVA (or three 600-MVA) GMS500/230 kV transformers.	55
6 SNK230 AC[4]	Branch Overload, 2L308 (598 MVA)	460	119	Add one 300-MVA GMS500/230 kV transformer. Upgrade 2L308/2L309 for higher thermal rating.	30
7 KLY230 AC	Potential Wind MW	350	164	not identified	
8 NIC230 & NIC138 AC	Potential Wind MW	300	(a) 54 (b) 16	Upgrade 1L244 for higher thermal rating.	0.5

Notes:

1. For POI # 1 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12, or 5L11&5L13.
2. For POI # 2 wind generation shedding was required at least after NC islanding, and double contingencies involving 5L11&5L12 or 5L11&5L13.
3. For POI # 3 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12 or 5L11&5L13.
4. For POIs # 4, 5, and 6, wind generation shedding was required at least after double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
5. For POI # 4 20% series compensation of the two wind interconnection lines was assumed (or more circuits).
6. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.
7. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

Table 10: Summary of the F2014 Reinforced System Results with Generation Sink in South Interior.

# & Name of POI & Type of Interconnection	Limiting Cause	Reinforced Limit (MW)	Shunt MVAR Estimate[6]	Proposed System Reinforcements	Preliminary Estimate[7] ($M)
1 SKA500 AC[1]	Transient Voltage Dip (5L63 1Ph)	1570	648	Add 50% series compensations to 5L61, 5L62, and 5L63. Increase 5L11, 5L12, and 5L13 series compensations from 50% to 70%. Add a ±190 MVAR STATCOM at SKA500. Add 100 MVAR switched shunt reactor at GLN138 bus.	165
2-I SKA287 DC[2]	Potential Wind MW	800	400	Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add a 90 MVA SVC at TKW500.	60
2-II SKA287 AC[2]	Potential Wind MW	800	500	Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 50% series comp to 5L61 and 5L62. Add a ±210 MVAR STATCOM at SKA500.	115
3-I RUP287 DC[2]	Branch Overload, 2L101 (630 MVA)	580	128	Upgrade 2L101 for higher thermal rating. Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 50% series compensation to 2L101.	45
3-II RUP287 AC[2]	Branch Overload, 2L101 (630 MVA)	580	194	Upgrade 2L101 for higher thermal rating. Add one 672-MVA SKA500/287/12.6 kV transformer with 37.5 MVAR tertiary reactor. Add 70% series compensation to 2L101. Add a 100 MVAR SVC at SKA500.	82
4 GMS500 AC[3]	Potential Wind MW	1600	438	Increase 5L1, 5L2, 5L3-5L7, 5L11, 5L12, and 5L13 series comp from 50% to 70%.	80
5 GMS230 AC[3]	Potential Wind MW	1600	1024[4]	Add five 300-MVA (or three 600-MVA) GMS500/230 kV transformers. Increase 5L1, 5L2, 5L3-5L7, 5L11, 5L12, and 5L13 series comp from 50% to 70%.	135
6 SNK230 AC[3]	Branch Overload, 2L308 (598 MVA)	460	119	Add one 300-MVA GMS500/230 kV transformer. Upgrade 2L308/2L309 for higher thermal rating.	30
7 KLY230 AC	Potential Wind MW	350	164	not identified	
8 NIC230 & NIC138 AC	Potential Wind MW	300	(a) 54 (b) 16	Upgrade 1L244 for higher thermal rating.	0.5

9 GLD230 AC[5]	Branch Overload, 2L154 (456 MVA)	240	134	Upgrade 1L121 for higher thermal rating.	4
10 PML132 & JUL132 & PHY132 AC[5]	Frequency Dip in Vicinity of DFIGs	140	(a) 15 (b) 6 (c) 8	not identified	

Notes:

1. For POI #1 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
2. For POIs #2, and 3 wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L11&5L12 or 5L11&5L13.
3. For POIs #4, 5, and 6 wind generation shedding was required at least after single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
4. For POI # 4 40% series compensation of the two wind interconnection lines was assumed (or more circuits).
5. For POIs #9 and 10 wind generation runback was required for loss of 2L154 radial line.
6. The estimate MVAR is the capacitive power in addition to the typical VAR capability of DFIG with 0.9 lagging power factor (PF) to meet the 0.95 PF lagging and leading requirement at POI.
7. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

Table 11: F2014 Alternative Reinforcement for POI #1 (NC 500 kV Lines 70% Series Compensated).

Generation Sink for POI #1 (SKA500 ac)	Limiting Cause	Reinforced Limit (MW)	Shunt Estimate MVAR	Proposed System Reinforcements	Preliminary Estimate[3] ($M)
GMS/PCN [1]	Potential Wind MW	2500	1413	Upgrade 5L61, 5L62, and 5L63 for higher thermal rating. Add 70% series compensations to 5L61, 5L62, and 5L63. Increase 5L11, 5L12, and 5L13 series compensations from 50% to 70%. Add a ±200 MVAR STATCOM at SKA500. Add 80 MVAR switched shunt reactor at GLN138 bus.	268
MCA/REV [2]	Transient Voltage Dip (5L11&5L12)	2160	1100	Upgrade 5L11, 5L12, 5L13, 5L61, 5L62, and 5L63 for higher thermal rating. Add 70% series compensations to 5L61, 5L62, and 5L63. Increase 5L11, 5L12, and 5L13 series compensations from 50% to 70%. Add a ±200 MVAR STATCOM at WSN500. Add 100 MVAR switched shunt reactor at GLN138 bus.	284

Notes:
1. With the PR sink, wind generation shedding was required at least after NC islanding, and double contingencies involving 5L11&5L12, or 5L11&5L13.
2. With the SI sink, wind generation shedding was required at least after NC islanding, and single contingencies involving 5L1, 5L2, 5L3, 5L7, 5L11, 5L12, or 5L13, and double contingencies involving 5L1&5L2, 5L11&5L12, or 5L11&5L13.
3. The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of cost and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

7. Summary of results

In general, the study has found that considerable wind generation could be integrated at various parts of the BC transmission system in F2011 and F2014 based on the above study approach. The F2014 system can accommodate slightly more wind generations than the F2011 system due to improved transmissions. With reinforcements that require short lead time such as line upgrades for higher thermal rating, new transformer banks, series capacitor compensations (existing compensation upgrade or new ones), switched shunt reactors for over-voltage relief, and dynamic shunt devices such as Static VAR Compensator (SVC) and Static Compensator (STATCOM), significant additional wind generation could be accommodated at North Coast and Peace regions. Preliminary Estimates of reinforcement costs are produced based on historical unit costs and estimates and provided for reference only.

Table 12 and 13 below summarize the existing system capability and Preliminary Estimate of upgrade cost for increasing the capability for accommodating known potential wind generation at each POI for two generation sink assumptions, generation sink in Peace Region and generation sink in South Interior.

BCTC interconnection requirements require the Independent Power Producers (IPP) to provide both leading and lagging power factor capability of 0.95 at the POI. Identifying the needed equipment for meeting the interconnection requirements is beyond the scope of this study, although an estimate of the shunt resource sizes needed at the collector/POI buses are provided.

Table 12: Summary of System Capability and Preliminary Estimate with Generation Sink in Peace Region

POI	F2011 System			F2014 System		
	Existing Limit (MW)	Reinforced System		Existing Limit (MW)	Reinforced System	
		Limit (MW)	Preliminary Estimate[1] ($M)		Limit (MW)	Preliminary Estimate[7] ($M)
1 SKA500 AC	700	1550	120	710	1570	120
1 SKA500 AC (Altn)[8]	700	2500	275	710	2500	268
2-I SKA287 DC[9]	400	800	18	420	800	18
2-II SKA287 AC	400	800	110	420	800	108
3-I RUP287 DC[3]	240	580	45	240	580	45
3-II RUP287 AC	240	580	80	240	580	78
4 GMS500 AC	1600	1600	not identified	1600	1600	not identified
5 GMS230 AC	160	1600	55	160	1600	55
6 SNK230 AC	160	460	30	160	460	30
7 KLY230 AC	350	350	not identified	350	350	not identified
8 NIC230 & NIC138 AC	260	300	0.5	260	300	0.5

[7] The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of costs and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.
[8] Alternative reinforcement option for a higher limit
[9] Due to high dynamic VAR capability assumed for the DC transmission option (0.9 lead – lag at the transmission POI), DC system reinforcement cost is significantly lower than the AC option.

Table 13: Summary of System Capability and Preliminary Estimate with Generation Sink in South Interior

POI	F2011 System			F2014 System		
	Existing Limit (MW)	Reinforced System		Existing Limit (MW)	Reinforced System	
		Limit (MW)	Preliminary Estimate[1] ($M)		Limit (MW)	Preliminary Estimate[1] ($M)
1 SKA500 AC	640	1550	165	650	1570	165
1 SKA500 AC (Altn)[2]	640	2000	270	650	2160	284
2-I SKA287 DC[3]	400	800	60	420	800	60
2-II SKA287 AC	400	800	115	420	800	115
3-I RUP287 DC[3]	240	580	45	240	580	45
3-II RUP287 AC	240	580	85	240	580	82
4 GMS500 AC	480	1600	80	620	1600	80
5 GMS230 AC	160	1600	135	160	1600	135
6 SNK230 AC	160	460	70	160	460	30
7 KLY230 AC	350	350	not identified	350	350	not identified
8 NIC230 & NIC138 AC	260	300	0.5	260	300	0.5
9 GLD230 AC	180	240	4	180	240	4
10 PML132 & JUL132 & PHY132 AC	140	140	not identified	140	140	not identified

[1] The Preliminary Estimates (in $2008) are based on historical unit costs and estimates, and included in this report to provide an idea of the order of magnitude of costs and for reference only. Using the Preliminary Estimates for making project and financial decisions is not advised. Detailed system impact and facility studies based on actual proposals are required to provide more accurate cost estimate.

[2] Alternative reinforcement option for a higher limit

[3] Due to high dynamic VAR capability assumed for the DC transmission option (0.9 lead – lag at the transmission POI), DC system reinforcement cost is significantly lower than the AC option.