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Eskom
Transmission

KUDU CCGT POWER STATION in Namibia
Pre-Engineering Transmission Integration study
Steady state analysis

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EXECUTIVE SUMMARY

This is a detailed steady state report that investigates the Transmission integration of the Kudu CCGT (Combined Cycle Gas Turbine) power station in Namibia. This report provides an outline of the following:

a) Transmission reinforcement possibilities
b) Network technical analysis
c) The impact of the reinforcement on network losses
d) The impact of the reinforcement on fault levels at various substation
e) Transmission preferred reinforcement option
f) Scope of work
g) Project timing
h) Environmental aspects

It is recommended that a project be initiated to complete the following scope of work before February 2009:

- 1 x 15km of 220kV line between Namibian Border and Oranjemund substation
- 1 x 390km of 400kV line between Namibian Border and Juno substation
- 1 x fully fitted 400kV line bay at Juno
- 1 x fully fitted 400kV line reactor bay at Juno
- 1 x line reactor at Juno on the Kudu line
- 1 x fully fitted 220kV line bay at Oranjemund
- 1 x line reactor at Kudu on the Juno line
- Bus couplers and bus sections as required by substation design.

It should be noted that possible project fast tracking could be required.

SSR studies to be initiated and completed.

Dynamic network analysis to be conducted.

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1 BACKGROUND

This is a detailed steady state report that investigates the Transmission integration of the Kudu CCGT (Combined Cycle Gas Turbine) power station in Namibia. This report provides an outline of the following:

a) Transmission reinforcement possibilities
b) Network technical analysis
c) The impact of the reinforcement on network losses
d) The impact of the reinforcement on fault levels at various substation
e) Transmission preferred reinforcement option
f) Scope of work
g) Project timing
h) Environmental aspects

The existing Transmission network is depicted in Figure 1. The location of the site under investigation is Kudu. It is expected that 2 x 400MW units will be installed at Kudu and be operational early in 2009. The new Kudu power station needs to be integrated into the Namibian and South African networks. This report provides information on the integration.

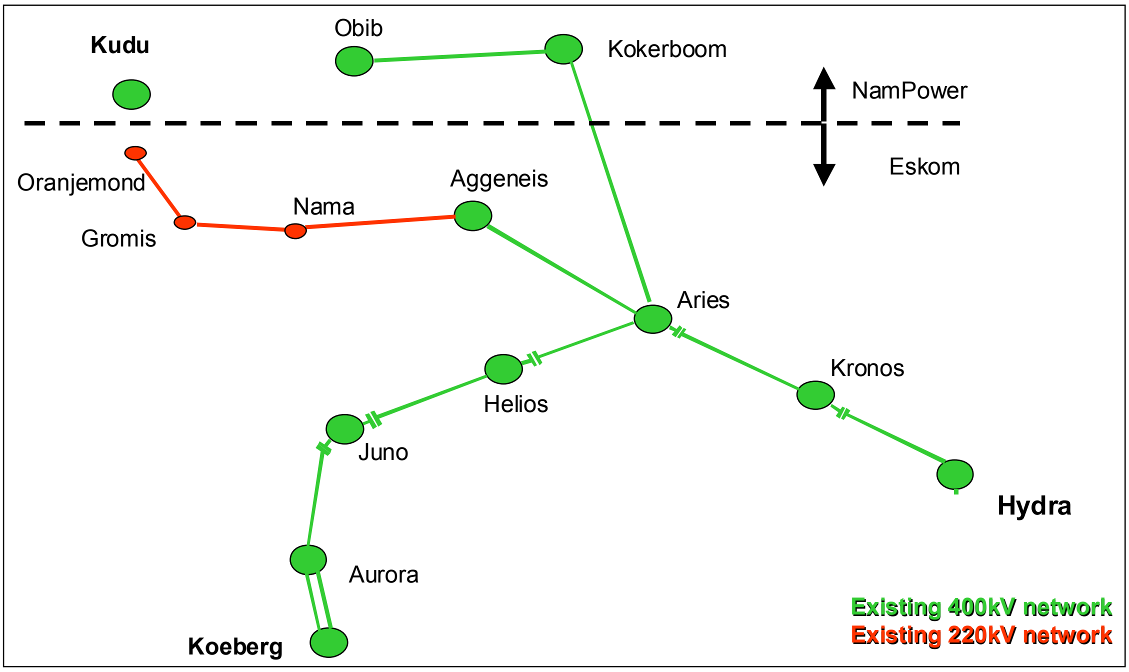

Figure 1 – Transmission network around 2009

2 ASSUMPTIONS AND INFORMATION USED

2.1 SA grid code - Network code section 7.6.5 integration of power stations:

a) Power stations of less than 1000MW:

- With all connecting lines in service, it shall be possible to transmit the total output of the power station to the system for any system load condition. If the local area depends on the power station for voltage support, the connection shall be made with a minimum of two lines.
- Transient stability shall be maintained following a successfully cleared single-phase fault.
- If only a single line is used, it shall have the capability of being switched to alternative busbars and be able to go onto bypass at each end of the line.

b) Power stations of more than 1000MW:

- With one connecting line out of service (n-1), it shall be possible to transmit the total output of the power station to the system for any system load condition.
- With the two most onerous line outages (n-2), it shall be possible to transmit 83% of the total output of the power station to the system.

c) Transient stability shall be retained for the following conditions:

- A three-phase line or busbar fault, cleared in normal protection times, with the system healthy and the most onerous power station loading condition; or
- A single-phase fault, cleared in ‘bus strip” times, with the system healthy and the most onerous power station loading condition; or
- A single-phase fault, cleared in normal protection times, with any one line out of service and the power station loaded to average availability.

d) Busbar layouts shall allow for selection to alternative busbars and the ability to go onto bypass, and not more than 1000MW of generation shall be connected to any bus section, even with one bus section out of service.

2.2 CCGT Generation

The following assumptions were specifically made in order to do network analysis:

- The number of machines studied are 2 (two).
- The size of the units is assumed to be 400MW each.
- The value of the sub transient reactance (X”d) is assumed to be 0.3107pu.
- Integration voltage in the Eskom Network at both 400kV and 220kV.
- Generator transformer with 12.5% impedance.

Purpose of the CCGT

It is foreseen that this plant will fulfill the need for base capacity. The plant could be used for voltage support and black start where applicable. The plant could also participate in the various ancillary services markets. These options need to be negotiated as part of the power purchase agreements.

2.3 Generation Assumptions

The following assumptions were made when generation was matched to the load condition studied:

Koeberg	2 x 900 MW units in service (77%) 1 x 900 MW units in service (22%) 0 x 900 MW units in service (1%) All scenarios were studied
Palmiet	2 x 200 MW units in service (Peak) 0 x 200 MW units in service (Light)
Atlantis OCGT	4 x 150 MW units in service (Peak) 0 x 150 MW units in service (Light), but SCO
Mosselbay OCGT	3 x 150 MW units in service (Peak) 0 x 150 MW units in service (Light), but SCO
Acacia	0 x 57 MW units in service, but SCO
Ruacana	2 x 80 MW units in service (Peak) 3 x 80 MW units in service (Light)
Zambian Interconnection	150 MW in service (Peak) 200 MW in service (Light)
Kudu	2 x 400MW units in service

NamPower Planners provided generation conditions within the NamPower network.

2.4 Loads

Western Grid in PSS/E	3965 MW 955MVAr (Future Peak) 1784 MW 430MVAr (Light = 45% peak)
NamPower in PSS/E	575 MW 156MVAr (Peak) 236 MW 64MVAr (Light = 41% peak)

Eskom Cape load forecast (this excludes the Namibian load from Aries and Aggeneis)

	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
East London	356	412	421	429	436	442	450	459	464	472
Karoo	240	246	248	249	251	252	254	255	256	258
Port Elizabeth	686	700	1637	1652	1735	2262	2328	2858	2932	3928
Namaqualand*	114	130	133	136	139	143	146	148	150	153
Peninsula*	2014	2043	2078	2117	2154	2187	2246	2282	2316	2351
Southern Cape*	610	628	640	650	662	677	689	703	715	727
West Coast*	461	472	477	482	488	493	497	502	507	512
TOSP* (West)	3199	3273	3327	3386	3443	3499	3579	3635	3689	3743
TORP* (West)	3350	3428	3484	3545	3606	3664	3748	3807	3863	3920

NamPower Planners provided load conditions within the NamPower network.

2.5 Transmission Network

The following Transmission projects will be commissioned by 2009 and were included in the base case files:

- North of Hydra project (completed early 2005)
- Cape Strengthening Western Grid project (completed end 2007)

- Beta-Delphi 400kV line (completed end 2007)
- 2nd Hydra-Beta 765kV (completed end 2008)
- Alpha-Tutuka 3rd 400kV line (completed end 2006)
- Gamma-Omega 1st 765kV line operated at 400kV (completed only in 2010 or beyond), not included in the case studied.
- No other base load power stations are included, since it would most probably only be in service beyond 2010 at the earliest.
- OCGT at Atlantis and Mosselbay peaking generation (completed by 2007 and 2008 respectively).

Figure below depicts the geographical layout of the existing network.

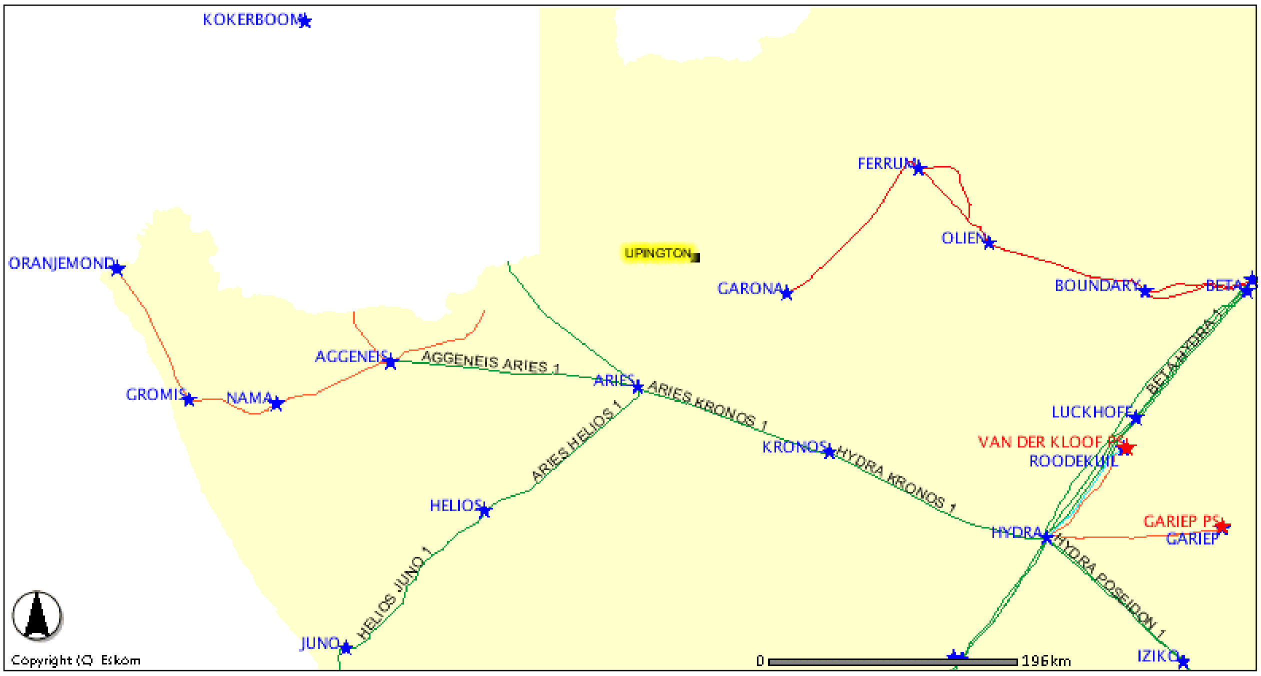

Figure – Geographical layout of existing Eskom network

2.6 Security of supply

In the design it is assumed that any single network component can be out of service, without thermal overloading of another component.

2.7 Thermal limits

It is assumed that a thermal limit is exceeded if:

- during system healthy the continuous equipment rating is exceeded and
- for a contingency, the emergency equipment rating is exceeded.

2.8 Switching Voltages

Bus voltages may not change by more than 3% during healthy conditions and 5% during contingency conditions when any equipment is switched. If these conditions are exceeded, either dynamic equipment such as a SVC should be installed or additional lines should be installed.

3 TRANSMISSION REINFORCEMENT OPTIONS

The Kudu CCGT site is situated within the Namibian border ±15 km from Oranjemund substation. Within the NamPower network, Kudu would be integrated into Obib substation at 400kV. A decision was made to integrate into the 220kV network at Oranjemund, since this is at minimum cost and directly impacts nearby customers. A 400kV line would be built from the power station towards the border, where Eskom need to interconnect.

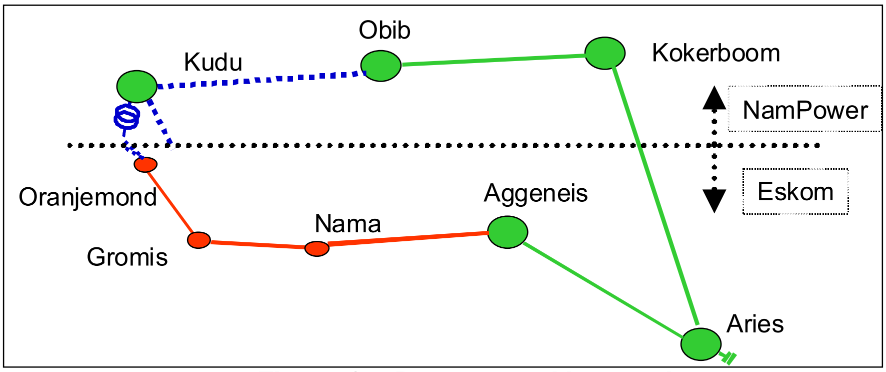

Figure 2 – Pre-selected integration

Integration into the rest of the Eskom network could be via various routes. Options are investigated in more detail and compared. The proposed option is then selected and recommended for implementation.

Three feasible options to integrate the new power station further into the Eskom network were considered. These are each described below in terms of scope and high level technical aspects.

3.1 Option 1 – Integration direct at Aggeneis

This option requires a direct line from the Namibian border to Aggeneis 400kV substation. The existing Aggeneis-Aries 400kV line ensures connection into the Cape network. Power could be distributed from Aries into the network, either towards Kronos or towards Helios, depending on the generation pattern and load profile. The line length would be approximately 250km within the RSA border.

Typically 1 line bay and 1 line reactor bay would be required at Aggeneis.

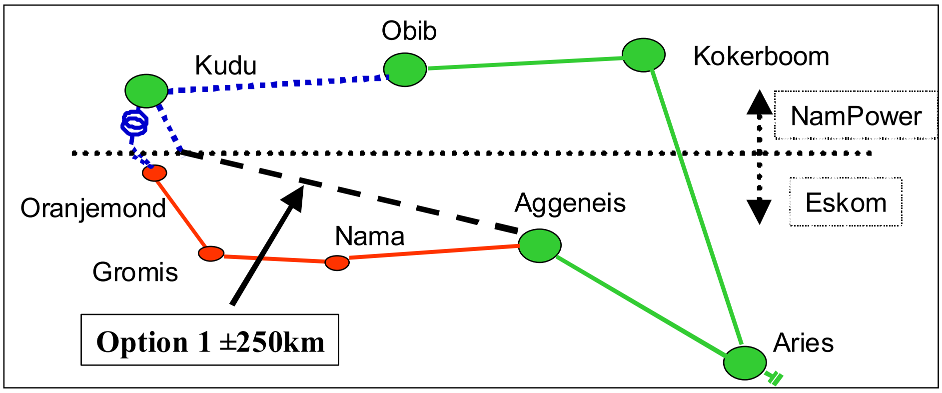

Figure 3 – Option 1

3.2 Option 2 – Integration at Juno

This option requires a direct line from the Namibian border to Juno 400kV substation. The line length would be approximately 390km within the RSA border. The future option to loop the line into Gromis substation exists, providing more reliable network when the second phase of Kudu becomes reality.

Typically 1 line bay and 1 line reactor bay would be required at Juno. A second line reactor would be required at the power station side of the line.

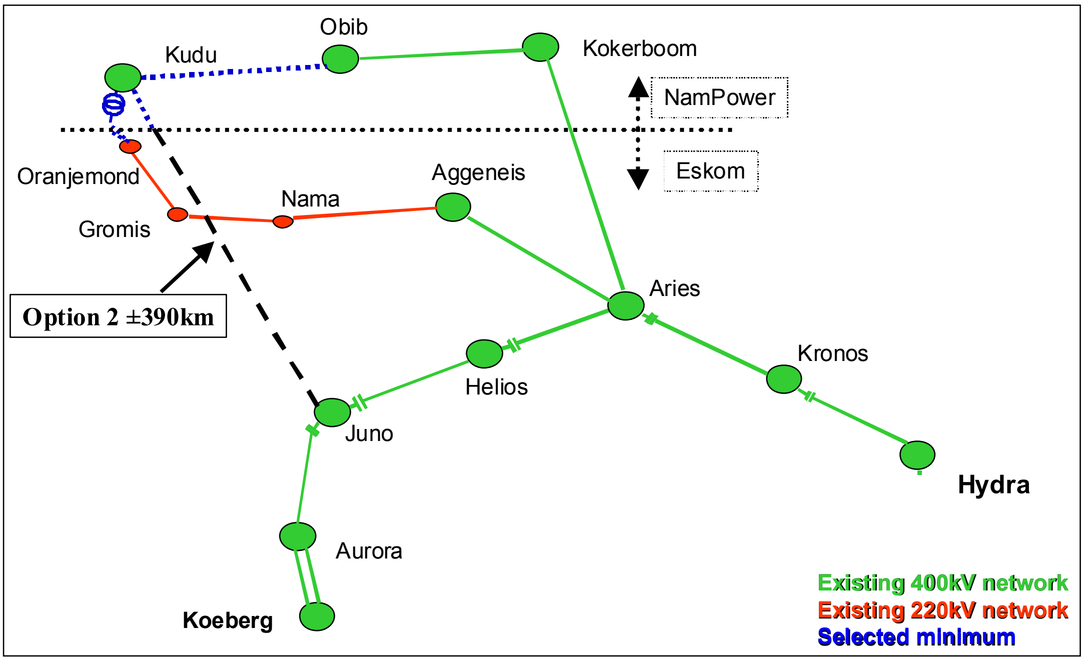

Figure 4 – Option 2

3.3 Option 3 – Integration at Aggeneis via Gromis

This option requires a direct line from the Namibian border to Aggeneis 400kV substation. The existing Aggeneis-Aries 400kV line ensures connection into the Cape network. Power could be distributed from Aries into the network, either towards Kronos or towards Helios, depending on the generation pattern and load profile. The line length would be approximately 300km within the RSA border.

The future option to loop the line into Gromis substation exists, providing more reliable network when the second phase of Kudu becomes reality.

Typically 1 line bay and 1 line reactor bay would be required at Aggeneis. A second line reactor might be required at the power station side of the line.

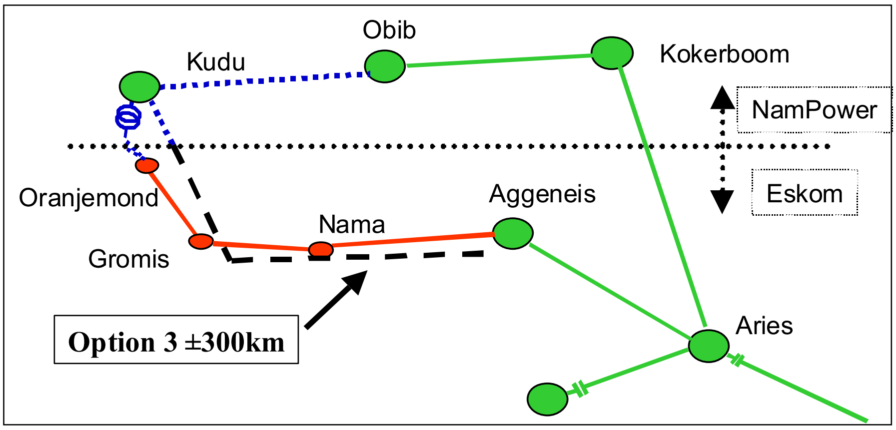

Figure 5 – Option 3

3.4 Summary of options

Table 1: Summary of options

Option	400kV Line distance (km)	New 400kV line bays	New 400kV Rx bays	Reliability	Environment
1	240	1	1	0	new
2	390	1	2	1	new
3	300	1	2	1	new

The high level cost comparison indicate Option 1 to be the preferred option for Transmission, since the line to be built is the shortest from all options. Technically Option 2 and 3 is providing for a more reliable network, seen from a futuristic viewpoint, where lines can be looped into Gromis substations. This would reduce extremely long lines and provide for better integration.

4 NETWORK ANALYSIS

The methodology used to analyze the network is as follows:

1. All options are tested to solve problem free for system healthy conditions for peak and light load. This includes the outage of at least 1 Koeberg generator. The scenario of 0 Koeberg is also evaluated.
2. All options are tested to solve problem free for system n-1 conditions for peak load only. This includes the outage of 1 Koeberg generator.

4.1 System Healthy

Basic load flow cases were prepared for the network with various Koeberg units in service for each of the possible options. All load flows are conducted with 2 x 400MW units in service at the Kudu CCGT power station.

4.1.1 Peak load

Table 2 provides values of power flow out of the power station. Table 3 provides the power flow on related Eskom lines.

Table 2: Power flow (MW) for system healthy peak load

Option	Koeberg Units in service	Kudu-Obib 400kV	Kudu-Oranjemund 220kV	Kudu-RSA 400kV
1	2	388	101	267
1	1	389	101	267
1	0	389	101	267
2	2	392	120	244
2	1	363	112	282
2	0	330	103	323
3	2	403	106	247
3	1	404	107	247
3	0	404	107	246

From the above it is evident that for integration into Aggeneis, the flow out of the power station stays constant. Integration at Juno is however closer to Koeberg, therefore the impact of Koeberg is to increase the flow into NamPower when Koeberg has more units in service. As soon as Koeberg's output reduce, Kudu sends more power via the Juno line to the load center. Option 2 would therefore be more supportive during Koeberg outages than option 1 or 3.

Table 3: Power flow (MW) in the network for system healthy

Option	Koeberg	Aggeneis-Harib 220kV	Aries-Kokerboom 400kV	Aries-Aggeneis 400kV	Aries-Kronos 400kV	Aries-Helios 400kV	Juno-Helios 400kV	Juno-Aurora 400kV
Before	**2**	45	365	270	-663	14	-2	-75
1	2	27	8	-136	-113	228	-213	136
3	2	24	-1	-126	-113	228	-213	136
2	2	7	41	71	-166	41	-28	191
Before	**1**	47	361	274	-951	304	-286	209
1	1	27	8	-135	-412	527	-500	423
3	1	24	-2	-126	-413	527	-500	424
2	1	10	65	86	-468	304	-287	488
Before	**0**	48	359	277	-1252	604	-568	491
1	0	28	6	-134	-724	839	-789	712
3	0	25	-3	-124	-725	840	-789	712
2	0	13	90	100	-785	582	-551	791

From the above it can be seen that:

- the direction of power flow on the 220kV remains into NamPower from Aggeneis
- Aries-Kokerboom will mainly float if integration option 1 or 3 is used. For option 2 power will be supplied towards Kokerboom.
- Direction of power flow on the Aries-Aggeneis line will be reversed for Kudu integration at Aggeneis. Integration at Juno ensures that power is send from Aries to Aggeneis.
- The Hydra-Kronos-Aries line will be more heavily loaded with the Juno integration option (2 series caps).
- The Aries-Helios-Juno line section will carry reduced load with the Juno integration option (2 series caps with lower ratings).
- The Juno-Aurora section will be more heavily loaded with the Juno integration option (1 series cap).

Only for the 0 Koeberg case, the series capacitor would exceed continuous thermal ratings for option 1 and 3 (Aggeneis integration) at Helios and Juno. The emergency thermal ratings will not be exceeded. For the Juno integration option 2, only the one Juno(Aurora) series cap would exceed its continuous limit, but the emergency limit is not exceeded.

The series capacitor thermal ratings are as follow:

Series Capacitor	**Continuous rating (Rate A)**	**Emergency rating (8h in 12) Rate B**
Kronos and Aries	1108 MVA	1274 MVA
Helios and both Juno	762 MVA	876 MVA

4.1.2 Light load

Table 4 provides values of power flow out of the power station. Table 5 provides the power flow on related Eskom lines.

Table 4: Power flow (MW) for system healthy light load

Option	Koeberg Units in service	Kudu-Obib 400kV	Kudu-Oranjemund 220kV	Kudu-RSA 400kV
1	2	311	81	365
1	1	311	81	365
1	0	311	81	364
2	2	310	105	342
2	1	281	97	379
2	0	251	89	417
3	2	331	89	337
3	1	331	89	337
3	0	331	89	337

From the above it is evident that for integration into Aggeneis, the flow out of the power station stays constant. Integration at Juno is however closer to Koeberg, therefore the impact of Koeberg is to increase the flow into NamPower when Koeberg has more units in service. As soon as Koeberg's output reduce, Kudu sends more power via the Juno line to the load center. Option 2 would therefore be more supportive during Koeberg outages than option 1 or 3.

Table 5: Power flow (MW) in the network for system healthy light load

Option	Koeberg	Aggeneis-Harib 220kV	Aries-Kokerboom 400kV	Aries-Aggeneis 400kV	Aries-Kronos 400kV	Aries-Helios 400kV	Juno-Helios 400kV	Juno-Aurora 400kV
1	2	1	-221	-329	457	87	-81	46
3	2	-3	-233	-316	457	87	-80	46
2	2	-24	-172	-45	380	-169	177	123
1	1	1	-221	-329	166	379	-366	331
3	1	-3	-233	-316	165	379	-366	331
2	1	-21	-149	-33	85	91	-85	420
1	0	1	-221	-329	-138	683	-653	618
3	0	-3	-233	-316	-139	683	-653	618
2	0	-19	-125	-20	-222	361	-349	721

From the above it can be seen that:

- Aries-Kokerboom will mainly send power into Eskom network. The amount of power is reduced for option 2, since the additional power is already send across the Juno line from Kudu.

- Integration at Juno ensures that power is reduce on the Aries - Aggeneis 400kV line.
- The Aries-Helios-Juno line section will carry reduced load with the Juno integration option (2 series caps with lower ratings).
- The Juno-Aurora section will be more heavily loaded with the Juno integration option (1 series cap).

Only for the 0 Koeberg case, the series capacitor are close to the continuous thermal ratings for option 1 and 3 (Aggeneis integration) at Helios and Juno. For the Juno integration option 2, only the one Juno (Aurora) series cap would be close to its continuous limit, but the limit is not exceeded.

The options need to be verified for line contingencies in the network. The next section describes this in more detail.

4.2 Contingency analysis

All three options were studied to verify if single (n-1) line contingencies could be accommodated for the peak load network. This was tested for the network with 1 or 2 Koeberg units in service.

Table 6 provides values of power flow out of the power station for the n-1 conditions. Table 7-9 provides the power flow on related Eskom lines for the n-1 conditions.

Table 6: Power flow (MW) for system n-1 contingency during peak load

Option	Koeberg Units in service	Kudu-Obib 400kV	Kudu-Oranjemund 220kV	Kudu-RSA 400kV
1	2	x	185	572
1	1	x	160	597
2	2	x	209	548
2	1	x	195	563
3	2	x	177	580
3	1	x	179	578
1	2	421	x	336
1	1	421	x	336
2	2	456	x	301
2	1	420	x	337
3	2	442	x	315
3	1	443	x	315
1	2	585	172	x
1	1	584	173	x
2	2	585	172	x
2	1	585	172	x
3	2	583	174	x
3	1	584	173	x

From the above it is evident that irrespective of which option is selected, the 400kV lines would not reach 600MW during an n-1 condition. The 220kV network would be loaded most during a Kudu-Obib 400kV line outage with option 2 (209MW). Note that the 220kV network would not be able to support an n-2 condition for both 400kV lines. Such a condition would need inter-tripping of the power station. If the n-2 however includes the 220kV line, all the power (800MW) can be absorbed into either the NamPower or Eskom networks.

Table 7: Power flow (MW) in the network for system n-1 contingency during peak load Kudu-Obib on outage

Option	Koeberg	Aggeneis-Harib 220kV	Aries-Kokerboom 400kV	Aries-Aggeneis 400kV	Aries-Kronos 400kV	Aries-Helios 400kV	Juno-Helios 400kV	Juno-Aurora 400kV
Before	**2**	45	365	270	-663	14	-2	-75
1	2	108	250	-337	-142	216	-201	124
2	2	66	325	107	-255	-190	205	248
3	2	109	249	-337	-141	216	-201	124
Before	**1**	47	361	274	-951	304	-286	209
1	1	110	247	-339	-433	512	-486	409
2	1	65	326	119	-543	85	-73	539
3	1	111	245	-332	-436	511	-484	407

Results as per table 7 indicate that a Kudu-Obib outage would be acceptable and not result in any thermal overloads. Option 1 and 3 (for 1 Koeberg scenario) result in an increase in power on 5 lines, compared to the network before Kudu integration (Juno-Aurora 400kV and the 220kV Harib lines). Option 2 (for 1 Koeberg scenario) result in an increase in power on 2 lines only. The impact of option 2 is therefore less than for the other options. Option 1 and 3 force more power along the 220kV network into NamPower, whereas option 2 utilizes the 400 kV more.

Table 8: Power flow (MW) in the network for system n-1 contingency during peak load Kudu-RSA 400kV on outage

Option	Koeberg	Aggeneis-Harib 220kV	Aries-Kokerboom 400kV	Aries-Aggeneis 400kV	Aries-Kronos 400kV	Aries-Helios 400kV	Juno-Helios 400kV	Juno-Aurora 400kV
Before	**2**	45	365	270	-663	14	-2	-75
1	2	-8	-111	-8	-120	226	-211	134
2	2	-8	-111	-8	-120	226	-211	134
3	2	-8	-111	-8	-120	226	-211	134
Before	**1**	47	361	274	-951	304	-286	209
1	1	-7	-112	-8	-418	525	-497	420
2	1	-7	-112	-8	-418	525	-497	420
3	1	-7	-112	-8	-418	525	-497	420

Results as per table 8 indicate that a Kudu-RSA 400kV outage would be acceptable and not result in any thermal overloads. The impact for all options is the same, since the options only lies within this interconnection, which is on outage.

Table 9: Power flow (MW) in the network for system n-1 contingency during peak load Kudu-Oranjemund 220kV on outage

Option	Koeberg	Aggeneis-Harib 220kV	Aries-Kokerboom 400kV	Aries-Aggeneis 400kV	Aries-Kronos 400kV	Aries-Helios 400kV	Juno-Helios 400kV	Juno-Aurora 400kV
Before	**2**	45	365	270	-663	14	-2	-75
1	2	17	-4	-121	-116	227	-212	135
2	2	-13	21	152	-182	-4	17	202
3	2	12	-16	-108	-116	227	-212	135
Before	**1**	47	361	274	-951	304	-286	209
1	1	18	-6	-119	-414	526	-499	423
2	1	-8	47	162	-482	261	-245	498
3	1	12	-16	-107	-415	525	-499	422

Results as per table 9 indicate that a Kudu-Oranjemund outage would be acceptable and not result in any thermal overloads. It is evident that option 1 and 3 impacts the Aries-Helios-Juno network in addition to the Juno-Aurora, compared to option 1 that mainly impacts on Juno-Aurora.

4.3 Concluding remarks

Results for all options indicate that with system healthy all the generated power can be absorbed into the Transmission network. No continuous thermal limits of lines or series capacitors are exceeded. All substation voltages remain within acceptable limits.

Results for all options indicate that with an n-1 condition all the generated power can be absorbed into the Transmission network. No continuous thermal limits of lines or series capacitors are exceeded. All substation voltages remain within acceptable limits.

The impact (increased power flow on existing network) of option 2 is less on the existing network compared to option 1 and 3.

Note that the 220kV network would not be able to support an n-2 condition of both 400kV lines on outage. Such a condition would need inter-tripping of the power station. If the n-2 however includes the 220kV line, all the power (800MW) can be absorbed into either the NamPower or Eskom networks.

It should also be noted that Aries substation is fairly remote. If something happens at the substation, it can take time to have people on site to attend to the problem. All connection to NamPower runs through Aries for option 1 and 3. This is a risk for option 1 and 3, which does not exist for option 2, which provide a second main route to the NamPower network.

Provision of a second route is increasing the operational security of the network, which is a big advantage for option 2.

The network stability will also increase due to a firmer interconnection of the power station and NamPower network when option 2 is utilized. The power station will be electrically closer to the load centre in Cape Town and at Aurora (Saldanha Steel).

The number of series capacitor overload possibilities are reduced for option 2, compared to the other options.

Technically, based on the load flows studied option 2 is the preferred option.

5 NETWORK LOSSES

The three options were studied and losses calculated, for the network with two, one or zero Koeberg units in service, for a variation in the number of CCGT generators in service. Results are presented in Table 10 and 11. The highest value represents the best saving in losses. Figure 8 depicts how the saving in losses change with an increase in the amount of generators. Note the assumptions that were used for peak load, these assumptions were also used in calculating the reduction in losses contributions.

Table 10: Losses in the Eskom network (MW) – both Koeberg in service

Relative	Generators in service		
Option	**0**	**1**	**2**
Before	0.0	0.0	0.0
Option 1	1.5	76.8	111.7
Option 2	4.6	77.0	114.5
Option 3	2.2	77.3	111.5

The variances between the different options for the same number of generators in service are very small. Option 2 provides the biggest saving in losses with full generation. Option 1 is the least effective with respect to reduction in losses.

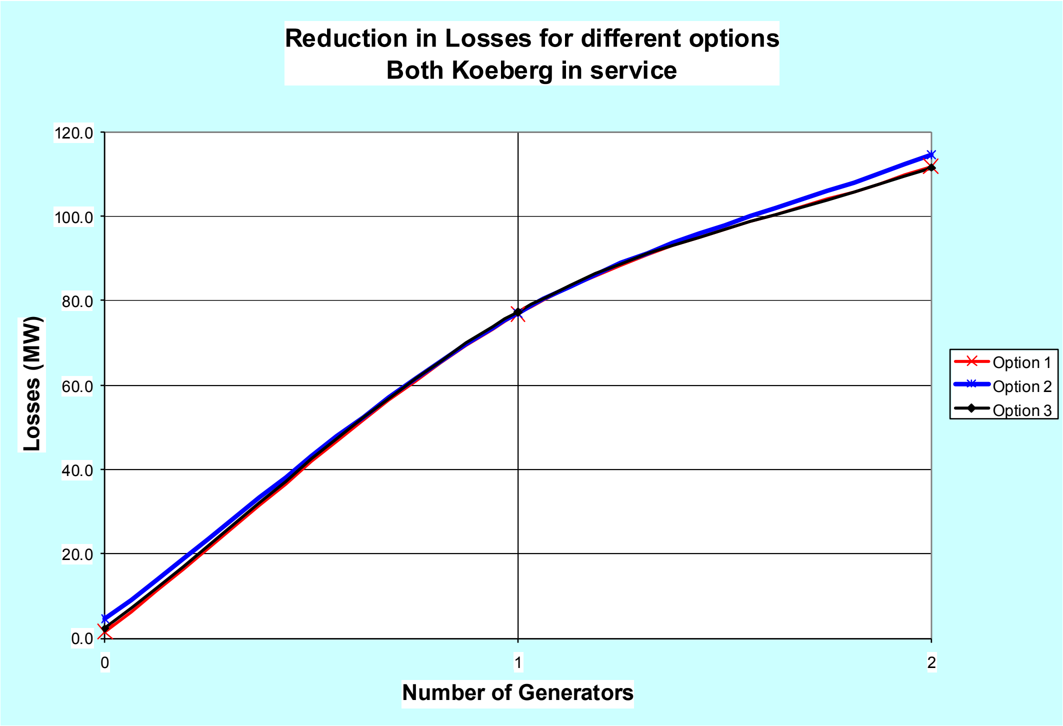

Figure 6 – Total reduction in losses – both Koeberg in service

Table 11: Saving in losses per generator (MW) – both Koeberg in service

Absolute	Generators in service		
Option	0	1	2
Before	0.0	0.0	0.0
Option 1	1.5	76.8	34.9
Option 2	4.6	77.0	37.5
Option 3	2.2	77.3	34.2

The substation integration increases losses slightly. The first generator provides the most reduction in losses in the order of 77MW. The second generator provides reduction in losses in the order of 35-38MW.

Option 3 provides the highest saving in losses with the first generator and Option 2 with the second generator.

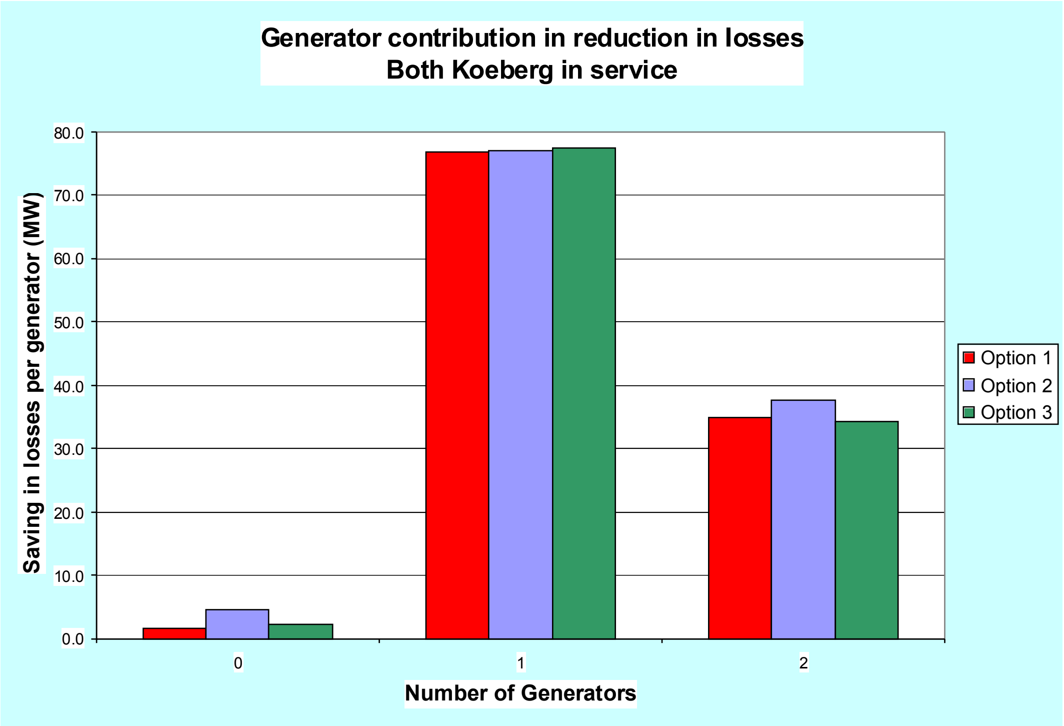

Figure 7 – Reduction in losses per generator – both Koeberg in service

Table 12: Losses in the Eskom network (MW) – one Koeberg in service

Relative	Generators in service		
	0	1	2
Before	0.0	0.0	0.0
Option 1	1.5	119.8	187.2
Option 2	2.8	121.7	198.8
Option 3	3.0	120.4	187.0

The variances between the different options for the same number of generators in service are very small. Option 2 provides the biggest saving in losses with full generation. Option 1 and 2 are less effective with respect to reduction in losses.

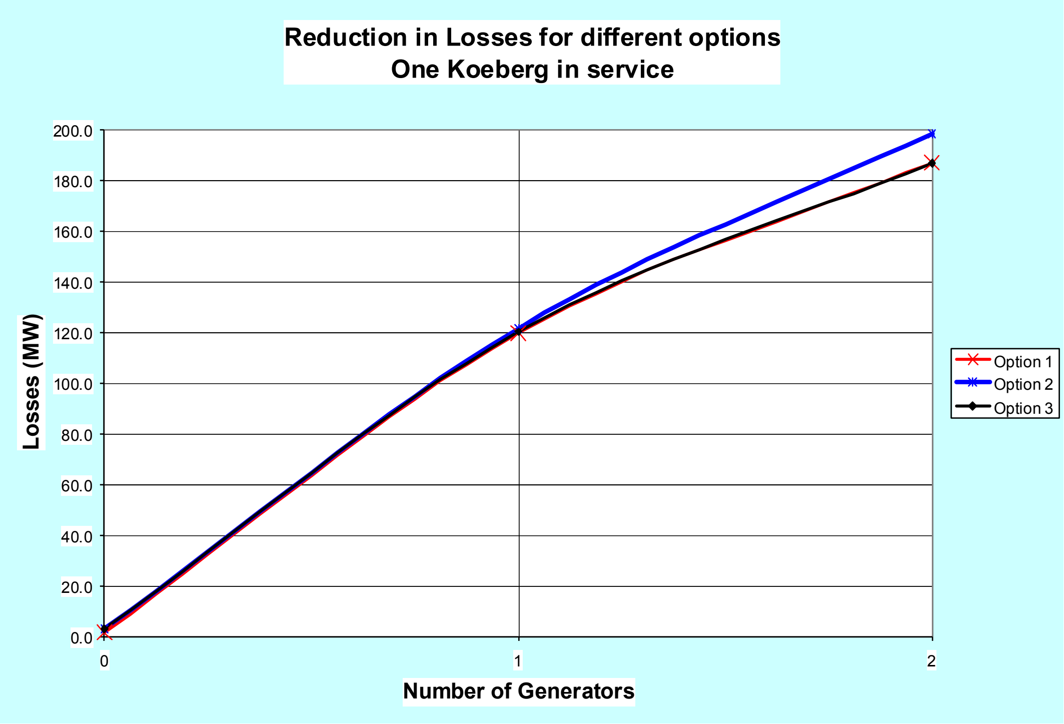

Figure 8 – Total reduction in losses – one Koeberg in service

Table 13: Saving in losses per generator (MW) – one Koeberg in service

Absolute	Generators in service		
	0	1	2
Before	0.0	0.0	0.0
Option 1	1.5	119.8	67.4
Option 2	2.8	121.7	77.1
Option 3	3.0	120.4	66.6

The substation integration decreases losses slightly. The first generator provides the most reduction in losses in the order of 120MW. The second generator provides reduction in losses in the order of 67-77MW.

It is interesting to note that Option 2 provides the highest saving in losses with the first and second generator.

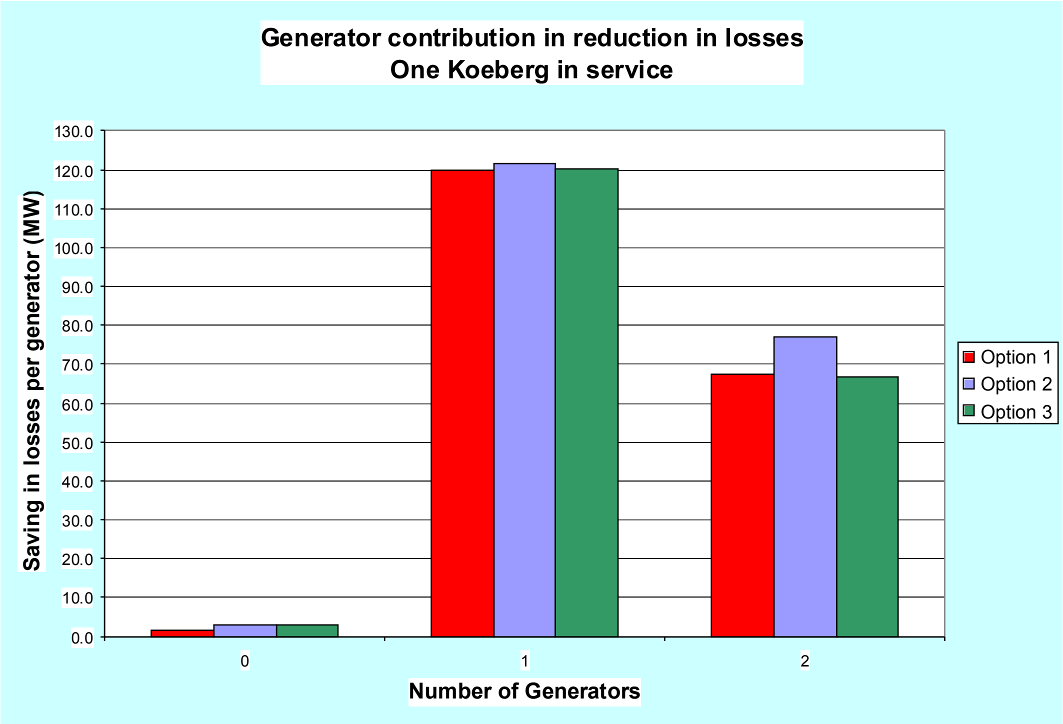

Figure 9 – Reduction in losses per generator – one Koeberg in service

An overall perspective indicates option 2 to be the preferred option from a reduction in losses viewpoint.

6 FAULT LEVEL ANALYSIS

6.1 General

Three phase and single-phase fault levels need to be calculated. The calculated values need to be verified against the existing equipment ratings (breaker rupturing capacities). Fault levels can increase beyond equipment installed capacities. This is an indication that equipment might explode when a fault is applied to that substation, which can be a safety risk. To reduce the safety risk a few options exist. Options include the installation of current limiting devices in series with transformers at a specific substation, replacement of breaking and related equipment with higher rated equipment or operating the substation busbars with open bus couplers during system healthy conditions. It depends on the magnitude of the problem to decide which option would be most suitable and relevant.

6.2 Studies

Fault levels have been calculated for the substations electrically closest to the integration points. The substations further away from the new generation would be exposed to a lessor extent.

- Table 14 to 17 summarizes all fault levels calculated at substations, with values specified in Ampere. Studies range from no generation to full Kudu generation for the preferred option only.
- Figure 10 to 13 depicts all fault levels calculated at substations, with values specified in Ampere. Studies range from no generation to full Kudu generation for the preferred option only.

The calculated values provide enough information to verify equipment ratings.

6.2.1 400 kV

In general, fault level values increase at and around the substation where generation is added. Typical 400kV equipment is rated with capacities of 40kA or higher. The assumption for this study would be that if any substation at the 400kV bus exceed 40kA, an investigation and detailed verification would be required. All single and three-phase faults however remained below 40kA. This indicates that no existing equipment would be at risk, having too high fault currents. Results are graphically illustrated in Figure 13.

Table 14: Fault current values calculated in PSS/E (Ampere) – 400kV

			No Kudu	No Kudu	With Kudu	With Kudu
Bus no	**Substation**	**Voltage**	**Three-phase**	**Single-phase**	**Three-phase**	**Single-phase**
450	**Koeberg**	400	20,520	25,915	21,033	26,423
445	**Aurora**	400	11,511	10,959	12,385	11,509
455	**Acacia**	400	15,008	15,886	15,232	16,041
1901	**Atlantis**	400	19,701	23,942	20,273	24,471
1307	**JunoSCA**	400	7,650	5,387	12,562	6,876
435	**Juno**	400	8,577	5,265	9,879	5,651
1308	**JunoSCH**	400	23,219	12,117	20,481	15,860
425	**Helios**	400	7,631	3,236	8,479	3,406
420	**HeliosSC**	400	13,297	3,889	17,459	4,156
410	**Aries**	400	8,001	3,665	8,980	3,865
405	**AriesSC**	400	11,552	4,501	16,932	4,928
400	**Kronos**	400	9,001	3,780	9,670	3,929
415	**Aggeneis**	400	3,060	3,086	3,543	3,305
7506	**Kudu**	400			6,100	9,137
6347	**Obib**	400	1,721	980	4,744	1,361
5753	**Kokerboom**	400	3,052	2,324	4,672	2,865

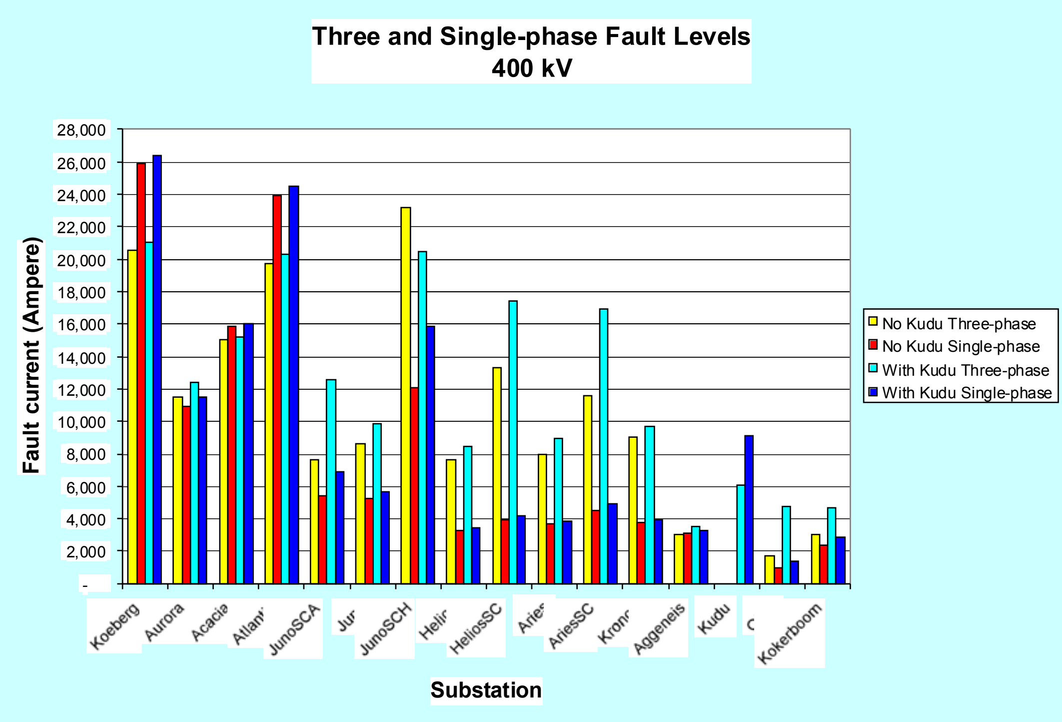

Figure 10 – Fault levels on 400kV substations

6.2.2 220 kV

In general, fault level values increase at and around the substation where generation is added. Typical 220kV equipment is rated with capacities of 20kA or higher. The assumption for this study would be that if any substation at the 220kV bus exceed 20kA, an investigation and detailed verification would be required. All single and three-phase faults however remained below 20kA. This indicates that no existing equipment would be at risk, having too high fault currents. Results are graphically illustrated in Figure 14.

Table 15: Fault current values calculated in PSS/E (Ampere) – 220kV

			No Kudu	No Kudu	With Kudu	With Kudu
Bus no	**Substation**	**Voltage**	**Three-phase**	**Single-phase**	**Three-phase**	**Single-phase**
5681	**Kokerboom**	220	4,797	4,114	6,435	4,856
5680	**Hardap**	220	3,219	2,773	3,748	3,043
5747	**Harib**	220	3,731	2,013	4,481	2,130
1760	**Aggeneis**	220	4,406	5,517	5,611	6,725
1755	**Nama**	220	1,860	2,292	2,995	3,286
1750	**Gromis**	220	1,286	1,528	2,854	2,724
1745	**Oranjemund**	220	922	1,211	4,261	4,830
7507	**Kudu**	220			4,760	5,467

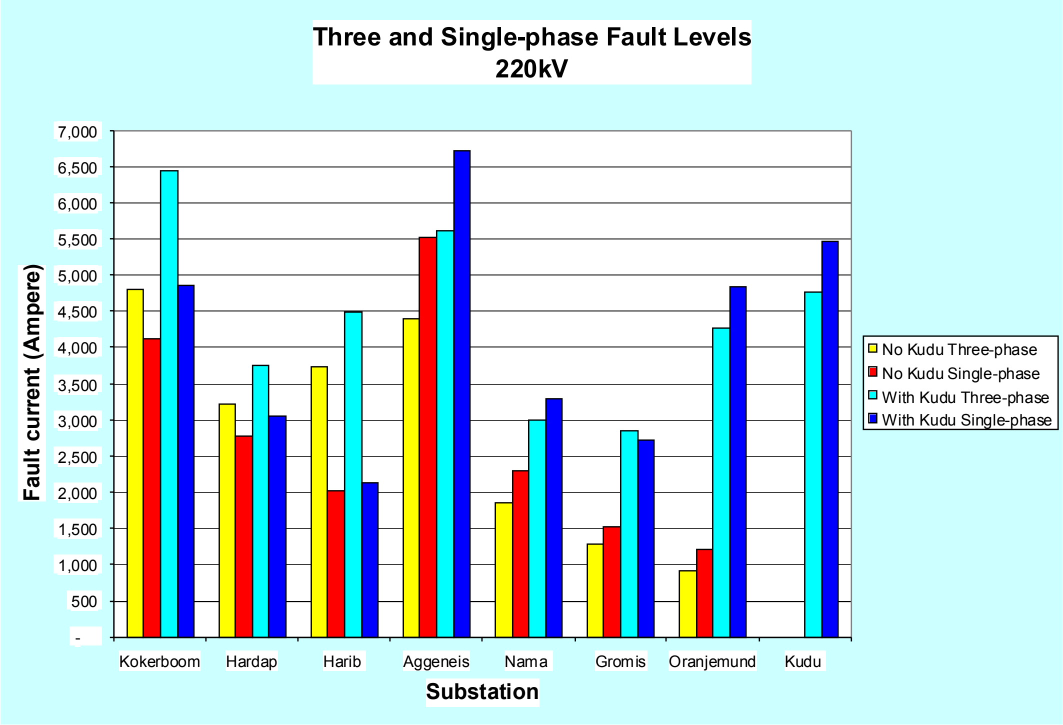

Figure 11 – Single-phase fault levels on 220kV substations

6.2.3 132 kV

In general, fault level values increase at and around the substation where generation is added. Typical 132kV equipment is rated with capacities of 20kA or higher. The assumption for this study would be that if any substation at the 132kV bus exceed 20kA, an investigation and detailed verification would be required. All single and three-phase faults however remained below 20kA. This indicates that no existing equipment would be at risk, having too high fault currents. Results are graphically illustrated in Figure 15.

Table 16: Fault current values calculated in PSS/E (Ampere) – 132kV

			No Kudu	No Kudu	With Kudu	With Kudu
Bus no	**Substation**	**Voltage**	**Three-phase**	**Single-phase**	**Three-phase**	**Single-phase**
1038	**AuroraA**	132	6,808	8,297	6,962	8,466
1787	**AuroraB**	132	14,433	17,094	14,943	17,602
91689	**Saldanha**	132	4,095	5,674	4,170	5,774
5748	**Harib**	132	2,029	1,875	2,138	1,938
60231	**Juno**	132	6,784	7,888	7,157	8,273

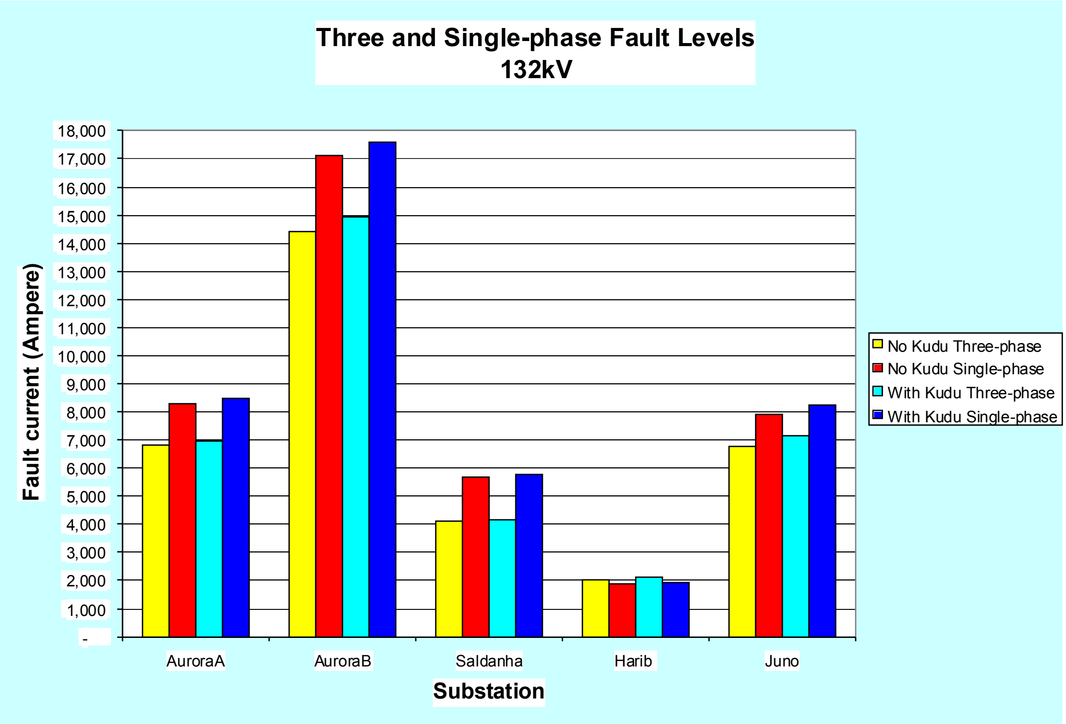

Figure 12 – Single-phase fault levels on 132kV substations

6.2.4 66 kV

In general, fault level values increase at and around the substation where generation is added. Typical 66kV equipment is rated with capacities of 10kA or higher. The assumption for this study would be that if any substation at the 66kV bus exceed 10kA, an investigation and detailed verification would be required. All single and three-phase faults however remained below 10kA. This indicates that no existing equipment would be at risk, having too high fault currents. Results are graphically illustrated in Figure 16.

Table 17: Fault current values calculated in PSS/E (Ampere) – 66kV

			No Kudu	No Kudu	With Kudu	With Kudu
Bus no	**Substation**	**Voltage**	**Three-phase**	**Single-phase**	**Three-phase**	**Single-phase**
6348	**Obib**	66	5,885	4,062	9,601	5,269
6363	**Scorpion**	66	5,505	3,645	8,625	4,592
6099	**Aggeneis**	66	6,844	7,082	7,559	7,529
60232	**Juno**	66	2,714	3,200	2,804	3,305
6109	**Gromis**	66	2,587	3,330	3,915	4,706
6120	**Oranjemund**	66	2,505	3,189	6,719	7,241
6119	**Nama**	66	4,124	4,674	5,580	5,777

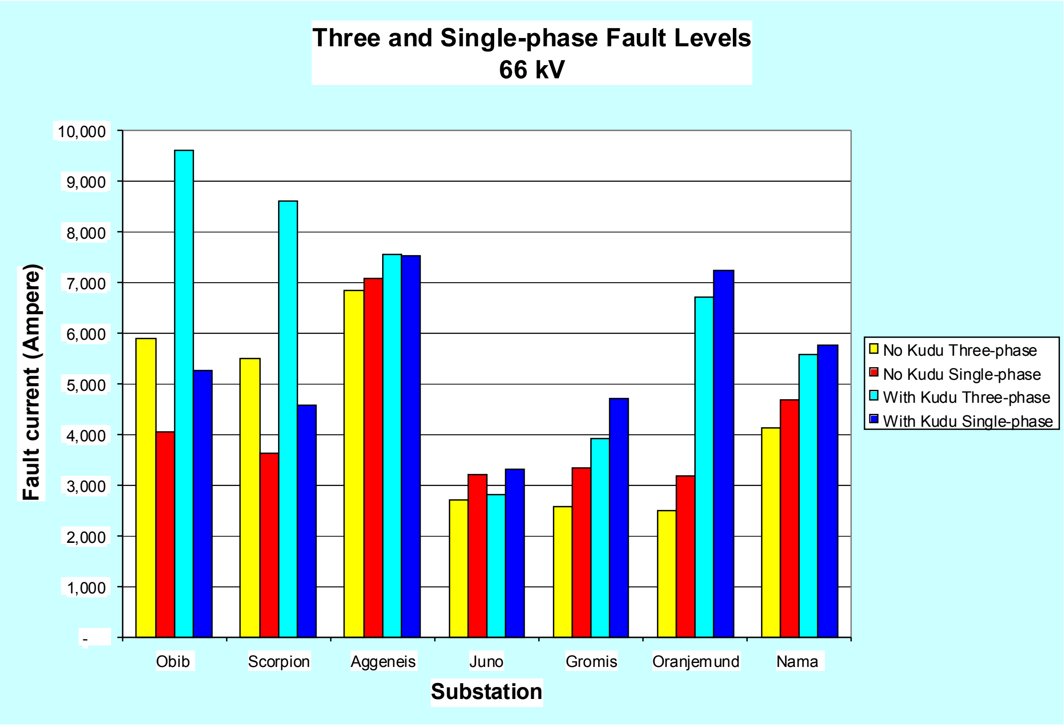

Figure 13 – Single-phase fault levels on 66kV substations

7 PREFERRED REINFORCEMENT OPTION

7.1 Evaluation of the options:

Losses:	Option 2, is the preferred option in terms of savings in losses.
Line length:	Option 1 would be least expensive line cost due to minimum line length required.
Reliability:	Option 2 would be most reliable, providing best operational security.
Stability:	Option 2 would provide better network stability during loss of equipment on the Kudu side, due to Namibian integration into more than just Aries at 400kV.
Environmental:	Any option requires new routes and EIAs to be initiated.

Option 2 is technically most acceptable and preferred and is recommended to be implemented.

7.2 Network requirements

The network layout for the preferred option is depicted in Figure 14. The blue dotted lines are new scope, as well as the blue transformer.

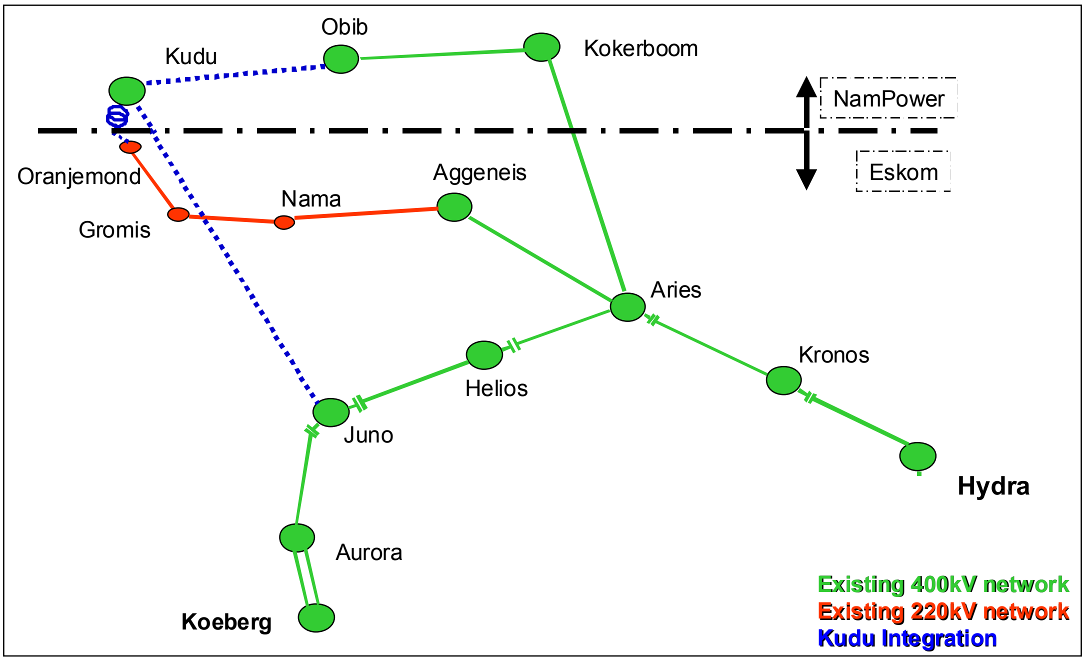

Figure 14 – Preferred Transmission integration option

From a high level perspective, two new 400kV lines need to be built, one to Obib (NamPower scope) and one to Juno (Eskom scope). A 220kV interconnection will be established via a 400/220kV transformer at the power station connected towards Oranjemund substation. Eskom scope includes the 220kV line from the border to the Oranjemund substation.

The line type should typically be capable to carry 1600MVA continuously to cater for possible future upgrade to 1600MW and capability for n-2 contingencies. The distance from the border to Oranjemund substation is ±15km. The distance from the border to Juno is ±390km. Lands and Rights department will determine the exact length of line required.

Substation design personnel will propose the final and optimized detailed design at substations that are impacted. The type and ratings of equipment required will be as per asset specifications.

7.3 High level scope of work

Lines:
- 1 x 15km of 220kV line between Namibian Border and Oranjemund substation
- 1 x 390km of 400kV line between Namibian Border and Juno substation

Bays:
- 1 x fully fitted 400kV line bay at Juno
- 1 x fully fitted 400kV line reactor bay at Juno
- 1 x fully fitted 220kV line bay at Oranjemund

Equipment:
- 2 x line reactors (one at Juno and one at Kudu on the Juno line)
- Bus couplers and bus sections as required by substation design

8 PROJECT - TIMING

The project needs to be in commercial operation by March 2009. As far as timing of the Transmission side of the project is concerned, a new 400kV line of 400km will take 24 months to construct from full project approval (expected October 2005) and after ROD is obtained (end 2006). Possible fast tracking of the project might be required.

9 ENVIRONMENTAL

New servitudes are to be initiated. The total lead-time may vary from 24 to 36 months, dependant on the length of line and the sensitivity of the area. Lead times to complete the Environmental process and have RODs available must not exceed 24 months, to still have 24 months available for line construction. This process needs to be managed very carefully.

10 CONCLUSION

Results for all options indicate that all the generated power can be absorbed into the Transmission network for system healthy and n-1 conditions. No continuous thermal limits of lines or series capacitors are exceeded. All substation voltages remain within acceptable limits.

The impact (increased power flow on existing network) of option 2 is less on the existing network compared to option 1 and 3.

Note that the 220kV network would not be able to support an n-2 condition of both 400kV lines on outage. Such a condition would need inter-tripping of the power station. If the n-2 however includes the 220kV line, all the power (800MW) can be absorbed into either the NamPower or Eskom networks.

It should also be noted that Aries substation is fairly remote. If something happens at the substation, it can take time to have people on site to attend to the problem. All connection to NamPower runs through Aries for option 1 and 3. This is a risk for option 1 and 3, which does not exist for option 2, which provide a second main route to the NamPower network.

Provision of a second route is increasing the operational security of the network, which is a big advantage for option 2.

The network stability will also increase due to a firmer interconnection of the power station and NamPower network when option 2 is utilized. The power station will be electrically closer to the load centre in Cape Town and at Aurora (Saldanha Steel).

The number of series capacitor overload possibilities are reduced for option 2, compared to the other options.

The preferred integration option is Option 2. It is possible to integrate the Kudu CCGT power station of 2 x 800MW into the Eskom Transmission network by one new 400kV line between Juno substation and the Namibian border (NamPower will connect this line further into the power station site). The line distance is approximately 390km. A 15 km 220kV line will be connected at Oranjemund substation to supply power directly to customers in the vicinity of the power station, fed from Oranjemund.

In general from a fault level perspective, all substations remain within acceptable limits.

Losses were calculated for all options, for two and one Koeberg units in service. The different options compare very similar in terms of the benefits related to reduction in losses, although option 2 provides for the biggest overall saving.

Dynamic studies and SSR studies need to be completed before the total scope can be finalized.

The most probable timeframe required by Transmission for construction is 24 months, excluding the requirements for servitudes. This needs to be managed very well. Servitude acquisition is required before line construction can start.

11 RECOMMENDATION

It is recommended that a project be initiated to complete the following scope of work before February 2009:

- 1 x 15km of 220kV line between Namibian Border and Oranjemund substation
- 1 x 390km of 400kV line between Namibian Border and Juno substation
- 1 x fully fitted 400kV line bay at Juno
- 1 x fully fitted 400kV line reactor bay at Juno
- 1 x line reactor at Juno on the Kudu line
- 1 x fully fitted 220kV line bay at Oranjemund
- 1 x line reactor at Kudu on the Juno line (NamPower scope)
- Bus couplers and bus sections as required by substation design

It should be noted that possible project fast tracking could be required.

SSR studies to be initiated and completed.

Dynamic network analysis to be conducted.