Grid Integration of Wind Energy in the Western Cape – Results of Feasibility Studies

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Grid Integration of Wind Energy in Western Cape: General Scope of Work

- Stage 1: Wind farm connection to a subtransmission grid
  - Identify potential issues and mitigation options
  - Example: Connection of 150MW wind farm at Laingsburg to 132kV grid

- Stage 2: Wind farm connection to the transmission grid
  - Identify potential issues and mitigation options
  - Example: Connection of 750MW of wind farms in Karoo area to the 400kV grid

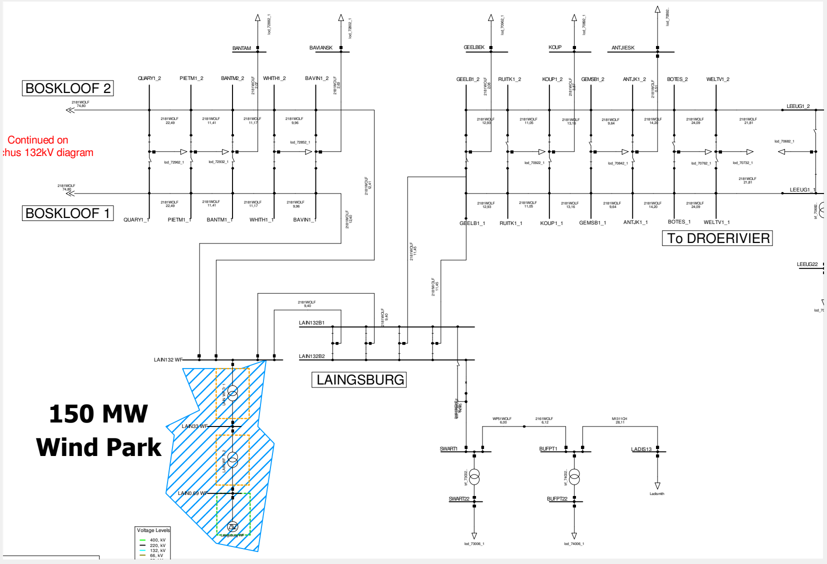
- Stage 3: Study the impact of all wind farms in the Western Cape, for which applications exist (2796MW in total), on the existing ESKOM transmission system (400kV/765kV network).
  - High level feasibility studies for the integration of up to 2800MW of wind generation into the Western Cape.
  - Analyse the impact of wind generation on the transmission system

Stage 1: Example for a Wind Farm Connection Study at Subtransmission Level

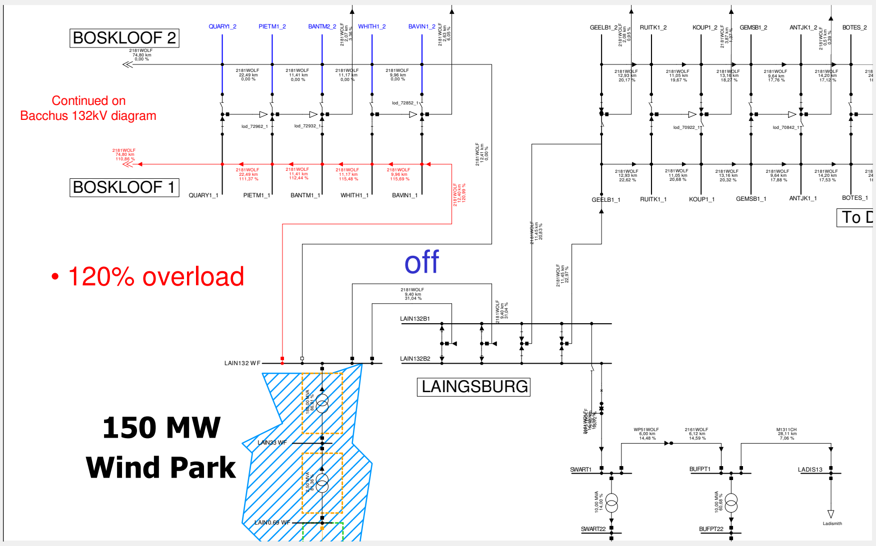
Stage 1: 150MW Wind Farm near to Laingsburg – Scope of Studies

- Impact on thermal limits in the surrounding distribution network
  - Identification of possible Issues
  - Mitigation options
- Impact on voltage variations at the connection point and the surrounding distribution system:
  - Required reactive power control method (const power factor, voltage control, fast/slow voltage control, droop control....)
  - Required reactive range of wind farm for maintaining the voltage.
- Impact on short circuit levels
- Impact on Power Quality aspects (Harmonics/Flicker, IEC 61400-21)

Stage 1: 150MW Wind Farm at Laingsburg - Overview



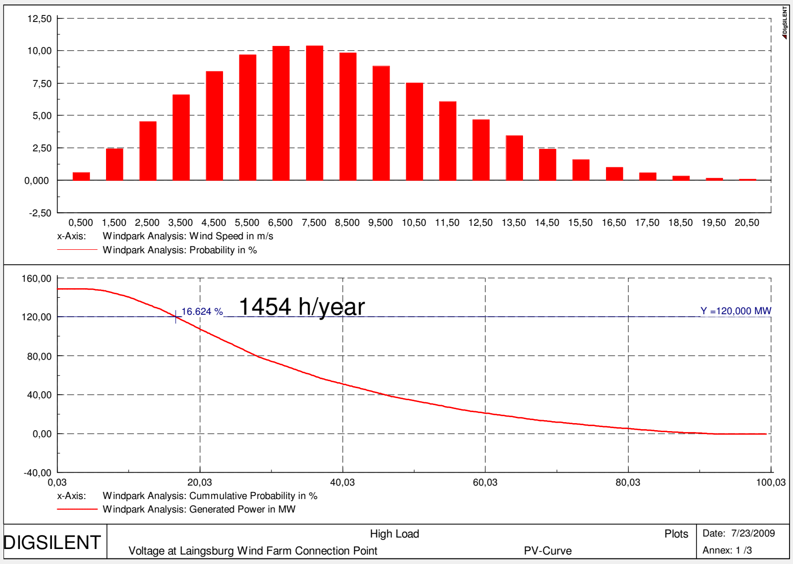
Stage 1: 150MW Wind Farm – Impact on Thermal Limits



150MW at Laingsburg – Impact on Thermal Limits

- Minor overload under n-1: 120% based on „normal ratings“.
- General mitigation options if thermal limits are exceeded:
  - Build a new line
  - Limit wind farm output to 120MW during all times (80% of rated output)
  - Limit wind farm output in case of actual line failure (manual or automatic inter-trip).
  - Consider dynamic line rating systems.

Violation of Thermal Limits – Cap Wind Farm Output



Violation of Thermal Limits – Mitigation Option 1

Not Delivered Energy depends on:

- Wind conditions (average wind speed)
- Site-specific aspects
- Power curve of turbines

Rough cost estimates:

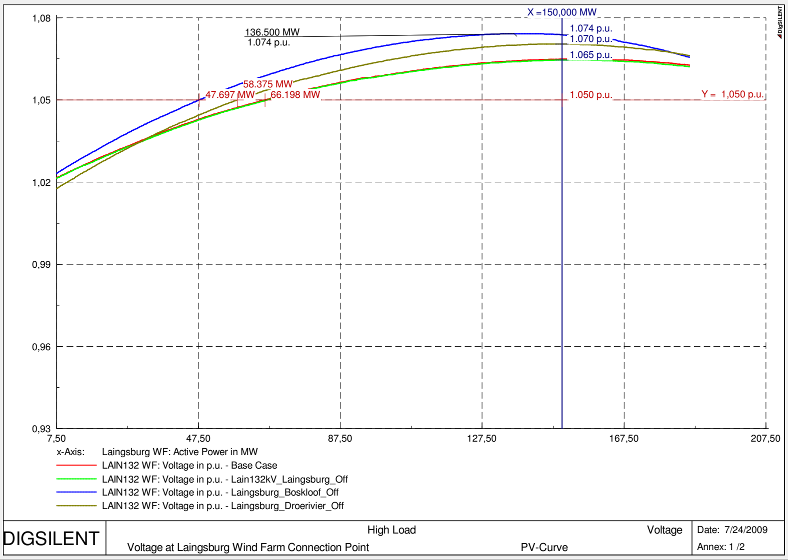
- vw=7m/s:
  - Energy not delivered around 5% of potential energy
  - 150 MW wind-farm: 19 000MWh not delivered -> 23 750 000 R/year
- vw=8m/s:
  - Energy not delivered around 7,5% of potential energy
  - 150 MW wind-farm: 37 000 MWh not delivered -> 46 250 000 R/year
- Must be compared to annualized costs of required line upgrade

Violation of Thermal Limits – Inter-trip

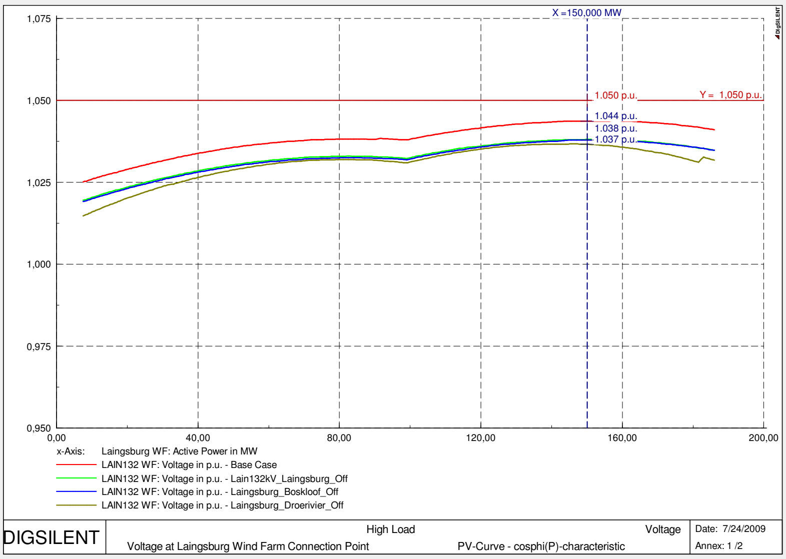
More cost effective solution:

- Limitation of wind farm output only in situations in which one circuit is available (planned outage, unplanned outage)
- In case of minor overloads (below emergency rating):
  - Manual action of system operator
- In case of major overloads (above emergency rating):
  - Automatic inter-trip scheme

Voltage Variations – cosphi constant (=1)



Voltage Variations – cosphi(P)-characteristic



Voltage Variations - Summary

- High voltages in case of cos(phi)=1
- Small voltage variations if cos(phi) adjusted to actually generated power.
- Voltage control at wind farm connection point is possible but not required in this particular case.
- Voltage control must be seen as ancillary service that stabilizes the grid and secures the grid against voltage collapse in case of major disturbances.
- But: Typically voltage control capability of wind farms not available in case of zero power output (vw<vw_cutin).

Impact on Short Circuit Currents

- DFIG:
  - Considerable contribution to peak short circuit current.
  - Contribution to thermal short circuit ratings: approx 1 p.u. shc-current
- WTG with fully rated converter:
  - Contribution to initial short circuit current: approx. 1 p.u. shc-current
  - Contribution to thermal short circuit ratings: approx 1 p.u. shc-current
- 150MW wind farm at Laingsburg:
  - Contribution to initial shc-current (Ikss): approx 2 kA (at 132kV)
  - Contribution to peak shc-current (ip): 4,4 kA
  - Contribution to transient shc-current (Iks): 0,67 kA
- Contribution to fault levels not critical in this particular example because of low fault level at wind farm connection point.

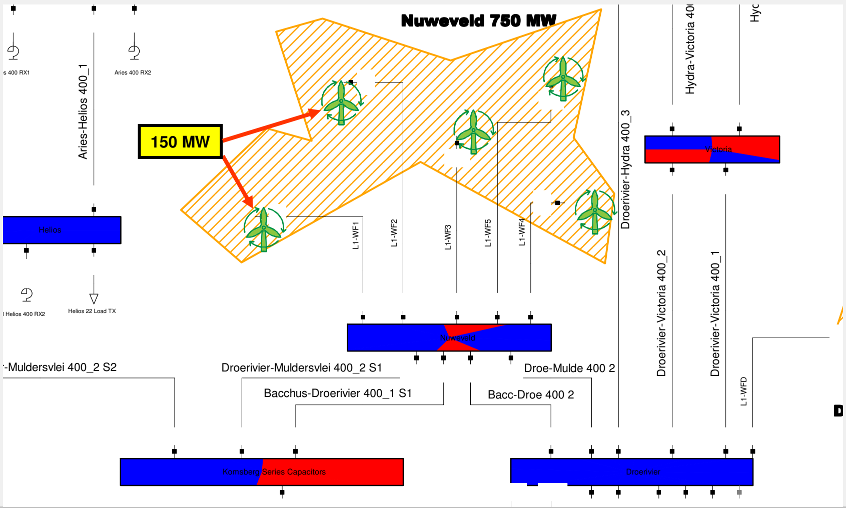
Impact on Flicker and Harmonics

- Analysis of Flicker and Harmonics using IEC 61400-21 data sheet of a typical variable-speed wind generator.
  - Flicker: Pst = 0,066 / Plt=0,08
  - Harmonics: THD=0,75%
- Flicker generally low in case of large wind farms because Flicker-relevant turbulences within a wind farm are only weekly correlated
- Harmonics of modern wind turbines (with IGBT-converters) very low. Almost no harmonic current injections.

Stage 2: Example for Wind Farm Integration into a Transmission Network

Stage 2 – 750MW of Wind Generation in Karoo Area

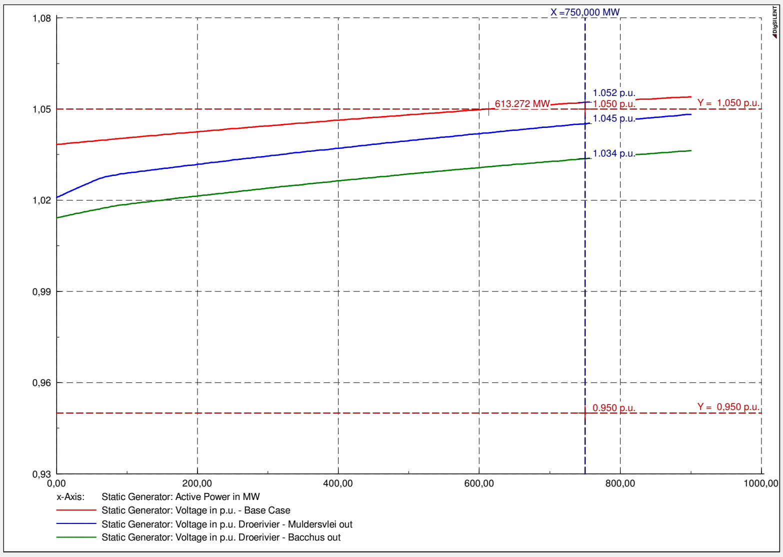
Connection to the 400kV grid:



Stage 2 – 750MW – Scenarios for Studies

- System 2009 (without new 765kV running into the Cape)
- Analysed cases:
  - High load, 1Koeberg units in
  - High load, 2 Koeberg units in
  - Low load, 1 Koeberg unit in
  - Low load, 2 Koeberg units in
- Generation Balancing/High Wind:
  - Reduction of Gas Turbine Generators (running in SCO mode where possible)
  - Reduction of pump storage generation at Palmiet
  - Reduction of coal power plants outside the Cape

Stage 2 – 750MW of wind capacity in Karoo area - Voltages



Stage 2 – 750MW – Summary of Results

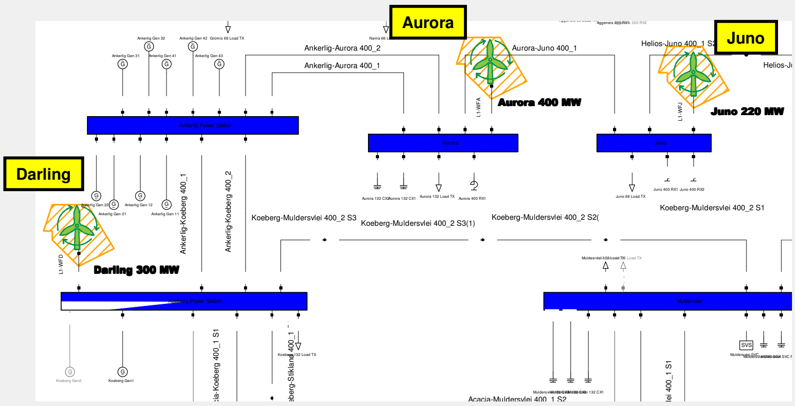
- No thermal overloads under n-1 conditions
- Voltage variations very small, even in constant power factor operation.
- Operation with constant Q (var-control) is appropriate. (Slow) voltage control is possible and should be considered.
- 4x100Mvar shunt reactors required at Nuveweld substation (or equivalent var-absorption of the wind farms) because of proximity to Komsberg series compensation.
- Series compensation at Komsberg should be resized for considering new line configuration.
- With adjusted series compensation, shunt reactors at Nuveweld might not be required.
- No power quality issues because of the large number of turbines and high fault level at the grid connnection point

Stage 3: Feasibility Studies for the Integration of up to 2800MW of Wind Generation in the Western Cape into the ESKOM Transmission Grid

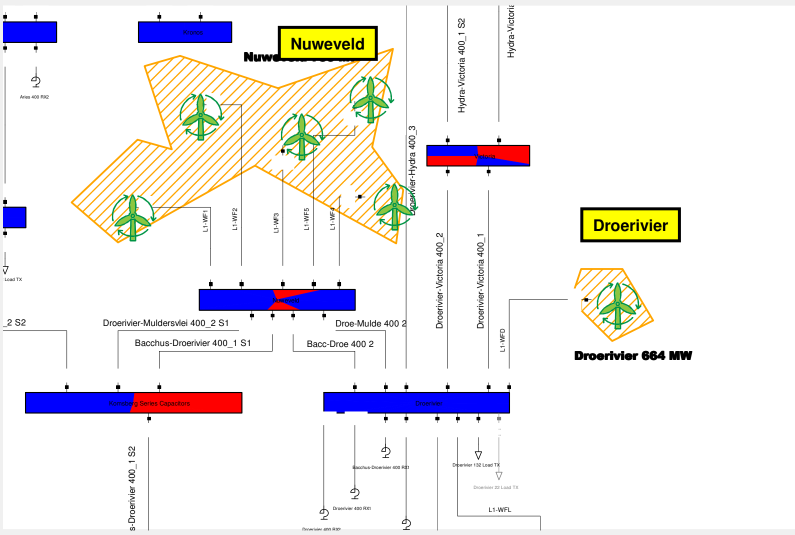
Stage 3 – 2800MW of Wind Generation in the Cape

- Consideration of all wind farms in the Western Cape, for which application exist (2798MW by end of March 2009)
- High level feasibility studies considering the existing ESKOM transmission grid (excluding subtransmission, <=132kV)
- Constraints:
  - No major network upgrades (such as new lines)
  - Minor network upgrade, such as additional var-compensation is allowed.
- System 2009 (without the new 765kV line running into the Cape)

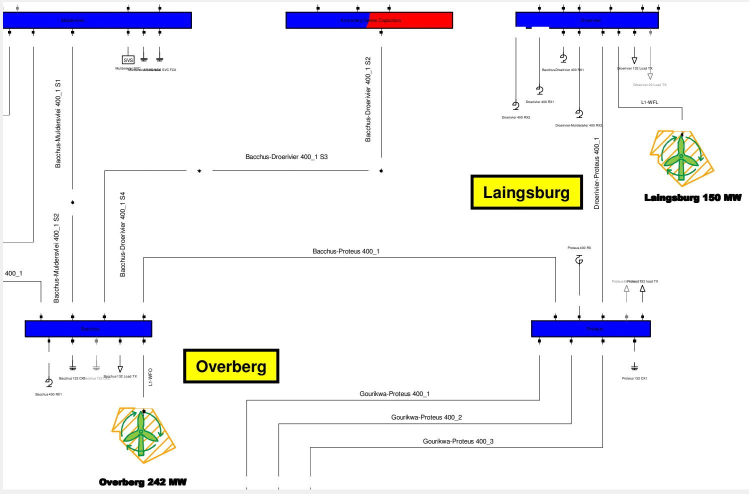
Stage 3 - 2800 MW of Wind Generation in the Western Cape



Stage 3: 2800 MW of Wind Generation in the Western Cape



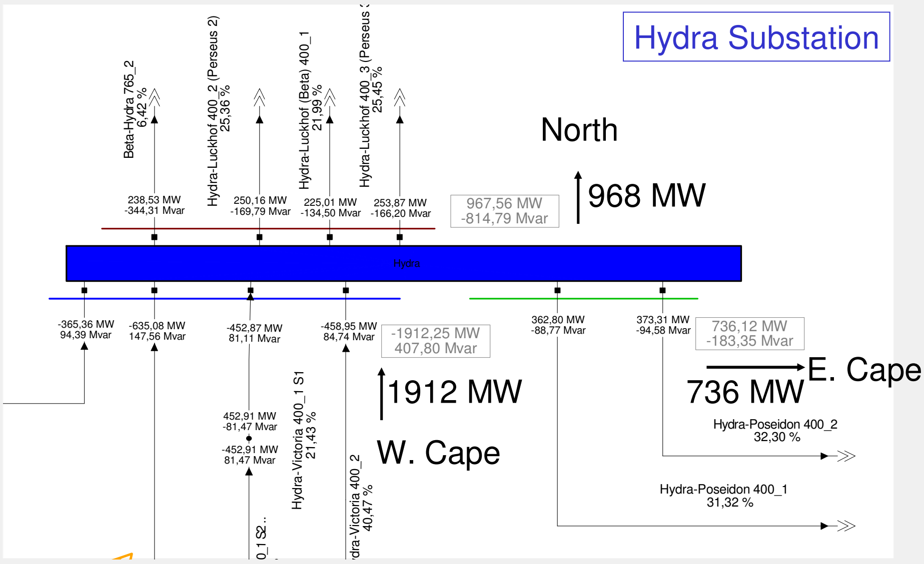
Stage 3: 2800 MW of Wind Generation in the Western Cape



Stage 3 – 2800MW – Scenarios for Studies

- Consideration of all wind farms in the Western Cape, for which application exist (2798MW by end of March 2009)
- Assumption: Max. wind generation = installed generation -> overestimates max wind generation by 10..20%, leaving some margins.
- Analysed cases:
  - High load, 1Koeberg units in
  - High load, 2 Koeberg units in
  - Low load, 1 Koeberg unit in
  - Low load, 2 Koeberg units in
- Generation Balancing – High Wind Scenarios:
  - Reduction of Gas Turbine Generators (running in SCO mode where possible)
  - Reduction of pump storage generation at Palmiet
  - Reduction of coal power plants outside the Cape

Stage 3 – 2800MW of Wind – Example: LL+HW, 2KB-Units



Stage 3 – 2800MW in the Western Cape – Summary of Results

- Up to 1000MW of export from the Cape to the North under Low load – High Wind conditions.
- No violation of thermal limits under n-1 conditions in all scenarios.
- Voltages can be maintained within appropriate limits, without any additional reactive power compensation in the Western Cape.
- The general feasibility of the integration of up to 2800MW of wind generation in the Western Cape, with regard to the impact on the transmission grid, could be demonstrated.
- However:
  - Operation of the system with considerable export from the Cape to the North must be studied in further detail.
  - Size of Komsberg series compensation must be verified/redefined (see stage 2 studies)
  - More detailed studies are required for confirming these results.

Integration of Wind Energy into the Western Cape System - Summary

Western Cape transmission system – excellent for wind integration:

- Cape system currently has an import problem (no export problem). Power import will be reduced during times of high wind generation.
- Large number of fast acting peak load units available that can be used for balancing wind variations.
- Pump storage can be used for supporting the balancing of wind variations.
- Some GTGs allow for SCO-operation – no need for additional dynamic reactive power compensation (SVC).

At subtransmission levels (<=132kV), transmission capacity will be limited in some cases.

What else needs to be done

- Additional, more detailed studies at transmission levels, including additional generation-load scenarios and alternative wind generation scenarios.
- Stability studies under various operating scenarios.
- Wind farm connection studies for every wind farm application.
- Studies related to transmission system operation under situations, in which the Cape exports power to the rest of the system
- Studies related to the expected total power variations of wind generation (variations, ramp-up and ramp-down speeds) for identifying additional reserve requirements have to be carried out.