Combined wind and solar feed-in to the grid

Crescent Mushwana¹ and Helen Ganal²
Research Group Leader, CSIR, South Africa¹
Research Engineer, Fraunhofer IEE, Germany²
PRESENTATION AGENDA

- South African wind and solar resources
- Case study on wind and solar PV combination
- Energy system design – the traditional vs new philosophy
- Changes in the Energy System – energy transition
- VRE integration – the conservative approach
- VRE integration – the optimal approach
- VRE curtailment analysis
- VRE integration grid analysis
- Conclusion
• South Africa’s wind and solar resources are excellent countrywide.
• EIA applications: estimated Wind (90), PV(330); land use is roughly 1.21% of SA land
• REDZ: estimated Wind (530 GW), PV (1780 GW); land use is roughly 4.4% of SA land
Aggregating 225 PV plants over 500 x 500 km reduces short-term fluctuations to almost zero.

Widespread spatial distribution makes aggregated PV power output very predictable and smooth.

Source: Cloud Cover study commissioned by Eskom done by GeoModel Solar and University of Stellenbosch (CRSES)
Aggregation across entire country: wind output very smooth

Simulated wind-speed profile and wind power output for 14 January 2012

14 Jan 2012 23:45 SAST

wind speed at 100m above ground
WIND AND SOLAR PV COMBINATION

- Individual plants have high ramp rates
- Individual plant power output very volatile; low predictability
- Area (aggregated) output is much smoother with low ramp rates
- Aggregated plant output is more predictable
- Wind and solar PV output are complimentary, peaking at different times

Port Elizabeth Area case study

21 June 2011

21 Sept 2011
ENERGY SYSTEM DESIGN - TRADITIONAL

YESTERDAY – centralised power system, fossil fuel driven, long lead times to build

TOMORROW – distributed (local), smart, clean power, short lead times to build

## Changes in the Energy System

<table>
<thead>
<tr>
<th>Traditional view of the energy system</th>
<th>New approaches to energy systems</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large centralised generation</td>
<td>Small decentralised generation</td>
</tr>
<tr>
<td>Base load generation (less flexible)</td>
<td>Flexible generation (baseload irrelevant)</td>
</tr>
<tr>
<td>Centralised grid design with transmission as backbone</td>
<td>Microgrids or minigrids are the building blocks of the grid</td>
</tr>
<tr>
<td>Consumers</td>
<td>Prosumers</td>
</tr>
<tr>
<td><strong>Load</strong></td>
<td><strong>Residual load (i.e. load – variable RE)</strong></td>
</tr>
<tr>
<td>Communication and control at transmission level</td>
<td>Distribution grid and customer levels are driven by smart systems; ICT central to the energy system</td>
</tr>
<tr>
<td>Unidirectional power flow</td>
<td>Bidirectional power flow</td>
</tr>
<tr>
<td>Electricity price largely depends on energy charge</td>
<td>Capacity charge is larger portion of the electricity price</td>
</tr>
<tr>
<td>Generation is largely owned by large corporations or the state</td>
<td>Community trusts and cooperatives can own distributed generation</td>
</tr>
<tr>
<td>Bulk power from centrally dispatched power plants</td>
<td>Bulk power from self/weather dispatched power plants (i.e. wind and solar)</td>
</tr>
</tbody>
</table>
**VRE INTEGRATION – CONSERVATIVE**

A: VRE generation = \( PV_{\text{max}}(t_1) + Wind_{\text{max}}(t_2) \)

B: VRE generation = \( PV_{\text{max}}(t_1) + Wind_{\text{max}}(t_2) + Load_{\text{min}}(t_0) \)

C: VRE generation = \( (PV_{t_1} + Wind_{t_1})_{\text{max}} + Load_{\text{min}}(t_0) \)

A: Load not considered, therefore transformation capacity is the limitation

B: Load considered, but no diversity for generation and load

C: Diversity for generation only, load diversity not considered
VRE INTEGRATION – OPTIMAL APPROACH

VRE generation = PV \(_{(t1)}\) + Wind \(_{(t1)}\) + Load \(_{(t1)}\)

- Generation and load diversity taken into account all the time, therefore more PV and Wind capacity that can be added far exceed the transformation capacity.
- Even if load is zero, PV and Wind diversity results in their capacities exceeding the transformation capacity.
VRE CURTAILMENT ANALYSIS – RESEARCH QUESTIONS

- How much VRE might be installed at substation level?
  - Should it be 100% of transformer capacity or more?
- How to estimate the installable capacity countrywide?

Additional aspects:
- Each transmission substation has a certain rated capacity in MW (maximum evacuation)
- Each solar PV/wind project has a certain rated capacity in MW (maximum output)
- Status quo: solar PV/wind projects can connect to a certain substation up to the point that the sum of the rated solar PV/wind capacity equals the rated capacity of the substation
- Solar PV and wind projects’ power output however is generally not highly correlated
- This means that the sum of rated solar PV and wind capacity at a substation could be higher than the rated capacity of the substation without running into excess power situation often
- This effect was analysed and the potential over-installation capacity of solar PV and wind was quantified for all substations across South Africa
FEED IN AND CURTAILMENT

- If feed-in exceeds transformer capacity, VRE feed in is curtailed.
- Overload up to 20% can be accepted up to 45 minutes.
- For the study a conservative approach was chosen: no overload is accepted.
FEED IN AND CURTAILMENT

- If feed-in exceeds transformer capacity, VRE feed in is curtailed.
- Overload up to 20% can be accepted up to 45 minutes.
- For the study a conservative approach was chosen: no overload is accepted.
Up to 20% over-installation is possible without curtailing energy – for the most conservative approach (no demand considered).
UP TO 20% OVER-INSTALLATION IS POSSIBLE WITHOUT CURTAILING ENERGY
– FOR THE MOST CONSERVATIVE APPROACH (NO DEMAND CONSIDERED)
UP TO 20% OVERINSTALLATION IS POSSIBLE WITHOUT CURTAILING ENERGY
– FOR THE MOST CONSERVATIVE APPROACH (NO DEMAND CONSIDERED)
10% CURTAILMENT
10% CURTAILMENT @ 240% RE CAPACITY
10% CURTAILMENT @ 240% RE CAPACITY
10% PROBABILITY
NOT FEED-IN BUT RESIDUAL LOAD MATTERS
RESIDUAL LOAD = DEMAND − VRE FEED-IN
CURTAILMENT OF RESIDUAL LOAD IS KEY

• Residual load (consumption at substation level minus VRE feed-in) has to be investigated
CURTAILMENT OF RESIDUAL LOAD IS KEY

- Residual load (consumption at substation level minus VRE feed-in) has to be investigated

![Graph showing normalized power (P/P_{Trans,max}) over time with 9 hours marked as a period of curtailment.](image)
UP TO 230% INSTALLED VRE CAPACITY (50% PV, 50% WIND) NO CURTAILMENT IS NEEDED (THREE YEARS AVERAGE)

- Rather use video clips if sound and recordings are required for your presentation.
- Please discuss this with the organisers so that arrangements can be made to accommodate your request.
## INSTALLABLE CAPACITY COUNTRY WIDE

<table>
<thead>
<tr>
<th>Only Feed-in 50% wind</th>
<th>Curtailed annual energy per total solar/wind energy</th>
<th>Minimum installable solar/wind power per substation capacity</th>
<th>Average installable solar/wind power per substation capacity</th>
<th>Maximum installable solar/wind power per substation capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0%</td>
<td>120%</td>
<td>120%</td>
<td>340%</td>
<td></td>
</tr>
<tr>
<td>5%</td>
<td>140%</td>
<td>190%</td>
<td>Not evaluated yet</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>180%</td>
<td>290%</td>
<td>Not evaluated yet</td>
<td></td>
</tr>
<tr>
<td>Feed-in and load (residual load) 50% wind</td>
<td>0%</td>
<td>230%</td>
<td>240%</td>
<td>340%</td>
</tr>
<tr>
<td>5%</td>
<td>280%</td>
<td>340%</td>
<td>Not evaluated yet</td>
<td></td>
</tr>
<tr>
<td>10%</td>
<td>320%</td>
<td>400%</td>
<td>Not evaluated yet</td>
<td></td>
</tr>
</tbody>
</table>

www.african-utility-week.com
CHANGING THE PV/WIND RATIO

10% wind / 90% PV capacity  
90% wind / 10% PV capacity
## INSTALLABLE CAPACITY COUNTRY WIDE

<table>
<thead>
<tr>
<th>Feed-in and load (residual load)</th>
<th>Minimum installable solar/wind power per substation capacity</th>
<th>Average installable solar/wind power per substation capacity</th>
<th>Maximum installable solar/wind power per substation capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wind 10%</strong></td>
<td>Curtailed annual energy per total solar/PV energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>230%</td>
<td>230%</td>
<td>260%</td>
</tr>
<tr>
<td>5%</td>
<td>270%</td>
<td>280%</td>
<td>310%</td>
</tr>
<tr>
<td>10%</td>
<td>300%</td>
<td>320%</td>
<td>350%</td>
</tr>
<tr>
<td><strong>Wind 50%</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>230%</td>
<td>240%</td>
<td>340%</td>
</tr>
<tr>
<td>5%</td>
<td>280%</td>
<td>340%</td>
<td>Not evaluated yet</td>
</tr>
<tr>
<td>10%</td>
<td>320%</td>
<td>400%</td>
<td>Not evaluated yet</td>
</tr>
<tr>
<td><strong>Wind 90%</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0%</td>
<td>200%</td>
<td>200%</td>
<td>250%</td>
</tr>
<tr>
<td>5%</td>
<td>240%</td>
<td>260%</td>
<td>340%</td>
</tr>
<tr>
<td>10%</td>
<td>260%</td>
<td>290%</td>
<td>400%</td>
</tr>
</tbody>
</table>
VRE CURTAILMENT ANALYSIS RESULTS

- 120% VRE capacity compared to transformer capacity can be installed at substation level for feed-in only without curtailment (20% additional VRE capacity compared to transformer capacity can be installed)

- About 230% VRE Capacity compared to transformer capacity can be installed at substation level considering a share of 50% PV and 50% wind

- Solar and wind both meet the demand well, even solely

- Solar is more consistent over time and substations than wind, thus results are less variable

- For the same installed capacity, the energy generation from wind is usually greater than that of solar PV as wind power plants are able to reach higher capacity factors and they can generate 24/7
COUNTRYWIDE MORE THAN 350 GW VRE CAPACITY CAN BE INSTALLED WITHOUT CURTAILMENT

- Evaluation done for 376 transmission transformers
- Average power 377 MVA
- Total transformer capacity 142 GW
- Total installable VRE capacity without curtailment: 377 GW
CONCLUSION

• The excellent wind and solar PV resources in South Africa provide a basis for larger shares in the future energy mix

• Spatial aggregation of wind and solar resources reduces variability and thus increases predictability

• Wind and solar resource profiles are complimentary, which makes them an ideal combination

• At least 20% additional wind/PV power can be installed per substation without any curtailment of wind/PV power (90% with 5% curtailment) – no load considered, thus conservative

• Considering load this value increases to 130% (180% with 5% curtailment)

• A better simulation of overload and allowable overload situations considering ambient temperature etc. should be carried out to refine the installable capacity results

• The special situation at that particular node, e.g. local load, grid stability on site etc., should be investigated further.
Thank you!

Crescent Mushwana  
CMushwana@csir.co.za  
++27 12 841 3553

Helen Ganal  
Helen.Ganal@iee.fraunhofer.de  
++49 561 7294 108

16 – 18 May 2017  
Site visit: 19 May 2017  
Cape Town, South Africa  
www.african-utility-week.com