Case Studies of Renewable Energy Power Quality

PES DLP Lecture
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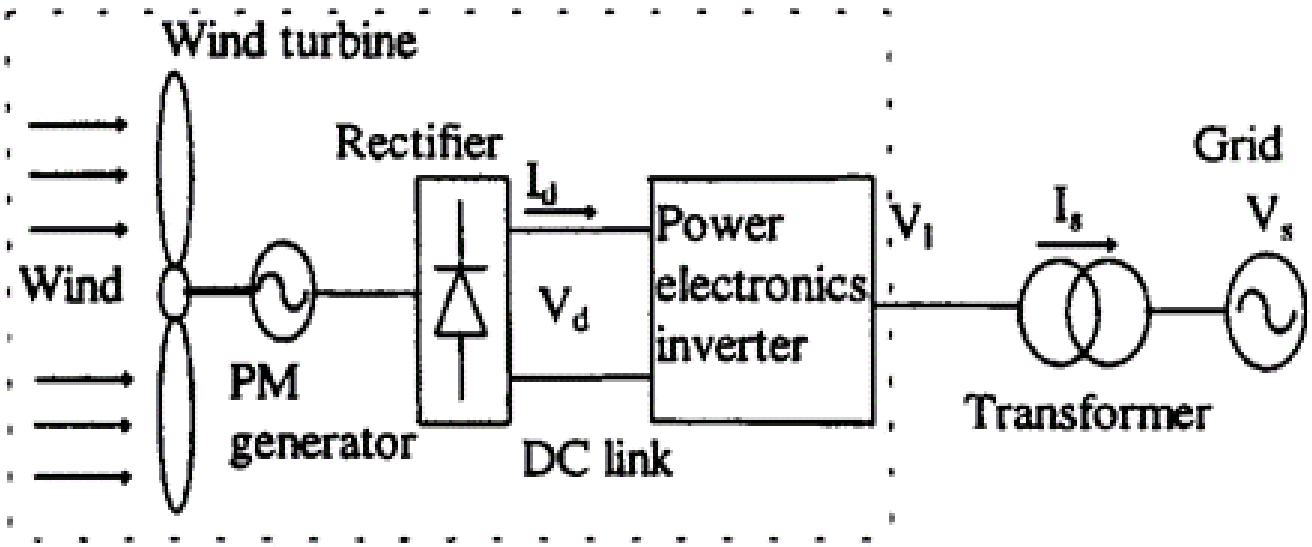
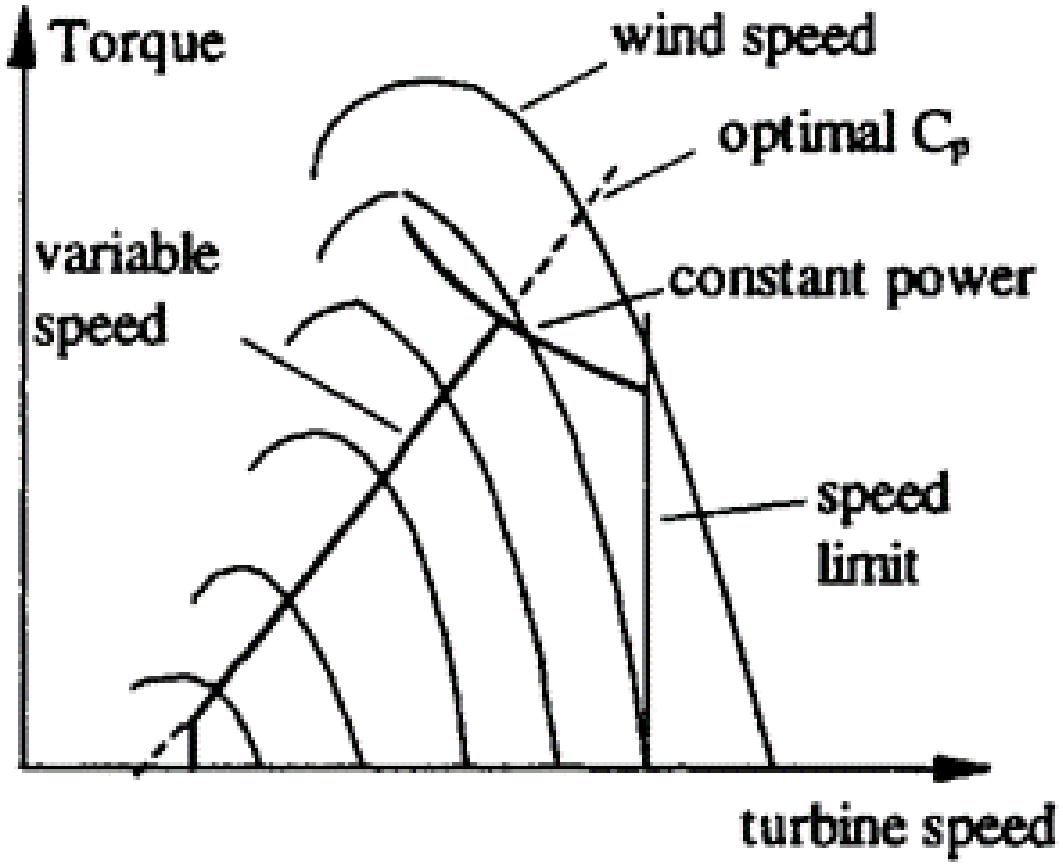
M. E. El-Hawary,
Dalhousie University,
Halifax, Nova Scotia

Test System

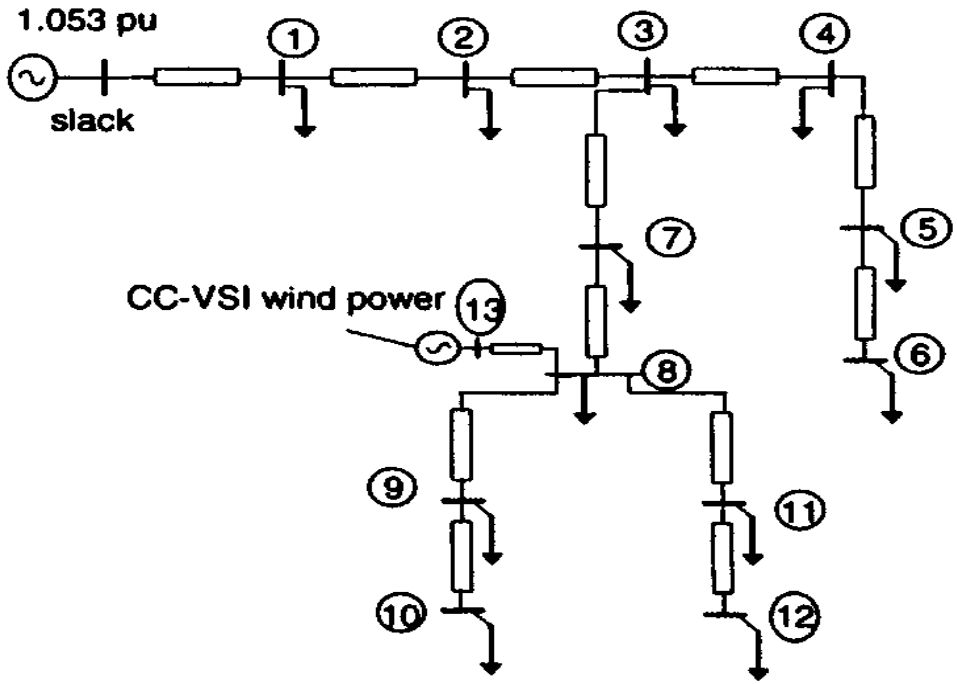
1. The system consists of a wind turbine, a high pole number modular PM generator
2. A modular rectifier system and
3. A controllable power electronics inverter.


Wind turbine
Rectifier
I_d
Power
electronics
inverter
V_1
I_s
Grid
V_s
Wind
V_d
PM
generator
DC link
Transformer

Variable speed operating Characteristic



System line diagram



- The slack bus keeps a voltage of 1.053 pu.
- An equivalent CC-VSI (which, in practice, would be a number of CC-VSIs) at bus 13 connects the wind farm to bus 8 of the grid.

- It is assumed that the loading at each node is kept constant during the analysis and the multi-machine wind farm has a total capacity of 32% system loading.
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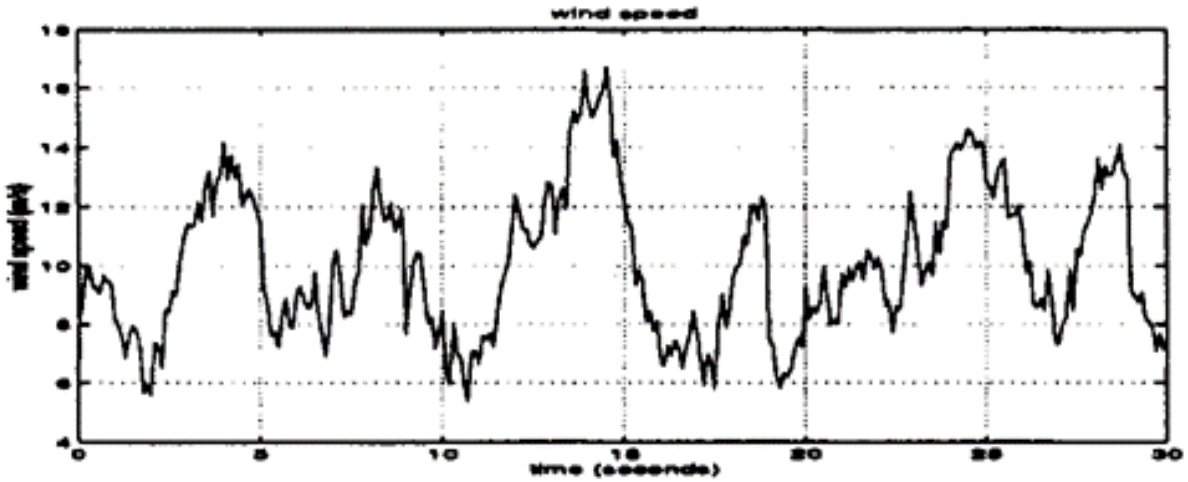
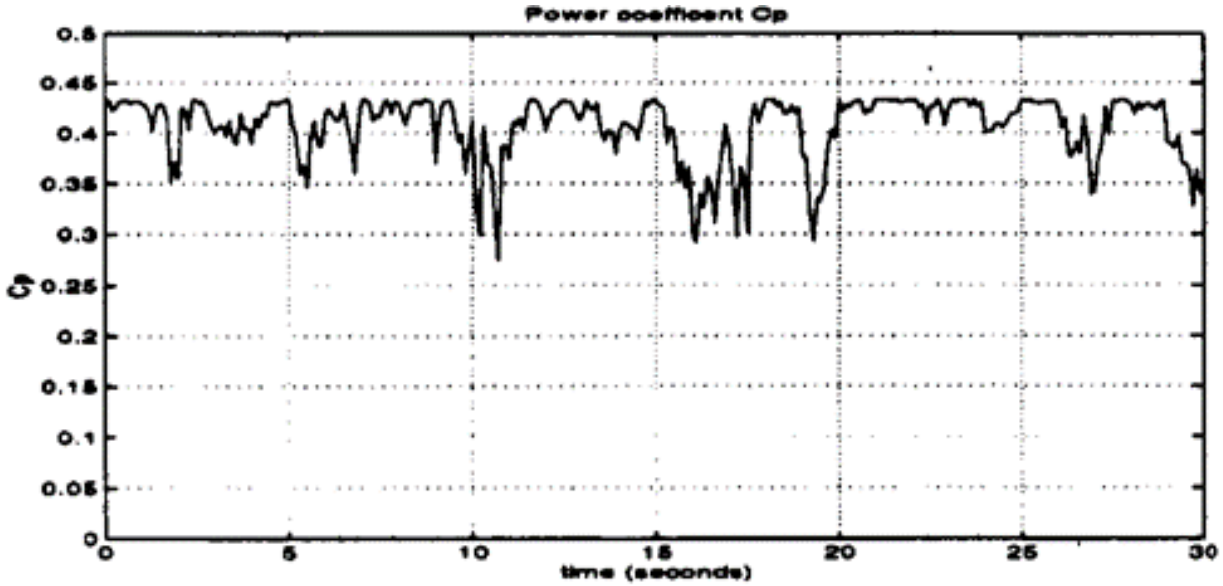
Voltage Fluctuation Analysis

- The wind speed curve used for the study is shown.

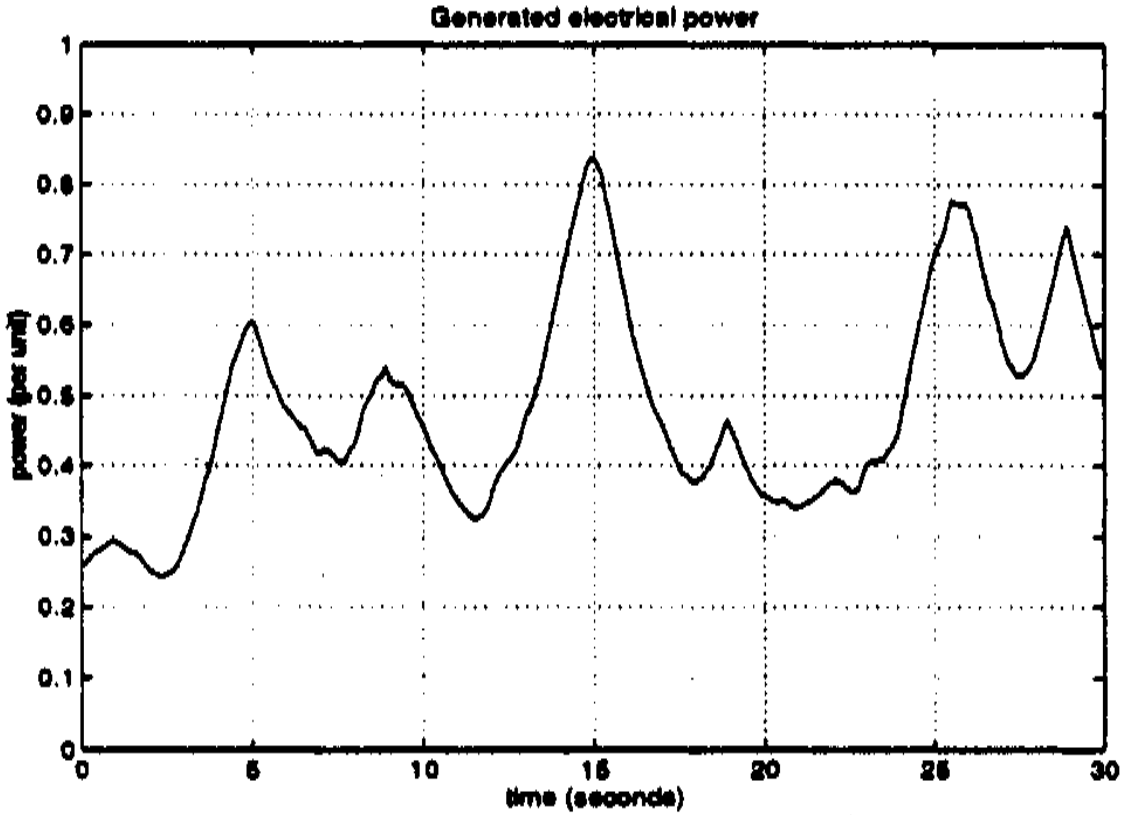


- The Cp trace of the equivalent machine is shown.



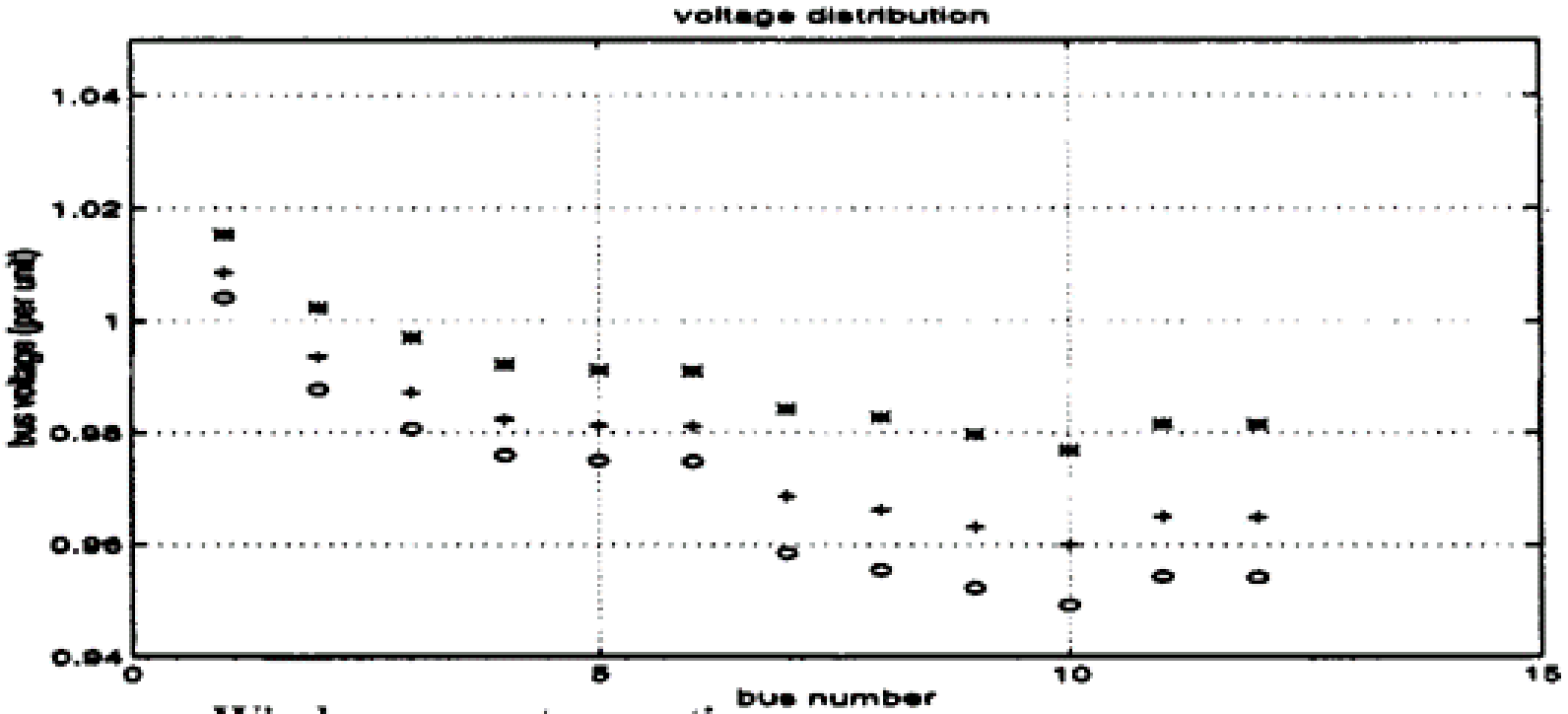
- The corresponding electrical power generated by the wind farm is shown.
- Inertia smoothing effects are apparent.
- A series of power flow analyzes have been carried out using the generated electrical power shown as the real power input at bus 13.

Generated electrical power



- Next is shown the bus voltages under the following conditions:
- i) wind power not connected,
- ii) wind power converter operating at Pmin and unity power factor,
- iii) wind power converter operating at Pmax and unity power factor.

Bus voltage distribution—1



o Wind power not operating

* Wind power operating at P_{max} with unit power factor

\+ Wind power operating at P_{min} with unit power factor

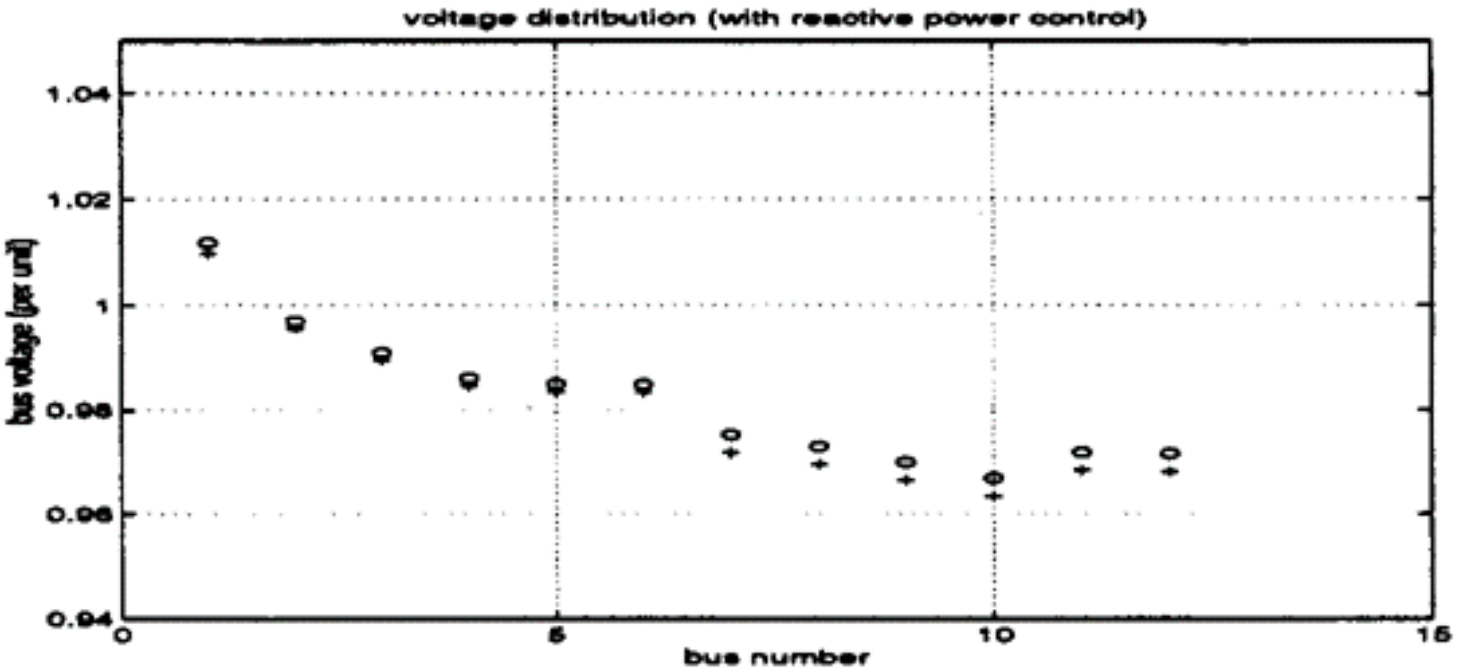
- It can be seen that unity power factor operation of the wind farm can increase the network voltage level.
- It is also noted that the injection of varying power can result in bus voltage fluctuation, although the voltage variation is less than 2% in this case.

- If the wind power varied over a wider range and if the load variation is taken into account, then voltage fluctuations may become unacceptable for loads connected on some buses even though the wind power generation is maintained at unity power factor.

- However, the bus voltage fluctuation can be reduced if the wind farm inverters are used to generate reactive power during system low voltage periods and to absorb reactive power during system high voltage periods.

- In this way, the inverters also work as Var compensators.
- A simple example of wind power converter operating under such control scheme is shown next.
- It can be seen that the bus voltage fluctuation has been greatly reduced.

Bus voltage distribution—2

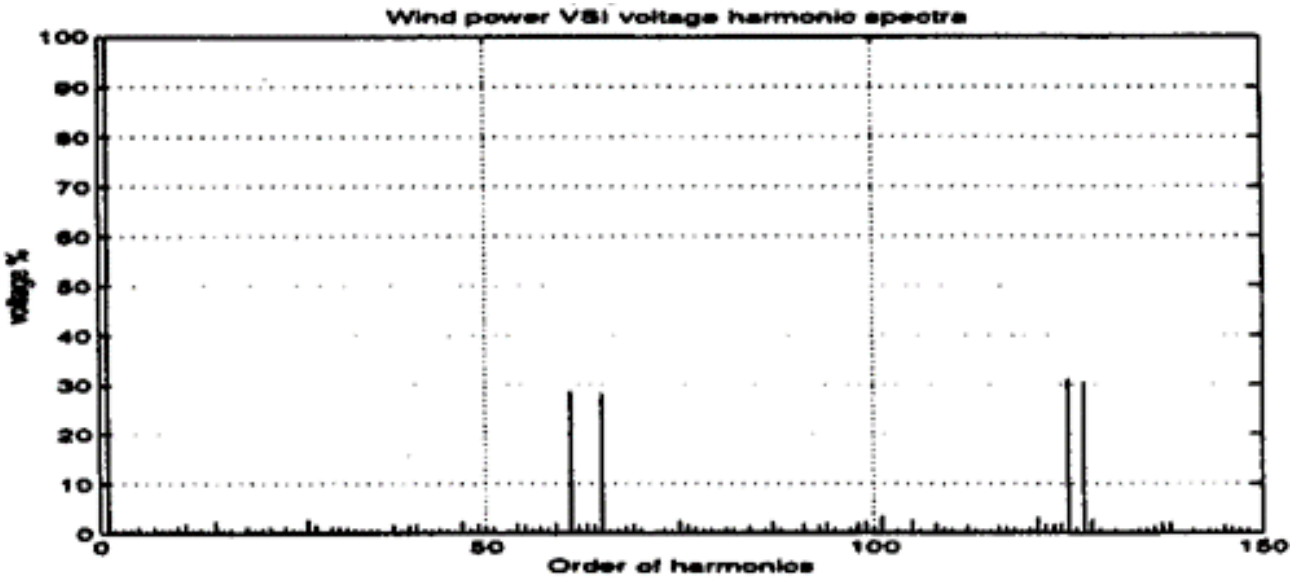


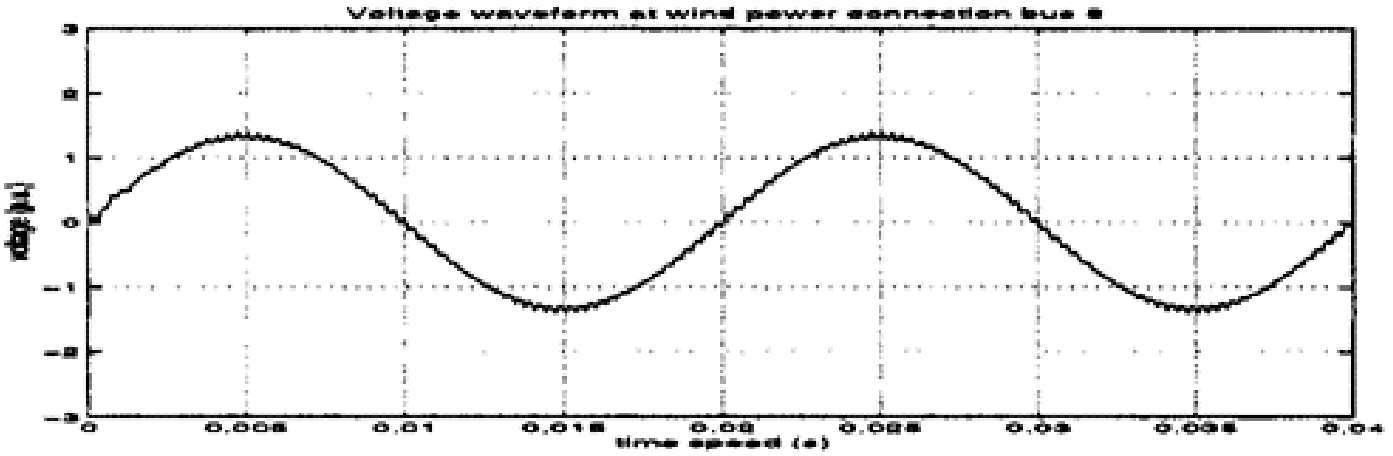
o Wind power operating at P_{max} with reactive power absorption

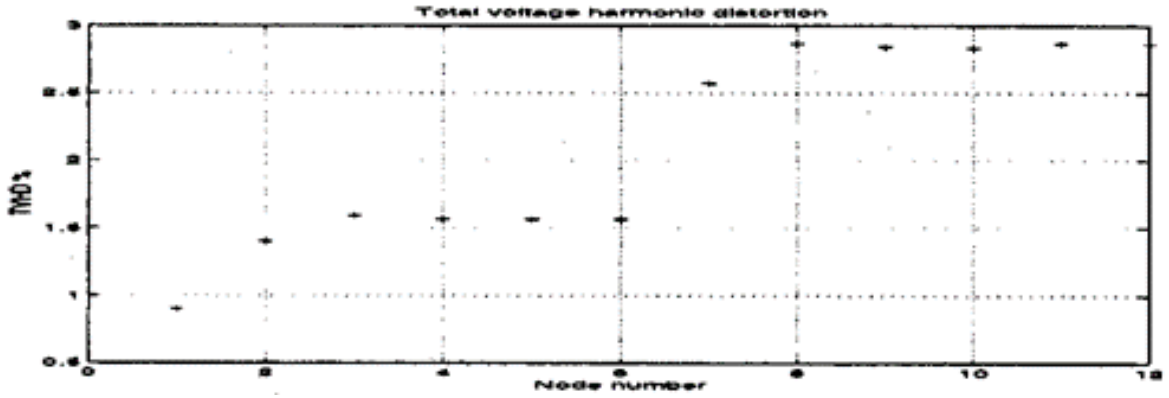
\+ Wind power operating at P_{min} with reactive power generation

Grid Current Harmonic Distortion

- The switching frequency of the grid interface inverter is 3.15 kHz.
- It is assumed that the system operates in a balanced condition. The voltage waveform and harmonic spectra of VSI wind power (bus 13) and bus 8 are shown.

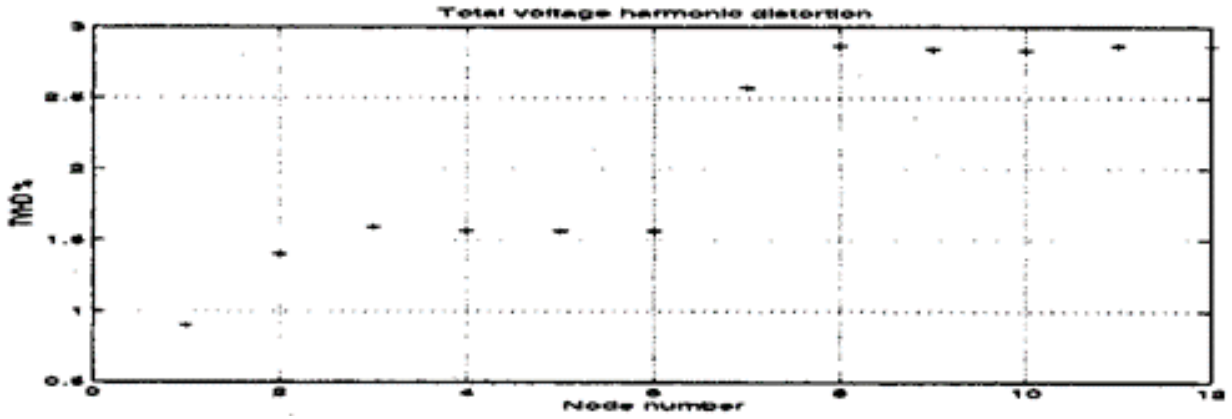

Wind power VSI voltage harmonic spectra
100
90
80
70
60
50
40
30
20
10
0
voltage %
0
50
100
150
Order of harmonics


Voltage waveform at wind power connection bus 8
time speed (s)


Total voltage harmonic distortion
THD%
Node number

The figure shows the total voltage harmonic distortion at each bus.

These results correspond to the earlier operating conditions.



- It can be seen clearly that the harmonic distortion can be reduced sufficiently to meet modern standards for the discussed type of distribution systems.

- Z. Chen; E. Spooner, Grid power quality with variable speed wind turbines, IEEE Transactions on Energy Conversion, 148 – 154, ,Volume: 16, Issue: 2, 2001