WIND INDIA 2006

Solutions for power quality and grid integration of wind turbines in India

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Outlines of the presentation

- ❖ Classification of Wind Turbines
- ❖ Power Quality Issues, Standards and solutions
- ❖ Grid Integration Issues, Standards and Indian Scenarios
- ❖ Conclusions

Classification of wind turbines

❖ Fixed speed WTG (Type-A)

1. A0: Stall control- Not suitable for weak grids, produces large voltage fluctuations, low price, no control over power
2. A1: Pitch control- controllable but slow control, unable to handle high wind speed
3. A2: Active stall control - flexible coupling of blades, high price

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Classification of wind turbines

All are pitch controlled.

❖ Limited variable speed WTG (Type-B1) [Gamesa]

❖ Variable speed WTG with Doubly Fed Induction Generator (DFIG) (Type-C1) [Vestas, NEG-Micon]

WRIG and partial scale frequency converter (30% of nominal generator power)

❖ WTG with full scale frequency converter (Type-D1) [Enercon]

Wound rotor/Permanent magnet synchronous generator with full scale frequency converter

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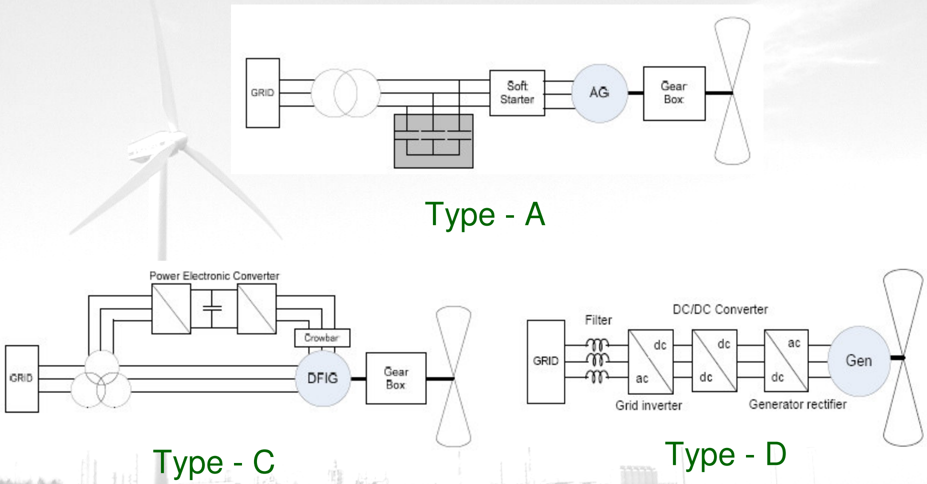
Types of Wind Turbine Technologies



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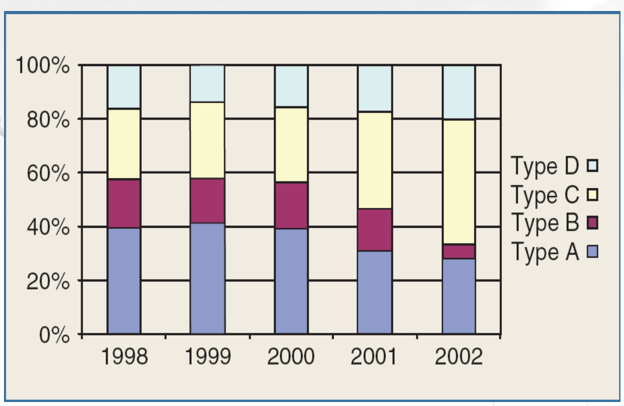
World market share of WTG (1998-2002)



A: Fixed speed WTG

B: Limited Variable speed WTG

C: Variable speed WTG with DFIG

D: Full scale frequency based WTG

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Power Quality Issues

- ❖ The power quality issues can be broadly classified in two categories :

1. Those caused by meteorological and geographical conditions like turbulence intensity, wind shear and fluctuations in wind speed and power production
2. Those affected by technology used by the wind turbine

It is important to note that many power quality issues can be effectively tackled by proper choice of the turbine

Power Quality Issues

- ❖ Wind power quality reflects the interferences of Wind power generation with the grid
- ❖ Wind power mainly influencing parameters are voltage fluctuations at the local level and harmonics for WTG with power electronics converters

Power Quality Issues

Parameters	Cause
Voltage rise	Power production
Voltage fluctuations and flicker	Switching Operations
	Tower shadow effect
	Blade pitching error
	Wind shear
	Fluctuations of wind speed
Harmonics	Frequency inverter
	Thyristor controller
Reactive power consumption	Asynchronous generator
Voltage peaks and drops	Switching operations

IEC 64100-21 (Power Quality) Standards

- ❖Wind turbine generator systems: Measurement and assessment of power quality characteristics of grid connected wind turbines
- ❖ Evaluation of Power quality parameters
- ❖ Measurement of power quality parameters
- ❖ Assessment of voltage during normal operation
- ❖ Estimation of maximum harmonic components

Power Quality Characteristics Parameters (Typical values for 750kW A0 turbine)

- ❖ Rated data (P_n, Q_n, S_n, U_n and I_n) (Pn=750, Qn=0 Un=0.69 kV)
- ❖ Maximum permitted power (P_{mc}) (1.2 Pn)
- ❖ Maximum measured power (P_{60}, $P_{0.2}$)
- ❖ Reactive power (Q)
- ❖ Flicker coefficient ($c[\Psi_k, v_a]$) (c=10.9)
  - Ψ_k is network impedance phase angle (55 degrees)
  - v_a is annual average wind speed (8.2 m/s)
- ❖ Maximum number of specified switching operations (N_{10}, N_{120}) (1 and 12)
- ❖ Flicker step factor ($k_f[\Psi_k]$) (1.2)
- ❖ Voltage change factor ($k_u[\Psi_k]$) (1.5)
- ❖ Maximum harmonic current (I_h)

Rated data (P_n, Q_n, S_n, U_n and I_n)

- ❖ Rated power, P_n, is the maximum continuous electric output power under normal operating condition
- ❖ Rated reactive power, Q_n, is the reactive power from the WTG at rated power, voltage and frequency
- ❖ Rated apparent power, S_n, is the apparent power from the WTG at rated power, voltage and frequency
- ❖ U_n is the rated phase-to-phase voltage
- ❖ Rated current, I_n, is the current from the WTG at rated power, voltage and frequency

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Maximum permitted power (P_{mc})

- P_{mc} serves to provide a clear definition of the maximum 10-minute average power that can be expected from the wind turbine.
- WTGs with active control of output power, typically provide $P_{mc}=P_n$
- WTGs with passive control of output power, are commonly set up with P_{mc} some 20% higher than P_n

Maximum measured power (P_{60}, $P_{0.2}$)

- Maximum measured power, P_{60}, measured as a 60-second average value
- Maximum measured power, $P_{0.2}$, measured as a 0.2-second average value
- P_{60}, $P_{0.2}$ are considered in conjunction with relay protection settings and for the operation of WTGs on isolated grids
- A variable speed wind turbine (Type –B,C,D) may typically provide $P_{60}= P_{0.2}=P_n$
- For Type-A, $P_{0.2}>P_n$

Reactive power (Q)

- The reactive power of the WTG is to be specified for 10-minutes average value
- Also, the reactive power at P_{mc}, P_{60}, and $P_{0.2}$ has to be specified
- Directly grid connected induction generator consumes reactive power, hence capacitor banks compensate Q locally
- Modern frequency converters are commonly capable of controlling the reactive power to supply to the grid

Flicker coefficient (c[Ψk,va])

- The power fluctuation from wind turbines during continuous operation cause voltage fluctuations on the grid
- The flicker coefficient is a normalized measure of the maximum flicker emission from a wind turbine during continuous operation:

$$c[\psi_k, v_a] = P_{st}\frac{S_k}{S_n}$$

Where,

P_{st} is the ficker emission from the wind turbine
S_n is the rated apparent power of the wind turbine
S_k is the short-circuited power of the grid

Maximum number of specified switching operations

- The acceptance of the switching operation depends on:
  - Impact on the grid voltage
  - how often switching may occur
- The maximum number of the switching operation within a 10-minute period N_{10}, and 2-hrs period N_{120} should be stated
- N_{10} ad N_{120} may be governed by modern wind turbine control system settings

Flicker step factor ($k_f[\Psi_k]$)

- The flicker step factor is a normalized measure of the flicker emission due to a single switching operation of a wind turbine:

$$k_f[\psi_k] = \frac{1}{130} P_{st} \frac{S_k}{S_n} T_p^{0.31}$$

Where,

P_{st} is the ficker emission from the wind turbine
S_n is the rated apparent power of the wind turbine
S_k is the short-circuited power of the grid
T_p is the duration of the voltage variation due to the switching opeation

Voltage change factor ($k_u[\Psi_k]$)

- The voltage change factor is a normalized measure of the voltage change caused by a single switching operation of a wind turbine:

$$k_u[\psi_k] = \sqrt{3}\,\frac{U_{max} - U_{min}}{U_n}\,\frac{S_k}{S_n}$$

Where,

U_{max} and U_{min} are the maximum and minimum phase-to-phase RMS value of voltage due to switching
U_n is the nominal phase-to-phase RMS value of voltage
S_n is the rated apparent power of the wind turbine
S_k is the short-circuited power of the grid
T_p is the duration of the voltage variation due to the switching opeation

Maximum harmonic current (I_h)

- The emission of harmonic currents during the continuous operation of a wind turbine with a power electronic converter has to be stated
- The individual harmonic currents will be given as 10-minute average data for each harmonic order up to the 50th
- Further, the maximum total harmonic distortion (THD) also has to be stated
- No need to specify for wind turbines without power electronics

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Summary: Solutions for Power Quality

Quantity	A0	A1	A2	B1	C1	D1
P_{mc}	$P_{mc}>P_n$	$P_{mc}=P_n$	$P_{mc}=P_n$	$P_{mc}=P_n$	$P_{mc}=P_n$	$P_{mc}=P_n$
P_{60}	$P_{60}>P_n$	$P_{60}=P_n$	$P_{60}=P_n$	$P_{60}=P_n$	$P_{60}=P_n$	$P_{60}=P_n$
$P_{0.2}$	$P_{0.2}>P_n$	$P_{0.2}>P_n$	$P_{0.2}>P_n$	$P_{0.2}=P_n$	$P_{0.2}=P_n$	$P_{0.2}=P_n$
Q	f(P)	f(P)	f(P)	f(P)	f(P)	f(P)
$c[\Psi_k,v_a]$	Avg.	High	Avg.	Low	Low	Low
N_{10}&N_{120}	CPS	CPS	CPS	CPS	CPS	CPS
$k_f[\Psi_k]$	High	Avg.	Avg.	Low	Low	Low
$k_u[\Psi_k]$)	High	Avg.	Avg.	Low	Low	Low
I_h	-NA-	-NA-	-NA-	-NA-	Low*	Low*

Where, CPS is Control Parameter Setting

* Modern IGBT based technology

Source : Wind Power in Power System by T. Ackermann

Grid Integration Issues

- ❖ Objective of grid operator is to match generation and system loads
- ❖ No control over system loads
- ❖ Generation output need to be controlled by input
- ❖ No control over input (wind) to the WTG
- ❖ Wind power is not always available as per the requirement
- ❖ Weather forecasting to tackle variability of wind

Wind variability (Wind Speed)

- Studies for 3300 MW capacity carried out on hourly basis for 3 years show that the large variations were rare and for 50% of the time, wind power production does not vary appreciably.
- 99% variations in wind speed caused output variations of 500 MW or less
- This is due to the fact that large turbines with variable speed operations tend to absorb gusts
- There is good dispersion on large geographical area.

Impact of variability

- The impact on operating costs are captured by examining three different intermediate time frames:
  - Frequency regulation – Few seconds
  - Load following – Few minutes
  - Unit Commitment – Hours
- The integration costs can be reduced with better forecasting (Errors of 20 to 50% can occur)
- With advance techniques, like ANN the errors can be restricted to around 15%
- It is critical to consider wind variations along with load variations ignoring which the impacts are overstated

Grid operation with large wind penetration

- With over 6000 MW of installed wind power generation so far in the United States, not a single conventional unit has been installed as a backup generator for wind

Study	Wind Capacity Penetration (%)	Regulation Cost (US$/MWh)	Load-Following Cost (US$/MWh)	Unit Commitment Cost (US$/MWh)	Gas Supply Cost (US$/MWh)	Total Operating Cost Impact (US$/MWh)	System Operating Cost Savings
Xcel-UWIG	3.5	0	0.41	1.44	NA	1.85	na
Xcel-MNDOC	15	0.23	0	4.37	NA	4.60	na
CAISO	4	0.59	0	na	NA	na	na
We Energies	4	1.12	0.09	0.69	NA	1.90	na
We Energies	29	1.02	0.15	1.75	NA	2.92	na
PacifiCorp	20	0	1.6	3.0	NA	4.6	na
Xcel-PSCo	10	0.20	0	2.26	1.26	3.72	na
Xcel-PSCo	15	0.20	0	3.32	1.45	4.97	na
GE-NYISO	10	na	na	na	NA	na	$350 million

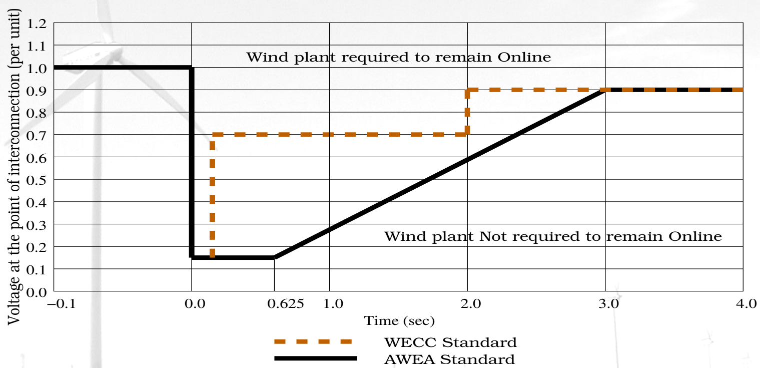
na=not available
NA=not applicable

Grid Code Requirements – A Germany Case Study

- If the voltage drops more than 20% during faults, the 'older' WTs without fault through capability may get disconnected. This worsens critical grid situation.
- There was no Fault ride-through (FRT) norm
- Even today, only few WTGs are able to fulfill the FRT capabilities
- Investigation to replacement or up-gradation of existing plant

Grid Code Requirements

❖ Fault ride-through (FRT) Requirements



Source : “Making Connections” IEEE Power and Energy magazine, Issue -6, Nov./Dec. 2005

IEEE 1547 standards

❖ IEEE 1547.1-2005 standard for conformance test procedure

❖ IEEE standard 1547.2 draft application guide for IEEE Std 1547-2003

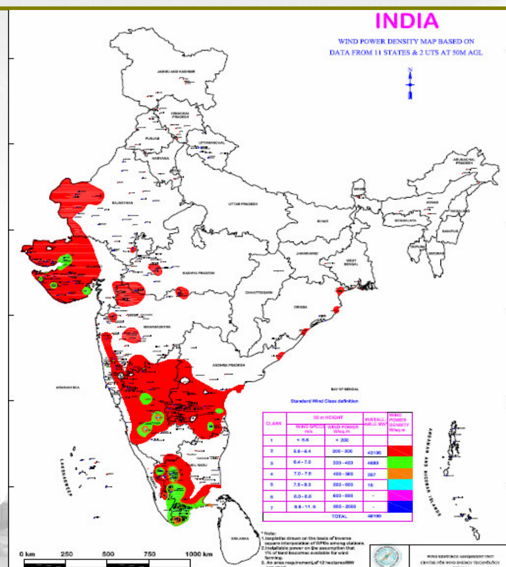
❖ IEEE standard 1547.3 for draft guide for monitoring, information exchange, and control of distributed resources interconnected with electric power systems

❖ IEEE 1547.4 draft guide for design, operation, and integration of distributed resource island systems with electric power systems

Grid Integration Issues of Wind power in India

- ❖ India ranks fourth amongst the wind-energy-producing countries of the world after Germany, Spain and USA.
- ❖ Estimated potential is around 45000 MW at 50 m above ground level.
- ❖ Currently, the total installed capacity of wind generation is around 3.4% of the total installed generation capacity.
- ❖ Installed capacity of wind power in India is more than 5000 MW.

Wind power capacity in India



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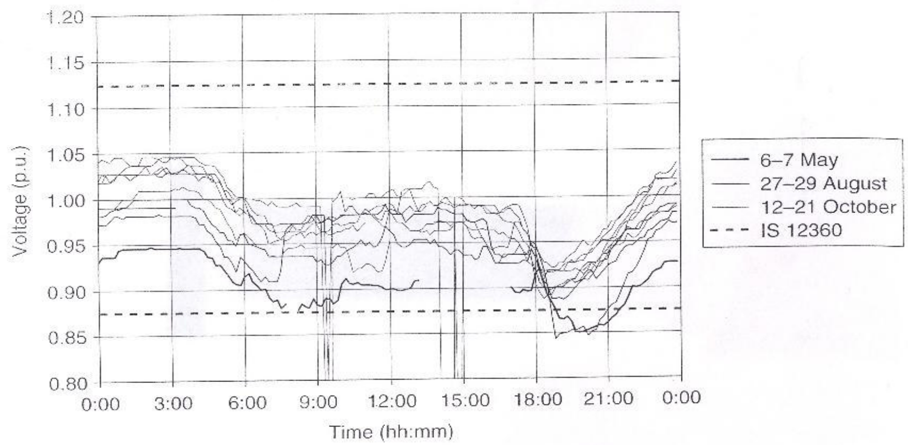
Transmission Capacity in India

- Wind farms are concentrated in rural areas, where the existing transmission grids are very weak.
- The thumb rule is that short circuit ratio should be more than 25. This gives pessimistic results.
- There is lack of coordination between transmission expansion planning and wind installation planning.
- The reinforcement of the transmission system has lagged behind the fast development of wind energy.

Indian Network Characteristics

- In Tamil Nadu, Muppandal, highly wind power penetrated area, has approx. 400 MW installed capacity of wind power connected to 110 kV ring mains.
- The steady-state voltage measured was about 15% below the rated voltage, which is below the tolerance of $\pm$12.5% specified in the IS 12360 (1988).
- frequency measured was about 51Hz at night and down to 48Hz during the day. According to IS 12360, the frequency should be 50Hz $\pm$3% (i.e. in the interval of 48.5Hz to 51.5Hz)

Steady-state voltage measured in Muppandal in 2000



Source : “Wind Power in Power Systems” by T. Ackermann

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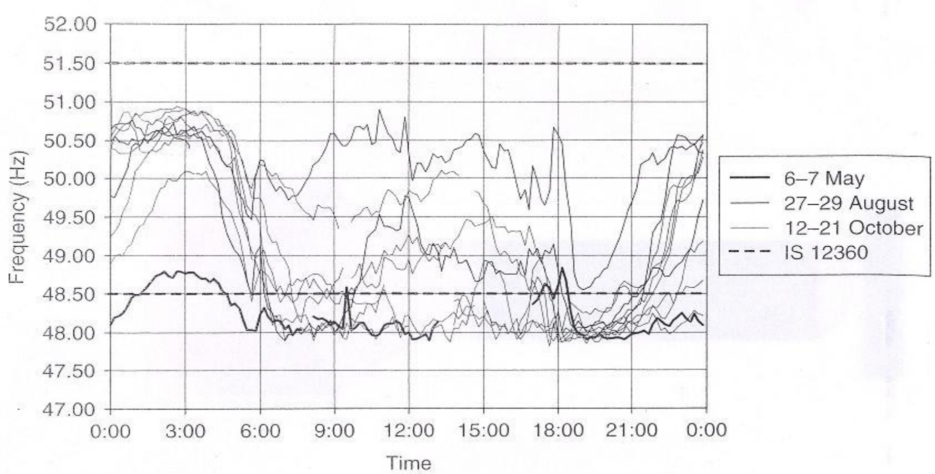

Source : “Wind Power in Power Systems” by T. Ackermann

WTG Technologies Installed in India

- ❖ The majority of WTGs installed in India use induction generators directly connected to the grid (type-A).
- ❖ Full-scale power converter based direct drive WTGs (type-D) are also used.
- ❖ Doubly fed induction generators (type-C) are not installed in India yet.

Conclusions

- ❖ The power quality and grid integration issues depend on the penetration level and grid characteristics like voltage level and strength of the grid.
- ❖ Power peaks, harmonic emission, reactive power, flicker and switching operation etc. should be measured in compliance with IEC 61400-21.
- ❖ Many the of power quality and grid integration issues can be tackled by proper choice of the wind turbine technology.
- ❖ India can learn lesson from experienced countries and the simple solution to both the problems is to either upgrade the turbine or adopt new technologies.

Thank You

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