Challenges and Opportunities in large scale integration of wind energy into grid in emerging countries:
An over view of Wind Power Development in India with specific reference to handling wind variability and power fluctuations

Dr. Venkatesh Raghavan, Member, National Council, Indian Wind Power Association
President, Power Quality Solutions, EPCOS India Pvt. Ltd (A TDK group company)
1.1. India – Power and Energy Scenario

- Installed capacity: 261 GW
- Electricity production: 1,052 Twh (3rd in world)
- Per capita consumption: 950 kWh
- Energy consumption: ≈30% of global average
- Estimated demand by 2032: 900 GW
- 79 million households yet to be electrified
- Electricity penetration: 70%
- Regional imbalances
- Peak shortage and energy deficit

<table>
<thead>
<tr>
<th>Country</th>
<th>Electricity production (TWh)</th>
<th>% Coal</th>
<th>% Natural gas</th>
<th>% Oil</th>
<th>% Hydropower</th>
<th>% Other renewable</th>
<th>% Nuclear power</th>
</tr>
</thead>
<tbody>
<tr>
<td>India</td>
<td>1,052.3</td>
<td>67.9</td>
<td>10.3</td>
<td>1.2</td>
<td>12.4</td>
<td>5</td>
<td>3.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Installed Capacity as on</th>
<th>Coal</th>
<th>Gas</th>
<th>Diesel</th>
<th>Sub-Total Thermal</th>
<th>Nuclear</th>
<th>Renewable</th>
<th>Total</th>
<th>% Growth (on yearly basis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>28-Feb-2015</td>
<td>158,496</td>
<td>22,971</td>
<td>1,200</td>
<td>182,667</td>
<td>5,780</td>
<td>40,867</td>
<td>75,218</td>
<td>263,665</td>
</tr>
</tbody>
</table>

@The break up of other renewable sources is small hydro (4,025 MW), wind power (22,644 MW), biomass power/Cogeneration (4,183 MW), waste-to-power (115 MW) and solar power (3,383 MW).
2.1 Indian Power Grid

• Constant voltage, constant frequency (50 Hz)
• 5 Regions, synchronously connected
• Federal structure, Each state to balance on its own generation and demand
• Transmission: 230 kV, 420 kV, 765 kV, (1200 kV), HVDC
• Sub-transmission: 66 kV, 132 kV
• Regulations: IEGC, ABT, IE act 2003…. 
3.1. Wind power Development in India

Key Statistics

- Cumulative capacity of **23,444 MW** added as on March 2015
- Wind capacity comprises **66%** of total RE installed capacity
- Wind capacity comprises **9%** of total installed capacity
- Wind generation contributes to **~6%** of total generation of the Country

Key Drivers

- Policy of Accelerated Depreciation, concessional import duty
- FIT for wind projects (for both inter & intra State projects)
- GBI for encouraging generation and IPPs
- RPO and REC Mechanism
- NAPCC with national level targets for RE procurement
3.2 Wind power Development in India

- Concentrated in mainly 7 states
  - Difficulties in balancing fluctuating power at inter state level

- 6 year CAGR of 15%
3.3. Capacity addition targets and vision 2022

NAPCC

- NAPCC target of 5% for RE Procurement in 2010
- Target to increase by 1% each year to reach 15% by 2020
- Estimations show a required Wind installed capacity of 40-45 GW by 2020 to meet the NAPCC target

Draft National Wind Mission

- Targets Cumulative Wind capacity of 60 GW by 2022 – to be achieved in phases.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Grid-connected Wind Power (Onshore &amp; Offshore) in MW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Phase 1 (2015-17) [12th Plan]</td>
<td>6,500</td>
</tr>
<tr>
<td>Phase 2 (2017-22) [13th Plan]</td>
<td>30,000</td>
</tr>
<tr>
<td>Total Capacity under Mission</td>
<td>36,500</td>
</tr>
<tr>
<td>Total Cumulative Capacity in 2022</td>
<td>60,000</td>
</tr>
</tbody>
</table>

RE Invest 2015

- Targets 175 GW by 2022
- Includes 60 GW from Wind, 100 GW from Solar and 15 GW from other RE
- 60 GW by 2022

State-wise share of 60 GW Target by 2022

(Source: MNRE)
3.4. Vision 2022 Implications >> Need to things differently

- **Installed capacity (MW)**
  - 2014: 7,500 (Wind), 3,000 (Solar), 22,500 (Others)
  - 2022: 15,000 (Wind), 10,000 (Solar), 60,000 (Others)

- **RE Penetration level (MU terms)**
  - 2014: 5%
  - 2022: 18%

- **Renewable Capacity in GW**
  - 2014: 3.5
  - 2017: 10
  - 2012: 25
  - 2017: 55
  - 2022: 165

- **Penetration in %**
  - 2014: 6%, 13%
  - 2017: 10%, 18%
  - 2022: 16%, 31%
4.1. Current Issues in wind power integration with grid

- WE generation is away from load centers and evacuation issues due to long lines
- Low voltage during high wind season due to high reactive power requirement of WEG (most WEG’s are of type 1)
- Over voltages during low wind season (No VAR drawl by WEG)
- Harmonic generation (both by type 1 as well as type 4 WEG’s)
- Multiple start ups and its impact on power quality (var, harmonics, motoring)
- Low PLF / CUF
- Under utilization of some transmission assets during low wind season
- Variations and over loading of transmission system
4.2. Current Issues in wind power integration with grid

- Must Run status & Merit Order Dispatch
  - Frequent ramp up and ramp down of conventional plants
  - Need to operate at or below technical minimum
  - Need to schedule costly power or back down cheaper power
- Wind variability and need for real time balancing
  - No adequate state level balancing power
  - Issues with balancing with conventional power
    - Coal – response time, wear and tear, poor heat rate below technical minimum
    - Gas – violates merit order when kept as isle reserve
    - Hydro – linked to irrigation projects, depends on monsoon and water reserve
- Forecasting & Scheduling
  - UI & DSM (150 MW or +/- 12% of schedule, whichever is lower)
- Mismatch between demand peak and generation peak
- Short gestation periods (leads infrastructure development!)
- Policy driven growth
4.3. Variation in power output

- High daily, Hourly and seasonal variations

<table>
<thead>
<tr>
<th>Variation in wind generation in MW in day in Gujarat</th>
<th>No of days 2012-13</th>
<th>No of days 2013-14</th>
<th>No of days 2014-15</th>
</tr>
</thead>
<tbody>
<tr>
<td>more than 1000 MW</td>
<td>60</td>
<td>82</td>
<td>94</td>
</tr>
<tr>
<td>more than 500 MW</td>
<td>252</td>
<td>267</td>
<td>257</td>
</tr>
<tr>
<td>less than 500 MW</td>
<td>113</td>
<td>98</td>
<td>108</td>
</tr>
<tr>
<td>Installed Capacity in MW as on March 2015</td>
<td>2694</td>
<td>3087</td>
<td>3342</td>
</tr>
</tbody>
</table>
4.4. Demand Generation mismatch

- Mismatch between demand peak and generation peak – Need for balancing power
5.1. Evolving grid codes and regulations- IEGC

- Harmonic injection shall not exceed limits specified in IEEE 519
- Flicker shall not be more than limits specified in IEC 61000
- Dynamic VAR support as to maintain power factor in the range of -0.95 to + 0.95 (+/- 30% VAR)
- Capability to operate in frequency range of 47.5 to 52 Hz and deliver rated output in the frequency range of 49.5 to 50.5 Hz
- LVRT and ability to supply reactive power for 300 ms or till recovery of voltage (for PCC > 66 kV)
- Real power injection control for generating stations connected to voltage level of 66 kV and above
- Scheduling, UI and DSM (for WF > 10 MW and connected at > 33 kV bus)
  - For intra state:
    - If variation is within +/- 30% of scheduled, no UI charge to generator, but host state has to bear UI charges, If variation is more than +/- 30% of scheduled, UI charges to be borne by the generator
  - For inter state:
    - A maximum of 150% of schedule will be allowed to be injected and +/- 12% of scheduled values.
    - Payment for under injection and over injection (Deviation of 150 MW or +/- 12% of scheduled)
6.1. Challenges & Opportunities

- Main focus is on improving predictability and controllability of wind power
- Classical control system
6.2. Elements to improve predictability & controllability

- Wind forecasting
- Load forecasting
- Hybrid ES
- Virtual Power plants
- REMC
- Capacity credits
- Non-grid connected
- Balancing Power
- Green Corridors
- DR / DSM / Flexible loads
- Energy Storage

Higher the better, efforts is to improve predictability

Higher the better, efforts is to increase controllability
6.3.1. Energy Storage - Drivers

• Drivers for energy storage
  • Peak demand
  • Ancillary services
  • Time shift
  • Defer / reduce need for new gen capacity and trans upgrades
  • RE integration
  • Solar Roof top
  • Micro grids
  • Electric Mobility

• Cost of energy storage to be compared with all benefits of storage systems

• MNRE call for EOI for energy storage demonstration projects (Rural micro grids (grid connected / off grid), Grid interactive micro grids, large stand alone systems, integration of large scale renewable farms)
6.3.2. Energy Storage - Technologies

• Battery:
  • Size: 1 to 20 MW, ……. Mwh
  • Application: Primary Power Balance (< 30 s), EV, Solar Roof top
  • Types
    • Lithium Ion, Advanced lead acid, Sodium Nickel chloride / Alkaline / Flow batteries
  • Estimated potential 28 GW

• CAES :
  • Size: 2 to 20 MW
  • Application: Secondary power balance (30 s – 5 min)

• Pumped storage :
  • Size: 50 to 500 MW
  • Application: Minute reserve (15 min to 4 hours)
  • Estimated potential 95 GW
6.3.3. Energy Storage – Some concepts / opportunities

• Integration with Electric mobility (V2G)
  • Department of Heavy industries, GOI in 2012 launched National Electric Mobility Mission (NEMM) in order to promote EV and targets include 4 million 2 wheelers and 2 million 4 wheelers on road by 2020.

• Integration with smart cities / smart grids
  • Development of medium sized micro grids (stand alone and grid interactive)
  • Development of distributed generation using roof top PV and small wind
  • Creation of EV charging infrastructure

• Integration commercial and residential UPS / inverters
  • India has proliferation of distributed home inverters / UPS due to power supply issues. These UPS / inverters can be tapped and used as distributed energy storage systems and / or as flexible loads
6.4.1. Hybrid energy systems

• Wind – Solar PV
  • Complementary nature of wind and solar
  • Effective use of resources (transformers, Power electronics, lines..)
  • O & M savings (approx. 25% savings compared to stand alone solar)
  • Metering and energy accounting mechanism

<table>
<thead>
<tr>
<th>Parameter</th>
<th>% savings Compared to Standalone Solar</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land</td>
<td>2.50%</td>
</tr>
<tr>
<td>Power Evacuation</td>
<td>5.00%</td>
</tr>
<tr>
<td>Yard Electricals</td>
<td>3.00%</td>
</tr>
<tr>
<td>Inverter</td>
<td>7.00%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>17.50%</strong></td>
</tr>
</tbody>
</table>

• Wind diesel, Wind - Gas
• Hybrid power for Telecom towers (Hydrogen fuel cells, Grid, SPV & Small wind)
  • 440,000 towers, with $ 1.7 bn fuel consumption every year!
6.4.2. Wind – solar PV hybrid: Complementary characteristics

Avg. annual hourly power gen comparison

Hour of day [hr]

Power in kW

Avg. hourly power production for Oct

Avg. hourly power production for Jun
6.5.1 Flexible loads / Demand Response

• Regulations to promote Demand Response / DSM

• Development of flexible loads
  • Off shore water De-salination plants (stand alone and grid connected)
  • Mobile energy storage systems (seasonal application)
  • Local load centers / industrial parks (seasonal industries!)
  • Specific manufacturing industries (construction material, white coal blocks, industrial gases,…)

• Rural Electrification / Energy services
  • Stand alone wind, wind Hybrid systems for rural electrification
  • Energy services (wind water pumping, solar thermal…. ) instead of electrification
6.6.1 Development of Green Corridor

- Dedicated transmission lines for RE power evacuation
- Facilitate inter state RE transmission
- Develop industrial corridors along green corridors
- Creation of International links (Bhutan, Nepal, Srilanka, Bangladesh)
- Existing IEGC does not allow dependence on ISTS / ISGS for balancing – this requires change. Make RE part of ISGS and allow ISTS transaction
- Carve out control area and manage RE at regional level as ISGS.
- Promotion of Grid ancillary services
- Promotion of energy storage services
- Promotion of intra day markets for power trading
- Replace ACSR conductors with HTLS conductors
- Assign dynamic rating for transmission assets
6.7. Creating Balancing Power

- Assigning capacity credits: Integrating RE into PS planning
  - Amount of spinning reserve – consider ES as spinning reserve
  - Voltage levels at which connected
  - Proximity to load centers – create dedicated industrial centers along GC
  - Size of power system / control area – expand control / balancing area
  - Variability of generator – reduce by hybrid systems and local ESS
  - Correlation between generation and demand peaks
  - PLF – increase through re-powering and inter cropping
  - Good power exchange through interconnection – Green corridor, changes in IEGC to allow RE transactions through ISTS and RE as part if ISGS

- Creating balancing power
  - Intra state
  - Inter state
6.8. Virtual Power Plants

- Wider control area and operation as VPP
- Installation of type 4 WEG’s
- Integration with Smart Grids / Smart cities
  - EV (V2G)
  - Solar roof top
  - Grid connected micro grids
- Installation of energy storage and power conditioning devices at wind power plant and network
  - 16 SVC’s / STATCOM’s (+300/-200, +400/-300, +600/-400, +/-200 x 7, +/-300 x )
6.9. Forecasting

- Launched on 13th May 2015
- NIWE + IWPA initiative (7500 MW of wind power)
- Forecasting to be done by RLDC as well as generator
- Composite models under study (Physical, statistical and ANN)
- To be supplemented by load forecasting!
6.10. REMC’s

Renewable Energy Management Centre (REMC) is the “hub” for all information regarding RE Power generation in its area of responsibility.

- Forecasting of RE generation (day ahead, intraday, ramp prediction and others ….)
- Online geospatial monitoring of RE Generation – at the transmission grid boundaries & at RE pooling Stations (through direct Data Acquisition OR through interface with RE Developer monitoring Systems)
- Responsible for quality and reliability of RE data
- Propagate RE related data to its partner xLDC, Forecasting, scheduling and balancing systems.
- Coordination agency on behalf of xLDC for interacting with RE Developers
- Coordinate with xLDC for dispatching and balancing RE power
- Central Repository for RE generation data for MIS and commercial settlement purposes
- Training and Skill building for RE integration into the grid.
- Co-located with the xLDC.

- equipped with advanced Forecasting Tools, Smart Dispatching solutions, & Real Time Monitoring of RE generation,
- closely coordinating with LDCs to facilitate smooth integration of RE generation and ensure secure and optimal operations of the entire grid
7. Summary

- RE penetration levels of 15% to 20% at national level is difficult, but not impossible
- Large scale integration of WE requires not just technical solutions, but economic and regulatory interventions
- Some of the aspects related to large scale integration include:
  - WEG with advanced control and protection features
  - Wider control / balancing areas
  - Green Corridors & REMC
  - Changes in grid codes, regulatory requirements etc.
  - Cost effective energy storage solutions
  - Innovative flexible loads and demand response techniques
  - Robust forecasting techniques integrated with scheduling methods
  - Hybrid energy solutions (wind – solar)
Thank You

Dr. Venkatesh Raghavan