Grid Integration Of RE – Challenges, Roadmap And Way Forward

Context Setting On Indian Experience

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Ministry Of Power, GOI
Section 86. **Functions of State Commission**: --- (1) The State Commission shall discharge the following functions, namely: -

(a)...

...

(e) **promote co-generation and generation of electricity from renewable sources of energy** by providing suitable measures for connectivity with the grid and sale of electricity to any person, and also specify, for purchase of electricity from such sources, a percentage of the total consumption of electricity in the area of a distribution licensee;

...
4.0 OBJECTIVES OF THE POLICY

The objectives of this tariff policy are to:

(a) ....

....

(e) Promote generation of electricity from Renewable sources;

(f) Promote Hydroelectric Power generation including Pumped Storage Projects (PSP) to provide adequate peaking reserves, reliable grid operation and integration of variable renewable energy sources;

....

...
5.11

.... Notwithstanding the above, power from those plants of a generating company, where either whose PPAs have expired or plants have completed their useful life, may be bundled with power from renewable generating plants to be set up through the process of bidding or for which the equipment for setting up such plant is procured through competitive bidding. .......

6.4 (5) In order to promote renewable energy sources, any generating company proposing to establish a coal/lignite based thermal generating station after a specified date shall be required to establish such renewable energy generating capacity or procure and supply renewable energy equivalent to such capacity, as may be prescribed by the Central Government from time to time......
6.4 Renewable sources of energy generation including Co-generation from renewable energy sources:

(1) Pursuant to provisions of section 86(1)(e) of the Act, the Appropriate Commission shall fix a minimum percentage of the total consumption of electricity in the area of a distribution licensee for purchase of energy from renewable energy sources, taking into account availability of such resources and its impact on retail tariffs. Cost of purchase of renewable energy shall be taken into account while determining tariff by SERCs. Long term growth trajectory of Renewable Purchase Obligations (RPOs) will be prescribed by the Ministry of Power in consultation with MNRE.
(i) Within the percentage so made applicable, to start with, the SERCs shall also reserve a minimum percentage for purchase of solar energy.

(iv) Appropriate Commission may also provide for technology based REC multiplier and vintage based REC multiplier.
Provision of competitive bidding/exemption of ISTS charges

(2) States shall endeavor to procure power from renewable energy sources through competitive bidding to keep the tariff low, except from the waste to energy plants. ........

(4) In order to incentivize the Distribution Companies to procure power from renewable sources of energy, the Central Government may notify, from time to time, an appropriate bid-based tariff framework for renewable energy, allowing the tariff to be increased progressively in a back-loaded or any other manner in the public interest......

...

(6) In order to further encourage renewable sources of energy, no inter-State transmission charges and losses may be levied till such period as may be notified by the Central Government on transmission of the electricity generated from solar and wind sources of energy through the inter-state transmission system for sale.
Break-up of generating capacity in India as on 31.5.2017 (in MW)

<table>
<thead>
<tr>
<th>Source</th>
<th>Capacity (in MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>195603</td>
</tr>
<tr>
<td>Gas</td>
<td>25185</td>
</tr>
<tr>
<td>Diesel</td>
<td>838</td>
</tr>
<tr>
<td>Nuclear</td>
<td>6780</td>
</tr>
<tr>
<td>Hydro</td>
<td>44594</td>
</tr>
<tr>
<td>Renewable Energy Sources</td>
<td>57260</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>330260</strong></td>
</tr>
</tbody>
</table>
Break-up of generating capacity in India as on 31.5.2017 – Total capacity 330260 MW.

- Coal, 1,95,603, 59%
- Hydro, 44,594, 14%
- RES, 57,260, 17%
- Nuclear, 6,780, 2%
- Diesel, 838, 0%
- Gas, 25,185, 8%
Target

1,75,000 MW from Renewable Sources of Energy by March 2022.

1,00,000 MW from Solar power

60,000 MW from Wind power

10,000 MW from bio-mass

5,000 MW from small hydro
LIKELY INSTALLED CAPACITY
(as on 31.03.2022)
(Considering Normal Retirement of 22716 MW)

Total IC 4,83,204 MW
LIKELY INSTALLED CAPACITY
(as on 31.03.2027)
(Considering Normal Retirement of 22716 + 25572 MW)

Total IC 6,17,772 MW
Indian Electricity Grid Code

System operator (SLDC/ RLDC) shall make all efforts to evacuate the available solar and wind power and treat as a **must-run station**.

However, System operator may instruct the solar /wind generator to back down generation on consideration of grid security or safety of any equipment or personnel is endangered and Solar/ wind generator shall comply with the same.

For this, **Data Acquisition System facility shall be provided** for transfer of information to concerned SLDC and RLDC.

SLDC/RLDC may direct a wind farm to **curtail its VAr drawl/injection in case the security of grid or safety of any equipment or personnel is endangered.**

**During the wind generator start-up, the wind generator shall ensure that the reactive power drawl** (inrush currents incase of induction generators) shall not affect the grid performance.

**Forecasting and scheduling** mandated.
Standards for Connectivity of Renewables


(for Connectivity below 33 kV)

Central Electricity Authority (Technical Standards for Connectivity to the Grid) (Amendment) Regulations, 2013.

(for Connectivity at 33 kV and above)
Notified on 7th August, 2015.

Effect from 1st November, 2015.

“Absolute Error” shall mean the absolute value of the error in the actual generation of wind or solar generators which are regional entities with reference to the scheduled generation and the 'Available Capacity' (AvC), as calculated using the following formula for each 15 minute time block: \[
\text{Error (\%)} = 100 \times \frac{\text{Actual Generation} - \text{Scheduled Generation}}{(AvC)}
\]
Table – I: Deviation Charges in case of under injection

<table>
<thead>
<tr>
<th>Sr. No.</th>
<th>Absolute Error in the 15-minute time block</th>
<th>Deviation Charges payable to Regional DSM Pool</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(\leq 15%)</td>
<td>At the Fixed Rate for the shortfall energy for absolute error up to 15%</td>
</tr>
<tr>
<td>2</td>
<td>&gt;15% but (\leq 25%)</td>
<td>At the Fixed Rate for the shortfall energy for absolute error up to 15% + 110% of the Fixed Rate for balance energy beyond 15% and up to 25%</td>
</tr>
<tr>
<td>3</td>
<td>&gt;25% but (\leq 35%)</td>
<td>At the Fixed Rate for the shortfall energy for absolute error up to 15% + 110% of the Fixed Rate for balance energy beyond 15% and up to 25% + 120% of the Fixed Rate for balance energy beyond 25% and up to 35%</td>
</tr>
<tr>
<td>4</td>
<td>&gt; 35%</td>
<td>At the Fixed Rate for the shortfall energy for absolute error up to 15% + 110% of the Fixed Rate for balance energy beyond 15% and up to 25% + 120% of the Fixed Rate for balance energy beyond 25% and up to 35% + 130% of the Fixed Rate for balance energy beyond 35%</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Absolute Error in the 15-minute time block</td>
<td>Deviation Charges payable</td>
</tr>
<tr>
<td>--------</td>
<td>-------------------------------------------</td>
<td>---------------------------</td>
</tr>
<tr>
<td>1</td>
<td>( \leq 15% )</td>
<td>At the Fixed Rate for excess energy upto 15%</td>
</tr>
<tr>
<td>2</td>
<td>( &gt;15% ) but ( \leq 25% )</td>
<td>At the Fixed Rate for excess energy upto 15% + 90% of the Fixed Rate for excess energy beyond 15% and upto 25%</td>
</tr>
<tr>
<td>3</td>
<td>( &gt;25% ) but ( \leq 35% )</td>
<td>At the Fixed Rate for excess energy upto 15% + 90% of the Fixed Rate for excess energy beyond 15% and upto 25% + 80% of the Fixed Rate for excess energy beyond 25% and upto 35%</td>
</tr>
<tr>
<td>4</td>
<td>( &gt;35% )</td>
<td>At the Fixed Rate for excess energy upto 15% + 90% of the Fixed Rate for excess energy beyond 15% and upto 25% + 80% of the Fixed Rate for excess energy beyond 25% and upto 35% + 70% of the Fixed Rate for excess energy beyond 35%</td>
</tr>
</tbody>
</table>
Renewable Rich State means a State whose minimum combined installed capacity of wind and solar power is 1000 MW or more.
## Deviation Limits for Renewable Rich States

<table>
<thead>
<tr>
<th>S.No</th>
<th>States having combined installed capacity of Wind and Solar projects</th>
<th>Deviation Limits (MW)- &quot;L&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1000– 3000 MW</td>
<td>200</td>
</tr>
<tr>
<td>2</td>
<td>&gt; 3000 MW</td>
<td>250</td>
</tr>
</tbody>
</table>
Coal-based thermal power plant
Generation from a coal-based thermal power plant

1000 MW
Wind Farm in Tamil Nadu
Wind generation on consecutive days
Wind generation on consecutive days

Wind Generation pattern on 11.05.12

Wind gen in MW

<table>
<thead>
<tr>
<th>Time</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>00:00</td>
<td>254</td>
</tr>
<tr>
<td>01:00</td>
<td>196</td>
</tr>
<tr>
<td>02:00</td>
<td>231</td>
</tr>
<tr>
<td>03:00</td>
<td>247</td>
</tr>
<tr>
<td>04:00</td>
<td>355</td>
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<tr>
<td>05:00</td>
<td>418</td>
</tr>
<tr>
<td>06:00</td>
<td>376</td>
</tr>
<tr>
<td>07:00</td>
<td>365</td>
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<tr>
<td>08:00</td>
<td>221</td>
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<tr>
<td>09:00</td>
<td>177</td>
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<tr>
<td>10:00</td>
<td>202</td>
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<tr>
<td>11:00</td>
<td>277</td>
</tr>
<tr>
<td>12:00</td>
<td>408</td>
</tr>
<tr>
<td>13:00</td>
<td>692</td>
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<td>14:00</td>
<td>1508</td>
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<td>15:00</td>
<td>1647</td>
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<td>16:00</td>
<td>1441</td>
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<td>17:00</td>
<td>527</td>
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<tr>
<td>18:00</td>
<td>690</td>
</tr>
<tr>
<td>19:00</td>
<td>824</td>
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<tr>
<td>20:00</td>
<td>1188</td>
</tr>
<tr>
<td>21:00</td>
<td>1522</td>
</tr>
<tr>
<td>22:00</td>
<td>1708</td>
</tr>
<tr>
<td>23:00</td>
<td>1356</td>
</tr>
</tbody>
</table>
Solar park
Typical solar generation over a day in Gujarat for a non-cloudy day
Solar generation on a cloudy day 1-9-2012 in the Charanka Solar Park Gujarat (capacity of about 200 MW)
Solar generation on a cloudy day 9-9-2012 in the Charanka Solar Park Gujarat
Issues and Challenges in Grid Operation

• Frequency Stability
• Voltage Stability
• Transmission congestion
• Angular Stability
Solutions – Frequency Stability

Intermittency of power to be balanced by quick acting generation like hydro (storage, pondage or pumped-storage storage) and gas based generating stations.

Future balancing sources, like MW scale batteries, Compressed Air Energy Storage (CAES), flywheel, thermal storage, etc.

Pumped storage plants, batteries, CAES, flywheel are all plants that have a double benefit of absorbing excess power and releasing the same when needed.

Preferable to have the balancing sources close to the wind and solar generation for optimum utilisation of the intermittent generation and the transmission system.
OPERATION OF PUMP STORAGE PLANT wrt FREQUENCY AT KADAMPARAI
Available energy storage technologies (Power vs Discharge Duration) (Source: EPRI / DOE Energy Storage Handbook)
Electrochemical EES - Battery Energy Storage System

- Lead Acid battery
- Lithium Ion (Li-ion) battery
  - Lithium Iron Phosphate (LFP)
  - Lithium Cobalt (LCO)
  - Lithium Manganese Oxide (LMO)
  - Lithium Nickel Manganese Cobalt Oxide (NMC)
  - Lithium Titanate (LTO)
Electrochemical EES - Battery Energy Storage System

- Sodium-Sulfur battery (NaS)
- Sodium Ion batteries
- Sodium Nickel Chloride (NaNiCl2) batteries
- Flow Batteries
  - Vanadium Redox battery (VRB)
  - Zinc Bromine battery (ZnBr)
  - Iron Chrome battery
- Nickel Cadmium (NiCd) battery
- Nickel Metal Hydride (NiMh) battery
Specifications of Battery Energy Storage System

While deciding economics of energy storage for renewable integration, a number of key factors need to be considered. These include:

- Size of storage (Power vs energy)
- Cycle life
- Depth of Discharge during each cycle (has impact on number of cycles for most electrochemical batteries)
- Charge / Discharge rate (C rate)
- Space and geographical requirements (specially required for pumped hydro and CAES projects)
Demand Response

• One of the biggest sources of balancing the intermittency, which is being increasingly used in developed countries, is demand response.
• Immediately available
• Rules and Smart Meters need to be put into place
• Essential and non-essential loads accompanied with 24x7 and Interruptible tariff
<table>
<thead>
<tr>
<th>Service</th>
<th>Service Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regulation</td>
<td>Power sources online, on automatic generation control, that can respond rapidly to system-operator requests for up and down movements; used to track the minute-to-minute fluctuations in system load and to correct for unintended fluctuations in generator output to comply with Control Performance Standards (CPSs) 1 and 2 of the North American Reliability Council (NERC 2002)</td>
</tr>
<tr>
<td>Spinning reserve</td>
<td>Power sources online, synchronized to the grid, that can increase output immediately in response to a major generator or transmission outage and can reach full output within 10 min to comply with NERC’s Disturbance Control Standard (DCS)</td>
</tr>
<tr>
<td>Supplemental reserve</td>
<td>Same as spinning reserve, but need not respond immediately; units can be offline but still must be capable of reaching full output within the required 10 min</td>
</tr>
<tr>
<td>Replacement reserve</td>
<td>Same as supplemental reserve, but with a 30-min response time; used to restore spinning and supplemental reserves to their pre-contingency status</td>
</tr>
<tr>
<td>Voltage control</td>
<td>The injection or absorption of reactive power to maintain transmission-system voltages within required ranges</td>
</tr>
<tr>
<td>ISO/RTO</td>
<td>Primary Frequency Control Reserve</td>
</tr>
<tr>
<td>---------</td>
<td>----------------------------------</td>
</tr>
</tbody>
</table>
| CAISO   | no market | Regulation Reserve  
Regulation Up  
Regulation Down | Spinning reserve  
Non-spinning Reserve |
| ERCOT   | no market | Regulation Services  
Reg Service - Up  
Reg Service - Down | Responsive Reserve Service  
Non-Spinning Reserve Service  
Replacement Reserve Service |
| ISO-NE  | no market | Regulation | Ten-Minute Spinning  
Ten-Minute Non-Spinning  
Thirty-Minute Operating |
| MISO    | no market | Regulating Reserve | Contingency Reserve  
Spinning Reserve  
Supplemental Reserve |
| NYISO   | no market | Regulation | 10-Minute Spinning Reserve  
10-Minute Non-Synchronized Reserve  
30-Minute Spinning Reserve  
30-Minute Non-Synchronized Reserve |
| PJM     | no market | Regulation | Contingency Reserve  
Synchronous Reserve  
Quick Start Reserve  
Supplemental Reserve |
| SPP*    | no market | Regulation  
Regulation Up  
Regulation Down | Contingency Reserve  
Spinning Reserve  
Supplemental Reserve |
Voltage Stability

Fluctuating wind and solar generation causes variation in reactive power exchange of the wind and solar generators with the grid, and, therefore, the fluctuations of voltage in the grid.

Mitigation measures of the effects of the multiple start-ups include provision of dynamic reactive power compensation i.e. SVC (Static VAR compensators)/ STATCOM (Static Synchronous Compensator).

Most of the advanced energy storage systems can also provide reactive power support without need for consuming active energy.

Locational requirement for reactive power could help in determining appropriate location for deploying energy storage systems that can provide multiple value propositions to the grid.
Transmission congestion

Flexible AC Transmission System (FACTS) devices like Thyristor Controlled Series Compensation (TCSC) and phase shifting transformers could be installed to shift power from heavily loaded lines to lightly loaded lines in parallel paths, depending on economics.

Strategically placed energy storage devices can also help in relieving transmission congestion by time shifting the flow of energy across constrained paths.

Alternately, In order to harness the huge potential of RES in specific States, high capacity Inter-State and Inter-Regional corridors transmission corridors could be constructed linking high concentration renewable generation areas to balancing generation already located elsewhere in the grid. Market Integration would have to be provisioned.
Angular Stability

Various type of FACTS devices, which would need to change dynamically, to change the power system parameters in accordance with changing topology of intermittent generation from renewable energy sources, may need to be installed.

System Operator should be aided in this by Phasor Measurement Units (PMUs) installed at critical points in the grid, for visibility in the grid w.r.t. real-time angular difference.
GREEN CORRIDORS

Green Corridors –

For expansion of wind, solar and small hydro in the states of Tamil Nadu, Gujarat, Rajasthan, Karnataka, Andhra Pradesh, Maharastra, Himachal Pradesh and Jammu & Kashmir.

The transmission system costing about Rs. 32,000 crores (5 billion US $) have been planned to cater to the needs of about 32 GW RE capacity addition program for the 12th Plan (2012-17).

These systems include both intra state and inter state transmission system of 132 kV, 220 kV, 400 kV and 765 kV voltage levels.

Green Corridors Phase-II – For 1,75,000 MW RES evacuation - under finalization. Some portion under operationalization.
Cost of balancing

• Keeping standby capacity for continued supply in case of dip in RES generation.

• Increase of fixed charge of Coal based/gas based generation due to operation at lower PLF.

• Operation of Coal based/gas based generation at sub-optimum levels, causing increase of fuel charge.

• Cost of Deviation from schedule as per the DSM mechanism/Cost of Ancillary Services to handle stochastic variation in generation, which cannot be predicted.

• Backing down cheaper generation in order to facilitate the must-run RES, even if costlier.
## Cost of balancing – Case Study of Gujarat

<table>
<thead>
<tr>
<th></th>
<th>Description</th>
<th>Value (Rs/Kwh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Total balancing charge for coal based station (fixed + fuel charge) (Rs/Kwh)- Spread over renewable generation</td>
<td>0.15</td>
</tr>
<tr>
<td>2</td>
<td>Impact of DSM per unit- Spread over renewable generation</td>
<td>0.30</td>
</tr>
<tr>
<td>3</td>
<td>Impact on tariff PER UNIT for gujrat discom for backing down coal generation assuming solar and wind at Rs. 4/kwh and coal fuel charge at Rs. 2.0/KWH-, considering 25% substitution - Spread over renewable generation</td>
<td>0.50</td>
</tr>
<tr>
<td>4</td>
<td>Stand by charge (Rs/Kwh)- Spread over renewable generation</td>
<td>0.20</td>
</tr>
<tr>
<td>5</td>
<td>Extra transmission charge (Rs/Kwh)- Spread over renewable generation</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td><strong>Total Impact- Spread over renewable generation (Rs/Kwh)</strong></td>
<td>1.41</td>
</tr>
<tr>
<td></td>
<td><strong>Total Impact- Spread over Total Energy Met (Rs/Kwh)</strong></td>
<td>0.51</td>
</tr>
</tbody>
</table>
Issues

• States yet to notify Forecasting and Scheduling mechanism for their intra-State wind and solar RES.

• Development of an Ancillary Services Market in India with different response times through competitive bidding.

• Sharing of Balancing Charges.

• Optimum use of resources for balancing – placement of balancing source near the source of RES vs strengthening of transmission system and use of balancing sources in another control area.
Thank You