Sponsors and Official GOI Lead

Prepared by:
Grid Integration Studies: Our Purpose

- If India develops **100** GW of solar and **60** GW of wind energy, how would the system operate in 2022?
- What can policy makers do to lower the cost of operating this system and better integrate RE?
  - Note: Fixed costs considered as sunk cost
Stakeholder Participation

• Grid Integration Review Committee
  o Peer Review and Guidance
  o Over 150 Experts
  o Four sets of meetings

<table>
<thead>
<tr>
<th></th>
<th>National (New Delhi)</th>
<th>Southern (Bengaluru)</th>
<th>Western (Mumbai)</th>
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<tbody>
<tr>
<td>1\textsuperscript{st} GIRC</td>
<td>13/10/15</td>
<td>15/10/15</td>
<td>19/10/15</td>
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<td>2\textsuperscript{nd} GIRC</td>
<td>19/4/16</td>
<td>21/4/16</td>
<td>22/4/16</td>
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<td>3\textsuperscript{rd} GIRC</td>
<td>18/7/16</td>
<td>20/7/16</td>
<td>22/7/16</td>
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<td>4\textsuperscript{th} GIRC</td>
<td>17/2/17</td>
<td>20/2/17</td>
<td>22/2/17</td>
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More than 2000 person hours
Methodology Overview

1. Build an operations model of today’s power system
2. For future year, forecast load and necessary capacity to meet load
3. Simulate power system operations in the future year

Greening the Grid uses the PLEXOS production cost model
## Studied scenarios

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Solar (GW)</th>
<th>Wind (GW)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>No New RE</td>
<td>5</td>
<td>23</td>
<td>Wind and solar capacities installed as of 2016</td>
</tr>
<tr>
<td>20S-50W</td>
<td>20</td>
<td>50</td>
<td>Total installed capacity as targeted in Green Energy Corridors &amp; National Solar Mission</td>
</tr>
<tr>
<td>100S-60W</td>
<td>100</td>
<td>60</td>
<td>Current Government of India target for 2022</td>
</tr>
<tr>
<td>60S-100W</td>
<td>60</td>
<td>100</td>
<td>Solar and wind targets reversed in comparison to official target</td>
</tr>
<tr>
<td>150S-100W</td>
<td>150</td>
<td>100</td>
<td>Ambitious RE growth</td>
</tr>
</tbody>
</table>
Modeling features

- High-resolution wind and solar resource data (both forecasts and actuals)
  - Wind: 5-minute weather profiles for each 3 x 3 km² area
  - Solar: 1-hour weather profiles for each 10 x 10 km² area, including impact of aerosols
- Unique properties for each generator
- CEA/CTU projections of properties and locations of new lines and power plants for 2022
- Enforced state-to-state transmission flows
- Interregional transmission limits that adhere to reliability standards
Transmission representation in the model

National study

- All generation and transmission located on a single node per state plus union territories (36 nodes total)
- No enforced intrastate transmission constraints

Regional study

- Full, planned transmission system in Southern and Western Regions plus Rajasthan (3,280 nodes)
- Loading limits enforced on all relevant intrastate lines; congestion limits enforced on all high-volume intrastate lines ( >400 kV)
India’s Power System in 2022—Achieving System Balance Every 15 Minutes

https://maps.nrel.gov/IndiaGTG/
Key Findings
Annual impacts: 175 GW RE can meet 22% of India’s annual electricity demand with minimal RE curtailment.
Daily impacts: Existing flexibility in the coal-dominated system can manage RE variability
Coal units are typically backed down midday

Coal commitment and dispatch for one week in July
Average coal plant load factors fall 63% to 50%, with over 19 GW of capacity that never starts*

* Compared to No New RE; Plant load factor (PLF) is calculated using weighted averages
Retiring 46 GW of coal (20% of coal capacity) may not negatively affect operations.

Change in coal plant load factors after 46 GW of coal plants are retired.

46 GW coal (205 units) operate very little in a high-RE future.

A system with 175 GW of RE could support some combination of higher demand growth or retirements of generation.

Each dot represents one unit.
Strategies for better operation can reduce the cost of RE integration and reduce curtailment

- Coordinated operations across states
- Lower technical minimums for coal plants

**Cost savings**
- **State**: Scheduling and dispatch
  - INR 6300 crore annually
- **Regional**: Scheduling and dispatch

**RE curtailment**
- **70%**: Technical minimum (as operated in 2014)
- **55%**: Technical minimum
Batteries do not add value to RE integration from scheduling/dispatch perspective

- 2.5 GW batteries reduce RE curtailment and peak coal consumption
- But batteries charge during the day, in part on coal, and have efficiency losses
- Electricity savings from reduced RE curtailment (1.2 TWh) is offset by battery efficiency losses (2.0 TWh)
- Total coal generation is not affected
- CO₂ emissions do not decline

Batteries provide value for other reasons outside scope of study:
  - Local transmission congestion, ancillary services...
Low and high hydro years do not handicap RE integration

<table>
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<tr>
<th>100 GW SOLAR, 60 GW WIND</th>
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<tbody>
<tr>
<td><strong>Normal operations</strong></td>
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<tr>
<td><strong>Production cost</strong></td>
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<tr>
<td>(230,000 crore)</td>
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<tr>
<td><strong>Coal generation</strong></td>
</tr>
<tr>
<td>(1000 TWh)</td>
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<tr>
<td><strong>CO₂ emissions</strong></td>
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<tr>
<td>(1,100 MMT)</td>
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<tr>
<td><strong>RE curtailment</strong></td>
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<td>(1.4%)</td>
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Priority Takeaways

1. India’s power system has significant latent physical flexibility to integrate 175 GW RE with existing plans.

2. Harnessing this flexibility is the key challenge. Need appropriate regulations, markets, incentives...

3. For example, consider ways at the state level to compensate coal plants for operating flexibly.

4. Additional planning could identify optimal locations for new RE and associated inter- and intrastate transmission.

Source: NREL PIX 19498