Addressing RE Intermittency and Operation Aspects of Generating Units in Long-term System Planning of Indian Power Sector

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Introduction

- Current installed capacity of India: 365 GW

- Driven by concerns of energy security and global warming, country is accelerating towards a renewable energy (RE) future

- INDC Targets of India –
  1) Reduction in CO₂ emission intensity of its GDP by 30% - 35% from 2005 level by 2030
  2) 40% capacity share of non-fossil fuel generation by 2030

- A huge potential of solar and wind energy resources available

- All planning models are at developing stage
Challenges in system planning with high RE

- Traditional planning approaches use low level of spatial, temporal and technical details to avoid associated computation

- Planning model with low spatial resolution fail to capture intra-regional intermittency of renewable energy sources (RESs) in large geographical regions

- Low-temporal definition does not facilitate inclusion of seasonal/diurnal variation of RE sources that demand additional system flexibility

- Neglecting techno-economic operational parameters may significantly alter the generation portfolio and results in a sub-optimal capacity mix
Indian power sector TIMES (IPST) model: General settings

- Spatial resolution: 5 Regions - NR, ER, NER, WR, SR
- Calibration years: 2015-2019
- Planning years: 2020-2040
- Timeslices: 288

![Fig: Timeslice level](image)

![Fig: Regional load dispatch centres](image)
Model description

- Existing generation technologies: Coal, Lignite, Gas, Nuclear, Large-hydro, RE (Small-hydro, Wind, Solar, Biomass)
- New generation technologies: Coal, Gas, Large-hydro, RE
- Discount rate: 10%
- Techno-economic parameters: Fixed and variable operating cost, availability factor, efficiency, start year of plant, plant life and investment cost for new technologies
- Solar and Wind energy: 1) Class wise categorization based on annual capacity factor
  2) Timeslice wise capacity factor
- Hydro power plants: Region wise seasonal availability factor
Intra-regional solar and wind variability

- Assessment of total land availability and capacity potential of solar and wind plants for each 1x1 degree grid cell – GIS based study
- Categorization of grid cells in 10 different classes based on annual availability factor
Demand projection and inter-regional trading

- Exogenous projection of annual electricity consumption
- Drivers: Past electricity consumption and GDP
- Regional electricity consumption: estimated based on historical share of regions
- AT&C losses: 21.04% in 2017, assumed to reduce to 9.2% by 2040
- Inter-regional links are represented by existing inter-regional transmission capacities to facilitate bi-directional trading - Total 7 links
Scenario and hypothesis

1) RE capacity targets: Interim target of 175 GW RE by 2022,
   100 GW RE addition between 2023 and 2027

2) Carbon tax: an increasing price on CO$_2$ emission

No new coal plants between 2023-2027 (except proposed or under commissioning)

Considered cases:

   a) Without Operational Constraint
   b) With Operational Constraint (Unit commitment – UC)

Fig: Carbon tax year wise
Case 1 (C1): Without operational constraints

- With 175 GW of RES in 2022, the remaining total installed capacity - 304 GW, comprising 47.7 GW Hydro, 215.8 GW coal, 25.4 GW Gas, 5.51 GW Lignite, and 9.6 GW nuclear.

- Total installed capacity - 803.44 GW in 2030 and 1412.80 GW in 2040.

- Solar and wind generation share - 36.38 % in 2030 and 45.02 % in 2040.

- Total installed capacity - 740.92 GW in 2030 and 1483.98 GW in 2040.

- Solar and wind generation share - 32.75 % in 2030 and 49.55 % in 2040.
Case 2 (C2): With operational constraints

- Indian power system is dominated by inflexible coal plants
- Without UC parameters, model treats inflexible generation to be highly flexible
- With UC parameters, model increases investment in flexibility resources
Comparative analysis of different cases

Case 2-a (C2a) - Inclusion of minimum stable generation in C1
Case 2-b (C2b) - Inclusion of ramp rate in C2a
Case 2-c (C2c) - Inclusion of startup and shutdown cost in C2b
Case 2-d (C2d) - Inclusion of partial load efficiency in C2c

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<thead>
<tr>
<th>Particulars</th>
<th>Scenario 1</th>
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<tbody>
<tr>
<td></td>
<td>C1</td>
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<tr>
<td>Solar capacity (GW)</td>
<td>635.5</td>
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<tr>
<td>Solar generation share (%)</td>
<td>25</td>
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<tr>
<td>Wind capacity (GW)</td>
<td>277.3</td>
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<tr>
<td>Wind generation share (%)</td>
<td>19.6</td>
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<tr>
<td>Storage capacity (GW)</td>
<td>77.5</td>
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<td>Non-fossil fuel generation share (%)</td>
<td>58.6</td>
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<td>Coal capacity (GW)</td>
<td>318.3</td>
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<td>Average CUF of coal plants</td>
<td>0.58</td>
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<tr>
<td>Carbon emission (Mt)</td>
<td>1386</td>
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Final results with all UC constraints

- Total installed capacity - 691.31 GW in 2030 and 1156.95 GW in 2040.
- Capacity share of solar and wind – 47.24 % in 2030 and 57.51 % in 2040.
- Total storage capacity - 16.25 GW in 2030 and 101.72 GW in 2040.

- Total installed capacity - 692.41 GW in 2030 and 1255.42 GW in 2040.
- Capacity share of solar and wind – 46.16 % in 2030 and 61.31 % in 2040.
- Total storage capacity - 25.54 GW in 2030 and 148.72 GW in 2040.
Spatial distribution of solar and wind capacity in 2040

(a) Solar energy

(a) Wind energy
CO2 emissions and emission intensity

- Total CO2 emission in 2030: 1270.73 Mt in scenario 1 and 1191.03 Mt in scenario 2
- Total CO2 emission in 2040: 1860.31 Mt in scenario 1 and 1685.41 Mt in scenario 2
Conclusions

- Explicitly targeting renewable generation may not fully ensure power sector decarbonization as fossil-fuel generation will continue to contribute to CO₂ emissions.

- An instrument like carbon tax can expedite decarbonization by promoting investments in green technologies and improving efficiency of existing thermal power plants.

- Methodology to classify RE sources in different classes, as opposed to increasing the resolution of planning model, reduces computational complexity.

- For a power system dominated by inflexible generation, incorporating all UC constraints is vital to ensure adequate quantification of flexibility resources and analyze emission related polices.

- Computational efforts can be further reduced by removing ramping constraints (if flexibility is not a concern).
Thank you for your attention!

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