Assessing Impact of Energy Storage on System Operational Cost with Large scale PV Integration

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RENEWABLE ENERGY IN INDIA

- Total installed capacity of power generation - 329204 MW
- Installed capacity of RE sources is 51360 MW i.e. 17.3% of total capacity
- Gross electricity generation of the country is 1236 billion kWh
- As of April 2017, generation share – 76.4% coal, 3.9% gas, oil 0.03%, nuclear 3.04%, hydro 9.9%, renewable sources 6.6%
DEVELOPMENT OF RENEWABLES IN INDIA

- RE potential - 896.602 GW
- RE target – 175 GW by year 2020-22
- 100 GW from Solar, 60 GW from wind power, 10 GW from bio power and 5 GW from small hydro power
- MNRE aims above 17% share of RE in electricity mix by 2022
ISSUES WITH GROWTH OF RENEWABLE ENERGY SOURCES

- Variable renewable energy (VRE) sources like wind and solar are intermittent
- Unpredictability due to nature
- Sunshine and wind are not available throughout the 24 hours of a day
- Lack of coincidence with the demand pattern
- Location specific potential
SOLUTIONS TO ADDRESS ISSUES RELATED TO VRE

- Following approaches to address VRE utilization:
  
  I. Better load forecasting
  
  II. Load shifting
  
  III. Energy Storage

- Energy storage systems (ESS) - characterized by power generation and storage capacity

- Store the surplus generation, utilize it during low or no generation
LITERATURE SURVEY

i. Black and Strbac (2007) – quantified storage value, determined fuel costs for conventional and wind generation systems

ii. Brown and Lopes et al (2008) – value of pump quantified as the reduction it causes in fuel costs and dynamic reserves it provides


v. Denholm Paul et al (2013) – overall system operations cost with and without storage

vi. De Siaternes et al (2016) – storage value quantified in terms of reduction in CO₂ emissions
PUMPED HYDRO ENERGY STORAGE (PHES) SYSTEMS

- Well established commercially available storage technology
- Stores and produces electricity from a hydroelectric plant
- Water discharge from upper to lower reservoir during generation
- Water pumped back to upper reservoir from lower to store electricity
- Quick start up and shut down with tighter ramping capabilities
- Ability to track load changes and adapt
PUMPED HYDRO ENERGY STORAGE (PHES) SYSTEM

Diagram showing the flow of electricity in and out of the system, with components such as Pump, Demand, Upper Reservoir, Lower Reservoir, Turbine, and Thermal units labeled.
## PUMPED STORAGE POTENTIAL IN INDIA

- Identified Sites: 63
- Potential capacity: 96,524 MW

<table>
<thead>
<tr>
<th>Region</th>
<th>Potential Installed Capacity (MW)</th>
<th>Capacity Developed (MW)</th>
<th>Capacity under Construction (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northern</td>
<td>13065 (7)</td>
<td>0</td>
<td>1000 (1)</td>
</tr>
<tr>
<td>Western</td>
<td>39684 (29)</td>
<td>1840 (4)</td>
<td>80 (1)</td>
</tr>
<tr>
<td>Southern</td>
<td>17750 (10)</td>
<td>2005.6 (3)</td>
<td>0</td>
</tr>
<tr>
<td>Eastern</td>
<td>9125 (7)</td>
<td>940 (2)</td>
<td>0</td>
</tr>
<tr>
<td>North Eastern</td>
<td>16900 (10)</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>96524 (63)</strong></td>
<td><strong>4785.6 (9)</strong></td>
<td><strong>1080 (2)</strong></td>
</tr>
</tbody>
</table>

(SO: CEA)
## MAJOR PUMPED STORAGE PLANTS IN INDIA

<table>
<thead>
<tr>
<th>Location</th>
<th>State</th>
<th>Capacity (MW)</th>
<th>Year of Commissioning</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kadamparai</td>
<td>Tamil Nadu</td>
<td>4 X 100</td>
<td>1987-88</td>
<td>Operating in pumping mode</td>
</tr>
<tr>
<td>Srisailam</td>
<td>Andhra Pradesh</td>
<td>6 X 150</td>
<td>2001-03</td>
<td>Operating in pumping mode</td>
</tr>
<tr>
<td>Sardar Sarobar</td>
<td>Gujarat</td>
<td>6 X 200</td>
<td>2002-06</td>
<td>Not operating in pumping mode</td>
</tr>
<tr>
<td>Parulia</td>
<td>West Bengal</td>
<td>4 X 225</td>
<td>2007-08</td>
<td>Operating in pumping mode</td>
</tr>
<tr>
<td>Ghatghar</td>
<td>Maharashtra</td>
<td>2 X 125</td>
<td>2008</td>
<td>Operating in pumping mode</td>
</tr>
<tr>
<td>Tehri</td>
<td>Uttarakhand</td>
<td>1000</td>
<td>2006</td>
<td>In construction phase</td>
</tr>
</tbody>
</table>
OBJECTIVES

1. To setup a unit commitment power system model to analyse the impact of energy storage in a power system with large scale PV integration
2. To assess the economic value of ESS like Pumped Energy Storage System in a PV dominated power system
METHODOLOGY – SCUC MODEL

- Security Constrained Unit Commitment (SCUC) model determines optimal order of operation of power generators with the objective of cost minimization while maintaining certain constraints.
- Mixed integer non-linear problem (MINLP) formulated in GAMS
- A model characterizing a power system with PV generating unit, thermal units and pumped hydro energy storage (PHES) unit with two scenarios,
  i. without pumping action of pumped hydro unit
  ii. with pumping action of pumped hydro unit
SCUC MODEL

- SCUC model developed with: Power balance, power generation capability limits of units, ramp rate limits, minimum uptime and down-time and transmission flow limits of lines constraints and hydrological constraints of PHES unit like reservoirs’ volume and discharge limits

- Objective of the SCUC model: minimize the total social cost of operation which includes the cost of generation and penalty for unserved load:

\[
Min \ \sum_{i=1}^{I} \sum_{t=1}^{T} \left\{ (a_i * u_{i,t}) + (b_i * G_{i,t}) + (c_i * G_{i,t} * G_{i,t}) + SU_{i,t} \right\} + C_p \sum_{n=1}^{N} \sum_{t=1}^{T} E_{n,t}
\]

- \(a_i\) Fixed cost of generation from unit \(i\) (Rs/hr)
- \(b_i\) Per unit variable cost of generation from unit \(i\) (Rs/MWh)
- \(c_i\) Per square unit variable cost of generation from unit \(i\) (Rs/MWh²)
- \(u_{i,t}\) Commitment status of thermal generator \(i\) in time period \(t\), 1 when it is on, 0 when off
- \(G_{i,t}\) Generation from thermal generator \(i\) in time period \(t\) (MWh)
- \(E_{n,t}\) Energy not served at bus \(n\) in period \(t\) (MW)
- \(SU_{i,t}\) Startup cost of thermal unit \(i\) in period \(t\) (Rs)
- \(C_p\) Penalty cost for unmet demand (Rs/MWh)
SYSTEM CHARACTERISTICS OF 6-BUS TEST MODEL

- The 6-bus test system - 2 thermal units – one coal fired (100 MW) and one gas fired (120 MW), 1 PV generating unit (150 MW), 1 PHES (230/200 MW) and 7 transmission lines

*Now also implemented on IEEE standard 30-bus system*
RESULTS (PHES without pumping)
RESULTS (PHES with pumping)
## PHES - ECONOMICS OF SYSTEM OPERATION

<table>
<thead>
<tr>
<th></th>
<th>Without pump</th>
<th>With pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total cost of operation (million Rs.)</td>
<td>2.87</td>
<td>2.11</td>
</tr>
<tr>
<td>Total generation from thermal units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal Unit G1 (MWh)</td>
<td>1246</td>
<td>1407</td>
</tr>
<tr>
<td>Gas Unit G2 (MWh)</td>
<td>328.5</td>
<td>0</td>
</tr>
<tr>
<td>Total Cost of generation from thermal units</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coal Unit G1 (million Rs.)</td>
<td>1.86</td>
<td>2.11</td>
</tr>
<tr>
<td>Gas Unit G2 (million Rs.)</td>
<td>0.88</td>
<td>0</td>
</tr>
<tr>
<td>Total energy demand shed (MWh)</td>
<td>13</td>
<td>0</td>
</tr>
<tr>
<td>Cost of load shedding (million Rs.)</td>
<td>0.13</td>
<td>0</td>
</tr>
<tr>
<td>Reduction in system cost (mill. Rs.)</td>
<td></td>
<td>0.76 (0.63)</td>
</tr>
<tr>
<td>Reduction in unit cost (Rs./kWh)</td>
<td></td>
<td>0.3 (0.25)</td>
</tr>
</tbody>
</table>
ECONOMIC VALUE OF PUMPED STORAGE

- Assumptions: same SCUC operation and same demand pattern throughout the year, life of PHES unit – 30 years and discount rate – 15%

<table>
<thead>
<tr>
<th>6-bus test system</th>
<th>Overall system operation cost without penalty</th>
<th>Overall system operation cost with penalty</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daily cost of operation (million Rs.)</td>
<td>Without pump</td>
<td>With pump</td>
</tr>
<tr>
<td></td>
<td>2.74</td>
<td>2.11</td>
</tr>
<tr>
<td>Savings/ year (million Rs.)</td>
<td>231</td>
<td>279</td>
</tr>
<tr>
<td>Present value (million Rs.)</td>
<td>1748</td>
<td>2107</td>
</tr>
<tr>
<td>Value of pump facility (million Rs./MW)</td>
<td>8</td>
<td>9.6</td>
</tr>
</tbody>
</table>

- Thus, the pumping facility of a hydro unit adds a value equivalent to Rs. 9.6 million /MW and Rs. 8 million /MW excluding the penalty costs.
CONCLUSIONS

- Spillage reduced by 91% in 6-bus test system. In a 6-bus test system, presence of pump reduced cost by 26.5% and by 23.48% excluding the penalty cost.
- Translates to present value of Rs. 9.6 million/MW including and Rs. 8 million/MW without the cost of unserved energy.

Policy and regulatory insights

- Emphasises proper utilisation of existing PHES systems in India to avoid RE spillage.
- Prioritise development of potential PHES capacity alongside push for high RE penetration in the country.
- Change in operational code for PHES (currently - night pumping (high freq.)) to store curtailed RE.
SHORTCOMINGS AND FUTURE SCOPE

- Increasing the granularity in time period.
- Economics of storage can be evaluated in a life-cycle context with a longer modelling horizon.
- The current model limited to a standardised 24-hour duration. Can be extended to cover a season or across a year.
- Impact of geographical diversity on PV generation profile.
- Impact of a mix of Solar and Wind.
REFERENCES

- International Energy Agency - Key world energy statistics, 2016 Retrieved 6 April 2017
REFERENCES


Thank You!