Managing Risk of RE curtailment in Indian Power market

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***Abstract*— The proportion of Renewable Energy (RE) capacity in the generation portfolio continues to expand in India as more and more renewable capacity is added to meet the 2022 target of 175 GW. As seen in the case of Tamil Nadu, rapid expansion of wind capacity led to significant curtailments. With rapid expansion of RE capacity this situation may get worse and spread to other states as well unless steps are taken to manage it. All stakeholders (planners, developers and lenders) today are looking for answers to a few questions: Is the system ready to absorb all of RE generation (as must run)? What measures (Regulatory, Market based, structural changes) does system need to adopt for successful integration of RE? Can states do it on their own or do they need to synergize amongst themselves? What levels of curtailments may be expected if adequate steps are not taken in time? Which states are more vulnerable to curtailment of renewables? Which indicators can developers look at to assess curtailment risk? In this paper the authors look at the curtailment issue in detail and how best to manage the risks.**

I. INDIAN POWER SYSTEM

A. *Background*

Renewable Energy deployment has witnessed an explosive growth globally and in India during the last few years. This growth is particularly outstanding because it has been achieved despite the falling global fuel prices (Coal, Gas and Oil) that offered a stiff competition to renewable energy which has generally been expensive compared to conventional energy. The recent ratification of the Paris Accord by India further highlights the country's resolve towards renewables deployment in a time bound manner.

Driven by the National Solar Mission, ~ 10 GW of solar power generation capacity has already been connected to the grid. At the same time, wind power capacity in the country nearly doubled to reach 28.3 GW [1]. By 2022 solar capacity is targeted to reach 100 GW and wind to 60 GW [2]. This large infusion of intermittent renewable generation is likely to bring forth some challenges in managing the grid and integrating the intermittent power with it [3][4][5][6]. Whilst system operators are developing mechanisms to tackle this issue, curtailment of renewable power may continue (as an unavoidable option to manage the grid) until technological solutions are devised and best integration practices are brought into practice. Wind and solar curtailments in some states in recent past have led to increased uncertainty and risk among investors and lenders.

B. *Types of RE curtailment*

Curtailment can be defined as *"When the dispatch order from the transmission system operator to the RE plant is to reduce or stop generation, even though the RE resource is available"*

In India, RE curtailment has been caused by one of the following two factors:

a. **Technical curtailments:** When a transmission system is incapable of accommodating the full dispatch of RE facilities due to technical transmission issues (involuntary curtailment). Many times grid availability becomes a constraint in the dispatch of RE power. Some of the key technical reasons leading to curtailment can be:
    - Transmission unavailability
    - System operating requirements leading to back down
    - Congestion management processes
    - Power plant performance constraints
    - Load amount and profile

b. **Economic curtailments**: Curtailments may also be driven by economic incentives or disincentives such as availability of cheaper power from other sources. Utilities sometimes may not be keen to buy RE power due to high tariffs of RE. Such curtailments are termed as economic or voluntary curtailments.

While economic curtailments are contestable (as they violate must run status of RE), technical curtailments are not. As such, all the curtailments are being currently reported under 'technical curtailments' by state DISCOMs.

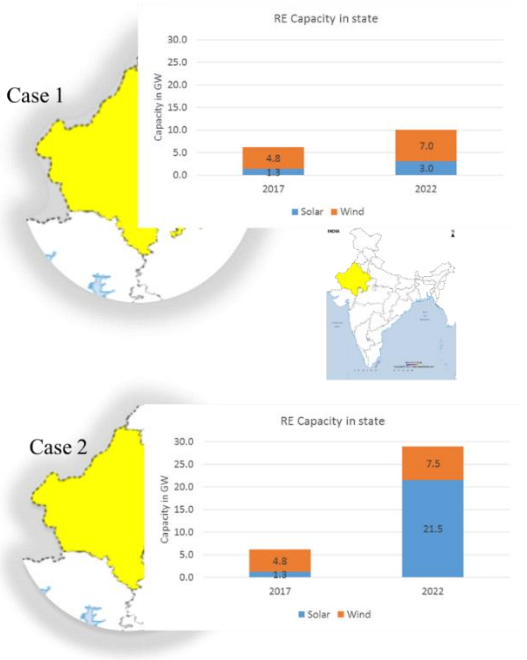
II. CAN INDIA INTEGRATE 175 GW OF RE CAPACITY?

A. *Impact of larger balacing area*

One of the primary measures that is being seen as solution for successful integration of RE is increasing the balancing area size (for example by creating REMCs)[3][4][5][6][7].

The mentioned strategy is quite effective and is likely to improve RE integration. Figure 1 below shows solar and wind capacity which can be absorbed by Rajasthan system as system moves from a limited state-only balancing to national balancing[1].

Figure 1: Modeling result - RE capacity integration in state of Rajasthan[2]



As system moves to centralized balancing, states which are rich in RE (like Gujarat and Rajasthan for solar; Tamil Nadu, Maharashtra and Karnataka for wind) are able to build much more RE capacity than they could if they only balanced within state. ICF modelling results show that, with national planning and balancing, system is able to successfully integrate 25 GW more of solar capacity in 2022 for the given wind capacity of 60 GW.

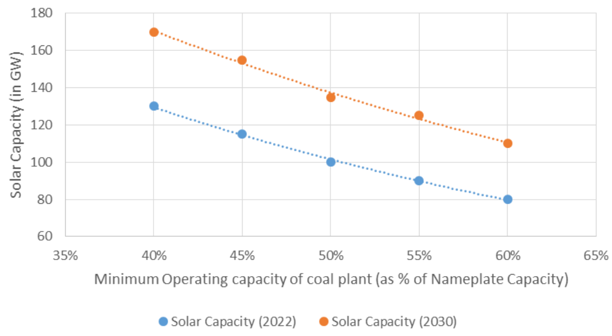
Additionally, centralized dispatch planning of RE also leads to lower system costs as solar and wind resources are utilized to the best of their availability. We have seen similar trends in recent wind bidding as well where (i) lowest bids were received from wind plants in Tamil Nadu [8][9] and (ii) Solar bids reached new low for solar park bids in Rajasthan [10].

B. *Availability of flexible generation (coal, gas hydro and pump storage)*

For integration of RE, availability of flexible generation is important. India primarily has a coal generation fleet and thus is expected to rely heavily on capability of coal based power plants to provide the required flexibility[4][7]. Currently, it is understood that coal based power plants can operate at technical minimum of 65% to 70%, however they have capability of operating at minimum load of 55% (thereby providing flexibility in the range of 55% to 85%).

Figure 2 below shows solar capacity which the power system is able to integrate with increase in flexibility of coal power plants[3] (reduction in technical minimum) in 2022[4] and 2030[5].

Figure 2: Relation between Solar capacity which can be integrated by the system and Coal's technical minimum

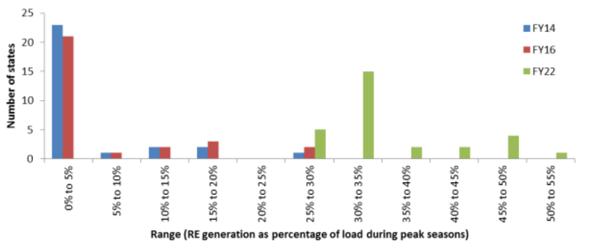


Improving flexibility in coal based power plants can help Indian power system avoid other expensive generation options (like pump storage and open cycle gas) thereby keeping system's operational cost low. However, operating coal plants in this manner will drastically impact the efficiency, cost and the emission levels. These factors must be evaluated and quantified before mandating coal plants to reduce the technical minimums. Other balancing methods (pumped hydro, storage and demand response) can also be very effective in managing the integration of renewables and must be evaluated properly against cycling coal plants

III. Why is it important to conduct detailed RE curtailment risk profiling of states?

Until now, share of RE generation as a percentage of load has been low in most of the states. However, by FY22, government has planned to reach target of 175 GW (with a YoY increase of 26%). If this indeed happens, then by FY22 it is expected that RE generation would be more than 25% of load during peak RE seasons in all the states (as shown by green bar graph in the Figure 3 below). In FY14 only one state (Tamil Nadu) and in FY16 only two states (Tamil Nadu and Rajasthan) had similar ratios. As the ratio of RE generation to load increases, the risk of curtailment also increases substantially. Therefore, assessing the risk profile of each state along with detailed load flow analysis to quantify level of curtailments for an RE plant can help states and developers prepare better to deal with such a situation.

Figure 3: RE as a % of load for different states (2014, 2016 and 2022)



A. ***For developers****: How to assess curtailment risk (A two pronged approach)*

While assessing curtailment risk, ICF recommends a two pronged approach:

- **State's risk profile:** Preparing state's risk profile helps in qualitative assessment of curtailment risk in the state. The assessment can highlight key matrices which determine the risk profile of state.

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[1] The analysis is based on detailed modeling of all the Indian states using IPM™ and GE's MAPS

[2] Case 1: Assumes state-wise balancing; Case 2: Centralized balancing

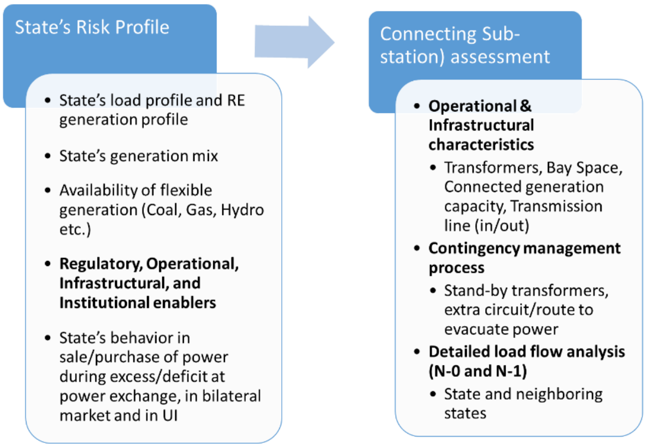
3 Based on detailed modeling of Indian power sector using IPM™

4 Along with 60 GW of wind capacity

5 Along with 125 GW of wind capacity

- **Detailed assessment of connecting sub-station:** Even within states, each of the sub-station has its own evacuation capacity. Congestion within states is one of the primary reason for technical curtailments. A detailed load flow analysis of states (along with neighboring states) can be used to assess congestion issues and curtailment volumes.

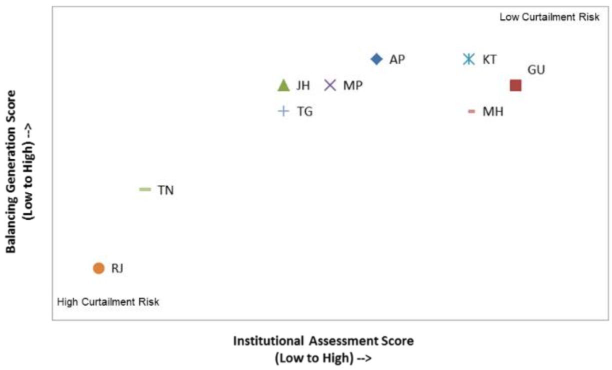
Figure 4: Two pronged approach for curtailment risk assessment



B. *Risk Profile of states*

Different states have different risk profiles when it comes to integrating respective targets of solar capacity (as under 100 GW of solar by 2022). Some states like Gujarat have a defined step-by-step process of managing variability of RE sources, while others have not formally adopted any such process. Apart from this, states have different load and generation profile/mix. States with larger share of storage based hydro and lower share of RE (as percentage of total demand) have lower risk of curtailment. The figure below (Figure 5) provides a summary of risk of RE curtailments in some key states.

Figure 5: Risk profile summary of key states



Factors Considered for evaluation of states (in Figure 5 above)

Institutional Assessment Score	Balancing Generation Score
RE generation as % of demand	Gas Capacity
DISCOMs' financial health	Hydro Storage capacity
Regulatory preparedness	Pump Storage Capacity
Transmission Connectivity	Cycling of coal capacity
Operational Characteristics	Sale purchase of electricity in intra-day market

1) *Case study 1: Gujarat a low risk state*

Gujarat is one of the states which has been able to integrate wind and solar effectively. Although state has 36% of RE capacity (at nameplate capacity) as percentage of peak demand, no curtailments have been observed in the state. State of Gujarat has been effective in putting regulatory, infrastructural, operational and institutional enablers in place to integrate RE capacity [11].

Table 1: Gujarat's analysis for RE integration

Enablers	Description
Regulatory	• GERC audits SLDC's operations and any decision to back down generation is closely monitored • Although there is no penalty as such, but any deviation from standard operating procedure or grid code requires detailed explanation to the regulator

Operational	• ABTs have been mandated on wind farms since 2010
	• State RE desk has been operational since 2013. Housed in SLDC and responsible for monitoring RE generation/dispatch
	• Forecasting and scheduling being done on regular basis as long-term pilot
	  ○ Provides day ahead forecast to SLDC for inclusion of RE generation in scheduling (pooling done substation-wise)
	  ○ Relatively accurate forecast is available and thus SLDC is able to manage variability properly
	• Typically, State SLDC takes one or more steps while managing grid during high wind months to accommodate RE as must run:
	  ○ Manage dispatch of Hydro --> Gas --> Coal plants (in order):
	    ✓ State owned or IPPs contracted by state: by reducing their dispatch to technical minimum
	    ✓ CGS: Managing flexibility in contract for the share allotted to Gujarat
	  ○ Sell excess (or buy deficit) power at (i) power exchange , (ii) bilateral contracts, (iii) UI

Institutional	• Well-defined hierarchy for flow of orders: SLDC --> sub-SLDCs --> substations --> generators • Supreme authority for backing down generation rests with the SLDC; no sub-SLDC or substation can take that decision without SLDC's approval
Infrastructural	• State is ramping up its transmission infrastructure and upgrading existing lines to accommodate more wind and prevent any curtailments • Participation in 'Green Corridor' development for successful evacuation of power outside state

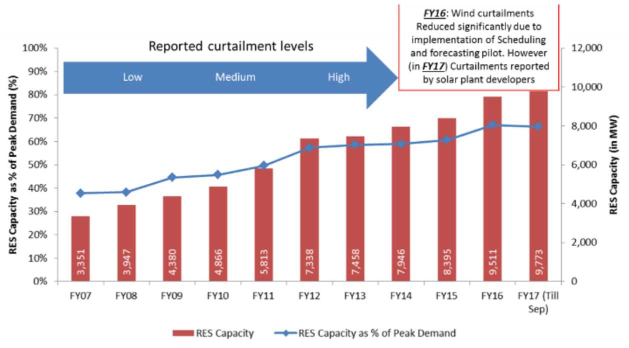
2) *Case study 2: Tamil Nadu - High wind curtailments reported in the past*

From a capacity of 3.3 GW in FY07 Tamil Nadu more than doubled its RE capacity by FY12 (adding primarily wind). By FY12, RE capacity (nameplate capacity) as percentage of peak demand increased to more than 60% and instances of RE curtailment increased substantially esp. in high wind seasons as majority of RE capacity is wind. State looked at various options to alleviate the situation and took two pronged approach in FY16

- Upgrade intra-state transmission network for effective evacuation of RE power from generation centres to demand centres, and
- Conduct a pilot on wind forecasting and scheduling (in association with IWPA).

Subsequently, during high wind seasons in FY17 significantly lower levels of curtailment were reported [12]. It's evident that these steps helped wind power evacuation however the situation is still very precarious. As per Solar Power Developers Association (SPDA) Assistant Sectary General now solar energy is being curtailed for the first time (sometimes in the range of 50-100% during peak generation periods) [12]. Curtailment of generation directly impacts the project IRR and dis-incentivises any new investment in the sector. The situation may worsen in coming years as more and more capacity is added into TN grid unless constructive measures are taken by state to limit curtailment levels.

Figure 6: Tamil Nadu story on RE curtailments



C. Quantification of curtailment through Network assessment (state network analysis)

It is equally important to conduct detailed load flow analysis of the state network to assess RE curtailment risk and expected curtailment volumes. Steady state load flow models (like GE's Positive Sequence Load Flow) are used to assess transmission flows in the system for both normal (N-0) and selected (N-1) contingency conditions when possibility of RE curtailment is the highest (like when ratio of RE generation to load is highest, or during periods of high RE generation). The model can quantitatively assess amount of RE curtailments that can happen with changing load and generation pattern.

Figure 7 and Figure 8 below shows schematic of changing power flow with installation of a wind plant (as an illustration case for Rajasthan, 2016). Line loading and voltage violation information can be used to assess possible level of curtailments.

Figure 7: Load Flow analysis of Rajasthan (2016, Base Case) for assessment of RE capacity addition

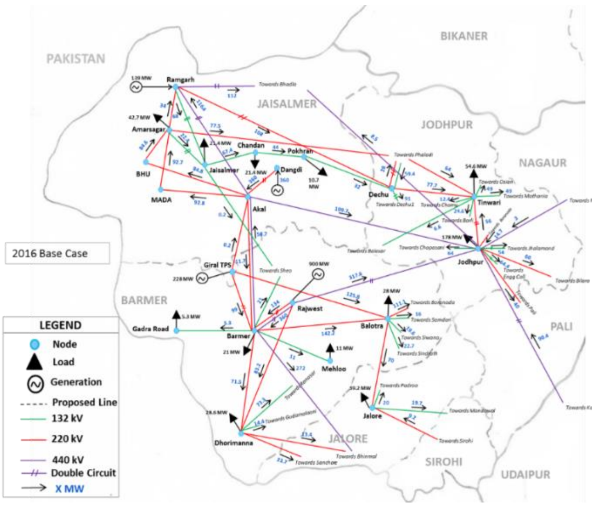
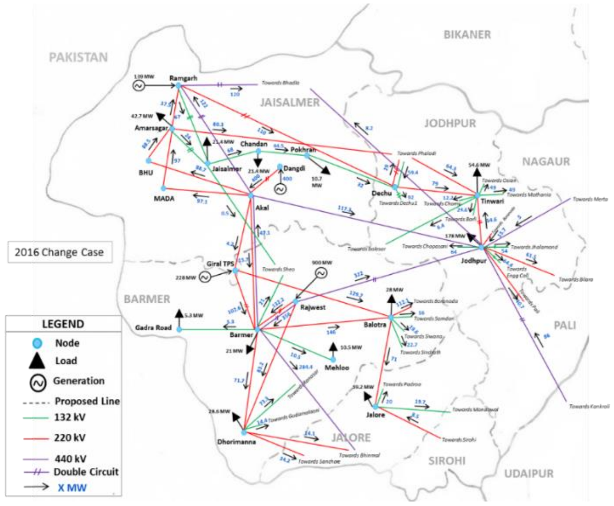


Figure 8: Load Flow analysis of Rajasthan (2016, change Case) for assessment of RE capacity addition



IV. CONCLUSION AND OUTLOOK

Curtailment risk is one of the primary concerns currently in the RE industry and will continue to be in the future as well. With increasing penetration of RE in the system, managing curtailment risk will become quite important and developers need to assess the risk carefully. The system as it is operating today, may not be sufficient to integrate 100 GW of solar based capacity. There are number of initiatives (both at regulatory level and market structural level) that system needs to take for successful integration of RE.

- Regulatory changes
  - Better forecasting and scheduling of RE generators
  - Use of hydro as flexible generators (intra-day flexibility)
  - Encouraging and ultimately allowing Demand Response to participate in ancillary markets
  - Creating an ecosystem for other technologies to come up (batteries)
  - Day-ahead load forecasting and dispatch planning
- Market Structures
  - Centralized dispatch and co-optimization (Larger balancing footprint)
  - Increasing liquidity in intra-day market at power exchange
  - Successful implementation of ancillary service market
    - Additional products and Increased market depth by allowing IPPs as well
  - Creating market for other options like storage, and demand response
  - Timely constriction of transmission capacity to avoid congestions

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BIOGRAPHICAL INFORMATION

Ashish singla joined ICF in 2007 and is Manager in the Power and Fuels group of the Wholesale Power Asia practice. He has been extensively involved in the areas of energy market modeling, RE and storage modeling, wholesale power market assessment, asset valuation and financial modeling, restructuring, techno economic feasibility. Mr. Singla's key areas of expertise include modeling of India power market using ICF's proprietary modeling tool—the Integrated Planning Model (IPM®) and other dispatch analysis tools like GE's MAPS. Mr. Singla is an expert in evaluating power sales contracts and valuation of generating assets. Mr. Singla's work includes the entire project life cycle phases for India power markets projects—from understanding of requirements to delivery—including market research, design and development of model, analysis of results and preparation of final deliverables. Mr. Singla has worked in number of key energy markets and his international expertise spans India, Sri Lanka, Nepal, USA, Canada and Singapore energy markets. Mr. Singla is a B.Tech from IIT Roorkee.

Gurpreet Chugh is currently Consulting Director, Energy at ICF Consulting. He has close to 15 years of experience in the global Energy sector in with a mix of consulting, M&A, business development and operations. He has structured private M&A deals in West Africa, Russia, Indonesia and India. In his professional career as a consultant, he has worked on consulting engagements for International energy majors and provided advisory services on issues across the gas value chain. He has worked in India, UK, Russia and West Africa. Gurpreet is a Chartered Financial Analyst (CFA®), has received an MBA in finance from Management Development Institute, Gurgaon and has a Bachelor's degree in Engineering from NSIT (formerly DIT), University of Delhi.