The Future of the Indian Electricity Sector with High Renewable Penetration

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Outline

A Big Push for Renewables

Renewable Energy Targets for 2022

- Wind: 23.8 GW $\rightarrow$ 60 GW
- Solar: 4.5 GW $\rightarrow$ 100 GW (20 distributed, 20 off-grid, 60 utility)
- Biomass: 4.4 GW $\rightarrow$ 10 GW
- Small Hydro: 4.1 GW $\rightarrow$ 5 GW

Relevant excerpts from India's INDC

- To reduce the emissions intensity of its GDP by 33 to 35 percent by 2030 from 2005 level.
- To achieve about 40 percent cumulative electric power installed capacity from non-fossil fuel based energy resources by 2030 with the help of transfer of technology and low cost international finance including from Green Climate Fund (GCF).
- Nuclear (2030 target): 5.5 GW $\rightarrow$ 63 GW (rather unlikely!)

A thought experiment

Some thumb rules:

1 kWp = 10m^2 = 1.5 MWh

OR

1 MWp = 1 hectare = 1.5 GWh

100 GWp = 1000km^2 = 150 TWh

India generated about 1030 TWh in 2014-15, with a peak demand of 140GW, on a capacity base of 270 GW.

Assuming doubling by 2022, India could use 2000TWh with a peak of 300-350GW.

Another thought experiment

What would it take if India went 100% electric and 100% solar by 2050?

Germany in 2012: population 82 million, 540 TWh electricity, 3800 TWh total primary energy

India in 2050: population 1500 million, 20000 TWh electricity

We will need about 100,000 km^2, assuming some improvement in solar technology. That is 3% of India's land area.

Are Renewables More Expensive than Conventional Power Sources?

Current Solar PV Bids in India

Figure: Winning bid range for solar tenders. Source: India Solar Map 2015 (Sep 2015), Bridge to India

Comparison with Recent Bids for Coal

Figure 19: Comparison of recent Solar and Coal bids

MP Solar - Jul'2015	Tariff (INR/kwh)	AP Coal - Jun'2015	Tariff (INR/kwh)	Likely Tariff after 5 years @ 4% coal cost escalation
Bid 1	5.051	Bid 1	4.27	4.58
Bid 2	5.109	Bid 2	4.35	4.74
Bid 3	5.298	Bid 3	4.49	4.70
Bid 4	5.38	Bid 4	4.69	4.92
Bid 5	5.398	Bid 5	4.83	5.06
Bid 6	5.451	Bid 6	4.83	5.05
Bid 7	5.452	Bid 7	4.98	5.17
Bid 8	5.456	Bid 8	5.25	5.66
Bid 9	5.457	Bid 9	5.39	5.80
Bid 10	5.61	Bid 10	5.6	5.86
Bid 11	5.63	Bid 11	5.72	6.03
Bid 12	5.641	Bid 12	6.31	6.99

Source: Deutsche Bank, media reports

Figure: Competitive bids for power from solar and imported coal. Source: Deutsche Bank, media

The Reason behind the Low Cost of Solar PV

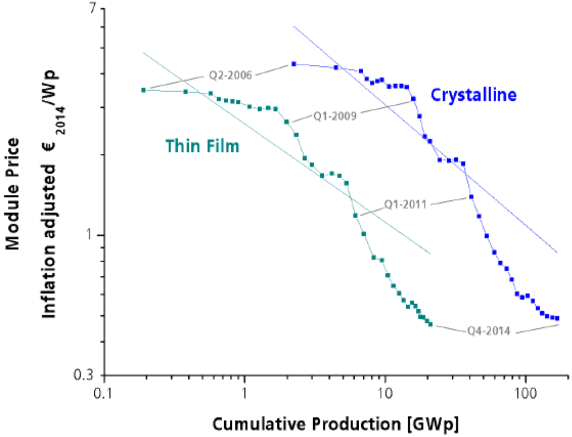

Figure: Learning rates >22% observed since 2006, 90% cost reduction since 2006. Source: Fraunhofer ISE (August 2015). Similar curves for wind exist (learning rate of 14%).

Learning in Battery Technology

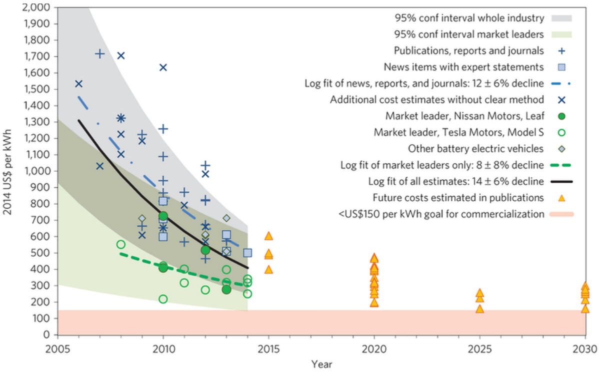

Figure: Battery costs are also declining fast. Source: Nykvist and Nilsson, Nature Climate Change 5, 329332 (2015)

Lessons from Spain, the Nordic Pool, and Germany

Variable Renewables are not Firm Power

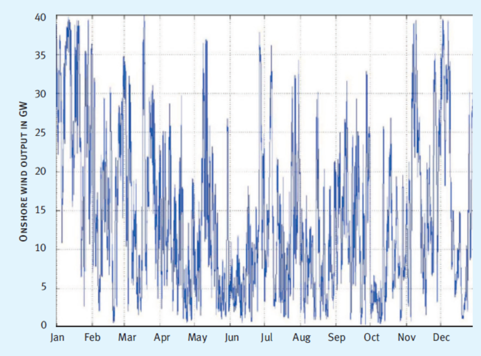

Figure: Wind Generation in a whole calendar year in Germany. Source: Flexible Generation, Backing up Renewables, Eurelectric

Suppose a region has 10 GW or wind turbines, and the minimum generation over a period of years is 10% of nameplate capacity. Then **firm power** is 1000 MW. Wind and solar power can be forecast using weather models, sunrise/sunset data etc. But there is always a margin of error, and this is higher in wind.

Meeting Demand in a Grid

- System 1: 40 GW peak demand, no renewables. Need 44 GW of **firm** conventional generation, assuming a reserve margin of 10%.
- System 2: 40 GW peak, 20 GW wind, 2 GW **firm** wind. Need 42 GW of **firm** conventional generation.

There is a big difference between the operation of System 1 and System 2. System 2 has to be more nimble, and is always under more stress. It must be more flexible, more reliable and should be able to ramp up or down very fast.

A Typical Day in Spain

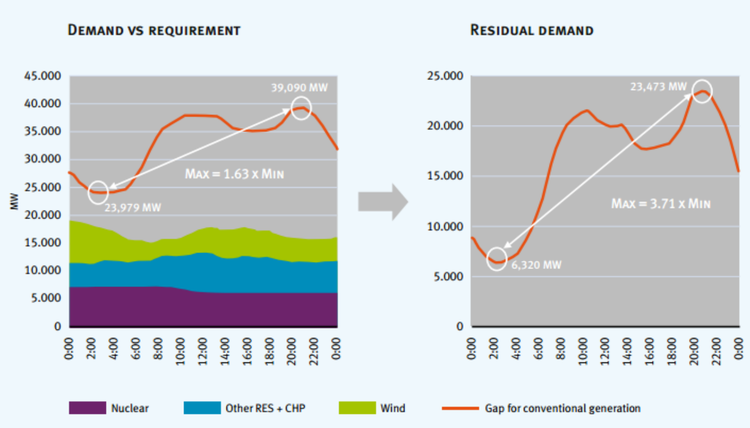

Figure: An example of the difference between Systems 1 and 2. Source: RES Integration and Market Design, Eurelectric

Ramp and Cold Start Times

	NPP	HC	Lign	CCG	PS
Start-up Time "cold"	~ 40h	~ 6h	~ 10h	< 2h	~ 0,1h
Start-up Time "warm"	~ 40h	~ 3h	~ 6h	< 1,5h	~ 0,1h
Load Gradient ↗ "nominal Output"	~ 5%/m	~ 2%/m	~ 2%/m	~ 4%/m	> 40%/m
Load Gradient ↘ "nominal Output"	~ 5%/m	~ 2%/m	~ 2%/m	~ 4%/m	> 40%/m
Minimal Shutdown Time	←		no	→	~ 10h
Minimal possible Load	50%	40%	40%	<50%	~ 15%

Figure: Flexibility of Conventional Power Generation Technologies. Source: Flexible Generation, Backing up Renewables, Eurelectric

A grid with renewables must have flexible generation. Gas in Spain, hydro in the Nordic Pool, and a combination of gas, hydro and power trade in Germany provide this flexibility.

An example from Germany

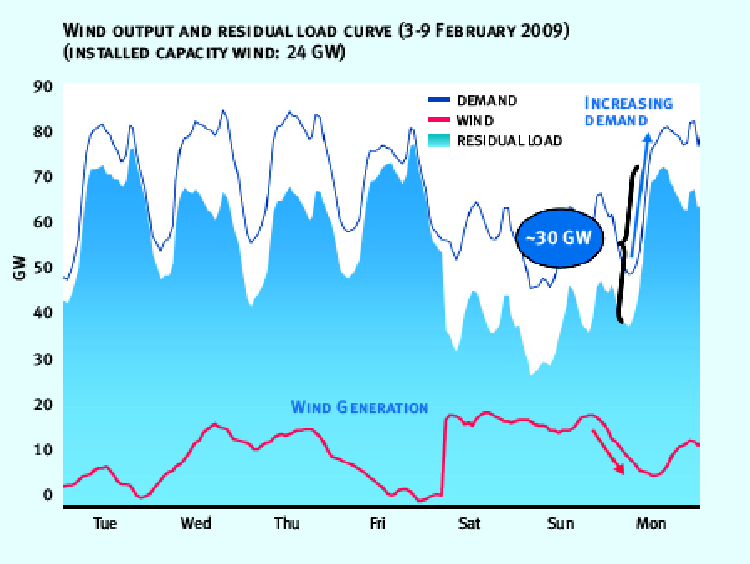

Figure: Wind output and residual load curve, 3-9 Feb 2009. The grid has to ramp up

An example from Spain

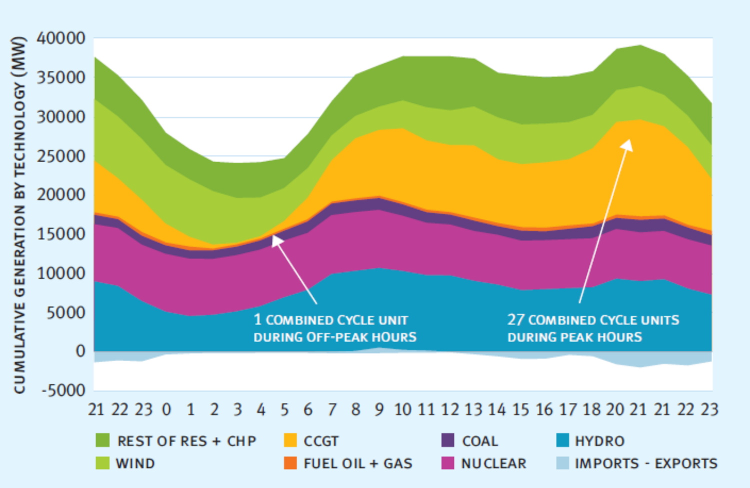

Figure: Managing wild fluctuations in wind output in Spain on 3rd March 2010. Source: Flexible Generation, Backing up Renewables, Eurelectric

Gas demand in Spain

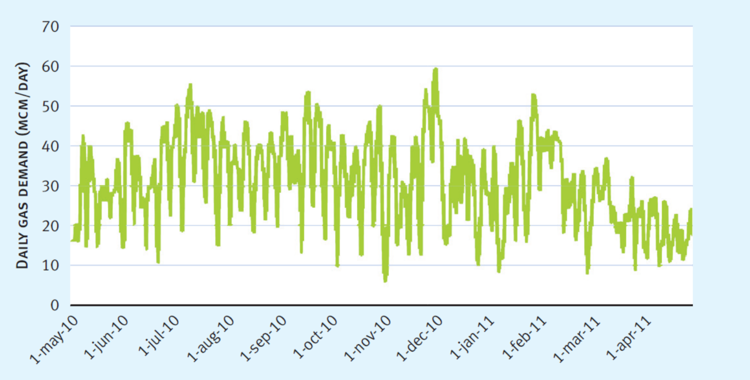

Figure: Managing the flexibility of Spanish gas supply. Spain is fortunate that its main source of gas is LNG. Source: Flexible Generation, Backing up Renewables, Eurelectric

Characteristics of the Successful Stories

1. Must have flexible generation like gas or hydroelectric power (or, at least, flexible load). Or, access to storage like pumped hydro.
2. Must have statistical forecasting of renewable generation, real time monitoring, and an intelligent grid.
3. Must have a large service area so that fluctuations can be balanced. Geographical spread, good transmission, diversity of options and shared reserve capacity are very important.

The Indian Grid and its Idiosyncrasies

The Indian Electricity Sector: Capacity in 2015

Technology	Capacity(GW)
Coal	169
Gas	23.1
Diesel	1.2
Nuclear	5.8
Hydro	45.3
Wind	23.4
Solar	3.7
Other	3.4
Total	271.7
Peak	141.2

Another 47 GW of private captive power and 75 GW of diesel gensets are not accounted for in the above table.

The Indian Electricity Sector: Generation in 2015

Technology	Generation(TWh)	Share
Thermal	836	75.6%
Nuclear	36.1	3.3%
Hydro	129.2	11.7%
Renewables	61.7	5.6%
Gas	41.1	3.7%
Total	1105	100%

Capacity factor of gas generation is ˜30% due to the high price of imported gas.
Wind generates about 3-4% of India's power.

Typical Monsoon Day in July 2011 in India

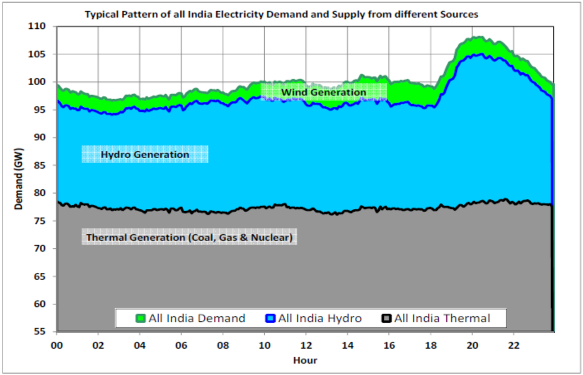

Figure: Flexible generation is provided by hydro only. Source: Report on Green Energy Corridors, Power Grids

Typical Monsoon Day in July 2011 in South India

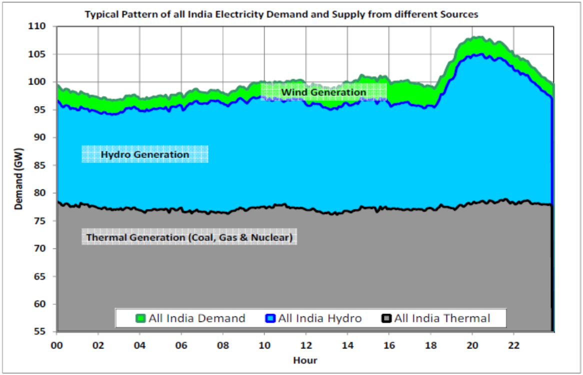

Figure: South India already has enough wind for its hydro to balance. Any further additions will require the thermal generation to respond too. Source: Report on Green Energy Corridors, Power Grids

Problems of the Indian Grid I

- The Indian grid is divided into five regional grids, each regional grid consists of state grids. Interconnections between the state and the regional grids are poor. Intragrid transmission infrastructure is often weak.
- The electricity sector is dominated by baseload power like coal. Hydro is used to meet peak demand to some extent.
- Utilities are forced to serve power to agriculture and the impoverished at below cost rates. Richer consumers cross-subsidize impoverished consumers. The utilities are often bankrupt.
- Agricultural loads are 18.5% of generation, and can be as high as 40% in some utilities. Agricultural loads are often not metered.
- Utilities have no incentive to meet a Universal Service Obligation, and often shed load to reduce losses.
- Utilities also curtail renewable energy if they do not have sufficient flexible generation.

Problems of the Indian Grid II

- Generators and Utilities enter into long term bilateral agreements which discourages the utilities from buying renewable power.
- Renewable Purchase Obligations are not enforced. The Renewable Energy Certificate market is not big enough to encourage the entry of renewable projects.
- Power generated by wind turbines are often invisible to the system operator.
- The open market in electricity is tiny (2% of total power) and is hampered by the absence of a robust transmission network.
- No Demand Side Management or Demand Response.

Options for India

Some Obvious Policy Prescriptions

- Strengthen the Transmission and distribution network (easier said than done)
- Expand and standardize the Renewable Purchase Obligations across all states.

Solar Power for Agriculture

- Separate feeders for irrigation pumps. Replace pumps with efficient ones, add a grid connected solar PV panel with a smart meter.
- Can use the solar PV panel pump combo as a flexible load (and generator) during the day.
- Switch off the feeder at night to restrict theft.

Efficiency Programs: Lighting and Air conditioners.

- Replacing all incandescents in India (700 million sold per year) with led lamps could reduce a lot of the evening peak demand.
- Some estimates suggest about 10 GW.
- Air conditioners with a connection to the internet via the cell network, wi fi, ethernet etc which can be remotely stepped up or down by a fixed amount.

Hybrid solutions.

- Add a small reservior down river to a dam, and use as a pumped hydro.
- Curtailing renewables: If renewables are cheap enough they can be used inefficiently to provide grid balancing.

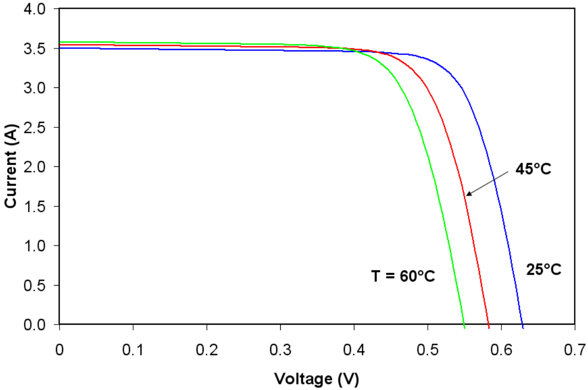

Figure: Change the point of operation in the PV cell to provide variable power.

Thank You.