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The Great Indian Electricity Transition

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Abstract

We are living through an unprecedented social and technological transformation of the Indian electricity sector. The patterns of electricity demand and supply are both changing; access in now almost universal; electricity end-use efficiency is rising rapidly; and renewables now provide the cheapest electricity when the sun is shining and the wind is blowing. In addition, climate change concerns are accelerating the need for reduction in the carbon intensity of electricity consumption. As a result, the electricity sector of tomorrow will be very different from that of yesterday: the demand will be more volatile; new generation capacity will be renewables-based; and balancing demand and supply will be the key challenge. This highlights the need for "managed flexibility" in electricity sector management, and underscores the need for a portfolio of flexibility options, as well as of research and capacity building for designing and implementing technical, economic and regulatory interventions to manage flexibility.

The Great Indian Electricity Transition

It is a great honour for me to be invited to deliver the inaugural Prof O D Thapar lecture at IIT-Roorkee. Prof Thapar brought renewable energy to the centre-stage, both in Indian academia and in energy policy making, through designs and policies, especially for small and micro hydro power projects. He was passionate in his advocacy for small and micro hydel projects and for other alternative energy technologies, leading to the creation of the Alternate Hydro Energy Centre (AHEC) at the then University of Roorkee in 1982; the first Centre anywhere in India, to focus on renewable energy design, implementation, and policy. It is a matter of great delight that the AHEC has now, in 2019, become a full-fledged Department in the Institute.

It has been my personal privilege to have been associated with Prof Thapar and AHEC for a very long time, and I am grateful for his vision and leadership which have placed AHEC as the leader in small hydro development, possibly in the world, and has simultaneously enabled, sustained, and supported renewable energy development in the country – to the point where renewables are now the least cost power generation option available; and this in turn has unleashed a series of changes which could well result in the electricity sector in the 2030s and beyond to be very different from the electricity sector of the 2010s and earlier.

I would like to focus on this great transition that the electricity sector in India is undergoing, and that we have the privilege of living through. Such transitions occur but rarely in History, when we undergo changes, not just in magnitude and diversity, but in the very principles and structural frameworks that form the basis of our understanding. I would suggest that change of the first type – in magnitude and diversity – is what we have witnessed till now. In 1982, when AHEC was created, the country had an installed electrical capacity of about 34 GW[1], and an electricity supply shortage, which was conservatively estimated as 6 %. More significantly, less than 40% of households were

[1] Interpolated from data in Economic Survey 2017-18, Statistical Appendix, Table 1.25A

connected to the electricity grid, and India's electricity generation was 192 kWh per person per year[2]. And despite adding 3 to 5 GW of installed capacity per year over the next twenty years, the energy shortage kept growing, from 6% in 1982 to 8.3% in 1992, and to 8.8% in 2002.

Today, the situation is quite different: nearly 100% of households have been connected into the grid. The electricity generation capacity connected to the grid is nearly 350 GW, and the maximum demand in 2018 was less than 180 GW. The era of electricity supply shortages is over; any brownout or blackout that occurs today is because of distribution-level problems, and not because of supply shortage. Electricity generation has increased to over 1000 kWh per capita per year, though it is still only one-fourth of the global average.

Electricity Demand Growth: Air Conditioning is the prime driver

As we look to the future, it is clear that the electricity demand would continue to increase; largely because increases in electricity use are an essential component in the enhancement of the quality of life. Statistically, all countries in the world which have been able to achieve a Human Development Index (a surrogate of the quality of life) of 0.9, on a scale of 0 to 1 with 1 representing an extremely good quality of life, have achieved electricity supply of at least 4000 kWh per capita per year[3]. In other words, as India ensures a high quality of life for its citizens, it will have to quadruple its energy supply.

The good news is that while some countries have been able to achieve a HDI of 0.9 with an energy consumption of 4000 kWh per capita per year, there are other countries which require upto two-and-half times as much electricity to reach the same HDI. In fact, countries that have industrialized and developed later in history have used

[2] Most data has been sourced from various issues of All India Electricity Statistics, General Review, an annual publication of the Central Electricity Authority, and from the website of the Ministry of Power.

[3] TERI analyses based on UNDP, Human Development Report, 2019, and World Bank, World Development Indicators.

less electricity to reach the same HDI level. This is primarily because countries that developed later are able to utilize more energy-efficient equipment and infrastructure. Consequently, it would not be surprising if India is able to move from the current HDI of 0.6 (with an electricity supply of 1000 kWh per capita per year), to a HDI of 0.9 with electricity supply in the range of 2500 to 3000 kWh per capita per year, instead of 4,000 kWh per capita per year, as current statistics would suggest. However, even that lower level of electricity requirement, would still necessitate a near trebling of the electricity supply in the country.

The question of course is whether Indian energy efficiency trends would move at this required pace.

Statistically, this is possible. In the past 15 years, the energy intensity of the Indian economy i.e. the amount of energy used for producing each rupee of GDP, has been declining at about 2.5% per year, one of the fastest decreases in the world. We have projected that if the current rates of GDP growth and of energy intensity decline continue over the next 20 years, India could expect to achieve a high HDI (in the 0.85 to 0.9 range) with electricity supply in the range of 2,500 to 3,000 kWh per capita per year, that is 2.75 times the current per capita electricity supply.

The second issue to consider is where will this electricity growth come from? While electricity demand would certainly come from the increased use in the industrial sector, as well as from new usage areas such as electric mobility, the largest growth is expected to occur because of the increased adoption of air conditioning. This is, in a sense, both expected and desirable. Expected because India consists of the largest agglomeration of population in the world living in hot and humid climates[4]. Consequently, the overall need for providing every person with an environment of

[4] Lucas Davis, Air Conditioning and Global Energy Demand, Energy Institute at Haas, Energy Institute Blog posted April 27, 2015, https://energyathaas.wordpress.com/2015/04/27/air-conditioning-and-global-energy-demand/

human comfort, requires a lot of air conditioning. And, desirable, because of the huge productivity increases associated with working in environment where human body works in thermal comfort[5].

Using a variety of forecasting methodologies, TERI has triangulated the electricity demand in 2030 to be between 2040 and 2973 Terra Watt hours, based on GDP growth and energy efficiency increase assumptions[6]. Our best guess is that the total demand of electricity wold be in the vicinity of 2300 TWh, compared to the 2017 demand (not supply) of 1130 TWh.

Electricity Supply: Renewables are now the source of the cheapest electricity

There are two challenges associated with meting this demand. The first is where will this electricity supply come from? What will be the fuel source; an issue of importance because of the Indian commitment to the United Nations Framework Convention on Climate Change (UNFCCC), that at least 40% of the total generating capacity in the country would be based on non-fossil fuels. In 2015 when this commitment was made, about 30% of the electricity capacity was based on non-fossil fuel and wind, solar, hydro and nuclear, and over 60% was based on coal generation. Consequently, the vast amount of the new electricity generation capacity that is added would need to come from the non-fossil fuel sources.

The second challenge is to meet the demand while catering to the change in load curve profile. The maximum amount of electricity, on a daily basis, has been and is consumed in the summer and monsoon months, i.e, in the approximately 200 days between mid-March and mid-October. Till a decade ago, the maximum demand, during this period of the year, used to occur at about 7 and 8 PM (on about 190 days); on a few days (less than 10 days), the peak occurred at 9 PM. However, during the past decade,

[5] William Nordhaus, Geography and Macroeconomics: New Data and New Findings, Proceedings of the National Academy of Sciences USA, 2006, March 7, 103(10), 3510-3517.
[6] Thomas Spencer and Ayushi Awasthy, Analysing and Projecting Indian Electricity Demand to 2030, TERI, 2019.

the nature of this peak has changed: it has steadily lengthened, and the number of days when the peak is at 7 or 8 PM is now about 150, and on the balance of days, the peak occurs, with about equal frequency, at 9, 10 and 11 PM. This reflects the growing penetration of air conditioning in households, and the utilisation of this at night as people come home from work. Already in some jurisdictions, such as Delhi, the maximum annual peak occurs at 11 PM on a late-August/early-September night, and possibly reflects the future, inasmuch as Delhi, as the richest state in the country, exhibits air-conditioning adoption trends that we will see tomorrow in the rest of the country. It can be expected that as incomes increases and as household air conditioning increases, the night peak would become even longer and spikier. Consequently, apart from the challenge of meeting the increased energy demand in a cleaner manner, there is also an additional challenge of meeting it late in the night.

The good news is that it seems feasible that we may be able to meet both these challenges, certainly before 2030, though the transition will not be simple and straightforward. The prime reason for this optimism is the sharp decline in the price of electricity from renewables (particular solar and wind electricity), and the increasingly sharp decline that continues to occur in the cost of battery storage. Already, electricity from solar and wind energy, at Rs.2.44 per kWh costs less than coal electricity at Rs.3.70 per kWh, when the sun is shining and the wind is blowing. However, by itself solar and wind energy would not be able to meet the 7-11 PM peak. This is where storage becomes important.

TERI has projected[7] that renewable electricity, with battery storage, would be cheaper than coal electricity in providing electricity on a firm 24-hour basis by the late 2020s. This implies that by the end of the decade of the 2020s, consumers, distribution companies, generation companies, and Banks would prefer buy and invest in renewables rather than coal plants. This would reflect a major transition in the Indian electricity sector, and even though coal would continue to be a major source of

[7] Raghav Pachouri, Thomas Spencer and G Renjith, Exploring Electricity Supply Mix Scenarios to 2030, TERI, 2019.

electricity for at least two more decades - till the existing coal power plants retire and are replaced by new capacity based on renewables + storage.

Balancing Demand and Supply: The Emerging Electricity Sector Challenge

We expect therefore that the major challenge to electricity sector management would be balancing the demand and supply, primarily because the cheapest form of electricity generation (renewables) would occur at a time which is different from what the maximum demand (home air conditioning at night) occurs. "Managing flexibility" is therefore of prime importance. We have noted earlier renewable electricity is already the cheapest form of electricity at the time of generation. We have also noted that, in about 10 years, storage technologies would be inexpensive enough so that renewable + storage are the sources of cheapest 24-hour firm electricity supply. In this 10-year interregnum, the balancing of coal + renewable supply and end-user demand requires strategic operational management and investment decisions so that, on the one hand the total cost of electricity supply does not increase, and on the other hand, reliability of supply continues to increase.

In a recent study, CPI and TERI[8] studied the managed flexibility options that are available to the Indian electricity sector. We note that currently this flexibility is provided by existing coal power plants which ramp down during the times when wind and solar energy are available, and ramp up as the production of variable renewable electricity declines. We suggest therefore that ramping up and ramping down of coal power plants is the first and the least-cost managed flexibility option, primarily because coal power plants have already been built, and the cost of flexibility is the difference between the cost of renewable energy (which, at the margin, is priced at Rs. 2.44 per kWh) and the variable cost of coal electricity generation (i.e. largely the cost of coal used in the generation of this electricity, which is about Rs. 2 per kWh). The Central Electricity Authority has recommended that all supercritical coal-based power plants

[8] Udetanshu, Brendan Pierpont, Saarthak Khurana and David Nelson, Developing a roadmap to a flexible, low-carbon Indian electricity system: interim findings, Climate Policy Initiative (CPI), 2019.

have ramping capacity of ±3% of rated capacity per minute[9]. Recently, Siemens, Steag, and NTPC have experimented on stable operation of coal power station at 40% load and issued protocols for this operation[10]. Currently, efforts are ongoing for stable operation even at lower capacity factors. It also seems possible, based on the experience of super-critical power stations in Germany that ramping rates that are higher than the CEA guidelines are possible. In other words, technological interventions at enhanced ramping rates while ensuring stability of operations is the challenge in achieving managed flexibility.

The second option for managing flexibility is demand reduction. This intervention is based on the regulator providing a discount in the period for those users who are able to achieve a significant reduction in their load in a very short time period. This would enable demand to be reduced rapidly enough so that reduced supply (due to, for example, reducing solar generation in the evening hours) can meet the reduced demand. As few distribution companies, for example, Tata Power Delhi Distribution Limited (TPDDL) in North Delhi, have experimented with such measures, though without the economic incentive of reducing performance, but are able to reduce demand in short notice. The TPDDL pilot focussed on 161 industrial and commercial consumers with sanctioned load of 63.5 MW. The aggregated average demand of these consumers was about 30 MW (ranging between 26 and 32 MW) on the 9 days that they were asked to reduce demand at short notice. On an average, the consumers were able to achieve aggregated average demand reduction of 5 MW (ranging between 3.04 and 7.22 MW) within one hour of the start of the DR reduction event. There was also a strong learning experience: in the first three events, the reduction was less than 3.8 MW; the reductions exceeded 4 MW in the last six events, with an average reduction of 6.28 MW, or about 20.7%.[11] Further the increasing use of air conditioning suggests that quick demand reduction opportunities also exist in the residential and commercial

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[9] Standard Technical Features of BTG System for Supercritical 660/800 MW Thermal Units, Central Electricity Authority, July 2013.

[10] B P Rao, Steag, Personal Communication, 2018.

[11] Ganesh Das, TPDDL, TPDDL Automated Demand Response, Powerpoint presentation dated 3rd February 2017, personal communication, 15th April 2019.

sectors: if users can change their air conditioner set points from 22 Deg C to 26 Deg C, it can result in demand reduction of upto 12%[12]. These suggest that large-scale demand reduction measures can be a successful component of managed flexibility; the Delhi Electricity Regulatory Commission has allowed, on a 2-year experimental basis, a 20% discount on commercial and industrial tariffs for consumers who are able to respond to DR events with more than 2 hours notification, and 40% discount in case of event with less than 2 hours notification.

The third and last component of the managed flexibility that the TERI-CPI study looked at is storage, both through pumped hydro projects and batteries. This is, as has been mentioned earlier, an expensive proposition today, but declining costs suggest that it could be cost effective by the middle of the 2020s. The greatest challenge in enabling storage is enabling the appropriate changes in system operation and management. Storage components in a system would require that they (batteries/pumped hydro) are charged whenever there is potential for excess generation (i.e., generation exceeds demand), and drained whenever there is excess demand.

This completely negates the received paradigm of balancing generation and demand in real time, which is the basis of system operation principles today. The operating protocols for this changed operating processes are yet to be established. A recent 10 MW battery storage system installed by AES and Mitsubishi for Tata Power in North Delhi[13] suggests that batteries are never be charged or drained to 100% or 0% respectively. The early results also suggests that the availability of the storage enables quick frequency correction as well[14].

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[12] www.meitavtec.com/EnergySaving/EnergySavingTips.pdf
[13] Economic Times, Tata Power commissions South Asia's largest grid-scale energy storage system, 13th February 2019
[14] Rajendra Shrivastav, AES, personal communication, 5th April 2019.

A major challenge in operationalizing storage is the development of a regulatory framework for incentivizes storage capacity to give online. Storage capacity is expensive and is used for a relatively short period of time at least in the next few years while the share of variable renewable electricity is still less than 10%. Consequently, investors in storage capacity do not see their investments providing returns. The CERC has recently brought out a discussion paper[15] which proposes a framework in which all electricity supply would be provided through the exchanges, leading to large-scale price discovery in each time slot of electricity supply. This process would completely eliminate long term power purchase agreements, and would introduce the time-of-supply pricing at the bulk level (which is very different both in practice and in operation from the time-of-day tariff for retail). It is to be noted that the discussion paper proposes an interim period in which there will be contracts for difference to compensate generators or distribution companies if the market clearing price deviates from the PPA price. This approach would incentivize investment in storage capacity since it would provide the price signal, of higher supply prices during the night peak, necessary to provide comfort to investors.

Conclusions

The Indian electricity system in 2019 is undergoing a great transition, driven primarily by the rapidly declining price of variable renewable electricity (primarily wind and solar) and the ongoing decline in the price of batteries. Together, these have the potential to replace coal as the preferred source of electricity supply. On the other hand, the increasing demand for air conditioning is changing the nature of the demand load profile which could be further exacerbated as new users of electricity, such as electric vehicles and their charging needs, come online.

We suggest therefore that balancing demand and supply, over various time periods – over a day, over seasons, and over years – is emerging as the greatest challenge in the electricity sector, and requires technical, economic, and regulatory

[15] Central Electricity Regulatory Commission, Discussion Paper on Market Based Economic Dispatch of Electricity: Re-designing of Day-ahead Market (DAM) in India, December 2018

interventions to ensure that cost of electricity supply keep declining while reliability of its supply keeps increasing.

We also suggest that there are at least three flexibility options to manage dissonance between demand and supply. These are: the rapid ramping up and ramping down capacity of coal power stations; demand reduction interventions; and addition of storage capacity to the grid. All of these managed flexibility options are currently under development, and used together in a portfolio mode to have the potential to satisfy the price, demand and reliability challenges of the transition.

I end this Lecture with the suggestion that targeted research and capacity building are necessary to achieve the technological, operational, regulatory and policy changes that would underpin the new paradigm of managed flexibility. These are essential for India to achieve this transition successfully, as well as to become a world leader in enabling other countries to also achieve this transition. I believe IIT-Roorkee, and DHRE, can be a global leader in this research and capacity building, just as AHEC has been a global leader in research and capacity building associated with micro and small hydropower.