Flexibility Requirement in Indian Power System

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1. Flexibility Considering the Fluctuating Demand Pattern

The rapid growth in installed generating capacity without commensurate increase in the loads, particularly during the off-peak hours, has brought about a sea change in the operation pattern of thermal power stations. With round the clock power shortages in the initial years, 100% plant load factor of thermal power stations was a much sought after performance indicator. The changing shape of load curve coupled with additions to the thermal capacity has led to a situation where 100% plant load factor would be an exception. . Now, with distributed renewable generation, system operators have to cope up with variation in generation too. Hence, dynamic load and generation pose difficulty in managing the grid even after harnessing diversity. One way to counter the above problem is to have flexible generation sources which can be ramped up and ramped down quickly. Since the conventional generation in India is thermal (coal) power dominant, thermal generation needs to be flexible to counter the variability and intermittency of the generation output of the renewables. This paper explains the need for flexibility, mainly in generation, in the Indian Power System.

2. All India load curve and demand patterns

Load curve of India has two typical humps, one in the morning and the other in the evening. Its characteristic shape varies with seasons. The typical maximum ramp rate while peaking is of the order of 200-300 MW/min which at times (say during Deepavali festival) is as high as 600 MW/min for few minutes.

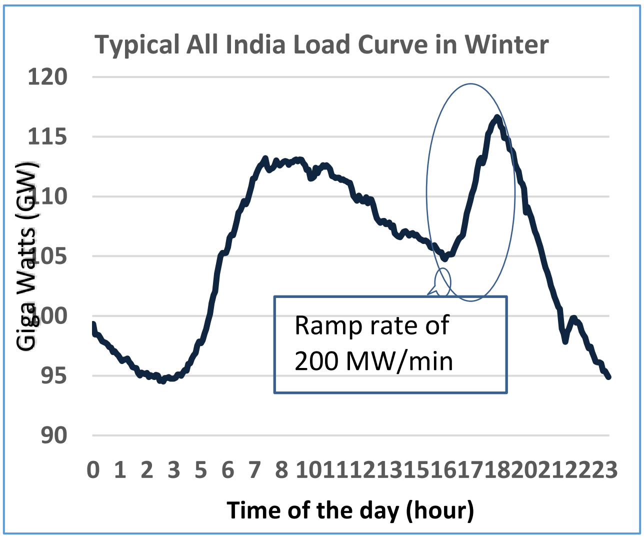


Figure 1: Typical All India Load curve in Winter

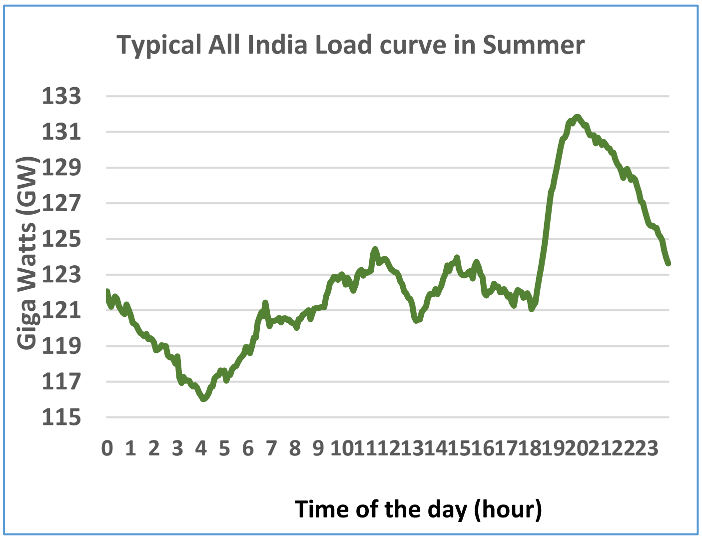


Figure 2: Typical All India Load Curve in Summer

Energy requirement in India is also growing year by year. Energy requirement also changes every season. For example, summers in India are hot and hence air conditioning load etc. pick up. Winter mornings have heating loads. All India maximum, minimum and average demand met is given below. The difference between maximum and minimum is also increasing gradually. The difference between daily peak and lean is increasing and would continue to increase. Figure below clearly shows that growth during peak hours is much more than lean hours and there is a need for more flexible generation to counter this gap. The flatter the load duration curve, lesser would be the requirement of flexible generation. It is observed that for 25 % of the time, at most 10000 MW more generation was needed. Hence, the flexible reserves requirement and unit commitment problem can be dealt by having a forecasted load duration curve. For example may be for

75 % of the time, the generation might run with full capacity factor and for 25 % of the time additional peaking units are needed in a day.

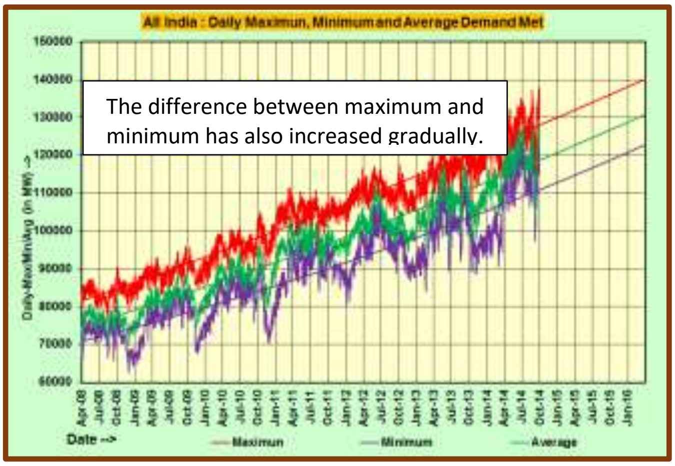


Figure 3: Difference between Max and Minimum Demand

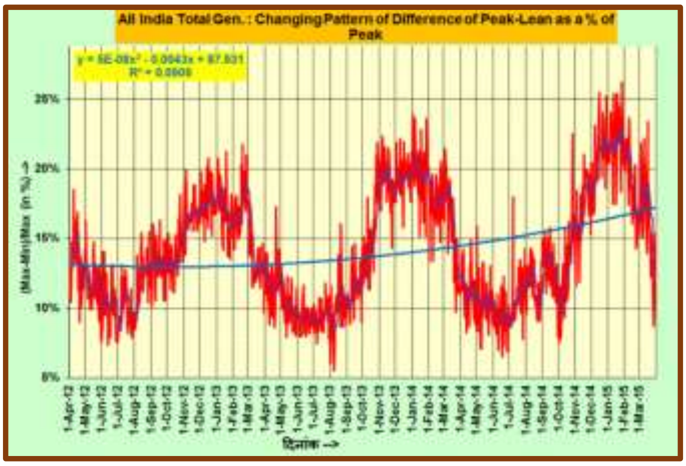


Figure 4: .Peak and off peak demand as percentage of peak

Both load duration curve and load curve must be used to decide the type of generation resources that would be required. Cochran et.al. [1] explain that flexibility is a time specific quality and the type of generation on bar, daily characteristics of solar, wind and hydro, seasonal variation of load and shape of load, all together contribute to flexibility of Power system. For example, load duration curve of state of Maharashtra which is more flat in nature indicating lesser flexible generation requirement than that of state of Assam. Load duration curve of Assam is kinkier in nature indicating that flexible generation which can do both ups and downs is necessary to cause economy.

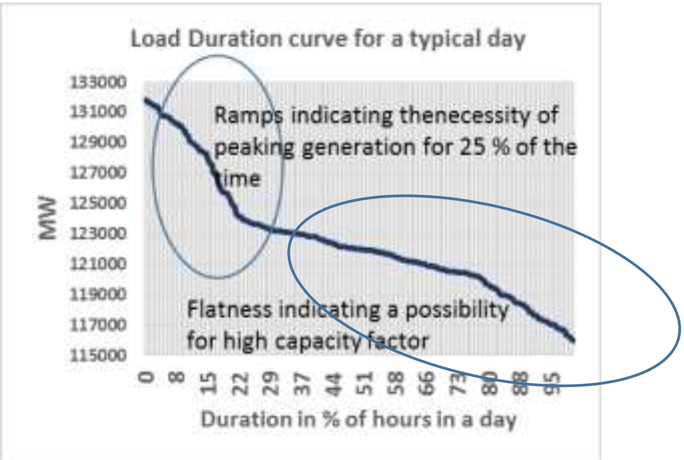


Figure 5: Load Duration curve for a typical day

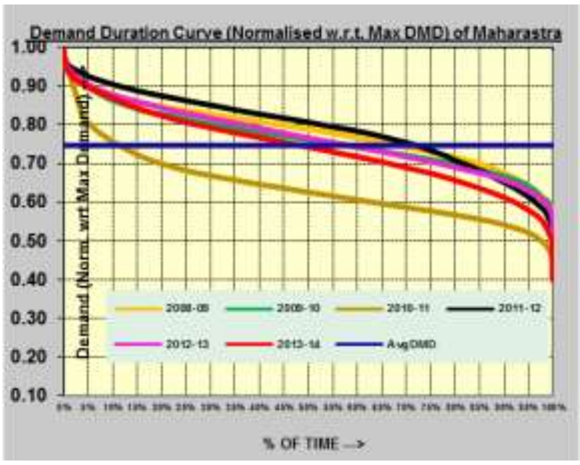


Figure 6: Demand duration curve of Maharashtra

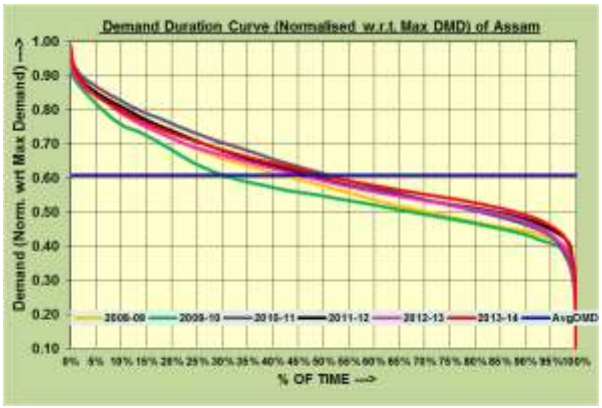


Figure 7: Demand duration curve of Assam

3. Diversity and Load factor

The All India diversity is almost to the tune of 5%. Diversity is calculated as given below

$$\text{Diversity} = \left(\left(\frac{\text{sum of individual maximum demands of the regions}}{\text{maximum load on the system}}\right) - 1\right) * 100$$

Having good diversity means that a lesser percentage of the installed capacity is required to be on bar to meet the demand. Diversity is a way of providing flexibility, if proper transmission is ensured between regions. During good diversity periods also, the short term operational planning has to be done carefully to avoid reserve shutdowns and consequential low PLF (Plant Load Factor), because sufficient flexible reserves may not be available in case of any contingency of a generator. That means generation resources capable of fast ramping should be kept on bar to make the whole exercise economical (less units are on bar) and the required ramping of resources is also ensured.

All India Daily Load factor was in an increasing trend till 2014, may be due to load shedding phenomena then, in vogue. If we examine the state-wise Annual Load Factors, it is seen that Delhi's Annual Load Factor has dropped from 64% in 2008-09 to 56% in 2014-15. It may be safely assumed that Delhi is by and large load shedding-free state with high per capita income levels. In contrast, Jammu and Kashmir's Annual Load Factor has increased from 66% to 74%. Apart from Delhi, the Annual Load Factor has declined in Haryana, Punjab, Uttarakhand, HP, Chandigarh, Goa, MP, Gujarat, Tripura and Manipur. It is expected that with emphasis on 100% electrification and 24 x 7 supply to consumers in all states, the Annual Load Factor would decline sharply. This coupled with the increase in RE penetration brings out the need for more flexible generation and turn down capability of conventional generator fleet.

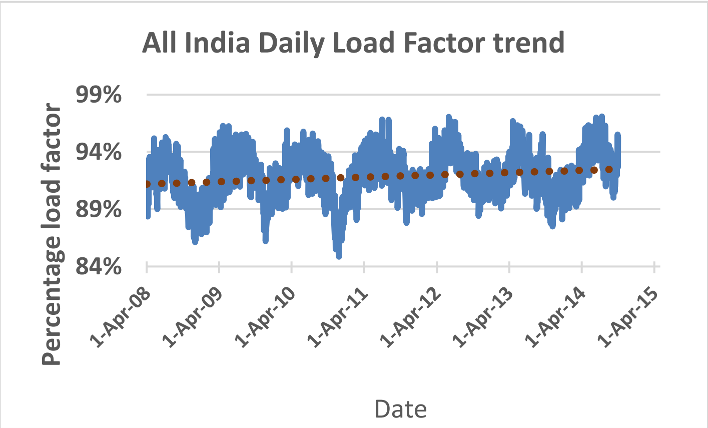


Figure 8: All India Load factor trend

4. Variability in the demand

Demand variability is one index for the requirement of flexibility needed for the present generation mix scenario. Variability in Demand is the average demand met of the present hour minus average demand met of the past hour. There is a need for explicit mention on unit ramping compliance in the Indian Electricity Grid Code along with 1% per minute ramp back after primary response. Generation planners may note that in future, with GoI target of 175 GW renewabs by 2022, of all the conventional generation fleet, fast ramping units like gas and hydro are the ones which are more important.

It can be observed that the envelope is only increasing, indicating the sharp increase and decrease of load. This is expected to increase with improvements in quality of life. Renewables also add to the generation variability in load generation balance. Flexible Power Reserves are necessary to take care of these variations in demand met.

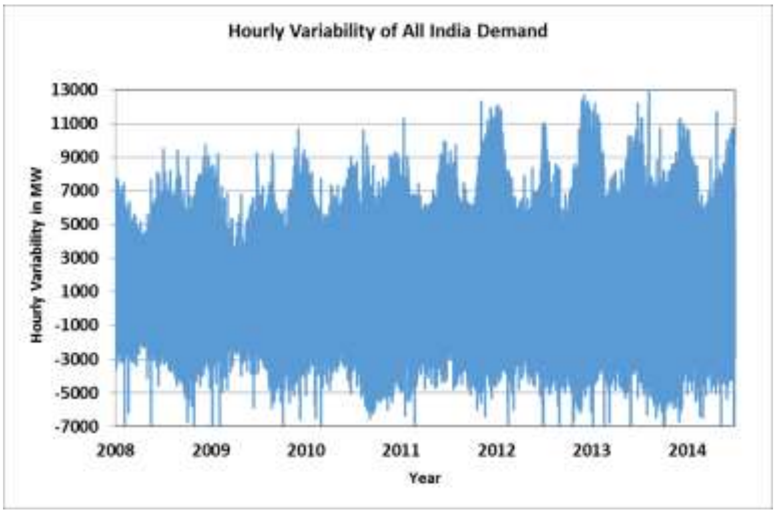


Figure 9: Hourly Variability of All India Demand

The load generation balance in the real time has to be restored quickly by varying the conventional generation output. This calls up for the necessity of having a good share of flexible generation in the overall generation mix and installing automatic controls like Primary and Secondary response in generators.

5. Pumped Storage as flexible generation

At present nine (9) pumped storage schemes with aggregate installed capacity of 4786 MW are available in the country. Out of these, only five (5) plants with aggregate installed capacity of 2600 MW are being operated in pumping mode. Purulia, Kadamparai, Ghatghar, Srisailam and Bhira pumped storage plants are working. Occasionally, even these PSPs are out of service due to planned/forced outages. If sufficient storage is not available, some other (may be costly) storage technologies, discussed in next section, have to be used or renewable energy could be partly curtailed while managing the load generation balance.

6. Other Storage options

Electricity market constituents are encouraging new technologies that are affordable for storage. NYISO and the Midwest ISO in USA modified their tariffs to allow energy storage facilities to participate in their wholesale markets as regulation energy providers [9]. Battery Energy Storage Systems (BESS), ultra-capacitors, fly wheels may become important in the future for peak changeover.

7. Role of Coal Fired stations for providing flexibility

From the flexibility point of view, factors such as the minimum technical limit of thermal generators, the ramp up and ramp down rates and number of starts and stops have to be taken under consideration [16]. In general, it has been observed, that many thermal stations are reluctant to back down their generation as per schedule to below 70% of their MCR (Machine Continuous Rating). Since Super Critical technology [14] is more favourable towards flexible generation, it can be encouraged as a part of the portfolio. CEA technical standards for construction of electrical plants give the following guidelines [12]:

- *The design shall cover adequate provision for quick start up and loading of the unit to full load at a fast rate. The unit shall have minimum rate of loading or unloading of 3% per minute above the control load (i.e. 50% MCR).*
- *The unit shall be capable of base load operation. However, the unit shall also be capable of regular load cycling and two-shift operation. The steam turbine shall be designed for a minimum of 4000 hot starts, 1000 warm stats and 150 cold starts during its life.*

Some large 660 MW, 800 MW and 1000 MW sets are being introduced recently. CEA Standard Technical Features for 660MW/800 MW sets recommends a technical minimum of 40%. Ramp rates are also important as the conventional generators have to ramp up and down fast during the sudden variations in the output of the renewables or in the event of any contingency. The spinning reserves also should respond with sufficient ramp rate in the AGC (Automatic Generation Control) process to catch up with the control signals.

Type of Plant	Block Load on Synchronization (MW)	Average pick-up and shutdown rates (MW/min)	Time to full load (min)	Minimum 'ON' Time (min)	Minimum 'OFF' Time (min)
500/660 MW Coal Fired	90	15 up/25 down	35	120	240
500/660 MW Oil Fired	50	15 up/25 down	35	60/120	60/120
200/300 MW	45	5 up/10 down	35	120	240
110/120 MW	20	4 up/10 down	25	60	240
60 MW	2	3 up/5 down	20	60	120

Source: Modern Power Station Practice, Volume L, Pergamon Elsevier, India 3/e 2008 [15]

	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%

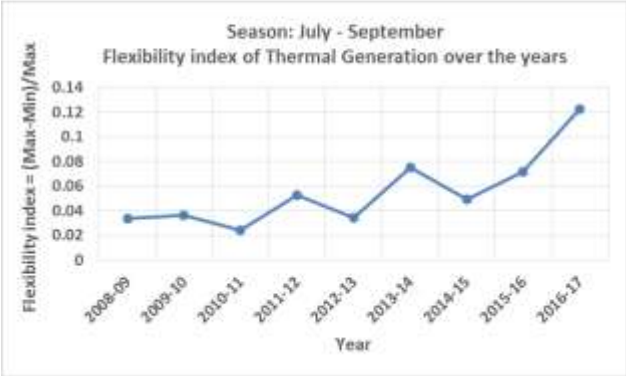
Source: EURELECTRIC/VGB enquiry

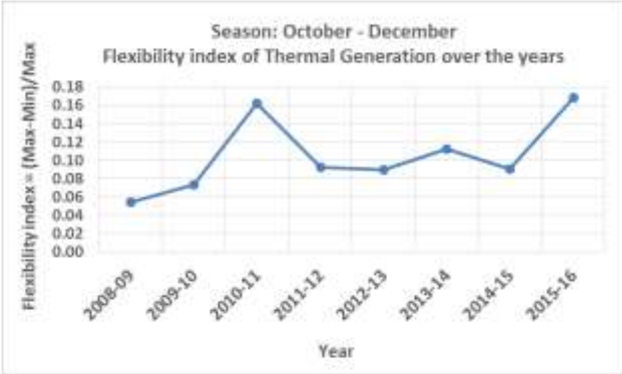
NPP – Nuclear Power Plant, HC – Hard Coal, LIGN – Lignite, CCG – Combined Cycle Gas, PS – Pumped Storage.

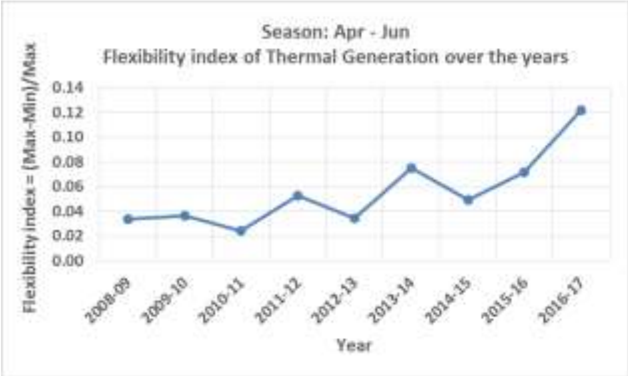
From the past data, graphs on thermal flexing and Plant Load Factors (PLF) over the years are provided below. It can be observed that the plant load factors are as good as at least 65% in these years. This might not be the case with huge inrush of renewables in the future.

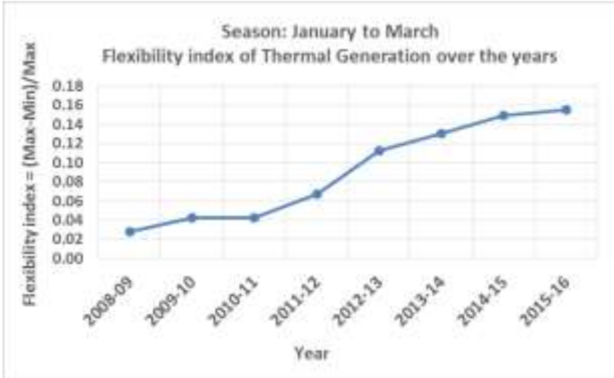
Measures have to be taken to increase flexibility in this regard. A simple flexibility index of thermal generation defined as (Max thermal gen-Min thermal gen)/(Max thermal gen) over the years plotted season wise is given below. It can be understood that the thermal flexibility has overall been on a rising trend. This increase was guided by operational practices and the necessity. But, after a certain limit of optimization of operational practices, design changes may also be inevitable.

Also, the present trend of load factors shows the operation of the thermal plants and their inherent reluctance to be flexible as a part of their design and operational practice. There is a declining trend in the PLF. Though fuel shortage is one of the contributing factor to this decline in PLF, the predominant factor is change in the 'Peak-to-off-Peak Ratio' which is becoming higher leading to less despatch and reserve shutdowns. Further, this change in peak-to-off-peak ratio has resulted in a scarcity for ramping sources.









CERC in its latest explanatory memorandum to CERC grid code (IEGC), draft fourth amendment regulations 2015 has proposed that *"the technical minimum may initially be kept as 55% of Installed Capacity/ MCR of unit/units for old as well as new plants."*

As per the draft, below 55% of MCR of units, the station may undergo for reserve shut down. The beneficiaries (DISCOMs) have been directed to compensate for the Heat rate degradation that occurs because of the operation of the thermal units below the technical minimum. Station Heat Rate (SHR) degradation norms for different levels of flexibility by the thermal units provided by the CERC is tabulated below. The generating company shall have to factor these norms in the Power Purchase Agreements (PPA) for sale of power in order to claim compensation for operating at the technical minimum schedule.

S. No.	**Unit loading as a percentage % of installed capacity of the unit**	**Increase in SHR for supercritical units (%)**	**Increase in SHR (for sub – critical units) (%)**
1	85-100	Nil	Nil
2	75-84.99	1.25	2.25
3	65 -74.99	2	4
4	55-64.99	3	6

Table: CERC Table showing compensations for the Heat rate degradation *(Source: CERC)*

Apart from the above, although the CEA Technical Standards for Construction of Electrical Plants prescribe a ramp rate of 3% for thermal plants, the actual typical ramp rates declared by power stations are lower. Some typical figures quoted by some generators to RLDCs for the purpose of scheduling are as under:

a) Ramagundam 500 MW unit at 24 MW per 15 minute time block (works out to 3.2 MW per minute; 48 MW divided by 15 minutes much lower than even the conservative IEGC limit of 5 MW per minute)

b) Simhadri 500 MW unit at 29 MW per 15 minute time block (approx. 4 MW per minute)

c) Sipat 660 MW unit at 4 MW per minute

d) Sasan 660 MW at 5.3 MW per minute

e) CGPL Mundra 830 MW unit at 8 MW per minute.

The low ramp rate quoted by generators necessitates further analysis at the plant level before suggesting measures such as retrofits. In addition to fast response in terms of ramp-up and ramp-down, two shift operations of power stations may be required in the future. Cochran et.al. in [20] based on a case study explain that *"Strategic modifications, proactive inspections and training programs, and various operational changes to accommodate cycling can minimize the extent of damage and minimize cycling-related maintenance costs."* Start up and shut down on the same day, even twice daily, capability of load following and running at minimum generation levels with gas support, Automatic Generation Control (AGC) capability, and operation at sliding pressure which increases efficiency and flexibility at part loads are the attributes which define a flexible coal generation plant [21].

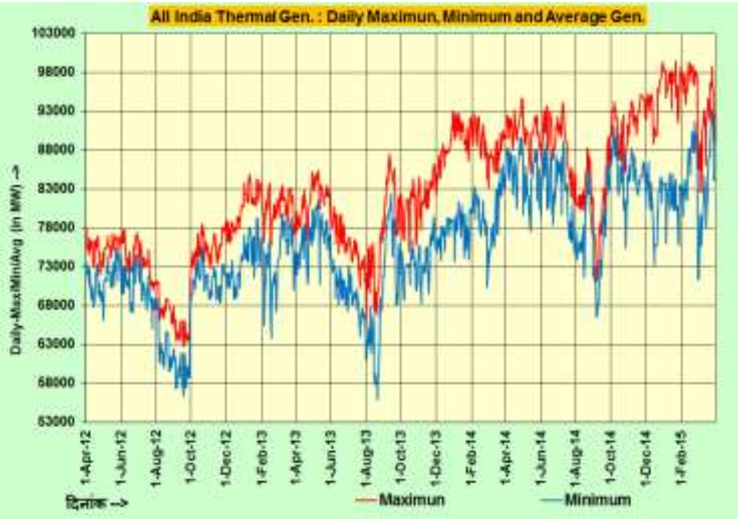


Figure 10: All India Maximum and Minimum Thermal Generation

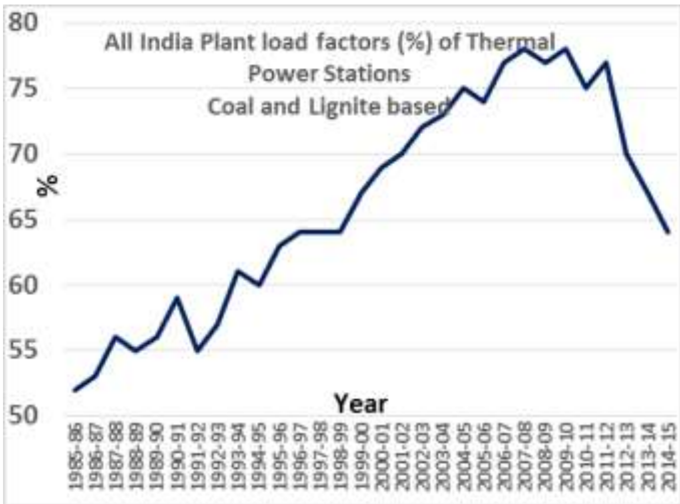


Figure 11: All India Plant Load Factors of Thermal Power Stations

8. Gas Stations

Gas turbine power plants are very flexible for adjusting the output power level. But, they are relatively expensive than other kinds of generation. Gas shortages also add to the problem. They should ideally be used as peaking units at times of maximum power demand. Amongst some power system constituents, particularly constituents with no surplus reserves, there is a tendency to operate gas generation as a base load. There is need to increase flexibility in this regard and resolve the dilemma with sound investment signals. Grid Code exempts gas turbines from primary response at present. Combined Cycle Gas Turbines (CCGT) have a typical ramp up time higher than the Open Cycle Gas Turbines (OCGT), hence are better candidates for flexibility.

9. Solar and Wind

An expected all India duck curve is provided below, extrapolated with just 20 GW of Solar generation connected to the grid, giving its rated output during Solar hours of a day. Despite having forecasts, the wind power output variability must be balanced by the system operator. With high wind potential areas getting occupied with less efficient and outdated technology wind turbines, India needs to have new and better equipped wind turbines technology which can perform well during low/moderate wind conditions and also stand against cyclonic winds. Special care must be applied with regard to grid interconnection than earlier in the planning stage. The machines should be selected in such a way which can give improved power factor and power quality. Latest turbines are incorporating fault ride through designs as a part of their manufacturing contracts. Latest technologies such as synthetic inertia addition using wind turbines, real and reactive power control, automatic response during system perturbations must be encouraged in the regulatory and planning stages. These also add indirectly to the flexibility of the power system. In Tamil Nadu, wind has about 50 % share in the total installed capacity. Considering 50 % Plant load Factor (PLF) in high wind season, there is a penetration level of 25 % on an average. Frequent Renewable energy injection curtailment citing technical reasons of "variability and intermittency" can be avoided if the resources are managed using proper grid management strategies. Hence, there is need for proper planning and flexible resources.

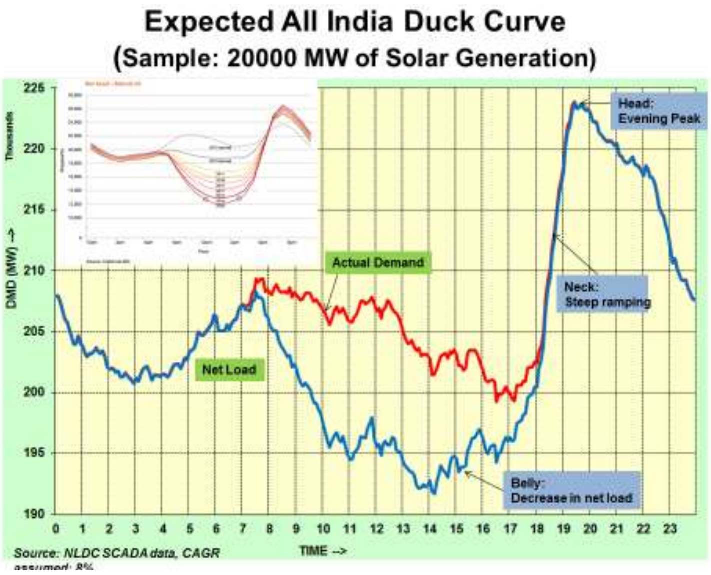


Figure 12: All India Expected Duck curve with 20 GW Solar injection in the grid

10. Hydro's role in flexibility

The present framework does not recognise ramping and flexibility as a separate asset. Flexibility is not being incentivized. Not only does peaking from hydro need to be properly valued, but the entire range of ancillary services must also be valued - including turn-down, ramp, etc. In the context of planning - losing efficiency at part load for Francis turbine is much steeper in comparison to that for Kaplan and Pelton turbines [4]. In the overlapping cases (considering Head) where both Francis and Pelton could be used, Pelton wheel can be a better choice than Francis turbine considering the overall efficiency. Issues such as high cavitation zone restricting operation of turbines over a certain range in case of Francis turbines are eliminated in case of Pelton wheel. Flexibility should influence the choice of turbines in the overlapping head ranges in the planning process itself at new stations. Policy incentives also should be provided to support system flexibility.

11. Spinning Reserves and flexibility in real time operation

There are a lot of uncertainties associated with power system. Historically from the power system statistics, it has been observed that large generators and transmission lines can and do suddenly fail. In the forecasting and scheduling part of the power system load, there are a lot of uncertainties associated with rainfall, humidity, temperature, thunder storms, and other weather related uncertainties. Also natural calamities, special days like festivals and celebrations affect the demand met of the power system, and many a times differ from that of the forecasted load demand. Effects of renewables have been already deliberated. Amidst of all these uncertainties, it is very important to have different 'Real Power Reserves' in the Power System to increase flexibility. Regulations must be brought in regard to spinning reserves, automatic generation control, and ancillary services which give flexibility in power system operation.

12. Demand Response – A future prospect for real time

Demand response is that in which users reduce or shift their non-essential power consumption on command from the control centres, can also be a very cost effective way to accommodate the variability of the renewable generation. Along with the development of the 100 smart cities proposed by the Government of India, regulations in this regard may be pursued by the Appropriate Commissions.

13. Consolidated list of action points

1. Plan and implement more pumped storage
2. Plan Pelton turbine Hydro stations wherever there is a choice
3. Better operational norms for Hydro under SERC jurisdiction
4. Plan for shift operation of thermal plants
5. IEGC should have clauses on flexibility, ramp up and ramp down
6. Look for incentives for flexible generation to promote competition
7. Plan implementation of primary control
8. Regulations on Reserves, Automatic Generation Control (AGC)
9. Regulations on ancillary services, better market design
10. Plan to override the present constraints in telemetry – all trending and analysis is done only when we have data! Regulations on communication requirement for Power sector
11. Policies and planning on Low Voltage Ride Through (LVRT) and new technologies with wind and solar which can help the grid
12. Introduction of Capacity Benefit Margin (CBM)
13. Load factors and the necessity to have target load factors

14. Way Forward

Firstly, the inherent natural flexibility that is available in the Power System in the form of controls and reserves in the existing fleet should be properly harnessed. There is a need to increase flexibility in the present power system itself in the form of spinning reserves. Considering the future of the Indian power system into account and the targets on renewable integration, steps must be taken right from the planning stage itself for a robust and flexible power system. Proactive regulatory intervention is also a necessity in this regard. Metrics for defining flexibility is still an evolving area [1], [22]. Some resources can be invested on it. Working only on the basis of metrics during this growth scenario in India may not also be very prudent as flexibility is situation and time dependant. Flexibility also should be kept in mind whilst drafting regulations, institutional practices and while taking planning decisions. Issues as normal as unit commitment, and sometimes as irrelevant as telemetry can decide the flexibility of the system in the real time. All the controls we have on the Power System and all the things related to the controls must be running smooth to harness the flexibility present in the Power System. As a way forward, some areas to work on the aspect of flexibility can be chosen and worked out like:

1. Solar and Wind – intermittency and variability in future Indian scenario, its quantification
2. Load forecast and renewable forecast
3. Unit commitment – ideal generation mix
4. Contingency handling with Reserves and Ancillary services
5. Thermal and Gas power plant issues while ramping
6. Metrics on quantifying flexibility
7. Planning requirements for future Power plants
8. Economic analysis on competition amongst flexible sources, technology dependent or independent.

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