Peaking & Reserve Capacity in India

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1.0 Abstract

India has been heavily reliant on coal for bulk of its electricity needs. Going by the recommendations of the 12th and 13th 5-year Plans, this dependence looks likely to continue well into the future. An addition of 73,000 MW of coal plants has been planned during the period from 2015 to 2022.

This paper will explain that focusing heavily on baseload, coal plants will lead to inefficiency and inflexibility. Power demand is increasingly following a cyclical pattern, characterized by sharp peaks during certain hours and marked troughs during off-peak hours and night. The demand for power changes continuously according to daily, weekly and seasonal load variations. Therefore, the combined output from electricity generators has to vary all the time to match the changing demand. The introduction of 1,75,000 MW of variable wind, solar and other renewable energy by 2022 will create additional dynamics in matching power demand & supply. The paper will explain the challenges of this balancing act. If capacity of baseload plants exceeds a certain threshold in the system, they will run at sub-optimal loads during off-peak hours. This leads to a significant drop in their efficiency. Many of the coal plants are already operating at a lower-than-normative annual plant-load factor (PLF).

This paper will present a case for changing the traditional mix and pruning down the baseload coal plants to about 80% of the planned capacity, replacing the balance 20% with internal combustion engine (ICE) based peaking plants. This modern distributed generation technology using natural gas with quick start/stop characteristics and fast ramp-up capability are ideal to meet peaking needs. They will enable baseload plants to operate at optimal load and best efficiency and will come online only as needed. The benefits of these hybrid systems can be quantified and further can be used for planning of power infrastructure in India.

2.0 Introduction

The Indian economy is the fourth largest in the world. Yet, weighed down by its large population of 1.2 billion people, the per capita income is among the lowest in the world. Similarly, the Indian electricity system (around 261 GW of installed capacity: Feb 28, 2015) is the fifth largest in the world. Yet its per capita utilization of electricity (917 kWh/person/year) is well below the global average (2900 kWh/person/year) and far below that of some of the more developed countries (over 10000 kWh/person/year).

Given the lower energy elasticity of developing economies, it is well recognized that India needs to scale up its electricity market rapidly to match its aspiration of becoming a global economic power. An estimate says that 300 million people in the country do not have access to electricity. To ensure inclusive growth, the needs of these potential consumers must be addressed too.

In trying to overcome the shortage and achieve adequacy of power at lowest possible cost, the emphasis, in all the country's planning exercises, has been on addition of base-load thermal plants that operate on coal. The reasoning has been that the country is rich in domestic coal resources and the price is controllable and not subject to global market dynamics. At present, coal plants account for 61% of total installed capacity (MW) and about 78% of total generation (MU). Coal will continue to play a dominant role in the future too, as an average addition of 11000 MW per year has been planned.

Fig 1: Installed Capacity MW on Feb 28, 2015: 261 GW

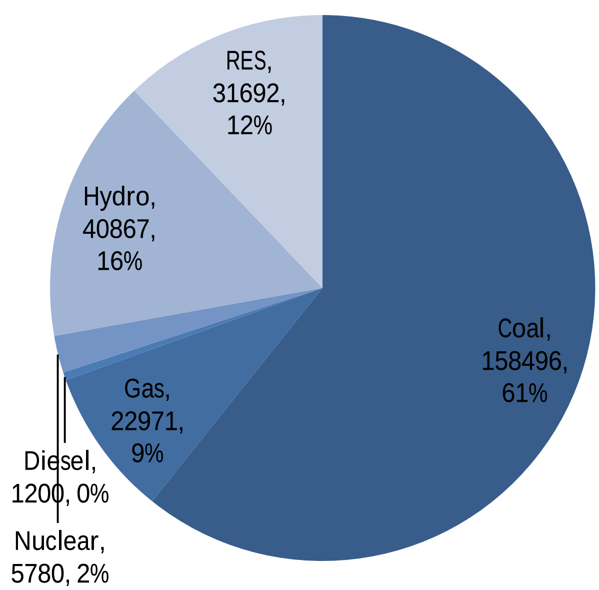
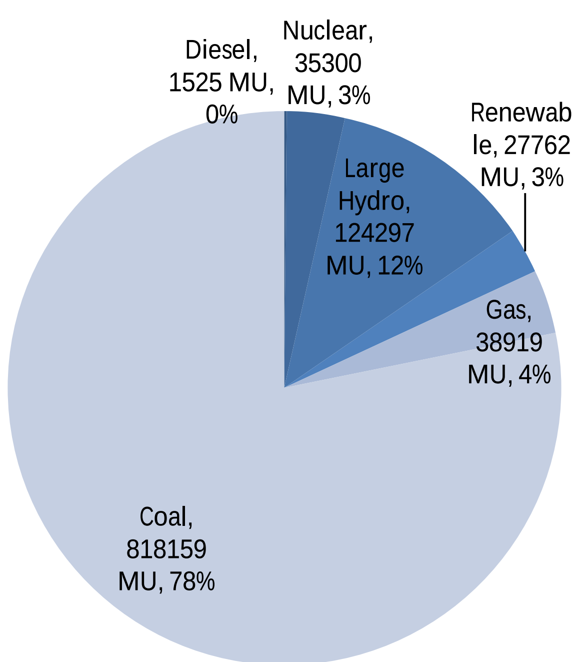


Fig 2:Total Generation in 2014 – 15: 1045 BUs

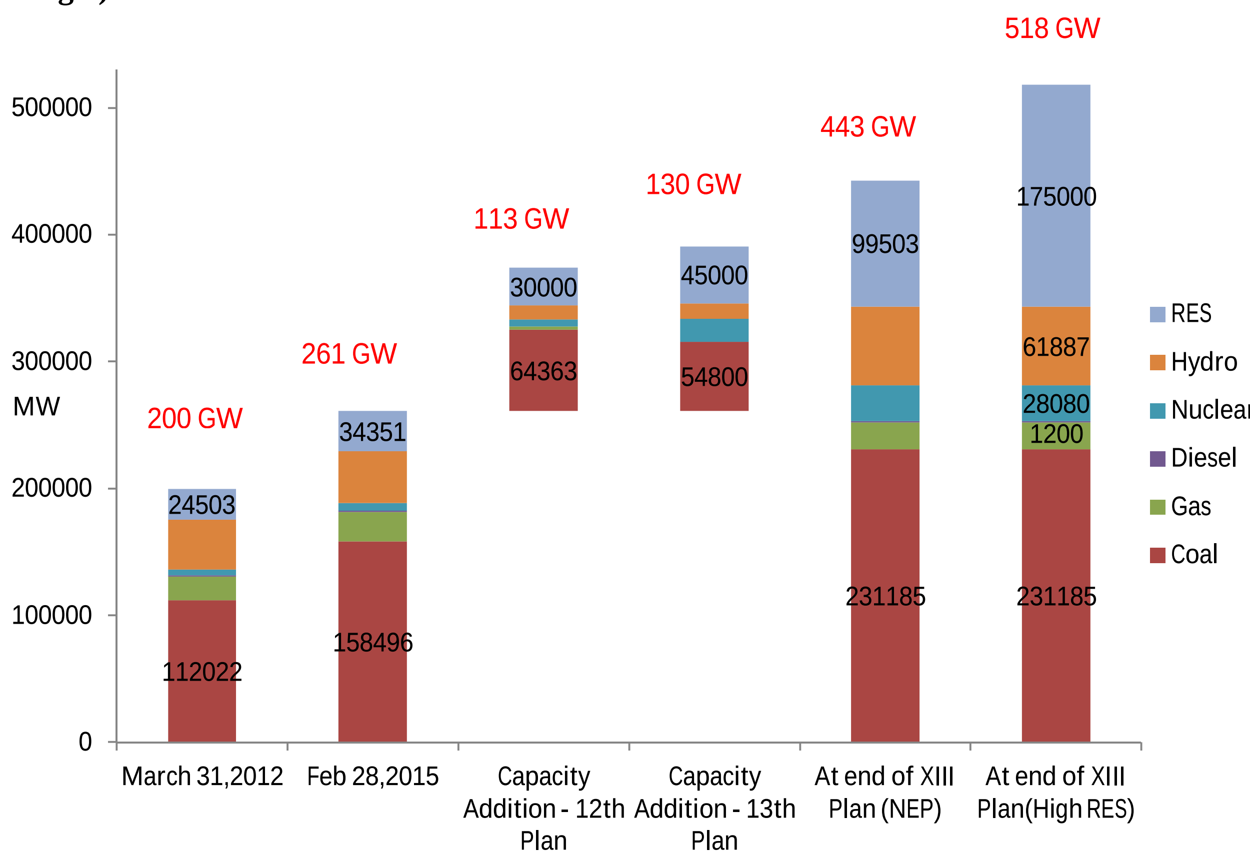


Source:http://www.cea.nic.in/reports/monthly/executive_rep/Feb15.pdf , http://www.cea.nic.in/reports/articles/god/generation_target_1415.pdf

About 15000 MW of gas-based generation plants (that used combined cycle gas turbines or CCGT) were added in the period 2000-2008, with the hope that production of domestic gas would be ramped up and that it would be supplied at a cost that would make power generation competitive with that from coal. Unfortunately, there have been problems with respect to both availability and price of domestic gas, with the result that most of these gas plants are under-utilized and are viewed as "stranded assets". They cannot be revived by using alternatives such as imported R-LNG as the cost is seen as "prohibitive".

Following the same tradition, the 12th and 13th plan envisages addition of coal plants totaling to 119 GW by 2022 and seeks to retain the dominant share of coal in the generation mix. India plans to install 175 GW of renewable by 2022, i.e. 100GW solar, 60GW wind, 10GW biomass and 5GW small hydroelectric projects. The percentage of hydro-based generation in the total mix is coming down by 2022. This will reduce the flexibility in the grid.

Fig 3: Installed capacity at the end of 13th plan i.e. 2022 (Based on NEP & latest Union Budget)



Source: CEA monthly reports, National Electricity Plan (NEP) - 2012

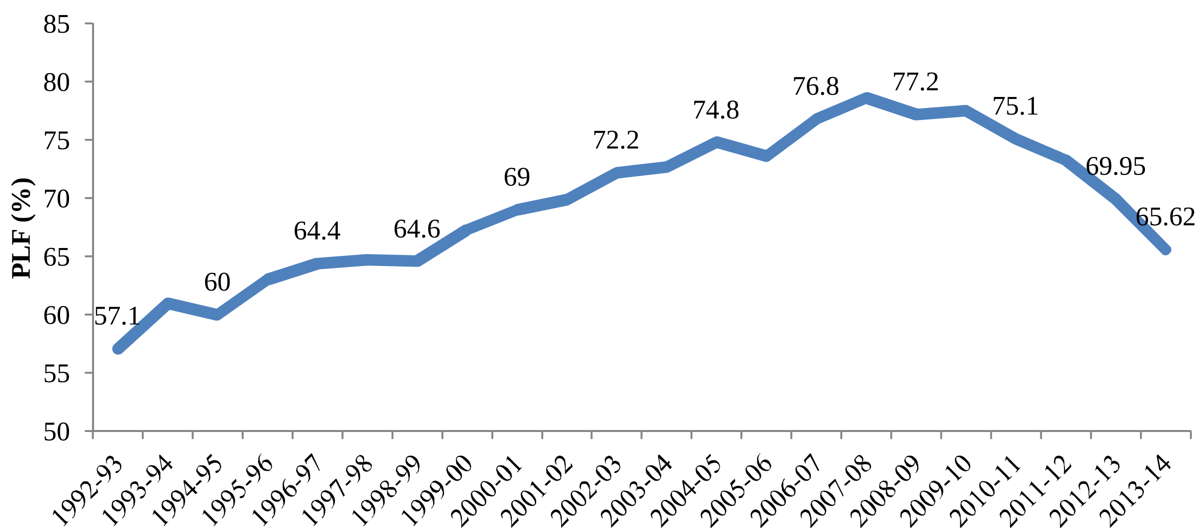
3.0 Challenges posed by variable load

Given the shortage of electricity and the absence of alternatives, one would conclude that the coal-powered plants must be running flat-out at close to full load most of the year round. But the reality is different.

a) Though India's total installed capacity (including coal, hydro, nuclear, gas as on 28-2-2015) was 261006 MW, and the peak demand was far less at 148166 MW – there was still a shortfall of 5% in meeting the demand. Shortages continue to exist in different parts of the country.

b) Coal plants are seen to be operating at close to full load during peak hours and cannot be ramped up further to overcome peak shortage. Yet, paradoxically, the average load-factor of coal-based plants has been coming down over the years, as can be seen below.

Figure 4: PLF of coal plants

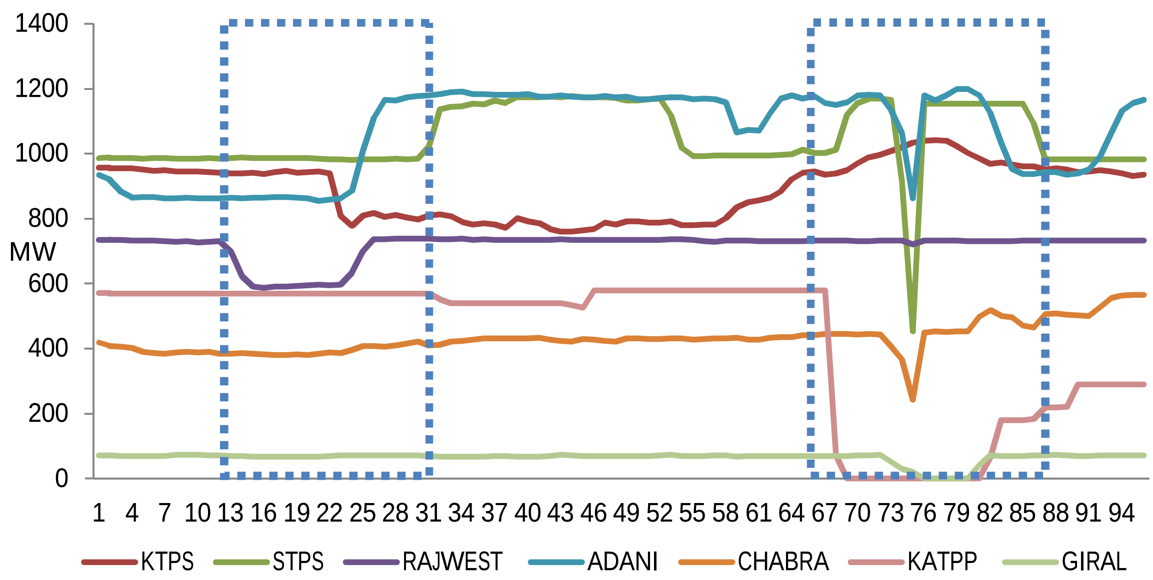


Source: CEA

There have been several attempts to explain the trend of falling PLF. One reason cited is that inadequate coal supply severely restricted generation in many of the thermal plants and resulted in lower average dispatch. Another explanation is that there are inter-state and inter-regional transmission constraints that prevent free flow of power. It is argued that once these bottlenecks are removed and when the southern grid is hooked up to the NEW grid to form a composite national grid, the offtake from coal plants would improve. Yet another explanation is that loss-making distribution companies (discoms) are reluctant to procure more power due to poor cost-realisation from the consumers, and – without a 24 x 7 supply obligation- would prefer to resort to load-shedding instead. All these explanations do have some basis, but the analysis in the paper shows that the most plausible reason for the lower PLF is the significant variation in power demand between peak and non peak-hours. While peak demand continues to grow rapidly, the average drawal over all hours of the day grows at a slower pace.

The cyclical pattern is getting more pronounced with increased urbanization and is evident from the daily load curve of Rajasthan. (Figure 5)

Figures 5: Cycling of Coal plants in Rajasthan on Dec 8, 2014



Source: Rajasthan SLDC

A similar cyclical pattern is discernible in many of the thermal plants across all seasons. The conclusion is this: If, to ensure adequacy, the system is packed with baseload capacity beyond a certain threshold, it can be counter-productive. The plants will be forced to operate at sub-optimal, lower load during off-peak hours and night. They will run at very poor efficiency, burning more fuel for every kWh generated and entailing more maintenance costs. This will increase the generation cost per kWh. In addition, when the plants are run at less than normative

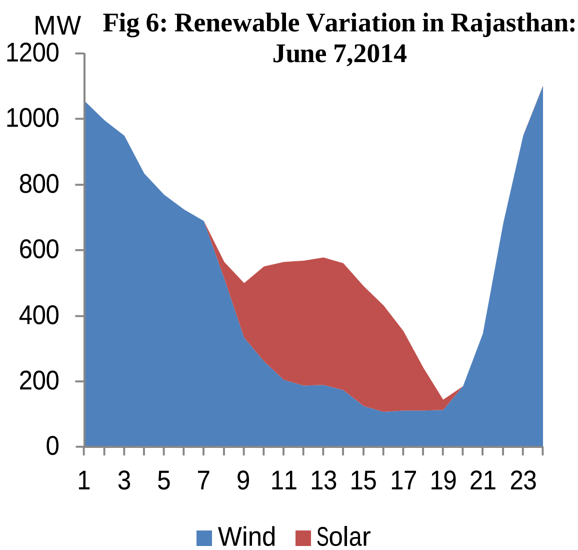
PLF, the fixed cost amortised on a kWh basis will go up in inverse proportion. Sub-optimal use of plants means also more CO2 emissions.

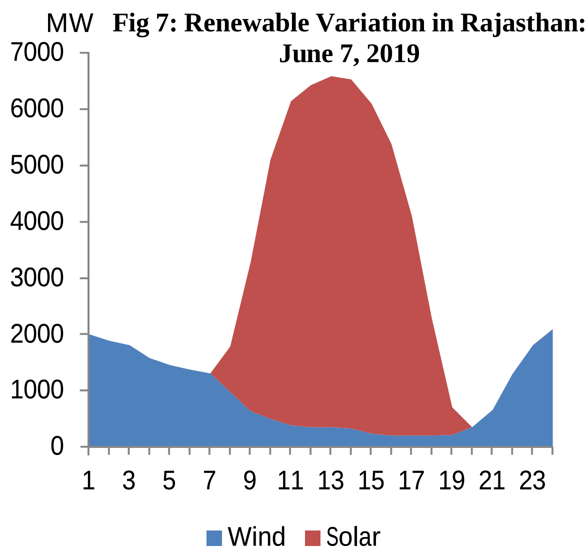
The problem threatens to worsen in the future. If the capacity addition of 73000 MW of coal-based plants is done during the period from 2015 to 2022, the average PLF of the plants could come down to 63% or even lower while meeting the energy demand projected for the period.

In latest union budget the government set ambitious target of 175000 MW for clean energy installations by 2022. This would comprise 1,00,000 MW of solar power, 60,000 MW of wind power, 10,000 MW of energy from biomass and 5,000 MW from small hydroelectric projects. Currently, India's clean energy capacity is 34,351 MW. The problem will be rendered more acute by the planned addition of wind and solar power plants. To allow preferential evacuation from these must-run plants, the average PLF of coal plants may have to dip below 60%. Or, the output from RE plants must be curtailed in the interest of grid stability, which would defeat the purpose of installing clean-energy plants.

4.0 Case Study: Renewable Integration in Rajasthan

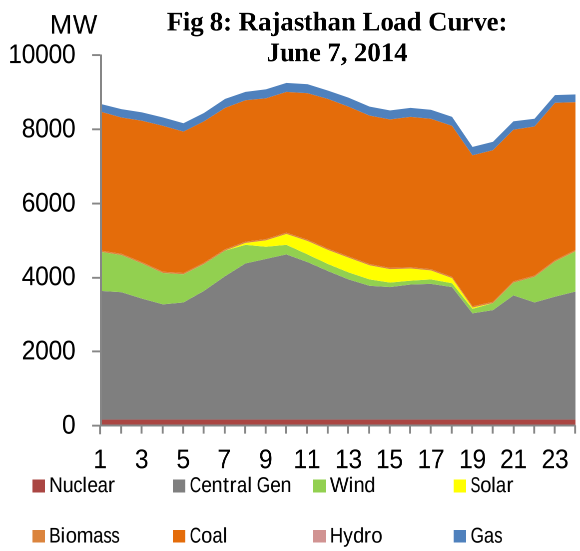
At present, Rajasthan has 3035 MW of wind and 500 MW of solar (Rajasthan share) installation. It plans to add 7500 MW Solar and 2740 MW Wind by 2019-20. Based on the Rajasthan SLDC data for 2014, we have projected the renewable variation in the state by 2019-20. This can be seen in the below graph.

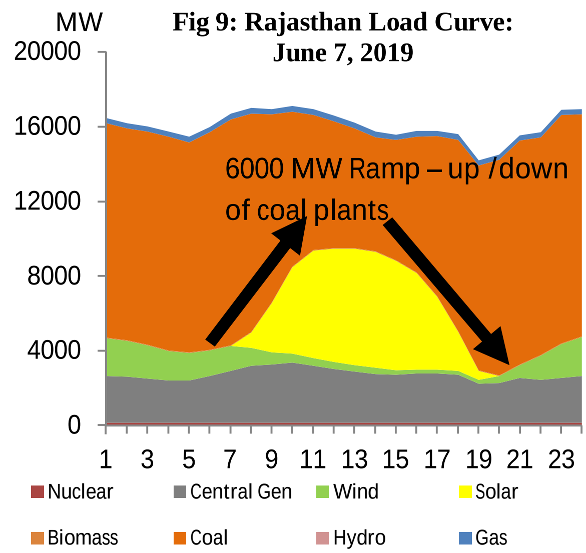




Rajasthan will have 8000 MW of grid connected solar plants by 2019-20. This will result in 6000

MW ramp up (during sunset) and down of coal plants (after sunrise). The cycling of coal plants can be seen in the below load curve of Rajasthan.(Variability of 5775 MW of wind generation can be unpredictable)





The system needs a lot of flexibility. There is a requirement of fast ramp-up and ramp-down internal combustion engine (ICE) based power plants to accommodate renewable energy and to match the demand. 100GW of solar and 60GW of wind energy in the whole country will further impact ramp up and down of coal plants across the country.

5.0 Coping with the challenges

Conscious of the need for specific action, a Task Force was constituted by CEA (Central Electrical Authority) in 2012 to deliberate over various aspects of setting up peaking power plants and creating adequate system reserves. The key observations made by the Task Force were:

- The load curves in different regions show that demand tends to peak during certain times of day and certain seasons.

- It is evident that dedicated peaking power plants are required to meet the spikes in demand. Pure base load plants will not be able to serve this need.

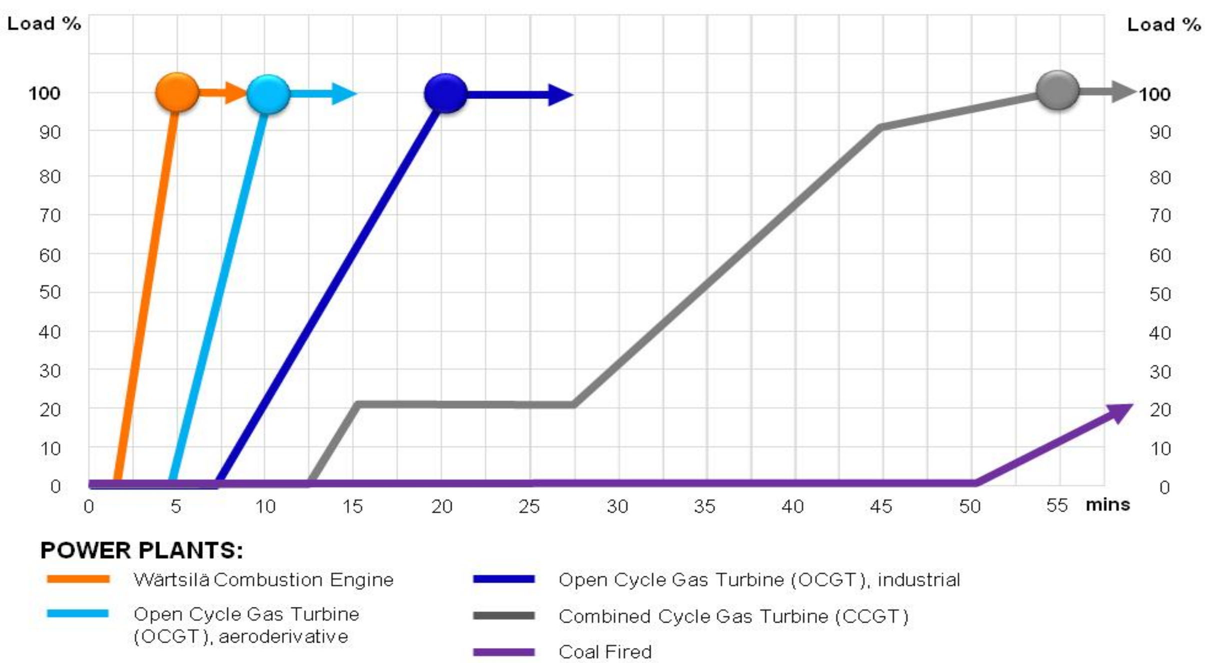
• Peaking plants must have definite characteristics such as quick starting time and ability to run at part-load without drop in efficiency.

• Such plants should also serve the purpose of 'standby reserve' – to come online rapidly.

• Plants that can meet the requirements are hydro-electric or gas-based power plants operated by open-cycle gas turbines or reciprocating engines.

The identified potential for hydro power is only 21020 MW during the period from 2015 to 2022. Another 56000 MW (apart from 25700 MW towards reserves) of peaking capacity in 12th and 13th five year plan is recommended by the Task Force must, therefore, come from gas plants that use aero-derivative turbines or large IC engines. The paper points out the advantages of using IC engine technology. The instant start and rapid ramp-up characteristics make it ideal for peaking and reserve applications among all technologies that use gas.

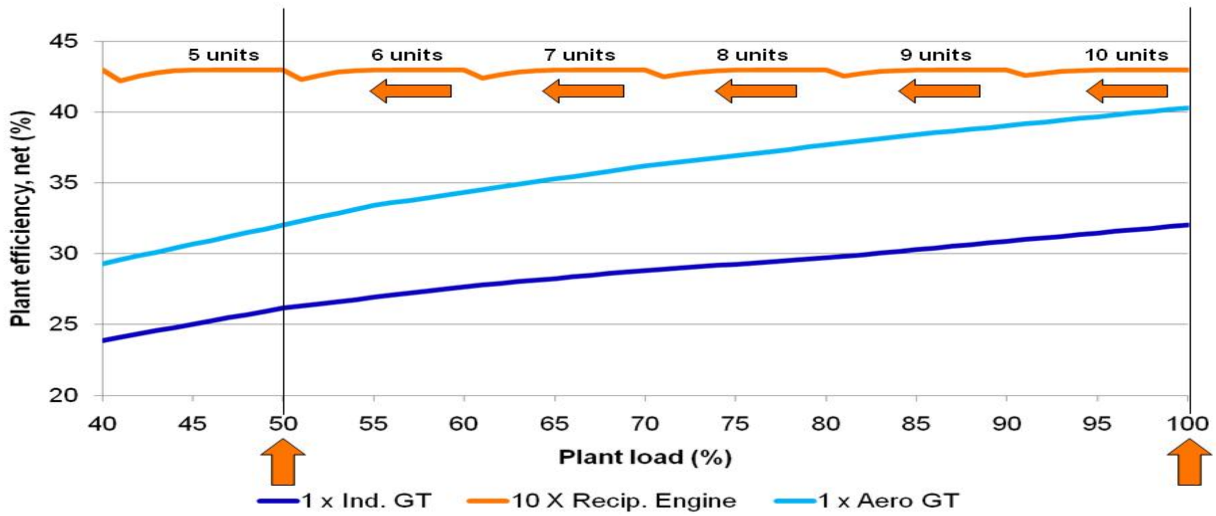
Figure 10: Start time per technology



Source: Wartsila

Plants using IC engines can be built to any size, even 500 MW or larger, in one phase or spread over a period of time. These plants consist of multiple engines each of which operates at a high efficiency. The modularity ensures highest efficiency at any plant load, as the number of engines pressed into service can be controlled to suit the variation in load. This feature is essential as peaking demand can vary and the plant may be required to cater to different loads at different times of day. IC engines excel on this count.

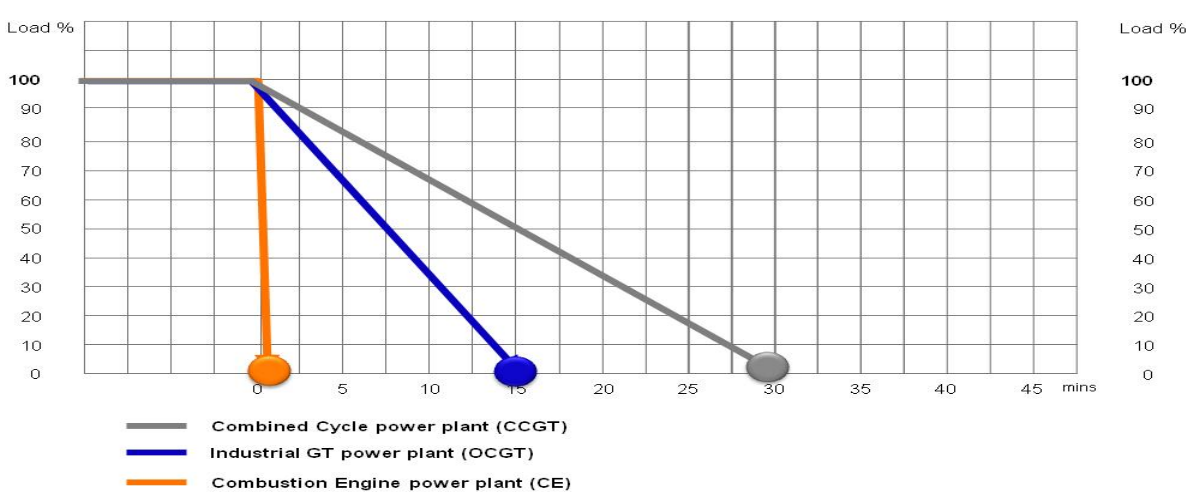
Figure 11: Load range & Part load Efficiency comparison



Source: Wartsila

The flexibility of reciprocating engines is extremely useful in countering the variability of renewable energy, as they can be brought on instantly if there is a drop in generation from RE sources and stopped to allow its evacuation into the grid when its generation picks up. They thus act as enablers of renewable energy and contribute to the reduction in carbon emission.

Figure 12: Unloading times per technology



Source: Wartsila

6.0 Cost of power generated from peaking plants that use gas

There is widespread belief that power generated from gas-based peaking plants will be far too expensive compared to that using coal and that distribution companies (discoms) will resist evacuation of such power due to the unwillingness of end consumers to pay a high price. Many examples are cited of existing gas plants in the country that are lying idle despite the willingness of gas companies to supply R-LNG, as they do not find it economically viable.

The fact is that most of the idle gas plants are based on combined-cycle gas technology and are designed for baseload operations. They cannot compete, on the merit-order, with coal plants that perform the same duty, unless domestic gas is made available to them at a special, administered price. Given the shortage of domestic gas in the foreseeable future, this is not likely. These plants couldn't fall back on option of using imported R-LNG as the landed cost of latter was far higher on the merit order and made it unviable for baseload operation, against coalplants. Also, like coal plants, combined-cycle gas turbine plants lack the flexibility to start/stop quickly to be effective for cyclical duty. This is why many gas-plants in India based on combined-cycle technology have had to remain idle. Their energy cost is far higher than that of coal plant for baseload duty, and they lack the flexibility to support peaking applications.

But when gas is used for peaking duty, considerations are different. Gas-based peaking plants being enablers of reliability, the cost of power from such plants needs to be assessed in a broader perspective:

1. Peaking plants typically operate only when needed, though they are designed to operate continuously if the situation requires them to. Their annual energy output (and therefore their gas consumption and cost) will be limited to the extent of top-up demand beyond what the baseload plants cater to.

2. It is incorrect to compare the variable cost of coal-based power with that of gas-based power from peaking plants, based on thermal efficiency of former at either normative or design load. As we've seen in the previous section, because of the sub-optimal PLF, the fuel cost per kWh of coal plants is much higher due to the lower average efficiency and higher average heat

rate. A comparison must be done based on the actual operating efficiency of the coal plants, corresponding to the lower PLF (say 67%) of the plants.

3. Instead of viewing the cost of generation from a gas-based peaking plant on a stand-alone basis and concluding that it is too expensive, a more holistic pricing approach should be followed. A hybrid combination of coal and gas plants can be planned for, and the weighted-average cost of generation worked out. The capacity of coal plants could be limited to 80% of peak demand of the system which could then be complemented with flexible gas-based plants sized for the other 20%. The benefits:

a) Coal plants would serve the baseload needs and allowed to operate at normative load (80-85%), where their efficiency is highest.

b) Efficient, quick-start, gas-based plants could be used to top up the power supplies for peaking needs. Though the PLF of these plants will be less than 15% (as they will come on only during demand peaks), they will, by design, operate at their highest efficiency at all loads. Although the capacity (MW) of these plants will be fully available, the gas consumption will be limited as the energy generated annually (MU), as a percentage of total, will be low.

This hybrid combination will offer the advantages of best efficiency and flexibility. The weighted-average cost of generation from the hybrid or 'optimized" combination can then be compared with that of coal plants operating at low PLF of 67%.

4. Based on a study on two representative coal plants of NTPC (at Farakka and Kahalgaon), and extrapolating the results to cover the 73000 MW capacity addition planned during the period from 2015 to 2022, the following conclusions could be drawn (the assumptions and methodology are can be shared on request)

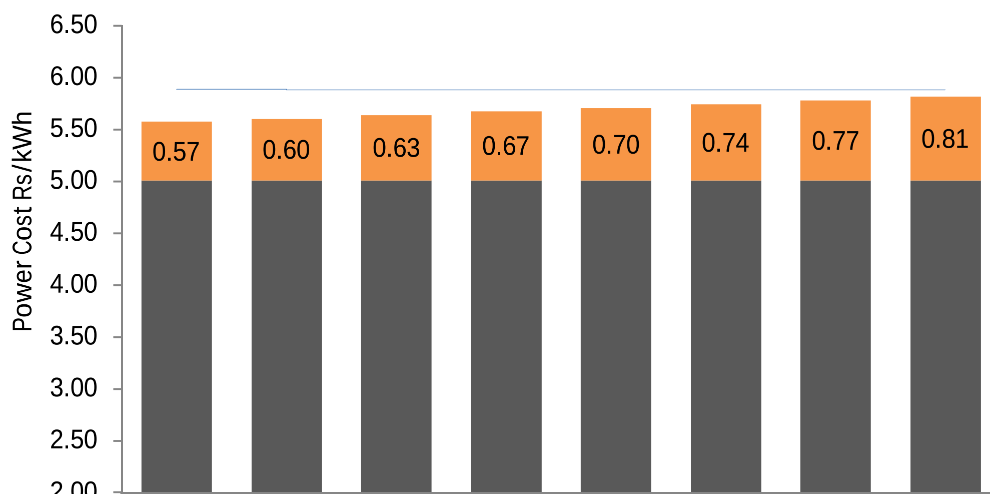
- Power from a hybrid combination of 80% coal and 20% gas is more cost-effective than that produced by the plants based on 100% coal and operating at lower PLF. This is valid even when using more expensive R-LNG instead of domestic gas.

- If the 80:20 hybrid principle is applied on the entire 73000 MW of coal plant capacity targeted from 2015-2022, the coal plant capacity addition can be limited to 58400 MW, and gas-based peaking plants can make up the remaining 14600 MW. Calculations show that the average cost of generation from this hybrid combination of plants will be cheaper by Rs 0.14/kWh than when entire addition of capacity comes from coal plants. This is after assuming a fairly high gas price of USD 18/MMBTU for operating the peaking plants. The savings spread over the entire 73000 MW capacity would be around Rs 5624 crores/year. The savings happen due to a) lower fixed cost/KWh of coal plants due to better amortisation of capital costs at normative PLF b) fuel saving by running the coal plants at best efficiency and heat rate, instead of partial load c) avoided maintenance costs due to high cycling.

• If, in the above case, it is assumed that domestic gas priced at around USD 8.4/MMBTU will be made available for peaking plants, the cost of generation from hybrid combination will be cheaper by Rs 0.31/kWh and the cost saved over the entire 73000 MW capacity would be over Rs 12394 crores per year.

5. Figure 13. shows the cost of generation on coal-only basis and hybrid basis. It is seen that the average generation cost from the hybrid combination is lower than when coal plants (on cyclical duty) are used. The optimization is the result of stable and fixed generation from coal plants at higher efficiency while flexible gas-based generation takes care of the peaks.

Figure 13: Coal-Gas Hybrid model graph



	8	10	12	14	16	18	20	22
Hybrid: Gas Component	0.57	0.60	0.63	0.67	0.70	0.74	0.77	0.81
Hybrid: Coal Component	5.01	5.01	5.01	5.01	5.01	5.01	5.01	5.01
Only Coal	5.88	5.88	5.88	5.88	5.88	5.88	5.88	5.88

Gas Price US$/MMBTU

For example at RLNG cost of $16/mmbtu, the stand – alone cost of coal based plant generation at lower PLF would be Rs 5.88/kWh. Due to hybridization of Coal and Gas, the overall cost of generation could be Rs 5.71/kWh (i.e. 5.01 + 0.70). The components of this hybridized cost are Rs 5.01/kWh from coal plants and Rs 0.70/kWh from flexible gas based plants. Thus the cost of generation of coal based plants comes down from Rs 5.88/kWh to Rs 5.01kWh due to optimized generation at higher PLFs. (A detailed calculation can be shared on request)

6. Flexible plants complement and act as enablers of solar and wind energy. With the security of instant back-up, full evacuation from such renewable energy plants can be done without worrying about the infirmness. This means that sourcing of this power with zero variable cost can be maximized. As the ‘zero cost’ will apply to wind and solar for all years to come, the differential will widen as the price of coal goes up.

For instance, in a state like Tamil Nadu, which has a significant amount of wind capacity, the evacuation of wind energy today poses a major challenge. During high wind season, the energy from wind turbines can be evacuated only by cycling down the coal plants. Due to high variability in the wind pattern, a decision cannot be taken to shut down the coal plants as they cannot be re-started quickly if/when wind energy drops. With a limited number of hydro plants, the system that relies primarily on coal plants is found to be too inflexible to cope with the intermittency of wind as well as the daily cycles on the demand side.

By following the 80:20 hybrid principle, Tamil Nadu would gain substantially. The capacity of coal plants online can be reduced by 20%, and flexible gas plants can ramp up or down instantly at best efficiency, counter-cyclic to the profile of wind energy generation.

Thus, flexible gas plants will not only enhance the reliability of the grid, but help in system-level cost optimisation by enabling baseload plants to operate at best efficiency and by allowing full evacuation of cheaper renewable energy.

7.0 Other advantages of gas-based plants

Furthermore, the flexible gas plants will offer the following benefits, over a period from 2015 to 2022:

a) As the burden on investment will be lower by nearly MINR 365000 (around MEUR 4562), financial closure will happen much faster. The IDC of these plants will be lower, as the modular plants can be constructed faster.

b) The requirement of land will be lower by 14000 acres.

c) The avoided water consumption will be nearly 500 million cu.m/year. To put this in perspective, this quantity is more than enough to satisfy the annual need of a large city like Bangalore.

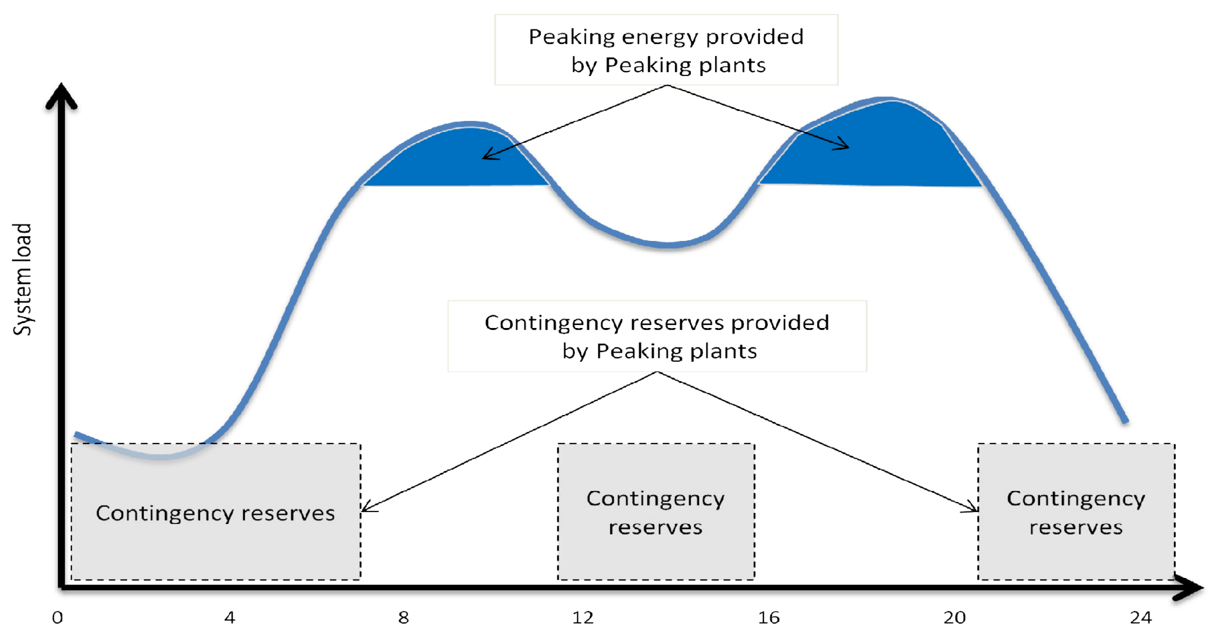
d) The CO2 emission will be reduced by 14 million tons/year. This happens on account of using a cleaner fuel like gas for peaking, as well as operating the baseload coal plants at improved efficiency.

e) The flexibility offered by the gas plants is of immense value in the following applications:

i) Ancillary services: Frequency support and regulation

ii) Reserve capacity: As these plants offer the comfort of ‘standby reserve”, they can meet a large part of the secondary and tertiary spinning reserve requirements.

Figure 14: Peaking & Reserve Margin



iii) Load-centre servicing: Gas plants can be located close to cities/towns and reduce the strain on the transmission system. Moreover, the black-start capability of these plants will be useful in evolving an islanding scheme for important load-centres.

8.0 Enabling policy

Obviously, such a concept needs to be supported with policy initiatives and regulatory framework. Setting up of dedicated peaking plants needs to be incentivised through a competitive bidding process which can be technology-neutral but which lays down minimum criteria for start/stop and ramp up/down characteristics. Also, the current system of ‘merit order despatch” stacks power plants unit-wise, based on energy cost. So, power from a gas-based plant on a stand-alone basis always appears more expensive than that from a coal plant. The existing system also considers the heat rate of coal plants at normative PLF, even though the plants, in reality, run at lower load-factor due to lower evacuation. A system which allows bids and despatches from hybrid plants, will pave the way for higher system efficiency.

9.0 Conclusion:

Relying only on baseload coal plants to meet India’s growth needs would be fraught with risks and would lead to inefficiency. A hybrid mix of coal and flexible gas plants, in the ratio of 80:20 would make the system flexible, more efficient, more capable of absorbing clean, renewable energy into the system and bring the country closer to realizing the vision of “24 x 7 power supply for all”.