Optimal Power Generation Mix

for India

Addressing Sustainability & Peak Demand Management

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India’s economic growth is inextricably intertwined with power availability. The correlation between GDP growth and addition to power generation capacity is close to 1. This means that to support a sustained GDP growth of say 9%, our country needs a similar growth in generation capacity, year after year. And this does not address the already existing deficit.

Despite the growth in energy needs, the National Action Plan for Climate Change has also envisioned a sizeable reduction in CO₂ emission. The challenge, therefore, is to meet the energy demand of a developing nation, while at the same time keeping the carbon footprint as low as possible. While the objective can be partly achieved through demand side management (energy efficiency and conservation), a bigger opportunity to cut down emission exists on the generation side.

A report titled “Real Cost of Power” published by Wärtsilä in July 2009 had brought out the grim reality and extent of power cuts in 21 cities in India, and the cost incurred by the citizens in coping with the shortage. The installed cost of back-up mechanisms such as inverters, batteries and gensets was estimated at Rs 100000 crores, while the annual recurring cost on account of maintenance and fuel was calculated as Rs 30000 crores. The report had pointed out that a small ‘reliability surcharge’ on power would fund investments in ‘efficient peaking’ plants and would enable the nation to do away with inefficient back-up mechanisms.

The problem of power shortage in the country cannot be resolved just by numerically matching the aggregate annual demand with generation. The demand for electricity varies widely with time of day and with season. It cannot be stored; therefore its generation must match the demand, dynamically, all the time.

The Indian power sector relies heavily on coal-based generation, as large quantum of fuel is available indigenously and at a low, albeit controlled, price. But the so-called economy of coal-based generation has a serious flip side. The technology is only suited for steady, rigid, base-load operations. It lacks the flexibility to respond efficiently to demand variations or the nimbleness to start and stop quickly. As more Ultra-mega coal plants get added into the system, the problem of inflexibility and consequent inefficiency would only worsen and the objective of reducing the carbon emissions will be defeated.

Countries with well-developed electricity markets have realised that over-reliance on inflexible, base-load generation, could lead to a collapse of the system. What is required is a judicious mix of base-load generation and peaking plants, the former to provide ‘bulk power’ at low cost, and the latter to top up flexibly, to suit the variation.

Wärtsilä commissioned a study to arrive at the judicious mix in the Indian context. The state of Maharashtra was chosen for this case study. We looked at two scenarios: An “As Is” scenario where growth in generation capacity happens pre-dominantly through addition of base-load plants (as per XI and XII Plans) and an alternative scenario based on a mix of base-load generation and peaking plants with their inherent feature of high efficiency & flexibility of operation. The results from the Maharashtra case study were extrapolated to arrive at an all-India macro-picture.

The study clearly establishes that the scenario evolving with Plan B which suggests introduction of High Efficiency – High Flexibility - Distributed Power (HEHFP) technology in the generation mix would offer the following significant benefits that can be readily monetised by the nation:

a) Higher efficiency, resulting in reduced fuel consumption to the extent of 264,191 bn Kcal per year leading to an improvement of over 6% of primary energy savings in Power Sector

b) The carbon emission would come down by 113 million tons per annum, which would be close to 10% reduction in carbon emissions from Power Sector

c) The water consumption would be lower by 470 million cubic meter per annum, enough to meet the water needs of a city like Mumbai year after year

d) The land requirement would be lower by 24483 acres which means saving deforestation or displacing people of a mid size town
e) The investment on transmission network could be reduced by Rs 12800 crores in the XII Plan period.

In over all terms the proposed model shows a potential revenue savings of Rs. 13050 crores/year & capex savings of upto Rs 38900 crores in the XII plan period.

The study lends further credence to the prediction in a report by McKinsey that, if additions to base-load capacity continue to happen in India as planned, we would, by the year 2017, be caught in a paradoxical situation in which there would be redundant capacity during off-peak hours, while power shortage would continue to haunt us during peak hours.

Such a situation can be prevented by limiting base-load generation to a defined, optimal level and topping up with HEFDP plants beyond this point. Such technology already exists in the global power market, including India, and can be deployed in a rapid fashion. Such a mix would provide much-needed flexibility and consequently deliver several, quantifiable benefits as stated above.

Our calculations show that nearly 80% of the cost of the HEFDP plants (running mostly on natural gas and in some cases on heavy fuel oil) can be recovered through a nominal additional levy of Rs 0.2/kWh in consumer tariff. A small price indeed for the comfort of 24 x 7 power reliability. We believe that there is a strong possibility to recover the remaining 20% of the cost, by promoting the HEFDP solution, as a national initiative to reduce GHG emissions (to the extent of 113 Mn tons per year) and to provide 24 x 7 power. Positioning the initiative as coherent national program will place it favorably for sectoral carbon crediting under some of the proposed new financing schemes of the UNFCCC.

Wärtsilä, with its vast global experience, is keen to partner with the stake holders in India to deploy such solutions for the ever growing power needs of the country.

This report is being circulated as a ‘discussion paper’ to various stakeholders in the energy and environment sector including experts in leading academic institutions. We are hopeful of receiving some valuable suggestions and comments that would help bring more rigor to the proposed model and enable the nation to derive the substantial benefits which the model offers.

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The study has looked at the demand side analysis going up to the end of 12th plan, i.e. 2017 and concurrent addition in the planned generation capacity in the same time frame. Considering the unique requirements of variable load during time of the day, a model has been developed by introducing high degree of flexibility and higher efficiency in the generation mix which can be rendered by technologies which exists today. The resultant benefit has thus been brought forward with use of such generation mix in terms of overall efficiency, carbon emission, saving in water, land and capital expenditure. To make it a workable model, the beginning has been made with the state of Maharashtra as it has a high peaking load, a good mix of consumers – industrial, commercial and rural- and a range of issues that are representative of the problems facing the Indian power sector. The findings have then been extrapolated at the country level.

Methodology

Overall Approach - Maharashtra

1. Demand Side Analysis
   - Plotted Unrestricted Load Duration Curve for 2008-09
   - Projected Load Duration Curve for 2016-17

2. Supply Side Analysis
   - Determined current generation capacity (July 2009)
   - Augmented capacity additions based on XI (2010-12) & XII five year plan
   - Projected ‘As Is’ Generation Mix for 2016-17 based upon efficiency & flexibility

3. Benefit Quantification with proposed HENFDP
   - Quantified benefits from optimal generation mix to meet peak demand viz-a-viz ‘As Is’ Generation Mix:
     - Efficiency
     - CO2 emission
     - Land usage
     - Water consumption
     - Capital expenditure

Unrestricted Load Duration Curve -2016-17

‘As Is’ Generation Mix 2016-17

Overall Benefits

Optimal Power Generation Mix for India
Unrestricted annual Load Duration Curve (LDC) for 2016-17 is projected for the state of Maharashtra in the following stages:

**Stage 1: Derive the unrestricted Load Duration Curve for 2008-09:**

In this stage, hourly data pertaining to met demand (in MW) along with frequency levels (in Hz) is collected from Maharashtra State Load Dispatch Centre (MSLDC) for the year.

Met demand at varying frequency levels are indicative of the mismatch between power demand and supply at every hour resulting in a reduction in frequency below the optimal level of 50 Hz in case of higher demand with respect to supply at that hour and vice versa. This serves as an input to calculate met demand at 50 Hz frequency level that is indicative of the actual demand that would have been met, had there been enough supply (Exhibit 1):

\[
\text{Met demand (in MW) at 50 Hz at } n^\text{th} \text{ hr} = \frac{\text{Met demand (in MW) at } n^\text{th} \text{ hr}}{\text{Frequency (in Hz) at } n^\text{th} \text{ hr}} \times 50 \text{ (Hz)}
\]

**Exhibit 1**

Met demand is calculated at 50Hz frequency levels based upon hourly data from MSLDC

**Illustrative:** Hourly met demand, frequency and calculated met demand at 50 Hz frequency for 1st of December, 2008

Note: The above graph has been plotted for a day. We have done the above calculations for hourly data for the time period (Sept-08 to Aug-09)

Source: Maharashtra State Load Dispatch Centre (MSLDC), UC Analysis
In addition to this, the state exercises planned load shedding hours during the day, given the existing deficit in power generation capacity. Such planned load shedding (in MW) is added to the met demand (in MW) at 50 Hz, as calculated above to arrive at the unrestricted demand (in MW) for the state (Exhibit 2):

\[
\text{Unrestricted demand (in MW) at } n^\text{th} \text{ hr} = \text{Met demand (in MW) at } n^\text{th} \text{ hr} + \text{Planned Load Shedding (in MW) at } n^\text{th} \text{ hr}
\]

In the absence of data, planned load shedding is assumed equal to the actual demand during the period and hence, is added 'as is' to the met demand calculated at 50 Hz frequency to provide us with unrestricted demand for that period.

**Exhibit 2**

Unrestricted demand is calculated taking into account planned load shedding data from MSLDC

Hourly met demand at 50 Hz frequency, Planned load shedding and Unrestricted demand for 1st of December 2008

Note: The above graph has been plotted for a day. We have done the above calculations for hourly data for the time period (Sept -08 to Aug-09)

Source: Load dispatch centre hourly data- Maharashtra SLDC, UC Analysis
In order to derive the Load Duration Curve (LDC) for Maharashtra, unrestricted demand (in MW) for 8,760 hrs (annual demand: 2008-09) is arranged in descending order and plotted on the graph with load (in MW) on Y-axis and time (in hrs) on X-axis. The curve, thus obtained is the Load Duration Curve for 2008-09.

Unrestricted Load Duration Curve (Exhibit 3) for Maharashtra State is drawn. The maximum load that the state demands is ~18,000 MW, which is required for approximately an hour. This is called the 'Unrestricted Peak Load'.

The area under Load Duration Curve represents the total power requirement by the state in MwHr (Million Units - MU) for the period. This is calculated using integral calculus function to arrive at 124,172 MU. Load Generation Balance Report (LGBR 2009-10) states that the total demand for Maharashtra in 2008-09 was 1,21,901 MU. This is ~98% of demand derived by calculating the area under the curve using unrestricted LDC for the state. The reason for this minor deviation is due to the standard error, which may arise while using the polynomial equation and also the data used to draw the LDC is for the period Aug.’08 – Sept.’09.

Source: Maharashtra State Load Dispatch Centre (MSLDC), UC Analysis
Stage 2: Derive the unrestricted Load Duration Curve for 2016-17:

Superimposing the derived LDC for 2008-09 on 2016-17 is the next step. Use the same equation of the curve for 2008-09 on 2016-17 and calculate the area under the curve with unrestricted peak demand as 28,348 MW (projected by 17th Electric Power Survey of India, 2007 - 17th EPS), we get the power requirement as 193,557 MU. This is way above the projections of the report, which is equal to 167,227 MU. The fact that using the LDC’09 as LDC’17 will result in significantly higher demand projections (193,557 MU) when compared with those projected by 17th EPS (167,227 MU) gives us an indication that the projected LDC’17 should be steeper than the existing LDC’09.

The extent of downward shift in LDC towards the x-axis is controlled to ensure that the area under the new LDC’17 formed after applying the correction factor is close to 167,227 MU, as projected by 17th EPS.

We use ‘optimum base load capacity’ to determine the axis around which the LDC could be pulled down gradually. Optimum base load capacity is defined as one for which it is feasible, both technically (w.r.t flexibility of the solution) as well as commercially (w.r.t its cost of operation and efficiency) to use base load sources to supply power.

The first step in the calculation of optimum base load is the derivation of ‘full power hours’. Full power hour is defined as a percentage of time for which a base load plant shall run at full load.

To derive full power hours for a given LDC, the first step is to draw a rectangle along the y-axis and stretch it along the x-axis till the point where the area of the rectangle is equivalent to the area under the LDC (Exhibit 4).

Exhibit 4

Optimum base load calculation based upon full power hours for 2008-09

Optimum base load for Maharashtra state: 2008-09

Source: 17th Electric Power Survey of India, 2007 - CEA, UC Analysis
‘Full power hours’ for 2008-09, thus obtained are equal to 78% of the time, while ‘optimum base load’ capacity is 64% of the unrestricted peak load. Optimum base load capacity, thus obtained is assumed to remain at this level (64%) for 20016-17 as well. Full power hours for 2016-17, calculated on similar lines as discussed earlier, is equal to 67% of time (Exhibit 5).

Replacing the proportions (%) in Exhibit 5 with actual unrestricted peak demand (in MW) as projected by 17th EPS provides us with the Unrestricted LDC for 20016-17 (Exhibit 6). The LDC for 2016-17, thus obtained can be validated by calculating the area under the curve using integral calculus function, similar to what was done in order to validate the accuracy of LDC for 2008-09 earlier. Here, the area represents a total requirement of 178,397 MU, which is ~94% equal to that project by 17th EPS (167,227 MU) as total demand for Maharashtra in 20016-17.
This section deals with the derivation of ‘As Is’ generation mix of power sources for the state of Maharashtra in 2016-17 and map the same on unrestricted Load Duration Curve for the state as derived in the previous section.

**Projection of generation capacity mix for the state of Maharashtra for 2016-17**

Every state has three prime sources to meet its annual power requirements:

A) Power plants under the ownership of state that are constructed primarily to meet the requirements of the state itself;

B) Power plants owned by the central government, which allocates a fixed share of load to the state; and

C) Inter-state/inter-regional import of power from other states or regions.

Given that the objective of the study is to understand the optimal generation mix in order to address the needs of sustainability and peak demand of power by 2016-17 for the state, we shall limit our consideration to the first two sources of power. Exhibit 7 depicts how a two-staged approach is adopted to arrive at the generation mix for 2016-17 with ‘As Is’ planning projections.

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### Exhibit 7

**Generation Mix for 2016-17 is projected based upon ‘As Is’ planned projects at the centre and state along with criteria for merit order of allocation in case of base and peak & intermediate load generation capacity**

**Maharashtra State Projected Unrestricted Load Duration Curve: 2016-17**

**Stage 1 is the aggregation of generation capacity mix by the end of 2016-17:**

In this stage, generation capacity dedicated to the state of Maharashtra from central and state resources as on July’09 is added to the planned capacity to be made available by 2016-17 under the XI and XII five year plans.

State level capacity additions by 2016-17 are estimated based upon an implementation rate of 100% and 80% for projects under XI and XII five year plans respectively. This would mean that even in case of projects that spill over from XI five year plan, 100% capacity under this plan will be up and running by the end of XII five year plan. Generation capacity planned by the state under the XII five year plan is expected to have a ~20% spill over to the XIII five year plan.

Central allocations to the state under the XI and XII five year plans are restricted based upon UMPP allocations projected by the centre in conjunction with an implementation rate of 80% assumed for these plants to come online by the end of 2016-17.

Power generated from captive power plants are not considered for the purpose of our study (Do not form part of the demand projected by 17th EPS)
Stage 2 is the determination of merit order of allocation of generation capacity mix between base, intermediate and peak load:

The criteria for determining the merit order of allocation is based upon the following set of parameters:

A) Chronology of implementation – This would ensure that projects planned to be online in the XI five year plan will be given priority in allocation to meet the demand over those planned in the XII five year plan irrespective of their efficiency & flexibility.

B) Efficiency of power system – This refers to the thermal efficiency of power system which is the ratio of the net power delivered at point of consumption (kWh) and the heat value of the fuel (Kcal) fed into the power plant.

C) Flexibility of power system – This refers to the requirement of the power system to respond dynamically to the varying (hourly as well as seasonal) demand and consumption pattern. This is a key parameter to assign merit order to power systems, especially to meet intermediate and peak power requirements.

D) There is in-firm generation from renewable energy sources (RES) which will increase the feed-in rights, and therefore will displace a part of the baseload power at the bottom.

E) Central allocation to the state, will also primarily serve as base load capacity.

With the help of these parameters, we determine the merit order allocation of power sources on derived Load Duration Curve for 2016-17 (Exhibit 8). Spinning reserves which is the buffer capacity required to be kept in the system to meet the requirement of outage of a baseload plant is assumed ~ 10% of base load capacity i.e. 1,843 MW that is used to meet power requirements during breakdowns.

Exhibit 8

Maharashtra State is expected to have up to 7,600 MW of surplus capacity by the end of 2016-17

As is’ generation mix for Maharashtra State: 2016-17

Note: Additional spinning reserve capacity of 1,214 MW comprises of 338 MW (250-499 MW coal plants) + 1476 MW (200 to 249 MW coal plants). The above graph and further calculations are based on 80% implementation rate for XII plan.

Source: 17th Electric Power Survey of India, 2017, I/UC Analysis
HEHFDP are reciprocating engine technology-based systems that have unique attributes as shown in Exhibit 9. They are modular in design, can start and stop quickly and can be ramped up and down rapidly while maintaining high efficiency and low emission at all loads.

**Exhibit 9**

Attributes of a High Efficiency, High Flexibility Distributed Plant (HEHFDP):
- High efficiency at all loads
- Modular
- Quick start-up & stop
- Minimal emission
- Fuel available through the year
- No strain on Water resources
- Close to load centres
- No effluent issues
Exhibit 10 depicts the methodology adopted to quantify the benefit of using HEHFDP as a peaking solution. Assuming HEHFDP is used as a peaking solution for 20% of time (1,752 hrs); it will replace 3,708 MW of peak and intermediate load capacity (Exhibit 11). This results in changing the proportion of other power sources otherwise contributing to intermediate and peak power requirements of the state in the 'As Is' scenario.

Exhibit 10

In the absence of peak power deficit, benefit quantification is done based upon comparison of net savings by using 'As Is' against with HEHFDP generation mix to meet peak and intermediate power requirements

Methodology and key Parameters considered for Benefit Quantification by using HEHFDP solution for peak time

Exhibit 11

Assuming a peaking solution for ~20% of the time, a 3,708 MW of Peak & Intermediate load capacity is replaced by Highly Efficient & Flexible Distributed Plants (HEHFDP)

'With HEHFDP' Generation Mix for Maharashtra State: 2016-17

Note: Additional Spinning reserve Capacity of 1.814 MW comprises of 338 MW (230 – 499 MW coal plants) + 1476 MW (500 to 249 MW coal plants). The above graph and further calculations are based on 80% implementation rate for XII plan

Source: 17th Electric Power Survey of India, 2007, CEA, UC Analysis
The benefits of introducing the suggested HEHDFP solution can be quantified by analyzing the 'top triangle' of the LDC 17 with 'As Is' and 'With HEHDFP' generation mix (Exhibit 12). Introduction of 3,708 MW of HEHDFP solutions has a dual impact on the overall efficiency of the triangle representing intermediate and peak demand. Firstly (Exhibit 12) the 3,708 MW of HEHDFP capacities replace equivalent capacity of coal and gas plants that are relatively inefficient, thus making the power system more efficient.

Secondly, being a highly flexible solution, HEHDFP serves the top portion of the peak and intermediate demand. This results in pushing other solutions such as CCGT, RES and Large Hydropower plants, which were earlier serving the upper part of the peak and intermediate load, towards its bottom, enabling them to run for a longer duration.

Increase in share of power contributed by these efficient systems once again displaces the share of relatively inefficient power systems, such as coal and open cycle based gas plants (OCGT), thus increasing the overall efficiency of power system.
The increase in overall efficiency of power system intermediate and peak demand will have a direct impact on reducing carbon emission levels, consumption of primary energy, and water. The inherent attribute of very low water consumption of HEFDP and their low land footprint enables substantial savings in water consumption as well as land usage.

HEFDP usage in peak and non-peak months (For a particular day) has been illustratively shown on a daily load curve for the state of Maharashtra (in Exhibit 13, 15) and Delhi (in Exhibit 14, 16).

Exhibit 13
HEFDP can operate to meet spurs in demand during peak season (1/2)

Maharashtra – Peak Month

Note: The above curve is for a particular day • Source: Maharashtra State Load Dispatch Centre (MSLDC), UC Analysis

Exhibit 14
HEFDP can operate to meet spurs in demand during peak season (2/2)

Delhi – Peak Month

Note: The above curve is for a particular day • Source: Delhi State Load Dispatch Centre (DelhiSLDC), UC Analysis
HEHFDP can also operate as peak & intermediate solution during non-peak months (1/2)

Maharashtra – Non Peak Month

Note: The above curve is for a particular day • Source: Maharashtra State Load Dispatch Centre (MSLDC), UC Analysis

Exhibit 16

HEHFDP can also operate as peak & intermediate solution during non-peak months (2/2)

Delhi – Non Peak Month

Note: The above curve is for a particular day • Source: Delhi State Load Dispatch Centre (DelhiSLDC), UC Analysis
Assuming that the concept of HEHFDP will be implemented towards the end of XI five-year plan, most of the investments committed under this plan would have been expensed. Therefore, it may not be practically possible to save land and capital invested in power projects already in operation by the end of XI plan, to the tune of 2,312 MW that will form part of excessive replaceable capacity (Exhibit 17). These plants may be kept available to meet the growing energy demand in the years beyond 2017.

**Exhibit 17**

**Introduction of HEHFDP will impact investments decisions on capacity additions in the XII five year plan**

Excess replaceable capacity investments which ‘Can’ and ‘Cannot’ be prevented due to introduction of HEHFDP in XII plan

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**Excess Replaceable Capacity**

- **Coal capacity available at the end of XI five year plan**: 1,988 MW
- **OGGT capacity available at the end of XI five year plan**: 324 MW

**Proposed capacity for HEHFDP**: 3,706 MW

- Concept proposed towards the end of XI five year plan

**Capacity available at the end of XII five year plan**: 2,312 MW

- This capacity will be available at the end of XI five year plan but will not be running assuming the introduction of suggested HEHFDP solutions
- Therefore, land and capital required to build this capacity ‘cannot be prevented’

**Coal capacity additions in XII five year plan**: 1,396 MW

- Coal capacity additions planned in XII plan can be avoided
- Therefore, land and capital required to build this capacity ‘can be prevented’

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Source: UC Analysis

With the introduction of HEHFDP solutions, the state of Maharashtra is expected to reduce CO2 emissions by 15 Mn tonnes. In addition to this, land savings to the extent of 3,181 acres; primary energy savings to the tune of 34,322 bn Kcal and water savings of 61 Mn cu.m. Moreover, capital expenditure of Rs.3, 384 Cr. can be saved by the state of Maharashtra. The increased savings are the result of an overall increment of 6.9% in the efficiency of power systems providing power to meet intermediate & peak requirements.

In addition to this, the state can also avoid planning additional capacity to the tune of 8,955 MW during the XII five year plan. (Exhibit 18). Also peak & intermediate load management through HEHFDP will at a minimum result in transmission savings of Rs.1,668 Cr (Exhibit 19).
Exhibit 18

Reduced Carbon emission, Water & Land conservation and Primary energy savings - HEHFDI serves as an ‘Environment Friendly’ solution

Performance of ‘As Is’ and ‘With HEHFDI’ generation mix on multiple parameters to meet intermediate and peak demand

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<th>Unit</th>
<th>‘As Is’ Generation Mix</th>
<th>HEHFDI</th>
<th>Savings</th>
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<tr>
<td>Efficiency</td>
<td>%</td>
<td>31.2%</td>
<td>38.2%</td>
<td>6.9%</td>
</tr>
<tr>
<td>Total Energy - Input</td>
<td>Bn Kcal</td>
<td>50,968</td>
<td>16,646</td>
<td>34,322</td>
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<tr>
<td>CO₂ Emission</td>
<td>M Tonne</td>
<td>19</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Land Required</td>
<td>Acre</td>
<td>3,826</td>
<td>646</td>
<td>3,181</td>
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<tr>
<td>Water Required</td>
<td>Mn Cu. M</td>
<td>74</td>
<td>13</td>
<td>61</td>
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<tr>
<td>Capex Required</td>
<td>Rs Cr</td>
<td>18,264</td>
<td>14,881</td>
<td>3,384</td>
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Surplus Reserve capacity - XI plan additions

8,955 MW

8,955 MW

Land Savings

7,279 Acres

Capex Savings

Rs. 38,325 Cr

Note: Overall savings in Land & Water are conservative as it excludes increased savings resulting from improved system efficiency and relatively smaller modular deployment of peaking solution

Source: UC Analysis

Exhibit 19

Replacing 3708 MW of centralised coal plants in Maharashtra with load-centre based HEHFDI plants = reduced investments on transmission systems

Reduced Investments in Transmission Systems

- Investments in transmission systems are estimated based on cost per ckm (circuit kilometers).

- Therefore, reduction in installed MW may not lead to proportionate reduction in investments in transmission systems. But following estimates considered by Work Group on Power (Planning Commission) for the XI Plan (pages 34, 35, 36 and 66 of Chapter 2) help arrive at the transmission investment required per MW

Transmission schemes for 44000 MW of Central sector for inter-state transmission = Rs 59000 crores

Transmission scheme for IPP generation of 6000 MW seeking open access = Rs 8000 crores

Transmission scheme for additional 16000 MW of intra-state transfer (peak demand) = Rs 14400 crores

- Assuming that “peak load management” with load centre plants help avoid only the investments on intra-state transmission systems, the saving per MW works out to 14400/16000 = 0.9 crores

- If transmission system equivalent to even 50% of 3708 MW is avoided, then reduction in investment = 50% of (3708 x 0.9) = 1668 crores

** With load centre plants, we have assumed that the distribution system will still be required, and so no savings considered
National savings are projected using an extrapolation factor of 7.7, a multiplier calculated based upon unrestricted peak demand of India and Maharashtra for 2016-17 (218,209 MW ÷ 28,348 MW = 7.7). Such solutions if deployed nationally can result in an estimated lump sum savings of ₹38,889 Cr. along with recurring savings of ₹13,051 Cr. per annum (Exhibit 20). This will require an estimated deployment of ~28,550 MW of HEHFD solutions.

**Exhibit 20**

HEHFD deployed nationally will take our nation a step closer to ‘Green’

Savings 'with HEHFD' generation mix from Maharashtra extrapolated at India level

- **Efficiency Savings**
  - 6.9%
  - Equivalent to ₹1,529 Cr of Primary Fuel

- **Energy Savings**
  - 264,191 Bn Kcal
  - Equivalent to ₹10,812 Cr of Certified Emission Reduction (CER) or ~18% of India’s current per annum CO2 emission from power sector

- **CO₂ Emission Savings**
  - 113 Mn Tonnes
  - Equivalent to ₹710 Cr of Industrial Water or equivalent to annual domestic water consumption by the city of Mumbai

- **Water Savings**
  - 470 Mn Cu m

- **Per Annum (Recurring Savings)**
  - ₹13,051 Cr

- **Land Savings**
  - 24,483 Acres
  - Equivalent to ₹6,365 Cr of Industrial Land or equivalent to a mid-sized town

- **Capex Savings**
  - ₹26,045 Cr

- **Transmission Capex Savings**
  - ₹12,844 Cr

- **One time Savings**
  - ₹3,8889 Cr

Source: UC Analysis, 17th EPS projections, CEA
HEHFDP solutions can be showcased as a national initiative to provide 24 x 7 power for all while reducing CO2 emissions. Emerging sectoral carbon crediting programs under the UNFCCC are well suited to encapsulate the "system efficiency gain" achieved through HEHFDP. In particular, the initiative would render itself well to a centrally-managed, policy-based national emission reduction program (Exhibits 21 and 22). About 80% of the cost can be recovered through additional levy of mere Rs 0.2/kWh in consumer tariff, while the other 20% could be funded through emerging credit mechanisms that recognize sectoral savings.

**Exhibit 21**

**Funding for HEHFDP plants**

- The HEHFDP solution offers vast savings in GHG emissions versus the BAU generation solution; on a national level reduction is 113 Mt CO2e per year
- One of the largest centralized energy efficiency GHG mitigation options
- The UNFCCC is currently debating several proposals on broadening carbon crediting to whole sectors and/or developing a new crediting mechanism for sector-wide emission reduction initiatives.

A power-system wide efficiency solution, such as HEHFDP, with backing from local regulator/government, falls comfortably within the boundaries of “sectoral crediting” of emission reductions that is being discussed by the UN.

**Exhibit 22**

If taken up as national initiative, HEHFDP plants can be financed in several ways.

1. Through avoided investments on planned coal plants.
2. Increase of mere 0.2 Rs/kWh in consumer tariff, to recover 80% of cost
3. Sectoral CO2 savings, allocated as tariff subsidy, to account for remaining 20% of the cost.

**Assumptions:**
- Base load tariff 3 Rs/KwHr
- Peak tariff 10 Rs/KwHr
- Base load energy demand 96.3% of total
- Peak load energy demand 3.7% of total
- 1 tCO2 19.5 USD
The slide below summarises the various assumptions made while arriving at the generation capacity in 2016/17.

### Key Parameters - Supply Side Analysis

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percentage Implementation of Xth 5 year plan by 2017</td>
<td>100%</td>
<td>Overflow of Xth 5 year plan is, if any, will be completed by 2017</td>
</tr>
<tr>
<td>Percentage Implementation of Xth 5 year plan by 2017</td>
<td>80%</td>
<td>Assumption</td>
</tr>
<tr>
<td>Additional Central Allocation - 2017</td>
<td>5,040 MW</td>
<td>UMKP Allocation of 6300 MW (8 Implementation rate of 80%)</td>
</tr>
<tr>
<td>Contribution from RES as a % to Unrestricted demand (in MU)</td>
<td>12%</td>
<td>Revised CERC norms for RES</td>
</tr>
<tr>
<td>RES for base load as %age of total RES</td>
<td>63%</td>
<td>Economic Survey of Maharashtra 2008/09, 2009-09 mix of RES (MU) which includes Wind (82%) &amp; Bagasse (11%) is considered as RES for base load</td>
</tr>
<tr>
<td>Plant Availability Factor - Central Allocation</td>
<td>90%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Coal Based Plant : 0 - 100 MW</td>
<td>75%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Coal Based Plant : 101 - 199 MW</td>
<td>75%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Coal Based Plant : 200 - 249 MW</td>
<td>85%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Coal Based Plant : 250 - 499 MW</td>
<td>85%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Coal Based Plant : &gt;= 500 MW</td>
<td>85%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - CCGT</td>
<td>88%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - OCGT</td>
<td>88%</td>
<td>11th Five year Plan, Planning Commission</td>
</tr>
<tr>
<td>Plant Availability Factor - Large Hydro</td>
<td>90%</td>
<td>Assumption</td>
</tr>
</tbody>
</table>

The slides below summarise the assumptions made while quantifying the benefits from HEHDP plants.

### Key Parameters - Benefits Quantification (1/2)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency - Coal based plants &gt;400 MW</td>
<td>38.6%</td>
<td>Power scenarios in India, Planning Wing CEA</td>
</tr>
<tr>
<td>Efficiency - Coal based plants 400 to 499 MW</td>
<td>38.3%</td>
<td>Power scenarios in India, Planning Wing CEA</td>
</tr>
<tr>
<td>Efficiency - Coal based plants 200 to 249 MW</td>
<td>38.3%</td>
<td>Power scenarios in India, Planning Wing CEA</td>
</tr>
<tr>
<td>Efficiency - Coal based plants 100 to 199 MW</td>
<td>34.4%</td>
<td>Power scenarios in India, Planning Wing CEA</td>
</tr>
<tr>
<td>Efficiency - Coal based plants &lt;100 MW</td>
<td>29.8%</td>
<td>Power scenarios in India, Planning Wing CEA</td>
</tr>
<tr>
<td>Efficiency - CCGT</td>
<td>56.7%</td>
<td>Primary Research (Heat rate = 1700 kcal/kWh)</td>
</tr>
<tr>
<td>Efficiency - Reciprocating Engines</td>
<td>44%</td>
<td>Reciprocating engine Technical Document</td>
</tr>
<tr>
<td>Efficiency - OCGT</td>
<td>38%</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Transmission Losses - Intro state</td>
<td>4.8%</td>
<td>Maharashtra Economic Survey</td>
</tr>
</tbody>
</table>

### Key Parameters - Benefits Quantification (2/2)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Consumption - Coal based plant (Cu m / MWh)</td>
<td>4</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Water Consumption - OCGT (Cu m / MWh)</td>
<td>1</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Water Consumption - CCGT (Cu m / MWh)</td>
<td>0.903</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Water Consumption - Reciprocating Engines (Cu m / MWh)</td>
<td>0.903</td>
<td>Wirtz &amp; Technical Document</td>
</tr>
<tr>
<td>Land requirement - Coal based plant (Acres/MW)</td>
<td>1.06</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Land requirement - CCGT (Acres/MW)</td>
<td>0.36</td>
<td>Reciprocating engine Technical Document</td>
</tr>
<tr>
<td>Land requirement - Reciprocating Engines &amp; OCGT (Acres/MW)</td>
<td>0.15</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Capital expenditure - Coal (Rs. Cr/MW)</td>
<td>4.5</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Capital expenditure - Reciprocating Engines , CCGT &amp; OCGT (Rs. Cr/MW)</td>
<td>3.5</td>
<td>Primary Research</td>
</tr>
<tr>
<td>Primary Energy Value - Coal - Rs. Cr/Mw Year</td>
<td>0.922</td>
<td>UC Analysis</td>
</tr>
<tr>
<td>Primary Energy Value - natural Gas - Rs. Cr/Mw Year</td>
<td>0.979</td>
<td>UC Analysis</td>
</tr>
<tr>
<td>Carbon - GWP - Rs. Cr/ Mtonne</td>
<td>95.56</td>
<td>GWP - Marketable Carbon Emission Exchange</td>
</tr>
<tr>
<td>Land - Rs. Cr/Acre</td>
<td>0.26</td>
<td>Industrial Land (Average of Gujarat, Maharashtra &amp; Tamil Nadu)</td>
</tr>
<tr>
<td>Water - Rs. Cr/Mn Cu.m</td>
<td>1.51</td>
<td>Industrial water supply (Average of Gujarat, Maharashtra &amp; Tamil Nadu)</td>
</tr>
</tbody>
</table>
Though the Power Ministry has planned addition in capacities in eleventh & twelfth plan to address the power needs, the capacity addition is largely focused around base load coal power plants. Even if we managed to add adequate base-load capacities there are some vexing questions?

1. Will we be able to get rid of the problem of load shedding?
2. Would we be able to manage the peak shortage problem?
3. What is the impact on the environment in the form of carbon-dioxide emissions from these coal based plants if they run sub-optimally during part of the day due to reduced load?
4. What will be the impact of the planned coal based capacities on natural resources like land and water? And above all . . . ,
5. Is there a better way to handle the developments in front of us

This study is an attempt to address the above questions.

Deployment of the model with about 28,550 MW of High Efficiency High Flexibility Distributed Plants as peaking solutions to meet the peak demand ~20% time of the day has substantial benefits which can accrue year after year. In addition to the monetary gains these benefits strongly point towards sustainability and de-stressing the environment in terms of carbon emission, water and land.
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