



**REPORT OF THE TECHNICAL COMMITTEE ON STUDY OF
OPTIMAL LOCATION OF VARIOUS TYPES OF BALANCING
ENERGY SOURCES/ENERGY STORAGE DEVICES TO
FACILITATE GRID INTEGRATION OF RENEWABLE
ENERGY SOURCES AND ASSOCIATED ISSUES**



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Central Electricity Authority
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EXECUTIVE SUMMARY

The Government of India has set up a huge target of Renewable Capacity Addition of 1,75,000 MW by the year 2021-22, comprising mainly of variable renewable generation of 100,000 MW of solar power and 60,000 MW of wind power. Simultaneously, and driven by volumes, prices of solar power have dropped dramatically from about Rs.17 per unit under the regulated tariff by CERC in 2010 to about Rs.2.50 per unit, as discovered through competitive bidding. Similarly, the regulated tariff of wind power has dropped substantially from over Rs. 4 per unit (depending on different wind zones) by CERC/SERCs to about Rs.2.60 per unit, discovered through auctions.

However, there are financial implications on the States where this variable generation is being set up, namely, the requirement of keeping standby capacity when the wind and solar power goes down, the necessity of having flexible generation which can ramp up and down in consonance with ramping down and up by the variable generation, the impact on the States Deviation Settlement Mechanism (DSM) charges for inter-State flow of power, the impact on coal-based generation, in terms of reduction of efficiency and operation at lower Plant Load Factor, as well as higher transmission charges on account of lower capacity utilization factor of wind and solar power. There have been various figures floating around, as to estimation of this financial implication.

This Report had done a detailed analysis of estimating this financial implication using test cases of Tamil Nadu and Gujarat during the renewable-rich season in 2017. The Report recommends methods for sharing of balancing responsibility.

The Report also recommends starting of ancillary services on permanent basis, in view of the increasing variable Renewable generation, and recommends policy and regulatory interventions required to deal with the increasing variable renewables to the Grid.

The Report finds that even after including the financial implication on account of variable Renewable generation, it would still be cheaper in the future to set up renewable generation capacity, as compared to coal-based capacity. The health costs have been excluded.

The Report also recommends setting up a MW Scale battery on pilot basis in the most wind-rich State of Tamil Nadu, to prevent curtailment on account of congestion/DSM Charges.

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CHAPTER 1

INTRODUCTION

In pursuance of the deliberations held in Ministry of Power, a Committee was constituted by CEA on 30th January, 2017 to undertake a study for identifying optimal locations for balancing energy sources/energy storage devices to facilitate grid integration of renewables, keeping in view the impact of variability of renewable generation on system operation and the ongoing plan for massive capacity addition of renewables, and also for determining optimal location of a MW scale battery in a highly renewable rich State. The Committee was chaired by Member (Planning), CEA with members from MNRE, Power Grid, POSOCO, NTPC, NHPC, SECI, Renewable rich States and Chief Engineers of the related Divisions of CEA. The Order constituting the Committee is at **Annexure I**.

The **first meeting** of the Committee was held on 23rd February, 2017 on an All-India basis at Delhi. Presentations were made by renewable rich States, as well by NREL (National Renewable Energy Laboratory), USA, LBNL (Lawrence Berkley National Laboratory), USA and NITI Ayog on the respective studies done by them in this field. NREL had done a study under “**Greening the Grid Project**” which looked at the technical flexibility available in the Indian System for integration of renewables to the grid by the year 2022. An important result of the study was that barriers between States have to be

removed and there has to be resource sharing among the States to reduce RE curtailment.

The presentation of LBNL was on the subject “**Techno Economic Assessment of integrating 175 GW of renewable energy into the Indian Grid by 2022**”. The presentation by NITI Ayog was on “**State level issues in implementation of the Renewable Energy target of 175 GW**”. It was decided in this meeting that a sub-group would be formed for deliberating on the issues in the Southern Region, which is the region with the highest share of renewables, to get a flavour of the issues with respect to integration of renewables with the grid. The minutes of the first meeting are attached at **Annexure II**.

The meeting of **sub-group** was held on 24th March, 2017 under the chairmanship of **Member Secretary, SRPC**. The sub-group suggested, among other things, accurate forecasting of load and renewable generation, provision of real time data of renewable generators to SLDC/RLDC/NLDC, proper network strengthening for evacuation of renewables, suitable renewable energy frame work for inter-state flow of power by CERC, planning of normal/alert/emergency reserves, balancing of variability of renewable generation to be done using gas based and hydro based generation, operationalising of existing pumped storage projects for balancing, amendment of take or pay contracts of GAIL for APM gas, facilitate RLNG through e-bidding for existing gas plants, flexible operation of coal based plants, implementation of automatic generation control, demand response from irrigation/agricultural and other loads, etc. The minutes of the meeting are attached at **Annexure III**.

It was felt that subsequent meetings should be focussed meetings, on the renewable rich regions, to ensure higher participation by these regions. Officers were also co-opted from CERC and the 5 RPCs, in order to get the views of these important stakeholders.

The **second meeting** of the main group was held on 9th May, 2017 at Chennai, focussing on issues of the **Southern Region**. However, officers from all Regions were encouraged to attend.

A detailed discussion was held and presentations made by all renewable rich States of Southern Region. Presentations were also made by PGCIL on the Battery Energy Storage System (BESS), which is under testing by them at Puducherry, using 3 different technologies i.e. **advanced lead acid, lithium ion and flow batteries**. A presentation was also made by NHPC, where they stated that in Karnataka, some pumped storage projects could be started by developing secondary reservoirs for the purpose. A presentation was also made by ORXA Grid, a company using Internet of Things (IoT) for communication of data from renewable generators to the SLDCs, which can be operationalised very quickly i.e. within about 2 hours, using GPRS System and can also be done cheaply.

TANTRANSCO was requested to propose an optimal location of MW scale battery on a pilot basis, near 1 or 2 adjacent pooling stations from wind farms, with a view to removing transmission congestion/curtailment of wind generation. They were also asked to provide the real time generation data pattern of these 2 pooling stations, so as to decide optimal sizing of battery. **TANTRANSCO** stated that the Plant Load Factor of their thermal power plants has been falling since 2012-13, due to increase of intermittent type of generation from Renewable Energy Sources (RES). During the high wind season, they were resorting to sale of power outside the State. They stated that they have proposed 3

more pumped Storage Plants, amounting to 3000 MW, in addition to their Kadamparai Pumped Storage Plant. They stated that in some cases, intra-State generators are asked to back down their generation to minimum. They also stated that they had to bear the expenditure of increased transmission corridors. They stated time-of-use tariff would help in the matter, by encouraging consumers to utilise electricity when high generation is available from RES.

The minutes of the meeting are at **Annexure IV**.

The **Third meeting** of the Committee was held, specifically concerning the **States of Western Region, on 5th June, 2017 at Vadodara**. Presentations were made by renewable rich States of Western Region i.e. Gujarat, Maharashtra & Madhya Pradesh.

SLDC Gujarat stated that during 2016-17, wind had supplied 7.4% of the total energy and solar 1.67%. They stated that they suffered financial losses on account of deviation beyond +/-250 MW at the State's boundary, backing down of cheaper conventional generation, including reserve shut down, in order to absorb costly renewable generation. The details of losses are given below:

Impact on account of Wind and Solar Generation - Gujarat

Item No.	Summary (Gujarat corresponding to 22.05.2017)	
1	Capping charges (Rs)	585309
2	Additional UI (Rs)	2483
3	Cheaper back down of conventional generation (less than Rs. 4.19/unit, preferential tariff of wind generation)	32071403
4	Total impact (Rs)	32659195
5	Total Renewable injection (kWh)	37139895
	Total Impact- Spread over renewable generation (Rs/Kwh)	0.88

They suggested relaxation of the limit of +/- 250 MW. They suggested that neighbouring States can collaborate by providing balancing capacity. They also stated

that no regulations for Intra-State renewable generation for forecasting and scheduling are available in Gujarat. They stated that they could not reduce generation on their coal based units below 70%, without oil support, and stated that the 55% lower limit as given by CERC for Inter-State Plants is not possible on their units, as many of their units are old. They stated that the threshold limit of their generating units has been decided after testing by CPRI. They also suggested that the Govt. of India should provide cheaper gas for gas based power plants for the purpose of balancing. They also stated that they were trying to operationalise their Kadana Pumped Storage Plant for pump mode operation. Gujarat stated that with their new SCADA System, real time data of all RES is available and they can visualize the variation of 1000-1200 MW generation capacity from RES.

Maharashtra stated that solar based agricultural feeder is proposed to be implemented in the State, to reduce subsidy burden on State Discoms. They stated that ancillary services need to be addressed through regulatory intervention. They stated that the cost of balancing should not be borne only by the renewable rich States.

MPPTCL stated that due to large scale of RES commissioned at certain substations, the transformers are facing overload problems. Further, they find it difficult to manage within the DSM limit of +/- 250 MW. They have to sometimes surrender cheaper power from Central Generating Stations during times of increase in wind injection. MPSTDC stated that the State regulations on forecasting, scheduling and deviation settlement of wind and solar generators is yet to be notified by MPERC. The minutes of meeting are at **Annexure V**.

The **4th meeting of the Technical Committee** was held **on 13th June, 2017 at New Delhi**, specifically for **the RE States of Northern Region**. A presentation was made by **REMC, Rajasthan**, where they stated that RE Sources are located in the western part of the State whereas load centres are located in the eastern part, forecasting and

scheduling regulations for Intra-State Renewable Generators are not in place in the State, the State suffers from under draw/over draw situation due to sudden change in wind energy generation, and frequent ramp up and ramp down of thermal units causes excess wear and tear. He stated that gas is a good balancing source but gas availability is a constraint. He stated that they anticipate that there would be an evacuation constraint since wind farms/solar farms come up within months, whereas the transmission system takes 2 to 4 years. They also suggested that wind-solar hybrids have better utilisation of grid infrastructure and lowering of intermittency.

PGCIL representative stated that there is a major issue on the voltage profile of the transmission system in Rajasthan and also the old wind turbines do not have Low Voltage Ride through (LVRT) capability.

Member Secretary, NRPC, who had earlier held the responsibility of Member (Power) of Sardar Sarovar Hydro Project (SSHP) stated that there should be proper integrated operation of reservoirs for deriving the maximum benefit for the purpose of balancing the intermittency of generation from renewable energy sources. It was decided that a Committee may be constituted under Member Secretary, NRPC with members from CEA, and concerned hydro plants for the integrated operation of reservoirs for SSHP as well as other hydro reservoirs in the country.

NTPC then made a presentation on the study of flexible operation of thermal power plants. He stated that old plants can be used for flexible operation after retro-fitting. He also stated **that the boiler would need more changes** than the turbine. Sub-critical plants should be used for flexible operation rather than super critical plants. He stated that the cost of cycling should be compensated to generating companies. He stated that the thermal stress would be lesser for load following than for cold start.

PGCIL representative then gave a presentation on the 3 different technologies of batteries they were experimenting within Puducherry. The minutes of the meeting of the 4th Meeting are given in **Annexure VI**.

CHAPTER 2

ANALYSIS OF TECHNICAL REQUIREMENT FOR BALANCING

The variation of wind and solar generation was studied across the most wind rich States i.e. **Tamil Nadu** and **Gujarat**. The variations of wind on typical days during the high wind season in the State of Tamil Nadu and Gujarat in the last wind season are given as below.

The 1-minute variation of wind generation in Tamil Nadu during the season is given in **Annexure VII**, which shows the ramp rate for each minute. It is seen from these figures that the maximum ramp rate required for balancing wind generation in Tamil Nadu is 210 MW per minute, which occurred only once during the entire wind season. All other ramp rates are less than this. Tamil Nadu's existing generation capacity (as on 31.7.2017) including Central and Private plants, consists of :

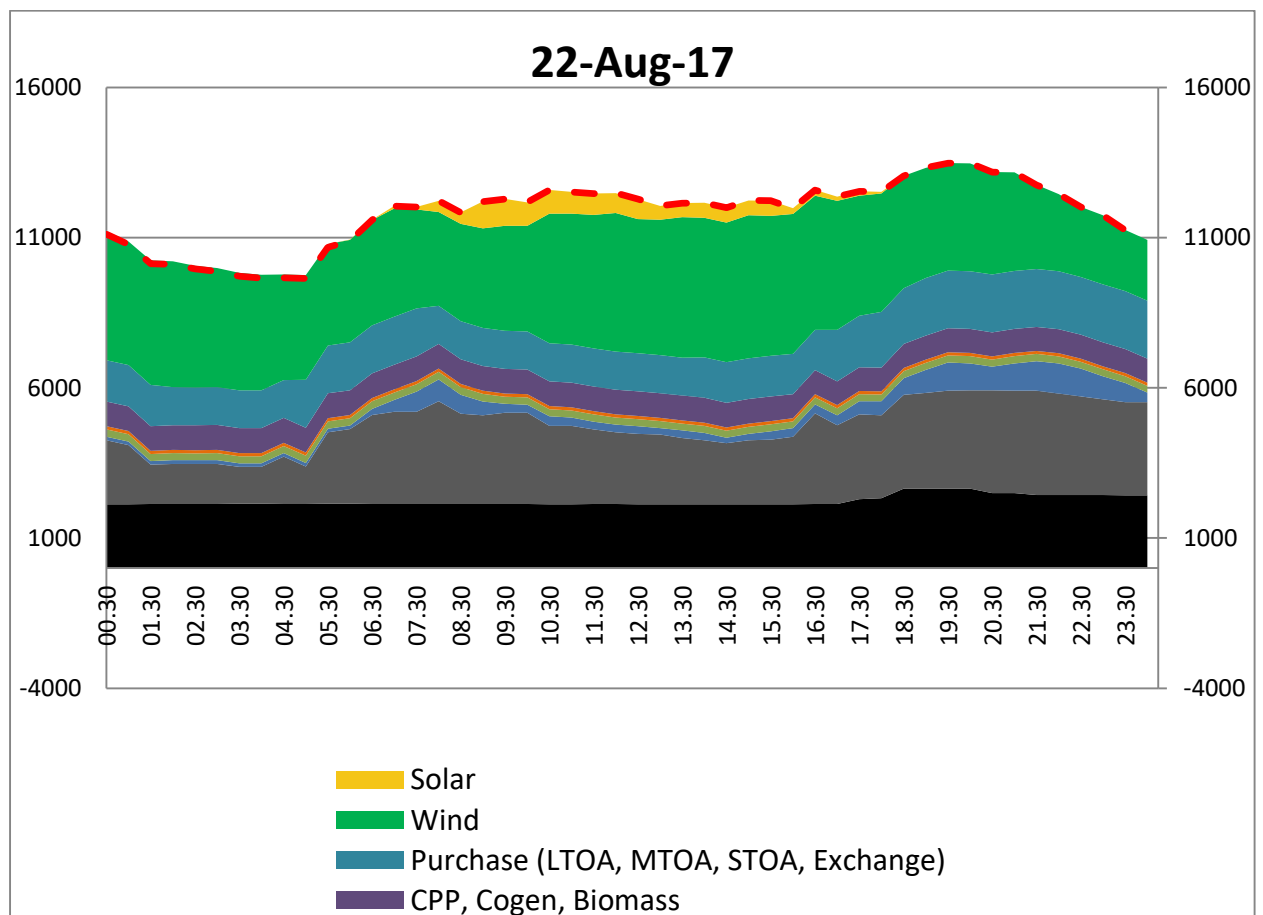
(i)	Coal/Lignite Based Plants	.....	13547 MW
(ii)	Hydro Plants	.....	2308 MW
(iii)	Nuclear Plants	.....	1448 MW
(iv)	Gas Plants	.....	1027 MW
(v)	Renewable Energy Sources	.....	10639 MW

The ramp rates of existing Coal Based Plants, as ascertained from NTPC for their Plants, is 1 % in the operating load range of 55% to 80% and 1.5% per minute in the operating load range of 80% to 100% for **Sub-Critical Plants** and 3% per minute in the operating load range of 55% to 100%, for **super-critical Plants**, whereas the ramp rates for **combined cycle Gas Based Plants** is upto 10% per minute. As determined from NHPC, SJVNL and THDC, the ramp rate of **pondage/storage Hydro Based Power Plants** is about 50% per minute.

It is seen from the generation capacity available with Tamil Nadu, that if the above ramp rates are considered, Tamil Nadu is capable of balancing all the present wind and solar generation by itself.

2.1 Case Study of Tamil Nadu

A case study was carried out for the **maximum wind generation day** in the current wind season in Tamil Nadu, which was on 22-08-2017. The demand in Tamil Nadu on this date, along with how this was met from various sources of generation available with Tamil Nadu, is shown below. The hourly figures for the same are shown in **Annexure VIII**.



It is seen from this graph, that **the peak demand of 13483 MW** is at 1930 hrs. The minimum demand is 9642 MW at 0500 hrs, which is 72% of the peak demand. The low demand period is from 0130 hrs to 0500 hrs. The demand during the day is in the range of 12000 MW to 12500 MW up till 1800 hrs and the peaking starts from 1830 hrs up till 2130 hrs, and is above 13000 MW. Tamil Nadu's wind and solar combined peak generation on this day was 5279 MW at 1200 hrs, consisting of 4618 MW of wind and 661 MW of solar power. The **wind generation peaked at 1500 hrs at 4758 MW (out of an installed capacity of about 7900 MW)**, whereas **solar generation peaked at 892 MW (out of an installed capacity of about 1700 MW) at 0930 hrs**. The penetration of renewable energy during the day was 34%. Therefore, solar and wind have mostly been complementary, and have taken care of a substantial part of the demand during the day. The Thermal Generation of Tamil Nadu is in the range of 2130 MW to 2644 MW, and considering the peak MW of the Thermal Generation, the load factor of the plant for that day comes to about 85%, whereas gas generation is almost constant throughout the day, ranging from 224 MW to 254 MW giving a load factor of the plant for that day of 93%, considering 254 MW as the peak generation.

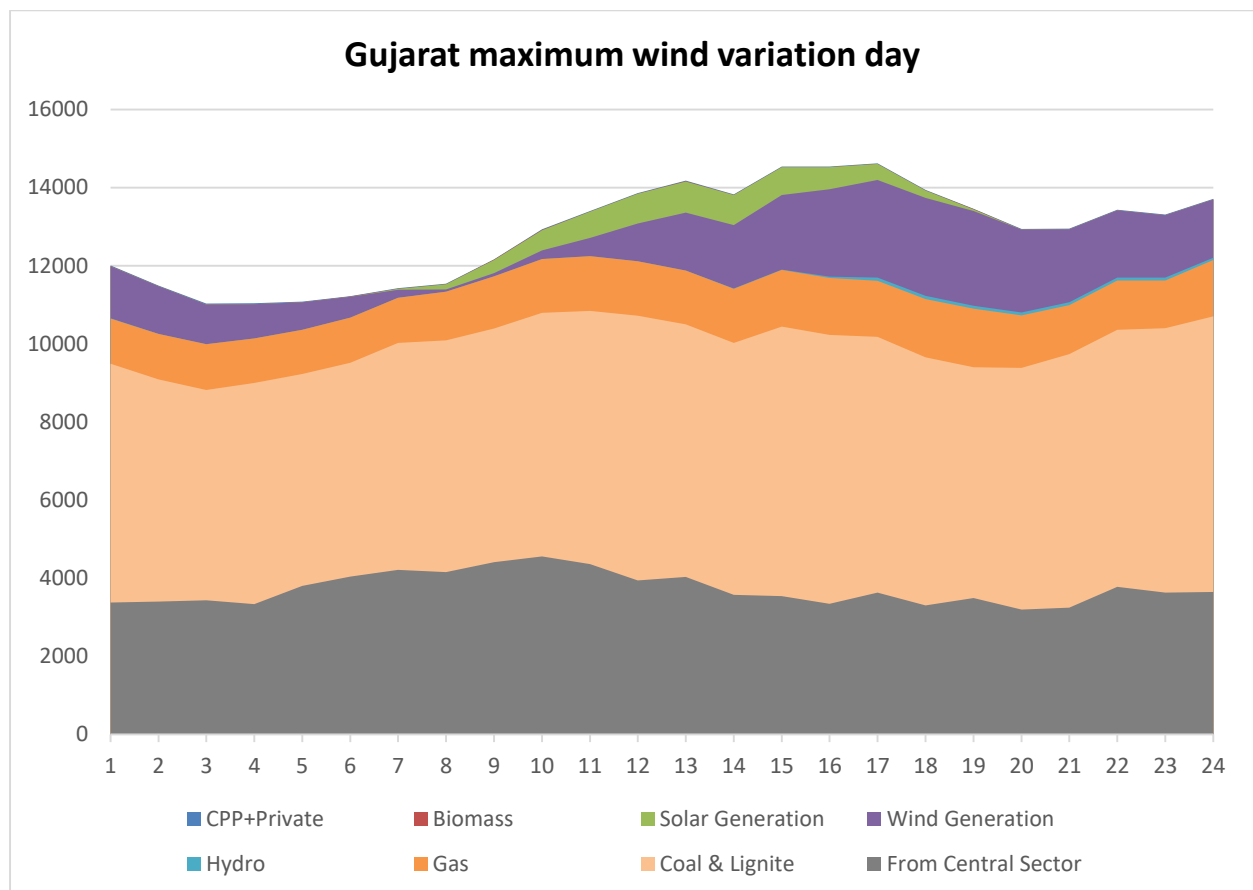
The generation that has been made to fluctuate, is the hydro generation which fluctuates from a minimum of 115 MW during off peak hours to 1006 MW at 2200 hrs and, to some extent, requisition from the Central Generating Stations (CGS), which fluctuates from a minimum of 1244 MW during off peak hours to 3472 MW during peak hours at 2130 hrs, resulting in CGS load factor for that day of 73%.

It is seen that if 15% deviation from the schedule is allowed for wind and solar generation, as is provided by CERC for inter-State renewable generators, 15% of the combined generation ranges from 304 MW to 792 MW during the day, whereas the limit on deviation allowed for the State of Tamil Nadu as a whole is 250 MW for a 15-minute

block, according to the Deviation Settlement Mechanism (DSM) Regulations of CERC for inter-state renewable generation. Therefore, the extra deviation beyond the limit of 250 MW ranges from 54 MW to 542 MW, which would result in extra financial implication to Tamil Nadu, on account of the DSM Regulations of CERC. The details of calculations are shown in **Annexure IX**.

2.2 Case Study of Gujarat

A similar case study was done for the State of Gujarat on the maximum wind variation day, i.e. on 22.5.2017. The peak demand of Gujarat, and how Gujarat has met the same from different sources of generation is shown below. The hourly figures for the same are shown in **Annexure X**.



It is seen that the Gujarat demand varies from a minimum of 11029 MW at 0300 hrs to a maximum of 14621 MW at 1700 hrs. The off-peak demand is 75% of the peak

demand. Gujarat has met this demand from a combined wind and solar generation ranging from 183 MW at 0800 hrs to 2910 MW at 1700 hrs. Therefore, it is seen that the combined peak generation of solar and wind on this day coincides with the peak demand. **The wind generation peaked at 1700 hrs, generating 2507 MW (out of an installed capacity of about 5400 MW)** and was minimum at 57 MW at 0800 hrs, whereas the **peak solar generation of 793 MW (out of an installed capacity of about 1260 MW) was at 1300 hrs.** The renewable penetration of Gujarat in energy terms on that day was 12%. Here also the solar and wind generation have complemented each other to some extent. The balance demand has been met by Gujarat, with gas generation almost remaining constant, ranging from 1132 MW at 0500 hrs to 1496 MW at 1900 hrs. Considering peak generation of gas during the day, the load factor of gas based generation for that day is 87%. Gujarat Coal Generation has also almost remained constant ranging from 5388 MW at 0300 hrs to 7059 MW at 2400 hrs. Considering the peak of 7059 MW of coal based generation, the load factor of coal based generation in Gujarat for that day is 88%.

Some of the fluctuation of generation in Gujarat is also done by the varying requisition of power from the Central Generating Stations, which fluctuates from a minimum of 3201 MW at 2000 hrs to 4559 MW at 1000 hrs, resulting in CGS load factor of 82% for that day.

Therefore, it can be seen that practically Gujarat has also been able to meet the fluctuations of wind and solar generation as well as demand fluctuation, using its existing generation as well as CGS share. The combined 15% deviation allowed for renewable generators, considering the combined wind plus solar generation, ranges from 27 MW to 436 MW, resulting in the deviation going beyond the 250 MW limit by up to 186 MW, which results in a financial implication to the State.

2.3 Financial implications in managing of renewable generation

There are, therefore, various financial implications in managing of renewable generation. These are enumerated below:

- (1) Availability of standby **balancing generating capacity**, which would be used for balancing of the intermittency of wind generation. Therefore, there is a fixed cost of assets of holding such generating capacity.
- (2) The **per unit fixed charge** would go up, **due to lower PLF**, if thermal and gas plants are ramped up and down for balancing, due to vagaries of wind and solar generation over the day.
- (3) Operation of various types of power plants i.e. gas and coal based plants at low levels compromises on the **efficiency of these power plants** and therefore the **specific heat rate** and **auxiliary consumption** (in % terms) rises. In other words, it takes more fuel to generate the same amount of electricity and therefore the **fuel charge** goes up.
- (4) There is also **wear & tear of plants** and **consumption of Equivalent Operation Hours (EOH)** if the plant is put under reserve shutdown and re-started from cold condition when required, and also, to some extent, while ramping up and down frequently. This results in thermal stress in the boiler and turbine and hence loss of EOH. Normally, a gas based station has a life of 1,00,000 EOH. For every start from cold condition, there is a loss of 20 EOH for a gas based power plant.
- (5) Since Solar and Wind Power Plants are must run power plants, Tamil Nadu has to absorb all this power, most of which is through a feed in or regulated tariff, fixed by the Tamil Nadu Electricity Regulatory Commission (TNERC). This rate ranges from Rs 2.75 per unit to Rs. 4.16 per unit. (This rate depends

on the date of commissioning of the unit fixed by TNERC; for wind mills commissioned prior to May 15, 2006, the rate is Rs 2.75 per unit; units commissioned between 15-05-2006 to 18-09-2008, the rate is Rs 2.90 per unit; units commissioned between 19-09-2008 to 31-07-2012, the rate is Rs. 3.30 per unit; units commissioned from 02-08-2012 to 31-03-2016, the rate is Rs. 3.96 per unit, and units commissioned on or after 01-04-2016 and upto 31-03-2018, the rate is Rs.4.16 per unit (all without accelerated depreciation benefits) as per the TNERC Order issued in RA No. 6 of 2013 dated 31-03-2016). **Tamil Nadu has to absorb this power, even if cheaper generation with a fuel charge of less than Rs 2.0 per unit is available from their coal based power plants.**

- 6) **DSM Charge** – This is due to difference between the schedule and actual generation allowed for intermittent renewable generators. Considering the limits of the renewable rich States to be the same as that set by CERC for inter-State generators, i.e. +/- 15% **w.r.t. the available capacity**, this would be quite a big figure. However, even if we take this **w.r.t. the schedule of** intermittent renewable generation, assuming a further narrowing of margins between the schedule and actual generation in the future, this does translate into a financial burden for the State.
- 7) **Extra transmission charge** – This is on account of **lesser utilization of transmission and distribution system used for evacuation of renewables**, because of their much lesser Capacity Utilization Factor (CUF).

Therefore, a renewable rich state is made to bear such costs.

This cost has been calculated considering typical day of wind and solar power variation in **Tamil Nadu**, as mentioned above, considering the flexing of the existing generation and other factors mentioned above, and comes to **Rs 1.57 per unit, spread over the renewable generation, as detailed below.**

Tamil Nadu Summary		
1	Total balancing charge for CGS Coal and gas based station (fixed +fuel charge)(Rs/kWh)- Spread over renewable generation	0.20
2	Total balancing charge for Tamil Nadu Coal based station (fixed +fuel charge)(Rs/kWh)-Spread over renewable generation	0.03
3	Impact of DSM per unit- Spread over renewable generation	0.35
4	Impact on tariff (Rs./Unit) for Tamilnadu discom for backing down Coal generation assuming solar and wind at Rs. 4/kWh and coal fuel charge at Rs. 2.0/kWh- Spread over renewable generation (Considering 25% on account of renewables)	0.50
5	Stand by charge (Rs/kWh)- Spread over renewable generation	0.23
6	Extra transmission charge (Rs/kWh)- Spread over renewable generation	0.26
	Total Impact- Spread over renewable generation (Rs/kWh)	1.57

The details of calculations are given in **Annexure IX**. For **Gujarat**, this works out to **Rs. 1.45 per unit, as detailed below.**

Details of calculation for Gujarat

Item No.	Balancing Cost	Rs./Unit
1	Total balancing charge for CGs Coal and gas based station (fixed +fuel charge)(Rs/kWh)-Spread over renewable generation	0.24
2	Total balancing charge for Gujarat Coal and Gas based station (fixed +fuel charge)(Rs/kWh)-Spread over renewable generation	-
3	Imapct of DSM per unit (Rs/kWh)- Spread over renewable generation	0.12
4	Impact on tarrif (Rs./Unit) for Gujarat discom for backing down Coal generation assuming solar and wind at Rs. 4/kWh and coal fuel charge at Rs. 2.0/kWh- Spread over renewable generation (Considering 25% on account of renewables)	0.5
5	Stand by charge (Rs/kWh)- Spread over renewable generation	0.33
6	Extra transmission charge (Rs/kWh)- Spread over renewable generation	0.26
	Total Impact- Spread over renewable generation (Rs/kWh)	1.45

If we compare this figure with the figure furnished by Gujarat in Chapter 1, it is seen that the extra transmission charges and standby charges have not been added by Gujarat. These amount to Rs 0.59 per unit. If this figure is added, the total comes to Rs.1.47 per unit, which is more or less the same as calculated by us. The details of calculations are given in **Annexure XI**.

It is seen that the major portion of the financial implication is on account of Rs. 0.50 per unit because of replacement of the cheaper fuel charge of Rs. 2 per unit with taking power from the must run renewable generation at an average of Rs. 4 per unit (considering 25% replacement). The charge of Rs. 4 per unit is on account of the feed-in

tariff as provided by the State Regulators. Presently, all procurement of generation from solar and wind power plants is through competitive bidding, which has lowered the tariff of solar power and wind power to about to Rs. 2.50 per unit. On the other hand, setting up of new coal based plant would entail a tariff of about Rs. 3.50 per unit for the first year, consisting of a fixed charge of Rs. 1.50 per unit (considering operation at 85% PLF) and a fuel charge of about Rs. 2 per unit, with escalation due to increase in coal prices with time, leading to an even higher levelized tariff. The levelized tariff of wind and solar generators, on the other hand remains the same in the case of non-escalable tariff. Therefore, **if we were to consider procurement of power from new capacity in future, this Rs. 0.50 per unit mentioned above would reduce to zero or may even be negative. If it is assumed that this is zero, the financial impact of renewable capacity would reduce to about Rs 1 per unit i.e. Rs. 1.07 per unit for Tamil Nadu and Rs. 0.95 per unit for Gujarat, or we can say an average of about Rs. 1.00 per unit.**

The **Renewable Purchase Obligation (RPO)** trajectory is uniform for all States and therefore, there is a need to share the balancing charges/financial implication associated with balancing requirements also on pro-rata basis. It is seen that the eight renewable rich States (viz. Tamil Nadu, Karnataka, Andhra Pradesh, Telangana, Gujarat, Maharashtra, Madhya Pradesh and Rajasthan) consume 65% of the total electricity consumption of the country. In case the financial implication is shared by all the States in the ratio of their RPOs, the charge per unit would come down to about Rs.0.70 per unit.

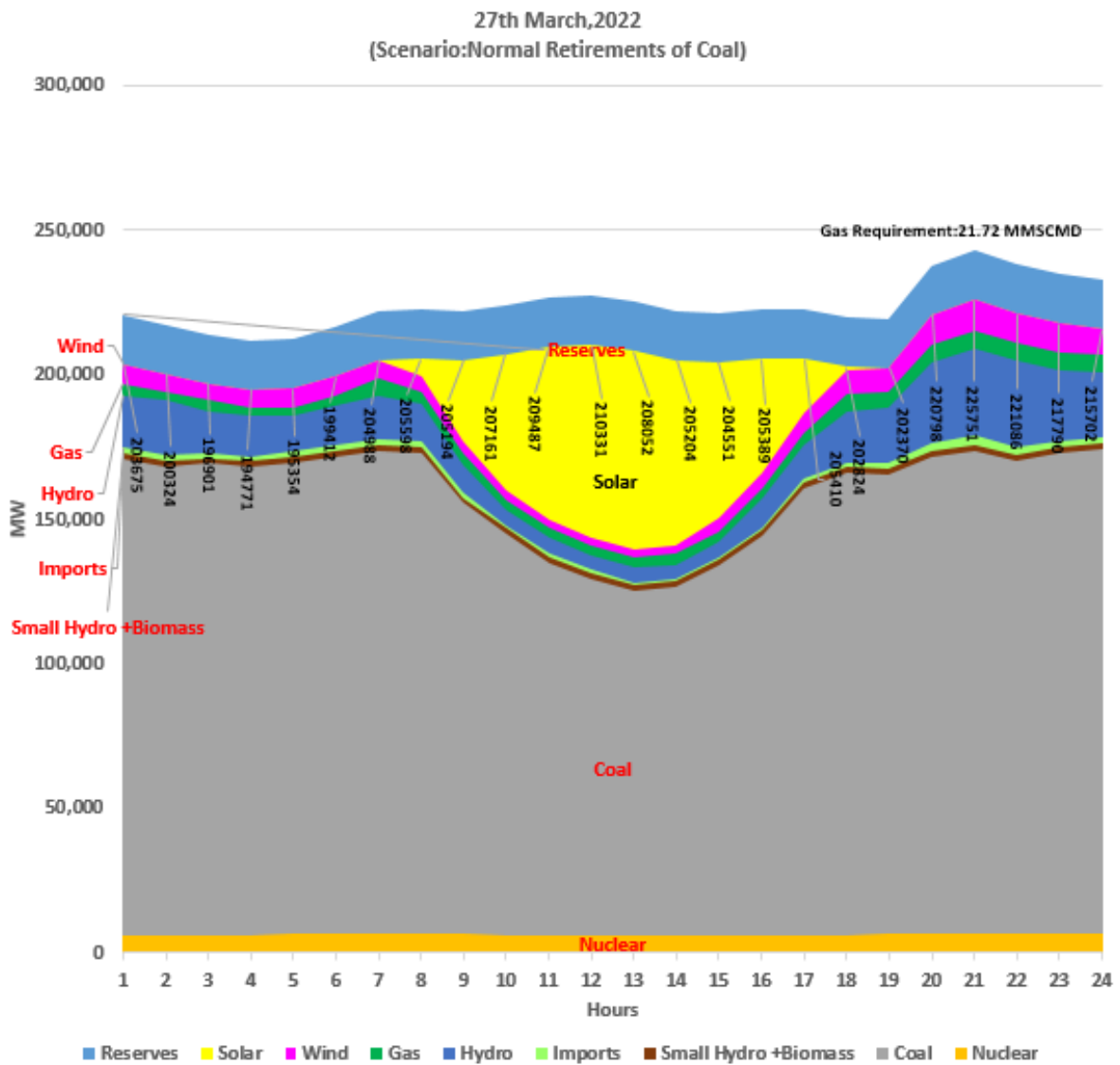
The method in which all India demand would be met in the **year 2022** is shown in the graph below. The hourly figures are given in **Annexure XII**. It is seen from the calculations that the financial implication on account of variation of renewable generation

is now Rs. 1.11 per unit, mainly due to fixed charge for standby capacity, charge due to DSM mechanism and extra transmission and distribution charge, as given below.

Details of calculation for All India scenario for 2022

Item No.	Balancing Cost	Rs./Unit
1	Total balancing charge for Gas based station (fixed +fuel charge)(Rs/kWh)-Spread over renewable generation	0.04
2	Impact of DSM per unit- Spread over renewable generation	0.30
3	Impact on tariff (Rs/kWh) for All India discom for backing down Coal based generation assuming solar and wind at Rs. 2.50/kWh and tariff of coal based generation at Rs. 3.50/kWh- Spread over renewable generation	0
4	Stand by charge (Rs/kWh)- Spread over renewable generation	0.50
5	Extra transmission charge (Rs/kWh)- Spread over renewable generation	0.26
	Total Impact- Spread over renewable generation (Rs/kWh)	1.11

The details of calculations are given in **Annexure XIII**. The DSM charge for the country cannot be calculated, since the DSM is for deviation across the States. However, this is taken as Rs. 0.30 per unit, which is the Gujarat DSM charge for maximum wind generation day in 2017, with renewable penetration of 33%. Therefore, even if we add this to the renewable energy charge at that time, it would be comparable or cheaper than the coal based charge.

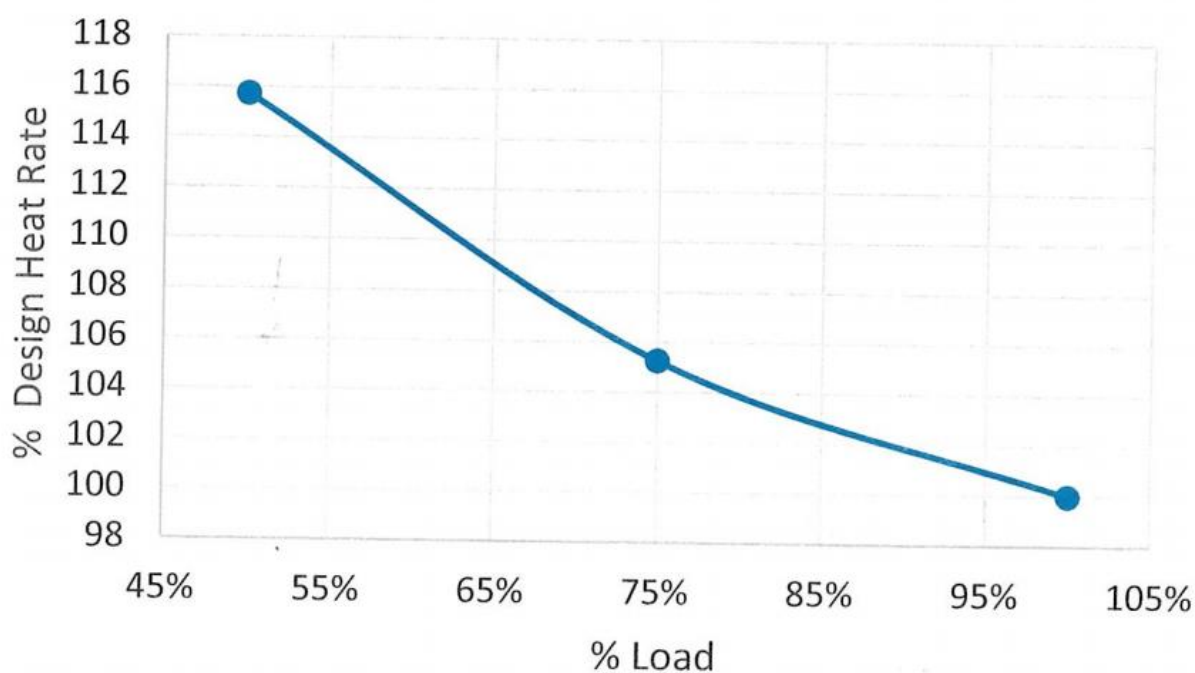


2.4 Assumptions in calculation of financial implications on account of managing intermittency of renewable generation

1. In case of standby capacity to take care of days when there is less of renewable generation, 10% of maximum renewable MW generation has been assumed.
2. For calculation of increase of fixed charge due to lower PLF, it is assumed that during the peak, coal based generation is operating at full capacity.

3. The decrease in efficiency (increase of heat rate and auxiliary consumption in percentage terms) is taken from the CERC norms given in the IEGC regulations. For combined cycle gas power plants, this is taken as per the curve shown below, as obtained from NTPC.

Heat Rate vs % Load of typical combined cycle plant



4. The loss of equivalent operating hours for every start from cold condition is taken after discussions with M/s Siemens and M/s GE.
5. It is assumed that 25% of the wind/solar generation (existing PPAs with an average tariff of Rs. 4.00 per unit) would replace the cheaper fuel charge of coal based stations with an average fuel charge of Rs. 2 per unit.
6. All wind and solar generators were not submitting their schedule in both Gujarat and Tamil Nadu; so the actual deviation could not be calculated in that way. Therefore, we have assumed the actual generation as the schedule. We have

assumed that the deviation could be to the extent of 15% w.r.t. the schedule, rather than w.r.t. the available capacity, as stipulated in the CERC's Deviation settlement mechanism. Deviation settlement mechanism charge is calculated, assuming that all the variation beyond the schedule is caused only by renewables, whereas the variation can be caused by inadvertent variation of both demand and renewable generation. Therefore, the impact of renewable variation on account of Deviation settlement mechanism may be higher.

7. There is a higher transmission charge due to lesser Capacity Utilisation Factor (CUF) of wind and solar power, which is in the range of 20-35%, as compared to about 85% for coal based plants and about 40% for hydro plants. (Coal based plants are also now running at an average of 60% PLF.) However, this is mainly to the extent of evacuation transmission system infrastructure from the solar park/wind pooling station to the Grid. There is no strengthening required in the infrastructure for drawal of power by the States off-taking power from the Grid, since the demand remains the same. The Grid is already designed for handling the peak power flows, whereas solar and wind power mainly occur at times other than the peak hours. Also, power from solar and wind is normally consumed locally. This is corroborated by the fact that for the Green Energy Corridors(GEC), Phase-1, for evacuation of power from wind and solar power, a total of Rs. 24,000 crores (Rupees 11,000 Crores for inter-State transmission system and Rs. 13,000 Crores for intra-State Transmission System) has been utilised for evacuation of 20,000 MW, coming to about Rs.1.2 Crore per Mega Watt. In the GEC Phase-2, for evacuation of power from solar parks, Rs. 12,000 Crores has been utilised for evacuation of 20,000 MW, coming to about Rs.0.6 Crore/MW. Against this, the normal evacuation system from a pit head coal-based plant to the load centre works out to about

Rs.1.5 Crore/MW to Rs.2.0 Crore/MW, which is 1.25 to 3 times higher. The utilization, on the other hand, may be, at an average, about 1/3rd for coal based plants and more than ½ for hydro power plants. Therefore, the financial implication on account of evacuation of power from wind and solar plants would only be marginally higher. The transmission charge consists of **injection charge** and **withdrawal charge**, under the Point of Connection Charge (**POC mechanism**) of CERC. For the long term access, CERC has now merged the injection and withdrawal charges. We will therefore consider the rates for short-term contracts, which shows the injection and withdrawal charges separately. We will consider enhancement of only the injection charge. We will consider that the extra transmission charge from evacuating wind and solar generation would have an additional impact of 26 paise per unit towards transmission charges, on account of **extra injection charge**, i.e. twice the injection charge, as compared to the **maximum** coal based **injection charge**. The present charging methodology of CERC is on MW basis and does not distinguish between time of day usage. Solar plants use the transmission system only for 9-10 hours, whereas they are charged for 24 hours in the present methodology. **The existing system of charging transmission charges for wind and solar plants based on maximum MW utilization during a quarter year and 24 hours basis should therefore change to a shorter period, may be on a monthly basis and hourly periods in line with scheduling of all generation, including solar and wind generation, since scheduling is done on an even shorter period, i.e. 15 minute basis, in order to be equitable for renewable energy sources. The unutilized transmission capacity can be used by other open access generators or in the power exchange.**

It is seen that the deviation of Inter-State flows is both due to **variation of demand** in the State as well as **variation in generation**. Since generation from conventional sources can be controlled, the **variation in generation** is mostly on account of **variation of generation from renewable energy sources**. Each State has to take care of the variation of demand through their own methods, whereas deviation on account of generation of renewables should be shared by all the States of the country in the ratio of their RPOs. Therefore, there is a need for the State Load Despatch Centre (SLDCs) to be able to know how much variation is on account of load variation and how much on account of variation from RES. This can easily be presented to the load dispatcher **after deducting the renewable generation variation w.r.t. the schedule**, on real time basis, and thus being able to monitor inter-state flow variations on account of load variations.

2.5 Sharing of balancing responsibility on account of renewables

Now, we come to how the balancing responsibility for tackling the intermittency of renewable generation is to be shared. **One of the methods** of sharing the balancing responsibility on account of RES on a pro-rata basis, could be that this responsibility is given to the RLDCs and NLDC using balancing sources all over the country i.e. expanding the balancing areas for the purpose for renewable generation variations. **The other method** could be to compensate the balancing charge on account of RES to the States where the RES are located, by collecting a balancing/renewable charge from the remaining States in the ratio of their RPOs. The balancing charge could be fixed on normative basis for a season or month, or calculated based on actual values, on weekly basis like the Deviation Settlement charge, depending on how much of the DSM was

caused by renewable generation. In this case the calculations would be done post facto. In this case, the deviation limits of CERC's DSM mechanism on account of load variation would be set the same in all States and DSM charges on account of load variation applied in accordance with these limits. For the RES therefore, this means expanding the balancing areas to the full country. Advantage could also be taken of hydro reservoirs in neighbouring countries for balancing and supplying these countries with firm base load power to them, through banking, in order to have a win-win situation for both countries.

The quantum of balancing sources required for balancing renewable generation in the whole country can be calculated only after we get real time variation of generation of RES over the whole country. Therefore, a separate dedicated meeting was taken to ensure obtaining of real time RES generation data from all renewable rich States. Once these are obtained, the quantum of balancing generation required with different response times would be known. It has been assured by all the States that the real time generation from RES would be fully available in about 2 months.

CHAPTER 3

OPTIMUM METHOD OF BALANCING

3.1 Ideal plants for balancing

In order to see that balancing is done in the most optimum manner, resulting in least cost to Distcoms and hence to consumers, it would be best to balance the variations from renewable generation with gas and hydro generation, which are the fastest to respond to fluctuations and affected to a lesser extent as compared to coal based stations. Pumped Storage Plants are very effective, in the sense that they can act as a load, when there is excess generation from wind and solar power and store this energy for delivering power during times of reduced generation. While using hydro generation for balancing has a limitation, also being related to irrigation needs, gas generation is presently not being varied because of gas being supplied on almost a constant rate as per existing practice. Hydro generation, under the existing limitations, could also provide flexibility by irrigating the fields when higher generation from hydro is required. The feasibility of this in different States would have to be studied. Gas generation can be varied during the day, if it is connected to a **gas grid pipe line**, and not too much in the case of gas being consumed locally or is off-grid, since the storage capacity of the gas lies in the grid pipe line. This can be done, within the supply constraints available in the gas pipe line and keeping total daily gas supply as before, and can be facilitated by GAIL and RELIANCE in their pipe lines. GAIL has already, in-principle, agreed to this.

It would be better for gas based stations to be operated at low PLFs, to be ramped up or down when required, rather than shutting down the gas power stations, and re-starting again, as that results in higher thermal stress and more loss of Equivalent Operating Hours (EOH). Among coal based stations, it would be preferable to operate

the efficient coal based plants viz., Super Critical and Ultra Super Critical Power Plants at higher loads, without much fluctuation, and allow fluctuation of generation in Sub Critical Plants. For generation and frequency fluctuations in the sub 15-minute range, it could be done by hydro generation, gas generation and MW Scale Batteries. For frequency variations in the half hour or higher scale, flexible coal based plants could also be used for balancing, in some cases through retro-fitting.

3.2 Ancillary Services

CERC has provided a framework for **ancillary services** in India by making available the un-requisitioned surplus power of Central Generating Stations (Coal/lignite Based and Gas based), as and when this power is available.

However, such un-requisitioned surplus may not be available at all times. Therefore, a permanent mechanism of ancillary services needs to be provided for the country to manage the balancing of renewables, as well as emergency situations for frequency control.

It is therefore recommended that **ancillary services in India may be started to ensure capacity on a permanent basis**. Capacities with different ramp rates may be made available at all times, for frequency stability, as well as to mitigate congestion in the transmission system and kept under the control of the RLDCs/NLDC. It is proposed that the response times of different types of ancillary services i.e. seconds reserves, 5 minute reserves as well as reserves which respond in about half an hour should be specified, under the functional requirements of ancillary services and any generator or bulk consumer (through demand response), which can achieve these functional requirements, should be allowed to bid for the same. **Such services should be procured through competitive bidding**, on a yearly basis, or three-yearly basis, as deemed fit. States who

have balancing sources and who want to bid in the common pool of ancillary services can also do so.

Payment to ancillary services should be through a fixed **commitment charge** and a **usage charge**. Evaluation of bids should be through levelled charge, consisting of both fixed charge and usage charge, assuming a certain usage. **Payment should be based on performance**, i.e. if they deliver the contracted services at least 95% of the time, they would be made full payment. If they deliver lesser than that, their payment would be reduced on pro-rata basis. If they do not deliver to the extent of at least 60%, their contract could be cancelled. The figures of percentages can be reviewed, depending on requirement.

Balancing resources of the States/Centre/Private sector generators could be surrendered and treated as common resources, and the owner of these assets compensated if they win the bid for ancillary services. For this, they would have to set aside the contracted quantity.

Cost of these resources need to be shared by all the beneficiaries.

3.3 Demand Response

Demand Response, i.e. incentivizing customers to reduce demand is a very quick and cheap way of substituting for frequency based ancillary services to some extent, to enable optimum utilization of generation and transmission assets. This should be encouraged by the Central and State Regulators. State Regulators must also attempt to **provide agricultural supply during the daytime, when solar power generation is**

maximum, instead of providing the same during night off-peak hours, as some States were doing, thereby also preventing snake bites to the farmers. **Electric vehicle charging tariff should also be structured** to be cheap during night off-peak hours and during the solar generation hours.

3.4 Intra-State Regulations on forecasting, scheduling and deviation settlement mechanism for renewable sources of energy

Many States still do not have final **regulations on forecasting, scheduling and deviation settlement mechanism for renewable sources of energy** and therefore the burden for the same comes on the State Distribution Companies, and the SLDCs are also put to hardship to manage the grid. It is proposed that till the time intra-state DSM Regulation by the SERCs is not operational, the mechanism of inter-state DSM should be followed.

CHAPTER 4

PLACEMENT OF GRID SCALE BATTERY ON PILOT BASIS

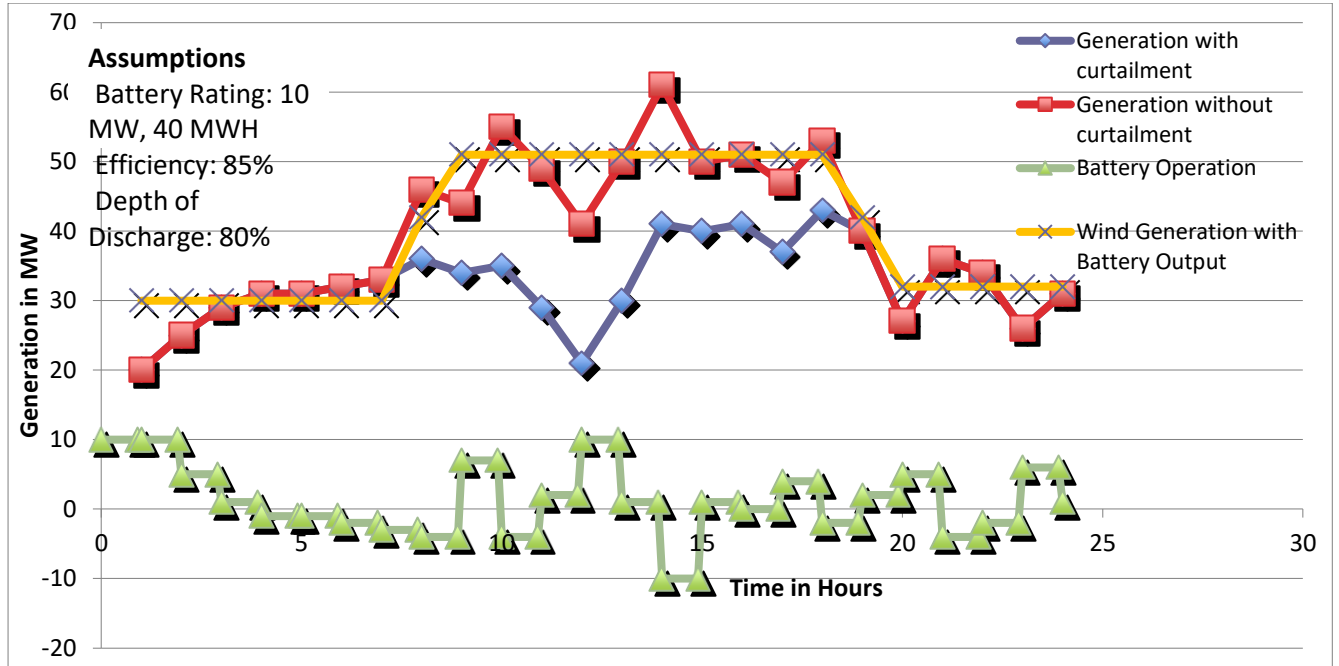
One of the terms of reference of the Committee was also to propose a location for installation of MW Scale Battery. This was also discussed and it was seen that this could be located at two locations in Transmission System in Tamil Nadu in the 110 kV Pooling Stations of Ayyanaruthu and Sundankurichi, since it was seen that there is normally congestion in the transmission lines leading from these pooling stations to the Tamil Nadu loads/deviation beyond the DSM limits, which results in curtailment of free wind power. A single line diagram of these sub stations is given in **Annexure XIV**.

4.1 Sizing of battery

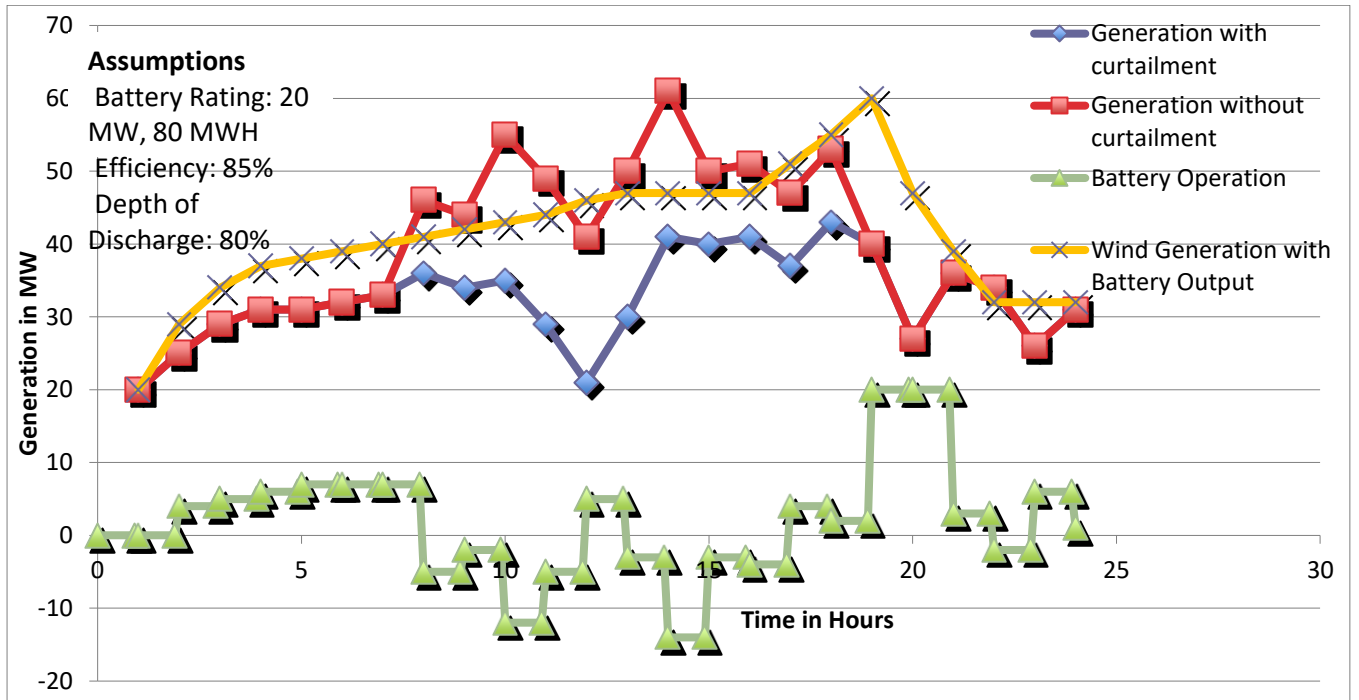
The sizing of the battery was carried out, based on variations of wind generation during the monsoon months. The battery would be charged above a certain real-time MW generation limit and discharged below a certain real-time MW generation limit, both limits dynamically varying for effective usage, depending on quantum of wind generation and battery capacity, as controlled by the Battery Management System (BMS), in order to deliver relatively more constant power, and also avoid the problem of overloading.

It was found that, based on loss of generation at Ayyanaruthu substation, a 10 MW battery for 4 hours, i.e. 40 MWh battery would be apt for placement at the substation. The details of calculations and graphical presentation are shown in **Annexure XV**. It has been assumed for the calculations that the system efficiency of the battery is 85% and the

depth of discharge is 80%, as is normally the case for a lithium battery. The variable wind generation is converted to a more constant generation, as shown in the graph below.



In case a higher capacity of battery (20 MW for 4 hrs, i.e. 80 MWh) is provided, it can convert the generation from a wind pooling station to even a peaking station, as shown in the graph below. The details of calculations are given in **Annexure XV**.



CHAPTER 5

RECOMMENDATIONS

Recommendations

1. The Renewable Purchase Obligation (RPO) trajectory as per the revised Tariff Policy, notified on 28.1.2016, is uniform for all States and therefore, there is a need to share the balancing charges/financial implication associated with balancing requirements also on pro-rata basis. As per present norms, RPOs have been prescribed on the basis of consumption of MUs, after deducting consumption by states from hydro power generation. The balancing charge/financial implication should therefore also to be shared in the same ratio.
2. There are two types of balancing generation required, the balancing for uncertainty, i.e. deviation of actual from schedule which cannot be forecasted within the accurate limits prescribed, and the generation capacity required to ramp up to meet the variability due to reduction of generation from wind and solar, even if these can be forecasted accurately and are known. Both these factors cause a financial impact on the existing thermal generation.
3. Efficiency of thermal power plants goes down at lower loads, and if they are to participate in balancing requirement, these need to be compensated on account of high availability of RE generation. High RE generation also calls for backing down of cheaper conventional sources, because of must run status of RE. Frequent start-stop of machines and frequent ramping up and down, subjects the boiler and turbine to greater deterioration of equipment

and higher O&M needs. The thermal stresses are highest in case of starting from cold condition and very less for ramping up and down. There is a cost to these.

4. Hydro and gas based power plants should preferably be used for balancing. To facilitate gas plants for balancing, gas supply needs to be modulated as per requirement.
5. Balancing source could be located either within the boundary of a State or outside the boundary of the host State.
6. There is a need to discriminate between balancing power needs on account of load variation from that on account of variability in RE generation. Real time renewable generation data acquisition is required by the States to see to what extent the states deviation under Deviation Settlement Mechanism (DSM) is due to renewable variation.
7. Ancillary Services in India may be started to ensure capacity on a permanent basis for grid security. Balancing sources should form part of the bigger umbrella of Ancillary services. There is a need to categorize various type of balancing sources, based on response time, to be activated within seconds, minutes and hours, and price for each category determined through bidding. The balancing generation should have a commitment charge and a usage charge for a certain pre-defined usage. If usage exceeds the same, there should be an additional payment for the extra usage, all pre-defined. Payment should also be based on performance.
8. The extent of balancing required for balancing renewables may be extracted from these Ancillary Services.
9. Balancing resources of the States/Centre/Private sector generators could be surrendered and treated as common resources, and the owner of these

assets compensated if they win the bid for ancillary services. For this, they would have to set aside the contracted quantity.

10. These Ancillary Services may be kept under the control of RLDCs. Cost of these resources need to be shared on pro-rata basis by all the beneficiaries.
11. Demand Response is a very quick and cheap way of substituting for frequency based ancillary services to some extent, to enable optimum utilization of generation and transmission assets and must be implemented by all States.
12. Limits of net DSM for load variation may be maintained as before, after segregating it from renewable variation, with ancillary services for renewable generation variation and frequency control under the control of the RLDCs, for managing the grid. Alternately, the renewable rich States may manage the same within their boundary and get paid for the financial implication by non-renewable rich States on pro-rata basis, based on consumption, depending on calculation of the financial implication per unit of renewable generation done on a normative seasonal basis or weekly basis, as is done for DSM charges.
13. In case of the latter option, settlement of balancing charges/financial implication for the uncertainty portion should be done post facto, on the lines of DSM charges.
14. Firm base load power could be supplied to neighbouring hydro rich countries in return for balancing power from them, through banking, in order to have a win-win situation for both India and the neighbouring countries.
15. Till the time intra-state DSM Regulation by the SERCs is not operational, the mechanism of inter-state DSM should be followed.

16. Cost benefit aspects need to be studied, as regard to location of new balancing sources, versus augmentation of transmission system. This aspect assumes a higher importance, in view of the increasing land cost in urban areas. In some cases, location of balancing sources in the form of storage elements, near the point of generation may be more economical.
17. A pilot battery project in Tamil Nadu has been proposed as a test case for a pilot project.