INSTITUTIONAL MECHANISMS FOR THE EFFECTIVE OPERATION OF WIND POWER IN INDIA

SHAKTI
SUSTAINABLE ENERGY
FOUNDATION

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ABBREVIATIONS

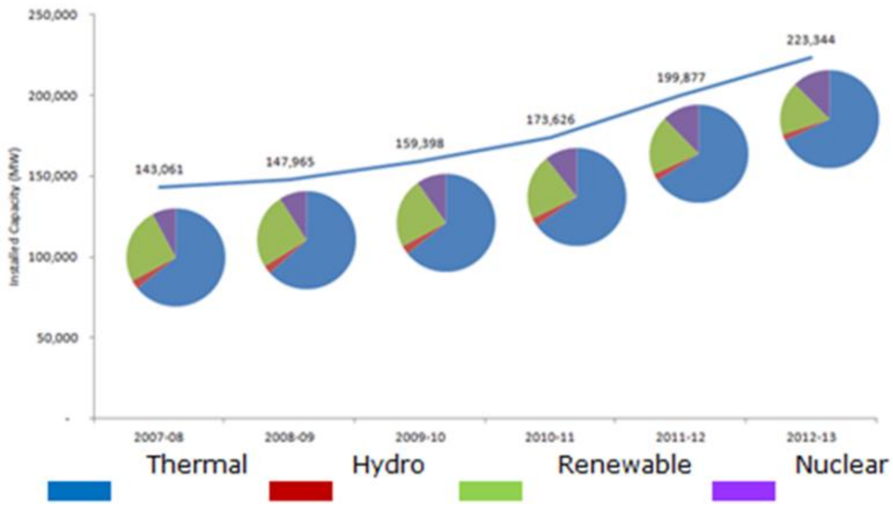
ACF	Auto Correlation Function
AGC	Automatic Generation Control
CEA	Central Electricity Authority
CUF	Capacity Utilization Factor
CWET	Centre for Wind Energy and Technology
EPS	Electric Power Survey
FiT	Feed in Tariff
FGMO	Free Governor Mode of Operation
GBI	Generation Based Incentive
GenCo	Generation Company
GoI	Government of India
GWEC	Global Wind Energy Council
HS	Host State
IEGC	Indian Electricity Grid Code
ISGS	Intra State Generating Station
MNRE	Ministry of New and Renewable Energy
NAPCC	National Action Plan on Climate Change
NLDC	National Load Despatch Centre
RE	Renewable Energy
REC	Renewable Energy Certificate
RLDC	Regional Load Despatch Centre
RPO	Renewable Purchase Obligation
RPC	Regional Power Committee
RRF	Renewable Regulatory Fund
SCADA	Supervisory Control and Data Acquisition
SLDC	State Load Dispatch Centre
SO	Systems Operator
SR	Southern Region
TN	Tamil Nadu
UI	Unscheduled Interchange
UIC	Unscheduled Interchange Cap rate
VRE	Variable Renewable Energy
WG	Wind Generator

I. INTRODUCTION

1.1. BACKGROUND

India with its focus towards lowering its carbon emissions and closing the demand supply gap for energy in the country has been placing emphasis on the contribution of renewable energy in the future production of electricity. The contribution of renewable sources of energy, consisting of wind, solar, small hydro and bio energy, in the electricity generation of the country has already been growing consistently over the past few years. In Figure 1 we can observe that share (installed capacity in MW) of renewable energy in the country's power generation installed capacity has increased from 8% in 2007-08 to 12% in 2012-13.

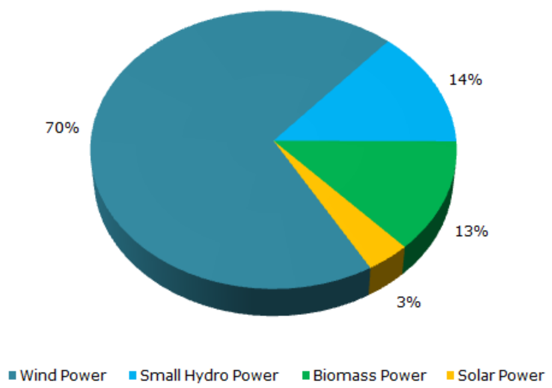
Figure 1: Share of Renewable Energy in the total Installed capacity in India (as on 31st March 2013)



Source: CEA

Amongst all the sources of Renewable Energy it is the Variable Renewable Energy (VRE) forms, consisting of Wind Power and Solar Power which has a 73% share in the installed capacity of Renewable Energy (as shown in Figure 2) and a share of over 8.5% in the overall installed capacity of the country.

Figure 2: Cumulative Installed capacity of Renewable Sources of Energy as on 31st March 2013



Further, **between the variable sources of renewable energy it is wind power, which has the largest share (70%) of the total installed capacity of renewable energy in India**. [1]As per estimates published by the Ministry of New and Renewable Energy[2] the wind potential in India at 50 meters hub height is more than 49 GW, while at 80 meters hub height it is 102 GW. **So far only a mere 17% of the potential, estimated by MNRE, at 80 m hub height has been tapped into**.

Further, recent studies have shown that MNRE has taken relatively conservative estimates of wind power potential in India. The Lawrence Berkeley National Laboratory (LBNL) estimates the on shore wind power potential to be 2,006 GW at 80 meter hub height and 3,121 GW at 120 meter hub height. Expert studies by Shakti Sustainable Energy Foundation (SSEF) in various wind resource rich states corroborates the magnitude of the LBNL estimates. Thus, wind power not only leads the list in terms of installed capacity of renewable energy but also has a high potential, most of which is still untapped. Thus, it can be concluded that wind power is ideally positioned to increase its share in India's energy mix and contribute towards bridging the energy deficit.

However, despite it being ideally positioned to bridge gap between the demand and supply of power in the country, increased penetration of wind power poses several challenges arising out of variability and its consequences. This report discusses the issues involved and analyses the initiatives taken by key agencies involved as on date. Basis the analysis the report suggests certain measures that can be undertaken to ensure higher and smoother VRE penetration in the generation mix in the coming years.

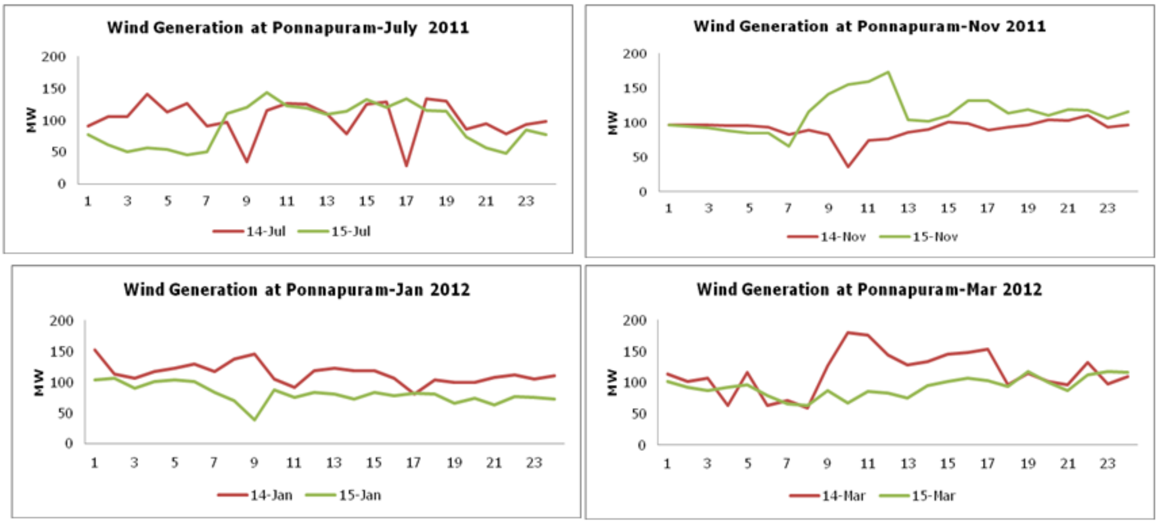
1.2. CHALLENGES WITH THE INTEGRATION OF WIND POWER

As mentioned, wind power poses significant challenges due to its intermittent and unpredictable nature. For bringing about a specific understanding of the issues and the interventions we have assessed the trends from the southern state of Tamil Nadu, which has the highest wind penetration in the country. The data used pertains to Tamil Nadu as a whole and also the specific subs station at Ponnapuram in the Udumalpet area of western Tamil Nadu that features a large wind generation capacity. Figure 3 provides an illustration of variability of wind generation in Tamil Nadu between months, and also between consecutive days in the same month, using data from the 220 kV sub-station at Ponnapuram, Tamil Nadu.

[1] For the purpose of this report we shall be analyzing the institutional mechanisms for grid integration of Renewable Energy only from the perspective of integration of Wind Power.

[2] http://mnre.gov.in/file-manager/annual-report/2012-2013/EN/chapter3.html; MNRE; Annual Report 2012-13

Figure 3: Wind Generation in Tamil Nadu during 2011



From Figure 3 it can be observed that the wind power generation not only varies during different months in a year, but also varies between two consecutive days. Even in the span of a day it fluctuates as much as between 50 MW and 200 MW, as can be observed in the data for 14th March 2012.

The uncertainties pertaining to wind generation as shown above have huge implications for the Host State (HS) and the System Operator (SO) as discussed below:

1. **For the Host State**: The HS has to bear the burden of high Unscheduled Interchage (UI) charges caused by the variability in wind power generation. Reserve resources cannot be planned adequately because wind generation is currently not forecasted. Alternatively, the Host State resorts to load shedding, which bears an adverse financial impact to the state economy.
2. **For the System Operator**: The SO faces difficulty in resource planning and unit commitment when faced with uncertain wind generation.

Hence, it is evident that the displacement of conventional power plants by wind power may have an adverse impact on a balancing area's performance standard at high wind penetration levels. Higher penetration causes degradation in frequency control performance of the interconnected system raising reliability concerns. There are several measures by which this can be mitigated. They are as follows:

1. Improve primary frequency control capability in the state
2. Improve the forecast accuracy of wind power
3. Control wind power output to be within a band around the forecasted value
4. Combine control areas

The CERC has implemented the Renewable Regulatory Fund (RRF) mechanism with the key objectives of improving the forecast accuracy and controlling the wind power output within a certain band. The RRF mechanism and its role in the integration of Wind Power has been discussed extensively in the following sections of this report. The report also covers the benefits of implementation of institutional changes such as larger control areas and a defined forecasting code in order to improve grid integration of wind energy.

1.3. MEASURES TO OVERCOME CHALLENGES

The Central Electricity Regulatory Commission (CERC) passed the order on the *"Procedure for the Implementation of the Mechanism of Renewable Regulatory Fund"* (hereafter called the Renewable Regulatory Fund or RRF mechanism), dated 9th July 2013. The Order on Renewable Regulatory Fund (RRF) mechanism was passed in continuation to regulation 6.1 (d) (read wit*h Clause 9 of Annexure I) of the Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2010*, which states:

"9. NLDC shall prepare, within one month of notification of these regulations, a detailed procedure for implementation of the mechanism of Renewable Regulatory Fund and submit the same for approval by the Commission."

*The provisions under the RRF mechani*sm also ties into the stipulations of the *Central Electricity Regulatory Commission (Unscheduled Interchange charges and related matters) (Second Amendment) Regulations, 2012* (Hereafter called the UI Regulations). The RRF Mechanism read with the UI Regulations attempts to lessen the burden on the states of paying higher UI charges as a result of deviations from scheduled generation caused due to the variability in generation of wind power.

The three interventions made by the CERC, namely the Draft on *Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Second Amendment) Regulations, 2013*; *Central Electricity Regulatory Commission (Unscheduled Interchange charges and related matters) (Second Amendment) Regulations, 2012* and the Order on the "*Procedure for the Implementation of the Mechanism of Renewable Regulatory Fund*" under Regulation 6.1(d) of Central Electricity Regulatory Commission (Indian Electricity Grid Code), Regulations 2010, and their implications on the generation of wind power have been discussed at length in the following sections.

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II. CURRENT REGULATORY INTERVENTIONS AND THEIR MECHANICS

The structured interventions to manage and promote VRE have largely been undertaken by the CERC, which has made several and sustained efforts to address the underlying issues. These interventions are been discussed below.

2.1. THE INDIAN ELECTRICITY GRID CODE

The Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2010, (IEGC) was notified on 28th April 2010, and has been amended since. The first amendment was made on 5th March 2012 and the draft of the second amendment was published on 12th August 2013.

One of the primary objectives of the Central Electricity Regulatory Commission (Indian Electricity Grid Code) Regulations, 2010 as spelled out in **Regulation 6.2** is as follows:

> *"The procedure for submission of capability declaration by each ISGS and submission of requisition/drawal schedule by other regional entities is intended to enable RLDCs to prepare the dispatch schedule for each ISGS and drawal schedule for each regional entity. It also provides methodology of issuing real time dispatch/drawal instructions and rescheduling, if required, to regional entities along with the commercial arrangement for the deviations from schedules, as well as, mechanism for reactive power pricing.* ***This code also provides the methodology for rescheduling of wind and solar energy on three (3) hourly basis and the methodology of compensating the wind and solar energy rich states for dealing with the variable generation through Renewable Regulatory charge.....****"*

The *Draft Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Second Amendment) Regulations, 2013,* includes stipulations and regulations required to bring the Renewable Regulatory Fund (RRF) into effect, and with respect to the scheduling of the variable energy resources, like wind, states in **regulation 6.5.23** that:

> *"(23)* ***With effect from 15.7.2013 scheduling of wind power generation plants would have to be done for the purpose of deviation settlement where the sum of generation capacity of such plants connected at the connection points (called Pooling Stations) to the transmission or distribution system is 10MW and above and connection point is 33kV and above, for pooling stations commissioned after 3.05.2010.*** *for capacity and voltage level below this, as well as for old wind farms (A wind farm is collection of wind turbine generators that are connected to a common connection point), it could be mutually decided between the Wind Generator and the transmission or distribution utility, as the case may be, if there is no existing contractual agreement to the contrary. The schedule by wind power generating stations (excluding collective transactions) may be revised by giving advance notice to SLDC/RLDC, as the case may be. Such revisions by wind power generating stations shall be effective from 6th time-block, the first being the time-block in which notice was given. There may be one revision for each time slot of 3 hours starting from 00:00 hours of a particular day subject to maximum of 8 revisions during the day."*

Thus, the provisions of IEGC are intended to bring parity between conventional generation and large VRE generators through commercially responsible dispatch albeit with some relaxations.

Further, the draft second amendment to the IEGC defines the roles and responsibilities of various players within the RRF Mechanism, such as the Coordinating Agency, the Pooling Station and the Wind Power Generator amongst others. Some of the related stipulations are quoted below.

Referring to Annexure 1, which provides the guidelines for forecasting, the Complementary Commercial Mechanisms of the *Draft Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Second Amendment) Regulations, 2013,* states that:

> *"3. Wind energy being of variable nature, needs to be predicted with reasonable accuracy for proper scheduling and dispatching of power from these sources in the interconnected system. Hence wind generation forecasting is necessary for increased penetration. Wind generation forecasting can be done on an individual developer basis or joint basis for an aggregated generation capacity of 10MW and above connected at a connection point of 33kV and above. If done jointly, the wind forecasting shall be built and operated by the wind developers in the area and sharing of the cost shall be mutually discussed and agreed. For the purpose of this Regulation, the agency which would be assigned the work of forecasting, scheduling, metering and energy accounting, etc., shall be designated as coordinating agency.*
>
> *This coordinating agency shall submit to SLDC an authorization on behalf of all generators that it is coordinating with copy endorsed to respective RLDC.*
>
> *The RLDCs/SLDCs shall interact with coordinating agency only for forecasting, scheduling, metering and energy accounting, deviation and RRF settlement. SLDCs/RLDCs shall not be a party or respondent for any dispute between coordinating agency and its Generators.*
>
> *4. The wind energy forecasting system shall forecast power based on wind flow data at the following time intervals:*
>
> *(i) Day ahead forecast: Wind power forecast with an interval of 15 minutes for the next 24 hours for the aggregate Generation capacity of 10MW and above.*
>
> *(ii) The schedule by such wind power generating stations supplying inter-state power under long-term access, medium-term and short-term open access (excluding collective transactions) may be revised by giving advance notice to respective SLDC/RLDC. Such revisions by wind power generating stations shall be effective from 6th time-block, the first being the time-block in which notice is given. There may be one revision for each time slot of 3 hours starting from 00:00 hours of a particular day subject to maximum of 8 revisions during the day.*
>
> *5.* ***The Wind Generators shall be responsible for forecasting their generation up to an accuracy of 70%. Therefore, if the actual generation is beyond +/- 30% of the schedule, Wind Generator would have to bear the UI charges. For actual generation within +/- 30% of the schedule, no UI would be payable/receivable by Generator, the Host State, shall bear the UI charges for this variation, i.e. within +/- 30%. However, the UI charges borne by the Host State due to the wind generation, shall be shared among all the States of the country in the ratio of their peak***

demands in the previous month based on the data published by CEA, in the form of a regulatory charge known as the Renewable Regulatory Charge operated through the Renewable Regulatory Fund (RRF). *This provision shall be applicable with effect from 1.1.2011, for new wind farms with collective capacity of 10 MW and above connected at connection point of 33 KV level and above , and where pooling station was commissioned on or after 3.5.2010 and total connected generating capacity is 10MW or above.*

5A. If the capacity of the pooling station for Wind Generator at present is less than 10 MW, as and when its connected capacity becomes 10 MW or above, it shall participate in forecasting and scheduling. The ABT metering at pooling station shall be provided by the concerned DISCOM/STU or CTU as applicable. The cost of this shall be borne by all generators connected at that pooling station in proportion to their connected capacity and shall be paid by coordinating agency working on behalf of generators connected at the pooling station. Forecasting, scheduling and energy accounting shall be done at pooling station level."

2.2. UI REGULATIONS

The commercial mechanism that is implemented to ensure that the schedule submitted to the State Load Despatch Centres (SLDC) and the Regional Load Despatch Centres (RLDC) is maintained, is the imbalance settlement mechanism, namely the *Central Electricity Regulatory Commission (Unscheduled Interchange charges and related matters) (Second Amendment) Regulations, 2012* (Hereafter called the UI Regulations).

Clause 5(1) of the regulation states:

"The charges for the Unscheduled Interchanges for all the time-blocks shall be payable for over drawal by the buyer or the beneficiary and under-injection by the generating station or the seller and receivable for under-drawal by the buyer or the beneficiary and over-injection by the generating station or the seller and shall be worked out on the average frequency of a time-block at the rates specified in the Schedule 'A' of these Regulations as per the methodology specified….."

The clause clarifies that any deviation from the schedule by both buyer and seller will be penalized; the rate of penalty being linked to the frequency at the time of deviation.

In India, the imbalance settlement charges are linked to frequency. The rates increase with frequency drop and total imbalance charges increase as energy withdrawals / under injections increase beyond their scheduled levels. The operating frequency band has been tightened over time by the regulator. In accordance with the latest draft proposition of the Central Electricity Regulatory Commission (Deviation Settlement Mechanism & Related Matters) Regulation 2013, the allowable frequency variation band is 49.95 Hz – 50.05 Hz. Further, the mechanism has penalties on volumetric deviations from scheduled withdrawals / injections irrespective of the grid frequency. This mechanism is further expected to impose the requirement of commercially responsible forecasting for VRE generators both on such generators and on the state distribution utilities.

However, the generation of power from VRE sources like wind within manageable accuracy is a challenge; the intermittent nature not only

imposes a burden on the Host State but poses considerable challenge to the grid operation as well. In states like Tamil Nadu, where the wind penetration is approximately 46% sudden ingress and withdrawal of wind imposes problems on the System Operator. During periods of sudden wind generation ingress, if the grid frequency increases and correspondingly the UI rate falls below the Feed in Tariff (FIT) rate, it becomes uneconomical for the state to accept the power generated using wind. Further, if wind generation suddenly increases and the frequency falls- the utility either has to shed load or the state has to overdraw from the grid (bears financial implication to the Host State). In such cases if the state has met its RPO obligation, they have no incentive to encourage more wind based generation. It can be understood that the inherent variability of wind often disincentivizes the Host State to absorb VRE generation. In order to protect the Host State from the financial burden and at the same time provide incentives to the wind generator to inform their schedule to as close as possible to the actual generation, the order on the Renewable Regulatory Fund namely *"Procedure for the Implementation of the Mechanism of Renewable Regulatory Fund" under Regulation 6.1 (d) of the Central Electricity Regulatory Commission (Indian Electricity Grid Code), Regulations, 2010* was issued on 9th July 2013 with the following objectives:

- To induce the VRE generator to maintain its scheduled generation as close as possible to the forecasted actual generation: The wind generators shall be responsible for forecasting their generation up to accuracy of 70%. Therefore, if the actual generation is beyond +/- 30% of the schedule, UI charges would be applicable to the wind generator. For actual generation within +/- 30% of the schedule, no UI would be payable/receivable by generator.
- To minimize the impact of VRE generation on the Host State: The Host State would also receive from the RRF, the difference between the UI rate and the cap UI rate for under-drawal beyond the percentage/MW prescribed in the UI Regulations, to the extent of under-drawal subjected to it, if any, on account of net over generation by solar and wind farms in the State as a whole.
- To insulate the renewable generator from impact of deviation of generation within + / - 30% of their schedule. The RRF would be used to compensate for deficit, if any, that arises due to the insulation provided to renewable energy generator.

The Renewable Regulatory Fund (RRF) Mechanism as proposed by Central Electricity Regulatory Commission (CERC) is a commercial mechanism which has been introduced with the objective of wind power scheduling. However, the implementation of this will require a conducive institutional mechanism discussed in details in the subsequent sections.

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III. RENEWABLE REGULATORY FUND

The RRF as discussed above has been introduced to encourage the VRE generators to maintain their scheduled generation as close as possible to the forecasted actual generation. In this section the workings of the RRF Mechanism are discussed.

3.1. APPLICABILITY

The RRF mechanism will be applicable to:

a. The Wind Power Plants that have been commissioned after May 2010 and are connected to Pooling Stations with a collective capacity of 10 MW and above at connection point of 33kV and above, either to the state transmission and distribution system or to the inter-state transmission system.

b. The Solar Power Plants that have been commissioned after May 2010 and are connected to the Pooling Stations with a collective capacities of 5 MW and above at connection point of 33kV and above, either to the state transmission and distribution system or to the inter-state transmission system.[3]

c. The coordinating agencies appointed by the wind and solar generators.

d. Regional agencies like Regional Power Committees (RPC) and RLDCs etc.

e. National Load Despatch Centre (NLDC)

The fund is to be maintained by the NLDC on the lines of Unscheduled Interchange Pool Account at the regional level; in accordance with provisions of the Grid Code.

3.2. DESIGN OF THE MECHANISM

The mechanism has separate designs for inter and intra state off-take of power for solar and wind. **In this report, only the implication of the RRF mechanism for intra-state off-take of wind power is discussed.**[4]

The settlement mechanism under the RRF has been designed so that it depends upon the deviations by the wind generator from its scheduled generation. The deviations are categorized as follows:

- Under scheduling within 30%
- Under scheduling between 30%-50%
- Under scheduling beyond 50%
- Over scheduling within 30%
- Over scheduling beyond 30%

Before proceeding to discuss the design of the mechanism, listed below are the factors on which the Pay-off to a wind generator, Host State and the RRF depend.

[3] Solar Power Plants and the implications of the RRF Mechanism on them have not been discussed in this report.

[4] Inter-State mechanisms have not been addresses in this Report as there is no inter-state off-take of wind power at present

(a) Contract Rate (CR): it is the rate at which the wind generator gets paid by the off-taker or in other words the rate specified in the Power Purchase Agreement between the two parties.

(b) Reference Rate (RR): As per the "Procedure for the Implementation of the Mechanism of Renewable Regulatory Fund" under Regulation 6.1 (d) of Central Electricity Regulatory Commission (Indian Electricity Grid Code), Regulations 2010, Reference Rate (RR) is defined as the rate, which shall be used for computing financial implications for the variability of wind energy generators under RRF Procedure. Clause 7A of Appendix 1, Complementary Commercial Mechanism of the Draft on Central Electricity Regulatory Commission (Indian Electricity Grid Code) (Second Amendment) Regulations, 2013 further defines RR as:

> *"7A. For computation of financial implication on account of deviation in generation of renewable energy under Renewable Regulatory Fund in accordance with paras 5 and 7 above, Reference Rate shall be the Deviation Settlement Rate of average frequency of last year for the respective synchronized Grid i.e. NEW Grid and Southern Grid."*

The Reference Rate for the NEW Grid is INR 3/unit while that for the Southern Grid is INR 5/Unit.

(c) UI: It is the frequency linked Unscheduled Interchange rate at which the Host State gets reimbursed/penalized by the Regional UI pool as and when it under/over draws from the grid. The additional UI and UI cap rate are also determinants of the pay-off.

The subsequent sections explain the interplay amongst these three factors which in turn influence the pay-offs of the wind generator, Host State and the RRF.

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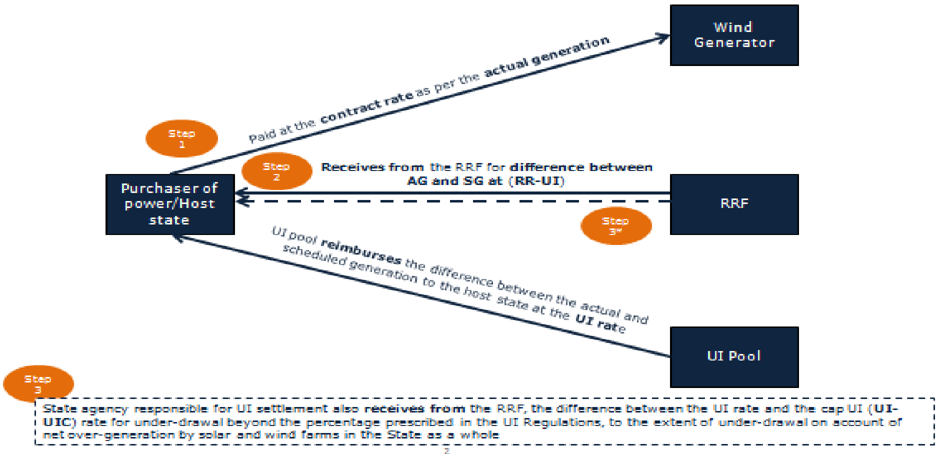
3.2.1. UNDER SCHEDULING WITHIN 30%:

When the wind generator (WG) under schedules within 30% or in other words over generates; the net financial impact is borne by the RRF. WG gets paid as per its actual generation at the contract rate from the Host State (it is assumed that the off-taker is the Host State). The Host State under draws from the regional UI pool owing to the increased generation by WG and hence gets reimbursed for the difference at the frequency linked UI rate. The state also gets compensated by the RRF on the difference between the actual and the scheduled generation at the (RR-UI) rate. Hence, it is observed that under scheduling within 30% insulates the WG and Host State from any risk. This is depicted in Figure 4. In summary:

- The WG is insulated as it gets paid as per its actual generation.
- The HS is insulated as it gets adequately compensated
- The RRF bears the financial impact

Figure 4: Pay-off flows under the current RRF mechanism for Intra state scenario: Deviation within +30%



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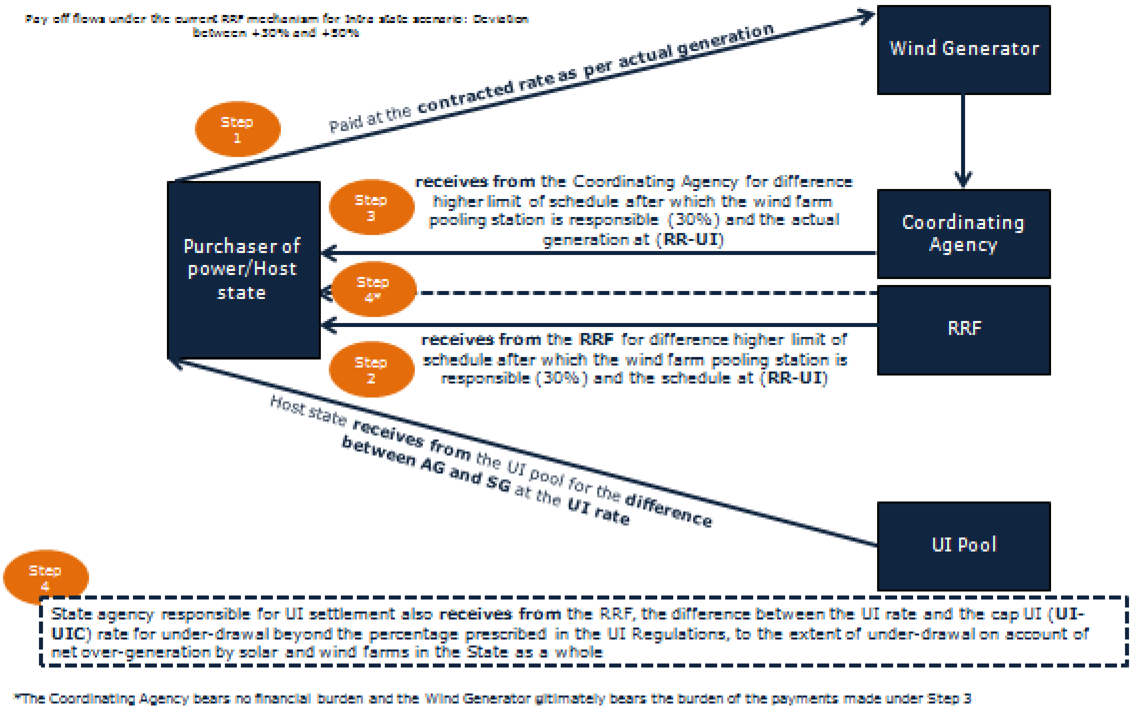
3.2.2. Under scheduling within 30% to 50%

When WG under schedules within 30%-50%; the payment is made as per its actual generation. WG gets paid at the contract rate by the Host State, assuming that the latter is the off-taker. The Host State under draws from the grid owing to the increase in generation by WG and hence gets compensated by the regional UI pool for the difference between the actual and the scheduled generation at the frequency linked UI rate. The RRF aims to insulate the Host State and the Wind Generator for up to 30% of its deviation from the schedule while the risks associated with any deviation beyond the band is to be borne by the Wind Generator. Thus, the state gets up to 30% of the schedule reimbursed from the RRF at the (RR-UI) rate; it also receives the difference between the actual and higher limit of 30% of its schedule at the (RR-UI) rate from the coordinating agency (which is appointed by WG). Hence, it is observed that WG is insulated while the RRF bears the financial impact. This is depicted in Figure 5. In summary:

- The WG is insulated as it gets paid as per its actual generation.
- The HS is insulated as it gets adequately.
- RRF bears the financial impact.

Figure 5: Pay-off flows under the current RRF mechanism for Intra state scenario: Deviation between +30% and +50%



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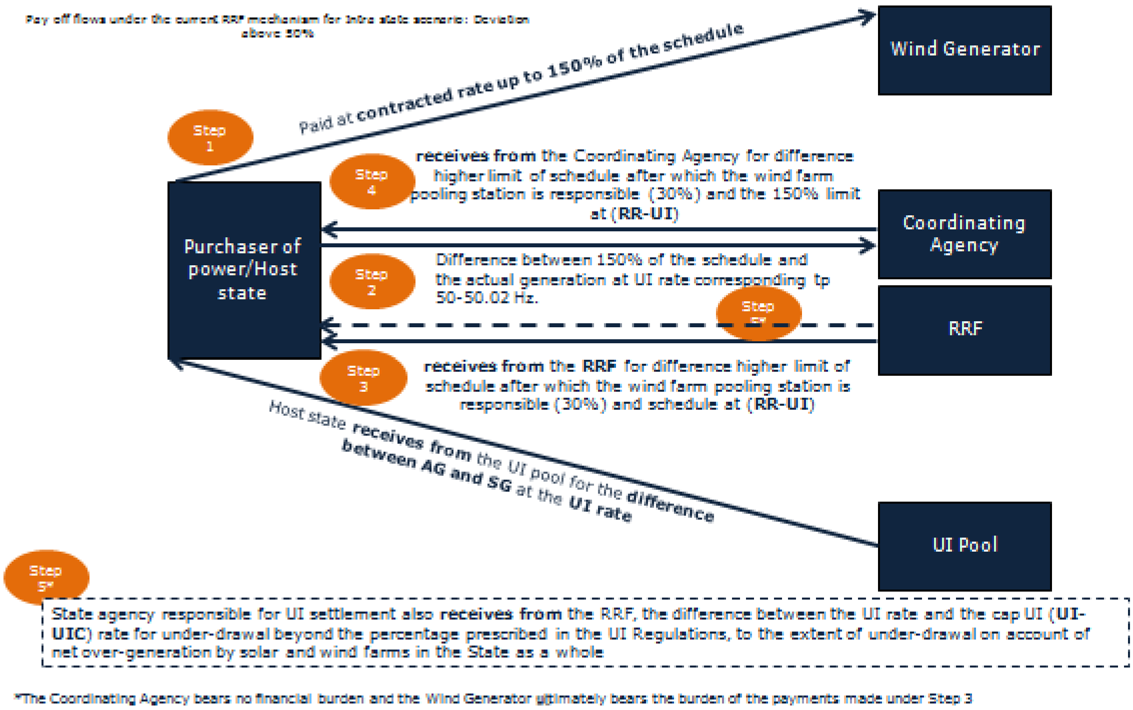
3.2.3. UNDER SCHEDULING BEYOND 50%

When WG under schedules beyond 50% of its schedule; it gets paid for up to 50% of the deviation at the contract rate from the Host State. The state under draws from the grid owing to the increased generation by the WG and gets compensated for the difference at the frequency linked UI rate. The state on the other hand pays for the difference between the actual generation and the higher limit of 150% of its schedule to the coordinating agency at the rate corresponding to frequency 50-50.02 Hz. State is compensated for up to 30% of the schedule from the RRF at the (RR-UI) rate. In this situation it is observed that the Wind Generator bears the risk of deviation beyond 150% of its schedule. The state gets compensated by the UI pool and RRF; however, it pays to the Coordinating Agency for deviation beyond 150% of the schedule. The net financial impact is borne by the RRF. This is depicted in Figure 6. In summary:

- The WG bears a part of the risk as it gets paid only upto 50% of its schedule.
- The HS is insulated as it gets adequately compensated.
- The RRF bears the financial impact.

Figure 6: Pay-off flows under the current RRF mechanism for Intra state scenario: Deviation beyond +50%



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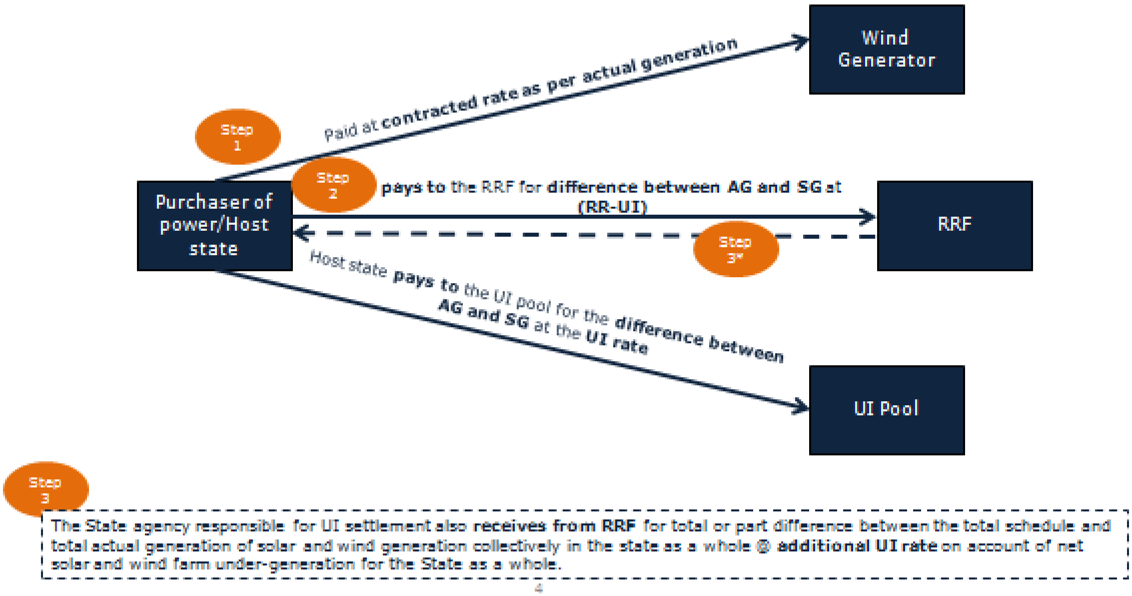
3.2.4. OVER SCHEDULING WITHIN 30%

When the WG over schedules within 30% or in other words under generates the net financial impact is borne by the Host State. The WG gets paid as per its actual generation at the contract rate from the Host State (the off-taker is assumed to be the Host State). The Host State over draws from the regional UI pool owing to the reduction in generation by WG and hence gets penalized for the difference at the frequency linked UI rate. The state pays to the RRF on the difference between the actual and the scheduled generation at the (RR-UI) rate. Hence, it is observed that over scheduling within 30% bears financial implication on the Host State. This is depicted in Figure 7. In summary:

- The WG is insulated as it gets paid as per its actual generation.
- The HS bears the financial impact.
- The RRF is insulated as it is adequately compensated.

Figure 7: Pay-off flows under the current RRF mechanism for Intra state scenario: Deviation within -30%



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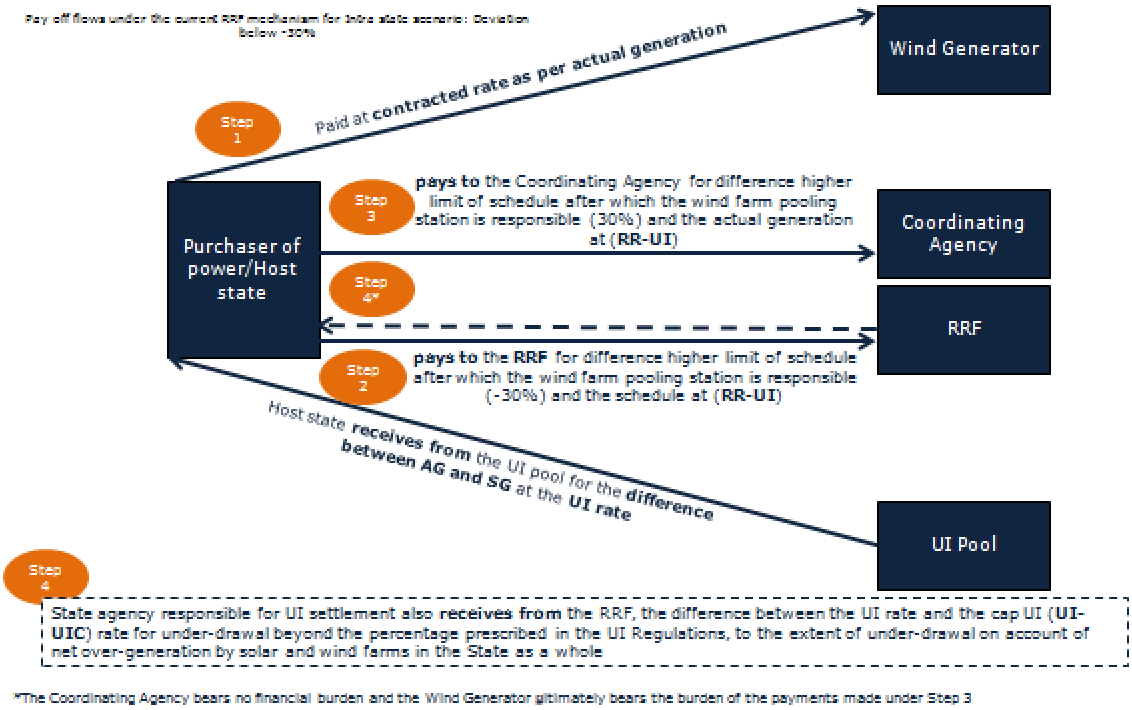
3.2.5. OVER SCHEDULING BEYOND 30%

When WG over schedules beyond 30%; the payment is made as per the actual generation. The Host State pays at the contract rate to WG. It is assumed that the Host State is the off-taker. The Host State over draws from the grid owing to the reduction in generation by WG and hence gets penalized by the regional UI pool for the difference between the actual and the scheduled generation at the frequency linked UI rate. The RRF aims to insulate the Host State and the Wind Generator for up to 30% of its deviation from the schedule while the risks associated with any deviation beyond the band is to be borne by WG. Thus, the state pays up to 30% of the schedule to the RRF at the (RR-UI) rate. The Host State is also liable to pay for the difference between the actual and higher limit of 30% of its schedule at the (RR-UI) rate to the coordinating agency. Hence, it is observed that in this situation the WG is insulated while the Host State bears the financial impact. This is depicted in Figure 8. In summary:

- The WG is insulated as it gets paid as per its actual generation.
- The HS bears the financial impact.
- The RRF is insulated as it gets adequately compensated.

Figure 8: Pay-off flows under the current RRF mechanism for Intra state scenario: Deviation beyond -30%



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3.3. PAY-OFF SCENARIOS

In order to analyze the Pay-off scenarios for the entities involved in the RRF mechanism for intra state off take of wind power, namely the Wind Generator, Host State, RRF and the UI Pool, the following assumptions have been made:

a. Actual Generation is 100 kWh

b. Under the RRF mechanism Scheduled Generation is the decision variable for the wind generator, which can influence its pay-off. Wind generator would therefore declare the scheduled generation that results in maximizing its pay-off. **Deviation from Scheduled Generation** is calculated as a percentage of "'Actual Generation minus Scheduled Generation' divided by Scheduled Generation", i.e. [{(AG-SG)/SG}*100]. It is measured along the X axis or the horizontal axis of the graphs in the following sub-sections. When Actual Generation is fixed at 100 (kWh) the various Scheduled Generations assumed in order to depict all the deviation bands is given in Table 1:

Table 1: Assumptions taken to depict deviation bands

Actual Generation (AG) (kWh)	**Deviation** (%)	**Scheduled Generation** (kWh) [AG/{(Deviation/100)+1}]
100	70%	59
100	60%	63
100	50%	67
100	40%	71
100	30%	77
100	20%	83
100	10%	91
100	0%	100
100	-10%	111
100	-20%	125
100	-30%	143
100	-40%	167
100	-50%	200

c. The Contract Rate is assumed to be INR 3.51/ kWh. This is the state Feed in Tariff of Tamil Nadu for the period up to 31st July 2014.[5]

d. The Reference Rate of the Southern Grid which as per the Order on RRF is INR 5/kWh has been taken.

e. The UI rates assumed in Table 2 have been used to generate different pay off scenarios for the Wind Generator, Host State, RRF and UI Pool (in graphs in the following subsections). These UI rates have been taken to demonstrate how the relationship of the UI rate with the reference rate impacts the pay offs of the various entities mentioned above.

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5 http://tnerc.tn.nic.in/orders/Tariff%20Order%202009/2012/T.R%20No.6%20of%202012%20dated%2031-07-2012-Wind.pdf

Table 2: Relationship between UI and RR

Indicative Label in Figures	UI rate (INR/kWh)	Relationship with RR
A	1	UI < RR
B	3	UI < RR
C	5	UI = RR
D	7	UI > RR
E	9	UI > RR

f. The UI rate at 50Hz has been taken as INR 1.65/kWh.

g. Pay-offs (the dependant variable) has been shown along the Y axis or the vertical axis in the graphs in the following subsections.

Based on the above mechanism and assumptions taken the Pay-off scenarios for the different entities involved has been analysed below.

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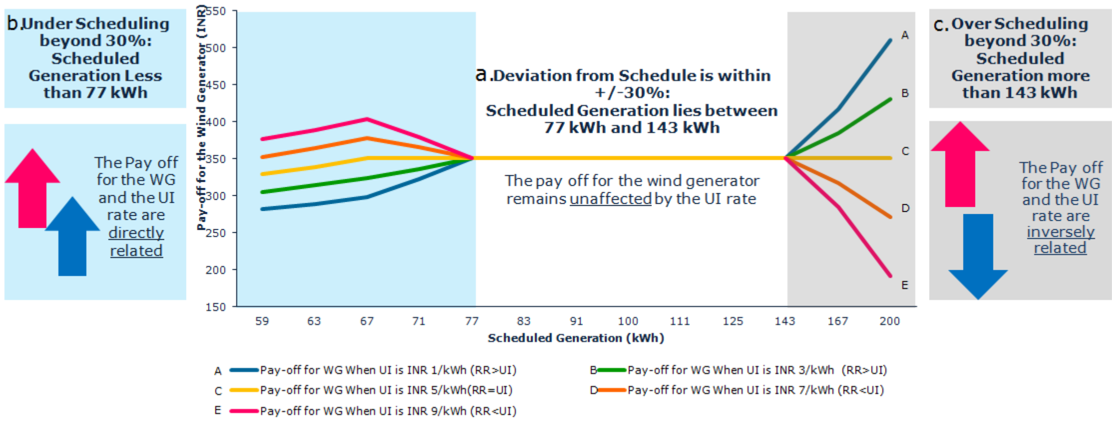
3.3.1. Pay-off Scenario for a Wind Generator

From the above it can be concluded that the scheduled generation is the independent variable that has to be maintained by the Wind Generator as close as possible to its forecasted actual generation, as per the objective of the RRF mechanism. The Pay-off to the Wind Generator is the dependent variable as it depends on:

a. The schedule provided by it and deviation between schedule and actual generation
b. The relative values of UI rate and the Reference Rate.

The Pay-off for the Wind Generator under various scenarios has been shown in Figure 9:

Figure 9: Pay-off for a Wind Generator under the current RRF mechanism



Observations from the above figure:

a. Deviation within +/-30%: When the deviation from schedule by the WG is within +/- 30% then WG Pay-off remains the same regardless of the UI rate.

b. Under scheduling beyond 30%:

- UI<RR: The Pay-off to the Wind Generator falls with decrease in the UI rate
- UI>RR: The Pay-off to the Wind Generator rises with the Increase in UI rate

c. Over Scheduling beyond 30%

- UI<RR: The Pay-off to the Wind Generator rises with decrease in the UI rate
- UI>RR: The Pay-off to the Wind Generator falls with the increase in the UI rate

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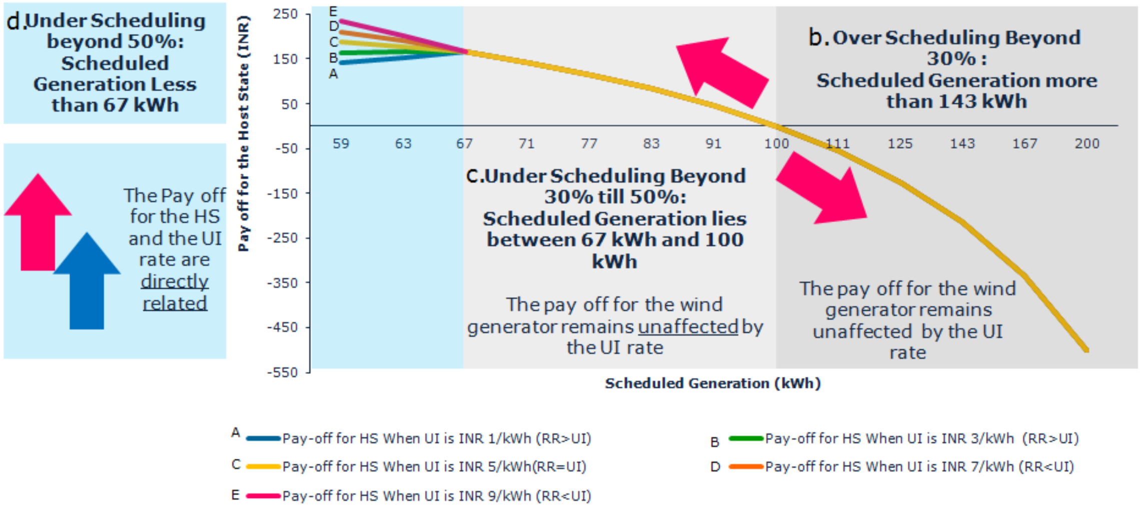
3.3.2. Pay-off scenario for the Host State

The Pay-off to the Host State depends on the scheduled generation given by the Wind Generator and how close it is to the actual generation. The Pay-off scenarios of the Host State has been depicted in the Figure 10.

Figure 10: Pay-off for the Host State under the current RRF mechanism



Observations from the above figure:

a. Deviation within +/- 30%: The Host State receives/gives money to the UI pool as and when the Wind Generator under schedules/over schedules. When the Wind Generator deviates by +/-30% from its schedule then the Host State pays/receives money from the RRF. It is seen that irrespective of the UI rate the impact on the Host State remains the same for a particular value of SG (within the 30% band)

b. Over Scheduling beyond 30%: The pay-off for the host-state remain unaffected by the UI rate when it over schedules beyond 30% for a particular value of Scheduled Generation. The larger the gap between the actual and the scheduled generation, higher is the amount of money that the Host State has to pay to the UI Pool.

c. Under scheduling beyond 30% up to 50%: The pay-off for the host-state remain unaffected by the UI rate when it over schedules beyond 30% for a particular value of Scheduled Generation. The larger the gap between the actual and the scheduled generation, higher is the amount of money that the Host State receives from the UI Pool.

d. Under scheduling beyond 50%:

- UI<RR: the pay-off for the Host State falls with a decrease in the UI rate.
- UI>RR: the pay-off for the Host State increases with the increase in the UI rate

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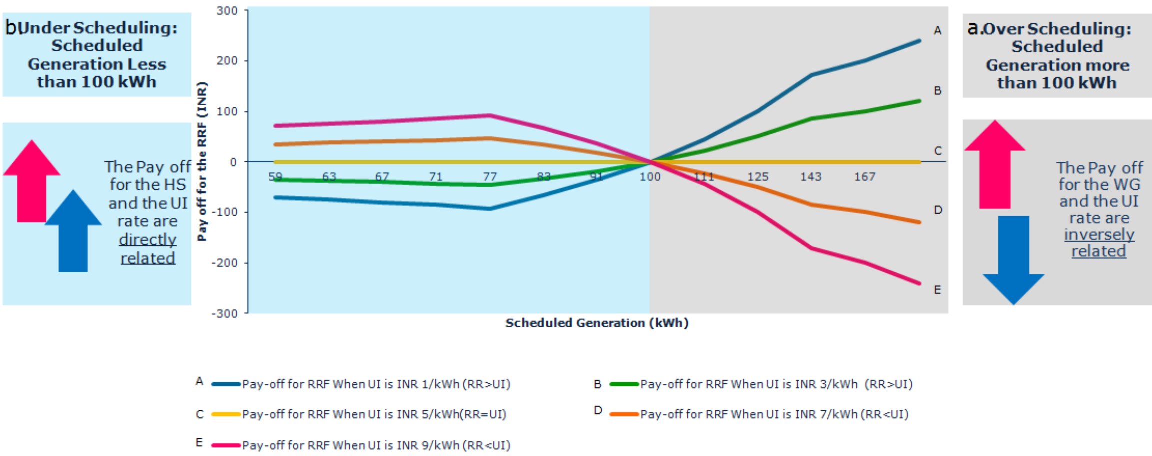
3.3.3. PAY-OFF SCENARIO FOR THE RRF

The Pay-off scenarios of the RRF has been depicted in the Figure 11.

Figure 11: Pay-off for the RRF under the current RRF mechanism



Observations from the above figure:

a. Over scheduling :

- UI<RR: there is an increased inflow into the RRF with the decrease in the UI rates.
- UI>RR: there is an increased outflow from the RRF with an increase in the UI rate.

b. Under scheduling:

- UI<RR: there is an increased outflow from the RRF with a decrease in the UI rates.
- UI>RR: there is an increased inflow into the RRF with an increase in the UI rates.

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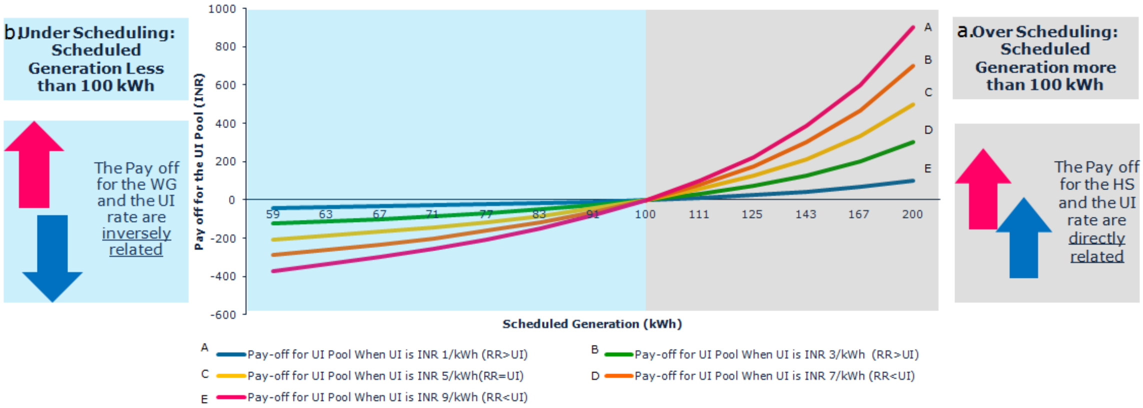
3.3.4. PAY-OFF SCENARIO FOR THE UI POOL

The Pay-off scenarios of the UI pool has been depicted in Figure 12.

Figure 12: Pay-off for the UI Pool under the current RRF mechanism



Observations from the above figure:

a. Over scheduling: There is an increased inflow into the UI pool with an increase in the UI rates when the wind generator over schedules. In this case, due to under generation the Wind Generator overdraws from the grid and pays to the UI pool.

b. Under scheduling: there is an increased outflow from the UI pool with an increase in the UI rates when the wind generator under schedules. In this case, due to over generation the wind generator under draws from the grid and receives money from the UI pool.

Thus, from the above Pay-off scenarios it is observed that the wind generator may choose to over schedule or under schedule its generation beyond the +/-30% band if it can predict whether the UI during a certain time block will be greater or lesser than the RRF. This has been analysed in the following section.

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IV. KEY ISSUES WITH CURRENT RRF MECHANISM

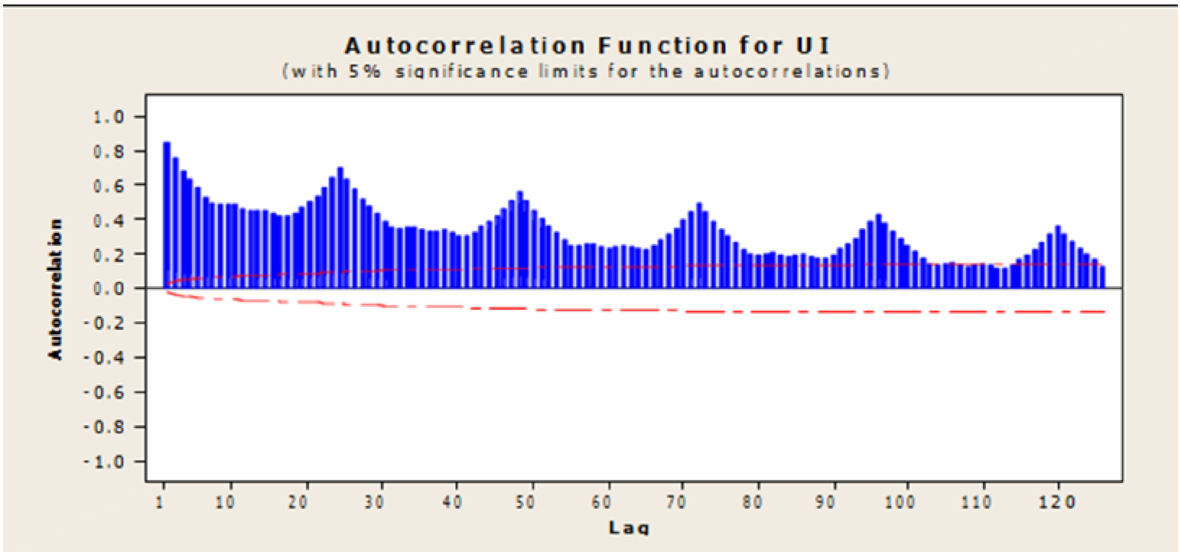
The analysis of the current RRF mechanism in the previous section brings forth several issues of key importance. In order to ensure that the main objectives of RRF mechanism is fulfilled the following key issues have to be addressed.

4.1. UI IS THE PRINCIPAL VARIABLE FOR SCHEDULING DECISIONS. THE PREDICTED VALUES OF UI WOULD DICTATE SCHEDULES

It is to be expected that the entities involved in the scheduling process will attempt to limit their risks. In the instant case of decentralized scheduling adopted in the IEGC for VRE generators, the decision variables are left to the wind generators. As the previous section has discussed, there are two principal parameters that are "variables" in the scheduling process - the declared schedules and the UI. The impact of the generator is determined by the interplay of these to variables.

It thus follows that for the scheduling to be undertaken as per the intent of the IEGC, the UI must not lend itself to prediction. If the UI is predictable, then the generators by default will schedule in a manner that limits their risks. Unfortunately, the UI lends itself to statistical predictions. The following auto correlation function shown in Figure 13 for the UI rate demonstrates that it is possible to predict whether it will be more than or less than the reference rate with a high degree of accuracy.

Figure 13: Auto Correlation function for UI



Thus under the current RRF mechanism it can be observed that:

- The Wind Generator will always choose to minimize risk under the current mechanism basing on the anticipated UI values. Since the above auto correlation functions shows that it is possible to predict the UI rate with a significant degree of accuracy and since the wind generator will be able to predict its actual generation within a significant range from past experience, data and a forecasting system, it will have an option to over or under schedule beyond the +/- 30% band in order to minimize financial risk.
- The Host State will be reimbursed by the RRF for the UI charges borne as a result of fluctuations in wind generation within the +/- 30 % band. However, it may suffer losses as a consequence RRF mechanism's design, if the wind generator

over or under schedules by more than 30%. The challenge for the Host State is that it is not in control of the variables, and thus cannot take any rational action to limit its risks or adverse impact.

The variability also has a physical impact on the Host State. The SO of the Host State will have to arrange for additional balancing power in case the wind generator chooses to over schedule in order to maximize its pay off. This will result in uncertainties during system planning and additional financial impact which has to be borne by the SO while arranging for additional balancing power.

4.2. THE SHIFTING OF PAY OFF BURDEN AS A RESULT OF THE RELATIONSHIP BETWEEN THE UI AND THE RR RATE MAY DEFEAT OBJECTIVES OF THE RRF MECHANISM

In the previous section it has been observed that under the current RRF mechanism the wind generator does not always get penalized when the Scheduled Generation disclosed by it deviates from the Actual Generation by more than +/- 30%. This occurs due to the relationship between the static RR rate and the dynamic, grid frequency linked, UI Rate. As a result, in certain cases, the host state instead of being protected from deviations beyond +/- 30% has to bear additional financial burden if it does.

The pay offs of the Wind Generator, Host State, UI Pool and the RRF Fund, before and after implementation of the RRF Mechanism has been shown in Table 3.

In Table 3 six cases, namely A, H1, H2, H3, L1 and L2, have been presented, depicting different pay off band when over or under scheduling of wind power generation occurs. Each case has three sub cases where the pay offs for each stakeholder is analyzed, for the following relationship between the UI Rate and the RR Rate:

a. UI = RR
b. UI < RR
c. UI > RR

The values of fixed factors used in the pay off calculations are as follows:

- Actual Generation: 100 units
- Contract Rate: INR 3.51/unit (Wind Power Tariff in Tamil Nadu for 2013-14)
- RR: INR 5/unit
- UI rate at 50.00 Hz to 50.02 Hz: INR 1.65/unit

Table 3: Pay off Analysis Table: Before and after implementation of the RRF Mechanism

Pay off Strategies under the RRF mechanism	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after RRF mechanism			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Case: A	UI = RR	100	5	351	-351	-	351	-351	-	-
Where; SG = AG	UI < RR	100	3	351	-351	-	351	-351	-	-
	UI > RR	100	7	351	-	-	351	-351	-	-

Pay off Strategies under the RRF mechanism	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after RRF mechanism			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
					351					
Case: H1	UI = RR	80	5	351	-251	-100	351	-251	-100	0
Where; SG: Under Scheduling within 30%	UI < RR	80	3	351	-291	-60	351	-251	-60	**-40**
	UI > RR	80	7	351	-211	-140	351	**-251**	-140	40
Case: H2	UI = RR	70	5	351	-201	-150	351	-201	-150	0
Where; SG: Under Scheduling Beyond 30% and within 50%	UI < RR	70	3	351	-261	-90	333	-201	-90	**-42**
	UI > RR	70	7	351	-141	-210	369	**-201**	-210	42
Case: H3	UI = RR	60	5	351	-151	-200	**332**	-132.4	-200	0
Where; SG: Under Scheduling Beyond 50%	UI < RR	60	3	351	-231	-120	308	-152.4	-120	**-36**
	UI > RR	60	7	351	-71	-280	356	**-112.4**	-280	36
Case: L1	UI = RR	120	5	351	-451	100	351	-451	100	0
Where; SG: Over Scheduling within 30%	UI < RR	120	3	351	-411	60	351	**-451**	60	40
	UI > RR	120	7	351	-491	140	351	-451	140	**-40**
Case: L2	UI = RR	150	5	351	-601	250	351	-601	250	0
Where; SG: Over Scheduling Beyond 30%	UI < RR	150	3	351	-501	150	361	**-601**	150	90
	UI > RR	150	7	351	-701	350	341	-601	350	**-90**

(Source: ÅF-Mercados EMI Analysis)

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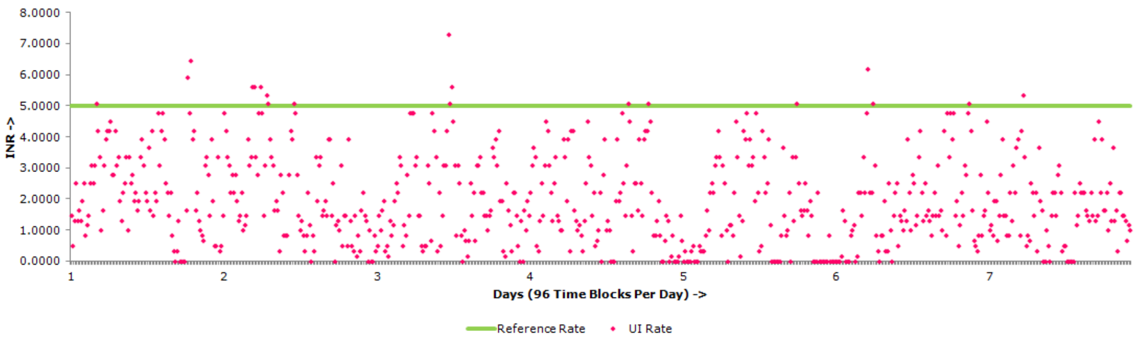
It is thus apparent from the table above that in cases such as L2 the HS pays disproportionate amounts into the UI pool and the RRF and also to the generator. In fact the payouts to the UI pool and RRF far exceeds that to the generator. Thus the unintended flows to the UI pool and RRF consequent to the risk minimization actions of the generator have enormous implications for the Host State. The intent of the system is thus defeated by design lacunae.

The actual behaviour of the generators corroborates the above analysis. The figure below demonstrates that at most times the generators in Tamil Nadu have over scheduled to avoid negative payoffs.

Figure 14: UI Rate and RR rate: Trend over a typical week (96 Time blocks per day) (15/07/2013 to 21/07/2013)



(Source: ÅF-Mercados EMI Analysis, SRPC)

In It is thus apparent from the table above that in cases such as L2 the HS pays disproportionate amounts into the UI pool and the RRF and also to the generator. In fact the payouts to the UI pool and RRF far exceeds that to the generator. Thus the unintended flows to the UI pool and RRF consequent to the risk minimization actions of the generator have enormous implications for the Host State. The intent of the system is thus defeated by design lacunae.

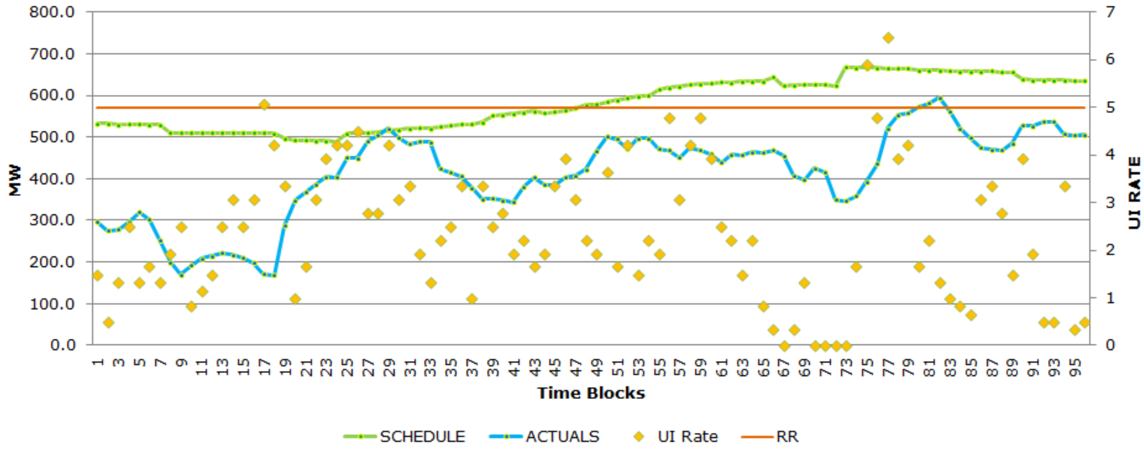
The actual behaviour of the generators corroborates the above analysis. The figure below demonstrates that at most times the generators in Tamil Nadu have over scheduled to avoid negative payoffs.

Figure 14, from real time data in the Southern Region, we observe that in a typical week (7 days) the UI rate is greater than the RR rate in less than 3% of the time blocks (a day contains 96 time blocks).

The following are the salient points that were observed from the real time data:

- Over Scheduling i.e. deviation by over -30% was recorded in **58%** of the sample time blocks. In the remaining sample time blocks i.e. **42%** of the sample time blocks the scheduled generation deviates within the +/-30% band. The scheduled generation presented by the wind generator is high and it would difficult to over generate beyond +30%. (The data used for this analysis is given in the Annexure 8.1. RRF Data for Tamil Nadu dated 15th July 2013 to 21st July 2013of this report.) A snapshot of the data is given in Figure 15.
- The changes in the Scheduled Generation are almost negligible between time blocks and also between consecutive days. This leads us to the conclusion that forecasting is not being carried out by the Wind Generators.

Figure 15: Trend line showing the difference between the SG and AG in Tamil Nadu on 15th July 2013



Source: Southern Region Power Committee

The Wind Generator, minimizing its risk, after observing the current trend of the UI rate, also leads to the following implications for the Host State and the System Operator, thus nullifying the core objectives of the RRF Mechanism.

4.3. ACCOUNTING AT A POOLING STATION LEVEL

The Regulation 4 of the CERC's *"Procedure for the Implementation of the Mechanism of Renewable Regulatory Fund"* under Regulation 6.1 (d) of *Central Electricity Regulatory Commission (Indian Electricity Grid Code), Regulations 2010* states that:

> *"4.1. Wind and solar generators shall submit a declaration clearly specifying the 'Coordinating Agency' who shall be responsible for coordinating on behalf of all the developers on issues like SCADA, metering, scheduling, UI charges, Renewable Regulatory Fund with concerned SLDC/RLDC etc. All wind and solar generators connected to the pooling station shall provide all the required support to the Coordinating Agency.*
>
> *4.5. Coordinating Agency at each Pooling Station shall provide Data Acquisition System Facility for transfer of information to the concerned SLDC/RLDC.*
>
> *4.7. **De-pooling arrangement shall be performed by the Coordinating Agency for commercial settlement including UI charges**."*

Thus, when over or under scheduling occurs at a pooling station level, it is the Coordinating Agency's responsibility to undertake de-pooling activities. Disputes with regards to de-pooling activities may occur on the method that has or would have been used for dividing the liabilities amongst the various Wind Generators (connected to the Pooling Station) when a payment has to be made by them into the RRF or to the Host State.

However, this issue is not a regulatory concern as it is determined through a purely commercial contract between the wind generator and the Coordinating Agency, in which the regulators have no role to play.

V. POSSIBLE SOLUTIONS TO THE CURRENT MECHANISM

As observed in the previous section, the RRF mechanism implemented by Central Electricity Regulatory Commission (CERC) neither:

(i) Induces the generator to schedule accurately, nor

(ii) Insulate the Host State from variations in inter-state drawals due to wind generation intermittency.

The various issues discussed in the previous section can be resolved by adopting either of two methods:

1. **Structural changes to the current mechanism:** Redesigning the RRF mechanism so that the wind generator is incentivised to schedule and remain within the +/- 30% band in order to meet the objectives of the RRF mechanism. The alternatives are based on a penalty system, in which the generator is penalized for deviating beyond the +/-30% band.
2. **Supporting Institutional Mechanism:** Developing a forecasting code in order to induce the Wind Generator to present an accurate forecasted generation and incorporate larger balancing areas to enable the System Operator to procure balancing reserves in view of fluctuations owing to the intermittent nature of wind. This has been discussed in the following sections.

5.1. ALTERNATIVE DESIGNS FOR THE RRF MECHANISM

ÅF-Mercados EMI has formulated three alternatives to the current RRF mechanism, which follows the two basic principles:

- **The wind generator is protected when the deviation from its generation schedule is within +/-30%**
- **The wind generator is penalized when the deviation from its generation schedule is beyond +/-30%**

Each mechanism has specific pay-off strategies that have been explained in the following sections. The different pay-off scenarios have also been illustrated.

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5.1.1. ALTERNATIVE MECHANISM 1

Alternative Mechanism 1 attempts to fulfil the objectives of the RRF Mechanism by imposing a fixed, pre decided, penalty on the Wind Generator when it deviates by more than +/- 30% from its schedule.

Under this mechanism five pay off cases, namely A, H1, H2, L1 and L2, have been assumed, depicting different pay off band when over or under scheduling of wind power generation occurs. Each case has three sub cases where the pay offs for each stakeholder is analyzed, for the following relationship between the UI Rate and the RR Rate:

a. UI = RR

b. UI < RR

c. UI > RR

The values of fixed factors used in the pay off calculations are as follows:

- Actual Generation: 100 units
- Contract Rate: INR 3.51/unit (Wind Power Tariff in Tamil Nadu for 2013-14)
- RR: INR 5/unit
- Penalty: INR 4.5/unit

The pay-off strategies under Alternative Mechanism 1 are given in Table 4:

Table 4: Pay-off strategies and numerical assumptions under alternative mechanism 1[6]

Pay off Strategies under AM1	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 1			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Case: A	UI = RR	100	5	351	-351	-	351	-351	-	-
Where; SG = AG	UI < RR	100	3	351	-351	-	351	-351	-	-
	UI > RR	100	7	351	-351	-	351	-351	-	-
Case: H1	UI = RR	80	5	351	-251	-100	351	-251	100	0
Where; SG: Under Scheduling within 30%	UI < RR	80	3	351	-291	-60	351	-251	-60	**-40**
	UI > RR	80	7	351	-211	-140	351	**-251**	-140	40
Case: H2	UI = RR	70	5	351	-201	-150	310.5	-201	-150	40.5
Where; SG: Under Scheduling Beyond 30%	UI < RR	70	3	351	-261	-90	310.5	-201	-90	**-20**
	UI > RR	70	7	351	-141	-210	310.5	**-201**	-210	100.5
Case: L1	UI = RR	120	5	351	-451	100	351	-451	100	0
Where; SG: Over Scheduling	UI < RR	120	3	351	-411	60	351	**-451**	60	40
	UI > RR	120	7	351	-	140	351	-	140	**40**

[6] The Pay off flows for AM 1 has been given in Annexure 8.3.

Pay off Strategies under AM1	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 1			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
within 30%					491			451		
Case: L2	UI = RR	150	5	351	-601	250	328.5	-601	250	22.5
Where; SG: Over	UI < RR	150	3	351	-501	150	328.5	-601	150	122.5
Scheduling Beyond 30%	UI > RR	150	7	351	-701	350	328.5	-601	350	-77.5

It can be observed that under this mechanism the Wind Generator will always choose to remain within the +/-30% band as it will minimize its risk and maximize its Pay-off. The adoption of this strategy fulfils the three objectives of the RRF mechanism namely:

(i) Induces the wind generator to schedule its generation as close as possible to the forecasted actual generation. The pay-offs are such designed that the generator is compelled to remain within the +/-30% band and is penalized as it goes beyond it.

(ii) The host state is insulated from the risk of the intermittent nature of wind by being adequately compensated by the RRF.

(iii) Assists the system operator in planning for optimal reserves.

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5.1.2. ALTERNATIVE MECHANISM 2

Alternative Mechanism 2 attempts to fulfil the objectives of the RRF Mechanism by imposing a penalty linked to the UI Rate only up to the UI cap Rate (so as to limit the losses to the Wind Generator) on the Wind Generator when it deviates by more than +/- 30% from its schedule.

Under this mechanism six pay off cases, namely A, H1, H2, H3, L1 and L2, have been assumed, depicting different pay off band when over or under scheduling of wind power generation occurs. Each case has three sub cases where the pay offs for each stakeholder is analyzed, for the following relationship between the UI Rate and the RR Rate:

a. UI = RR

b. UI < RR

c. UI > RR

The values of fixed factors used in the pay off calculations are as follows:

- Actual Generation: 100 units
- Contract Rate: INR 3.51/unit (Wind Power Tariff in Tamil Nadu for 2013-14)
- RR: INR 5/unit
- UI Cap rate: INR 4.5/unit
- UI50 (UI rate at 50.00 to 50.02 Hz): INR 1.65/unit

The pay-off strategies under Alternative Mechanism 2 are given in Table 5:

Table 5: Pay off strategies and assumptions under Alternative Mechanism 2[7]

Pay off Strategies under AM 2	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 2			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Case: A	UI = RR	100	5	351	-351	-	351	-351	-	-
Where; SG = AG	UI < RR	100	3	351	-351	-	351	-351	-	-
	UI > RR	100	7	351	-351	-	351	-351	-	-
Case: H1	UI = RR	80	5	351	-251	-100	351	-251	-100	0
Where; SG: Under Scheduling within 30%	UI < RR	80	3	351	-291	-60	351	-251	-60	**-40**
	UI > RR	80	7	351	-211	-140	351	**-251**	-140	40
Case: H2	UI = RR	70	5	351	-201	-150	**310.5**	-160.5	-150	0
Where; SG: Under Scheduling Beyond 30% and within 50%	UI < RR	70	3	351	-261	-90	**324**	-192	-90	**-42**
	UI > RR	70	7	351	-141	-210	**310.5**	-142.5	-210	42
Case: H3	UI = RR	60	5	351	-151	-200	**278.4**	-78	-200	0
Where; SG: Under	UI < RR	60	3	351	-231	-120	**296.4**	-122	-120	**-36**

[7] Pay off flows under AM 2 has been given in Annexure 8.4.

Pay off Strategies under AM 2	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 2			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Scheduling Beyond 50%	UI > RR	60	7	351	-71	-280	**278.4**	-4	-280	36
Case: L1	UI = RR	120	5	351	-451	100	351	-451	100	0
Where; SG:	UI < RR	120	3	351	-411	60	351	**-451**	60	40
Over Scheduling within 30%	UI > RR	120	7	351	-491	140	351	-451	140	**-40**
Case: L2	UI = RR	150	5	351	-601	250	**328.5**	-578.5	250	0
Where; SG: Over	UI < RR	150	3	351	-501	150	**336**	-576	150	**-90**
Scheduling Beyond 30%	UI > RR	150	7	351	-701	350	**328.5**	-588.5	350	90

It can be observed from the table above that under this mechanism the Wind Generator will always choose to remain within the +/-30% band as it will maximize its pay-off. The adoption of this strategy fulfils the three objectives of the RRF mechanism namely:

(i) Induce the wind generator to schedule its generation as close as possible to the forecasted actual generation. The pay-offs are such designed that the generator is compelled to remain within the +/-30% band and is penalized as it goes beyond it.

(ii) Insulate Host State from the risk of the intermittent nature of wind by being adequately compensated by the RRF.

(iii) Assist the system operator in planning for optimal reserves.

5.1.3. ALTERNATIVE MECHANISM 3

Alternative Mechanism 3 attempts to fulfil the objectives of the RRF Mechanism by imposing a penalty linked to the UI Rate on the Wind Generator when it deviates by more than +/- 30% from its schedule. The initial payment made to the Wind Generator is on the basis of Scheduled Generation in this case, and not Actual Generation as observed in the current RRF Mechanism and the other Alternative Mechanisms.

Under this mechanism five pay off cases, namely A, H1, H2, L1 and L2, have been assumed, depicting different pay off band when over or under scheduling of wind power generation occurs. Each case has three sub cases where the pay offs for each stakeholder is analyzed, for the following relationship between the UI Rate and the RR Rate:

a. UI = RR

b. UI < RR

c. UI > RR

The values of fixed factors used in the pay off calculations are as follows:

- Actual Generation: 100 units
- Contract Rate: INR 3.51/unit (Wind Power Tariff in Tamil Nadu for 2013-14)
- RR: INR 5/unit

The pay off strategies under alternative 3 are given in Table 6:

Table 6: Pay off strategies and assumptions under Alternative Mechanism 3[8]

Pay off Strategies under AM 3	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 3			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Case: A	UI = RR	100	5	351	-351	-	351	-351	-	-
Where; SG = AG	UI < RR	100	3	351	-351	-	351	-351	-	-
	UI > RR	100	7	351	-351	-	351	-351	-	-
Case: H1	UI = RR	80	5	351	-251	-100	380.8	**-280.8**	-100	0
Where; SG: Under Scheduling within 30%	UI < RR	80	3	351	-291	-60	380.8	-280.8	-60	**-40**
	UI > RR	80	7	351	-211	-140	380.8	**-280.8**	-140	40
Case: H2	UI = RR	70	5	351	-201	-150	350.7	-245.7	-150	0
Where; SG: Under Scheduling Beyond 30% and within 50%	UI < RR	70	3	351	-261	-90	350.7	-245.7	-90	**-42**
	UI > RR	70	7	351	-141	-210	350.7	**-245.7**	-210	42
Case: L1	UI = RR	120	5	351	-451	100	**321.2**	-421.2	100	0

[8] Pay off flows under AM 3 has been given in Annexure 8.5.

Pay off Strategies under AM 3	Relationship of UI with RR	Values		I. Pay- offs before RRF mechanism			II. Pay- offs after AM 3			
		Variable SG	Variable UIR	Wind Generator	Host State	UI Pool	Wind Generator	Host State	UI Pool	RRF
Where; SG: Over Scheduling within 30%	UI < RR	120	3	351	-411	60	321.2	**-421.2**	60	40
	UI > RR	120	7	351	-491	140	321.2	-421.2	140	**-40**
Case: L2	UI = RR	150	5	351	-601	250	**251.5**	-526.5	250	0
Where; SG: Over Scheduling Beyond 30%	UI < RR	150	3	351	-501	150	271.5	**-526.5**	150	90
	UI > RR	150	7	351	-701	350	231.5	-526.5	350	**-90**

It is observed from the above table that under this mechanism the Wind Generator will always choose to **under schedule within the +30% band** as this strategy maximizes its pay-off. The adoption of this strategy fulfils the three objectives of the RRF mechanism namely:

(i) Induces the wind generator to schedule its generation as close as possible to the forecasted actual generation. The pay-offs are so designed that the generator is compelled to remain within the +/-30% band and is penalized as it goes beyond it.

(ii) Insulate host state from the risk of the intermittent nature of wind by being adequately compensated by the RRF.

(iii) Assist system operator in planning for optimal reserves.

Thus the alternate mechanisms induce the generator to schedule accurately, and as a consequence limit the risks for the HS. It however must be noted that in case the generator deviates, there is a huge collateral costs for the HS, with large transfers to the UI pool and the RRF. These cannot be avoided unless the mechanism is completely redesigned. It also builds a case for the HS (and potentially even the RLDC) to run independent centralized forecasting and scheduling exercises to minimize undue transfers to the UI or the RRF.

VI. INSTITUTIONAL AND OPERATIONAL PROCESS RELATED CHANGES TO AID GRID AND MARKETS INTEGRATION OF RENEWABLES

The RRF mechanism implemented by the CERC intends to alleviate the following difficulties in grid and market integration of renewables:

(i) Induce the wind generators to schedule as close as possible to the forecasted actual generation.
(ii) Insulate the Host State from the financial burden imposed due to the variability of wind generation pattern.
(iii) Assist the system operator in planning for optimal reserves.

However, a regulatory/commercial mechanism such as RRF can be successfully implemented only if the institutional mechanisms and supporting operational processes are in place. The two essential pre-requisites for this are:

(i) A robust forecasting code
(ii) Institutional arrangements between control areas to enable better utilization of wind/land diversity and availability of flexible generation over a larger area.

The challenge can be met with improved forecasting resulting in better visibility of output and changes in market design that recognize the unique attributes of wind, solar and other variable renewable energy resources. To this end, we propose the following framework of regulatory and technical guidelines that are expected to facilitate the growth and integration of renewable energy while also securing grid reliability. The following sections discuss the following aspects in details.

6.1. FORECASTING CODE

It is a foregone conclusion through many studies and experience gained elsewhere that accurate forecasting of wind generation output is important. Although already in use by some system operators, it can still be considered a research area – because the models have to be adapted to local conditions. Accurate forecasting will allow less conservative operating strategies to be adopted.

A framework for Forecasting and Planning, proposed for implementation in India may based on the following principles:

1. The ability to develop an accurate real time production forecast for any particular wind generator strongly correlates to the availability of site specific and precise real time data.
2. The RLDC/SLDC must obtain accurate forecasts of renewable energy production to maintain reliable and efficient system operation.
3. Commercially responsive forecasting must be done at the level of sub-stations by Scheduling Coordinators or Aggregators of renewable energy.
4. Centralized forecasting must be done by the system operator also.
5. For the forecasting services availed by the RLDC/SLDC, the charges would be payable by all the wind generators.

It should be clearly understood that forecasts are made for two main reasons: (1) market scheduling, to encourage efficient competition in the wholesale market (key reason for the need for decentralized forecasting) ; and, (2) security scheduling,

including to ensure that sufficient generation capacity will be available in real time to meet demand (key reason for the need for centralized forecasting).
Proper forecasting requires both physical site data along with the meteorological and production data. The information must include:

a. The location (latitude and longitude coordinates), and elevation of each wind turbine hub height and
b. The location (latitude and longitude coordinates), and elevation of meteorological data.

To facilitate the proper transmission of meteorological and production data the following recommendations have been proposed:

1. Each Wind Generator must install and maintain equipment required by the RLDC/SLDC to support accurate power generation forecasting and the communication of such forecasts, meteorological and other needed data to the RLDC/SLDC. Communication of such data to the RLDC/SLDC will remain via the Data Processing Gateway (DPG).
2. In accordance with this requirement, the Wind Generator would install
   a. A minimum of one (1) meteorological station measuring barometric pressure, temperature, wind speed and direction that is representative of the microclimate and winds at hub height on the prevailing upstream side of the wind farm.
   b. A second meteorological station is required to measure barometric pressure, temperature, wind speed and direction. The second meteorological station may be co-located on the primary meteorological station tower. The height of the second station should be approximately [30] meters below the average hub height. This requirement will not require any Wind Generator with an existing meteorological station tower(s) or final regulatory approvals to construct a meteorological station tower(s), to modify the location or configuration of such meteorological station(s).
   c. Further, in instances where placement of the meteorological station tower(s) is in accordance with this requirement would cause a reduction in production or violation of a local, state, or central statute, regulation or ordinance, the RLDC/SLDC, in coordination with any applicable forecast service provider, will cooperate with the Wind Generator to identify an acceptable placement of the meteorological station tower.
3. RLDC/SLDC should issue directives as conditions for grid connectivity, such guidelines - which have as their objective - to ensure a dataset that adequately represents the variability in wind within the farm. It is recognized that individual Wind Generators may have circumstances that prohibit them from reasonably satisfying these requirement. In these cases, a cost-effective distribution of DTs[9]

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[9] DTs are Designated Turbines - A turbine for which nacelle wind speed is provided. A few other definitions are in order:

Average Horizontal Spacing (AHS): The average horizontal distance between a turbines and its closest neighbor.

Vertical Distance (VD): The elevation difference between the height of a turbine's base and the height of the base of another turbine

Requirement:

DTs should be selected such that each turbine within a wind farm is within a horizontal distance of 5 X AHS and a vertical distance of 75m of a DT.

that approximates this guideline and adequately measures the variability of the wind within the Wind Farm will be formulated by mutual agreement among the park owner, the RLDC/SLDC forecast service provider and the RLDC/SLDC. Wind Generators seeking a variance from this requirement should do so as part of development of their Interconnection Agreement and for those Wind Generators with an Interconnection Agreement, as part of entering into any further power sales / OA agreement.

4. It is understood that wind data collected at the nacelle will not represent the true wind value at a park, but instead will represent the apparent wind, which can be correlated to the co-located turbines. The need for this requirement is to:
   a. Ensure multiple data streams for anemometer information and;
   b. Ensure a more accurate representation of the data points to calculate wind energy production at the park
5. Each meteorological station must have a backup power source that is independent of the primary power source for the station.
6. Production and meteorological data will be collected for a minimum of sixty (60) days before the Wind Generator can be certified to be scheduled for new Wind Generators. For the existing Wind Farms, production and meteorological data will be collected regularly and submitted to the SLDC/RLDC after the enforcement of these guidelines. This data must be collected in advance in order to train the forecast models responsible for producing the power production (MW) forecast for each site.
7. A centralised forecast by the SLDC/RLDC would need information about the power curve for each wind farm. This could take the form of historical meteorological information from an on-site mast, which can then be compared with historical output (and historical turbine availability) to form a power curve. The power curve is likely to be different for different wind directions, and may also require an adjustment for barometric pressure.
8. The SLDC/RLDC shall receive real time information about wind turbine availability. Intermittent generators must provide to the SLDC/RLDC, at least once every 8 seconds, the maximum output capacity of the wind farm (the number of connected generating units multiplied by the MW capability of each turbine). However, a high quality centralised forecast would need to obtain additional information about future intentions with respect to turbine availability. It would also require information about any intentions to spill wind (other than in response to a dispatch instruction).

The points mentioned above along with the centralized and decentralized planning plays a pivotal role in integrating the intermittent generation by improving the forecasts provided by the wind farms.

6.1.1. DECENTRALIZED AND CENTRALIZED FORECASTING AND PLANNING

The system operator’s focus is on the need for a security forecast. In our view, adequate security forecasts with associated error and correlation estimates will not be

In addition to the wind information from the DT, the real time production power data will be required. The DT must be capable of sending the wind and power information to the SLDC/RLDC via DPG along with data received from the meteorological tower(s) and MW production data.

able to be produced with sufficient certainty simply by aggregating every wind farm's market forecast. Consequently, the system operator will need to provide a separate, centralised security forecast. In practice, this centralised forecast is likely to be based on an ensemble forecasting approach that uses and adds value to the information in the decentralised market forecasts. The intent of considering both the centralised and the decentralised approach is to best combine the two to achieve the objectives of both market and security forecasting.

1. Decentralised wind generation forecasting means that each wind farm is responsible for forecasting its own generation over the schedule period as an input into schedules submitted to the system operator.
2. Under a centralised regime, system operator (SLDC/RLC) is responsible for forecasting generation from each wind farm for market schedules.
3. RLDC/SLDC shall be appointed to govern the central forecast. An alternative would be for the Commission (or the Central Electricity Authority) to establish a separate service provider role.
   i. It is proposed that NLDC takes up the job because
      a. The system operator has important internal uses for a centralised forecast. The learning process, and the process of developing the centralised forecast would be enhanced by the close involvement of the system operator; and
      b. The system operator is the organisation that has the most detailed knowledge of the needs of the industry as a whole in terms of scheduling information, and is the party responsible for preparing schedules.
4. Wind farm generation forecasts, individually or collectively, are not available to other participants. Instead these forecasts will feed into "schedules".
5. Schedules provide information to participants about scheduled (projected) quantities, and about the scheduled price at each point on the grid.
6. Day ahead and intra-day forecasts will be submitted by either the scheduling coordinator(s) responsible for delivering power at 33 kV and above sub-stations or by the generator itself. Further, any 10 MW of above wind generator may also submit its forecast to SLDC/RLDC directly.[10]
7. Centralized forecasting allows for consistent and accurate forecasts. Standardized data would be submitted to a centralized forecaster for each renewable generator. The central forecaster can then compile this data and use it to create a forecast.
8. This will also be accomplished through decentralized forecasting and very specific market rules that would specify form, format and accuracy requirements for each individual forecast. This would require forecasts to be submitted for each generator (embedded and non-embedded).
9. Rules may be required to set limits on the ownership rights of the central body; for example it might not be appropriate for the central body to sell the data to an entrepreneur who is considering the construction of a wind farm next door to the other wind farm. Requiring wind farms to provide meteorological data might also give rise to a question of whether a wind farm should be required to build a met tower on site, where exactly on the site the met tower should be located, and whether small wind farms should be exempt from these requirements. This might

[10] The idea is that each wind generators should also take a direct commercial responsibility of its own forecasts. If owners of wind farms realize that individually they cannot get reasonably accurate forecasts, it may make sense to for them to take combine with other wind generators and approach wind forecast.

give rise to some regulatory complexity, although the complexity would appear to be manageable.

10. There can be a number of stages in the forecasting process. Stages might include the running of one or more Numerical Wind Prediction (NWP) models, the post-processing of the results of the NWP model output to get meteorological forecasts at the relevant wind farm site, and the conversion of the meteorological forecasts into MW forecasts using information about turbine availability, intended wind spill and electrical losses etc. Forecasting regime shall use a centralised approach for some of these stages while other stages remain decentralised. For example, it would be possible for a central body to contract with a service provider for site specific meteorological forecasts, but for wind generators to be responsible for creating their own offers (in MWs) based on the information from the central meteorological forecast.
11. Instead of doing their own forecasts, in certain cases wind farms may submit decentralised forecasts that are informed by the centralised forecast. A centralised forecast is prepared including a forecast for each wind farm, and each wind farm receives its own forecast. The wind farm can simply submit the centralised forecast number as its own forecast, or it can submit a revised forecast. There are usually direct monetary implications associated with the forecast, providing an incentive to the wind farm to improve the forecast if it can. The incentive arises from the lower UI burden (or a lower allocation of Frequency Support Ancillary Services Costs, when Ancillary Services Mechanisms are developed) (better forecasting would reduce the wind farm's share of those costs).

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6.2. LARGER BALANCING AREAS

Larger Balancing Areas facilitate easy integration of the wind power into the system by taking advantage of the natural diversity of the variable resources. Spreading of wind power over a large geographical area reduces variability, increases predictability and reduces the occasions of near-zero or peak output. Given that the conventional generators are not fully reliable, if a part of the total generation comes from variable sources, the loss or gain in generation can be made up through primary/secondary/tertiary control of grid frequency.

The integration of wind into the electrical system depends upon the size of the balancing area. The SLDC is responsible to manage the imbalances at the state level. However, in certain situations the interchanges cannot be managed locally and require the intervention of RLDC. For example, the peak load in Tamil Nadu in July is in the rage of 11500 MW. For a deviation beyond 150 MW, the state would be penalized under the draft regulations. Given that the installed capacity in the state is more than 7000 MW with the highest instantaneous wind generation being 4500 MW for the year, it is highly probable that such deviation would take place in the state. It is not uncommon for the state to lose around 1000 MW of wind within an hour. Given such a situation, the state would be requiring a flexible capacity of about 700 MW in order to manage variability and avoid the penalty. This becomes all the more necessary in the view of RRF as only 14% of the wind farms are under its purview (commissioning after 3rd May 2010). If Andhra Pradesh has surplus balancing reserves it can provide to Tamil Nadu. However, what incentive does Andhra Pradesh have to provide reserves to Tamil Nadu? Situations like these call for the need of enhanced balancing areas. With this, the procurement of flexible generation will be made available and the cost of balancing will reduce subsequently.

Studies undertaken by us highlight the above mentioned point. The high wind month of June for the years 2012, 2014, 2016 and 2022 for Tamil Nadu and SR (including Tamil Nadu, Andhra Pradesh and Karnataka) has been considered and the penetration level has been defined at the instant when maximum wind capacity is available as a percentage of demand (in MW) in the corresponding system.

The balancing costs have been computed by considering three distinct types of markets two of which are currently operational in India:

1. Day-ahead markets that clear the day before power is provided (currently operational);
2. Intraday markets that allow for adjustments after the closure of the day-ahead market until gate-closure (currently operational, but has very low volumes), typically about three hours before real time; and
3. Ancillary services markets that are used by the system operator to resolve remaining imbalances (currently not operational, and in proposal stage).

Procurement of balancing energy/capacity in each of the above markets presents three cases – each of which has different policy implications. The assumptions for the analysis are given in the Appendix 1.

The three cases considered are:

Case 1: 100% of the capacity required to provide positive balancing energy is procured through capacities designated for balancing and remain available for a "call" for generation from the system operator. Such capacities are normally procured through the **Ancillary Services Markets**;

Case 2: 50% of the capacity required for positive balancing energy is procured through Ancillary Services Market and 50% from the intra-day/day ahead energy market;

Case 3: 100% of the positive balancing energy is procured through the energy market – intraday and day ahead.

Table 7 provides the balancing costs in the three cases:

Table 7: Balancing Costs

Maximum Volatility of VRE generation (High Wind Season)										
Year	Tamil Nadu					Southern Region				
	Penetrati	Balancing Capacity (MW)	Balancing Cost (Rs/kWh)			Penetrati	Balancing Capacity (MW)	Balancing Cost (Rs/kWh)		
			Case 1	Case 2	Case 3			Case 1	Case 2	Case 3
2012	34%	624	0.68	0.44	0.21	18%	334	0.3	0.2	0.11
2014	39%	835	0.72	0.48	0.23	22%	798	0.43	0.27	0.12
2016	45%	1126	0.78	0.53	0.28	27%	1112	0.44	0.28	0.13
2022	55%	2533	1.2	0.89	0.58	35%	2465	0.51	0.32	0.14

Following inferences can be drawn from the above table:

1. With increase in penetration of wind energy:
   - The balancing costs increase
   - The balancing capacity requirement increases
2. With larger control areas (when SR is considered as a single area within which balancing resources are available)
   - The balancing cost declines
   - The balancing capacity decreases

The above analysis though indicative, is instructive for policy purposes. In the Indian context, this gains importance since Electricity is on the concurrent list. Creation of larger balancing areas aids the system operator by providing it access to available resources in the neighbouring control areas. Larger control areas can be created by:

(a) Consolidating balancing areas into larger entities,
(b) Accessing a larger balancing area through the use of dynamic scheduling, or
(c) Implementing shared area control error or energy imbalances among multiple control areas act to facilitate the integration of larger amounts of wind into the system.

There are key technical prerequisites for operationalization of large control areas in India:

1. An SLDC may contract Primary Reserve in a neighboring control area or inside a control block (region). Contracts for providing this service may be signed as SLDC-SLDC or as SLDC-Genco. This implies that an agreement between the concerned SLDCs has been signed, e.g. concerning the setting of the B-factors[11] on the Secondary Controller. The "SLDC-Forum" will perform simulations to check the consequences for the overall system security on an annual basis. As a result, ultimate limits can be given to individual SLDCs.

[11] A value given in megawatts per Hertz (MW/Hz) for a SLDC control area / Region that defines the frequency bias of that Control Area for Secondary Control (dependency between system frequency and deviation from power exchanges due to expected Primary Control Activation in this Control Area / Region)

   a. This implies that all SLDCs will have SCADA and AGC controls fully operational
   b. All the generators (or atleast those designated or those who choose) to provide primary, secondary and tertiary reserves would be required to operate in FGMO mode and have real time communication with SLDCs
2. "SLDC-forum" will need to set out the following rules. Inter-State tertiary control reserve can be provided subject to following pre-requisites:
   a. **Fixed Share of Reserves inside the Control Area:** A fixed share of pre-ddetermined percentage of the total needed secondary control reserve and tertiary control reserve must be kept inside the Control Area.
   b. **Transmission Capacity:** Sufficient transmission capacity must be allocated between the reserve receiving SLDC and the reserve providing SLDC. In case one or more reserve transiting SLDCs/RLDCs are involved, transmission capacities across all the borders must be available.
   c. **Directly Activated Reserve:** In the case of directly activated tertiary control reserve only "direct activation of power by the reserve receiving SLDC and transfer of measurement value" or "power request by the reserve receiving SLDC through the reserve providing SLDC" could be allowed as technical realizations.
   d. **Schedule Activated Reserve:** In the case of schedule activated tertiary control reserve only "direct activation of power by the reserve receiving SLDC and transfer by pre-decided electricity exchange schedule" or "power request by the reserve receiving SLDC through the reserve providing SLDC" could be allowed as technical realizations.
   e. **Data Exchange and Checking:** A day-ahead data exchange about contracted reserves must be set up between the bidders and both the reserve providing SLDC and the reserve receiving SLDC. The reserve providing SLDC has to check consistency on the basis of the available information.
3. Legal Framework: SLDCs / RLDCs need to be legally allowed to procure electricity on behalf of the constituents.

The various alternatives for procuring flexible generation are discussed in the following sub sections.

6.2.1. Designated Resources With Centralized Control

In this case the dispatch and scheduling control of the designated generators is handed over to the RLDCs who monitor the Area Control Error of each region and utilize the generators to minimize the Regional Control Error. The states designate primary, secondary and tertiary control reserves; as one takes over, the other is relieved.

Primary Control Reserve: This requires generators which are capable of sensing grid frequency and are capable of operating in free governor mode operation. However, given the frequency range in India, the generators might resist FGMO until they are adequately compensated for deterioration in heat rate and increase in life cycle cost.

Secondary Control Reserve: This requires the power plants to be available between 30 seconds-15 minutes. The service can be provided by gas engines/turbines, which can ramp up to approximately 6% of their capacity per minute and are operating at about 70%. Similar service can be provided by pumped storage hydro.

Tertiary Control Reserve: The service is provided by generators that can minimize UI drawals by the state. In Tamil Nadu it is being provided by Kadamparai hydro power plant while in Maharashtra by Koyna hydro power plant.

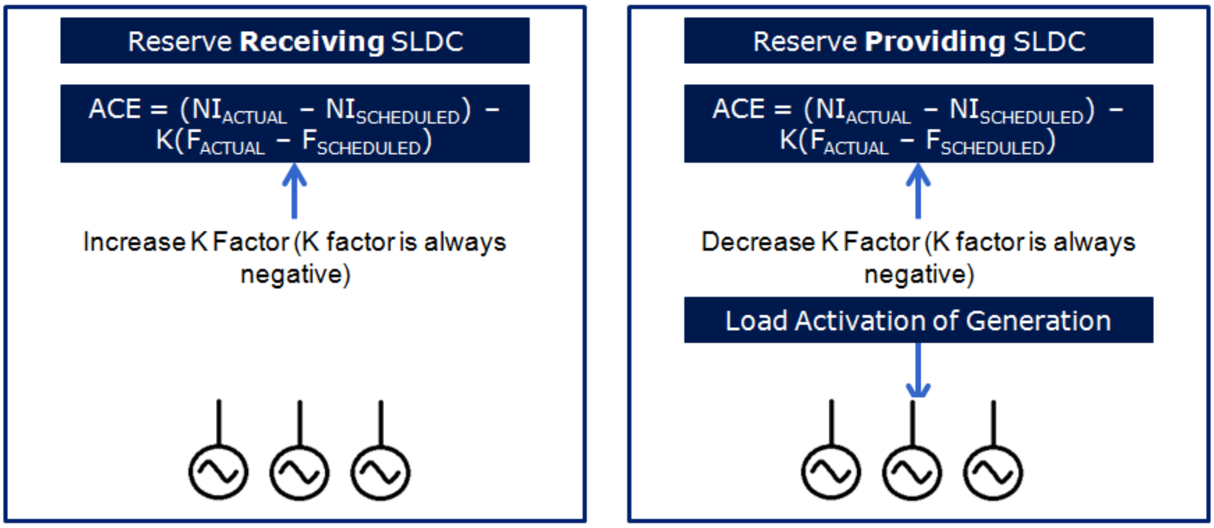
The SLDCs are responsible for the dispatch of all conventional generation and demand in their states. While the dispatch control of VRE generators and primary, secondary and tertiary reserves rests with the RLDCs. The UI of the states is managed by the Deviation Settlement Mechanism while the RLDC will be responsible for maintaining the regional control errors within limits. However, this mechanism may not be practical to implement as the system operator balances net load after duly taking into account the impact of variable generation and demand.

6.2.2. Designated Resources With Pluralistic Control

Designated resource is dispatched by the controlling SLDC. The service providing SLDC incorporates some or all of the other Control Areas tie lines into its own AGC/ACE equation. This arrangement would require contractual agreements between various frequency control services.

Processes and Contracts for Primary Frequency and Services

Figure 16: Designated Resources with Pluralistic Control - Primary Control



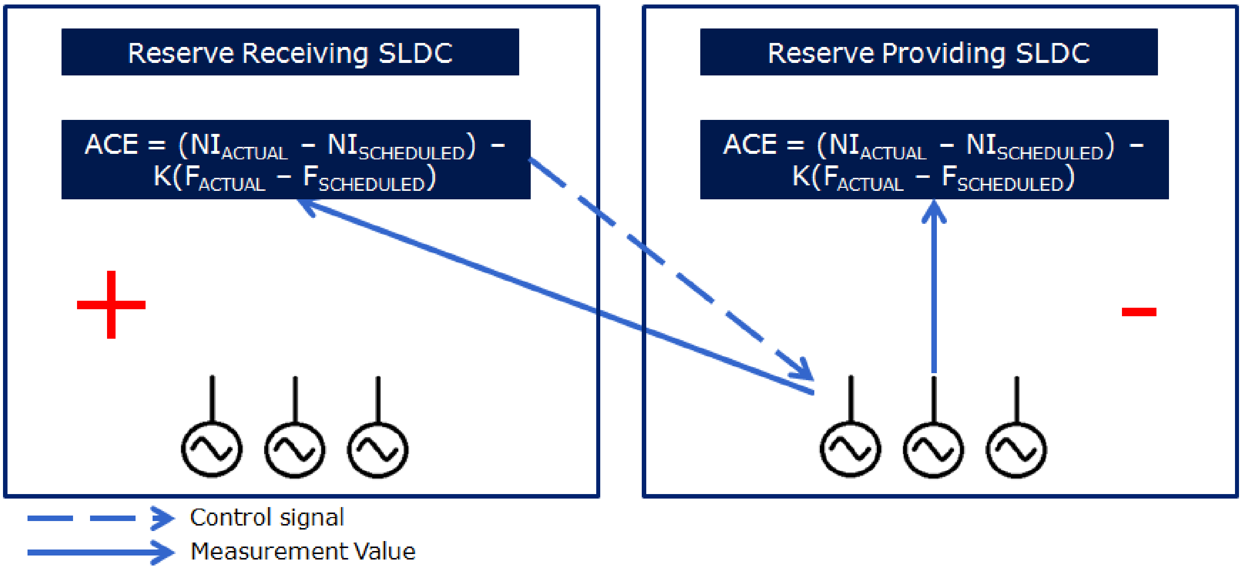
In this arrangement a SLDC may contract the primary reserves available in the neighbourhood control area. The contracts can be signed between the SLDCs or SLDC-Genco, which for example, may concern with the setting of the K-factors on the Secondary Controller. The SLDC forum performs simulations on an annual basis to check the overall system security. Trading of primary reserves requires the adaptation of default setting. The rate at which the reserve receiving SLDC pays to the reserve providing SLDC is regulated by the Central Commission.

Processes and Contracts for Secondary Frequency and Services

ALTERNATIVE 1: Control of Generation Unit by Reserve Receiving SLDC and delivery of the activated Reserve by Measurement Value from Generation Unit

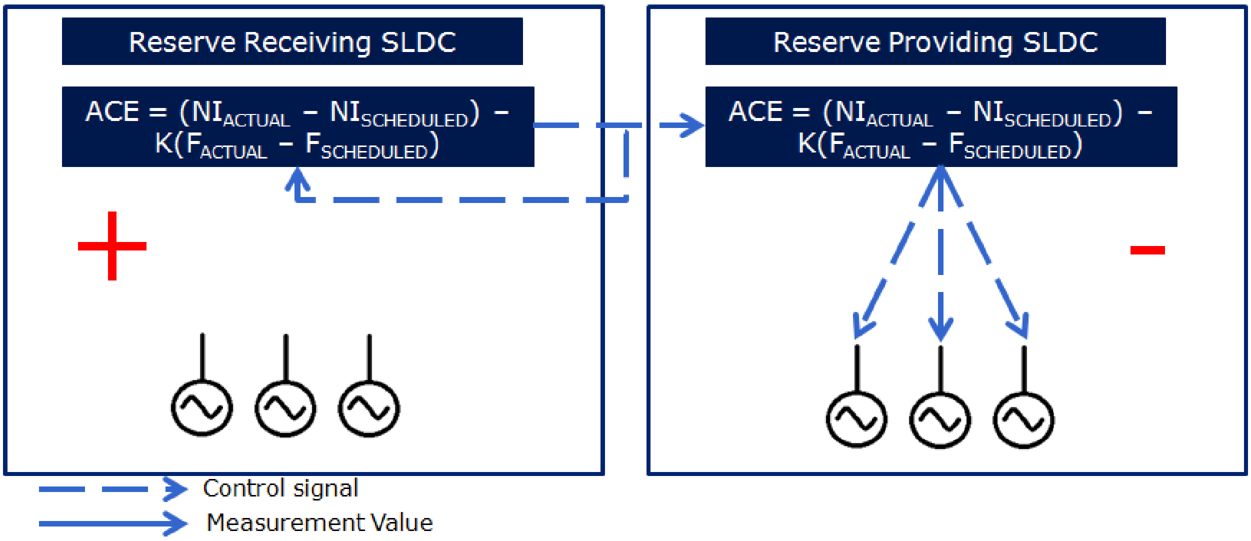
In this case the reserve receiving SLDC sends its request for power directly to the generating unit located in the neighbourhood control area. Adaptation of the secondary controllers of both reserve receiving and providing SLDC is done using the measurement value. This arrangement requires the introduction of the concept of virtual tie-lines connecting the generation unit in the reserve providing SLDC to the control area of the reserve receiving SLDC.

Figure 17: Designated Resources with Pluralistic Control : Secondary Control - Alternative 1



<u>ALTERNATIVE 2:</u> Control by Reserve Receiving SLDC through the Reserve Providing SLDC

Figure 18: Designated Resources with Pluralistic Control: Secondary Control - Alternative 2



Under this arrangement, the reserve receiving SLDC contracts the generators in other control areas through the reserve providing SLDCs.

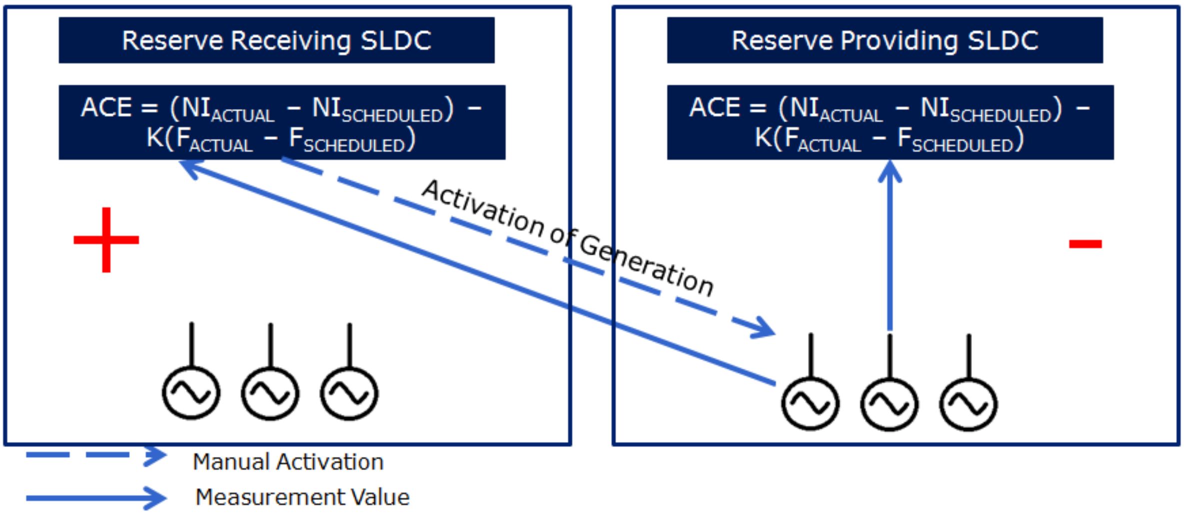
Under both the alternatives, it is important for the system operators (SLDC/RLDC) to take into account the expected capability of total generation and load in the Control Area/Region or generation reserves contracted through inter-state agreements/contracts to follow changes in the electricity exchange programs.

Creation of inter-state secondary reserves requires approval of all the involved SLDC/RLDC along with the declaration of the amount and time of the inter-state Secondary Control Reserve by all the involved SLDC/RLDC. The involved parties need to adhere to their responsibilities for the effective working of Secondary Control Reserves.

Processes and Contracts for Tertiary Frequency and Services

ALTERNATIVE 1: Direct Activation of the Generation Unit by the Reserve Receiving SLDC and Delivery of the activated Reserve by Measurement Value

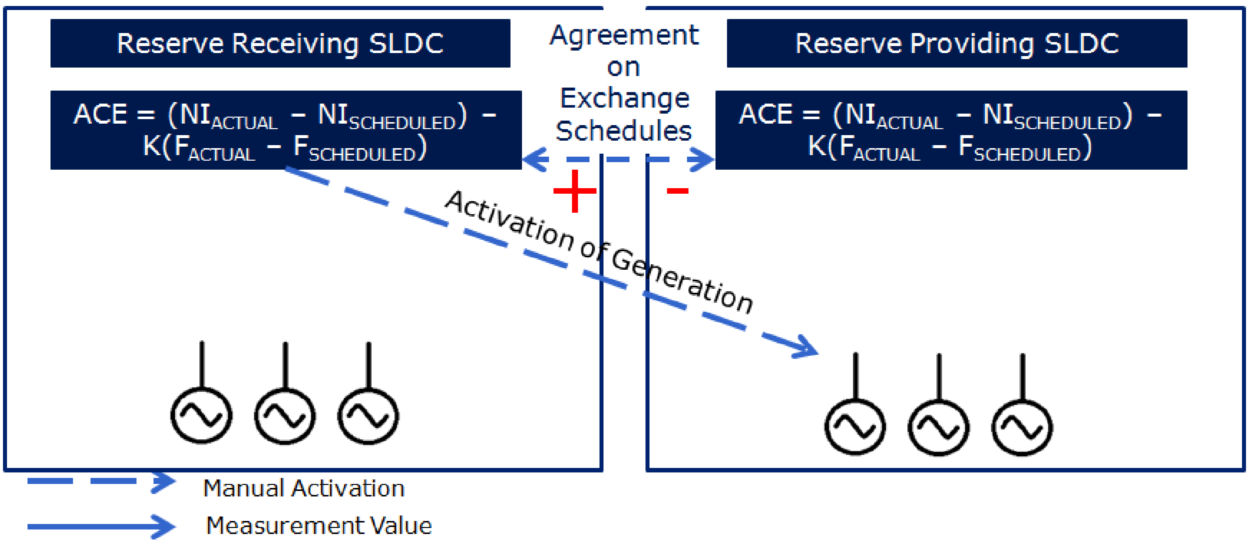
Figure 19: Designated Resources with Pluralistic Control : Tertiary Control - Alternative 1



The activation signal is sent by the reserve receiving SLDC directly to the generation unit or load with which tertiary control reserve was contracted. The on–line measurement value of active power is sent from the generation unit or load back to the secondary control of both the reserve receiving SLDC and the reserve providing SLDC. If the generation unit or load produces according to an underlying schedule additional to tertiary control reserve the schedule has to be subtracted from the measurement value accordingly.

ALTERNATIVE 2: Direct Activation of the Generation Unit by the Reserve Receiving SLDC and Delivery by electricity exchange Schedule.

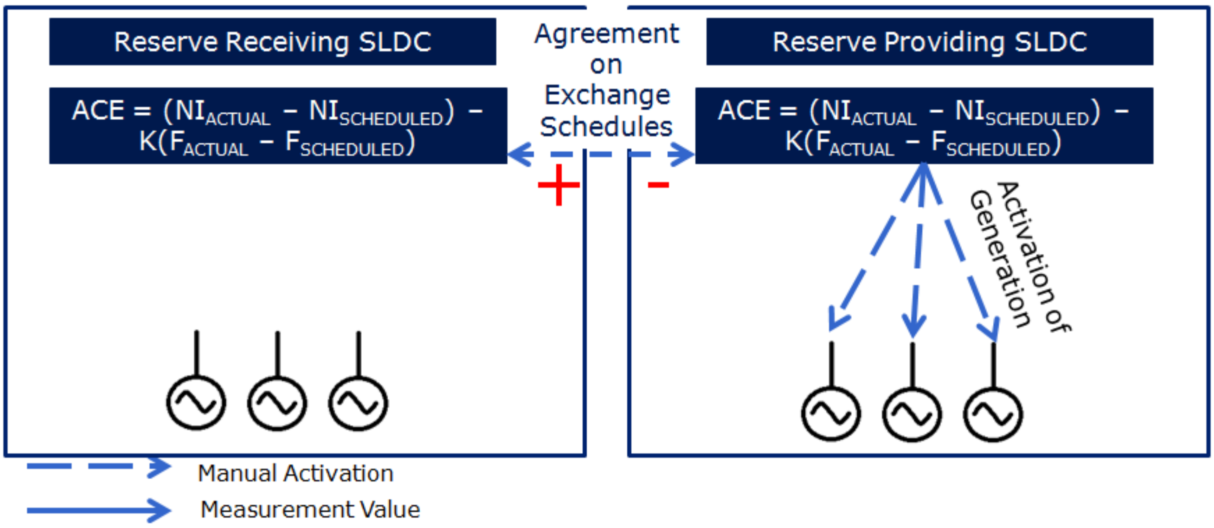
Figure 20: Designated Resources with Pluralistic Control : Tertiary Control - Alternative 2



The activation signal is sent by the reserve receiving SLDC directly to the generation unit. The electricity exchange schedule regarding inter-state tertiary control reserves, agreed between the reserve receiving SLDC, the reserve providing SLDC and the generation unit, is used to adapt the secondary control of both the reserve receiving and reserve providing SLDC.

ALTERNATIVE 3: Power Request by the Reserve Receiving SLDC through the Reserve Providing SLDC

Figure 21: Designated Resources with Pluralistic Control : Tertiary Control - Alternative 3



The reserve providing SLDC provides tertiary control reserve to the reserve receiving SLDC. In this case the reserve receiving SLDC has to agree with the reserve providing SLDC on an electricity exchange schedule, which will be used to adapt the Area Control Error of both the reserve receiving SLDC and the reserve providing SLDC. The reserve providing SLDC activates the generation from either a set of units contracted by the reserve receiving SLDC or from a set of units contracted by the reserve providing SLDC itself.

The facilitation of inter-state tertiary control reserve services requires certain prerequisites. Sufficient transmission capacity should be allocated between the reserve receiving and providing SLDC and a fixed percentage of total needed secondary and tertiary control reserves must be kept inside the control area. In the case of directly activated tertiary control reserve only "direct activation of power by the reserve receiving SLDC and transfer by measurement value" or "power request by the reserve receiving SLDC through the reserve providing SLDC" are allowed as technical realizations. In the case of schedule activated tertiary control reserve only "direct activation of power by the reserve receiving SLDC and transfer by pre-decided electricity exchange schedule" or "power request by the reserve receiving SLDC through the reserve providing SLDC" are allowed as technical realizations. The consistency of the data has to be checked regularly by the SLDCs on the basis of the available information.

6.2.3. Hierarchical Control With Ancillary Services Market

Hierarchical control is performed in a decentralized way with more than one control area. A single System Operator (the RLDC), operates the superposed regional controller, which directly influences the subordinate secondary controllers of all SLDCs of the region. The RLDC may or may not have regulating capacity on its own.

Processes and Control for procurement of Primary Frequency Reserve

The primary frequency reserves need to be well distributed over the network. Along with the SLDCs, the RLDCs can also procure primary frequency control reserve services from inter-state generators which are in their jurisdiction. It is argued that the generators should provide primary frequency reserves since their fixed costs are mostly recovered. However, this task has not been easy as most generators still do not operate in FGMO/RGMO despite regulatory requirements. An alternative for such procurement can be done through a market which requires close coordination between the SLDCs, DISCOMs and the power purchase coordination cells. Similarly, at the regional level, RLDCs could collaborate with the RPCs (which comprise state functionaries), to determine the "frequency responsive reserve" requirement and the constituent states can procure the volumes required in the market. The delivery of these reserves has to be made within 30 seconds of the disturbance. The creation of a frequency responsive market would obviate the need for FGMO as well.

Processes and Controls for procurement of Secondary Frequency Reserve

Under this arrangement, the RLDC gets the signal from receiving SLDC. The information for dispatch is issued to participating generators connected in the control area of the RLDC and also any participating SLDC with surplus secondary reserves. The RLDC is required to maintain Block Control Error (BCE) within the limits prescribed by the regulator and it may procure (through appropriate state agencies), secondary reserves in the intraday or day ahead market. Each SLDC is also responsible for maintaining its ACE within prescribed limits.

Figure 22: Hierarchical Control with Ancillary Services Market: Secondary Control

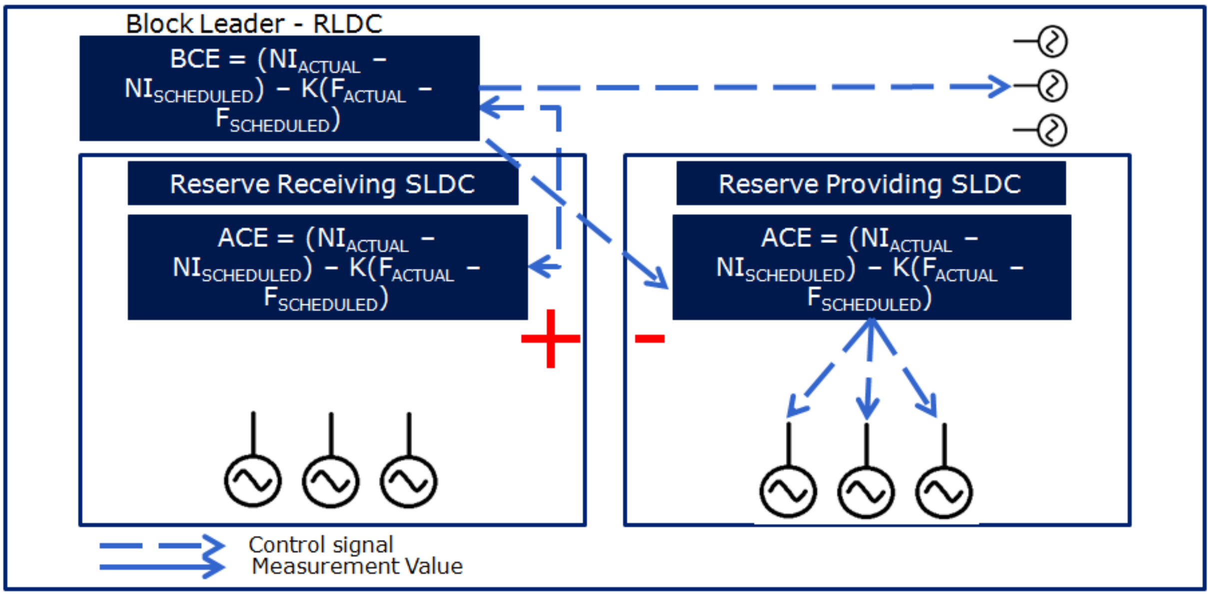


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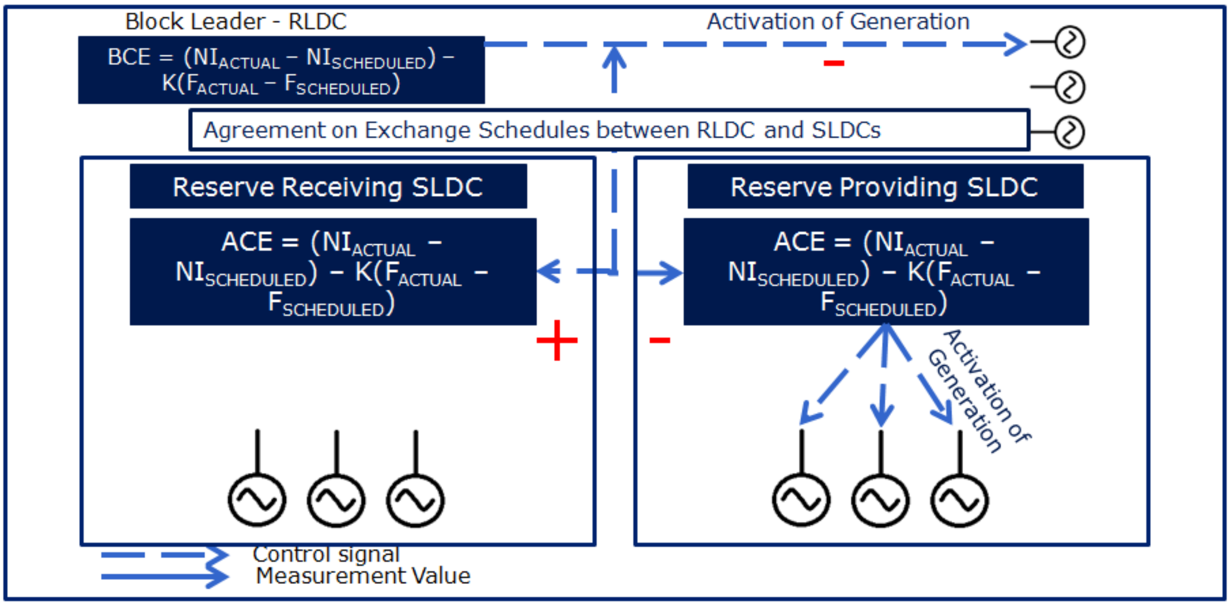
Figure 23: Hierarchical Control with Ancillary Services Market: Tertiary Control



The RLDC provides tertiary control reserve to the reserve receiving SLDC. In this case the reserve receiving SLDC has to agree with the RLDC on an electricity exchange schedule, which is used to adapt the Area Control Error of both the reserve receiving SLDC, RLDC and the reserve providing SLDC (if the State is selected to provide tertiary ancillary service). The RLDC activates the generation from either a set of units contracted through the ancillary services market or from a set of units contracted by the reserve providing SLDC, if the state is selected to provide the service.

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VII. CONCLUSIONS

The Renewable Regulatory Fund introduced by the Central Electricity Regulatory Commission is intended to induce the wind generators to forecast and schedule. The requirement of submission of good quality forecasts by these generators aids the System Operator in planning reserves for the system and in dispatching generation reserves and demand. Another important objective of RRF is to reduce the commercial burden of uncertainties due to VRE generation on the state utilities. Several amendments have been made to the Indian Electricity Grid Code in order to implement the RRF mechanism. These amendments require the wind generators to forecast and schedule.

The analysis of the RRF mechanis`m in the report brings out the following points:

- Under the current mechanism of RRF, there is minimal incentive for the wind generators to schedule.
- Alternatively, there are windfall gains for the wind generators, which could be predicted ex-ante from the current design of the mechanism. This has been substantiated through field data from Tamil Nadu.
- The Host States, like Tamil Nadu, are likely to be adversely affected.
- System operator has to undertake the task of planning for balancing reserves owing to the intermittent nature of wind. With the wind generator not forecasting and scheduling properly, the system operator is at risk while preparing for adequate balancing reserves.

The mechanism, therefore, does not meet the objectives for which it was proposed. Alternative mechanisms that can be introduced to make the mechanism effective has been proposed in the report. The alternatives are based on the requirement that while the wind generators remain protected within +/- 30% band around their scheduled generation, their payoffs decline beyond this band (on either side) irrespective of the real time realizations of UI.

It is also recognised, that RRF is a commercial arrangement, and thus its utility addressing the VRE challenge is limited. The mechanism has to be backed by institutional changes and these also have been discussed at length in the report. There also a need to strengthen the amendments made to the Indian Electricity Grid Code through introduction of **a robust forecasting code**, which has been discussed briefly in this report. More importantly, **amendments have to be made in the State Electricity Grid Codes because most of the wind generators are interconnected in the state network**.

Given the issues with the design of the RRF mechanism it may be worthwhile to have the IEGC and the State Grid Codes mandate forecasting without application of penalties for a period of time (say 2 years). Penalties could however be applied if the generators do not establish forecasting systems or do not communicate its forecasts and actual generation data to the SO. Once the data regime and the practices on forecasting as per the forecasting code are established, the scheduling process will be greatly improved. In other words, data discovery in this case has to be accorded greater primacy over penalization for deviation from schedules till there is greater understanding and maturity. Similar mechanism designs are also practiced in ERCOT and MISO in the United States

Our report suggests alternative institutional mechanisms like **creation of larger control areas** and how these could function in the Indian set-up, with electricity being on the concurrent list. Larger control areas can aid the system operator by providing access to balancing reserves spread over a bigger control area if adequate reserves are not available within its own control area. This gains importance in the Indian context as most of the wind generators are in the control area of the state.

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VIII. ANNEXURE

8.1. RRF DATA FOR TAMIL NADU DATED 15TH JULY 2013 TO 21ST JULY 2013

The real time data used for the analysis carried out in section III.1. has been given in the excel sheet attached below.

Source: Southern Region Power Committee

8.2. APPENDIX FOR LARGER BALANCING AREAS

Assumptions in Computation of Balancing Costs and their Rationale

Balancing services are currently not provided by system operator in India. The grid connected entities (State Distribution Utilities, Generators) are required to remain committed to their schedules or pay Unscheduled Interchange (UI) charges for deviation from their schedules. The UI mechanism is therefore a commercial mechanism for balancing.

Balancing, in more developed power systems with very low/zero wind/solar generators, is only necessary for events of small probabilities (power station failures) or for small volumes (as in the case of load prediction errors); the amount of reserve capacity contracted is thus large compared to the small share of actual electricity requested. Balancing services were provided nationally, or in the case of Germany, within the region of the Transmission System Operator. In recent years, globally, renewable energy and newly installed wind power have prompted additional demand for reserve and response operations. This demand arose predominantly due to the inadequate levels of accuracy in day-ahead forecasts for renewable feed-ins. These characteristics of balancing markets cause us to make the following assumption in our determination of balancing costs:

Assumption 1: Currently there is a considerable shortage both in Tamil Nadu and Southern Region Grid which .

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Figure 24: Load shedding in Tamil Nadu

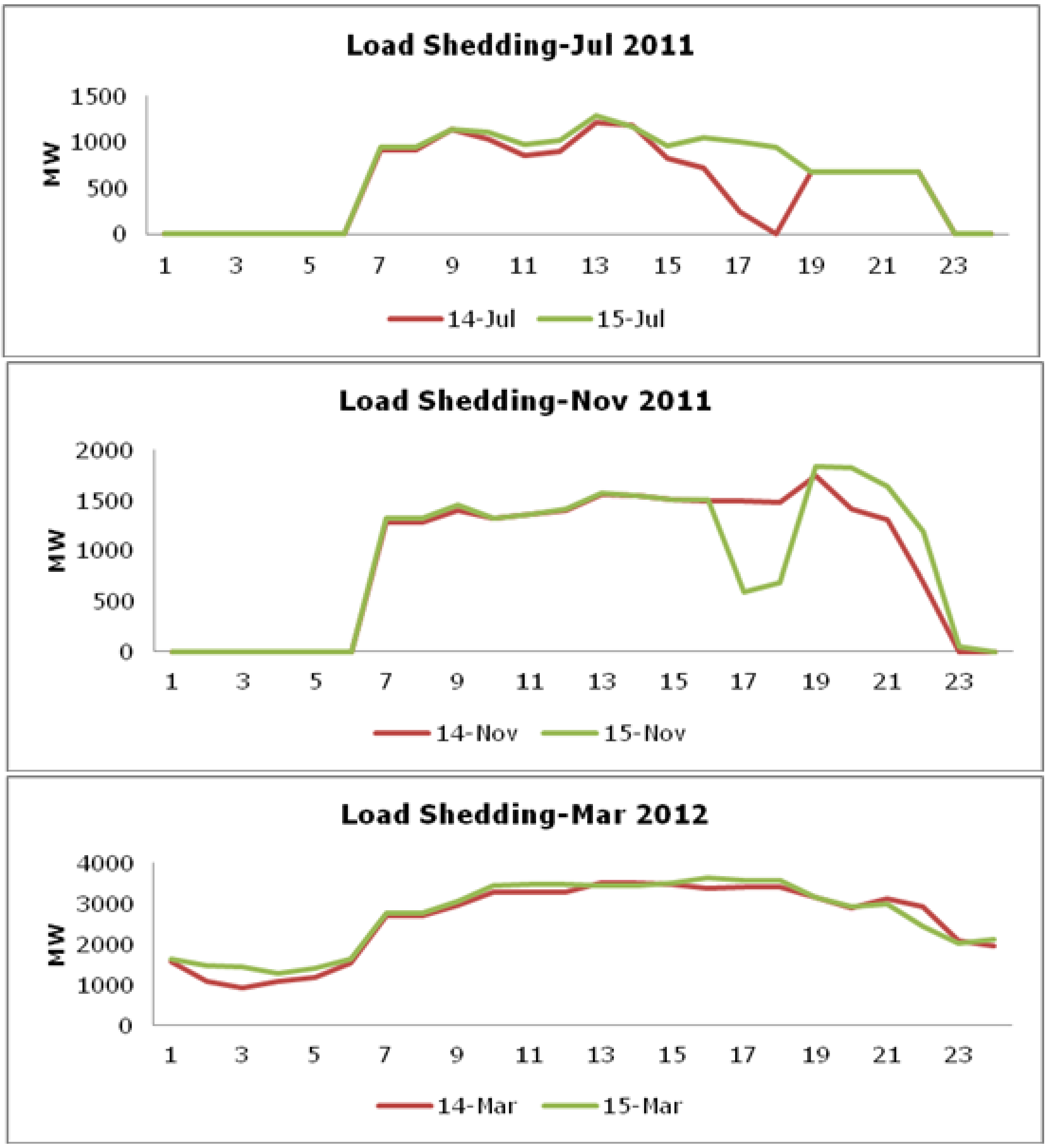

Figure 24, above indicates load shedding between 3000-4000 MW in March. This entire shortfall cannot be considered as procured in "Balancing Market". Therefore, we determine the capacity that Tamil Nadu and other states in SR need to procure through mechanisms other than "balancing mechanisms/markets". **Therefore the "balancing capacity" and "balancing energy" requirements are computed with respect to Coal Based Capacity + CCGT Capacity + Nuclear Capacity + Hydro (Storage) Capacity + Capacity procured through mechanisms/markets other than balancing mechanisms/markets.**

Many generation assets can only adjust their output close to real-time, if they are already operating (nuclear, lignite, coal, and certain gas power plants). Only the plants that are operating can provide negative balancing reserve, while these plants have to operate in part-load to be able to provide positive balancing power. Moreover, a power plant is only willing to decrease its energy sales to provide reserve capacities for balancing markets if the expected price it gets for actually providing those reserves is able to compensate for the foregone margin (price minus marginal cost) in the energy market. Adjustable capacity is therefore highly dependent on the commitment of conventional generation units as part of energy sales in day-ahead and longer-term markets and the ability to adapt this day-ahead commitment to the changes in the market within the last 24h before physical dispatch.

Assumption 2: When Tamil Nadu SLDC is required to manage wind, with "visibility" only on generation resources within its control area, it can require such generators to provide negative balancing power or reduce level of generation when wind generation suddenly increases. Since such generators were initially designed to serve base load and have limited flexibility, low ramping down rates have been considered – as a conservative assumption. For Tamil Nadu, as a whole, it is assumed that no more than 20% of the maximum operating capacity can be reduced in an hour. Further, no thermal generator has been constrained to not operate below 60% of the maximum capacity, unless the system is left with no alternative. In such instances hydro generators reduce their generation. Similar operational assumptions have been made when SR is considered as a whole.

Assumption 3: All thermal generators in Tamil Nadu which are owned by TANGEDCO are assumed to be not charging any amount for ramping down or ramping up – unless they are required to ramp below 60% of their maximum capacity. Actually the model allows the system operator to minimize costs of operation and select whether it is more economical for a generator to continue to generate and inject excess power into the grid or reduce its generation below 60% at a higher per unit cost. Further, as recognized in this document elsewhere that cycling of generators imposes costs on the generators – these have not been considered in this analysis.

Assumption 4: The Transmission Network has been considered as presenting no constraints. As discussed elsewhere in this document – transmission capacity addition and its costs have been estimated in a parallel study being conducted by Power Grid Corporation of India Limited.

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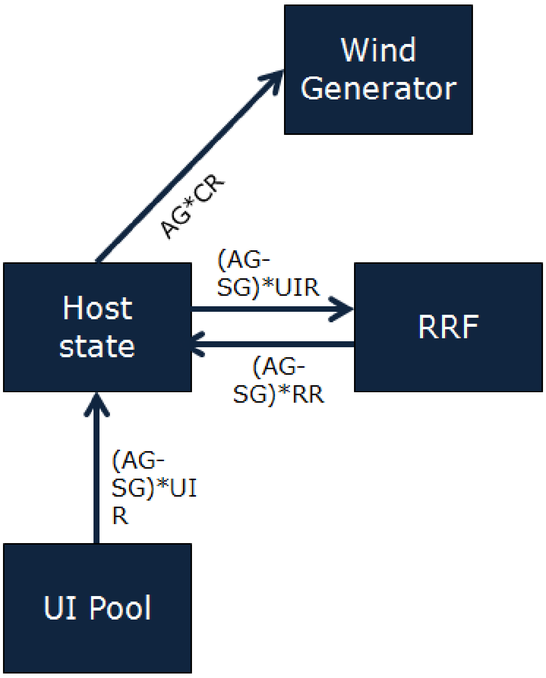
8.3. PAY OFF FLOWS UNDER ALTERNATIVE MECHANISM 1

The Pay-off flows under this Alternative Mechanism 1 are as follows:

8.3.1. UNDER SCHEDULING WITHIN 30%

When the Wind Generator deviates up to +30% from its schedule then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State receives payment from the UI pool for the difference between the actual and scheduled generation at the UI Rate (UIR) which it then passed on to the RRF. The RRF pays to the Host State for the difference between the actual and scheduled generation at reference rate. Thus, at the end of these transactions the wind generator gets paid for its actual generation. This has been depicted in Figure 25.

Figure 25: Deviation from Scheduled Generation within +30%



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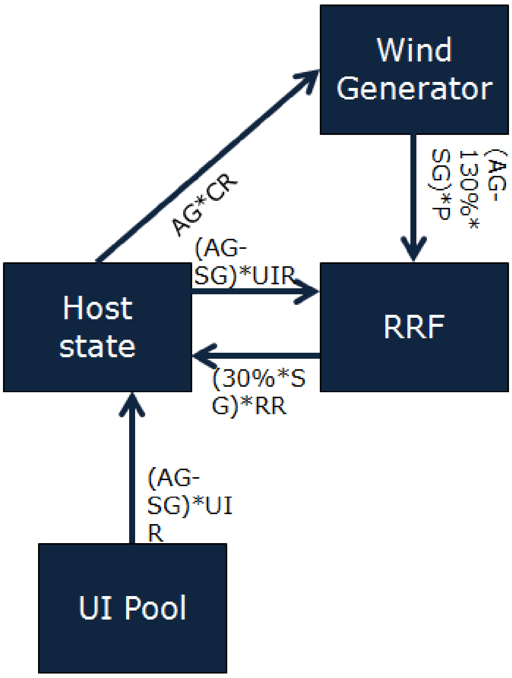
8.3.2. UNDER SCHEDULING BEYOND 30%

When the Wind Generator deviates beyond 30% from its schedule, then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State receives from the UI pool for the difference between actual and scheduled generation at the UI rate which it then passes on to the RRF. The RRF pays to the Host State for 30% of the scheduled generation at reference rate. However, the Wind Generator is penalized at the Penalty Rate for that part of its generation which exceeds the +30% deviation band. It pays this amount into the RRF. Thus, at the end of these transactions the Wind Generator gets paid for up to 30% of its deviation from the schedule and is penalized on the remainder. This has been depicted in Figure 26.

Figure 26: Deviation from Scheduled Generation beyond +30%



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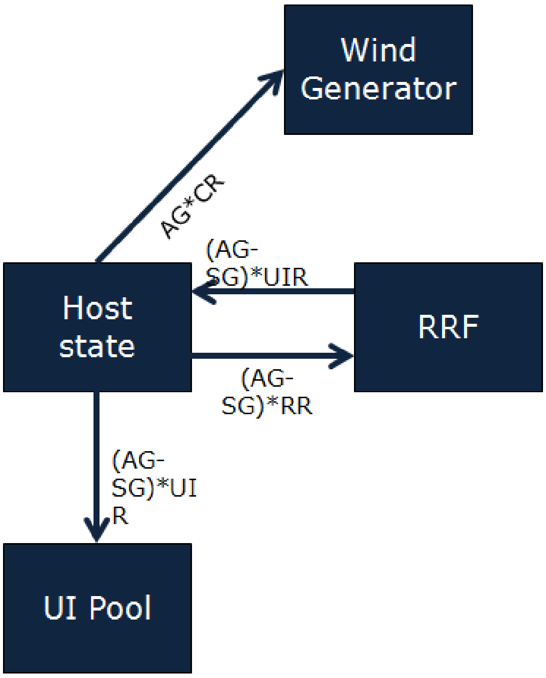
8.3.3. Over Scheduling within 30%

When the Wind Generator deviates up to -30% from its schedule, then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State pays to the UI pool for the difference between actual and scheduled generation at the UI rate which it receives from the RRF. The RRF receives from the Host State for the difference between the actual and scheduled generation at reference rate. Thus, at the end of these transactions the Wind Generator gets paid for its actual generation. This has been depicted in Figure 27.

Figure 27: Deviation from Scheduled Generation within -30%



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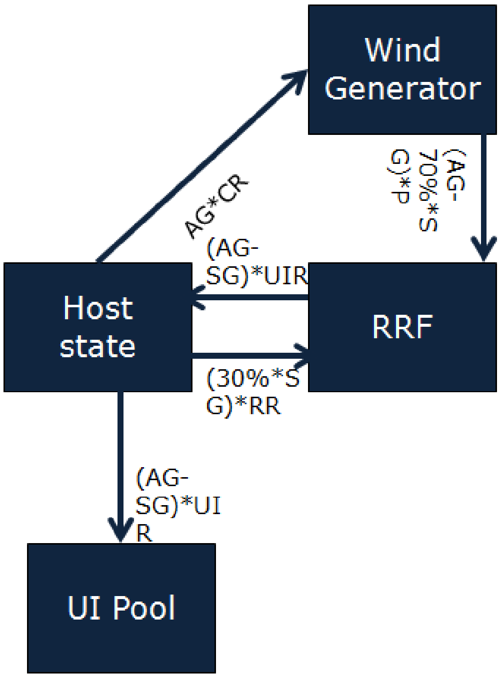
8.3.4. Over Scheduling beyond 30%

When the Wind Generator deviates beyond -30% from its generation schedule then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State pays to the UI pool for the difference between actual and scheduled generation at the UI rate, which it then receives from the RRF. The RRF receives from the Host State for 30% of the scheduled generation at reference rate. However, the Wind Generator is penalized at the penalty rate for that part of its generation which exceeds the +30% deviation band. It pays this amount into the RRF. Thus, at the end of these transactions the Wind Generator gets paid for up to 30% of the deviation from schedule and is penalized on the remainder. This has been depicted in Figure 28.

Figure 28: Deviation from Scheduled Generation beyond -30%



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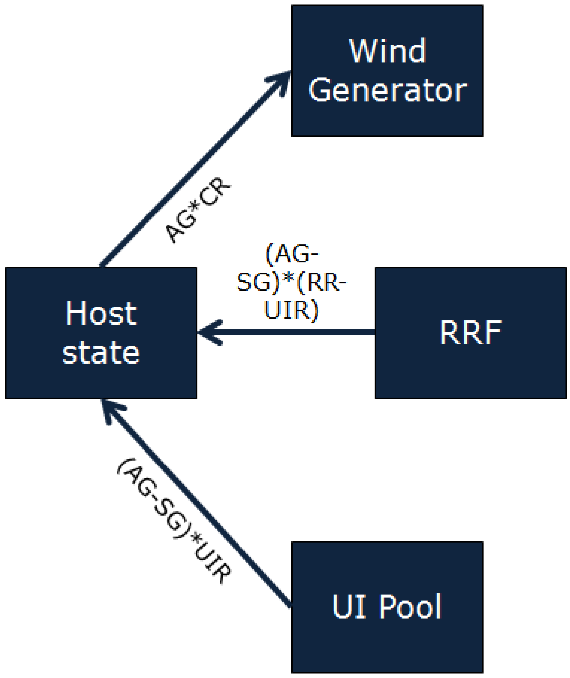
8.4. PAY OFF FLOWS UNDER ALTERNATIVE MECHANISM 2

The pay-off flows under this mechanism are as follows:

8.4.1. UNDER SCHEDULING WITHIN 30%

When the Wind Generator deviates up to +30% from its schedule, it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State receives payment from the UI pool for the difference between actual and scheduled generation at the UI rate. The RRF pays to the Host State for the difference between the actual and scheduled generation at (RR-UI) rate. Thus, at the end of these transactions the Wind Generator gets paid for its actual generation and the Host State is cushioned for the quantum of the deviation. This has been depicted in Figure 29.

Figure 29: Deviation from Scheduled Generation within +30%



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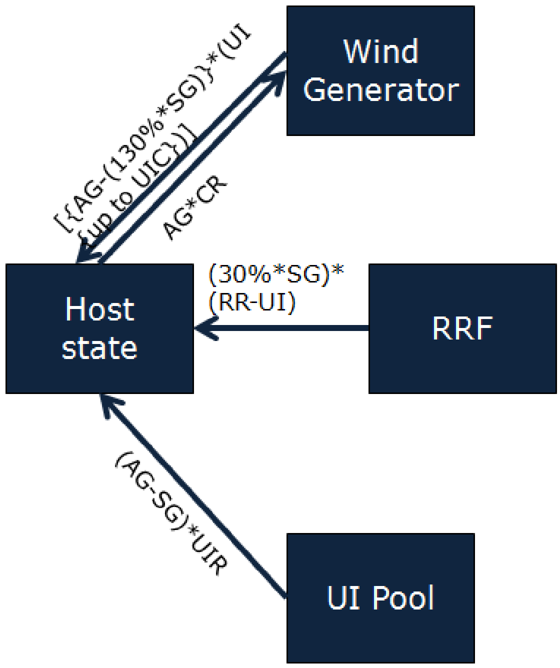
8.4.2. Under Scheduling between 30% and 50%

When the Wind Generator deviates beyond 30% from its schedule but within 50% then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State receives from the UI pool for the difference between actual and scheduled generation at the UI rate. The RRF pays to the Host State for 30% of the scheduled generation at (RR-UI) rate. However, the Wind Generator is penalized at the UI rate up to UI cap rate for that part of its generation which exceeds the +30% deviation band. The amount is paid to the Host State. Thus, at the end of these transactions the Wind Generator gets paid for its deviation up to the 30% band and gets penalized for the remaining amount. This has been depicted in Figure 30.

Figure 30: Deviation from Scheduled Generation between +30% and +50%



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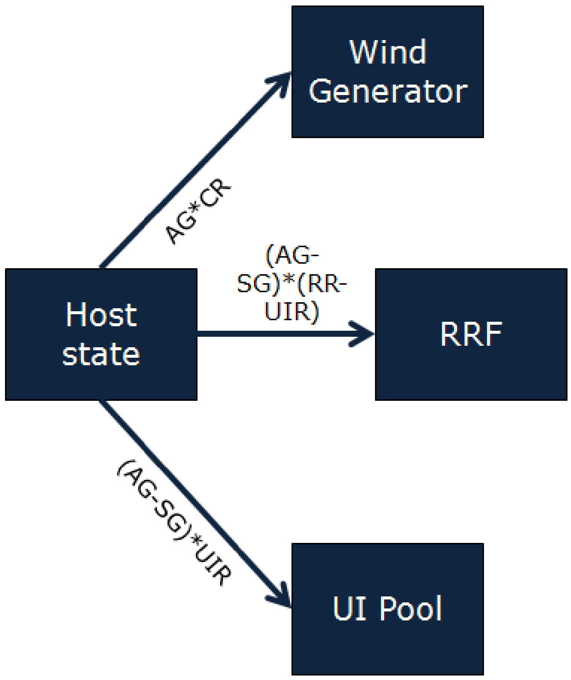
8.4.3. Over Scheduling within 30%

When the wind generator deviates up to -30% from its schedule then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State pays to the UI pool for the difference between the actual and scheduled generation at the UI rate. The RRF receives from the Host State for the difference between the actual and scheduled generation at (RR-UI) rate. Thus, at the end of these transactions the Wind Generator gets paid for its actual generation and the Host State pays as per the scheduled generation. This has been depicted in Figure 31.

Figure 31: Deviation from Scheduled Generation within -30%



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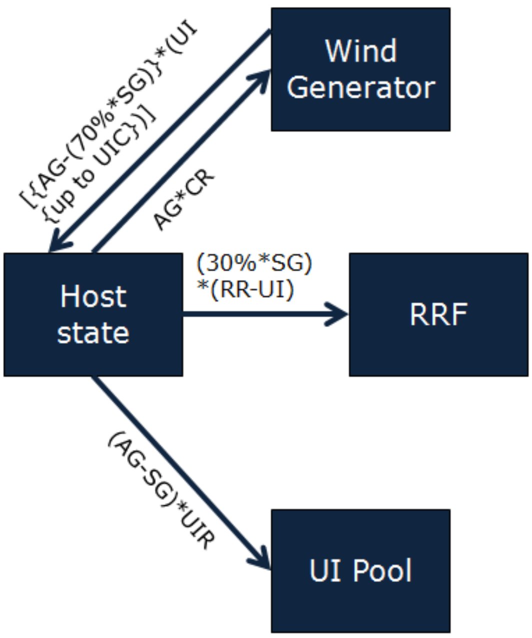
8.4.4. Over Scheduling beyond 30%

When the Wind Generator deviates beyond -30% from its schedule then it is paid by the off taker (Host State) at the contract rate as per its actual generation. The Host State pays to the UI pool for the difference between actual and scheduled generation at the UI rate. The RRF receives from the Host State for upto 30% of the scheduled generation at (RR-UI) rate. However, the Wind Generator is penalized at the UI rate up to the UI cap rate for that part of its generation which exceeds the +30% deviation band. The amount goes into the UI pool. Thus, at the end of these transactions the Wind Generator gets paid for up to 30% of its deviation from the schedule and gets penalized for the remaining amount. This has been depicted in Figure 32.

Figure 32: Deviation from Scheduled Generation beyond -30%



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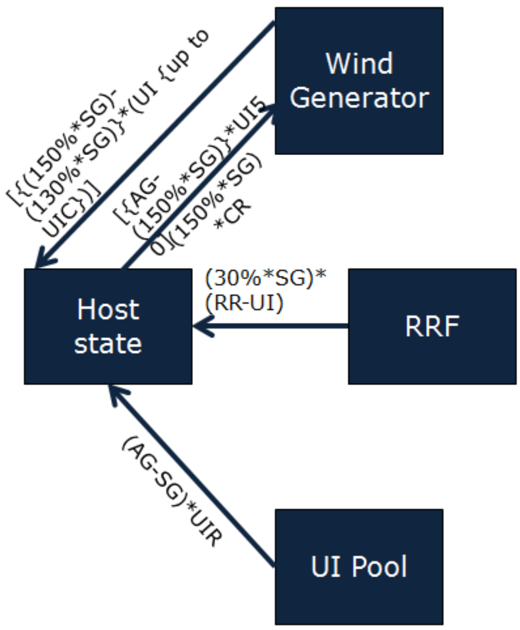
8.4.5. UNDER SCHEDULING BEYOND 50%

When the Wind Generator under schedules beyond 50% of its schedule, it gets paid for up to 150% of the schedule, at the contract rate, by the Host State. The Host State gets compensated for the difference between actual and scheduled generation at the frequency linked UI rate through the UI pool. The state on the other hand pays for the difference between the actual generation and the higher limit of 150% of its schedule to the Wind Generator at the rate corresponding to frequency 50-50.02 Hz. State also receives for up to 30% of its schedule from the RRF at the (RR-UI) rate. The wind generator then bears a penalty at the UI rate up to the UI cap rate for the quantum of generation between higher limit of its schedule i.e. 150% and for the quantum of its schedule beyond the 30% band, which is paid out to the Host State. In this case the Wind Generator bears the risk of deviation beyond 150% of its schedule and gets penalized for its deviation beyond 30%. This has been depicted in Figure 33.

Figure 33: Deviation from Scheduled Generation beyond +50%



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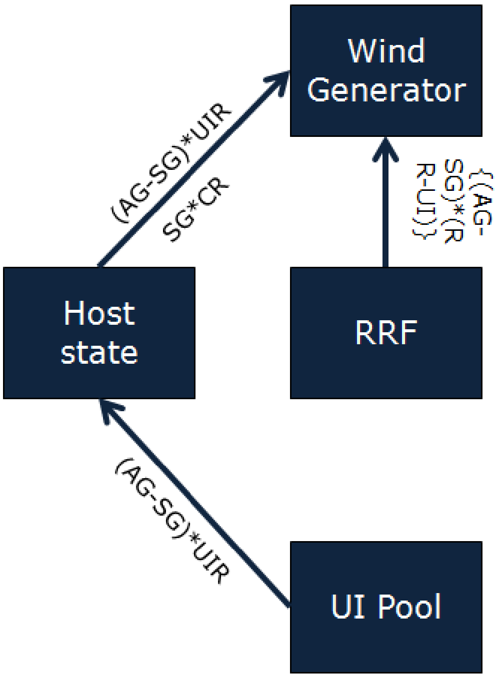
8.5. PAY OFF FLOWS UNDER ALTERNATIVE MECHANISM 3

The pay-offs under this mechanism are as follows:

8.5.1. UNDER SCHEDULING WITHIN 30%

When the Wind Generator deviates upto +30% from its schedule then it is paid by the off taker (Host State) at the contract rate as per the scheduled generation. The Host State receives payment from the UI pool for the difference between actual and scheduled generation at the UI rate which is then passes on to the Wind Generator. The RRF pays to the Wind Generator for the difference between the actual and scheduled generation at (RR-UI) rate. Thus, at the end of these transactions the Wind Generator **gets paid for its actual generation**. This has been depicted in Figure 33.

Figure 34: Deviation from Scheduled Generation within +30%



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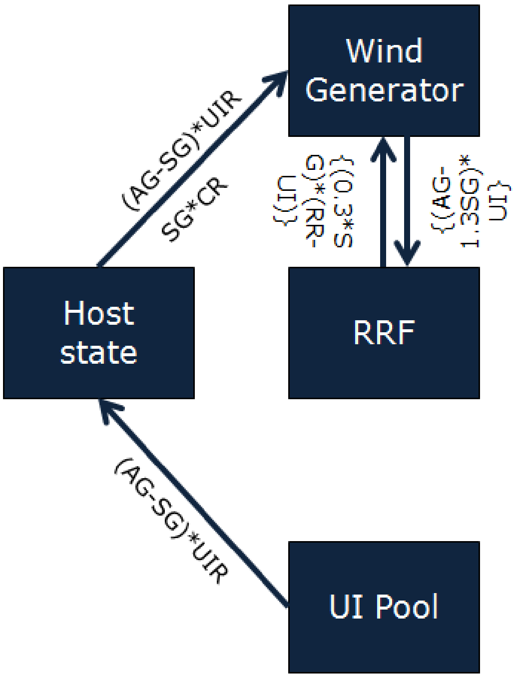
8.5.2. Under Scheduling beyond 30%

When the Wind Generator deviates beyond 30% from its schedule then it is paid by the off taker (Host State) at the contract rate as per its scheduled generation. The Host State receives from the UI pool for the difference between actual and scheduled generation at the UI rate which is then passes on to the Wind Generator. The RRF pays to the Wind Generator for 30% of the scheduled generation at (RR-UI) rate. However, the Wind Generator is penalized at the UI rate for that part of the generation which exceeds +30% deviation band. The amount goes into the UI pool. Thus, at the end of these transactions the Wind Generator gets paid for up to 30% of its deviation from the schedule and is penalized on the remainder. This has been depicted in Figure 36.

Figure 35: Deviation from Scheduled Generation beyond +30%



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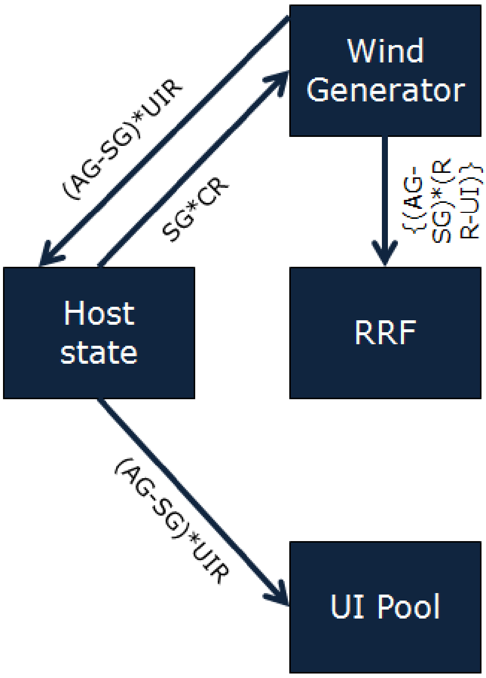
8.5.3. Over Scheduling within 30%

When the Wind Generator deviates till -30% of its schedule, it is paid at the contract rate as per the scheduled generation by the off-taker (Host State). The Host State pays to the UI pool for the difference between actual and scheduled generation at the UI rate which it receives from the Wind Generator. The RRF receives from the Wind Generator for the difference between the actual and scheduled generation at (RR-UI) rate. Thus at the end of these transactions the Wind Generator gets paid for its actual generation. This has been depicted in Figure 34.

Figure 36: Deviation from Scheduled Generation within -30%



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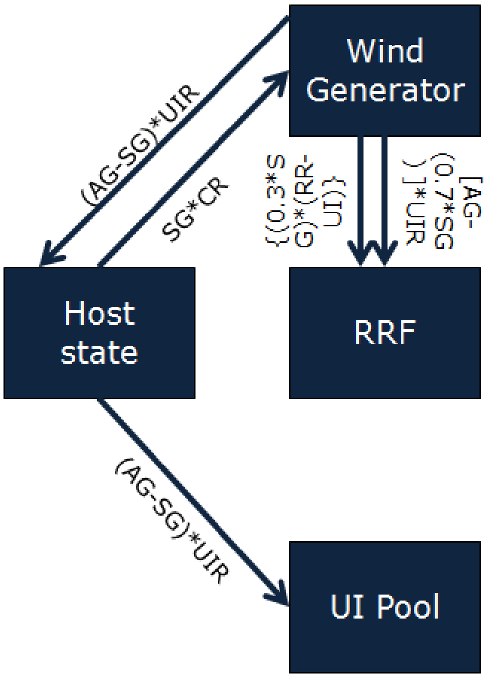
8.5.4. Over Scheduling beyond 30%

When the Wind Generator deviates by beyond -30% of its schedule then it is paid by the off taker (Host State) at the contract rate as per the scheduled generation. The Host State pays to the UI pool for the difference between actual and scheduled generation at the UI rate which it receives from the Wind Generator. The RRF receives from the Wind Generator for up to 30% of the scheduled generation at (RR-UI) rate. However, the Wind Generator is penalized at the UI rate for that part of its generation which exceeds the +30% deviation band. The amount goes into the UI pool. Thus at the end of these transactions the Wind Generator gets paid for up to 30% of its deviation from the schedule and is penalized on the remainder. This has been depicted in Figure 35.

Figure 37: Deviation from Scheduled Generation beyond -30%



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IX. GLOSSARY

Words	Definitions
ACE (Area Control Error)	The instantaneous difference between net actual and scheduled interchange, taking into account the effects of frequency bias including a correction for meter error.
Dynamic Scheduling	It is the service that provides for the real-time metering, tele metering, computer software, hardware, communications, engineering, and administration required to electronically move a portion or all of the energy services associated with generation or load out of the Control Area to which it is physically connected and into a different Control Area.
FGMO (Free Governor Mode of Operation)	Frequency instability occurs due to the mismatch between load an degeneration caused by tripping of generators and/or rejection of loads giving rise to a sudden change in frequency. When the turbo-generator is on bars, the governor of the turbine, if its wings are not clipped, responds to a change in frequency by varying the control valve lift and so varying the generation. The change in generation depends upon the droop characteristics of the governor. All the turbo-generators in the grid participating in the governing action tend to annul the change in frequency by increasing or decreasing the generation. This mode of governor operation compensates the change in frequency by change in generation and is called Free Governor Mode of Operation (FGMO).
K-factors	The K-factor is a value, usually given in megawatts per Hertz (MW/Hz), which is normally determined for a (single) control area / block; it defines the frequency bias of that control area for secondary control (especially to assure the functionality of the network characteristic method); it is not to be confused with the network power frequency characteristic.
Primary Control	Primary control maintains the balance between generation and DEMAND in the network using turbine speed governors. Primary control is an automatic decentralised function of the turbine governor to adjust the generator output of a unit as a consequence of a frequency deviation / offset in the synchronous area.
Secondary Control	Secondary control is a centralised automatic function to regulate the generation in a control area based on secondary control reserves in order to maintain its interchange power flow at the control program with all other control areas (and to correct the loss of capacity in a control area affected by a loss of production) and, at the same time, (in case of a major frequency deviation originating from the control area, particularly after the loss of a large generation unit) to restore the frequency in case of a frequency deviation originating from the control area to its set value in order to free the capacity engaged by the primary control (and to restore the primary control reserves).

Secondary Controller	A secondary controller is the single centralised TSO-equipment per control area / block for operation of secondary control.
Tertiary Control	Tertiary control is any (automatic or) manual change in the working points of generators (mainly by re-scheduling), in order to restore an adequate secondary control reserve at the right time.

The views/analysis expressed in this report/document do not necessarily reflect the views of Shakti Sustainable Energy Foundation. The Foundation also does not guarantee accuracy of any data included in this publication nor does it accept any responsibility for the consequences of its use.

About the study

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About Shakti Sustainable Energy Foundation

Shakti Sustainable Energy Foundation works to strengthen the energy security of India by aiding the design and implementation of policies that encourage energy efficiency as well as renewable energy. Shakti works in sectors with the maximum potential for energy and carbon savings: Power, Transport, Energy Efficiency and Climate Policy. A Section 25 non-profit organization under the Companies Act, Shakti is governed by a national board of directors, and supported by both Indian and international philanthropies. It convenes NGOs, universities, business, think tanks, and domestic and international experts to design and implement smart energy policies in India

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