Wind/Solar Power Generation Forecasting

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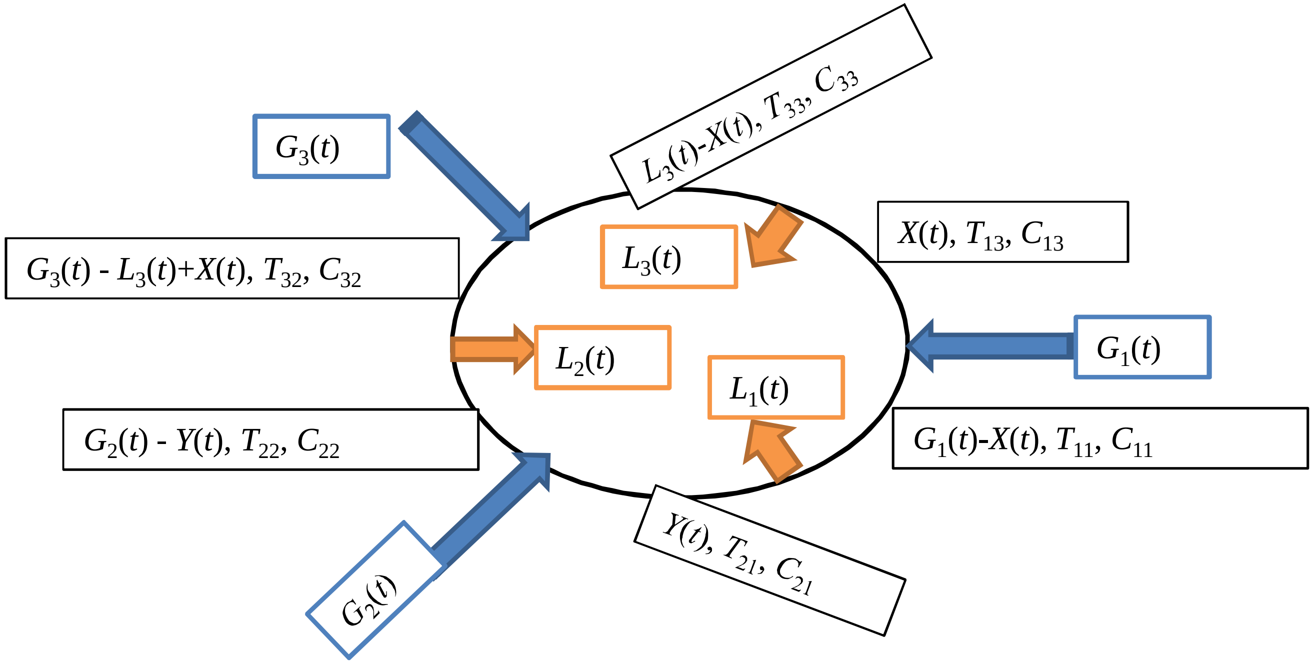


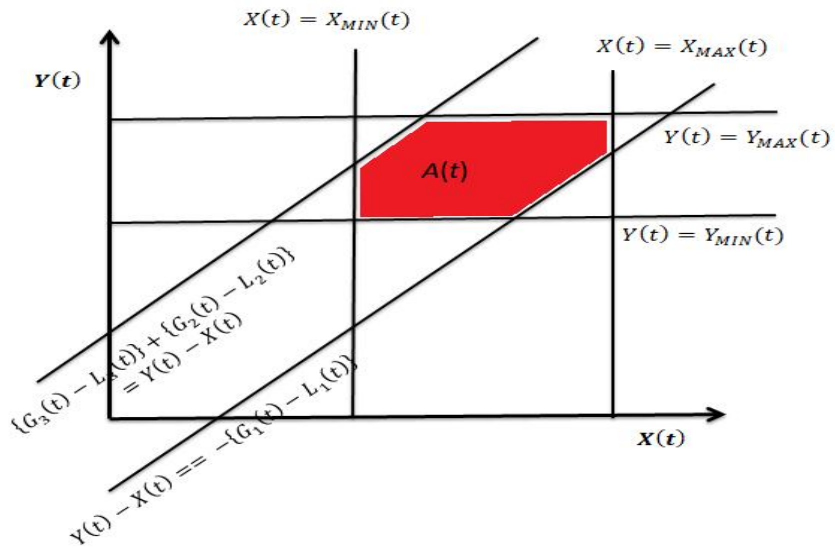
Without going complex structure of grid network let define a simple structure where we have three variable generation grid nodes say G_1, G_2 and G_3 for simplicity let define three Load dispatch points L_1, L_2 and L_3 such that L_1 lies between G_1 and G_2, L_2 lies between G_2 and G_3, and L_3 lies between G_3 and G_1. The structure is made as simple as possible for the energy flow such that a generation station can distribute its generation in its two nearest Load dispatch points. For simplification, this analysis considers only energy flow in the network to find the stability of the network.

$$\min\{G_1(t), L_3(t), T_{13}, T_{32} - (G_3(t) - L_3(t))\} \geq X(t)$$
$$\geq \max\{0, G_1(t) - T_{11}, L_3(t) - T_{33}\}$$

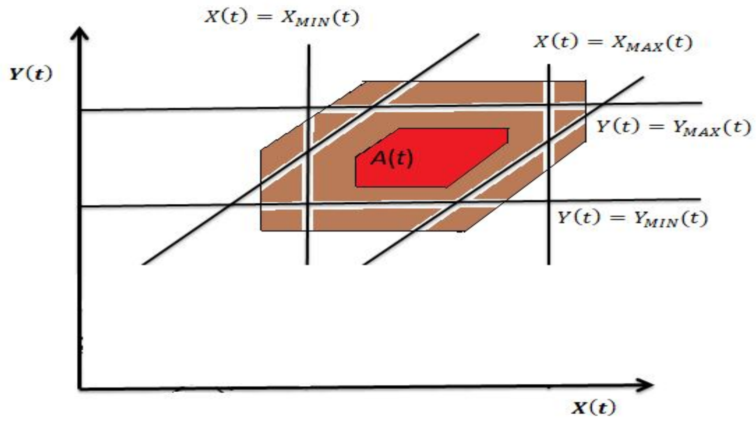
$$\min\{G_2(t), L_1(t), T_{21}\} \geq Y(t) \geq \max\{0, G_2(t) - T_{22}\}$$

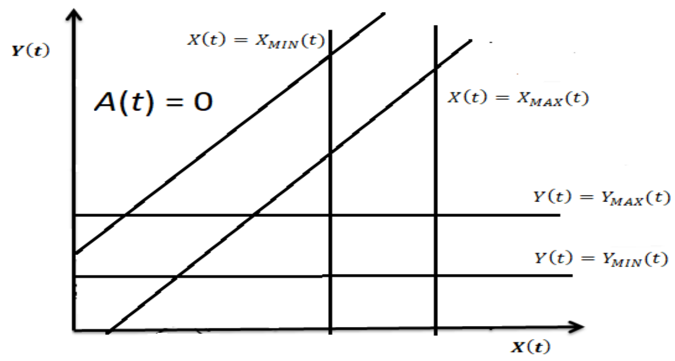
$$\{G_3(t) - L_3(t)\} + \{G_2(t) - L_2(t)\} \geq Y(t) - X(t) \geq -\{G_1(t) - L_1(t)\}$$

Linear Programming Pr



A(*t*) depends on the each value of G_1, G_2 and G_3 but not on the sum of its values i.e. $G_1 + G_2 + G_3$. Interestingly since it is a variable generation and A(t) is not constant but to get the +ve value of A(t) we need a prediction of G_1, G_2 and G_3 separately but not as a sum or aggregation of those values.



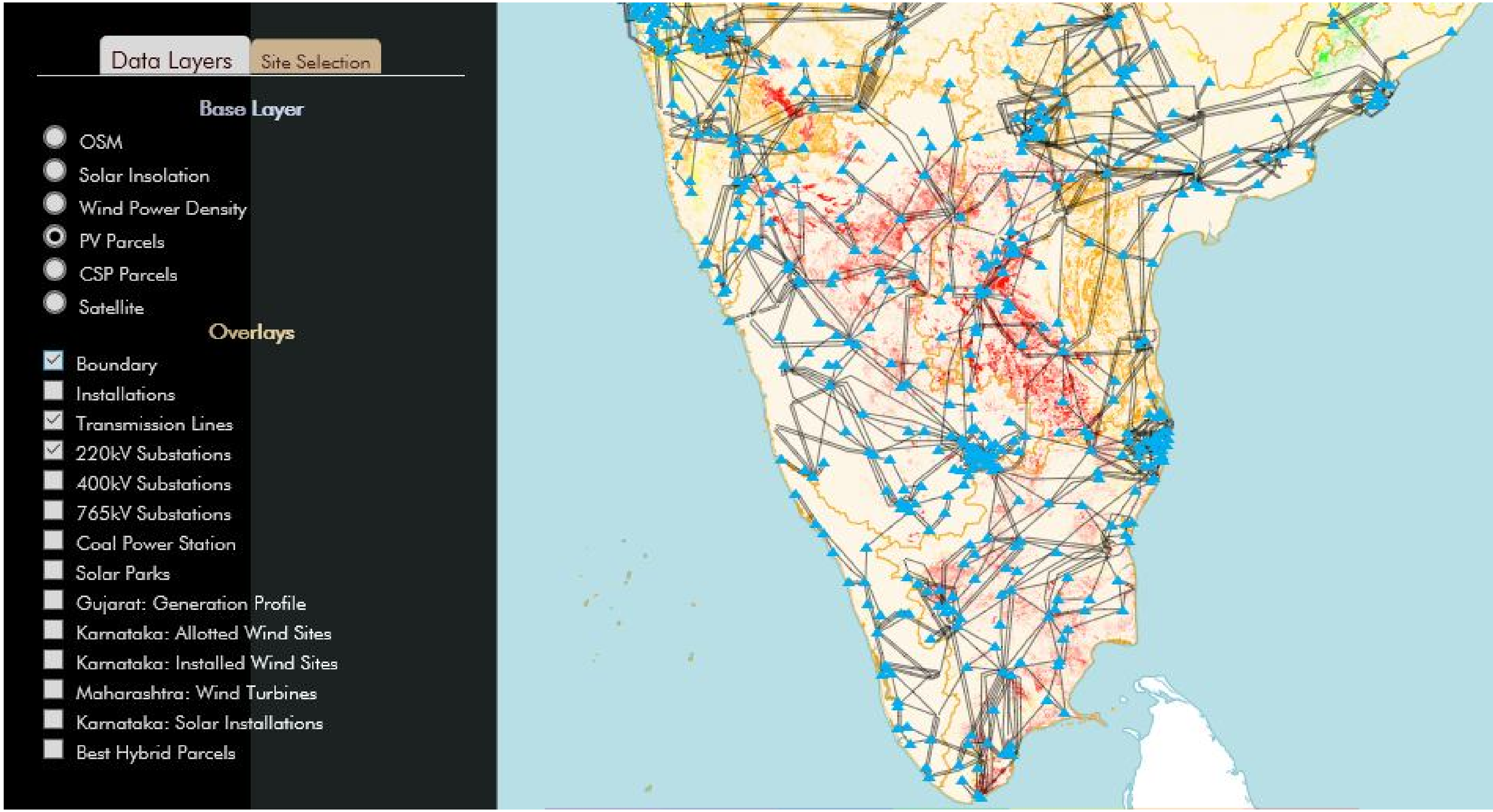


Here the red area is actual requirement and the area of A(t) decreases due to the uncertainty of the generation.

Suppose schedule generation of G_1, G_2 and G_3 are not known separately, then the above situation may arise:

The aggregated forecast creates instability when A(t) is not positive.

The Complex Network



Data support by CSTEP, India

For ***M*** Generating point and ***N*** Load point of a Complex Network, $A(t)$ is approximately $\boldsymbol{(M+N-4)}$ dimensional space.

If $A(t)$ is not a connected space then it creates the instability

Hence what is the minimum temporal and spatial granularity of Forecasting?

Minimum Temporal Granularity = 15 min already fixed

Minimum Spatial Granularity ?
Minimum Capacity of Generation?

Statistical Forecasting

Statistical Forecasting problem is an error minimization problem

$$\min_{P} \int_{\Omega} F(\mathbf{x}, P(\mathbf{x}), \nabla P(\mathbf{x}))\, d\mathbf{x}$$

$$\min_P \int_\Omega F(\mathbf{x}, P(\mathbf{x}), \nabla P(\mathbf{x}))d\mathbf{x}$$

Solve it using Euler-Lagrange:

$$\nabla\left(\frac{\partial F(\mathbf{x}, P(\mathbf{x}), \nabla P(\mathbf{x}))}{\partial(\nabla P(\mathbf{x}))}\right) = \frac{\partial F(\mathbf{x}, P(\mathbf{x}), \nabla P(\mathbf{x}))}{\partial P(\mathbf{x})}$$

And get an Iterative (or Dynamic) equation:

$$P_{t+1}(\mathbf{x}) = \phi(P_t(\mathbf{x}))$$

Few Computational Techniques in Solving the Dynamic Problem for Wind / Solar Forecasting

- Markov -> Hidden Markov
- ANN -> DNN
- PDE -> Stochastic PDE
- Single Hypothesis -> Multiple Hypothesis -> Scenario based Analysis

- Fractional Calculus !

Fractional World

- $\frac{d}{dx}, \frac{d^2}{dx^2}$ exists

- What about $\frac{d^{0.5}}{dx^{0.5}}$ or $\frac{d^{0.9}}{dx^{0.9}}$ or $\frac{d^{1.1}}{dx^{1.1}}$?

Fractional Derivative

Riemann fractional derivative (Left) is defined as

$$ {}_{L}D_{x}^{\alpha} f(x) = \frac{d^{\alpha} f(x)}{dx^{\alpha}} = \frac{1}{\Gamma(n-\alpha)} \frac{d^{n}}{dx^{n}} \int_{L}^{x} (x-s)^{n-\alpha-1} f(s)ds $$

Riemann fractional derivative (Right) is defined as

$$ {}_{x}D_{L}^{\alpha} f(x) = \frac{d^{\alpha} f(x)}{dx^{\alpha}} = \frac{(-1)^{n}}{\Gamma(n-\alpha)} \frac{d^{n}}{dx^{n}} \int_{x}^{L} (x-s)^{n-\alpha-1} f(s)ds $$

Other forms of Fractional derivative also exist like Riesz or Caputo fractional derivative

Why Fractional Derivative ?

- It is non-local convolution type

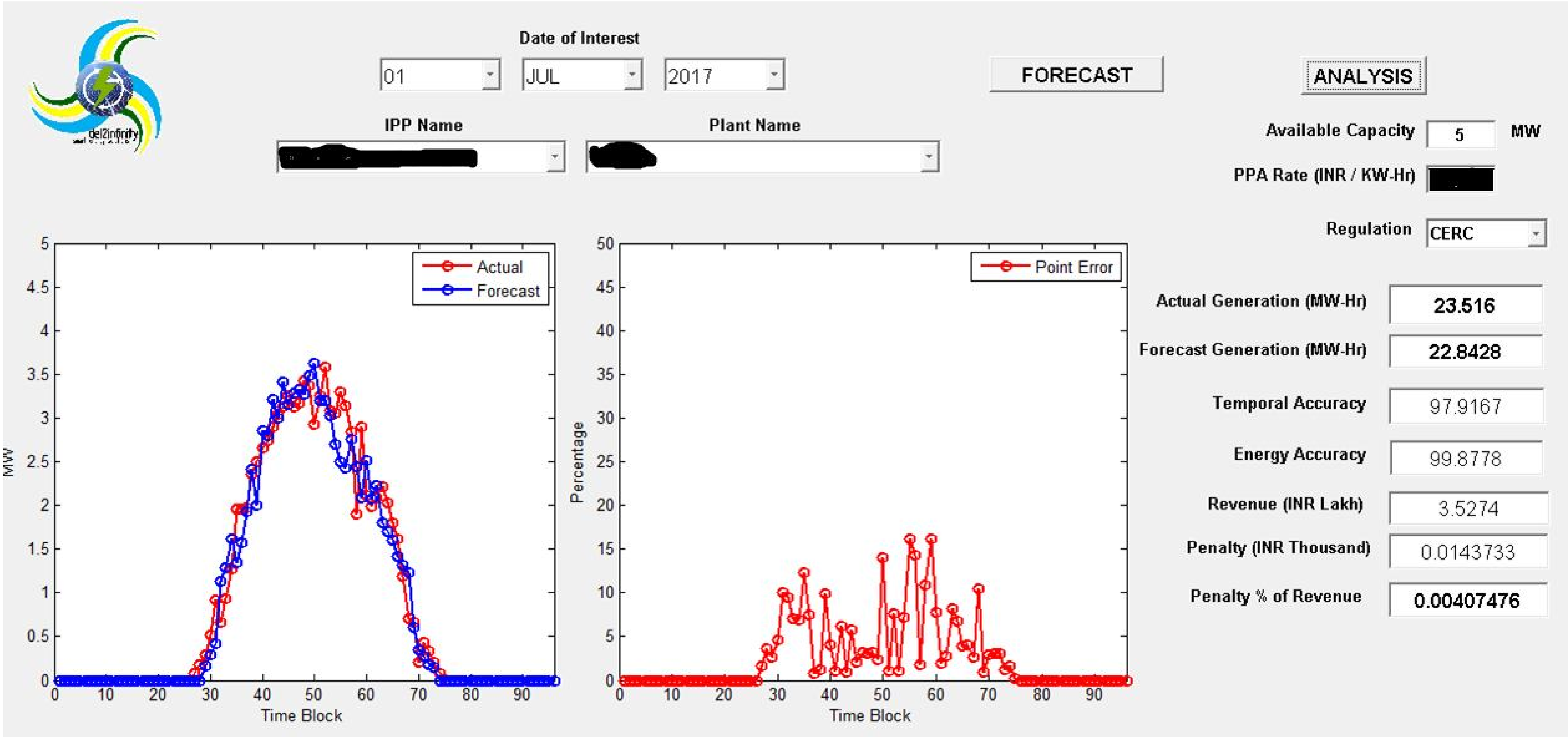
L=0 => Riemann-Liouville Form of fractional derivative

Define the error minimization problem as

$$\min_{P} \int_{\Omega} F(\mathbf{x}, P(\mathbf{x}), \nabla^{\alpha,\beta} P(\mathbf{x})) d\mathbf{x}$$

And solve using Fractional Euler Lagrange as

$$\nabla^{\beta,\alpha} \left(\frac{\partial F(\mathbf{x}, P(\mathbf{x}), \nabla^{\alpha,\beta} P(\mathbf{x}))}{\partial(\nabla P(\mathbf{x}))} \right) = \frac{\partial F(\mathbf{x}, P(\mathbf{x}), \nabla^{\alpha,\beta} P(\mathbf{x}))}{\partial P(\mathbf{x})}$$



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Date of Interest
01
JUL
2017
FORECAST
ANALYSIS
IPP Name
[redacted]
Plant Name
[redacted]
Available Capacity
5
MW
PPA Rate (INR / KW-Hr)
[redacted]
Regulation
CERC
Actual Generation (MW-Hr)
23.516
Forecast Generation (MW-Hr)
22.8428
Temporal Accuracy
97.9167
Energy Accuracy
99.8778
Revenue (INR Lakh)
3.5274
Penalty (INR Thousand)
0.0143733
Penalty % of Revenue
0.00407476
Actual
Forecast
MW
Time Block
Point Error
Percentage
Time Block

Forecast Accuracy in Wind (R12) & Solar (R1) Forecast Plant Level

Absolute Error Margin	Probability (%) Wind	Probability (%) Solar
< 15%	93.36 +/- 5	98.69 +/- 2.5
15%-25%	4.37 +/- 5	1.27+/-2.5
25%-35%	1.16 +/- 5	0.04+/- 2.5
>35%	1.11 +/- 5	0

Thank you !

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