RENEWABLE ENERGY SCHEDULING & DEVIATION SETTLEMENT

From Intermittency to Discipline

India's Regulatory Journey — Lessons for South Asia's Emerging Grids

Presenter Name | Renewable Energy Forecasting & Grid Advisory
Date

Leader in Power Sector Services

Manikaran Group

Manikaran Power Limited

Category - I Inter State Trading License
Among Top 3 Power Trading Cos in India
10+ Billion Units Annual Trade Volume
2000+ Industrial Clients including all most all Utilities and IPPs Across India
600MW Plant Capacity with long term PPA under Tolling Arrangement

Manikaran Analytics Limited

Leading Forecasting & Scheduling (F&S) Company in India
95+ GW – Current RE F&S Portfolio
2100+ Clients
6500+ Forecasts with Real Time Updates Every 30 minutes
5000+ Day ahead and intra day schedules on a daily basis to various SLDCs across India

50 Hertz Limited

Leading Software Solutions provider in Power Sector
SaaS based Web Architected applications with option to deploy on Premises or on Cloud
Innovative solutions to achieve technical excellence
Deployed and successfully running products and Services across various Utilities and IPPs

Manikaran Renewables Limited

EPC Services Provider for Solar Projects
Empaneled with various State Nodal Agencies
Experienced in- house Design, Survey and Project Planning and Management Teams
Best Technology Partners for invertors and BOS
Successful track record of project implementation

Manikaran Hydro Pvt Ltd.

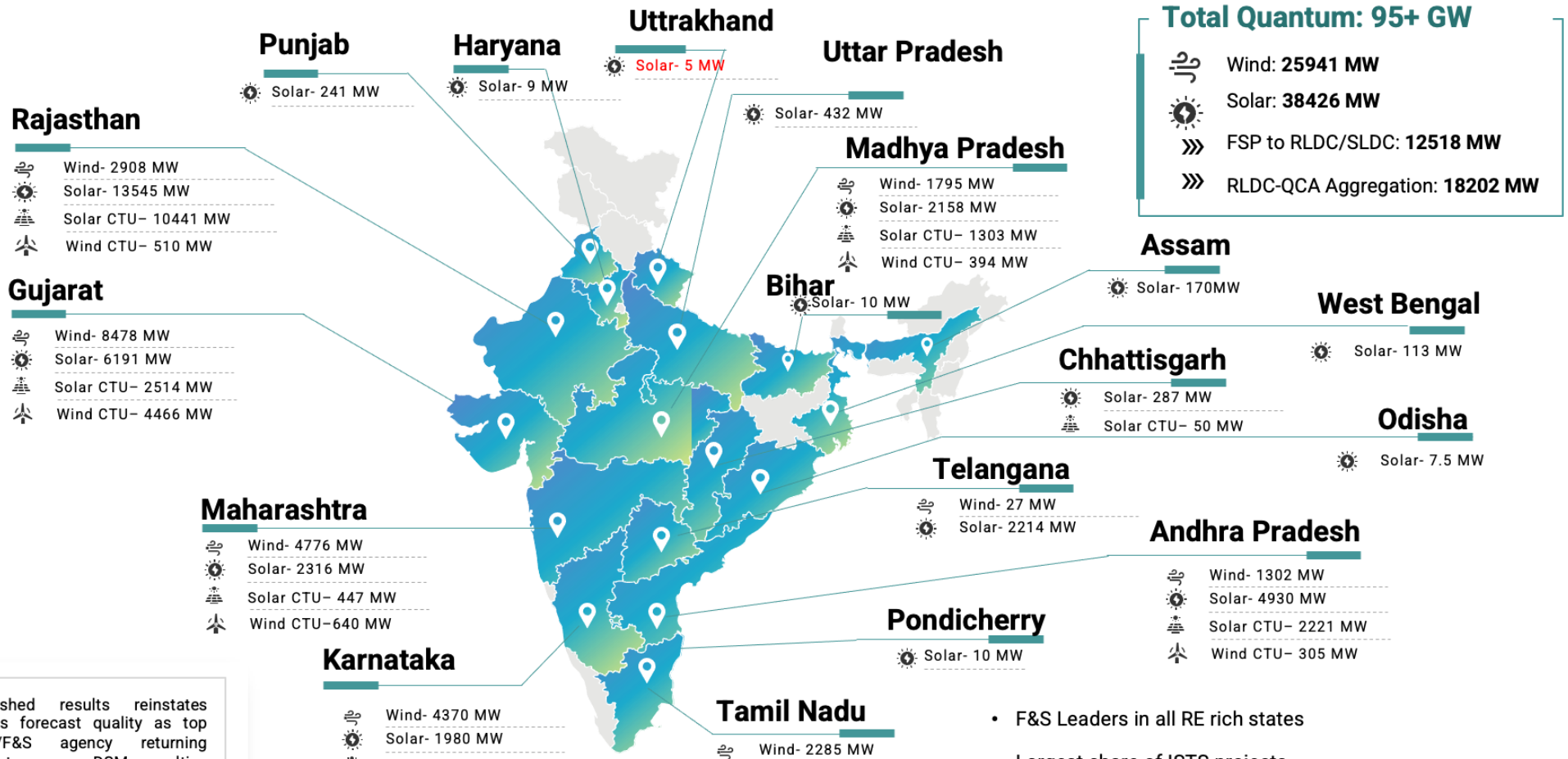
15 MW Operational Asset

Corporate Office:
New Delhi

Branch Offices:
- Mumbai
- Kolkata
- Chennai
- Hyderabad
- Bengaluru
- Ahmedabad

850+
Employees

Pan India Capacity under our QCA/FSP services



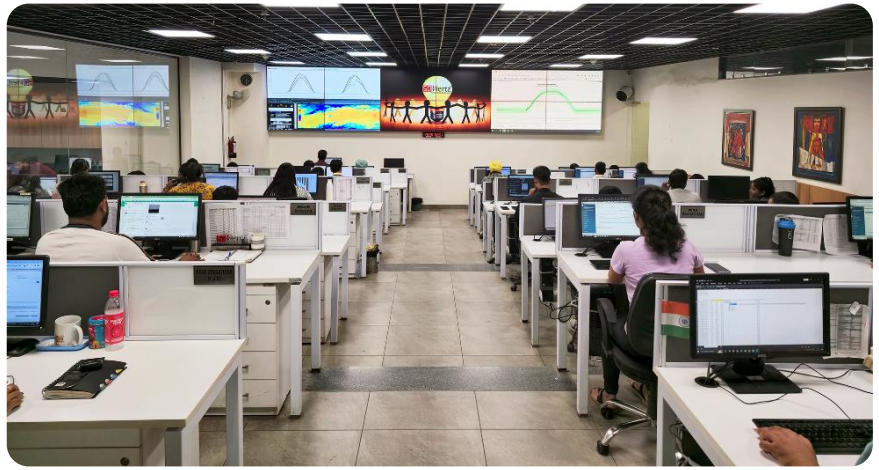
Total Quantum: 95+ GW

- Wind: **25941 MW**
- Solar: **38426 MW**
- FSP to RLDC/SLDC: **12518 MW**
- RLDC-QCA Aggregation: **18202 MW**

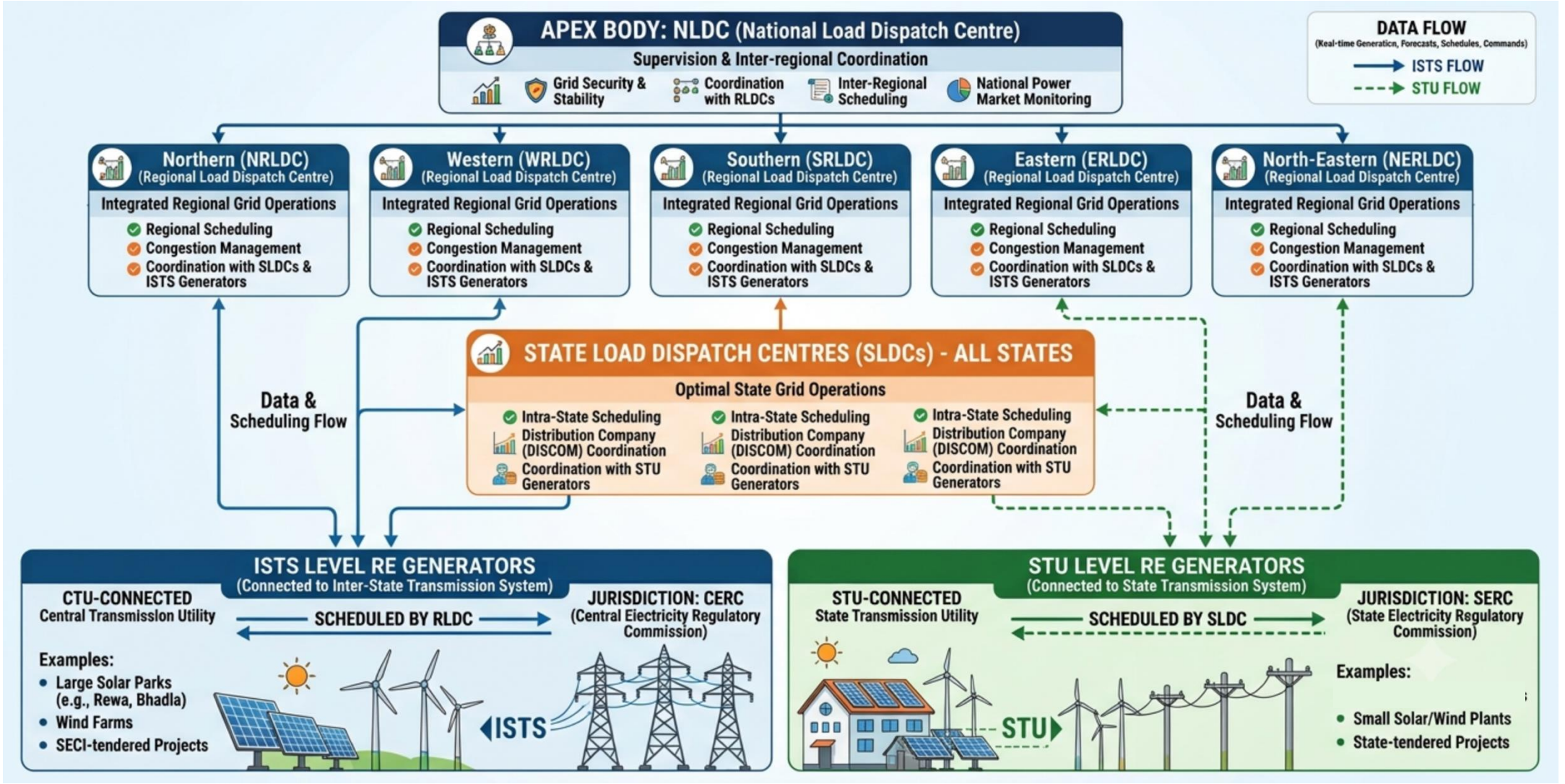
Published results reinstates MAL's forecast quality as top QCA/F&S agency returning lowest average DSM penalties among big F&S players in the country

- F&S Leaders in all RE rich states
- Largest share of ISTS projects
- Representing as QCA to most ISTS PSS under aggregation projects

24*7 Operations, Monitoring & QA Team at Our Delhi CC

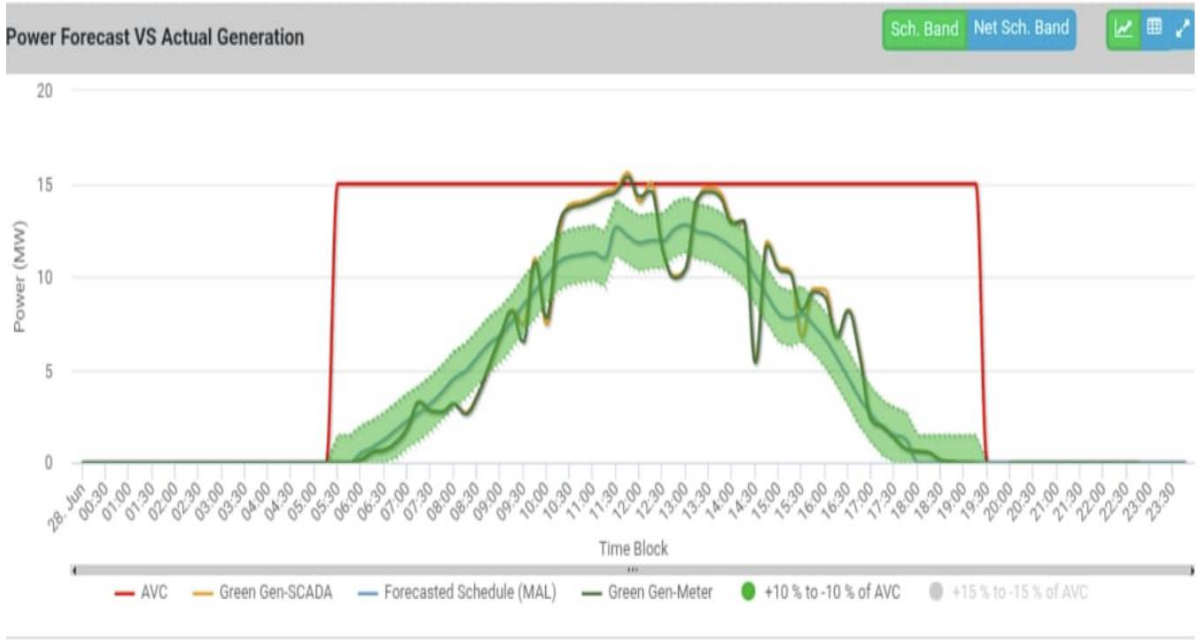


Relationship between NLDC,RLDCs, SLDCs, RE-Generators



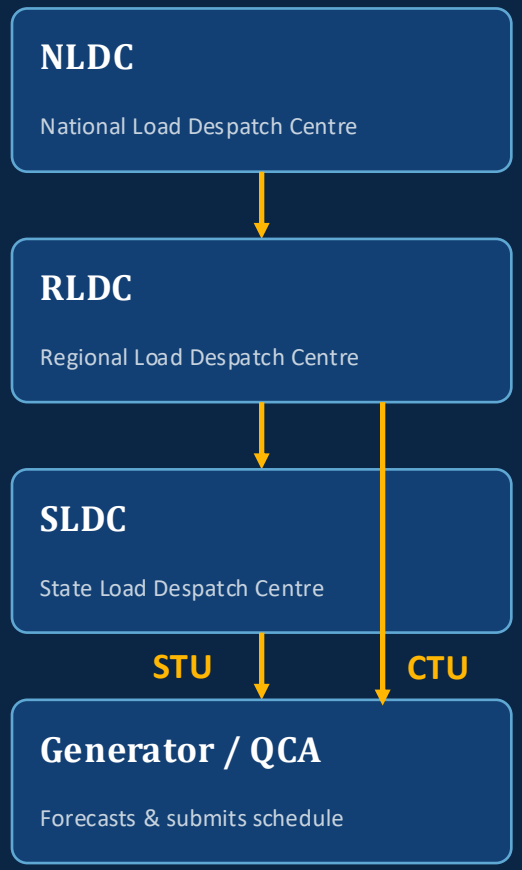
RE Generation Is Variable — the Grid Is Not Forgiving

- Solar and wind output changes minute-to-minute with cloud cover, wind speed & temperature
- Unlike thermal/hydro, RE output cannot be commanded up or down on demand
- Grid frequency must stay within a tight band (India: 49.90–50.05 Hz) at every instant
- Every MW of unscheduled deviation must be absorbed by someone else, instantly



The gap between the orange and blue lines **is the deviation** — the very thing scheduling & DSM regulations exist to price and manage.

Scheduling Is How Every Grid Stays in Balance



If a schedule is not followed:

- Frequency swings outside the safe operating band
- Other generators must ramp up/down in real time to compensate
- Cascading imbalance can trip protection systems on interconnected lines
- Left unpriced, deviation becomes a free option — everyone over-schedules "just in case"

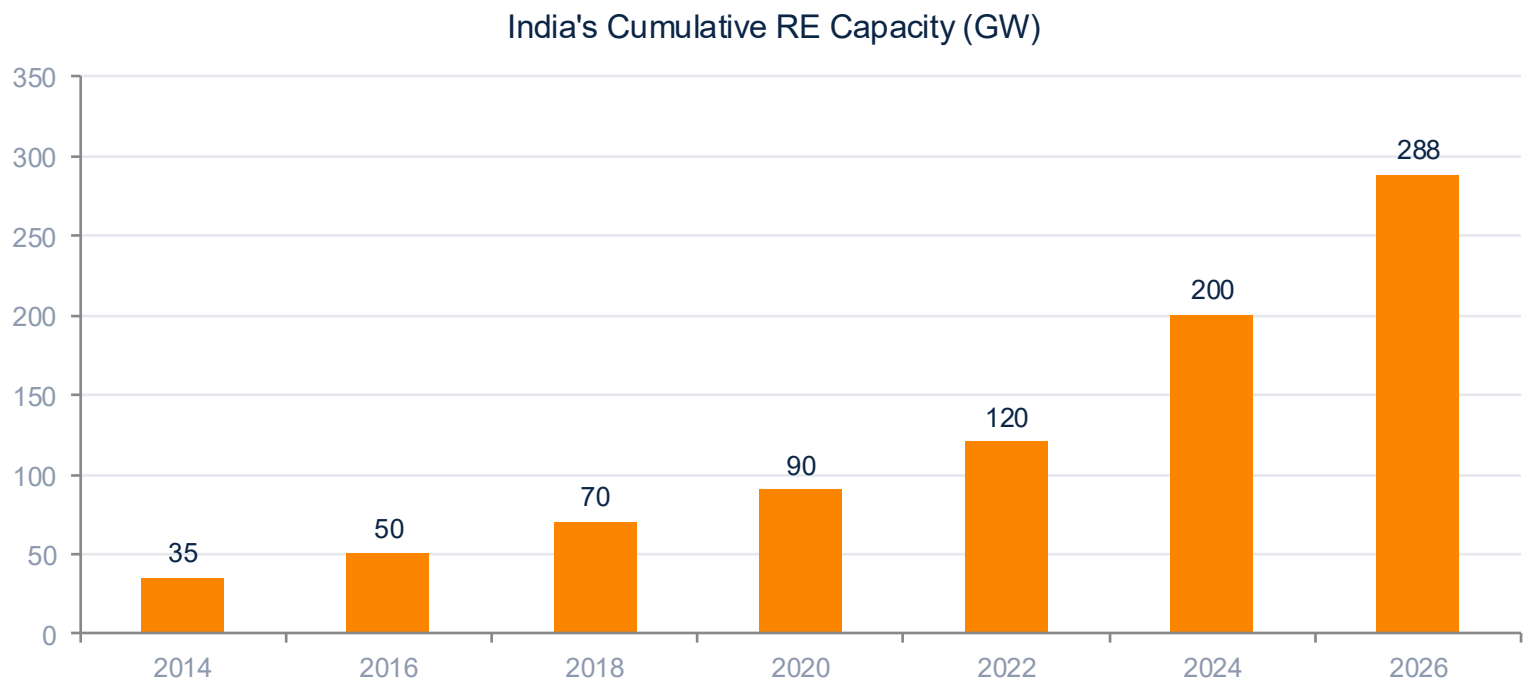
A commercial mechanism — reward accurate scheduling, price deviation — turns grid discipline into everyone's self-interest, not just an operational instruction.

India's RE Fleet Grew 8x in 12 Years

35 GW
Installed RE capacity, Apr 2014

288 GW
Installed RE capacity, mid-2026

500 GW
Non-fossil capacity target, 2030

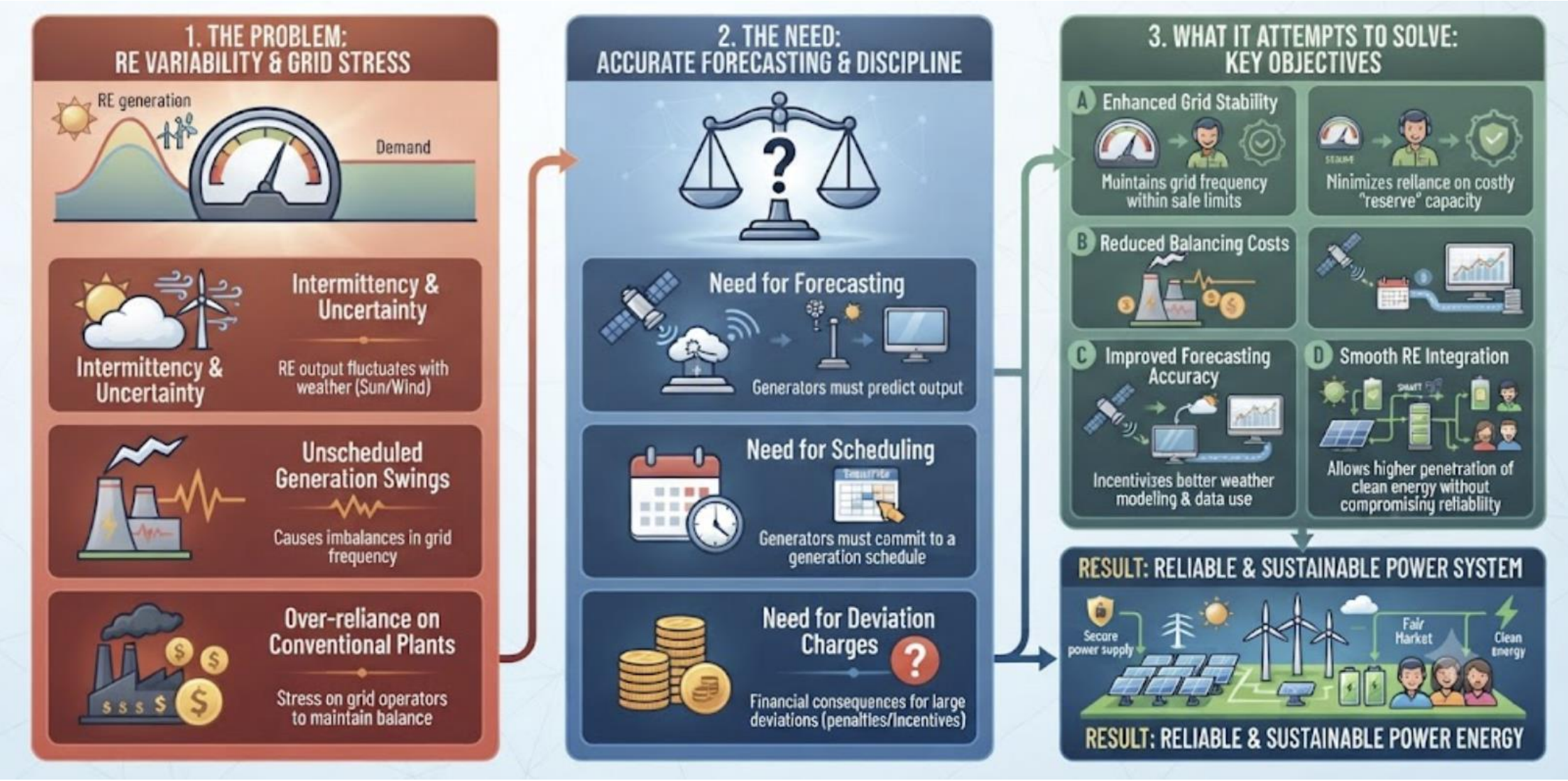


The Regulatory Lag

Every doubling of RE capacity multiplied the grid's exposure to forecast error. Scheduling & DSM rules had to evolve in step — starting gentle, tightening as the market matured.

This phased approach — not an overnight switch — is the central lesson for grids starting this journey today.

The need, objectives & the problem it attempts to solve



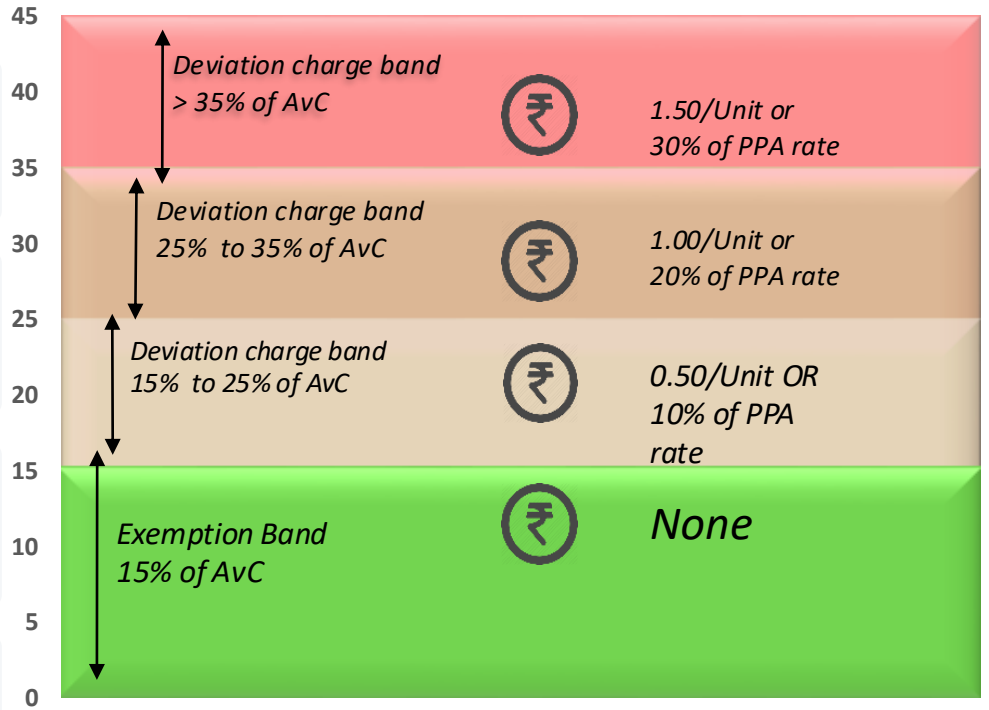
Importance & relevance

- Ensures grid security by aligning commercial incentives with frequency discipline and reserve sufficiency (DSM).
- Enables large-scale RE integration via forecasts that system operators can rely on for commitment, ramping, congestion management and reserve procurement.
- Provides settlement certainty for market participants across bilateral, exchange, ancillary and real-time market operations defined in IEGC procedures.

CERC DSM Regulations, 2014

Notified 6 January 2014 · CERC (Deviation Settlement Mechanism and Related Matters) Regulations

Applicability	Regional entities / ISTS (CTU)-connected generating stations, including wind & solar
Reference base	Deviation measured against Available Capacity (AvC) — the schedulable potential, not just the forecast
No-penalty band	Deviations within a defined percentage of AvC attracted no charge at all
Penalty trigger	Only deviations beyond the band were charged — a deliberately soft entry point for a nascent RE sector



Note: Deviation in Rs/Unit for State Transmission connected projects and % of PPA rate for Inter State Transmission connected projects

Error (%) = 100 X [Actual Generation– Scheduled Generation] / (AvC)

Rising RE Share Forcing Regulator to tighten bands

Common Band

Deviation: UI & OI of 15%/25%/35% of AvC
DSM: 10%/20%/30%
Max loss limited to 30%

Wind Band

Deviation: UI & OI of 15%/20% of AvC

Solar/Hybrid Band

Deviation: UI & OI of 10%/15% of AvC
DSM: 10%/50% for UI & 100% of OI

Max loss limited to 50% (UI) and 100% (OI)

Wind Band

Deviation: UI & OI of 15%/20% of AvC

Solar/Hybrid Band

Deviation: UI & OI of 10%/15% of AvC
DSM: 10%/100%

Max loss 100% beyond deviation of 20% for Wind and 15% for Solar/Hybrid of AvC

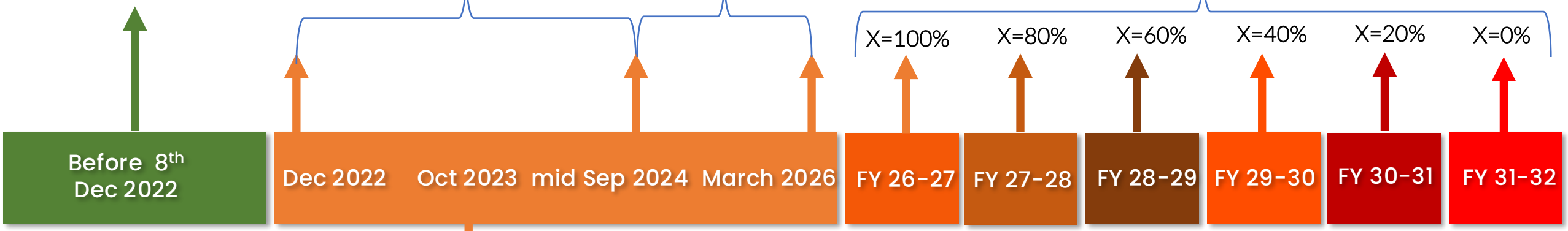
Wind Band

Deviation: UI & OI of 10%/15% of sum of X% of AvC and (100%-X%) of Schedule

Solar/Hybrid Band

Deviation: UI & OI of 5%/10% of sum of X% of AvC and (100%-X%) of Schedule
DSM: 10%/100%

Max loss 100% beyond deviation of 15% for Wind and 10% for Solar/Hybrid of value shifting from AvC towards Schedule



Schedule Implementation from 4th Time Block

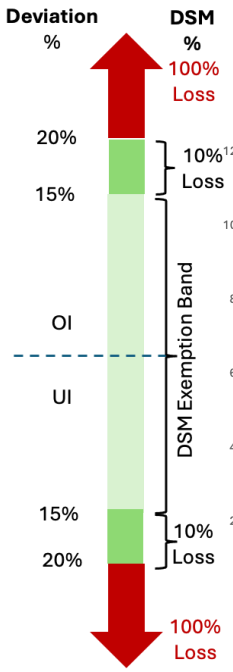
Schedule Implementation from 7th/8th Time Block

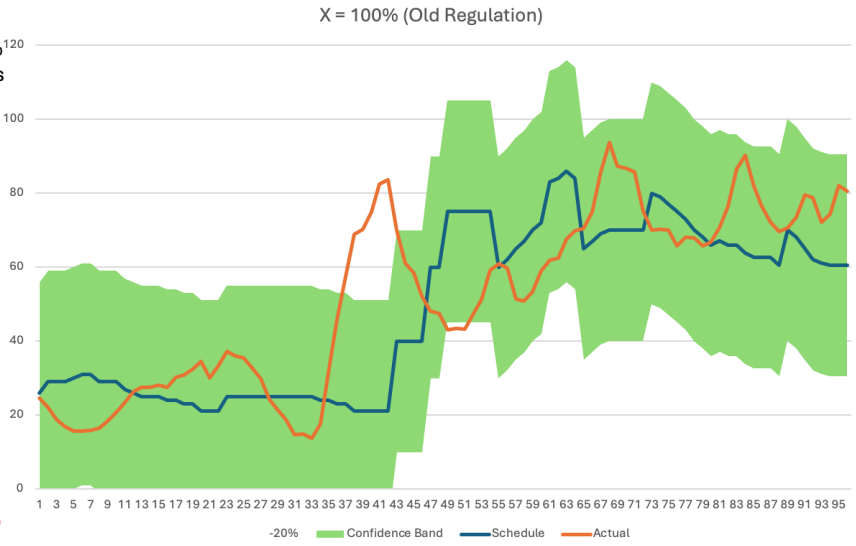
Major Evolution

CERC Wind Regulation way forward

CERC Regulation till March 2026

For WIND

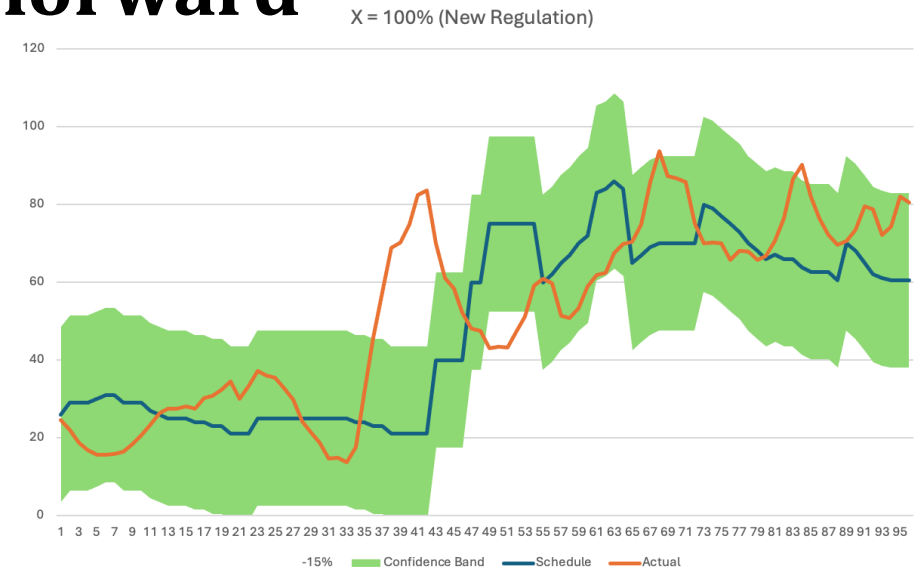




Deviation % = (Actual-Scheduled)

100% of AvC

CERC Regulation for FY26-27

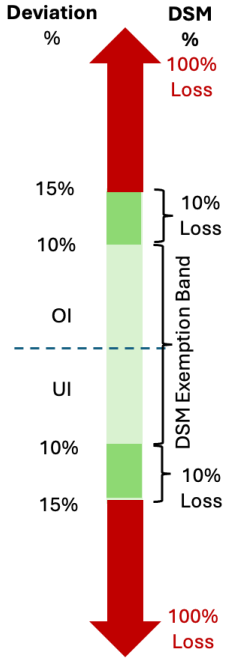


Deviation % = (Actual-Scheduled)

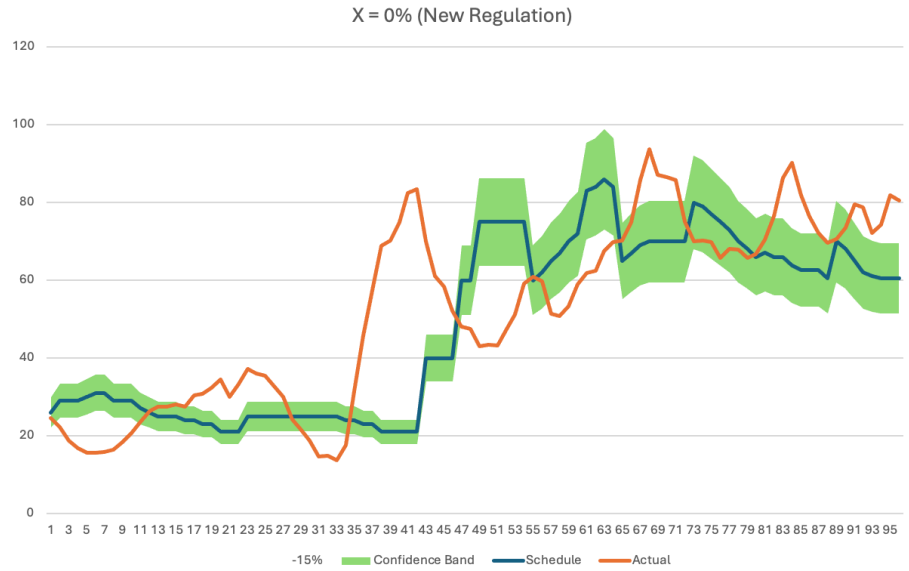
100% of AvC+0% of Schedule

X=100%

For WIND



CERC Regulation meant for FY31-32



X=0%

Deviation % = (Actual-Scheduled)

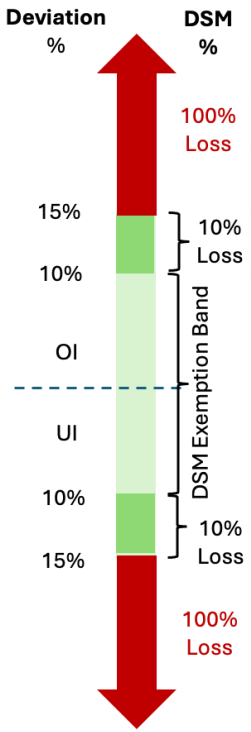
0% of AvC+ 100% of Schedule

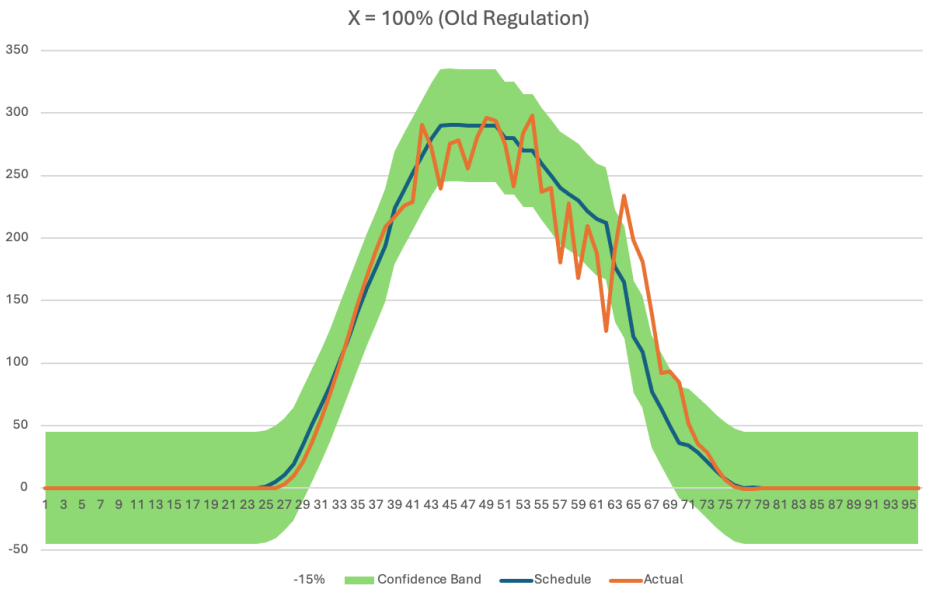
Major Evolution

CERC Solar Regulation way forward

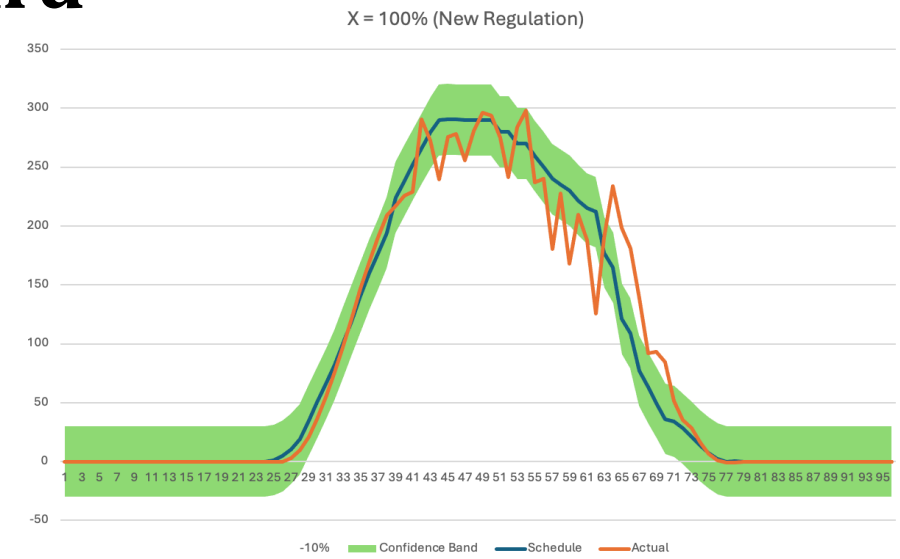
CERC Regulation till March 2026

For Solar

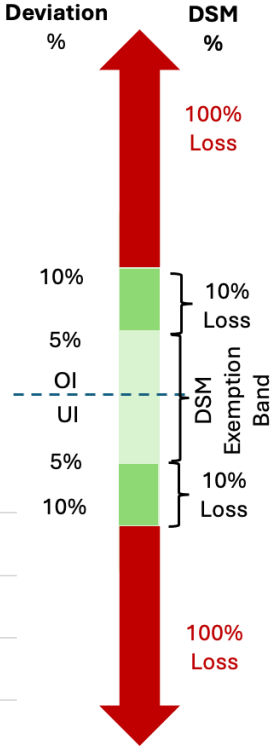




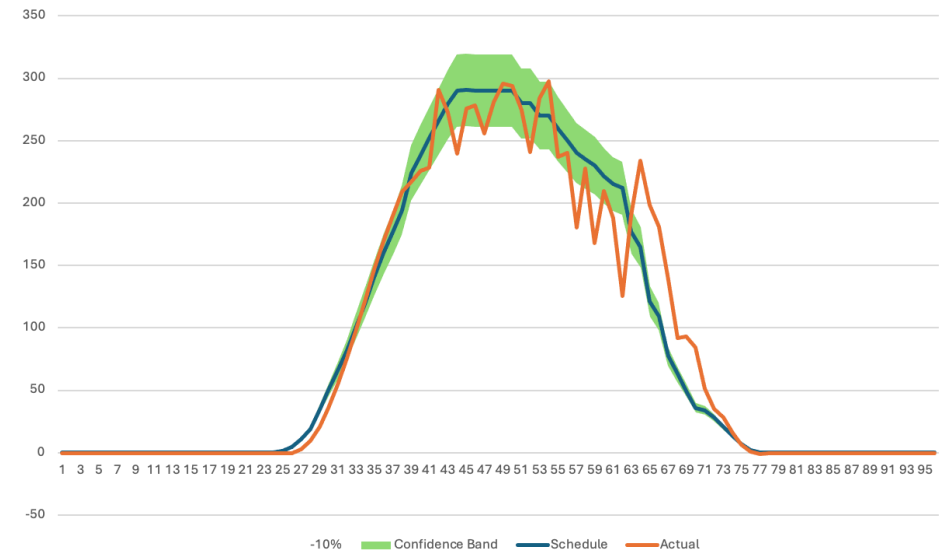
CERC Regulation applicable for FY 26-27



For Solar



CERC Regulation applicable for FY 2031 onwards



What changed conceptually?

UI (2000–2014):

frequency-linked charge mainly to discourage undisciplined deviations.

DSM (2014 onward):

A full commercial framework—clear caps/limits, settlement timelines, treatment of sustained deviations, and progressive integration with forecasting/ancillary services.

2009–2014:

UI → DSM shift; first CERC DSM (2014) linked charges to frequency bands. States began adopting FOR model F&S/DSM for RE.

2015–2019:

Early state F&S regulations (e.g., KERC 2015; GERC 2019) set QCA concept, forecast bands, and RE deviation charges at state periphery.

2024:

Comprehensive CERC DSM 2024 notified—granular limits for buyers/sellers, segregation among sellers (General sellers/ RoR/ Wind/ Solar/ Hybrid/ Municipal Solid Waste), ramping violations, RRAS/AGC interactions.

2023–2024:

IEGC 2023 overhauls scheduling/dispatch (reserves, SCUC concepts, revision windows, ESS treatment).

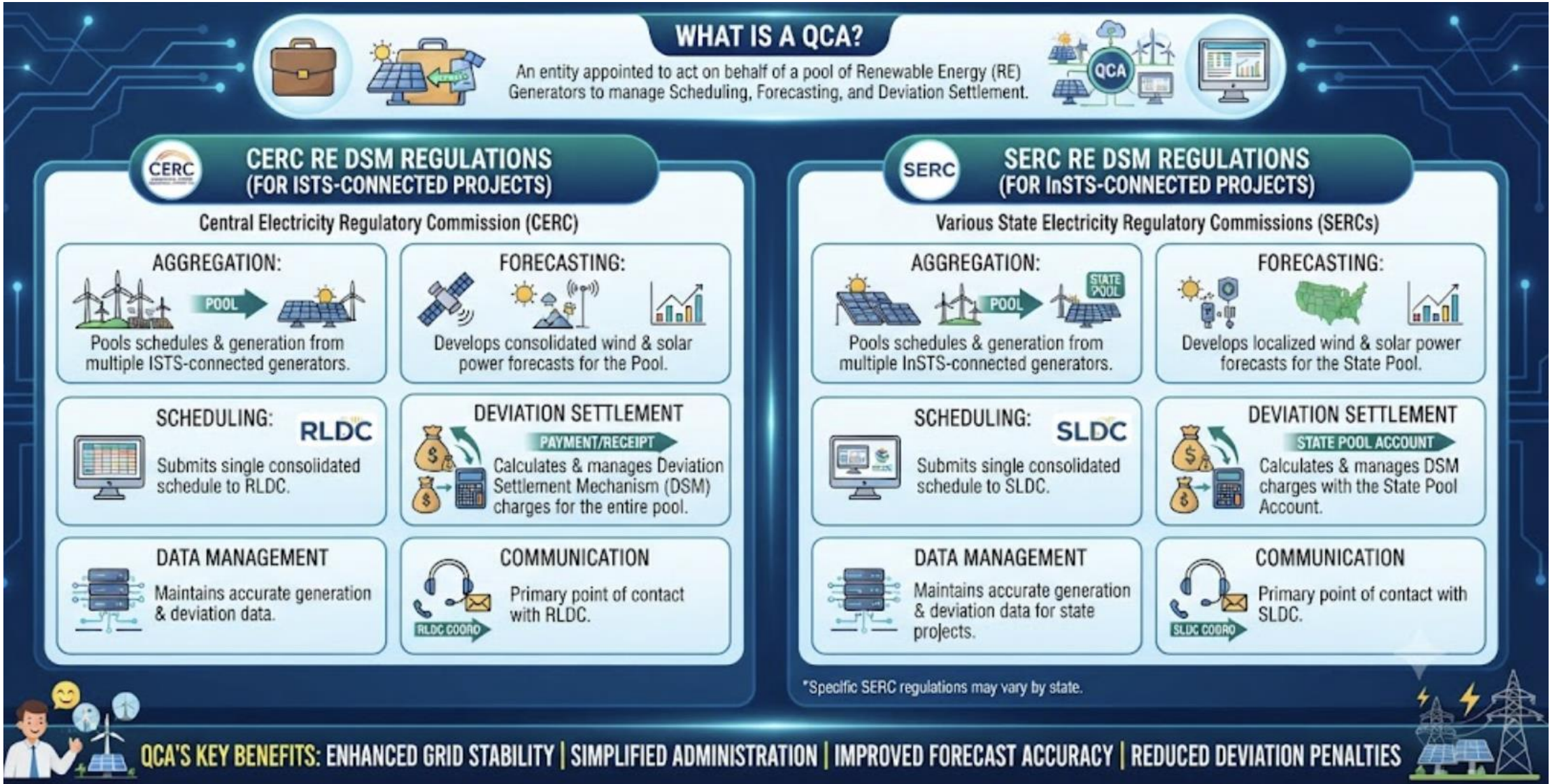
Role of Qualified Coordinating Agency (QCA) in RE DSM

Means the agency coordinating on behalf of Wind/Solar Generators connected to a pooling station. QCA may be one of the generators or any other mutually agreed agency for the following purposes:

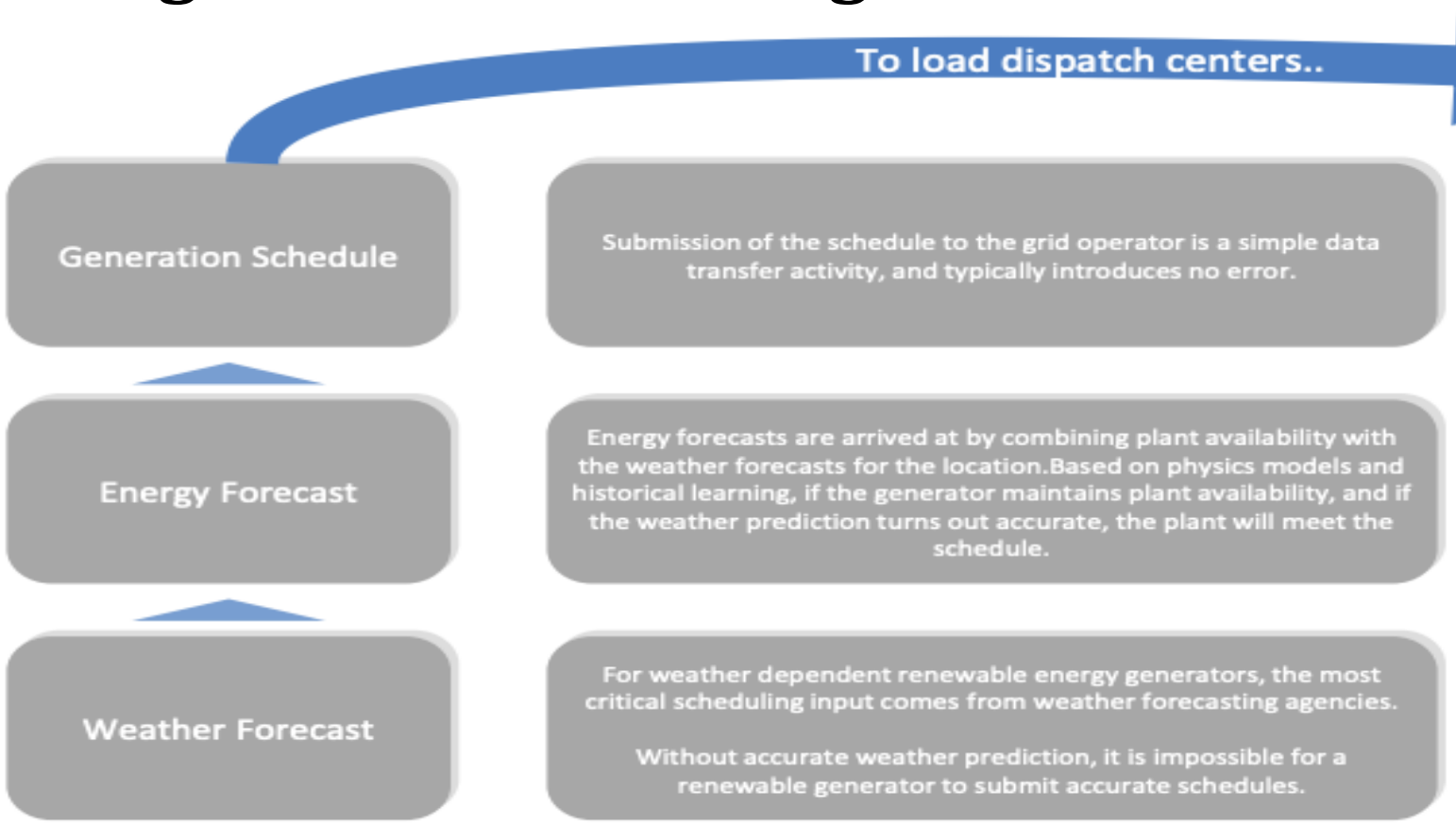
- Provide schedules with periodic revisions as per this regulation on behalf of all the Wind/Solar Generators connected to the pooling station(s).
- Responsible for metering, data collection/transmission, communication, Coordination with DISCOMS, RLDC/SLDC and other agencies.
- Undertake commercial settlement of all charges on behalf of the generators, including payments to the State UI pool accounts through the concerned RLDC/SLDC.
- Undertake de-pooling of payments received on behalf of the generators from the State UI Pool account and settling them with the individual generators.
- Undertake commercial settlement of any other charges on behalf of the Generators as may be mandated from time to time.

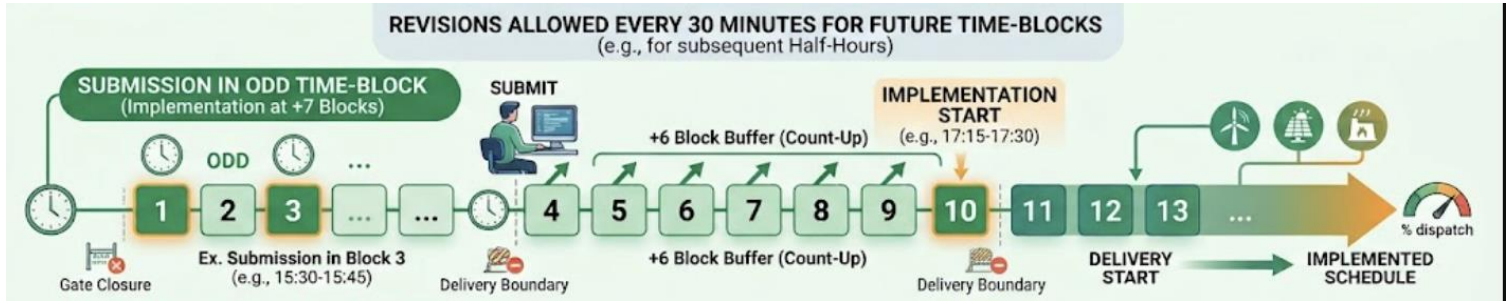
- QCA shall be treated as a State Entity/Nodal Agency.

Role of Qualified Coordinating Agency (QCA) in RE DSM



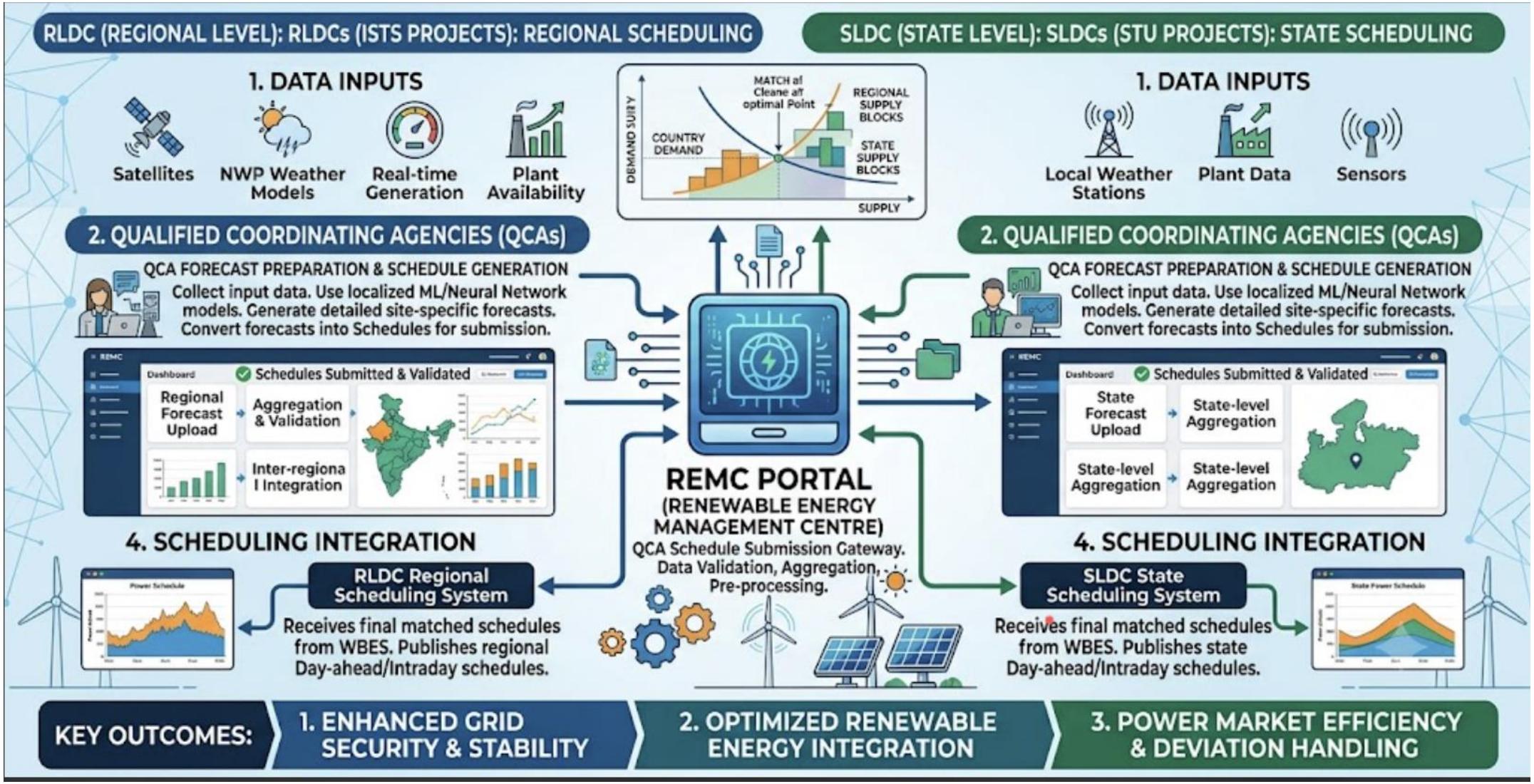
What goes into Scheduling





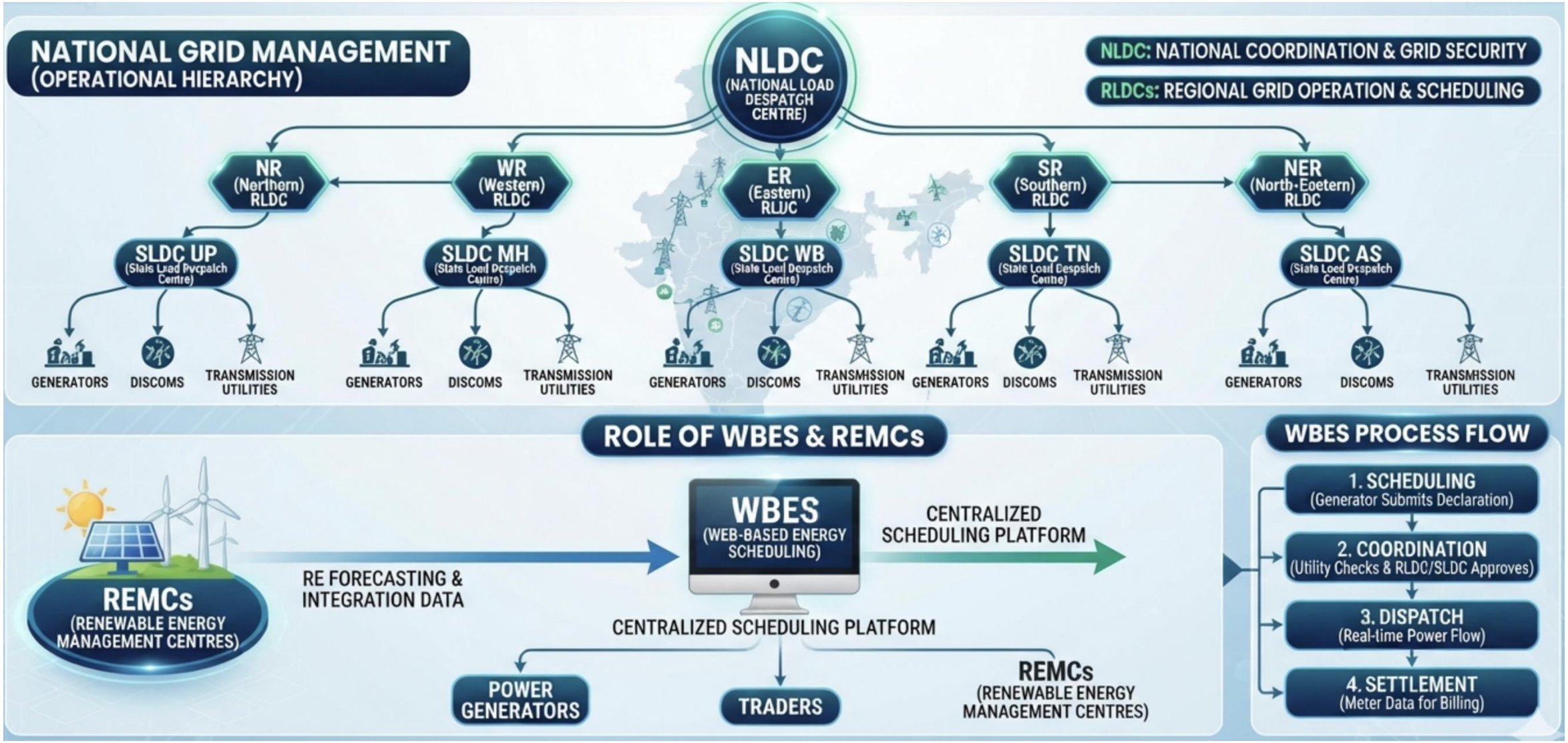
- Day Ahead Planning for every 15 minute time block based on Forecasting Result and Real time Sudden Changes.
- Schedules take into consideration issues such as Grid availability, Machine maintenance, Feeder Availability, No. of turbine/inverter availability etc.
- The process of generating schedules based on the forecast created on day ahead or intra-day basis for a certain time block (fifteen minutes) for the proper dispatch of energy.

How Schedules submitted by QCA are consumed by LDCs



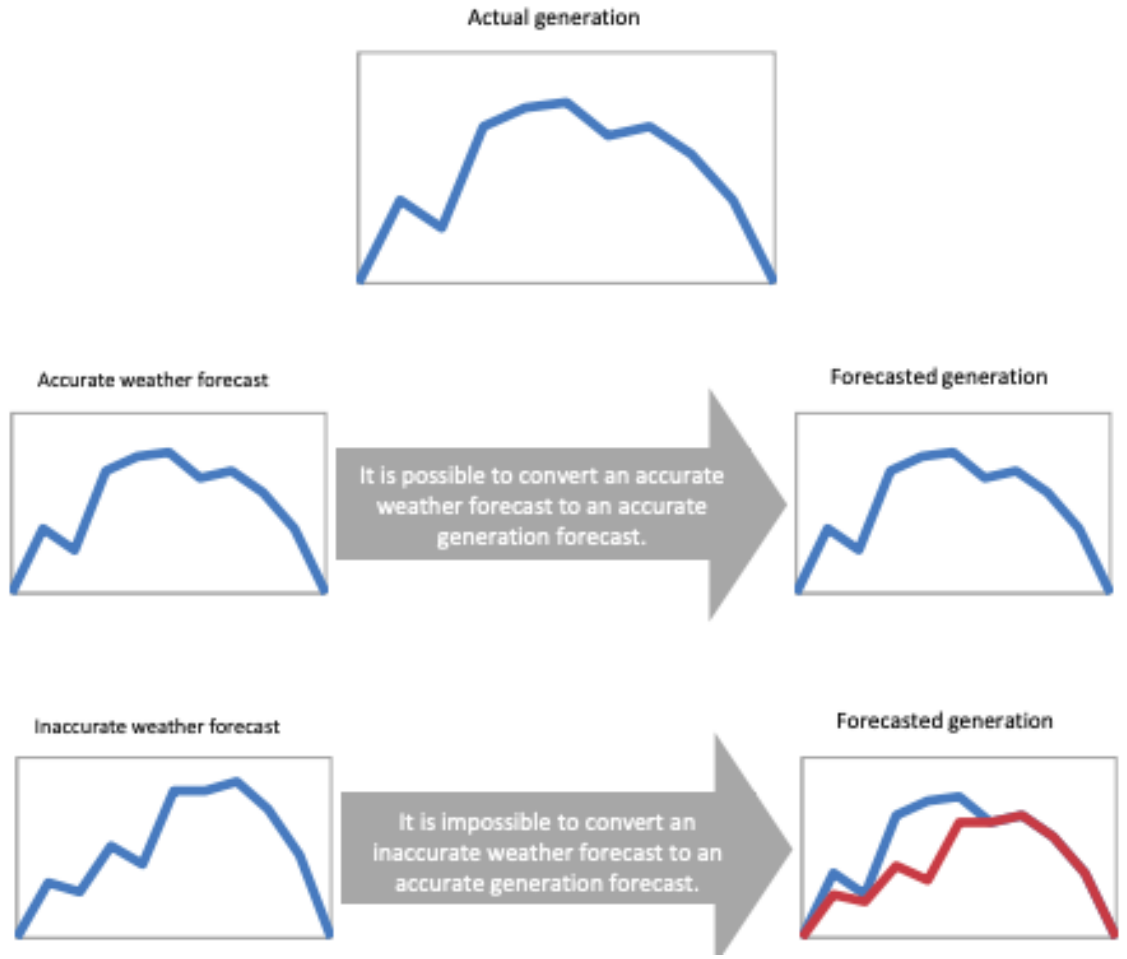
Forecasting and Scheduling Workflow

How RE Schedules finally integrate with One India Grid



What is Forecasting

- Process of prediction of power of wind/solar energy that will be available for generation on next day.
- Forecasting is done with the help of forecasting tools which combines different types of data from different sources and is combined into an algorithm based on machine learning for better accuracy .
- Wind and solar forecasting is the process wherein weather parameters at given geographical locations are predicted which involves the knowledge of wind speed/Sun's path and the other atmospheric conditions , the scattering process and the characteristics of a solar energy plant which utilizes wind or sun's energy to generate power.



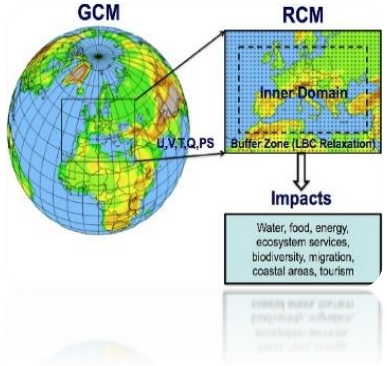
The major source of in-accuracy is the weather.

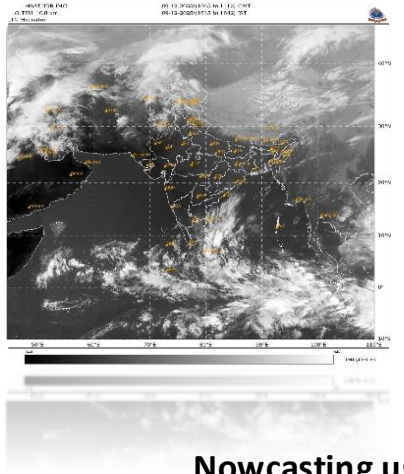
Details of Forecasting Methodology used Globally

	NWP based forecasting	Satellite based forecasting	Total sky imager	Statistical approaches with AI/ML
Refresh rate	6-24 hours	0.5-24 hours	< 1 minute	0.5 - 2 hours
Forecast's temporal resolution	1-6 hours	Minutes	Minutes	< 15 minutes
Forecast's spatial resolution	4-120 sq km	> 1 sq km	Local surroundings	< 1 sq km
Best forecast accuracy achieved	> 6 hours ahead	1-6 hours ahead	< 0.5 hour ahead	Short term
RMSE (local, hour ahead)	Very high	20-25%	Not available	N/A
RMSE (large grid, day ahead)	20-60%	~ 5%	No long term forecast	N/A

Approaches to Forecast

Approaches of Forecast





Nowcasting using satellite imagery

cloud motion vectors

Ultra Short Term Forecast / Nowcasting

Few min. to 3 hr. ahead

NWP Prediction & statistical model

- WRF
- LSTM/XGBOOST/RF etc.

Short Term Forecast

(3hr to 72hr)

- **Global and regional NWP models**
- Use with higher lead-time
- Ensemble NWP systems (Ensemble Prediction System) to capture spread/uncertainty

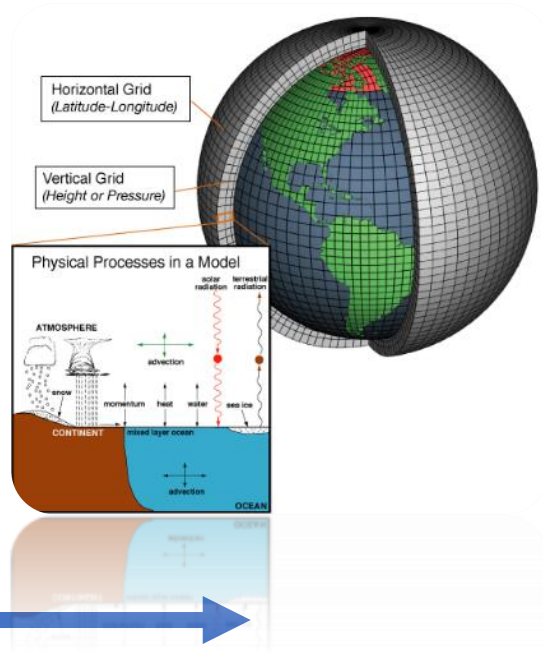
Medium Term Forecast

(3 days to 1 week)

- **Climate Data for RE**
- Historical climatology + anomaly prediction
- Downscaled climate projections for RE planning

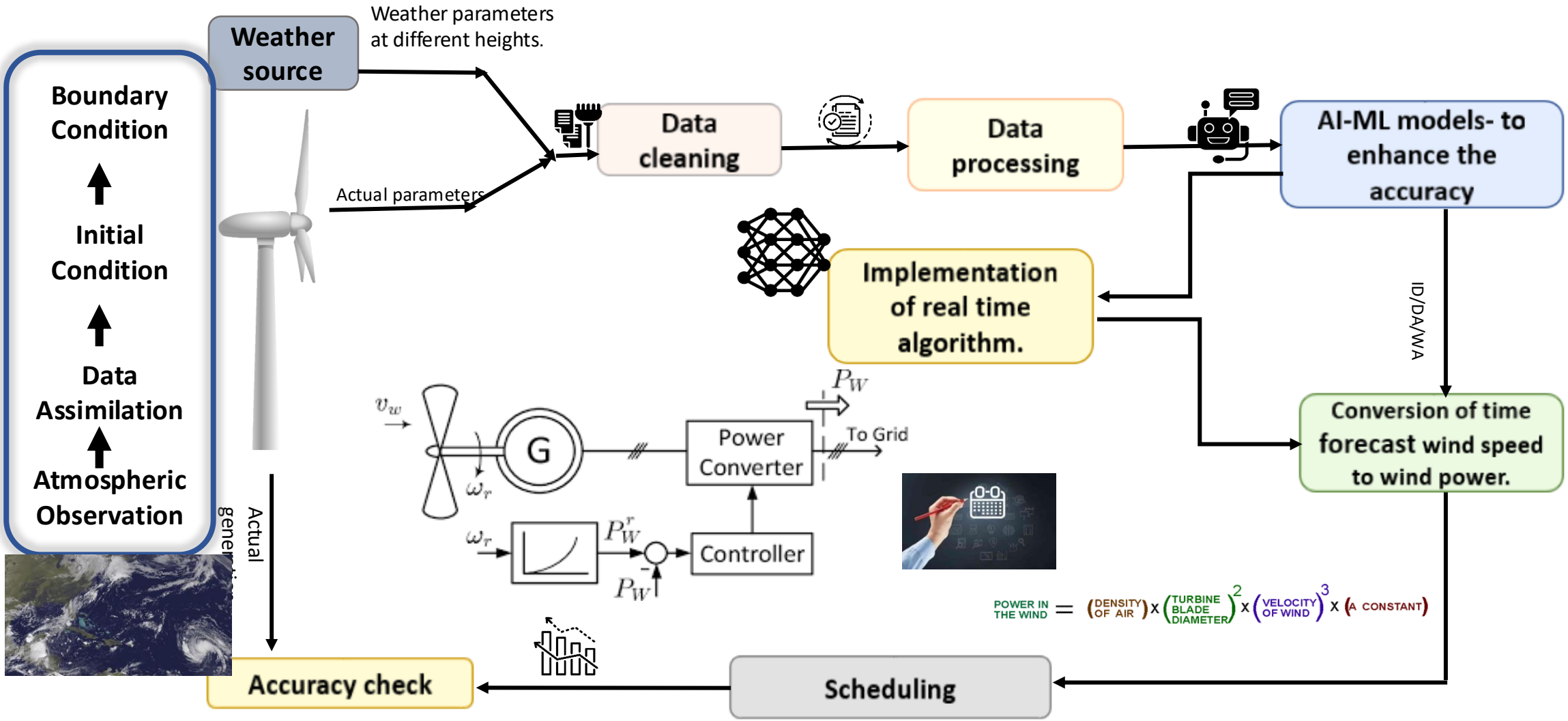
Long Term Forecast

(1 month to 1 yr. ahead)

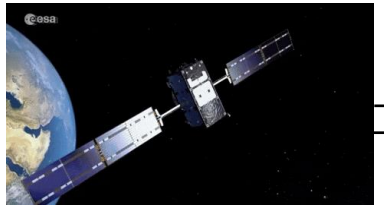


Forecast Lead Time

Wind Forecasting



Solar Forecasting



Satellite Data

Level-1,Level-2, etc.

Cloud classification

Cloud movement

GHI Forecasting

Scheduling

Accuracy check

MAE,MAPE, RMSE,NMAPE,NRMSE.

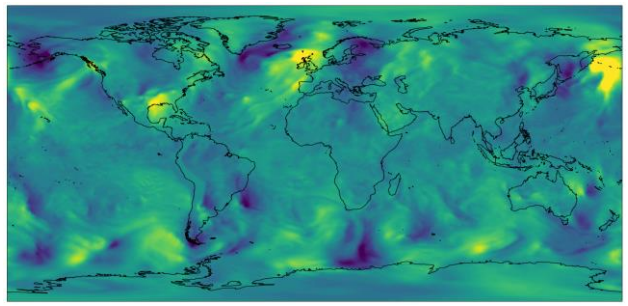
Actual data from SCADA

Data preparation

Extract data for required hour.

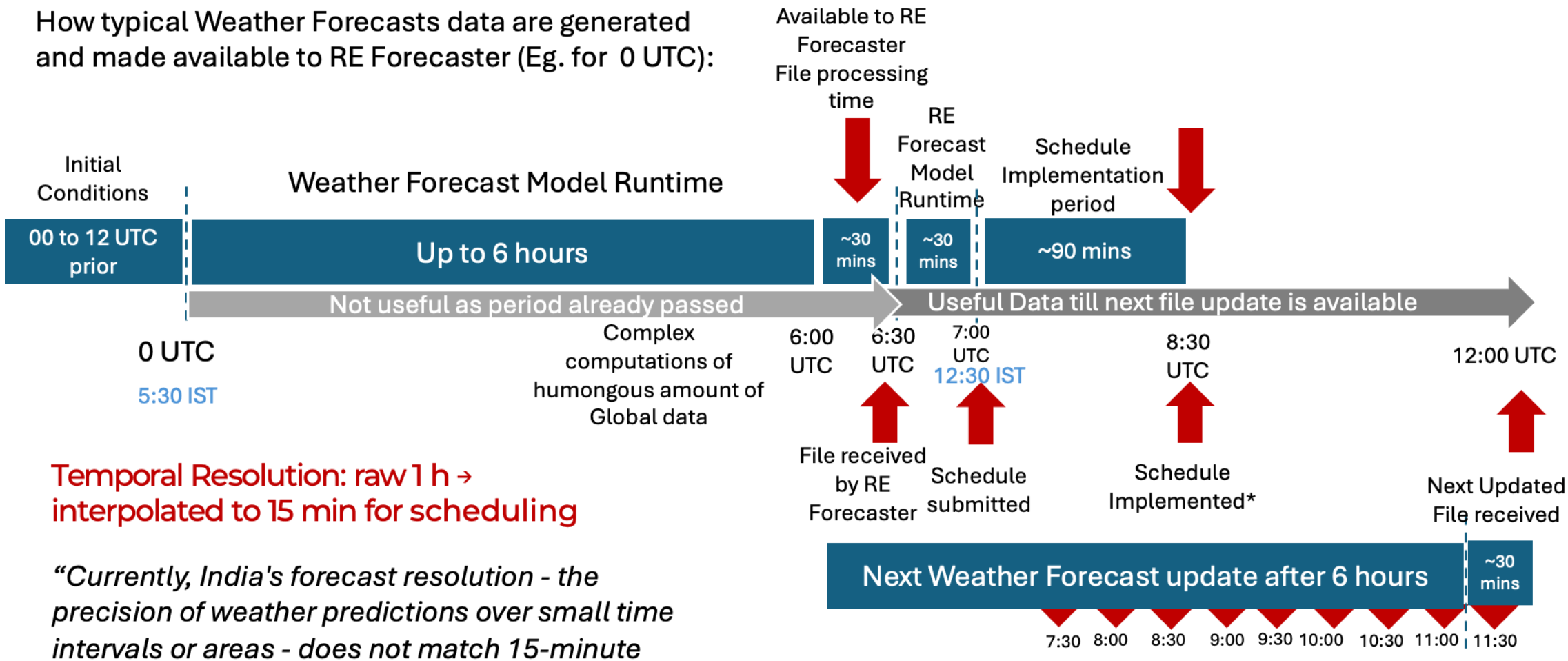
Weather forecast

Irradiance, Cloud cover, Temperature, Wind speed and Direction



Impact of Frequency/Timings on Forecast Accuracy

How typical Weather Forecasts data are generated and made available to RE Forecaster (Eg. for 0 UTC):



Subsequent half hourly Revision window open but no new weather forecast available to make changes on weather input. Any schedule revision relies on real-time site data but the 7/8 TB implementation

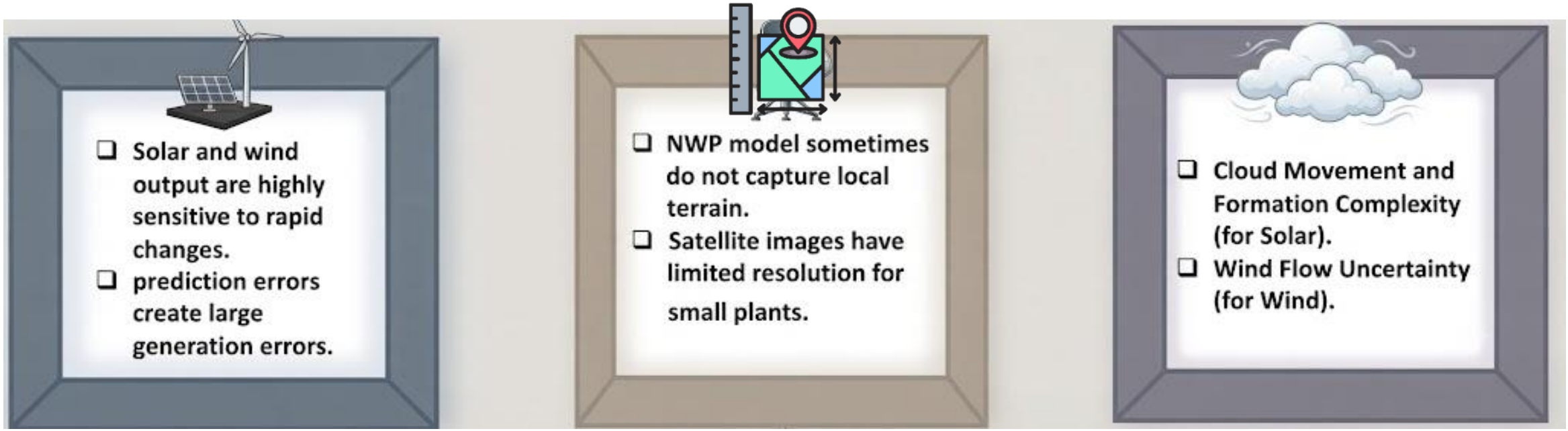
Temporal Resolution: raw 1 h → interpolated to 15 min for scheduling

"Currently, India's forecast resolution - the precision of weather predictions over small time intervals or areas - does not match 15-minute operating cycles of the power grid."

* On initial condition data that is more that 12 hour older

Solar & Wind Forecasting

Spatial and Temporal Resolution Limitations



Strong Dependence on Weather Uncertainty

Uncertainty in Wind, Cloud, and Fog

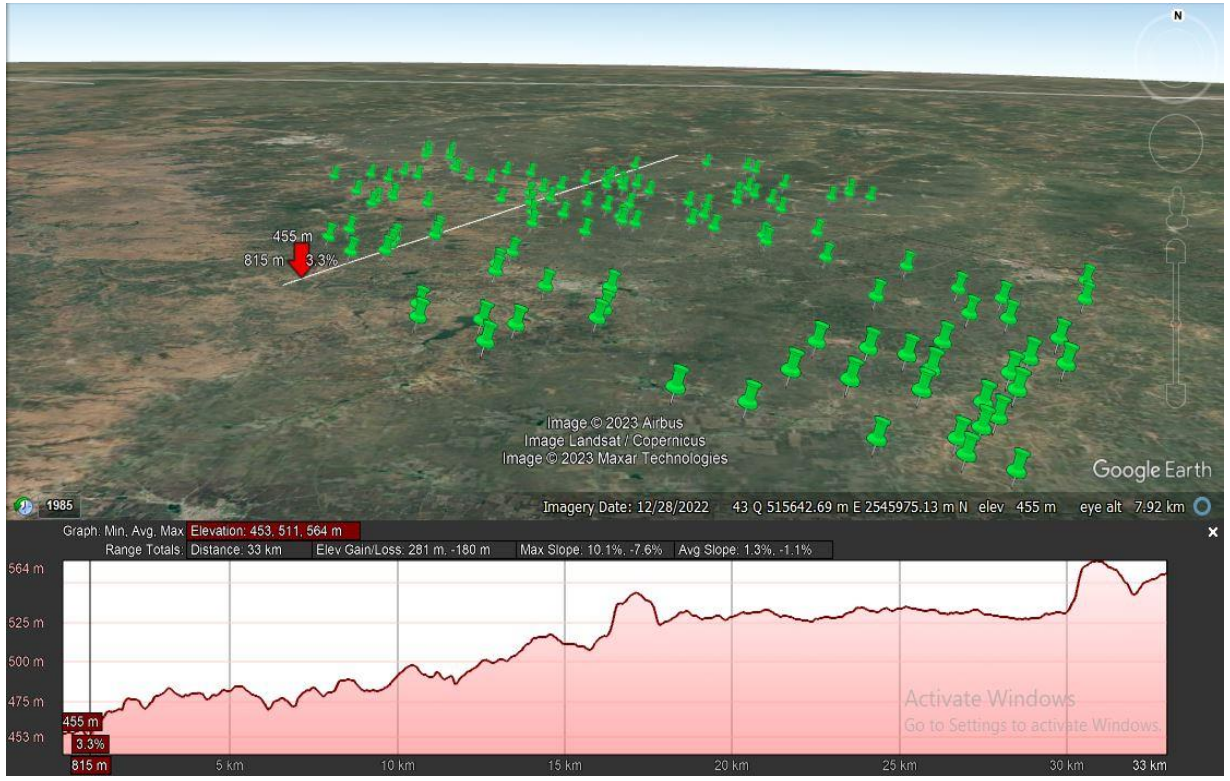
Dynamics of Cloud: Local Cloud Formation Uncertainties

Sudden cloud emergence and dissapearence over a large area not captured in any weather forecast

Dynamics of Cloud: Cloud Movement Uncertainties

Strong cloud Emerding from West but dissappearing close to the border on first day but similar clouds on next day is reaching and covering almost half of North India

SITE CONDITIONS and COMPLEXITY



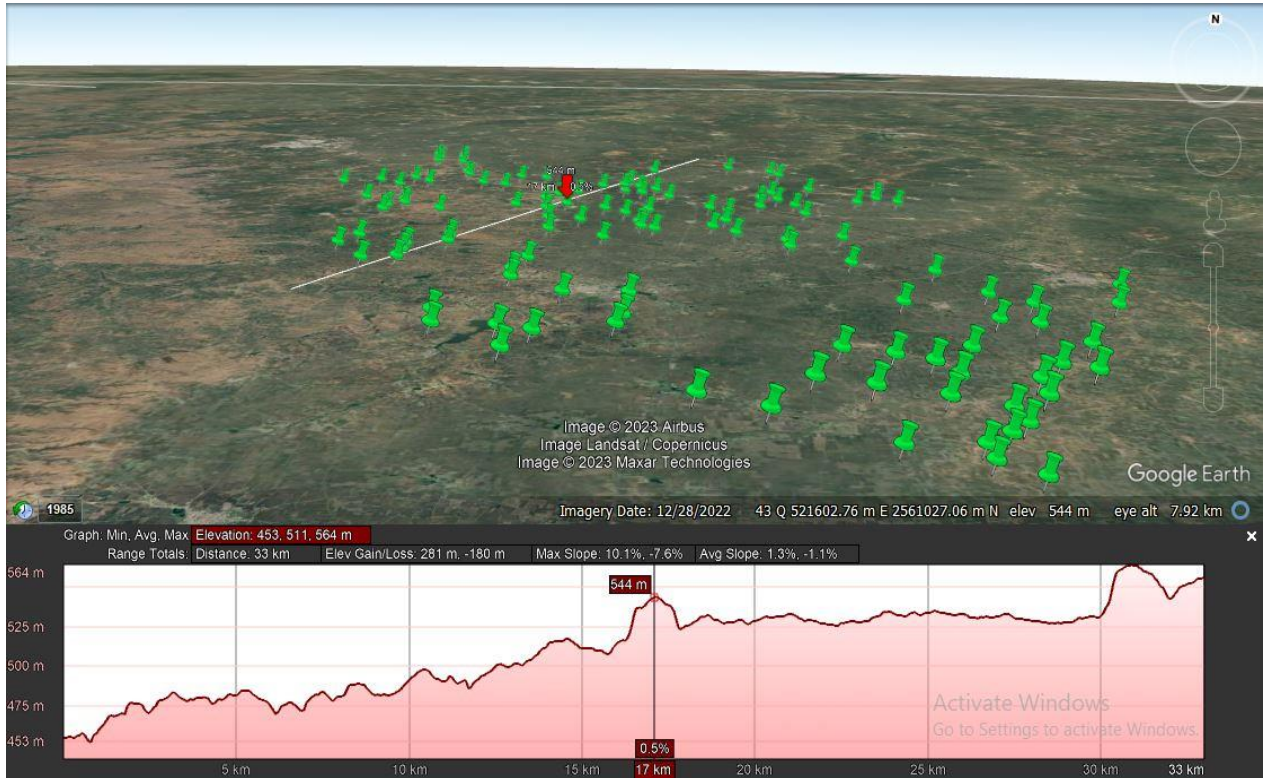
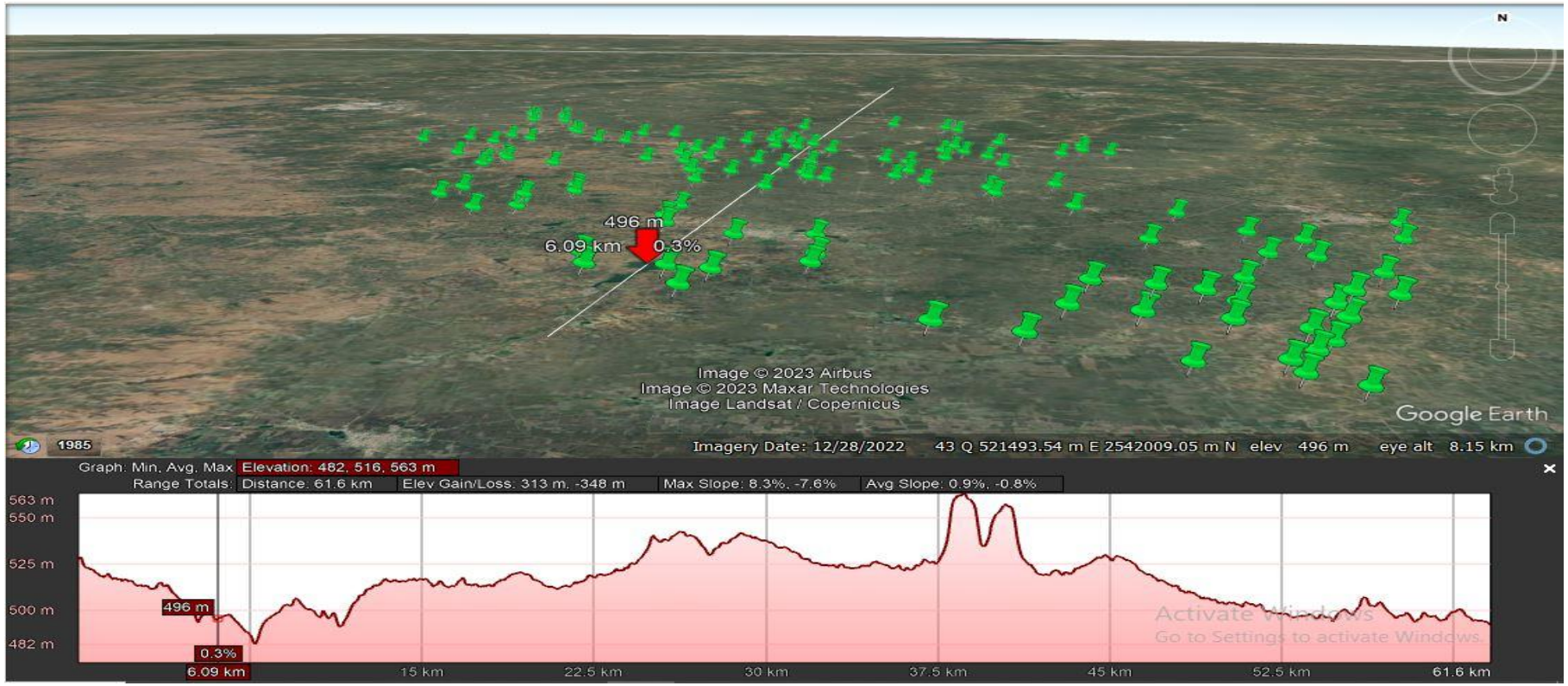


Image 1 ***Image 2***

Pre-dominant wind speed direction view: The site is surrounded by uneven surface. Deep depressions at 455 meters above MSL creates local disturbances due to turbulence characteristics (refer Image 1), while the turbines are located at higher altitudes around 540 mtr. (refer image 2).

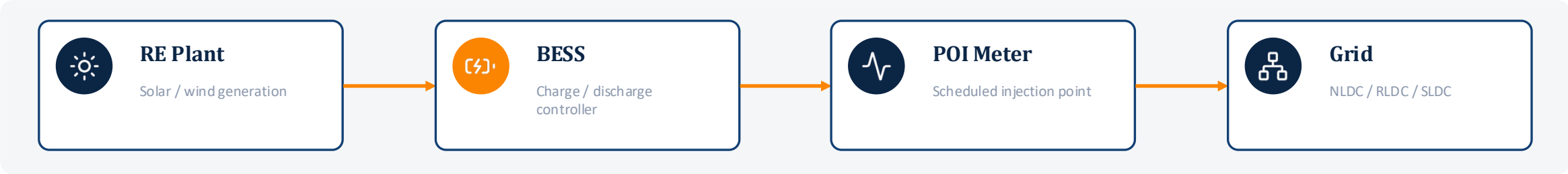
SITE CONDITIONS and COMPLEXITY



Water body affecting wind: On South-West side of the sites has a water body at 496 meters above MSL and many such water bodies present in site vicinity. Resulting local disturbances due to temperature difference caused by water body which drastically changes the wind velocity.

How BESS Plugs Into an Existing RE Plant

One physical asset, two possible jobs — a mandatory one and an optional one that depends on the regulator.



Excess generation charges the battery; the controller times discharge to keep injection on schedule at the meter.

DISPATCH PRIORITY — WHAT THE BATTERY DOES FIRST

PRIORITY 1 — ALWAYS ON

DSM / Deviation Correction

Charge/discharge automatically to hold injection within the contracted schedule and avoid deviation charges — the primary, regulator-mandated use case today.

PRIORITY 2 — CONDITIONAL

Energy Arbitrage (DAM / RTM)

Use spare headroom to buy low / sell high across day-ahead & real-time prices. Not currently permitted under India's DSM framework for RE-paired storage — forward-looking only.

Illustrative revenue index (DSM-only = 100)

Arbitrage doesn't replace the DSM use case — it rides alongside it, using the same battery more fully, only once regulation allows it.

At Full Parity: Sizing for the Whole Distribution

When X = 0% — new projects bid from 2027, and all existing projects from April 2031 — there is no band left to lean on. Every MWh of deviation is chargeable, so storage must buffer the full intraday error profile.

	Case 1: Residual Band (pre-2027/31)	Case 2: Full Parity (post-2027/31)
Design target	Cover tail excursions beyond the band	Buffer the full forecast-error distribution
Duration profile	Short-duration, event-triggered response	Longer duration to hold schedule through ramp events — similar to firm/RTC RE-plus-storage designs
Indicative sizing*	Smaller — roughly 10–15% of AC capacity, ~1-2 hr	Larger — roughly 25–40% of AC capacity, 2–4 hrs
Primary revenue logic	DSM-avoidance first, arbitrage as upside	Firming capability is priced into the bid itself
Bidding implication	Retrofit / optional value-add	Becomes a mandatory design input at RFP stage

**Illustrative ranges only — actual sizing is resource- and project-specific (solar vs wind error profiles, plant location, contracted band, arbitrage market depth).*

BESS Shifts From Optional to Essential

Once the exemption band disappears, forecast error stops being "free" — storage becomes the tool that absorbs it before it reaches the meter.

Without Paired Storage

- Full exposure to every MW of forecast error, from the first block
- Deviation charges scale directly with resource variability — cloud transients, wind gusts, ramp events
- Revenue becomes materially less predictable, raising the cost of capital for the project
- DISCOMs still expect near-scheduled delivery — mismatch risk falls entirely on the generator

With Paired Storage

- Short-term forecast errors are buffered inside the plant, before they ever hit the interconnection meter
- RE + BESS starts to behave like a "schedule-following" resource, not a pure weather-dependent one
- Deviation-charge exposure becomes a design parameter — sized deliberately, not left to chance
- Opens the door to additional revenue: ancillary services and price arbitrage alongside DSM mitigation

BRINGING IT HOME

Takeaways for Grids Starting This Journey

Start early

Put a scheduling & settlement framework in place before RE penetration becomes a systemic grid-security risk — not after.

Phase it in

Follow India's 2014→2019 arc: a generous grace band first, tightened gradually and predictably as forecasting infrastructure matures.

Standardise first

Build QCA capacity, metering, and a single national formula before tightening penalties — RRF failed on fragmentation, not intent.

Price risk forward

Signal future tightening in today's PPAs and tenders so tomorrow's regulation is priced in, not litigated after the fact.

Design for storage early

Build BESS/firming expectations into bid design as RE share grows, rather than retrofitting after grid stress appears.

Calibrate to your grid

Match error bands and any 'X-factor'-style glide path to your own RE penetration level and forecasting maturity — don't copy a template blindly.

Definitions & basic concepts

Scheduling: Day-ahead and real-time issue of injection/drawl schedules for each entity by NLDC/RLDC/SLDC as per the Indian Electricity Grid Code (IEGC) 2023. Revisions, ramping limits, reserves, technical minimum, curtailment hierarchy, etc., are codified there.

Forecasting (RE): Wind/solar generators (or their QCA/aggregators) submit time-block (15-min) generation forecasts used to form schedules; errors against schedule trigger deviation charges under SERC/CERC frameworks. Model regulations were drafted by the Forum of Regulators (FOR) and adopted (with variations) by states.

DSM: Commercial mechanism that settles deviation = actual – schedule at deviation charges linked to grid frequency and caps/limits, to enforce discipline and system security. The operative rule at inter-state level is CERC (Deviation Settlement Mechanism and Related Matters) Regulations, 2024 (as updated, and read with IEGC 2023 & its 2024 amendment.)

Thank You

Questions & Discussion

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