Predicting RE and Demand for Efficient Grid Management

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Introduction

Renewable energy (wind & solar) has become an important part of electrical generation in many countries and its importance is continuing to increase.

The amount of RE generation is growing rapidly and individual farms are growing in size and complexity.

The operation of the RE and its response to disturbances or other impacts on the power system is an increasing concern.

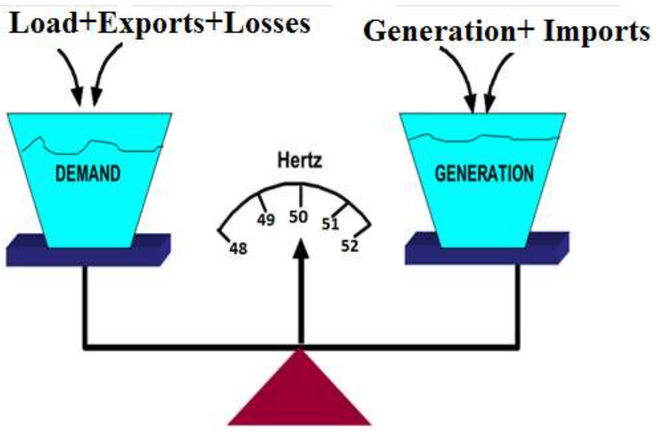
RE as a resource directly from the nature, is characterized by both variability and unpredictability and are thus coining them as Variable Generation (VG).

Introduction

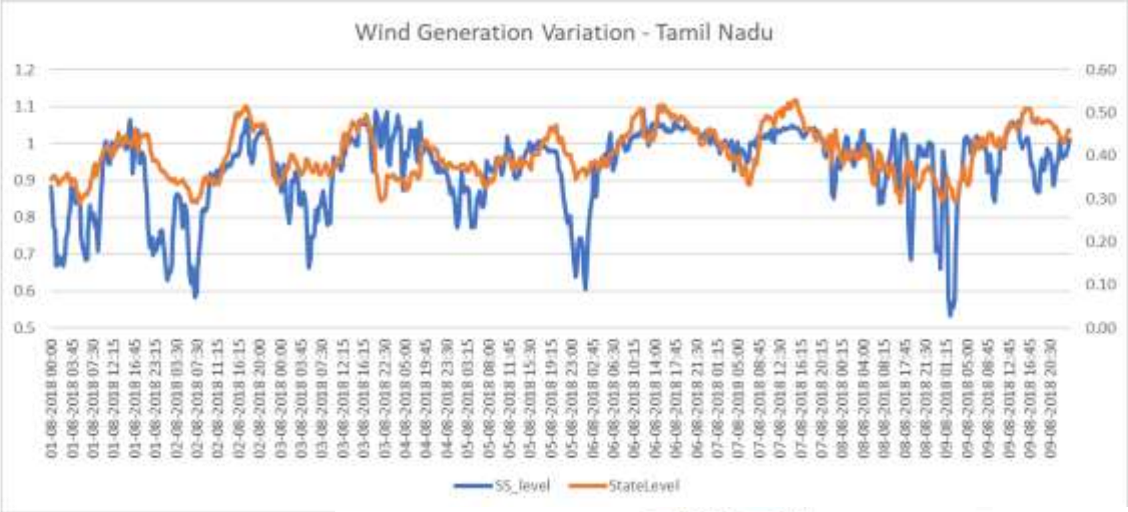
Curtailment of generation from wind and solar is a growing concern across the world

There is a need for operating the Renewable Energy as a Virtual Power Plant which should behave similar the conventional power plants in its operational characteristics

Challenges in System Operations

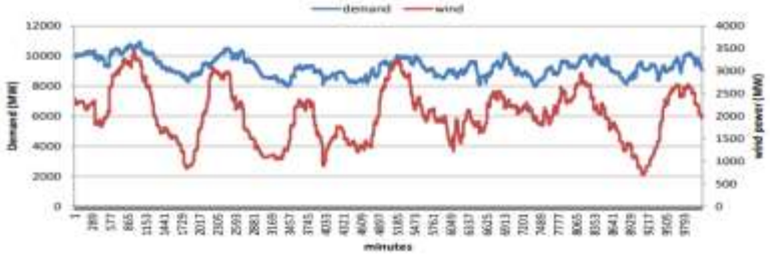


Load-Generation Balance



Conventional System

Only Demand is varying -> Demand Forecasting -> Generation follows the load



Addition of RE Generation

Both Demand and RE Generation are varying -> Demand + RE Power Forecasting

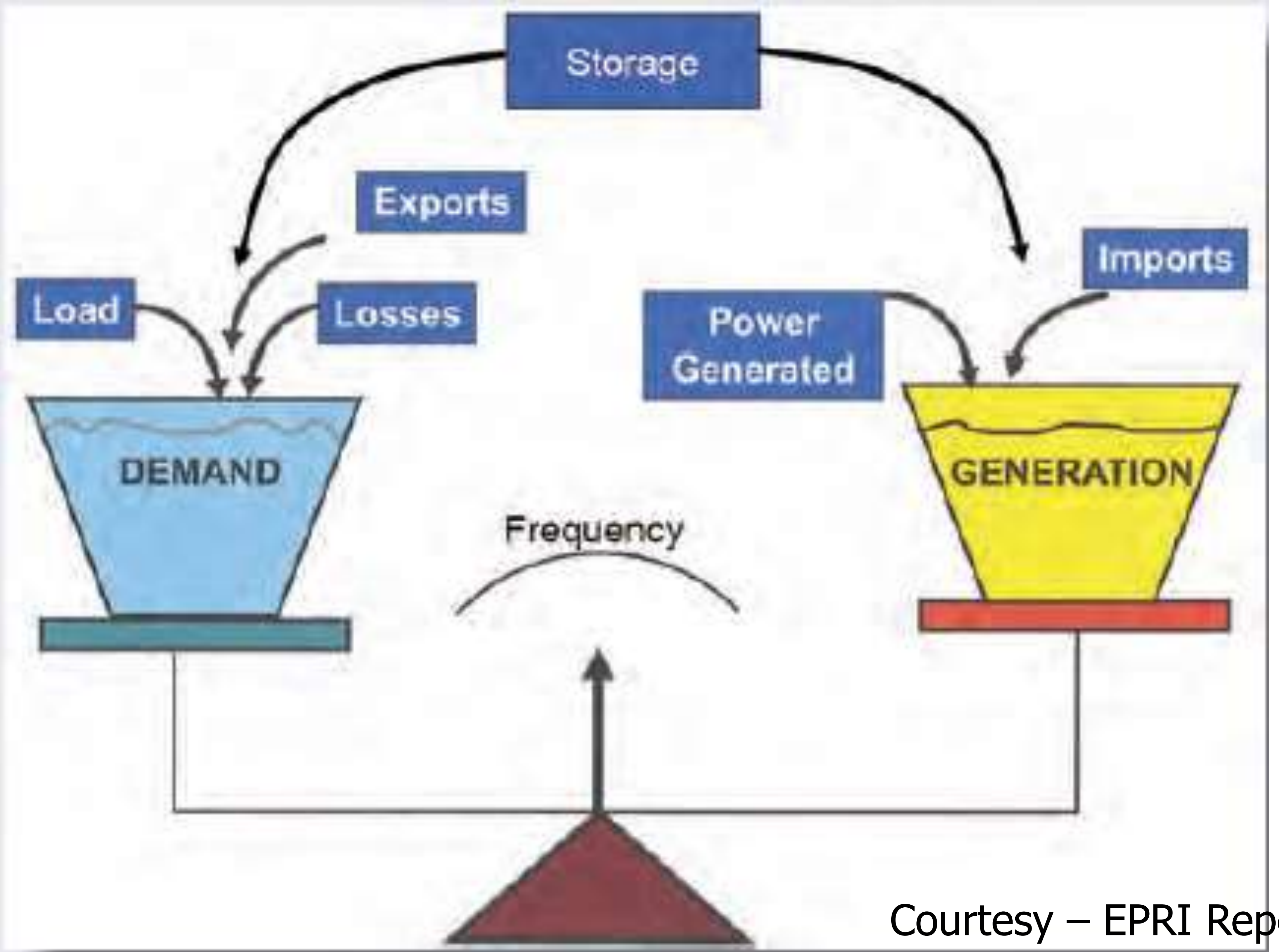
Efficient Grid Management

The objective of power system operation & control is to efficiently generate, transmit and distribute electric energy

For satisfactory operation of power system, the frequency should remain nearly constant

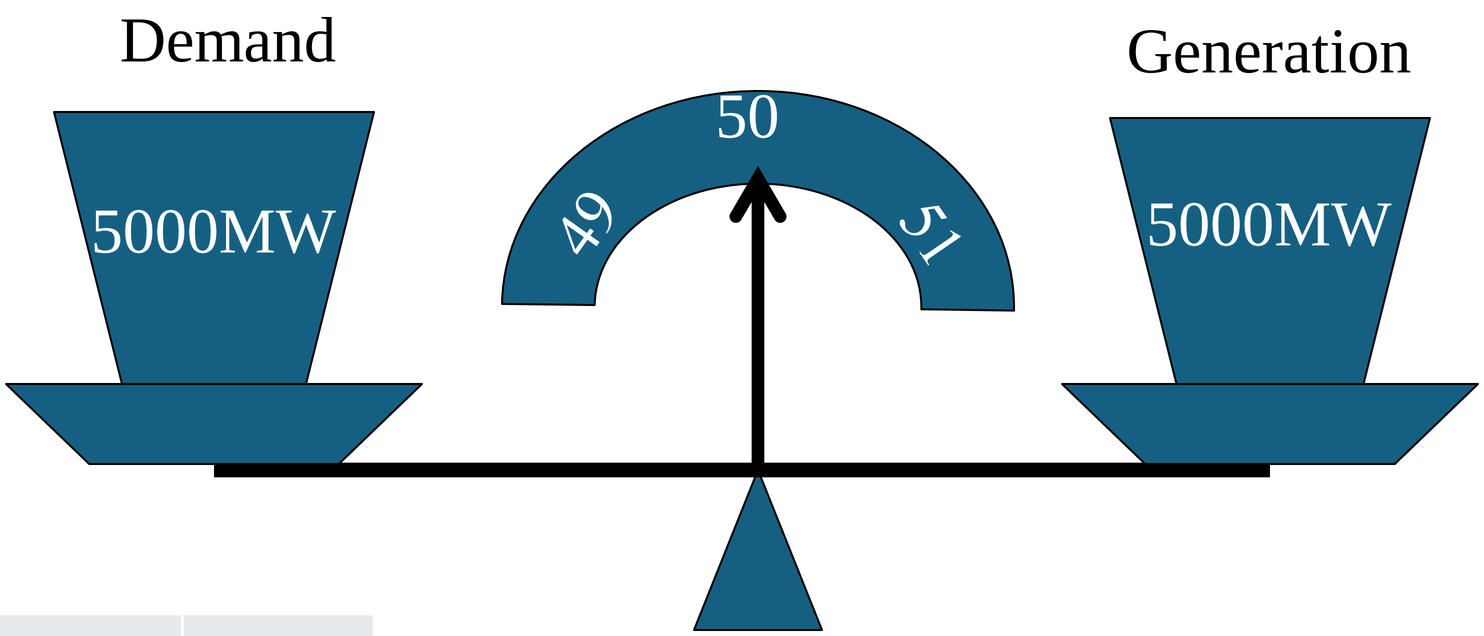
The frequency of the system is dependent on active power balance

Predicting Renewable Energy (RE) and demand becomes crucial, especially as the share of renewables in the energy mix increases

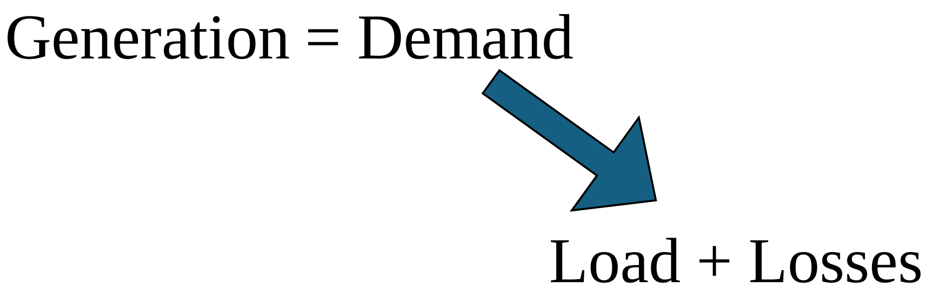


Courtesy – EPRI Report

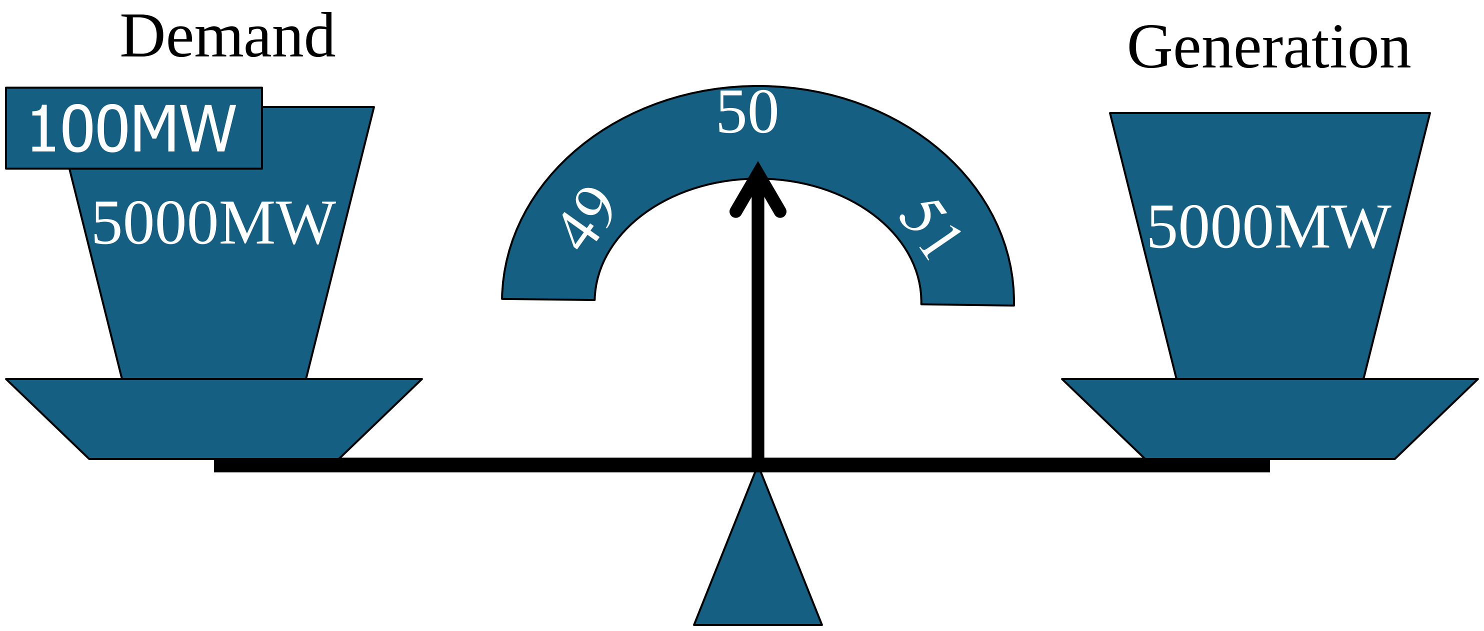
Grid management-An example



Total System load	5000
Load Damping	2%
Regulation	4%
Spinning reserve	5%



Grid management-An example...

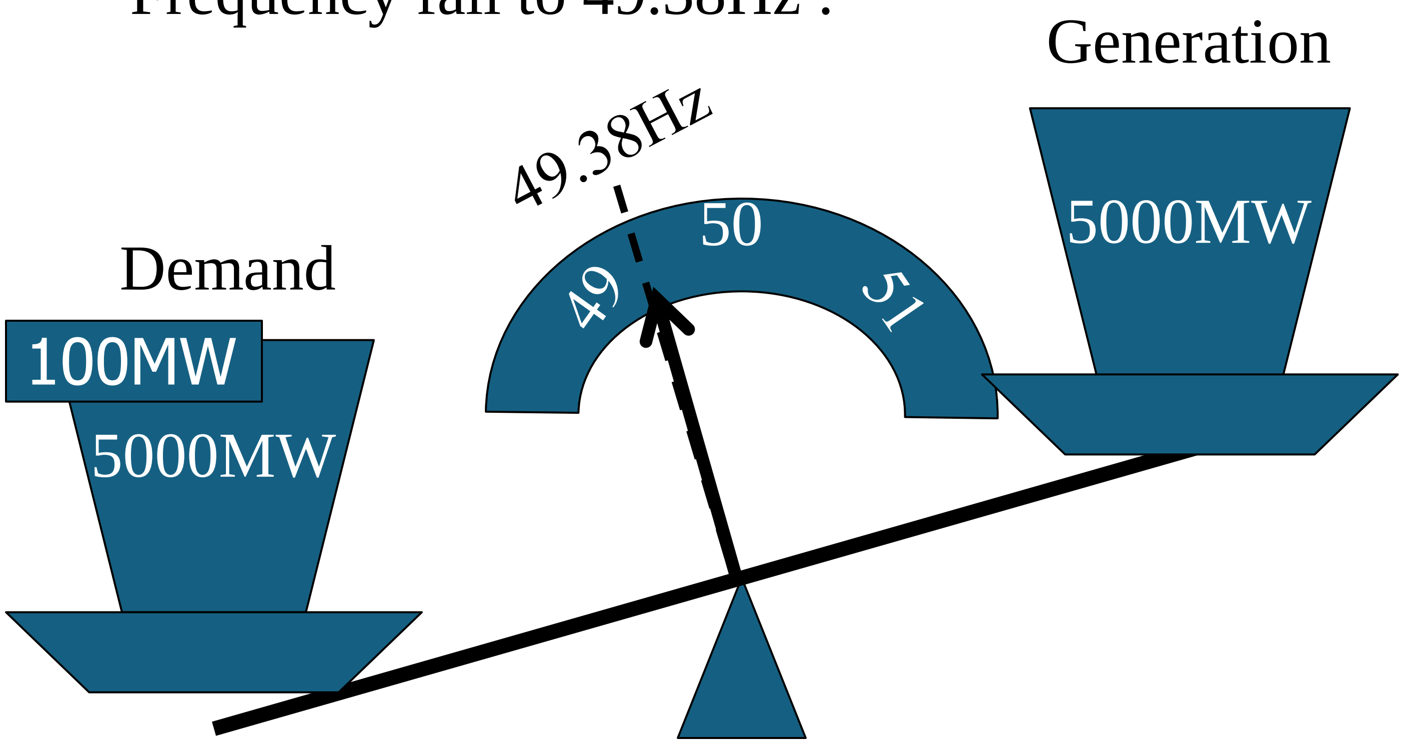


In milli second to second time frame:

Inertia of the rotating machine will supply addition load

Grid management-An example....

Frequency fall to 49.38Hz :



Seconds to Minute time frame:

Generation

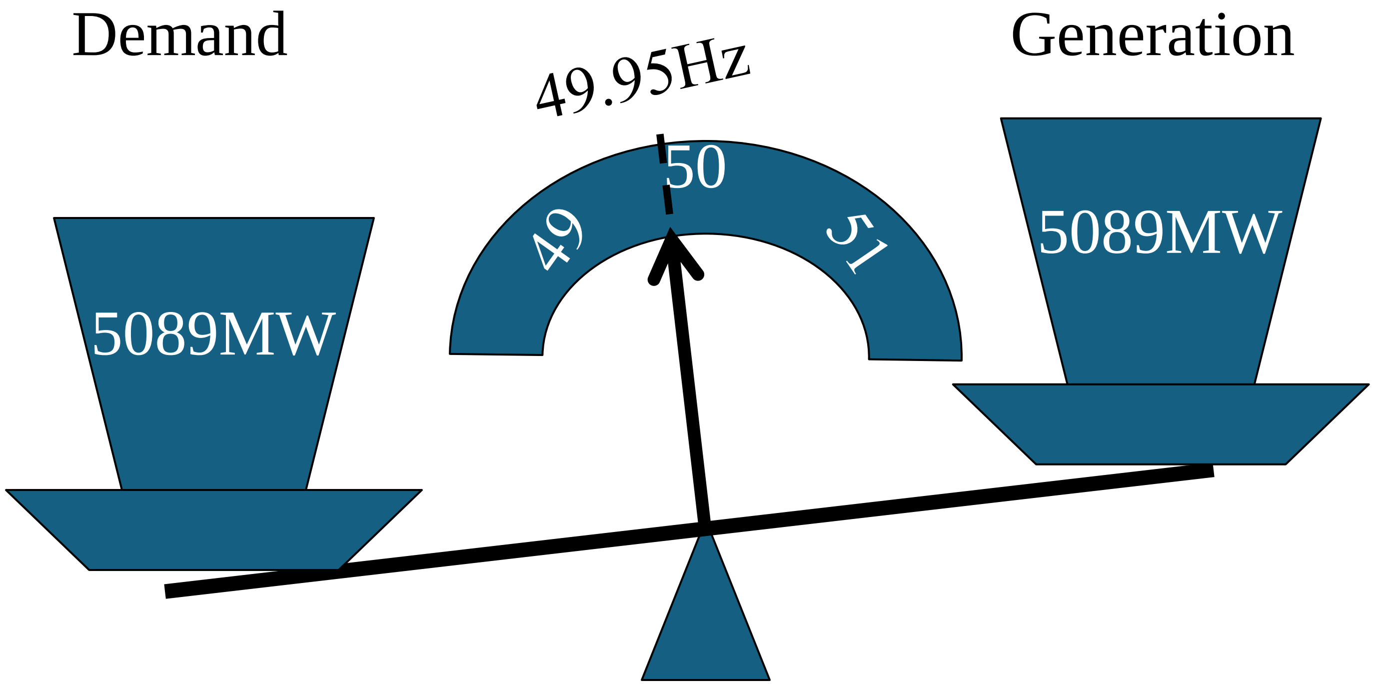
Primary reserve is activated

Governor of each Turbine-generator activated and allows additional fuel/water

Load

Load Regulation Initiated

Grid management-An example.....



Seconds to Minute time frame:

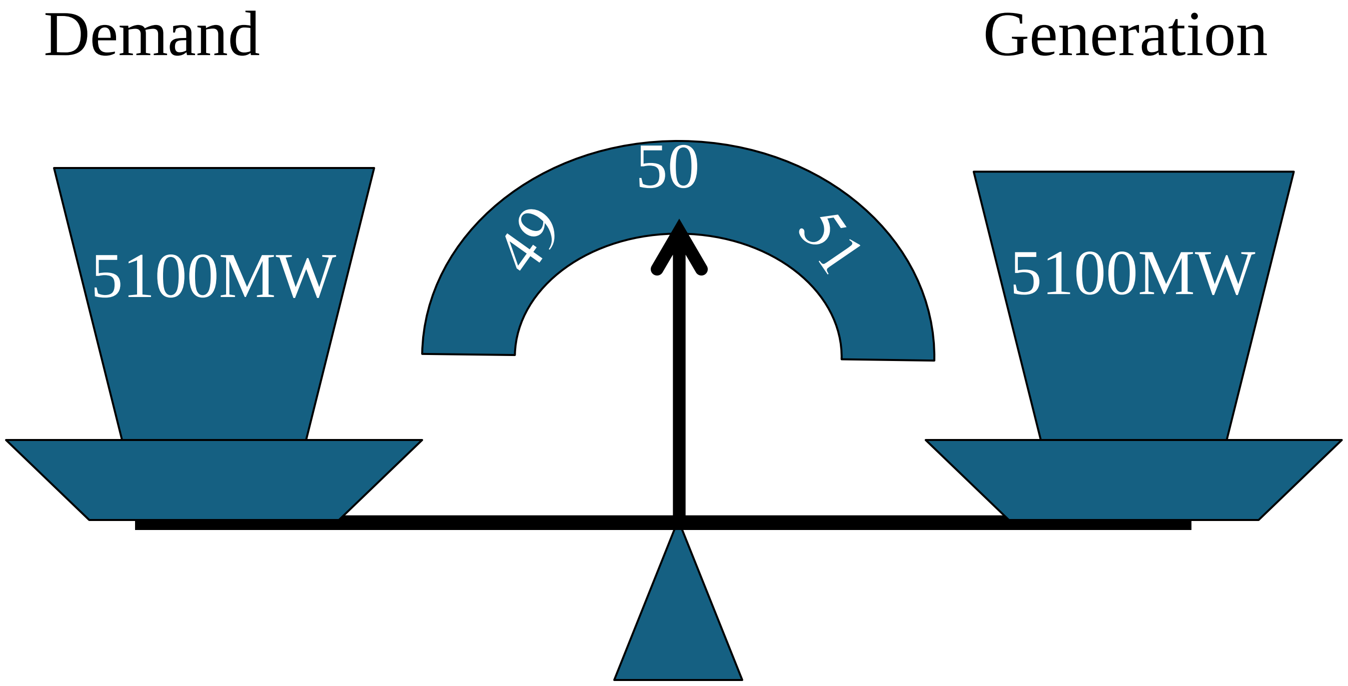
Generation

Increase by 89 MW

Load

Load drops by 11MW

Grid management-An example……



Few Minutes time frame:

Secondary response of Generation operated - AGC mechanism

Generation increase by 11MW and frequency restored to 50 Hz

Integrating RE and Demand Prediction

In order to balance the demand supply at every point of time, prediction of both load and VG is critical

Load Forecasting:

- Accurate prediction of electricity demand helps in planning the required capacity and balancing supply and demand.

VG Forecasting:

- Helps in predicting the availability of variable generation, plan for other generation/storage requirement which is crucial for grid reliability.

Load Forecasting

Subject of load forecasting is very broad in nature and includes many detailed engineering consideration and economic analysis

Load forecasting encompasses wide spectrum of time frame right from long range with a time span of few years to very short time with time span of few minutes.

At each time spectrum the subject of load forecasting is very critical as entire decision making in the power system depends on the results of the load forecasting

Load forecasting

Short Term Load forecasting is critical for operation of electric power system and is very critical with large VG penetration.

The short to very short term forecasting should not only predict the future demand but also the demand response potential for each of these periods in the future

Medium term and long term forecast is necessary for the resource adequacy analysis

Literature Survey

There are several approaches of load forecasting models reported in literature

The earliest techniques for load forecasting was published in 1918

The earlier techniques used in the short term load forecasting were mainly on State-estimation, Time series and Regressions models and the recent techniques are essentially based on AI tools - ANN, Fuzzy Inference, Support vector machines, etc.

Approaches

One approach treats the load pattern as a time series signal and predicts the future load by using various time series analysis techniques

- It is a non-weather sensitive approach & is based on extrapolation.
- General problems with the time series approach include the inaccuracy of prediction, and numerical stability
- It is time consuming method.
- It does not utilize weather information.

Approaches

The second approach recognizes that the load pattern is heavily dependent on weather variables and finds a functional relationship between the weather variables and the system load

- The future load is then predicted by inserting the predicted weather information into the predetermined functional relationship.
- Many of the techniques assume, without justification, a linear relationship in the load pattern & does not have the versatility to address the temporal variations
- The main disadvantage is that these models require complex modeling techniques and heavy computational efforts .

Approaches – AI

In recent times Artificial Intelligence finds greater application in addition to the classical statistical forecasting models

- The application of AI for Load forecasting was started during 1990’s.
- It has been proved as the most promising application area, since they do not rely on human experience, but attempt to draw a link between sets of input data and observed outputs.
- It has the capability to adapt to a changing forecasting environment through the concept of self learning.

WIND & SOLAR FORECASTING

Wind generation forecasting is widely implemented among power systems with modest to high levels of wind power generation

Solar power forecasting is relatively new and not as widely used, though methodologies and best-practices are rapidly evolving.

Both wind and solar forecasts utilize NWP models to predict variables such as temperature, humidity, precipitation and wind. Solar forecasts also uses satellite images to track and predict cloud formations at different timescales.

Forecasting – Time Frames

Near Term (5 - 60 minutes)	• Uses: Regulation, real-time dispatch decisions	Phenomena: Large eddies, turbulent mixing transitions Methods: Largely statistical, driven by recent measurements	Phenomena: Density of Cloud Methods: Cloud imaging camera and driven by recent measurements
Very Short term (1-6 hours ahead)	• Uses: Load-following, near term unit commitment (Hydro units & short start up generator commitment)	Phenomena: Fronts, sea breezes, mountain-valley circulations Methods: Blend of statistical, NWP models	Phenomena: Cloud cover Methods: Cloud motion vector and Satellite Imagery
Short Term (Day-ahead/Multi-Day)	• Uses: Unit commitment and scheduling, market trading	Phenomena: “Lows” and “Highs,” storm systems Methods: Mainly NWP with corrections for systematic biases	Phenomena: Cloud Cover, rainfall.. Methods: Mainly NWP with corrections for systematic biases
Medium Term (Seasonal – Year or couple years)	• Uses: Resource planning, contingency analysis	Phenomena: Climate oscillations, global warming Methods: Based largely on analysis of cyclical patterns	Phenomena: Dust & Aerosols, Climate oscillations, global warming Methods: Based largely on analysis of climate change
Long Term (10 to 20 years ahead)	• Uses: Project Siting, Long Term Planning	Phenomena: Long term averages Methods: Meso scale modelling coupled with long term measurements	Phenomena: Long term averages Methods: Meso scale modelling coupled with long term measurements

Short term forecasting of wind and solar output

Better forecasting is critical for grid operations to accommodate changes in wind and solar generation more efficiently and prepare for extreme events during which renewable generation is unusually high or low.

Forecasts can help reduce the amount of fast response operating reserves needed for the system, thereby reducing the cost of balancing the system.

Day-ahead forecasts support unit commitment decisions, driving operational efficiency and cost savings.

Short-term forecasts determine the need for a quick-start generator, demand response, or other mitigating options to support reliable operation of the electricity system.

Methods of VG Forecasting

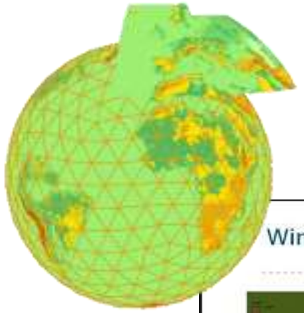
Physical Approach

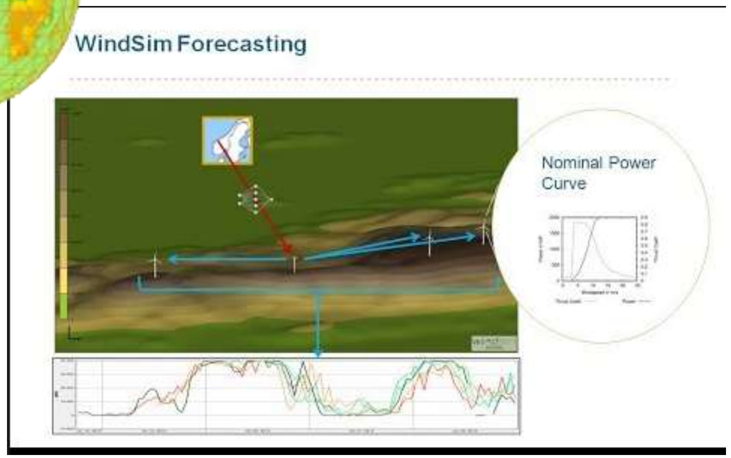
- Using Numerical Weather Prediction
  - Power Curve to convert power
- Using Wind Flow Modeling
  - Computational Fluid Dynamics
  - Linear wind flow modeling

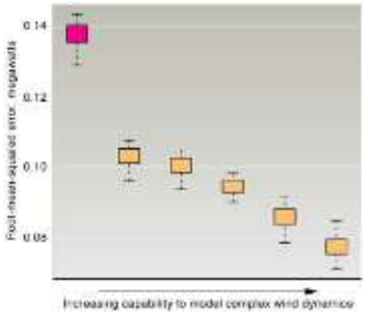
Statistical Approach

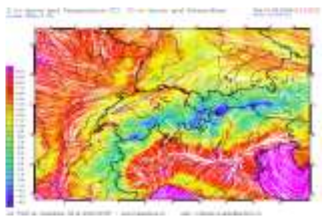
- Using Statistical Models
- Using Machine Learning / Artificial Neural Networks

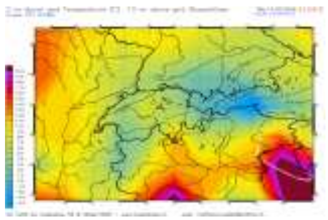
Mixed Physical – Statistical Approach

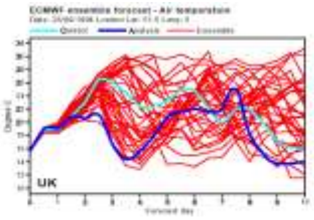




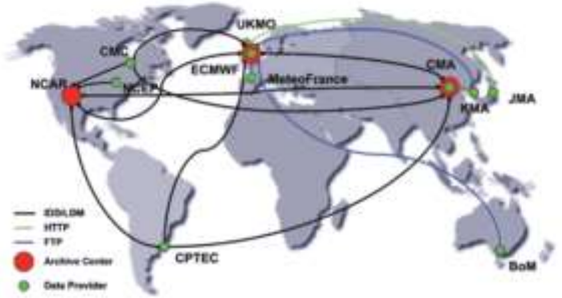




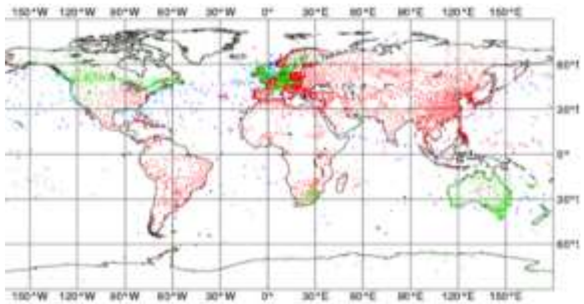




Numerical Weather Prediction

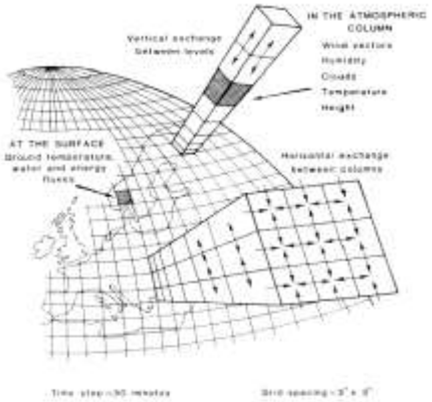


NWP Sources



Weather Measurement Stations

Source of Weather Measurement



Gridding the World

- NWP Model components
  - Initial Conditions:
    - Input data and Initialization
  - Governing Equations
  - Numerical Procedures
    - Grid Point Models
    - Spectral Models

- ✓ NWP Model components
  - ➢ Physical Process
    - o Modeling Local Effects
    - o Parameterization
  - ➢ Model Output
    - o File with Model forecast
    - o Post processing

Momentum:

$$\frac{\partial u}{\partial t} = -u\frac{\partial u}{\partial x} - v\frac{\partial u}{\partial y} - w\frac{\partial u}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial x} - fv$$

$$\frac{\partial v}{\partial t} = -u\frac{\partial v}{\partial x} - v\frac{\partial v}{\partial y} - w\frac{\partial v}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial y} + fu$$

$$\frac{\partial w}{\partial t} = -u\frac{\partial w}{\partial x} - v\frac{\partial w}{\partial y} - w\frac{\partial w}{\partial z} - \frac{1}{\rho}\frac{\partial p}{\partial z} - g$$

Mass:

$$\nabla \cdot (\rho \vec{u}) = -\frac{\partial \rho}{\partial t}$$

Heat

$$Q = c_p\frac{dT}{dt} + \frac{1}{\rho}\frac{dP}{dt}$$

Moisture

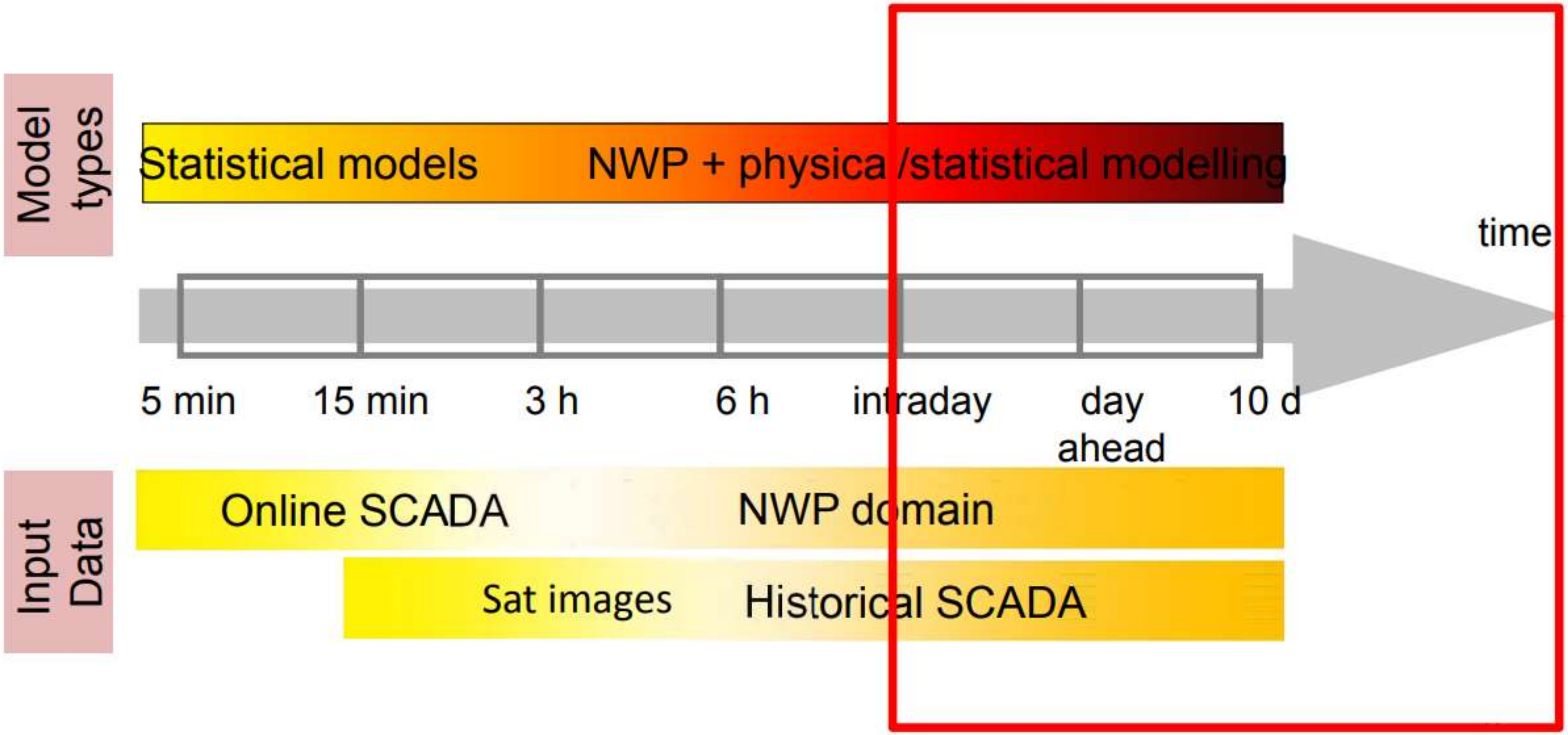
$$\frac{\partial q}{\partial t} + \vec{u} \cdot \nabla q = E - C$$

Gas law

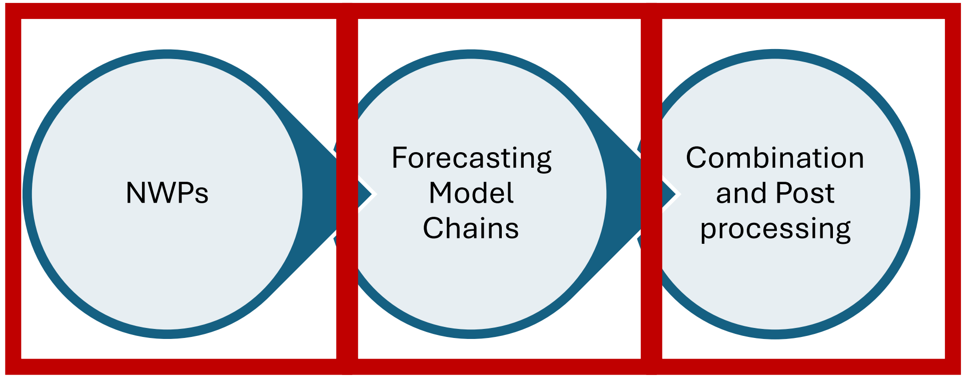
$$P = \rho RT$$

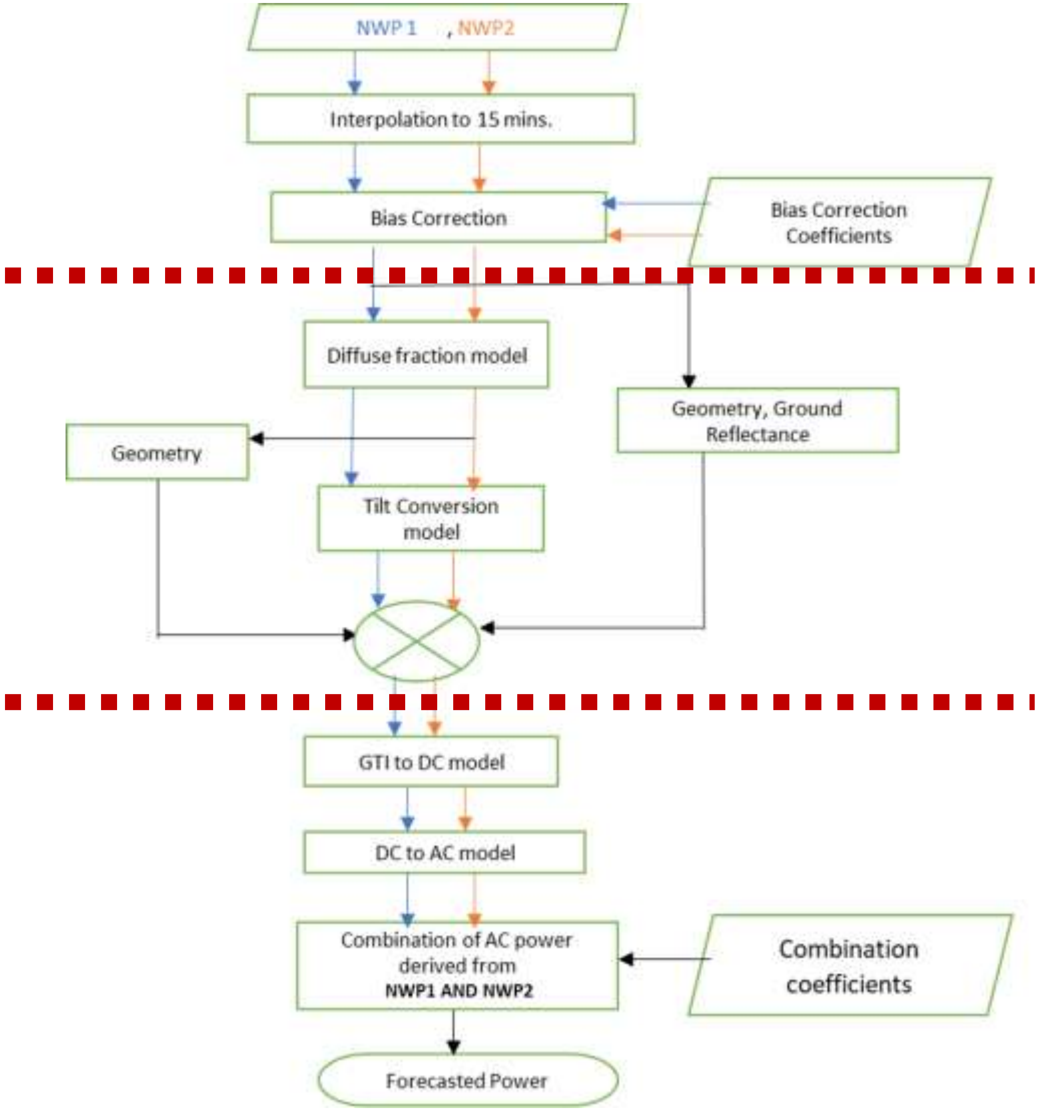
- ✓ Conservation of Momentum
  - ➢ 3 equations for accelerations of 3-d wind (F=ma)
- ✓ Conservation of mass
  - ➢ 1 Eqn for conservation of air
  - ➢ 1 Eqn for conservation of water
- ✓ Conservation of energy
  - ➢ 1 Eqn for the first law of thermodynamics
- ✓ Relationship among p, V and T
  - ➢ 1 Eqn of state (Ideal gas law)

Solar Power Forecasting Modelling Techniques for Different Time Horizon

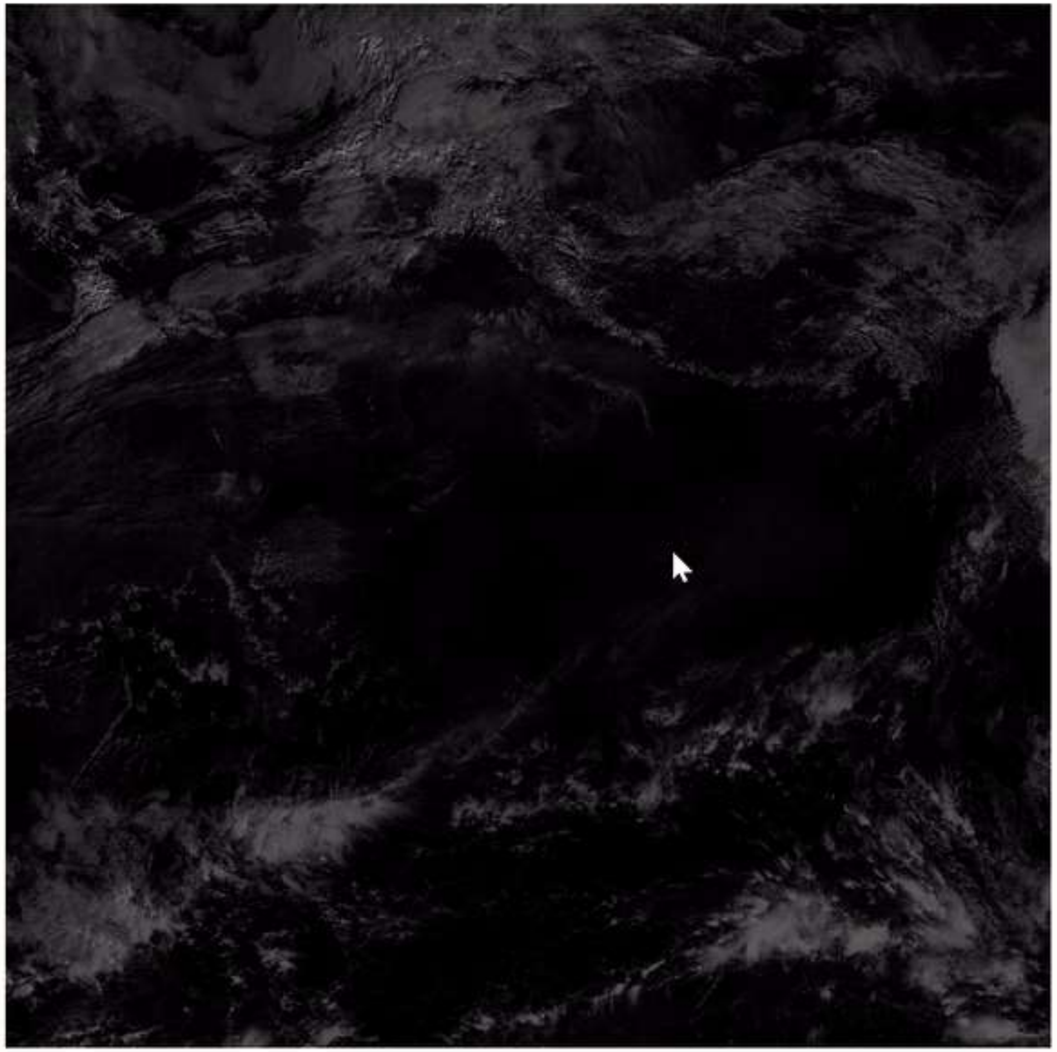


Solar Power Prediction Model Chain Flowchart

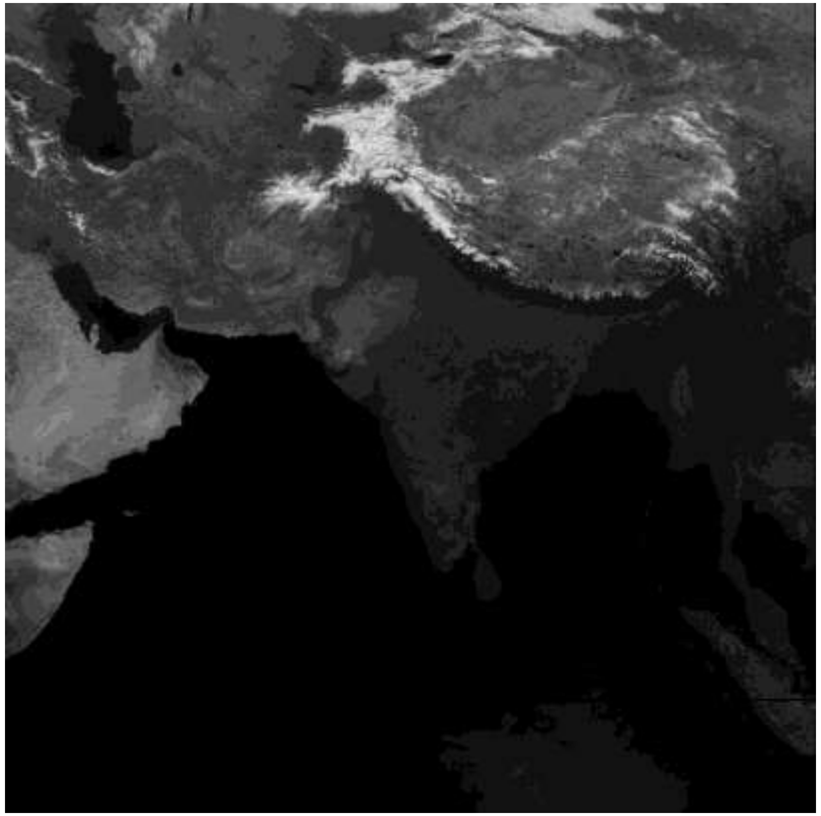




Satellite Based Irradiance Forecasting: INTRADAY FORECASTS

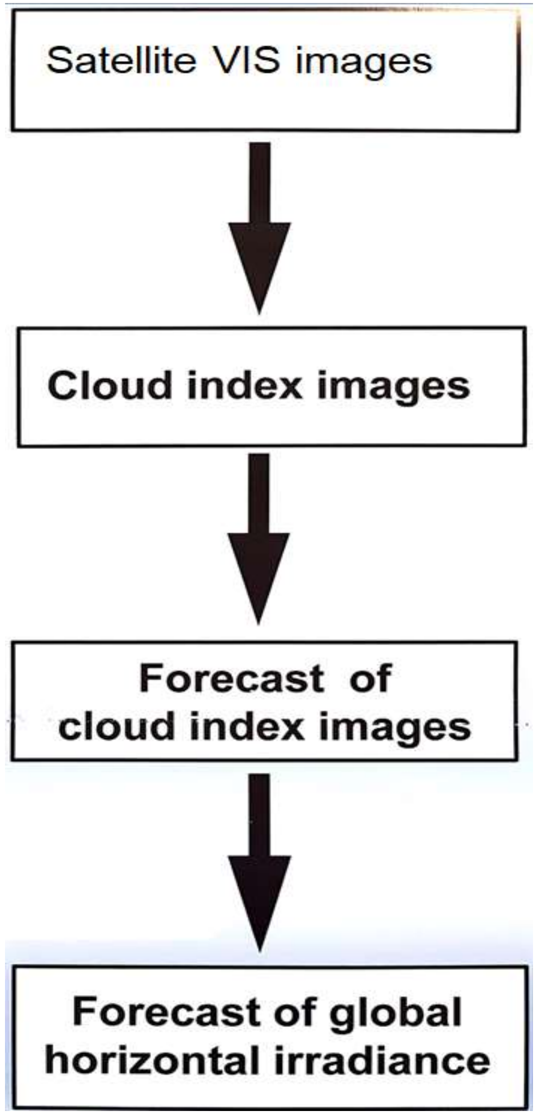


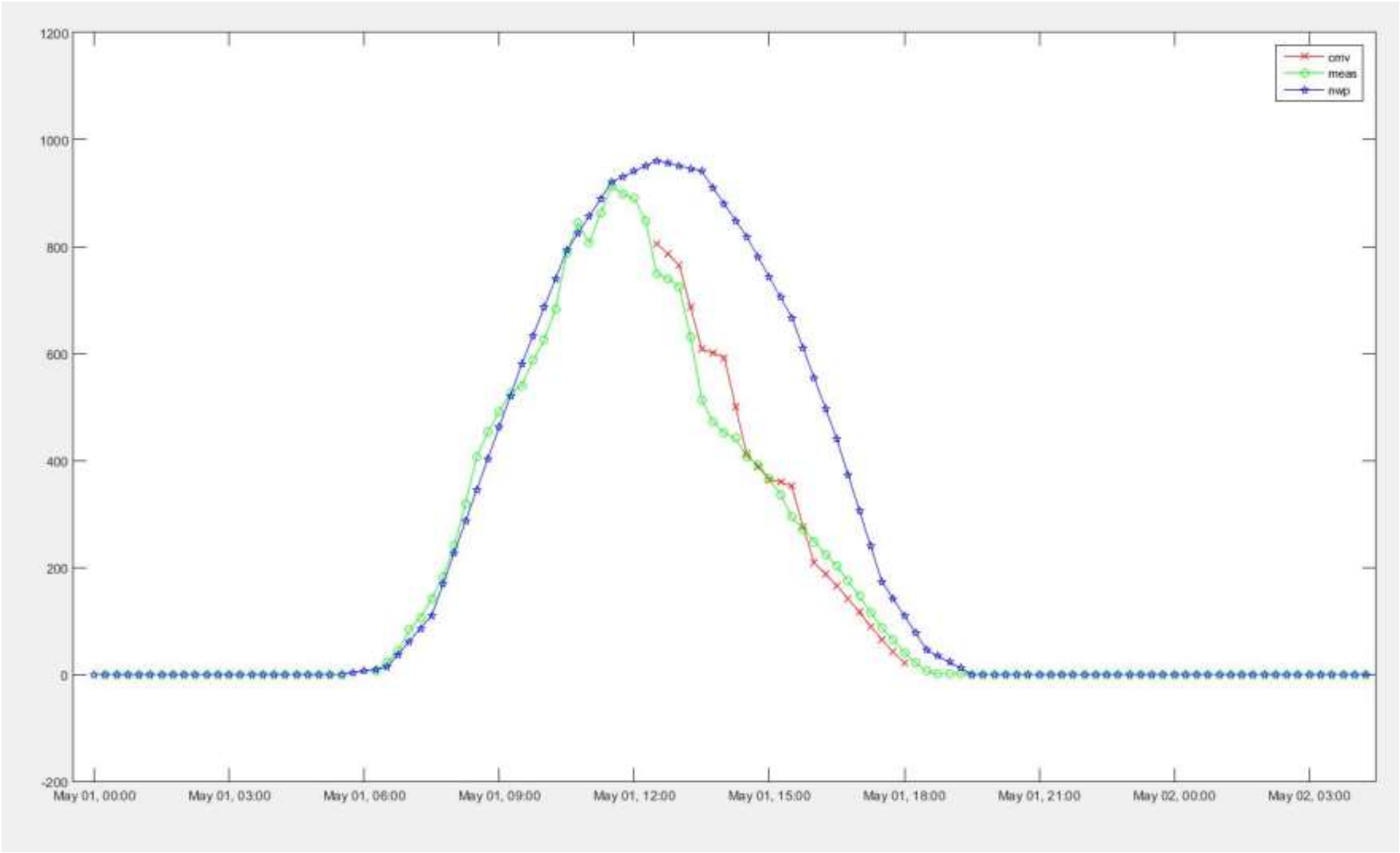
Cloud Index Animations, ISRO-INSAT3D Images



Ground reflectance Image, ISRO-INSAT3D

Satellite Based Irradiance Forecasting: INTRADAY FORECASTS





Skycam Based Irradiance Forecasting: INTRAHOUR FORECASTS

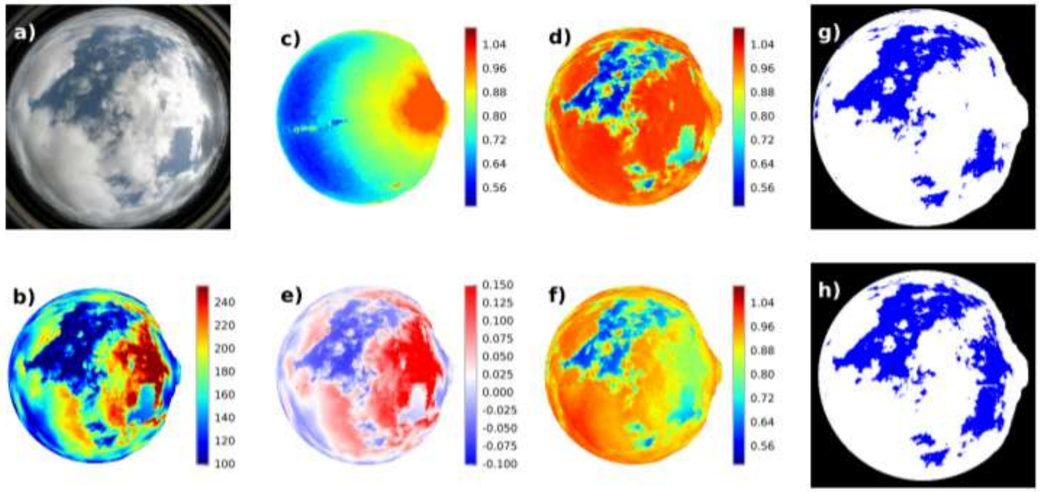
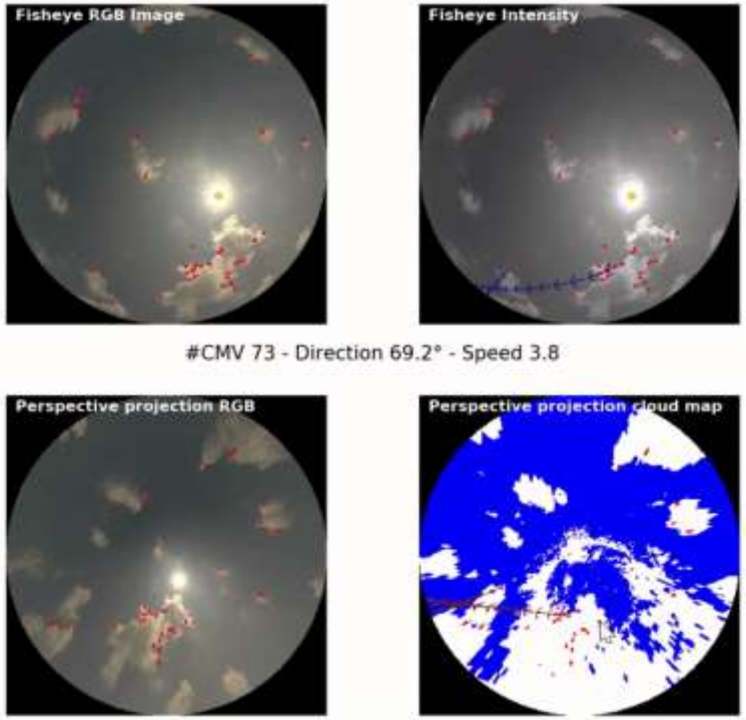
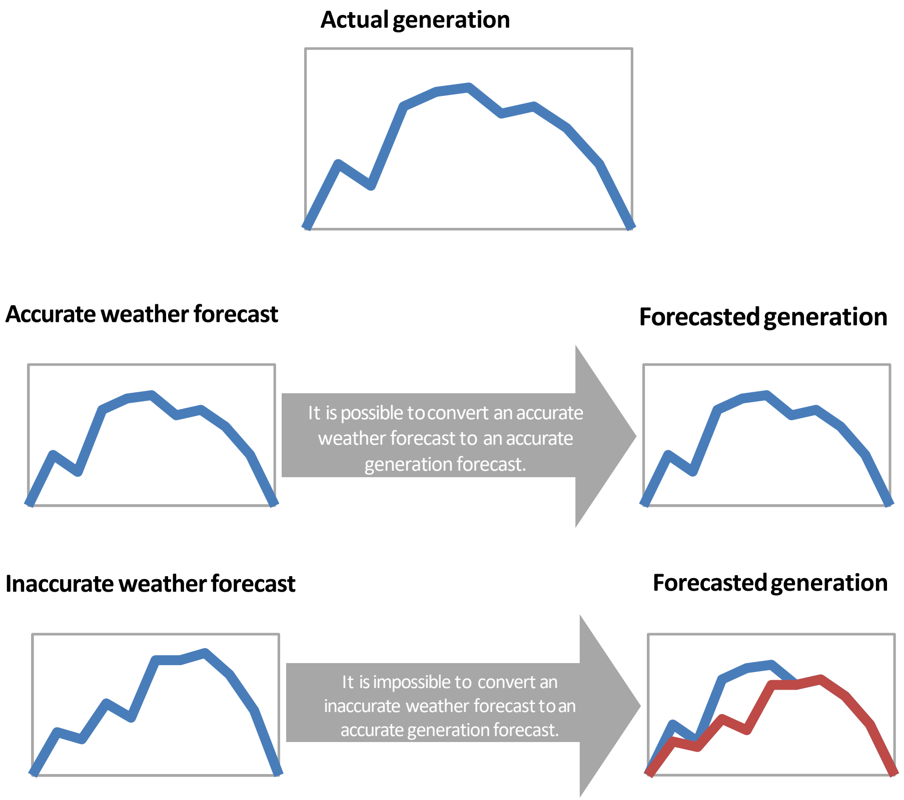


Figure 3. Cloud detection. **(a)** Original image. **(b)** Pixel intensity. **(c)** RBR clear sky reference. **(d)** RBR without correction. **(e)** Absolute RBR correction. **(f)** RBR with correction. **(g)** Binary cloud map without correction. **(h)** Binary cloud map with correction.



The major source of in-accuracy is the weather



Without accurate weather forecast, a generator cannot submit accurate schedules

Major Forecasting Challenges

The major challenges in developing and scheduling the forecast model are:

- Accurate and timely updating of static information
- Non-availability of Dynamic status of the wind turbines generators (WTG)
- Accurate historical generation data
- Accurate and timely updating of real-time generation
- Selection of appropriate statistical / machine learning algorithms and its internal configuration
- Inaccuracy in Numerical Weather Prediction data
- Non-availability of SCADA information at WTG level

Approach for RE Forecasting

Centralized Forecasting: :

- Best practice approach for economic dispatch.
- Administered by the balancing authority or system operator.
- Centralized forecast provide system wide forecasts for all R E generators.

Decentralized Forecasting-:

- Individually done at plant level.
- Systems operators rely on individual plants performance for system balance.
- Generators get penalized for their deviation at individual plant level

Centralised Forecasting provides:

- **Greater consistency in results** due to the application of a single methodology.
- **Lower uncertainty** due to the system operator's ability to aggregate uncertainty
- across all generators
- **Reduced financial burden** for RE plants to produce and submit individual forecasts.

Centralised Forecasting is more effective and efficient for scaling up RE over decentralised forecasting.

Thank you