AI & ML Applications to transform Indian Power Sector

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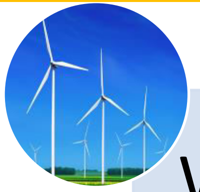
Smart, Sustainable, Secure, Self healing Grid

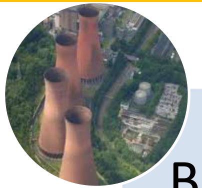
Add more Renewable Generations

Solar



Wind

Hydro



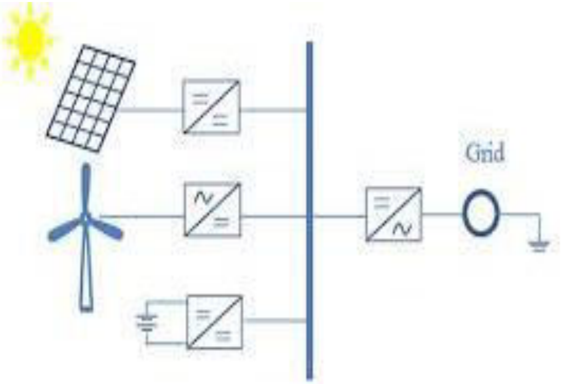
Biomass

Grid Tied

Off Grid

With storage backup

Without storage backup



Variability can be mitigated by STORAGE

As Solar and Wind generation is associated with variability and uncertainties, meeting the targets of generation in a generation mix , the Power Grid involves major challenges pertaining the planning , operations, management and protection of the Grid

With the increase in penetration of Renewable Energy (RE) and with the increase in the number of EVs, the Grid Operators face a challenge to maintain the Grid Reliability, Stability

Make the GRID GREEN and CLEAN

Autonomous Grid : Meeting point AI, Renewable Energy, and Energy Storage to optimize the grid

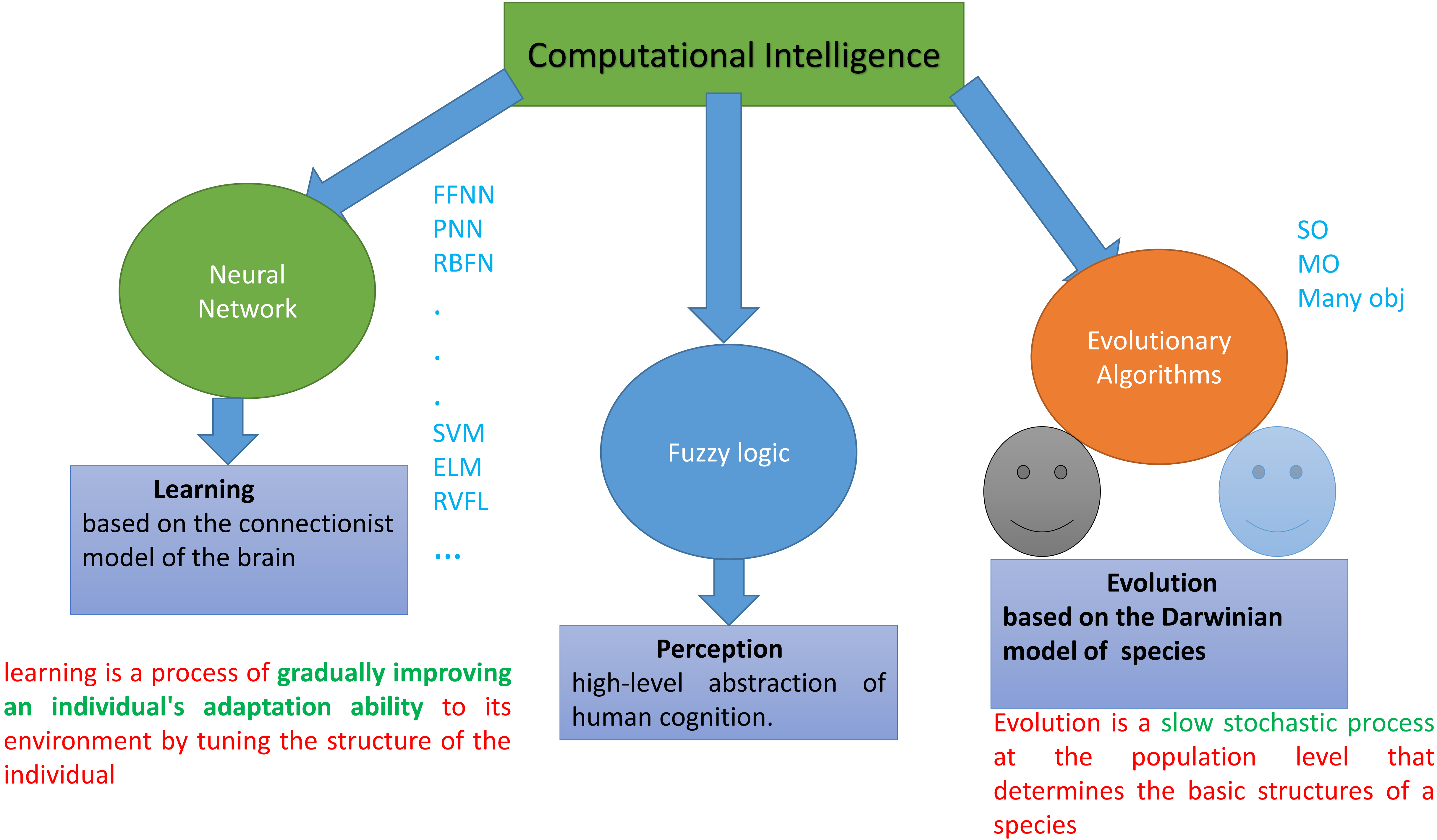
IEEE Spectrum : 23rd NOV 2020

- In the Colorado neighborhood of Basalt Vista, a microgrid allows 27 households to seamlessly share electricity when needed

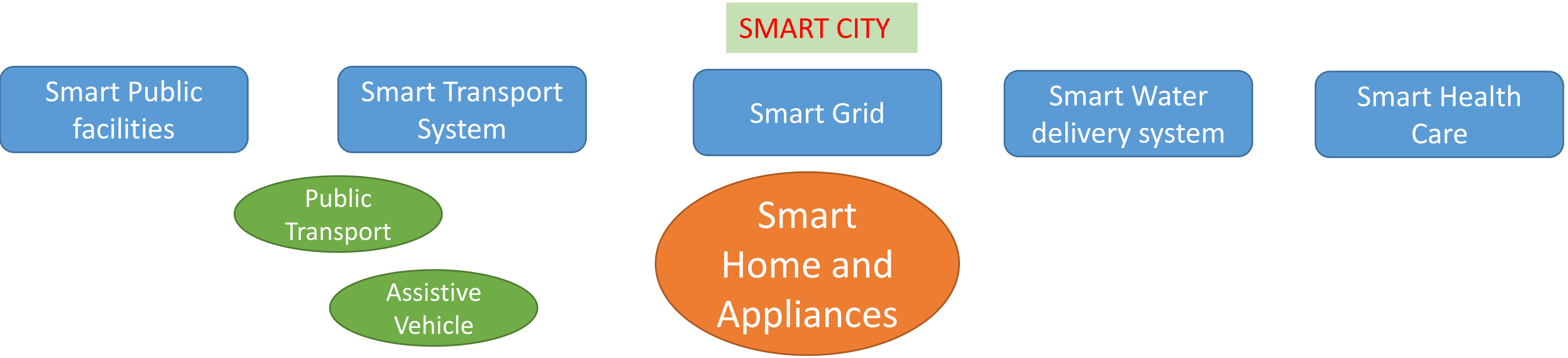
- All Electric Home

- The Basalt Vista autonomous energy grid uses a 900-megahertz radio antenna to communicate with Holy Cross Energy's dispatch center, about 50 kilometers away.

An autonomous energy grid composed of local units, comprising of **electricity generation**, **storage**, and **consumption**.


Computational Intelligence
Neural Network
FFNN
PNN
RBFN
.
.
.
SVM
ELM
RVFL
...
Learning
based on the connectionist model of the brain
learning is a process of **gradually improving an individual's adaptation ability** to its environment by tuning the structure of the individual
Fuzzy logic
Perception
high-level abstraction of human cognition.
Evolutionary Algorithms
SO
MO
Many obj
Evolution
based on the Darwinian model of species
Evolution is a slow stochastic process at the population level that determines the basic structures of a species

AI plays an Important Role in the following Sector



Niti Aayog. 2018. National Strategy for Artificial Intelligence: #AIforall. Discussion Paper, June 2018. https://niti.gov.in/writereaddata/files/ document_publication/NationalStrategy-for-AI-Discussion-Paper.pdf.

Energy Management:

Energy management involves the planning, monitoring, and optimization of energy consumption in various sectors to ensure efficient and sustainable use.

Importance of Energy Management:

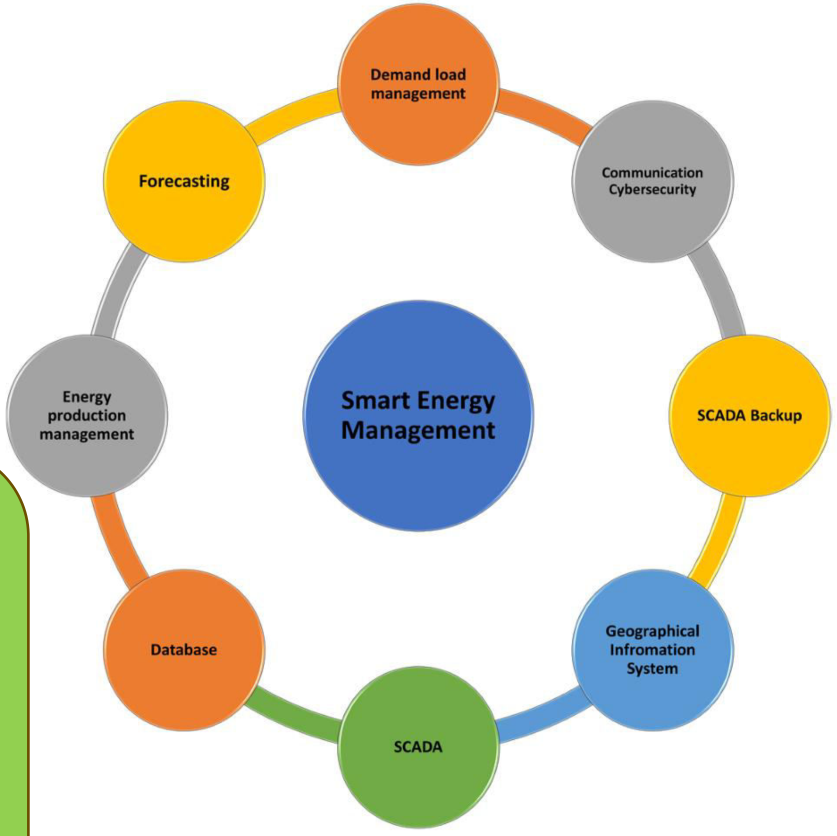
•Crucial for achieving economic savings, environmental sustainability, and social responsibility.

•Efficient energy management mitigates the impact of energy-related challenges.

Challenges in Traditional Approaches:

•Conventional methods face limitations in accurately predicting demand and integrating renewable sources.

•Grid stability becomes a challenge with increasing complexities in energy systems.



Global Energy Trend

•Global energy demand is on the rise, driven by population growth, industrialization, and technological advancements.

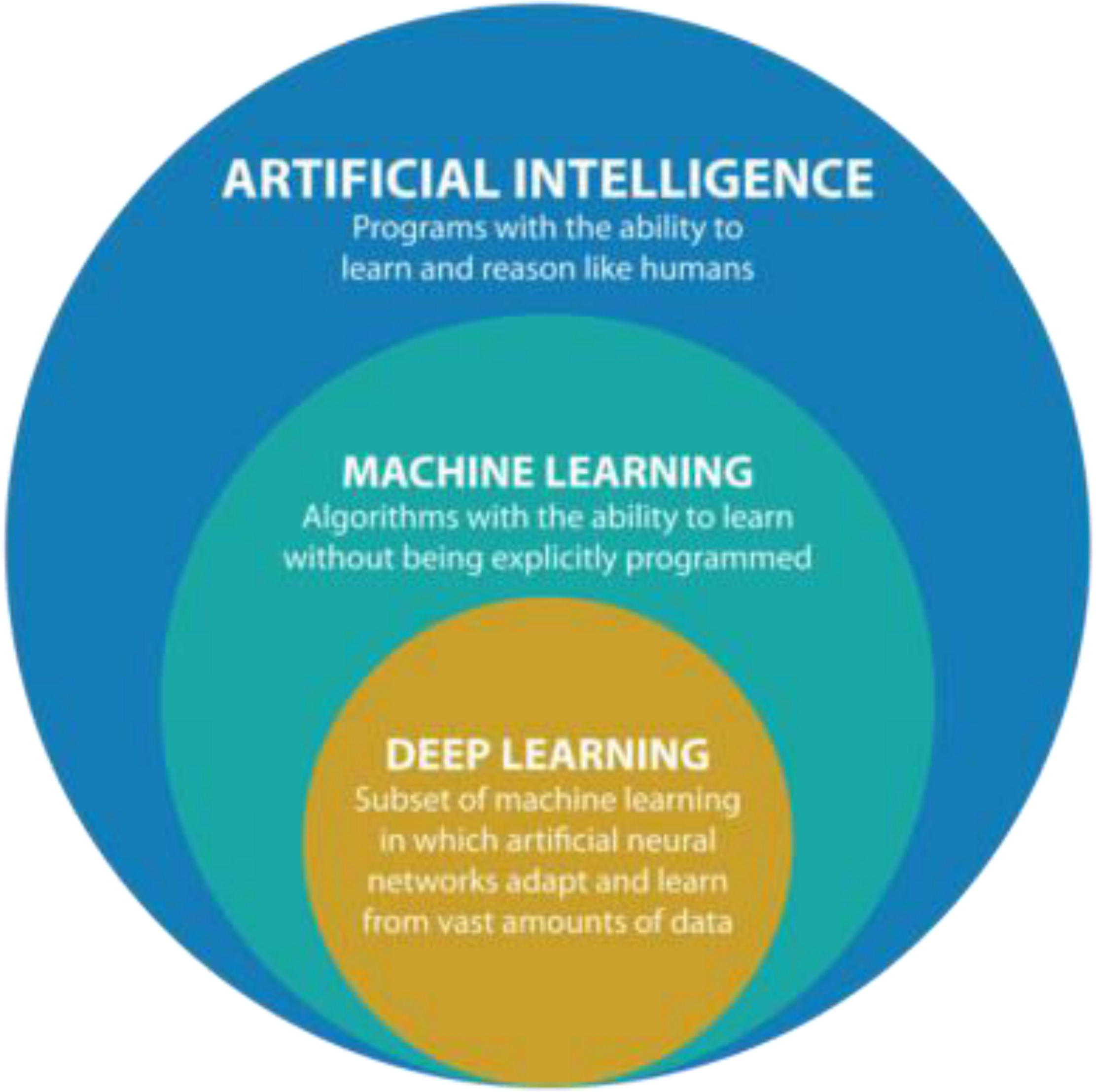
•Aligning with global initiatives, energy management contributes significantly to achieving sustainability goals.

• **Artificial Intelligence (AI) and machine learning (ML) can analyze vast and complex datasets, learn from patterns, and provide actionable insights**.

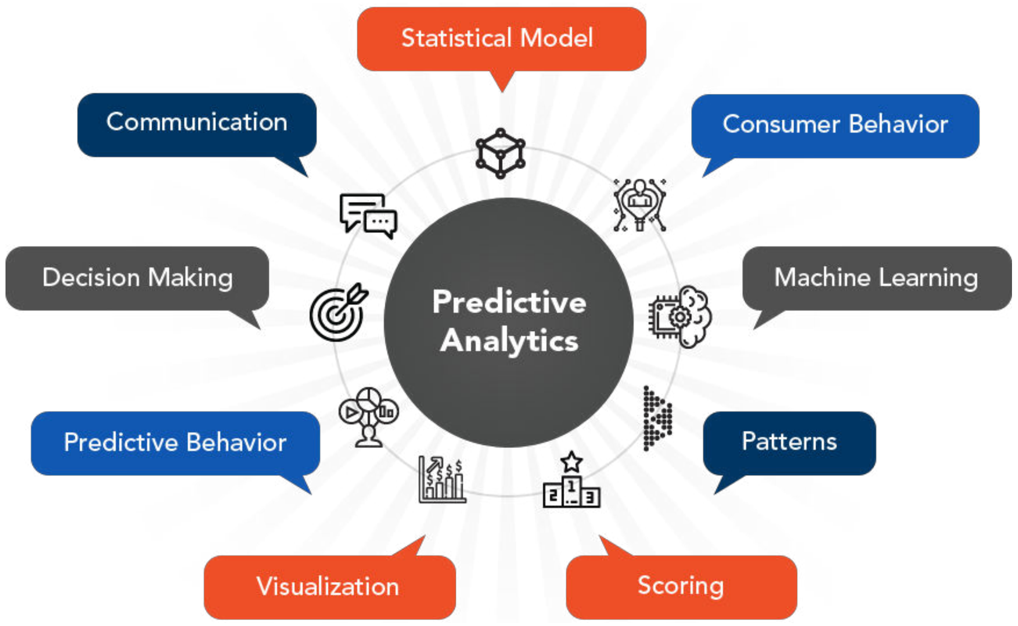
•They can enhance efficiency, reliability, and sustainability across the entire energy ecosystem.

Data-Driven Energy Management and AI/ML Integration

- Energy management in a power system handles an immense amount of data from sensors, meters, and other sources.
- Data is integral for monitoring, control, and decision-making in power generation, distribution, and consumption.
- Power systems involve diverse and intricate data sets, including grid conditions, demand patterns, and equipment health metrics.
- Handling this complexity requires advanced analytical approaches.
- AI and ML leverage large datasets to extract valuable insights from historical and real-time data.
- The more extensive the dataset, the more accurate and reliable the predictions and optimizations become.
- The integration of AI and ML with large datasets is pivotal for optimizing power systems, improving efficiency, and ensuring a reliable and sustainable energy future.



- **Advanced Predictive Analytics:**
  Challenge: Traditional methods struggle to accurately predict energy demand, making it challenging to match production with consumption.
  Transformation: AI and ML algorithms analyze vast datasets, including historical consumption patterns, weather data, and real-time information, enabling precise demand forecasting. This ensures more efficient planning and resource allocation.

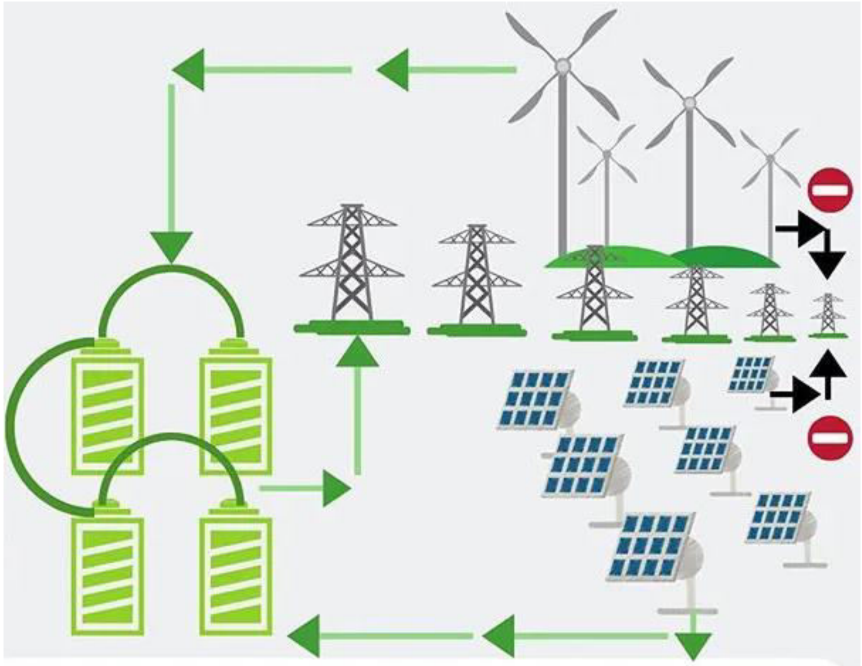


- **Grid Management and Stability:**
  Challenge: Traditional grids face difficulties in managing the complexities of a modern energy landscape with intermittent renewable sources.
  Transformation: AI and ML contribute to real-time monitoring, fault detection, and dynamic grid management. These technologies help balance supply and demand, enhance grid stability, and efficiently integrate renewable energy sources.

- **Renewable Energy Integration:**

  Challenge: The unpredictability of renewable energy sources, such as solar and wind, poses challenges for grid operators.

  Transformation: AI algorithms analyze weather patterns, historical data, and real-time conditions to predict renewable energy production. This allows for better integration into the grid and effective management of fluctuations.



- **Predictive Maintenance:**

  Challenge: Traditional maintenance practices are often reactive, leading to downtime and increased operational costs.

  Transformation: AI and ML enable predictive maintenance by analyzing sensor data and performance metrics. This allows for the identification of potential equipment failures before they occur, minimizing downtime and reducing maintenance costs.

- **Energy Storage Optimization:**

  Challenge: Efficiently managing energy storage systems, such as batteries, to maximize their lifespan and performance.

  Transformation: ML models optimize the charging and discharging cycles of energy storage systems based on usage patterns, grid demand, and other variables thereby extending the life of storage infrastructure.

- **Energy Trading and Market Analysis:**

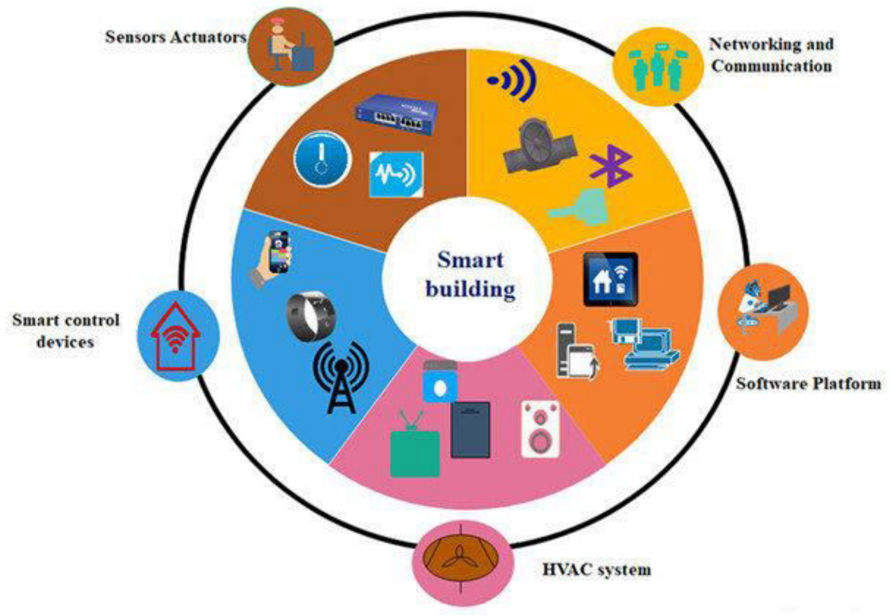
  Challenge: Energy markets are complex, and decision-making is often based on historical data and limited insights.

  Transformation: AI and ML algorithms analyze market trends, pricing data, and external factors to make informed decisions in energy trading. This enhances market participation, improves risk management, and optimizes trading strategies.

- **Carbon Emission Reduction:**

  Challenge: Achieving carbon emission reduction targets is a complex task.

  Transformation: AI applications help monitor and analyze energy consumption patterns, identify areas for efficiency improvement, and contribute to the development of strategies for reducing carbon emissions in energy production and consumption.

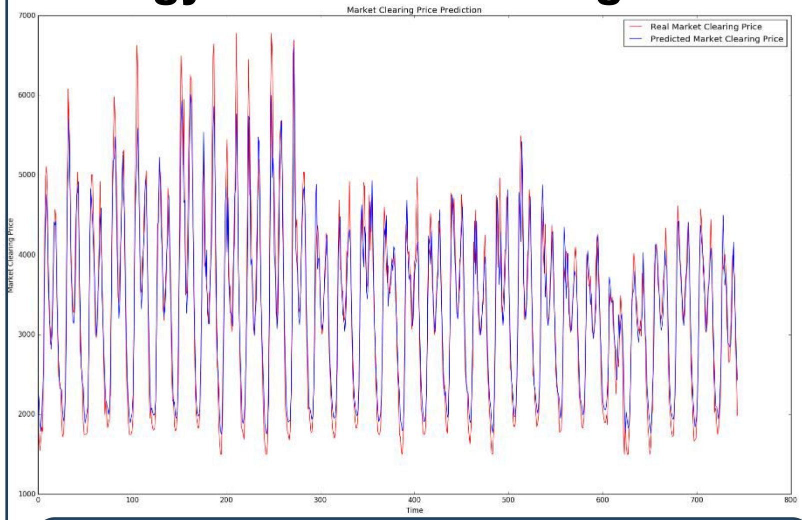


- **Optimizing Energy Consumption in Smart Buildings:**

  Challenge: Conventional buildings lack adaptability to occupants' behavior and environmental conditions.

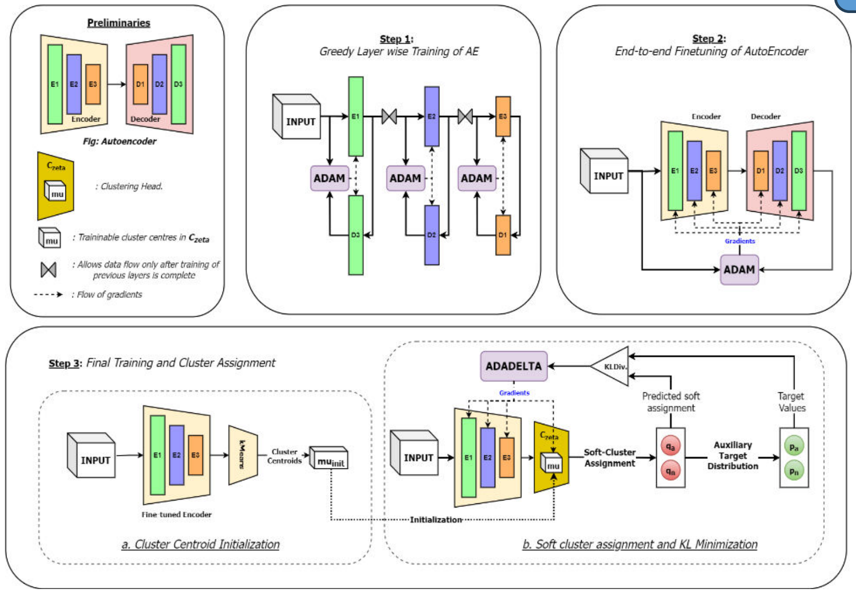
  Transformation: AI-powered systems in smart buildings learn and adapt to occupant preferences, adjusting lighting, heating, and cooling in real-time. This leads to significant energy savings without compromising comfort.

Energy Price Forecasting

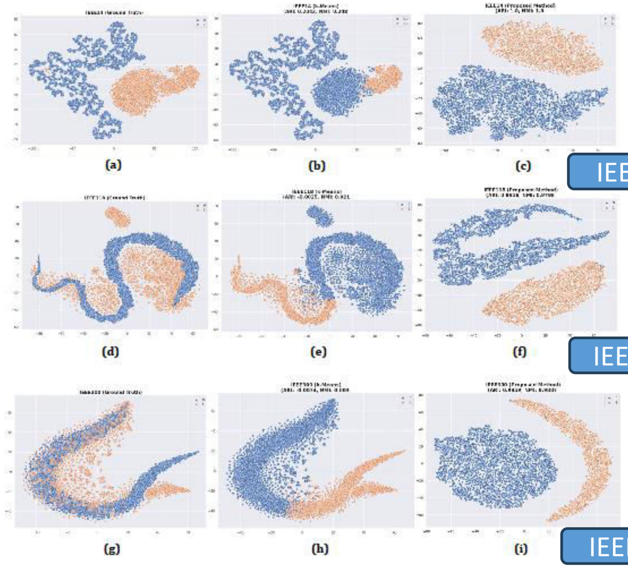


Market clearing price prediction using LSTM network

Cyber-attack Detection



Ground truth | K-means clustering | DLSC algorithm



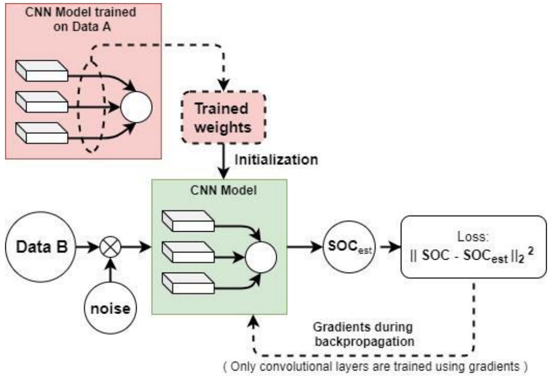
IEEE-14 bus

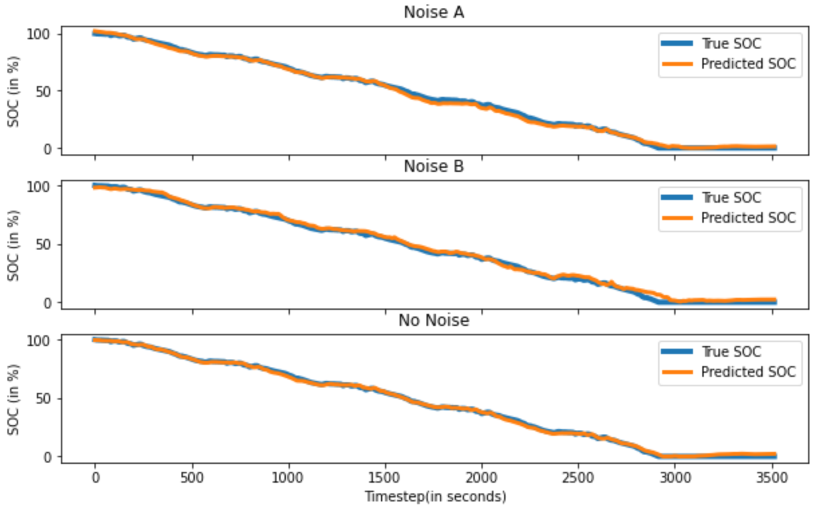
IEEE-118 bus

IEEE-300 bus

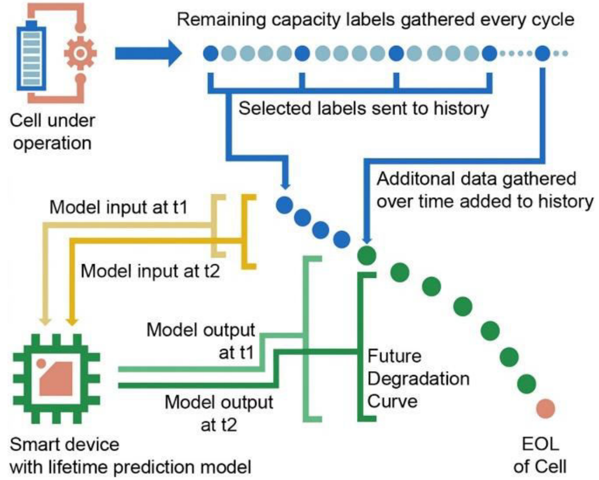
Battery Energy Storage Management

State Estimation





Prognosis Framework



Reference: Weihan Li, Neil Sengupta, Philipp Dechent, David Howey, Anuradha Annaswamy, Dirk Uwe Sauer,"One-shot battery degradation trajectory prediction with deep learning", Journal of Power Sources, Volume 506, 2021, 230024, ISSN 0378-7753, https://doi.org/10.1016/j.jpowsour.2021.230024.

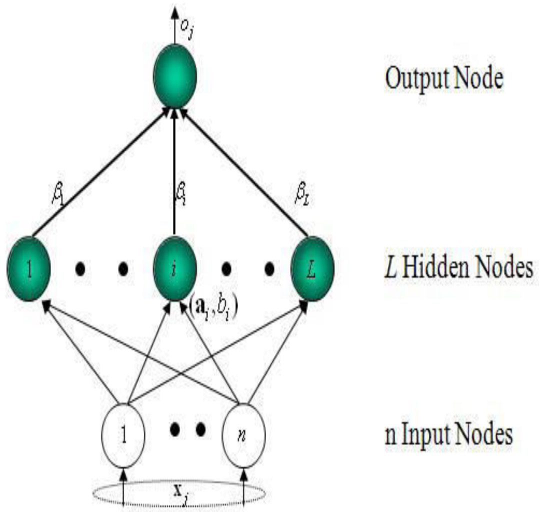
Benefits of AI and ML in Energy Management:

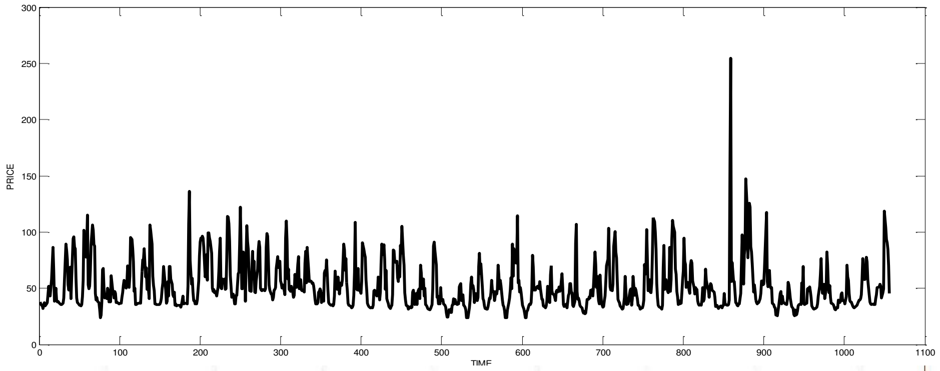
- **Improved Efficiency:** AI and ML optimize energy consumption patterns, leading to increased operational efficiency.
- **Cost Reduction:** Smart predictive analytics helps minimize operational costs through better resource planning and demand forecasting.
- **Enhanced Sustainability:** AI supports the integration of renewable energy sources, promoting a more sustainable and eco-friendly energy ecosystem.
- **Real-time Monitoring:** Continuous monitoring enables real-time adjustments, ensuring efficient energy use and quick response to anomalies.
- **Predictive Maintenance:** ML models predict equipment failures, allowing for proactive maintenance and minimizing downtime.
- **Optimized Energy Storage:** AI optimizes energy storage systems, extending their lifespan and improving overall efficiency.
- **Grid Stability:** AI contributes to dynamic grid management, enhancing stability and reliability in energy distribution.
- **Market Analysis for Trading:** ML algorithms analyze market trends, facilitating informed decisions in energy trading and risk management.
- **Carbon Emission Reduction:** AI applications contribute to the identification of opportunities for reducing carbon emissions in energy production and consumption.
- **Adaptability to Changing Conditions:** AI and ML systems adapt to evolving energy landscapes, ensuring resilience in the face of dynamic conditions.

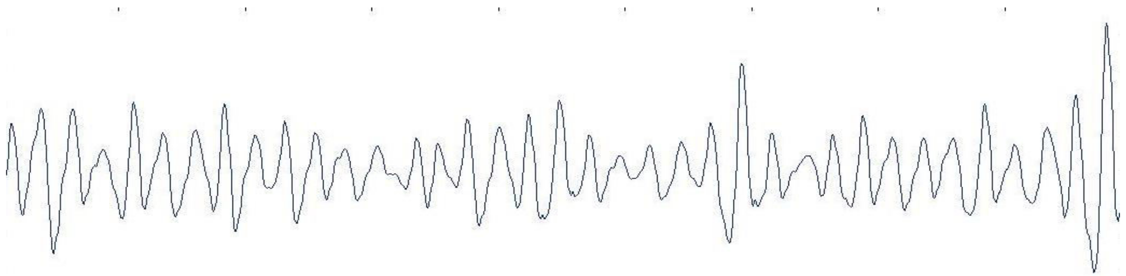
Forecasting

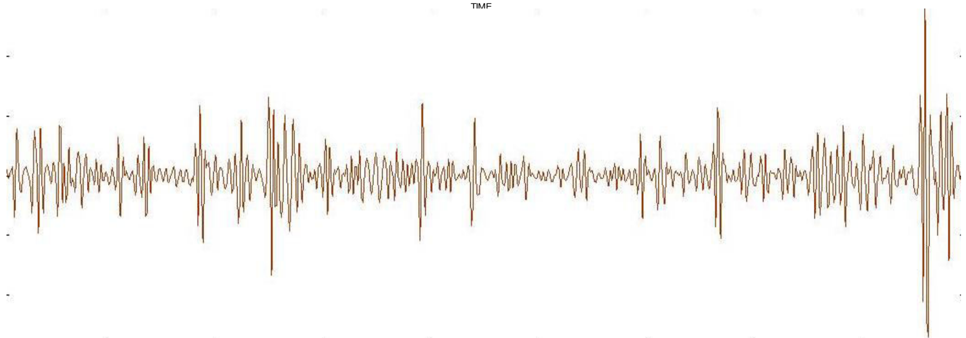
- Electric Load
- Electric Price
- Wind Speed
- Solar Insolation

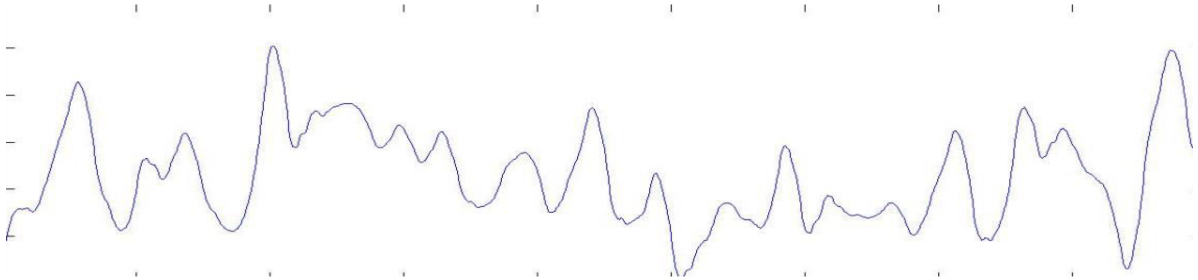
- ANN
- ANFIS
- SVM
- ELM

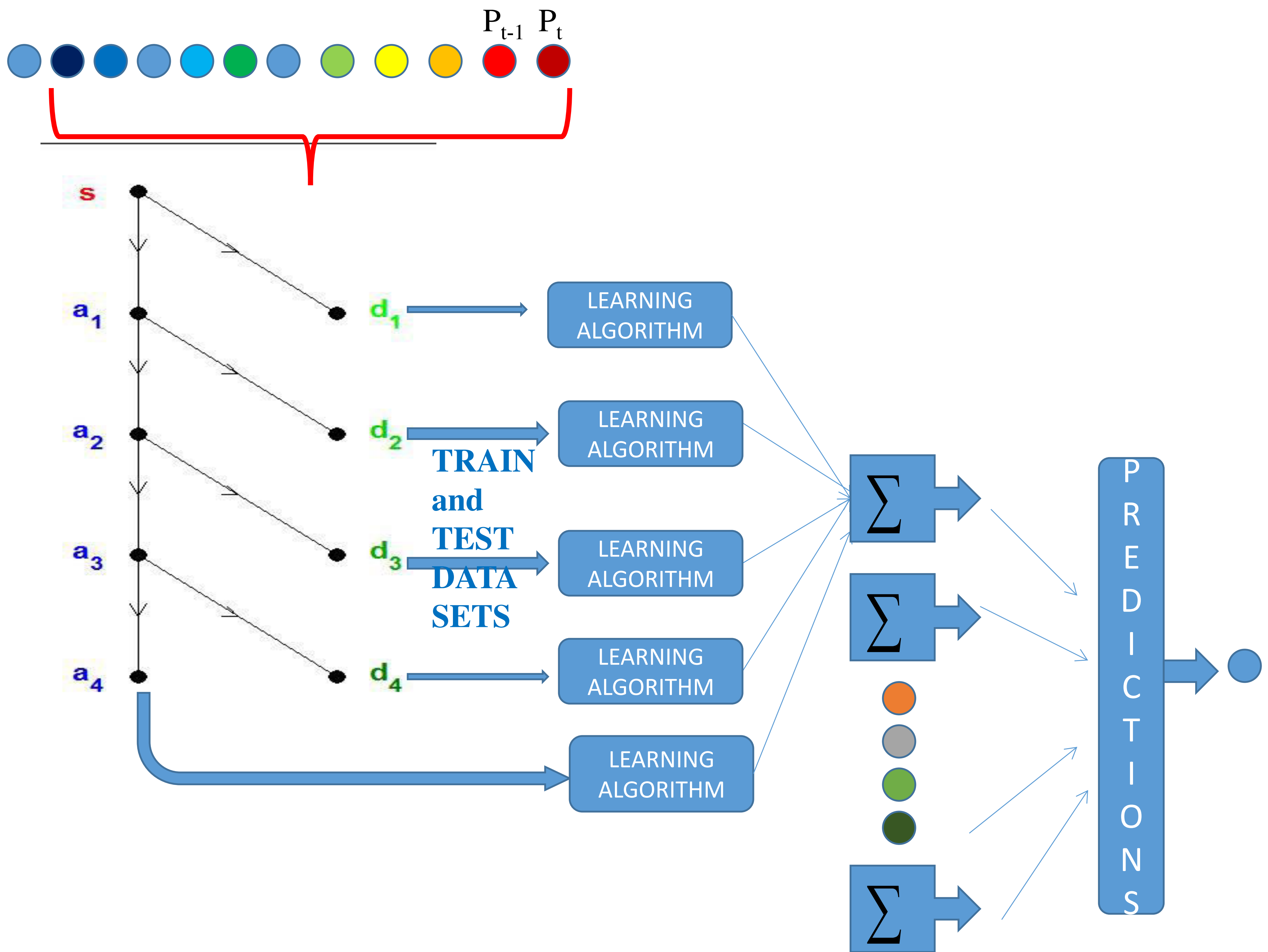












P_{t-1}
P_t
s
a_1
a_2
a_3
a_4
d_1
d_2
d_3
d_4
TRAIN and TEST DATA SETS
LEARNING ALGORITHM
LEARNING ALGORITHM
LEARNING ALGORITHM
LEARNING ALGORITHM
LEARNING ALGORITHM
$\sum$
$\sum$
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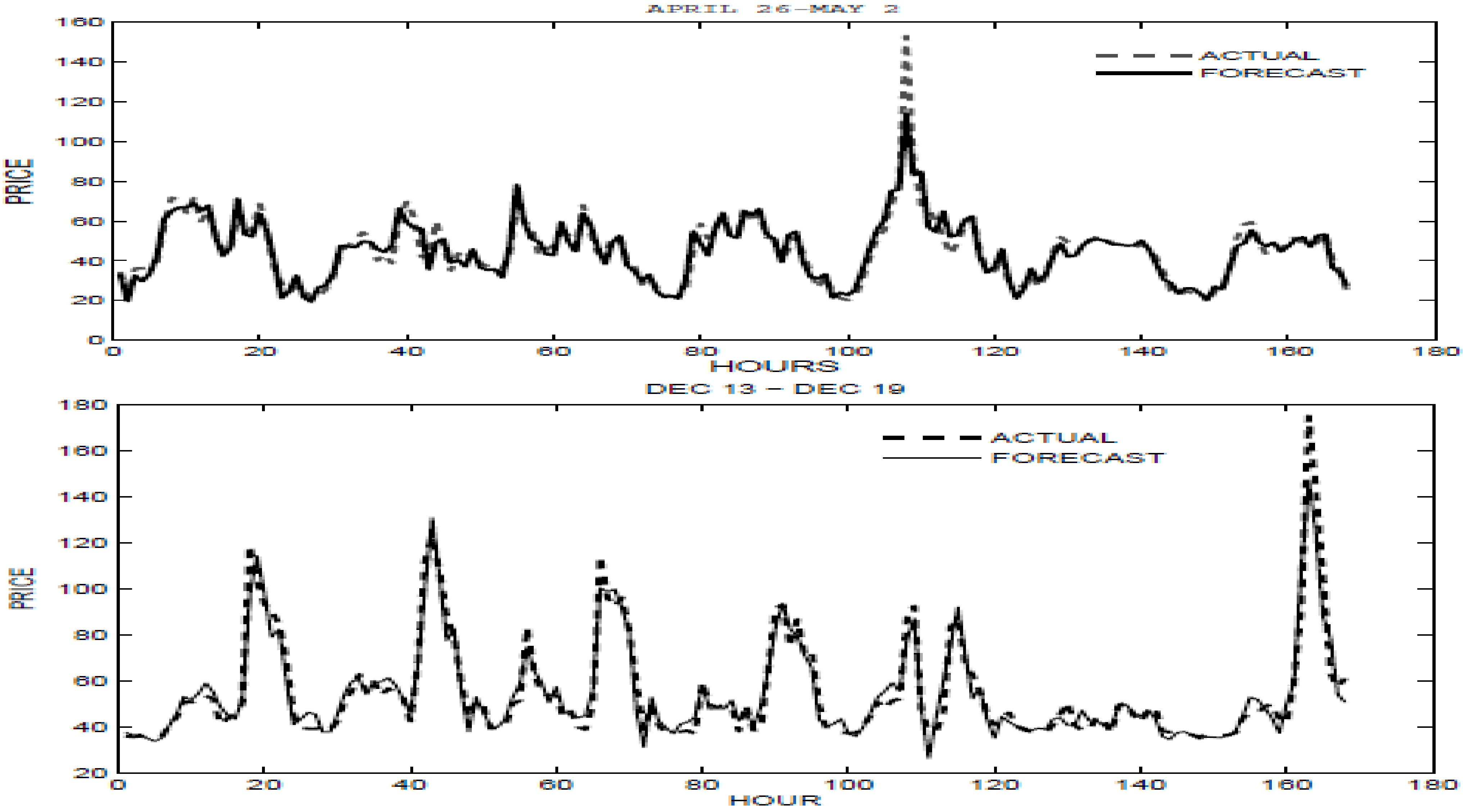
PREDICTIONS


APRIL 26–MAY 2
ACTUAL
FORECAST
PRICE
HOURS
DEC 13 – DEC 19
ACTUAL
FORECAST
PRICE
HOUR

Need for incorporating uncertainties

- When forecast results are presented to end users, they should be informed as **to what extent they can be trusted**.
- Availability of prediction intervals will allow the decision makers to efficiently **quantify the levels of uncertainties** associated with the point forecasts, and to consider **a multiple of solutions for different conditions**.

Confidence Intervals and *Prediction Intervals*

$t(x) = f(x) + e(x)$

$t(x)$ *observed target value*

$f(x)$ *true regression*

$e(x)$ *noise with zero mean*

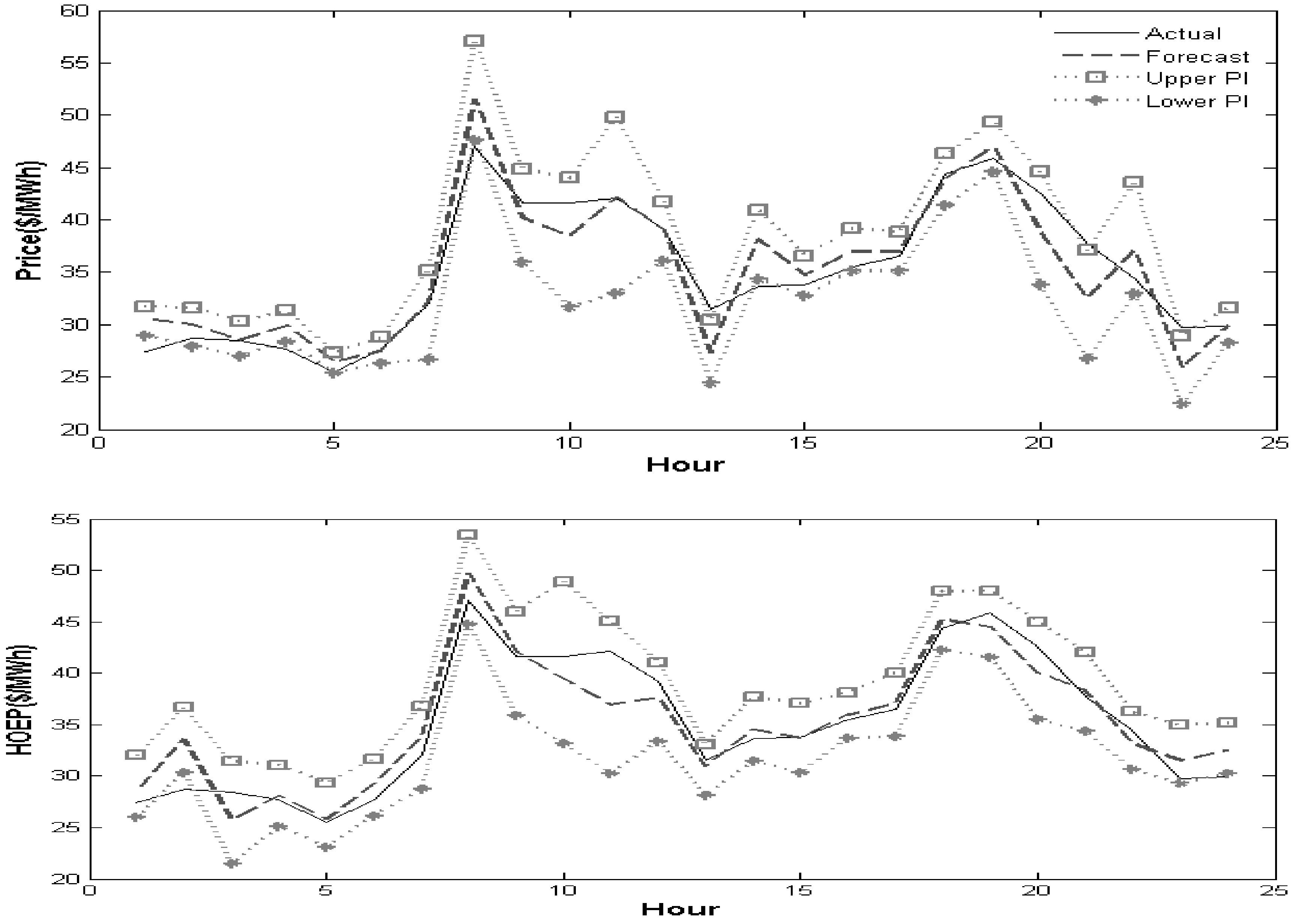
Training a ML algorithm is meant to estimate $\varphi(x)$ i.e. an approximation of $f(x)$.

It is an estimation of the mean of the distribution of the target values given an input vector x.

- Two measures of the confidence of this point prediction

1. Confidence intervals: accuracy of our estimate of true regression i.e. distribution of quantity $f(x)- \varphi(x)$
2. Prediction intervals: estimate of confidence in prediction of targets themselves i.e. distribution of quantity $t(x) - \varphi(x)$

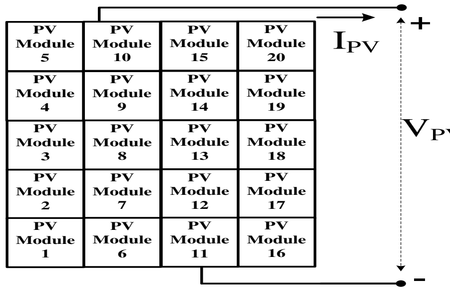
- $t(x)- \varphi(x)= [\, f(x)- \varphi(x)\,] + e(x)$



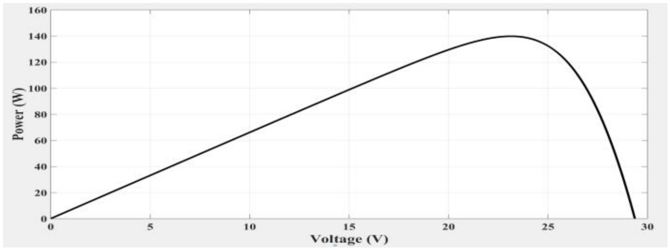
Price($/MWh)
Hour
Actual
Forecast
Upper PI
Lower PI
HOEP($/MWh)
Hour

Maximum Power Point Tracking from Solar Array

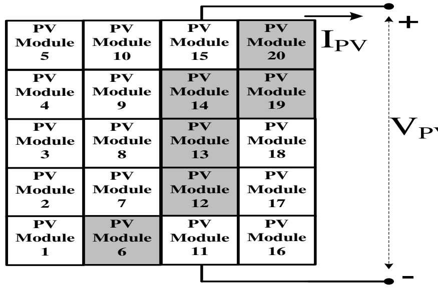
Partially Shaded Solar PV Array Conditions



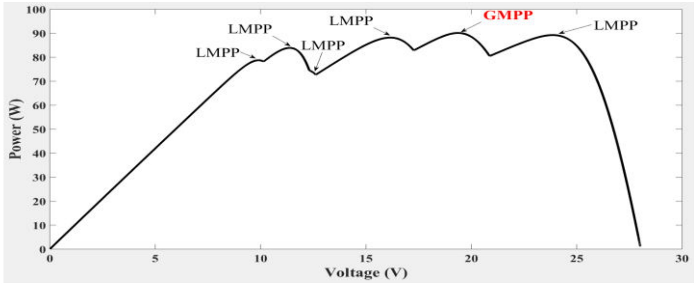
(a)



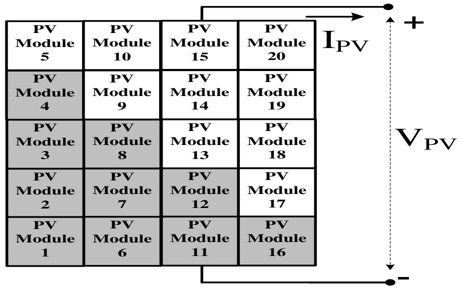
Pattern-1



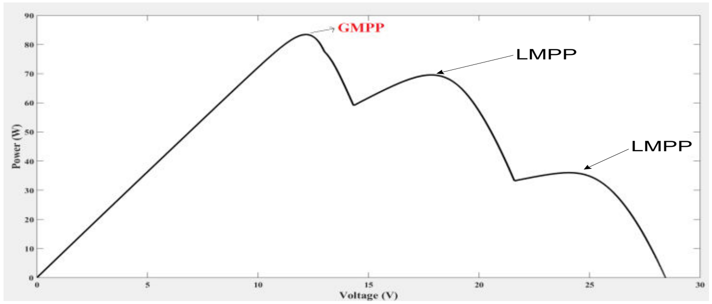
(b)



Pattern-2



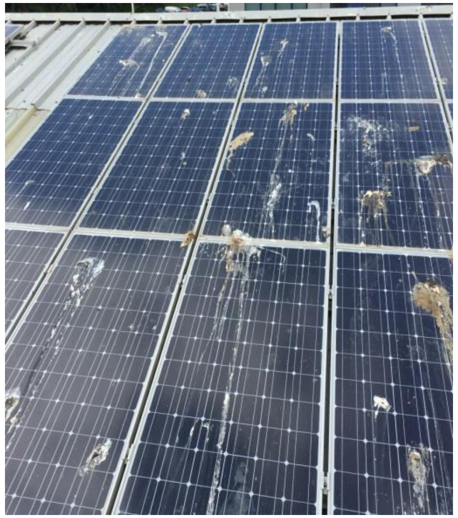
(c)



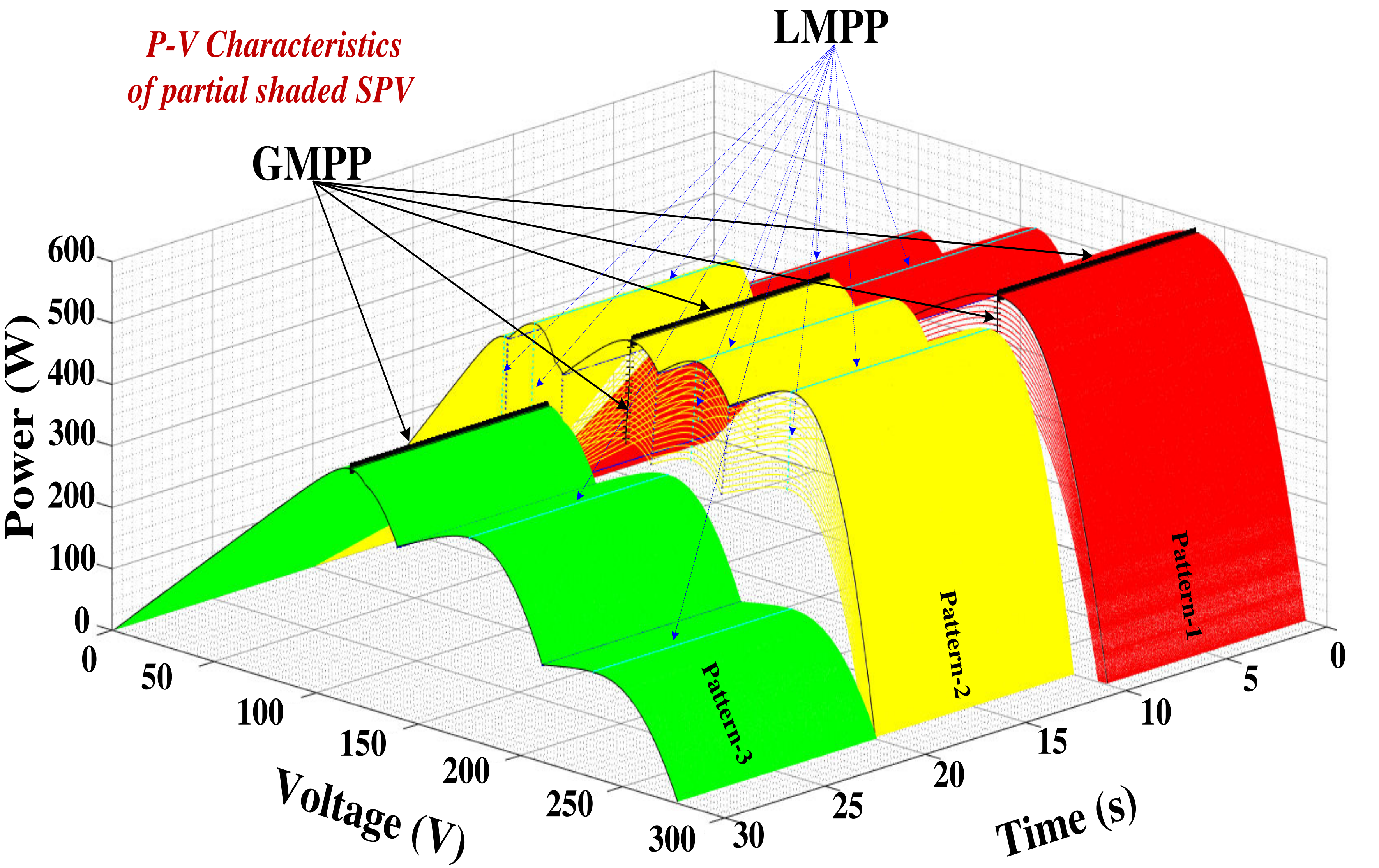
Pattern-3

Partial Shading on PV Array

- ❖Cloud
- ❖Tree
- ❖Tall building, Pole, pillars
- ❖Snow
- ❖Dust particles….. etc



PARTIAL SHADED Patterns



Problem Formulation

- The objective function (f) is defined as,

$$\begin{aligned} f(\mathrm{D_i}) &= \max P_{PV}(\mathrm{D_i}) \\ &= \max \{ V_{PV}(\mathrm{D_i}) \times I_{PV}(\mathrm{D_i})\} \end{aligned}$$

Where, $P_{PV}(\mathrm{D_i})$, $V_{PV}(\mathrm{D_i})$ and $I_{PV}(\mathrm{D_i})$ are instantaneous power, voltage and current at duty cycle $\mathrm{D_i}$.

- The constraint is described as,

$$0 < \mathrm{D_i} < 1$$

Relay Coordination in Distribution Network with DG Penetration

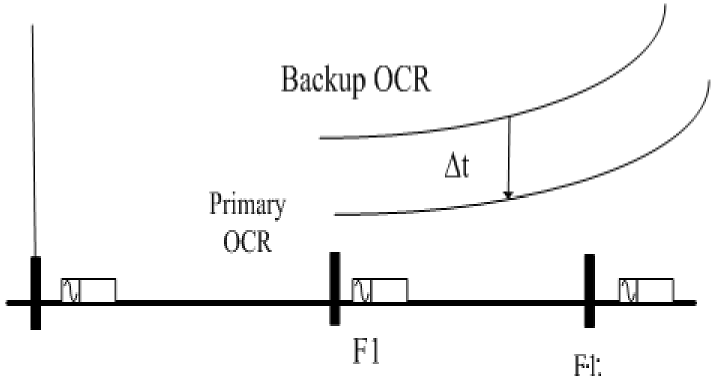
➢Problem formulation for optimal relay coordination

➢The main objective is to minimize total operating time of relay all primary relay (OF) as well as coordination time interval (CTI).

$$\min \ (OF) = \sum_{k=1}^{FL} \sum_{i=1}^{N_r} (T^{i}_{pri\_near} + T^{i'}_{pri\_far}).$$

$$T^{i}_{pri\_near} = \frac{\alpha * TDS^{i}}{[(\frac{I^{i}_{pri\_near}}{PS^{i} * CT^{i}_{ratio} * I^{i}_{ctsc}})^{\beta} - \gamma]} \qquad T^{i'}_{pri\_far} = \frac{\alpha * TDS^{i'}}{[(\frac{I^{i'}_{pri\_far}}{PS^{i'} * CT^{i'}_{ratio} * I^{i'}_{ctsc}})^{\beta} - \gamma]}$$

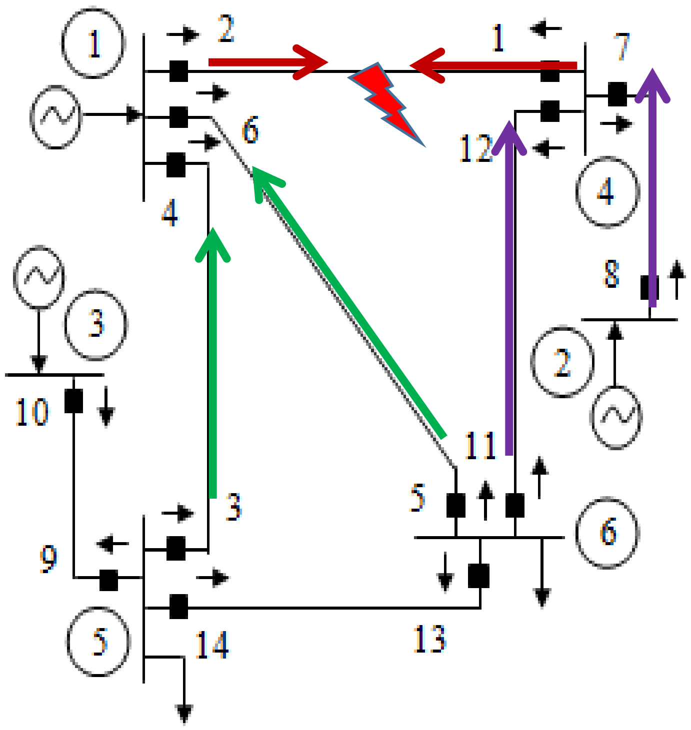
$$TDS_i^{min} \le TDS_i \le TDS_i^{max}. \qquad PS_i^{min} \le PS_i \le PS_i^{max}.$$



Types of characteristics	α	β γ	
Standard inverse (SI)	0.14	0.02	1
very inverse (VI)	13.5	1	1
Extremely inverse (EI)	80	2	1

Network Topology storage: Primary/backup relay pairs

6 Bus System



Primary and Backup relay pairs for Near-end faults				
Fault near to	Primary Relay	Backup Relay	Primary Relay	Backup Relay
Relay 1	1	8	1	11
Relay 2	2	3	2	5
Relay 3	3	10	3	13
Relay 4	4	5	4	1
Relay 5	5	12	5	14
Relay 6	6	3	6	1
Relay 7	7	11	7	2
Relay 8	8	0	8	0
Relay 9	9	13	9	4
Relay 10	10	0	10	0
Relay 11	11	14	11	6
Relay 12	12	8	12	2
Relay 13	13	12	13	6
Relay 14	14	10	14	4

Coordination Constraints sets

Limits on Problem Variables

1. **Bounds on time dial setting (TDS)**

$$TDS_i^{\min} \le TDS_i \le TDS_i^{\max}$$

2. **Bounds on pickup current setting**

$$I_{pickup}^{\min} \le I_p \le I_{pickup}^{\max}$$

3.Limits on Primary Operation Time

less than a maximum allowed time delay and more than some minimum predefined time considering transient conditions

4.Coordination criteria (Selectivity Constraint):

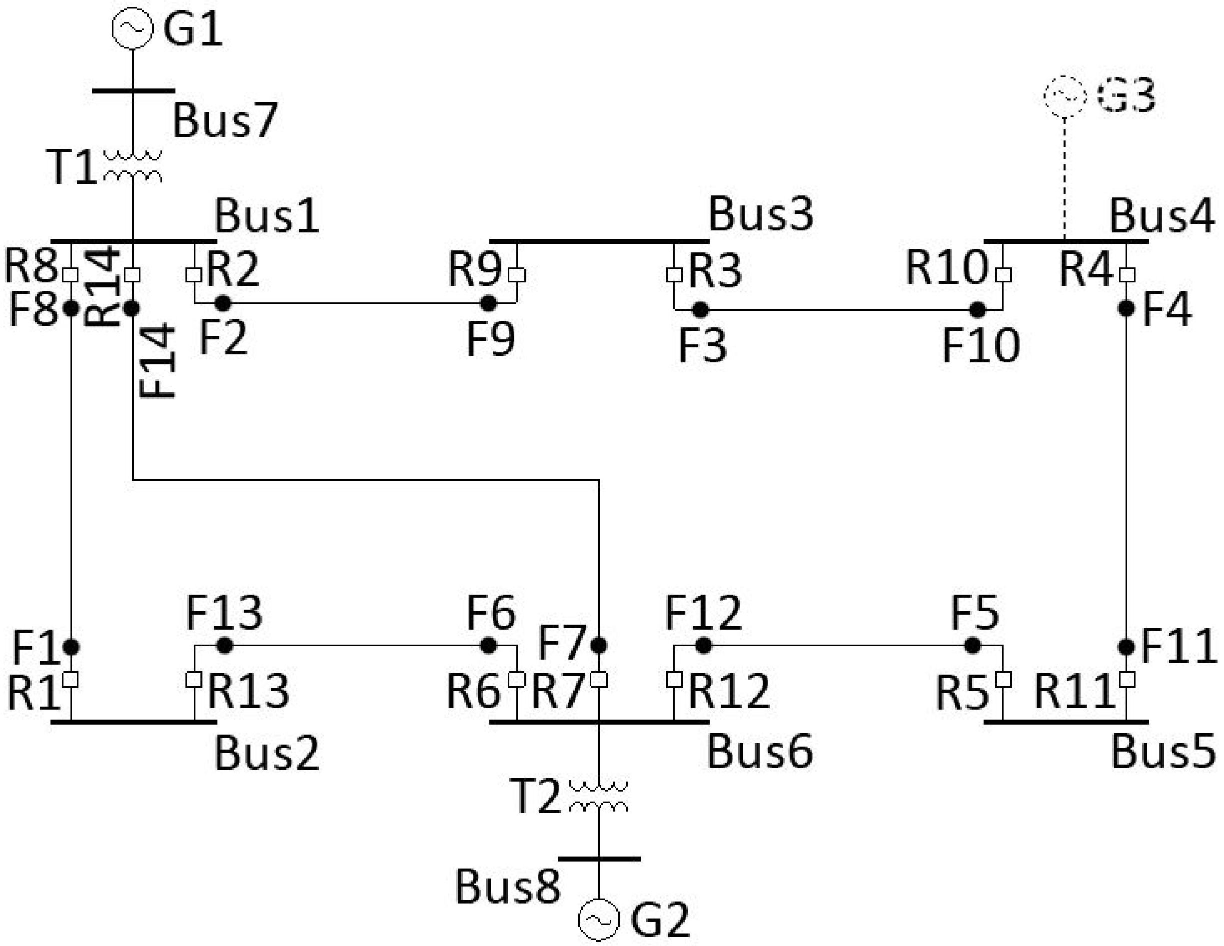
$$t_{i,k} - t_{j,k} = \Delta t$$

5. For a fault location, both near and far-end primary relays should operate before their respective back-up relays

Coordination time interval (CTI) generally taken as 0.2 to 0.3

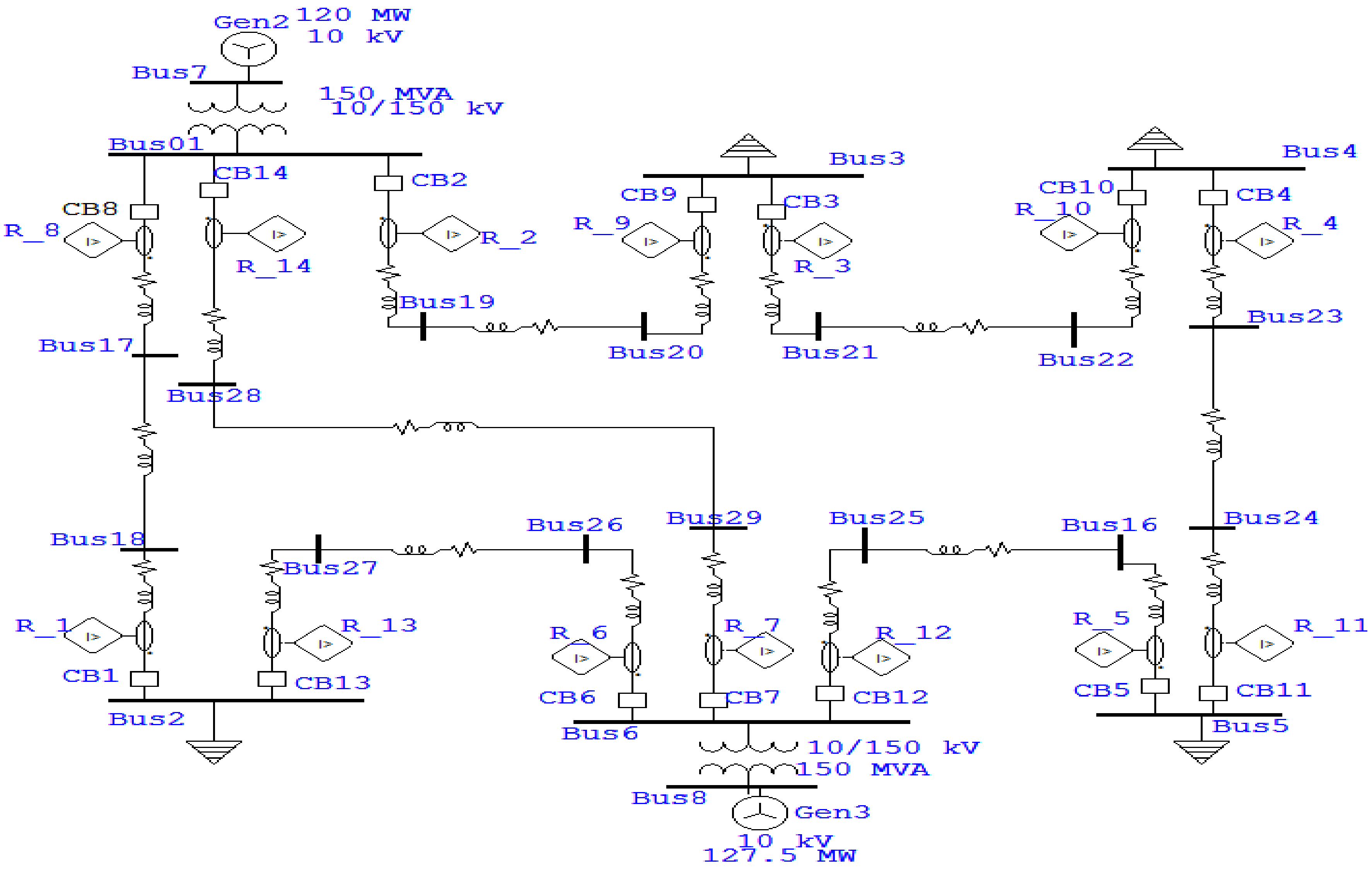
Detailed analysis of 8 Bus System with ETAP

8 bus system



G1
Bus7
T1
Bus1
R8
R14
R2
F8
F14
F2
Bus3
R9
R3
F9
F3
G3
Bus4
R10
R4
F10
F4
F1
R1
F13
R13
Bus2
F6
R6
F7
R7
F12
R12
Bus6
F5
R5
F11
R11
Bus5
T2
Bus8
G2

ETAP Model of 8 Bus System



Fault locations and their corresponding near end, far end primary and backup relays with their CT ratio:

Fault location	Primary relay near end	Primary relay far end	Backup relay near end	Backup relay far end
Bus 17	8	1	9,7	6
Bus 18	1	8	6	9,7
Bus 19	2	9	1	10
Bus 20	9	2	10	1
Bus 21	3	10	2	11
Bus 22	10	3	11	2
Bus 23	4	11	3	12
Bus 24	11	4	12	3
Bus 16	5	12	4	13,14
Bus 25	12	5	13,14	4
Bus 26	6	13	5,14	8
Bus 27	13	6	8	5,14
Bus 28	14	7	1,9	5,13
Bus 29	7	14	5,13	1,9

Relay no	CT Ratio
1	240
2	240
3	160
4	240
5	240
6	240
7	160
8	240
9	160
10	240
11	240
12	240
13	240
14	160

Specifications

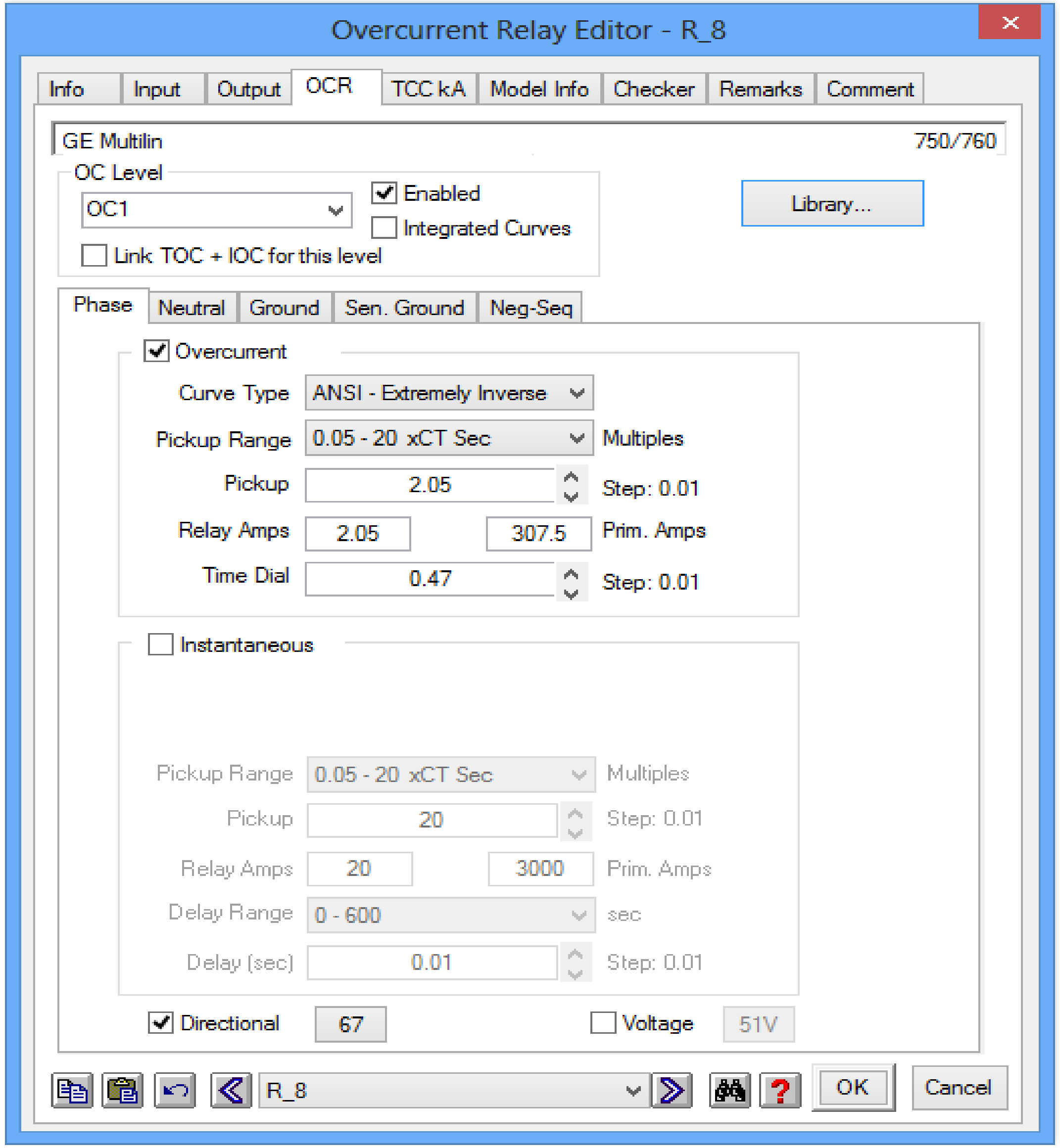
- **Relay:**

Manufacturer: GE Multilin

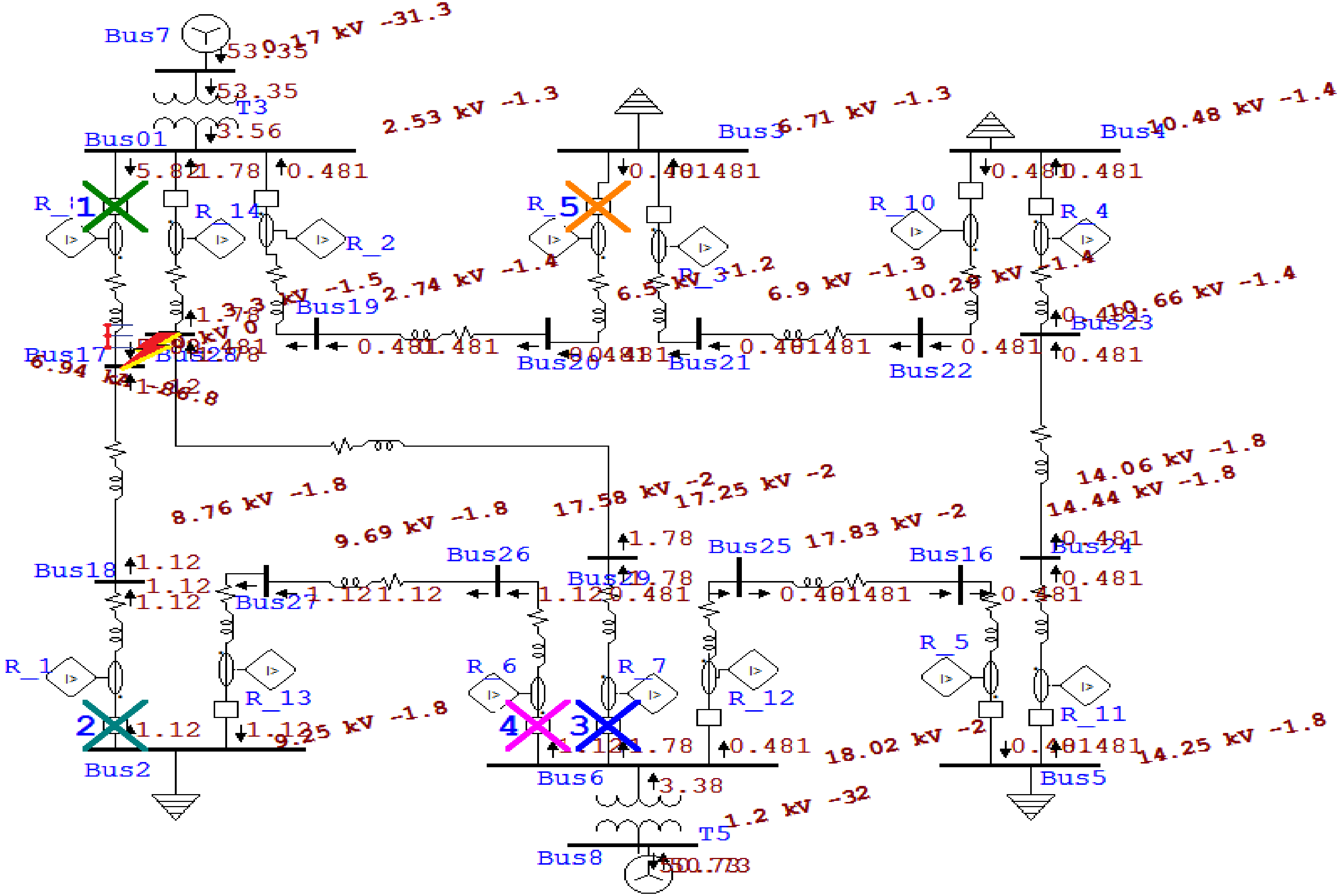
Model: 750/760

Type: Overcurrent Directional Relay

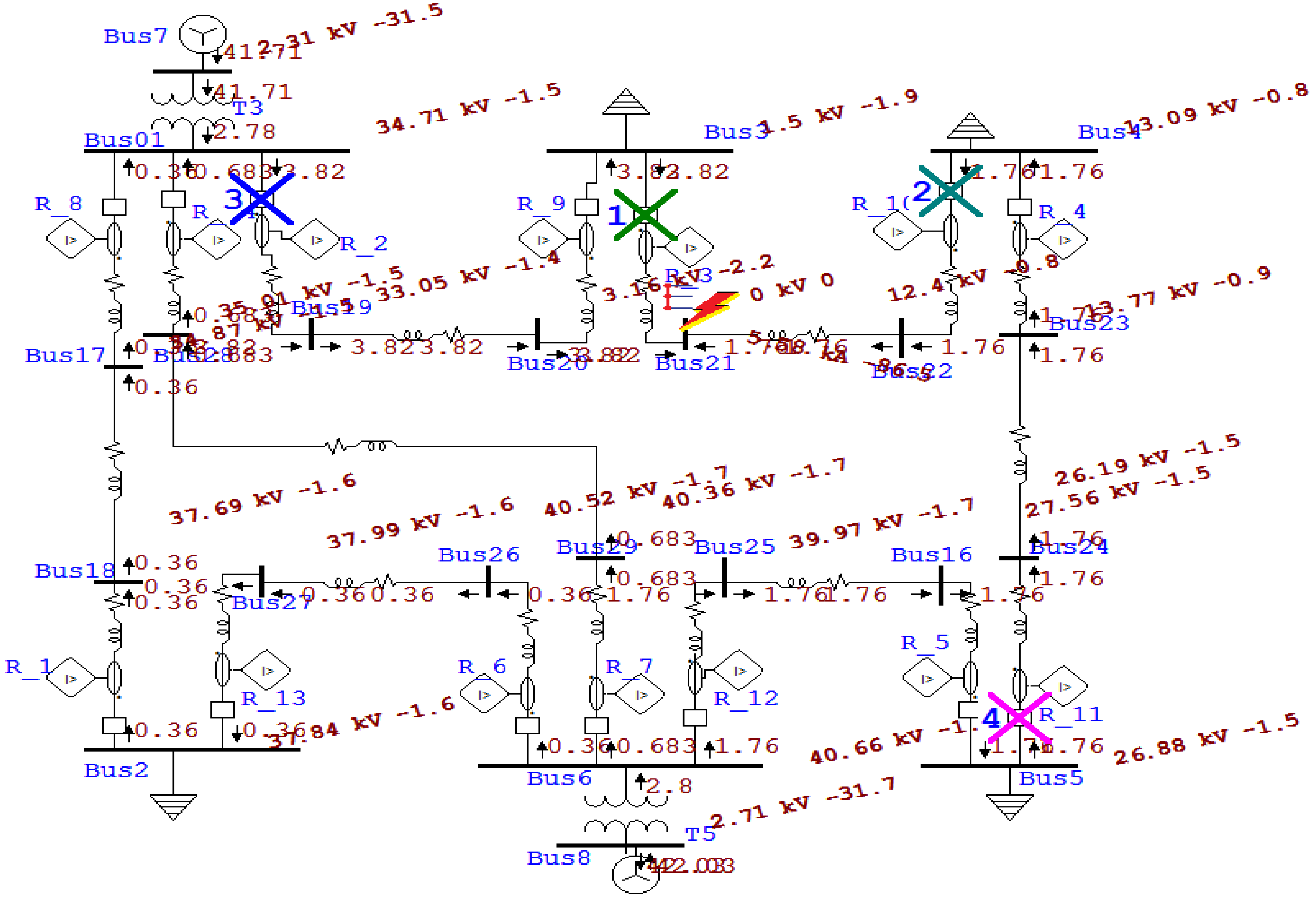
Curve type: ANSI Extremely inverse



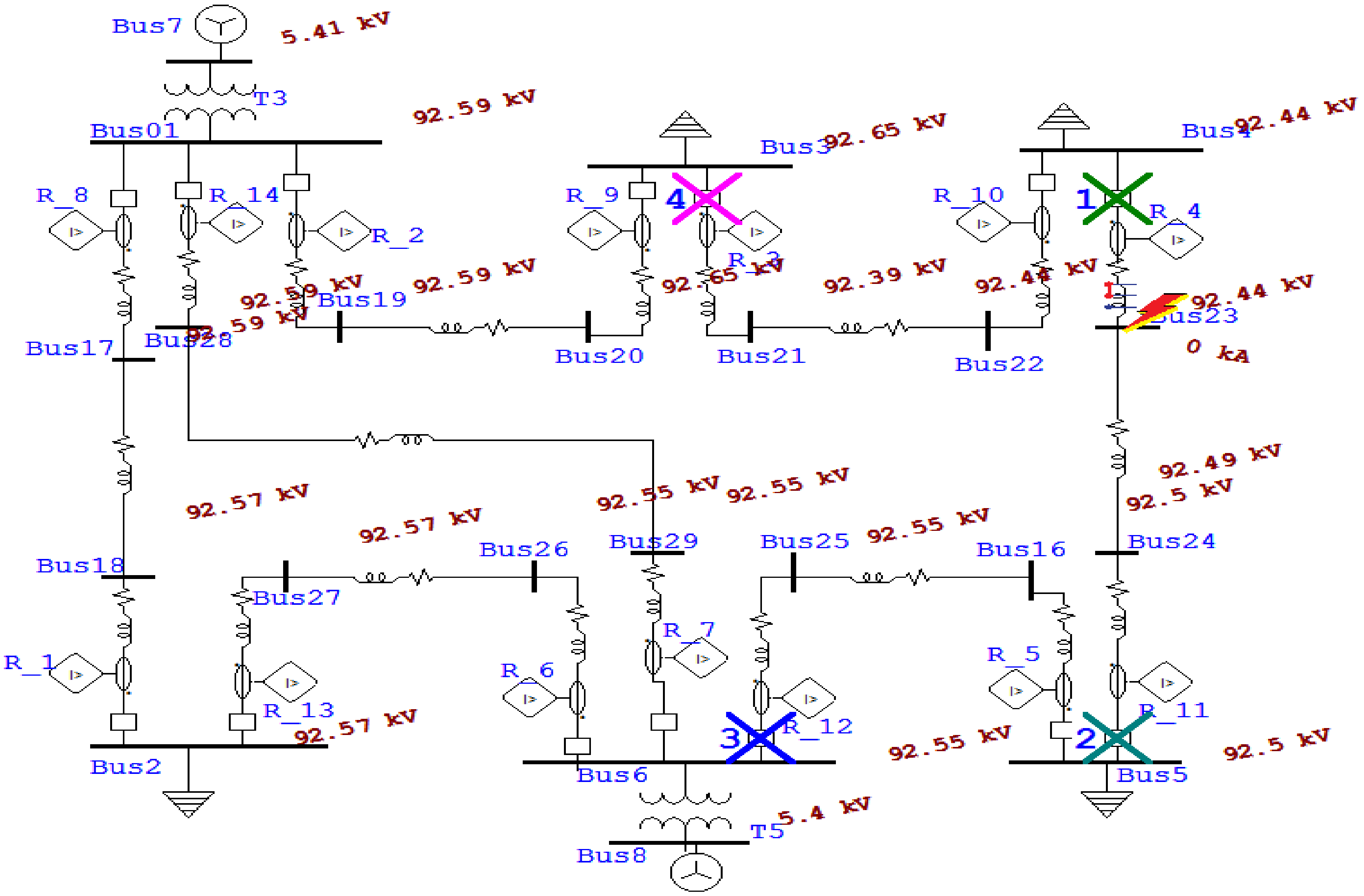
Relay and circuit breaker operation while fault on BUS 17



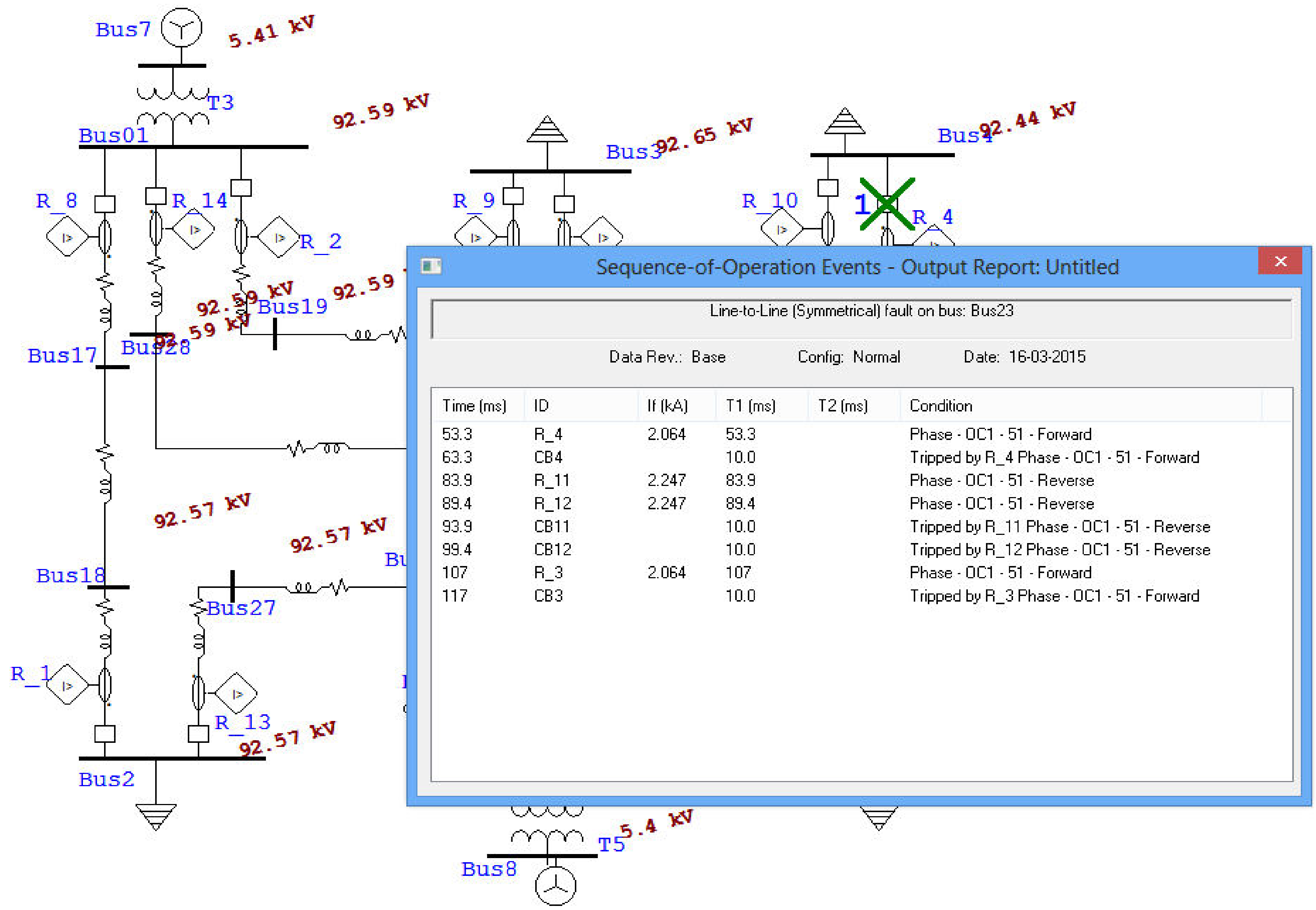
Relay and circuit breaker operation while fault on BUS 21



Relay and circuit breaker operation while fault on BUS 23



Operating time of relays and circuit breakers while fault on BUS 23



Time (ms)	ID	If (kA)	T1 (ms)	T2 (ms)	Condition
53.3	R_4	2.064	53.3		Phase - OC1 - 51 - Forward
63.3	CB4		10.0		Tripped by R_4 Phase - OC1 - 51 - Forward
83.9	R_11	2.247	83.9		Phase - OC1 - 51 - Reverse
89.4	R_12	2.247	89.4		Phase - OC1 - 51 - Reverse
93.9	CB11		10.0		Tripped by R_11 Phase - OC1 - 51 - Reverse
99.4	CB12		10.0		Tripped by R_12 Phase - OC1 - 51 - Reverse
107	R_3	2.064	107		Phase - OC1 - 51 - Forward
117	CB3		10.0		Tripped by R_3 Phase - OC1 - 51 - Forward

Automotive Health Monitoring

Automotive

Four Wheeler

Two Wheeler

Major Components

Engine

EV Motor

Failures in Components

Gear Failure

Bearing Defects

Rotor Eccentricity

Coupling Failure

Crack Shaft

Simulators and Test Setup

Machinery Fault Simulator

Bearing Test Rig

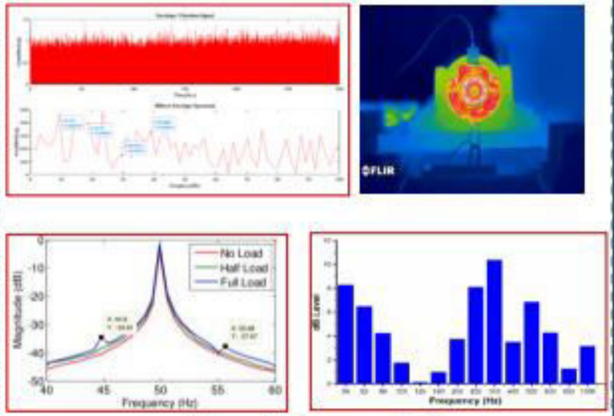
Noise Source Identification

Interior & Exterior Sound Quality Analysis

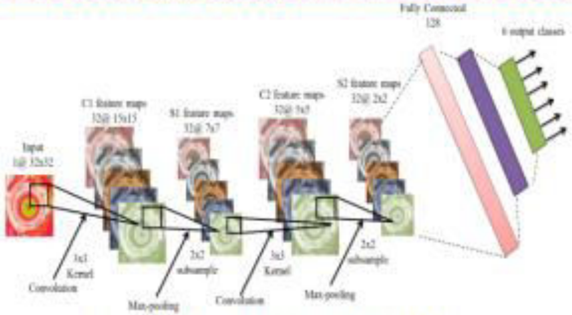
Health Monitoring Fault Diagnosis Techniques

- Vibration Analysis
- Noise Monitoring
- Motor Current Signature Analysis
- Infrared Thermography
- Acoustic Emission
- Sound Quality
- Acoustic Holography and Beam Forming

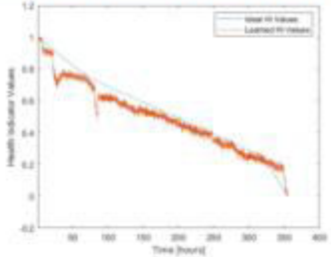
Signal Processing, AI, IoT and RUL Prediction



Signal Processing



Fault Diagnosis Using AI

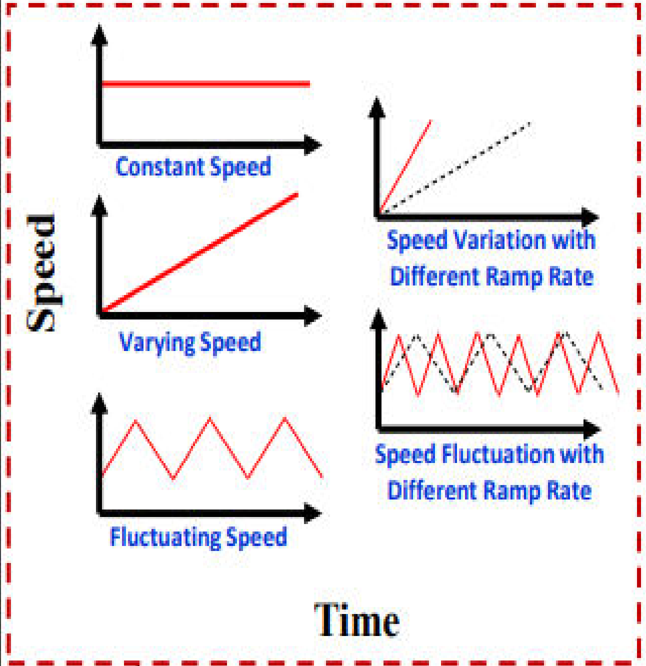


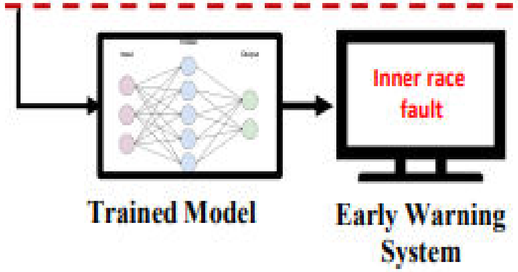
Remaining Useful Life Prediction

1) Development of Speed Independent Multi-fault Diagnosis System

What does speed independent model means?

A machine learning model that work irrespective of speed conditions is known as speed independent model.





Used techniques in brief

Technique	Examples
Data pre-processing	Data profiling, data cleansing, data transformation, data enrichment etc.
Signal Processing	Fourier Transform, Hilbert Transform, Empirical Mode Decomposition, Wavelet Transform etc.
Feature Engineering using Metaheuristic Algorithms	Henry Gas Solubility Optimization, Genetic Algorithm, Particle Swam Optimization etc.
Hyperparameter optimization	Kernels, support vectors, neurons, stride etc.
Classification	ANN, SVM, kNN, Random Forest, Decision Trees, CNN etc.
Model Performance Evaluation	Accuracy, Precision, Recall, F1-Score etc.

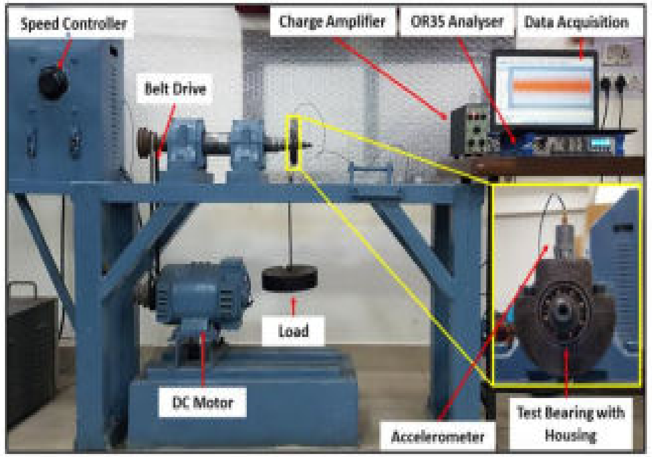
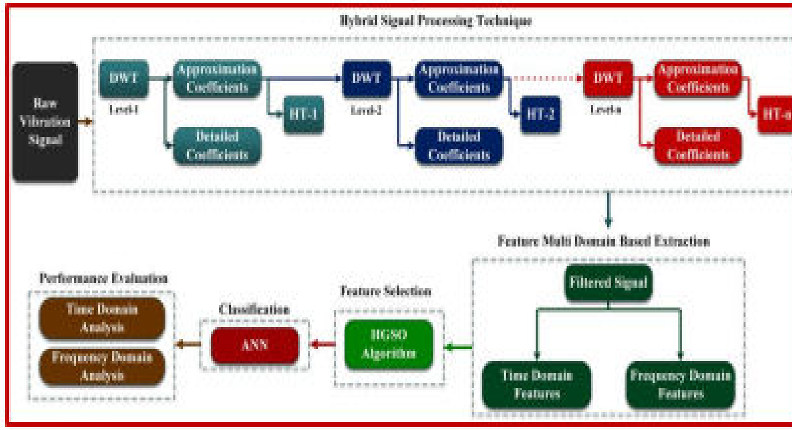


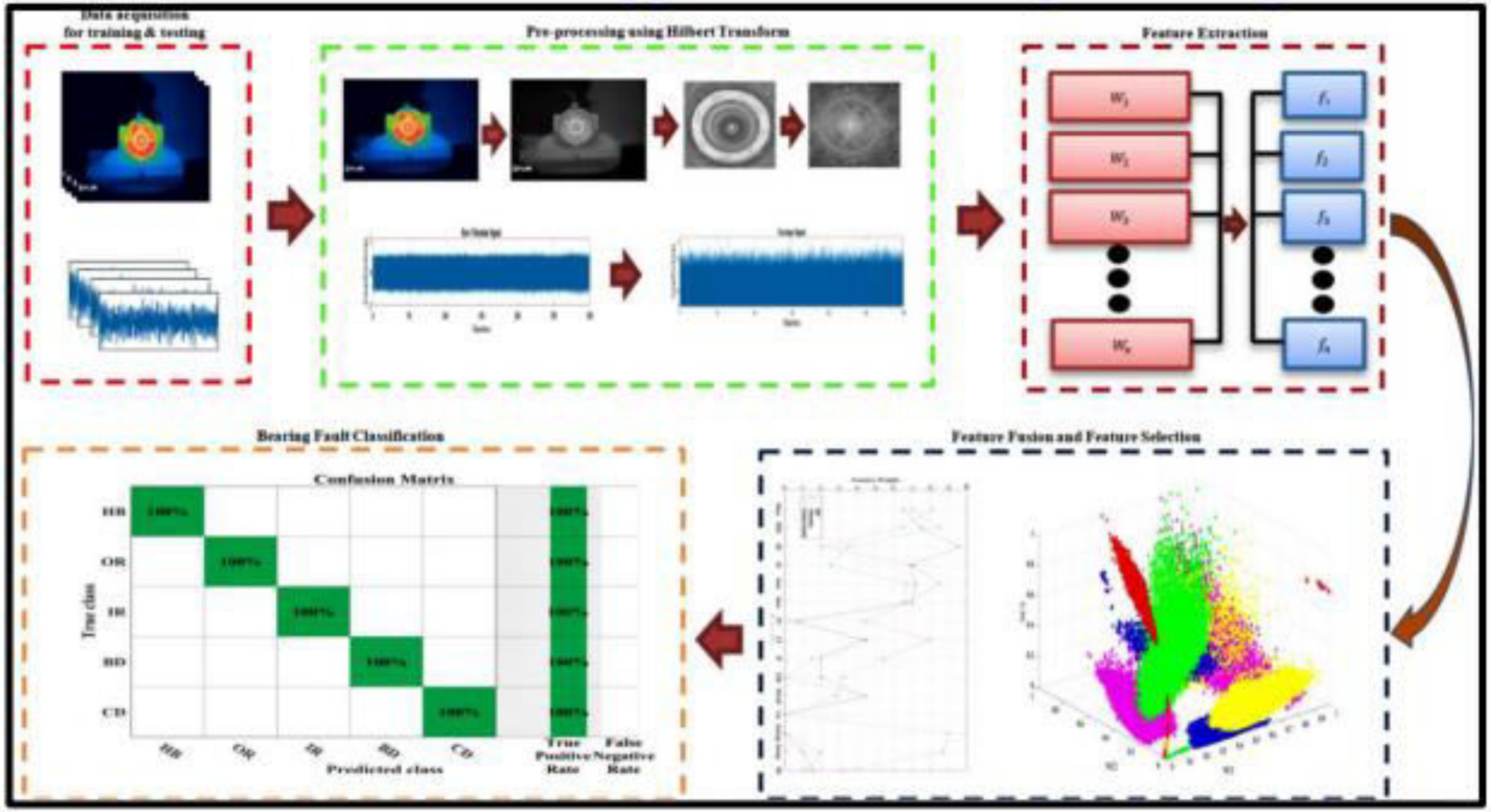
Figure-Bearing test rig



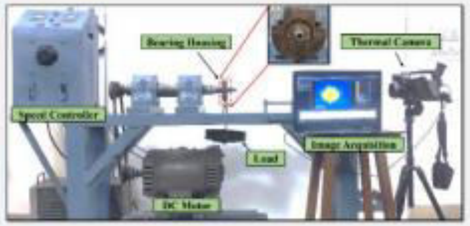
2) Intelligent Predictive Maintenance Approaches on Rotating Machines

Sensor fusion- based approach for bearing fault diagnosis

Sound quality based fault diagnosis of bearing



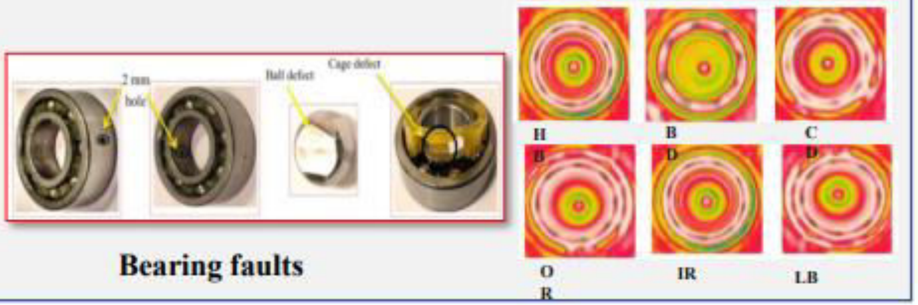
3) Development of Fault Diagnostic System for Electric Vehicle



Experimental-setup

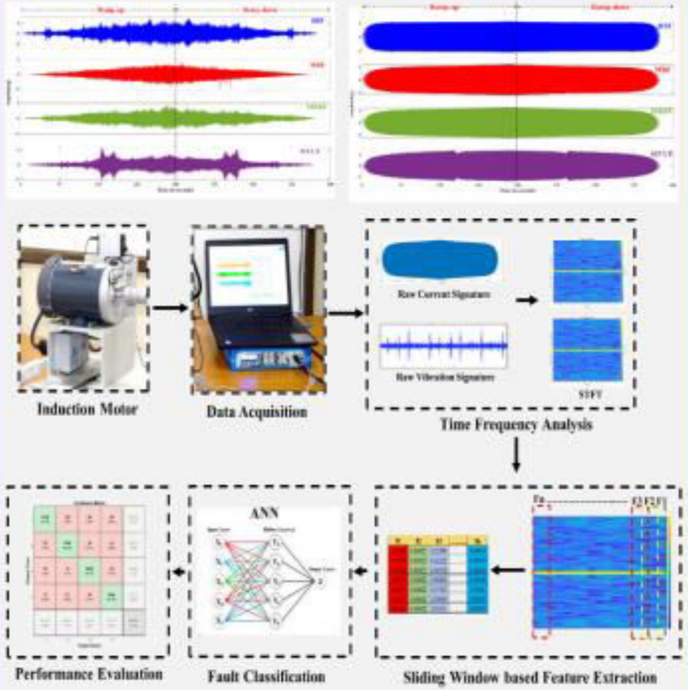
Two Wheeler Fault Simulator

Four Wheeler Fault Simulator

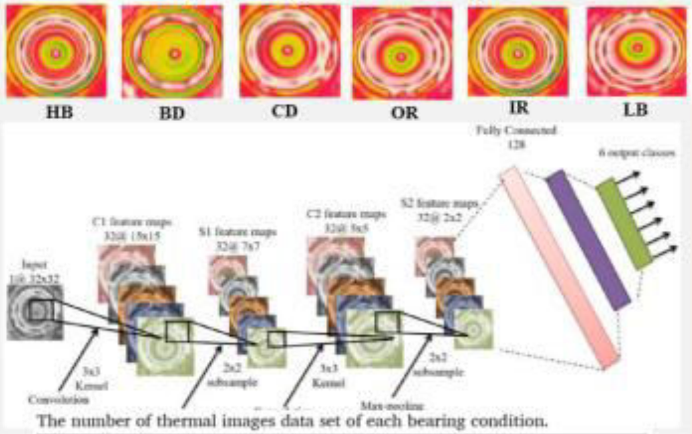


Bearing faults

Machine Learning Based Fault Diagnosis



Deep Learning Based Fault Diagnosis

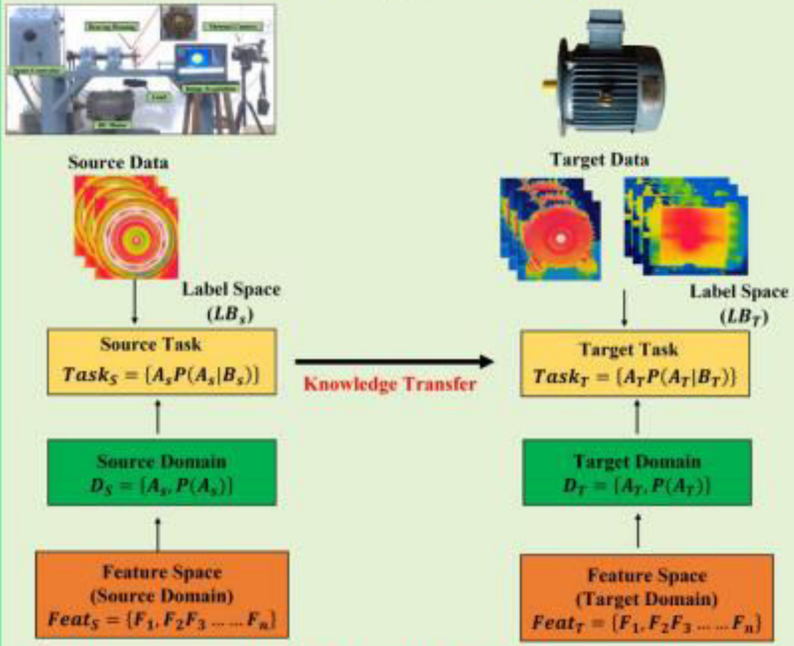


The number of thermal images data set of each bearing condition.

Bearing condition	No. of dataset			Thermal image dimension	Total data
	Speed				
	19 Hz	23 Hz	29 Hz		
HB	2100	2100	2100		
OR	2100	2100	2100	640 × 480(Raw)	37,800
IR	2100	2100	2100	32X32 (Selected)	
BD	2100	2100	2100		
CD	2100	2100	2100		
LB	2100	2100	2100		

*Source : Anurag Choudhary, T. Mian and S. Fatima, "Convolutional Neural Network Based Bearing Fault Diagnosis of Rotating Machine Using Thermal Images", Measurement, pp. 109196, 2021.

Transfer Learning Based Fault Diagnosis



*Source : Anurag Choudhary, Tauheed Mian, S. Fatima and B. K. Panigrahi, Passive Thermography Based Bearing Fault Diagnosis using Transfer Learning with Varying Working Conditions, IEEE Sensor Journal (2022), doi: 10.1109/JSEN.2022.3164430

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Ajinkya Waradpande | | Updated on November 16, 2020 | Published on November 16, 2020

Grid infrastructure and stability

Energy Storage

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By Jeffrey D. Bean & Kartikeya Singh

July 9, 2019

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The Role of AI and ML in Solar Energy

ASOKE K. LAHA,
President and CEO,
Interra Information Technologies Inc

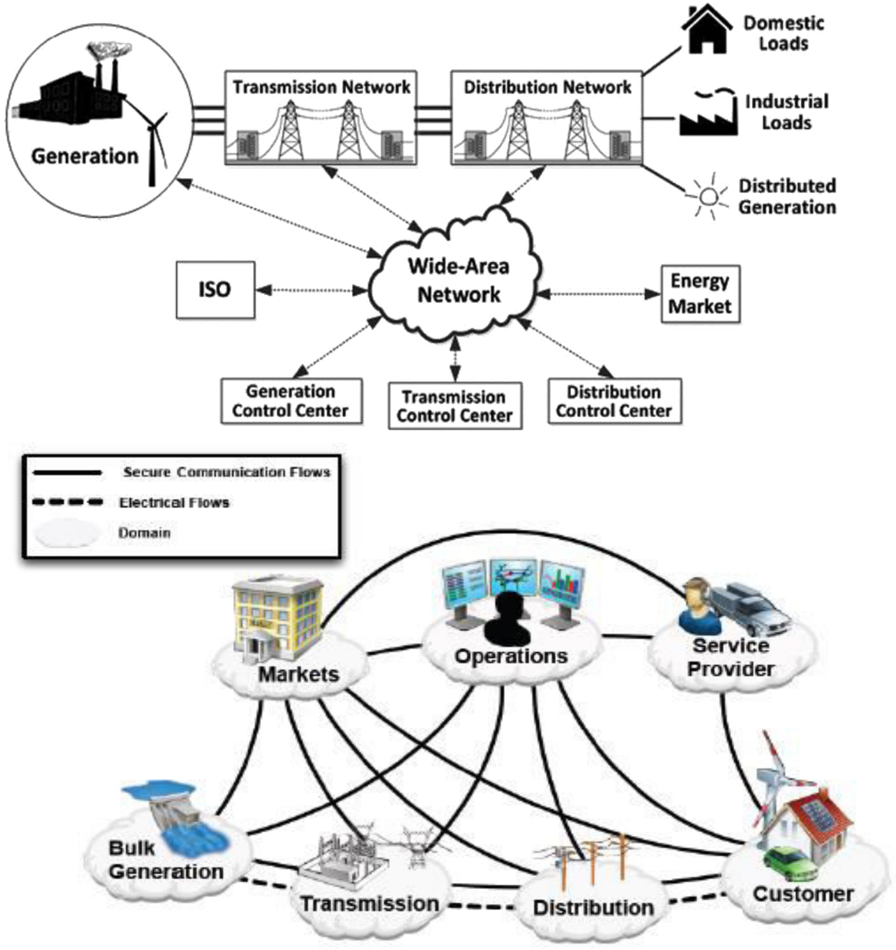
Smart, Centralized Control Centers

Improved Integration of Microgrids

Improved Safety and Reliability

SMART GRID AS A CYBER PHYSICAL SYSTEM

- Traditional Power grid with communication technology overlaid on top.
- Convergence of Operational Technology (OT) and Information Technology (IT)
- More-Data increases Situational Awareness
- Automation (increased reliability and efficiency)
- Cyber Security

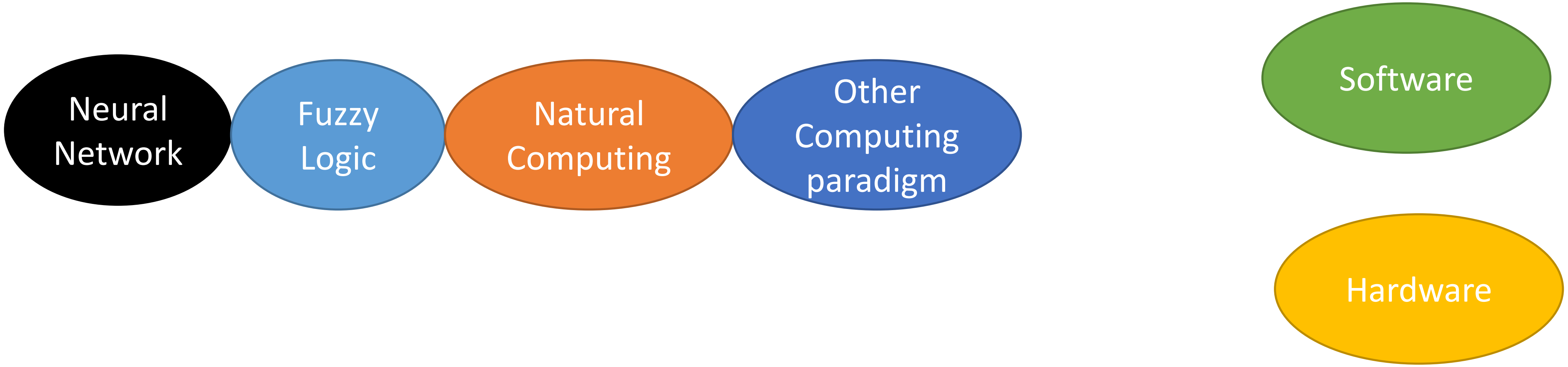


Source: NIST Framework for Smart Grid Security

Digital Twins for Energy Sector
Enhance Efficiency and Boost Productivity

- **Energy Systems Simulation (Grid, Storage, Vehicle etc) (Model based and Data Driven based approaches)**
- **Performance Analysis, Monitoring, Maintenance**

AI and ML tools techniques for Energy Sector



THANKS