RESEARCH TOPICS ON POWER SYSTEMS

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https://www.pbs.org/video/america-revealed-birth-power-grid/

https://www.power-grid.com/executive-insight/power-gen-europe-confidence-index-european-power-report/#gref

TOPICS THAT WILL BE COVERED

- ✓Advancements in Generation System
- ✓Advancements in Transmission system
- ✓Advancements in Distribution system
- ✓Machine learning for power systems (Time permits!)

ADVANCEMENTS IN GENERATION SYSTEM

➢Modeling and Validation of Hydropower Plants

- Physics driven (Based on differential equation)

energies

MDPI

Article

Frequency Containment Control of Hydropower Plants Using Different Adaptive Methods

Doğan Gezer [1,*], Yiğit Taşcıoğlu [2] and Kutay Çelebioğlu [3]

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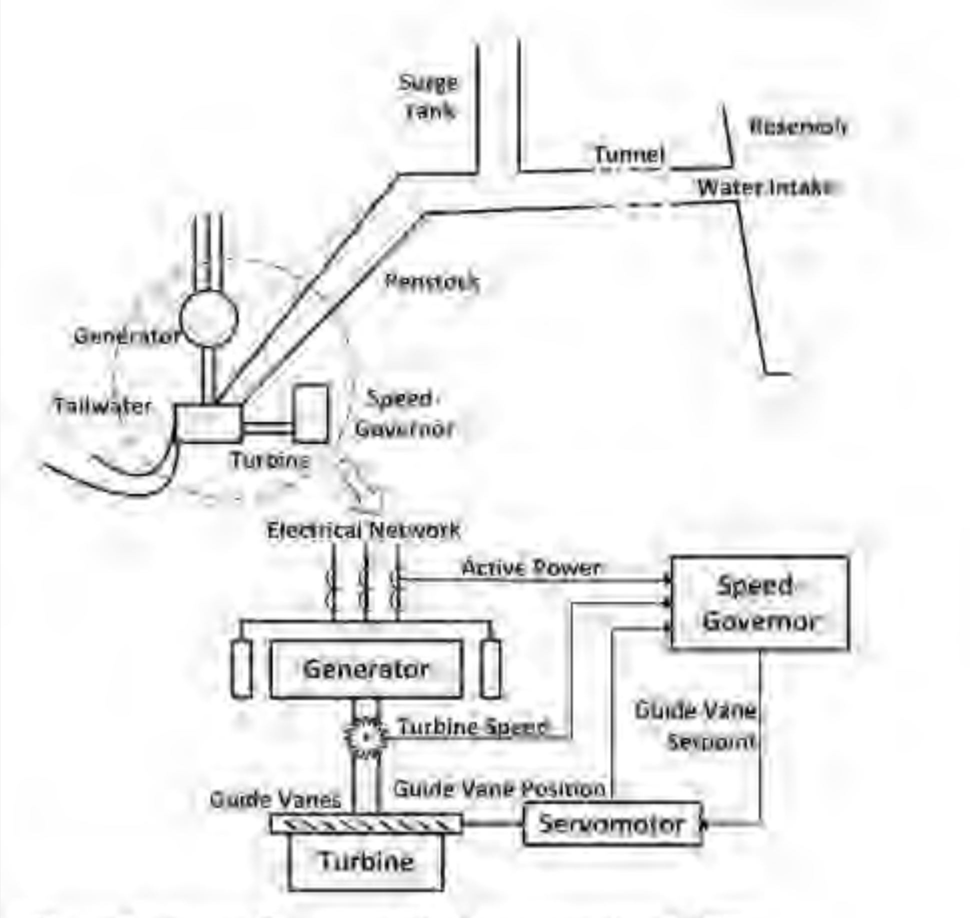
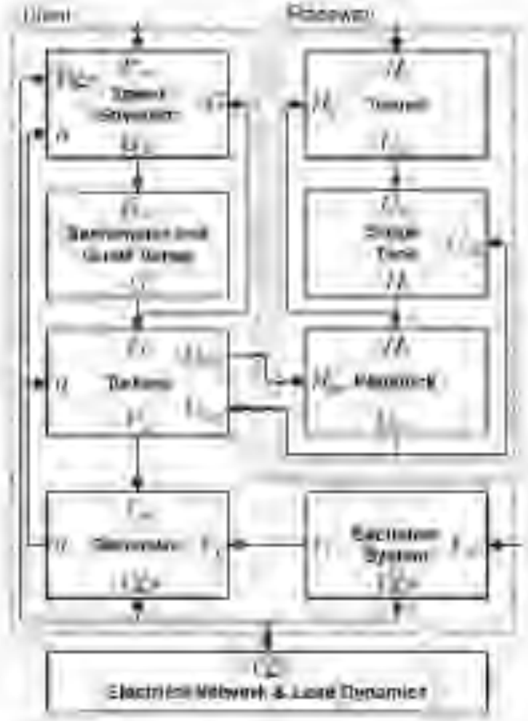
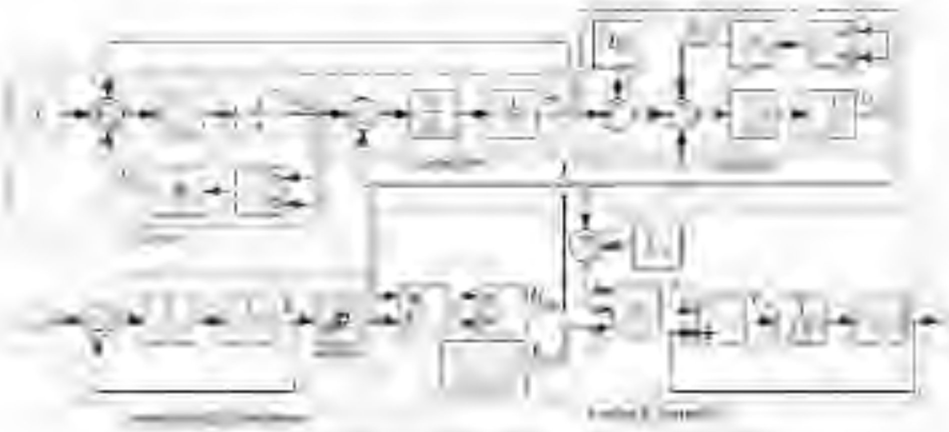


Figure 1. General layout of a hydropower plant (HPP)





2.1. System Description

In this study, Seyhan I HPP was modeled with the characteristic parameters listed in Table 1. Seyhan I HPP is an aged hydropower plant that started operation in 1957. It has three vertical Francis turbines with 22.5 MVA of installed capacity each.

Table 1. Characteristic parameters of Seyhan I HPP.

Parameter	Value	Unit
Nominal net head	32	m
Nominal flow rate	77	m^3/s
Surge tank storage capacity	124.8	s
Surge tank cross-sectional area	380	m^2
Penstock length	81.7	m
Penstock cross-sectional area	21.2	m^2
Penstock friction factor	0.05	
Guide vane opening at no-load	11	%
Guide vane opening at full load	65	%
Servomotor time constant	1	s
Guide vane delay time	2	s
Flywheel effect of the generator	3320	$ton{\cdot}m^2$
Turbine nominal speed	125	rpm
Apparent power of the generator	22.5	MVA
Inertia constant of the generator	3.14	s

- Software: Open-Modelica, Simulink..

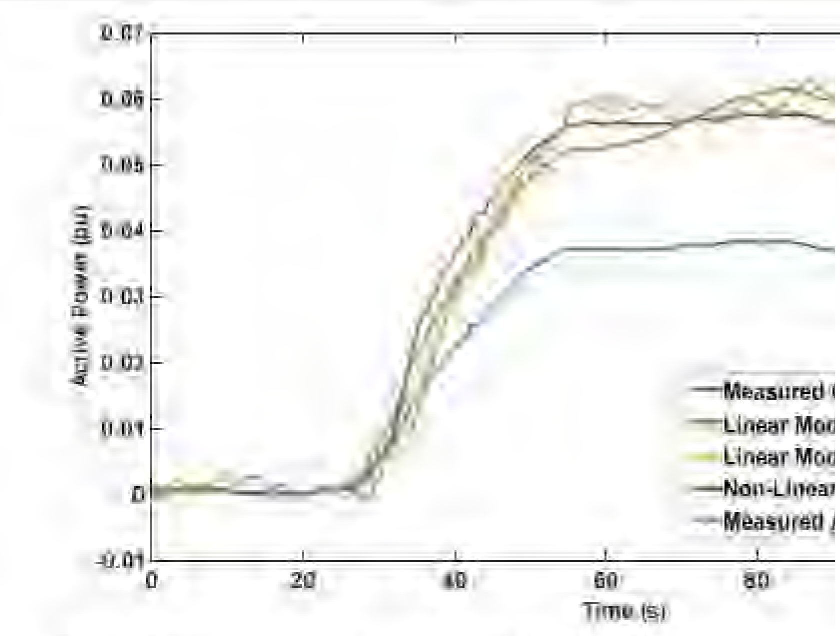


Figure 5. Comparison of various models with site measurements.

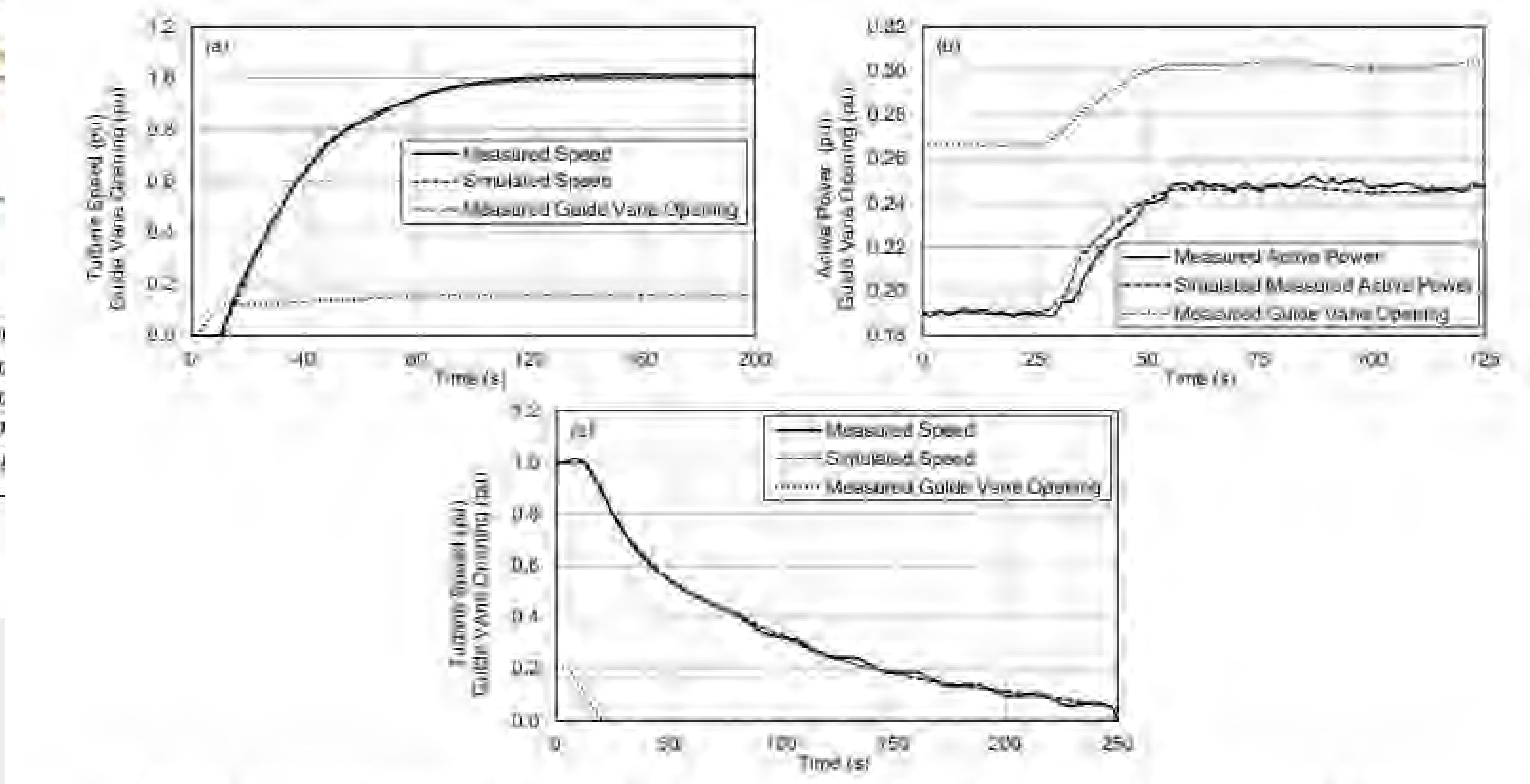
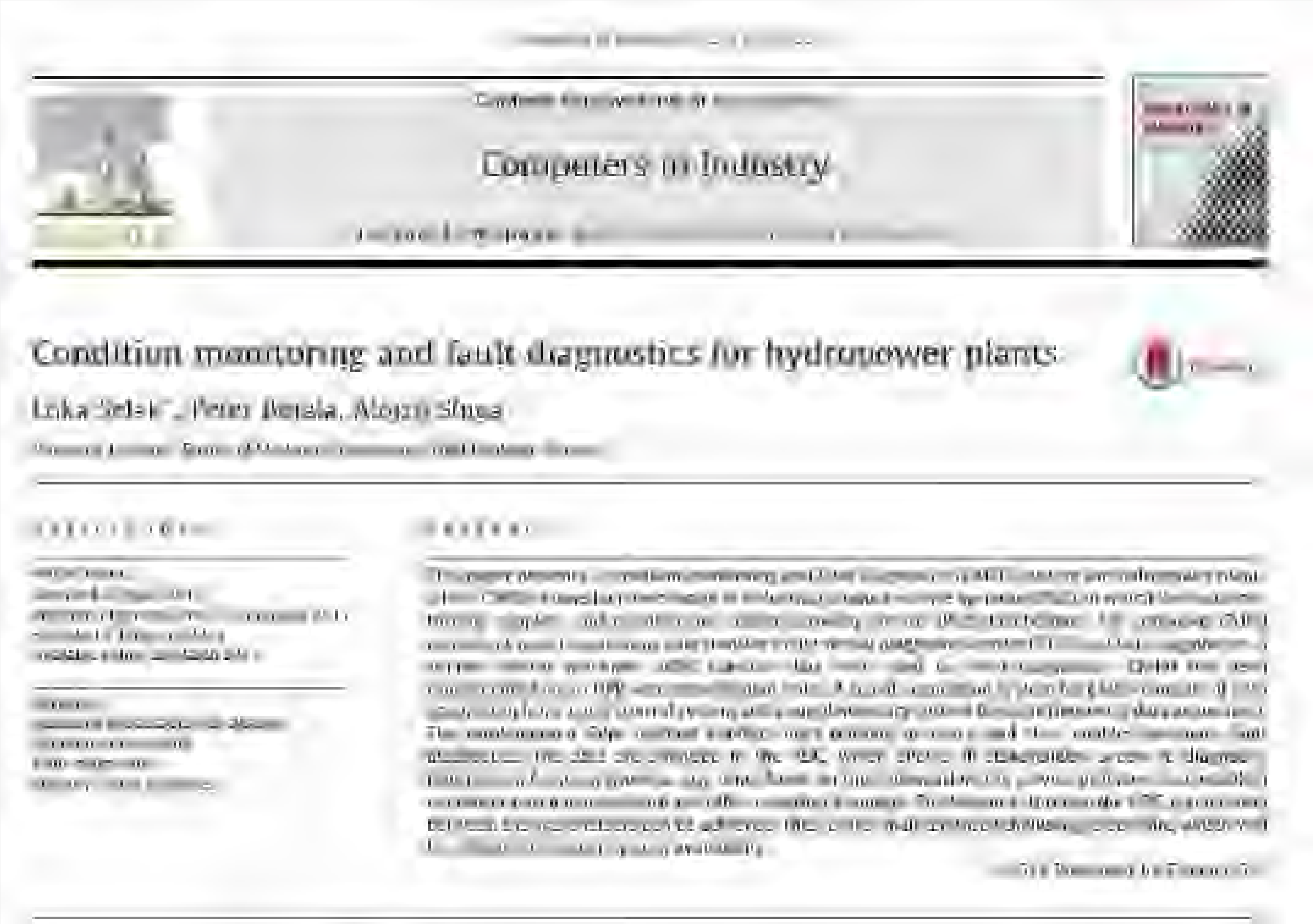


Figure 4. Model validation of Seyhan I HPP with site measurements during (a) start-up, (b) loading, and (c) shutdown.

- Can be further extended to data-driven models

➢Condition Monitoring for Hydropower plants

- Sensors, Signal Processing, Internet of Things (IOT), AI..



Computers in Industry

Condition monitoring and fault diagnostics for hydropower plants

Luka Selak*, Peter Butala, Alojzij Sluga

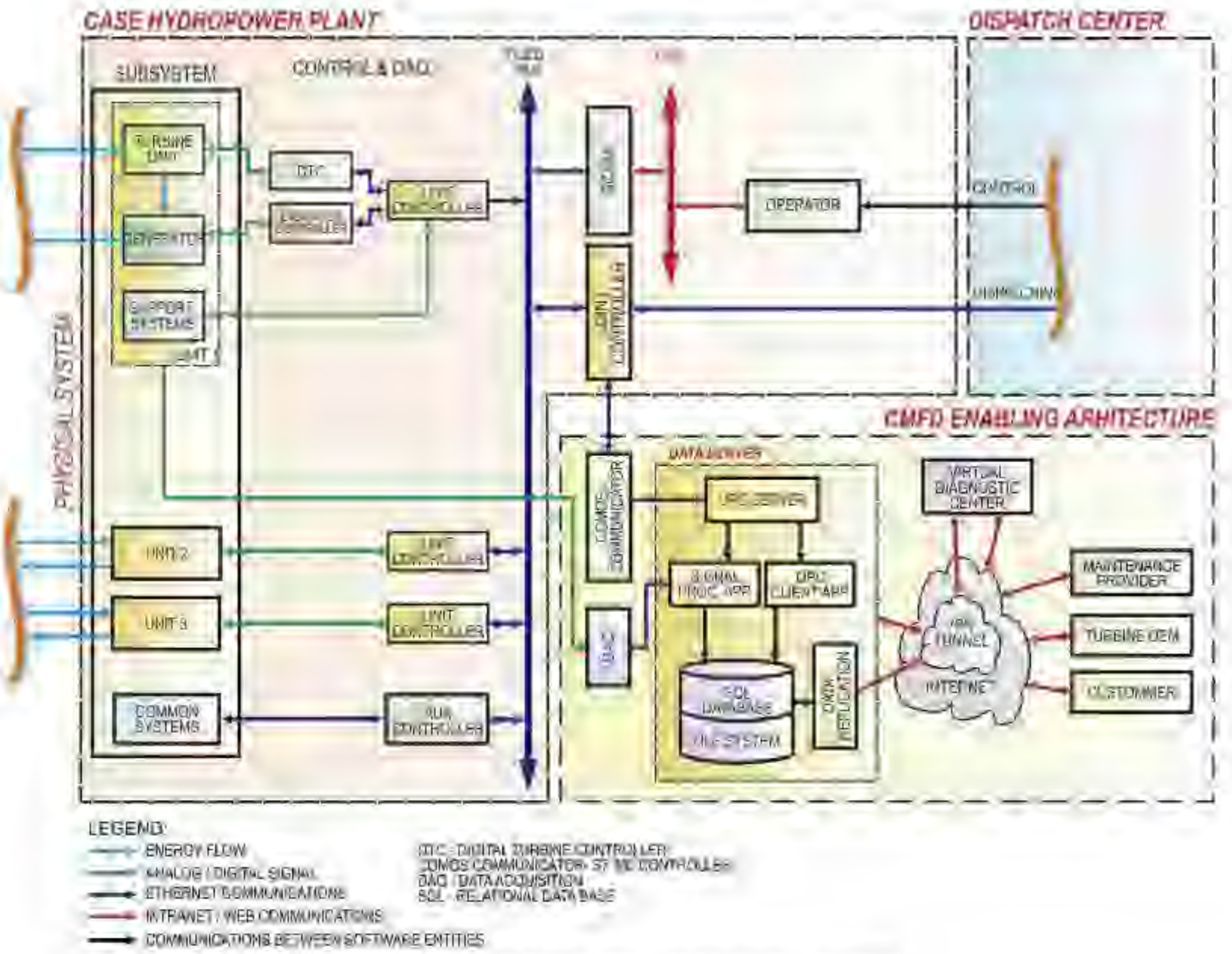


Fig. 7. Implementation of CMFD architecture for the case-study HPP

CMFD: Condition Monitoring and Fault Diagnostics

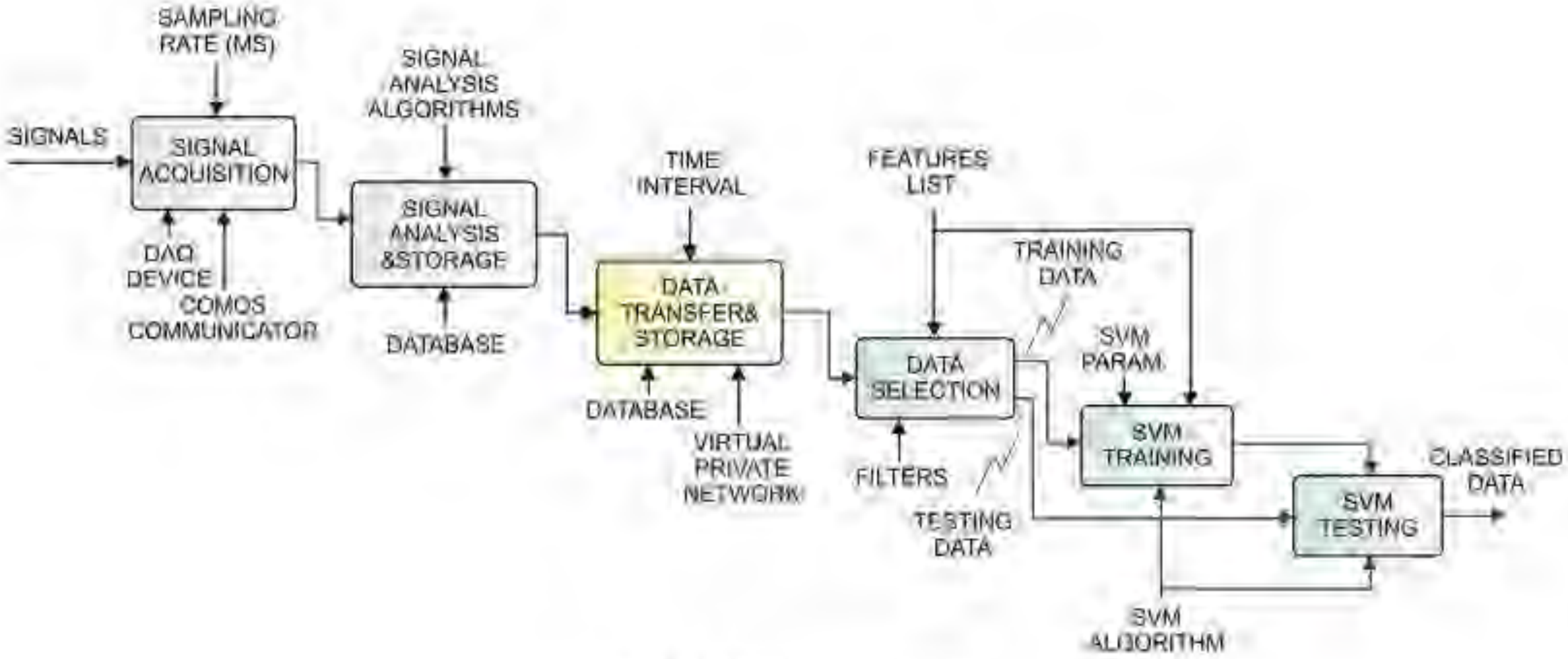


Fig. 4. The CMFD functional model.

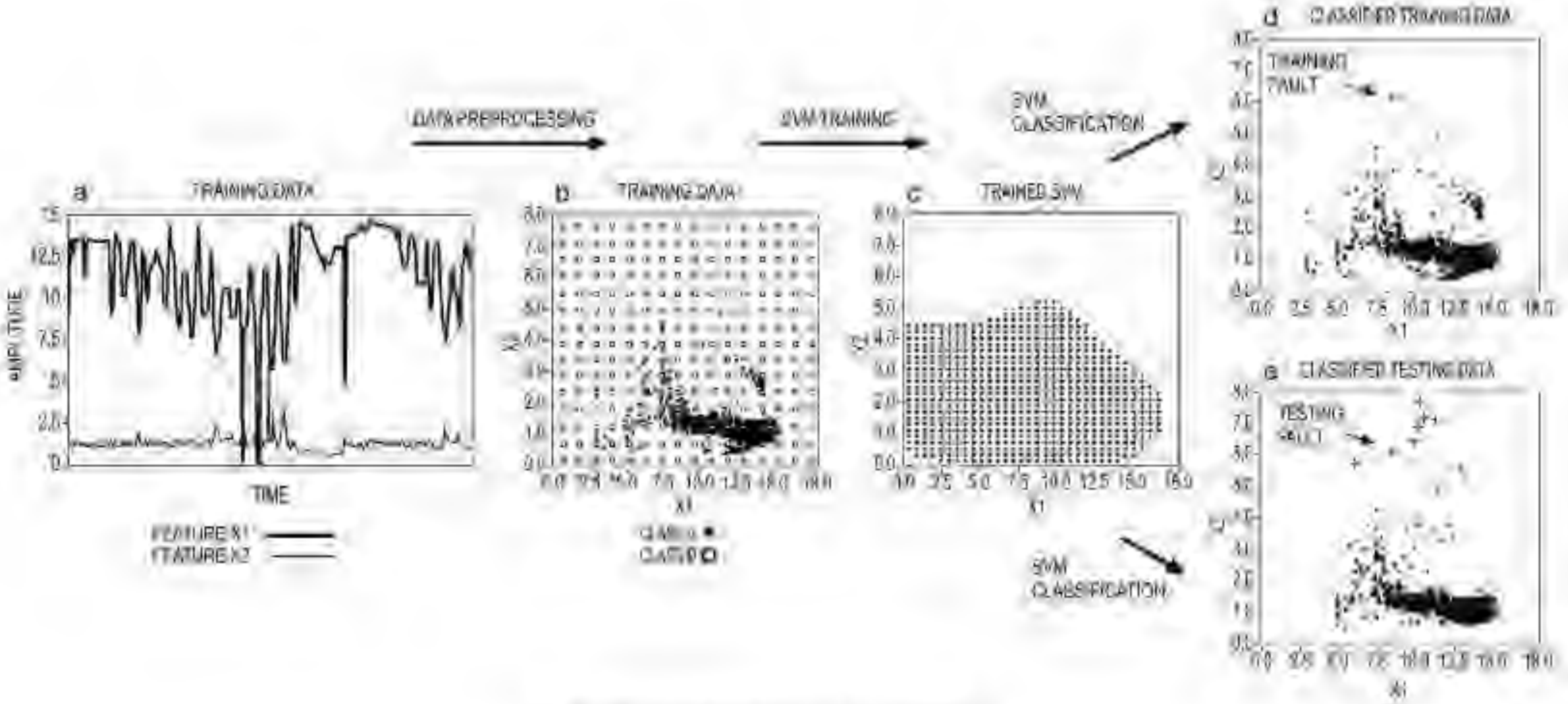
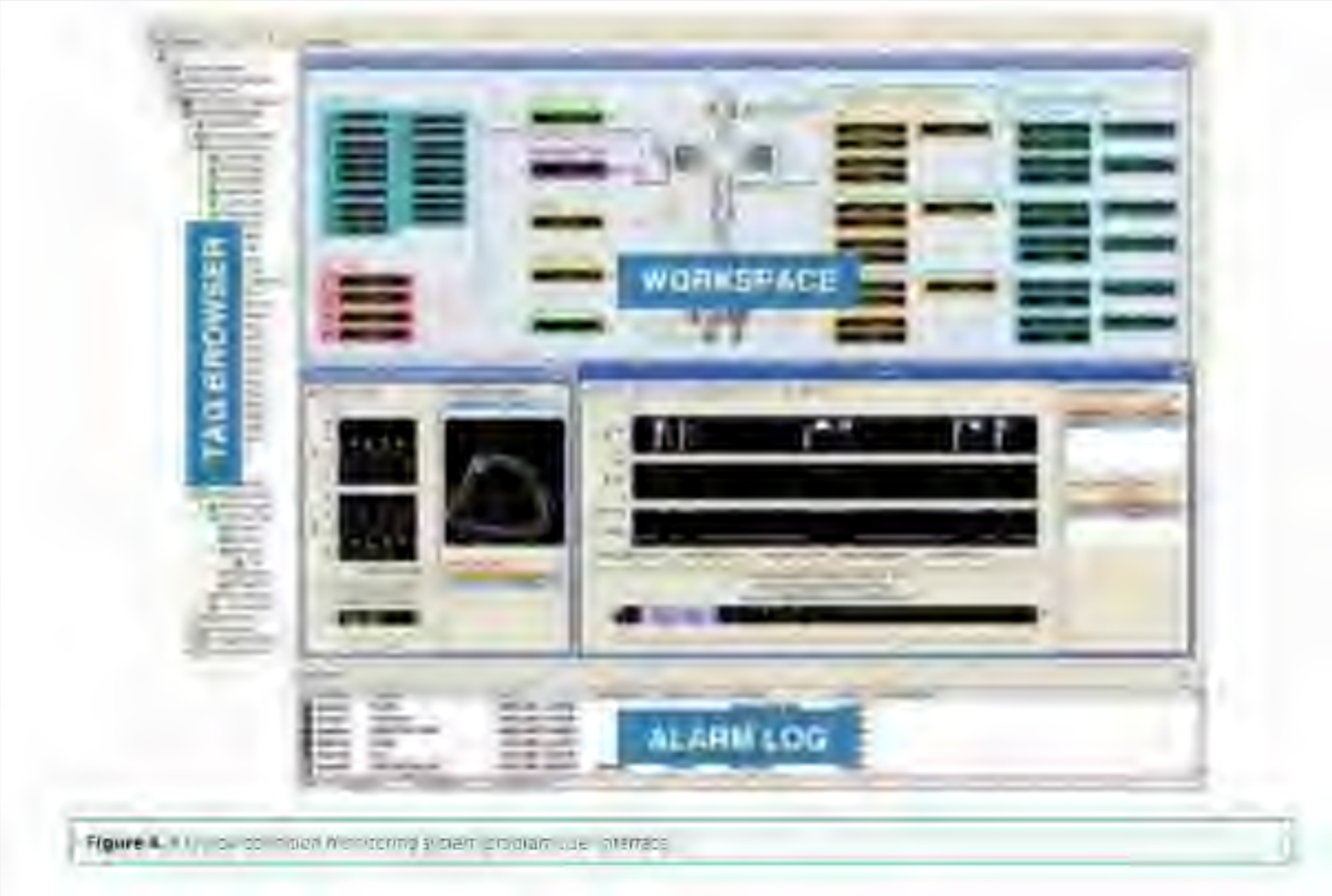


Fig. 6. Fault classification of one causality.

Table 1
Causalities of faults and indicators for thrust bearing.

Causality ID	Fault description	Feature					
		Output power	Rotation frequency	Bearing babbitt temperature	Oil level	Oil temperature	R.M.S. velocity
9	Overheating of bearing	X1		X2			
10	Bearing lubrication oil consumption		X1		X2		
11	Insufficient heat transfer from the bearing cooling system	X1				X2	
12	Bearing performance degradation	X1					X2
30	Excessive bearing babbitt temperature			X1			
31	Bearing lubrication oil consumption				X1		
32	Overheating of bearing					X1	
33	Bearing performance degradation						X1



Alagöz, İzzet, Mehmet Bulut, Veysel Geylani, and Arif Yıldırım. "Importance of real-time hydro power plant condition monitoring systems and contribution to electricity production." *Turk. J. Electr. Power Energy Syst* 1, no. 1 (2021): 1-11.

SOLAR PHOTOVOLTAIC GENERATION IN NEPAL

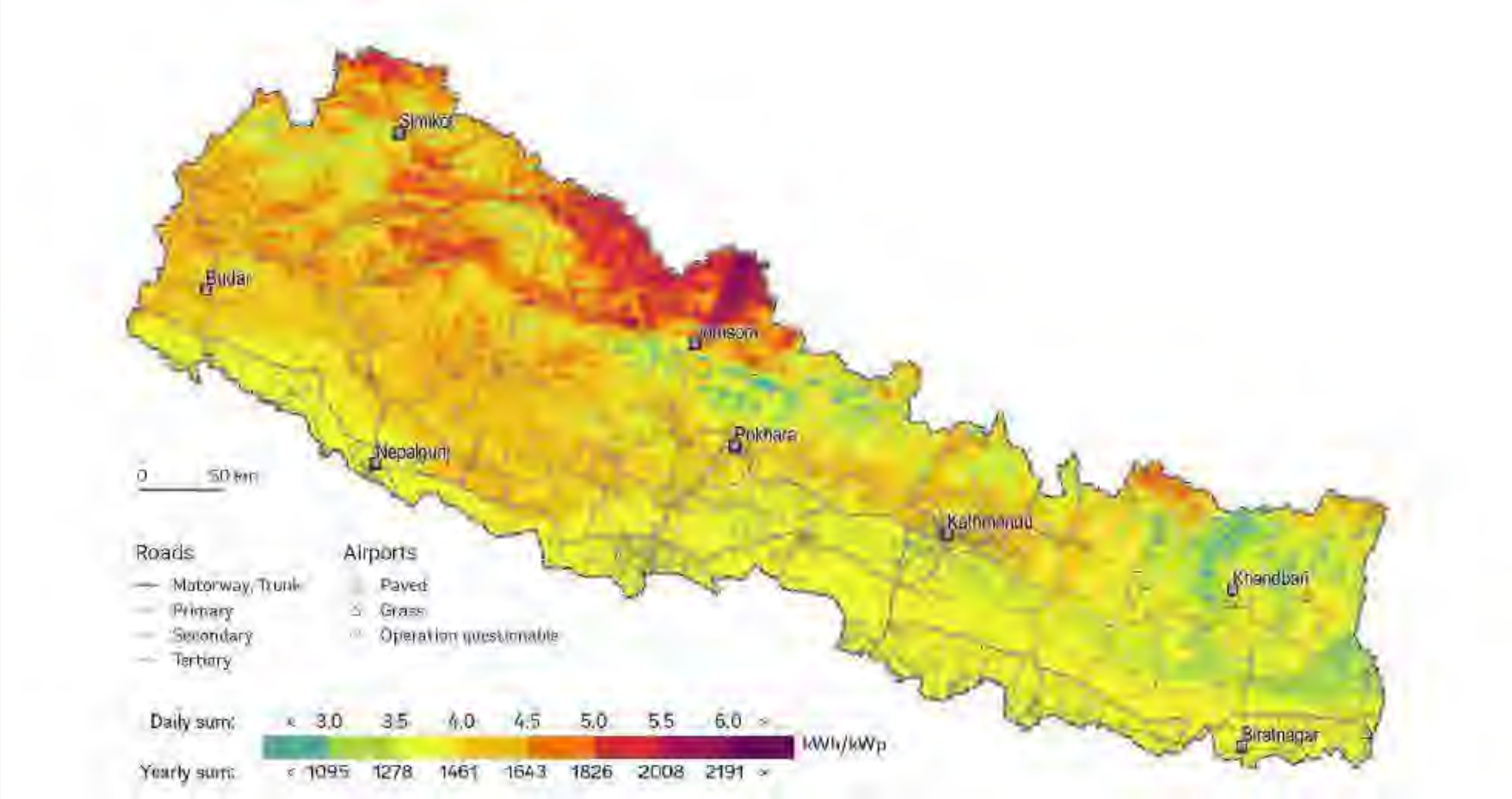


Fig. Solar PV potential in Nepal

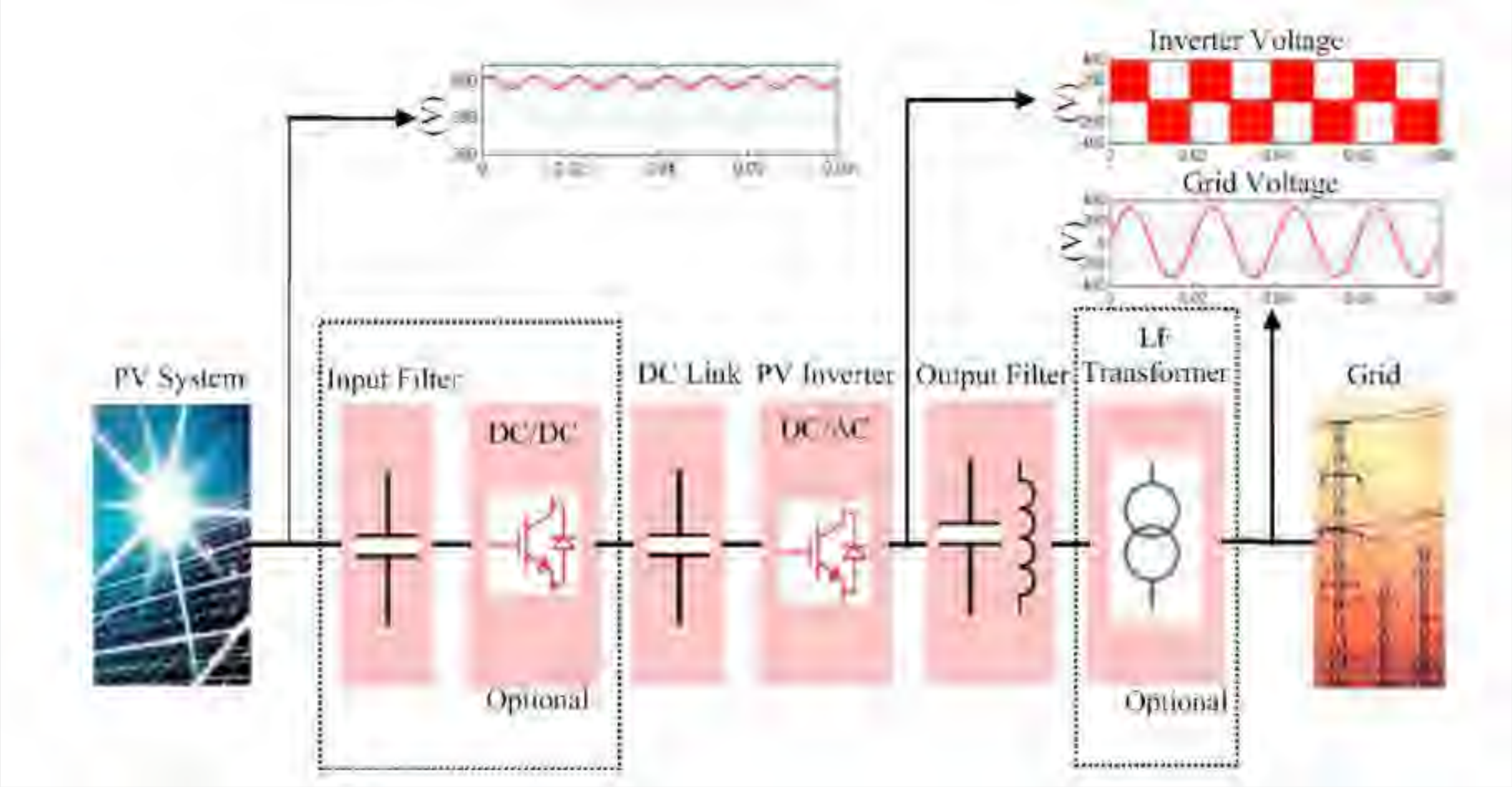
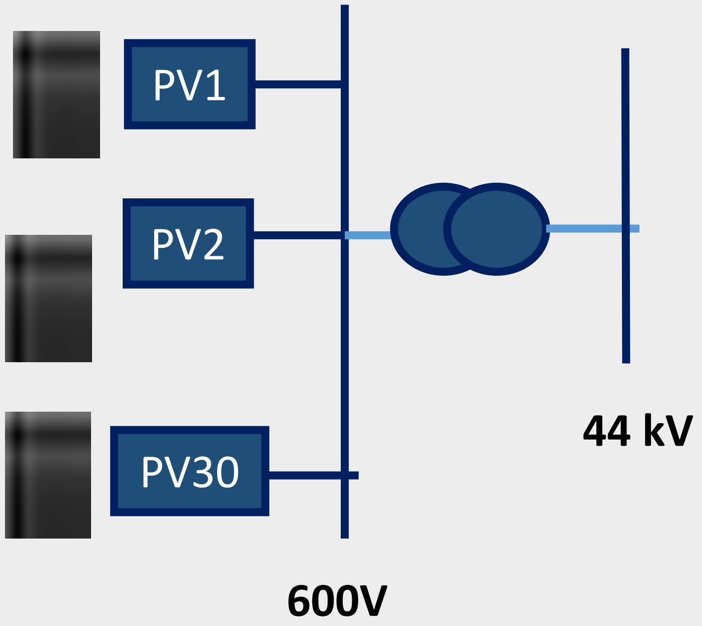


Fig. PV schematic diagram

➢Controller Interaction

- Parallel operation of 30 inverters a 500 kW solar plant connected to a 44kV feeder via 600V/44kV



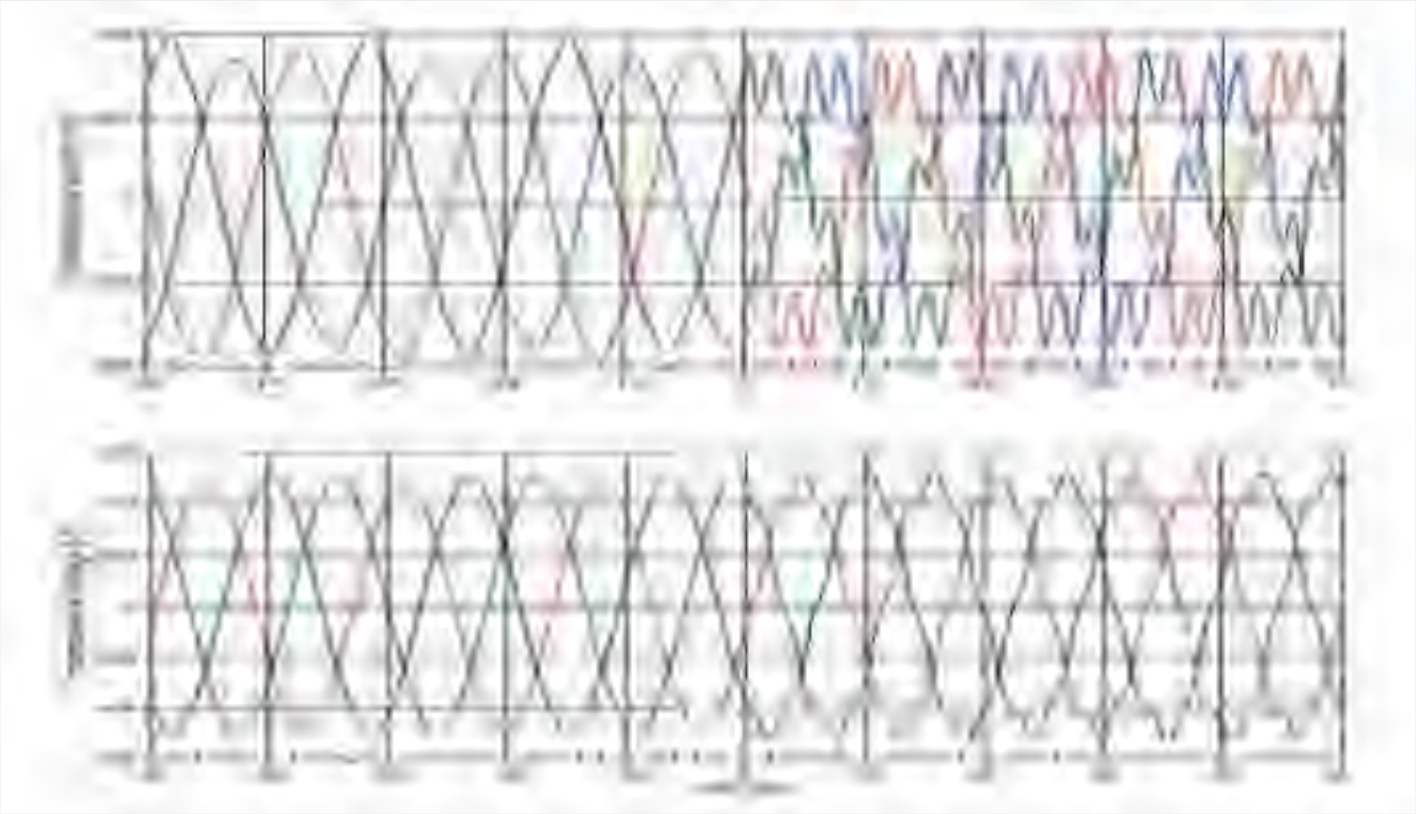
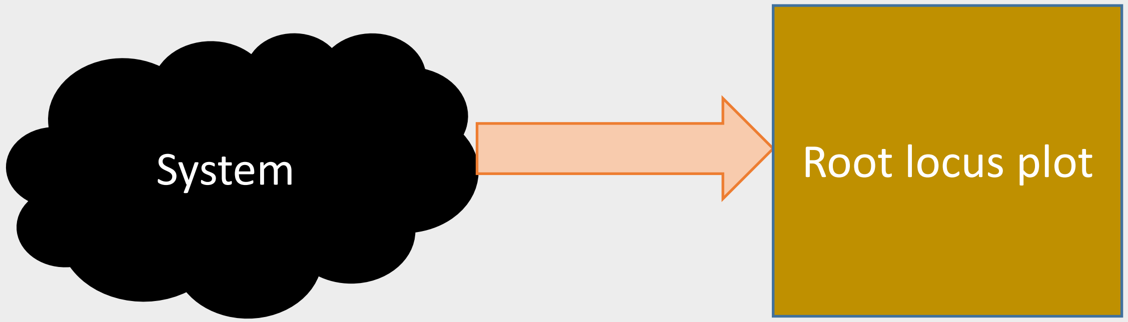
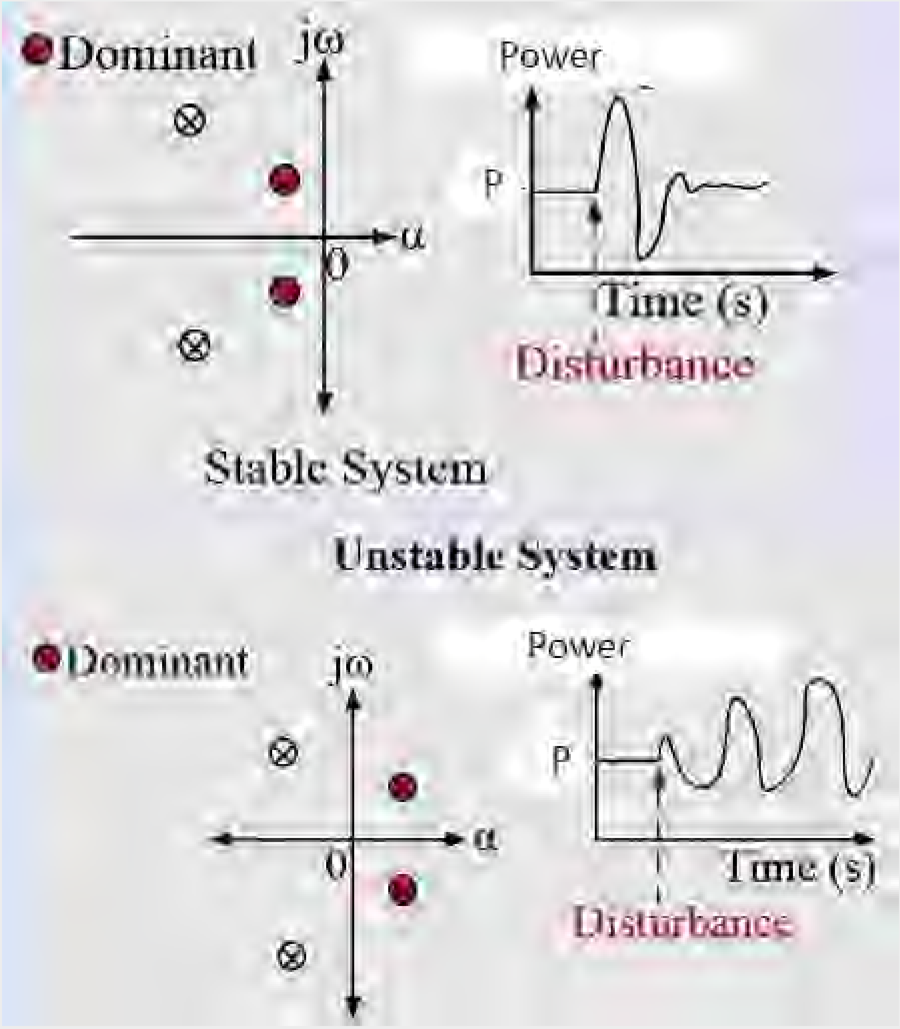


Fig. Current and voltage waveforms under normal and unstable operations


System
Root locus plot


Dominant
jω
α
0
Power
P
Time (s)
Disturbance
Stable System
Unstable System
Dominant
jω
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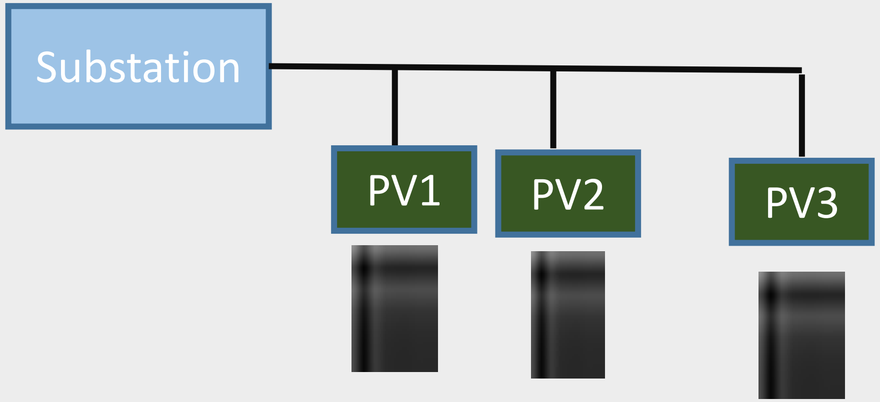
0
Power
P
Time (s)
Disturbance



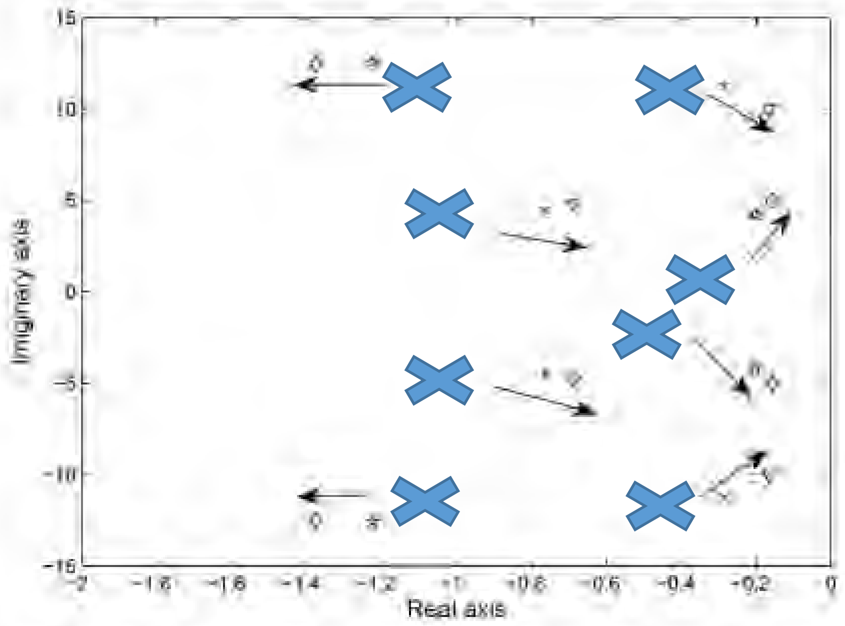


Fig. Two PV case (buses 12 and 13): Movement of dominant complex modes of the system with two PV units due to change in gain parameter of one PV unit (bus 13) from 0.1 to 0.5 pu unit (PV bus 13: '+' gain 0.1, '◇' gain 0.5; PV bus 12: '×' gain 0.1, '▽' gain 0.5 pu).

OTHER REQUIREMENTS OF SOLAR INVERTER

- Active power curtailment
- Reactive power support
- Inertia support
- Low Harmonic content….

Ancillary services (Reactive power support, Inertia support)

➢ Solar converter must be able to be able to **fulfill all the requirements** specified by the country grid code

Retrofit controllers for Active Power Curtailment

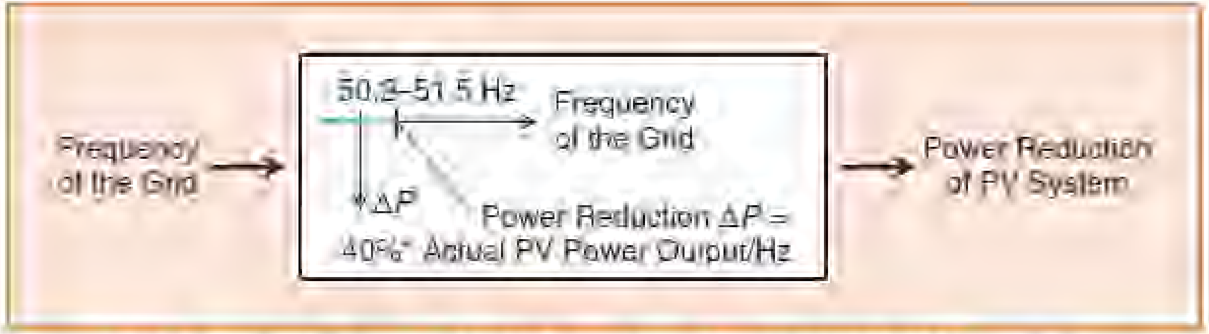
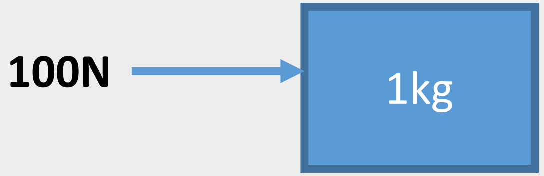


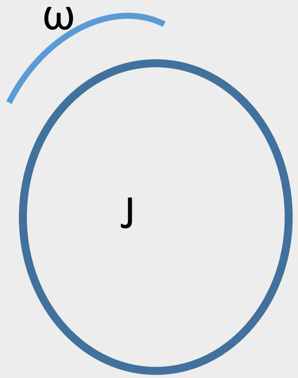
Figure 4. Characteristic curve for reducing the power output of PV systems according to frequency deviations.

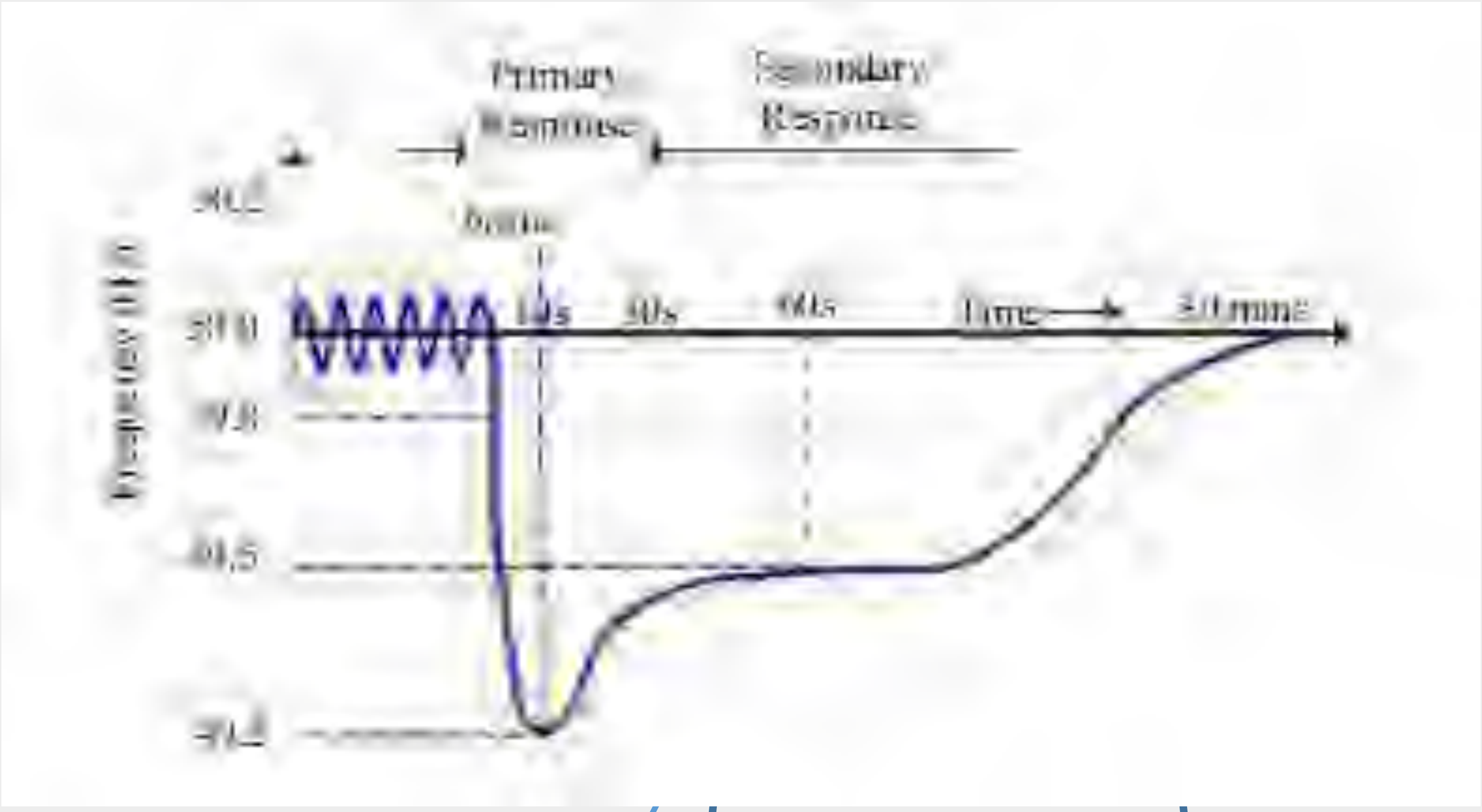
Fig. Block diagram of dq control strategy

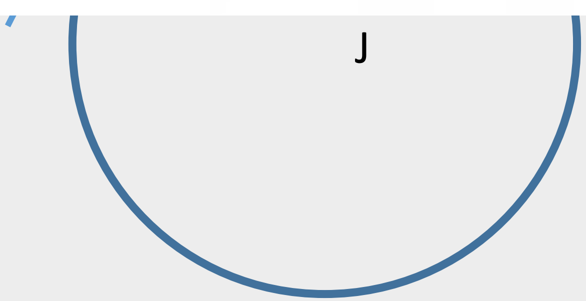
Retrofit controllers

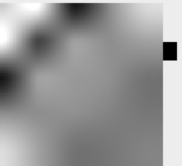
Problem of Inertia









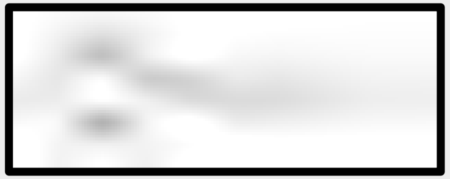


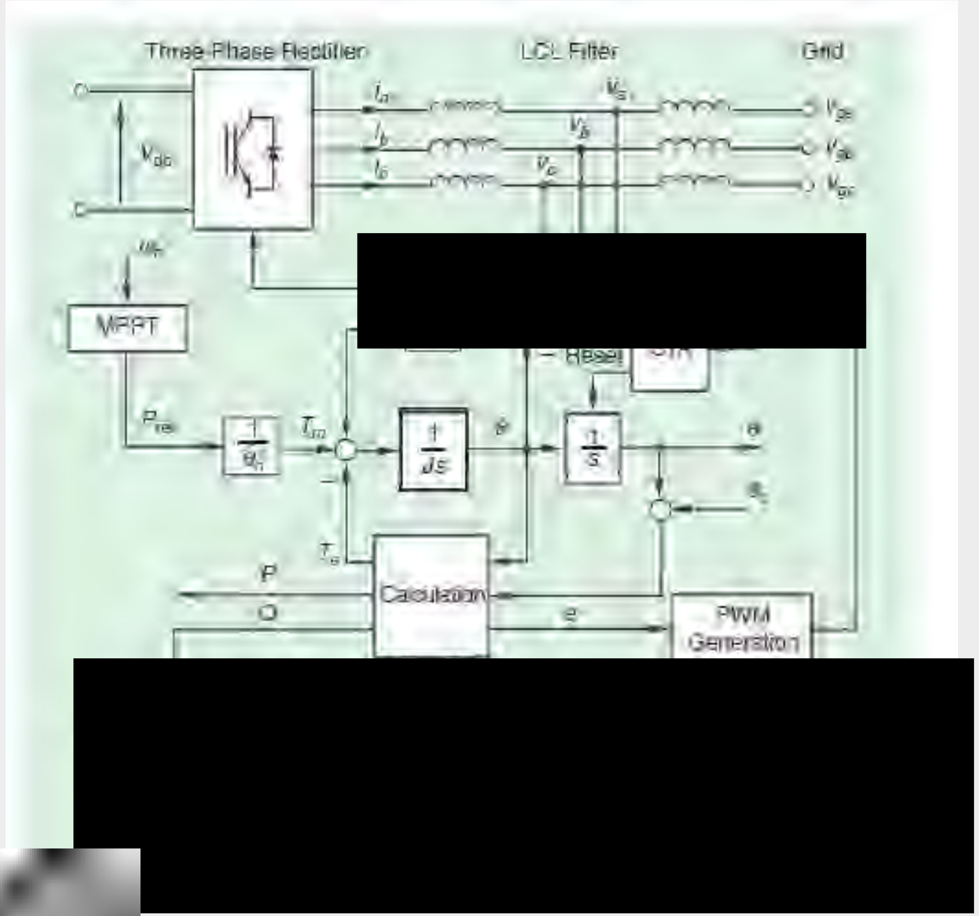
$$\frac{df}{dt} = \frac{fo}{2H_{sys}S_B}(P_m - P_e)$$

- SG provides inertia wh

VIRTUAL SYNCHRONOUS MACHINE (VSM)

- Allows renewable converters to behave like conventional generators-> **(Synthetic inertia)**





[redacted]

Fig. Virtual synchronous machine

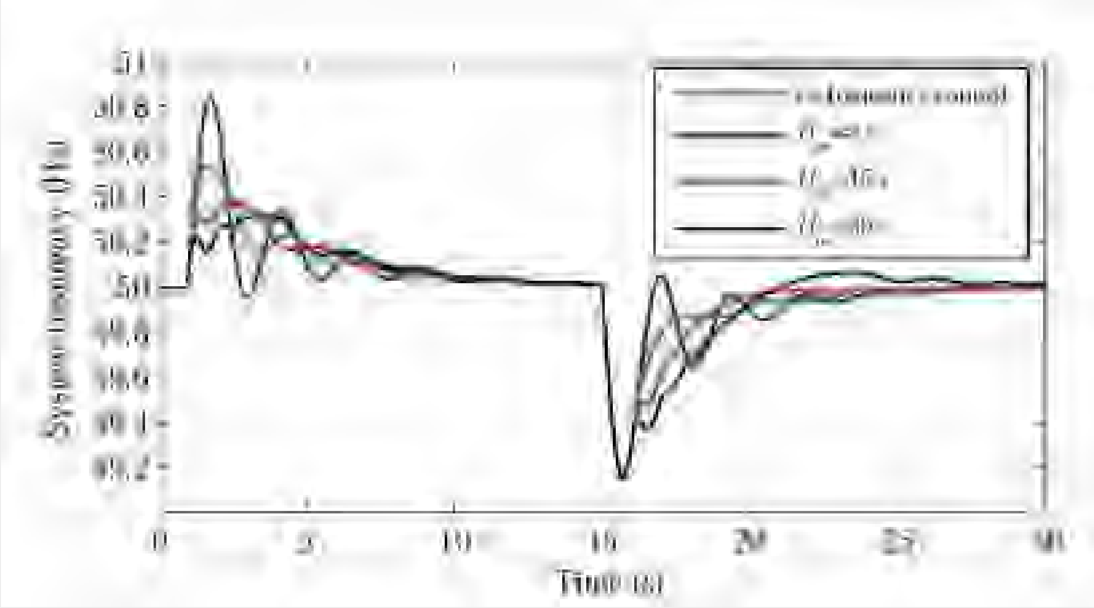


Fig. System Frequency

Problem Assessment Project
Mid Term Progress

FREQUENCY STABILITY ASSESSMENT OF POWER SYSTEM NETWORK OF BAGMATI AND GANDAKI PROVINCE

Presenter:
Amrit Parajuli
Graduate Student
M.E., Electrical Power Engineering

Supervisors:
Asst. Prof. Dr. Samundra Gurung
Lecturer Anil Lamichhane

Frequency Regulation standards in Nepal

- Regulations set by Nepal Electricity Authority (NEA).
- The fundamental frequency of the system should be maintained between 48.75 Hz and 51.25 Hz i.e., +/- 2.5% of 50 Hz.
- The grid operating states is classified into 3 operating states from the perspective of frequency regulation as:
  1. Normal State: The System Frequency is within the limits of 49.5 Hz and 50.5 Hz.
  2. Alert State: The System Frequency is outside the limits of 49.5 and 50.5 Hz but within the limits of 48.75 Hz and 51.25 Hz.
  3. Emergency State: The System Frequency is outside the limits of 48.75 Hz and 51.25 Hz.


NEA GRID CODE

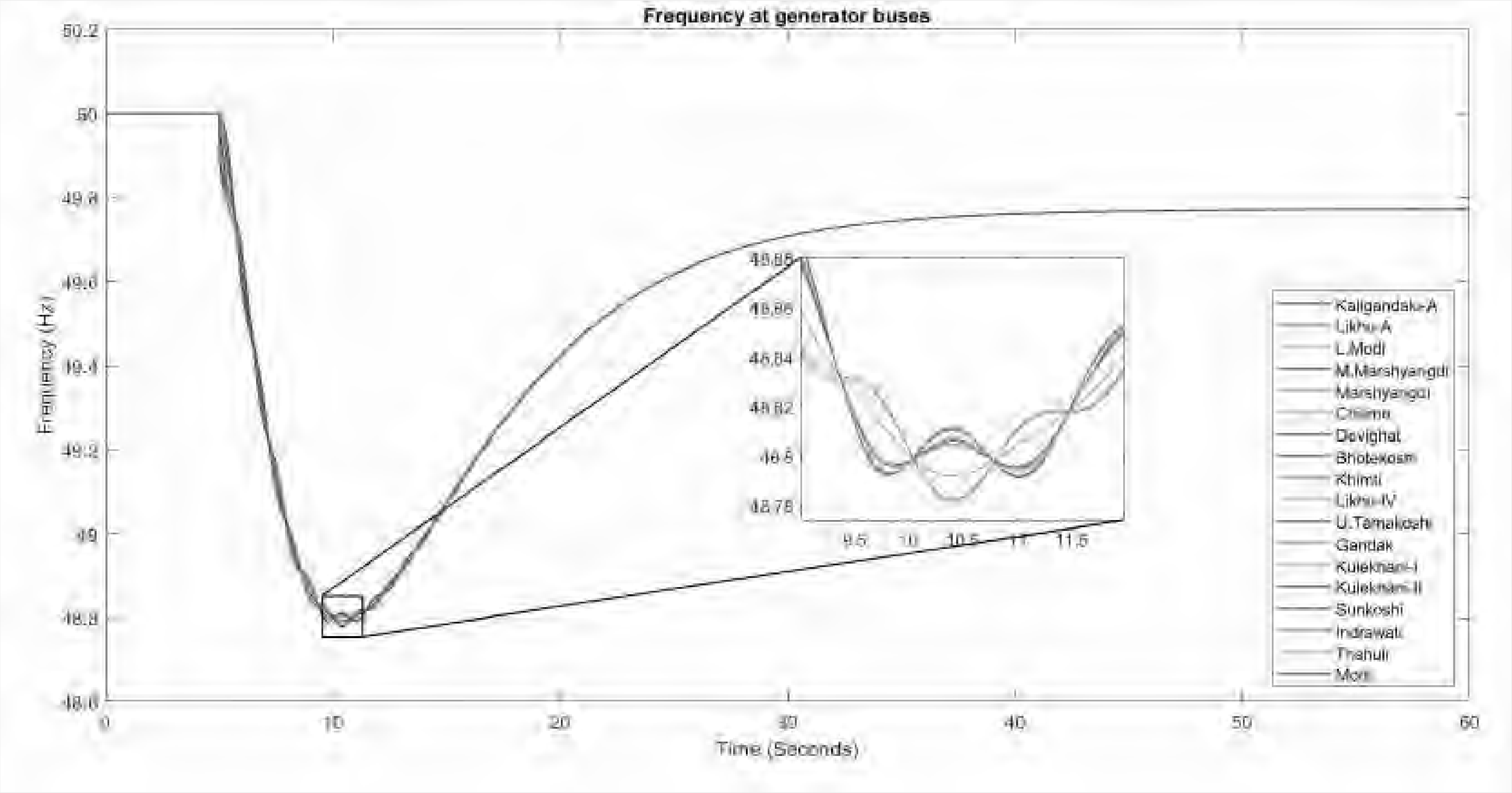


Fig 7: System Frequency Response with IEEEG3 Governor

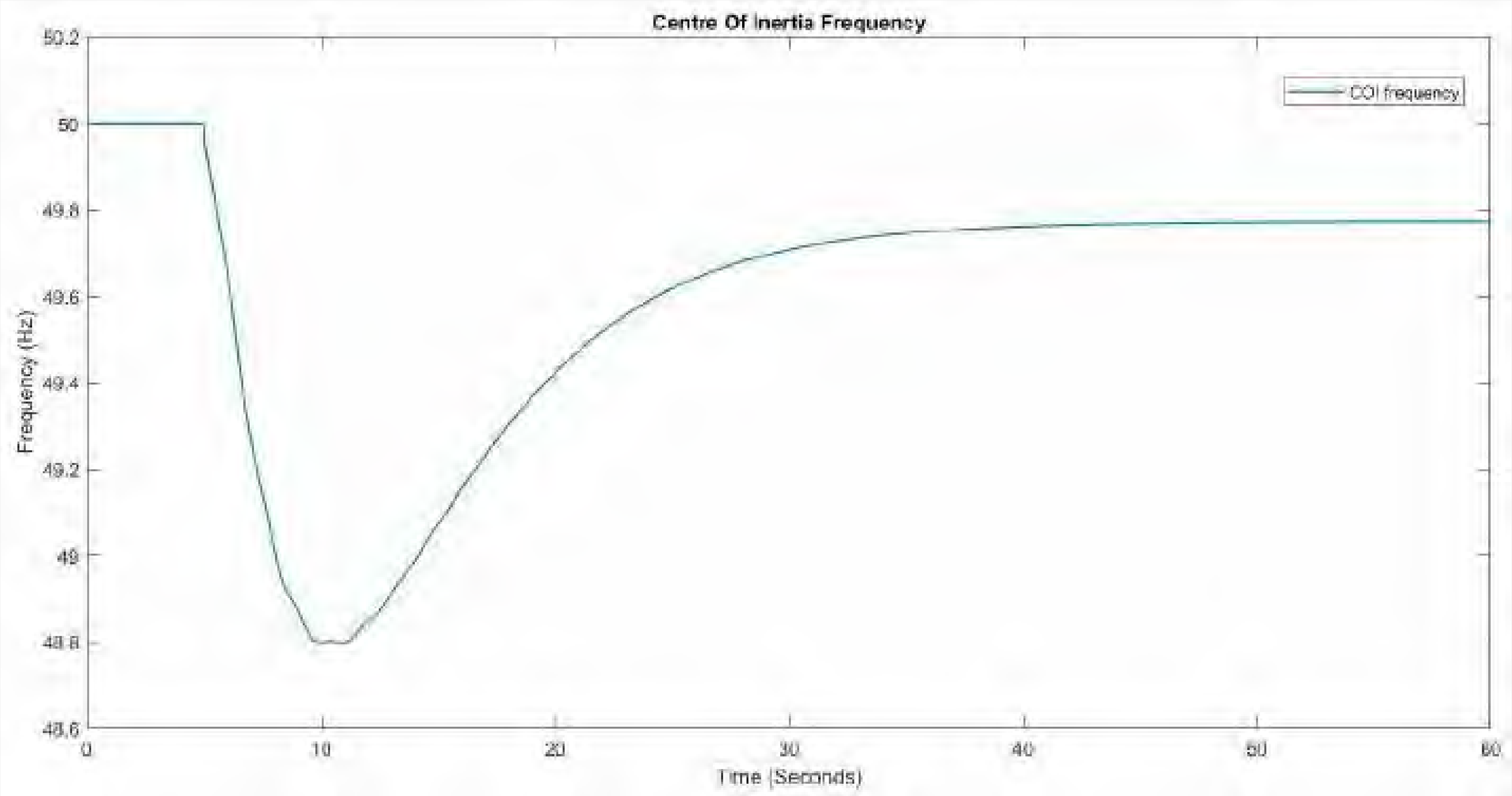


Fig 7: Centre of Inertia frequency (f_{COI}) of the system

Table 2: Frequency nadir and RoCoF of generating buses

Bus Name	f_{nadir} (Hz)	RoCoF (Hz/s)
Kaligandaki – A	48.79227	0.2013
Likhu - A	48.78238	0.2255
Lower Modi	48.79182	0.2014
Middle Marshyangdi	48.79146	0.2011
Marshyangdi	48.79254	0.2009
Chilime	48.79344	0.2493
Devighat	48.79556	0.2014
Bhotekoshi	48.79212	0.2241
Khimti	48.78258	0.2254
Likhu – IV	48.78167	0.2256
Upper Tamakoshi	48.78077	0.2258
Gandak	48.79213	0.2013
Kulekhani – I	48.79518	0.2018
Kulekhani – II	48.79487	0.2015
Sunkoshi	48.79603	0.2020
Indrawati	48.79618	0.2020
Trishuli	48.79482	0.2009
Modi	48.79185	0.2010

Table 3 : Frequency stability indices for selected system

Frequency Stability Indices	Measured point	Value
System lowest Nadir	Upper Tamakoshi	48.7077 Hz
System highest RoCoF	Chilime	0.2493 Hz/s
System frequency Nadir	COI	48.7976 Hz
System RoCoF	COI	0.2038 Hz/s

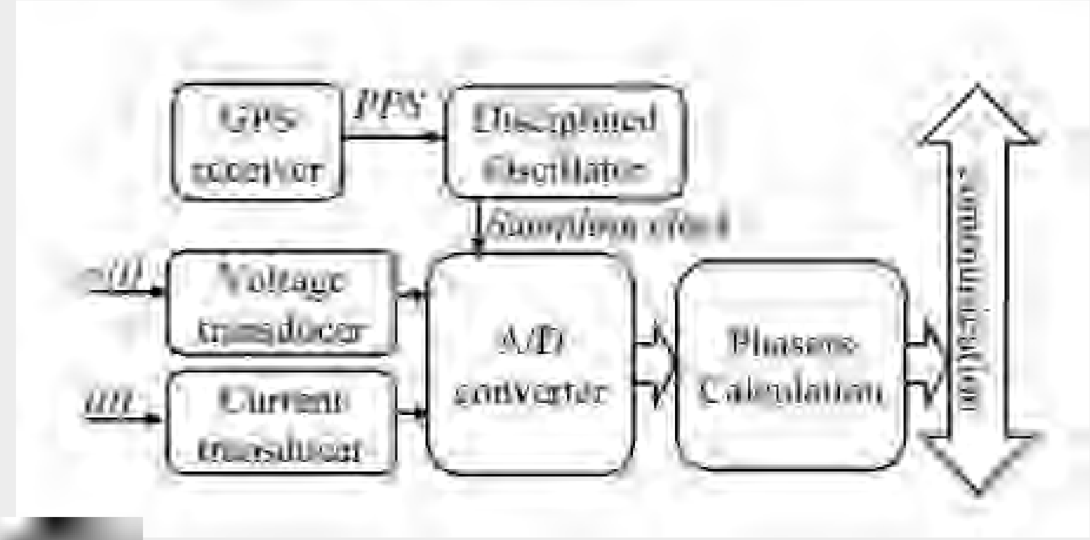
Research Opportunities

- Retrofit of Grid Connected Solar Farm Controller for frequency response support (Curtailment)
- Impact of VSM in Frequency Response "Inertial response Frame"
- Optimal loadshedding strategy
- Energy storage as an ancillary service (Pricing)

TRANSMISSION TECHNOLOGIES

WIDE AREA MONITORING SYSTEM

- PMUs can measure from 20 to 150 samples per second
- Typically it measures the voltage and angle of the bus where it is connected



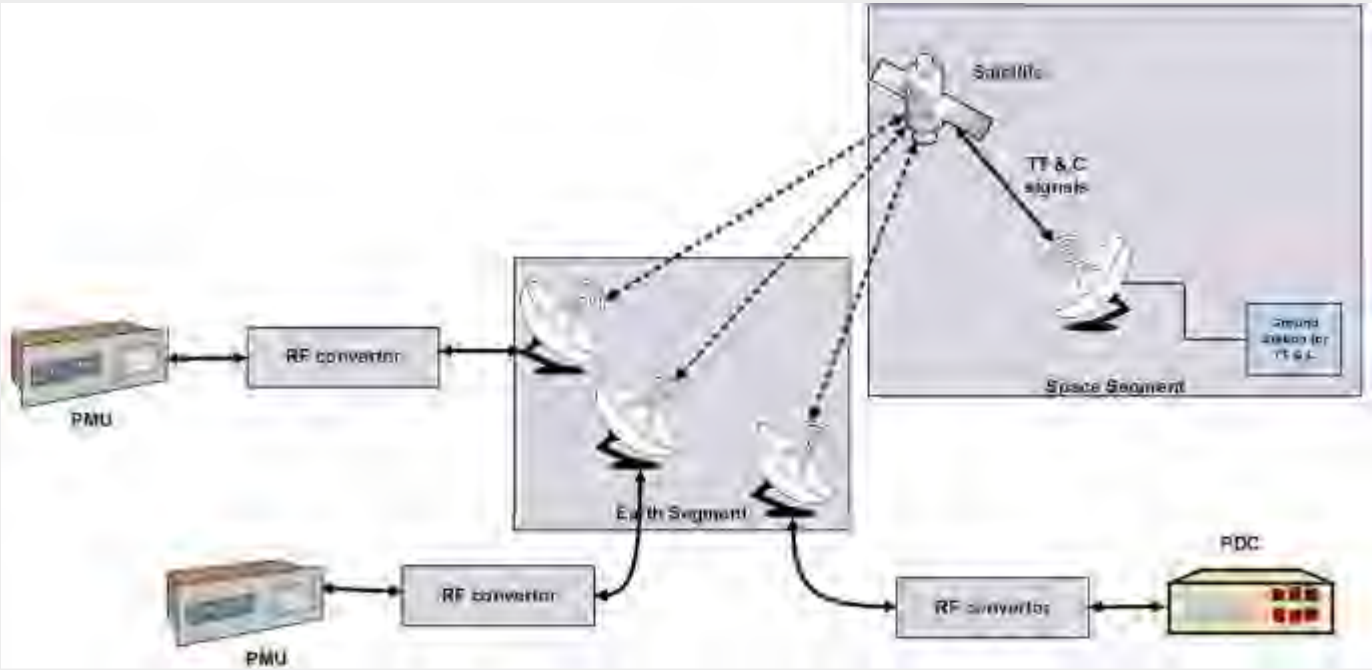
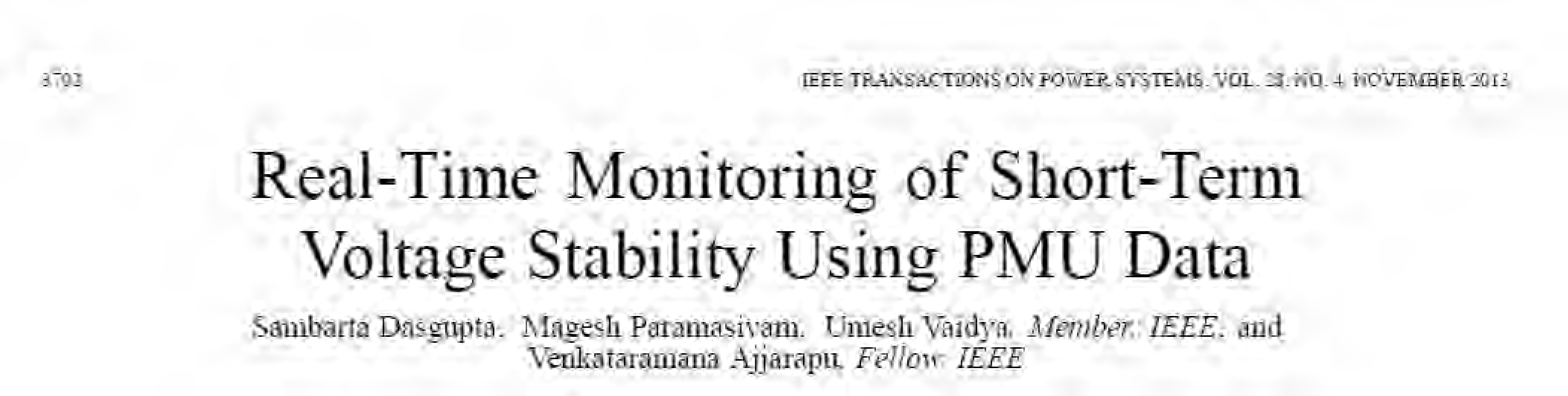


Fig. PMUs in North-American grid

- Currently, NEA is also planning to install PMU at EHV substations
- PMU data can be used for many purpose including **faster estimation/ prevention of stability issues (STVS)**



3703 IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 28, NO. 4, NOVEMBER 2013

Real-Time Monitoring of Short-Term Voltage Stability Using PMU Data

Sambarta Dasgupta, Magesh Paramasivam, Umesh Vaidya, *Member, IEEE*, and Venkataramana Ajjarapu, *Fellow, IEEE*

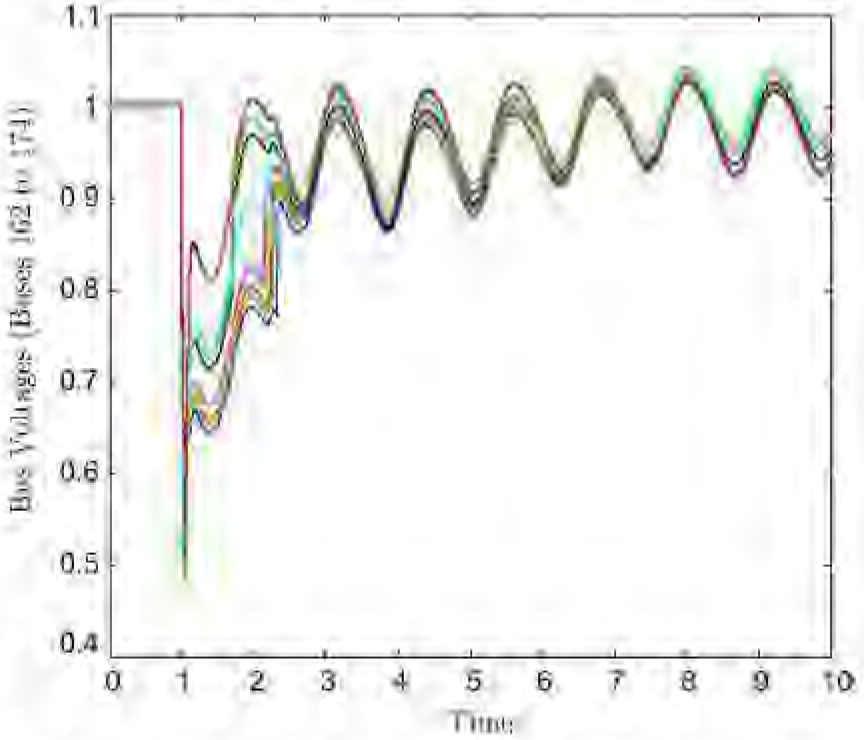


Fig. 2. Evolution of bus voltages (for buses 162—174) for clearing time t_{cl} = 1.080 s for IEEE 162-bus system.

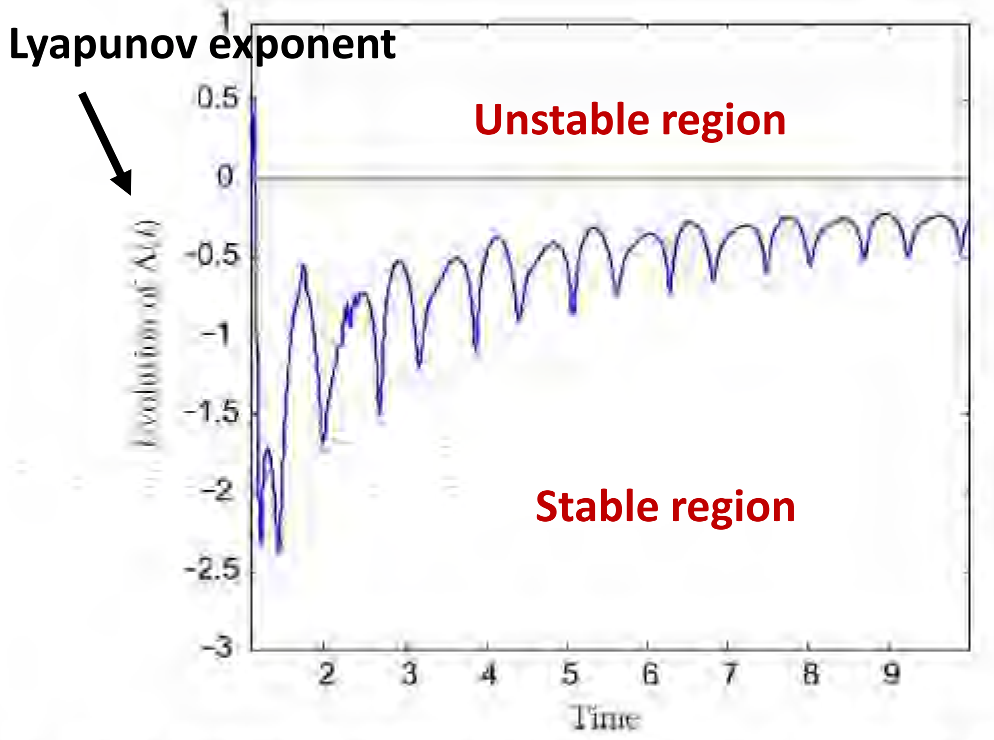


Fig. 3. Evolution of exponent for clearing time t_{cl} = 1.080 s for IEEE 162-bus system.

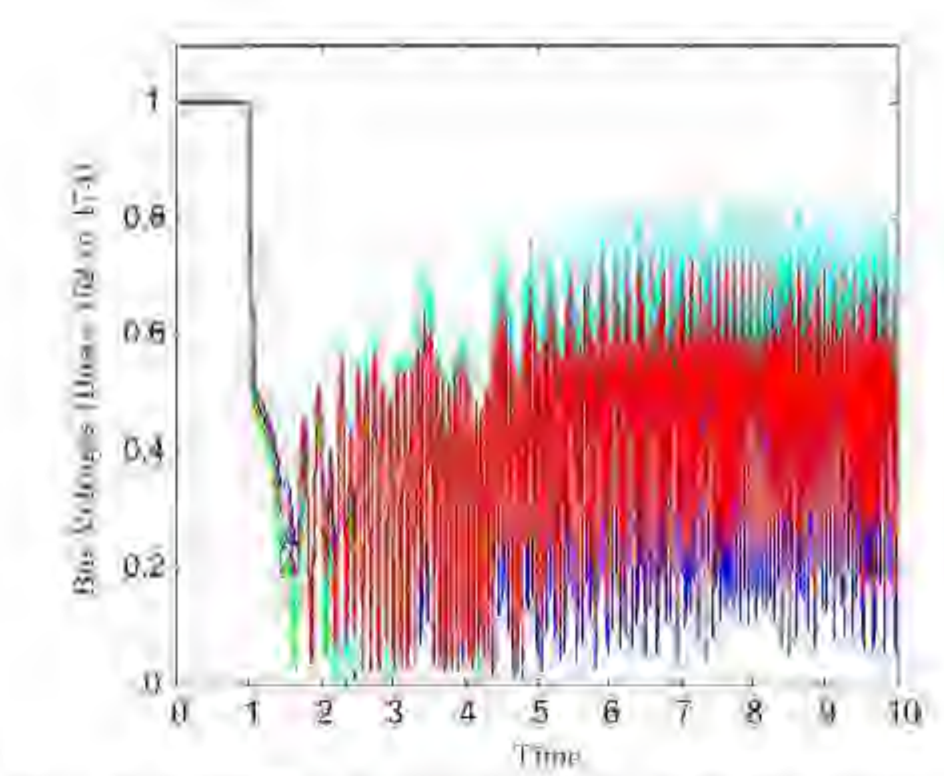


Fig. 4. Evolution of bus voltages (for buses 162 – 174) for clearing time t_{cl} = 1.38 s for IEEE 162-bus system.

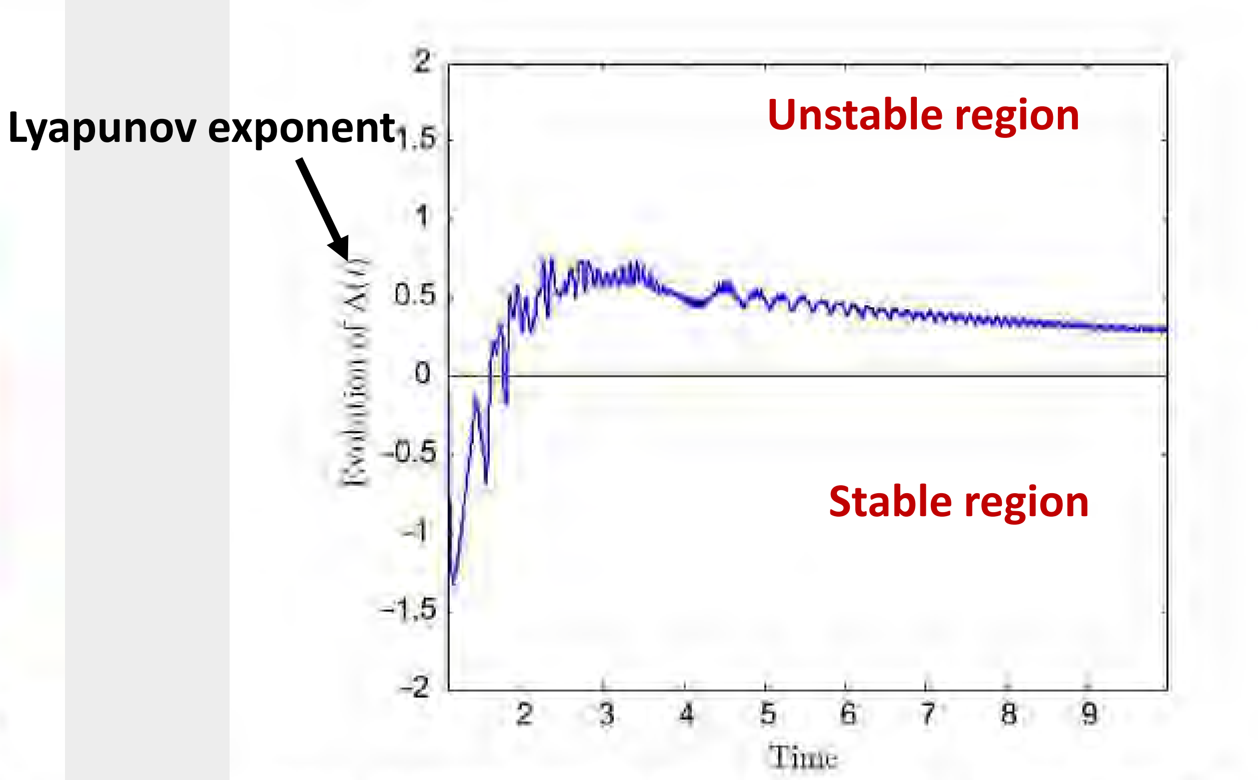


Fig. 5. Evolution of exponent for clearing time t_{cl} = 1.38 s for IEEE 162-bus system.

TABLE II
CRITICAL CLEARING TIME COMPUTED FOR IEEE 162-BUS SYSTEM

Fault Case	Fault Location	Trip Line	CCT (in sec)
[illegible]	1	1 – 2	0.120
[illegible]	5	5 – 1	0.154
[illegible]	26	26 – 25	0.104
[illegible]	120	120 – 5	0.175
[illegible]	120	120 – 112	0.140
[illegible]	129	129 – 5	0.207

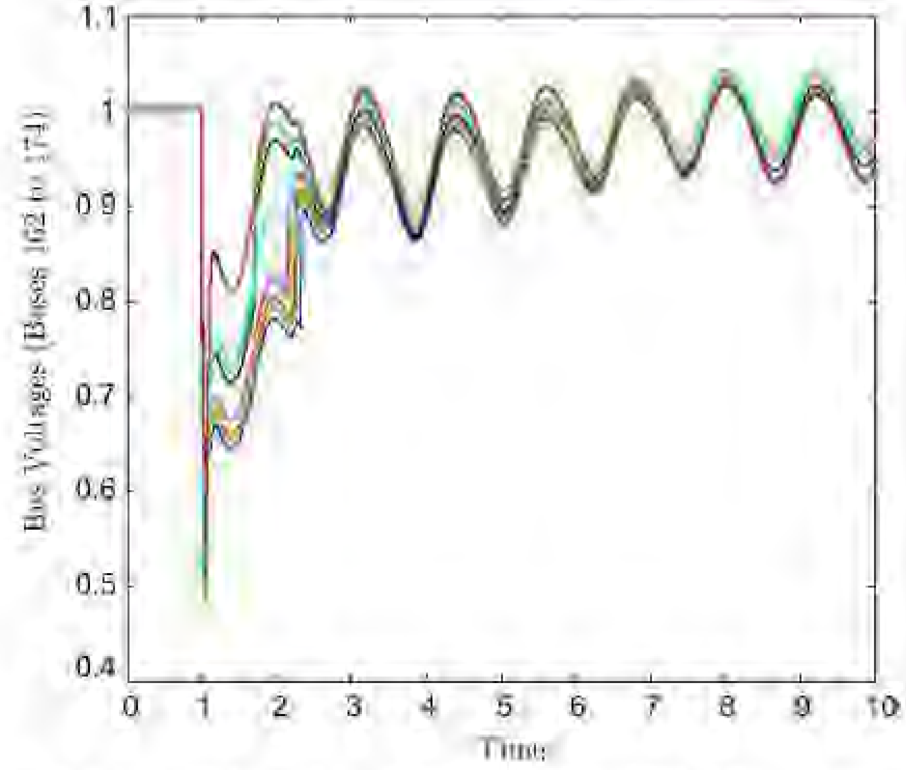
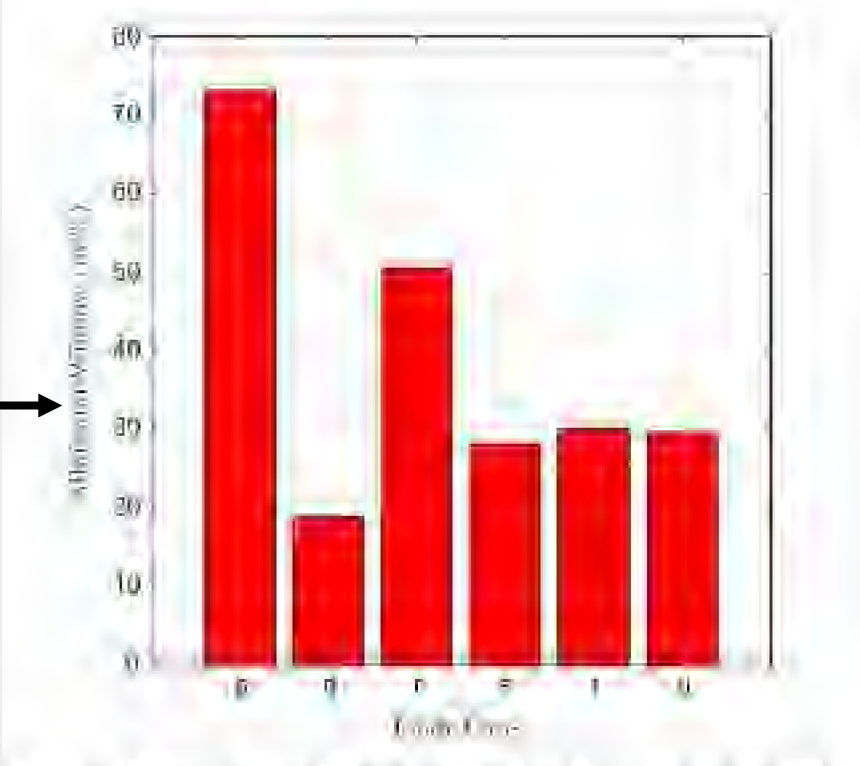
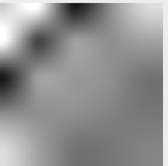


Fig. 2. Evolution of bus voltages (for buses 162 – 174) for clearing time t_{cl} = 1.080 s for IEEE 162-bus system.

Based on Data Length Considered





IEEE 9 bus system results

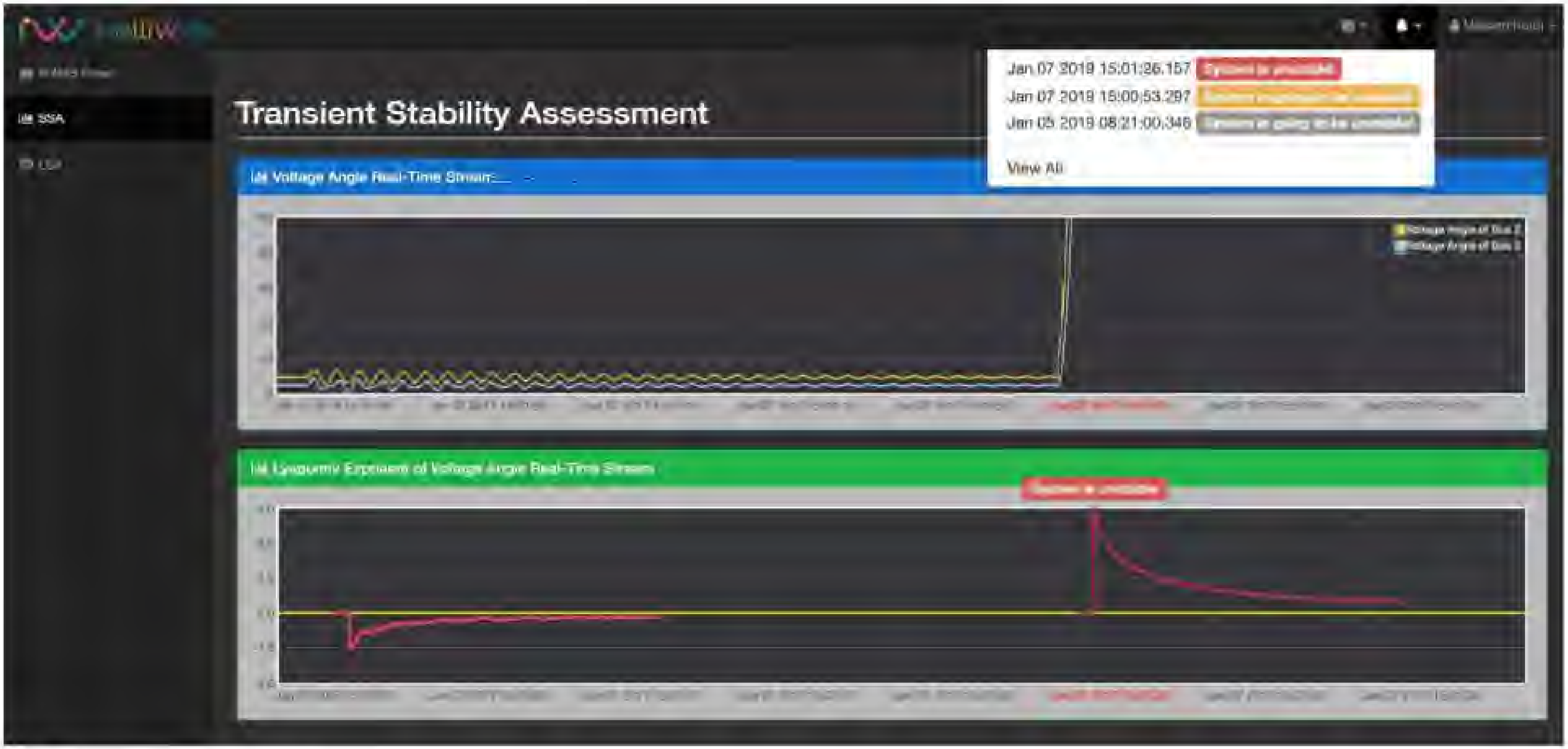


Fig. 11 *GUI for TSA (Scenario 2)*

Safavizadeh, Arash, Meysam Kordi, Fariborz Eghtedarnia, Roozbeh Torkzadeh, and Hesamoddin Marzooghi. "Framework for real-time short-term stability assessment of power systems using PMU measurements." *IET Generation, Transmission & Distribution* 13, no. 15 (2019): 3433-3442.

IEEE 9 bus system results

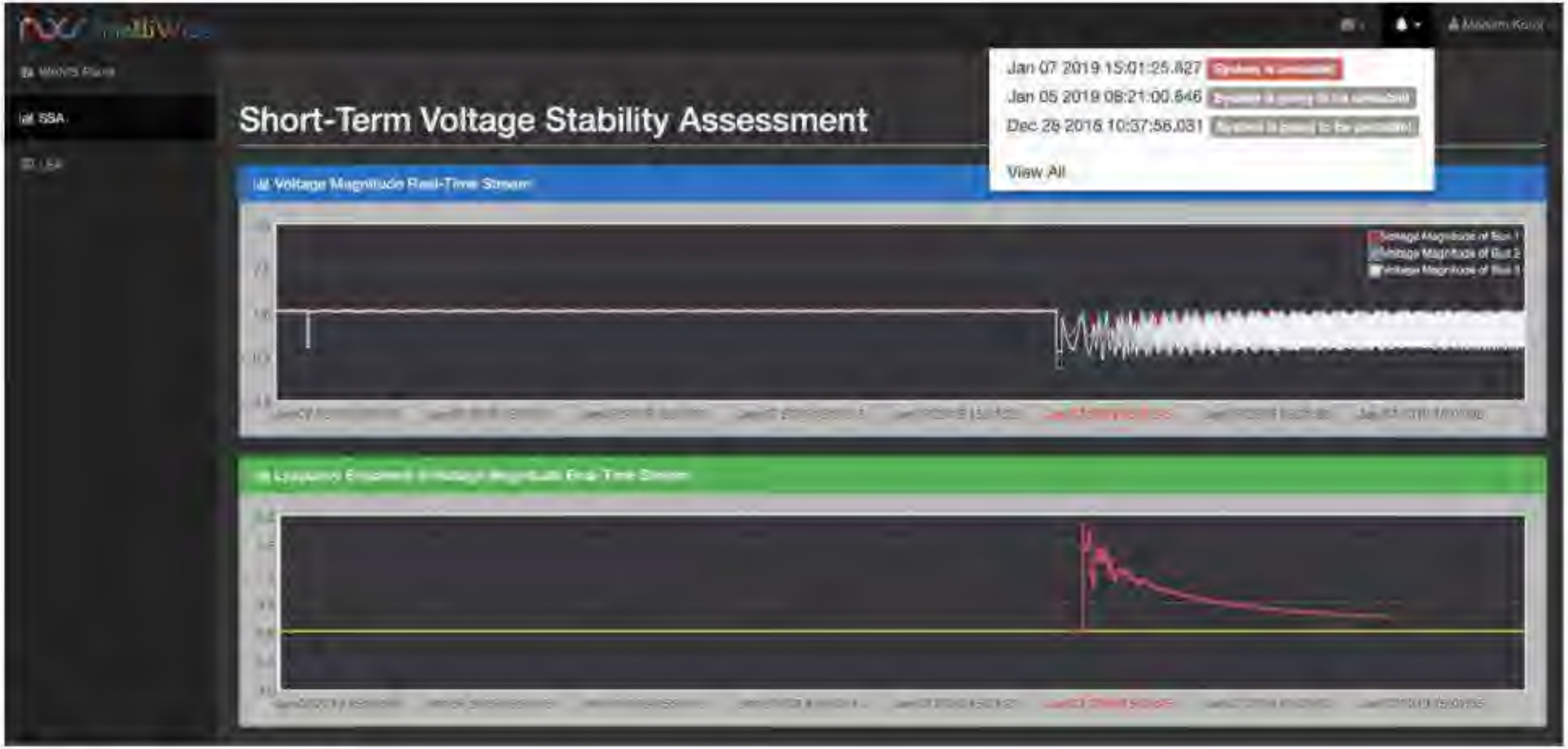


Fig. 12 *GUI for SVSA (Scenario 2)*

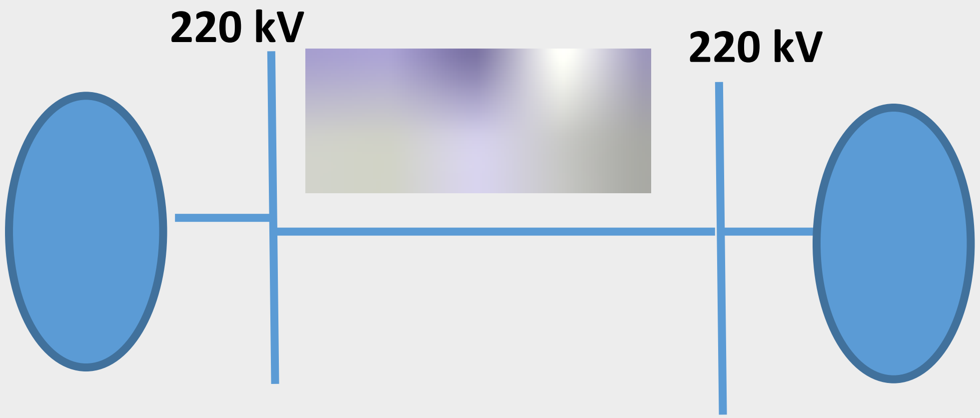
Safavizadeh, Arash, Meysam Kordi, Fariborz Eghtedarnia, Roozbeh Torkzadeh, and Hesamoddin Marzooghi. "Framework for real-time short-term stability assessment of power systems using PMU measurements." *IET Generation, Transmission & Distribution* 13, no. 15 (2019): 3433-3442.

- **Challenges remaining**

1. Develop a tool for real-time monitoring and early warning system based on PMU measurements
2. How to make system more observable with limited number of PMUs?
3. Effect of PMU noise and communication latency in estimation
4. ………..

DYNAMIC LINE RATING ESTIMATION

- Over head lines normally are limited by **thermal limit (Heat)**
- They are usually sized based on worst criterion (65 degree celsius, low wind velocity and full radiation)



Ampacity= 506 A

Thermal limit =sqrt(3)*220* 506 = 193 MW

✓However, conductor can carry more current when the solar radiation is low and wind velocity is high **(Cooling effect)**

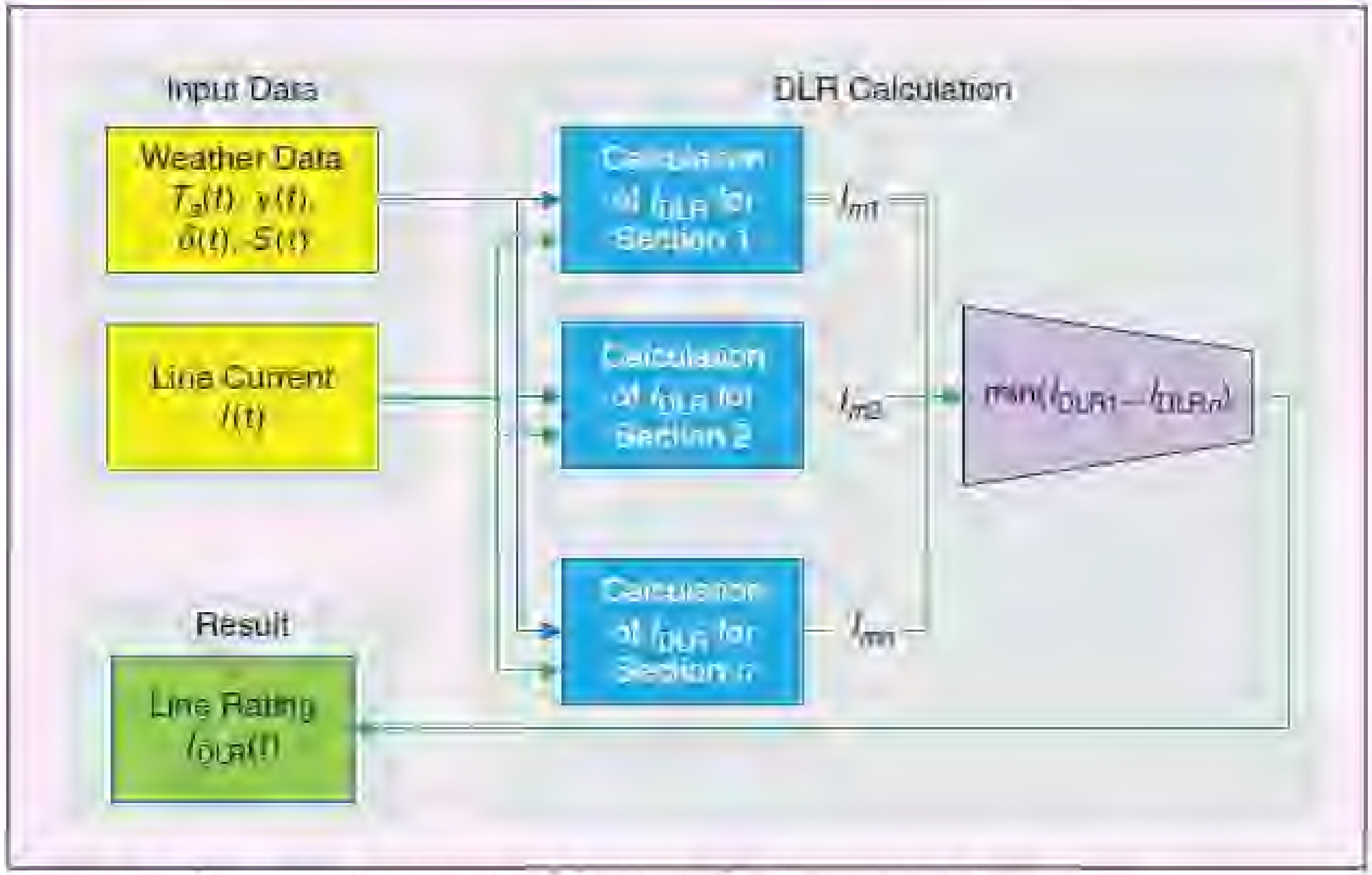


Figure 9. The general principle of dynamically determining line rating.

Technology developed by the Slovenia grid

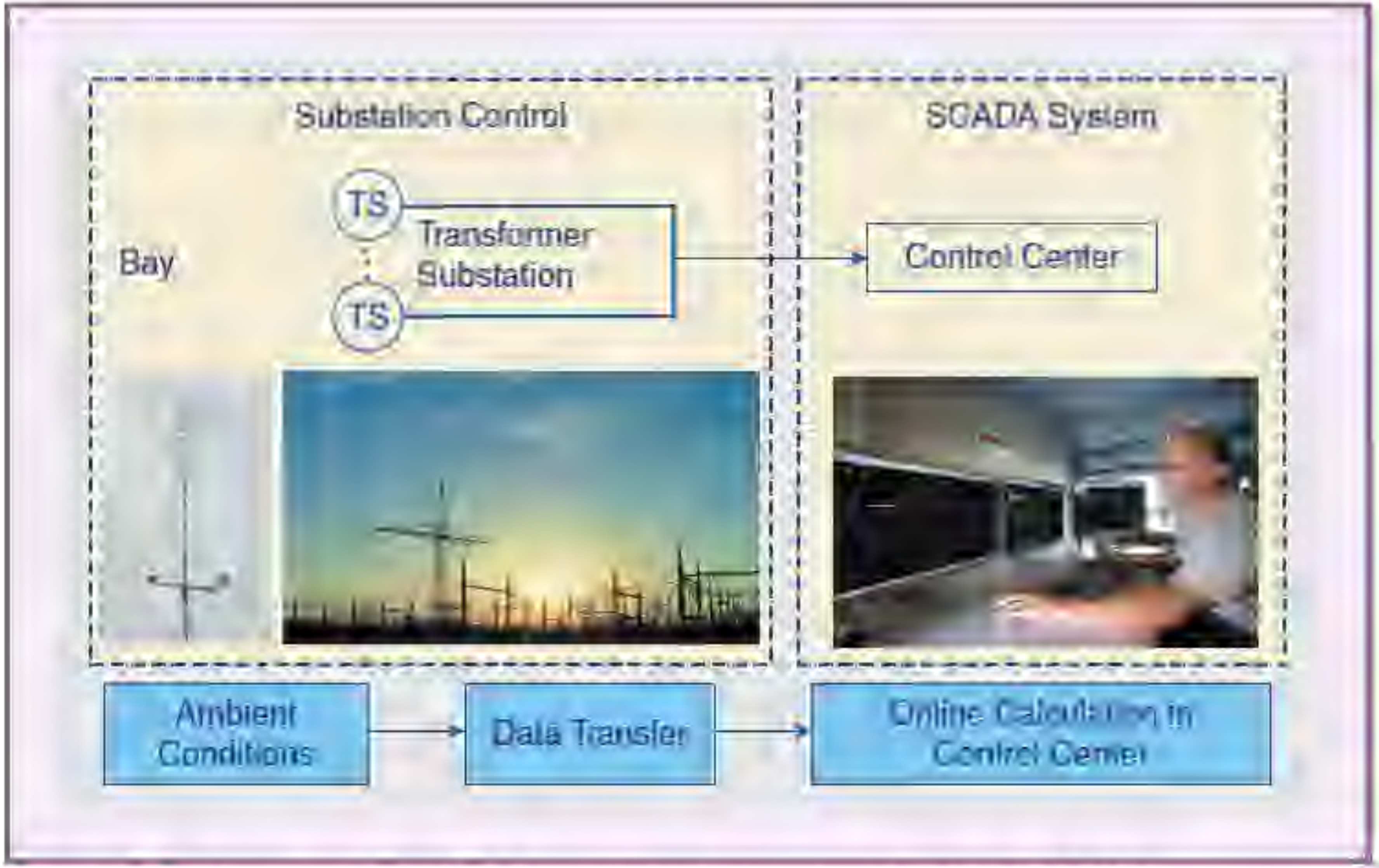


Figure 15. The principle of the dynamic rating system for 380-kV OHLs.

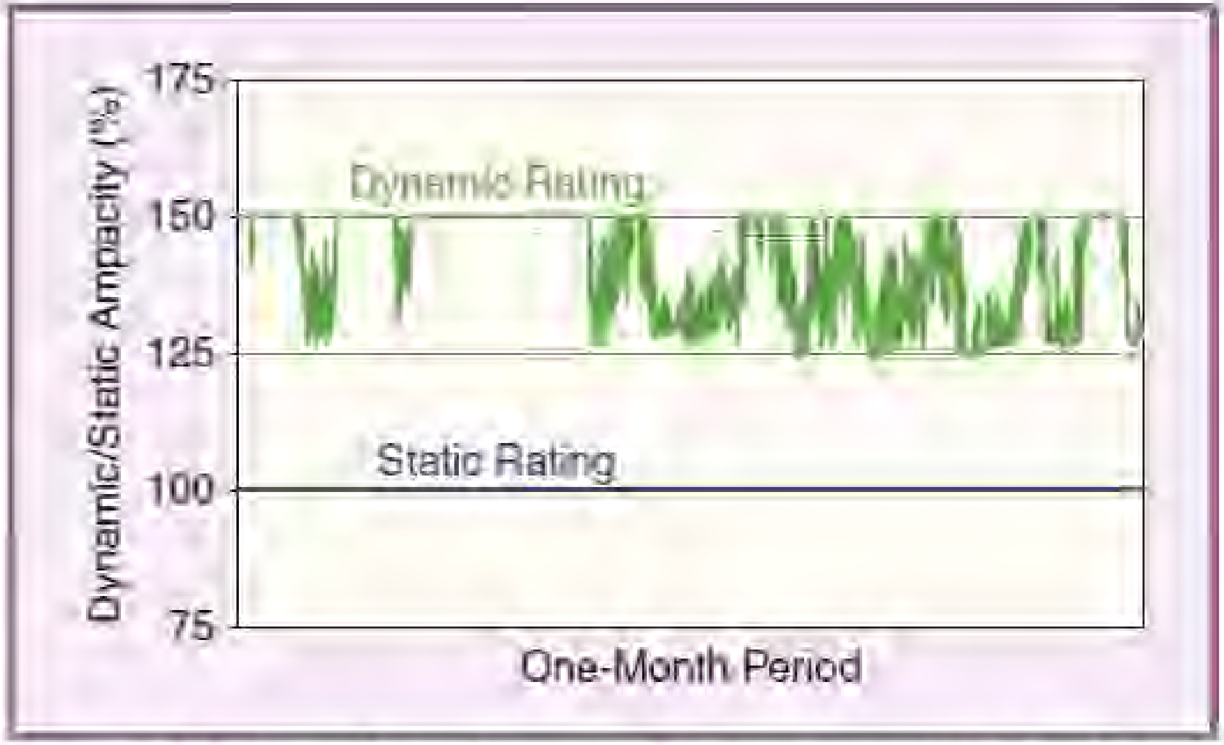


figure 16. The dynamic current rating compared with the static rating over one month for TenneT OHLs.

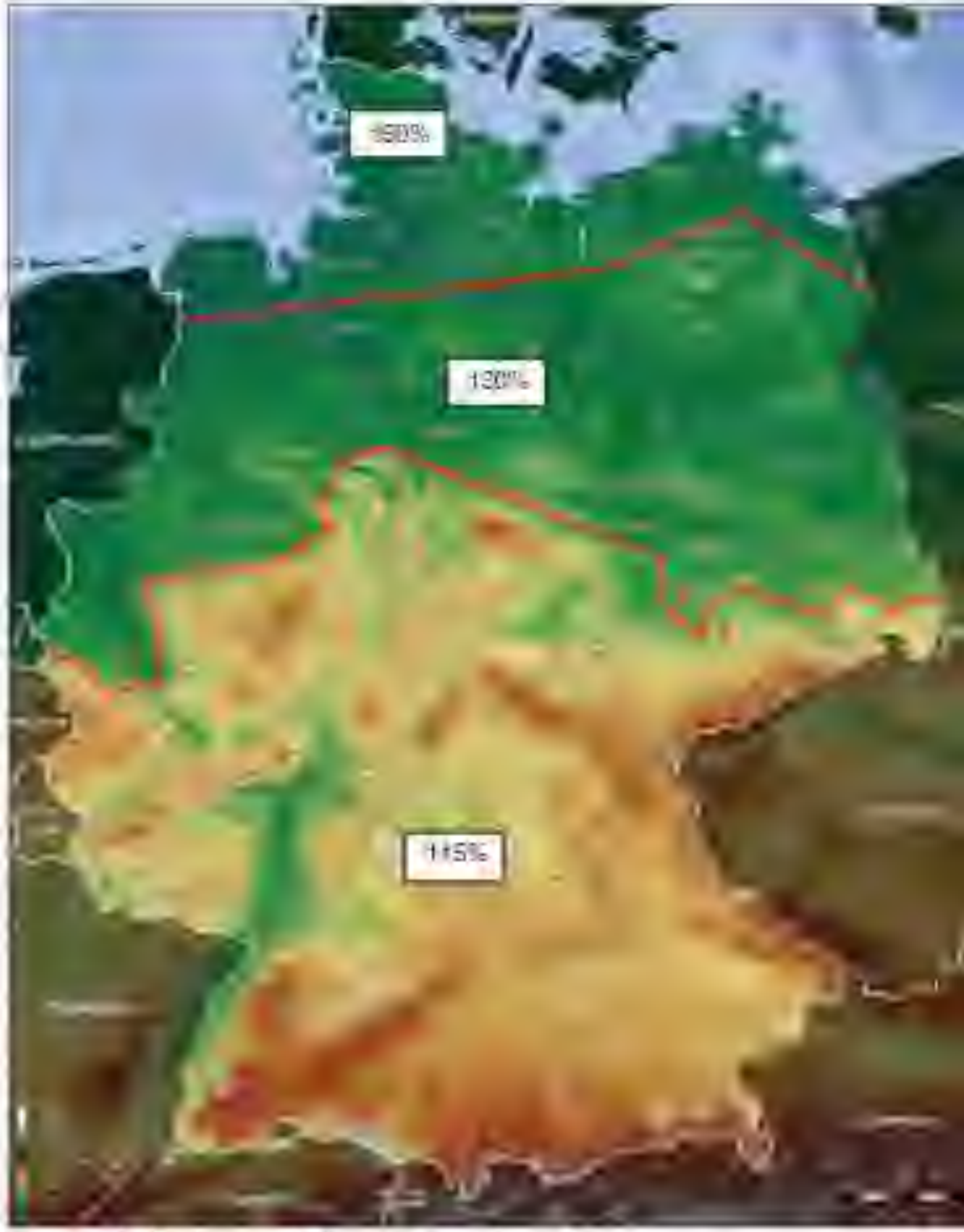
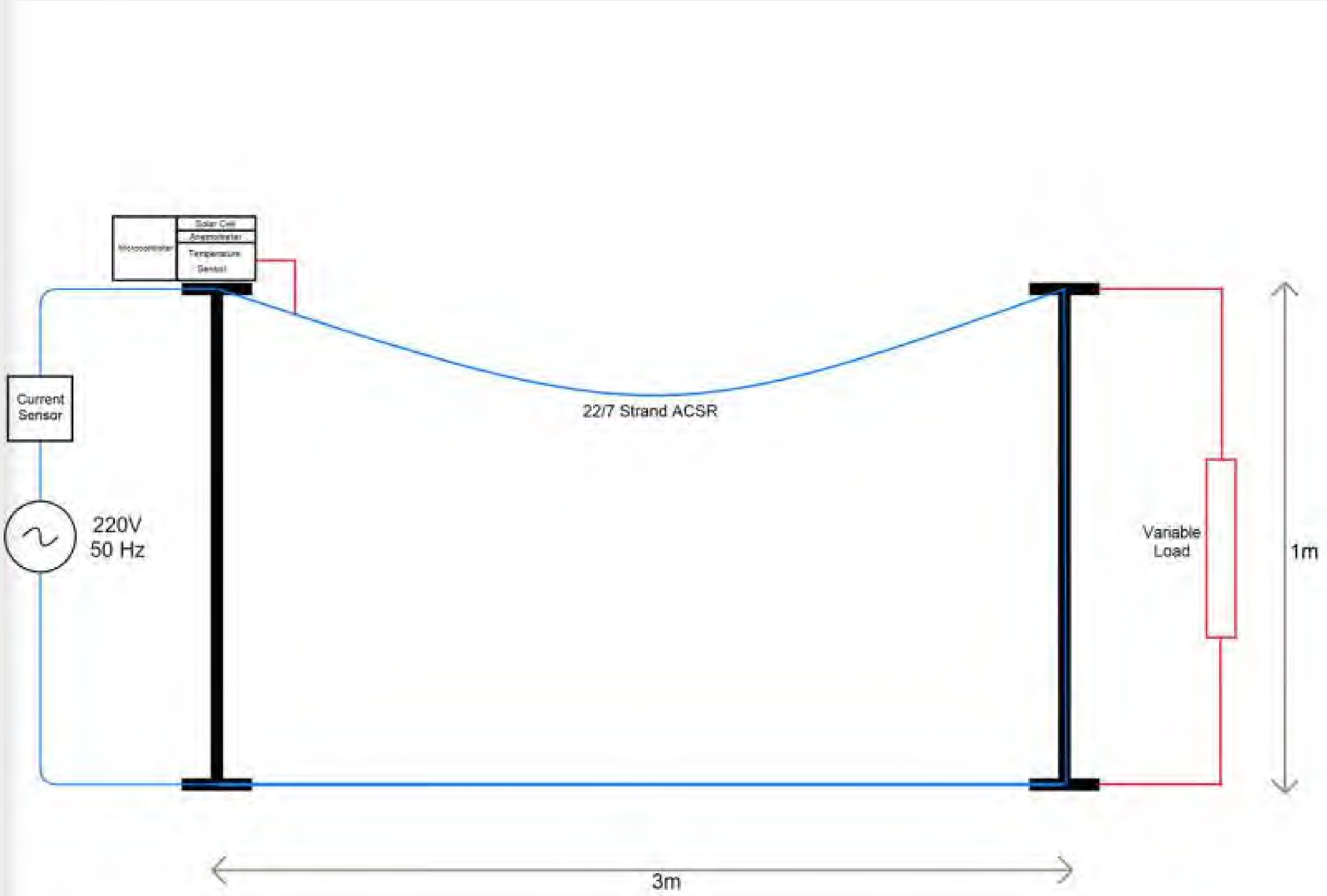
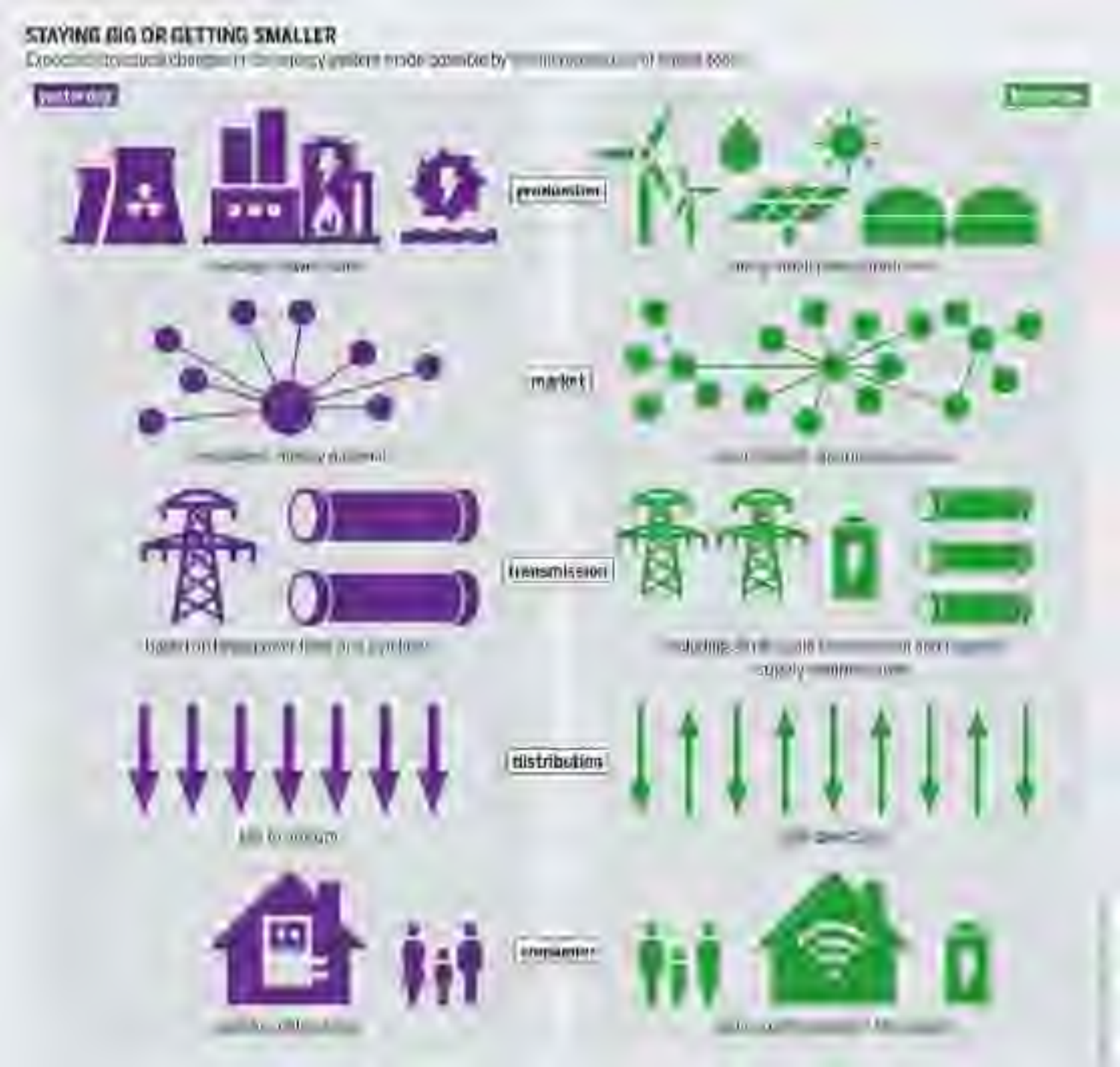


figure 14. Application of dynamic line rating in Germany.



Undergraduate project work of
Phurba, Sristhi and Polarj (Running), KU

ADVANCEMENTS IN DISTRIBUTION SYSTEMS


STAYING BIG OR GETTING SMALLER
production
market
transmission
distribution
consumer

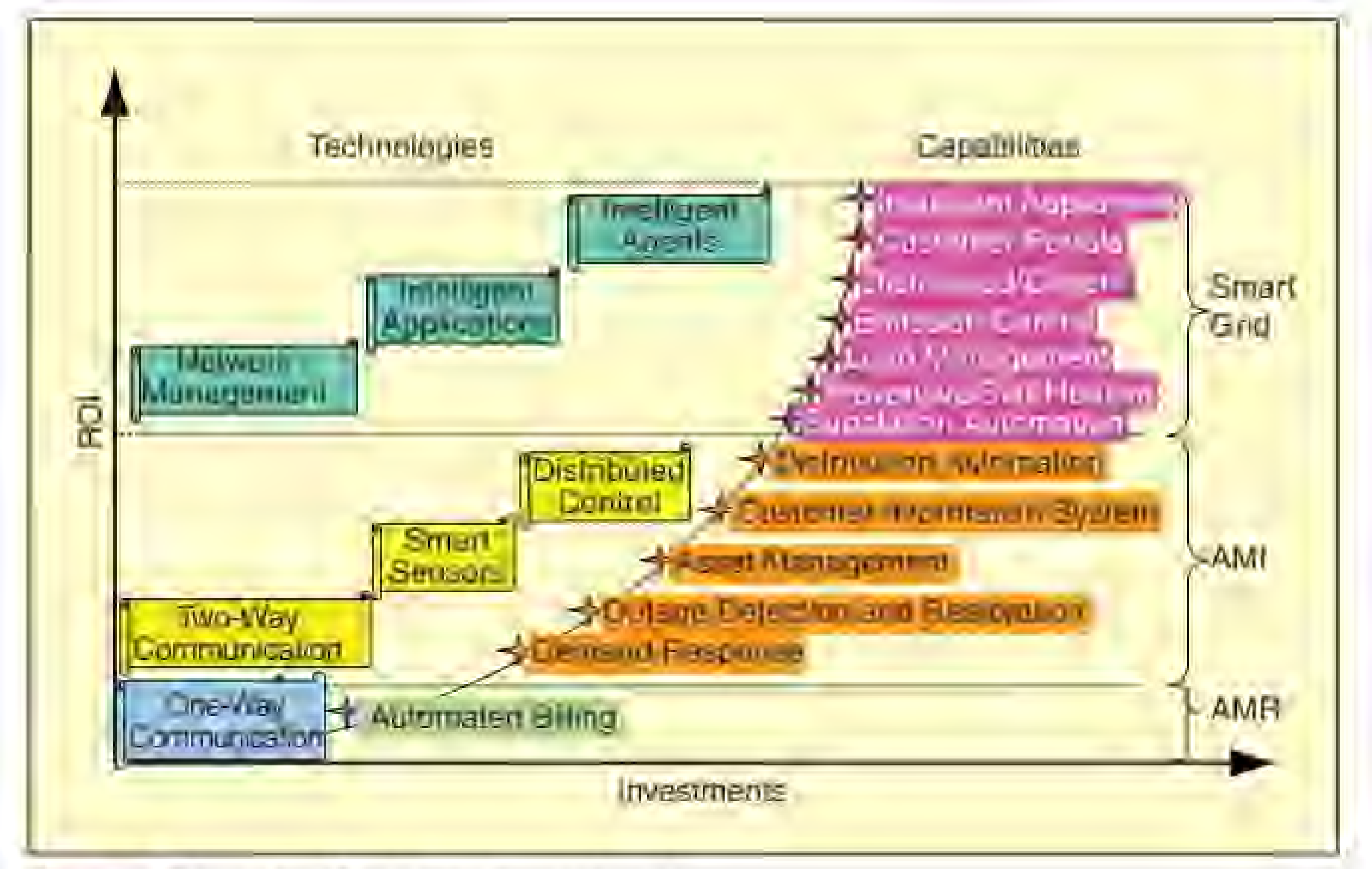
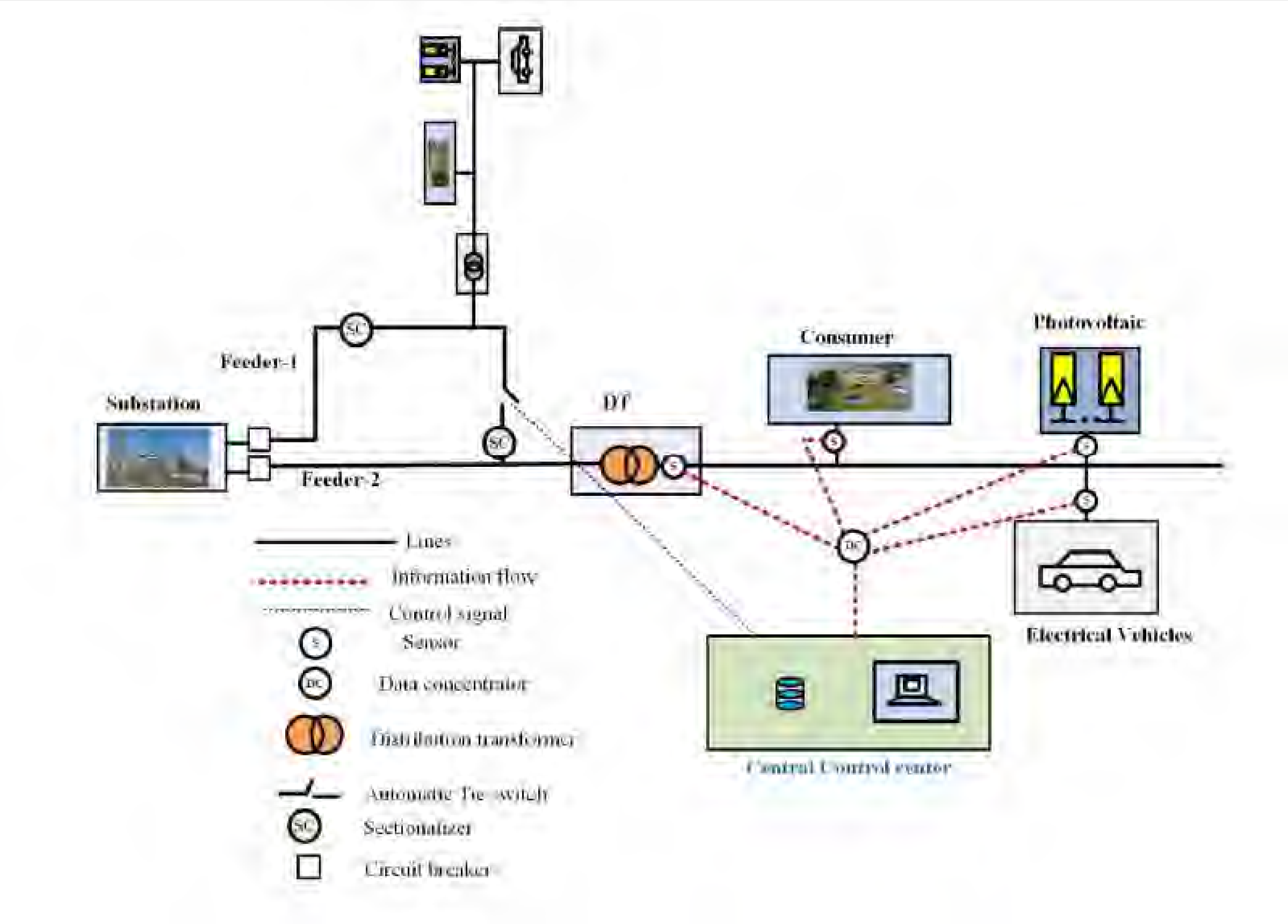


figure 7. Smart grid return on investments.

• Distribution Grid Visualization (Ongoing Project)



- Transmission Grid Visualization

https://www.rechargenews.com/transition/the-final-piece-of-the-puzzle-how-will-the-future-grid-work-/2-1-515137?zephr_sso_ott=cKZMLw

• Distribution Grid Visualization

Smart meter

https://techlekh.com/nea-smart-electricity-meters/

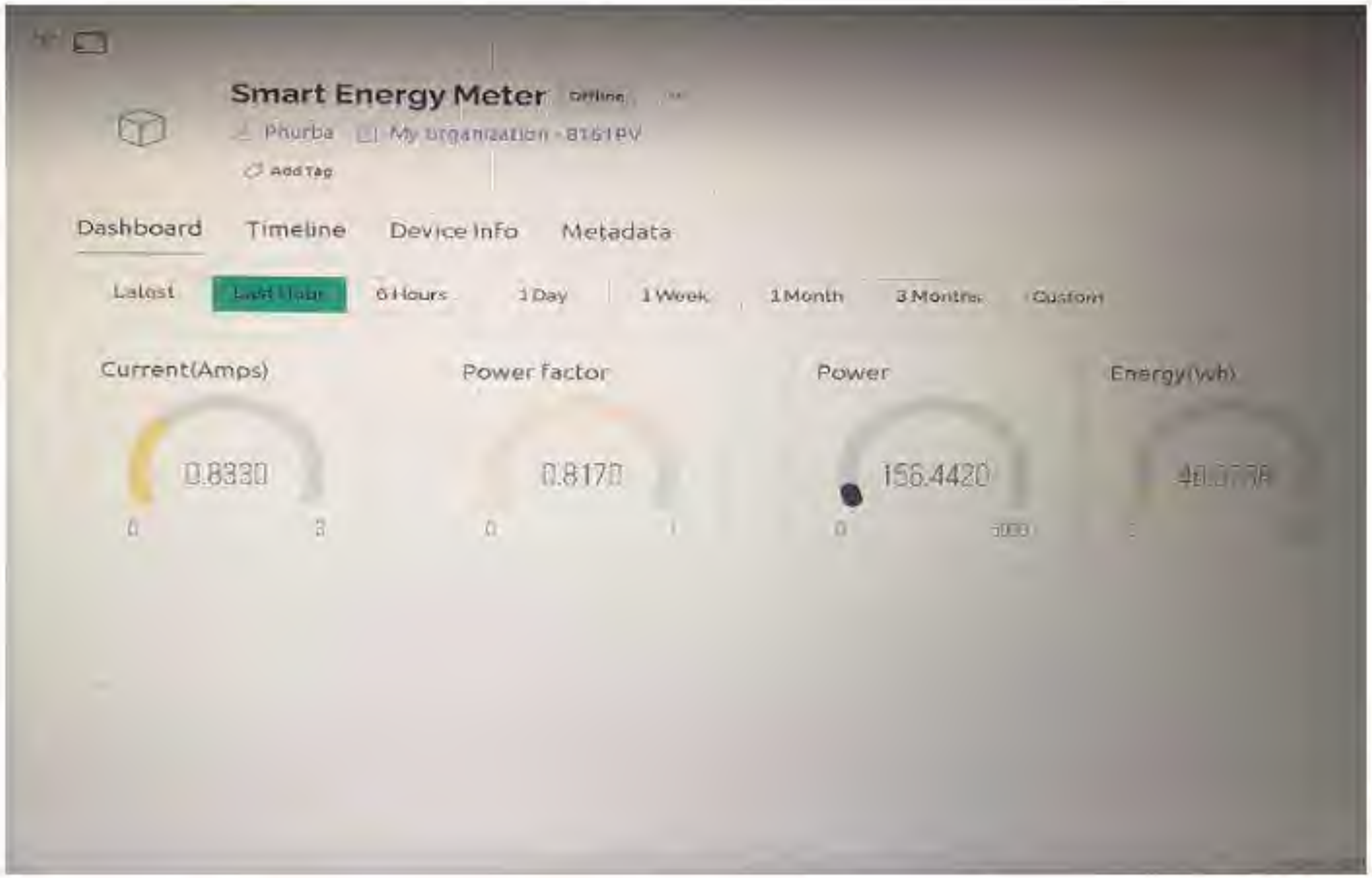
Micro phasor measurement unit

https://powerside.com/products/power-monitoring/micropmu/

- Distribution Grid Visualization (Ongoing Project)

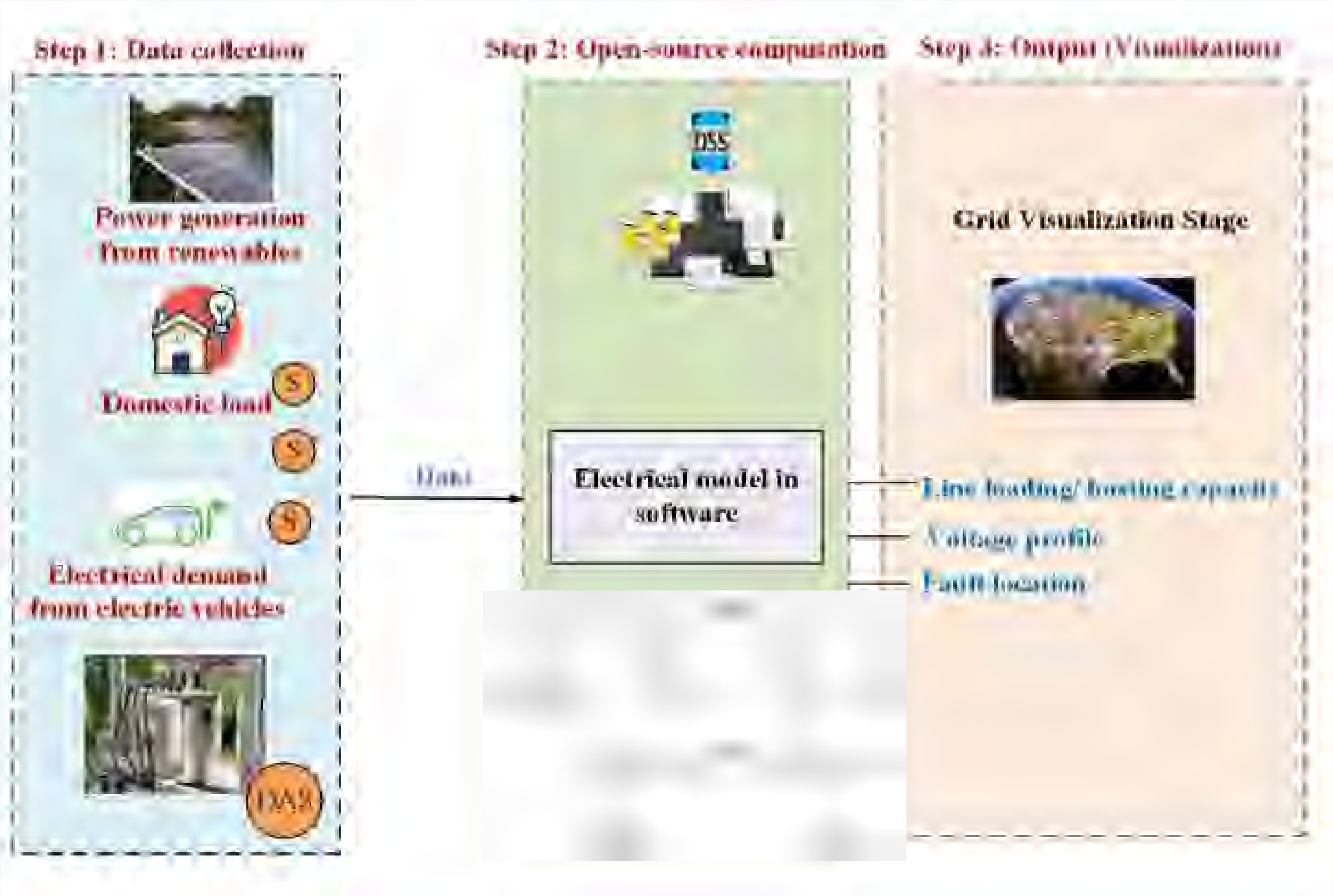
- Distribution Grid Visualization (Ongoing Project)

Fig 13: Circuit Setup of SEM



Undergraduate project work of
Phurba, Sristhi, Abhisekh and Prakash, KU

• Distribution Grid Visualization (Ongoing Project)



- Distribution Grid Visualization

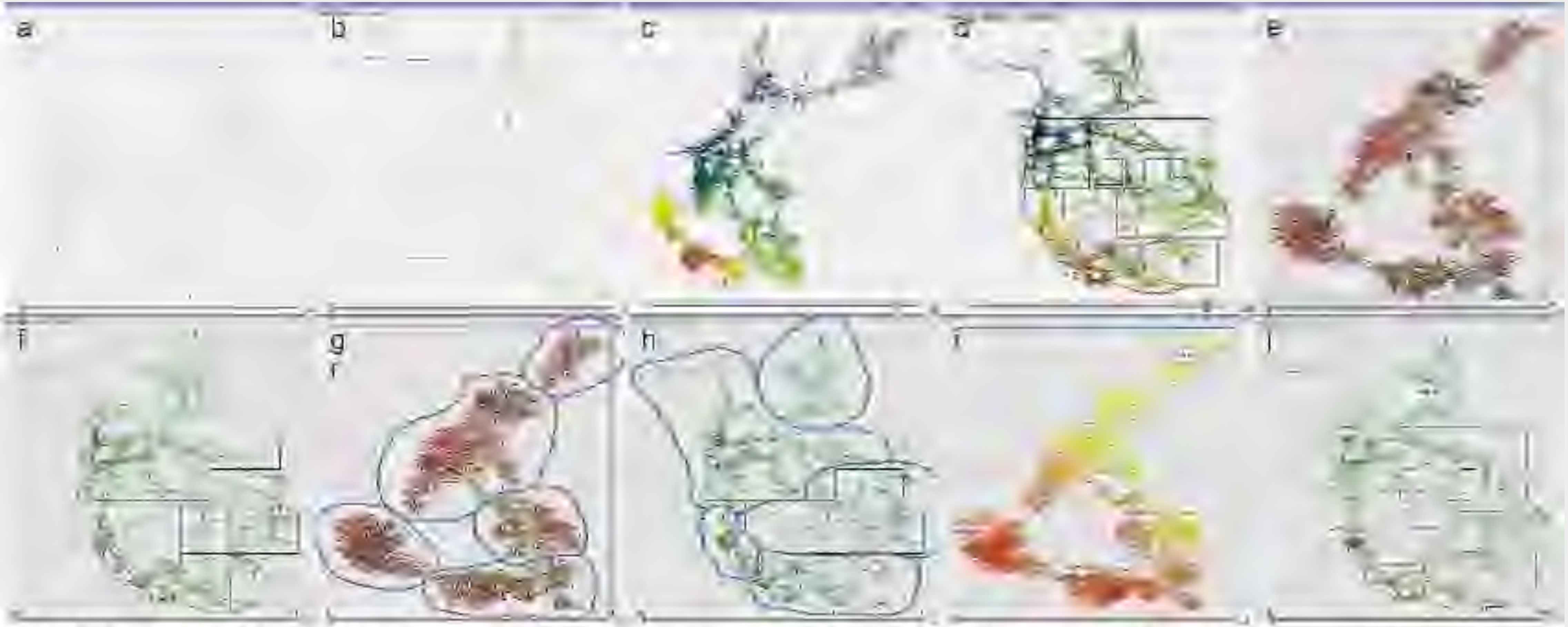
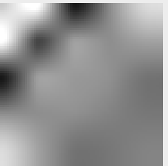


Figure 7. Sample set of GreenGrid and geographic layout visualizations applied used in usability evaluation. Graphs show simulated electric power



https://www.semanticscholar.org/paper/A-Novel-Visualization-Technique-for-Electric-Power-Wong-Schneider/36c2e19e3d9fd4b10e3fe9d9b0422c979f0bafae

- Distribution Automation -> Outage Management System

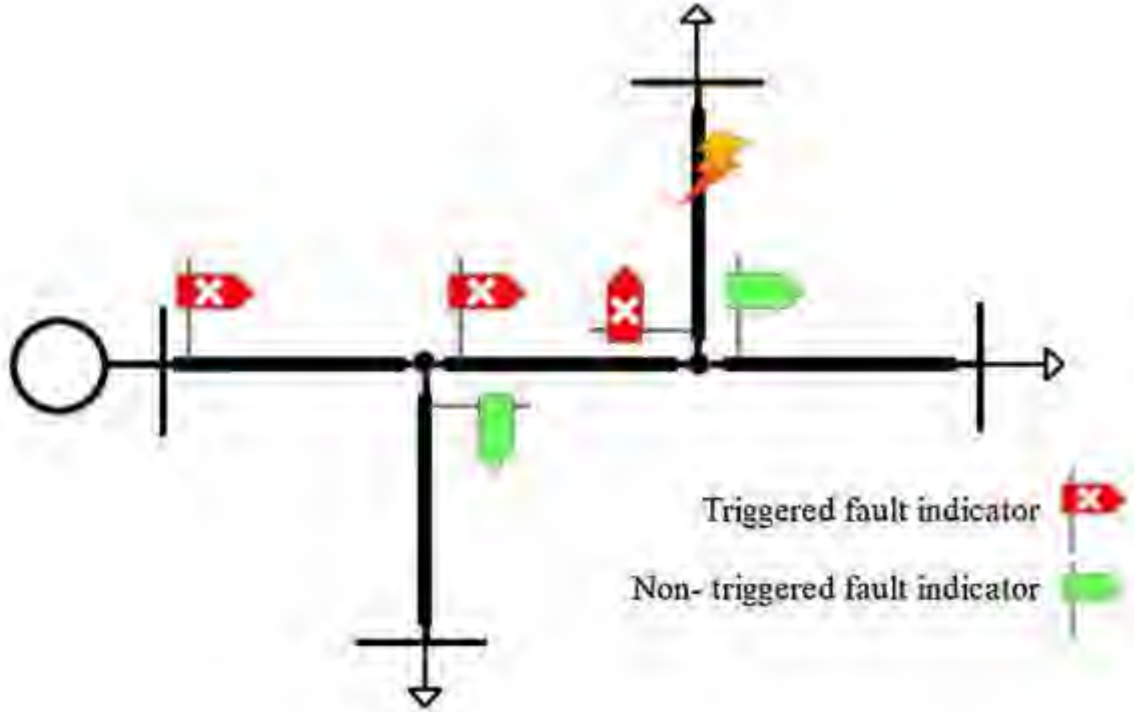


Fig. 2. Faulted area detection using fault indicators.

- Distribution Automation (Ongoing Project) -> Outage Management System

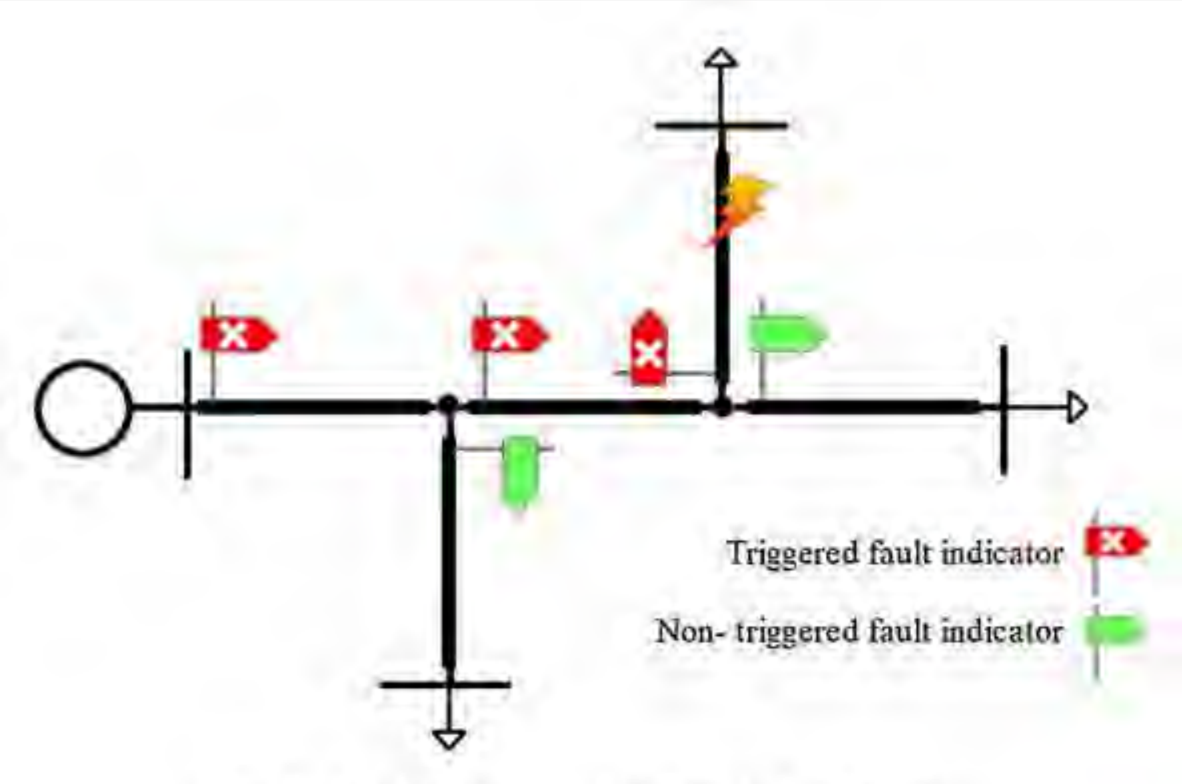
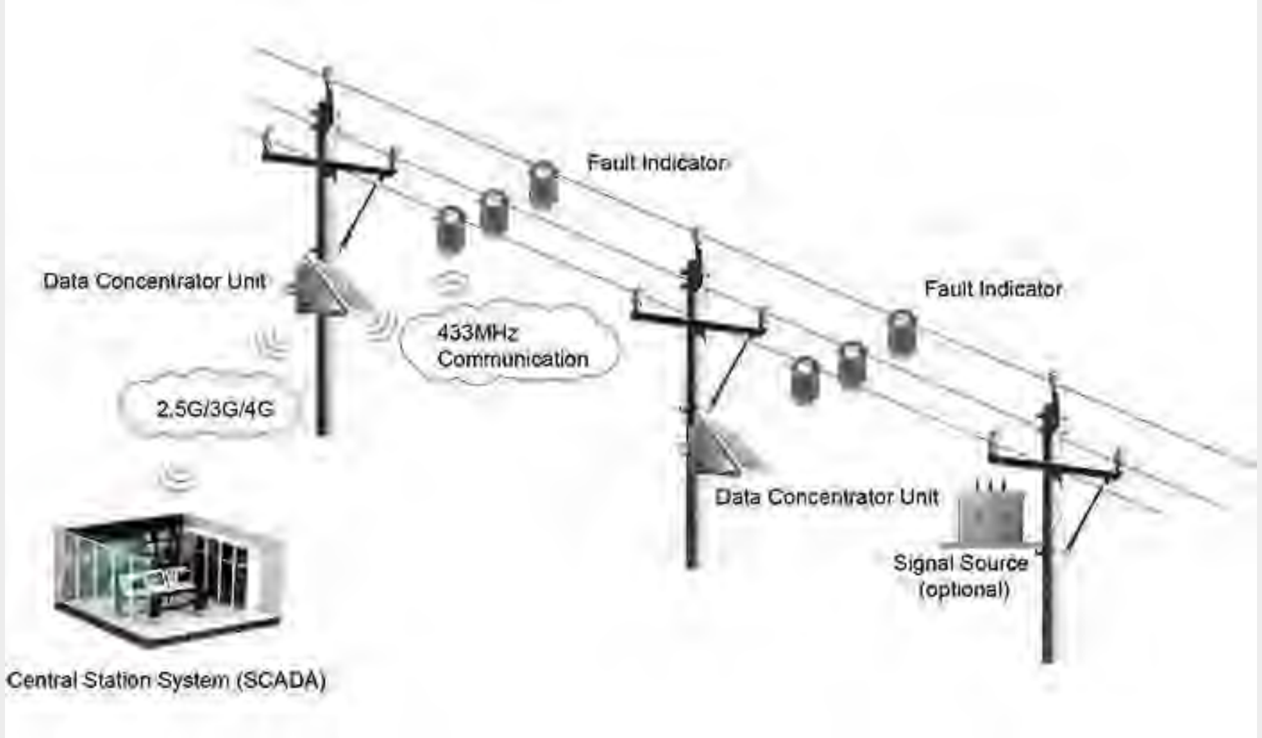
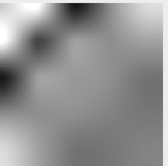


Fig. 2. Faulted area detection using fault indicators.

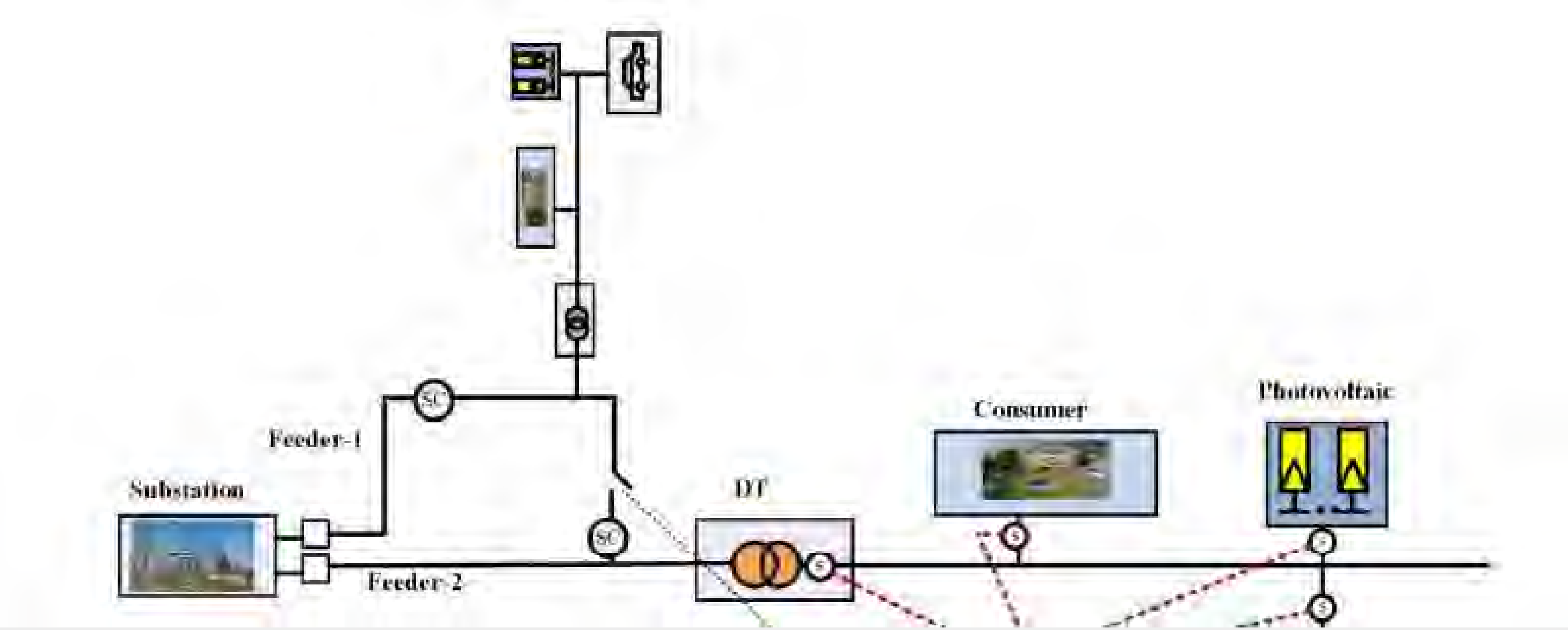



Outage Management System
OMS
Customer
Customer
Customer
Call Centre
1. Prediction
2. Grouping
3. Prioritisation
4. ETR
5. Escalation
SCADA
GIS
Field Crew / Linesmen
Zonal Office



- **Distribution/ Feeder Automation (In lab)**

- More complex algorithm/ AI (maybe) required in complex system (Mesh, loop etc)



Lab model

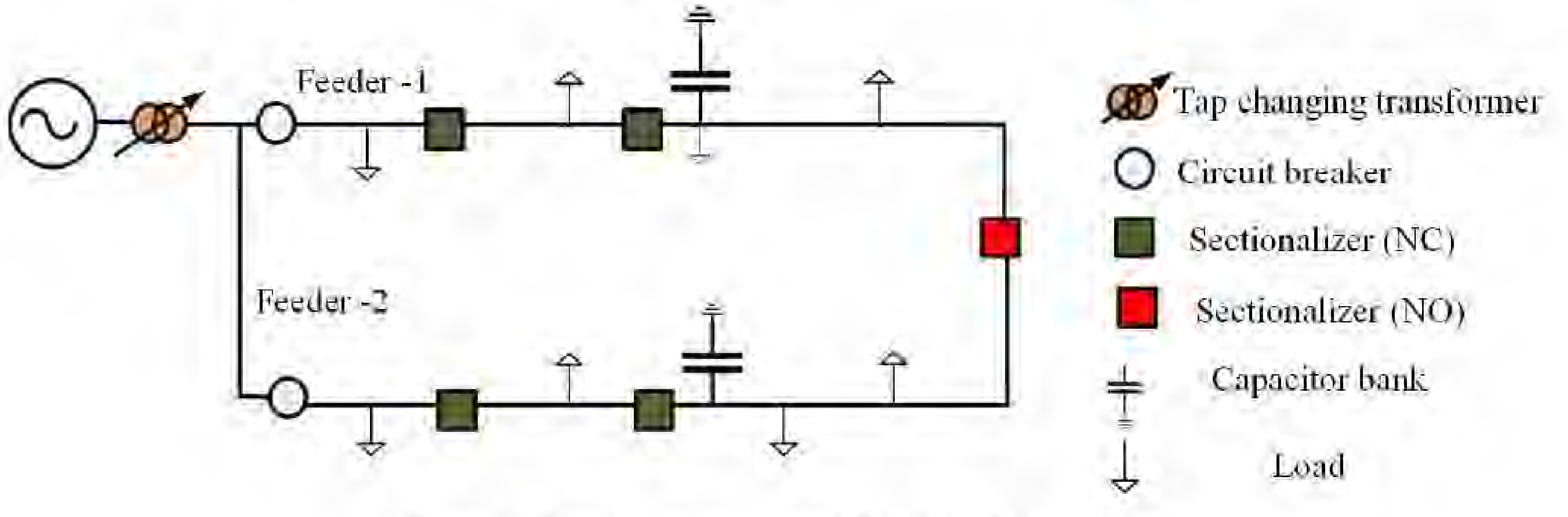


Figure 11: Distribution system model for Lab implementation

Table 2: Equivalent distribution components for DA lab implementation

Components	Equivalent
Supply (11kV)	12V (AC)
Feeder	Resistor and inductor
Sectionalizer	Contactor
Load	Resistive bank

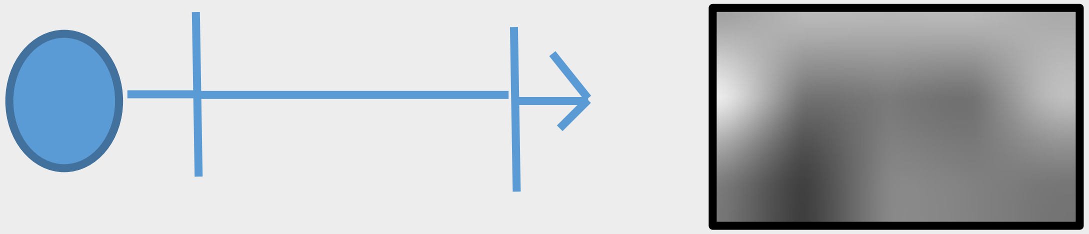
Figure 42: Monitoring the system status from Web app.

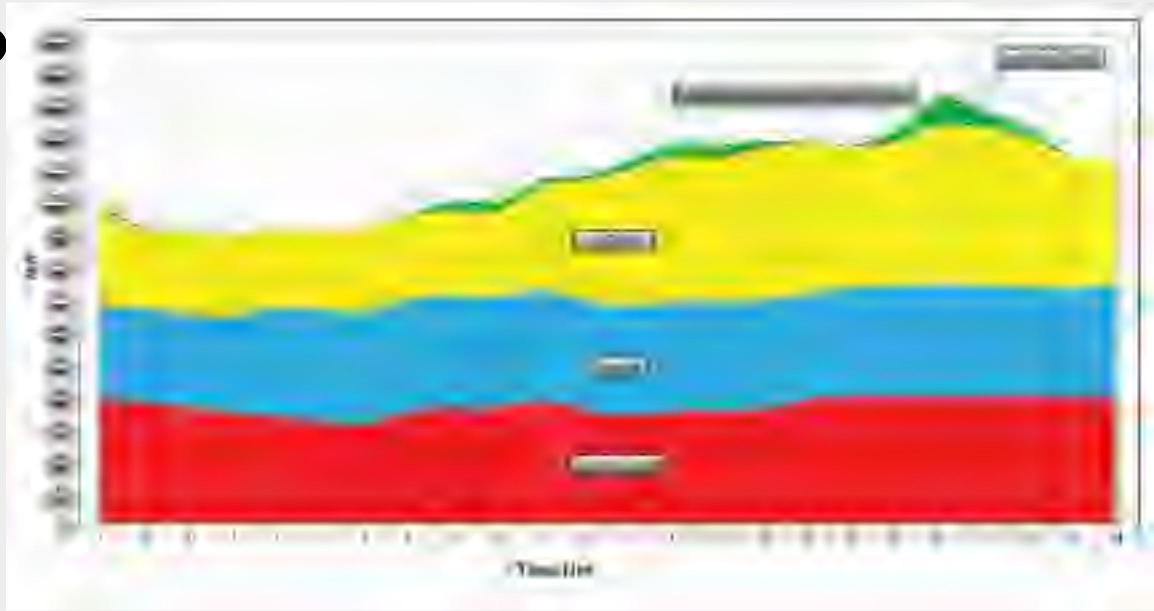
Figure 43: Overall hardware

Undergraduate project work of Yubraj, Aship and Abhijeet, KU

PROBABILISTIC METHODS

- Provide statistical information about system→ Better tool for decision making
- Better method to analyze the effect o
(renewable, load etc)





- **Task:** Find voltage profile for load for every hour
- **Solution:** Take hourly load data of every hour and run the loadflow (Newton Raphson)

➢Tedious work

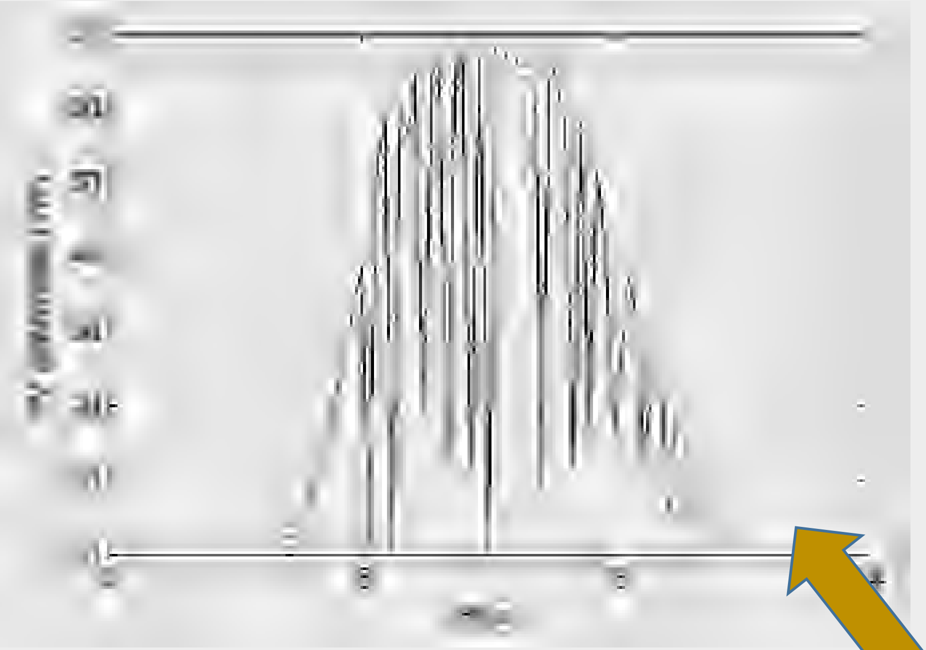


Fig. PV output power [*Fan et al. (2012)*]

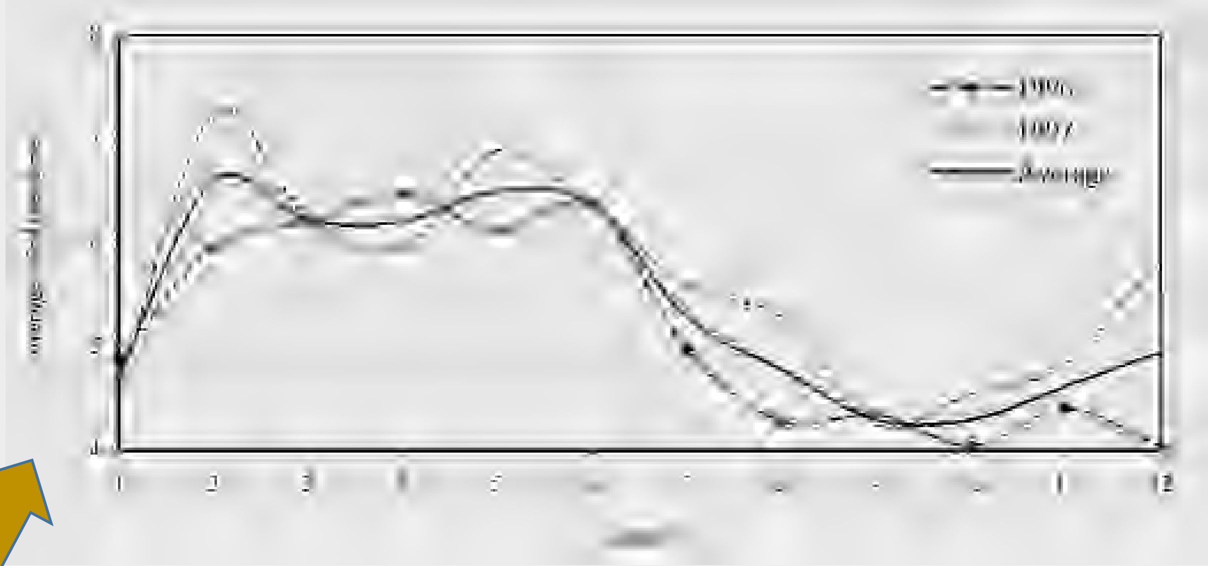
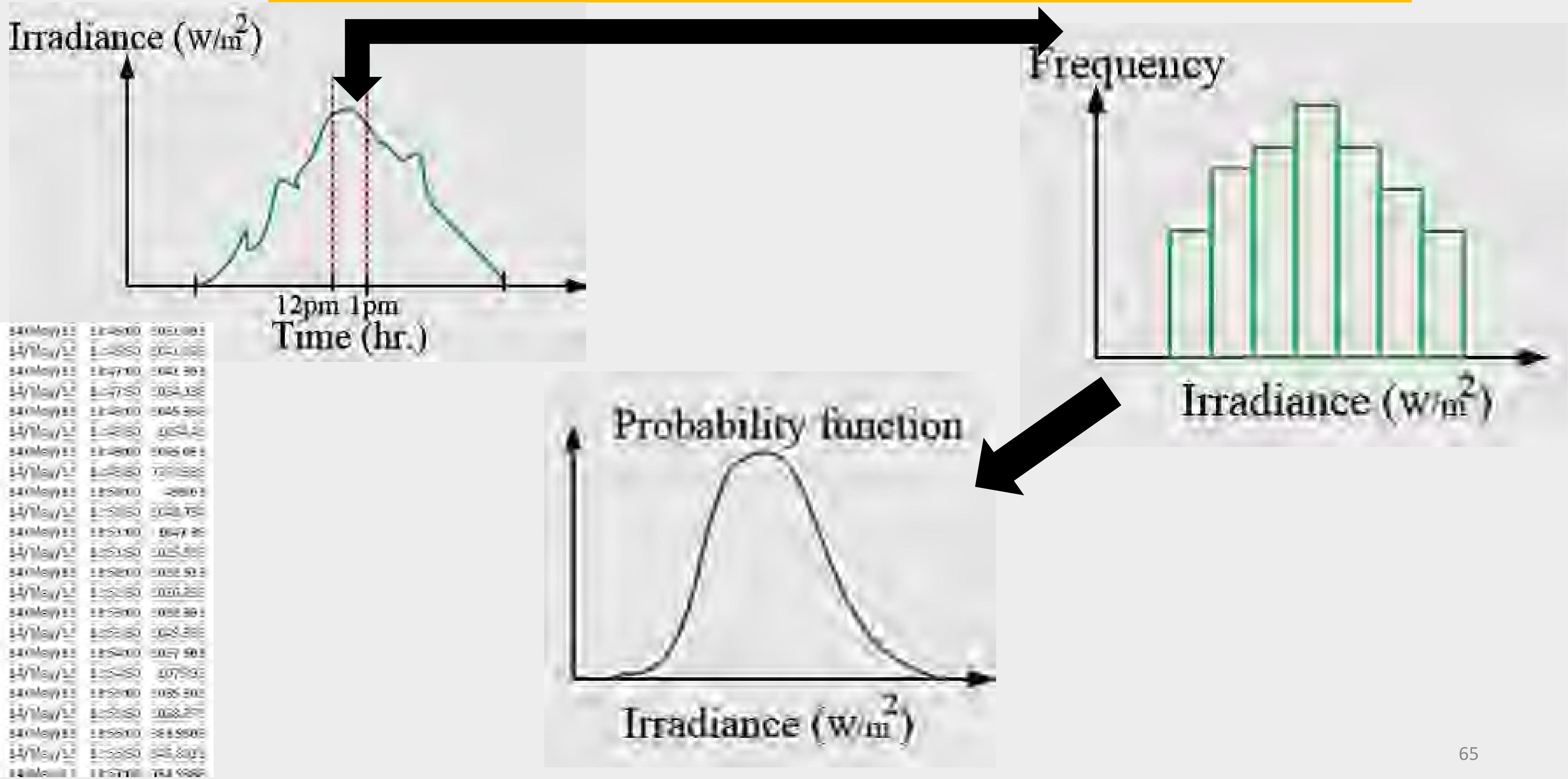


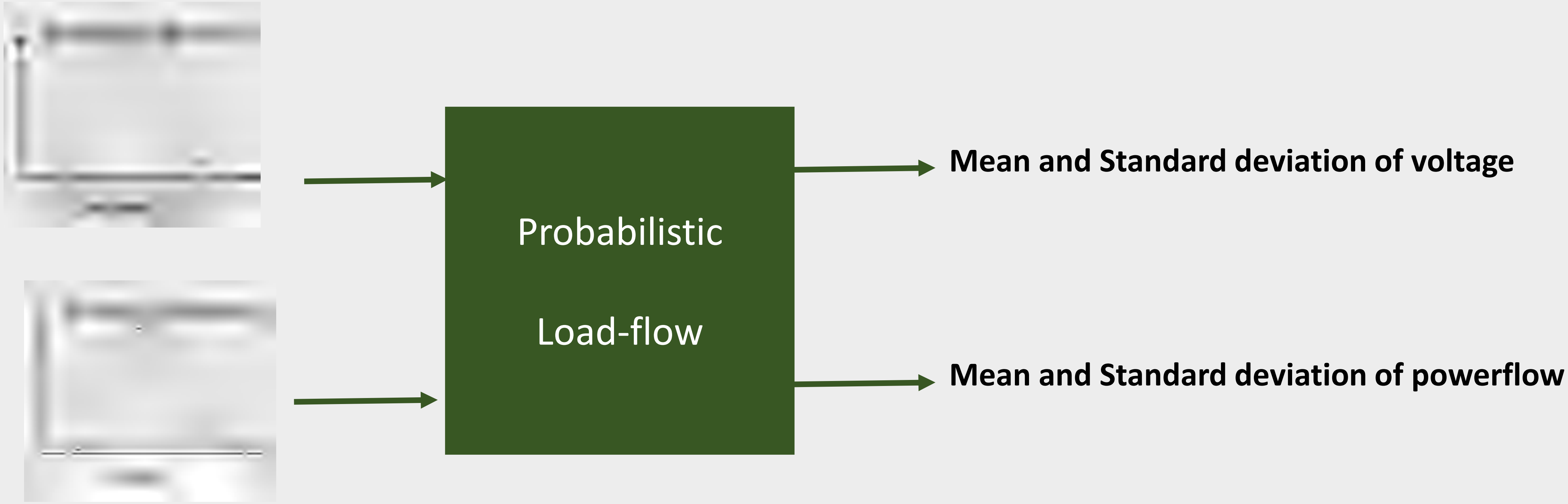
Fig. Wind velocity [*Weisser et al. (2002)*]

POWER SYSTEM UNCERTAINTIES

FLUCTUATIONS TO PROBABILITY



PROBABILISTIC LOADFLOW



- ✓ Uses Monte Carlo Simulation or some analytical methods such as cumulant, point estimate etc

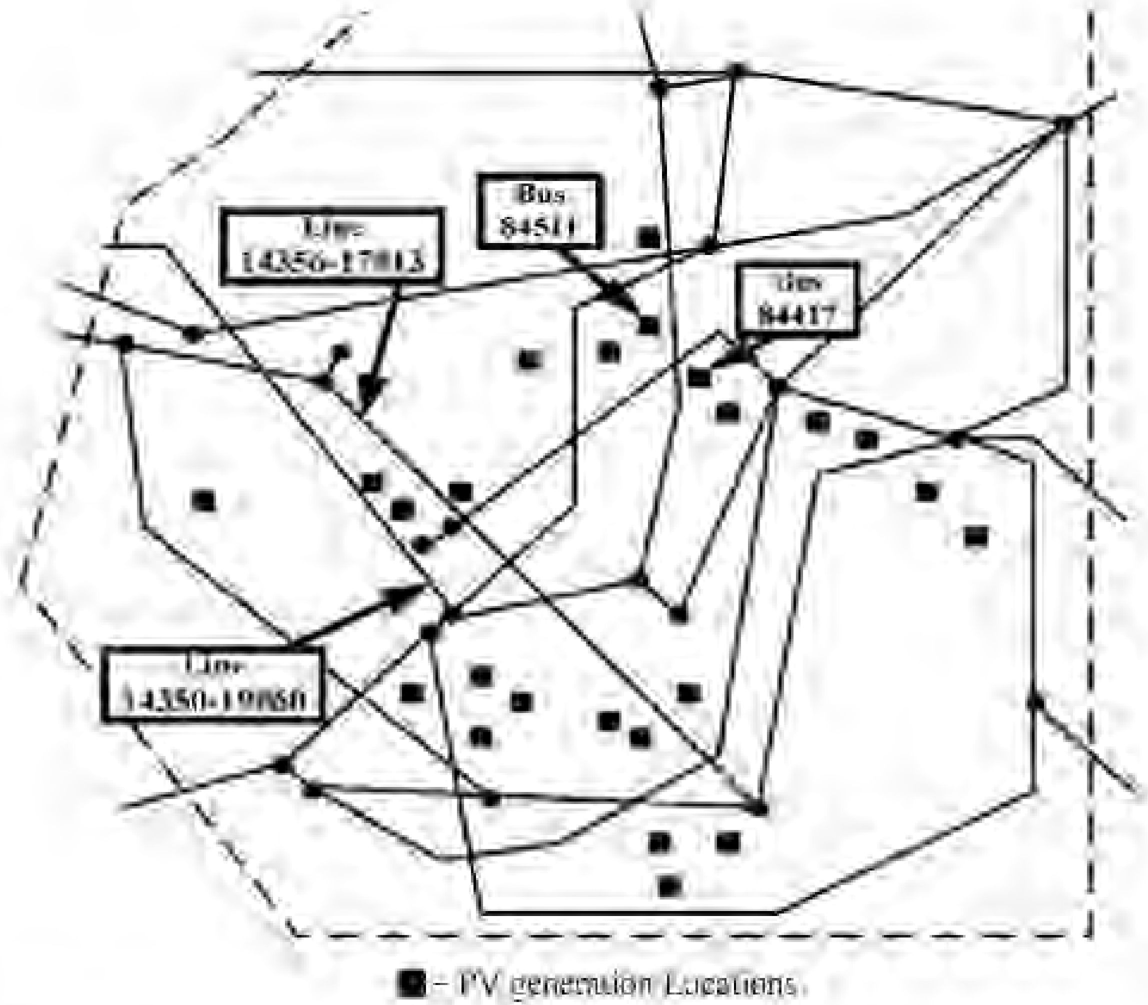


Fig. 6. Simplified portion of the WECC in Arizona.

PVG supplies 20% of the load demand

INPUTS

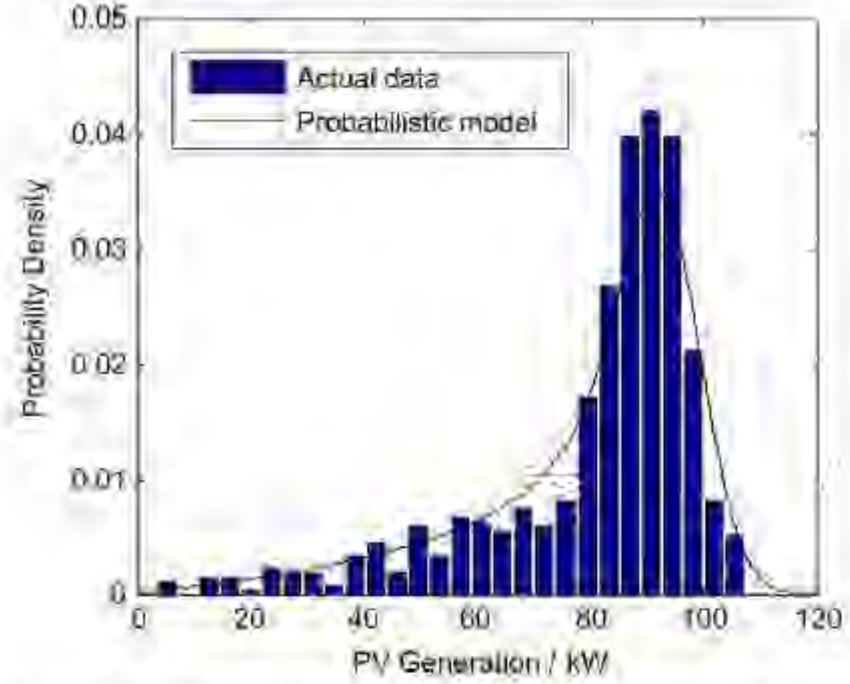


Fig. 4 PDF curve of PV generation for both probabilistic model and actual data

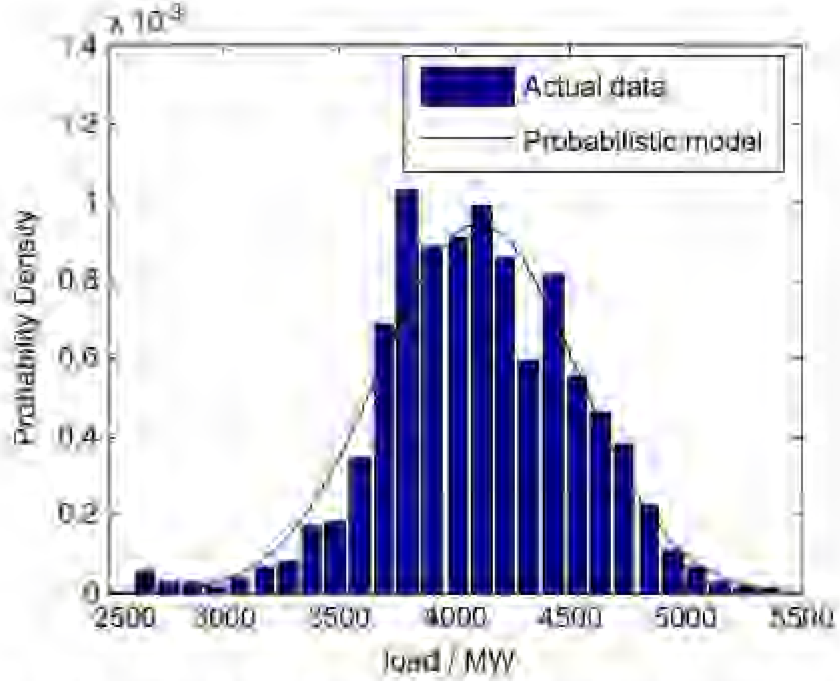


Fig. 5 PDF curve of load for both probabilistic model and actual data

TABLE II
COMPARISON OF THE RESULTS FOR THE VOLTAGE MAGNITUDE AT BUS 84417*

	MCS	
AAMS	0	[redacted]
10% CL / pu	1.0955	
90% CL / pu	1.15060	
OVP (>1.1 pu)	83.25%	
Time / s	514730	

*CL – confidence level; OVP – steady-state overvoltage probability; GC – Gram-Charlier; EW – Edgeworth; CF – Cornish-Fisher.

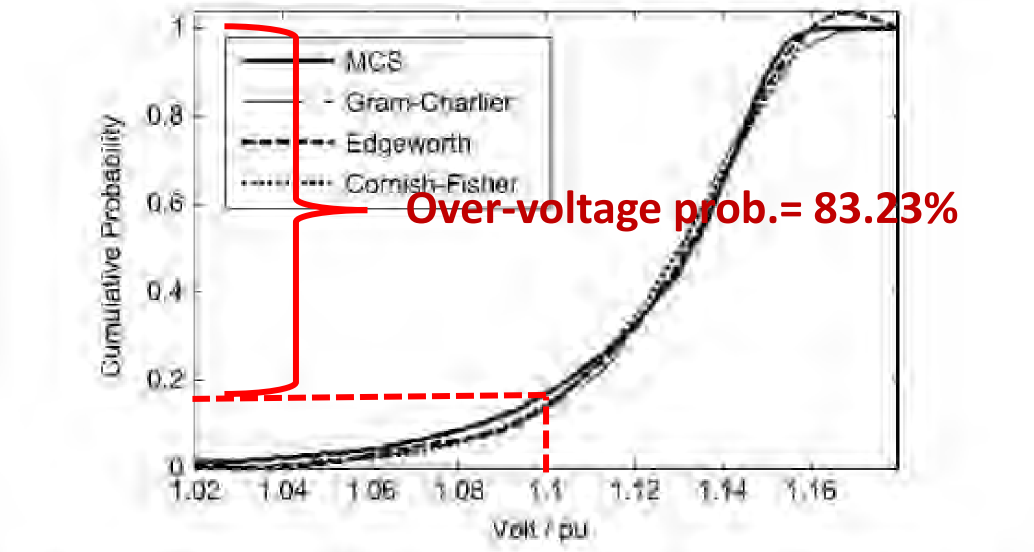


Fig. 7. CDF curves of the voltage magnitude at bus 84417 in three different types of expansions.

TABLE III
COMPARISON OF THE RESULTS FOR THE APF FLOW THROUGH LINE 14356-17015*

	MCS	
AAMS	[illegible]	[redacted]
10% CL / pu	[illegible]	
90% CL / pu	[illegible]	
OLP (>1.2 pu)	[illegible]	

*OLP – overload probability

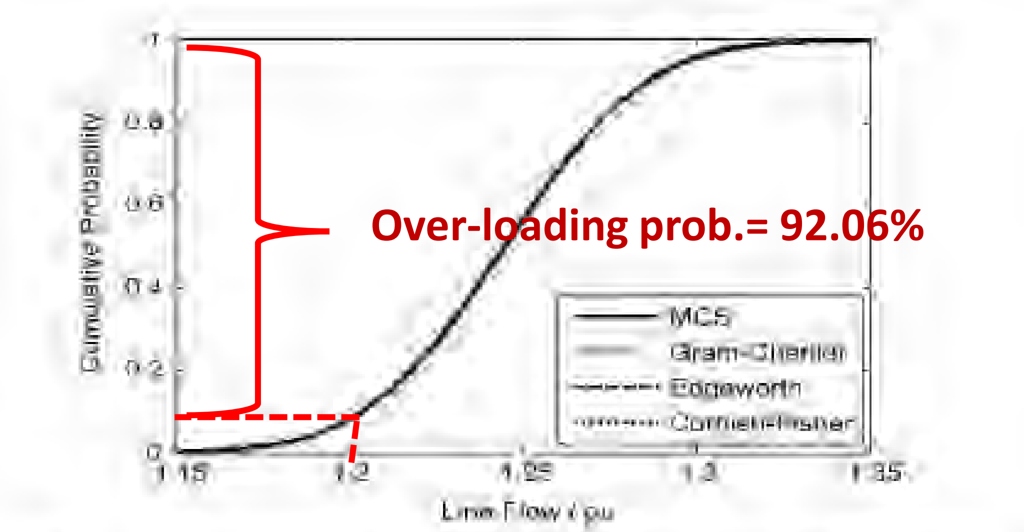


Fig. 8. CDF curves of the line flow through line 14356-17015 in three different types of expansions.

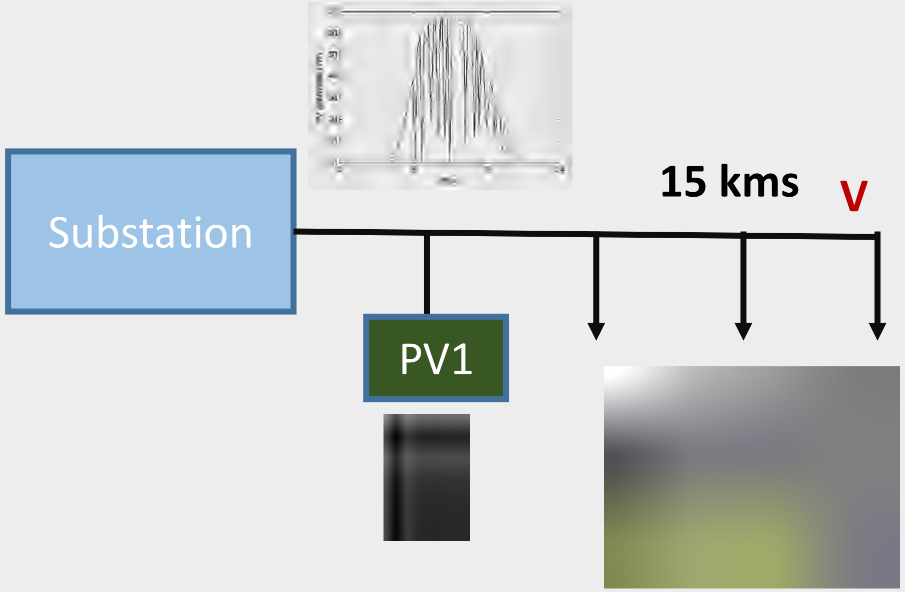
Other applications

❑Probabilistic optimization

- Task: Put a capacitor bank of appropriate size to keep the voltage near desired voltage (1 pu)
- System has a lot of photovoltaic generation

▪ **Solution:**

- *Minimize* $\sum_{i=1}^{N_{bus}} \boldsymbol{P(V_i < 0.95)}$
- Constraints: $\boldsymbol{Q_{min} \leq Q_{capacitor} \leq Q_{max}}$



✓ This problem can be solved by different optimization algorithms such as particle-swarm optimization, genetic algorithm etc.

- Volt-Var Control (Distribution Automation)

Energy Reports 8 (2022) 8630–8651

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Review article

State-of-the-art technologies for volt-var control to support the penetration of renewable energy into the smart distribution grids

Khalil Gholami [a], Md. Rabiul Islam [b], Md. Moktadir Rahman [c,1], Ali Azizivahed [d], Afef Fekih [e,*]

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[b] School of Electrical, Computer and Telecommunications Engineering, University of Wollongong, New South Wales 2522, Australia
[c] Renewable Energy Unit, Ingeteam Australia Pty Ltd, New South Wales 2500, Australia
[d] Faculty of Engineering and Information Technology, University of Technology Sydney, Sydney, Australia
[e] Department of Electrical and Computer Engineering, University of Louisiana at Lafayette, Lafayette, LA 70504-3890, USA

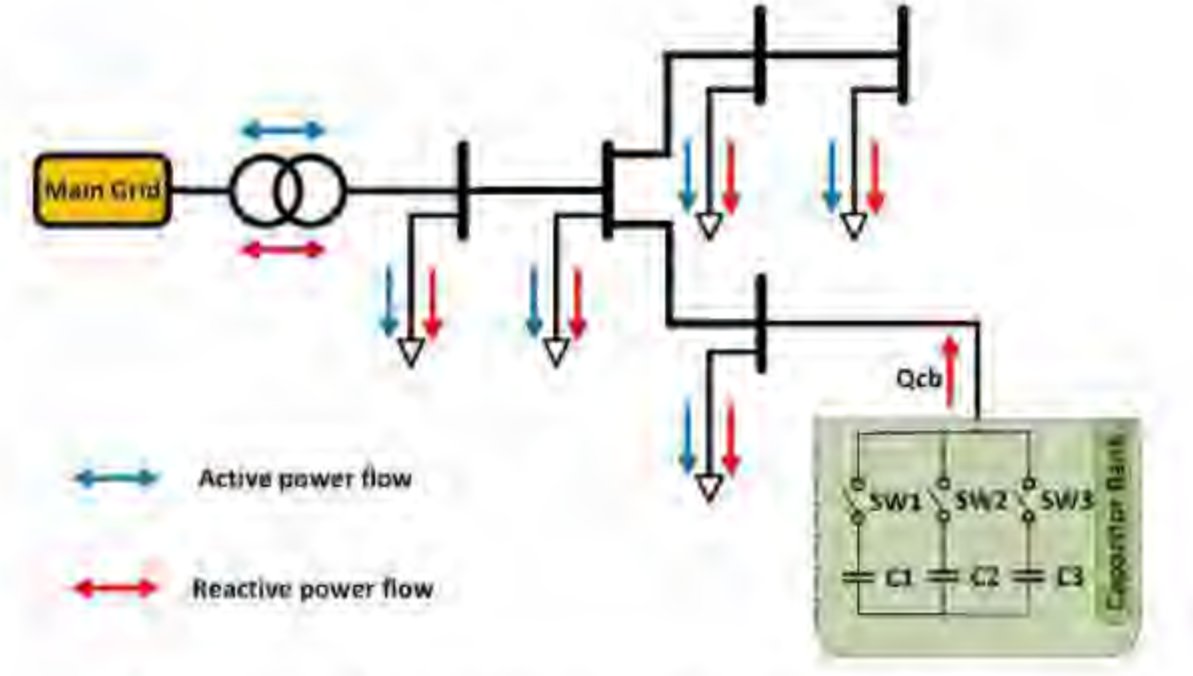


Fig. 3. Capacitor bank in a distribution network for reactive power compensation.

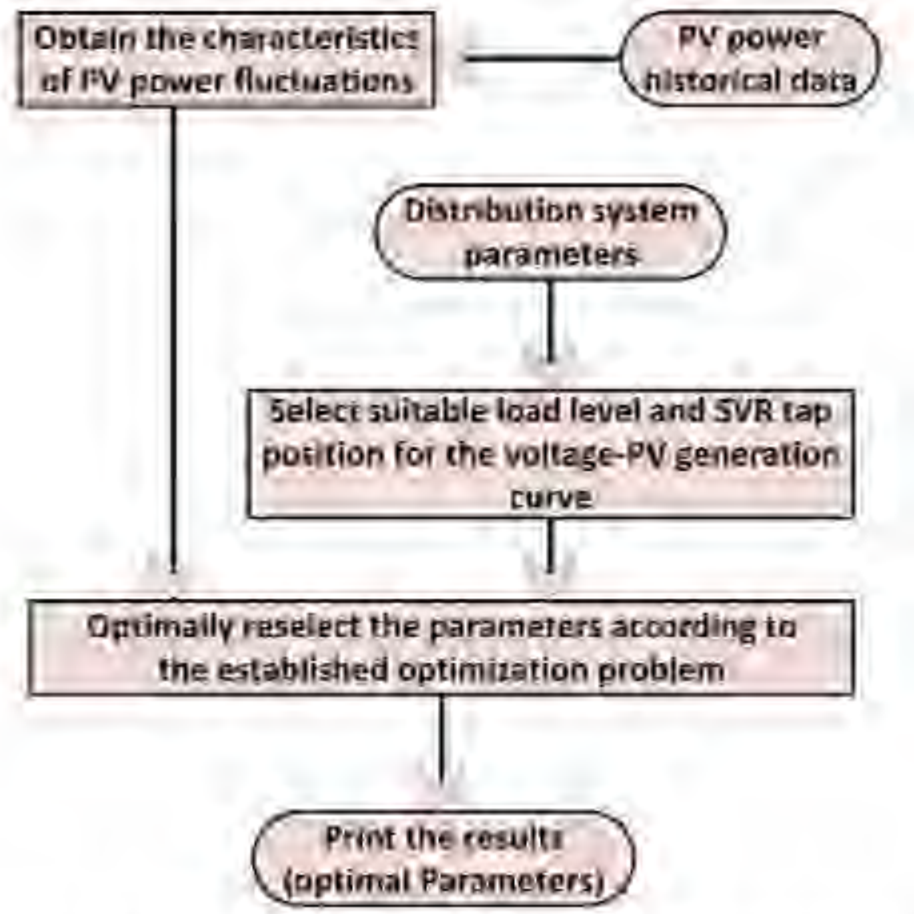
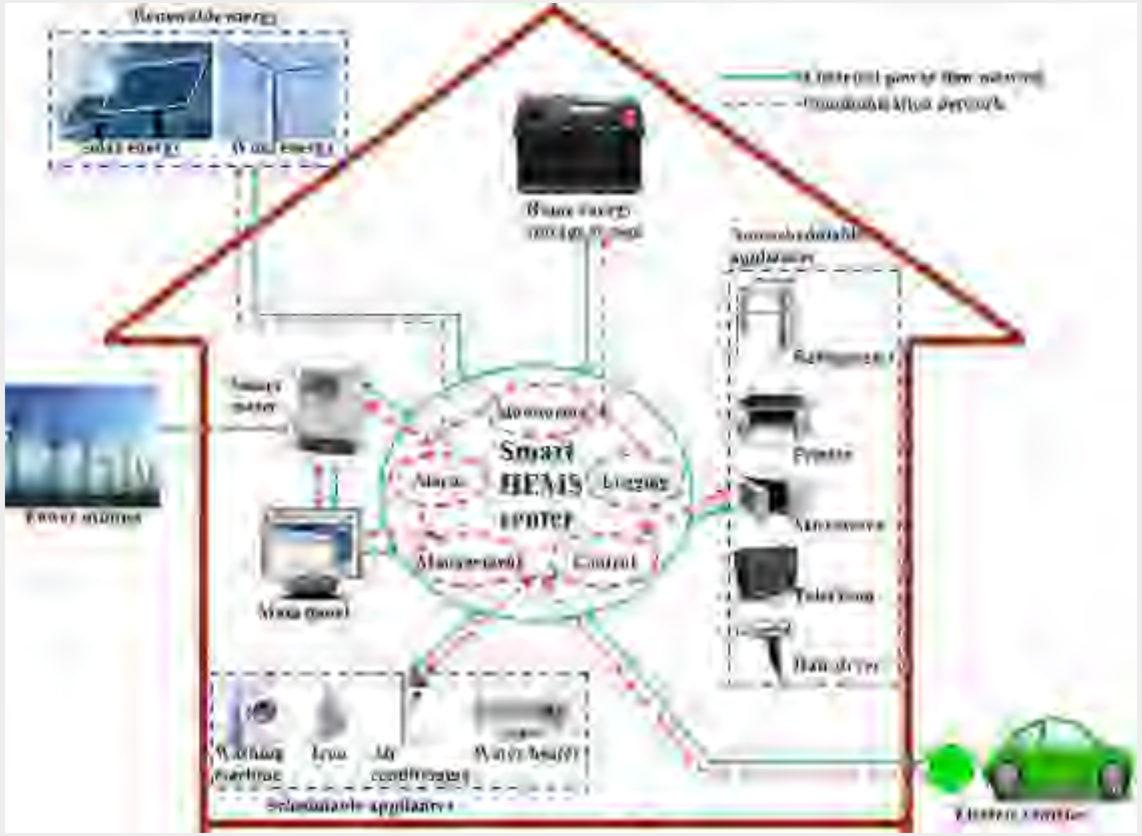


Fig. 5. The process of managing step voltage regulators and the PVs' reactive power.

OTHER RESEARCH AREAS

- ✓Machine learning in power systems
- ✓Home Energy Management Systems
- ✓Electric Vehicles (Vehicle 2 Grid)…



Thank you for your attention

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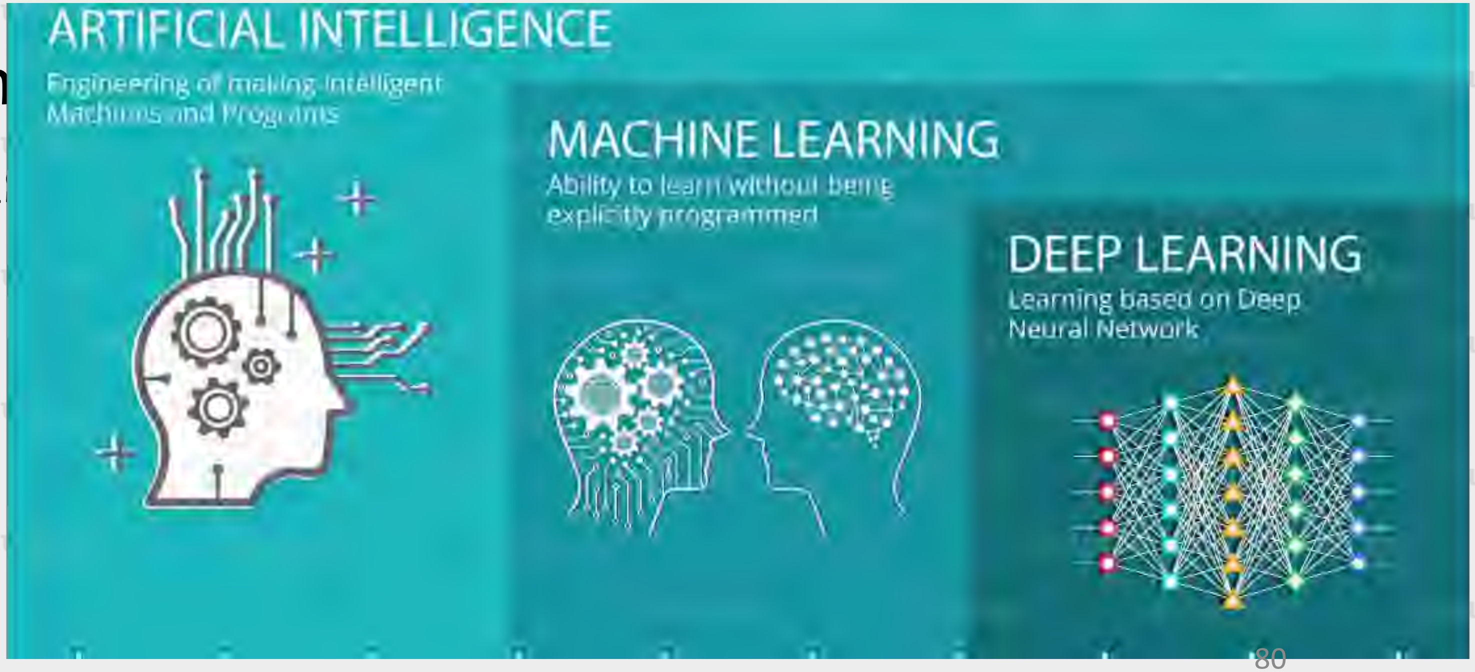
- https://pcmp.springeropen.com/articles/10.1186/s41601-018-0110-4

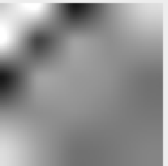
MACHINE LEARNING FOR POWER SYSTEMS

✓**Artificial Intelligence is** a bigger concept t
machines that can simulate human thinkin
behavior

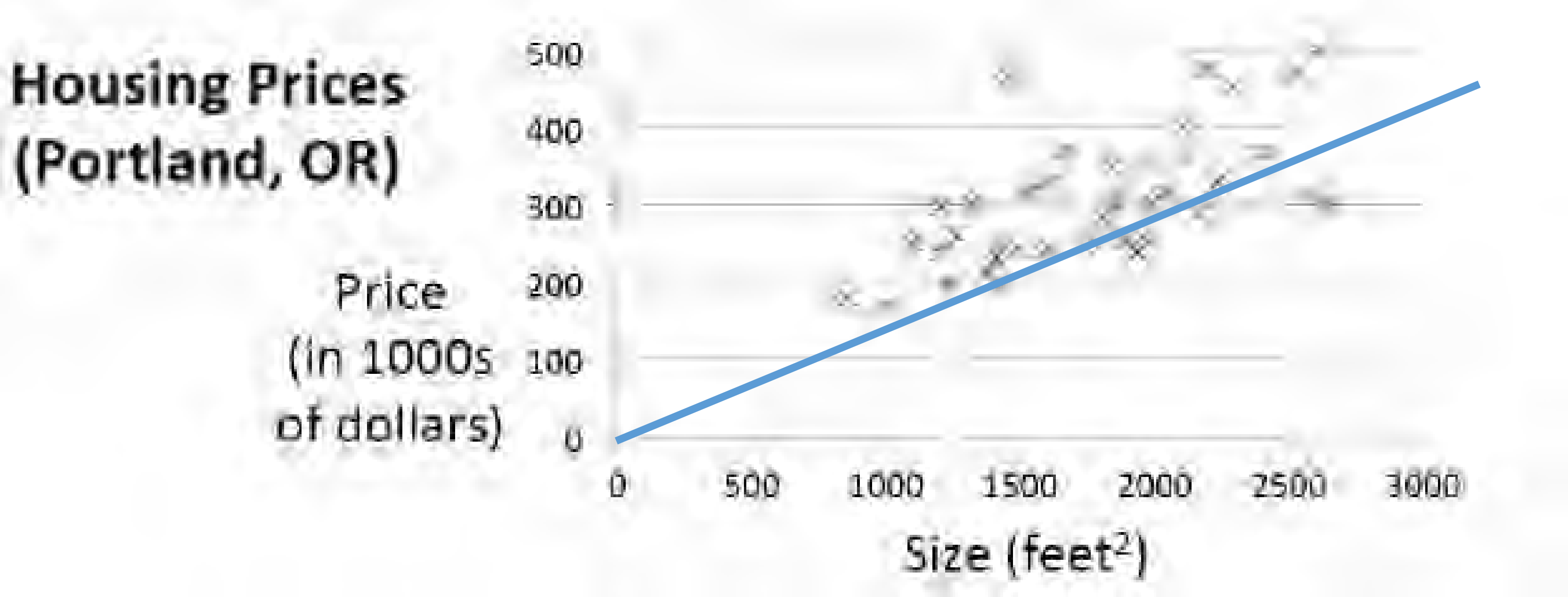
✓M**achine learning is** an application or subs
allows **machines** to learn from data withou
explicitly

✓Machine learning algorithm
Supervised and Unsupervi





Regression

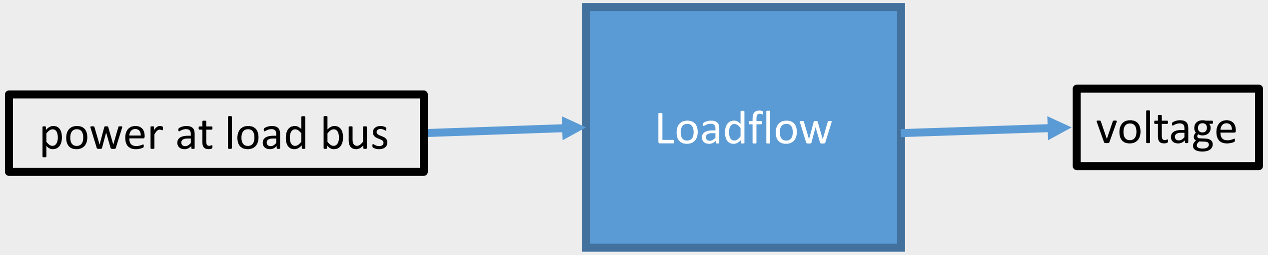


X	Y
1000	200
2500	300

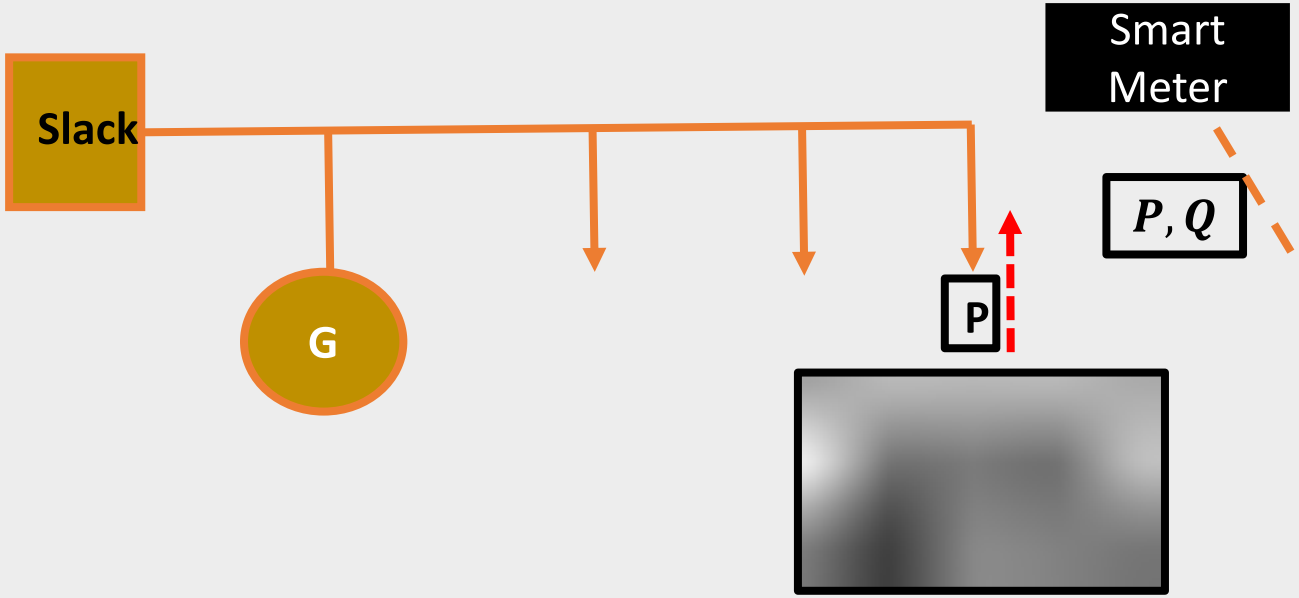
Regression Problem

Predict real-valued output

CONVENTIONAL CPF



- Takes large computational time for large system
- **Security assessment** is done every 5 to 15 minutes



$Voltage = f\ (P, Q)$

Active Power (P)	Reactive Power (Q)	Voltage
5MW	1MVAR	1.02 pu

"Data-Driven Method"

Real-time implementation

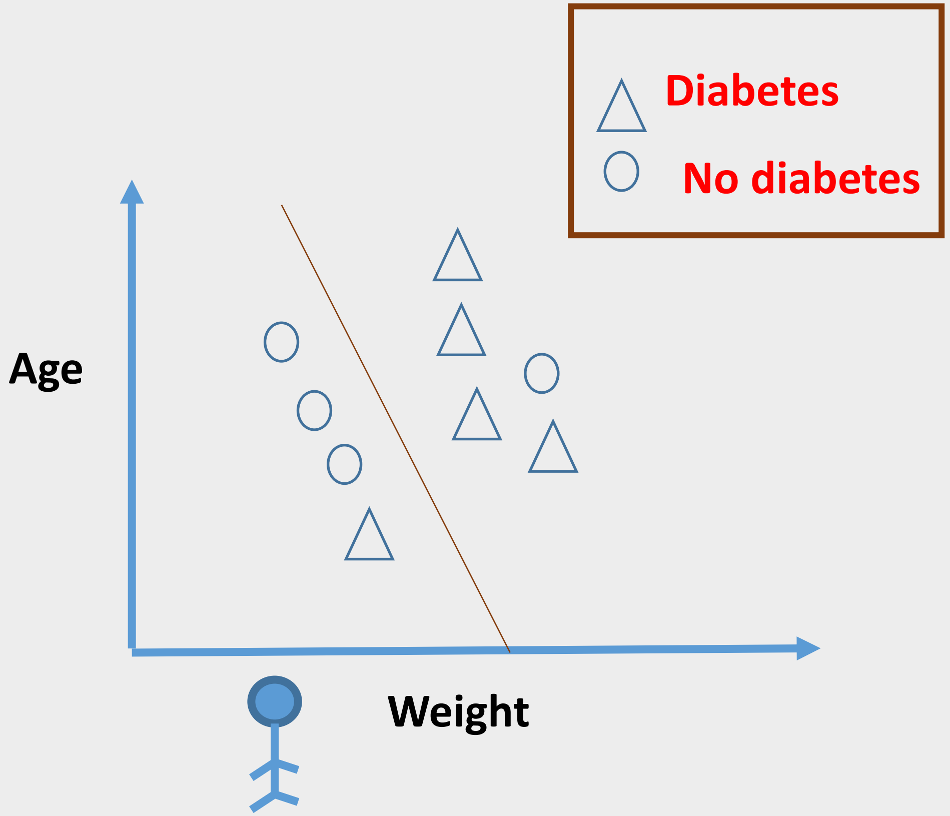
Prepare the model offline

$$Voltage = 0.5 * P + 0.8 * Q$$

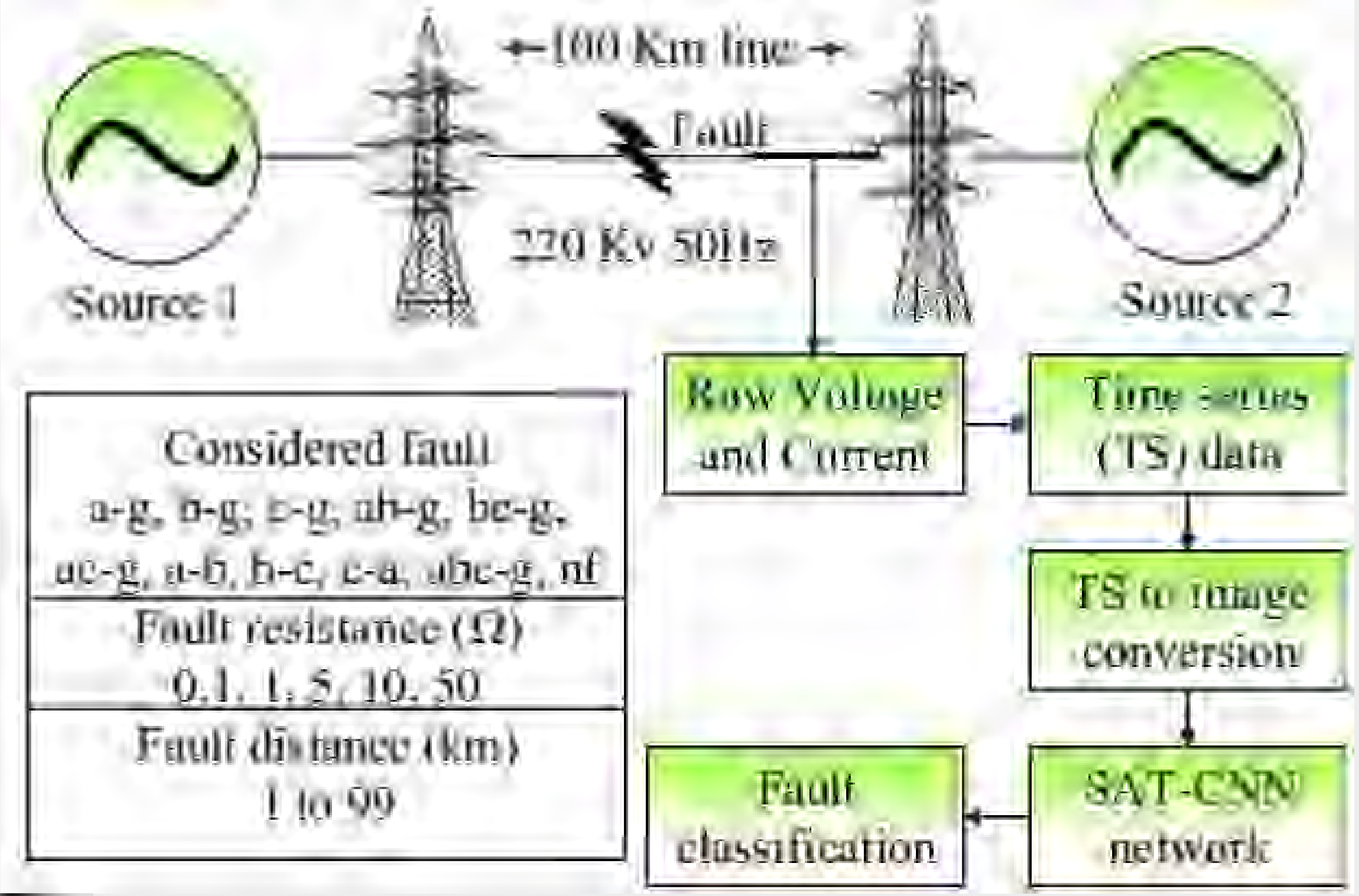
Calculate the voltage (output)

Classification: Supervised learning

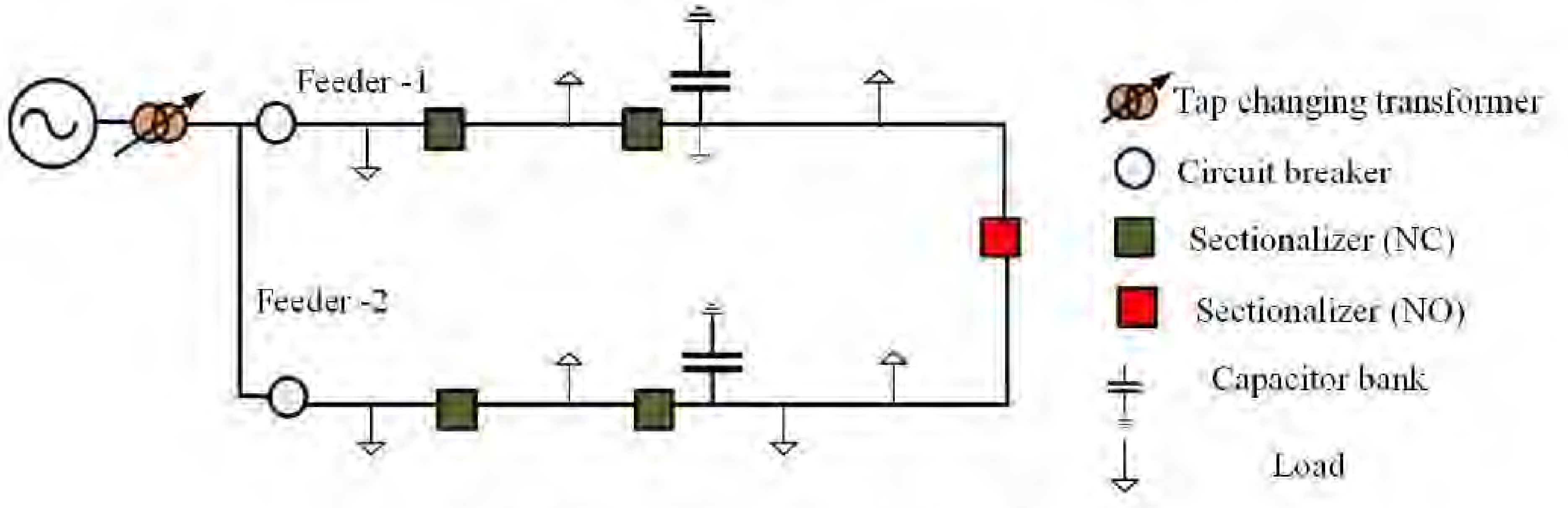
Age	Weight	Diabetes
30	90	1 (Yes)
50	60	0 (No)
.	.	.



Classification: Line fault classification



Lab model



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