

CIGRE CROATIA

Next Generation Network (NGN)

November 2023

Data Science in Power System Control



cigre

For power system expertise

Bojan Franc

University of Zagreb
Faculty of electrical engineering
and computing

The Idea

...by  **HOPS**



Europska unija

Abstract

This paper describes a Weather Impact Model (WIM) capable of serving a variety of predictive applications ranging from real-time operation and day-ahead operation planning, to asset and outage management. The proposed model is capable of combining various weather parameters into different weather impact features of interest to a specific application. This work focuses on the development of a universal weather impacts model based on the logistic regression embedded in a Geographic Information System (GIS). It is capable of merging massive data sets from historical outage and weather data, to real-time weather forecast and network monitoring measurements, into a feature known as weather hazard probability. The examples of the outage and asset management applications are used to illustrate the model capabilities.

Proceedings of the 51st Hawaii International Conference on System Sciences | 2018

Systematic Framework for Integration of Weather Data into Prediction Models for the Electric Grid Outage and Asset Management Applications

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Philadelphia, PA, U.S.A.



Data

- MeteoHOPS
- ~EUMETSAT
- ESA Kopernik
- SLAP
- WRF HOPS

Table I. Weather Data Sources and Characteristics

Source	Data Type	Temporal Coverage	Spatial Coverage	Temporal Resolution	Spatial Resolution	Measurements
Automated Surface Observing System (ASOS) [17]	Land-Based Sensor Stations Data	2000-Present	USA	1 min	900 stations	Air Temperature, Dew Point, Humidity, Wind Direction, Altimeter, Sea Level Pressure, Visibility, Wind Gust, Cloud Height, Present Weather Code
Level-2 Next Generation Weather Radar (NEXRAD) [18]	Radar Data	1991-Present	USA	5 min	160 high-resolution Doppler radar sites	Precipitation and Atmospheric Movement
NOAA Satellite Database [19]	Satellite Data	1979 - Present	USA	Hourly, daily, monthly	4 km	cloud coverage, hydrological observations (precipitation, cloud liquid water, total precipitable water, snow cover, and sea ice extent), pollution monitoring, smoke detection, surface temperature readings
Vaisala U.S. National Lightning Detection Network [20]	Lightning Data	1989-Present	USA	Instantaneous	Median Location Accuracy <200m	Date and Time, Latitude and Longitude, Peak amplitude, Polarity, Type of event: Cloud or Cloud to Ground
National Digital Forecast Database (NDFD) [21]	Weather Forecast Data	Present – 7 days into future	USA	3 hours	5 km	Wind Speed, Direction, and Gust, Temperature, Relative Humidity, Convective Hazard Outlook, Prob. Critical Fire, Prob. Dry Lightning, Hail Probability, Tornado Probability, Probability of Severe Thunderstorms, Damaging Thunderstorm Wind Probability, Extreme Hail Probability, etc.



Europska unija

Scientific and Research Projects



Europska unija

AACES – Advanced power system management in conditions of uncertainty arising from climate changes – ESIF, 2020. – 2023.



DESme – Razvoj ekspertnog sustava mjerenja parametara udara munja i zaštita lopatica vjetroagregata radi smanjenja kvarova i zastoja, EFRR, 2020. – 2023.



APSCCS – Advanced Power System Control supported by Copernicus Services – projekt financiran od strane European Space Agency, 2022. – 2023.



RESData

Data Hub Tumbri - Uspostava HOPS Data Lake - NextGenerationEU, 2022.-2023.

comping_

DINGO – Optimizacija gubitaka u naprednim distribucijskim mrežama – ESIF, 2020. – 2023.



INTIS – Punionica električnih vozila s integriranim baterijskim spremnikom – ESIF, 2020. – 2023.



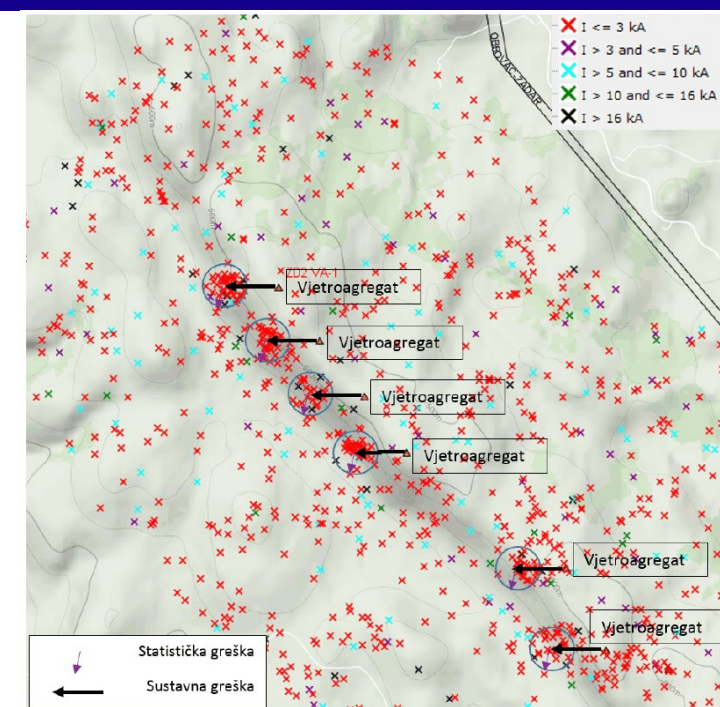
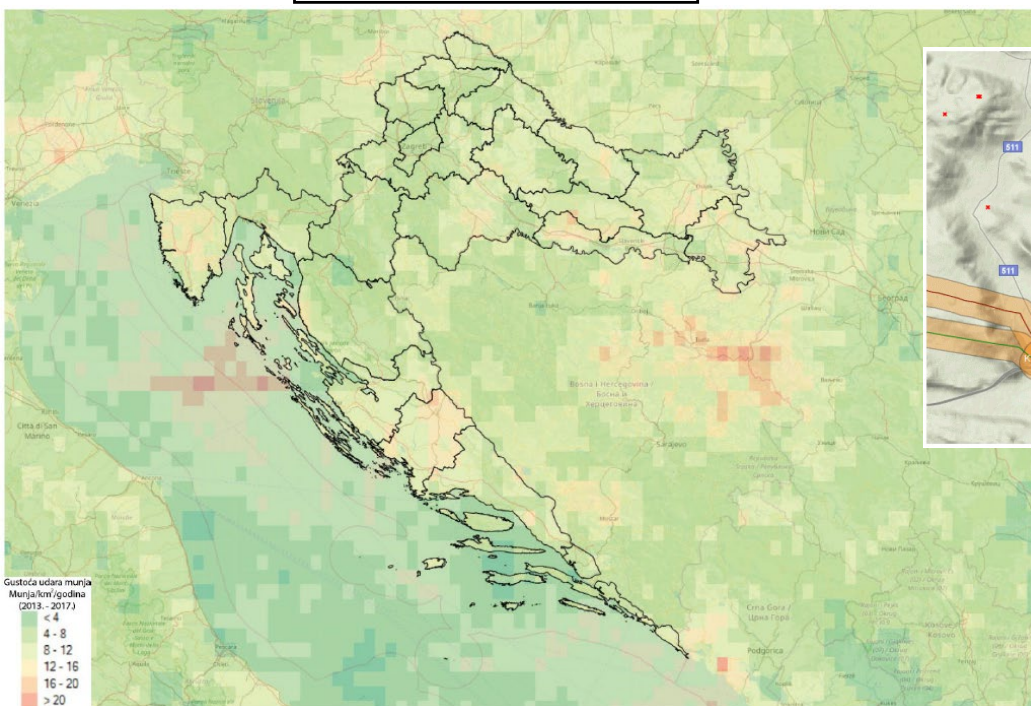
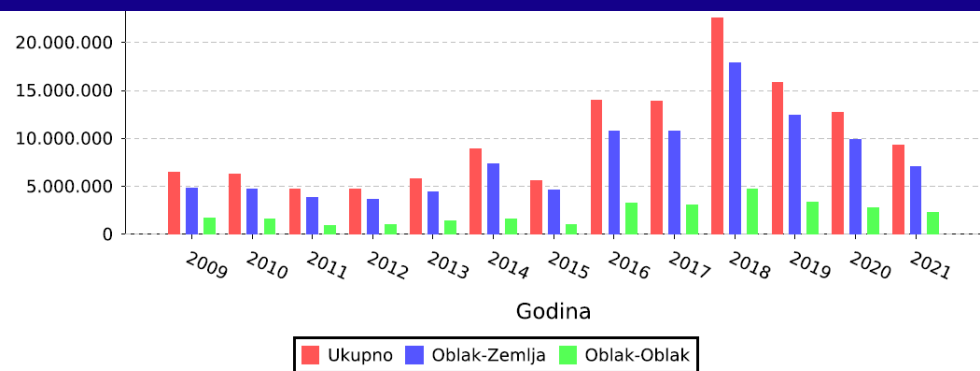


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Lightning strikes to wind turbines

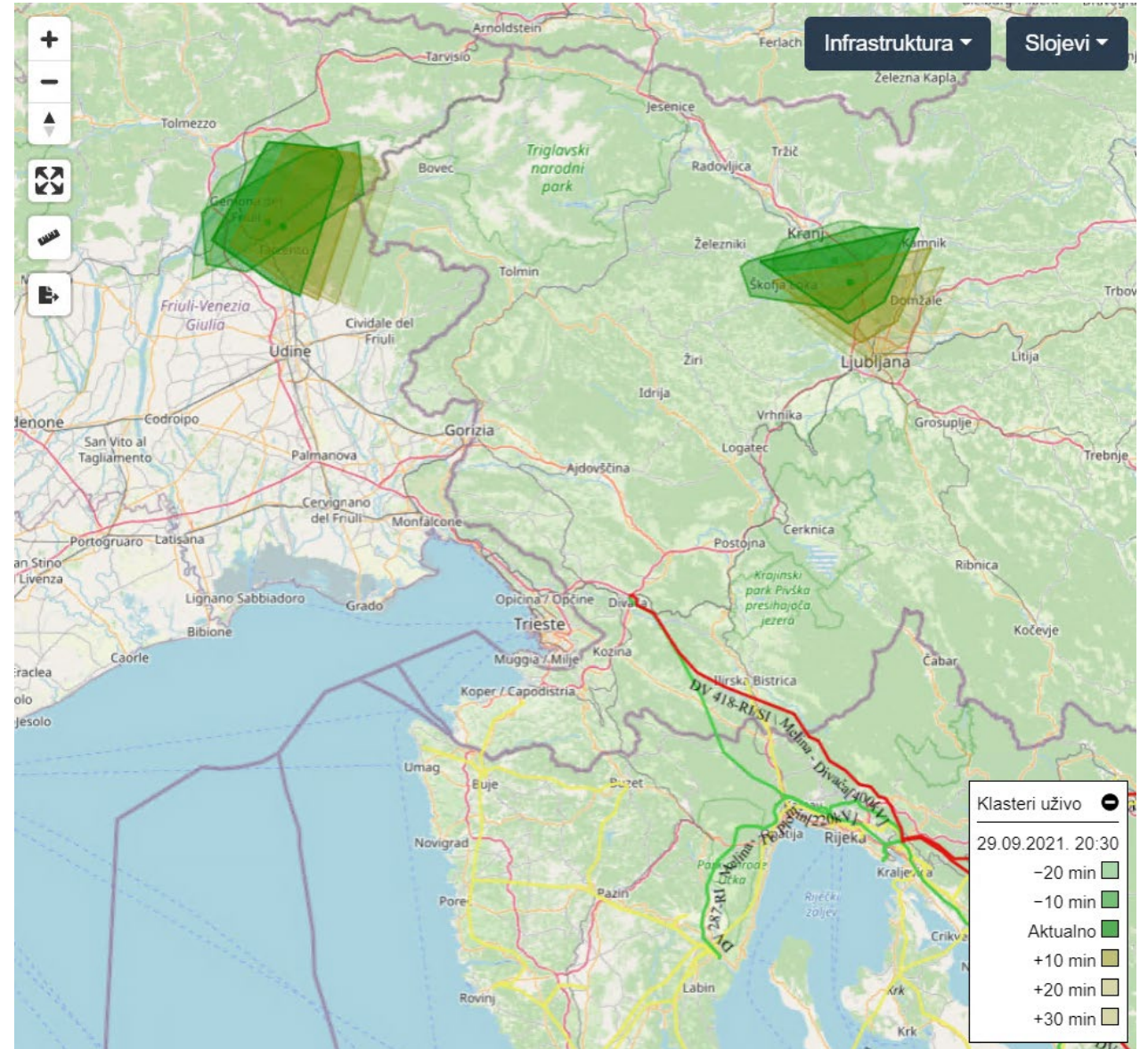


Lightning Location System



Lightning nowcasting

- Predicting lightning movement in the near future
 - +10 min
 - +20 min
 - +30 min
- Based on real-time lightning data (LLS)
- Extended by meteorological data and forecasts

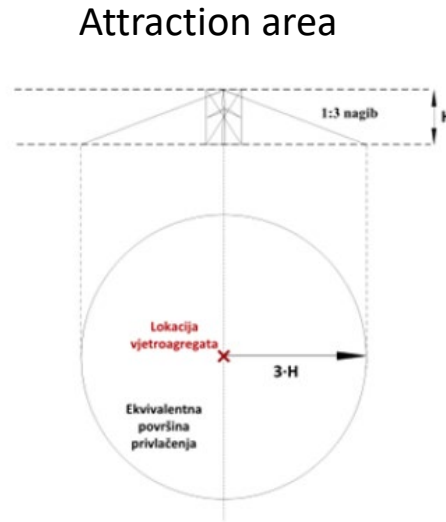


LLS and WPPs

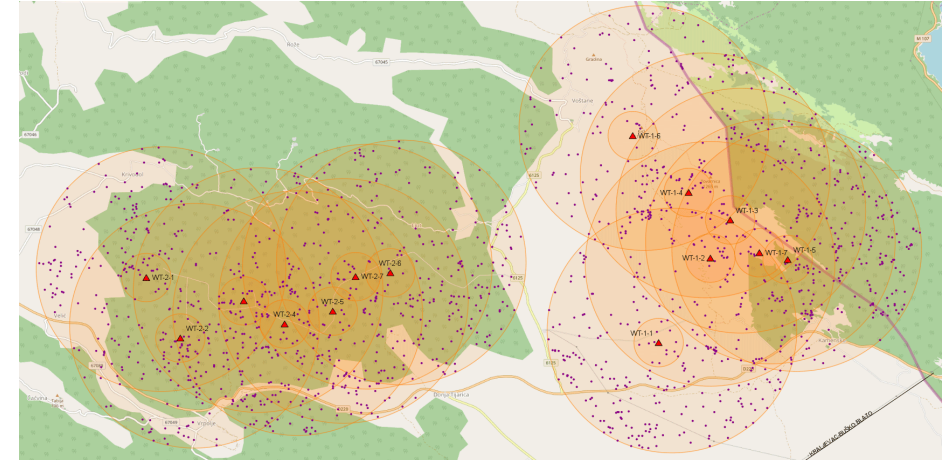
- Wind turbine lightning attraction area

$$A_d = (3 \cdot H)^2 \cdot \pi = 9\pi H^2$$

- Up to 5x more lightning after tower installation
- Needs to be considered during planning phase



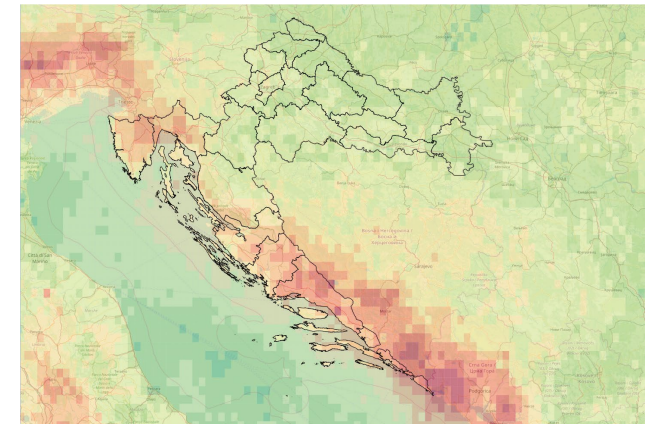
BEFORE WT INSTALLATIONS,
STROKES RECORDED 2009-2012



AFTER WT INSTALLATIONS,
STROKES RECORDED 2013-2017

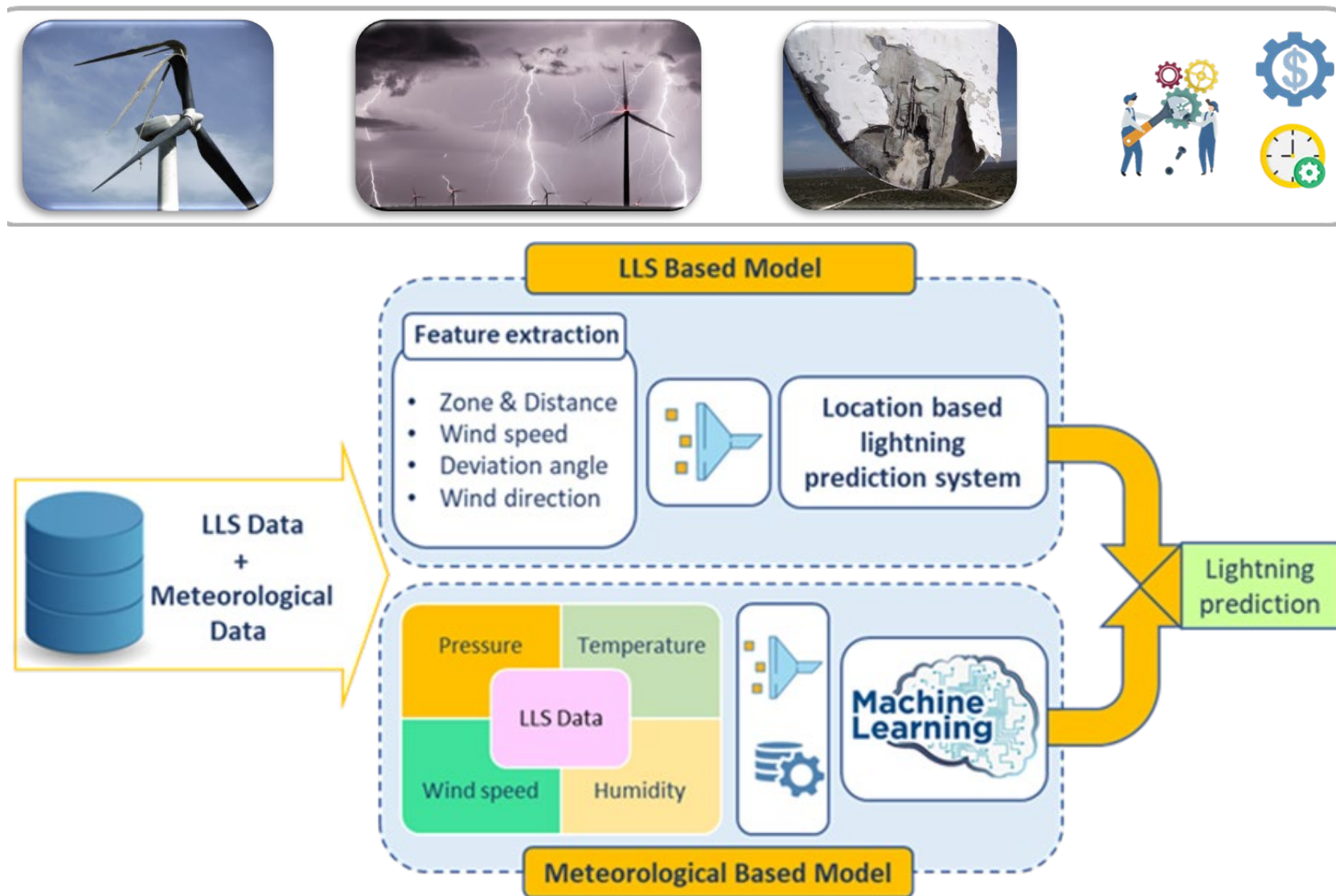


Measured
isokeraunic levels



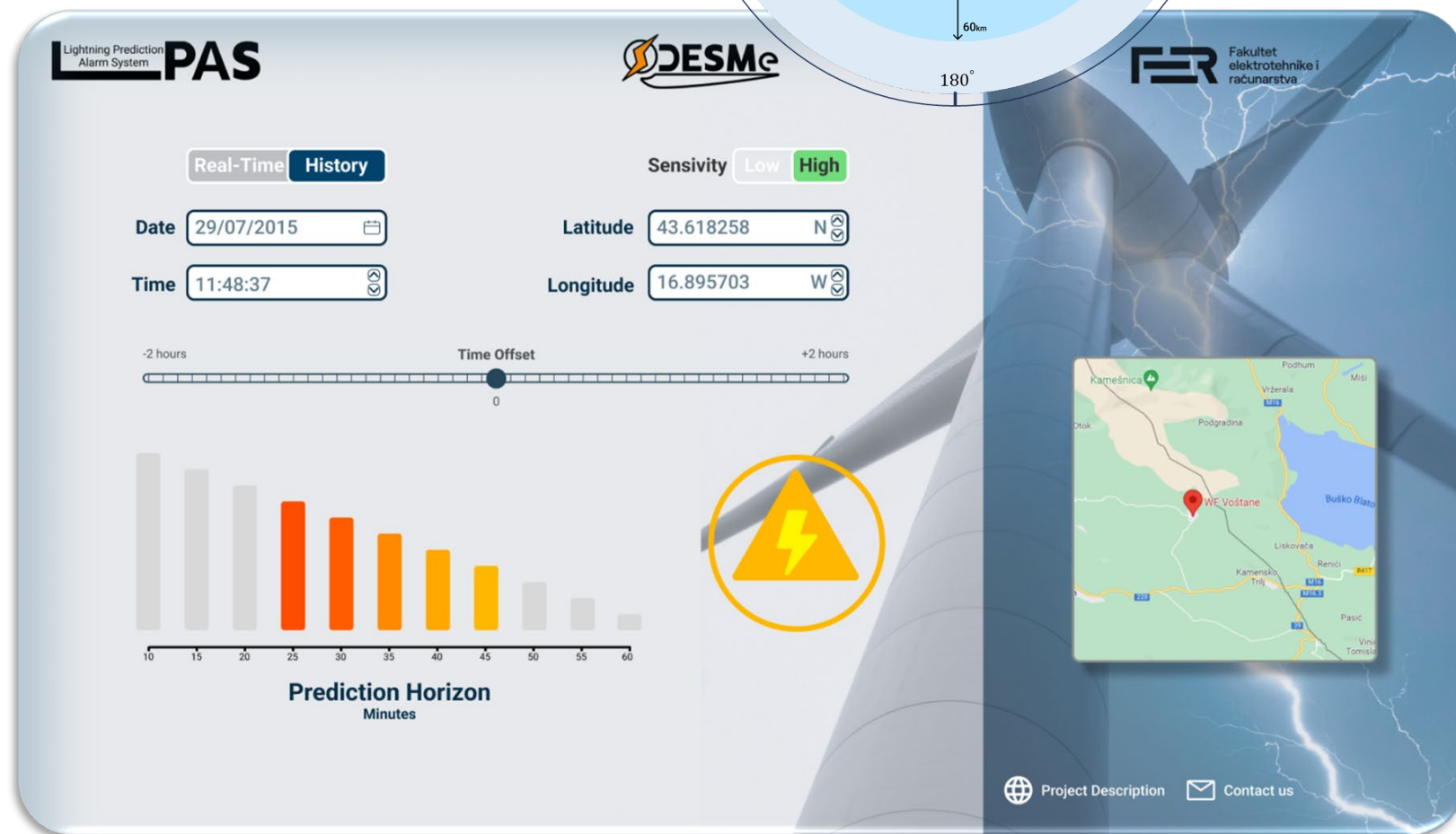
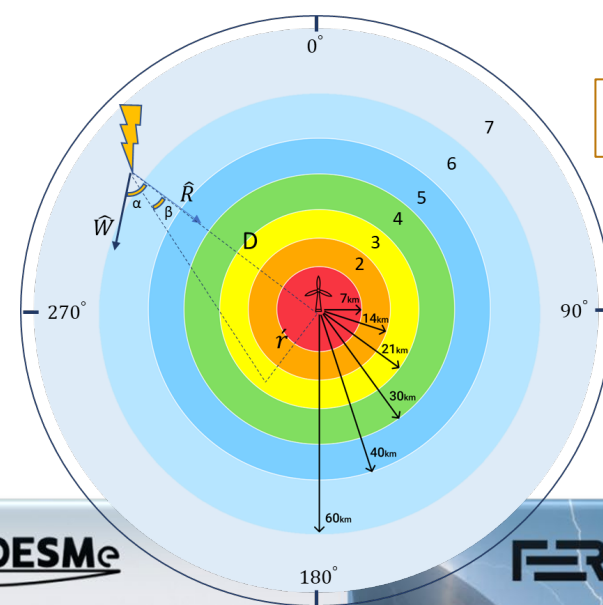
Lightning Prediction Alarm System

- Predicting lightning activity on monitored location (WPP)
- Originally made to alarm WPP crews of incoming thunderstorms
 - Preparation of works
 - Mitigate risks for people and equipment
- LLS and meteo data based



Lightning Prediction Alarm System

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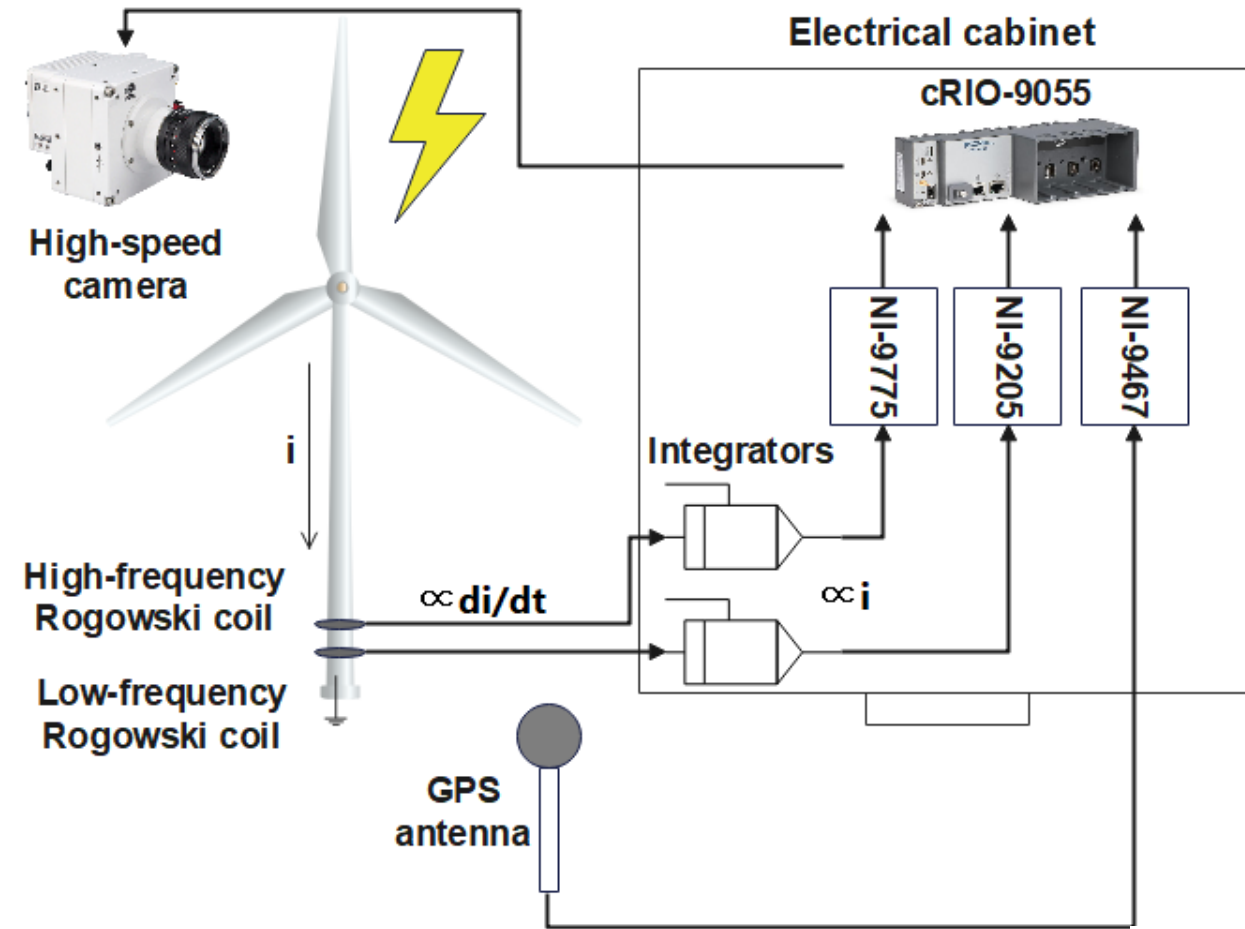




Europska unija

Lightning Current Measurement system

- Lightning Current Waveforms
 - Precise GPS timestamps
- Two current sensors
 - High-frequency Rogowski coil + integrator (1 MHz and 250 kA)
 - Low-frequency Rogowski coil + integrator (10 kHz and 12.5 kA)
- cRIO real-time controller
 - High-speed digitizer
 - Low-speed digitizer
 - GPS synchronization module



Lightning Current Measurement system

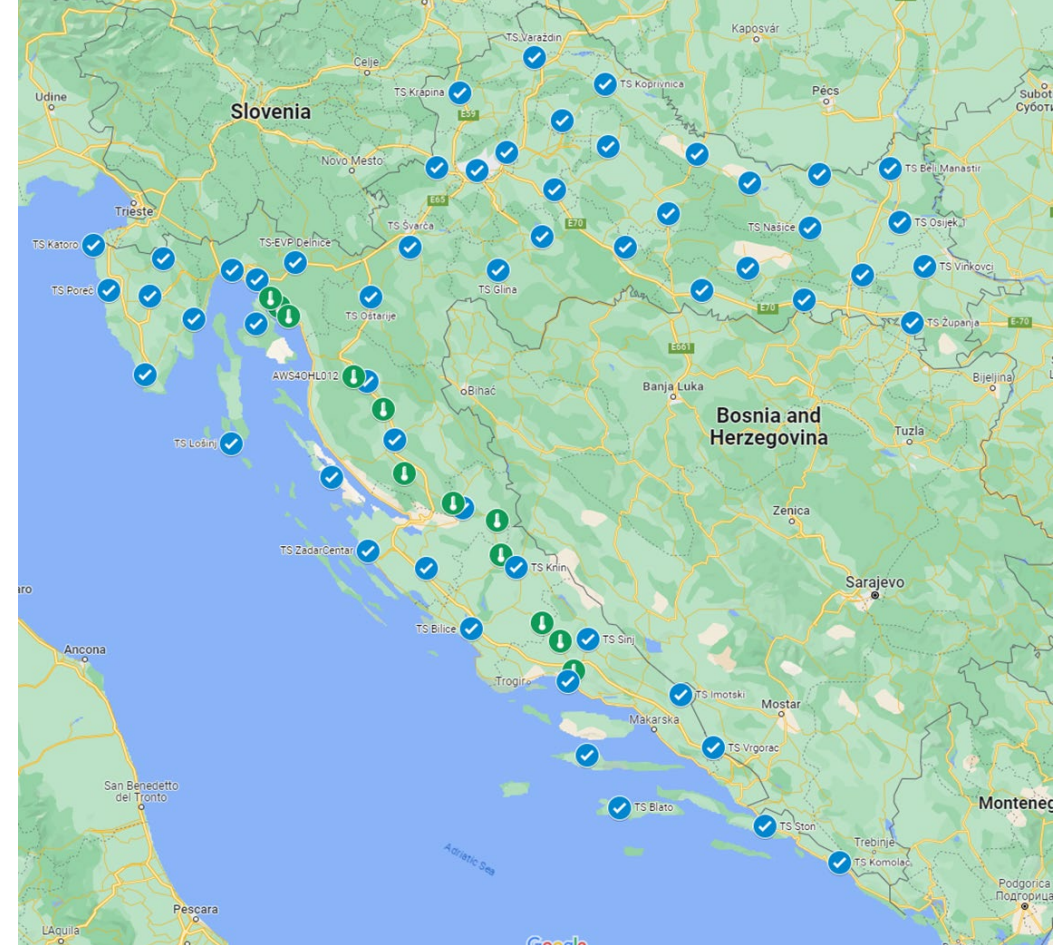


- 3 impulses (500 μ s each, 700 A, 2100 A and 900 A)
- Duration approx. 15 ms



Meteorological Data applied in Power Systems (Data providers and consumers)

- Meteo – TSO system
 - Meteo stations
 - 55 in substations
 - 15 on overhead line towers
 - WRF Numerical Weather Predictions (NWP)
 - 4x a day
 - 1h rezolution
 - 72h horizon
- Satelite data
 - ESA Kopernik
 - EUMETSAT
- Lightning Location System
- WPP and PV plants – predictions and measurements
- SCADA, TMS, WAMS, and other monitoring systems...



Data Lake – handling Big Data, AI and Analytics



Europska unija

- From an IT perspective, one of the challenges in power systems is acquisition of **continuous, comprehensive, high-quality data** as those systems tend to require a high level of legacy system compatibility
- With increased involvement of IT in power system and application of **machine learning and big data technology** shortcomings and limitations in data acquisition and storage are being discovered
- To mitigate issues, problems, and challenges in acquiring relevant data a **Data Lake platform is being developed**
- Data is stored as close as possible to raw format as gathered from the source systems, enabling data modelling and transformation at a later stage, upon identification of the needed business processes

Data Lake

Data Lake

comping_



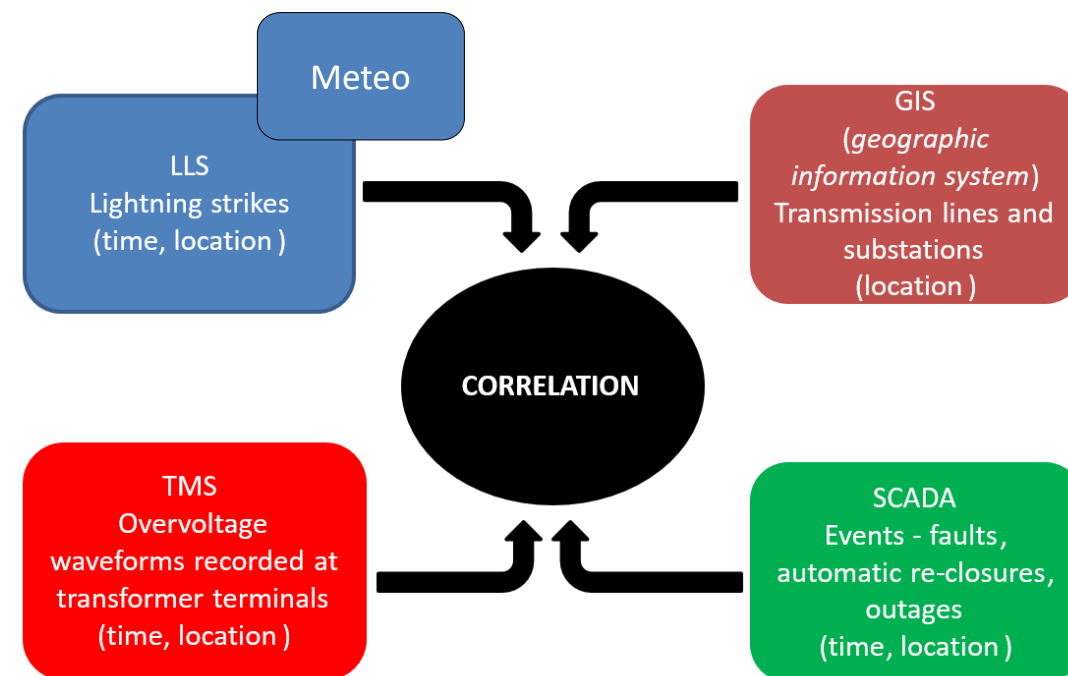
Europska unija

- Data sources
 - **SCADA** (Supervisory Control and Data Acquisition) – events and alarm data;
 - **Relay Protection** (relay protection of the high voltage equipment;) – relay protection data: measurement, alarm and event (pickups, overvoltage, overcurrent, ground fault, CB operation command) signals;
 - **WAMS** (Wide Area Monitoring System) – phasor monitoring;
 - **PQM** – Power quality measurements;
 - **TMS** – Transformer Monitoring System – continuous measurements and triggered event recordings;
 - **Copernicus** – satellite-based imaging and measurements covering the area of the observed transmission network.

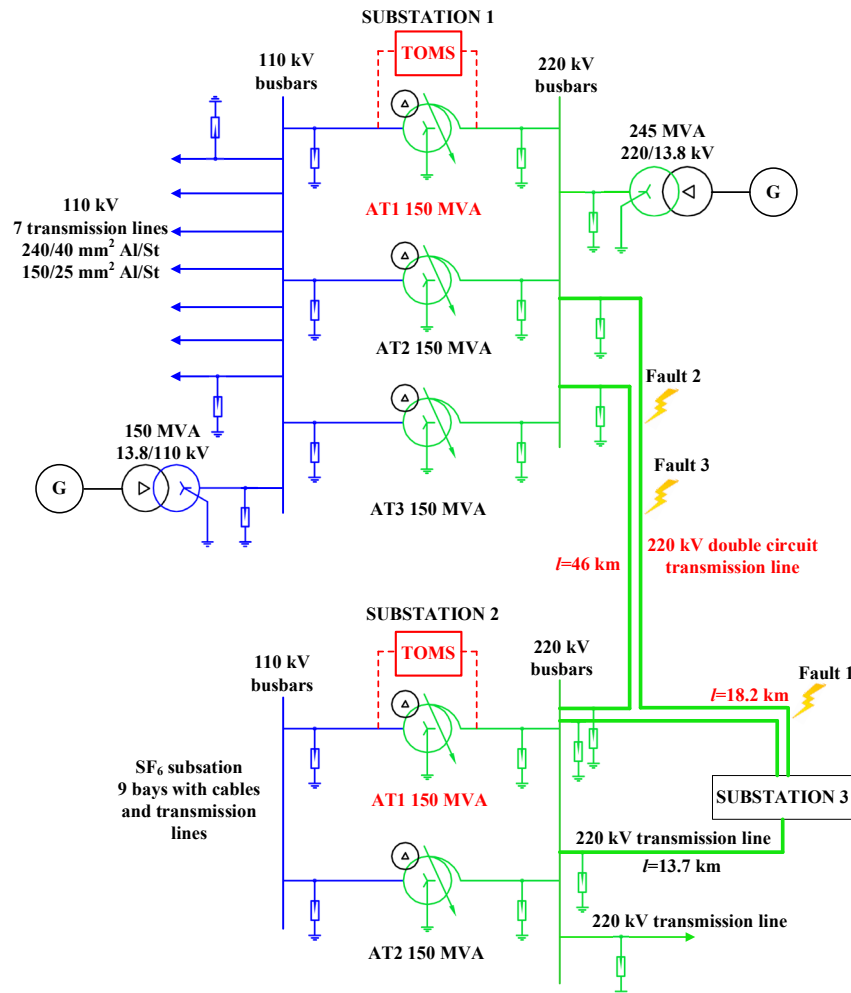
- Data source outside Data Lake used

- **LLS** (Lightning Location System) – lightning activity around lines and substations;
- **MeteoHOPS** – terrestrial weather measurements and forecasts;
- **GIS** – geoinformation system (line and substation geometries).

Tip produkta	Broj produkata	Veličina
GRD (Sentinel-1)	1757	1.5 TB
S2MSI2A (Sentinel-2)	4225	2.8 TB
SL_2_LST___ (Sentinel-3)	3637	227 GB
SL_2_FRP__ (Sentinel-3)	1955	134 GB
Ukupno 2021. godina	11574	4.6 TB



Data science applied in Power Systems – Data Lake



Case study – multiple lightning strike to 220 kV transmission line connecting substations 1 and 2 causing insulator flashover in three phases

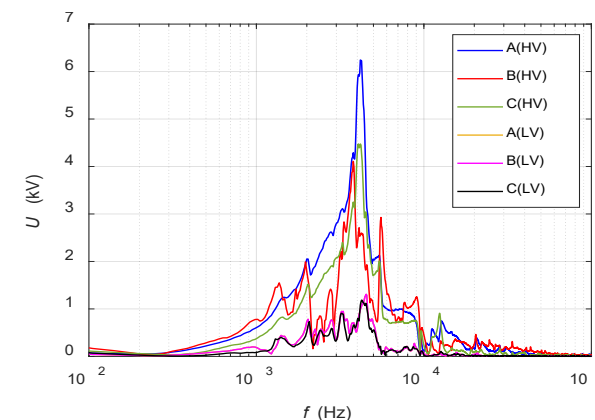
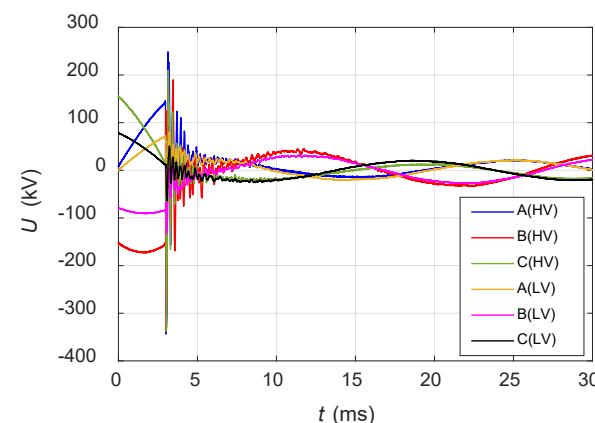
- Multiple lightning strike occurred on the 220 kV transmission line route, at a distance of 16 km from the substation 1 (30 km from substation 2)
- At the same time, SCADA system detected three phase to ground fault, following the auto-reclosure operation of circuit breakers in the line bays in substation 1 and 2

Casy study

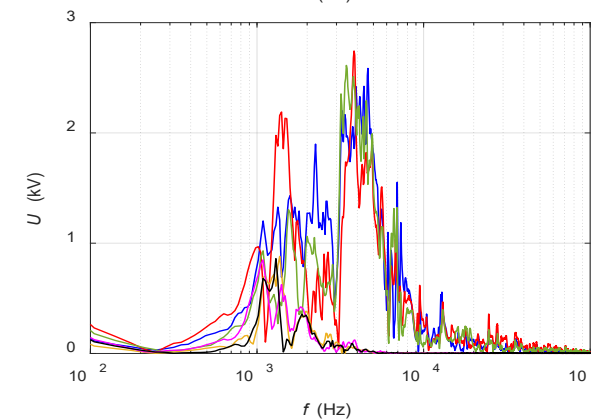
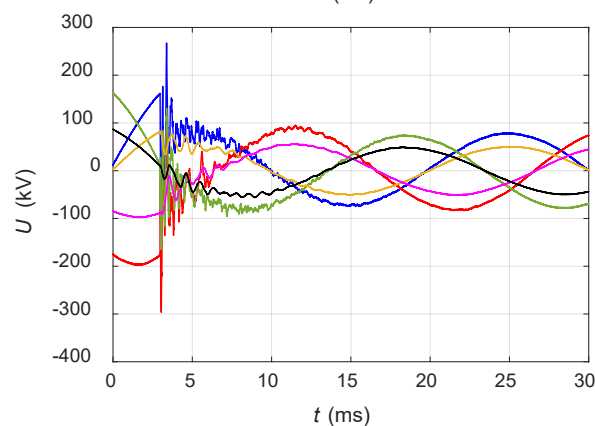
SCADA system detected line to ground fault in three phases, following the auto-reclosure operation of circuit breakers in the line bays in substations 1 and 2. Circuit breakers interrupted short-circuit current firstly in substation 2.

Lightning strike number	Time (h:min:sec.milisecc)	Lightning current amplitude (kA)	Time difference between subsequent lightning strikes Δt (ms)
1	01:02:12.257	15.5	-
2	01:02:12.261	-80.2	4
3	01:02:12.274	-20	13
4	01:02:12.293	-8	19
5	01:02:12.294	-30.3	1
6	01:02:12.306	-19	12
7	01:02:12.319	-12.7	13

Substation 1:

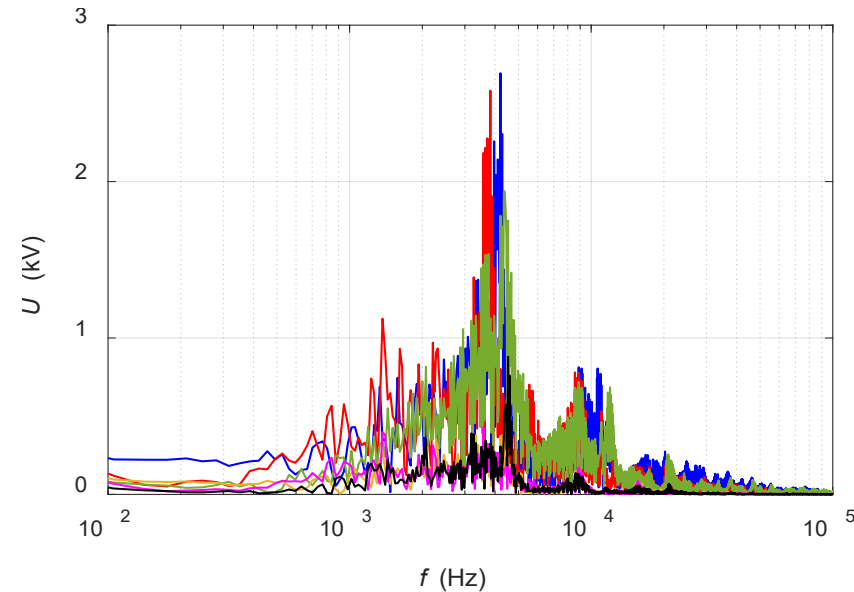
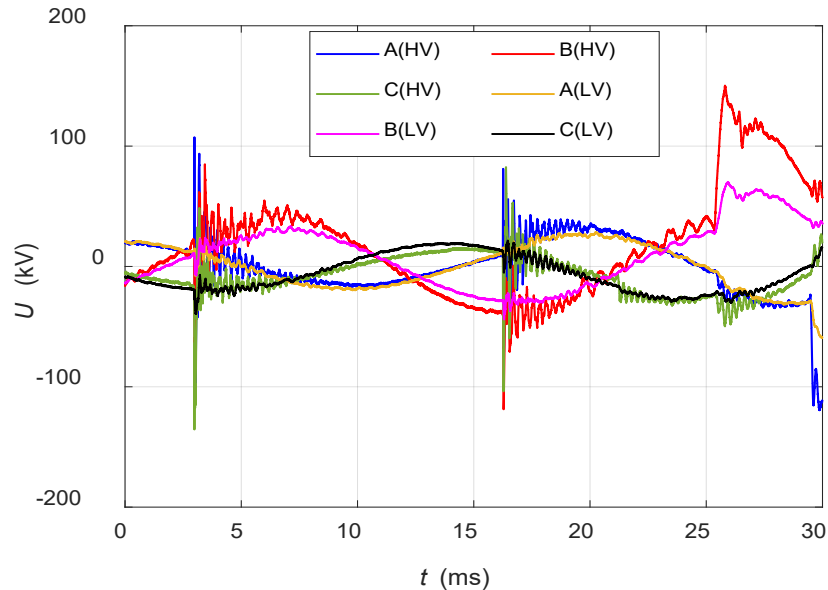


Substation 2:



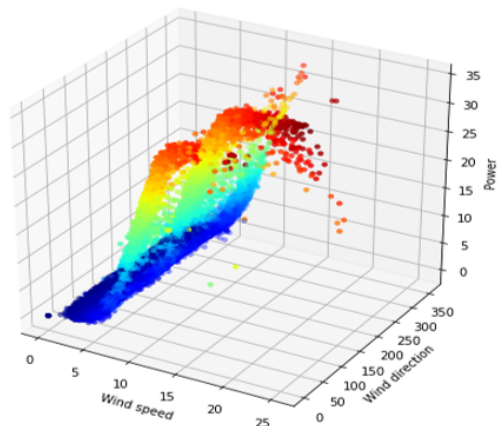
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7	01:02:12.319	-12.7	13

While short-circuit current was still supplied from substation 1, two successive lightning strikes 13 ms apart hit transmission line, and overvoltages were recorded by TMS in substation 1.

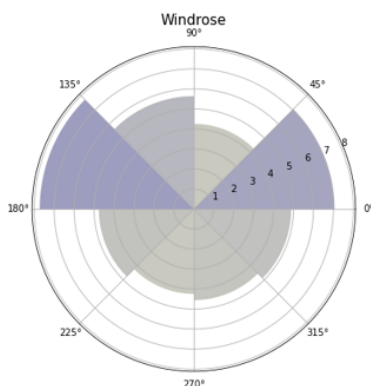


- Repetitive transient overvoltages reduce the insulation withstand capability of the transformer insulation system
- The breakdown characteristics of solid materials due to high frequency transients are still not well known and deserve future work

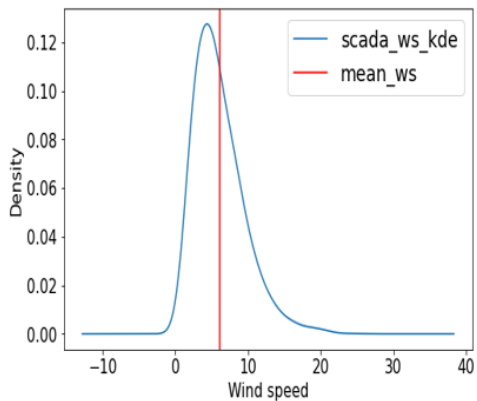
Prediction of generation of a WPP



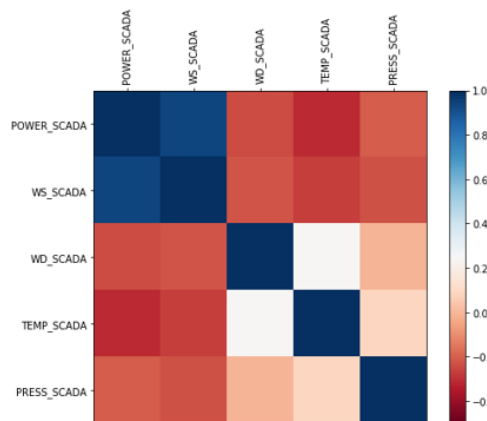
Sl. 4.: Proizvodnja VE u odnosu na brzinu i smjer vjetra



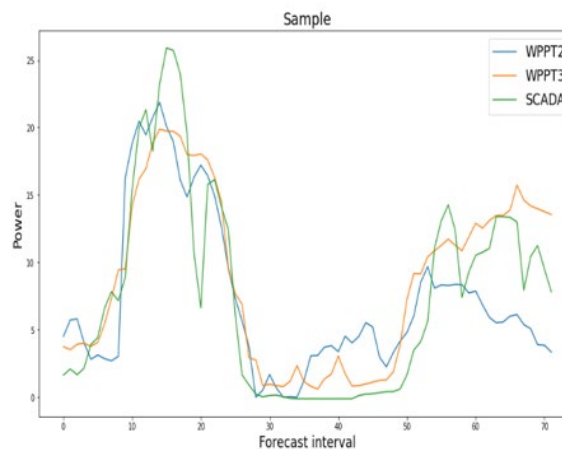
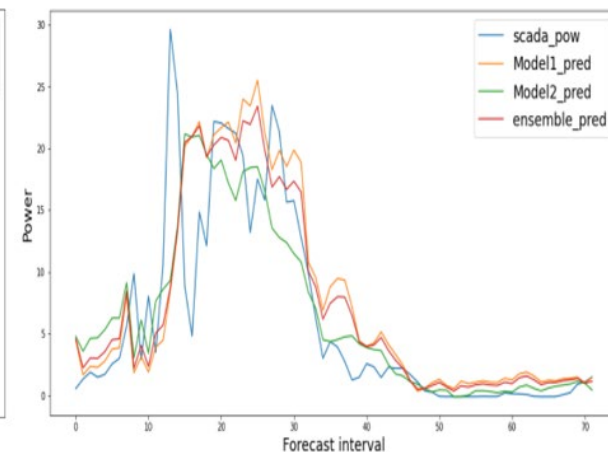
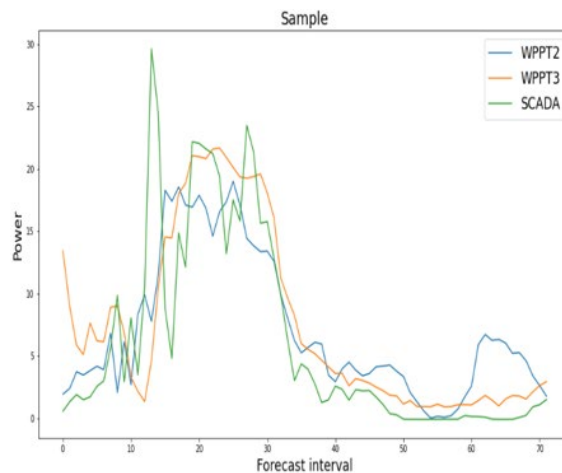
Sl. 5.: Ruža vjetrova sa srednjom brzinom vjetra



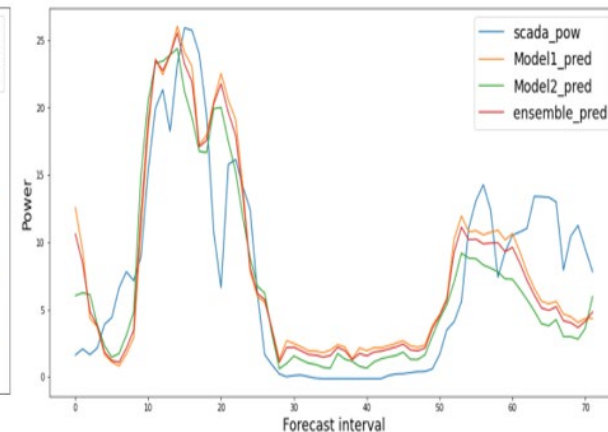
Sl. 6.: Distribucija brzine vjetra na lokaciji VE



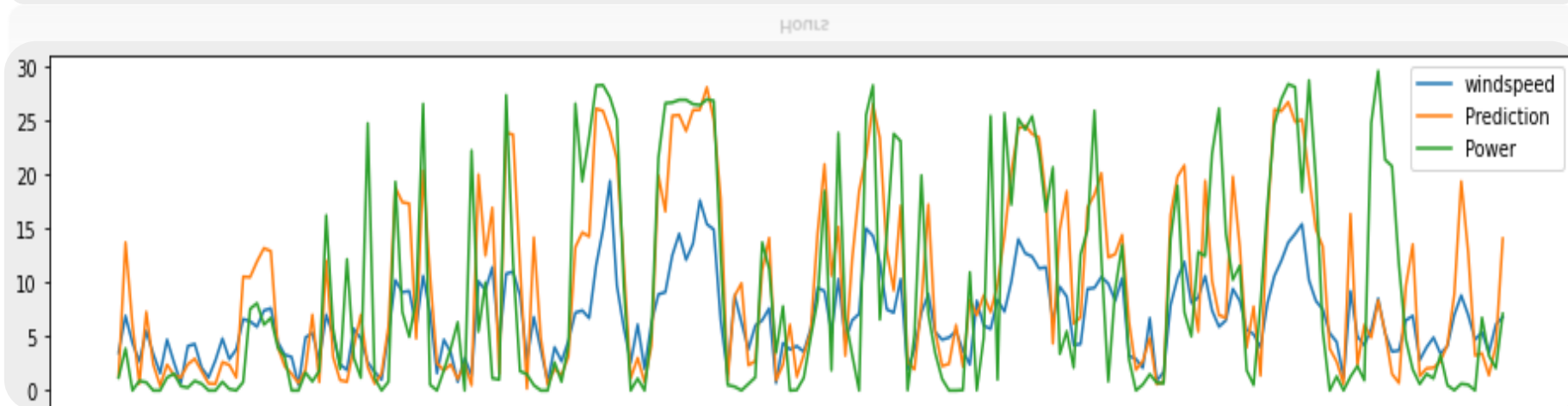
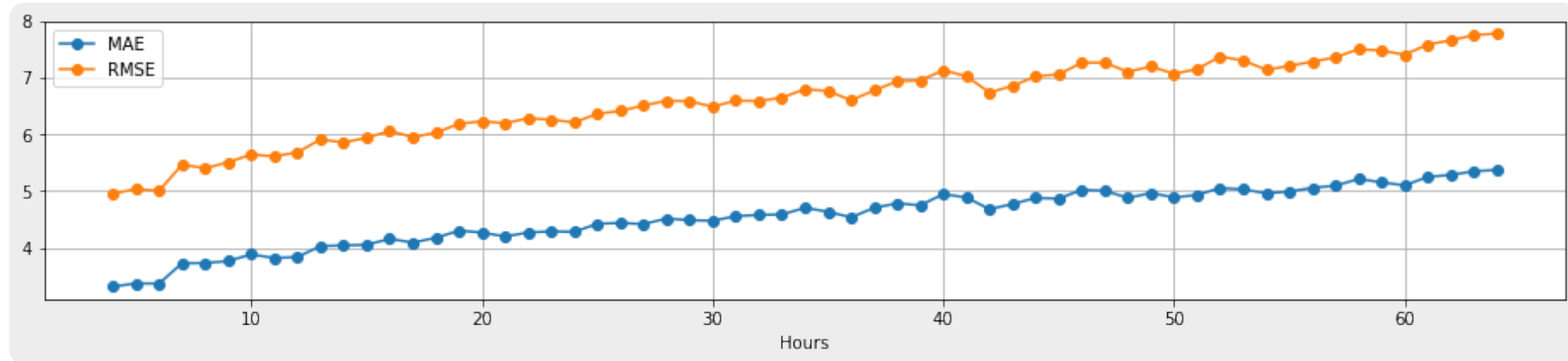
Sl. 7.: Matrica korelacija mjerenih parametara



a)

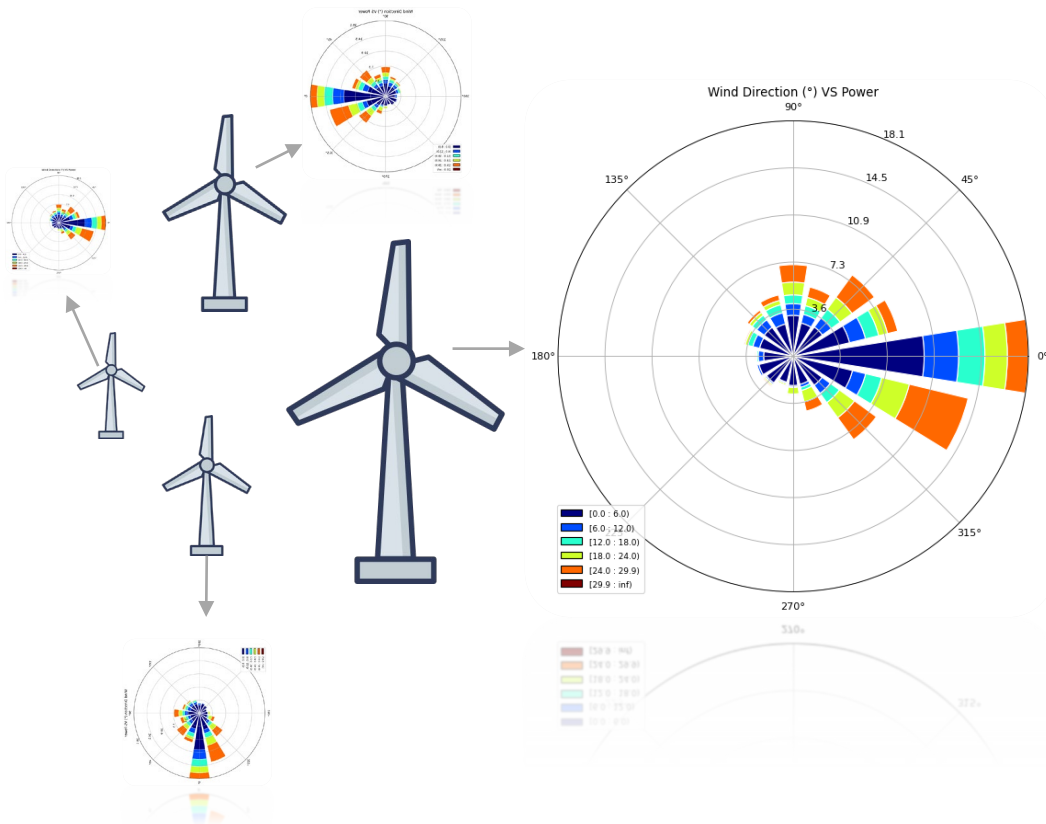


Wind prediction at specific WTG



Wind prediction at specific WTG

Wind direction classification

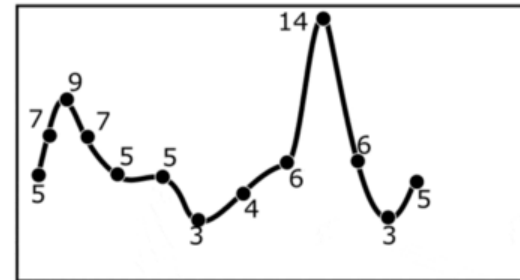
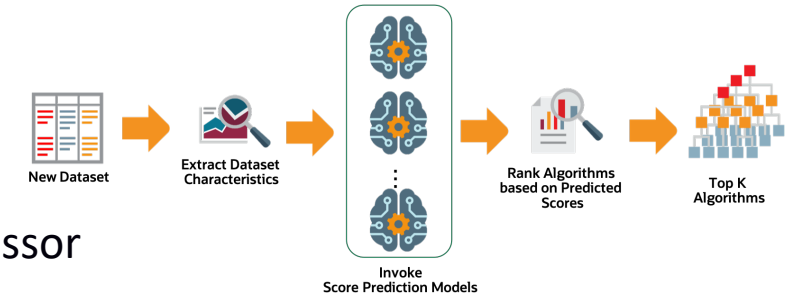


Auto ML for last 6 hours

AutoML

XGB

Extra Trees Regressor



Last 6 hours: wind speed + wind direction + humidity + temperature



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Machine Learning Forecast platform

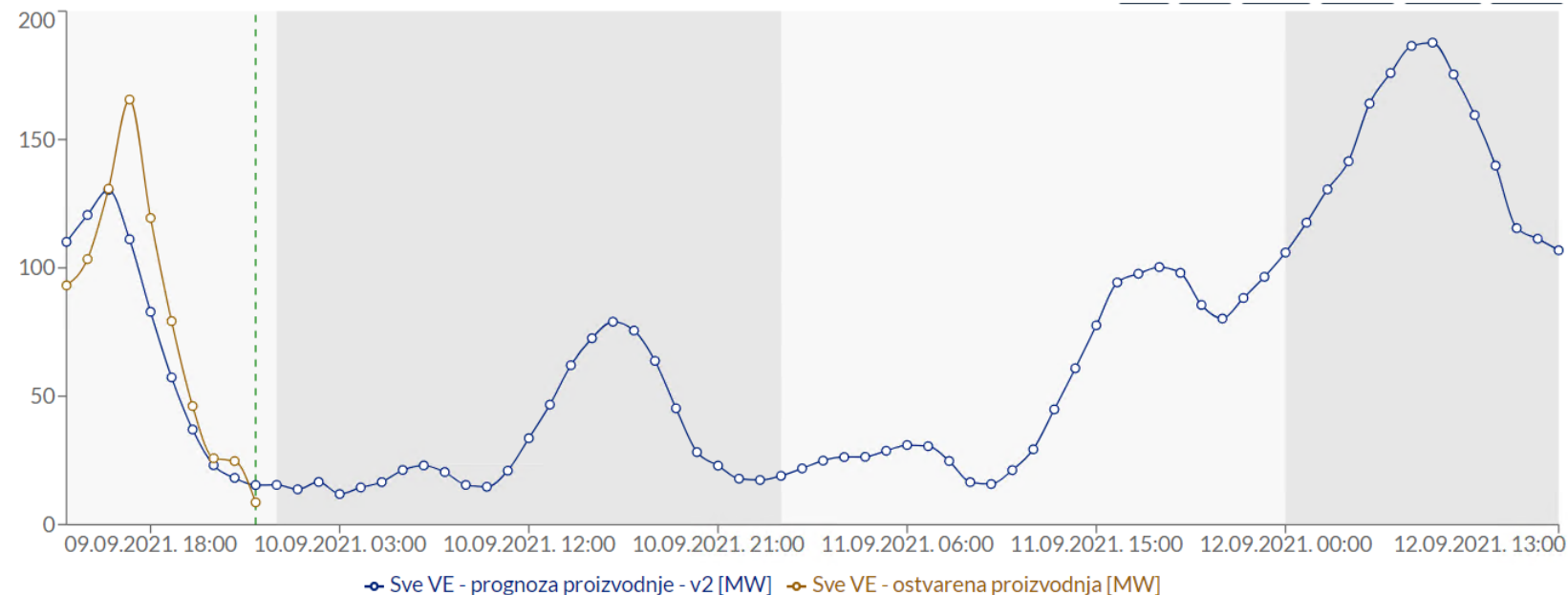




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MachineLearningForecast MLF

- Machine Learning Forecast platform
- Time-series forecasting
 - Power plant production
 - (hydro, wind, solar, etc.)
 - Load forecast
 - Loss forecast
 - Etc.
- ML Keras models
 - Machine learning, deep learning models, regression, LSTM, random forrest, etc.
- MATH models
 - Physical models, combination of existing models



MLF

- Automatic forecasting with scheduling
- Manual forecasting by user
 - Scenario forecasting
- Storage of all inputs and forecasted data
- Input data to output data dependency



AACES



Spremi

Prognoza

Model

Nazivna vrijednost

Vremenska oznaka prve vrijednosti

Vrijeme izrade

Simulirano trenutno vrijeme

Inicirao

Validacija

Vrijeme izrade

Simulirano trenutno vrijeme

Inicirao

VE Jelinak - prognoza proizvodnje - v1

09.09.2021. 00:00

10.09.2021. 00:16

10.09.2021. 00:16

Ručno pokrenuto

10.09.2021. 00:16

10.09.2021. 00:16

Ručno pokrenuto



Europska unija

☒ Nazivne vrijednosti

☒ VE Jelinak - prognoza proizvodnje - v2 [MW]

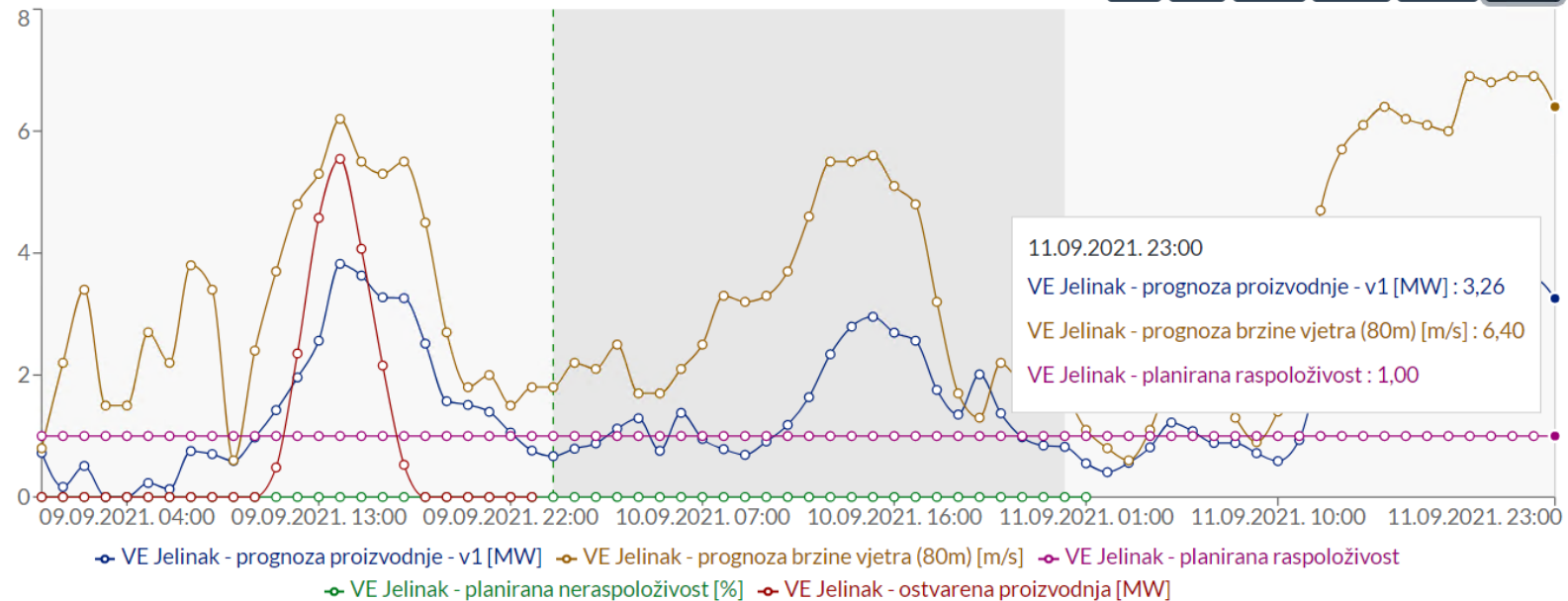
☐ VE Jelinak - prognoza brzine vjetra (80m) [m/s]

☐ VE Jelinak - prognoza smjera vjetra (80m) [°]

☐ VE Jelinak - planirana raspoloživost

☐ VE Jelinak - planirana neraspoloživost [%]

☒ VE Jelinak - ostvarena proizvodnja [MW]



MLF

- Wind Power Plant production forecast in MLF platform
- Keras
- Deep Learning
- LSTM – Long Short-Term Memory models



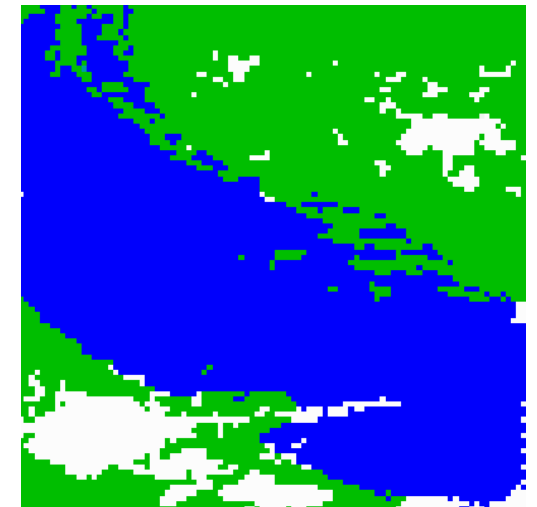
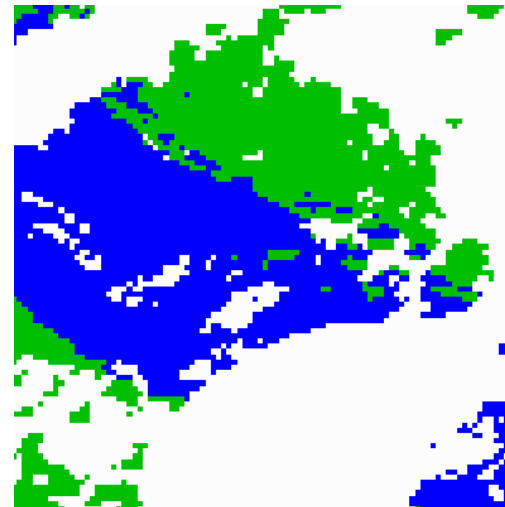
Vrijeme od 03.09.2021.

Duljina intervala 1 mjesec

		Prognoza		
Vremenska oznaka	Model	Vrijeme izrade	Simulirano vrijeme	Stanje
09.09.2021. 14:00	VE Velika Popina ZD6P - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Ponikve - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Trtar Krtolin - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Rudine - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Vrataruša - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Voštane - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Glunča - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Benkovac - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Orlice - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Velika Popina ZD6P - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Trtar Krtolin - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Jasenice - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Velika Popina - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Zelengrad - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Jelinak - prognoza proizvodnje - v2	09.09.2021. 22:00	09.09.2021. 22:00	Spremna
09.09.2021. 14:00	VE Velika Glava - prognoza proizvodnje - v1	09.09.2021. 22:00	09.09.2021. 22:00	Spremna

Solar plant generation prediction

- 72 h in advance
- 1 h in advance
- Generation data (since 14.07.2020.)
 - 15-min resolution
- WRF NWP forecasts (since 03.09.2020.)
 - 1-h resolution
 - NWP 72h horizont, run every 6h
- UV index
 - 15-min resolution
- EUMETSAT satelitske imaging (5 / 15-min res.)
- Cloud movement



Solar plant generation prediction

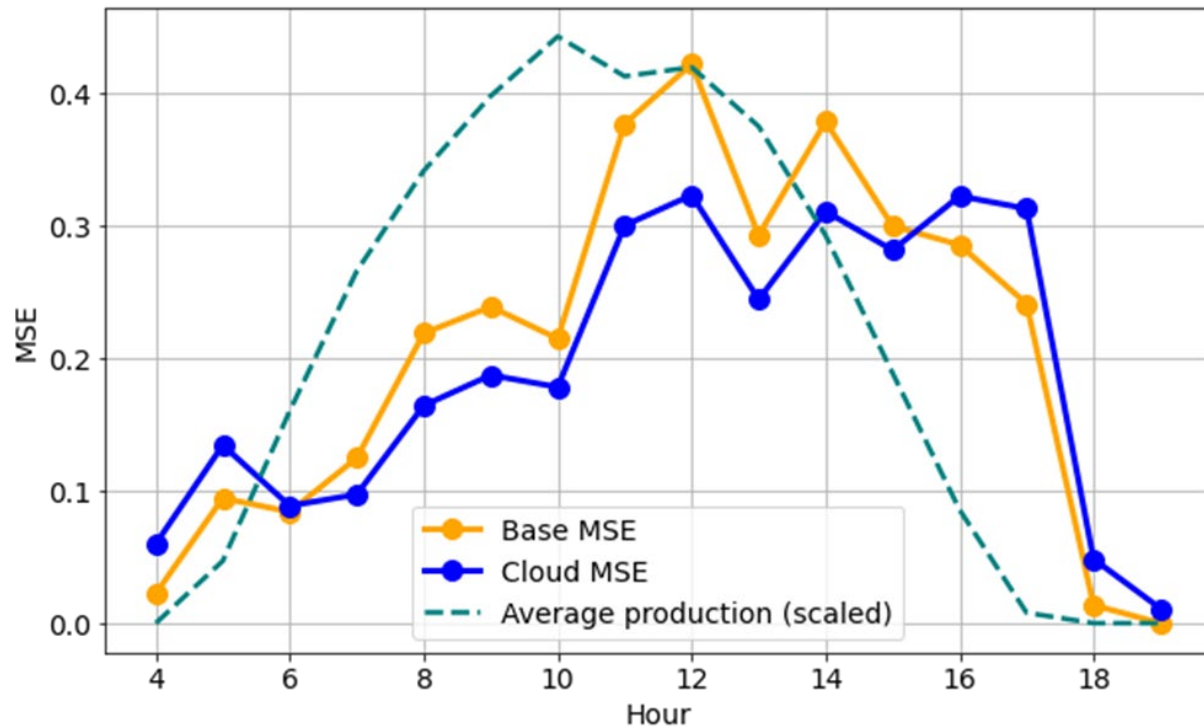


Table 2. Average MSE for total and peak hours

	MSE (total)	MSE (peak hours)
<i>base</i>	0.206	0.283
<i>cloud</i>	0.191	0.225
improvement	7.3 %	20.5 %

Prediction of losses

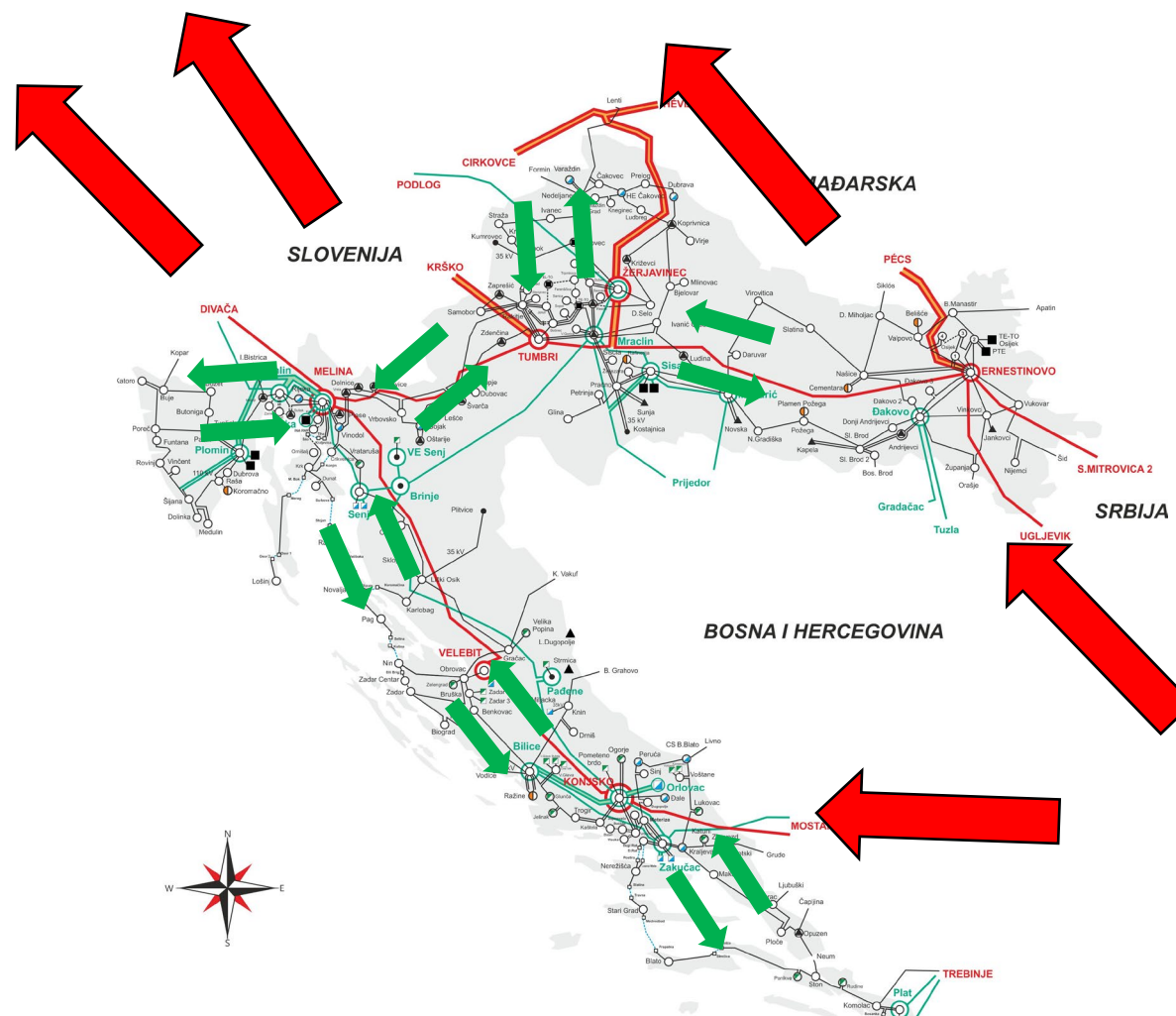
Gubici od tokova snage unutar HR:

- Periodični, lakše predvidivi
- Modeli strojnog učenja dobro predviđaju gubitke



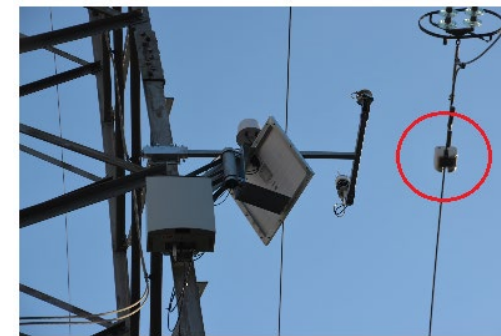
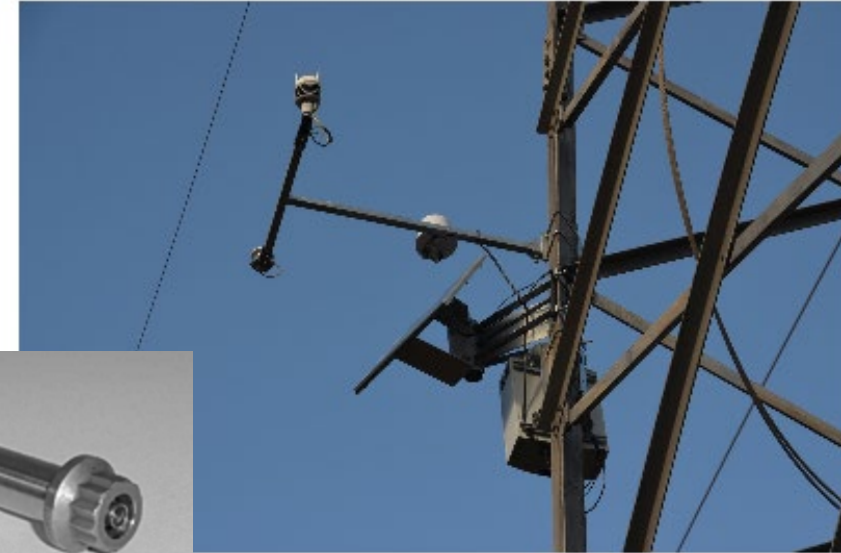
Gubici od tranzita snage kroz HR:

- Neperiodični, teže predvidivi
- Fokus budućeg istraživanja
- Ubacivanje prognoza tokova snaga u modele strojnog učenja

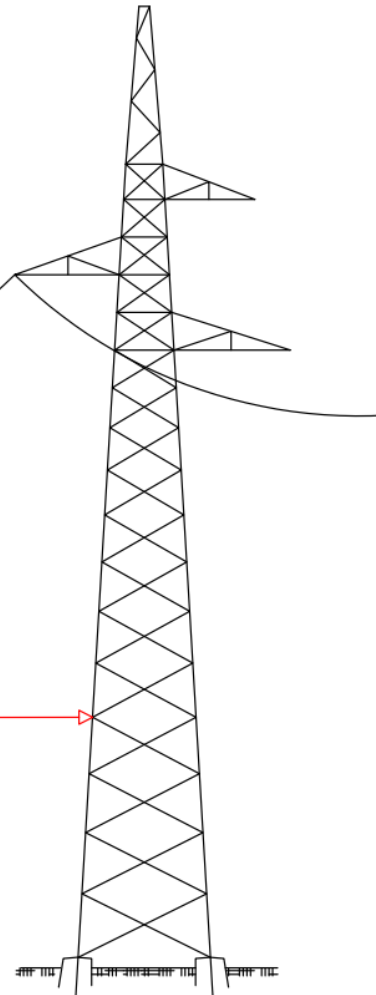


Automated OHL monitoring station

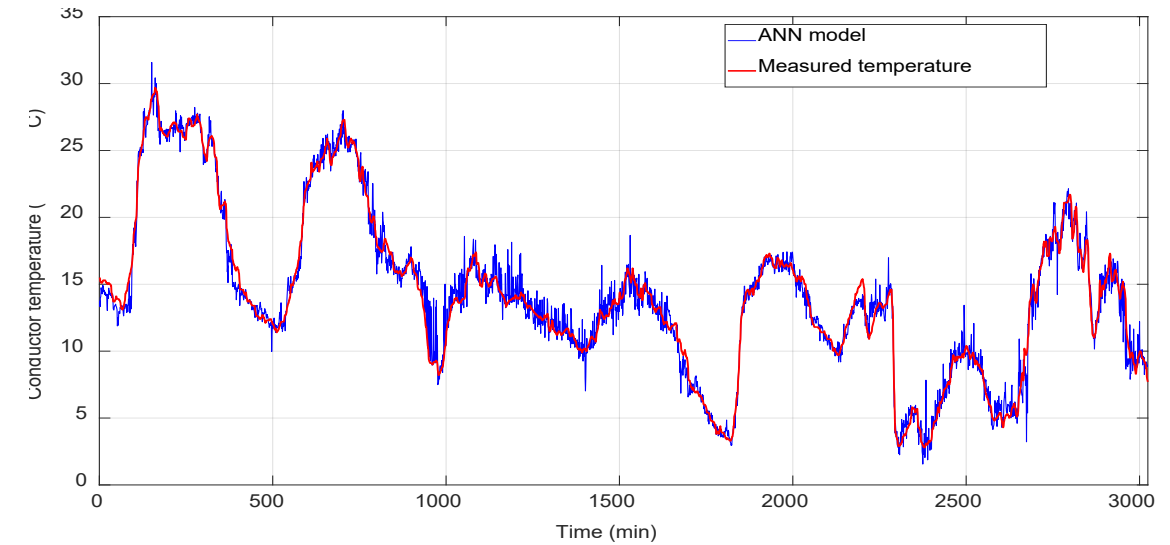
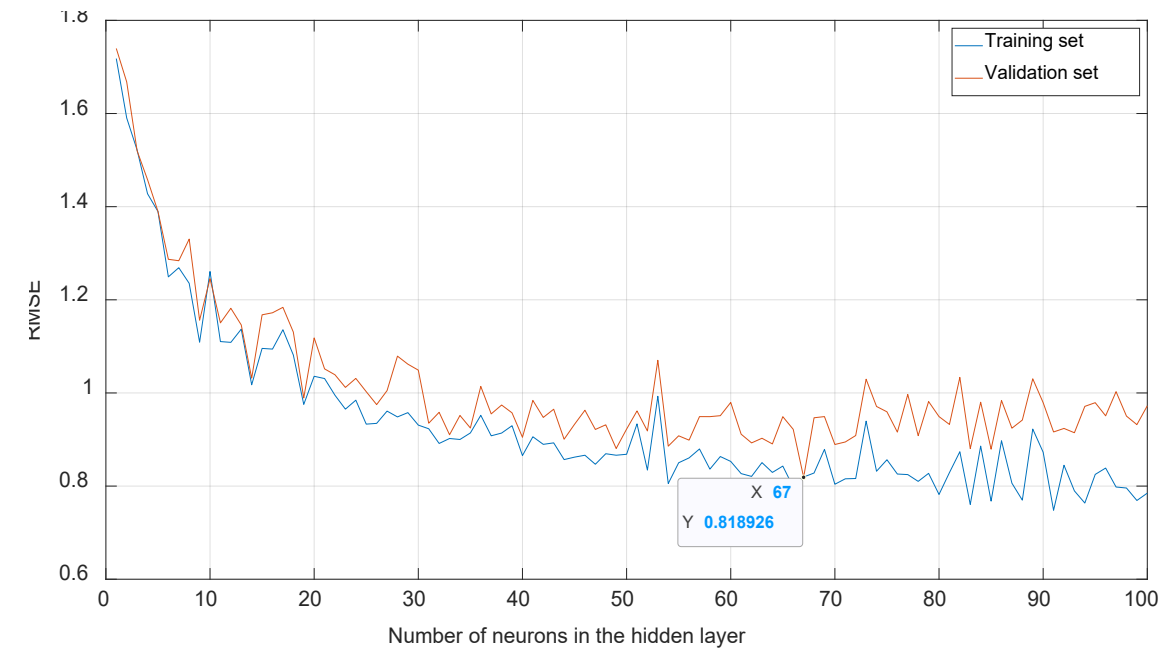
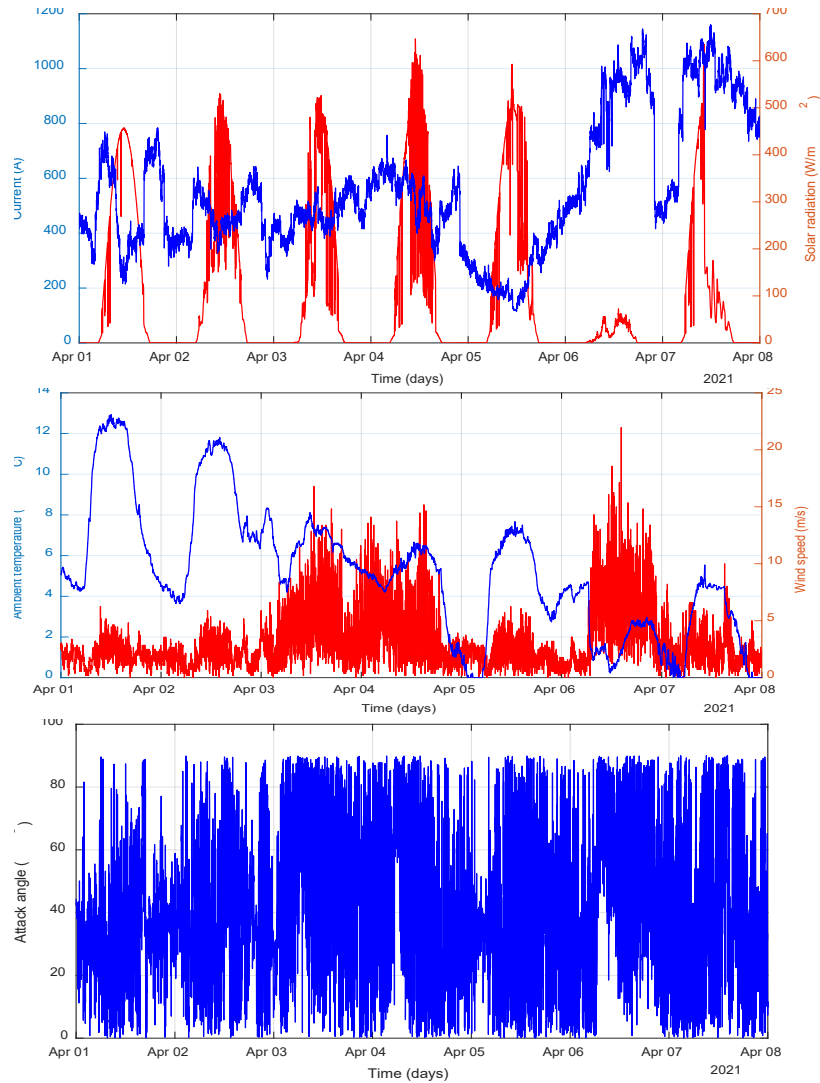
- Key features
 - Self powered
 - Autonomous, „always-on”
 - Real-time
 - Remotely managed
 - 2-way continuous data stream
- Modular
 - Weather station
 - Strain gauge sensor
 - Lightning overvoltage sensor
- OTLM sensor integration
 - Receive data from OTLM sensor and send to server using 1 (LTE) connection



- Artificial Neural Network model
- Particle swarm optimization trained neural network for overhead line conductor temperature prediction
- Data
 - Automated weather station measures meteorological parameters
 - Overhead Transmission Line Monitoring (OTLM) device measures line temperature in one spot



FER DTR – ANN method



FER Big Data in hydro generator behavior analysis



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- Disturbance classification
- Root-cause analyses
- Mitigation of faults
- Real-time monitoring
- Post-mortem analyses
- Vibrodynamical behavior of bulb units in hydro power plants
- Power swing
- Etc.

