Anomaly Detection of Photovoltaic Plants

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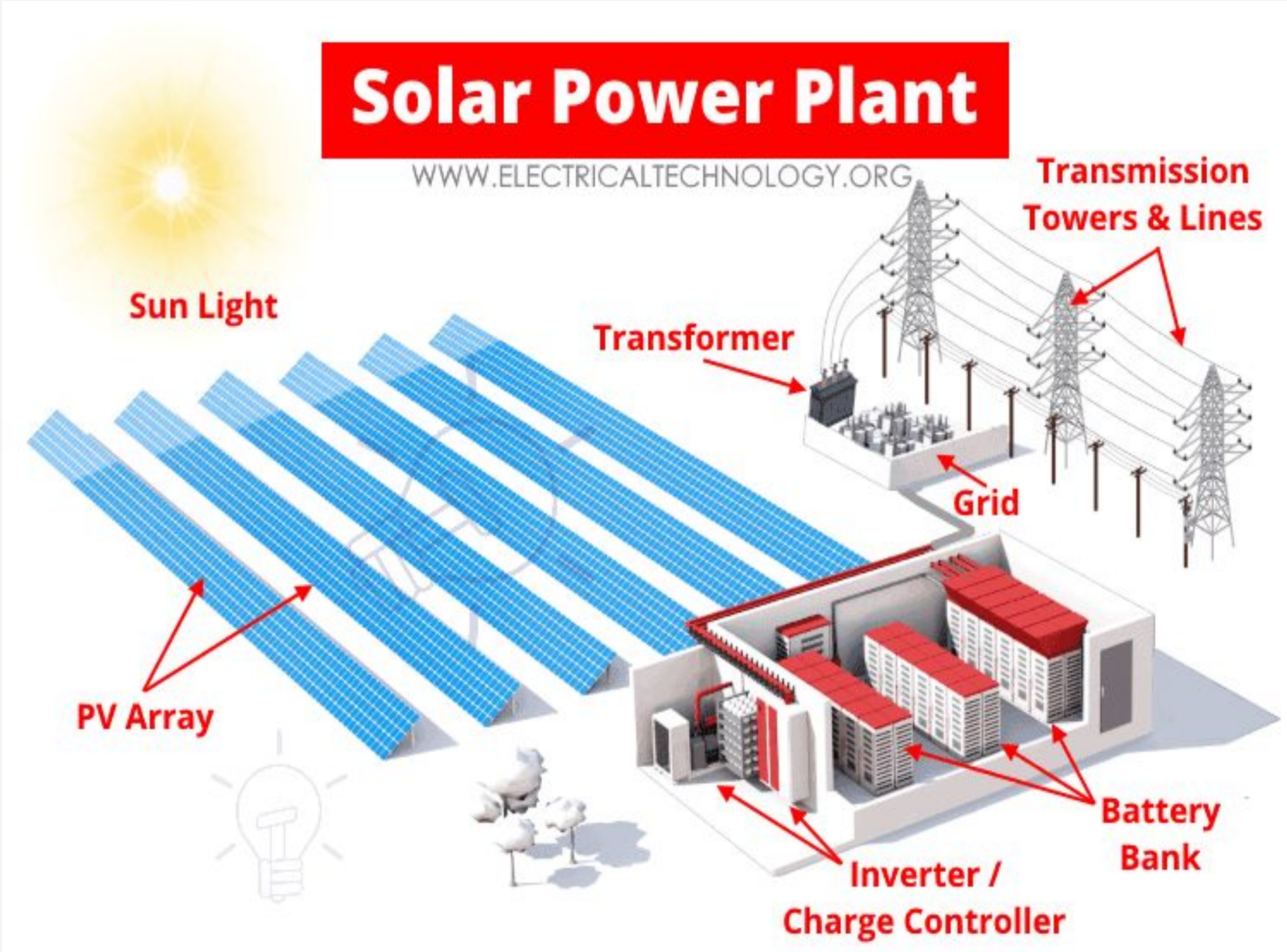
Renewable energy forms the backbone of the global energy revolution. Use of **natural resources** such as sun, wind, water, and biomass provides a sustainable solution to environmental and climate challenges. PV systems form the core of this revolution as they provide clean and sustainable sources of **energy free from emissions**. However, like any technological system, their maintenance can be optimized using advanced fault detection and forecasting techniques. Efficiency can be improved by a big margin by analyzing electrical and physical data from PV components using IoT sensors and imaging techniques-optical, thermal, and electroluminescence.

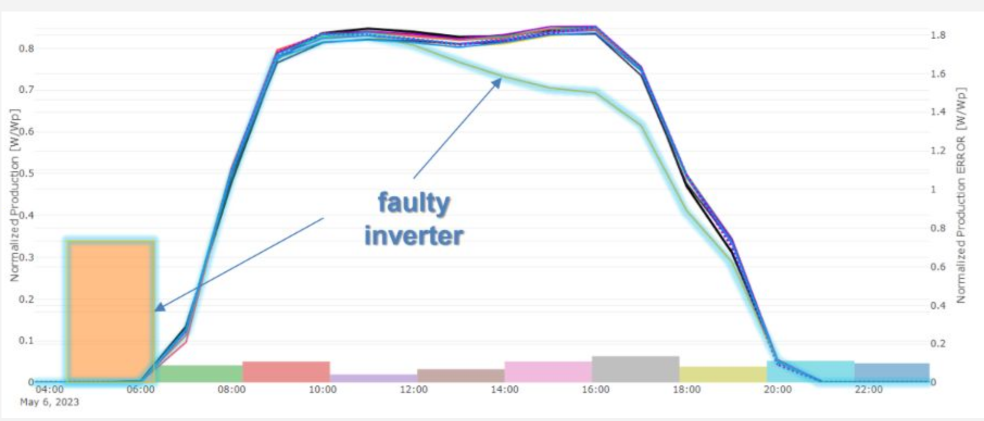
Goal

This thesis investigates the application of machine learning techniques for anomaly detection in photovoltaic (PV) systems, focusing on time series classification models. The study encompasses a thorough evaluation of existing state-of-the-art methodologies, analyzing their effectiveness in identifying faults and deviations in PV system performance. Based on these insights, a novel experimental model will be developed, integrating advanced learning algorithms to enhance detection accuracy and robustness under varying environmental and operational conditions.

Anomaly Detection

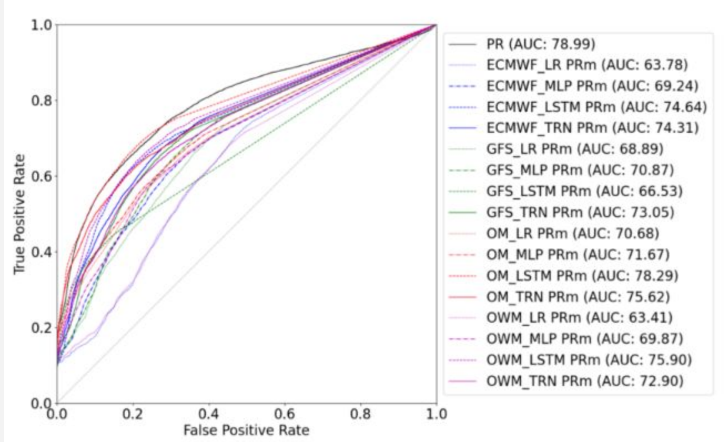
It points to the anomalies within the normal photovoltaic system performance, which could suggest faults, inefficiencies, or disrupted external factors. Predictive models ensure very high system efficiency through maximum energy reliability, the early detection of faults, and the enabling of proactive maintenance.





Key idea:

- Well defined nowcasting model is able to provide approximately **less than 1% error**
- By comparing the forecasted and the measured values on a whole day inverter by inverter is possible to discriminate faulty inverters



$$PR = \frac{E_{DC}}{P_0} \Big/ \frac{H_{PoA}}{H_0}$$

$$PE = \left| \frac{E_{DC}}{P_0} - \frac{\widehat{E_{DC}}}{P_0} \right|$$

$$mPR = \frac{E_{DC}}{P_0} \Big/ \frac{\widehat{E_{DC}}}{P_0}$$

Preliminary results obtained by total daily Normalized Production Error with respect to the predicted production is **able to detect an anomaly at inverter-level.**

Impact
Human Centered Aspect

- **Reliable Supply of Energy**: Failure prevention in PV systems ensures uninterrupted and stable electricity supply, thus minimizing the power outage.
- **Lowered Cost of Energy**: Efficient anomaly detection reduces maintenance cost and prolongs the life span of PV panels, which ultimately lowers the cost of electricity for the consumer.
- **Higher Accessibility to Renewable Energy:** Improved reliability makes solar energy a more feasible source of energy for households, businesses, and even remote communities.

- **Disaster Resilience:** Sound and reliable PV systems would back up the supply during emergencies, improving resiliency during disaster situations.
- **Intelligent Energy Grid**: Anomaly detection, powered by AI, integrated with grid systems promotes better management and efficiency in terms of energy.
- **Reduced Impact on the Environment**: The highest effectiveness of the utilization of energy minimizes waste and the carbon footprint produced while generating solar energy.

- **Safety for Workers**: Predictive maintenance minimizes the need for dangerous manual inspection, hence reducing workplace hazards.
- **Democratization of Energy Data**: With the right anomaly detection methods, individuals and businesses can now optimize their own energy use.
- **Global Climate Change Mitigation**: Efficient PV system operation accelerates the transition to clean energy and supports climate action goals.

Reference:

Piantadosi, G., Dutto, S., Galli, A., De Vito, S., Sansone, C., & Di Francia, G. (2024). Photovoltaic power forecasting: A Transformer-based framework.