THE 21ST INTERNATIONAL OPERATIONS & MAINTENANCE CONFERENCE IN THE ARAB COUNTRIES

Integrating Deep Learning and Machine Learning for Defect Detection and Maintenance Prediction in Photovoltaic Systems

Predictive Analytics for Solar Energy Reliability

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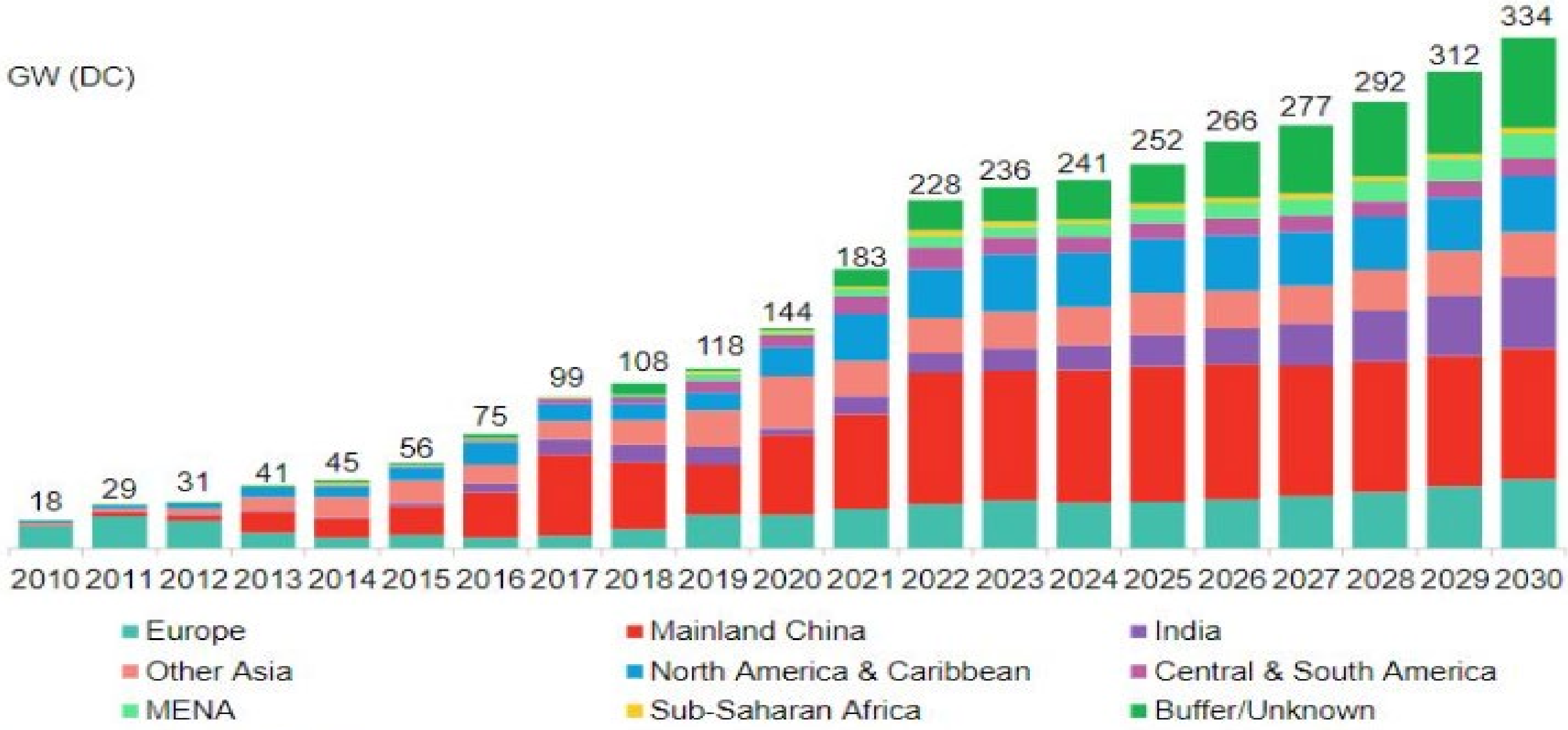
Embracing Solar: The Future Powered Today

The Bloomberg New Energy Finance (BNEF) reports of analysts expect newly installed PV capacity to be between 252 and 260 GW in 2025.

Commercial and industrial systems will also see their share increase, as these are becoming more and more profitable against the background of rising electricity prices and electricity shortages in the country.



Source: BloombergNEF

Overview of PV System Challenges

Here are some common types of defects (intrinsic, extrinsic) found in PV panels:

1.Micro-Cracks
2.PID (Potential Induced Degradation)
3.Snail Trails
4.Hot Spots
5.Soiling
6.Delamination and Discoloration
7.Corrosion
8.Cell Mismatch and Shading
8.Inverter and Junction Box Failures

Method	Process
Visual	Discoloration, surface soiling, browning,
Thermal	Thermal extraordinary heating
Electrical	Illuminated I-V curve measurement, Transmittance line diagnosis

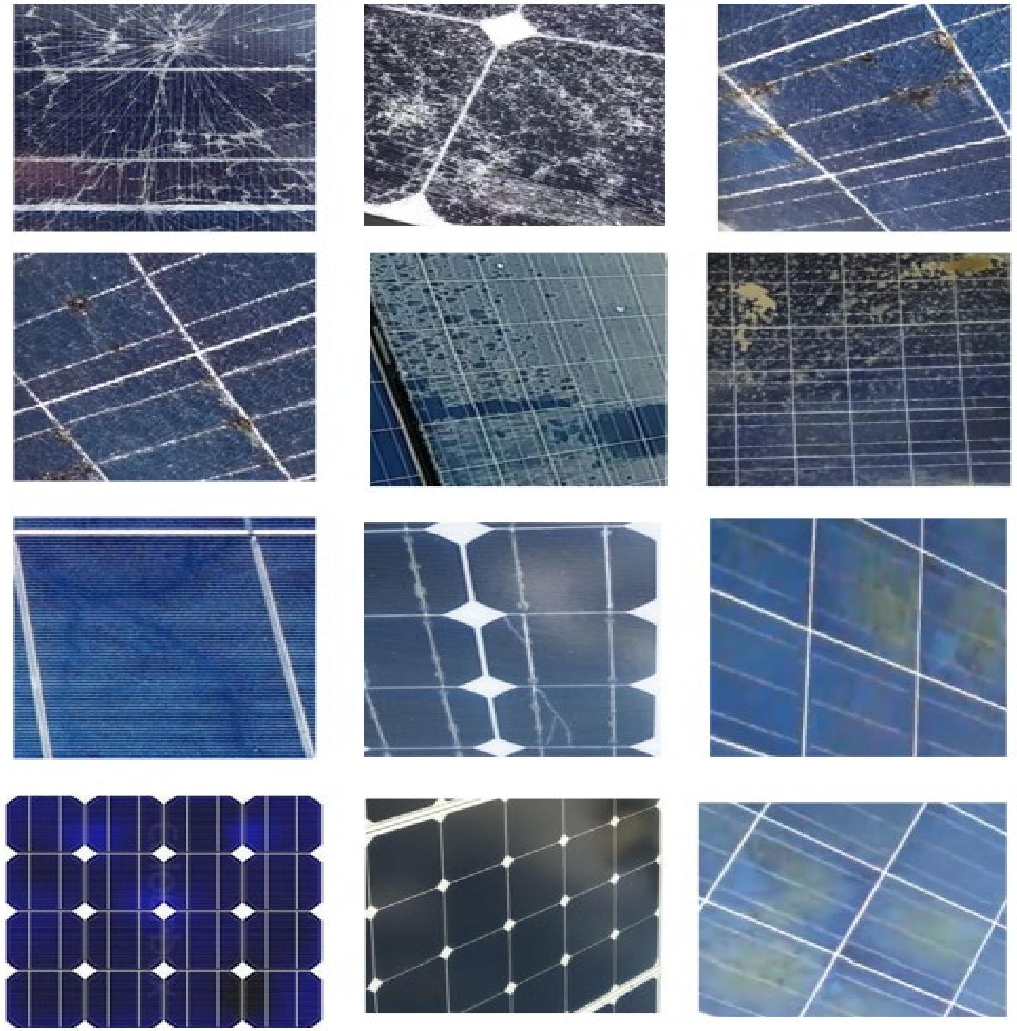


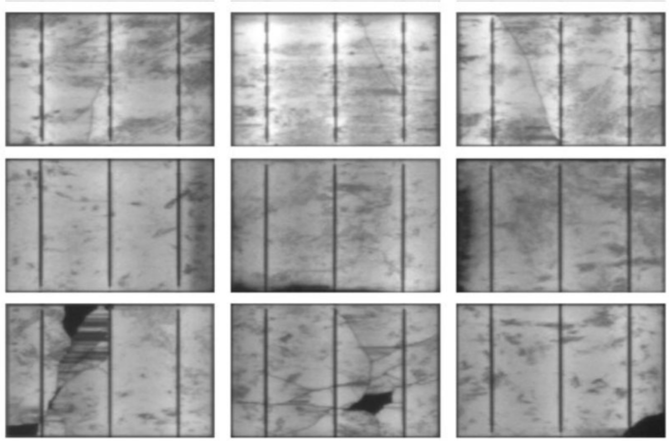
Fig. 3. Samples of solar panels with defective and normal surfaces.

Problem statement

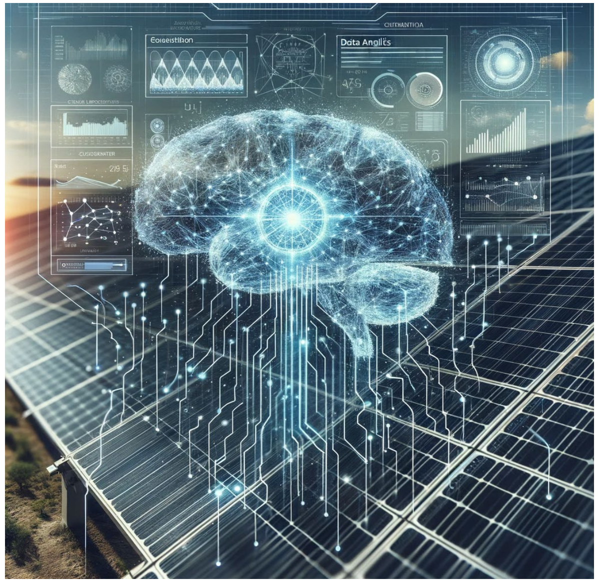
- Regular monitoring and maintenance of PV panels are essential to detect these defects early and address them promptly.
- Traditionally, maintenance teams conduct visual inspections and use instruments like I-V curve tracers to detect anomalies.
- limitations: Time-consuming, Subjective, Intermittent, Reactive.

- Solution: the advanced predictive capabilities offered by data analysis, machine learning and deep learning. to predict when a failure is likely to occur and taking preventative measures before it happens.

- Advanced techniques like thermal imaging, electroluminescence, and the use of drones for inspection are increasingly employed to identify and analyze these defects efficiently.



Role of Machine Learning (ML) and Deep Learning (DL)



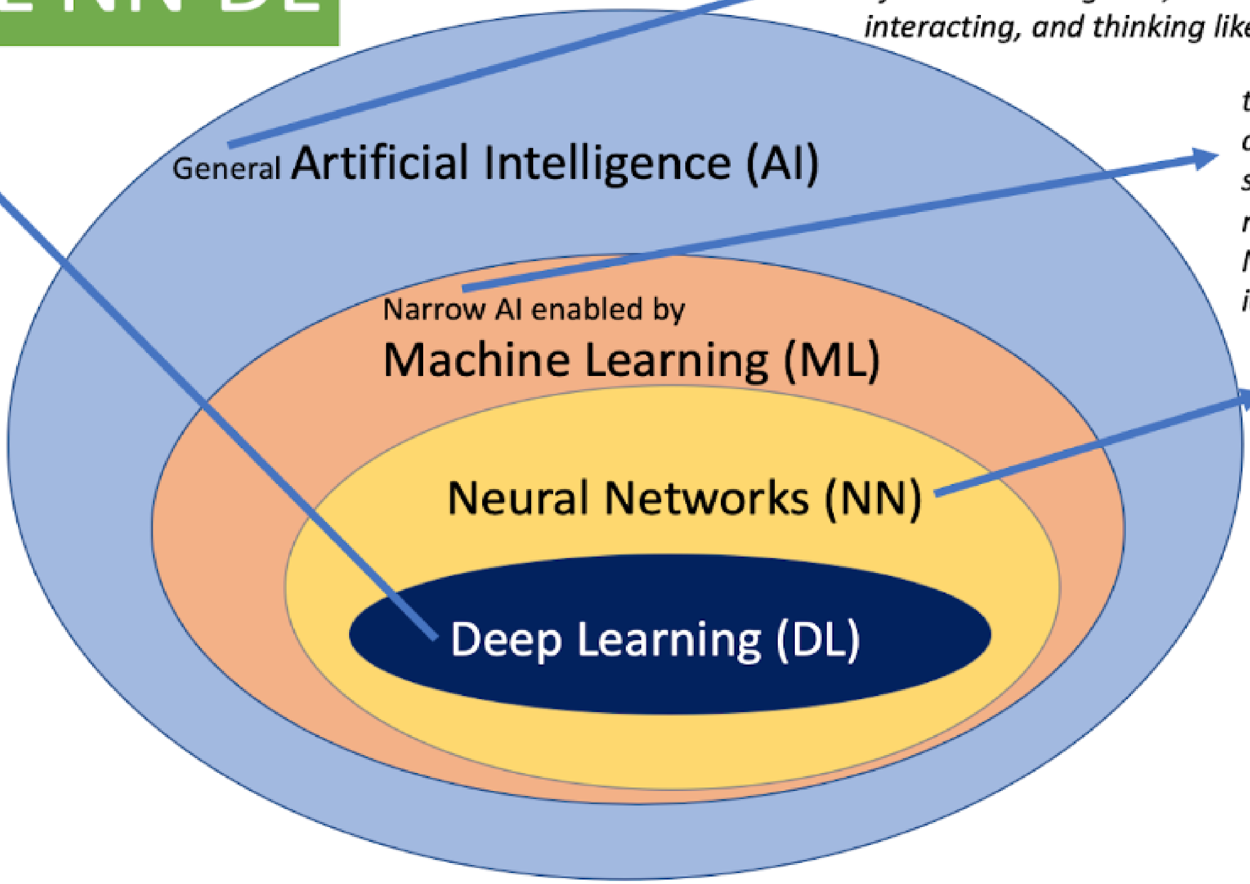
These technologies enable:

- Anomaly Detection
- Pattern Recognition
- Predictive Insights

AI ML NN DL

the word "deep" comes from the fact that DL algorithms are trained/run on deep neu ral networks. These are just neural networks with (usually) three or more "hidden" layers

computers possessing the same characteristics of human intelligence, including reasoning, interacting, and thinking like we do



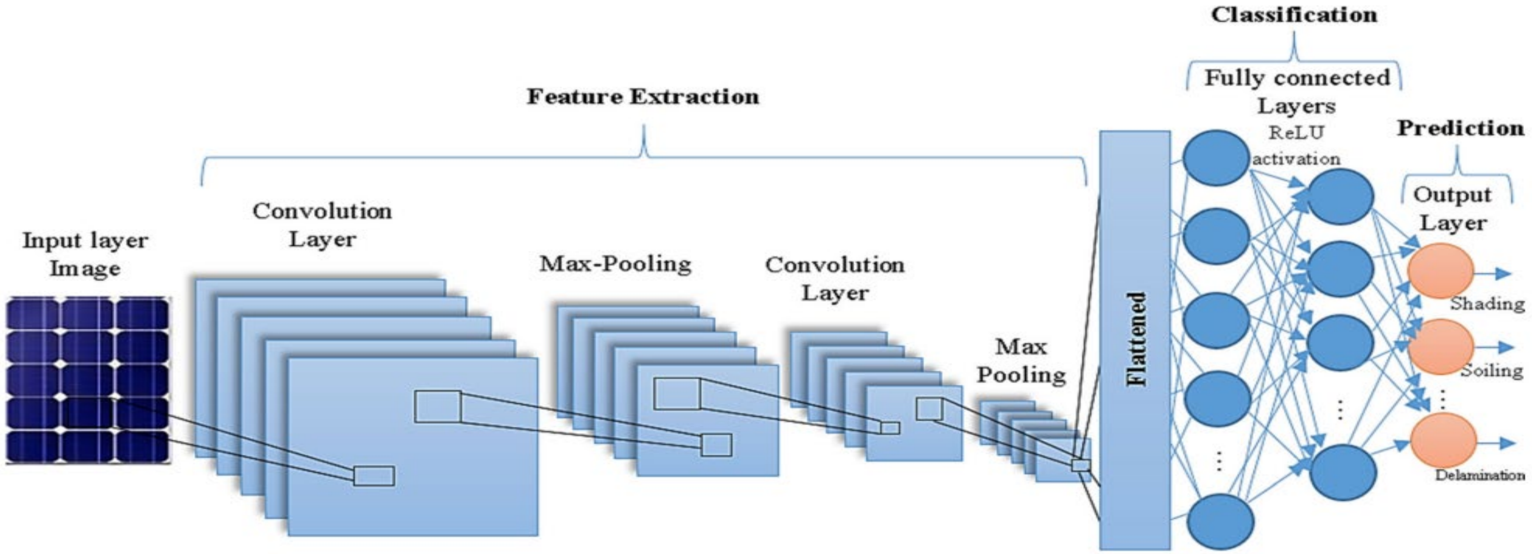
technologies that can accomplish specific tasks such as playing chess, recommending your next Netflix TV show, and identifying spam emails

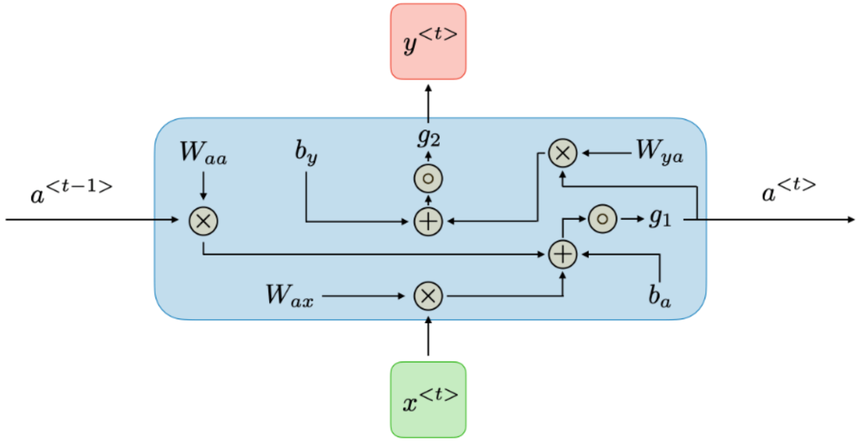
neural networks are a specific group of algorithms used for machine learning that model data using graphs of Artificial Neurons. Those neurons are a mathematical model that "mimics approximately how a neuron in the brain works"

Examples of AI models

Once data is collected, ML/DL algorithms come into play, offering advanced defect detection capabilities:

- **Convolutional Neural Networks (CNNs)**
- **Recurrent Neural Networks (RNNs)**
- **Autoencoders**
- **YOLO**





Transfer learning models

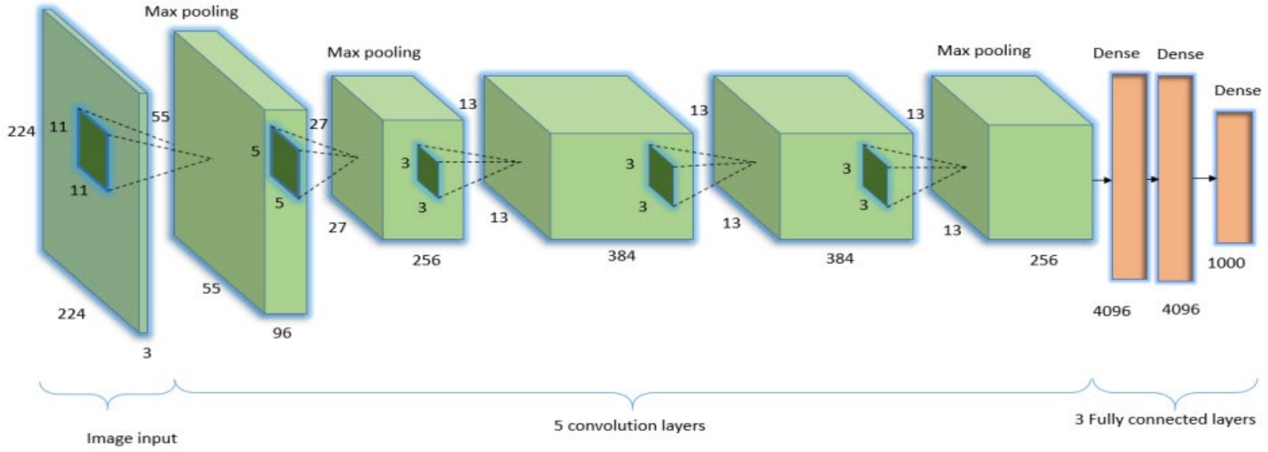


Fig. 2. AlexNet Architecture

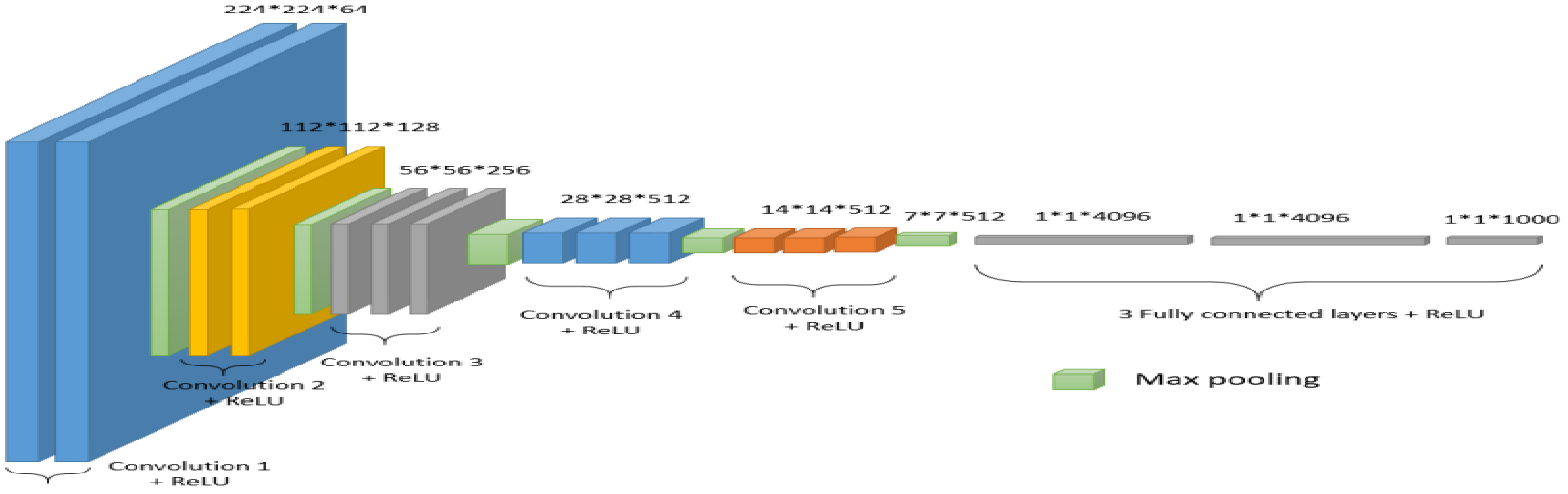
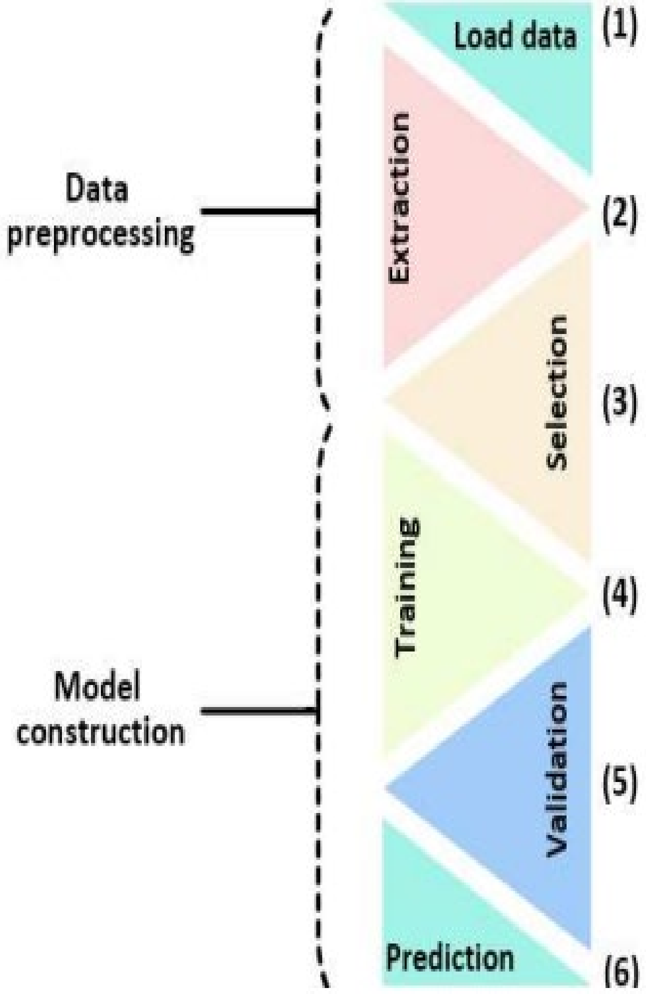


Fig. 3. VGG16 Architecture



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Our papers

BA-CNN: Enhancing Photovoltaic Cell Quality Evaluation and Anomaly Detection through Deep Learning

Eman Ashraf *dept. of Electronics and Communications Engineering* *Faculty of Engineering* *Delta University for Science and Technology* Gamasa, Egypt https://orcid.org/0000-0003-0928-3580	*Shady Yehia EL Mashad* *Associte Professor, Faculty of Engineering at Shoubra, Benha University*	Kabeel A. E.[1,2] *[1] Faculty of Engineering, Delta University for Science and Technology, Gamasa, Egypt* *[2] Mechanical Power Engineering Department, Tanta University, Tanta, Egypt* *kabeel6@f-eng.tanta.edu.eg*	Warda M. Shaban *dept. of Communications and Electronics Engineering* *Nile Higher Institute for Engineering and Technology, Artificial Intelligence Lab,* Mansoura, Egypt warda_mohammed@nilehi.edu.eg

Integrating Deep Learning and Machine Learning for Defect Detection and Maintenance Prediction in Photovoltaic Systems

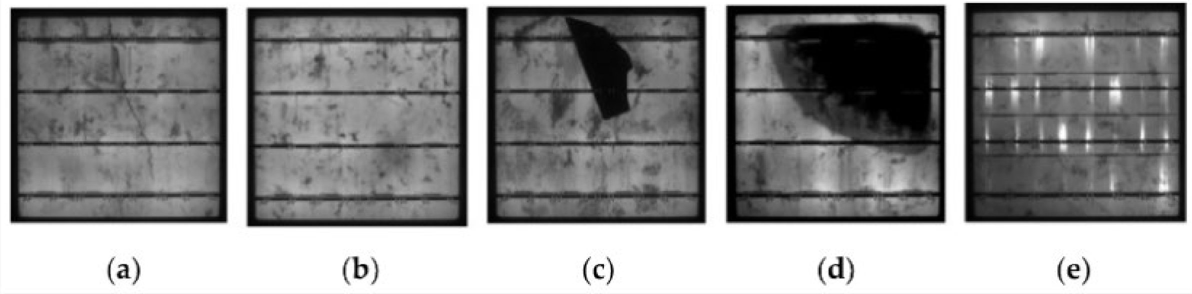
Eman Ashraf *dept. of Electronics and Communications Engineering* *Faculty of Engineering* *Delta University for Science and Technology* Gamasa, Egypt https://orcid.org/0000-0003-0928-3580	A.R. Habieeb[1, 2] *[1] Faculty of Engineering, Delta University for Science and Technology, Gamasa, Egypt,* *[2]Mechatronics Engineering Program, Faculty of Engineering, Mansura University, Mansura, Egypt* *abedrabiee@gmail.com*	Kabeel A. E.[1,2] *[1] Faculty of Engineering, Delta University for Science and Technology, Gamasa, Egypt* *[2] Mechanical Power Engineering Department, Tanta University, Tanta, Egypt* *kabeel6@f-eng.tanta.edu.eg*	Warda M. Shaban *dept. of Communications and Electronics Engineering* *Nile Higher Institute for Engineering and Technology, Artificial Intelligence Lab,* Mansoura, Egypt warda_mohammed@nilehi.edu.eg

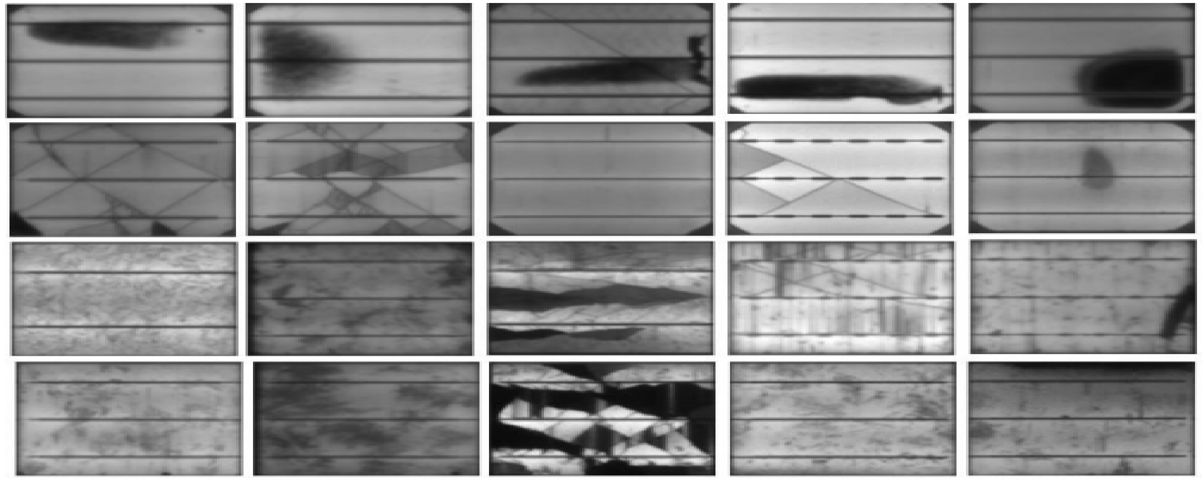
Data sets

These algorithms are trained on vast datasets, Example of public dataset that consists of high-resolution electroluminescence (EL) images derived from both
monocrystalline and polycrystalline PV modules

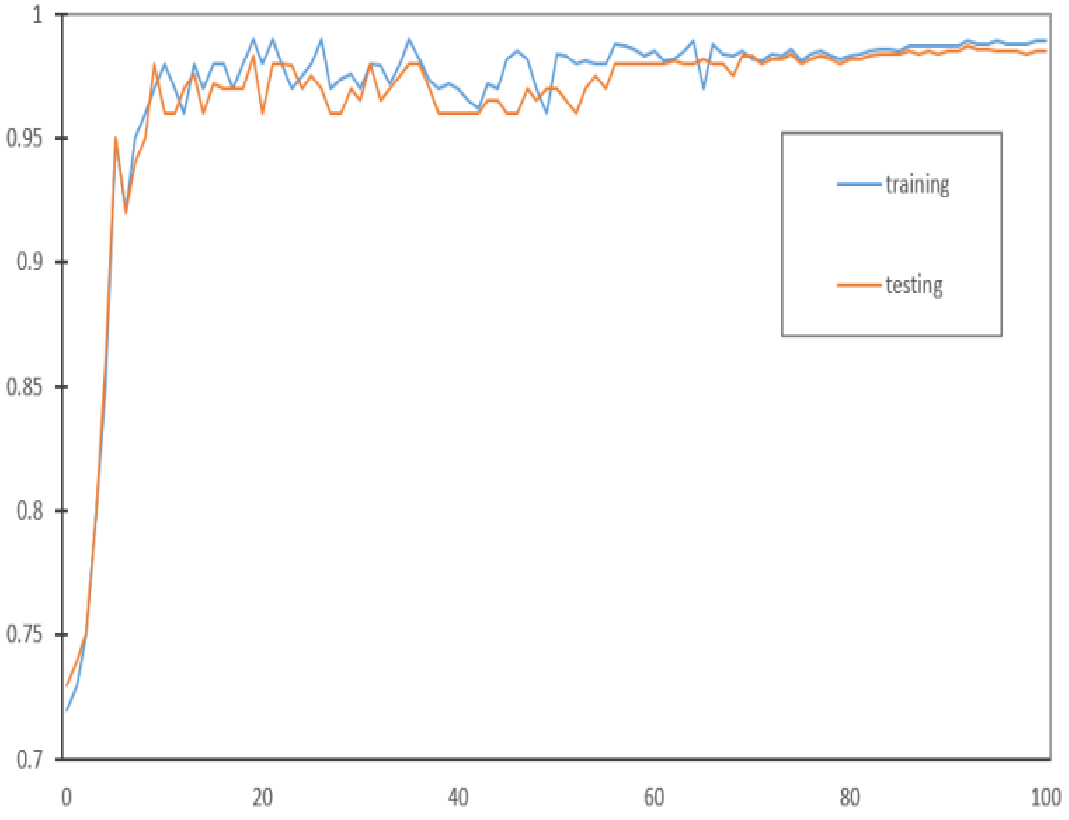
- **ELPV:** a total of 2,624 grayscale images, each with a resolution of 300×300 pixels and an 8-bit depth.
- **PVEL-AD:** contains 36,543 images with various internal defects and heterogeneous background. 10 different categories such as crack (line and star), finger interruption, black core, misalignment, thick line, scratch, fragment, corner, and material defect.

Figure 1. Different forms of defects in photovoltaic cells: (**a**) crack; (**b**) thick line; (**c**) fragment; (**d**) black core; (**e**) horizontal dislocation.

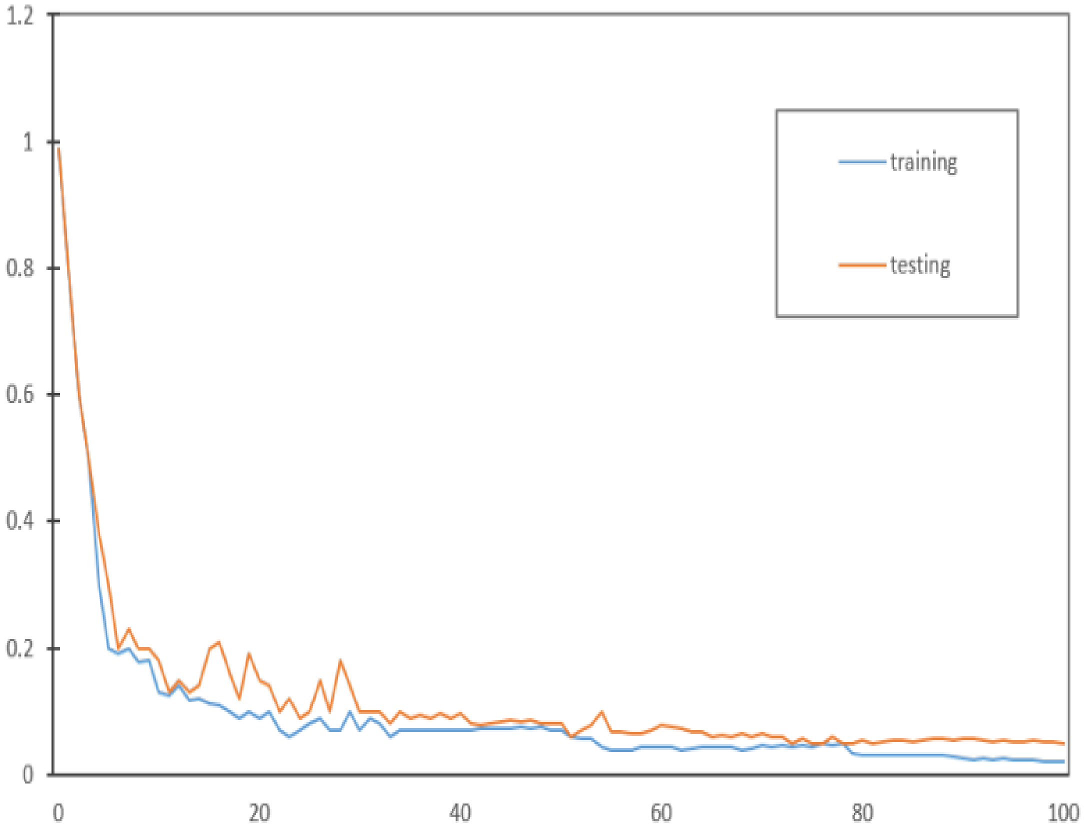




Results



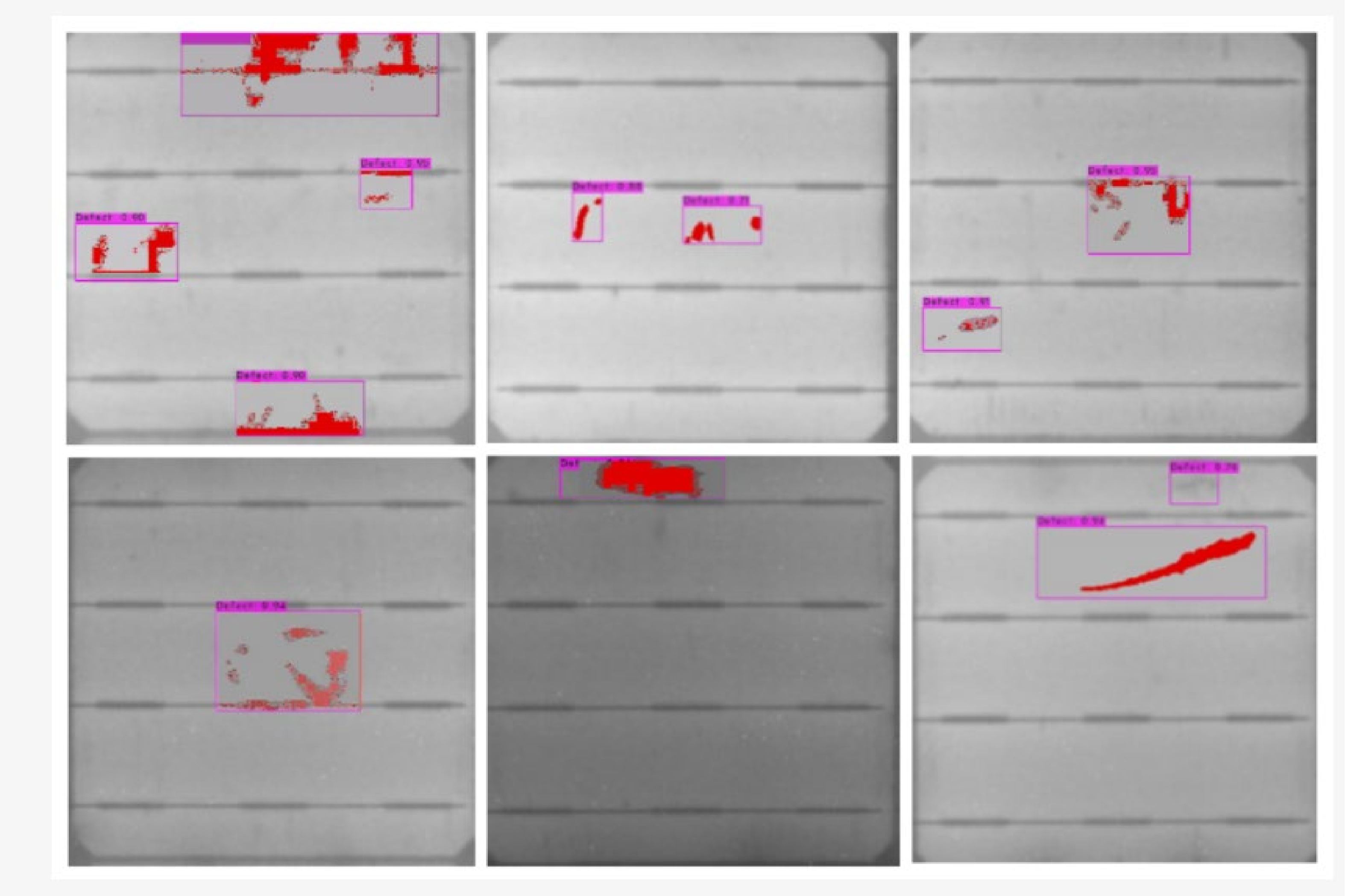
(a) accuracy



(b) losses

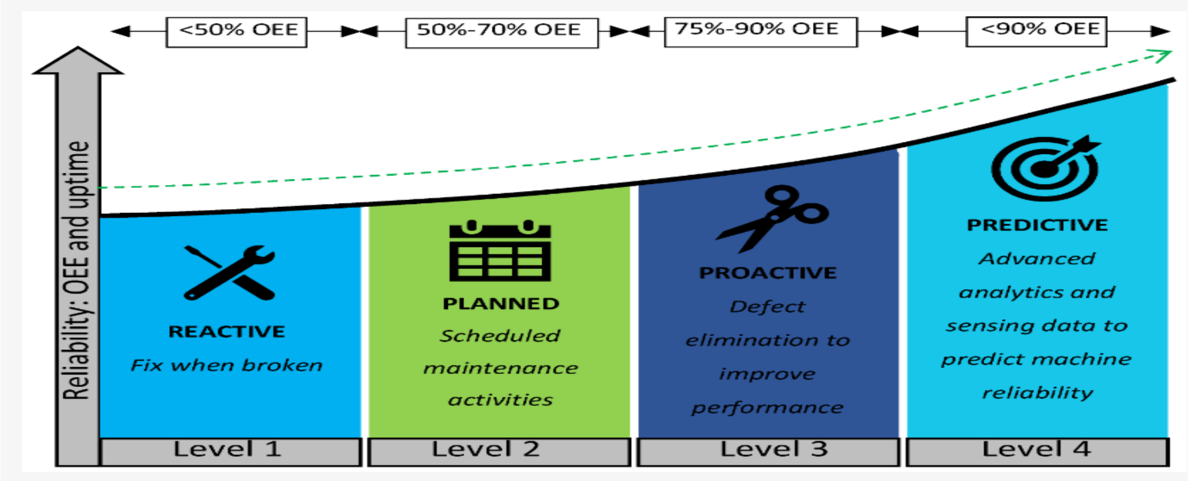
Fig. 9, The training and testing: (a) accuracy (b) losses.

Detecting PV Defects with ML/DL



Predictive Maintenance with AI

- To shift from reactive to proactive maintenance, The proposed Maintenance Prediction Model capitalizes on the previously localized defect regions from the defect detection process.
- The localized defect features are then utilized as inputs for a specialized maintenance prediction model.
- These attributes encapsulate critical information about the type, size, and severity of defects.
- Subsequently, the maintenance prediction model is trained to harness the relationship between extracted defect features and maintenance requirements.



Algorithm 3: maintenance prediction model

```
1:  function MaintenancePredictionModel(defect_features, maintenance_data):
2:  # Train the maintenance prediction model
    model = train_maintenance_model(defect_features, maintenance_data)
3:  return model
4:  function TrainMaintenanceModel(defect_features, maintenance_data):
5:  # Prepare training data
    X_train = defect_features
    y_train = maintenance_data
6:  # Initialize and train the maintenance prediction model (SVM)
    model = initialize_model()
7:  model.train(X_train, y_train)
8:  return model
9:  # Main process
    defect_features = extract_defect_features(localized_defect_regions)
10: maintenance_data = load_maintenance_data()
11: maintenance_model = MaintenancePredictionModel(defect_features, maintenance_data)
```

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Field Successes: ML/DL in Action

American

.5 خطوط الطيران الأمريكية: تستخدم خطوط الطيران الأمريكية (American Airlines) تقنيات الذكاء الاصطناعي لتحسين عمليات الصيانة، حيث يتم استخدام الذكاء الاصطناعي للكشف عن الأعطال المحتملة في المحركات ومكونات الطائرة والتنبؤ بالصيانة اللازمة، وذلك لتقليل مدة التوقف الفني وتحسين كفاءة الطائرات.

On·Site TECHNOLOGY

أدنوك ADNOC

أدنوك تكمل بنجاح المرحلة الأولى من مشروعها للصيانة التنبؤية المعتمدة على الذكاء الاصطناعي

من المتوقع أن يسهم المشروع بخفض التكاليف بنسبة 20% بعد انتهاء مراحله الأربع في عام 2022

المشروع يأتي في إطار سعي أدنوك لاعتماد أحدث التقنيات المتطورة عبر مختلف مجالات ومراحل أعمالها لتعزيز كفاءة الأصول والارتقاء بالأداء

ORACLE

Oracle Maintenance

Oracle Fusion Cloud Maintenance is a connected, smart maintenance management solution. Powered by advanced technologies, it enables predictive maintenance and helps you increase reliability and uptime while reducing overall costs.

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Field Successes: ML/DL in Action

RapidValue (Aspire Systems) > Case Studies > Remote Monitoring & Predictive Maintenance App for a Solar Energy System

GreenPowerMonitor a DNV GL company

RapidValue Enabling Mobility

Remote Monitoring & Predictive Maintenance App for a Solar Energy System

WORLD FUTURE ENERGY SUMMIT

هيئة كهرباء ومياه دبي
Dubai Electricity & Water Authority

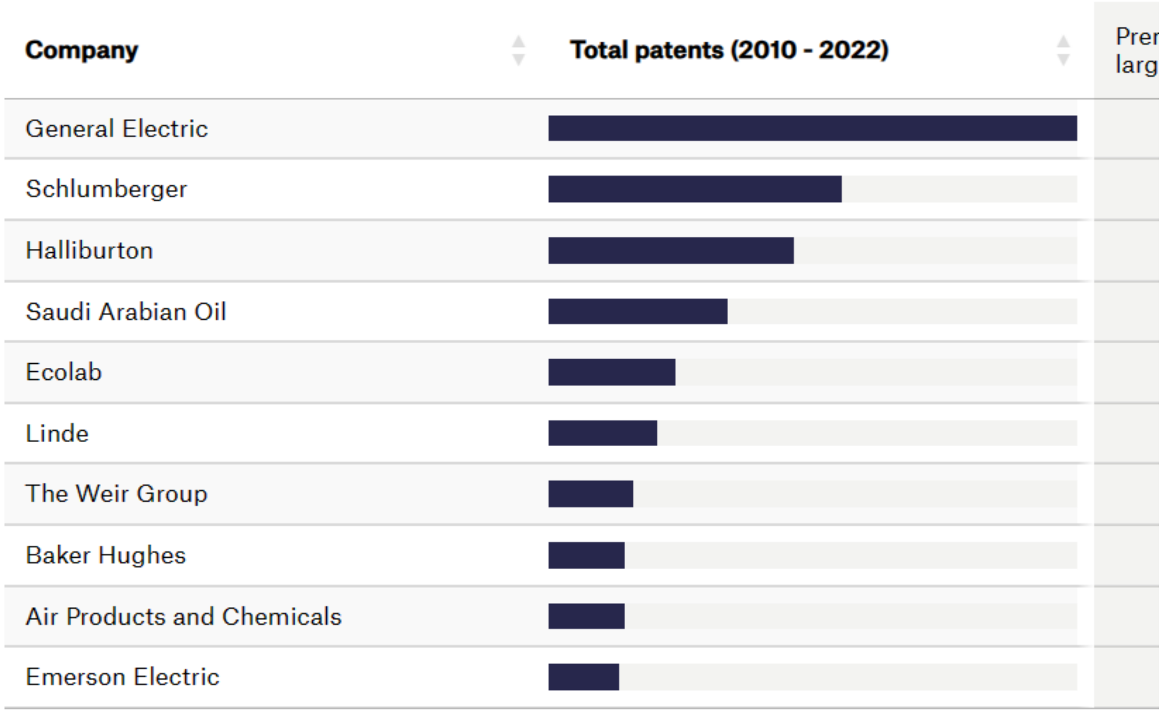
DNV and GreenPowerMonitor, a DNV company, have developed a predictive maintenance system for solar inverters that uses machine learning models to represent an inverter's normal operation and to identify anomalous behaviour within new streaming data.

نظام التحكم والفحص الذكي لـ BCS و AOI

يتميز نظام التحكم والاختبار الذكي الخاص بنا لـ BCS و AOIلإنتاج الألواح الشمسية بكفاءة عالية والدقة والتشغيل الآلي الكامل. خصوصاً، يتم استخدام نظام BCS من أجل التثبيت الدقيق للوحة وتجميع اللوحة بجودة عالية. يستخدم نظام AOI لاكتشاف عيوب اللوح، بما في ذلك الشقوق، الأضرار، والخ. يدمج نظام التحكم الذكي التقنيات المتطورة مثل الذكاء الاصطناعي (AI)، الخوارزمية المرنية، التحكم التلقائي لتعزيز أتمتة الإنتاج وكفاءته. يمكنه أيضا تحديد الأخطاء المحتملة وتصحيحها لتقليل التكلفة والمخاطر

Field Successes: ML/DL in Action

Patent volumes related to intelligent predictive maintenance



Here we present highlights from companies benefitting from PdM, including example successes, why they matter, and the chosen tools and methods.

- U.S. industrial products manufacturer
- Tennessee snack food manufacturer
- Louisiana alumina refinery
- San Diego energy utility
- Singapore rail operator
- Australian iron ore mine

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