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المؤتمر الدولي الثاني والعشرون لإدارة الأصول والمرافق والصيانة

The 22nd International Asset, Facility & Maintenance Management Conference

Digitization - Excellence - Sustainability

Optimizing Asset Performance: The Strategic Integration of Smart Power Transformers in the Saudi Arabia Electricity Network

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The Ritz-Carlton Jeddah, Kingdom of Saudi Arabia

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Speakers:

Ayyoub Hourani received the Master of Science degree in Electrical Power Engineering from King Fahd University of Petroleum & Minerals (KFUPM) in 2017, Dhahran, Saudi Arabia. He received the BSc degree in Electrical Engineering from University of Jordan in 2010, Jordan. He is currently at the end of the PhD journey in Electrical Engineering at KFUPM. He is working as an Engineering Manager at Saudi Power Transformers Company (SPTC) in Dammam, Saudi Arabia. He has +14 years of experience in transformers engineering.

Speakers:

Mahmoud Elsayed received the BSc degree in Electrical Engineering from Zagazig University in 2012, Egypt. He is working as a Control and Protection Design Lead at Saudi Power Transformers Company (SPTC) in Dammam, Saudi Arabia. He is PMP® Certified. He has +12 years of experience in LV/MV switchgear and transformers engineering.

Covered Topics in this Workshop:

- Introduction
- Understanding Smart Power Transformers
- Integration Strategies
- Case Studies and Best Practices
- Live Demonstrations
- Q&A Session

Introduction

Welcome & Introduction to SPTC

Workshop Overview

Introducing the Importance of Smart Power Transformers.

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Company Overview

Number - B04 - رقم

SPTC
شركة محولات الطاقة السعودية
SAUDI POWER TRANSFORMERS COMPANY

- **SPTC** is the leading and First HV power transformers manufacturing company in Saudi Arabia.
- **SPTC** was established in 2010 and it is 100% Saudi Owned by EIC (Electrical Industries Company).
- **SPTC** manufactures and provides services for HV Power Transformers up to 150 MVA, 245 kV.

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SPTC

SPTC APPROVALS

الشركة السعودية للكهرباء
Saudi Electricity Company

نقــــل الكهــــرباء
National Grid SA

ارامكو السعودية
Saudi Aramco

سابك
sabic

MA'ADEN معادن
Saudi Arabian Mining Company شركة التعدين العربية السعودية

المؤسسة العامة لتحلية المياه المالحة
Saline Water Conversion Corporation

مرافق
MARAFIQ

أدنوك
ADNOC

EWA
هيئة الكهرباء والماء
Electricity & Water Authority

المملكة العربية السعودية
KINGDOM OF SAUDI ARABIA

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Workshop Overview:

This workshop aims to explore the strategic integration of **Smart Power Transformers** within the Saudi Arabia Electricity Network to optimize asset performance.

Participants will explore the latest advancements in transformers technology and how they can be effectively utilized to enhance the efficiency, reliability, and sustainability of the electricity network.

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Workshop Motivation:

Smart Power Transformers offer advanced functionalities:
- ✓ Real-time Monitoring
- ✓ Predictive Maintenance

Integration of Smart Power Transformers can lead to:
- ✓ Reduced Operational Costs
- ✓ Improved Energy Efficiency
- ✓ And Enhanced Grid Stability

By leveraging these smart technologies:
- ✓ Utilities can better minimize outages
- ✓ Paving the way for a sustainable energy future
- ✓ Aligns with Saudi Arabia's Vision 2030 goals

Understanding Smart Power Transformers

Traditional Electric Power Grid with Traditional Power Transformers.

Transformers Components & Related Failure Mechanism.

Exploring the Latest Advancements in Transformers Technology.

Benefits of Smart Power Transformers in Asset Performance Optimization.

Traditional Electric Power Grid with Traditional Power Transformers.

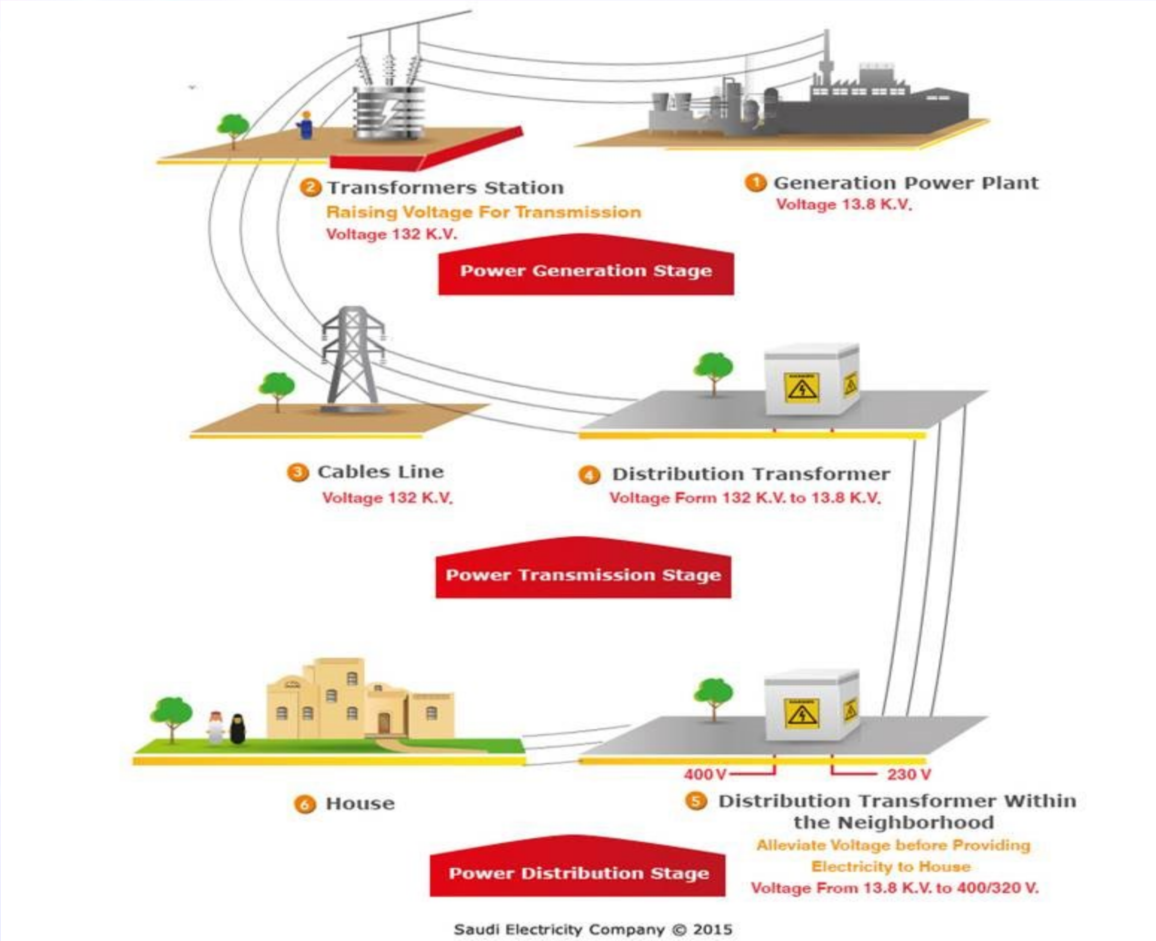
- Traditional Electric Power Grid
- Traditional Power Transformer

Traditional Electric Power Grid

- **Power Generation**: Electricity is generated in power plants at voltages ranging from normally 11kV up to 25kV.

- **Transmission**: For the transmission of power over longer distances, the generated voltages are stepped-up to a much higher level. A step-up transformer is used for this purpose.

- **Distribution**: Power from the transmission system is then stepped-down to lower voltage using a step-down transformer. The power is then carried to distribution substations.



Why do we need a Transformer ?

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Transformer Components & Related Failure Mechanism

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Power Transformer Failures During Operation: Causes, Development, Precautions, and Recommendations.

Power transformers are critical components in electrical power systems, serving to step-up or step-down voltage levels for efficient transmission and distribution of electricity.

Power Transformer failures during operation can lead to significant operational disruptions, financial losses, and safety hazards. Understanding the causes of such failures, their development, and implementing preventive measures is essential for maintaining the reliability and durability of power transformers.

Power Transformer Components

Major Failure Causes of Power Transformers

- **Insulation Breakdown**: One of the most common causes of transformer failure is the breakdown of insulation materials. Over time, insulation can degrade due to thermal stress, electrical stress, moisture ingress, or contamination. This can lead to short circuits and transformer failure.

- **Overloading**: Operating a transformer beyond its rated capacity can cause overheating, which accelerates insulation degradation and can lead to catastrophic failure.

- **Thermal Management Issues**: Inadequate cooling or thermal management can result in overheating, which can damage the insulation and other components of the transformer.

- **Electrical Faults**: Faults such as short circuits, ground faults, or phase-to-phase faults can create excessive currents that damage transformer windings and insulation.

Major failure causes of power transformers

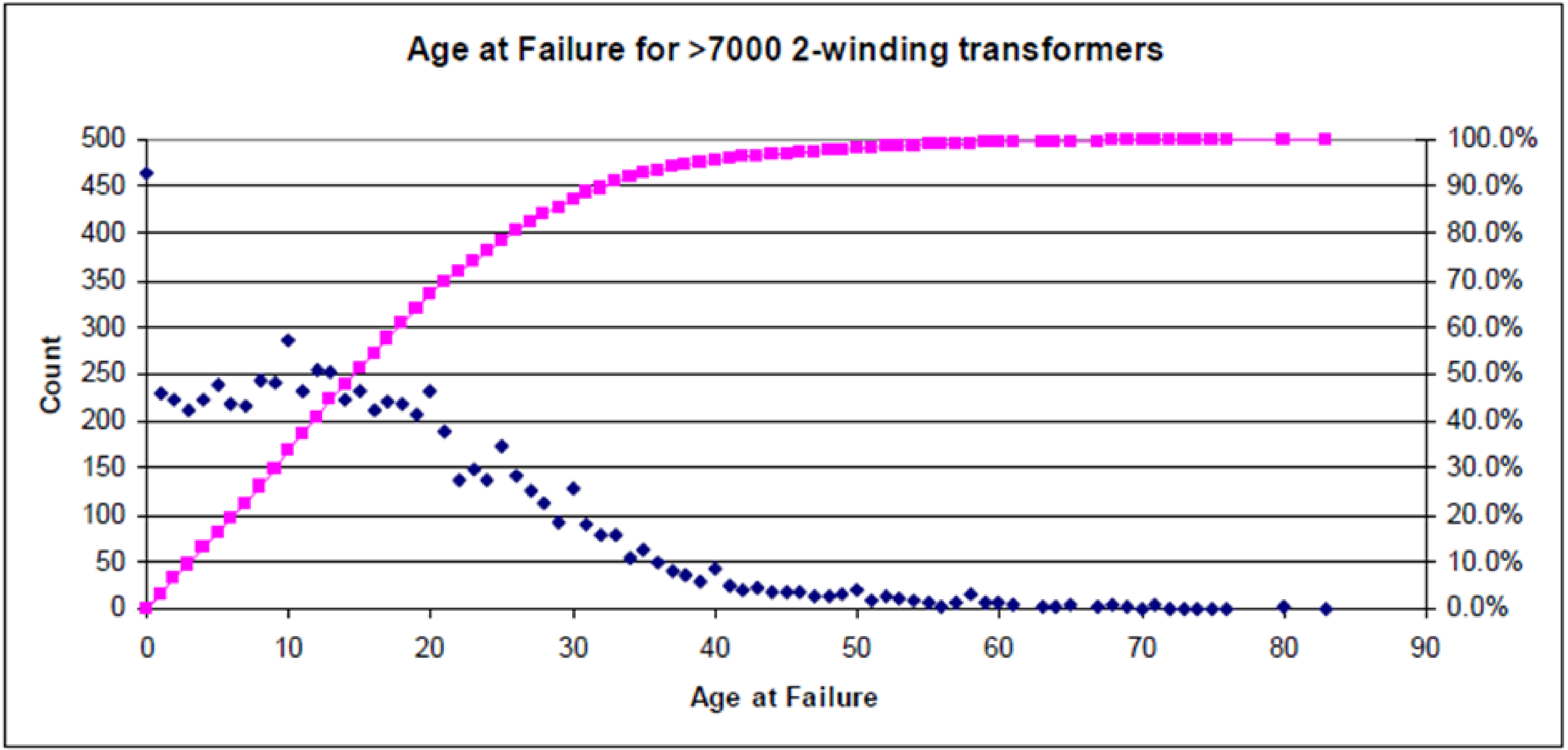
- **Environmental Factors**: External conditions such as humidity, temperature extremes, and pollution can negatively affect transformer performance. Moisture ingress can lead to insulation breakdown, while extreme temperatures can cause thermal stress.
- **Mechanical Stress**: Physical damage due to vibrations, or improper handling during installation or maintenance can lead to structural failures.
- **Manufacturing Defects**: such as poor quality materials or inadequate testing, can lead to early failures in transformers.
- **Contamination of Insulating Oil**: The presence of moisture, particulate matter, or other contaminants in the insulating oil can reduce its effectiveness and lead to insulation failure.
- **Poor Maintenance Practices**: Lack of regular inspections, testing, and maintenance can result in undetected issues that escalate into significant failures.

Major failure causes of power transformers

- **Voltage Fluctuations**: Frequent voltage spikes or dips can stress the transformer and lead to insulation breakdown or other electrical failures.

- **Aging**: As transformers age, the materials and components naturally degrade, leading to increased susceptibility to failures.

Below Figure shows actual failure counts for a set of 7,000 reported failures, recorded by Doble Engineering



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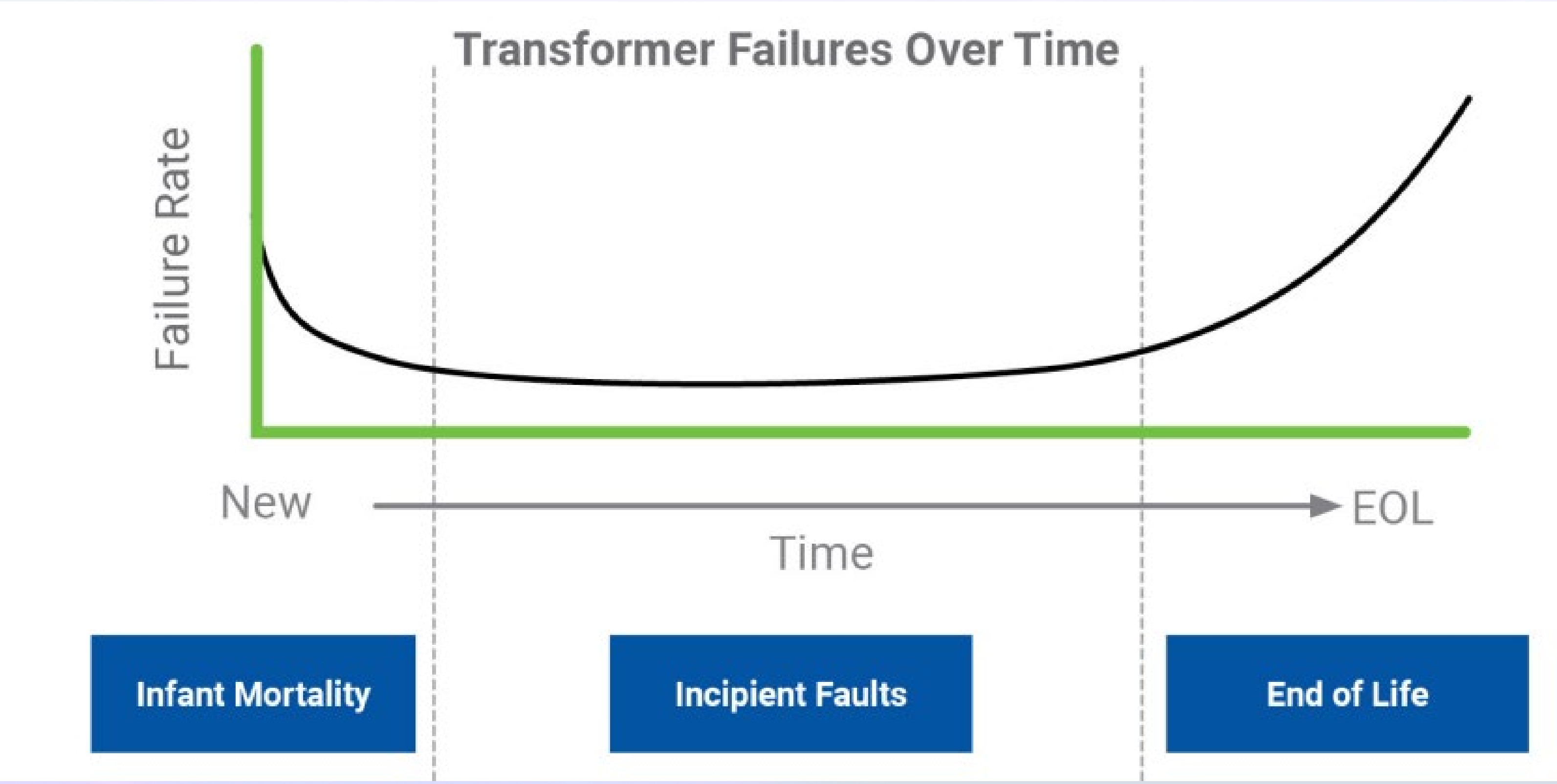
Life Expectancy of Transformers

The Bathtub Curve

The failure rate of components follows a trend called a "**bathtub curve**" where the failure rate starts high due to design, manufacturing, or transportation issues and quickly drops (the burn-in period), followed by a low, constant failure rate period, and ending in the wear-out period where the failure rate steadily increases with time.



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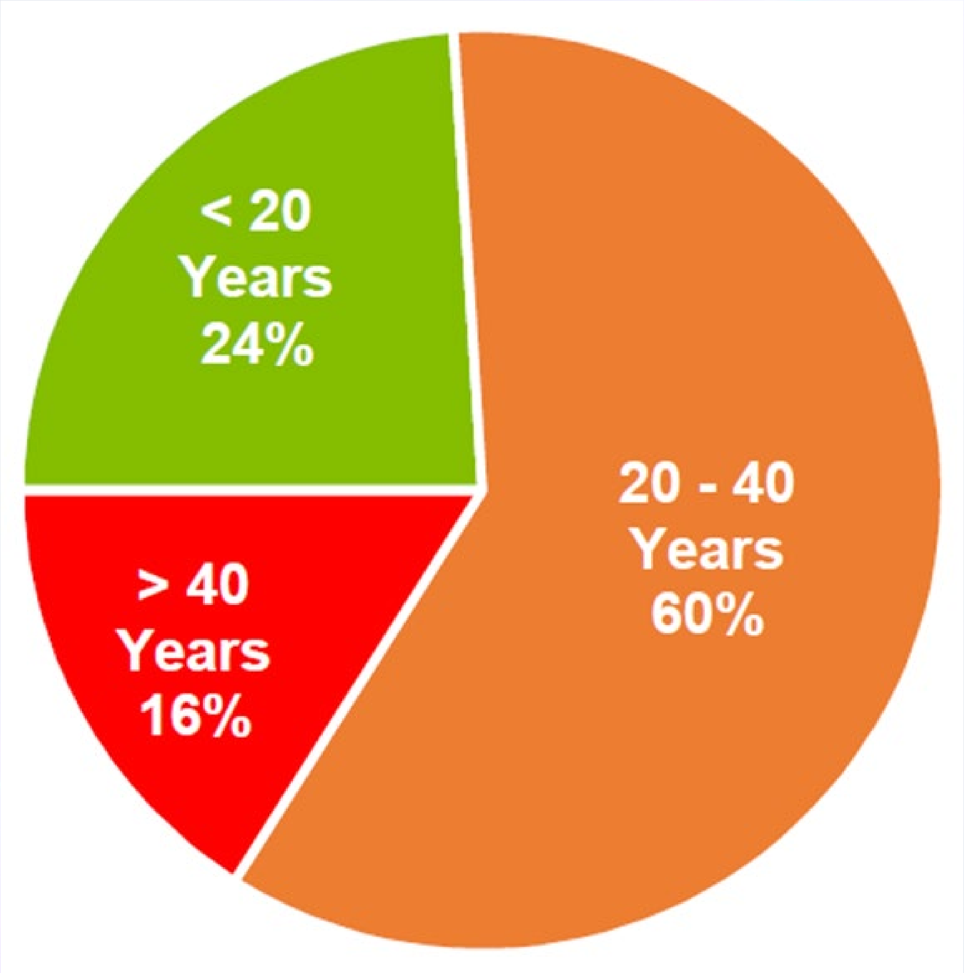
Another Figure shows ARAMCO Power Transformers Distribution by age *



*Reference: H. Tuaimi, I. Alkadi and M. Algahtani, "Power Transformer Condition Management Program for Oil and Gas Industrial Facilities," 2019 IEEE International Conference on Environment and Electrical Engineering and 2019 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), Genova, Italy, 2019, pp. 1-6, doi: 10.1109/EEEIC.2019.8783468.

Development of Failures

Transformer failures can develop gradually or occur suddenly.
Initially, minor issues such as insulation degradation or overheating may go unnoticed. Over time, if not addressed, these problems can escalate, resulting in:

- **Partial Discharge**: This phenomenon occurs when there are small electrical discharges within the insulation material, leading to gradual deterioration.
- **Thermal Runaway**: Continuous overheating can cause a cycle of increased temperature and further degradation, ultimately resulting in insulation failure.
- **Sudden Catastrophic Failure**: In some cases, a fault can occur suddenly, leading to an explosion or fire, posing risks to personnel and equipment.

TRANSFORMER COMPONENTS AND ITS RELATED FAILURE MECHANISM

Here some selection of possible faults, assigned to the related component will be described:

- TRANSFORMER MAIN TANK.
- TRANSFORMER OLTC.
- TRANSFORMER COOLING SYSTEM.
- TRANSFORMER BUSHINGS.

TRANSFORMER COMPONENTS AND ITS RELATED FAILURE MECHANISM

A. TRANSFORMER MAIN TANK CONTAINING

(OIL, ACTIVE PART “Core & Winding”, DISSOLVED GASES, MOISTURE, PAPER INSULATION**):**

- Overheating and Moisture.
- Bubble creation at high moisture.
- Dissolved gas content combined with high temperatures.
- Loose parts, sharp edges, conductive particles in oil, bad contacts and gas bubbles in oil are having the potential to weaken the liquid and solid insulation system and to create partial discharges (PD) and Arcing.

TRANSFORMER COMPONENTS AND ITS RELATED FAILURE MECHANISM

B. TRANSFORMER OLTC:

It allows for voltage regulation by changing the turns ratio, accommodating variations in load and ensuring stable output voltage.

On Load Tap Changers are the only part in a transformer which will be actively moved. **Wear and Tear** of the mechanical parts and contacts play an important role.

C. TRANSFORMER COOLING SYSTEM:

This includes **radiators**, **fans** that help dissipate heat, maintaining an optimal operating temperature is crucial for transformer efficiency and durability.

If the cooling system is disturbed by malfunctions of fans or pumps, the transformer cannot be cooled down in an appropriate way so that it can lead to an Overheating and failing of the transformer.

D. TRANSFORMER BUSHINGS:

Bushings are insulators that allow electrical connections to pass through the tank.

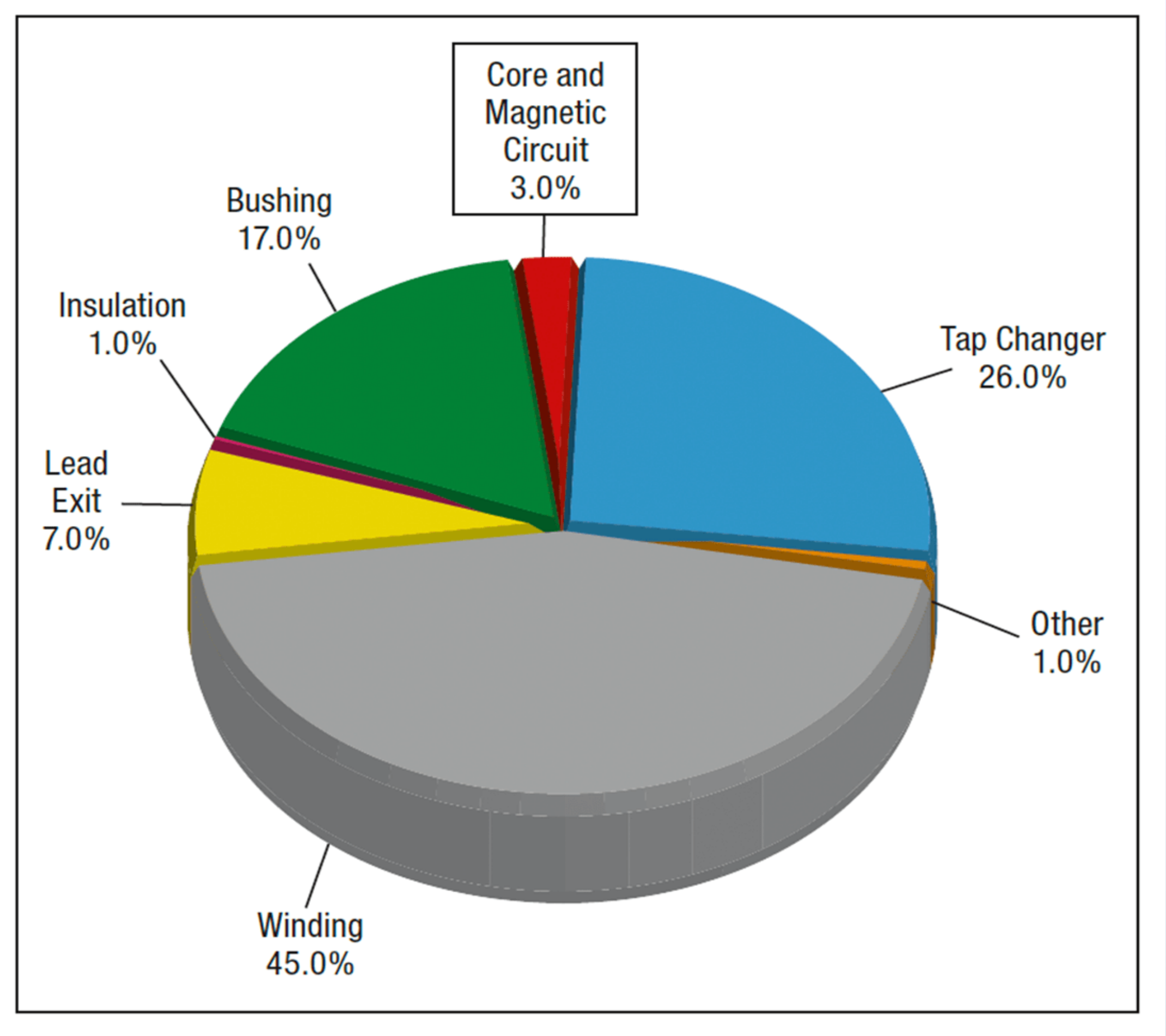
The major failure causes for bushings are partial breakdowns due to over voltages or pre-deterioration due to partial discharges or leakages in case of oil impregnated paper bushings (OIP).

TRANSFORMER COMPONENTS RELATED FAILURE MECHANISM

FAILURE STATISTICS

In reference to transformer reliability study published in: (**Transformer Reliability Survey: Interim Report**).

- It shows that the **windings** with 45% as the major cause of failing transformers, followed by **tap-changers** with 26%, **bushings** with 17% and **lead exits** with 7%.



TRANSFORMER COMPONENTS AND ITS RELATED FAILURE MECHANISM

The overall transformer failure rate according to (**Transformer Reliability Survey: Interim Report**) is reported with **0.44%**, while transformers for Extra High Voltage (EHV) and the lower end of high voltage are showing a failure rate around **1%**.

Failure rate was calculated according to the definition in "An International Survey on Failures in Large Power Transformers in Service" – Final report of CIGRE", which was expressed as:

$$\lambda = 100 \cdot \frac{\sum_i n_i}{\sum_i N_i} \%$$

Where:

ni = The number of transformers that failed in the ith year.

Ni = The number of transformers in service during the ith year.

FAILURES & POPULATION INFORMATION	HIGHEST SYSTEM VOLTAGE [kV]					
	69 ≤ kV < 100	100 ≤ kV < 200	200 ≤ kV < 300	300 ≤ kV < 500	kV ≥ 700	All
Failures	145	212	163	154	11	685
Transformer - Years	15220	48994	47473	41569	959	156186
FAILURE RATE	0.95%	0.43%	0.34%	0.37%	1.15%	0.44%

Various factors play a significant role in extending the life of a transformer

1. **Regular Maintenance**: Implement a routine maintenance schedule that includes inspections, testing, and repairs. This can help identify potential issues before they escalate.

2. **Temperature Monitoring**: Utilize temperature monitoring systems to keep track of operational temperatures. Installing cooling systems can help manage heat levels effectively.

3. **Load Management**: Ensure that transformers are not operated beyond their rated capacity. Load management strategies can help distribute electrical loads evenly.

4. **Moisture Control**: Employ moisture control measures, such as using desiccants and ensuring proper sealing, to prevent moisture ingress.

5. **Surge Protection**: Install surge protection devices to safeguard against electrical faults and surges, which can damage transformers.

Various factors play a significant role in extending the life of a transformer

6. **Environmental Controls**: Implement environmental controls to mitigate the effects of humidity, dust, and other pollutants that can affect transformer performance.

7. **Invest in Advanced Monitoring Systems**: Utilizing advanced monitoring technologies, such as online condition monitoring systems, can provide real-time data on transformer health, allowing for proactive maintenance.

8. **Conduct Regular Training**: Ensure that personnel are adequately trained in transformer operation, maintenance, and emergency procedures to minimize human error.

9. **Implement a Failure Analysis Program**: Establish a program for analyzing transformer failures when they occur, to understand the root causes and prevent recurrence.

Various factors play a significant role in extending the life of a transformer

10. **Collaborate with Manufacturers**: Work closely with transformer manufacturers for guidance on best practices, maintenance schedules, and upgrades to improve reliability.

11. **Develop an Emergency Response Plan**: Create a comprehensive emergency response plan to address potential transformer failures, ensuring safety and minimizing downtime.

Exploring the Latest Advancements in Transformer Technology.

Advanced Technologies and Best Practices in Transformer Management

- ✓ **Adoption of Continuous Monitoring Systems (CMS):** Many power transformers in Saudi Arabia are now equipped with Continuous Monitoring Systems. These systems enable **real-time** data acquisition and analysis, allowing operators to **monitor** critical parameters such as temperature, voltage, and insulation condition. This **proactive approach** helps in **early fault detection**, thereby reducing the risk of transformer failures and enhancing **reliability**.

- ✓ **Focus on Maintenance Practices**: Emphasizing the importance of **regular** inspections and **preventive** maintenance. By adhering to international standards and best practices, utilities aim to extend the operational life of transformers and minimize downtime.

Advanced Technologies and Best Practices in Transformer Management

- ✓ **Thermal Management Initiatives**: Effective thermal management is crucial in the hot climate of Saudi Arabia. This is essential for maintaining the integrity of insulation materials and ensuring the longevity of transformers.

- ✓ **Quality of Materials**: The use of high-quality materials in transformer manufacturing and installation has been prioritized to enhance durability and performance. Saudi Arabia's commitment to using superior insulation and core materials helps mitigate risks associated with thermal and electrical stresses.

Advanced Technologies and Best Practices in Transformer Management

- ✓ **Training and Development**: The investment in **human** capital is essential for the effective management of transformer systems.

- ✓ **Regulatory Compliance and Safet**y: Saudi Arabia has established regulatory frameworks to ensure compliance with international standards for transformer operation and maintenance. Continuous monitoring systems assist in meeting these regulatory requirements, thereby enhancing safety and reducing liability risks.

Conventional Transformer Protection Techniques

Conventional transformer protection techniques primarily focus on safeguarding transformers from electrical faults and abnormal operating conditions. These methods typically include:

1. Overcurrent Protection: This technique employs current relays that trip the transformer circuit when the current exceeds a predetermined threshold, protecting against overloads and short circuits.

2. Differential Protection: This method **compares** the current entering and exiting the transformer. If a significant difference is detected (indicative of internal faults), the relay will trip, isolating the transformer from the system.

3. Buchholz Relay: Used in oil-immersed transformers, this device detects gas accumulation due to insulation breakdown or other internal faults. It triggers an alarm or trips the transformer when gas is detected.

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Conventional Transformer Protection Techniques

4. Temperature Monitoring: Conventional systems often include temperature sensors that monitor the transformer's operating temperature. If the temperature exceeds safe limits, alarms are triggered, and protective measures can be initiated.

5. Voltage Protection: Voltage relays are utilized to monitor voltage levels and protect against overvoltage or undervoltage conditions that could harm the transformer.

While these conventional techniques provide essential protection, they often rely on **fixed thresholds** and **may not offer real-time insights** into the transformer's health or operational conditions.

Smart Transformer Protection with Continuous Monitoring Systems (CMS)

Smart transformers equipped with Continuous Monitoring Systems (CMS) represent a significant advancement in transformer protection and management. Key features of smart transformers include:

1. Real-Time Monitoring: CMS continuously collects data on critical parameters such as temperature, voltage, current, and insulation condition, providing real-time insights into the transformer's performance.

2. Predictive Maintenance: By analyzing the data collected, CMS can predict potential faults before they escalate, allowing for proactive maintenance rather than reactive measures. This reduces the risk of unexpected failures.

3. Enhanced Fault Detection: Smart transformers can detect Unusual occurrences and discrepancies in operation much earlier than conventional methods. Advanced algorithms analyze trends and patterns, enabling early intervention.

Smart Transformer Protection with Continuous Monitoring Systems (CMS)

4. Environmental Monitoring: CMS can monitor environmental factors such as humidity and temperature fluctuations that can impact transformer performance, allowing for better management of external conditions.

5. Data-Driven Insights: The continuous data collection allows for in-depth analysis and reporting, which can inform operational strategies, design improvements, and investment decisions.

6. Integration with Smart Grids: Smart transformers can communicate with other components in a smart grid, enabling coordinated responses to system demands and enhancing overall grid reliability.

Comparison of Conventional and Smart Transformer Protection Techniques

Feature	Conventional Protection Techniques	Smart Transformer with CMS
Monitoring	Periodic checks and fixed thresholds	Continuous real-time monitoring
Fault Detection	Relies on predefined thresholds and manual checks	Advanced algorithms for early fault detection
Maintenance Approach	Reactive maintenance based on alarms	Predictive maintenance based on data analysis
Data Insights	Limited data collection and analysis	Extensive data collection with trend analysis
Response to Anomalies	Manual intervention required after alarms	Automated alerts and proactive measures
Environmental Factors	Limited monitoring of external conditions	Comprehensive environmental monitoring
Integration	Standalone systems with limited communication	Integrated with smart grid technologies

Benefits of Smart Power Transformers in Asset Performance Optimization

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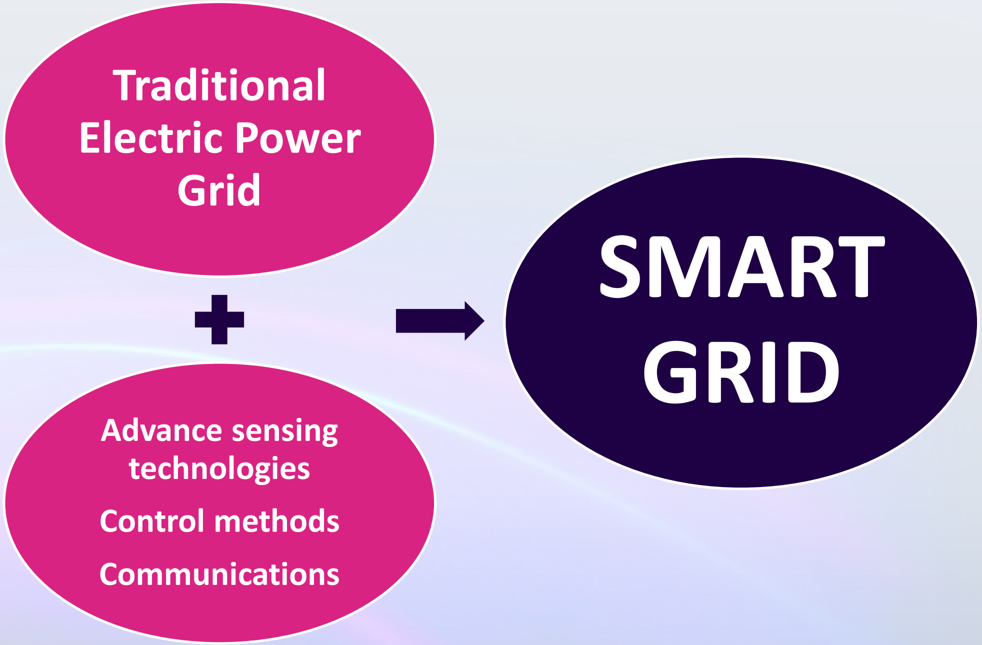
Benefits of Smart Power Transformers in Asset Performance Optimization

Traditional Electric Power Grid

- **One-Way Energy Flow**: Electricity flows in a single direction.
- **Limited Monitoring and Control:** minimal visibility into the real-time performance
- **Susceptibility to Outages.**

SMART GRID

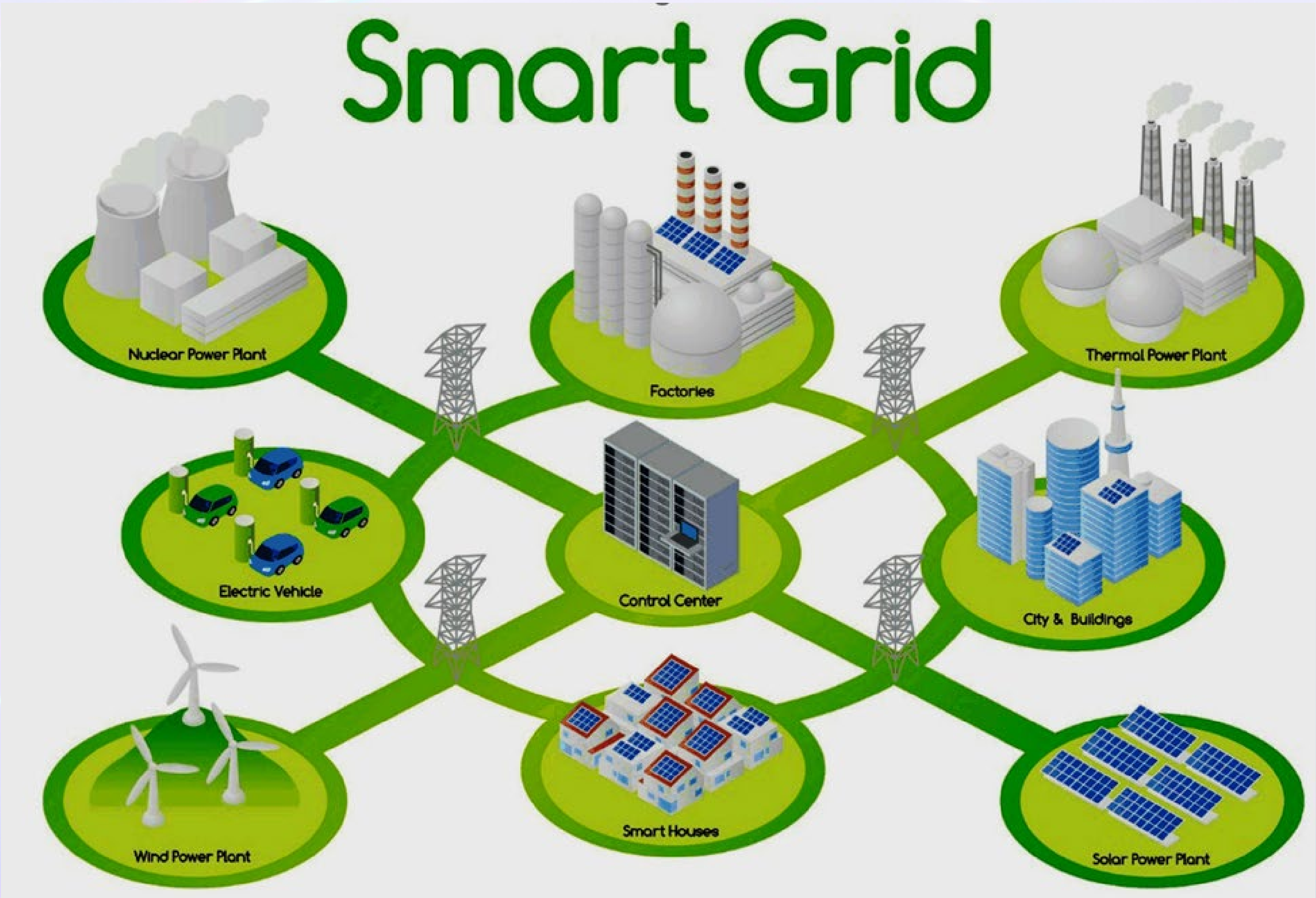
- A **Smart Grid** is an electricity network/grid enabling a two-way flow of electricity and data whereby smart metering is often seen as a first step. Smart grids – as a concept – became known over a decade ago and are essential in the digital transformation of the electricity sector.
- A smart grid puts information and communication technology into electricity generation, delivery, and consumption, making systems cleaner, safer, and more reliable and efficient.
- The Smart Grid is a combination of hardware, management and reporting software, built a top an intelligent communications infrastructure



Benefits of Smart Power Transformers in Asset Performance Optimization

SMART Grid

- **Two-Way Communication**: Enabling real-time data exchange between utilities and consumers.
- **Advanced Metering Infrastructure (AMI):** remote monitoring and management of energy consumption.
- **Enhanced Reliability and Resilience**: quickly detect and respond to faults, minimizing outages and improving service quality.



SMART Transformer

Today's transformers include multiple **Intelligent Electronic Devices**, which can assess the condition of the transformer and make intelligent recommendations based on design and component data.

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SMART Transformer

Transformers equipped with a Continuous Monitoring System (CMS) offer numerous benefits that enhance their performance, reliability, and lifespan. Here are some key advantages:

1. **Real-Time Data Acquisition**: CMS provides continuous, real-time monitoring of critical parameters such as temperature, voltage, current, and insulation condition.

2. **Early Fault Detection**: By continuously analyzing data, CMS can identify potential faults before they escalate into serious issues. Early detection of problems such as insulation degradation or overheating can significantly reduce the risk of transformer failures.

3. **Improved Maintenance Practices**: With real-time insights from CMS, maintenance can be performed based on actual condition rather than on a fixed schedule. This predictive maintenance approach helps in optimizing maintenance activities, reducing downtime, and extending the lifespan of the transformer.

SMART Transformer

4. **Enhanced Safety**: Continuous monitoring helps in ensuring that the transformer operates within safe parameters. By detecting issues such as overheating or insulation breakdown early, CMS can prevent catastrophic failures that could pose safety risks to personnel and equipment.

5. **Optimized Performance**: CMS allows for better management of transformer loads and operational conditions. By monitoring performance metrics, operators can make informed decisions to optimize efficiency, reduce losses, and enhance overall system performance.

6. **Data-Driven Insights**: The data collected by CMS can be analyzed to identify trends and patterns in transformer performance over time. This information can inform design improvements, operational strategies, and investment decisions.

7. **Extended Lifespan**: By addressing potential issues proactively and ensuring optimal operating conditions, CMS contributes to extending the operational life of transformers. This can lead to significant cost savings over time by delaying the need for replacements.

SMART Transformer

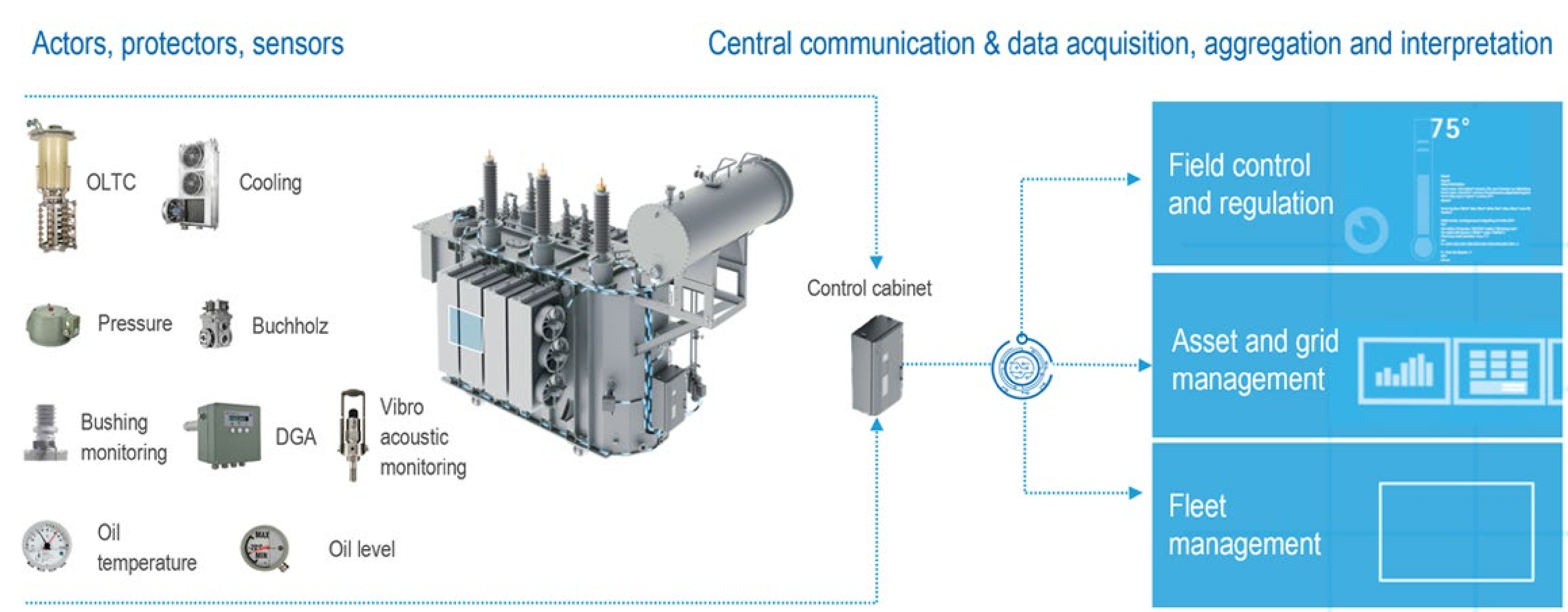
8. **Environmental Monitoring**: CMS can also monitor environmental conditions around the transformer, such as humidity and temperature fluctuations, which can impact performance. This allows for better environmental controls to be implemented.

9. **Regulatory Compliance**: Continuous monitoring can assist in meeting regulatory requirements and industry standards for transformer operation and maintenance, ensuring compliance and reducing liability risks.

10. **Enhanced Reliability**: With the ability to monitor and analyze performance continuously, transformers with CMS are less likely to experience unexpected failures, leading to increased reliability in power distribution systems.

SMART Transformer

- The operator can **Remotely Monitor** the behavior of the Transformer Core, Windings, Oil, Tap Changer and Bushings, thereby, keeping a close watch on critical transformer components.
- Close monitoring of Power Transformer Components conditions will **Improve Power Quality** and significantly **Reduce the Down-time** of electricity supply.



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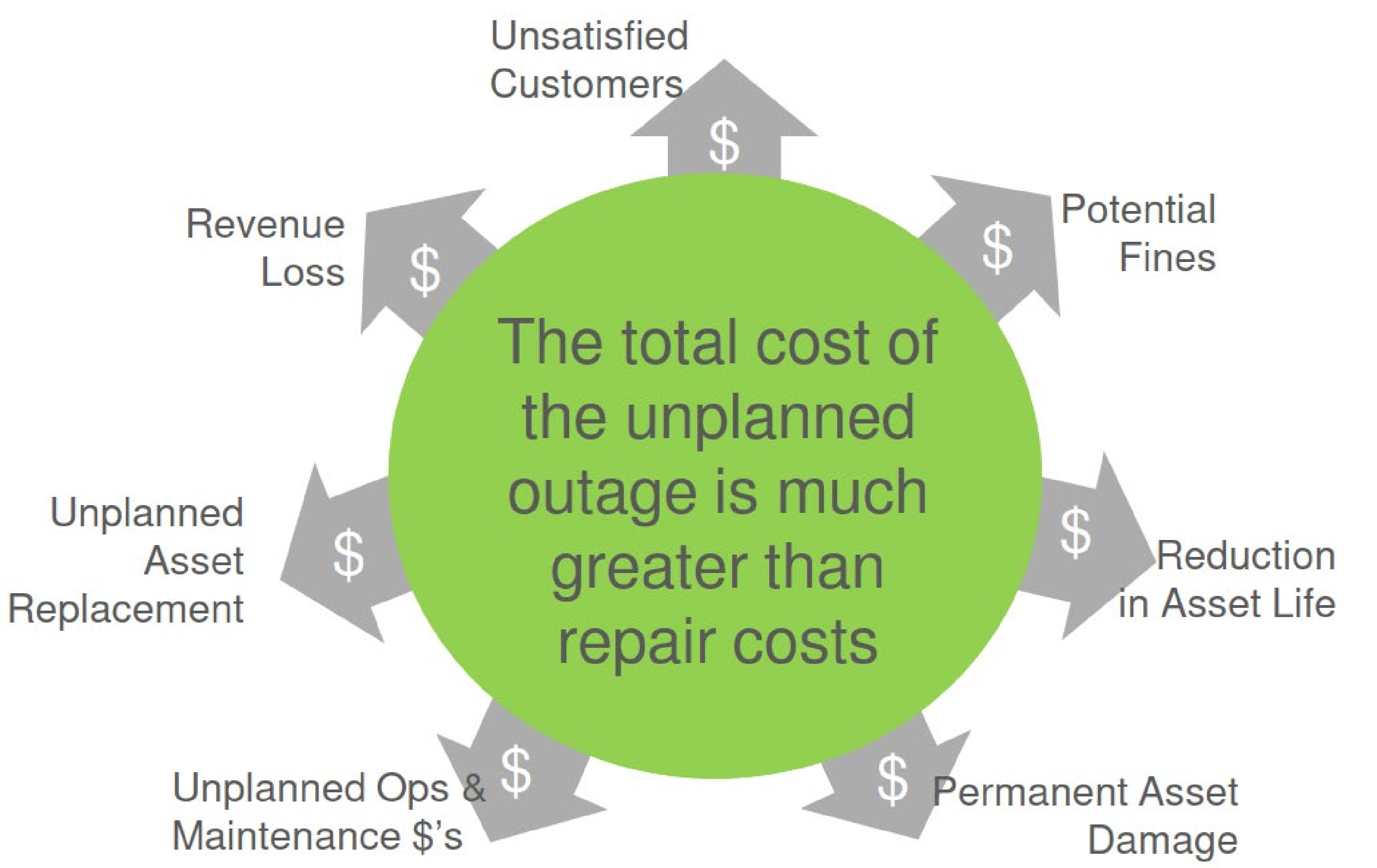
The Importance of Asset Management

The role of power transformers in the electrical infrastructure cannot be overstated. However, like all assets, transformers are subject to wear and degradation over time.

Advanced asset management practices are crucial for:

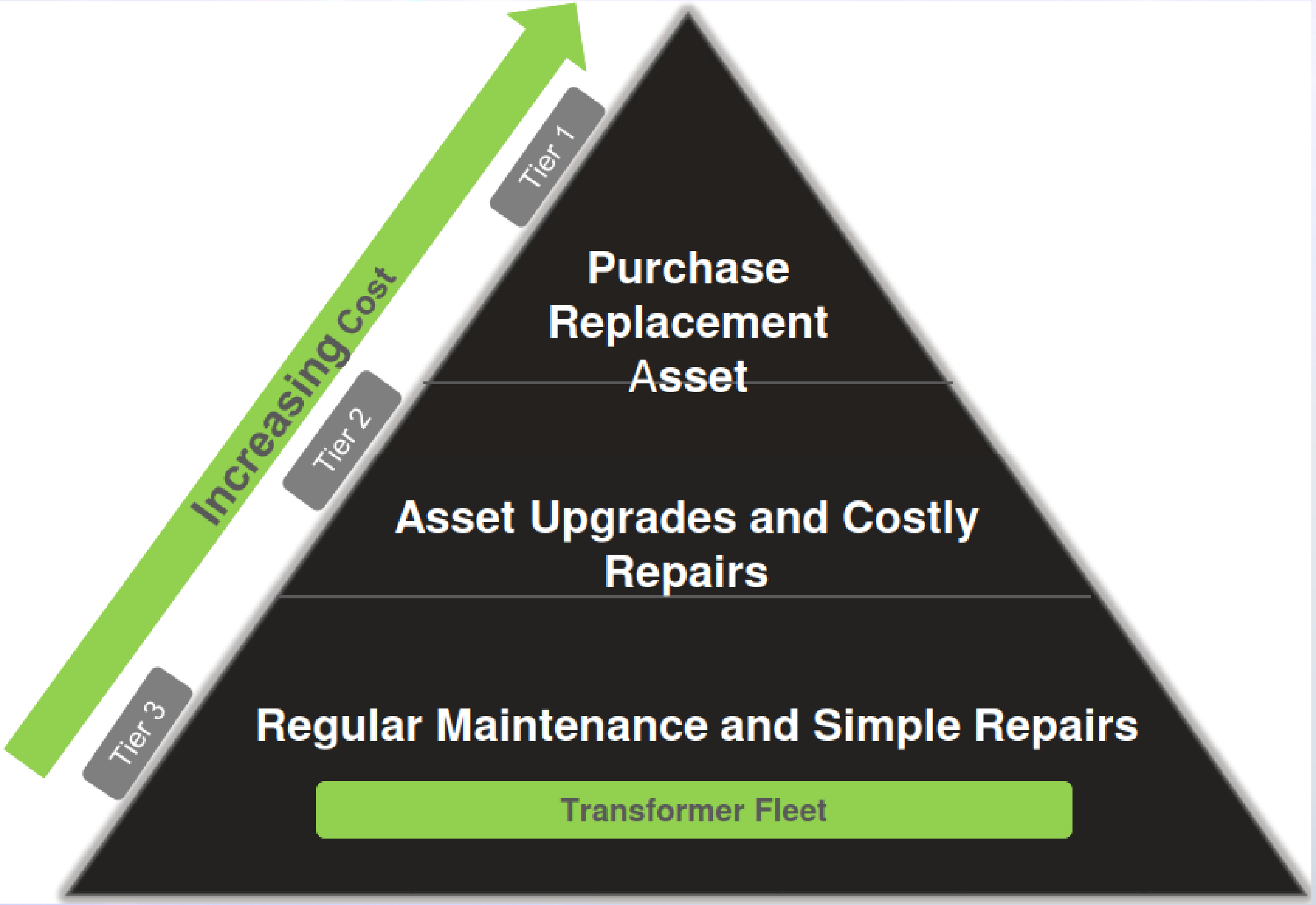
- ✓ **Maximizing Asset Lifespan.**
- ✓ **Ensuring Reliability.**
- ✓ **Optimizing Performance.**
- ✓ **Cost Reduction.**



The Importance of Asset Management

The integration of such advanced technology:

- **Paves the way for smarter energy management practices.**
- **Allowing utilities to respond swiftly to changing demands and maintain a stable grid.**



Integration Strategies

Strategic Integration of Smart Power Transformers in the Saudi Arabia Electricity Network.

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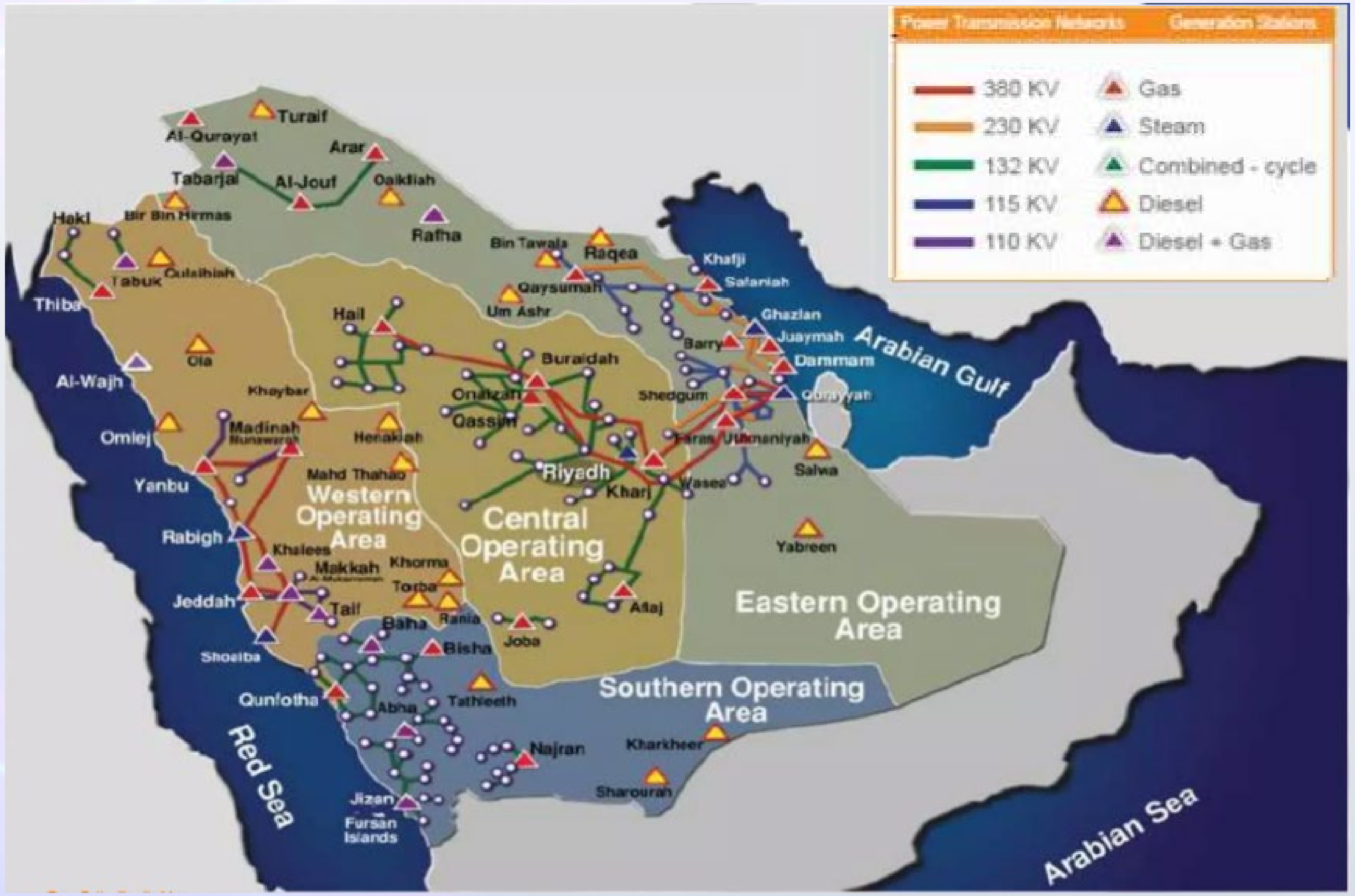
The Power System Network in Saudi Arabia: An In-Depth Exploration

Saudi Arabia has been rapidly developing its electricity infrastructure to meet the demands of its growing population and economy.

The **SEC** operates an extensive network of over **60,000** kilometers of transmission lines.

❑ Voltage Levels

The transmission system operates at various voltage levels, including 110 kV, 230 kV, and 380 kV. The higher the voltage, the more efficient the transmission of electricity over long distances.



Reference: Saudi Electricity Company's presentation at the 2010 U.S.-Saudi Business Opportunities Forum in Chicago, IL.

❑ Challenges in Transmission

The transmission network faces several challenges, including:

- **Aging Infrastructure**: Some parts of the transmission network are aging and require upgrades to maintain reliability.
- **Capacity Constraints**: Rapid population growth and industrialization have led to increased electricity demand, putting pressure on the transmission system.
- **Integration of Renewables**: The integration of renewable energy sources poses technical challenges, requiring upgrades to the existing transmission infrastructure.

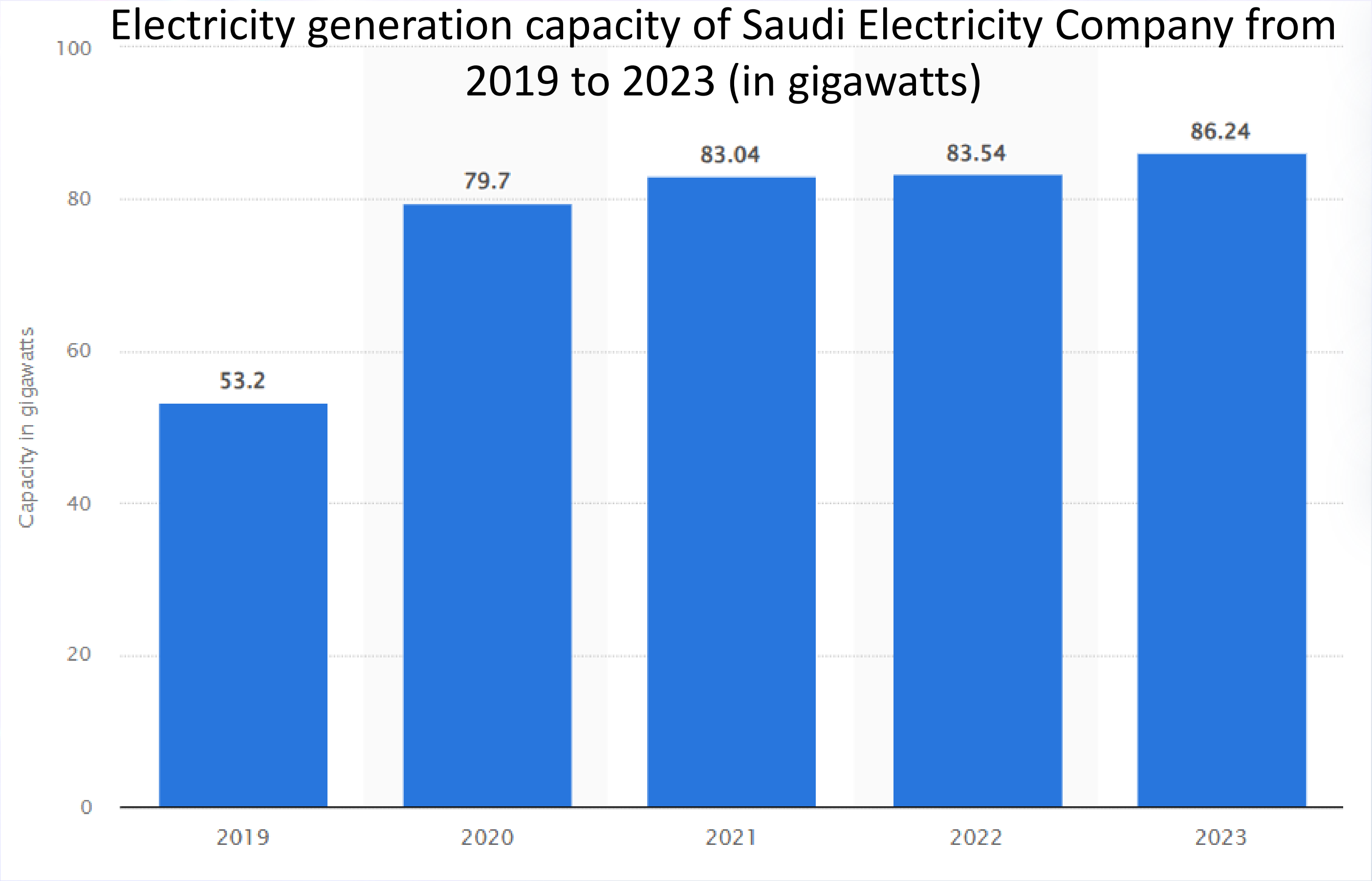
The Power System Network in Saudi Arabia: An In-Depth Exploration

❑ Electricity Generation Capacity

As of now, Saudi Arabia's total electricity generation capacity is approximately **86.24 gigawatts (GW) in 2023.** The majority of this capacity is derived from natural gas and oil-fired power plants, with a growing contribution from renewable energy sources.

Saudi Arabia is focusing on expanding its electricity generation capacity, integrating renewable energy, and addressing the challenges posed by increasing demand to ensure a reliable power supply for the future.

In the first nine months of 2024, KSA's power generation capacity connected to the grid increased by 1.4% (**87.424GW**) compared to 2023-year end.



Reference: SEC website, Earnings Release Report FY 2023. 06 MARCH 2024.

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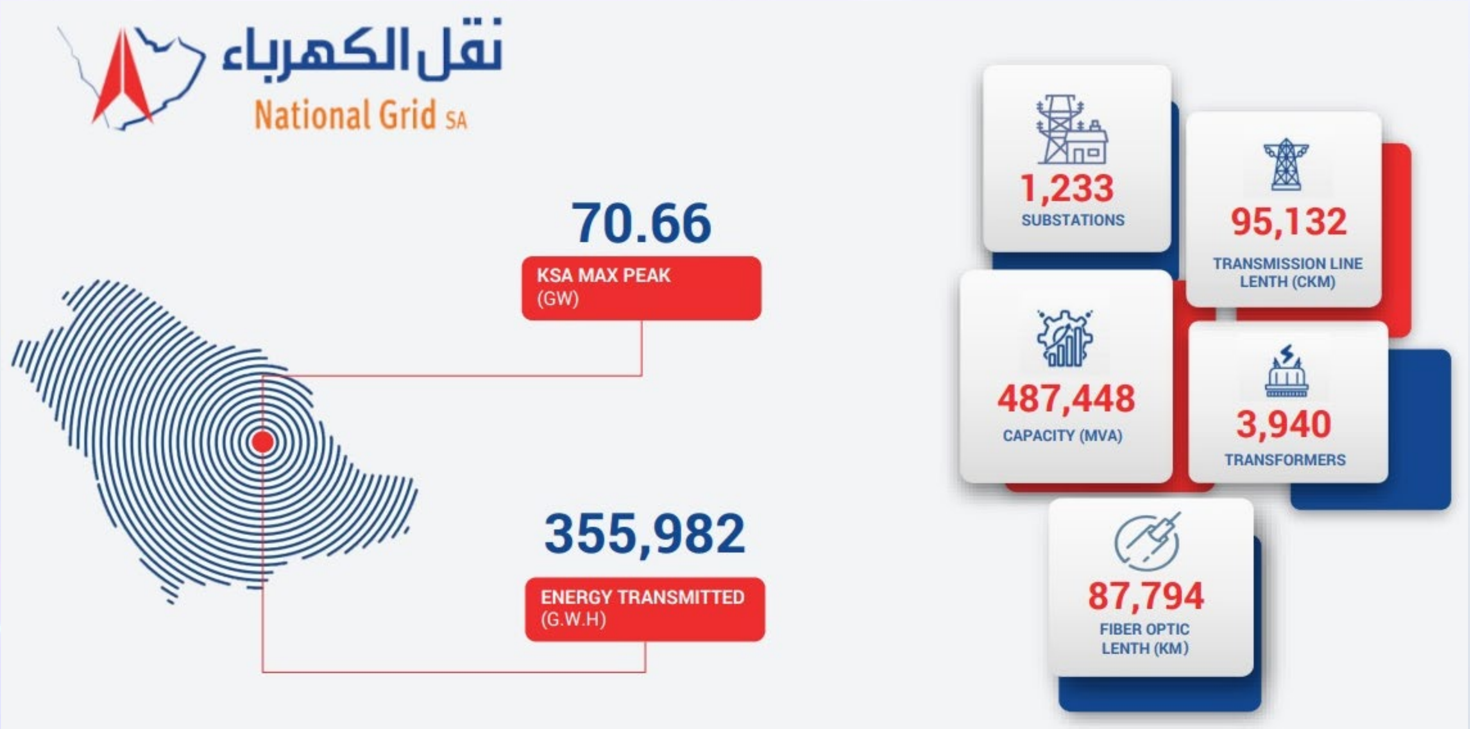
The Power System Network in Saudi Arabia: An In-Depth Exploration

❑Maximum Load

The maximum load in Saudi Arabia has reached around **70 GW**, reflecting the peak demand for electricity during high consumption periods. This demand is driven by factors such as population growth, urbanization, and industrialization.



Reference: National Grid SA website.

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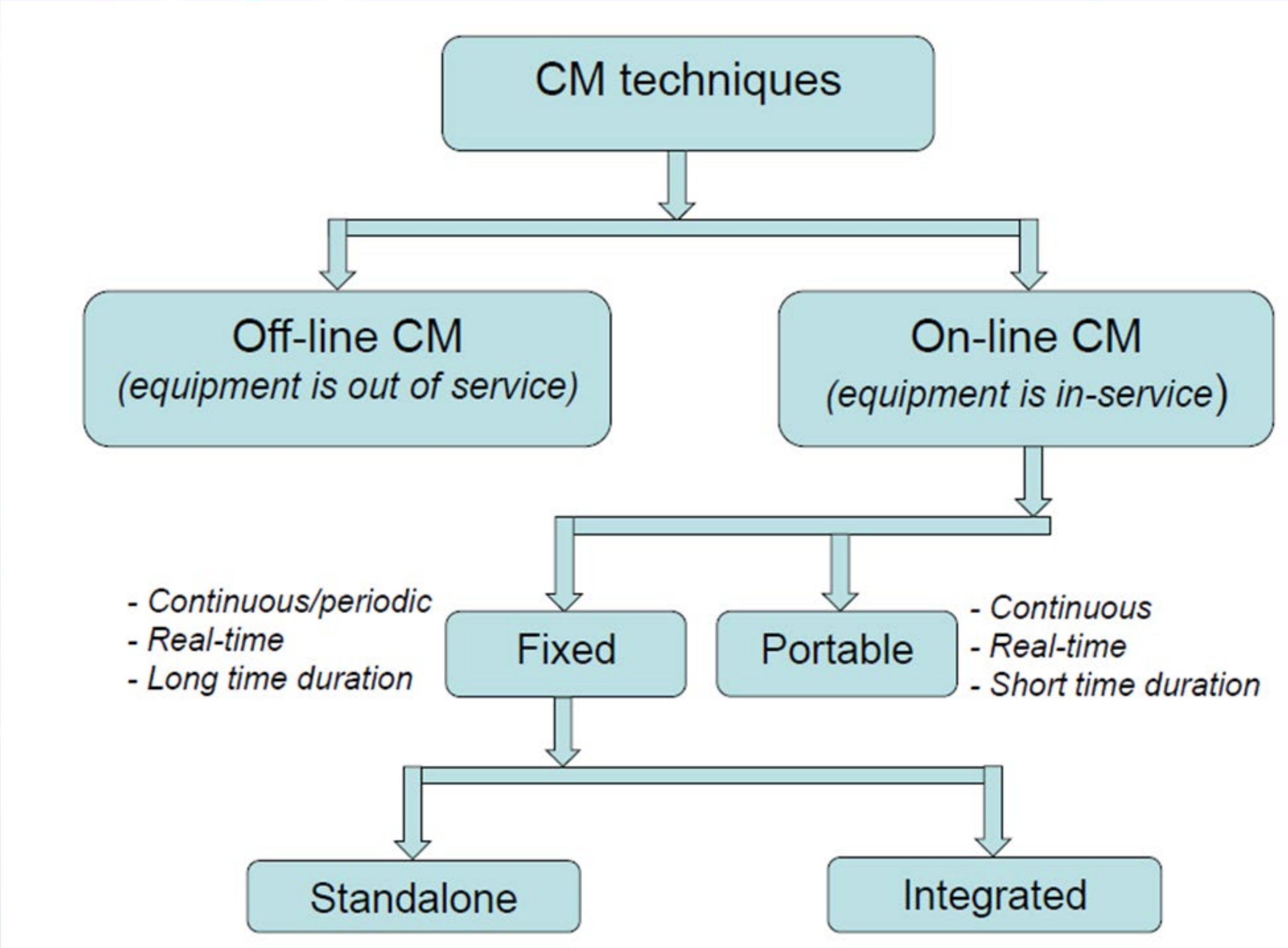
Condition Monitoring System integration in Saudi Arabia Network

Off-line CM techniques are applied when equipment is out-of-service.

On-line CM techniques can be applied when equipment is in-service. Online CM techniques can be further classified based on fixed or portable sensors used to take measurements as shown in this Figure.

The fixed sensors can be standalone or integrated into SCADA for enhanced power system automation (PSA).



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Strategic Integration of Smart Power Transformers in the Saudi Arabia Electricity Network.

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Case Studies and Best Practices

Examples of Successful Integration & CMS Best Practices in Saudi Arabia

CMS different configurations

SPTC partnership with CMS vendors

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Examples of Successful Integration & CMS Best Practices in Saudi Arabia

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Examples of Successful Integration in SEC Network

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Successful integrations with SEC Network

Key Monitoring Functions successfully integrated in SEC network.

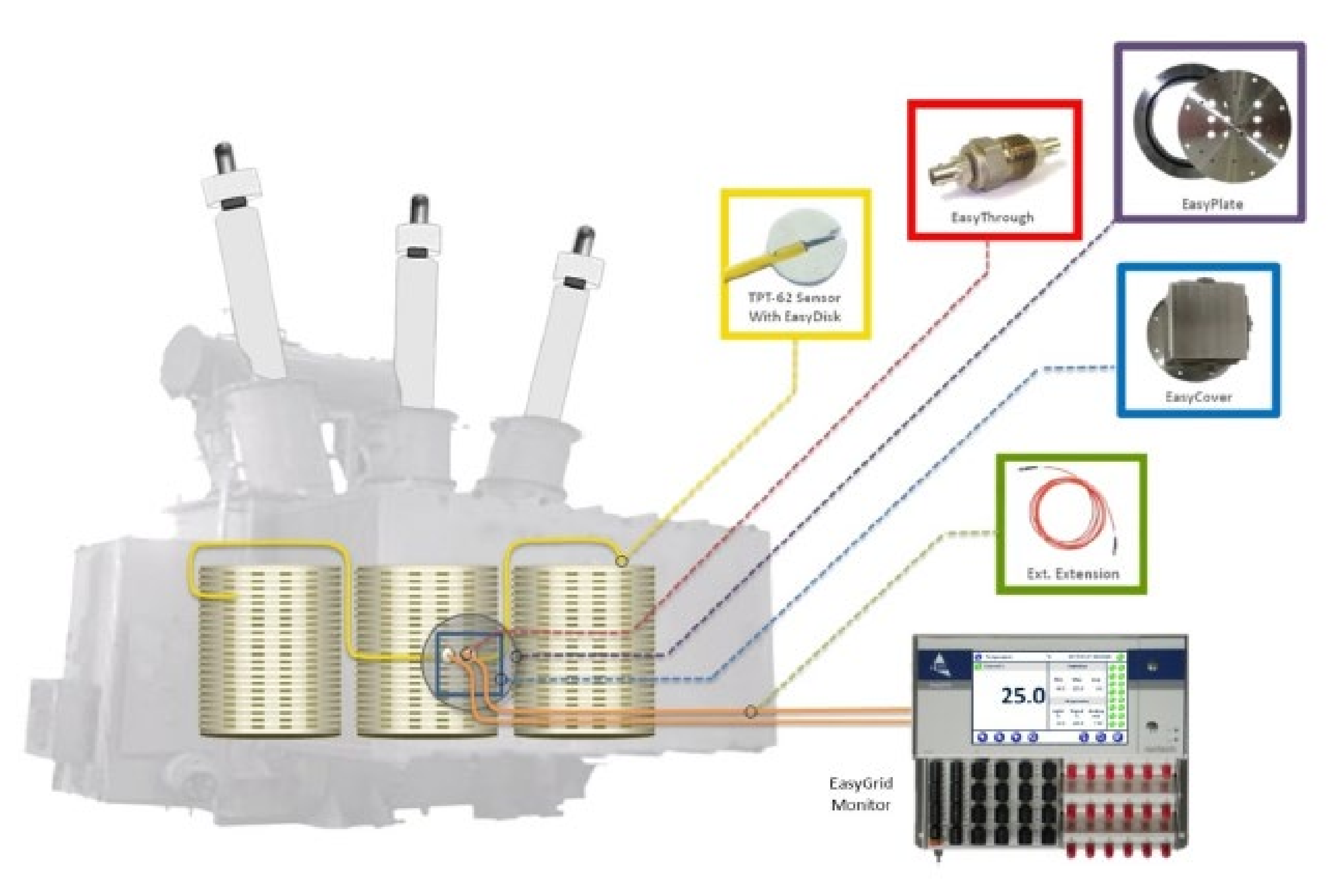
- **Direct Winding Hot Spot Monitoring from reputed OEMs like Qualitrol, Rugged Monitoring, FISO and MR.**

One of the most critical aspects of transformer health is the monitoring of winding hot spots. These hot spots can lead to insulation breakdown and eventual failure if not detected early. Real-time temperature sensors placed within the windings provide continuous data.

Successful integrations with SEC National Grid Projects

How it works:

Fiber optic internal sensors placed within the windings and terminated to Tank wall plate "TWP" though Optical feed though "OFT", where an external FO cord is connected to the monitoring device for further **real time** temperature monitoring and further alarm signals sent directly to SAS, allowing operators to identify abnormal temperature rises and take appropriate action to prevent damage.



Successful integrations with SEC National Grid Projects

Key Monitoring Functions successfully integrated in SEC network.

- **Dissolved Gas Analysis (DGA) from reputed OEMs like Doble/Morgan Schaffer, GE Kelman Minitrans, GE DGA900, Camlin TOTUS G9.**

Dissolved gas analysis is a critical monitoring technique used to assess the condition of transformers. It involves analyzing gases dissolved in transformer oil, which can indicate potential faults. Regular DGA sampling provides a consistent view of transformer health, and online DGA monitors offer continuous data, bridging the gap between periodic samples and providing early warnings of potential failures.

Successful integrations with SEC National Grid Projects

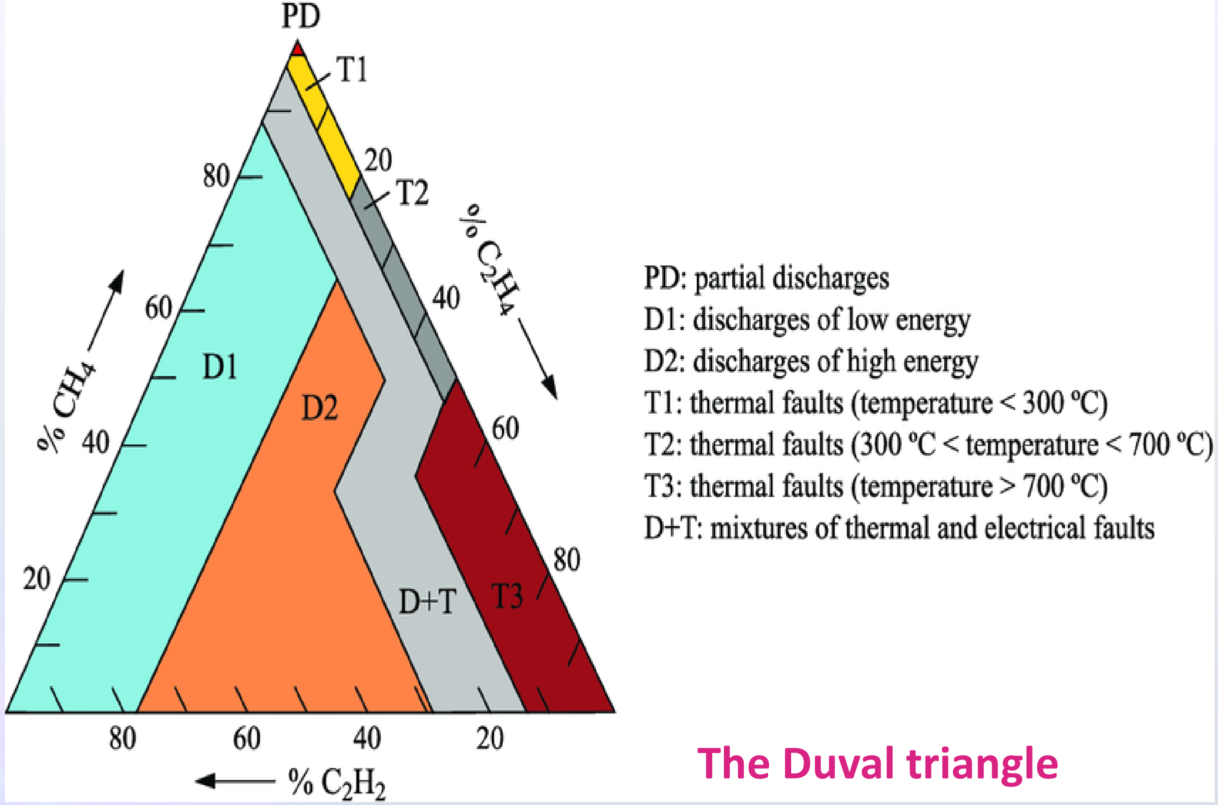
Enhancing Transformer Reliability with Dissolved Gas Analysis (DGA)

Dissolved Gas Analysis (DGA) is an essential technique in improving the reliability of power transformers. Here's how it contributes to enhanced reliability:

- **Early Detection of Faults.**
- **Regular Monitoring.**
- **Trend Analysis.**
- **Flexible Monitoring Options**
- **Data-Driven Decision Making.**

Gases Indicating Specific Transformer Faults

- **Hydrogen (H_2)**: The presence of hydrogen can indicate a range of issues, including **partial discharges**.
- **Methane (CH_4) and Ethylene (C_2H_4):** The presence of these gases can indicate **overheating** of the oil or cellulose insulation.
- **Acetylene (C_2H_2)**: Acetylene is a strong indicator of **arcing** within the transformer.
- **Ethane (C_2H_6):** It can be produced alongside methane and ethylene, providing additional context for **thermal faults**.
- **Carbon Monoxide (CO) and Carbon Dioxide (CO_2):** High levels of carbon monoxide and carbon dioxide suggest that the paper insulation is **breaking** down.



The Duval triangle

Successful integrations with SEC National Grid Projects

Let's do an example. From a lab measurement we get the following DGA values:

H_2: 8 ppm. **<u>CH_4: 1313 ppm</u>**. **<u>C_2H_2: 2908 ppm</u>**. **<u>C_2H_4: 616 ppm</u>**.

C_2H_6: 420 ppm. CO: 450 ppm. CO_2: 1069 ppm.

We only need the values of C_2H_2, CH_4 and C_2H_4. The other values are not used in the Duval triangle method.

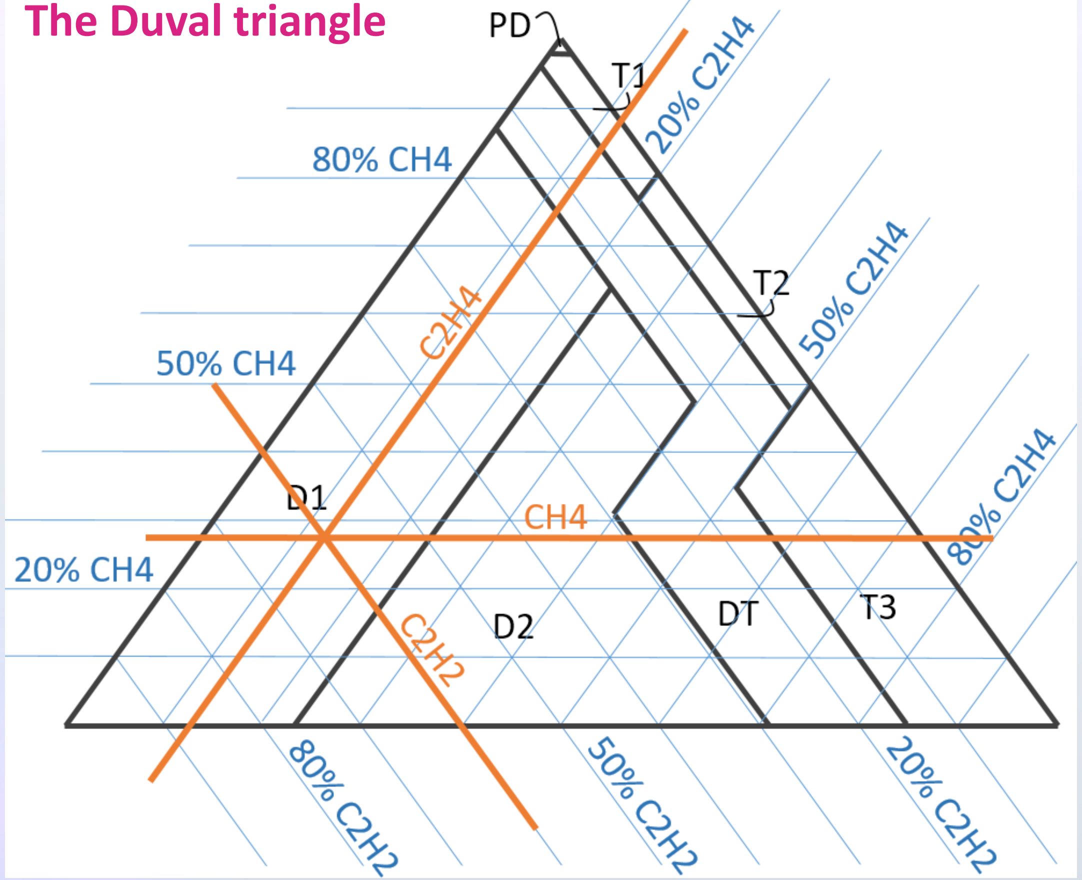
- **Example Calculation**
- The percentage of **C_2H_2** is 2908/(2908 + 1313 + 616) = 0.601 = **60.1%**.
- The percentage of **CH_4** is 1313/(2908 + 1313 + 616) = 0.271 = **27.1%**.
- The percentage of **C_2H_4** is 616/(2908 + 1313 + 616) = 0.127 = **12.7%**.

The corresponding lines are drawn parallel to the labelling of the axes.

The point of intersection lies in the area called **D1**, meaning **low energy discharge, or sparking.**

The Duval triangle can only be used for fault classification, but not for fault detection. In other words: Before doing any of this, be sure that your transformer is actually faulty.

The Duval triangle

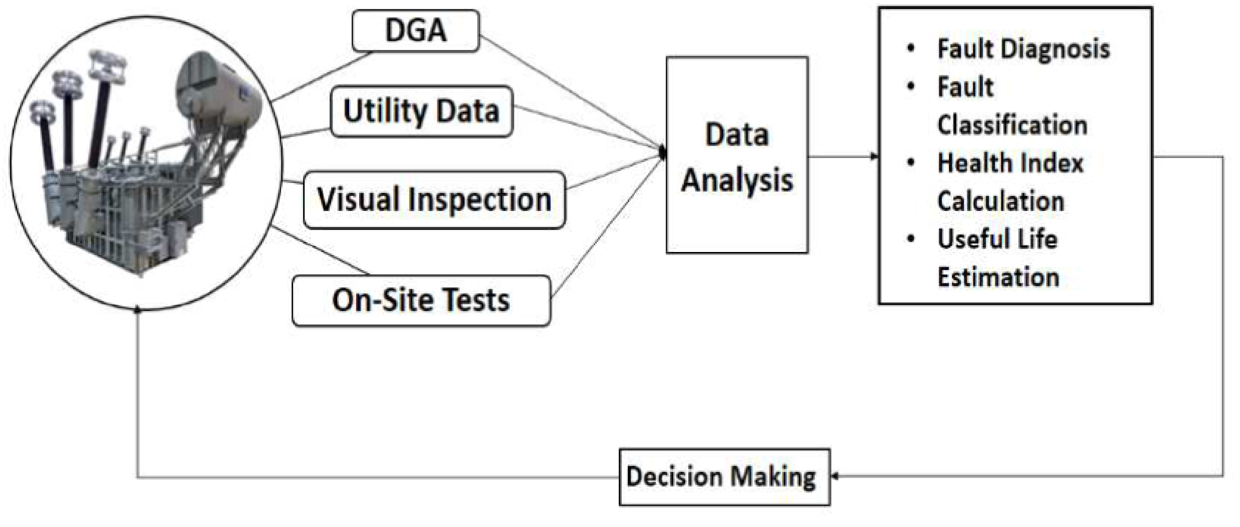


Successful Integrations with SEC National Grid Projects

Integration of DGA with Asset Management

Dissolved Gas Analysis (DGA) plays a crucial role in the asset management of power transformers by providing insights into the condition and health of these critical assets. Here's how DGA integrates with asset management:

- ✓ **Condition Monitoring.**
- ✓ **Short and Long-Term Analysis.**
- ✓ **Early Warning System.**
- ✓ **Decision Making.**
- ✓ **Response Planning**
- ✓ **Balancing Interventions.**



Proposed power transformer monitoring system

By integrating DGA into asset management practices, organizations can ensure the reliability and durability of their transformer assets, optimizing maintenance schedules and minimizing the risk of unexpected failures.

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Examples of Successful Integration in Saudi ARAMCO

Condition Monitoring System

Successful Integrations with SAUDI ARAMCO

In addition to the key functions previously illustrated (Direct Winding Hot Spot Monitoring) & (Dissolved Gas Analysis (DGA)), here we can see that for ARAMCO the most advanced system are successfully integrated including below main key functions, like:

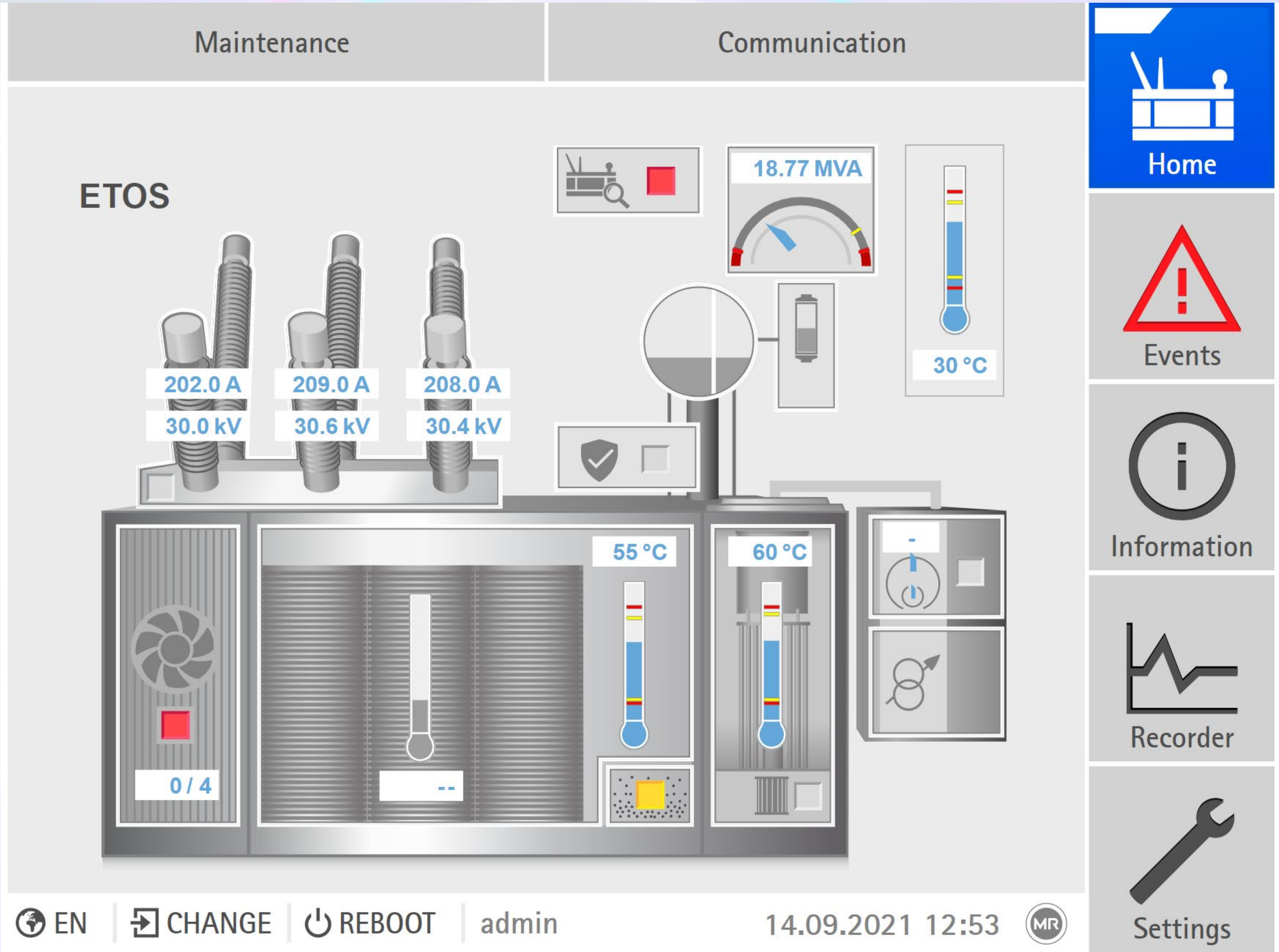
- **Bushing Monitoring Integration.**
- **Load, Power, and Losses Monitoring.**
- **Partial Discharge Detection.**
- **Essential Monitoring Parameters.**
- **Cooling Monitoring and OLTC Monitoring.**
- **Voltage regulation.**

Leading us to know more about the identity of Smart Transformer.

Condition Monitoring System Definition

- **Transformer Monitoring** Solution combines the outputs from all available transformer **Sensing Devices**. It correlates and **Analyses** these data, to provide not only an aggregated view of the **Transformer's Health** (to minimize the risk of outage) but also to help you **Optimize** its operation and maintenance.

- An "**all-in-one expert system**" to help you manage your valuable transformers, maximizing transformer availability, reliability and performance at lowest life-cycle cost through monitoring of all transformer main components.



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Why Condition Monitoring System?

- **Power Transformers** are **Critical** part of an electrical utility's asset base. Loss of a transformer due to an Unexpected **Failure** in a utility, generation plant or process can cost many **millions of dollars**, depending on the failure consequences and how long it is out-of-service.

- Power transformers are critical and expensive component, its safe operation with good **Reliability** is always considered important by the utilities. In the last few years, **On-Line Monitoring** has gained popularity, since it has the advantage over periodic tests allowing for instant detection of sudden growth of any defects.

- **On-Line Monitoring** increases the **Reliability** of transformers and helps **Managing** the growing **Risk** of an aging of power transformers and its components.

Condition Monitoring System Benefits

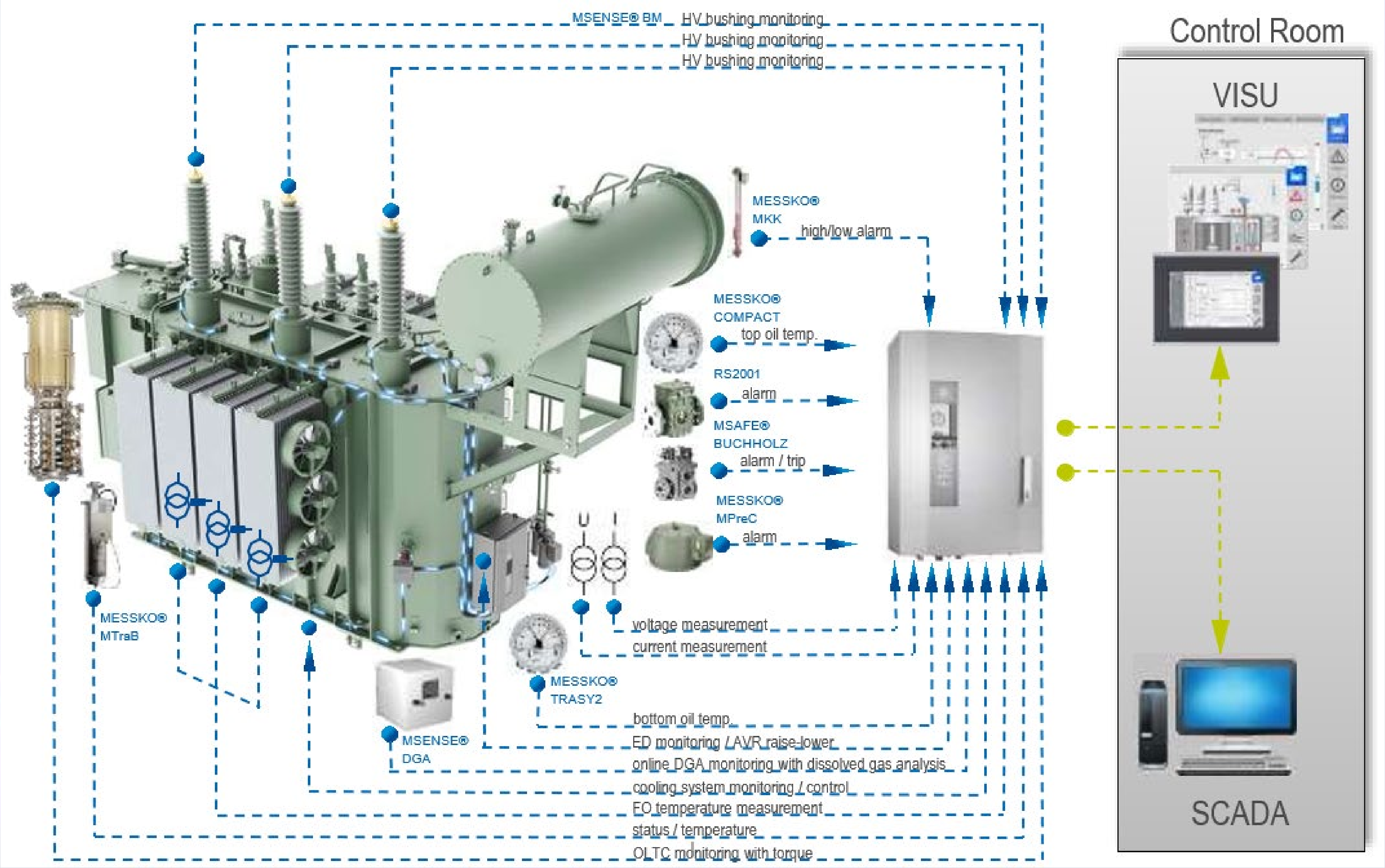
- **Incipient Fault Detection:**
  - ✓ Prevention of unplanned outages
  - ✓ Reduction of major failures
  - ✓ Enhancement of operational safety

- **Optimized Operation:**
  - ✓ Dynamic loading/overloading
  - ✓ Reduced auxiliary power usage

- **Intelligent Maintenance:**
  - ✓ Of OLTC, Bushings and Cooling System
  - ✓ From fail-and-fix and time-based maintenance to condition-based maintenance

- **Asset Management:**
  - ✓ Health diagnostic
  - ✓ Extended lifetime program
  - ✓ Asset replacement plan

Condition Monitoring System Architecture



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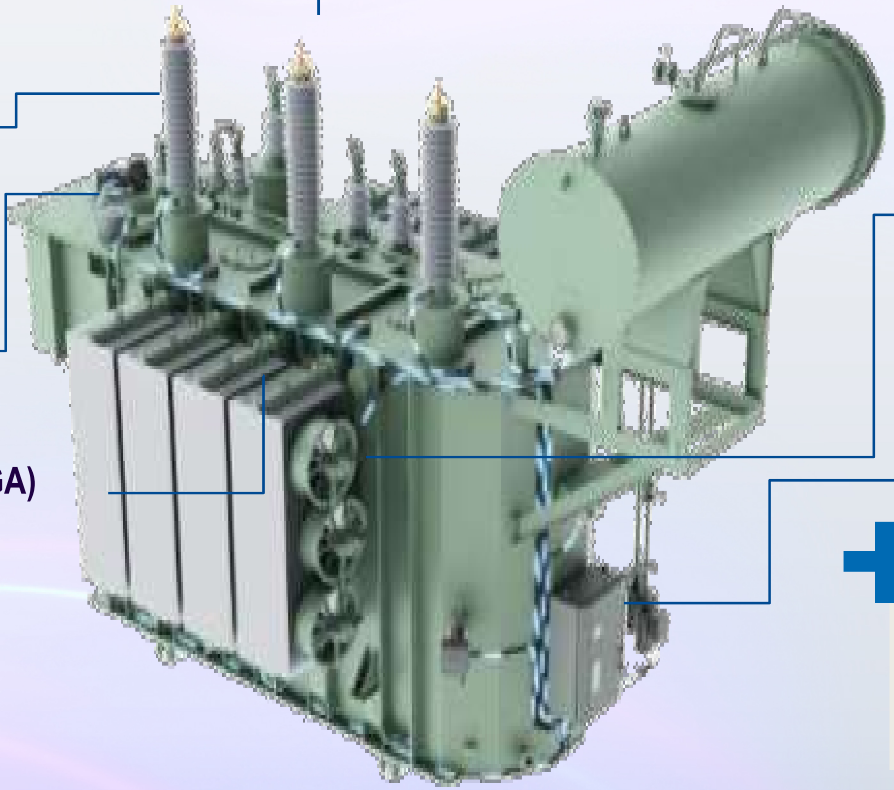
Reference: MR system Architecture.

CMS Key Monitoring Functions



Monitoring

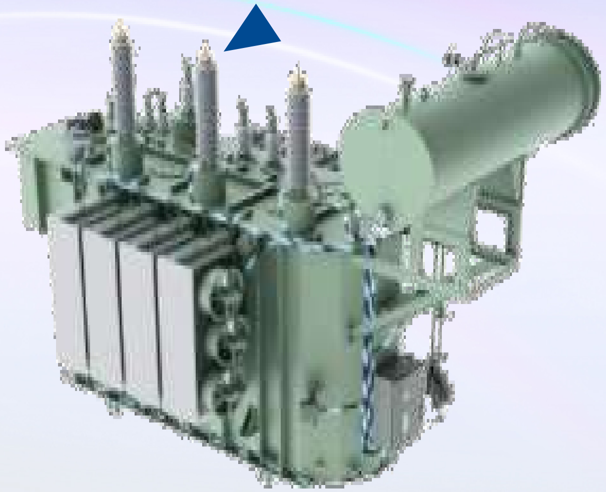
- Transformer monitoring
- Bushing monitoring
- OLTC monitoring
- Dissolved Gas Analysis (DGA)

Regulation / Control

- Cooling system control and monitoring
- Voltage regulation

+ Additional functions
- visualization and communication
- Integration of a standard cooling control cubicle
- Integration of an oil filter unit

CMS Key Monitoring Functions

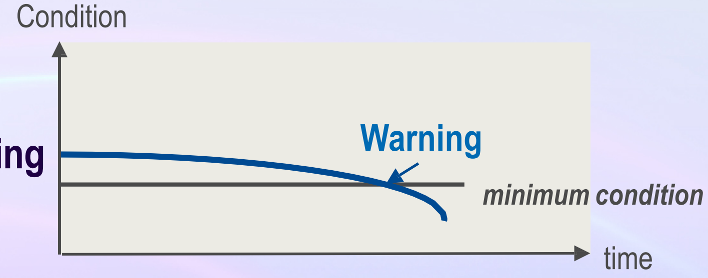


Bushing Monitoring Integration

Functions

- I Monitoring of changes in C1 capacitance
- I PD Partial Discharge Monitoring
- I Monitoring of the dissipation factor (tanδ)
- I Preset limits for optimal monitoring
- I Recording system voltage for effective elimination of network imbalances
- I For new transformers or retrofit

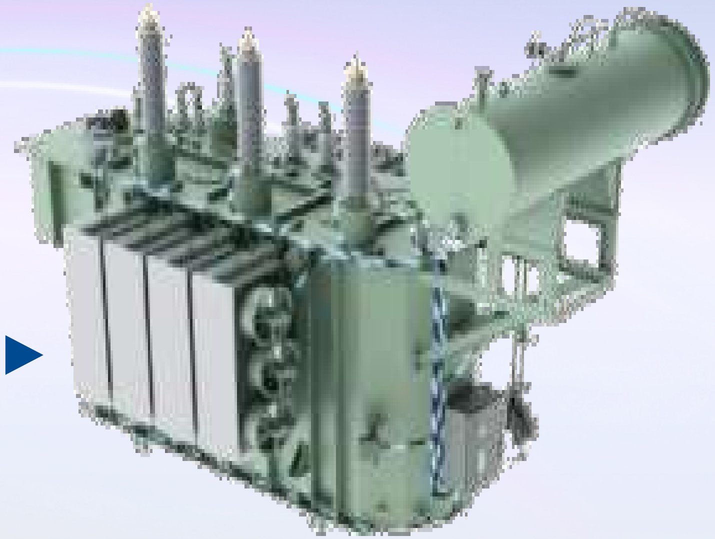
Continuous status monitoring of bushings



HV

	Phase L1		Phase L2		Phase L3
F1: C1	0.662 nF	F1: C1	0.600 nF	F1: C1	0.600 nF
F1: ΔC1	129.76 %	F1: ΔC1	0.00 %	F1: ΔC1	0.00 %
F1: tanδ	0.30 %	F1: tanδ	0.30 %	F1: tanδ	0.30 %
F1: Δtanδ	0.00 %	F1: Δtanδ	0.00 %	F1: Δtanδ	0.00 %
F1: U ref	190.1 kV	F1: U ref	192.9 kV	F1: U ref	190.7 kV

CMS Key Monitoring Functions



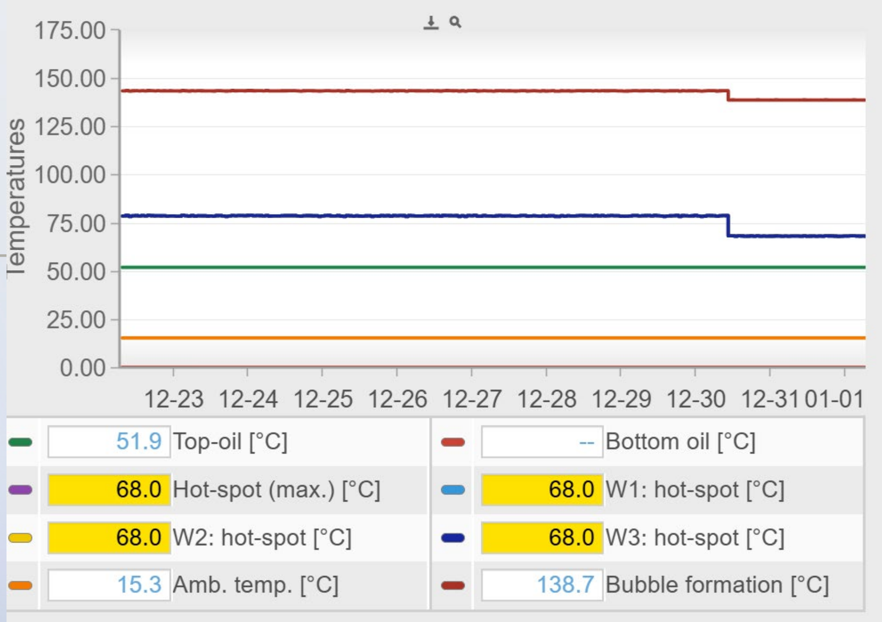
Essential Transformer Monitoring

Basic functions

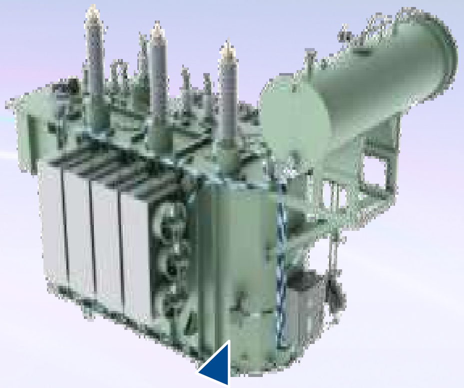
- Status monitoring RS2001, Buch. relay, PRD, cooling fans monitoring
- Monitoring of oil temperature
- System voltage, load current, frequency, load factor, active power, reactive power, apparent power
- Hot-spot calculation in accordance with IEC 60076-7 or ANSI/IEEE C57.91
- Calculation of aging rate and loss-of-life
- Tap position capture of the OLTC
- Measured value memory.

Extended functions

- Calculation of the bubbling temperature
- Calculation of paper moisture content



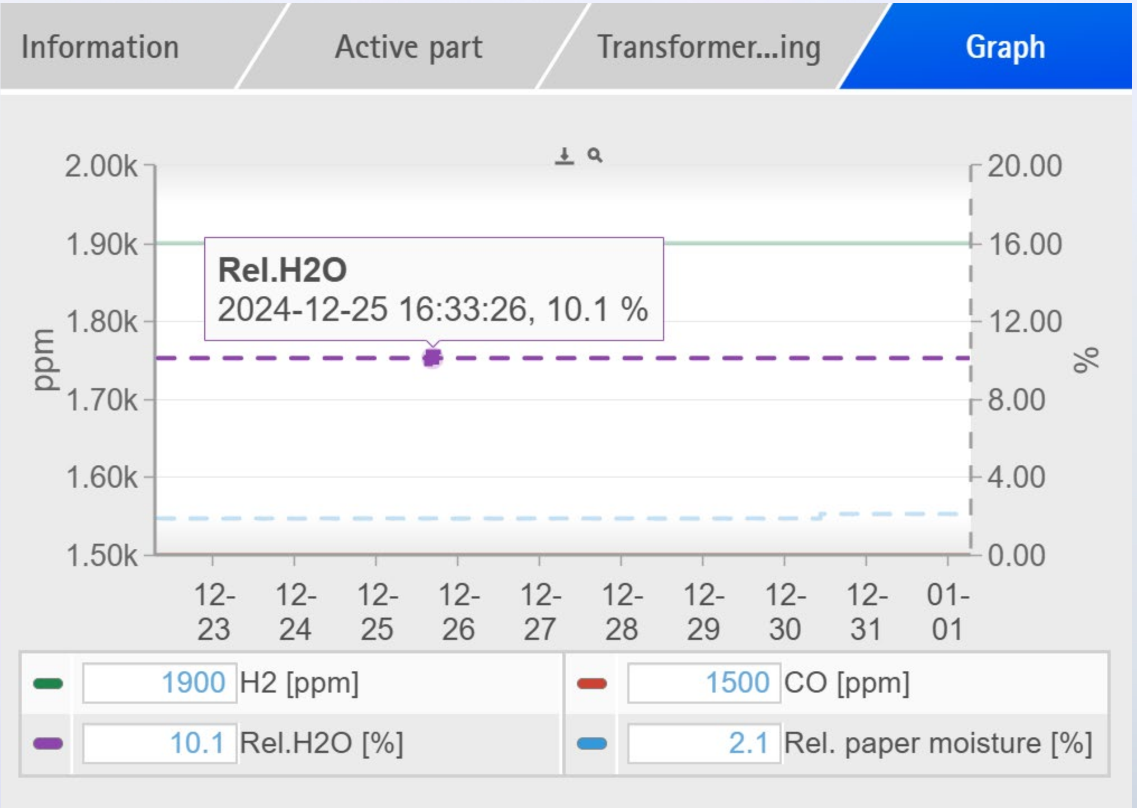
CMS Key Monitoring Functions



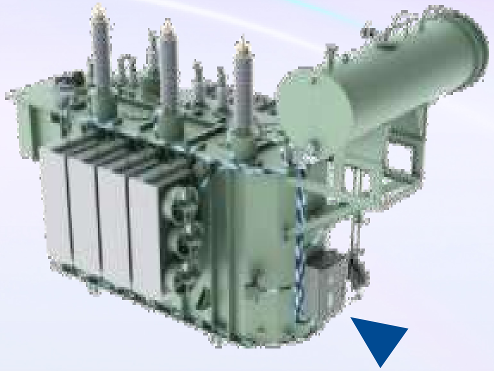
Online Dissolved Gas Analysis (DGA)

Basic functions

- Online recording of up to nine dissolved gases, relative moisture in oil, and relative overall gas content
- Configurable limit value for each gas
- Curve display of the measured values
- Universal 4…20mA or Modbus RTU interface for capturing the DGA sensor signals.



CMS Key Monitoring Functions



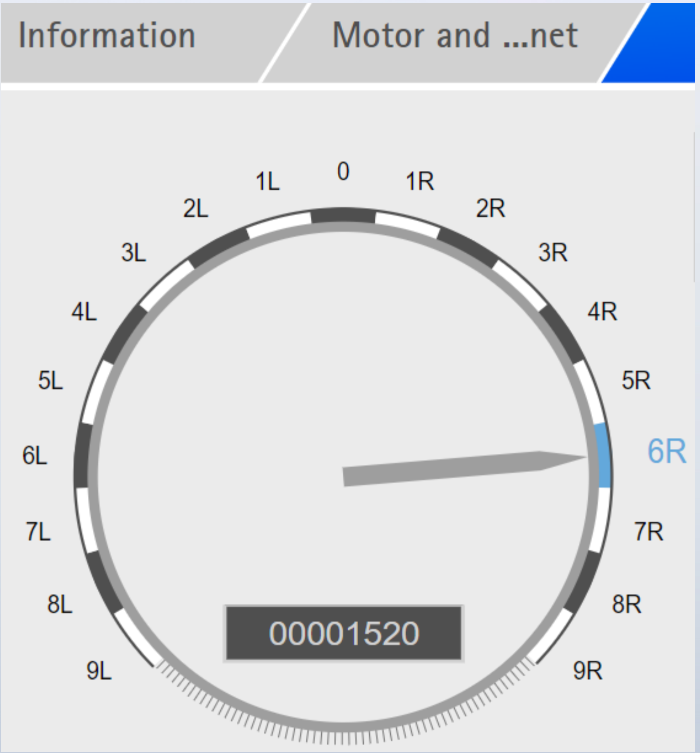
OLTC Monitoring

Basic functions

- Status monitoring of the motor-drive signals
- Maintenance recommendations / maintenance interval calculation OLTC.
- Calculation of contact wear.
- Tap-position statistics for the OLTC (number of tap-change operations per tap, duration per tap)
- Monitoring of OLTC oil temperature

Extended functions

- Motor Current Index (MCI) in accordance with IEEE PC57.143



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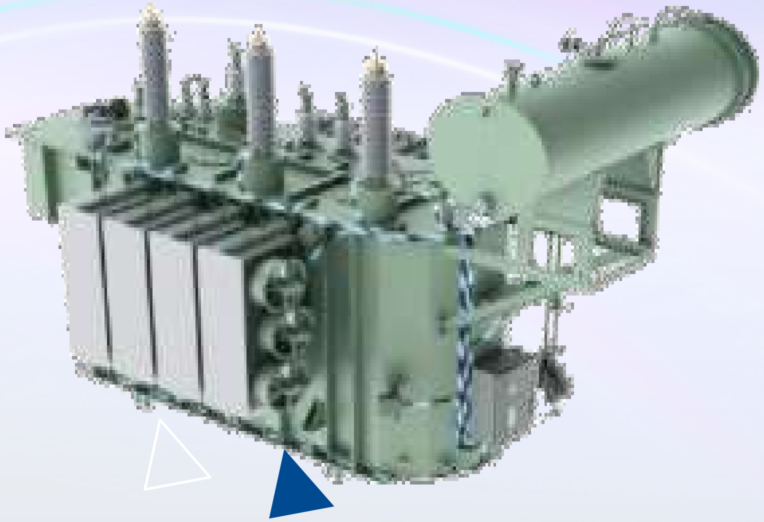
CMS Key Monitoring Functions



Cooling system control and monitoring

Intelligent cooling system monitoring

I Number of starts per cooling stage I Operating time per cooling stage

I Monitoring of motor protective switches Trips/Overload.

Intelligent cooling system control

I Switching points, hysteresis and delay times adjustable to your needs

I Fail-safe mode - Activation of the cooling system in case of signal error

Integration of complete conventional transformer cooling system control

I Including motor protective switches and fuses; for 1, 2 or more cooling stages

Information | Cooling system | Cooling syste...rol

Group 1

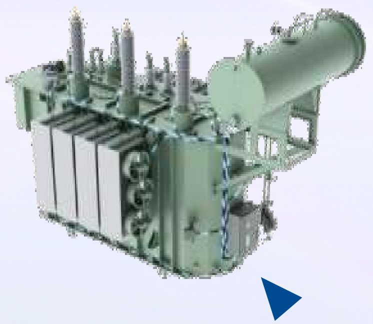
Status	
Number of starts	500
Operating time	0d 2h
Delay	2 Min
Hysteresis	1.2 K
Switching point	60.0 °C

Group 2

Status	
Number of starts	500
Operating time	--
Delay	2 Min
Hysteresis	5.0 K
Switching point	65.0 °C

CMS Key Monitoring Functions

Automatic voltage regulation

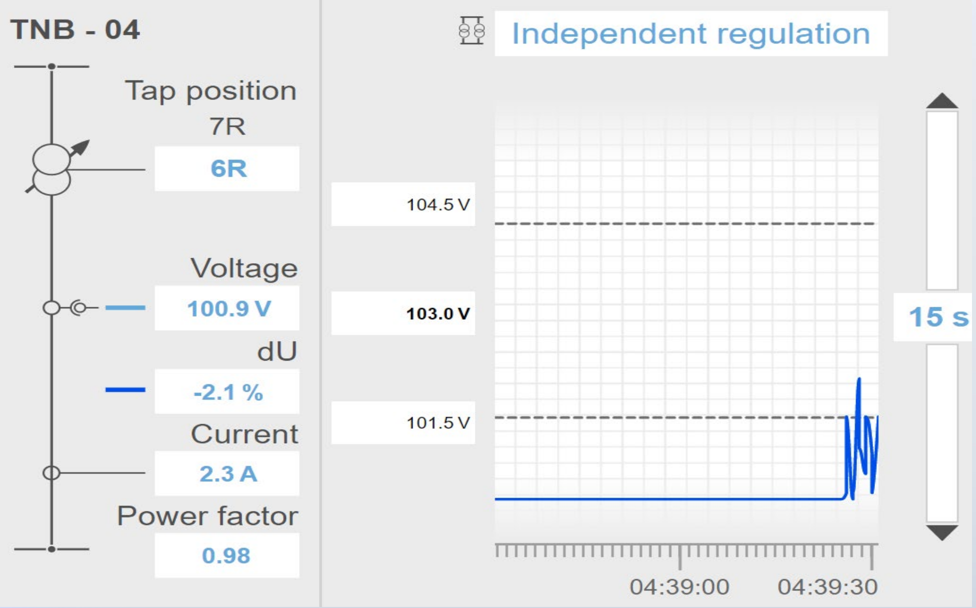


Basic functions

- Measurement of system voltage and load current (one-phase or three-phase)
- One desired value
- Voltage regulation with delay time T1
- Status of the motor-drive unit

Extended functions

- Various types of desired-value setting (3 or 5 desired values, TAPCON® Dynamic Setpoint Control, desired-value setting via analog value)
- Automatic voltage regulation with linear or integral time characteristics and two delay times T1 and T2
- Parallel operation via CAN bus (up to 16 transformers)
- Monitoring of bandwidth
- Function monitoring
- Limit-value monitoring



Communication & Visualization

Additional functions

I DIO configuration - freely programmable digital inputs and outputs

I AIO configuration - freely programmable analog inputs and outputs

I TPLE – Program by yourself easily with function blocks

Visualisation

I Visualization via web server (SVG and HTML 5) for various end devices included as standard. No software installation needed.

Communication protocols

IEC61850 Ed. 1 und Ed 2. MMS und GOOSE IEC60870-5-101, -103, -104

DNP3

Modbus TCP, RTU, ASCII

CMS Successful Integration Reference List
Saudi ARAMCO

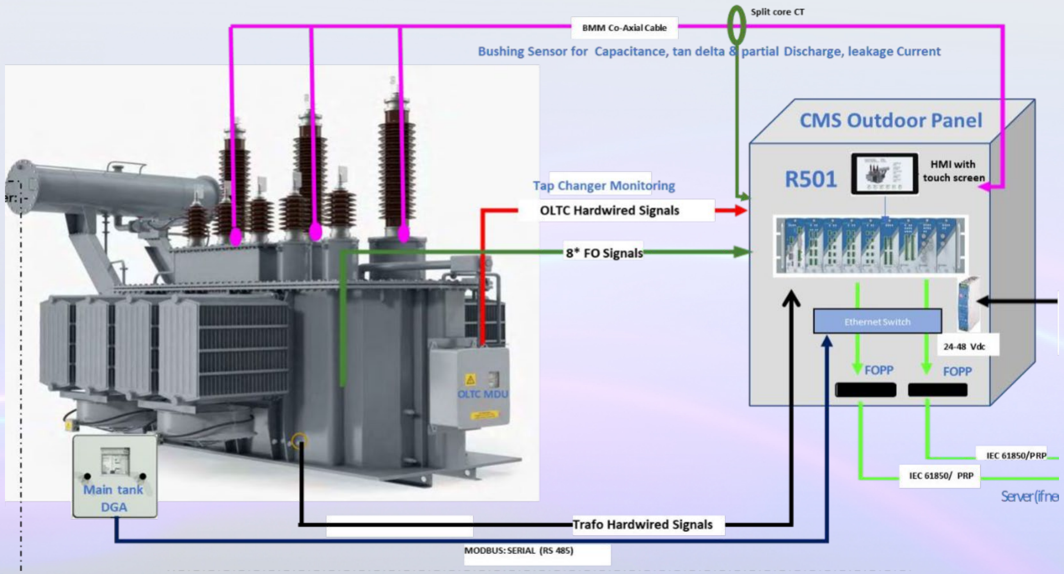
S/N	Project Name	Smart Transformer rating
1	Marjan Package 7.	60/80MVA, 115/13.8kV
2	Marjan Package 6.	60/80MVA & 100/133MVA, 230/13.8kV
3	Marjan Package 12.	60/80MVA & 75/100MVA, 230/13.8kV
4	ZULF, BRRI, and SFNY.	60/80MVA, 115/13.8kV
5	Marjan Package 2.	30/40MVA, 69/13.8kV
6	Marjan Package 1.	30/40MVA, 69/13.8kV
7	South Gawar.	20/26.667MVA, 230/13.8kV
8	ZULF	60/80MVA & 50/66MVA, 230/13.8kV
9	SFNY (SAF6).	30/40MVA, 115/13.8kV Power Transformer
10	SFNY TP-21	50/66MVA, 115/13.8kV

CMS different configurations

CMS Configurations

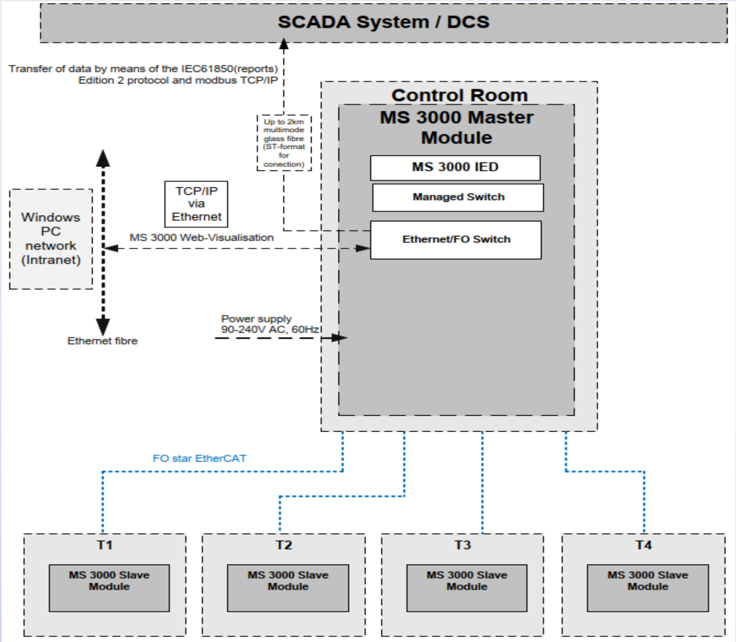
Standalone

Each Transformer are monitored by one CMS.



Master-Slave

Each group of Transformers are monitored By one CMS.



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SPTC Partnership with CMS Vendors

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Live Demonstrations

Live demonstrations for Smart Power Transformer technologies.

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Live Demo

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Q&A Session

Open Floor for Questions and Discussions

Under the patronage of **HRH Prince Khalid Al-Faisal**
Advisor to the Custodian of the Two Holy Mosques & Governor Iof Makkah Region

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