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SUSTAINABLE DEVELOPMENT
STRATEGIES FOR T&D

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Resilient Transformers: Designing for Performance in Harsh Environmental Conditions

Sofiane Allou
R&D Director - UTEC

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Introduction

Reliability in Extreme Conditions: Why It Matters?

Harsh Environments & Importance of Preventing Downtime

- Critical industries face extreme conditions like heat, dust, humidity, and corrosion.
- Transformer failures can cripple operations.
- Reliability is essential to prevent unexpected failures.

Impact of Downtime: Financial & Operational Losses

- Solar plant failures risk blackouts and power shortages.
- Offshore rigs and industries lose millions per day.
- Utility disruptions hurt reputation and finances.

Fire at London Heathrow Airport

Challenges with Sourcing Transformers with Custom Requirements

- Custom transformers have longer lead times.
- Supply chain issues delay procurement.
- Emergency replacements are costly and inefficient.

Harsh Operating Environments in the Middle East: Challenges for Transformers

- **Extreme Heat** – Extreme temperate stresses the equipment.
- **Dust & Sandstorms** – Reduce efficiency, cause abrasion & overheating.
- **Harsh UV** – Speeds up insulation & component aging.
- **Grid Dependence** – Failures risk power shortages.
- **Remote Sites** – Difficult repairs & maintenance.

Solar Power Plants (Emerging Sector)

- **Corrosive Salt Air** – Speeds up electrical component corrosion.
- **High Humidity** – Causes insulation breakdown & failures.
- **Constant Vibrations** – Mechanical stress from waves & drilling.
- **Explosion Risk** – Requires explosion-proof equipment.
- **Difficult Logistics** – Costly & slow offshore repairs.

O&G (Offshore) (Primary Revenue Stream)

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Solar

Environmental Factors at Solar Farms

	Normal Conditions	Harsh Conditions
Corrosion	Inland areas with low humidity and minimal exposure to corrosive agents.	Regions with high salinity levels, leading to increased corrosion of equipment. GCC states, for example, face challenges due to corrosive conditions affecting the durability of structures.
Temperature	Ambient temperatures range from 30°C to 40°C (86°F to 104°F).	Desert areas where temperatures can exceed 50°C (122°F).
Dust & Particulate Matter	Minimal dust accumulation requiring standard maintenance.	Frequent dust storms in arid regions such as Iraq and Saudi Arabia lead to significant dust accumulation on solar panels, reducing efficiency.

Environmental Factors at Solar Farms

	Normal Conditions	Harsh Conditions
Humidity	Relative humidity levels between 80% and 100%.	Coastal and certain inland regions experiencing high humidity levels, which can affect equipment durability
Dynamic Loads	Stable power loads with minimal fluctuations.	Fluctuating power demands leading to dynamic loads and potential harmonic distortion due to inverter-based resources, affecting transformer efficiency.

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O&G (Offshore)

O&G (Offshore)

	Normal Conditions	Harsh Conditions
Corrosion	Minimal exposure to corrosive agents, typically found in inland installations.	Continuous exposure to high salinity, humidity, and marine pollutants, leading to accelerated corrosion of equipment.
Temperature	Ambient temperatures range from 30°C to 40°C (86°F to 104°F).	Exposure to varying temperatures, with potential extremes due to marine weather patterns.
Dust & Particulate Matter	Minimal dust accumulation requiring standard maintenance.	Presence of salt spray and marine aerosols leading to salt deposition on equipment surfaces.

O&G (Offshore)

	Normal Conditions	Harsh Conditions
Vibrations	Low to moderate vibrations from platform movement and auxiliary equipment, with occasional shocks that remain within design limits.	Continuous high-frequency vibrations from drilling, pumps, and seismic activities, combined with severe mechanical stress, accelerate insulation degradation and structural fatigue.
Humidity	Relative humidity levels between 80% and 100%.	Consistently high humidity levels, often approaching 100% in states like Qatar & Kuwait, leading to condensation and potential equipment degradation.
Dynamic Loads	Stable power loads with minimal fluctuations.	Dynamic loads originating from drilling rigs, subsea pumps, and heavy lifting, causing voltage fluctuations and inrush currents. VFDs and high-power motors add harmonic distortion, stressing transformers.

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Transformer Requirements

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Transformers Requirements

Dynamic & Harmonic Distortion Loads (IEEE Std 519-2014)

Provides clear guidelines for managing harmonic distortion and dynamic load effects in distribution systems.

Parameter	Limit
Voltage THD	≤ 5%
Individual Voltage Harmonics	≤ 3%–5% (depending on voltage)
Current THD (ISR ≥ 20)	≤ 8%
Current THD (ISR < 20)	≤ 5%

Vibrations (IEEE Std C57.12.90-2021)

Provides a systematic approach to measuring and evaluating vibrations in liquid-immersed distribution transformers.

Parameter	Limit
Measurement Tools	Accelerometers or vibration sensors.
Frequency Range	10 Hz to 1 kHz (typical).
Operating Conditions	Rated voltage, current, and load.
Acceptable Limits	Consistent with manufacturer specifications.
Core/Winding Design	Proper clamping and bracing to reduce vibrations.
Tank Design	Robust construction to minimize amplification.

Transformers Requirements

Corrosive Atmosphere (IEEE Std C57.12.29)

Offers guidelines for designing and manufacturing of distribution transformers and pad-mounted equipment for corrosive environments.

Parameter	Limit
Material Selection	Corrosion-resistant materials (e.g., stainless steel, aluminum, galvanized steel).
Environmental Classification	Moderate or Severe Corrosion (based on location).
Enclosure Protection	IP54 or higher (resistance to water and dust).
Testing	Salt spray, humidity, and cyclic corrosion tests.
Gaskets/Seals	High-quality, corrosion-resistant seals.
Service Life	30–40 years under specified corrosive conditions.

Soil & Dust (NEMA Type 4X)

NEMA Type 4X enclosures are specifically designed to meet the stringent requirements of soil and dust protection for distribution transformers.

Parameter	Description
Soil/Dust Protection	Fully dust-tight; prevents ingress of soil, dust, and fine particles.
Water Protection	Watertight; resists rain, sleet, snow, and hose-directed water.
Corrosion Resistance	High resistance to rust and chemical damage (stainless steel, aluminum).
Environmental Suitability	Ideal for coastal, industrial, and high-dust environments.
Common Applications	Coastal areas, chemical plants, outdoor installations, dusty/desert regions.

Transformers Requirements

Humidity and High Temperatures (IEEE Std C57.12.00)

Provides comprehensive guidelines for designing and operating distribution transformers in environments with high humidity and elevated temperatures.

Parameter	Requirement
Relative Humidity	Up to 95% (non-condensing).
Ambient Temperature Range	–20°C to +40°C (standard); wider ranges for special designs.
Top Oil Temperature Rise	≤ 65°C above ambient.
Winding Hot Spot Rise	≤ 80°C above ambient (Class A insulation).
Insulation System	Moisture-resistant materials; vacuum drying and oil filling.
Cooling Systems	Adequate cooling to dissipate heat effectively.
Corrosion Protection	Enhanced sealing and corrosion-resistant materials.

Self Cooled Transformers (IEEE Std C57.12.34-2015)

Provides guidelines for the design, construction, and performance of pad-mounted distribution transformers.

Parameter	Description
Cooling Mechanism	Natural convection (oil-air cooling).
Temperature Rise Limits	Top oil: ≤ 65°C; Winding hot spot: ≤ 80°C (Class A insulation).
Ambient Temperature Range	–20°C to +40°C (standard); wider ranges for special designs.
Enclosure Type	NEMA Type 3R or higher for outdoor installations.
Maintenance Requirements	Minimal; focus on oil quality and radiator cleanliness.
Applications	Suburban, rural, or remote areas with moderate ambient temperatures.

UTEC's Assessment

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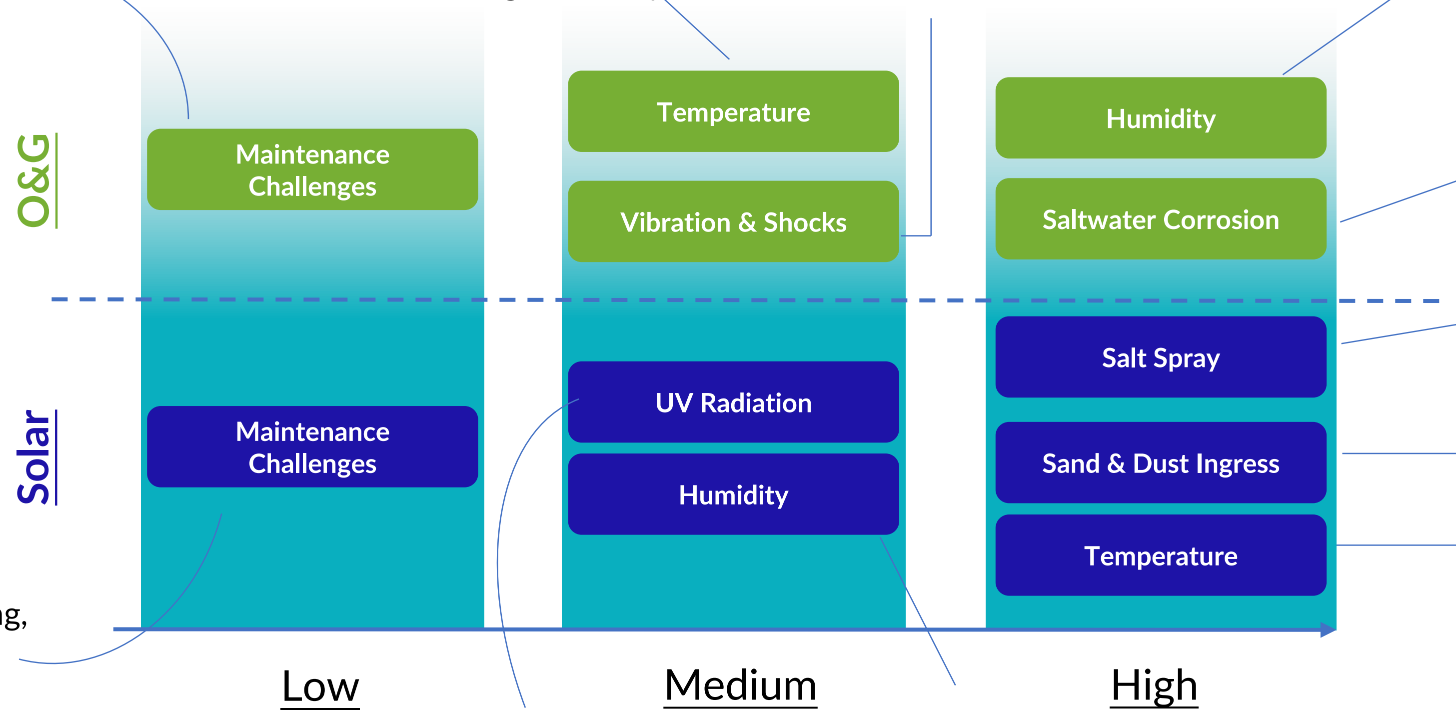
Ranking of Environmental Factors



Remote offshore locations make repairs and replacements difficult, increasing operational risks.

Fluctuating temperatures due to weather and ocean currents affect cooling efficiency.

Wave action and rig movement cause mechanical stress on transformer components

Humidity levels near 100% cause internal condensation, risking insulation failure.

Continuous exposure to salt spray and seawater leads to rapid corrosion of metallic parts.

Salt-laden air accelerates corrosion of metallic components and enclosures.

Fine sand particles and dust infiltrate transformer enclosures, causing abrasion and insulation degradation.

Remote desert locations make regular maintenance challenging, increasing downtime risks.

Desert regions experience temperatures exceeding 50°C, leading to thermal stress on insulation and cooling systems.

Prolonged exposure to intense sunlight degrades external coatings and insulation materials.

High humidity levels lead to condensation inside transformers, risking insulation failure.

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Losses, Efficiency and Life Cycle

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Load & No-Load Losses

Transformers operate continuously, and energy losses impact power system efficiency.

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Lower losses mean better performance, reduced operational costs, and improved lifespan.

=

Lesser Losses equal prolonged life of transformer

Load Losses (Copper Losses)

- Occur when the transformer is supplying a load.
- Caused by the resistance of the windings (heat generated by current flowing through copper/aluminum).
- Increases with higher current draw.

Case Scenario

- An 800 kVA, 6.6 kV/440V distribution transformer installed on an offshore oil rig operates at 90% load during drilling operations.
- Given the harsh offshore environment, excessive heat combined with humidity and salt exposure can accelerate insulation degradation, requiring enhanced cooling and regular maintenance to ensure transformer efficiency and longevity.

No-Load Losses (Core Losses)

- Occur even when the transformer is not supplying a load.
- Caused by magnetization and demagnetization of the core due to alternating current.
- Depends on core material and design.

Case Scenario

- A 500 kVA, 33 kV/400V transformer at a solar farm remains energized even when solar panels are not generating power at night. Despite no load, the transformer experiences core losses (no-load losses) due to continuous magnetization of the iron core
- With 1.2 kW no-load losses, the transformer wastes 28.8 kWh daily, even when idle.

Overloading & Short Circuit Withstanding Capacity

Overloading

Overload Level	Duration at 30°C	Duration at 40°C
133% Load	240 minutes	155 minutes
150% Load	98 minutes	65 minutes

Short Circuit Withstanding Capacity

Transformer Rating (kVA)	Short-Circuit Withstand (kA) for 2 sec
100-300	25× Full Load Current
500	20× Full Load Current
1000-1500	17× Full Load Current

Significance

- Transformers must handle temporary overloads and short circuits without failing.
- Their durability depends on load, temperature, and design.
- Distribution transformers have lower short circuit limits, but proper design ensures reliability.

Temperature Control & Thermal Limitations

- Transformers generate heat during operation.
- Excessive heat can degrade insulation, damage windings, and shorten transformer life.
- Maintaining safe temperature levels ensures long-term reliability.

Maximum Temperature Limits

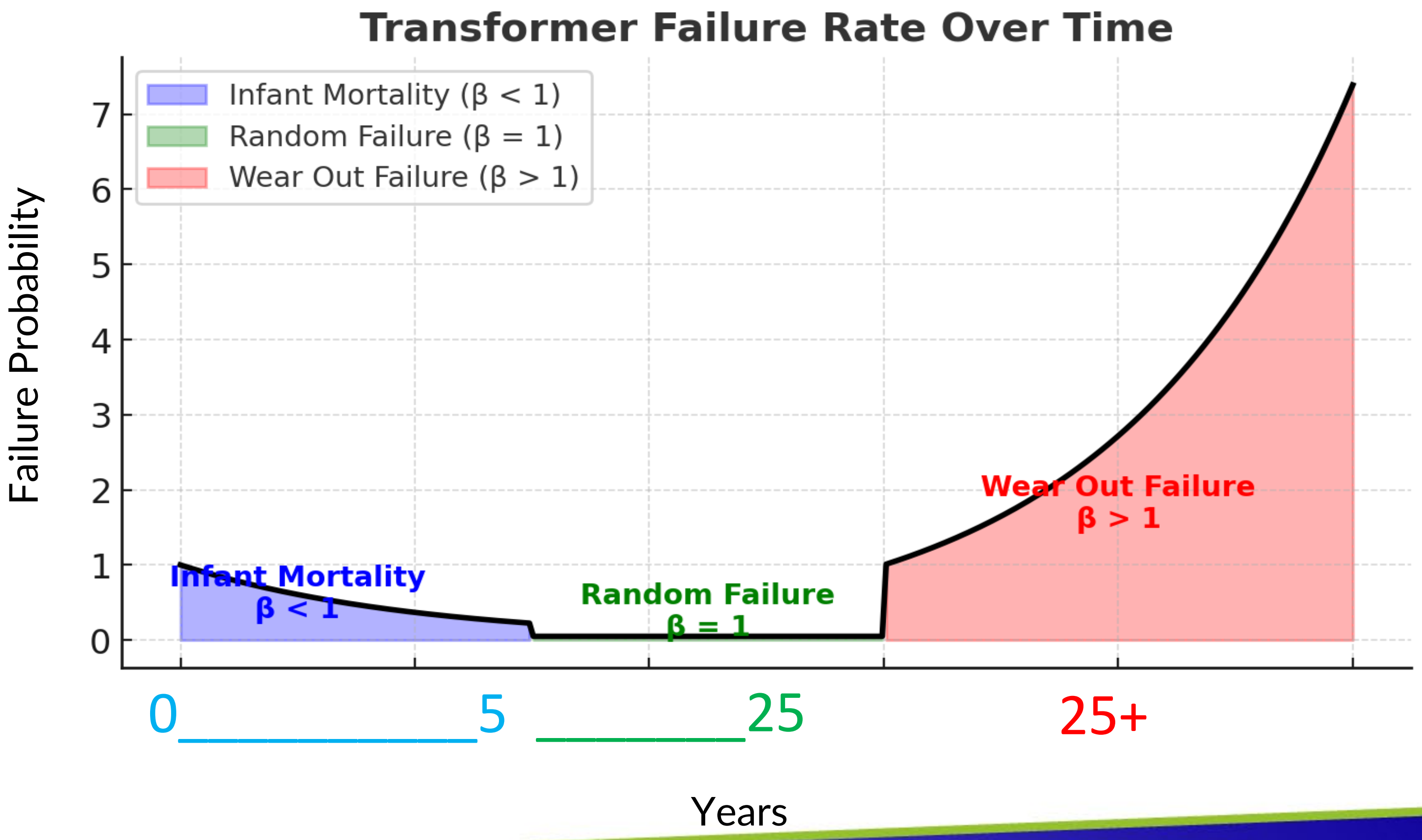
- **Top-Oil Temperature Rise (45°C)**
  - Measures the temperature increase of the insulating oil above ambient temperature.
  - Controls cooling efficiency (higher oil temp = reduced performance).
- **Winding Temperature Rise (50°C)**
  - Measures heat generated in the copper/aluminum windings due to current flow.
  - Excessive heat can degrade winding insulation and reduce efficiency.
- **Hot-Spot Temperature (98°C)**
  - The hottest point inside the transformer (measured in windings).
  - Critical for insulation lifespan—higher hot-spot temperatures lead to faster aging.
- **Maximum Short-Circuit Temperature (200°C)**
  - Represents instantaneous heating during a fault condition.
  - Must remain below the thermal breakdown limit of insulation materials.

Typical Transformer Life Cycle/Failure Rate

Infant Mortality (0-5 Years)
Causes: Manufacturing defects, poor craftsmanship, substandard materials, and inadequate temperature tolerance.

Random Failure (5-25 Years)
Causes: Transient over-voltages, power surges, overloading, faulty protection, environmental factors, lightning strikes.

Wear Out Failure (25+ Years)
Causes: Long-term exposure to heat, vibration, electromagnetic & mechanical stress.



UTEC Product Offerings

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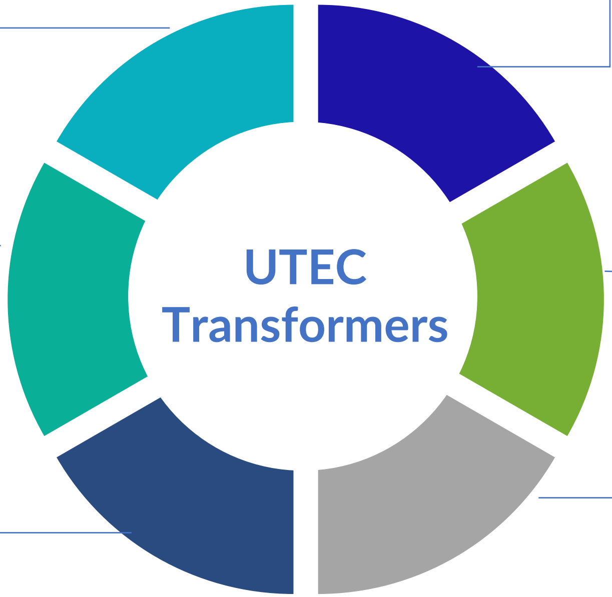
UTEC Transformers: Engineered for Extreme Conditions



Corrosion Resistance

Transformers use VOC-free coatings, corrosion-resistant materials, and durable metals for harsh environments

Structural & Mechanical Durability

Sealed tanks, corrugated steel, and IEEE 693-compliant design ensure durability in extreme marine and seismic conditions

Thermal Performance

Transformers use INSULutions® DPE insulation paper for improved thermal performance

Fire Safety Measures

Eco-friendly vegetable oil insulation improves fire safety, lowers environmental impact, and meets global standards.

Cooling Techniques

ONAN, ONAF, and smart controls optimize cooling and temperature regulation

Environmental Sustainability

UTEC's green transformers use recyclable materials to cut CO_2 emissions and power losses

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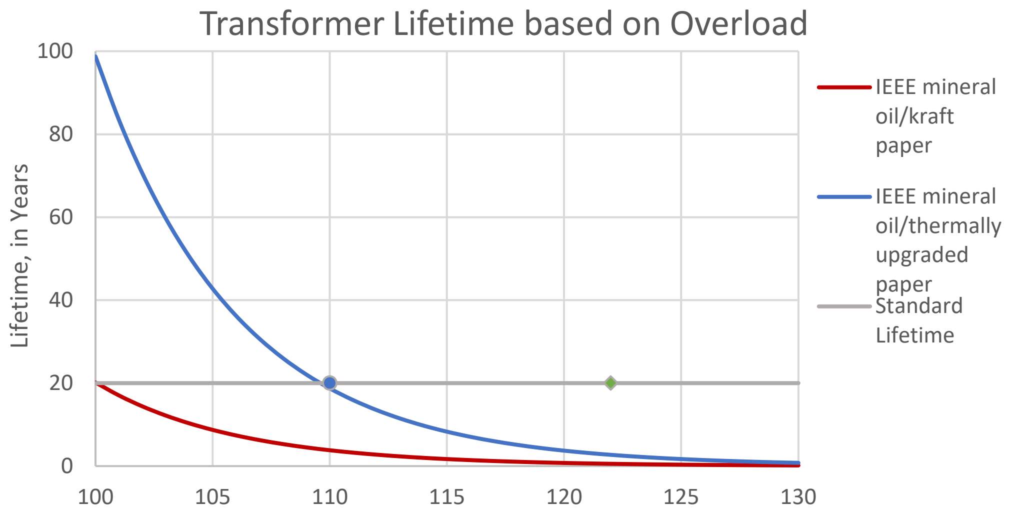
Key Design Features

1. Temperature & Thermal Management



- Our products are designed to operate up to +60°C using thermally upgraded insulation, which provides a 120°C Thermal Class with mineral oil. This ensures:
  - Extended transformer life at rated ambient conditions.
  - Allows operation at higher ambient temperatures without loss of life.
  - Enables continuous overloading without compromising durability.

2. Durability and Longevity

- The material used (both metals and insulators are durable enough to withstand the harsh environment for an extended period, reducing the need for any frequent replacements.
- Sealed access points to prevent ingress of moisture and contaminants.
- High Ingress Protection (IP) rating for water and dust resistance.
- More efficient transformer with less power losses and higher K factor.
- Reliable design can support dynamic grids with multi generation and active consumers.

Key Design Features

3. Corrosion Protection

- External metal parts are protected with anti-corrosion epoxy (C5H) coatings, while corrosion-resistant materials like HDG radiators and tanks enhance durability.
- Additionally, oil filtration prevents moisture buildup and internal corrosion, ensuring long-lasting performance.

4. Vibration & Shock Resistance

- The reinforced structural design ensures resistance to vibrations, while flexible mounts and damping systems absorb mechanical stress.
- Proven short-circuit-resistant windings enhance durability, and seismic-resistant features make these transformers ideal for high-earthquake-risk areas.

Key Design Features

5. Humidity & Moisture Control

- Modern technology ovens dry active parts to remove moisture before tanking, while oil filling under vacuum chambers ensures insulation integrity.
- Sealed tanks prevent moisture ingress, and live monitoring enables real-time DGA solution analysis for enhanced reliability.

6. Fire & Explosion Safety

- Fire-resistant insulation fluids, such as natural or synthetic esters, offer 2.5 times more fire safety than mineral oil.
- An explosion-proof design with safety valves enhances protection, while installed devices safeguard against abnormal temperature rises.

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Key Design Features

7. Lightening & Surge Protection

- Designed for lightning and surge protection, the insulation ensures durability against impulses.
- Pole-mounted transformers feature higher creepage polymer bushings; while shielding and proper grounding minimize electrical surge risks.

8. Protection & Monitoring Systems

- Real-time remote monitoring detects failures, tracks temperature, load, oil levels, and humidity, enabling proactive maintenance.
- Protective relays and circuit breakers, including PRD and temperature sensors, detect faults and overheating, preventing severe damage.

Key Design Features

9. Eco Friendly Design

- Biodegradable ester-based FR3 oil reduces ecological impact in case of leaks.
- Noise reduction minimizes sound pollution, while low-loss design lowers environmental costs and ensures reduced CO_2 emissions during manufacturing.

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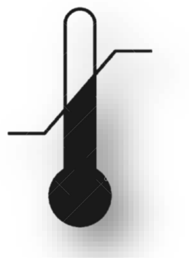
UTEC Monitoring Technologies

UTEC's Monitoring Technologies and Devices

1. Real-Time Thermal and Load Monitoring

- Measurement of oil temperature, winding temperature, and hotspot analysis.



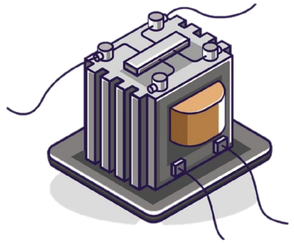
- Estimation of thermal aging to predict insulation lifespan.

- Cooling control systems to optimize performance based on load conditions

UTEC's Monitoring Technologies and Devices

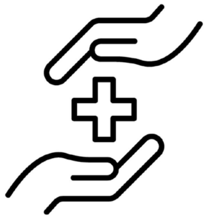
2. Electrical and Operational Health Monitoring

- Load current and voltage measurements to assess transformer efficiency.



- Detection of dynamic load fluctuations that may cause harmonic distortion.

- Overvoltage resilience tests to ensure longevity.



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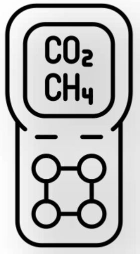
UTEC’s Monitoring Technologies and Devices

3. Gas and Moisture Detection

- Hydrogen measurement systems to predict paper aging and detect early-stage faults.

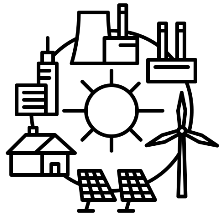


- Moisture sensors to monitor oil degradation and prevent insulation failures.

UTEC's Monitoring Technologies and Devices

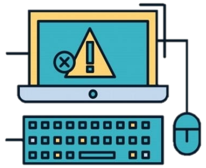
4. Smart Grid Integration & IoT Capabilities

- IoT-enabled transformers provide remote monitoring and predictive analytics.



- Data transmission to SCADA systems and built-in web pages for real-time access.

- Smart relay systems such as DMCR (DGPT2) for protection against internal transformer faults.



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UTEC’s Monitoring Technologies and Devices

5. Protective and Safety Features

- Dial-type oil thermometer, oil level indicators, and pressure relief devices with alarm contacts.

- Buchholz relay integration for early fault detection in conservator-type transformers.

- Expulsion and bay-o-net fuses for ANSI/IEEE standard transformers.

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Case Studies

UTEC Transformers in Action