

Risk-Based Inspection and Quality Control of Electrical Infrastructure

Research Scholar: Mohammed Abdul Lateef

Abstract:

Electrical infrastructure in oil, gas and industrial facilities is exposed to ageing, variable loading, harsh environments, construction defects, maintenance backlogs and operational change. Conventional inspection programmes often apply fixed intervals to broad equipment classes, even though failure probability and consequence differ substantially between assets. This review evaluates risk-based inspection as an integrated method for prioritizing electrical inspection and quality-control resources according to asset condition, failure likelihood, consequence and uncertainty. It covers transformers, switchgear, cables, motors, protection systems, earthing, hazardous-area installations and supporting supervisory data. The analysis combines asset-management, reliability, inspection, quality and operational-safety perspectives and proposes a framework linking asset registers, criticality screening, failure modes, condition evidence, inspection planning, defect control and performance review. Particular attention is given to Saudi industrial facilities, where heat, dust, salinity, high production criticality and extensive brownfield interfaces can accelerate degradation or complicate access. The review concludes that risk-based inspection improves value only when scoring is transparent, measurements are technically valid, acceptance criteria are controlled, and corrective actions are closed through an auditable quality system. Risk scores should guide professional judgment rather than replace it. The proposed approach supports Saudi Vision 2030 through improved asset availability, efficient maintenance expenditure, safer industrial operations, stronger local engineering capability and more reliable energy infrastructure.

Keywords: Risk-based inspection; electrical infrastructure; quality control; asset integrity; condition monitoring; reliability; oil and gas; Saudi Arabia; Vision 2030

1 Introduction

Electrical infrastructure is the enabling system behind production, safety, control, communications and emergency response in modern oil and gas facilities. Transformers, substations, switchgear, cables, motors, protection relays, earthing systems and standby supplies must operate as a coordinated network. A single failure can interrupt several process units, disable protective functions or create escalation risks. Inspection is therefore essential, but inspecting every asset with equal frequency and depth is neither technically justified nor economically efficient.

Traditional preventive programmes usually rely on calendar intervals, manufacturer recommendations and statutory requirements. These foundations remain important, yet they can allocate effort poorly when assets have different duties, environments and failure histories. A lightly loaded indoor panel may receive the same attention as a critical outdoor switchboard exposed to heat and contamination. Conversely, an inaccessible cable joint or protection setting error may remain underexamined despite high consequence. Risk-based inspection addresses this imbalance by linking inspection decisions to credible failure scenarios and their operational impact.

The method is not simply a ranking spreadsheet. It requires reliable asset information, engineering knowledge of failure modes, defensible condition indicators, inspection competence, controlled acceptance criteria and disciplined corrective action. It also depends on quality assurance. Inspection data are meaningful only when instruments are calibrated, procedures are approved, technicians are qualified, findings are traceable and nonconformities are closed. Risk analysis without quality control can create precise-looking priorities from uncertain evidence.

Saudi industrial facilities provide a demanding application environment. High ambient temperature, dust, humidity, salinity near coastal sites, long cable routes, hazardous areas and continuous operating schedules influence degradation. Many facilities also combine legacy equipment with new digital protection, condition monitoring and supervisory systems. These conditions make prioritization valuable, but they require local calibration rather than imported generic thresholds.

This review examines risk-based inspection and quality control as one integrated asset-integrity process. It focuses on practical decisions relevant to electrical engineers, QA/QC teams, inspectors, maintenance planners and project managers. The subject aligns closely with professional experience in electrical commissioning, inspection, SCADA coordination, high- and low-voltage systems, standards compliance and corrective-action management.

2 Aim Objectives and Research Questions

The aim is to develop a technically grounded framework for risk-based inspection and quality control of electrical infrastructure in industrial and oil and gas facilities.

The objectives are to identify major electrical failure mechanisms and consequences; explain how criticality and condition evidence should influence inspection; integrate quality-control requirements with the inspection cycle; define balanced performance measures; and interpret implementation priorities for Saudi facilities and Vision 2030.

The research questions are: How can electrical assets be prioritized without overlooking hidden or low-frequency hazards? Which inspection methods provide decision-relevant evidence for each asset class? How should uncertainty, data quality and human judgment be

governed? Which quality controls ensure that defects are correctly identified and closed?
What phased implementation model is appropriate for Saudi industrial infrastructure?

3 Review Methodology

An integrative review method was selected because risk-based electrical inspection draws on asset management, power engineering, reliability, non-destructive testing, quality management and industrial safety. The conceptual search scope included Scopus, Web of Science, IEEE Xplore, ScienceDirect and standards repositories. Search concepts combined electrical infrastructure, risk-based inspection, asset criticality, condition monitoring, transformer diagnostics, switchgear maintenance, cable ageing, protection reliability, quality control, nonconformity and industrial asset management.

Priority was given to recent peer-reviewed studies and current editions of recognized standards and technical guidance. Earlier sources were retained where they established widely used reliability or condition-based maintenance principles. Sources were considered relevant when they informed failure mechanisms, diagnostic methods, risk assessment, inspection governance, maintenance prioritization or quality assurance. Commercial promotional claims and sources without sufficient technical transparency were excluded from the conceptual synthesis.

The literature was organized into themes: risk and criticality, failure-mode analysis, inspection technologies, quality-control integration, data governance, human competence, performance measurement and Saudi implementation. Evidence was interpreted qualitatively because equipment populations, operating contexts and risk definitions are heterogeneous. No fabricated screening counts, pooled effect sizes or universal failure probabilities are presented. The framework is a structured synthesis requiring site-level validation rather than a prescriptive numerical model.

Risk registers should distinguish inherent risk from residual risk. Inherent risk describes exposure before safeguards while residual risk reflects protection redundancy monitoring and procedural controls. Keeping both values visible prevents a highly consequential asset from appearing unimportant merely because safeguards are assumed effective. Safeguard health must itself be verified. A standby feeder that has not been load tested a relay with unconfirmed settings or a spare transformer requiring extensive connection work cannot be treated as dependable redundancy. The inspection strategy should therefore include the systems that make risk reduction credible not only the primary equipment.

4 Electrical Asset Risk and Criticality

Risk is commonly expressed as a combination of likelihood and consequence, but practical electrical prioritization requires more detail. Consequence may include personnel safety, fire, loss of containment, production interruption, equipment replacement, environmental impact, regulatory exposure and restoration time. Likelihood should reflect failure mechanisms, condition, duty, age, environment, maintenance history and design vulnerabilities. Uncertainty must be shown separately because limited evidence is not the same as good condition.

Criticality screening begins with the function of the asset within the electrical network. A component may appear inexpensive yet be highly critical because no operational bypass exists or because it supplies emergency systems. Network studies, single-line diagrams, protection coordination and process dependency maps reveal the consequences of loss.

Common-mode dependencies such as shared rooms, cooling, direct-current supplies, communication links and fire exposure should also be considered.

A useful hierarchy separates rapid screening from detailed assessment. Screening places assets into broad attention tiers using consequence, redundancy and known condition. Detailed assessment is then applied to high-priority assets and credible dominant failure modes. This prevents excessive modeling of low-consequence equipment while ensuring that complex high-consequence systems receive engineering review. The assessment should record assumptions, evidence dates, missing information and the person accountable for approval.

Numerical scores can support comparison, but they should not create false precision. Multiplying ordinal categories may imply mathematical relationships that do not exist. Facilities should define what each category means, establish rules for mandatory escalation and test rankings against experienced judgment. Safety-critical defects, statutory noncompliance and active deterioration should bypass normal ranking and trigger immediate control.

Failure-mode libraries should remain specific enough to guide inspection. The label electrical failure is too broad to determine a useful task. Insulation moisture, loose bolted joints, cooling loss, mechanism wear and configuration error require different evidence. For every dominant mode, the team should record the initiating factors, detectable symptoms, progression rate, existing controls and technically appropriate inspection methods. This structure also reveals blind spots. If a high-consequence mode has no practical indicator, management may need redundancy, planned replacement, operating restrictions or a contingency plan instead of relying on inspection.

Table 1. Risk dimensions used to prioritize electrical inspection

Dimension	Key question	Representative evidence
Consequence	What happens if the function is lost?	Safety, production, restoration and redundancy
Likelihood	How credible is the failure mechanism?	Condition, duty, age, environment and history
Uncertainty	How reliable and current is the evidence?	Data age, missing tests and confidence
Safeguards	What prevents or limits escalation?	Protection, redundancy, monitoring and procedures

5 Failure Modes Across Electrical Infrastructure

Transformers can fail through insulation ageing, moisture, thermal overload, winding deformation, bushing deterioration, oil contamination, partial discharge and tap-changer defects. Risk assessment should distinguish slow degradation from rapidly developing faults. Loading, cooling performance, dissolved-gas trends, oil quality, thermography, electrical tests and protection operations provide complementary evidence. No single test establishes overall health.

Switchgear risks include contact wear, loose joints, insulation contamination, mechanism failure, arc-flash exposure, loss of control power and incorrect interlocking. Visual inspection, infrared surveys, timing tests, insulation measurements, partial-discharge methods and maintenance records may be appropriate depending on voltage and design. Intrusive maintenance can itself introduce errors, so task selection must consider equipment history and manufacturer requirements.

Cable systems deteriorate through thermal ageing, water treeing, mechanical damage, poor terminations, sheath defects and installation stress. Hidden joints and inaccessible routes increase uncertainty. Diagnostic choices may include insulation resistance, very-low-frequency testing, dielectric-loss measurement, partial-discharge testing, sheath testing and thermography at accessible terminations. Test voltage and interpretation must suit cable type and service history to avoid damage or misleading results.

Motors and generators experience bearing wear, insulation deterioration, contamination, cooling problems, misalignment, vibration and electrical imbalance. Current, temperature, vibration, insulation condition and operating duty should be interpreted together. Protection relays and control systems introduce different failure modes: incorrect settings, firmware or configuration errors, communication failure, time-synchronization problems and untested logic. These assets require functional testing and configuration assurance, not only physical inspection.

Earthing, lightning protection, hazardous-area equipment, batteries and uninterruptible supplies require dedicated strategies. Corrosion or broken earth connections may remain hidden until a fault. Hazardous-area integrity can be compromised by incorrect glands, damaged seals or unauthorized modifications. Batteries may fail through capacity loss, connection resistance or environmental stress. Risk-based programmes must therefore preserve mandatory inspection requirements while varying depth and frequency according to evidence.

Baseline measurements are particularly valuable after commissioning overhaul or equipment replacement. Later results can then be compared with a known operating state rather than only with broad generic limits. The baseline should record loading, ambient conditions, instrument details and equipment configuration because these factors influence interpretation. Where no historical baseline exists, the first inspection should establish one and clearly identify uncertainty. Trend rules should specify the magnitude and persistence of change that warrants review. Automatic alerts based on minor variation can generate noise, while thresholds that are too wide may conceal meaningful deterioration.

Outage-based inspections require coordinated planning because opening equipment affects availability and can introduce foreign material, loose connections or assembly errors. The work package should define isolation boundaries, photographs, before disturbance, cleanliness controls, torque requirements, replacement consumables and independent restoration checks. Post-maintenance testing should verify both electrical performance and correct return to service. A risk-based programme should consider the risk created by the inspection itself. When intrusive work has limited diagnostic value and a strong non-intrusive evidence base exists, unnecessary disassembly may be avoided, subject to mandatory requirements and competent approval.

6 Inspection Methods and Condition Evidence

The value of an inspection method depends on the failure mode it can detect, the sensitivity of the measurement, access conditions and the decision that follows. Visual inspection remains fundamental because it can reveal contamination, corrosion, leakage, overheating, loose hardware, blocked ventilation, labeling problems and unauthorized changes. Its reliability improves when checklists contain objective acceptance criteria and when photographs are linked to asset identifiers.

Infrared thermography can identify abnormal heating under load, but interpretation requires comparable phase loading, emissivity awareness, safe viewing access and knowledge of environmental effects. A temperature difference is evidence, not a diagnosis. Ultrasonic and partial-discharge methods may reveal insulation activity, yet noise, sensor placement and equipment design influence results. Trending under consistent conditions is often more informative than an isolated reading.

Electrical tests provide direct evidence but may require outages or disconnection. Insulation resistance, polarization index, winding resistance, turns ratio, circuit-breaker timing, contact resistance, relay secondary injection and earth resistance testing address different failure mechanisms. Test plans should specify prerequisites, instruments, tolerances, environmental corrections and restoration checks. Results outside acceptance criteria require an engineering disposition, not automatic acceptance based on schedule pressure.

Online monitoring expands visibility through temperature, gas, current, vibration, breaker-operation and environmental sensors. Supervisory systems can consolidate trends and alarms, but data quality must be governed. Missing points, frozen values, sensor drift and time misalignment can distort risk. Monitoring should be targeted where failure consequence, deterioration rate or access difficulty justifies life-cycle cost.

Inspection intervals should respond to evidence. Stable condition under controlled duty may support extension where regulations and manufacturer limits permit. Active deterioration, repeated defects, increased loading or environmental change should shorten intervals. Every adjustment should be documented with its technical basis, reviewer and next reassessment date.

Supplier quality influences long-term inspection demand Technical bid evaluation should review ratings environmental suitability maintainability diagnostic provisions documentation and spare-part strategy Factory inspection should focus on characteristics that are difficult to correct after delivery Site receiving and preservation controls are essential because moisture impact contamination or incorrect storage can damage equipment before energization When recurring defects are traced to a product family or subcontractor practice the response should extend beyond the individual asset Population review vendor notification and revised surveillance may prevent the same nonconformity from entering other installations.

Defect classification should combine technical severity with response urgency A condition may have high potential consequence but remain stable enough for a planned outage while another may show rapid deterioration requiring immediate de-energization The record should state the temporary controls monitoring frequency responsible owner and expiry date for any deferral Extensions should require fresh evidence and approval at the appropriate authority level This prevents temporary acceptance from becoming permanent through administrative delay Closure should include field verification and document updates so that drawings asset records and risk scores reflect the completed condition.

7 Integrating Quality Control with Risk Based Inspection

Quality control converts inspection from an observation activity into a controlled assurance process. The inspection and test plan should identify hold points, witness points, applicable drawings, procedures, acceptance criteria, records and responsible parties. Asset-specific risk can influence the level of surveillance, but critical requirements must not be waived by a low score.

Material receiving inspection protects the future asset baseline. Certificates, ratings, hazardous-area markings, type-test evidence, storage conditions and physical condition should be verified before installation. Installation inspection should cover cable routing, bending radius, segregation, termination, torque, earthing, enclosure integrity, identification and environmental protection. Commissioning should verify functionality, protection settings, interlocks, alarms, control interfaces and safe restoration.

Nonconformity management is central. Findings should describe the requirement, observed condition, location, evidence and immediate risk control. Root-cause analysis should distinguish isolated workmanship from systemic problems involving design, procurement, supervision, competence or procedure. Corrective action must be verified for effectiveness; closure based only on a contractor statement weakens assurance.

Calibration and measurement traceability are equally important. An advanced diagnostic result has little value if the instrument is out of calibration, unsuitable for the range or used under invalid conditions. Records should link equipment, instrument, technician, procedure, environmental state, raw result, interpretation and approval. This traceability supports audits, trend analysis and defensible maintenance decisions.

Quality assurance reviews the system behind individual inspections. Internal audits, supplier surveillance, competency assessment, document control and management review identify recurring weaknesses. Risk-based inspection and ISO-aligned quality management are therefore complementary: risk directs attention, while quality control ensures that attention produces reliable evidence and completed action.

Data migration deserves formal quality control when new asset-management platforms are introduced. Legacy records may use inconsistent equipment names, units and dates, and automated import can propagate errors at scale. Reconciliation should compare migrated records with drawings, nameplates and representative field samples. Critical documents should remain linked to stable asset identifiers. The organization should define which system owns each data element and how corrections are authorized. Without ownership rules, different departments may maintain conflicting versions of criticality, inspection status or equipment configuration, weakening both planning and auditability.

8 Data Governance Digital Tools and SCADA Integration

A risk-based programme depends on a trustworthy asset register. Each record should connect the equipment identifier, location, function, manufacturer, rating, commissioning date, maintenance history, test results, failure modes, criticality, open defects and document references. Duplicate or inconsistent identifiers break this chain and make risk calculations unreliable.

Computerized maintenance systems can schedule inspections and track work orders, while asset-performance platforms can combine condition trends with risk. SCADA and electrical monitoring systems contribute loading, temperature, trips, alarms and power-quality information. These sources should inform rather than automatically determine risk. Operators must understand how missing data, inhibited alarms or configuration changes affect conclusions.

Digital dashboards should show the components of a risk score, not only a color. Users need to see consequence, condition, confidence, active defects and due actions. Version control is necessary when algorithms or thresholds change. Automated recommendations should remain within approved rules, and high-consequence decisions should require competent review.

286 Cybersecurity protects inspection evidence and control integrity. Unauthorized alteration of
287 relay settings, condition data or work history can produce unsafe priorities. Role-based
288 access, backups, change logs, network segmentation and recovery testing support trustworthy
289 asset management. Digital efficiency should never create a single unverified source of truth.

290 Competency management should be evidence based A matrix can map roles to equipment
291 classes test methods authorization levels and refresher requirements Supervisors should
292 observe practical work and review reports for technical reasoning not only completion
293 Lessons from failures and difficult diagnoses should be incorporated into training Mentoring
294 is particularly important where experienced personnel hold undocumented knowledge about
295 legacy systems Capturing that knowledge through controlled asset notes failure-mode
296 workshops and reviewed procedures supports succession without turning personal opinion
297 into an uncontrolled requirement.

298 **9 Human Competence and Inspection Governance**

299 Inspection quality varies with competence. Electrical inspectors need knowledge of
300 equipment, failure mechanisms, test limitations, safety rules, standards and documentation.
301 Specialized methods require additional training and demonstrated practical ability.
302 Certification alone does not confirm familiarity with a particular asset or operating
303 environment.

304 Governance should define who may collect data, interpret results, approve risk scores, defer
305 work and accept residual risk. These roles should be separated where independence matters.
306 Contractors can provide specialist expertise, but the asset owner retains accountability for
307 acceptance criteria and operational decisions. Conflicts between production pressure and
308 inspection findings should follow a documented escalation route.

309 Pre-job planning must address isolation, arc-flash boundaries, induced voltage, stored energy,
310 hazardous areas and simultaneous operations. Where inspection requires equipment to remain
311 energized, the expected diagnostic value must justify exposure and safer alternatives should
312 be considered. Stop-work authority should be clear.

313 Cross-functional review improves decisions because electrical condition has process
314 consequences. Operations, maintenance, protection, instrumentation, process safety, quality
315 and cybersecurity personnel may hold different evidence. A structured review prevents a
316 narrow technical score from overlooking production dependencies or safety barriers.

317 The framework should connect inspection priorities with spare strategy and contingency
318 planning A critical asset with long replacement lead time may justify more sensitive
319 monitoring strategic spares or engineered temporary supply arrangements Conversely readily
320 replaceable equipment with verified redundancy may require less diagnostic investment
321 Restoration time should include fault location access isolation procurement installation
322 testing and operational approval This broader view prevents consequence scoring from
323 relying only on the purchase price of the failed component and helps management compare
324 inspection renewal and resilience investments on a common operational basis.

325 **10 Integrated Risk Based Inspection Framework**

326 The proposed framework begins with governance and scope. The facility defines objectives,
327 mandatory requirements, risk criteria, roles and controlled data sources. The second stage
328 establishes the asset and dependency register. The third identifies credible failure modes and

available evidence. The fourth evaluates consequence, likelihood, uncertainty and existing safeguards. The fifth converts priority into an inspection plan specifying method, interval, acceptance criteria and competence.

Execution then produces controlled records and defects. Immediate hazards are made safe, while other findings enter a graded nonconformity and work-management process. Engineering disposition determines repair, replacement, monitoring, operating restriction or justified deferral. Verification confirms that corrective action restored the requirement. The final stage reviews performance and updates assumptions.

The framework contains feedback. A confirmed defect changes condition and may reveal a population-wide issue. A false alarm may indicate an unsuitable threshold. A failure after apparently acceptable inspection may reveal a missing mechanism or inadequate method. Learning should modify the failure-mode library, inspection plan and competency requirements.

Risk should be recalculated after major changes, abnormal events, protection operations, load growth, environmental exposure or extended shutdown. A yearly administrative refresh is insufficient for dynamic assets. At the same time, continuous score movement from noisy data can destabilize planning. Governance should distinguish triggers requiring immediate review from trends considered during scheduled assessment.

Management review should examine the distribution of risk rather than only an average score. A falling average may conceal a small number of extreme exposures. Reports should separate active hazards, overdue decisions, accepted residual risks and improvement projects. They should also identify systemic themes such as moisture ingress, termination workmanship or obsolete relays. Trend review across equipment families can reveal common causes earlier than asset-by-asset reporting. Decisions and actions from management review should be recorded, funded and tracked to completion so that oversight produces operational change.



Feedback updates condition, uncertainty, intervals and corrective-action priorities

Figure 1. Integrated risk-based electrical inspection and quality-control cycle. Source: Author synthesis.

11 Performance Measurement and Decision Assurance

Programme performance should be assessed through leading and lagging indicators. Leading measures include overdue high-risk inspections, calibration validity, defect closure time, repeat nonconformities, data completeness and restoration-test success. Lagging measures include unplanned outages, electrical fires, protection misoperations, equipment failures, production loss and safety events. Cost should be evaluated alongside risk reduction and availability.

Simple completion percentages can be misleading. Completing many low-value inspections while critical actions remain overdue creates apparent compliance without assurance. Reports should therefore weight work by risk tier and show unresolved exposure. The age and confidence of condition evidence should also be visible.

Decision assurance requires periodic challenge of the model. Samples of high-, medium- and low-ranked assets should be reviewed against field condition and expert judgment. Back-testing can examine whether previous scores distinguished failed or deteriorated assets, although rare events and changing populations limit statistical certainty. Independent audit should verify that scoring rules, data and approvals are applied consistently.

Benefits should be stated carefully. Reduced failures may reflect renewal investment, operational change or favorable duty as well as improved inspection. Strong evaluation uses documented baselines, comparable populations and transparent concurrent changes. The aim is credible learning rather than an exaggerated return figure.

Saudi organizations can also use phased localization to strengthen sustainability of the programme. Early stages may rely on international specialists for advanced diagnostics but contracts should include knowledge transfer method documentation and joint interpretation. Local laboratories and engineering teams can then assume increasing responsibility under controlled competency criteria. This reduces dependence on intermittent external support and improves response time. Localization should be judged by demonstrated capability and quality outcomes rather than headcount alone. Complex or rare investigations may still require independent expertise especially where safety.

Table 2. Balanced performance measures for programme assurance

Area	Leading measure	Outcome measure
Inspection	Overdue high-risk tasks	Condition found before failure
Quality	Calibration and record completeness	Repeat nonconformities
Corrective action	Defect closure time	Recurring or escalated defects
Reliability	Monitoring and test coverage	Unplanned outage and trip recurrence
Governance	Score review and audit completion	Residual risk accepted and controlled

12 Saudi Arabia and Vision 2030 Alignment

Risk-based electrical inspection supports Saudi industrial objectives by improving reliability, safety and capital efficiency. Large oil, gas, petrochemical, utility and infrastructure assets require dependable power while undergoing expansion and digital modernization. Better prioritization can direct scarce specialist resources to the assets whose failure would most affect national production and services.

Local environmental factors must be built into the model. High temperature accelerates insulation ageing and challenges cooling. Dust affects ventilation and surface insulation. Coastal salinity promotes corrosion and contamination. Remote locations increase restoration time and spare-part dependency. Hazardous areas require disciplined equipment integrity. Generic scores should therefore be calibrated with Saudi operating evidence.

Brownfield interfaces deserve particular attention. New switchgear, digital relays and monitoring devices may be installed alongside legacy equipment with incomplete records. Commissioning and management of change must verify protection coordination, control logic, communication behavior, labeling and as-built documentation. Risk-based inspection can prioritize missing evidence as well as physical deterioration.

Vision 2030 alignment should be demonstrated through measurable industrial outcomes: stronger asset availability, reduced avoidable loss, efficient energy use, safer work, local technical competence and better life-cycle investment. It should not be asserted as a slogan. Partnerships among operators, universities, testing laboratories and local suppliers can build validated methods while protecting sensitive facility information.

13 Research Gaps and Future Research

Research is needed on Saudi-specific deterioration models for electrical assets exposed to heat, dust, salinity and variable loading. Longitudinal datasets could evaluate which combinations of tests provide the best warning for transformers, cables, switchgear and motors. Studies should report unsuccessful predictions and inspection-induced defects as well as successes.

Further work should examine uncertainty explicitly. Bayesian updating, confidence scoring and value-of-information methods may improve decisions when data are sparse, but models must remain interpretable to engineers. Digital twins and hardware-in-the-loop systems can test protection, loading and failure scenarios without exposing live facilities.

Human factors also require study. Research should evaluate how inspectors use dashboards, how production pressure affects deferral, and how competency influences defect detection. Common reporting definitions would support comparison across facilities without disclosing sensitive details.

14 Practical Managerial and Policy Implications

Managers should authorize risk criteria, escalation rules and resources before requesting rankings. Engineering teams should maintain the asset and dependency baseline. QA/QC teams should control procedures, instruments, records and nonconformities. Maintenance planners should connect findings to executable work, while operations should define access and process consequence.

Implementation should begin with a limited high-value asset group, such as main transformers, critical switchgear and essential motors. The facility should verify data quality, trial scoring, compare results with expert review and close identified defects before scaling. Vendor software should be evaluated for transparency, exportability and change control.

Policy and sector guidance can encourage common competency expectations, laboratory capability, data terminology and secure digital practices. Requirements should preserve engineering flexibility because risk differs by site. Audits should test traceability from hazard and asset to inspection evidence, decision, corrective action and verified closure.

15 Limitations

This review synthesizes diverse standards and literature but does not provide a meta-analysis or universal numerical risk model. Asset populations, failure definitions, environmental conditions and inspection methods vary widely. No original facility dataset was available. The proposed framework therefore requires local validation, legal review and calibration against manufacturer guidance, mandatory requirements and plant-specific hazards.

16 Conclusion

Risk-based inspection can improve electrical infrastructure reliability by directing competent attention toward the assets, failure modes and uncertainties that matter most. Its value depends on more than a risk score. Reliable asset registers, dependency analysis, valid diagnostic methods, calibrated instruments, qualified personnel, controlled acceptance criteria and verified corrective action are essential.

The integrated framework links governance, criticality, failure modes, condition evidence, inspection planning, quality control and performance review. It preserves mandatory requirements while allowing inspection depth and frequency to respond to risk. It also treats uncertainty and missing evidence as management concerns rather than assuming that an unreported problem does not exist.

For Saudi oil and gas and industrial facilities, the approach can support Vision 2030 through safer operations, higher availability, efficient maintenance expenditure and stronger local engineering capability. Implementation should begin with critical assets, transparent criteria and measurable outcomes, then scale through learning. Risk scores should inform professional judgment, never replace it, and every deferred action should remain visible, owned and time bounded.

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