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Original Research Article

ETAP-Enabled Electrical System Planning for Reliable and Smart Industrial Facilities in Saudi Arabia

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Abstract: Saudi Arabia's industrial expansion is increasing the importance of electrical systems that can sustain production, protect critical process loads and accommodate frequent modification without creating hidden reliability weaknesses. This paper studies ETAP-enabled electrical system planning as a lifecycle engineering process for reliable and smart industrial facilities in Saudi Arabia. The emphasis differs from broad smart-grid planning: the review focuses on industrial network architecture, critical-load classification, redundancy, contingency operation, motor acceleration and reacceleration, load shedding, restoration, maintenance switching, equipment duty, and expansion planning. A structured narrative review of recent power-system reliability and maintenance literature, technical standards, Saudi energy-sector sources and ETAP engineering documentation was used to identify planning practices that can be translated into industrial decision-making. The review proposes a Reliability-Centred ETAP Planning (RCEP) framework in which a verified digital model is used to compare normal, maintenance, outage, disturbance and future-production scenarios before physical changes are approved. Particular attention is given to main-tie-main arrangements, transformer and feeder contingencies, process load priorities, large motor restart sequences, generator-supported operation, selective protection and the use of operational and maintenance data to keep the model current. The analysis shows that ETAP creates the greatest planning value when study cases are tied to explicit acceptance criteria such as retention of critical loads, acceptable voltage recovery, adequate interrupting duty, selective fault isolation and realistic restoration sequences. For Saudi industrial facilities, this approach supports safer capacity growth, stronger outage preparedness, more disciplined maintenance planning and better transfer of engineering knowledge from projects to operations. The paper concludes that smart industrial electrical planning should be treated as a controlled cycle of modelling, scenario testing, field validation and change management rather than as a one-time software study.

Keywords: ETAP, Industrial Electrical Planning, Reliability, Contingency Analysis, Load Shedding, Motor Acceleration, Maintenance Planning, Saudi Arabia, Vision 2030.

1. INTRODUCTION

Industrial facilities depend on electricity in ways fundamentally different from many ordinary commercial loads. In a petrochemical complex, metal plant, mine, water facility, manufacturing line, food-processing plant or large logistics operation, an electrical disturbance can interrupt a production sequence, stop rotating equipment, trigger emergency shutdown logic, damage work in process, or extend restart time long after supply is restored. The planning problem is therefore not limited to whether the installed transformers and cables can carry the expected demand. It is also necessary to determine which loads must remain energised, which equipment may be shed, how the network behaves after a component outage, whether large motors can start or reaccelerate, whether protection isolates only the affected zone, and whether operators have a feasible restoration path after a disturbance. ETAP provides an integrated environment in which these questions can be assessed against a common electrical model [1-4].

Saudi Arabia provides a particularly important context for this type of planning. Vision 2030 is associated with continuing industrial development, infrastructure investment, localisation of manufacturing and changes in the national electricity system. Saudi Electricity Company has reported major network expansion, smart-meter deployment and distribution modernisation, while the Ministry of Energy keeps to advance the Kingdom's energy-transition and renewable-energy programmes [5, 6]. Industrial facilities connected to this developing system are also expanding internally. New production trains, compressors, process pumps, large HVAC systems, conveyors, variable-speed drives, utility packages, electric vehicle infrastructure, solar generation or energy-storage systems may be added over several project phases. Each modification changes loading, fault levels, switching options, protection behaviour and maintenance requirements. A network that was adequate at initial commissioning can therefore become vulnerable if growth is treated as a sequence of isolated projects rather than as one evolving electrical system.

The central argument of this review is that ETAP should be used as an industrial planning environment rather than only as a calculation tool. A single study result, such as a load-flow report or a short-circuit value, answers only one question. Industrial reliability requires a coordinated set of scenarios that represent how the facility is actually expected to operate. Examples include normal production with all sources available, a transformer out of service for maintenance, loss of one utility incomer, an emergency generator supplying essential loads, restart of large induction motors after a voltage depression, closure of a bus-tie breaker, temporary operation during switchgear replacement, and a future production expansion with higher demand. ETAP can help engineers evaluate these cases consistently and compare technical options before committing capital [2, 3].

This focus distinguishes the present paper from a general smart-grid discussion. The subject here is the internal electrical planning of industrial facilities: how to configure sources, buses, feeders, motors, generators, protection and operating states so that the plant can tolerate credible disturbances and remain maintainable as it grows. Smartness is interpreted as better engineering visibility, controlled operating scenarios, data-supported maintenance and faster decision making, not simply the presence of sensors or distributed energy resources. This reliability-centred framing is consistent with recent work on power-system maintenance, fault diagnosis, restoration and digitally enabled asset management [13-21].

2. Aim, Scope and Review Contribution

This paper aims to develop a reliability-centred view of ETAP-enabled electrical system planning for Saudi industrial facilities. Four questions guide the review. First, how can an ETAP model be used to select and verify network architecture, redundancy and capacity for process-critical plants? Second, how can contingency, motor acceleration, transient stability, load shedding and protection studies be combined to test continuity during disturbances rather than being issued as unrelated reports? Third, how can the same model support planned maintenance, equipment replacement and production expansion after commissioning? Fourth, what governance is required to keep the model a trusted engineering record instead of an obsolete project file?

The scope is intentionally limited to industrial facilities and their internal distribution systems. Commercial buildings, broad utility smart-grid planning and general renewable-integration strategy are not the primary subjects. Renewable generation or battery storage is considered only where it changes industrial operating states, protection, islanding or restoration. The paper also does not attempt to produce universal reliability targets or cost savings because acceptable risk depends on the process, outage consequence, spare philosophy and production value of each facility.

The main contribution is a Reliability-Centred ETAP Planning (RCEP) framework that links load criticality, verified network data, scenario analysis, protection, continuity actions, maintenance feedback and future expansion. A second contribution is a practical scenario library for Saudi industrial plants that gives engineers a repeatable set of test cases. A third contribution is the distinction between equipment adequacy and functional continuity: a system can satisfy normal load flow and still fail to sustain production if a transformer outage, motor restart, bus transfer or protection sequence has not been evaluated. This distinction is important because the engineering objective isn't only to obtain acceptable numbers in a study report, but to demonstrate that credible plant operating states have workable electrical responses.

3. REVIEW METHODOLOGY

A structured narrative review method was used because industrial electrical planning draws on several evidence types that are not captured by a single academic literature stream. Sources included peer-reviewed work published mainly from 2020 to 2025 on distribution reliability, restoration, predictive maintenance, digital twins and fault diagnosis; current technical standards and safety guidance; Saudi utility and energy-sector publications; and ETAP technical documentation describing relevant analysis and operational functions [1-30]. Older standards were retained where they continue to provide normative technical framework, particularly for short-circuit and arc-flash calculations.

Sources were screened against four inclusion questions. The first was whether the source contributes to industrial continuity, reliability or maintainability. The second was whether it addresses an electrical planning decision which can be represented in a network model. The third was whether its findings can be translated into design, operating or maintenance scenarios. The fourth was whether it helps explain the Saudi industrial context as well as the transition from static engineering documents to model-based decision support. The evidence was grouped into five themes: (1) network architecture and capacity, (2) contingency and restoration, (3) motor and generator dynamics, (4) protection and electrical safety, and (5) maintenance and digital model governance.

The method is review-based rather than case-study-based. No confidential ETAP project, relay file, plant event record or measured Saudi industrial load profile was available for computational validation. Consequently, the paper does not claim a specific percentage improvement in availability, energy efficiency or maintenance cost. Instead, it develops an engineering framework and scenario set that can be applied to a real plant when site data are available. This limitation matters because the reliability benefit of modelling depends strongly on data quality, equipment condition, operator practice, and whether the studied configurations match actual switching arrangements. Current maintenance research likewise stresses that digital tools become useful when maintenance and operational data are integrated with decision processes instead than treated as separate information stores [13-17].

4. Reliability-Centred Planning Challenges in Saudi Industrial Facilities

The first planning challenge is classifying load criticality. Industrial loads do not have equal consequences when lost. A practical hierarchy can separate process-safety and emergency loads, production-critical loads, essential utility loads and deferrable loads. Process-safety loads may include control systems, emergency lubrication, instrument air auxiliaries, fire and gas systems, emergency lighting or shutdown-related equipment. Production-critical loads may include feed pumps, compressors, furnaces, conveyors or process cooling whose interruption causes loss of throughput or a lengthy restart. Essential utility loads support plant operation but may tolerate short interruptions, while deferrable loads can be disconnected during a contingency. Electrical, process, operations, and safety teams should agree on the classification because it directly determines redundancy, generator sizing, load-shedding priorities, and restoration sequences.

The second challenge is choosing a network architecture that reflects outage consequence rather than copying a standard arrangement. Radial systems are simple and economical but expose downstream loads to upstream equipment outages. Double-ended substations, main-tie-main arrangements, ring networks, redundant transformers and alternate feeders can improve continuity, but they also change fault levels, protection coordination, switching complexity and capital cost. Credible contingencies should therefore justify the appropriate degree of redundancy. In ETAP, alternative topologies can be represented as study cases so engineers can compare normal operation, one-transformer-out operation, bus-tie closure, generator-supported operation and planned maintenance states using the same equipment database [1, 2]. Reliability and availability assessment functions can supplement deterministic contingency checks where component failure and repair data are credible [2].

The third challenge is capacity growth. Industrial demand rarely remains fixed after commissioning. Production debottlenecking, new packaged units, additional motors and expanded utility systems can consume spare transformer and feeder capacity. A future-load study should not simply add the new megawatts to the existing peak.

Engineers should evaluate coincidence of process loads, motor operating patterns, reactive demand, transformer loading, feeder current, bus voltage, power factor and the effect of the new equipment on contingency states. In a two-transformer substation, for example, the normal case may be satisfactory while the one-transformer-out case becomes overloaded after expansion. This is a reliability problem even if the normal load-flow result appears acceptable.

Saudi industrial environments add practical stressors to these decisions. High summer ambient conditions increase the importance of thermal margins and verified equipment ratings. Dust, coastal exposure in some locations, long cable routes and large outdoor substations can increase upkeep requirements. Rapid project schedules and multi-contractor construction can create record gaps between design and as-built condition. These factors make field verification and controlled model updating especially important. Resilience research for Saudi distribution systems additionally reinforces the wider need to examine credible disturbance states rather than assume that a single normal operating point represents system performance [27].

5. ETAP as a Lifecycle Planning Environment

A reliable industrial ETAP model should begin as a design basis and continue as an operational engineering record. The baseline model should include utility sources, transformers, generators, buses, switchgear, feeders, cables, major motors, variable-speed drives, UPS systems, capacitor banks, large static loads and the protective devices that determine fault isolation. Equipment names must match site tags so that model findings can be connected to drawings, maintenance systems and operating procedures. Ratings, impedances, cable lengths, relay settings and source fault levels should be traceable to approved data rather than generic assumptions.

The next requirement is controlled scenario management. Instead of maintaining one 'normal' single-line model, the project should contain defined operating cases. Each case answers a specific planning question: all sources in service, one transformer unavailable, one feeder isolated for maintenance, emergency generation active, bus tie open or closed, large motor starting, partial process shutdown, or future expansion. ETAP's study-case approach supports repeated analysis of these conditions without rebuilding the system from scratch [1-3]. This matters because a change that improves one case can weaken another. Closing a tie may improve voltage support yet raise short-circuit duty. Increasing relay delay may improve selectivity but increase arc-flash incident energy. Adding a generator may improve continuity as changing fault contribution and coordination. Reliability-centred planning therefore requires cross-checking outcomes across several studies.

Commissioning should then calibrate the model. Actual transformer tap positions, motor data, breaker and relay settings, generator operating limits, measured loading and switching logic should replace temporary design assumptions. Where practical, modelled bus voltages and currents can be compared with measurements. The result becomes a verified baseline for later changes. This is consistent with the wider digital-twin concept, in which value increases when a digital representation is connected to physical-system data and is updated as the real asset evolves [22].

After handover, the model should be governed through change control. Major motor additions, transformer replacements, relay changes, cable rerouting, generator modifications, new inverters, bus reconfiguration and operating philosophy changes should trigger model review. Maintenance events can also reveal information that changes planning assumptions. A breaker with repeated slow operation, a transformer with abnormal thermal behaviour or a cable with deteriorating condition may justify a temporary contingency restriction or accelerated replacement. Predictive and reliability-centred maintenance research shows the importance of combining failure consequence, asset condition and system role when prioritising work [13-17]. Figure 1 summarises this cycle.

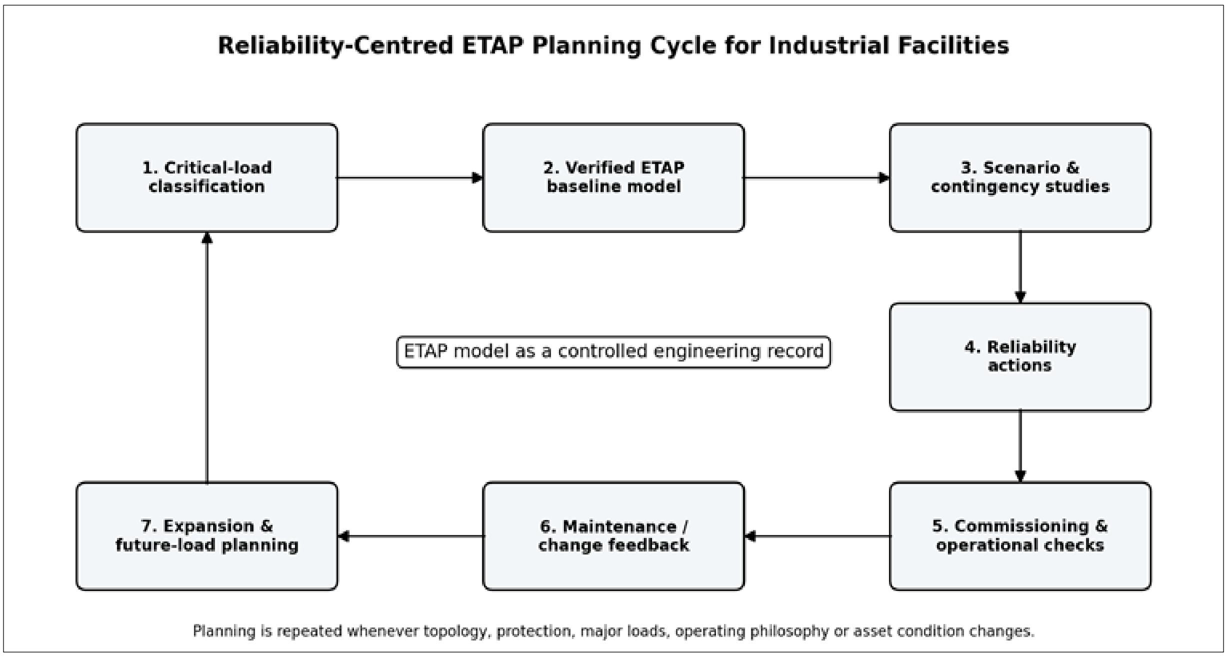

Fig. 1: Reliability-centred ETAP planning cycle for industrial facilities.

6. Capacity, Redundancy and Expansion Studies

Capacity planning in an industrial facility should be performed beyond the annual maximum demand. At minimum, engineers should evaluate a normal production case, a summer or high-cooling-demand case (where relevant), a maintenance configuration, a credible single-component outage, and a future-production case. Load flow provides the bus voltages, feeder currents, transformer loading, losses and reactive demand needed to assess each condition [1, 2]. The planning decision is based on the limiting case, not necessarily the normal case.

Transformer redundancy illustrates the difference. Consider a substation with two transformers that normally share the load. If the plant requires continued operation after one transformer is removed, the remaining transformer, cables and bus sections must be checked for the transferred load. The study should identify which lower-priority loads must be shed if full transfer is not acceptable. This may lead to a deliberate operating philosophy in which critical loads are preserved while discretionary loads are disconnected. The same philosophy can be tested during future expansion so that spare capacity is defined in terms of contingency capability rather than simple nameplate headroom.

Feeder and bus configuration should be assessed similarly. A normally open tie may offer an alternate supply path during maintenance, but closing it can change short-circuit current and protection directionality. A ring arrangement may provide two supply paths, yet operators need a clear switching sequence and verified protection for each permitted state. In high-criticality plants, the most valuable ETAP result may therefore be a set of approved configurations with documented limits rather than a single preferred one-line diagram.

Expansion planning should also examine the electrical behaviour of new production equipment before procurement is final. Large motors can affect starting voltage; additional drives can change harmonic loading; new transformers can raise fault duty; and a new packaged generator can affect grounding and protection. Early modelling lets these effects influence equipment specifications, transformer impedance selection, bus rating, starter type, feeder size, and protection requirements. This reduces the risk of discovering an electrical constraint after mechanical equipment has already been purchased. Table 1 translates common industrial planning decisions into the ETAP studies and acceptance evidence that should support them.

Table 1: Industrial planning decisions and ETAP evidence

Planning decision	Primary ETAP study / model use	Acceptance evidence
Transformer and feeder capacity	Load flow for normal, peak, maintenance and N-1 cases	Voltage and loading remain within approved limits; critical loads can be retained
Network redundancy and tie operation	Contingency cases plus short-circuit check	Alternate supply path is feasible and equipment duty remains adequate

Planning decision	Primary ETAP study / model use	Acceptance evidence
Large motor connection	Motor acceleration and voltage-dip assessment	Motor reaches rated speed and other process buses remain stable
Post-disturbance restoration	Transient stability / motor reacceleration	Restart sequence does not cause unacceptable voltage or frequency depression
Emergency generation and load shedding	Dynamic generation-load balance and priority logic	Essential loads are retained and generator response remains stable
Protection changes after expansion	Short circuit, device duty and coordination	Faults are selectively isolated and interrupting ratings are not exceeded
Planned maintenance outage	Reconfigured load flow and protection review	Remaining network can support the approved maintenance state

7. Dynamic Continuity: Motor Starting, Reacceleration and Load Shedding

Large motors are a defining feature of many industrial power systems. Compressors, pumps, fans, crushers, mills and process drives can draw substantial current during starting. If the source is weak or several motors start together, bus voltage may fall enough to slow acceleration, drop contactors, upset drives, or disturb other process equipment. ETAP motor-acceleration studies are intended to test starting current, terminal voltage and acceleration performance under the actual system configuration [2]. The planning question is not only whether one motor can start, but whether it can start under the weakest credible operating state, such as with one transformer unavailable or a generator supplying part of the system.

Reacceleration after a disturbance is equally important. A short voltage interruption can leave several motors coasting. When voltage returns, simultaneous reacceleration may create a demand greater than the pre-disturbance load. ETAP transient-stability tools can evaluate motor dynamic behaviour, generator response and system voltage recovery, and can be used to test reacceleration, load shedding and bus transfer strategies [3]. For a process plant, this is directly linked to restart philosophy. Some motors may need immediate restoration to preserve lubrication or cooling, while others should be delayed to avoid a second voltage collapse.

Load shedding converts load criticality into an automated or procedural response. A credible industrial scheme needs priorities, triggers and validation. Triggers may include generator under-frequency, loss of an incomer, transformer overload or a severe generation-load imbalance. Priorities should follow process consequence, not simply feeder size. ETAP's load-shedding and transient analysis capabilities can be used to test whether the selected amount and sequence of shedding preserves the plant's stable operation [1-3]. The 2023 ETAP case study of a fertiliser plant illustrates the practical use of model-driven intelligent load shedding and digital-twin validation to improve response to power disturbances and motor-related operating constraints [30].

Fast bus transfer and alternate-source transfer are further continuity tools. Their success depends on source phase relationship, residual motor voltage, transfer time, protection logic and the electrical stress imposed on motors. A transfer scheme should therefore be validated dynamically rather than assumed to work because two sources are physically available. Similar reasoning applies to black-start or generator-supported restoration. Engineers should verify which auxiliary loads are required to start generators, which buses are energised first, how many motors can be restored in each step, and whether generator frequency and voltage remain acceptable during the sequence.

The key planning principle is that continuity is a sequence problem. Static adequacy, dynamic response, protection and operator action must be compatible. A plant may have adequate installed megavolt-amperes but still experience a prolonged outage if the first restoration step produces excessive motor inrush or if load priorities are unclear. Figure 2 therefore treats disturbances, tested responses and acceptance checks as one logic chain.

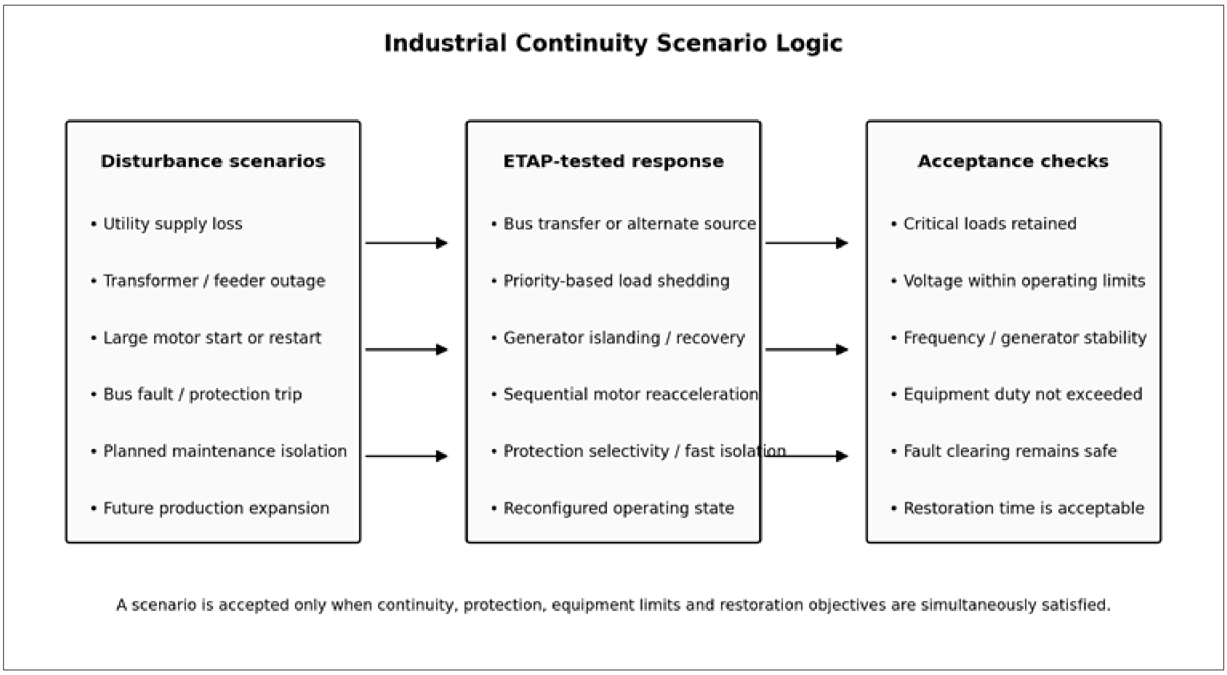

Fig. 2: Industrial continuity scenarios, model-tested responses and acceptance checks.

8. Protection, Selectivity and Electrical Safety as Reliability Constraints

Protection design in an industrial facility must isolate faults quickly enough for safety and equipment protection while avoiding unnecessary loss of healthy process areas. This is particularly important where several production units share upstream transformers or buses. A feeder fault should not trip an upstream incomer if downstream protection can clear it within acceptable limits. Time-current coordination, relay settings, breaker characteristics and device duty should therefore be reviewed for each permitted operating configuration, not only the normal one [1-4].

Short-circuit current changes when transformers, generators and tie breakers are added or removed. A breaker that is adequate in a radial condition may be exposed to higher duty when two sources are paralleled. IEC 60909 and other accepted short-circuit methods provide the calculation basis, while ETAP can compare calculated fault levels with equipment ratings [11]. This makes expansion planning inseparable from fault-duty verification. If an upgrade raises available fault current above switchgear capability, the project may require equipment replacement, current-limiting reactors, different transformer impedance or a revised operating restriction.

Arc-flash assessment introduces another design trade-off. Incident energy depends on fault current and protective-device clearing time. A coordination change that delays an upstream device may improve selectivity but increase exposure at some locations. Conversely, very fast tripping can reduce incident energy but may increase the risk of wider process interruption if settings are not selective. IEEE 1584 and NFPA 70E provide established calculation and workplace-safety frameworks [9, 10]. In reliability-centred planning, arc-flash results should therefore be evaluated alongside protection coordination, operating modes, and maintenance procedures. Options can include maintenance-mode settings, remote switching, zone-selective methods, current-limiting devices or equipment redesign where technically justified.

Fault isolation also affects restoration. Modern distribution research on fault location, isolation and service restoration demonstrates the importance of identifying the faulted section and restoring healthy sections through available alternate paths [19-28]. Industrial networks are smaller than utility distribution systems. Still, the principle is transferable: the electrical design should make it clear what can remain energised, what can be transferred, and what must be inspected before re-energisation. This turns protection from a stand-alone calculation into part of the plant continuity strategy.

9. Maintenance Outage Planning and Asset Integrity

Industrial reliability depends as much on maintainability as on installed redundancy. Transformers, switchgear, relays, generators and cables require inspection, testing and replacement, and some tasks require equipment to be isolated. A network that is reliable only when every component is available may be difficult to maintain safely. ETAP can be used before a planned outage to simulate the temporary configuration, confirm loading of the remaining equipment, identify voltage constraints and verify that protection settings stay appropriate. This allows maintenance work to be planned around electrical limits rather than relying on informal operating experience.

Reliability-centred maintenance provides a useful decision principle: maintenance priority should reflect both the likelihood of failure and the consequences of failure. Enjavimadar and Rastegar applied failure-mode and effect concepts to maintenance prioritisation in distribution systems, while Musthopa, Harsanto and Yunani examined a maintenance model expressly for industrial electrical distribution customers [13, 14]. These approaches support the idea that an industrial ETAP model should include equipment criticality, not just electrical ratings. A breaker feeding a noncritical auxiliary and a breaker feeding a process-safety bus may have similar electrical characteristics but very different business and safety consequences.

Condition data can progressively improve planning. Medium-voltage switchgear sensor data, thermal inspections, breaker operation counts, transformer condition indicators, protection event records and repeated power-quality complaints can reveal which assumptions deserve review. Predictive-maintenance research has studied sensors and machine learning for switchgear and power-distribution assets [15-17]. The purpose is not to turn ETAP into a maintenance-management system, but to use maintenance evidence to update operating restrictions and study priorities. If an asset is identified as deteriorated, the model can test how the plant will operate while it is removed from service and whether a replacement outage can be accommodated.

A controlled change log is a simple but important governance mechanism. Every major model revision should record the physical change, data source, affected study cases, responsible engineer, and approval status. The same discipline should apply to relay settings. An approved coordination study loses value if site settings are later changed without updating the model. By linking maintenance, protection and model control, the facility creates an engineering memory that survives staff turnover and multiple project contractors.

10. Smart Industrial Operation and Digital Integration

The term 'smart industrial facility' is most useful when it describes better situational awareness and decision support rather than a collection of disconnected digital technologies. An ETAP model can support this direction by serving as the electrical reference against which measured data, switching states, and events are interpreted. Interfaces with SCADA, intelligent electronic devices, historian data and power-management systems can provide actual loading, breaker status and event information. IEC 61850 and related digital-substation practices provide a wider framework for interoperable communications and device information [12].

Operational coordination can improve three tasks. The first is state awareness: operators can understand which sources and buses are carrying the plant and how close equipment is to an approved limit. The second is disturbance analysis: event playback and recorded measurements can be compared with the model after a trip, allowing engineers to revise assumptions or settings. The third is predictive planning: load trends can identify when future expansion will erode contingency margin before an overload occurs. Digital-twin research similarly emphasises that a model becomes more valuable when it receives data from the physical system and is kept aligned with real operating conditions [22].

Renewable generation and battery storage may be added to industrial sites, but this paper treats them as new operating states rather than the main objective. Their planning impact includes reverse power flow, fault-current contribution, islanding philosophy, generator interaction, harmonic effects, protection and energy-management logic. Saudi research on renewable and storage applications shows the growing relevance of these resources [25-29]. The reliability-centred question remains the same: does the new resource improve continuity amid credible events, and have the resulting operating states been tested? Smart operation should therefore extend the scenario library rather than replace the fundamental requirements for verified data, selective protection and maintainable network architecture.

11. Proposed Reliability-Centred ETAP Planning Framework for Saudi Industry

The proposed RCEP framework has six implementation stages. Stage 1 is criticality definition. The facility identifies process-safety loads, production-critical loads, essential utilities and discretionary loads, and records the consequence of interruption. This creates the basis for redundancy and load-shedding priorities. Stage 2 is verified model development. Equipment data, origin features, cable routes, relay settings, motor data and operating configurations are reconciled with field conditions. Stage 3 is scenario qualification. Engineers create approved study cases for normal production, summer peak, maintenance, single-source loss, transformer or feeder outage, tie operation, major motor starting and future expansion. Each case receives explicit acceptance criteria.

Stage 4 is dynamic continuity validation. Motor starting, reacceleration, transient stability, generator response, bus transfer and load shedding are tested where relevant. The objective is to demonstrate a feasible sequence from disturbance to stable operation. Stage 5 is risk-ranked action planning. Findings are converted into decisions such as transformer or cable upgrades, additional redundancy, new protection settings, revised load-shedding priority, changed starting method, alternate switching sequence, or maintenance restrictions. Actions should be ranked by safety consequence, production impact, likelihood and implementation cost. Stage 6 is lifecycle feedback. Commissioning measurements, maintenance evidence, trips, equipment replacements and new project modifications are fed back into the model and scenario library.

For Saudi industrial owners and EPC contractors, the framework also has procurement implications. Handover should include the editable ETAP model, equipment-data assumptions, defined study cases, relay-setting files, protection curves, arc-flash outputs where required, critical-load register, approved switching configurations and a model change log. Assign model ownership to a named engineering function. These requirements are practical because the most expensive part of future analysis is often rebuilding or validating data that should already exist.

Table 2 presents a minimum scenario library. It is not intended to replace site-specific hazard or reliability studies. Instead, it provides a disciplined starting point so that project teams do not evaluate only the normal case. The scenario set is especially useful for plants that operate continuously, use large motors, have multiple sources, or expect staged production expansion. It also supports localisation of engineering capability by giving Saudi facility teams a repeatable method for reviewing contractor studies and updating the model after handover.

Table 2: Minimum ETAP scenario library for Saudi industrial facilities

Scenario	Purpose	Key outputs to review
Normal full-production operation	Confirm baseline adequacy	Bus voltages, transformer/feeder loading, power factor, losses
Summer / high-cooling-demand operation	Check thermal and voltage margin during seasonal peak	Loading margin, voltage profile, reactive demand
One transformer or incomer unavailable	Verify contingency continuity	Transferred loading, loads to shed, alternate feeder path
Planned bus / switchgear maintenance	Validate temporary configuration	Remaining capacity, protection validity, switching restrictions
Largest motor start and post-trip reacceleration	Protect process continuity during dynamic events	Voltage dip, acceleration time, restart sequence
Emergency generator / islanded essential bus	Verify emergency operating philosophy	Frequency, voltage, generator loading, priority loads
Tie breaker closed / alternate-source transfer	Check changed fault and protection conditions	Short-circuit duty, relay directionality, transfer feasibility
Future production expansion	Protect long-term reliability margin	Normal and contingency capacity, equipment duty, required upgrades

12. DISCUSSION

The review indicates that the strongest distinction between ETAP-enabled industrial planning and generic power-system analysis is the use of scenarios tied to operating consequences. Traditional project deliverables often divide load flow, short circuit, motor starting, coordination and arc flash into separate reports. That framework is useful for documentation, but it can hide interactions. Industrial reliability depends on the combination of these studies. A tie breaker may solve a maintenance-supply problem while increasing fault duty. A relay delay may improve selectivity while worsening arc-flash energy. A future production load may be acceptable in normal operation but unacceptable during a transformer outage. A generator may provide emergency capacity but be unable to support the proposed motor restart sequence. The planning model becomes valuable when it exposes these trade-offs before they appear during operation.

A second finding is that reliability should not be equated with maximum redundancy. Additional transformers, feeders and generators increase capital cost and may increase system complexity. The appropriate design depends on the consequence of interruption and the ability to restore production. In some facilities, full N-1 capacity for all loads may be economically justified. In others, continuity may be achieved more efficiently through selective load shedding, spare feeder paths, staged restart and protected critical buses. Reliability assessment methods and outage indices can support comparison, but the final decision requires process and business input in addition to electrical calculations [8-14].

A third implication concerns maintenance. Planned outages should be treated as design scenarios from the beginning of a project. If a transformer, bus section or switchboard cannot be isolated without shutting down the entire plant, that is a maintainability decision with lifetime consequences. Model-based maintenance planning can identify temporary overloads, voltage issues or protection changes before an outage window begins. Digitally enabled maintenance literature supports the wider shift from reactive work toward condition- and risk-informed decisions [15-17].

A fourth implication is the importance of model governance. A highly detailed ETAP file is not automatically trustworthy. Its value depends on whether the model reflects site tags, actual settings, verified cable data, current operating philosophy and approved modifications. The Saudi industrial environment, with rapid development and multiple EPC packages, makes this especially important. The most useful digital model is not necessarily the most complex; it is the one whose assumptions are known and whose case studies are controlled.

Subsequent research should test the proposed framework using measured Saudi industrial data. Useful case studies would compare pre- and post-modification contingency margins, motor reacceleration performance, load-shedding effectiveness, restoration time, nuisance trips, maintenance outage duration and process interruption cost. Another research direction is integrating asset condition with system consequences: for example, using transformer or breaker health indicators together with ETAP contingency results to prioritise replacement. Studies could also examine the effect of severe ambient conditions, dust, coastal exposure and seasonal demand on the reliability margin of industrial networks. Such work would move ETAP-enabled planning from a conceptual framework toward quantified Saudi industrial reliability benchmarks.

13. CONCLUSION

ETAP-enabled electrical system planning can support reliable and smart industrial facilities in Saudi Arabia when it is organised around lifecycle reliability instead of isolated software calculations. The most important planning tasks are to classify critical loads, select network architecture according to outage consequence, verify capacity under normal and contingency conditions, test large motor starting and reacceleration, validate load shedding and restoration, coordinate protection for every approved operating state, and plan maintenance arrangements before equipment is taken out of service.

The proposed Reliability-Centred ETAP Planning framework treats the model as a controlled engineering record that follows the facility from design through commissioning, operation, maintenance and expansion. Its value comes from scenario discipline: every important network state is represented, analysed and checked against explicit acceptance criteria. This approach makes the content of the present paper distinct from broad smart-grid planning because the main goal is industrial continuity, maintainability and controlled expansion.

For Saudi industrial owners, the practical recommendation is to require editable models, verified data, critical-load registers, defined contingency cases, relay-setting control, and model-update procedures as part of project handover. Future expansions and maintenance changes should be tested against this baseline before implementation. With this governance, ETAP functions not only as a study package but a reusable planning system that helps engineering teams retain critical production, improve outage preparedness and make safer electrical investment decisions as Saudi industry grows.

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