Global Academic Journal of Economics and Business

Available online at https://www.gajrc.com
DOI: https://doi.org/10.36348/gajeb.2026.v08i04.036

OPEN ACCESS

ISSN: 2706-9001 (P)
ISSN: 2707-2584 (O)

Original Research Article

ETAP-Based Power System Analysis for Smart Grid Planning in Saudi Industrial and Commercial Facilities

Zohaib Dildar Khan[1]*
[1]Electric House: Jeddah, Saudi Arabia, SA - Project Manager/Researcher, Project Management/ R N D

***Corresponding Author**
Zohaib Dildar Khan
Electric House: Jeddah, Saudi Arabia, SA - Project Manager/Researcher, Project Management/ R N D

Article History
Received: 14.06.2026
Accepted: 06.08.2026
Published: 12.08.2026

Abstract: Saudi Arabia's industrial and commercial facilities are becoming increasingly electrically complex. Manufacturing expansion, data centres, petrochemical integration, metro systems, healthcare campuses, tourism developments and renewable generation all increase the demand for safe, reliable and flexible power systems. Electrical Transient Analyser Programme based studies provide a practical engineering platform for converting drawings, asset data and operating assumptions into coordinated planning decisions. This paper reviews the possible support of the ETAP based power system analysis to smart grid planning in Saudi industrial and commercial facilities through the integration of load flow, short circuit, protection coordination, motor starting, harmonic, arc flash, reliability and renewable interconnection studies. We used a structured narrative review methodology to examine sources published between 2020 and 2025, including peer-reviewed smart grid literature, power system study research, utility reports, technical standards and ETAP-oriented engineering references. The review finds ETAP to be most valuable when it is not used merely as calculation software, but as a digital planning environment that links the design of facilities, operational reliability, safety compliance, asset loading and future distributed energy integration. The most impactful planning applications for Saudi facilities are transformer and cable sizing validation under high cooling loads, fault level and breaker duty verification, relay coordination to avoid unnecessary shutdowns, arc flash exposure estimation, power quality assessment with variable speed drives and PV, battery and microgrid options prior to capital deployment. The paper proposes a phased ETAP enabled smart grid planning framework aligned with Vision 2030, industrial localisation and grid reliability objectives. It concludes that robust modelling governance, verified field data and periodic model updates are critical if ETAP studies are to underpin resilient, safer and more efficient Saudi facilities.

Keywords: ETAP, Power System Analysis, Smart Grid Planning, Saudi Arabia, Industrial Facilities, Load Flow, Short Circuit, Arc Flash, Power Quality.

1. INTRODUCTION

Industrial and commercial facility power systems are no longer simple downstream networks receiving energy from a utility point of common coupling. In Saudi Arabia, large facilities increasingly house multiple transformers, medium-voltage switchboards, low-voltage motor control centres, standby generators, photovoltaic systems, battery storage, variable-speed drives, sensitive electronic loads, fire pumps, chillers, data infrastructure and

Citation: Zohaib Dildar Khan (2026). ETAP-Based Power System Analysis for Smart Grid Planning in Saudi Industrial and Commercial Facilities; *Glob Acad J Econ Buss, 8*(4), 932-941.

automated building-management systems. This growing complexity means that planning decisions can no longer be based on nameplate margins or static single line drawings. Engineers must test the network's behaviour in the event of normal loading, contingency operation, fault conditions, motor acceleration, harmonic distortion, renewable variability and maintenance switching. The ETAP-based analysis provides a structured approach to perform these evaluations within a single digital model using modules for load flow, short circuit, arc flash, motor starting and network analysis [1, 2].

Saudi Arabia is a relevant setting for this review, as Vision 2030 has accelerated industrial diversification, renewable-energy development and smart-grid modernisation. Saudi Electricity Company reported 100 percent smart-meter coverage, an increasingly automated grid and major network expansion in its 2024 results presentation [3]. The national renewable energy programme is also intended to optimise the share of renewable energy in the electricity mix of the Kingdom and to support energy-transition targets [4]. Such developments affect private and public facilities as the interconnection to the grid, peak demand, power quality, protection selectivity and internal resilience become more important with increasing loads and distributed energy resources. Industrial cities, hospitals, universities, airports, retail districts, hotels and commercial towers cannot afford to have unnecessary outages or unsafe electrical conditions. ETAP studies in such environments can be an engineering decision support layer that connects smart grid planning to facility-level reliability. The problem addressed in this review is the gap between expansion of facilities and verified planning of power system. Many facilities grow in stages. Based on the original electrical design, additional equipment such as chillers, production lines, pumps, UPS systems, EV chargers or PV inverters may be added. Without a continuous analytical model, transformer overloads, excessive voltage drop, poor power factor, mis-coordinated protection, underestimated fault duty and unsafe arc flash energy can result from cumulative changes. Research on smart grids emphasises the need for data-driven planning, integration of renewable energy sources, and communication and control capabilities in future electrical systems [5, 6]. But these capabilities need accurate power system studies before automation is implemented. "ETAP can help engineers move from isolated calculations to an integrated model where load growth, network topology, equipment ratings and safety constraints are considered in concert.

2. Aim, Objectives and Review Contribution

This review aims to evaluate the contribution of ETAP-based power system analysis to facilitate smart grid planning for Saudi industrial and commercial facilities. The first objective is to identify the planning studies most relevant to facility reliability, including load flow, short circuit, protection coordination, motor starting, harmonic assessment, arc flash analysis and renewable interconnection. The second objective is to discuss the contribution of these studies to the readiness of smart grids by enhancing visibility, operational flexibility, safety and the prioritisation of investment. The third goal is to map ETAP outputs to the needs of Saudi facilities, considering high ambient temperatures, large cooling loads, industrial process continuity, power quality from drives, standby generation, distributed PV, and battery storage. The fourth objective is to outline a phased implementation roadmap for using ETAP as a living digital model instead of a one-time design deliverable. Our review makes three contributions. Firstly, it integrates recent literature on smart grids, power system reliability, predictive maintenance, renewable integration and facility level electrical studies into a focused planning perspective. Second, it interprets ETAP-based analysis for Saudi industrial and commercial facilities not only for utility planning. Thirdly, it provides a pragmatic framework linking analytical modules with operational decisions, such as transformer upgrades, protection settings adjustments, power factor improvements, filtering, increasing the redundancy, or reconfiguration of low- and medium-voltage networks. The review does not state that software makes a facility smart. Instead, it argues that a facility is smart when validated models, real operating data, protection logic, safety procedures and investment decisions are coordinated [7, 8]. This is a crucial distinction because poor input data or outdated single line diagrams can lead to misleading advanced calculations. Therefore, planning based on ETAP must include model governance, field verification and periodic re-calibration.

3. REVIEW METHODOLOGY

This paper employs a structured narrative review methodology appropriate for an engineering topic where evidence is drawn from academic research, technical standards, software documentation, utility reports and professional power system practice. The review scope was limited to sources published or updated between 2020 and 2025 unless a current standard or software page is used as technical context. Keywords: ETAP power system analysis, load flow study, short circuit study, arc flash analysis, motor starting, harmonic analysis, smart grid planning, Saudi Arabia power systems, industrial electrical reliability, renewable integration, distribution automation, commercial facility power quality. The sources were screened to determine whether they are relevant to any of the following three questions: 1. Does the study support planning at the facility level? 2. Does the study deal with reliability or safety? 3. Can the findings of the study be applied to Saudi industrial or commercial environments? The included literature was categorised into six themes. The first theme focuses on smart grid planning and renewable integration, as industrial and commercial facilities interact increasingly with distributed generation and storage [5-10]. The second theme is on the power system study functions such as load flow, short circuit and arc flash assessment [1-11]. The third theme is protection coordination, switching selectivity and fault containment that determine if a fault will cause localised disconnection or more wide spread facility shutdown [12, 13]. The fourth theme is power quality and harmonics, especially when variable speed drives, UPS rectifiers, inverters and industrial automation generate waveform distortion. The fifth theme concerns reliability, predictive maintenance and asset health as modelling should be improved based on field evidence [14, 15]. The sixth theme consists of Saudi implementation conditions including smart metres, network expansion, renewable targets, industrial growth and hard environmental stresses [3-16]. The review is not without its limitations. No vendor project files, confidential facility measurements, or a numerical ETAP case study based on proprietary data are included. It does not make general claims about exact savings as the results depend on load profiles, condition of equipment, switching configuration and maturity of maintenance. Instead, this paper provides a review-based framework for where ETAP analysis can be used to reduce risk and improve planning decisions. The methodology follows a review logic similar to that of recent technology review manuscripts: define the problem, synthesise functional domains, classify enablers and barriers, and develop a planning pathway for future implementation [6-17].

4. ETAP-Based Studies as a Facility Planning Platform

ETAP is extensively employed for modelling, simulating and analysing electrical networks by using an intelligent one-line diagram and a database that can support multiple studies from the same equipment records [1]. This is valuable for industrial and commercial facilities because a transformer, cable, bus, breaker or motor should not be represented differently in separate calculations. When the model is built carefully, one validated data structure can support load flow, short circuit, protection coordination, arc flash and motor-starting studies. This reduces fragmentation and enables engineering teams to reliably compare design options. The first step is usually loading flow analysis. Analyses bus voltages, branch currents, transformer loading, power factor, losses, and reactive power requirements for operating scenarios. Load flow is important in Saudi facilities due to the high air-conditioning and process cooling loads, the impact of ambient temperature on cable and transformer ratings, and the potential for rapid growth in demand. A load flow model can be used to identify undervoltage at remote panels, overloaded feeders, poor power factor and transformer capacity constraints before an outage or overheating event occurs. It can also determine if planned additions like chillers, compressors, elevators, EV chargers or production lines can be connected without exceeding voltage and loading limits. The short circuit analysis provides the fault currents at the buses and the equipment terminals. This determines whether or not the breakers, switchboards, cables and busbars are rated high enough to interrupt or withstand. Fault levels can change when utility sources are upgraded, generators are added, transformers are replaced, or tie breakers are closed. For industrial facilities with multiple sources, a short circuit model prevents unsafe assumptions about available fault current. It also provides a basis for coordination of protection and arc flash studies. Research on microgrid arc flash and short circuit modelling shows that the safety of the facility is determined by the correct representation of the sources, impedances, protection devices and operating modes [11]. Protection coordination is the next level of planning. The purpose of selective coordination is to have the device closest to the fault operate first to minimise the outage. In a commercial tower or an industrial plant, poor coordination can cause a small feeder fault to trip the whole building. Time-current-curve evaluation, in the ETAP style, lets engineers compare relay, fuse and breaker settings. It also helps to evaluate if settings are still valid when network configuration changes. As facilities adopt generators, PV inverters and battery systems, protection becomes more complex because fault current contribution may vary with operating mode [18]. Arc flash analysis translates fault current, clearing time, equipment configuration and working distance into incident energy and personal protective equipment (PPE) requirements. ETAP arc flash tools support AC and DC analysis for LV, MV and HV systems and can be integrated with protection coordination [2]. This is important in Saudi facilities where maintenance teams regularly access electrical rooms. Arc flash results are more than just labels; they enable safer switching, remote operation, setting optimisation and maintenance procedures. Therefore, an engineering study should treat arc flash as a planning and safety control process, not a compliance formality.

5. Smart Grid Planning Needs in Saudi Facilities

Planning a smart grid within a facility means designing an electrical system that can be monitored, analysed, controlled and upgraded without loss of reliability. "It's not simply a question of putting in sensors. It means coordinating the analytical models, the metering, the protection, the communications, the automation and the maintenance. Saudi Arabia's wider electricity sector is also heading this way with SEC reporting progress on smart metres, network expansion and distribution automation [3]. The utility-side modernisation will increase the value of accurate facility models and responsive load behaviour, so industrial and commercial facility owners should align with this transition. Special needs for Saudi industrial establishments Petrochemical plants, steel works, mining operations, food-processing plants and logistics centres often have large motors, variable-speed drives, redundant transformers and critical process loads. A motor starting study can examine voltage dips that occur during direct-on-line, soft-starter or variable-frequency-drive starting. ETAP analysis can compare mitigation options such as staged starting, transformer resizing, reactive support or drive-based control if a large motor creates an unacceptable voltage sag. Harmonic studies are required to prevent transformer heating, neutral overloading, nuisance trips and power quality complaints for facilities with high drive penetration. Therefore, smart grid planning should include power quality dashboards linked to model-based thresholds. The needs of commercial facilities may differ, but are no less important. Hospitals need reliable supply for operating rooms, life-safety systems, imaging equipment, chillers and UPS-backed loads. Airports, data centres, malls, universities and hotels require continuity, energy efficiency and safe switching. ETAP can compare operating modes normal, emergency and maintenance. It can also evaluate generator start-up sequences, automatic transfer schemes, load shedding and UPS coordination. Smart grid planning for these facilities should focus on operational continuity and maintainability. The model should be able to answer practical questions such as: which loads are restored first, how much spare capacity is there, which breaker opens under a fault, what is the effect of one transformer being out of service. Modelling needs increase with renewable integration. Opportunities exist for facility-scale PV, batteries and microgrids to meet Saudi Arabia's renewable energy goals [4]. The ETAP case study of renewable microgrid control in the Red Sea region shows how digital modelling and control can support reliable operation with PV, battery storage and secondary control layers [19]. Similar principles, on a smaller scale, are applicable for industrial and commercial facilities. Before PV or storage installation, engineers should consider reverse power flow, voltage rise, contribution to short circuit, harmonic effects, protection settings, islanding logic and load matching. A model-based approach reduces the risk of operational problems of renewable assets after commissioning. The proposed planning architecture is summarised in Fig. 1. This positions the ETAP model in the hub of facility smart grid planning with field data, utility interface, engineering studies, automation logic, safety outputs and executive decisions all around it. The figure shows the main argument of the review that analysis becomes useful when it links technical calculations with operational governance.

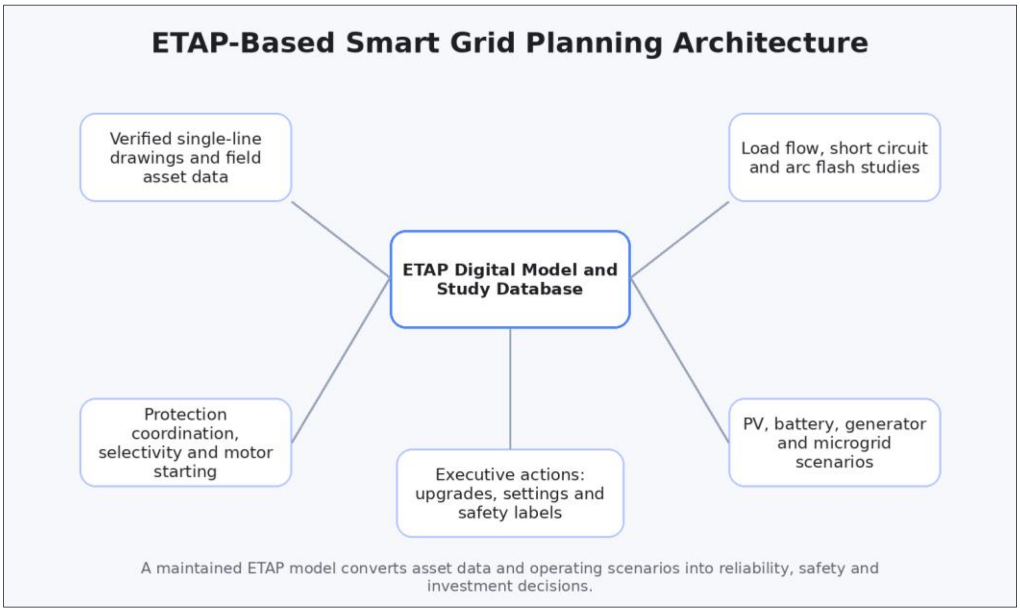

Fig. 1: ETAP-based smart grid planning architecture linking field data, engineering studies and executive decisions

6. Reliability, Safety and Power Quality Outcomes

The ETAP-based analysis reliability value appears when the study results are converted into corrective actions. The load flow results may justify the need to upsize the cable, place capacitors, balance the transformer, or transfer load. Short circuit results can identify equipment that is under-rated and should be replaced before expansion. Coordination results may avoid unnecessary upstream trips. Justification for relay setting optimisation, remote switching or current-limiting devices can be made using arc flash studies. Harmonic results may justify derating of filter or transformer. Motor-starting results can avoid voltage dips that would otherwise shut down sensitive process controls. These outputs are engineering decisions, not merely report tables. The reliability literature states that modern grids require planning methods that can deal with renewable resources, storage and changing load behaviour [9, 10]. Facility systems have a similar challenge. The internal voltage and protection behaviour may change when the PV output changes or a battery changes operating mode. Adding power electronic drives to a production line can increase harmonic distortion. During summer peaks, when the cooling load increases, thermal margins become smaller. ETAP scenarios can test these conditions prior to them becoming events. It supports proactive reliability instead of reactive troubleshooting. Safety results are just as important. Fault current and clearing time strongly influence the arc flash hazard. A coordination setting that improves selectivity may increase incident energy in case of delay in fault clearing. Conversely, decreasing trip times may reduce arc energy but may cause nuisance outages. The ETAP-based evaluation enables engineers to compare these trade-offs. The importance of short circuit and arc flash modelling for equipment labelling and safe operations was demonstrated by a microgrid facility study published in 2021 [11]. In Saudi facilities, this is applicable to maintenance work in electrical rooms, substations and industrial panels where safe access procedures are vital. Power quality is another planning output. Smart facilities have many non-linear loads such as VFDs, LED lighting drivers, UPS systems, rectifiers, inverters and data centre power supplies. Harmonics may lead to excess heating, resonance and mis-operation. Harmonic analysis based on ETAP can assess distortion at buses, transformer loading and filter performance. If capacitor banks are installed for power factor correction, resonance risk should be checked. For industrial plants, harmonic issues can impact production reliability. For commercial facilities, it can decrease equipment life and raise maintenance costs. The reliability also depends on the model maintenance after commissioning. A study done once becomes stale when loads change, relays are replaced or maintenance switching creates new configurations. Digitally enabled proactive maintenance studies show that power distribution reliability improves when asset data, maintenance evidence and analytics are integrated into decision systems [15]. Consequently, ETAP models should be updated following major modifications, changes in protection settings, fault events and annual maintenance reviews. This makes the model a living engineering record.

7. Barriers and Enablers

The first obstacle to implementation is the quality of the data. The ETAP results are based on accurate data including transformer impedance, cable length, conductor size, motor data, utility fault level, relay curves, breaker settings and operating modes. Existing facilities often have incomplete drawings or undocumented changes. Also, before starting the analysis, the teams should conduct field verification, obtain nameplate data and reconcile the single line diagram with the actual status of the switchgear. Bad input data can produce a professional looking report that is not technically safe. The second barrier is organizational disconnect. Design consultants. Facility managers. Contractors. Protection engineers and safety officers. They might all have different information. Operations may not be supported if the ETAP model is provided as a project closeout file only. A better approach is to define ownership, who owns the model, who approves updates, who checks settings, how do study findings become work orders. This governance problem becomes especially relevant in Saudi facilities that are constructed in phases or with multiple contractors.

The third barrier is the skill of the software. ETAP can do a lot of studies but you still have to interpret them correctly. Engineers shall be aware of assumptions, standards, simplifications of the model and site constraints. A load flow report can identify a voltage problem but the solution may involve tap settings, conductor replacement, load balancing or reactive compensation. An arc flash result may require equipment replacement, changes in protection settings or remote operation. Therefore, the training should include software skills and the basics of power engineering. The fourth barrier is integration into smart grid operations. ETAP models could be independent of SCADA, metres, building-management systems and maintenance records. This reduces their usefulness. Future planning needs to connect study models with measured loading, demand profiles, outage history and asset health data. This model-operational link is increasingly stressed in smart grid platforms and digital twins [5-19]. Critical enablers are also present. Saudi Arabia has national momentum for grid modernisation, smart metres, industrial development, and renewable energy [3, 4]. Industrial cities and large commercial portfolios can standardise modelling requirements across their facilities. Localisation can be the development of ETAP capability in local engineering companies. Adding a major load may require facility owners and utilities to update their power system studies. Safety regulations and insurance expectations can be drivers for arc flash and short circuit studies. These enablers can turn the ETAP based planning from an academic exercise into a practical modernisation tool.

8. Proposed ETAP-Enabled Planning Framework

The proposed framework consists of five stages. Stage one is the basic model. The facility is capable of producing a verified single-line model that includes utility sources, transformers, switchgear, cables, buses, motors, generators, UPS systems, capacitor banks and major loads. Field verification is a must. The second stage is steady-state adequacy assessment. Under normal, peak, maintenance and future load scenarios, load flow, voltage drop, transformer loading, cable loading and power factor are evaluated. The third stage is fault and protection assessment. Short circuit, device duty, protection coordination and arc flash studies are carried out for normal and alternative operating modes. Stage four is the smart grid readiness assessment. PV, battery, generator, microgrid, demand response, EV charging and automation scenarios are tested. Stage five is lifecycle governance. The model is updated by: Measured data, Findings from maintenance, Event records, Project modifications. Table 1 presents the translation of ETAP study modules into smart grid planning value. Table 2 shows a Saudi implementation roadmap. Data foundations are the first step in the roadmap because you cannot have reliable analysis without verified records. It then moves into core safety and reliability studies, renewable integration, automation and continuous improvement. The sequence avoids the common error of buying advanced tools before the basic electrical data are correct. The framework also offers priority criteria. Facilities with large motors, multiple sources, critical loads, high fault levels, poor power quality, repeated nuisance trips, planned PV integration, major expansion or limited spare capacity should be prioritised for ETAP studies. Commercial portfolios should include hospitals, data centres, airports, malls and high-rise buildings. In industry, the priority should be given to petrochemical plants, manufacturing lines, water facilities, mining sites and logistic hubs.

Figure 2 shows the workflow from data collection to continuous improvement. The workflow is intentionally circular because facility planning is not a one-report process. Any new load, feeder, transformer, inverter or generation load changes the network. Information on assumptions is provided for each fault or maintenance finding. A living ETAP model enables engineered memory and renders future expansions faster, safer and more reliable.

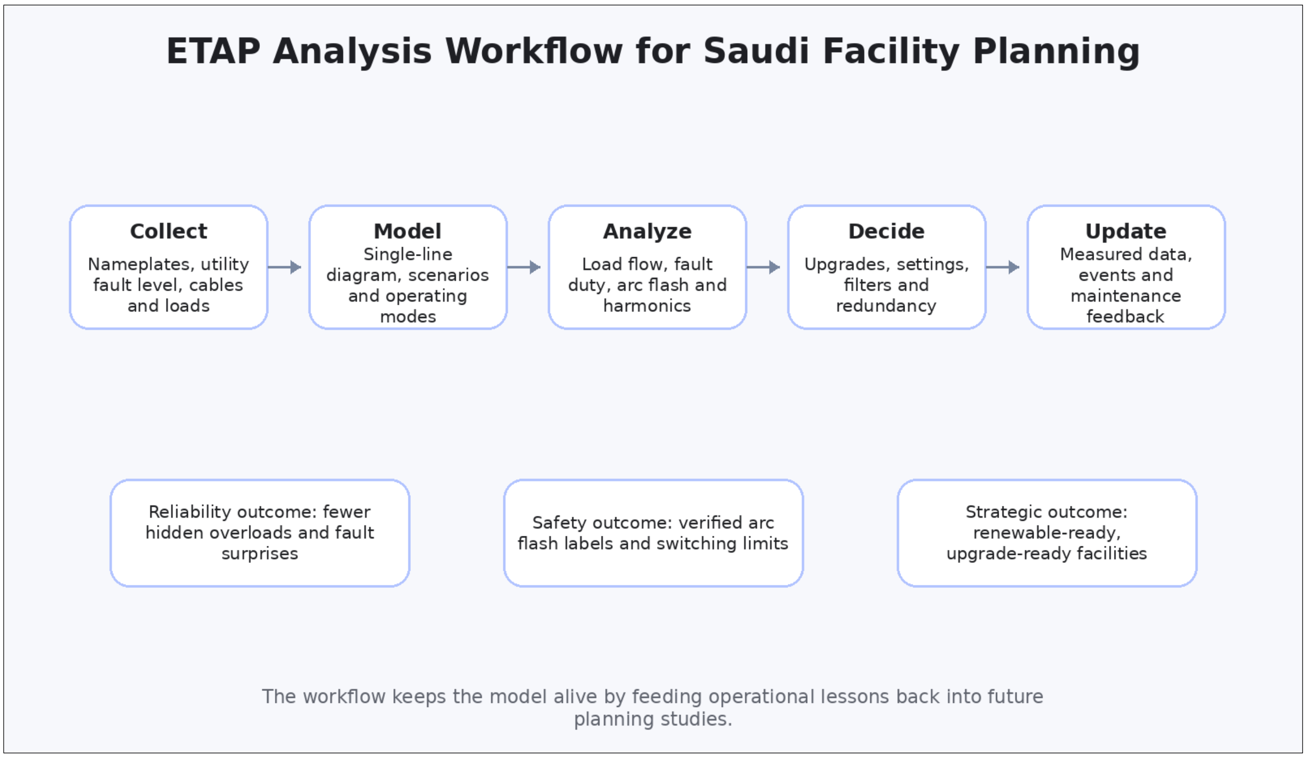

Fig. 2: ETAP analysis workflow for Saudi industrial and commercial facility planning

Table 1: ETAP study modules and their smart grid planning value

ETAP study module	Planning question addressed	Smart grid planning value	Saudi facility relevance
Load flow and voltage drop	Can the network serve present and future loads without overload or undervoltage?	Supports capacity planning, transformer loading, cable sizing and power factor decisions.	Important under high cooling demand, staged expansion and commercial peak loads.
Short circuit and device duty	Are switchgear, breakers and busbars rated for available fault current?	Prevents unsafe equipment selection and supports reliable fault containment.	Relevant where utility source upgrades, generators or tie breakers change fault levels.
Protection coordination	Will the nearest protective device isolate the fault first?	Limits outage area, avoids nuisance trips and improves continuity.	Critical for hospitals, airports, petrochemical plants and industrial production lines.
Arc flash analysis	What incident energy and PPE level apply at each electrical panel?	Improves worker safety, labelling, switching rules and setting optimization.	Supports safer maintenance in LV/MV rooms and industrial substations.
Harmonic and power quality	Will non-linear loads distort voltage or overheat equipment?	Guides filter design, resonance checks and drive-integration decisions.	Relevant for VFDs, UPS systems, inverters, LED drivers and data centers.
Motor starting and transient checks	Will large motors cause unacceptable voltage sag or instability?	Compares DOL, soft-starter, VFD and staged-start options.	Important for chillers, compressors, pumps, crushers and process motors.

Table 2: Saudi implementation roadmap for ETAP-enabled facility planning

Phase	Focus	Priority actions	Expected output
1. Data foundation	Verified electrical records	Collect single-lines, nameplates, cable routes, utility fault level and load history.	A reliable baseline model suitable for multiple studies.
2. Core safety studies	Load flow, short circuit and arc flash	Run peak, normal, emergency and maintenance scenarios; issue risk-ranked findings.	Validated capacity, fault duty and safety labels.
3. Selectivity and power quality	Protection, harmonics and motor starting	Review relay settings, TCC curves, VFD impacts, capacitor resonance and motor voltage dips.	Reduced nuisance trips and improved process continuity.
4. Smart grid readiness	DER, PV, BESS and microgrid scenarios	Evaluate reverse power flow, islanding, generator operation, storage dispatch and EV charging.	Renewable-ready and automation-ready facility planning.
5. Lifecycle governance	Living model and continuous improvement	Update the model after changes, events, audits and maintenance observations.	Sustainable planning discipline and stronger Saudi engineering capability.

9. DISCUSSION

The literature available suggests that ETAP based analysis can facilitate smart grid planning if embedded into facility governance. The strongest value is not just the calculation engine, but the disciplined link of model, data and decision. Capacity planning is improved by load flow analysis. Protection of equipment selection short circuit analysis. Coordination analysis minimises unnecessary shutdowns. Arc flash analysis enhances safety. Studies of harmonic and motor-starting protect power quality and process continuity. Renewable and microgrid studies prepare facilities for Saudi Arabia's energy transition path. These functions together create a planning environment in industrial and commercial facilities that must run 24/7 and grow. However, ETAP should not be considered as a substitute for engineering judgement. Old drawings, incorrect utility fault levels, missing cable data, generic motor assumptions or unverified relay settings can skew the results. The model needs to be audited. Engineers should compare simulated results with measured load data and update assumptions. Facility owners should be required to update studies following major electrical modifications. Operators need to know which operating configurations were studied and which were not. Without this discipline a report may generate false confidence. The Saudi context also enhances the practical relevance of the topic. The rapid growth of commercial developments, industrial cities and infrastructure projects make electrical planning more complex. High ambient temperatures and cooling demand eat into margins. The arrival of renewable energy and storage is creating new ways of operating. Smart grid modernisation at the national level sets expectations for more responsive facility systems. ETAP analysis can help facilities adapt to this environment by improving the transparency and upgrade-readiness of their internal networks. Another discussion point is the relation between ETAP and digital twins. A digital twin is often described as a living representation tied to operational data. ETAP can support this direction if the model is updated and linked to measurements. For many Saudi facilities the first step should be a validated engineering model not a full real-time twin. When the model is trusted, the value can be incrementally increased with data from metres, sensors and maintenance systems. This approach in phases is practical and cost-effective. In practice begin with a pilot plant where the owner has good drawings, switchgear that can be gotten at and a well-defined reliability problem. The pilot allows the comparison of the existing study process with an ETAP centred workflow for four deliverables: a verified model, a risk ranked deficiency register, a protection and safety action plan, and an update procedure for future projects. It eschews general digital transformation speak, and focuses on tangible engineering outputs. A second practical implication is procurement. Tender documents for new Saudi industrial and commercial facilities should include editable ETAP models, source assumptions, study reports, relay setting files, arc flash labels and model handover training. Without this requirement, the analytical value may remain with the contractor and not move over to the operating team. A third implication is related to asset management. The ETAP model should be linked to maintenance records, so that a breaker trip (or multiple trips), thermal alarm, observation of transformer loading, or power quality complaint can trigger a review of the model. You don't need full real-time integration right out of the gate. A spreadsheet-based change log can work well when the person responsible is clear. Finally, future work should compare the ETAP study recommendations with real operating records of Saudi facilities. Useful metrics would be voltage complaints, nuisance trips, transformer loading, arc flash category reduction, planned outage duration, maintenance cost and incident frequency before and after model-based improvements. Such evidence would help to move the topic from conceptual review to quantified engineering practice. Further studies can also look at the effects of desert ambient temperatures, dust accumulation, coastal humidity, high occupancy seasons and utility-side automation on facility margins. Combining ETAP results with smart-meter demand profiles, thermal inspections and breaker-event logs would provide stronger evidence to prioritise upgrades. This would be a Saudi benchmark for practical electrical digital twins in non-utility facilities, particularly where expansion is rapid and reliability expectations are high. The benchmark should categorise the type of facilities, critical loads, documentation maturity, automation readiness and the minimum study package required for safe energization and subsequent expansion.

10. CONCLUSION

The use of ETAP for power system analysis provides a good basis for smart grid planning in Saudi industrial and commercial facilities. The review reveals that facility reliability, safety and energy-transition readiness depend on coordinated studies, not isolated calculations. The load flow analysis checks the capacity and voltage performance. Short-circuit studies verify equipment duty. Protection coordination minimises the impact of outage. Arc flash analysis protects workers." The motor-starting and harmonic studies safeguard process continuity and power quality. Renewable and microgrid studies prepare facilities for PV, battery storage and flexible operations. The main conclusion is that ETAP functions best as a living planning model. Saudi facilities should hold verified electrical data, refresh models when changes occur, use measured loading and convert study results to corrective actions. This approach can reduce electrical risk, support safer maintenance, improve asset utilisation and prepare facilities for smart grid integration for Vision 2030 aligned industrial and commercial growth. Future work should develop Saudi facility case studies using real measured load profiles, utility fault levels, renewable scenarios and life cycle cost analysis. Such studies would help standardise ETAP-based planning practices across industrial cities, commercial portfolios and critical infrastructure and would increase the evidence base for investment decisions. Clear model ownership helps auditors, insurers and engineering managers to understand why a setting, rating or investment decision was accepted. Scenario libraries should cover summer peak demand, utility contingency supply, generator operation, maintenance switching, renewable export limitation and emergency restoration. A disciplined review meeting after every major event can translate operational lessons into updated assumptions and safer future operating procedures. This pragmatic feedback loop is especially valuable where facilities are growing rapidly and where documentation may otherwise lag behind the construction reality. Standardised templates may also benefit local consultants who are delivering similar studies across industrial cities and commercial portfolios.

Connected to training, the same model becomes a teaching tool for young engineers learning protection, safety and reliability planning. Such governance practices increase the trustworthiness and ease of repetition of numerical studies during future upgrades. They also reduce reliance on individual memory by maintaining the design intent in a maintained engineering record. What this means is a tighter link between capital expenditure, operational risk and tangible reliability performance for facility leaders. Therefore, the ETAP-based planning should be viewed as an engineering management process rather than a single software exercise.

REFERENCES

1. ETAP. Network Analysis: integrated AC and DC system simulation, load flow, short circuit, arc flash and motor starting modules. ETAP official technical package page. 2025.
2. ETAP. Arc Flash Software: AC and DC arc flash analysis for LV, MV and HV systems. ETAP official product page. 2025.
3. Saudi Electricity Company. FY 2024 results presentation: smart meters, increasingly automated grid and network expansion. Riyadh: SEC; 2025.
4. Ministry of Energy, Saudi Arabia. Renewable Energy Program and Saudi Vision 2030 energy mix objectives. Riyadh: Ministry of Energy; 2025.
5. Dileep G. A survey on smart grid technologies and applications. Renewable Energy. 2020; 146:2589-2625.
6. Ohanu CP, Rufai A, Olakulehin S, et al. A comprehensive review of recent developments in smart grid through renewable energy resources integration. Heliyon. 2024;10:e25705.
7. Ali SS, Choi BJ. State-of-the-art artificial intelligence techniques for distributed smart grids: a review. Electronics. 2020;9(6):1030.
8. Khalid M. Smart grids and renewable energy systems: perspectives and grid-integration challenges. Energy Strategy Reviews. 2024; 51:101276.
9. Sajadi A, Strezoski L, Kolacinski R, Loparo K. Transmission system planning for integration of renewable electricity generation units. arXiv:2001.03449. 2020.
10. Ghania SM, Alghamdi AS, Almutairi A. Reliability study of renewable energy resources and storage systems for electric networks. Engineering, Technology and Applied Science Research. 2022;12(4):8921-8928.
11. Schmitt KEK, Negri CA, Daneshvardehnavi S, Bayne S, Giesselmann M. Short circuit and arc flash study on a microgrid facility. arXiv:2105.09927. 2021.
12. Srivastava I, et al. Fault detection, isolation and service restoration in electric distribution systems. Energies. 2022;15(19):7264.
13. Leniston D, et al. Implementation of a software-defined FLISR solution on a distribution network. Heliyon. 2022;8:e10218.
14. Hoffmann MW, Wildermuth S, Gitzel R, et al. Integration of novel sensors and machine learning for predictive maintenance in medium voltage switchgear. Sensors. 2020;20(7):2099.
15. Mortensen LK, et al. Designing digitally enabled proactive maintenance systems for power distribution: a scoping review. Journal of Industrial Information Integration. 2024;41:100635.
16. Afzal AB, Mohammed N, Ahmed S, Konstantinou C. Advanced resilience planning for distribution systems under climatic hazards: a Saudi grid case study. arXiv:2409.20219. 2024.
17. Arefifar SA, Alam MS, Hamadi A. A review on self-healing in modern power distribution systems. Journal of Modern Power Systems and Clean Energy. 2023;11(6):1761-1779.
18. Javid Z, Ul Nazir F, Zhu W, Chakravorty D, Aboushady A, Galeela M. A new paradigm in inverter-based resource modeling for power flow and short circuit analysis. arXiv:2504.10181. 2025.
19. ETAP. Red Sea region renewable microgrid control case study: digital twin validation for PV, BESS and secondary control layers. ETAP case study. 2025.
20. Alam M, Muttaqi KM, Sutanto D. A review of smart grid communication technologies and applications. IEEE Access. 2021; 9:115535-115565.
21. Rubio S, Bogarra S, et al. Smart grid protection, automation and control: challenges and opportunities. Applied Sciences. 2025;15(6):3186.
22. Khan S, Paul D, Momtahan P, Aloqaily M. Artificial intelligence framework for smart grid predictive maintenance. IEEE Transactions on Industrial Informatics. 2022;18(10):7035-7046.
23. Jiang H, Zhang J, Gao W, Wu Z. Fault diagnosis for power distribution systems using data-driven methods: a review. Electric Power Systems Research. 2021; 199:107373.
24. Fan D, Ren Y, Feng Q, Liu Y, Wang Z, Lin J. Restoration of smart grids: current status, challenges and opportunities. Renewable and Sustainable Energy Reviews. 2021; 143:110909.
25. International Energy Agency. Electricity Grids and Secure Energy Transitions. Paris: IEA; 2023.
26. IEEE Power and Energy Society. IEEE Std 1366-2022: Guide for Electric Power Distribution Reliability Indices. New York: IEEE; 2022.

27. NFPA. NFPA 70E: Standard for Electrical Safety in the Workplace. Quincy, MA: National Fire Protection Association; 2024.
28. International Electrotechnical Commission. IEC 61850 communication networks and systems for power utility automation: implementation guidance and technical updates. Geneva: IEC; 2021.
29. Saudi Arabia Smart Grid Conference. Conference themes on automation, smart meters, grid codes, cybersecurity and localization. Riyadh: SASG; 2024.
30. AbdElrazek AS, Soliman M, Khalid M. Techno-economic evaluation of a hybrid renewable system for an electric vehicle charging station in Khobar, Saudi Arabia. arXiv:2502.05654. 2025.