Final Year Project Showcase Batch 2022
Year 2026

Department: Electrical Engineering Programme: Electrical Engineering	
1	**Project Title** Development of a Coded Logic System for Proactive Transformer Health Monitoring
2	**Project Idea** Distribution transformers are critical and costly assets in power systems, and unplanned failures cause prolonged outages, safety hazards, and high replacement costs. Conventional maintenance practices are largely reactive or time-based, meaning faults are usually identified only after damage has already occurred, particularly in dense urban distribution networks such as Karachi's, where long feeder lengths, mixed single- and three-phase consumers, and unauthorized load tapping frequently cause voltage/current unbalance and transformer overheating. This project proposes a coded logic system that converts real-time-style electrical parameters (voltage, current, and power factor per phase) into clear health indicators - Normal, Warning, or Critical - using rule-based thresholds derived from IEC standards (IEC 60038, IEC 60076-1/2/7, IEC 61000-3-13) rather than complex black-box AI models. The system is intended to give utility operators early, transparent, and actionable warnings before insulation or thermal damage occurs, enabling a shift from reactive to proactive transformer maintenance.
3	**Process** The project was executed in an integrated hardware-free, software-driven workflow combining data simulation, database automation, and visualization: **i. Data Generation & Simulation Validation:** Operational datasets for 1,000 distribution transformers (8 kVA ratings: 50-1000 kVA) were generated at 15-minute intervals over 7 days, and a representative sample of 35 transformers (~3% per rating, engineering rule-of-thumb) was modeled in DIgSILENT PowerFactory 2021 SP2 on an 11 kV feeder to validate the AI-generated data against real load-flow behavior under Balanced, Unbalanced, and Overloading case studies.

ii. Database & Logic Development: The validated dataset (672,000+ readings) was stored in a MySQL database and processed using a centralized Python script (VS Code) that calculates voltage/current unbalance, overload percentage, phase overcurrent, and power factor against IEC-derived thresholds, classifying each transformer's condition.

iii. Diagnostic Classification & Alerting: Three escalating diagnostic cases were defined - Case 1: Critical Alert (fault duration >= 2 hours/day), Case 2: High Alert (3 consecutive faulty days), and Case 3: Medium Alert (4+ faulty days in a rolling week) - with automated email notifications triggered for Critical and High alerts.

iv. Visualization: Power Query and Power BI were used to build an interactive 'Smart Transformer Health Monitoring Dashboard' showing transformer counts, fault classifications, priority levels, and 7-day trend analysis per transformer.

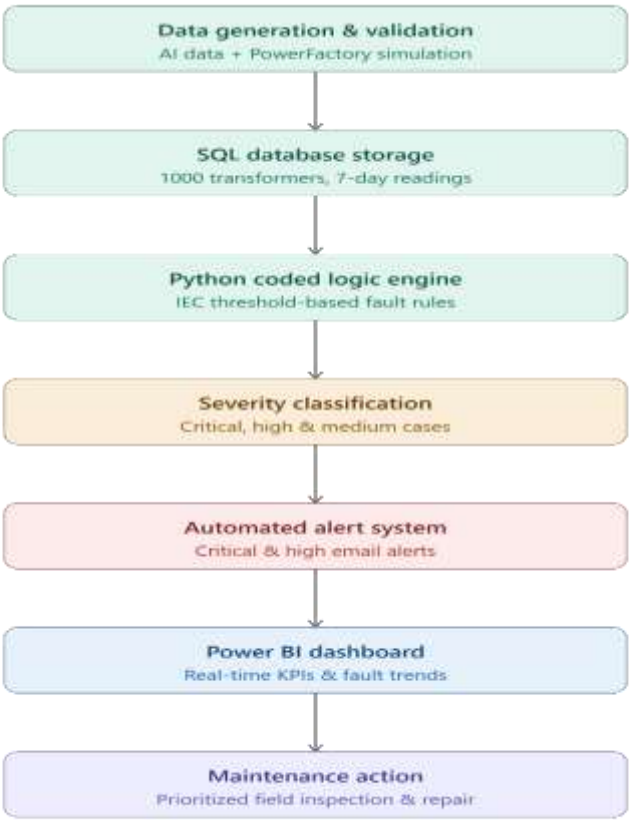

Fig 01: Flowchart of the project

4	**Outcome** The project delivered a fully functional, transparent coded logic system validated against simulated power-system behavior. Key outcomes include: - Successful classification of 1,000 transformers across 672,000 readings, with the logic isolating just 120 critical low-power-factor events (0.02%) amid massive normal operation volumes, demonstrating high diagnostic precision. - Identification of 8 transformers requiring Immediate Maintenance (Critical) and 19 transformers requiring Urgent Inspection (High Alert), automatically reported via email alerts. - DIgSILENT simulation confirmed that unbalanced loading raised transformer loading from ~92% (balanced case) to ~109%, and overloading scenarios reached ~133.4% of rated capacity, validating that the coded logic's thresholds correspond to physically realistic and damaging operating conditions. - A real-time-style Power BI dashboard providing operators with at-a-glance fault summaries, priority levels, and per-transformer historical trends. Overall, the system proves that a simple, rule-based logic approach - rather than a complex AI/black-box model - can reliably and transparently detect early-stage transformer stress conditions, supporting preventive maintenance and improved distribution network reliability.
5	**Evidence (Theoretical Basis)** The system's logic is grounded in internationally recognized power engineering standards rather than arbitrary thresholds. Voltage unbalance is computed as the ratio of negative- to positive-sequence voltage per IEC 61000-3-13/IEC 60038 (limit: <=2% continuous, <=3% short-term), while current unbalance is kept below 10% (practical/derived limit) to prevent winding overheating. Transformer voltage, frequency, and temperature-rise tolerances follow IEC 60076-1 and IEC 60076-2 (e.g., oil temperature rise <=60K, winding temperature rise <=65K), and short-term overload limits (120-130% of rated current) follow IEC 60076-7.

	Rated per-phase currents for each transformer rating were derived analytically using the standard three-phase rated current formula $\left(I = \frac{S * 1000}{\sqrt{3} * V}\right)$ for a 400V, 50Hz oil-immersed distribution transformer, and cross-checked against DIgSILENT PowerFactory load-flow simulations of Balanced, Unbalanced, and Overloading cases to confirm that AI-generated data reflects technically feasible operating conditions. On the software side, the coded logic was implemented in Python (VS Code) using a MySQL relational database (pymysql) for data storage and retrieval, with automated SMTP-based email alerting (smtplib) for Critical/High alert cases. Data transformation and relational modeling were performed in Power Query, with Power BI used for interactive dashboard visualization of transformer health indices and fault trends.
6	**Impact on Sustainability of Urban Regions or SDG-11 "Sustainable Cities and Communities"** Karachi's distribution network suffers from long feeder lengths, mixed single- and three-phase loading, and frequent transformer overheating/failures that disrupt power supply to urban residential and commercial consumers. By enabling early, automated detection of voltage/current unbalance and overloading - before failures occur - this project directly supports SDG 11 (Sustainable Cities and Communities) by reducing unplanned outages, improving the resilience and reliability of urban electricity infrastructure, and minimizing the safety hazards (fire/explosion risk) associated with transformer failures in densely populated areas. It also contributes to SDG 9 (Industry, Innovation and Infrastructure) by modernizing conventional reactive maintenance practices with a transparent, software-driven, data-centric monitoring infrastructure that can be scaled across the wider distribution network.
7	**Competitive Advantage or Unique Selling Proposition**
a	**Attainment of any SDG** This project primarily supports SDG 11: Sustainable Cities and Communities by enabling early detection of transformer stress in urban distribution networks, reducing outages and improving the resilience of city power infrastructure. It also aligns with SDG 9: Industry,

	Innovation and Infrastructure by replacing manual/reactive inspection with an automated, data-driven, rule-based monitoring infrastructure that is simple to scale across thousands of distribution transformers
b	**Environmental Aspect** Every transformer fault this system catches early is a fault that does not turn into oil leakage, fire, or a full replacement. Prolonged overload and unbalance the two conditions the logic is built to detect accelerate insulation aging, increase oil degradation and gas formation, and raise the probability of catastrophic failure; preventing this protects against oil leaks and the associated soil/water contamination, and reduces the carbon and material footprint of manufacturing replacement units. On the efficiency side, balanced three-phase operation minimises copper losses and neutral-conductor heating, so keeping transformers within IEC tolerance bands (voltage unbalance ≤2%, current unbalance ≤10%) directly reduces wasted electrical energy across the network a meaningful efficiency gain when applied at the scale of a 1,000-transformer fleet. Fewer outages also means less reliance on diesel backup generation in affected areas, an indirect but real carbon-reduction effect in cities where outages routinely trigger generator use.
c	**Cost Reduction of Existing Product** The established industry techniques for transformer condition monitoring are Dissolved Gas Analysis (DGA), fiber-optic hot-spot temperature sensing, and AI/neural-network-based diagnostic systems. DGA requires periodic oil sampling, specialised laboratory equipment, and expert interpretation of results, making it slow and costly to apply across many transformers at once. Fiber-optic sensors give precise internal temperature readings but are expensive to install and difficult to retrofit onto transformers that are already in service. AI/neural-network monitoring can achieve high accuracy but needs large historical training datasets and significant computational and implementation effort, putting it out of reach for routine, fleet-wide use. Our coded logic system avoids all three of these cost drivers because it requires no new sensing hardware to be installed on any transformer. It is built entirely from a SQL database, a Python script implementing IEC-standard threshold rules, and a Power BI dashboard all running on ordinary computing infrastructure a utility already has. For a utility managing

	hundreds or thousands of distribution transformers, this removes the single largest cost barrier to fleet-wide condition monitoring: the marginal cost of monitoring one additional transformer is close to zero, since it only requires one more row of data in the database rather than one more sensor purchased, installed, and maintained in the field.
d	**Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** Conventional transformer maintenance in Karachi-type distribution systems is reactive or time-based: faults such as overloading and phase unbalance are typically discovered manually, after damage has occurred or complaints are raised, due to delays in field inspection. This project improves the process by continuously evaluating 15-minute interval data against IEC-based thresholds, automatically classifying transformers into Critical/High/Medium alert tiers, and sending immediate email notifications for the most urgent cases - eliminating manual data review and significantly shortening the time between fault onset and maintenance response, all using a low-cost, transparent software stack (Python, MySQL, Power BI) rather than expensive proprietary SCADA/AI diagnostic systems.
e	**Expanding of Market share** **Problem with the current market:** most commercial transformer-monitoring products are designed and priced around large power/grid transformers, where the per-unit value justifies expensive sensors and specialist analysis. Distribution companies (DISCOs) operating thousands of small distribution transformers across a city are left with a choice between very basic SCADA alarms or no condition monitoring at all for these units, because deploying DGA or fiber-optic monitoring on every 50–1000 kVA transformer in a network is not commercially viable. **How this expands the market:** because the coded logic system is software-only and scales with data rather than hardware, a DISCO can monitor its *entire* distribution-transformer fleet not just its largest assets, at a fraction of the cost of sensor-based systems. This opens the monitoring market downward, to the tens of thousands of small distribution transformers that utilities currently leave essentially unmonitored, and it is directly portable to any DISCO

	in Pakistan or any utility internationally facing similar mixed-load, long-feeder urban distribution challenges.
f	**Capture New Market** The unaddressed niche this project targets is exactly the segment described above: fleet-scale digital health monitoring of small-to-medium kVA distribution transformers (50 kVA–1000 kVA) in dense urban secondary networks the transformers that sit on street poles and inside neighbourhood kiosks, not the substation-level power transformers that existing commercial monitoring products are built for. This segment is large in volume (a single mid-sized city distribution network can have thousands of such units), under-served by current diagnostic vendors, and uniquely suited to a software-only, rule-based approach because the per-unit economics of expensive sensor-based monitoring simply do not work at this scale.
g	**Any Other Aspect** **Scalability**: The architecture validated here on 1,000 transformers can be extended to a full real-world fleet of any size purely by adding rows to the SQL database; no architectural redesign is required. **Transparency & auditability:** Every alert the system raises traces back to a specific, human-readable IEC-based rule, which matters for utilities that must justify maintenance decisions to regulators. **Data-driven asset management**: Beyond fault alerts, the Power BI dashboard enables longer-term planning: identifying which kVA ratings or geographic areas are systematically more prone to unbalance, informing future investment and replacement decisions.
8	**Target Market** The primary target market is electric power distribution companies and utilities (e.g., K-Electric and similar DISCOs) responsible for operating and maintaining large fleets of distribution transformers across urban networks. Secondary markets include grid asset-management teams, power system maintenance contractors, and SCADA/smart-grid solution integrators who could embed this coded logic framework into existing monitoring infrastructure to support condition-based maintenance planning.

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