Final Year Design Project Showcase
Batch-2022
Year 2026

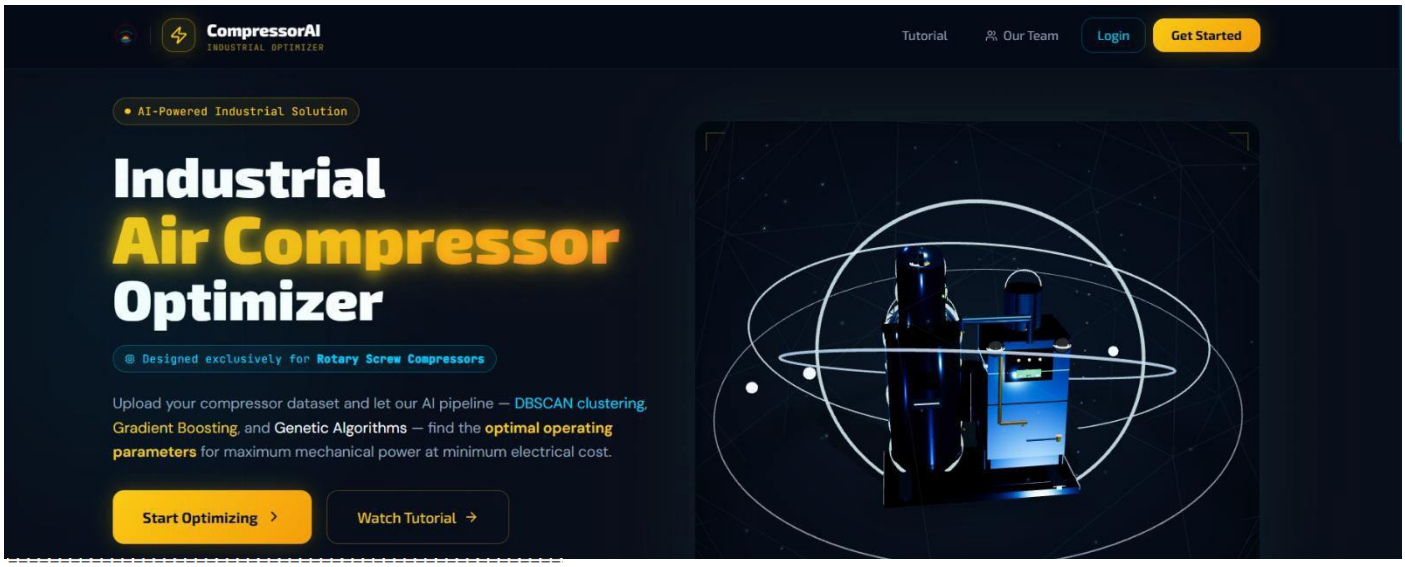
	Department: Mechanical Engineering Programme: Mechanical Engineering
1	**Project Title:** AI-Driven Lifecycle Cost Analysis and Operational Optimization of Compressors at FPCL
2	**Project Idea** The project aims to develop an intelligent decision-support platform that helps industries reduce the lifecycle cost of rotary screw air compressors through Artificial Intelligence (AI), Machine Learning (ML), and maintenance analytics. Since air compressors are among the largest consumers of electrical energy in industries, inefficient operation leads to excessive energy consumption, increased maintenance costs, and reduced equipment life. The proposed framework analyzes real industrial operational and maintenance data to identify optimal operating conditions, improve maintenance planning, minimize unnecessary energy usage, and support data-driven industrial decision-making. The developed system provides industries with a practical and scalable solution to improve compressor efficiency without requiring hardware modifications.
3	**Process** The project was completed through the following phases: 1. Conducted an extensive literature review on compressor operation, lifecycle cost analysis, maintenance strategies, and machine learning techniques. 2. Performed industrial outreach by contacting more than 170 industries and 650 industrial professionals to collect real compressor operational and maintenance data. 3. Collected, cleaned, and preprocessed compressor operational datasets. 4. Developed four hybrid AI models combining: i. Clustering Algorithms (K-Means & DBSCAN) ii. Regression Models (Random Forest, Gradient Boosting, Gaussian Process Regression & XGBoost) iii. Optimization Algorithms (Bayesian Optimization & Genetic Algorithm) 5. Evaluated all developed models using: i. R^2 Score ii. Cross Validation iii. Silhouette Score iv. F1 Score v. Convergence Performance 6. Developed a Preventive Maintenance Compliance Analysis framework to evaluate maintenance effectiveness, overdue maintenance activities, compliance percentage, and maintenance costs. 7. Designed and deployed a cloud-based interactive dashboard integrating: i. Operational Optimization ii. Maintenance Analytics iii. Visualization iv. Automated Report Generation

4	**Outcome** The project successfully developed an integrated AI-driven framework capable of improving compressor operational efficiency and reducing lifecycle costs. Major outcomes include: 1. Development of four hybrid AI optimization models. 2. Identification of the DBSCAN+Gradient Boosting Regressor+Genetic Algorithm framework as the best-performing model. 3. Development of a Maintenance Compliance Analysis module for preventive maintenance monitoring. 4. Development of a web-based dashboard for industrial decision support. 5. Demonstrated reduction in energy consumption through optimized operating conditions. 6. Enabled industries to make data-driven operational and maintenance decisions using a single integrated platform.
5	**Evidence (Theoretical Basis)** Industrial rotary screw air compressors are among the most energy-intensive machines used in manufacturing and process industries. Inefficient operating conditions and poor maintenance practices lead to excessive energy consumption, increased operating costs, reduced equipment reliability, and higher lifecycle costs. This project presents an integrated AI-driven framework to optimize compressor operation and improve lifecycle cost using real industrial operational and maintenance data. The proposed framework combines machine learning, optimization algorithms, maintenance analytics, and a web-based decision-support dashboard into a unified platform. Operational data, including pressure, temperature, current, flow rate, and power consumption, were preprocessed and analyzed using four hybrid AI models that integrated clustering, regression, and optimization techniques. These models were evaluated using multiple machine learning performance metrics to identify the most effective approach for minimizing energy consumption while maintaining stable compressor performance. Among them, the DBSCAN+Gradient Boosting Regressor+Genetic Algorithm framework demonstrated the highest prediction accuracy and the best capability to identify energy-efficient operating conditions. To complement operational optimization, a Preventive Maintenance Compliance Analysis framework was developed to evaluate maintenance schedules, identify overdue activities, measure compliance, estimate maintenance costs, and support proactive maintenance planning. Both optimization modules were integrated into an interactive web-based dashboard that enables industries to upload operational data, visualize system performance, generate optimization recommendations, monitor maintenance compliance, and produce analytical reports. The developed framework demonstrates that integrating artificial intelligence with maintenance analytics can significantly improve compressor efficiency, reduce energy consumption, lower operational and maintenance costs, and extend equipment life. The proposed system offers a practical, scalable, and industry-ready solution that supports data-driven decision-making, predictive asset management, and sustainable industrial operations.
6	**Competitive Advantage or Unique Selling Proposition** (Cost Reduction, Process improvement, Attainment of any SDG (Sustainable Development Goal), increase of market share or capturing new market or having superior performance over a competitor. In summary, any striking aspect of the project that compels the industry to invest in FYP or purchase it. Some detailed description is required in terms of how, why when what. You can select one or more from the

	following dropdown and delete the rest of them). Please keep relevant options, delete the rest of them, and correct the sequence
a	**Attainment of any SDG** (e.g. How it is achieved and why it is necessary for the region) **SDG 9 - Industry, Innovation and Infrastructure** The project enables industries to retrofit compressor systems for sustainability and cost savings. The project contributes to industrial research and innovation, applying data-driven methods to real-world challenges.
b	**Any Environmental Aspect** (e.g. carbon reduction, energy-efficient, etc.) The proposed framework significantly improves energy efficiency by identifying optimal compressor operating conditions. Lower electrical power consumption directly reduces greenhouse gas emissions associated with electricity generation, minimizes resource wastage, and promotes sustainable industrial operations without requiring replacement of existing equipment.
c	**Cost Reduction of Existing Product** The framework reduces lifecycle cost by optimizing the two largest controllable cost components of industrial compressors: • Operational Energy Cost • Maintenance Cost By minimizing unnecessary energy consumption, reducing maintenance delays, preventing over-maintenance, and improving maintenance compliance, industries can substantially lower annual operating expenses while extending compressor service life. We were able to save **~4.71%** power consumption of the currently running compressor at FPCL.
d	**Process Improvement which Leads to Superior Product or Cost Reduction, Efficiency Improvement of the Whole Process** (e.g. What is the issue is current process and what improvement you suggests) Current industrial practice relies heavily on manual monitoring, fixed operating parameters, and reactive decision-making. The proposed system transforms this process into an intelligent, AI-assisted workflow by: 1. Automatically analyzing operational data. 2. Predicting optimal operating conditions. 3. Evaluating maintenance performance. 4. Generating visual reports. 5. Supporting data-driven maintenance scheduling. This improves overall operational efficiency, reliability, and maintenance planning.
e	**Any Other Aspect** The project's most distinctive feature is the integration of: • AI-based operational optimization • Preventive maintenance compliance analysis • Lifecycle cost improvement • Cloud-based dashboard • Automated visualization and reporting into a **single unified industrial platform**. Unlike conventional optimization tools that address only one aspect of compressor management, this framework simultaneously supports energy optimization, maintenance management, lifecycle cost reduction, and strategic decision-making. Its modular architecture also allows adaptation to other industrial rotating equipment such as pumps, blowers, and fans, increasing its commercialization potential.
7	**Target Market** (Industries, Groups, Individuals, Families, Students, etc) Please provide some detail about the end-user of the product, process, or service The proposed solution targets industries that extensively use rotary screw air compressors, including:

	Oil & Gas, Petrochemical, Fertilizer, Textile, Cement, Power Generation, Food & Beverage, Pharmaceutical, Chemical Processing, Manufacturing Industries, Automotive Industries, Paper Industries, Steel Industries The primary end users include: Maintenance Engineers, Reliability Engineers, Plant Managers, Utility Engineers, Energy Managers, Operations Managers, Industrial Asset Management Teams The framework can also be adopted by compressor manufacturers, maintenance service providers, and industrial consulting firms to enhance equipment performance and support predictive maintenance services.	
8	**Team Members** (Names along with email address)	Malik Muhammad Rafay (rafay4500403@cloud.neduet.edu.pk) Ali Rashid (rashid4501202@cloud.neduet.edu.pk) Muhammad Bilal Akber (akber4501927@cloud.neduet.edu.pk) Maaz Ahmed Siddiqui (siddiqui4501176@cloud.neduet.edu.pk)
10	**Supervisor Name** (along with email address)	Dr. Tariq Jamil (tariqjamil@neduet.edu.pk)
11	**Video (If any)**	https://mega.nz/folder/1clBSTrR#5z85x0jHbC9YLd-w_Aj3ag
12	**Dashboard Link**	https://compressorai.netlify.app/

Pictures (to be pasted below

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============================================================
            AIR COMPRESSOR MODEL PERFORMANCE REPORT
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1. DBSCAN SCORE:
   -> Silhouette Score:              40.08

2. XGBOOST SCORE:
   -> R2 Score:           100.00
   -> F1 Score:        64.24
------------------------------------------------------------
FINAL RESULTS & TARGETS:
   -> Best Electrical Power:         252.64
   -> Best Mechanical Power:         169.17
   -> Best SPC (Specific Power):     5.5654
------------------------------------------------------------
OPTIMAL INPUT PARAMETERS:
   -> Loading Pressure (bar)       : 7.47
   -> Unloading Pressure (bar)     : 7.64
   -> Inlet Pressure (bar)         : 0.99
   -> Discharge Pressure (bar)     : 7.56
   -> Discharge Temperature ( C ) : 49.75
   -> Current (Amp)                : 390.38
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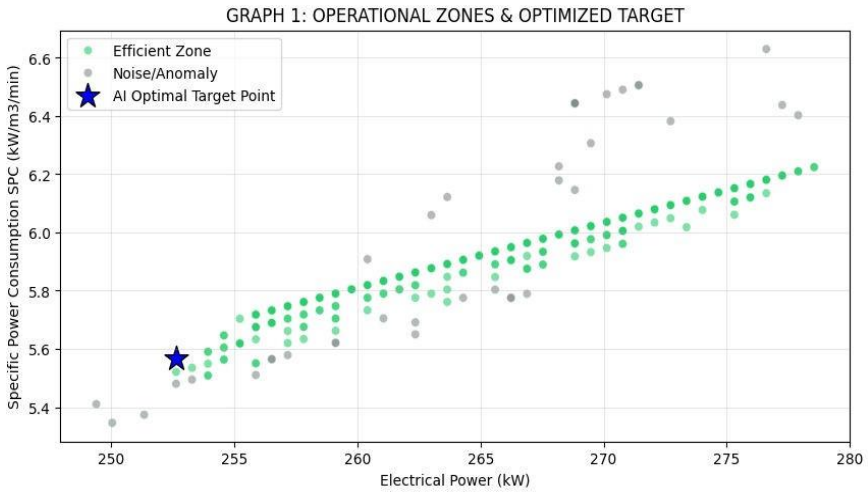
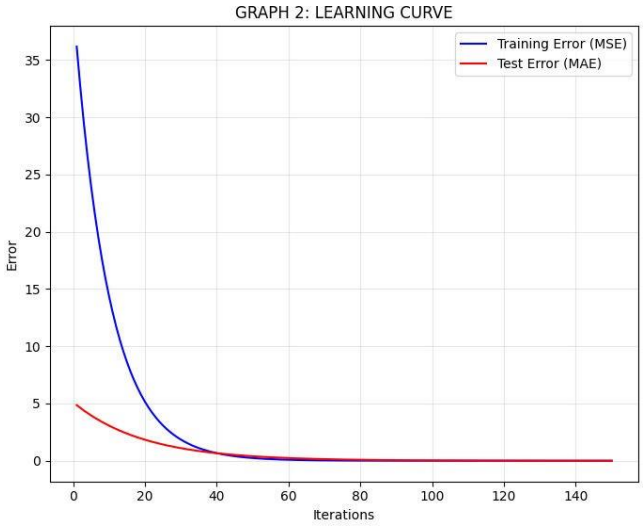
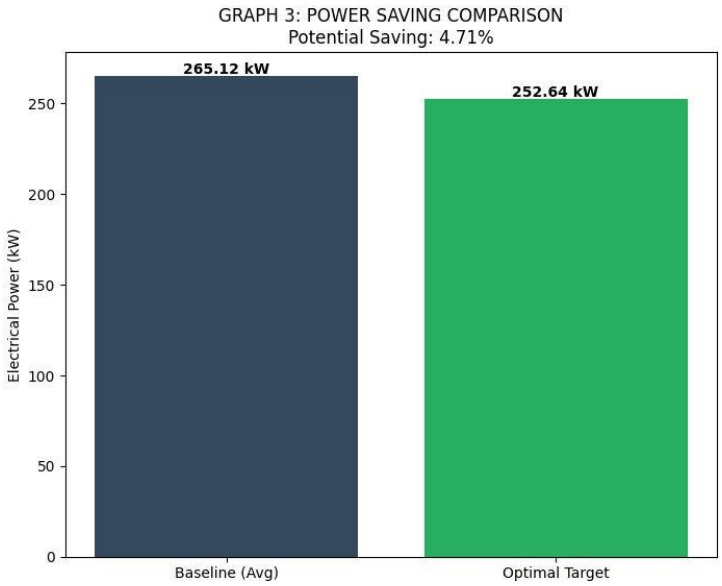
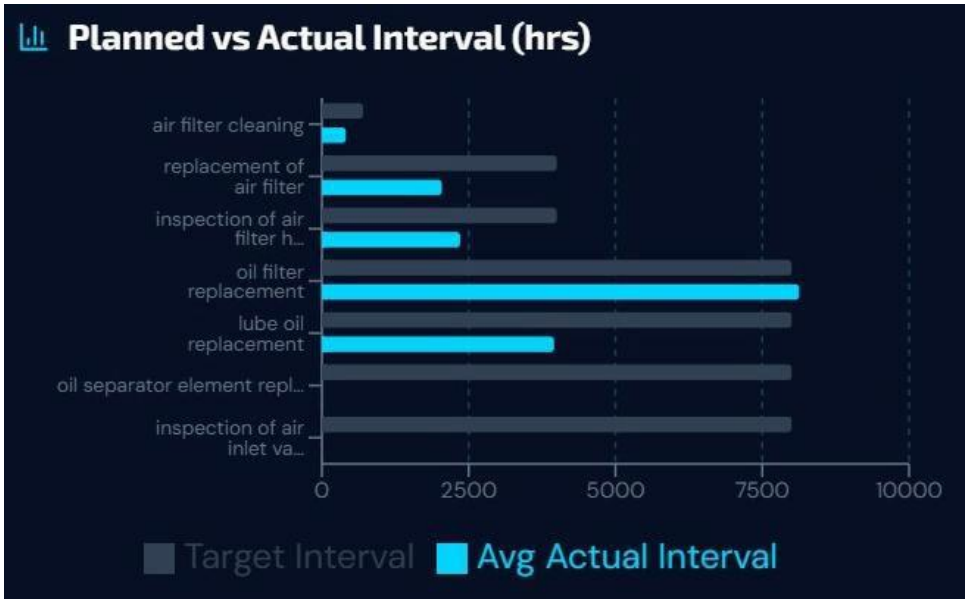
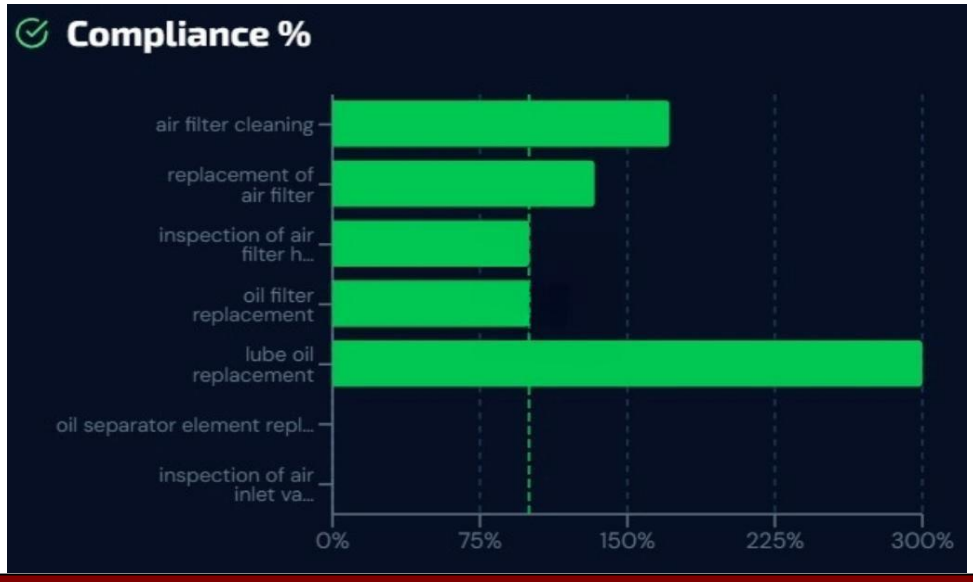



GRAPH 2: LEARNING CURVE
Training Error (MSE)
Test Error (MAE)
Error
Iterations
0
5
10
15
20
25
30
35
0
20
40
60
80
100
120
140


GRAPH 3: POWER SAVING COMPARISON
Potential Saving: 4.71%
265.12 kW
252.64 kW
Electrical Power (kW)
Baseline (Avg)
Optimal Target
0
50
100
150
200
250


Planned vs Actual Interval (hrs)
air filter cleaning
replacement of air filter
inspection of air filter h...
oil filter replacement
lube oil replacement
oil separator element repl...
inspection of air inlet va...
0
2500
5000
7500
10000
Target Interval
Avg Actual Interval


Compliance %
air filter cleaning
replacement of air filter
inspection of air filter h...
oil filter replacement
lube oil replacement
oil separator element repl...
inspection of air inlet va...
0%
75%
150%
225%
300%

Detailed PM Task Analysis

48 WO rows matched · 358 total WO rows

PM TASK	COMPLIANCE	EXPECTED	ACTUAL	RAW WOS	INTERVAL RATIO	STATUS	DELAY	COST
air filter cleaning Every 700 hrs	171.4%	21	36	37	0.58x Over	OK	–	–
replacement of air filter Every 4,000 hrs	133.3%	3	4	4	0.51x Over	Overdue	+2,758.5 hrs	PKR 252,073
inspection of air filter hose b/w air filter and compressor element Every 4,000 hrs	100%	3	3	3	0.59x Over	Overdue	+3,862.8 hrs	–
oil filter replacement Every 8,000 hrs	100%	1	1	1	1.02x OK	Due Soon	–	PKR 327,578
lube oil replacement Every 8,000 hrs	300%	1	3	3	0.49x Over	OK	–	PKR 1,388,546
oil separator element replacement Every 8,000 hrs	0%	1	0	0	– Never Performed	Overdue	+6,928 hrs	–
inspection of air inlet valve & minimum pressure valve Every 8,000 hrs	0%	1	0	0	– Never Performed	Overdue	+6,928 hrs	–