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AUTOMATED ONLINE ELECTRIC MOTOR TESTING

PROBLEM STATEMENT

The current industrial practice of evaluating electric motor performance is impeded by a labor-intensive and manual process, resulting in inefficiencies, human errors, and delays in the identification of emerging motor issues. The primary objective of this initiative is to revolutionize motor testing through the centralization and automation of the analysis process, the incorporation of continuous monitoring, and the automation of critical actions based on analysis results. The overarching goal of this project is to enhance the reliability and performance of electric motor systems, optimize resource allocation, and improve workplace safety.

CONSTRAINTS

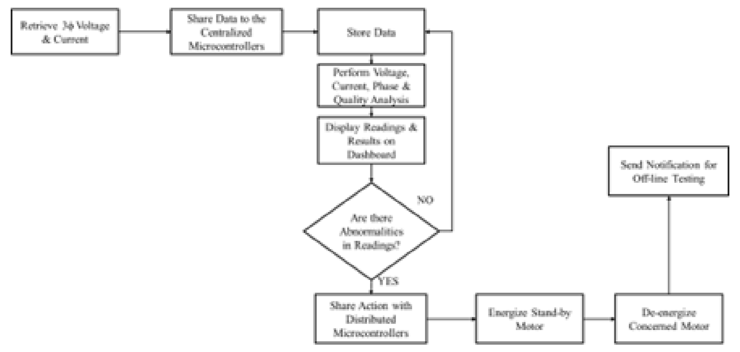
- Ability to reflect large scale electrical networks
- Communication channels security
- Need for large amount of data
- Safety constraints (Dealing with high current)

TARGET SPECIFICATIONS

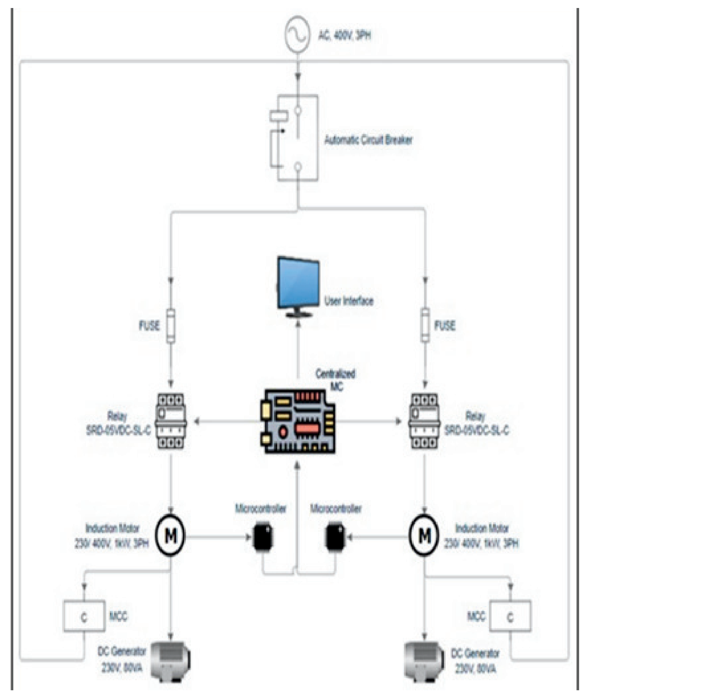
- Decision Making Time: between less than 150ms.
- Analysis Time: between less than 150ms.
- Installation Cost: less than 6000 SAR.
- Operational Cost: Prototype - None; Scaled-up - Less than 5000 SAR/year.
- Latency: between les than 200ms
- Error Percentage: less than 2%
- Testing Voltage and Ampere (Prototype): 220-240 volts and 1-3 amp
- Coverage: up to 10 meters

PROTOTYPE DESIGN

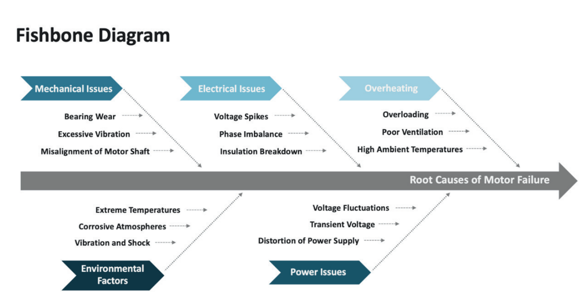
- Flow chart of the system



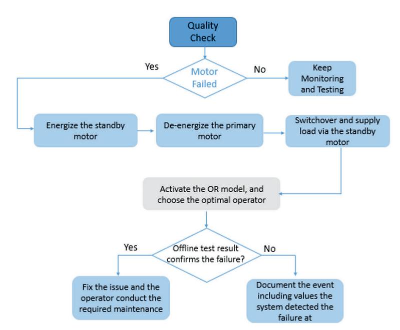
- Final Product Design



- Root Causes



- Out Of Control Action Plan



SYSTEM ELEMENTS

- 400V AC 3-Phase Power Supply:
- Protective Fuses:
- Relays for Automated Switching:
- Induction Motors:
- Induction motors are the focal point of the system, representing the devices under test.

Table I: LD-Didactic Three Phase Induction Motor Name Plate

Rated Voltage		Y - △ 400 - 230 V		Rated Current		2.2 / 3.81 A	
kW Rating		1 kW		Cos φ		0.81	
Speed Rating		1710 U/min		Frequency		60 Hz	
is	2.0	IP	2.0	5 4 3 5 4		VDE	0530

- DC Generators (Controlled Loads):
- DC generators serve as controlled loads within the system, allowing the simulation of various operational scenarios.

Table II: LD-Didactic DC generator Name plate

Voltage Rating	230 V	VA Rating		80 VA	
Frequency	50 / 60 Hz	IP	22	VDE	0411

- Microcontrollers:
- A centralized microcontroller serves as the brain of the operation, responsible for data analysis, storage, and decision-making. Secondly, distributed microcontrollers are strategically placed on individual motors, enabling real-time data retrieval and transmission to the centralized unit.

ANALYSIS

1. Voltage Variations Analysis:
   - The equation to calculate voltage variation (ΔV) is as follows: $\Delta V = V_{nominal} - V_{actual}$
   - Where:
   - ΔV represents the voltage variation.
   - $V_{nominal}$ is the rated or nominal voltage.
   - V_{actual} is the measured actual voltage.

2. Current Variations Analysis:
   - The equation to calculate current variation (ΔI) is as follows: $\Delta I = I_{nominal} - I_{actual}$
   - Where:
   - ΔI represents the current variation.
   - $I_{nominal}$ is the rated or nominal current.
   - I_{actual} is the measured actual current.

3. Phase Sequence Variations Analysis:
   - Let θ1, θ2, and θ3 represent the phase angles of the three phases. The phase sequence can be determined as follows:
   - For a correct sequence (e.g., A-B-C),
   - $\theta1 < \theta2 < \theta3$
   - For a reversed sequence (e.g., C-B-A)
   - $\theta1 > \theta2 > \theta3$

4. Polarization Index (PI):

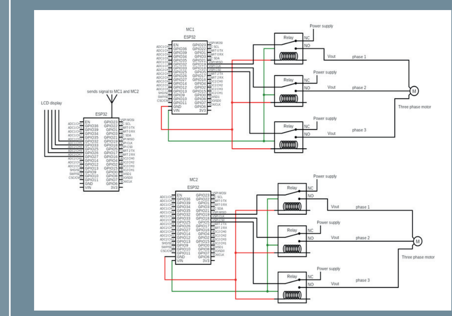
$$PI = \frac{R\,(10\ min)}{R\,(1\ min)}$$

Where:
PI represents the Polarization Index.
R(10 min) is the insulation resistance measured at 10 minutes.
R(1 min) is the insulation resistance measured at 1 minute.

5. Power Factor Testing:
$PF = COS\,(\theta_V - \theta_V)$

A high-power factor (close to 1) indicates good motor efficiency, while a low power factor (close to 0) suggests inefficient operation.

Final Design of COE Part



Functionality of Components:
- ESP32 Microcontrollers:
  - Central ESP32: Conducts calculations based on motor data, evaluates PI, and initiates control decisions.
  - Peripheral ESP32s: Control relay modules to switch motors based on signals from the central ESP32.
- Motors:
  - The motors are connected to the power supply via relay modules controlled by the peripheral ESP32s.
  - The central ESP32 continuously monitors the motor's voltage and current values for analysis.
- Relay Modules:
  - Three relay modules, one for each phase of the three-phase motor.
  - Control the motor's power supply; the motor is "on" when all three relay modules are active.
- Polarization Index (PI) Analysis:
  - The central ESP32 calculates the PI by comparing the resistance at the first and tenth minutes.
  - If PI is less than two, indicating potential insulation issues, the central ESP32 sends signals to the peripheral ESP32s to switch motors.

System Operation:
- Data Collection:
  - The central ESP32 collects voltage and current data from the motors over the first and tenth minutes.

- PI Calculation:
  - Calculates the PI based on resistance values derived from the collected data.
- Decision Making:
  - If PI is less than two, indicating potential insulation issues, the central ESP32 initiates motor switching.
  - If PI is greater than or equal to two, no action is taken.
- Motor Control:
  - Peripheral ESP32s receive signals to switch motors based on the central ESP32's decision.
  - Relay modules control the power supply to the motors, ensuring synchronized operation.
- Notification:
  - In the case of a motor switch, the central ESP32 sends a message to notify operator or relevant personnel.

- Peripheral microcontrollers

Peripheral microcontrollers receive signals from the central microcontroller, deciding whether to activate or deactivate the motor based on computed outputs. They also send voltage and current values back to the central microcontroller. The main motor's relay modules stay active unless issues are detected by the central microcontroller, which then turns off the relay modules and the motor. The standby motor's microcontroller is alerted to activate its relay modules and the motor after this deactivation.

- Central microcontroller:
  - Calculate the RMS for the voltage and current based on the values it receives from the peripheral microcontrollers.
  - Calculate the polarization index based on the resistance value obtained from the voltage and the current.
  - Decide whether to switch to the standby motor or not.
  - Decide the most optimal operator to conduct the offline testing.

- Operation Research Model
- Our system design requires an operator to conduct offline testing post online test failures. When selecting an operator from our facility, our main focus is on efficiency for the task at hand.

Model of the operation research

- Assumptions:
  - Operators should belong to the same facility area where the motor failure occurred to conduct the offline test.
  - Optimizations based on minimizing operator utilization during their shift (utilization = hours worked / total shift hours).
  - Operators work 8 hours per shift.
  - Operators are available 24/7.
  - Operators qualifications based on experience and certifications.
  - Each offline test requires approximately one hour for completion.
  - Three levels of operator qualification exist.
  - All qualified operators are available within a single shift.
  - The facility comprises three distinct areas

- Definitions:

1. Index:
   - i: Specific area within the facility.
   - j: Unique operator identification number.
   - m: Specific motor within the facility.
2. Parameters:
   - Uj: Operator "j" utilization during an 8-hour shift.
   - Yji: Input denoting if Operator "j" works in Area "i".
   - Lmi: Input indicating Motor "m" location within Area "i".
   - fm: Input indicating if Motor "m" failed the online test.
   - Qjm: Input indicating if Operator "j" is qualified to test Motor "m".

Decision Variable: $X_j = \begin{cases} 1, & \text{if operator j is assigned to perform an of f line} \\ 0, & \text{O/W} \end{cases}$

Objective function: $\text{Min} \sum_{j=1}^{j} X_j U_j$

Constraints:

- An operator works in the same area as the Motor that faced the failure.

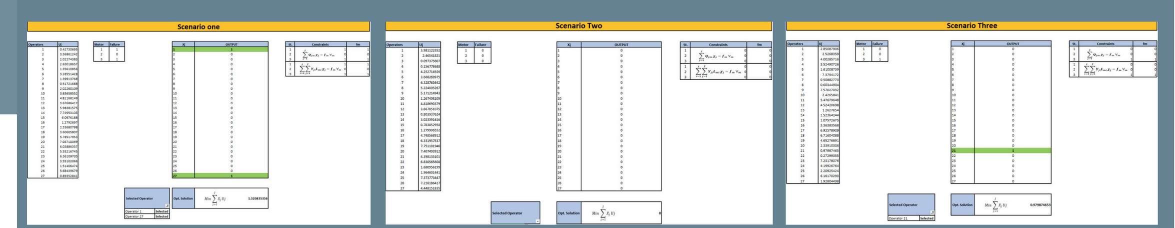
$$\sum_{i=1}^{I} \sum_{j=1}^{J} Y_{ji} L_{mi} X_j = f_m \quad \forall_m$$

- Operator qualification for Offline Test

$$\sum_{j=1}^{J} Q_{jm} X_j = f_m \quad \forall_m$$

Domain:

$X_j = \{0,1\}$, $i = 1,2,3$, $j = 1,2,3, .. ,27$, $m = 1,2,3$



TESTING / VALIDATION

- Testing Voltage limits:

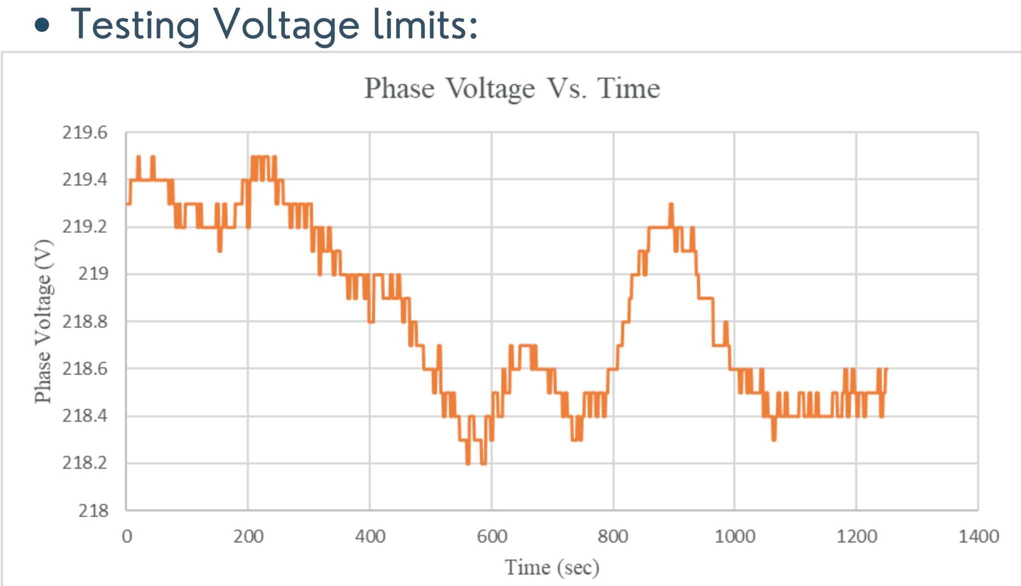


Figure 43: Sample Testing Phase Voltage Readings

- Testing Current limits:

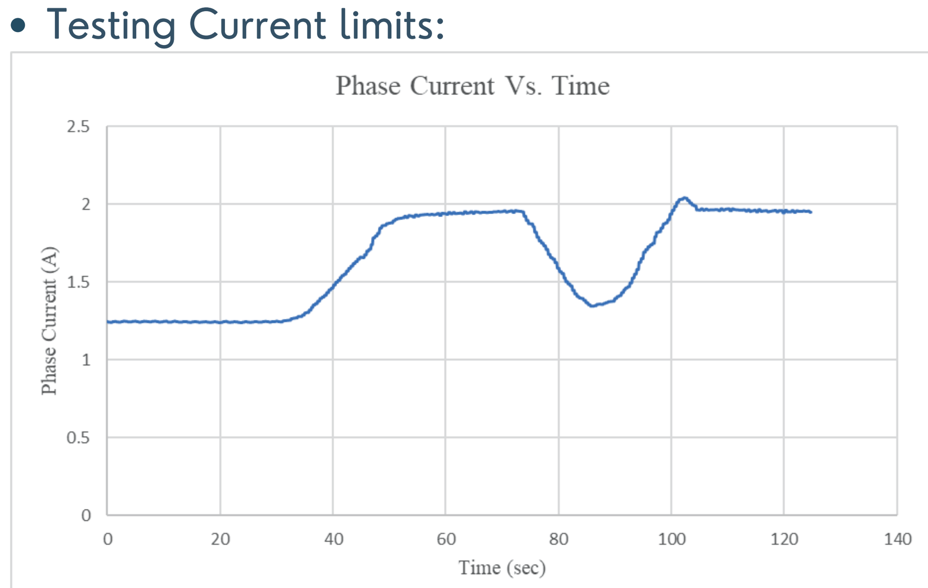


Figure 44: Sample Testing Phase Current Readings

- Operational cost

Less than 6000/year

- Coverage (up to 10 m):

For nearby communication (less than 10 meters) we will be using Wi-Fi. The ESP32 has an integrated Wi-Fi module that supports IEEE 802.11 b/g/n (Espressif, 2023) which is rated for up to 75m.

- Error Percentage (maximum error due to quantization) less than 2%:

- $\text{Resolution} = \frac{\text{Voltage Range}}{2^n}$

Where: n is the number of bits of the ADC module.
The resolution will be in this case:
$\text{Resolution} = \frac{22}{2^{12}} = 5.371 \times 10^{-3}\ V$
which represents the maximum ΔV allowed.
For the current network configuration:
$\text{Resolution} = \frac{3.81 - 1}{2^{12}} = 0.686 \times 10^{-3}\ A$

which represents the maximum ΔI allowed.

- Installation cost less than 6000 SAR:
- Decision making & analysis time (less than 150 ms):

41 instructions
1-4 CPU cycles/ instruction
41 instructions * (1-4 cycles/instruction) = 41-164 CPU cycles.
1/80 MHz = 12.5ns, 1/160MHz = 6.25 ns and 1/240 = 4.17ns
41-164 CPU cycles* 4.17ns = 170.97-683.88 ns
41-164 CPU cycles * 6.25 ns = 256.25-1025ns
41-164 CPU cycles*12.5 ns = 512.5-2050 ns
170.97ns <decision making time =<2050 ns
So, our final approximate decision-making time is between 170.97ns and 1968ns.

- Latency:

Wi-Fi:
Wi-Fi latency is difficult to estimate as it's very dependent on the environment.
LoRa:
Just like Wi-Fi, LoRa latency is also very dependent on the environment and obstructions that can cause collisions.

CONCLUSION

The goal is to revamp how we evaluate electric motor performance by automating analysis, enhancing reliability, and ensuring safety. We're building a system that centralizes data, monitors motors, and automates actions based on analysis, meeting technical specs and cost limits. Our design involves microcontrollers, motor testing, and efficient operator selection for offline testing. The prototype aligns with set specifications, promising better motor evaluation and workplace safety.