

# **Construction of a Fault Analysis and Normal-State Database for Safety-Grade PLC Modules in Nuclear Power Plants**

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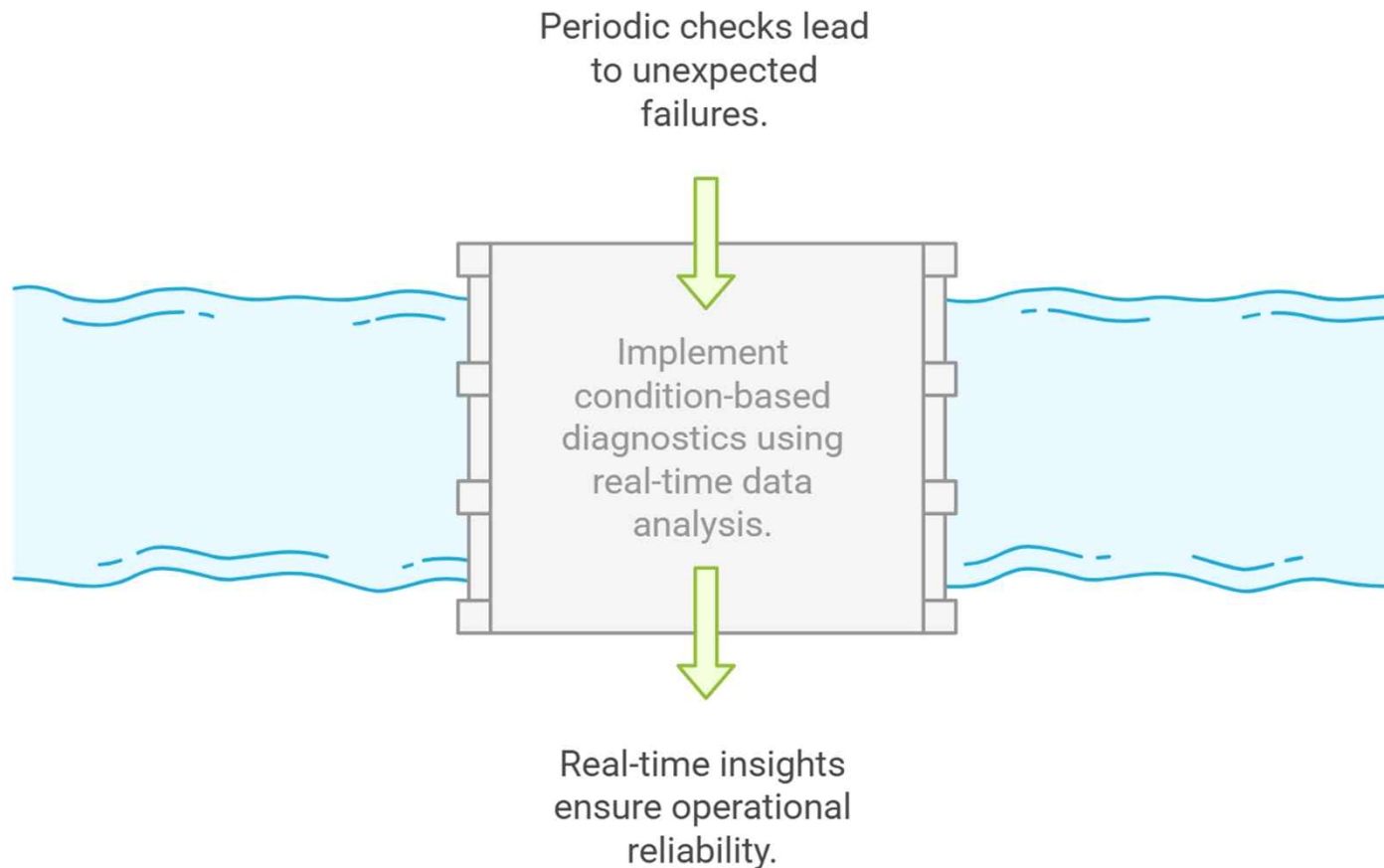
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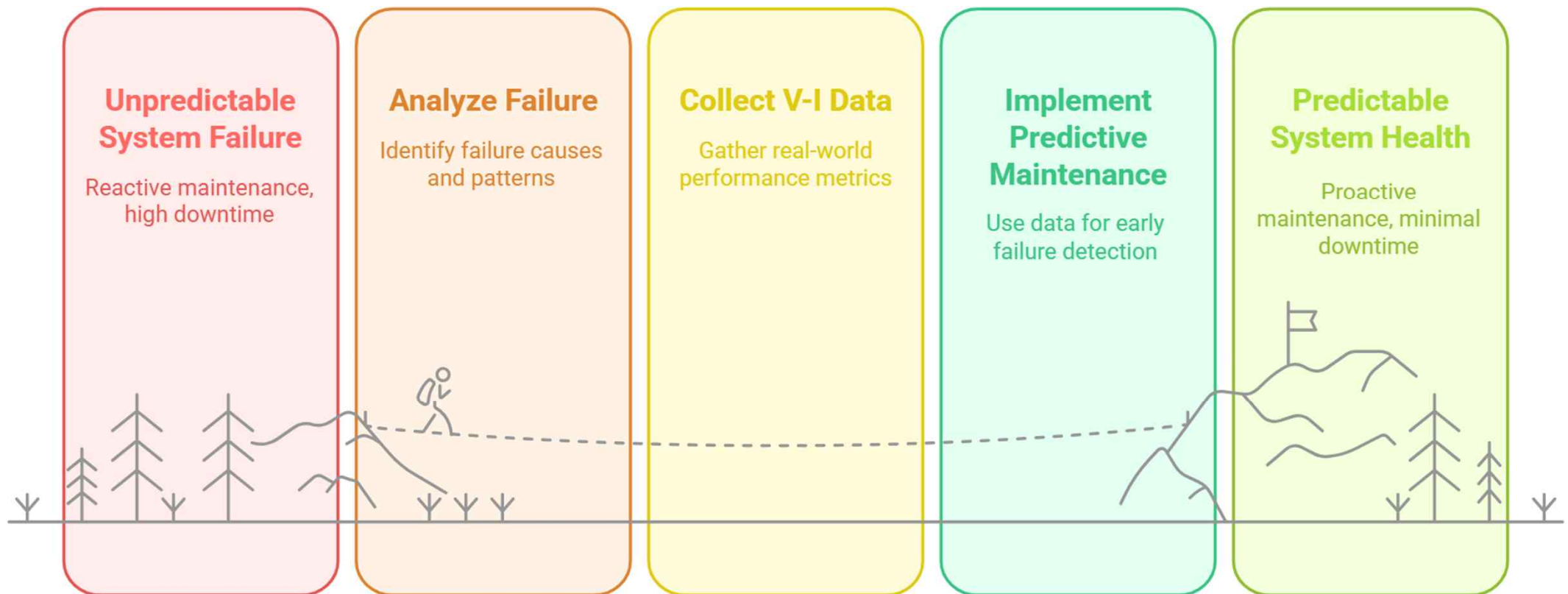
# 01. Introduction

- Digital I&C systems enhance operational reliability
- Sudden failures in PLC modules pose critical risk
- Preventive maintenance is periodic, not condition-aware
- **Need:** Condition-based diagnostics using real data



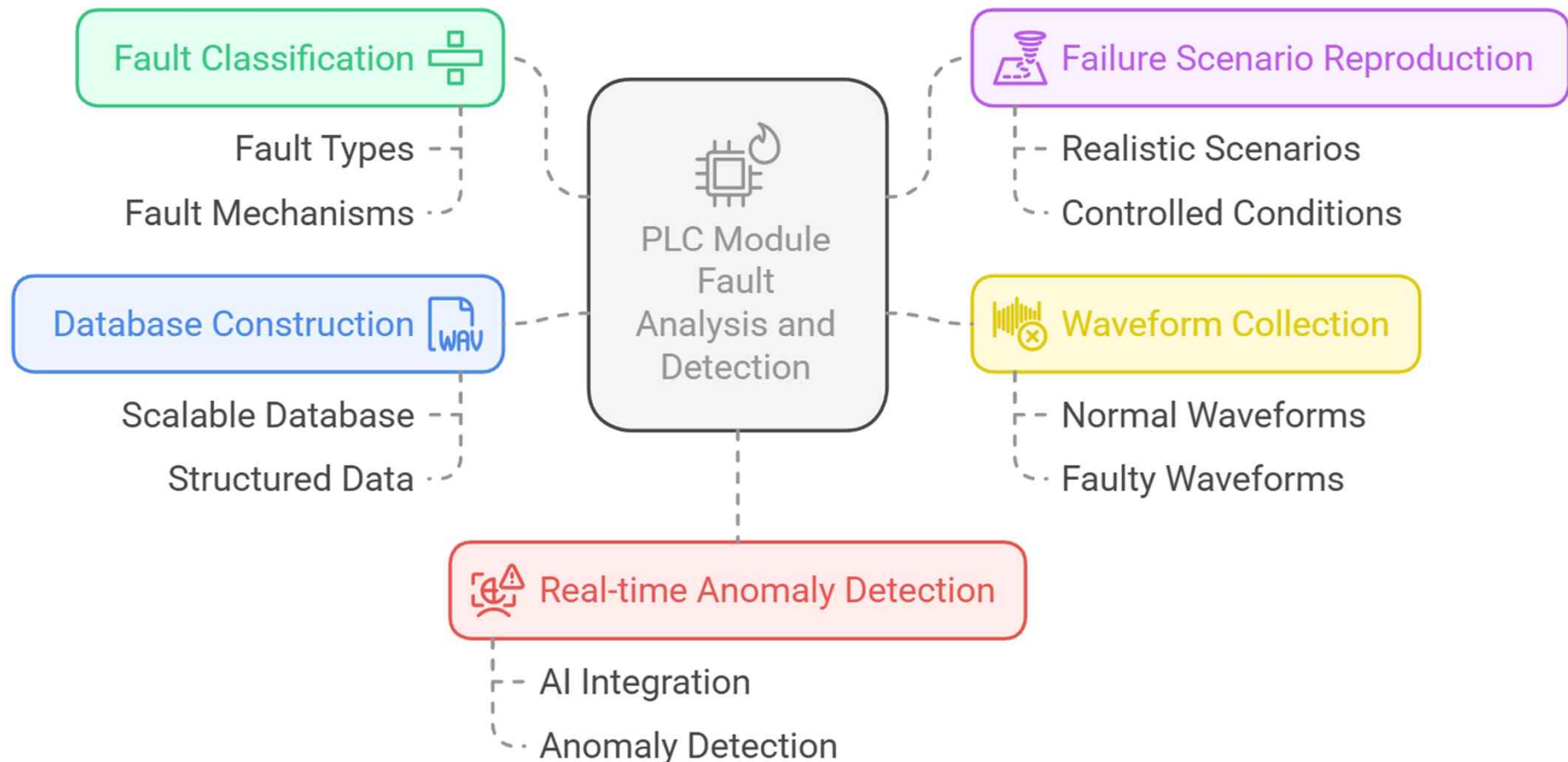
# 01. Introduction

- Target: POSAFE-Q PLCs in APR-1400 Reactor Protection System
- Focus on failure analysis and diagnosis
- Contribution: DB supports predictive maintenance in nuclear safety systems
- Extends beyond literature by collecting real-world V-I curve data



# 01. Introduction

- Classify fault types and mechanisms in PLC modules
- Reproduce realistic failure scenarios
- Build scalable and structured waveform database
- Enable real-time anomaly detection and AI integration



## 02. Fault Analysis

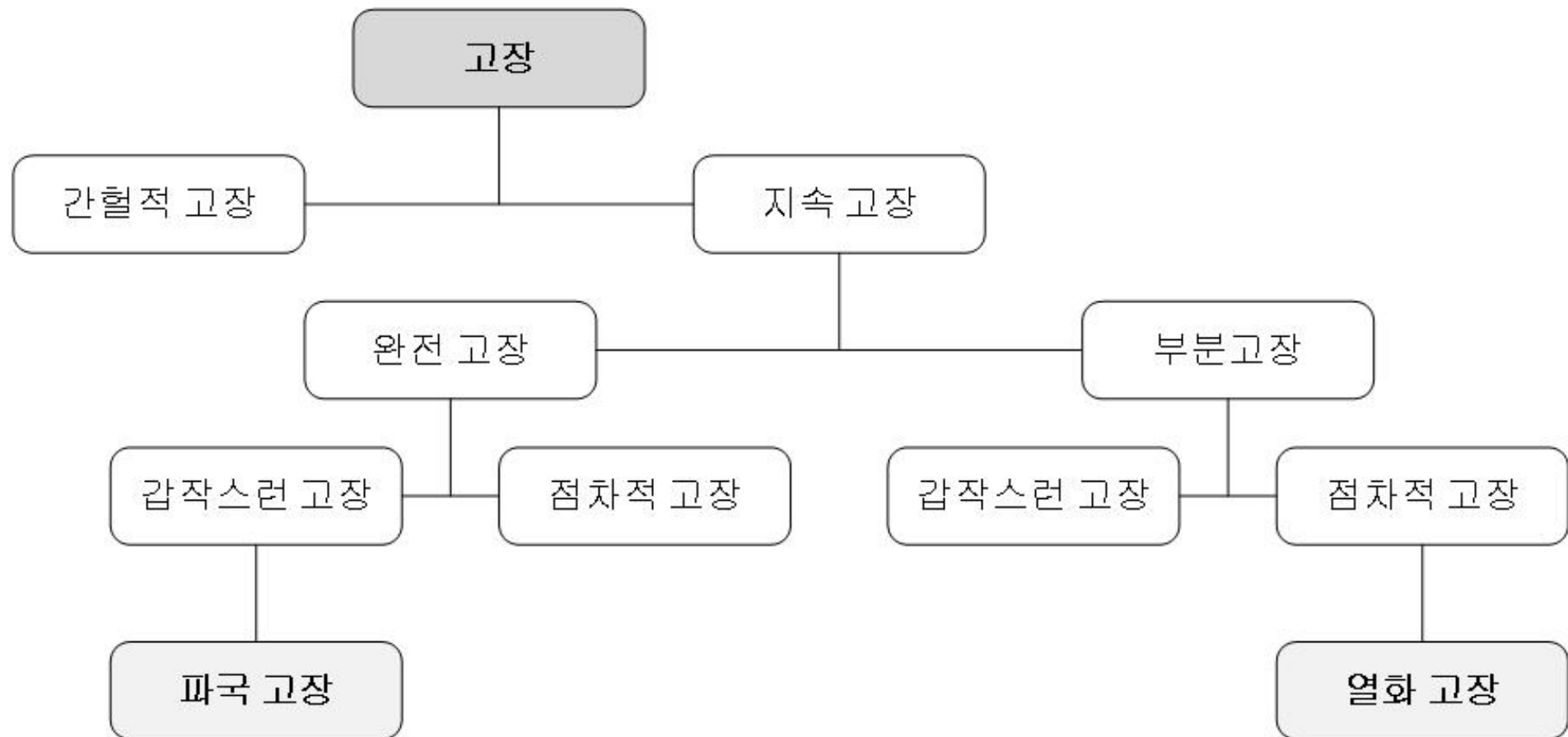
### ▪ Definition of failure

- **Failure** : The inability of a system or component to perform its required function within specified limits.
- **Fault** : A defect in a hardware component that has the potential to cause a failure.
- **Defect** : A physical imperfection or flaw in a hardware component.
- **Error** : A discrepancy between a computed, observed, or measured value or condition and the true, specified, or theoretically correct value or condition.

| 용어      |          | 정의                                                   | 예시                    |
|---------|----------|------------------------------------------------------|-----------------------|
| Failure | 고장       | 시스템이 의도된 기능을 수행하지 못한 상태 (결과적으로 사용자에게 노출)             | 전원이 들어오지 않음, 출력 오류 발생 |
| Fault   | 고장 원인 결함 | 오류를 유발하는 물리적 또는 논리적 원인 (회로 이상, 전원 불량, 비트 플립 등)       | NAND 게이트 단선, 캐패시터 누설  |
| Defect  | 결함 하자    | 제조 또는 설계 시 존재하는 물리적 불량 (잠재적으로 fault를 유발)             | PCB 납땜 불량, 설계 누락      |
| Error   | 오류       | 하드웨어가 잘못된 출력을 생성하거나, 잘못된 동작을 수행한 상태 (일시적, 확률적일 수 있음) | EMI 간섭으로 데이터 비트 반전    |

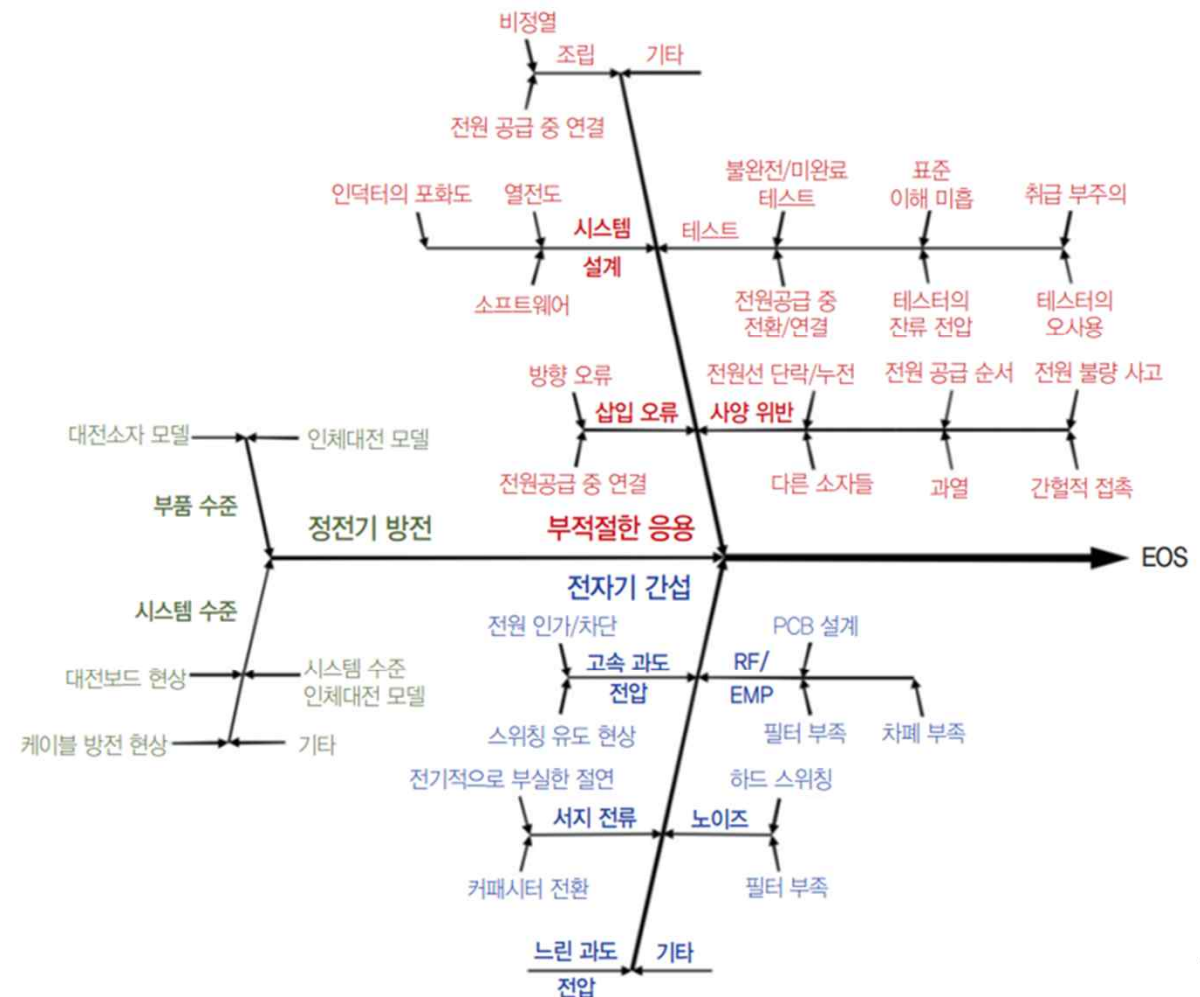
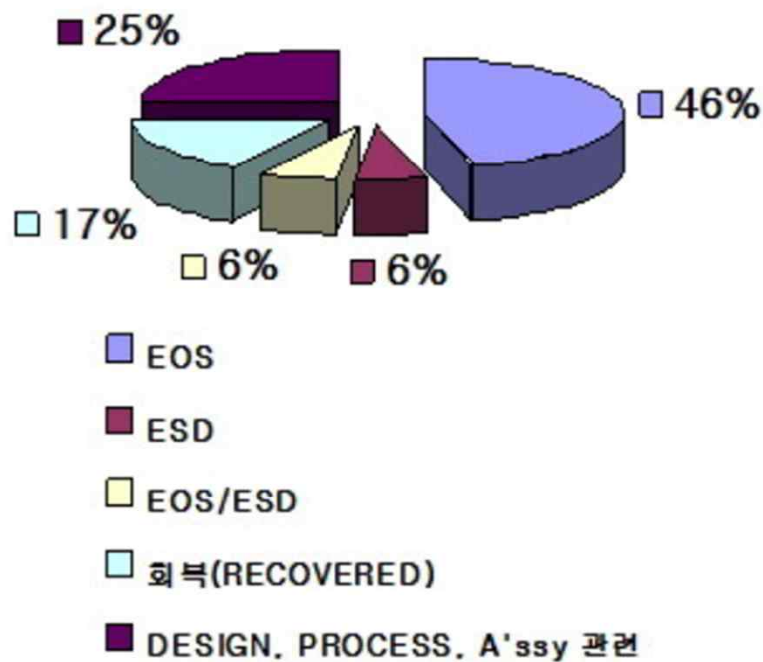
## 02. Fault Analysis

- Classification of failures



## 02. Fault Analysis

- Classification of failures (cause-base)
  - Time base : Early, Random, Wear-out failures
  - Cause base : Design flaws, manufacturing defects, misuse
  - Stress categories : Electrical, Thermal, Mechanical, Radiation



### 03. Data Collection

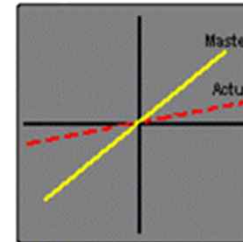
- Scope of Database Construction for PLC Condition Diagnosis
  - The database construction focuses on modules applied to the Reactor Protection System (RPS) of APR-1400 (Shin-Kori Units 5 and 6)

| Type    | Model                     |
|---------|---------------------------|
| Power   | NSPS-2Q                   |
| CPU     | NCPU-2Q                   |
| NETWORK | NFD2-1Q, NFD1-5Q, NFD1-6Q |
| AI      | NADF-1Q, NAD8-3Q          |
| PI      | NHSC-1Q                   |
| DI      | NI-D23Q                   |
| DO      | NQ-D23Q, NQ-A24Q          |



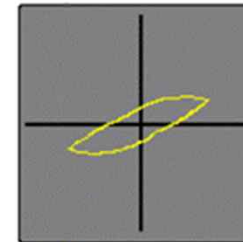
### 03. Data Collection

- Types of PLC Condition Diagnosis Data
  - Relay: Condition assessment through voltage and current waveform analysis following activation of the driving coil pulse power.
  - Resistors, Inductors, Capacitors, Diodes: Condition assessment using current characteristics in response to input voltage
  - Operational Amplifiers (Op-amps): Condition assessment through channel-wise gain (linear test) and IC saturation tests
  - Comparators: Condition assessment through IC saturation tests
  - Transistors / MOSFETs: Condition assessment using current characteristics in response to input voltage.
  - Regulators: Condition assessment based on predefined input voltage and output voltage measurements.



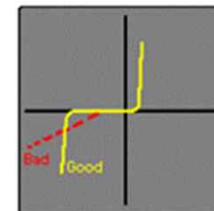
**820 Ohm Resistor**  
SETTINGS

Frequency : 1.2kHz  
Source Impedance : 1k Ohms  
Curve : sine wave  
Voltage : 10V peak to peak



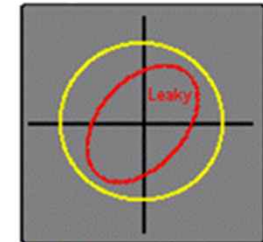
**10mH Inductor**  
SETTINGS

Frequency : 1.2kHz  
Source Impedance : 100 Ohms  
Curve : triangle wave  
Voltage : 4V peak to peak



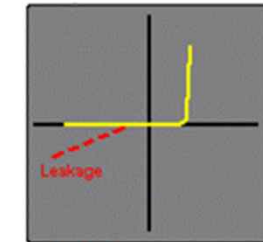
**BZX55C5V1 Zener Diode**  
SETTINGS

Frequency : 60Hz  
Source Impedance : 1k Ohms  
Curve : sine  
Voltage : 20V peak to peak



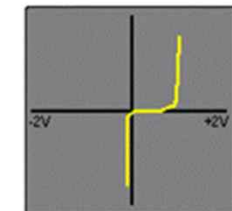
**0.47uF Capacitor**  
SETTINGS

Frequency : 4.8kHz  
Source Impedance : 100 Ohms  
Curve : sine wave  
Voltage : 2V peak to peak



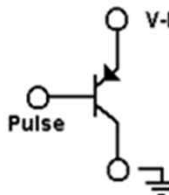
**1N4148 Diode**  
SETTINGS

Frequency : 60Hz  
Source Impedance : 1k Ohms  
Curve : sine  
Voltage : 6V peak to peak



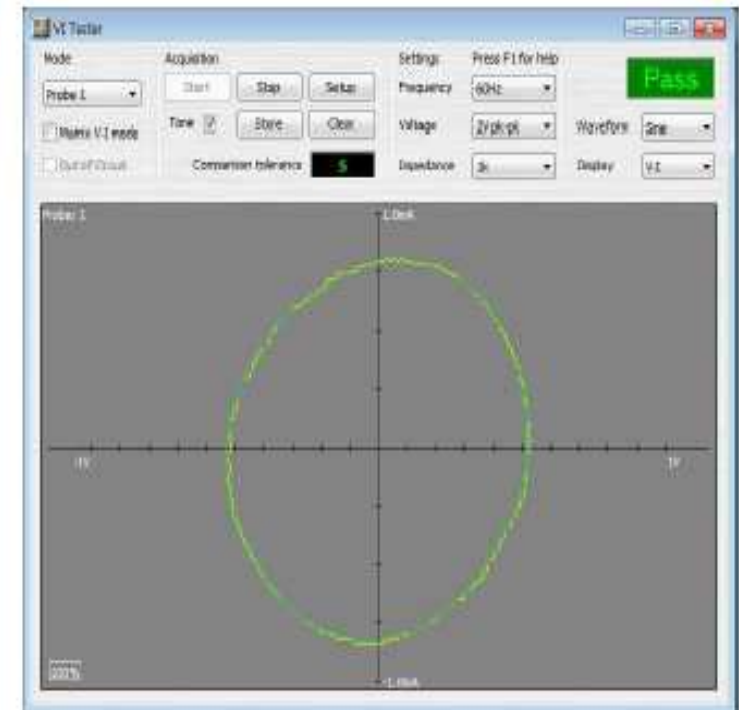
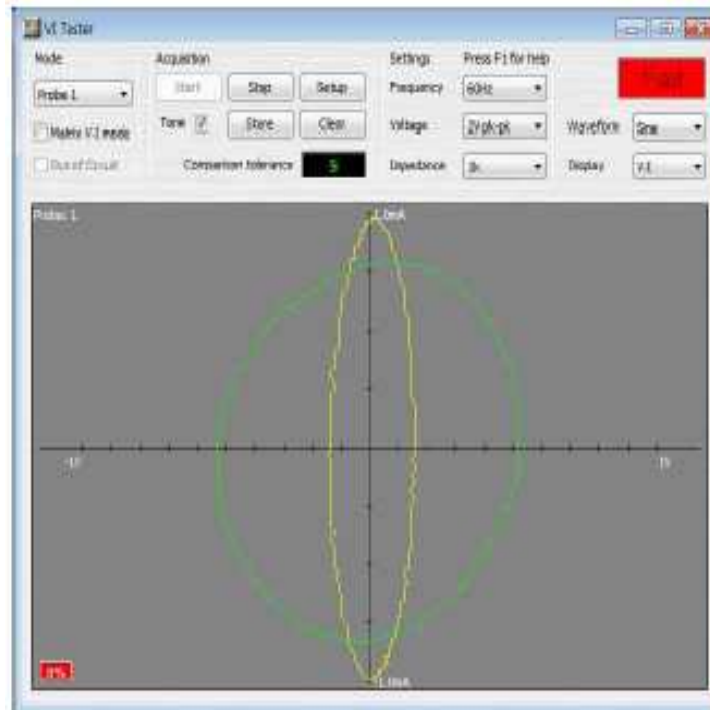
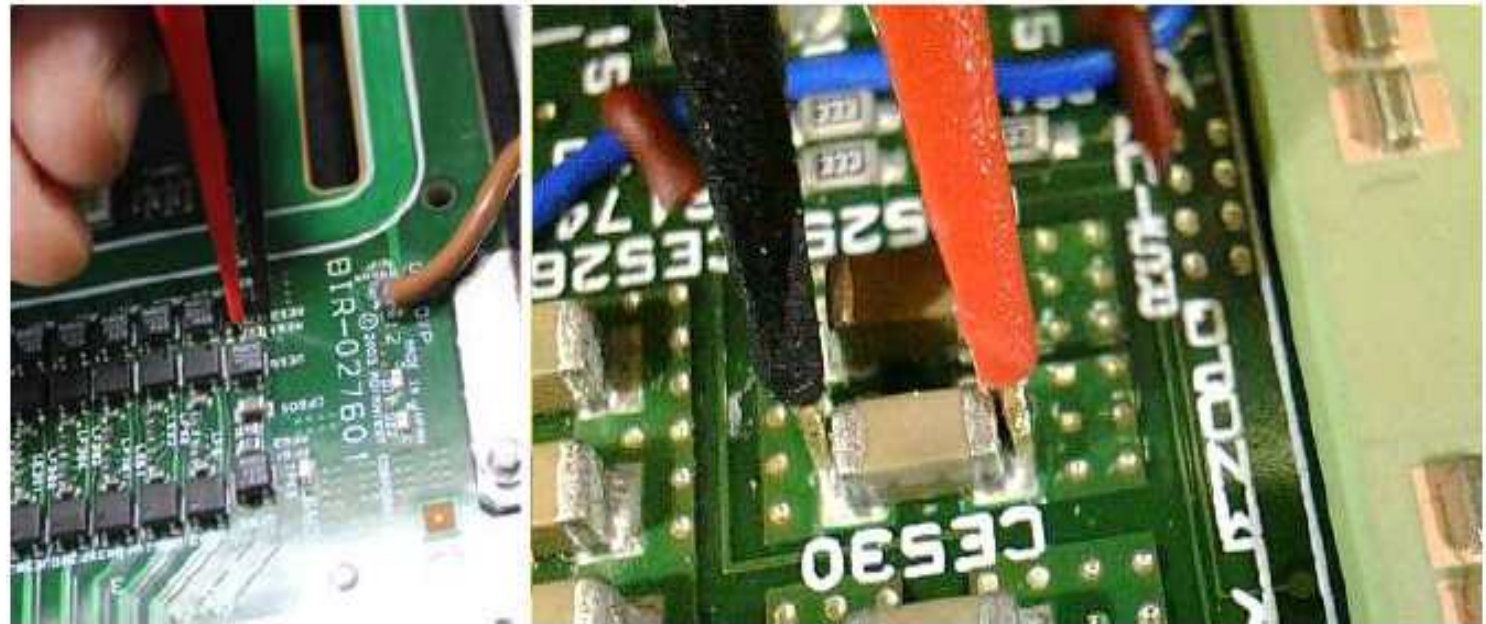
**PNP Transistor**  
SETTINGS

Frequency : 120Hz  
Source Impedance : 1k Ohms  
Voltage : 4V peak to peak  
Pulse Type : Bipolar : (V+ 0.12) (V- -0.7V)  
Positive start : 0us stop : 4.18ms  
Negative start : 4.18ms stop : 8.33ms

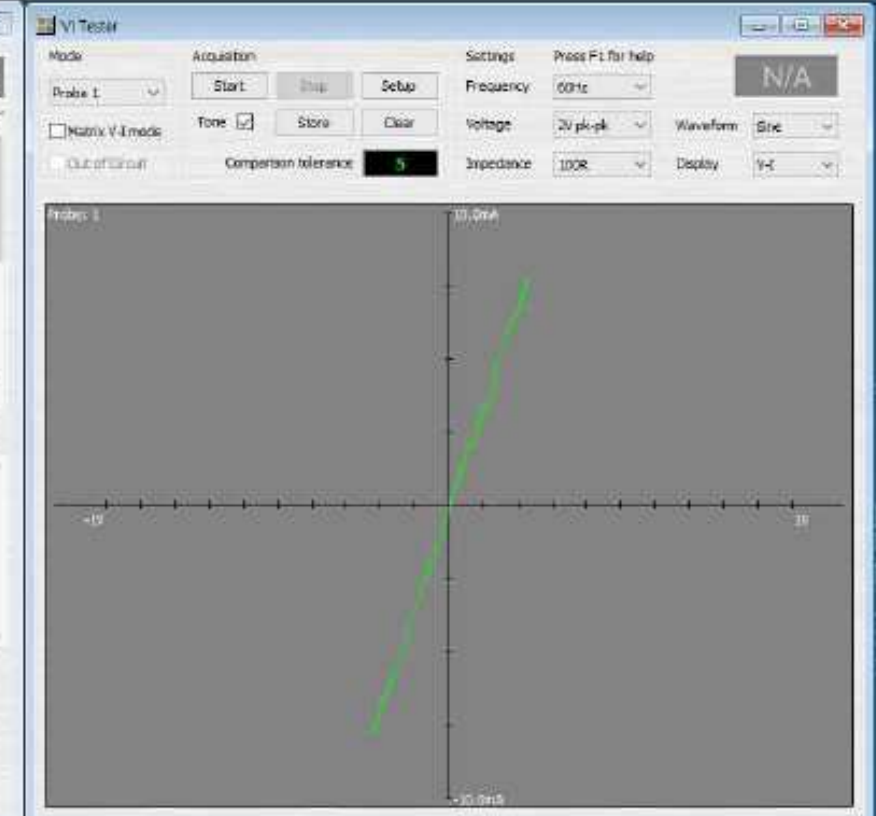
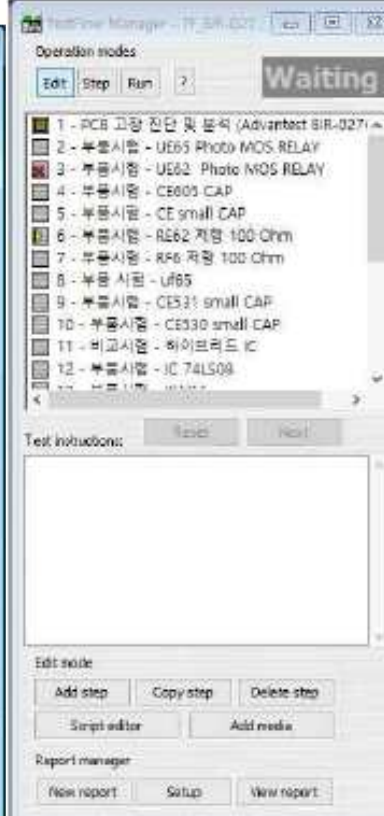
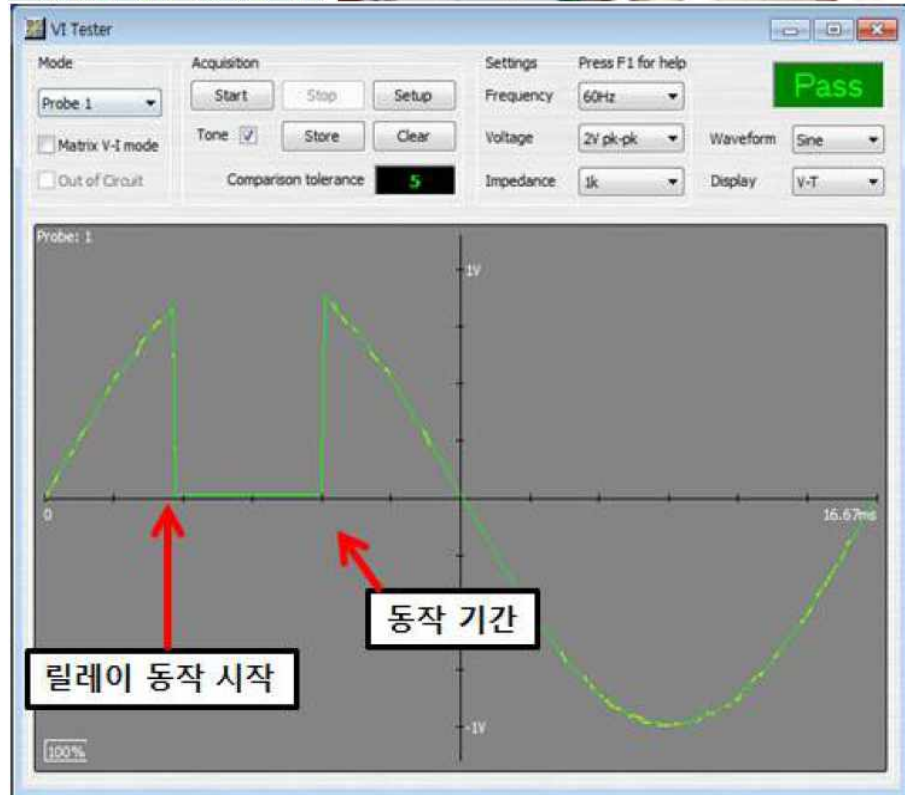
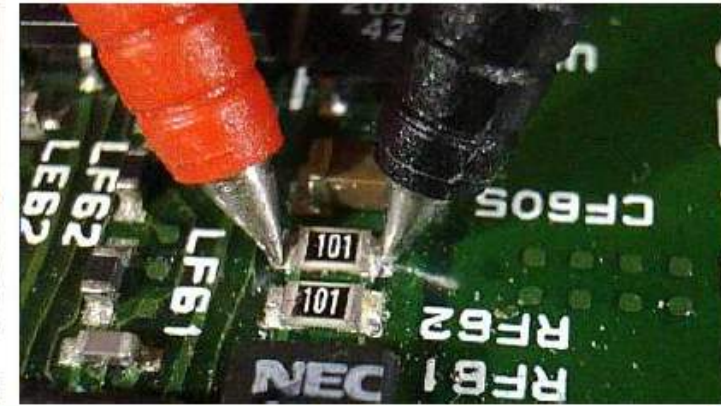
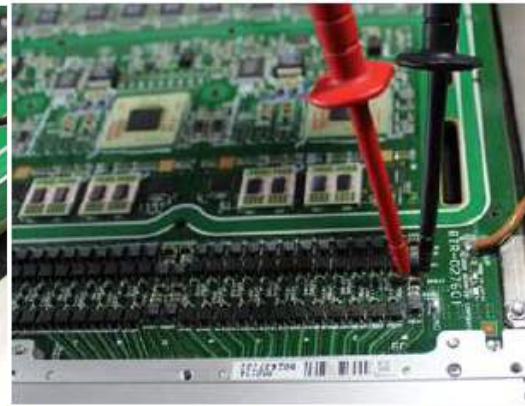
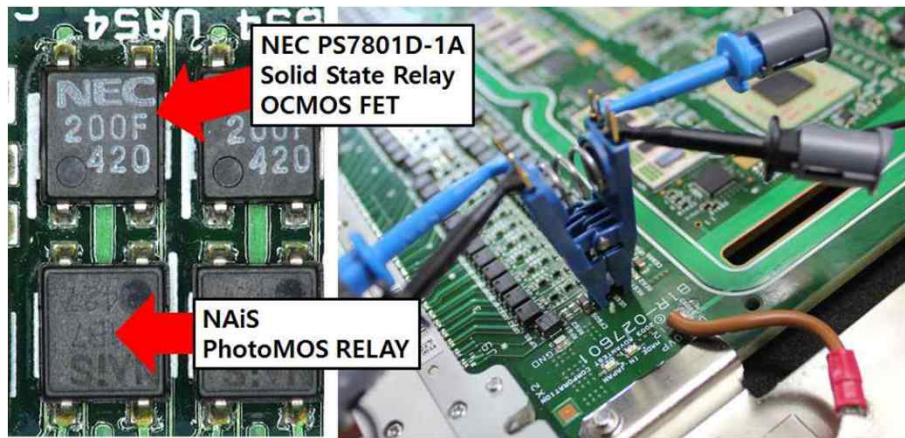


### 03. Data Collection

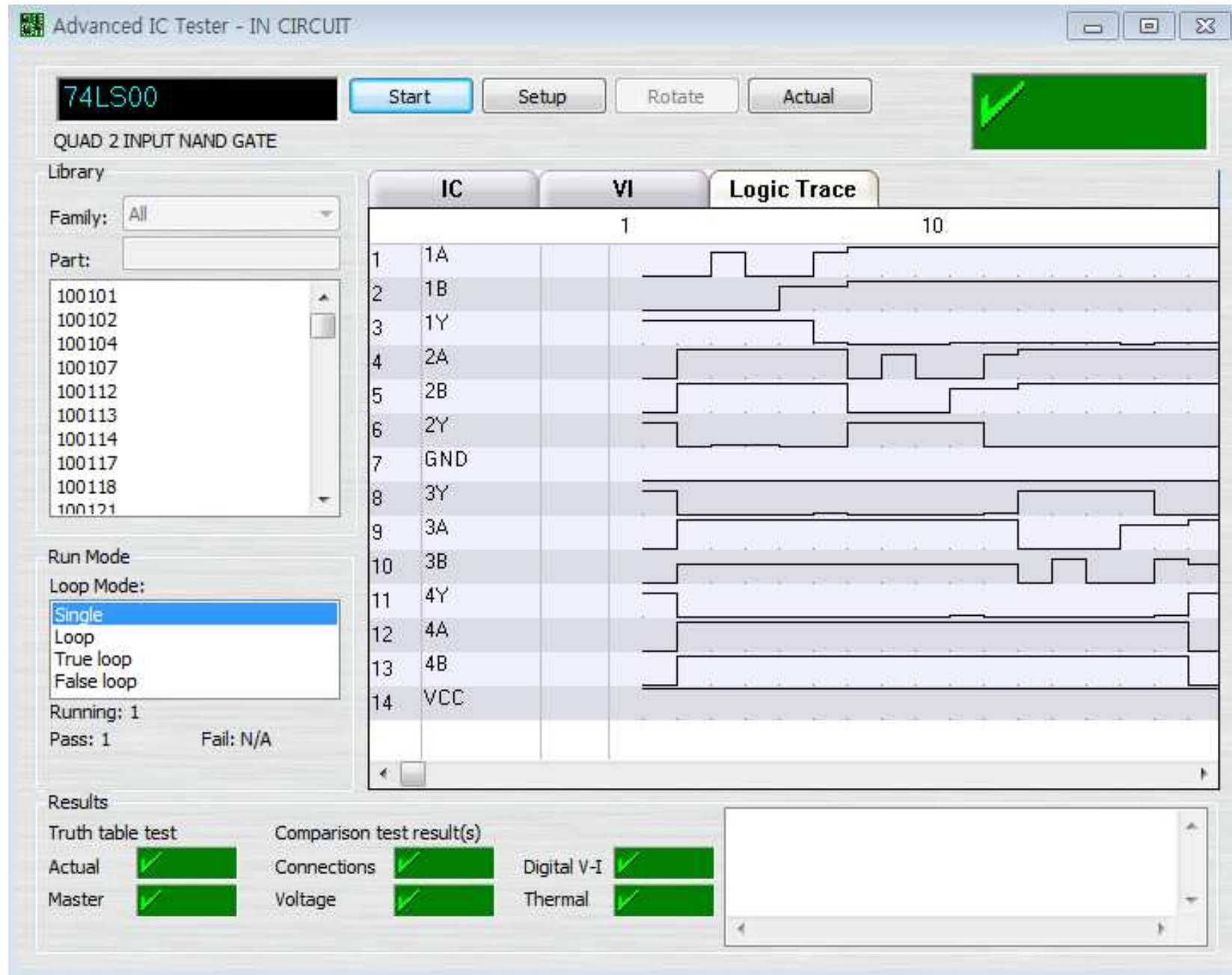
The V-I Curve data for voltage and current characteristics is injected in the form of a sine wave at each measuring point, separated into 1024 measuring range voltages (e.g. -5 ~ 5V), and the current value is stored.



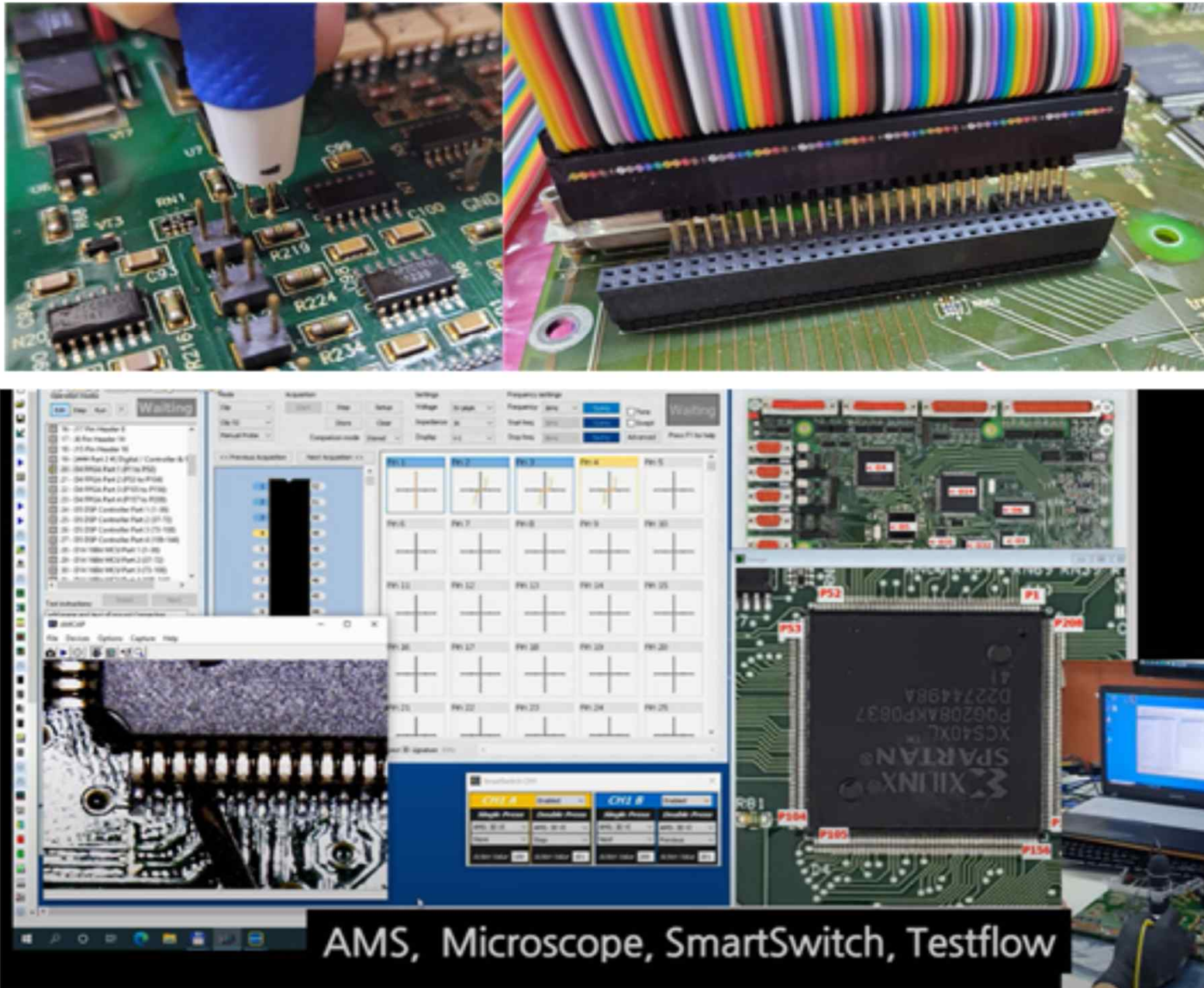
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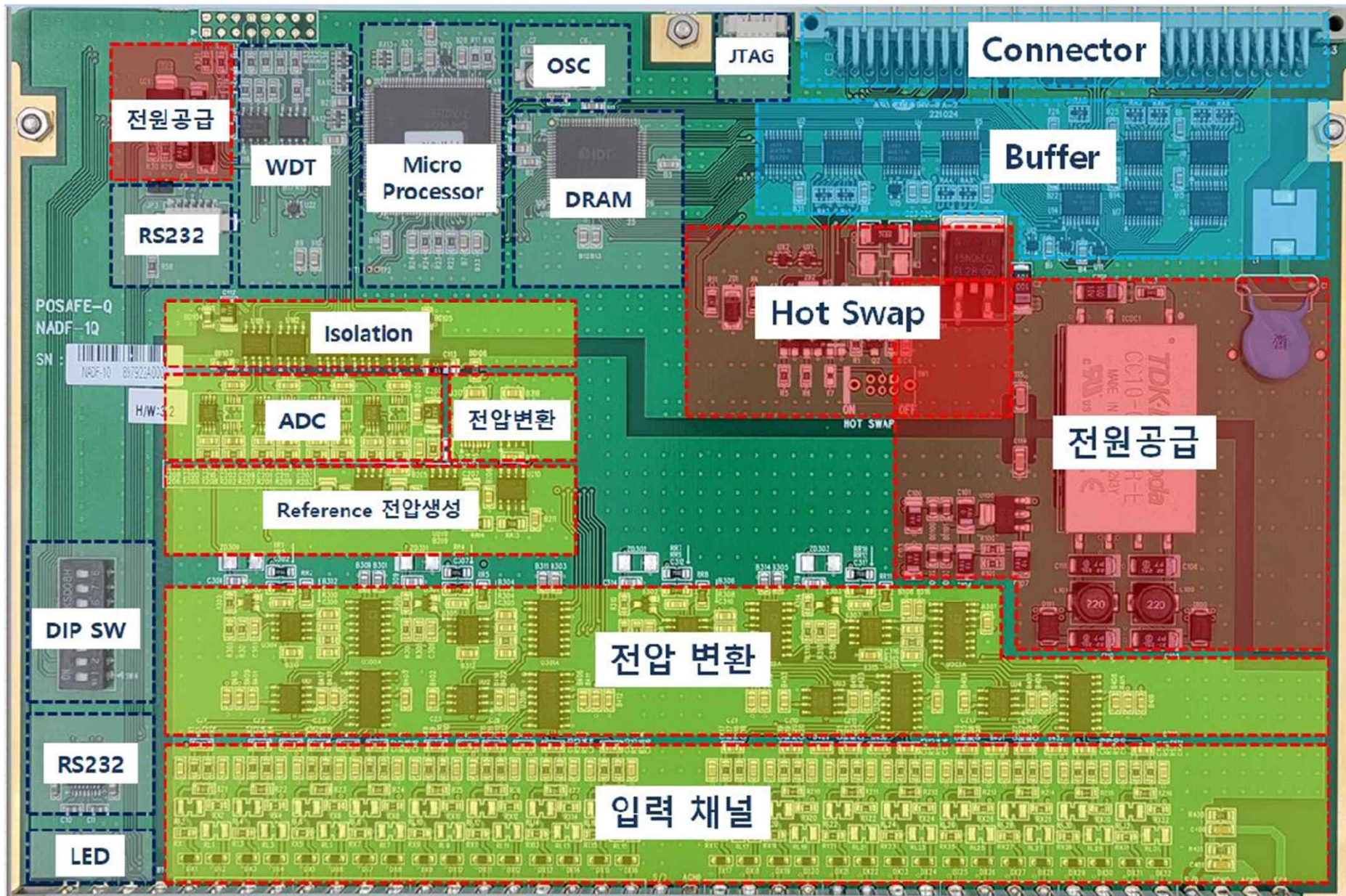
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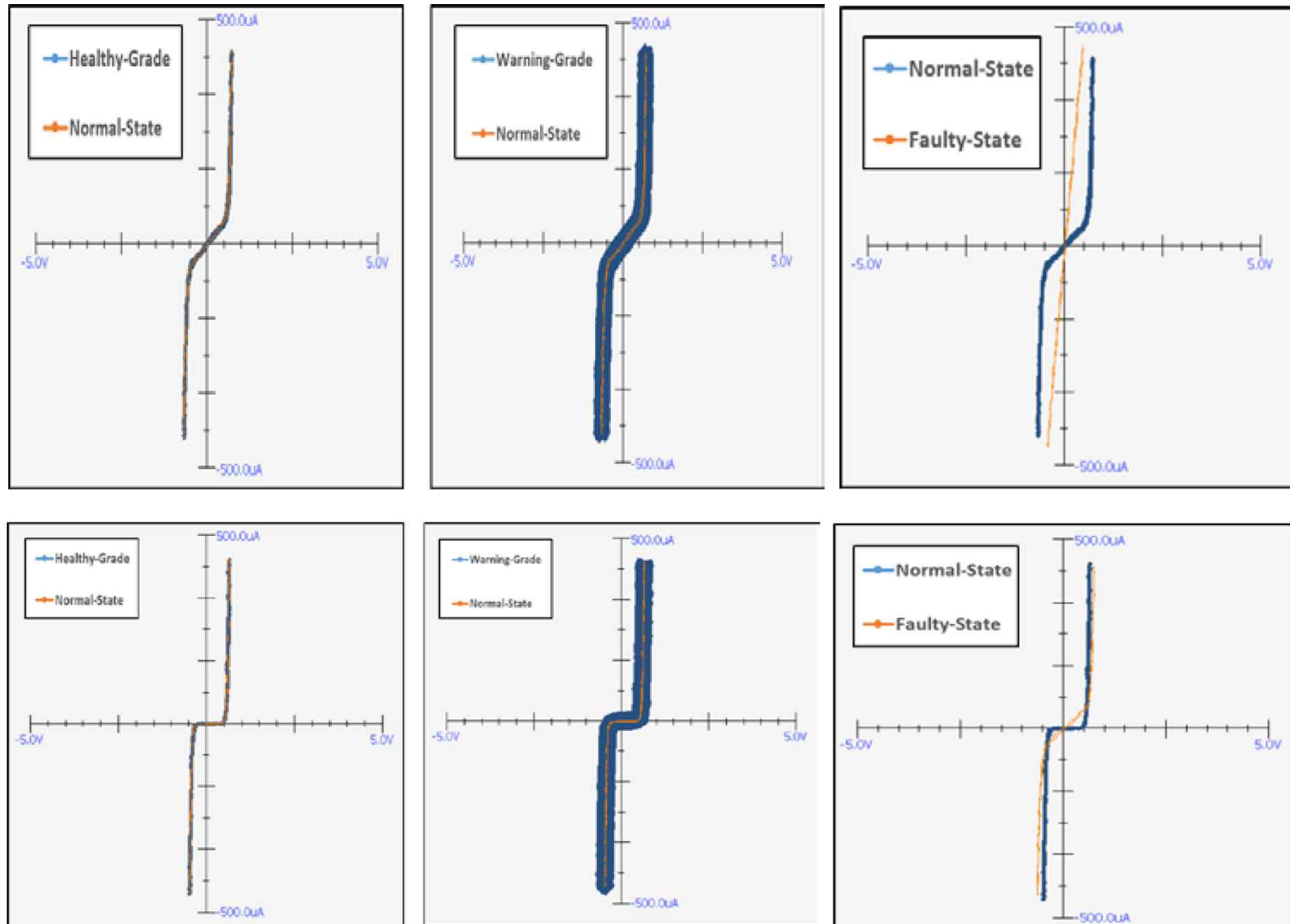


## 04. Data Structures



## 05. Data Utilization

- Board fault Detection (NCPU Memory, Reference Clock)



## 05. Data Utilization

- **State Diagnosis**

- **Normal Operation**

- ✓ Performance degradation observed, but functional requirements are met

- **Anomaly:**

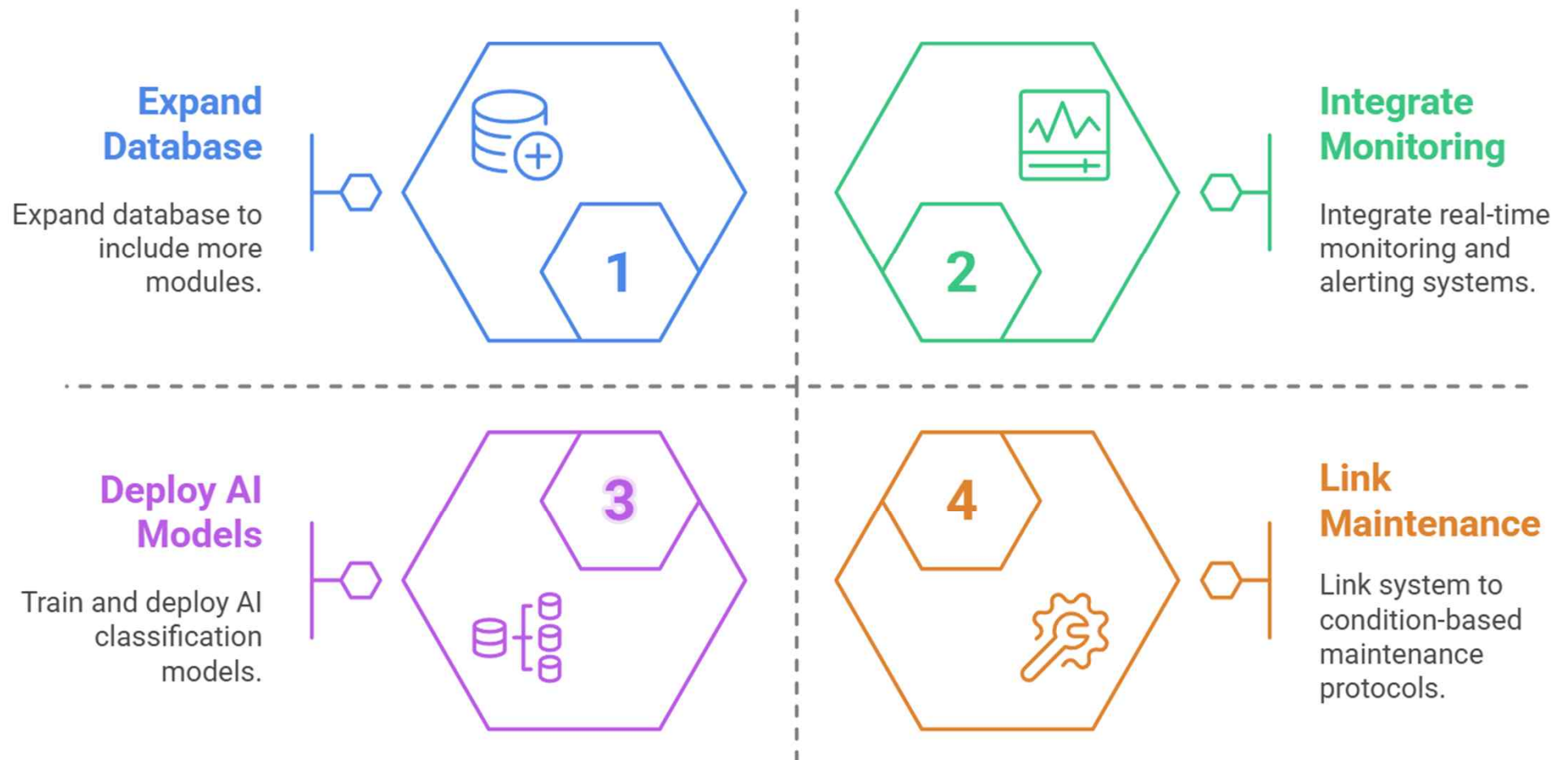
- ✓ Irregular or abnormal condition compared to normal operation
    - ✓ Performance degradation:
      - Component-level degradation
      - Board-level degradation
      - System-level degradation

- **Failure:**

- ✓ Unable to perform required functions
      - Hardware failure
      - Software error
      - Combined HW + SW error

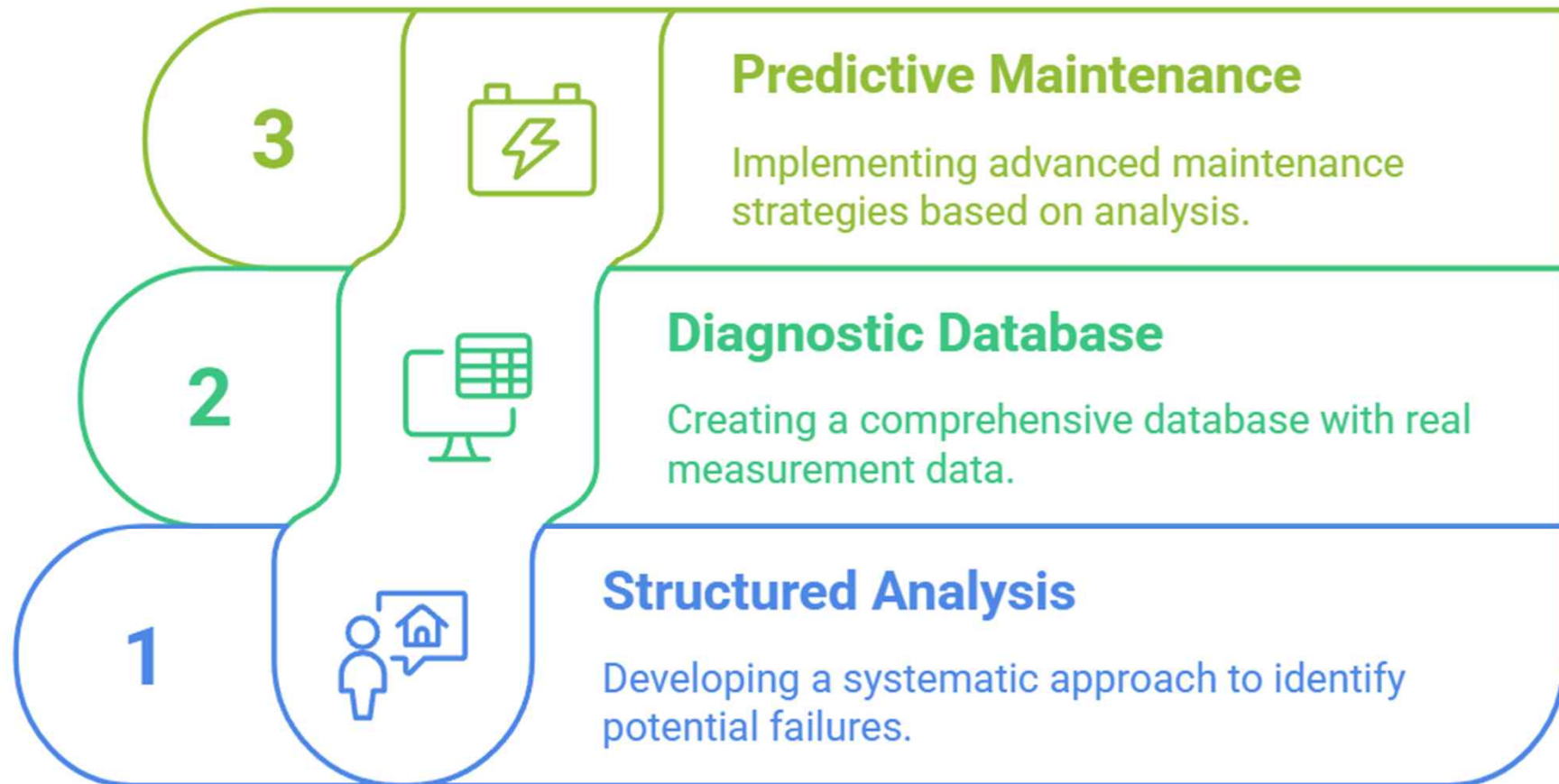
## 06. Future Work

- Expand DB to additional modules
- Integrate real-time monitoring systems
- Train and deploy AI-based classification models
- Link to condition-based maintenance protocols



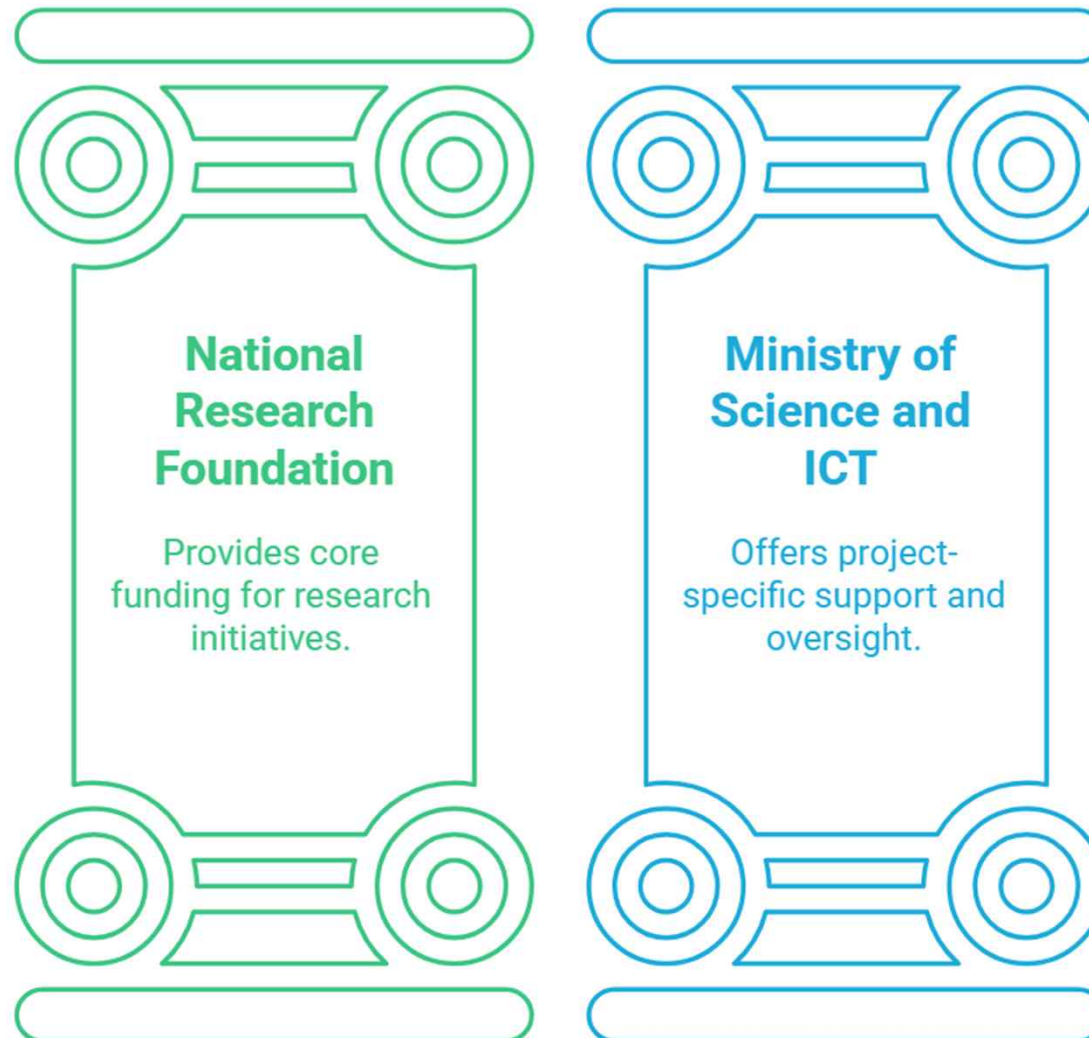
## 07. Conclusion

- Developed method for structured failure analysis
- Built and applied diagnostic DB with real measurement data
- Enhances predictive maintenance in nuclear PLCs



## 07. Acknowledgments

- Funded by National Research Foundation of Korea
- Supported by Ministry of Science and ICT (Project No. RS-2022-00144239)



Thank you for your attention

