



# Advanced Control Systems for Electrical Distribution in Nuclear Power Plants



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# 1. Introduction

- **Crucial Role:**

Ensures reliability and safety in electrical distribution

- **Technologies:**

Real-time monitoring, predictive maintenance, automated fault detection

- **Enhancements:**

Stability, efficiency, reduces outages, improves response times

- **Sustainability:**

Integrates renewable energy, supports energy storage

- **Compliance:**

Meets stringent safety and regulatory requirements



## 2. Challenges in Electrical Distribution Control

- **Reliability and Stability:**

Critical for nuclear operations

- **Integration Complexity:**

Managing onsite generators and off-site grid connections

- **Transient Disturbances:**

Advanced monitoring and rapid response needed

- **Cybersecurity Measures:**

Protect against potential threats

- b) Safety Concerns:**

- Risks with Battery Energy Storage Systems
- Ensuring fire detection and suppression
- Maintaining system integrity in extreme conditions
- Compliance with safety standards

- a) Operational Challenges**

- Maintaining reliability and stability
- Integrating diverse power sources
- Managing transient disturbances
- Cybersecurity threats
- Aging infrastructure
- Compliance with regulations

- c) Integration Issues**

- Modern digital vs. older analog equipment
- Redundant safety systems complicate integration
- Significant design changes needed, costly and time-consuming
- Extensive testing and validation required



### 3. Advanced Control Systems Overview

- **Essential for:** Safe, reliable, efficient electrical distribution
- **Technologies:** Real-time monitoring, predictive maintenance, automated fault detection

#### a) Principles

- **Feedback Control:** Monitors output, adjusts inputs
- **Feedforward Control:** Anticipates, adjusts for disturbances
- **PID Control:** Simple, effective stability
- **Robust Control:** Performs under varying conditions
- **Adaptive Control:** Real-time parameter adjustment
- **Optimal Control:** Best performance criteria



## b) Benefits

- **Reliability & Safety:**

Real-time monitoring, automated fault detection

- **Operational Efficiency:**

Predictive maintenance reduces downtime and costs

- **Energy Management:**

Smart grids and AI optimize distribution and load balancing

- **Sustainability:**

Supports renewable energy and energy storage solutions

- **Cybersecurity:**

Protects critical infrastructure from threats



## 4. Design Considerations for Advanced Control Systems

- **Single-Failure Criterion:**

Ensures no single failure compromises system integrity

- **Quality Assurance:**

Rigorous testing and validation of components

- **Independence & Redundancy:**

Backup systems for failures

- **Defense in Depth:**

Multiple layers of protection

- **Digital Integration:**

Compatibility with existing infrastructure

- **Cybersecurity:**

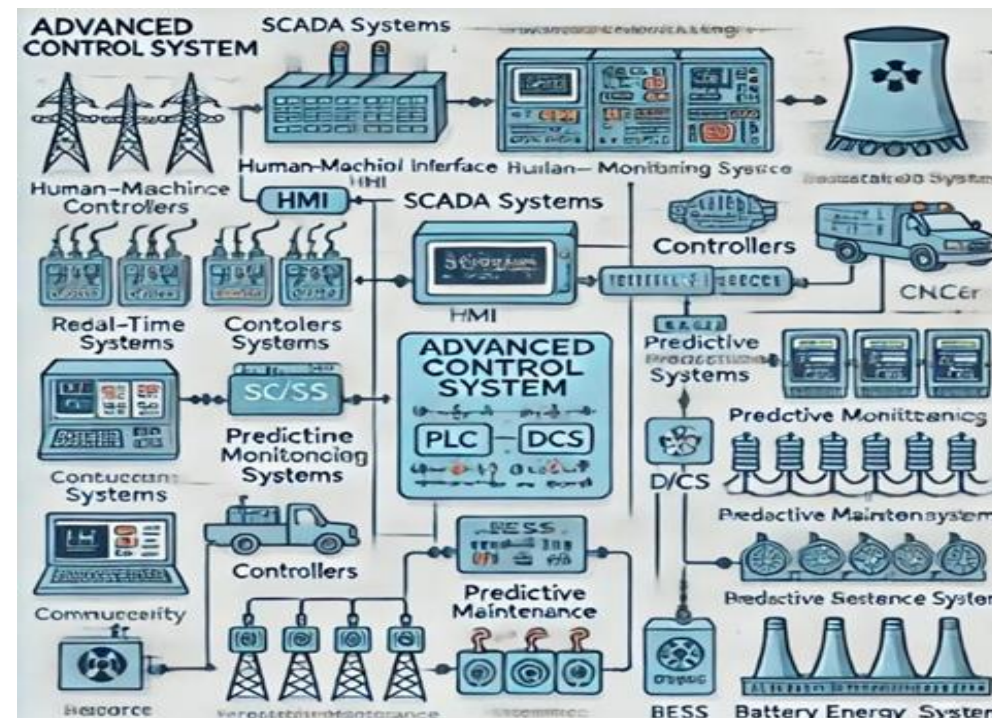
Protects against potential threats

### a) System Architecture

- Multi-layered structure; HMI, controllers
- Prevents single points of failure
- Seamless data exchange
- Protection against threats
- Enhances performance and reliability

### b) Automation Features

- Tracks electrical parameters, detects anomalies
- Predictive maintenance to prevent failures
- Integrates diverse energy sources, optimizes load
- Performs inspections, reduces human intervention



Schematic diagram of the proposed system architecture





### **c) Real-Time Monitoring**

- On-line Monitoring (OLM) for calibration, condition monitoring
- Digital twins for real-time simulation
- AI, machine learning for predictive maintenance
- Remote monitoring for off-site supervision
- Advanced sensors, robust communication networks

### **d) Cybersecurity:**

- Isolate critical systems with air gaps, hardware isolation
- Multi-layered defense: physical security, network segmentation, intrusion detection
- Regular cybersecurity impact analyses
- AI and machine learning for threat detection
- Continuous monitoring, real-time threat assessment

## 5. Benefits and Challenges

### • **Benefits:**

- Improved operational efficiency
- Heightened safety measures
- Significant economic advantages

### • **Challenges:**

- Requires substantial investment
- Meticulous planning needed
- Technical complexities to overcome

### a) **Operational Efficiency:**

- Real-time monitoring, predictive analytics, automated controls
- Precise allocation of electrical power
- Reduces energy wastage, minimizes downtime
- Seamless integration of electrical components
- Faster decision-making, quick issue resolution
- Longer equipment lifespan, reduced maintenance costs

### b) **Safety Enhancements:**

- Real-time surveillance, early fault detection
- Automated issue isolation, risk reduction
- Better coordination of safety systems
- Supports predictive maintenance
- Enhanced situational awareness, precise control



### **c) Economic Impact**

- Improved operational efficiency, cost savings
- Enhanced equipment lifespan, reduced maintenance costs
- Increased reliability, safety, higher productivity
- Long-term profitability and sustainability

### **d) Implementation Challenges:**

- Technical complexity and infrastructure upgrades
- High initial and ongoing costs
- Regulatory compliance and testing
- Requires meticulous planning and expertise



## Conclusions

### Efficiency & Safety:

- Enhanced operational efficiency, safety, reduced energy wastage, minimized downtime
- Advanced diagnostics and early fault detection

### Economic Impact:

- High initial investment, but long-term cost savings
- Extended equipment lifespan, reduced maintenance expenses
- Increased reliability, productivity, and sustainability

### Challenges:

- Technical: Integrating modern systems with existing infrastructure
- Economic: Securing funding, managing ongoing costs
- Regulatory: Ensuring compliance with safety standards



## Future Directions

- **AI & Machine Learning:**

Enhance predictive maintenance and anomaly detection

- **Cybersecurity:**

Develop robust measures against evolving threats

- **Advanced Sensors & Analytics:**

Optimize performance and response times

- **Modular & Scalable Architectures:**

Facilitate upgrades, integration with new tech

- **Collaboration:**

Align advancements with safety standards, regulations



Thank you for attention!