Case Studies: Designing Protection Systems That Minimize Potential Hidden Failures

Xiang Gao and James S. Thorp
Virginia Tech

Daqing Hou
Schweitzer Engineering Laboratories, Inc.

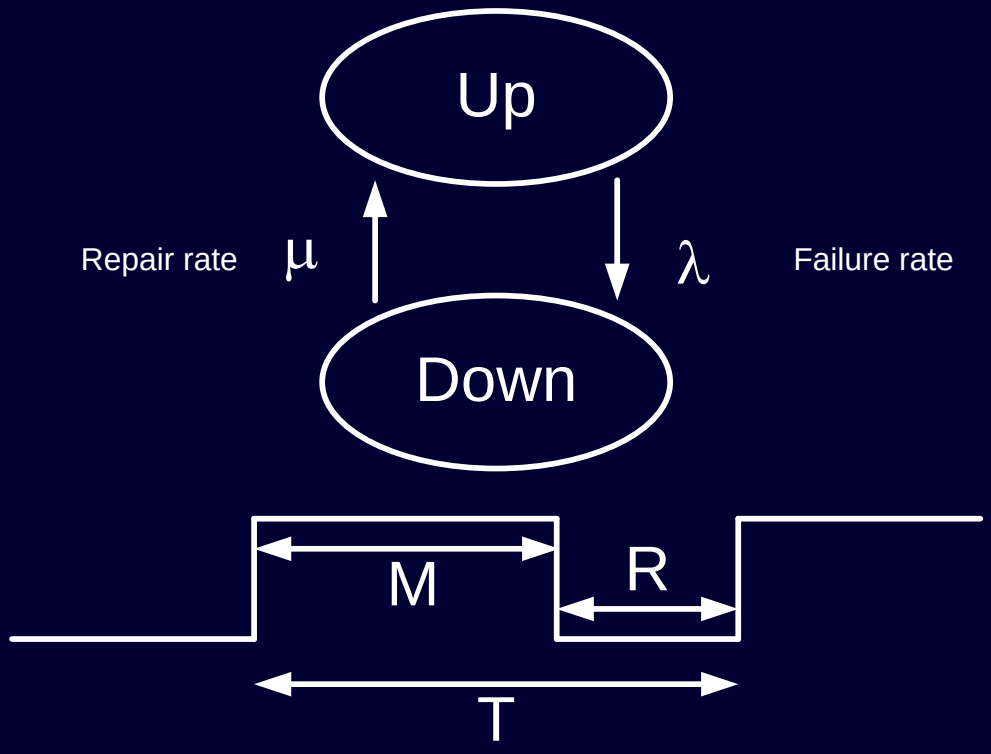
Introduction

- Nearly 70% of *n* – 2 contingencies are caused by relay misoperations due to hidden failures
- Hidden failure
  - Is permanent defects within relay system
  - Appears “healthy” under normal power system conditions
  - Causes relay system to incorrectly remove a circuit element as a direct consequence of another switching event
  - Is stochastic events and damage assumption of *n* – 1 contingency

Hidden Failure versus Normal Failure

- Normal Failures
  - Explicitly visible when occur
    - Generate an immediate alarm
    - May result in an immediate misoperation – causing N-1
- Hidden failures
  - Appear “healthy” under normal power system conditions
    - Electromechanical relays
    - Improper settings
    - Changing system operation conditions
    - Cause N-2 contingencies

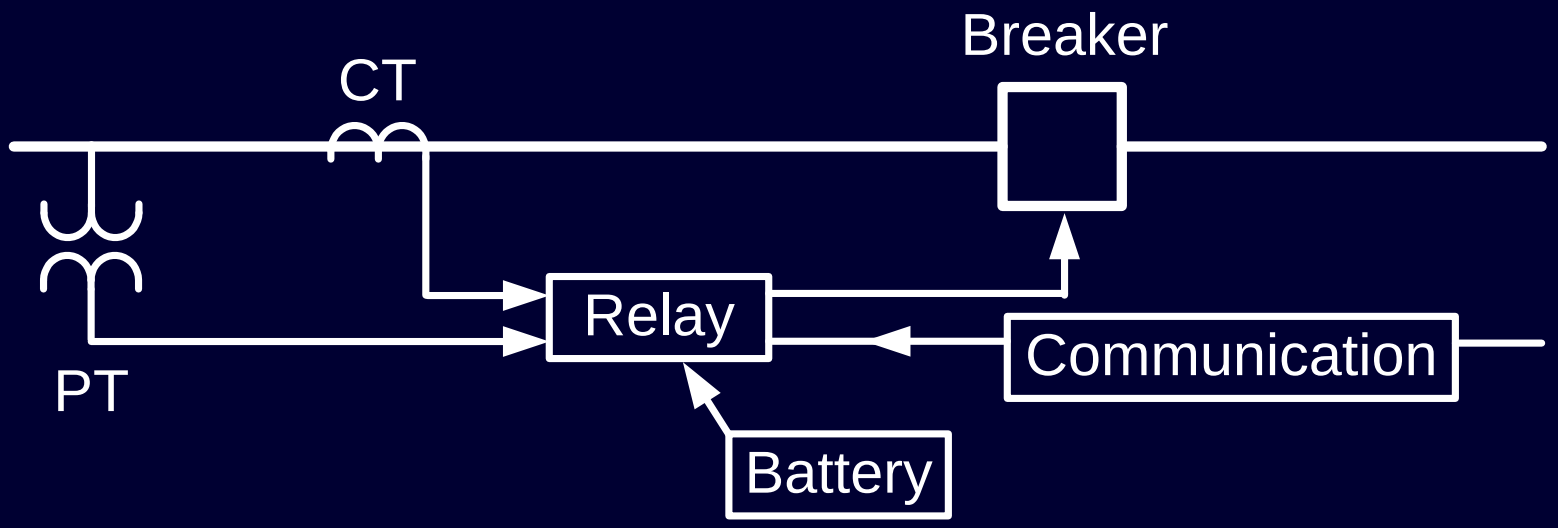
Increase M and decrease R with Protection System Maintenance



M = MTBF, average time of up state
R = MTTR, average time of down state
T = time, M + R

PRC-005 Defines Protection System

- Five specific elements



Protection System Maintenance

- NERC PRC-005 requirements - PSMP
  - Time-based maintenance
  - Performance-based maintenance
- Main activities of maintenance

Verify	Determine that a component is functioning correctly
Monitor	Observe the routine operations of an in-service component
Test	Apply signals to ensure functional performance or to diagnose problems
Inspect	Detect visible signs of failure, reduced performance and degradation
Calibrate	Adjust operating threshold or measurement accuracy to meet requirement

Routine Maintenance Issues

- Determine a time interval – what determines the optimal interval (1994 paper)
- Determine activities
- Cost of routine maintenance
  - Outages of primary equipment
  - Labor (unmanned remote substations)
  - Human mistakes
- Insufficient maintenance (unavoidable)

Condition-Based Maintenance

- Condition-based maintenance
  - May mitigate probability of hidden failures
  - Depends on online monitoring of protection system
  - Availability depends on relay attributes
- Dividing specific components of protection system is necessary for clarifying routine maintenance

Features of Modern Digital Relaying

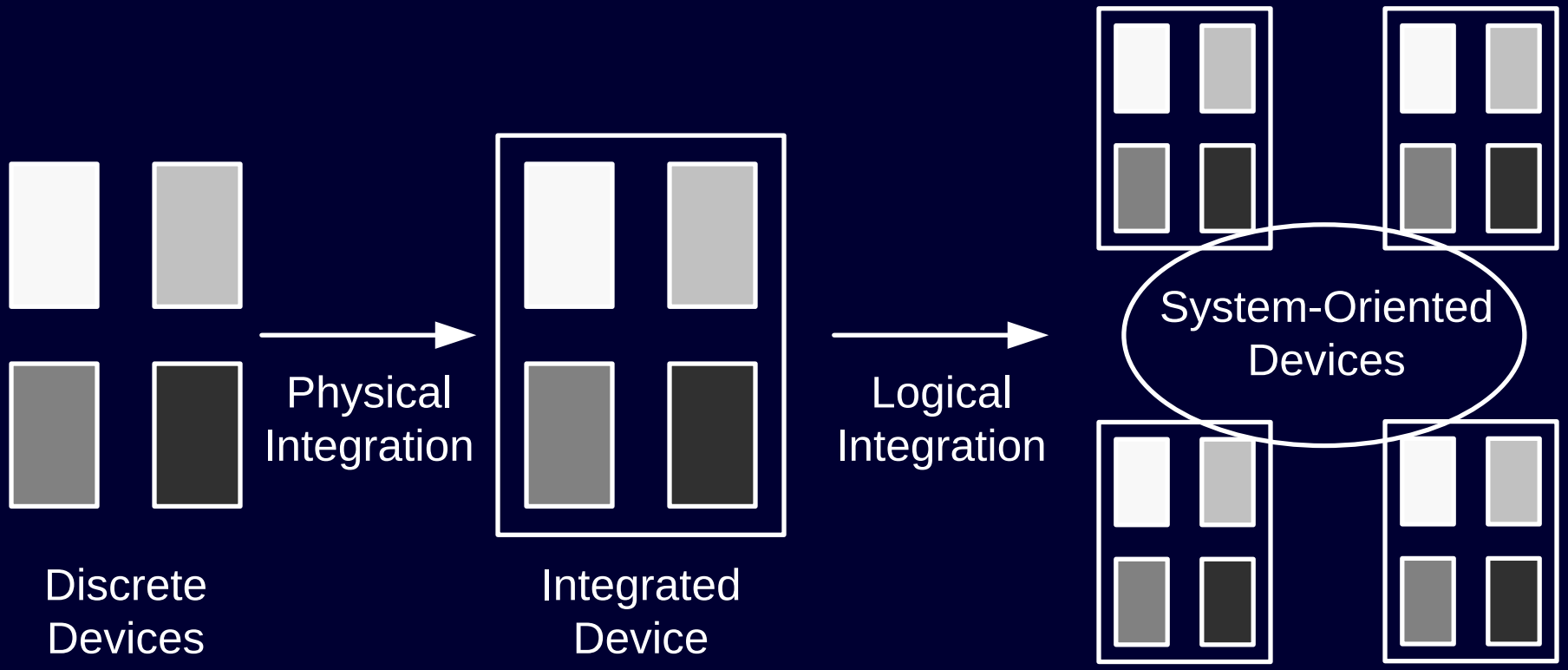
- Relay firmware defines the relay function characteristics
- Configuration is based on PLC and project requirements
- Analysis is based on “black box” event reports instead of traditional relay logic diagram

Features of Modern Digital Relaying

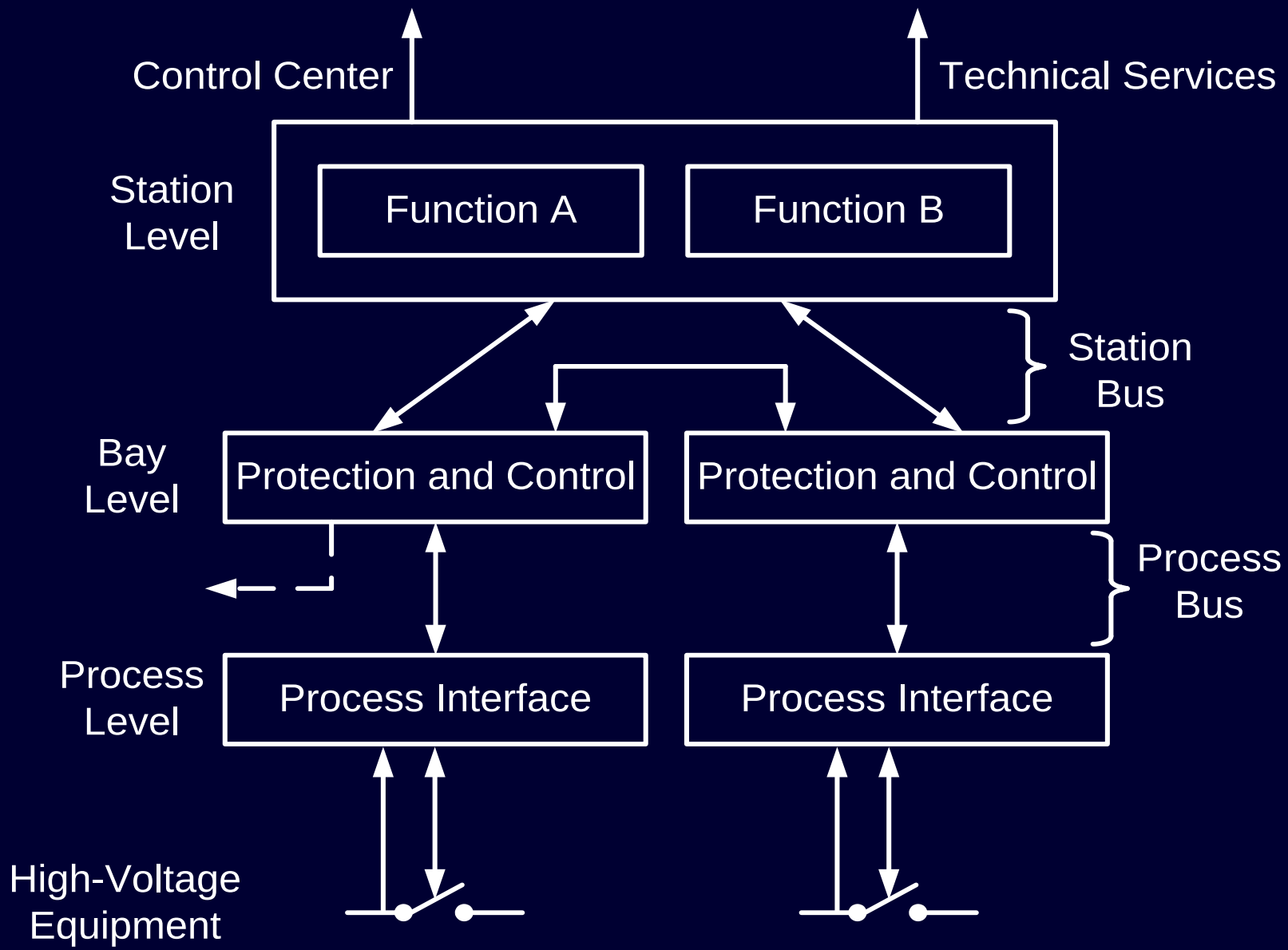
- Self-test function
  - about 80% effective (1995 paper)
  - not include CT/PT inputs and breaker control circuitry
- additional monitoring functions
  - loss of potential (LOP); Open CT
  - breaker wearing monitor; close\trip coil monitor
  - DC battery monitor

Features of Modern Digital Relaying

IEC 61850 adds an additional level of configuration



SAS Structure Based on IEC 61850



Possible New Mode of Hidden Failures
Of IEC 61850 Relays

- LNs of relay are associated with SCD file
- Lack of definition of input data set in IEC 61850
- CID of relays may change due to testing SCD
- Conventional boundary of relay terminal has been violated

Relay Supervisory System (RSS) for Protection System Monitoring

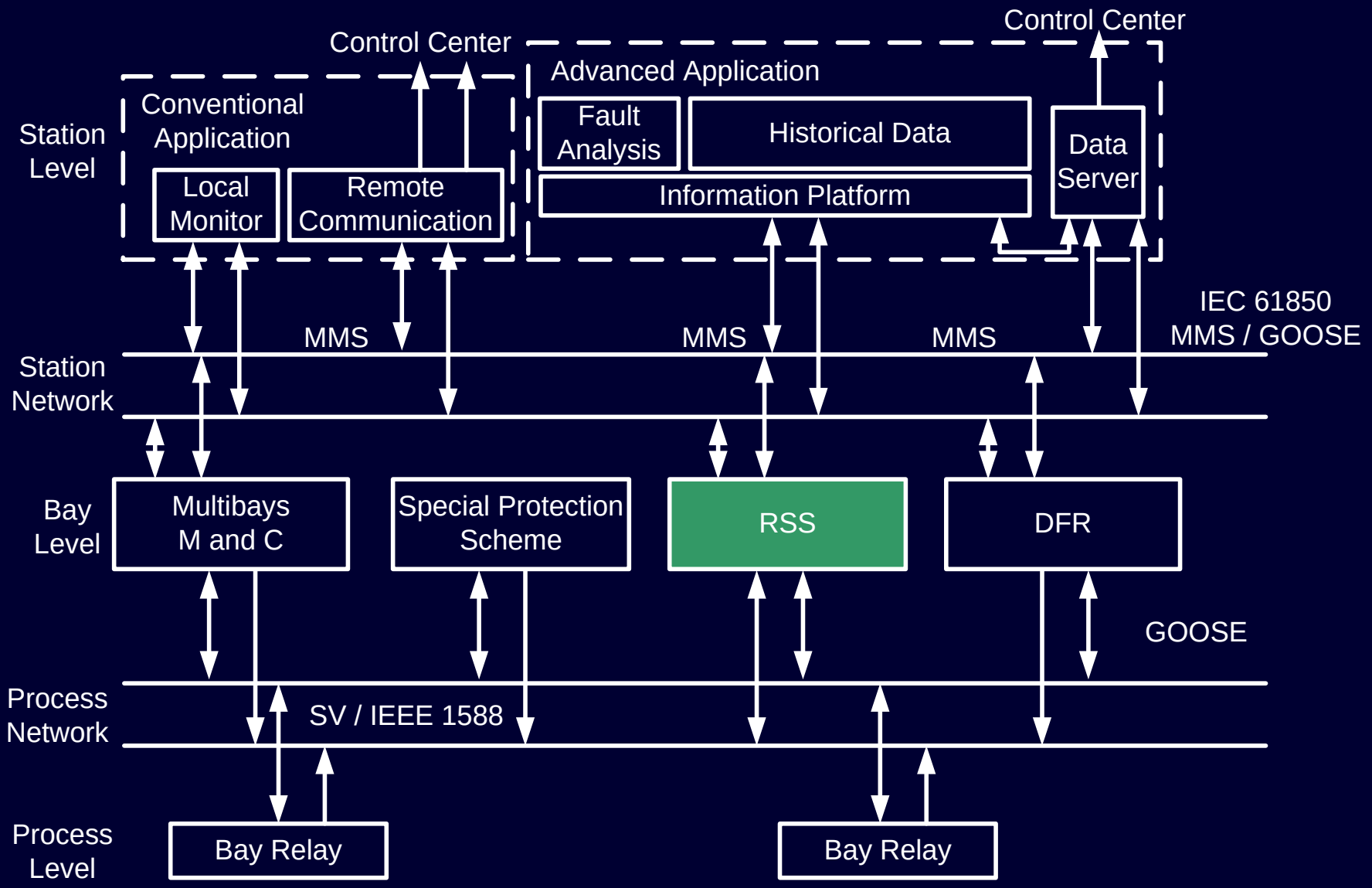
Main Considerations of Condition-Based Maintenance

- Process level provides information for monitoring interface between RSS and primary equipment
- IED PLC emulates trip and close operations of circuit breakers based on virtual manufacturing device (VMD) of IEC 61850
- Control circuits may be monitoring completely

RSS Activities Associated With Hidden Failures

Component	Verify	Monitor	Test	Inspect	Calibrate
Relay	Yes	Yes	Yes	Do not apply	Do not apply
Communication	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
CT / PT Input	Yes	Yes	Yes	Do not apply	Do not apply
Battery	Do not apply	Do not apply	Do not apply	Do not apply	Do not apply
Control Circuit	Yes	Yes	Yes	Do not apply	Do not apply

RSS Structure



RSS Functions

- Compare CT/PT inputs from different sources
- Compare relay settings and configuration with the reference
- Check output control circuit with closed-loop information
- Provide traceable causes to protection outputs

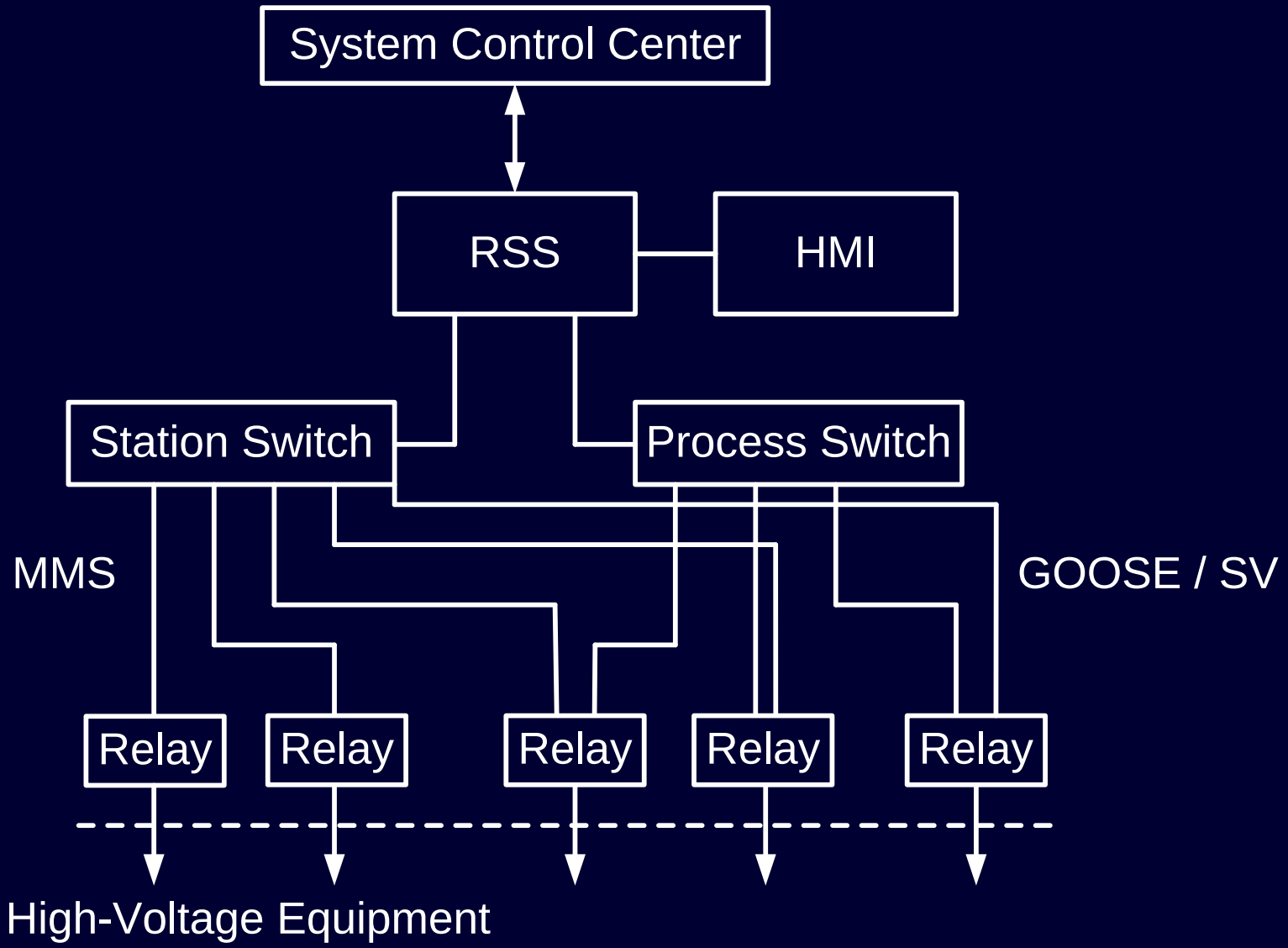
RSS Functions

- Analyze margins of primary and backup protection functions
- Manage IED CID files
- Prevent unauthorized access from substation communications network
- Log system event
- Provide visual alarms

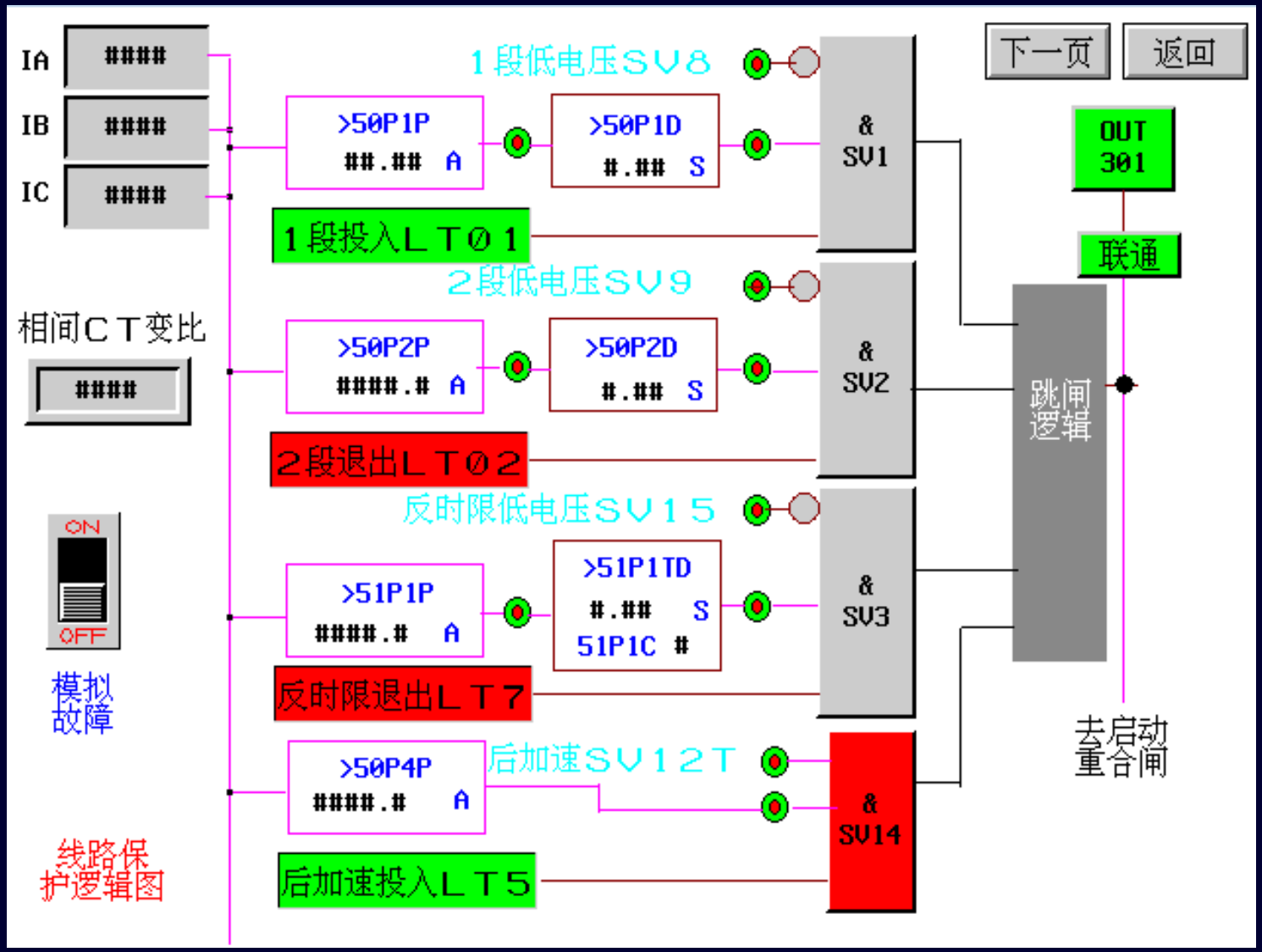
110 kV Liang Shuijing Substation Project

- Decentralized allocation of relays inside cubicle of outdoor GIS and substation transformers
- Substantial reduction of copper cables
- Use of substation-based HMI technology (displays functions of installed relays)
- Use of remote maintenance technology for closed-loop testing

Decentralized Protection System



Visualized Functional Logic



Conclusion

- Hidden failures of protection systems damage power system reliability
- IEC 61850 SAS architecture may introduce new mode of hidden failures
- Routine maintenance tests may not solve all concerns of hidden failures
- RSS helps complying to NERC-005 requirements and mitigates hidden failure concerns

Conclusion

- Available software and hardware information inside modern relays is crucial for mitigating hidden failures
- PLC-based configuration is helpful to implement a condition-based maintenance strategy based on RSS

Questions?