ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Operation, Monitoring and Control Technology of Power Systems

Course 227-0528-00

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Course Outline

1. Introduction
2. Monitoring and Control Technology
3. Operation Principles
4. Algorithms and Computations

Contents

- Hierarchical Concept
- SCADA/EMS
- Power Systems Protection

Functions

- Tasks Crossing Hierarchical Layers (SCADA/EMS)
- Local Autonomous Functions

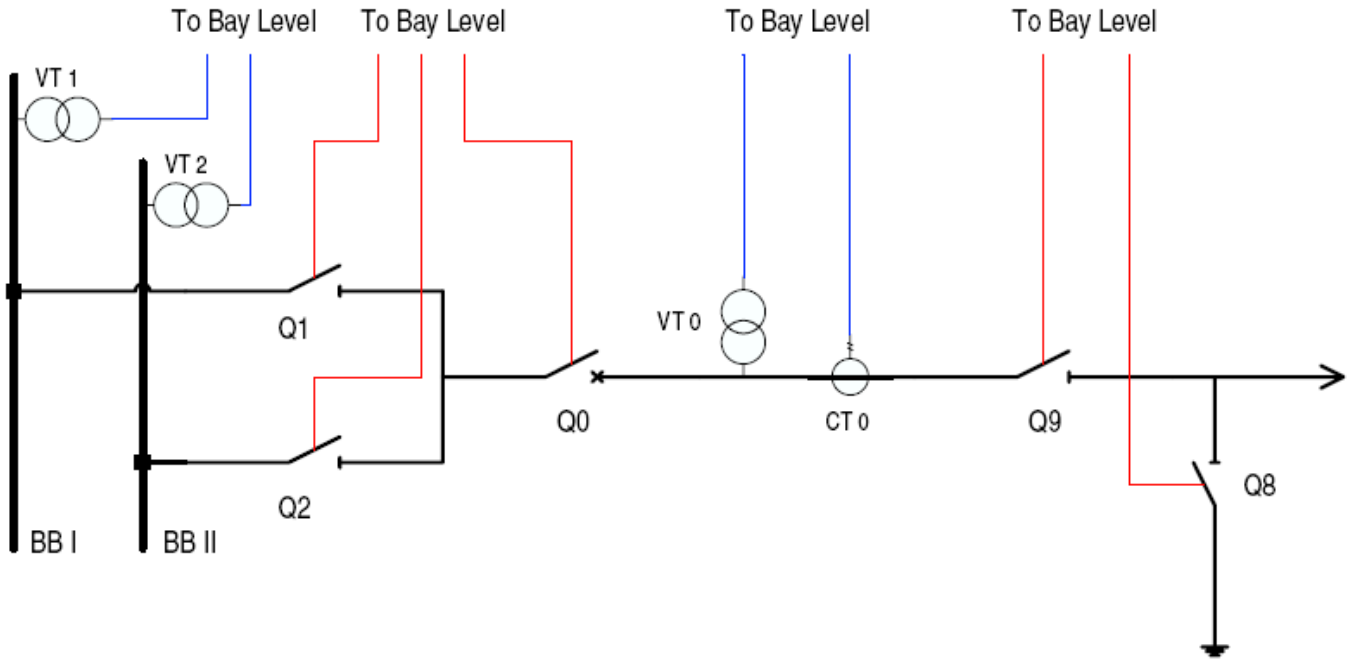
Hierarchical Concept

- Control Center Level
  - SCADA/EMS
- Substation Level
  - SCADA/EMS
  - Local Autonomous Functions
- Bay Level
  - SCADA/EMS
  - Local Autonomous Functions
- Process Level

Hierarchical Concept

- Control Center Level
- Substation Level
- Bay Level
- Process Level

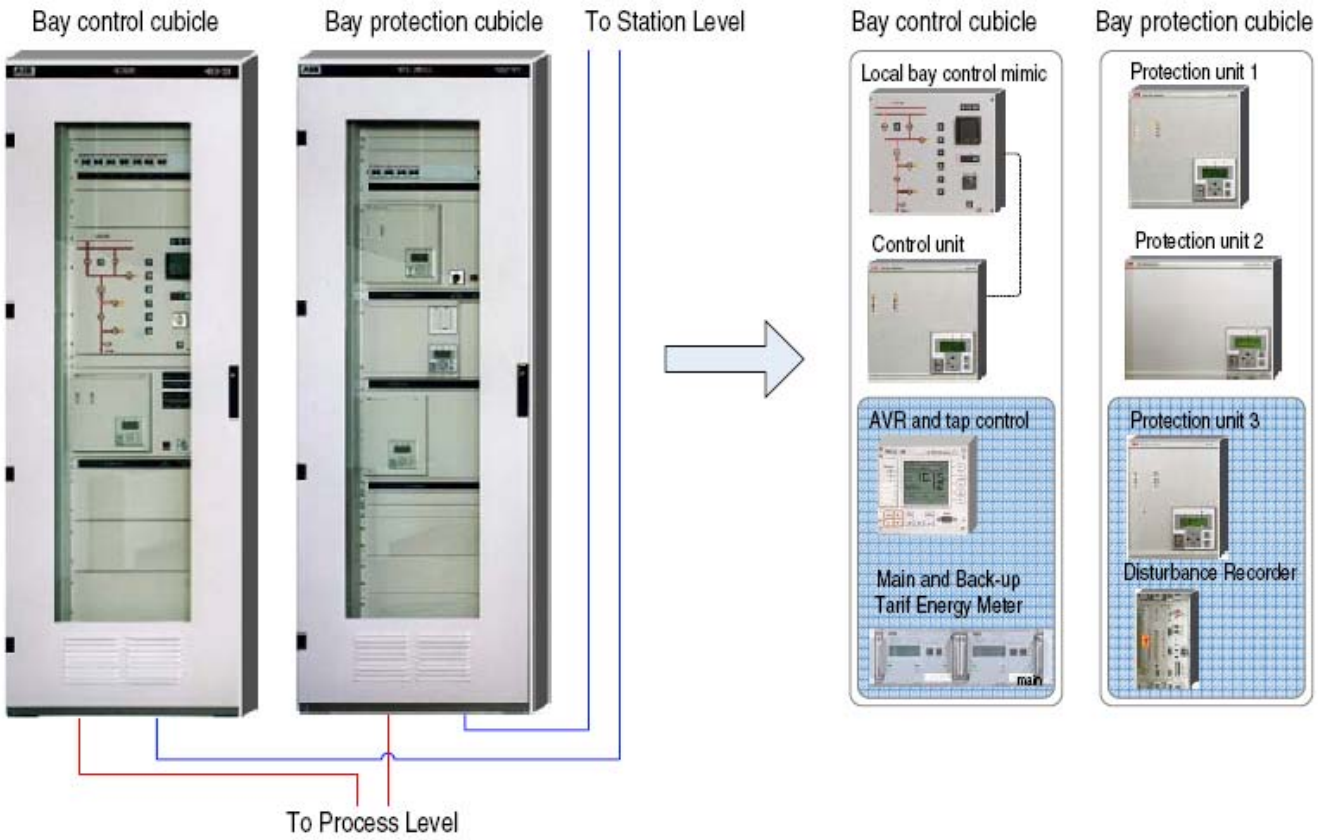
Process Level



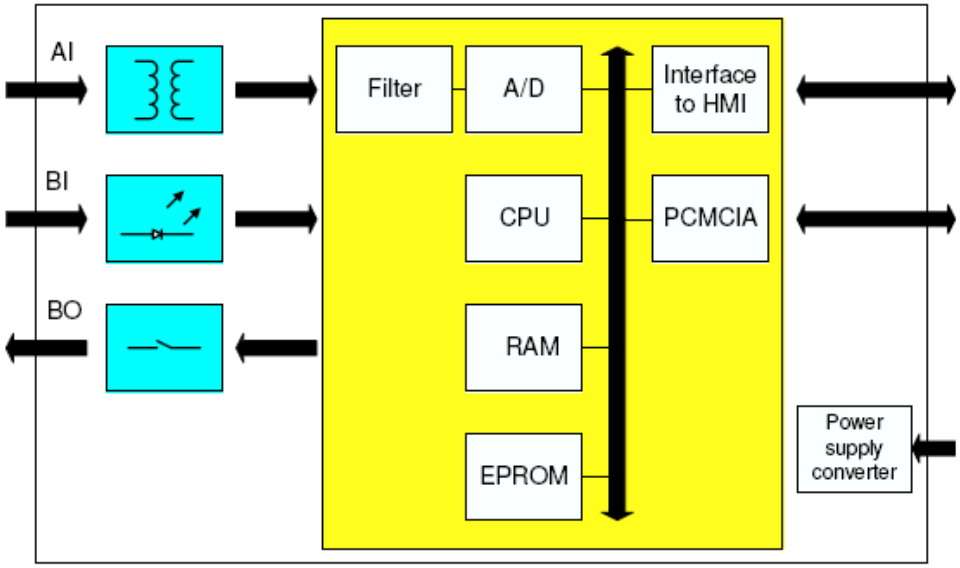
Hierarchical Concept

- Control Center Level
- Substation Level
- Bay Level
- Process Level

Bay Level


Bay control cubicle
Bay protection cubicle
To Station Level
To Process Level
Bay control cubicle
Bay protection cubicle
Local bay control mimic
Control unit
AVR and tap control
Main and Back-up
Tarif Energy Meter
Protection unit 1
Protection unit 2
Protection unit 3
Disturbance Recorder

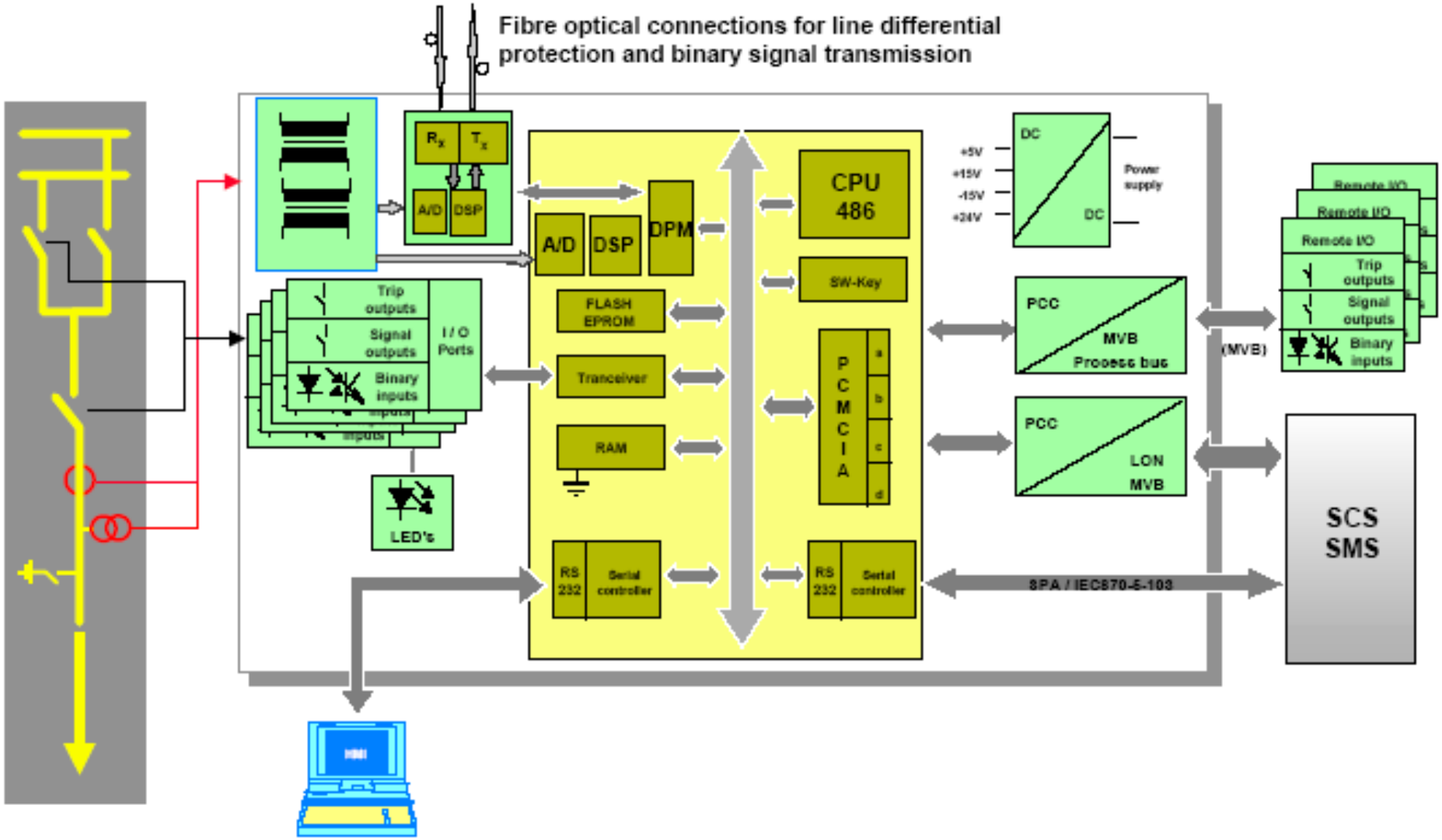
Intelligent Electronic Device



Bay Level Functions

- Components protection:
  - Protection
  - Fault location, Autoreclosure and synchrocheck (for line protection)
- Data acquisition:
  - Rectification
  - A/D conversion
- Disturbance recording
- Control:
  - Switching operations (manual or automatic – initiated by protection): Sequencer and Interlocking
  - Tap-changer control

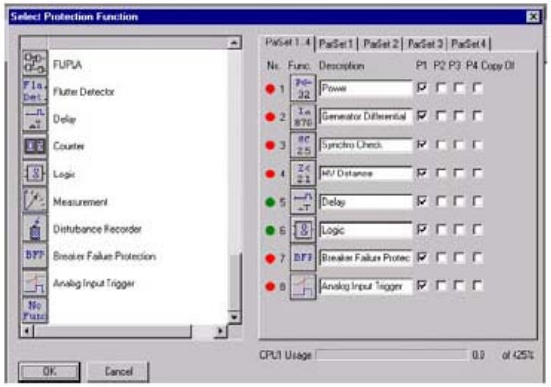
Fibre optical connections for line differential protection and binary signal transmission

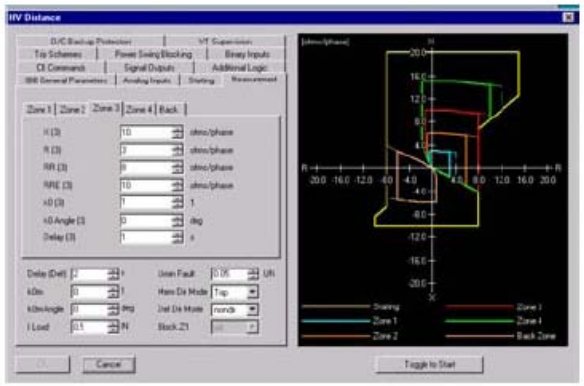


Source: ABB Switzerland Ltd.

IED Example

- Same hardware platform for:
  - Line protection
  - Transformer protection
  - Generator protection
  - Substation control unit
- Functionalities chosen and set in engineering process



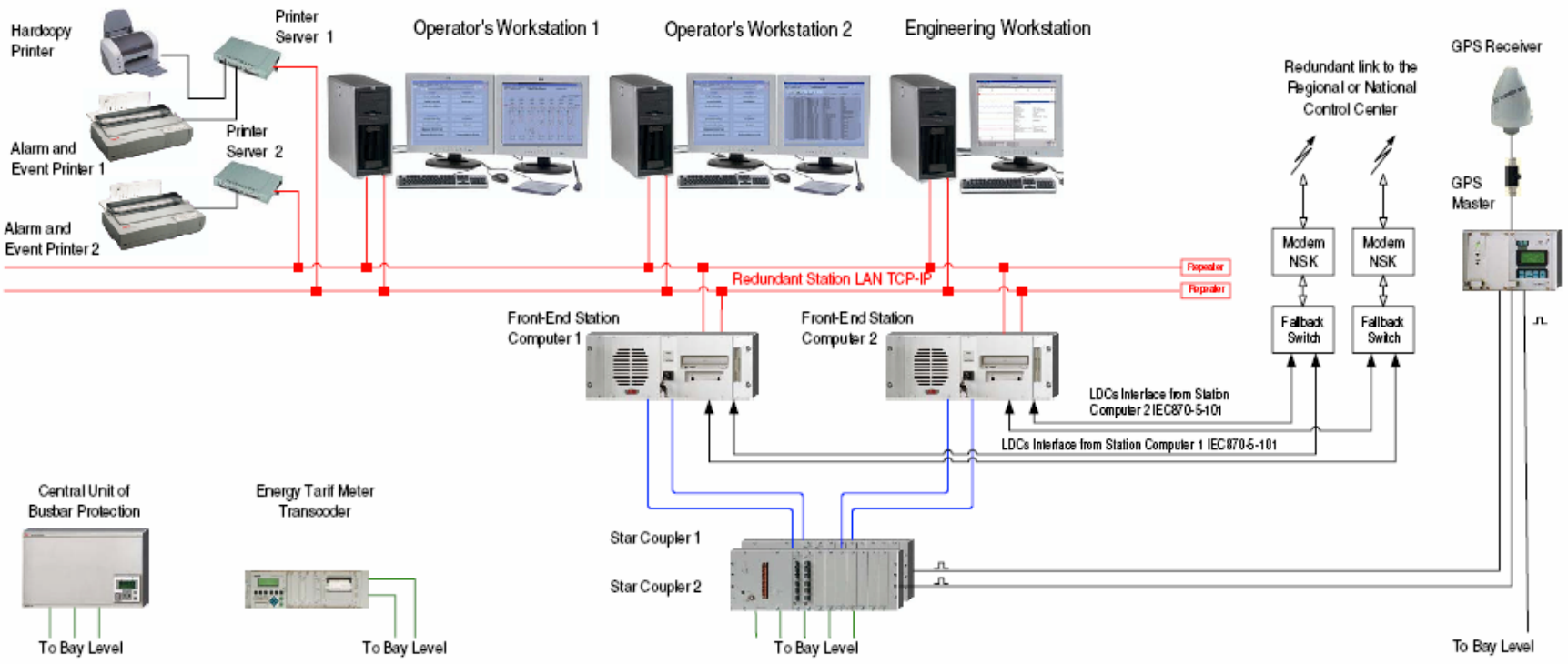


Source: ABB Switzerland Ltd.

Hierarchical Concept

- Control Center Level
- Substation Level
- Bay Level
- Process Level

Substation Level



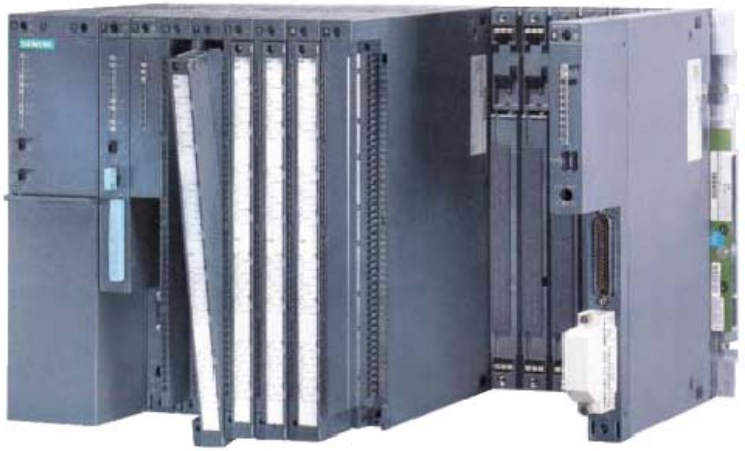
Substation / Field PC

- Industrial PC Example
  - ABB PCU400

RTU

- RTU:
  - Remote Telemetry Unit
  - Remote Terminal Unit
- Flexibility in application areas (electric networks, oil, gas etc.)
- Usually modular structure:
  - I/O modules (analog input, binary input, binary output)
  - Communication modules
- Number of data points:
  - Small: < 100
  - Medium: 100 – 1000
  - Large: > 1000

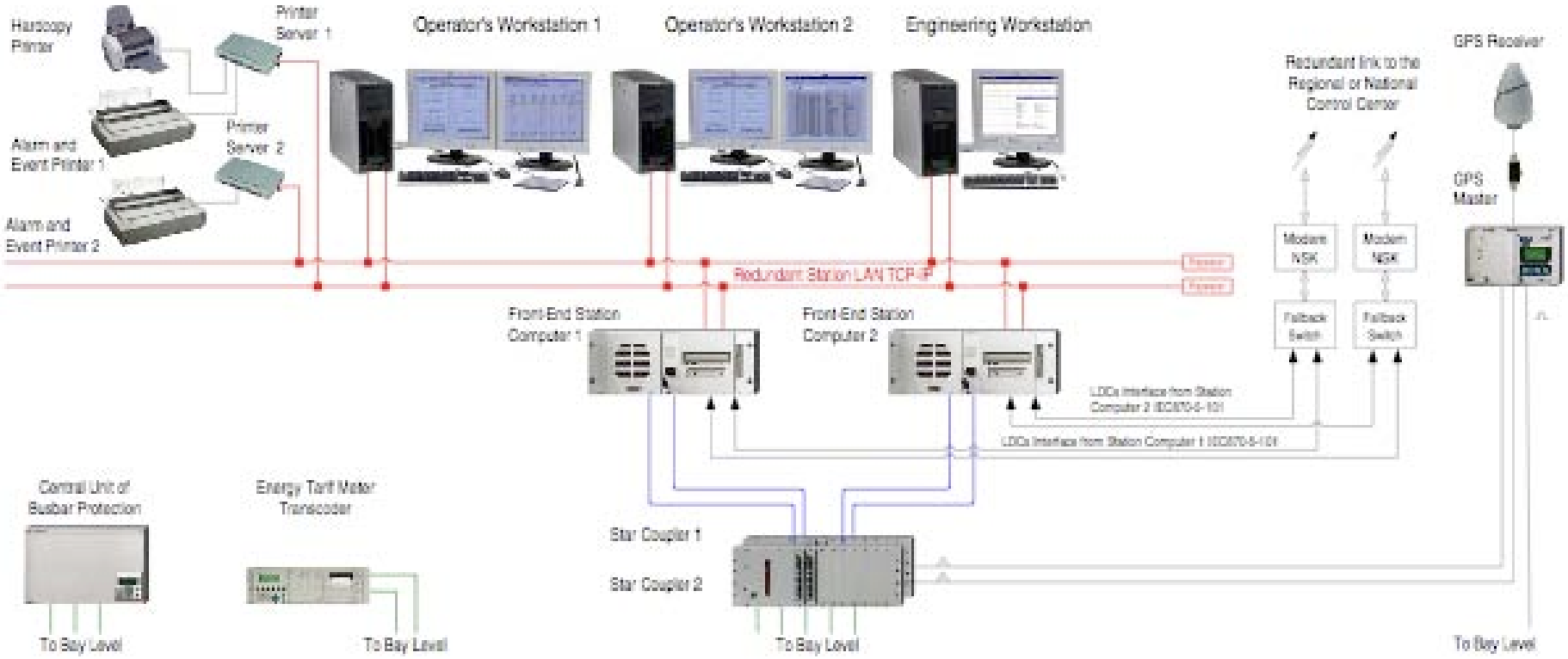
- Usually RTU input data are preprocessed, i.e. RMS values are computed etc.
- Example:
  - SIEMENS SICAM RTU 6MD201

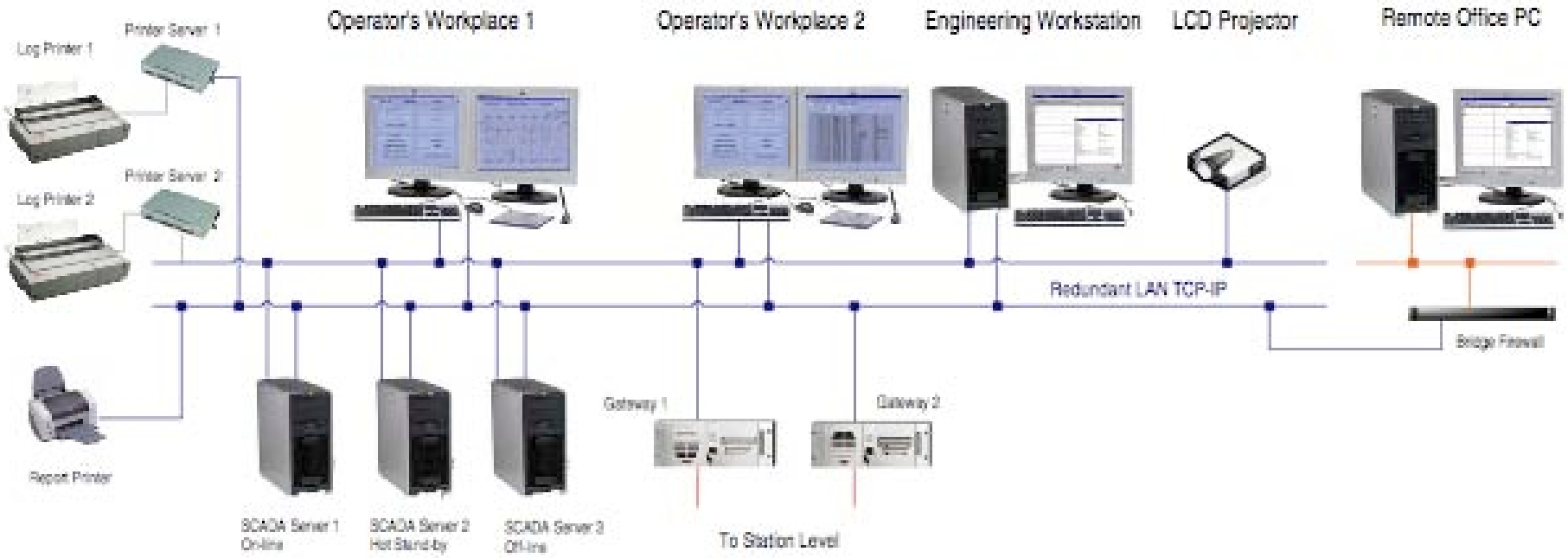


Source: SIEMENS

Substation Level Functions

- Station protection (busbar protection)
- Gateway for remote communication:
  - Allows integration within SCADA concept
- Time synchronization:
  - GPS master clock, or mutual communication and time server
- Switching operations:
  - Sequencer and Interlocking
- Archiving
- Components condition monitoring:
  - E.g. circuit breaker lifetime estimation
- Station monitoring:
  - Measurements display, alarms etc.

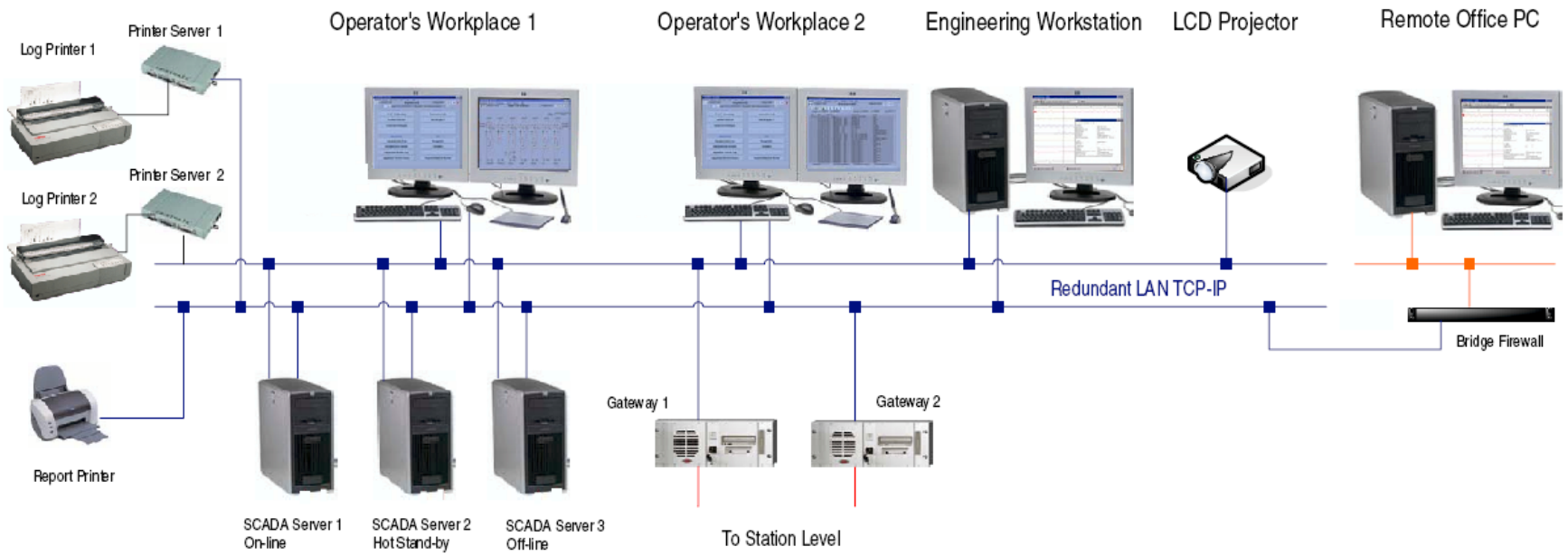

Hardcopy Printer
Printer Server 1
Operator's Workstation 1
Operator's Workstation 2
Engineering Workstation
Redundant link to the Regional or National Control Center
GPS Receiver
Alarm and Event Printer 1
Printer Server 2
GPS Master
Alarm and Event Printer 2
Modem NSK
Modem NSK
Redundant Station LAN TCP/IP
Fallback Switch
Fallback Switch
Front-End Station Computer 1
Front-End Station Computer 2
Central Unit of Busbar Protection
Energy Tarif Meter Transceiver
Star Coupler 1
Star Coupler 2
To Bay Level
To Bay Level
To Bay Level
To Bay Level

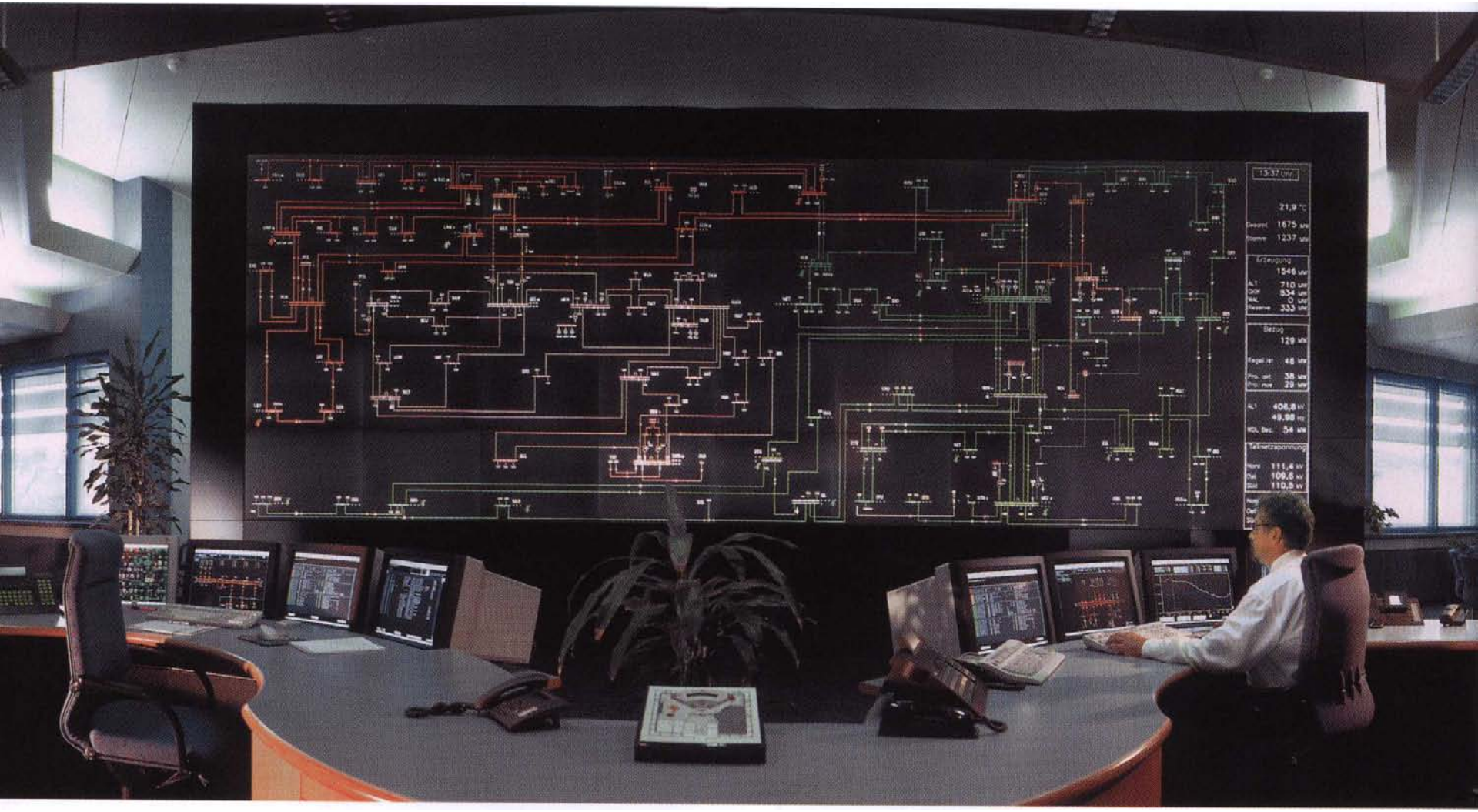

Operator's Workplace 1
Operator's Workplace 2
Engineering Workstation
LCD Projector
Remote Office PC
Printer Server 1
Log Printer 1
Printer Server 2
Log Printer 2
Redundant LAN TCP-IP
Bridge Firewall
Gateway 1
Gateway 2
Report Printer
SCADA Server 1
On-line
SCADA Server 2
Hot Stand-by
SCADA Server 3
Off-line
To Station Level

Hierarchical Concept

- Control Center Level
- Substation Level
- Bay Level
- Process Level

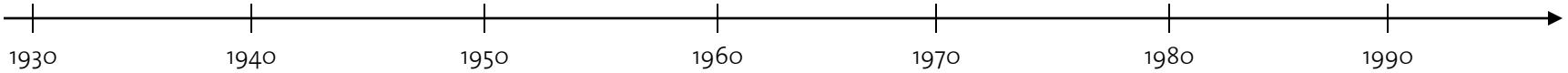
Control Center Level





Contents

- Hierarchical Concept
- SCADA/EMS
- Power Systems Protection



Full-graphics interface

Training simulator

Preventive and corrective control actions

Integrated SCADA/EMS,
Security Assessment

State Estimation, Optimal Power Flow

Central control loop

Computer for off-line studies

Frequency control

Digital data acquisition and transfer, SCADA

Analog data acquisition and transfer

Local measurements,
Phone Communication

SCADA

- SCADA – Supervisory Control and Data Acquisition
- Although not explicitly mentioned in the name, SCADA implies on-line remote monitoring of systems spread over large geographical areas
- Application areas of SCADA systems:
  - Electric transmission systems
  - Water networks
  - Gas, oil networks

SCADA

- SCADA functionality:
  - Continuous collection of measurements (very individual sample rate!)
  - Providing input data for further processing by advanced (i.e. SE/EMS) applications
  - Continuous display of measurements, topology and SE/EMS applications results (10 seconds – several minutes update rate)
  - Alarms
  - “Save Case”
- Hierarchical System Architecture:
  - Network (National) Control Center – data collection and provision to other processes
  - Regional Control Centers
  - Communication – data transfer
  - Substation level – data measurement

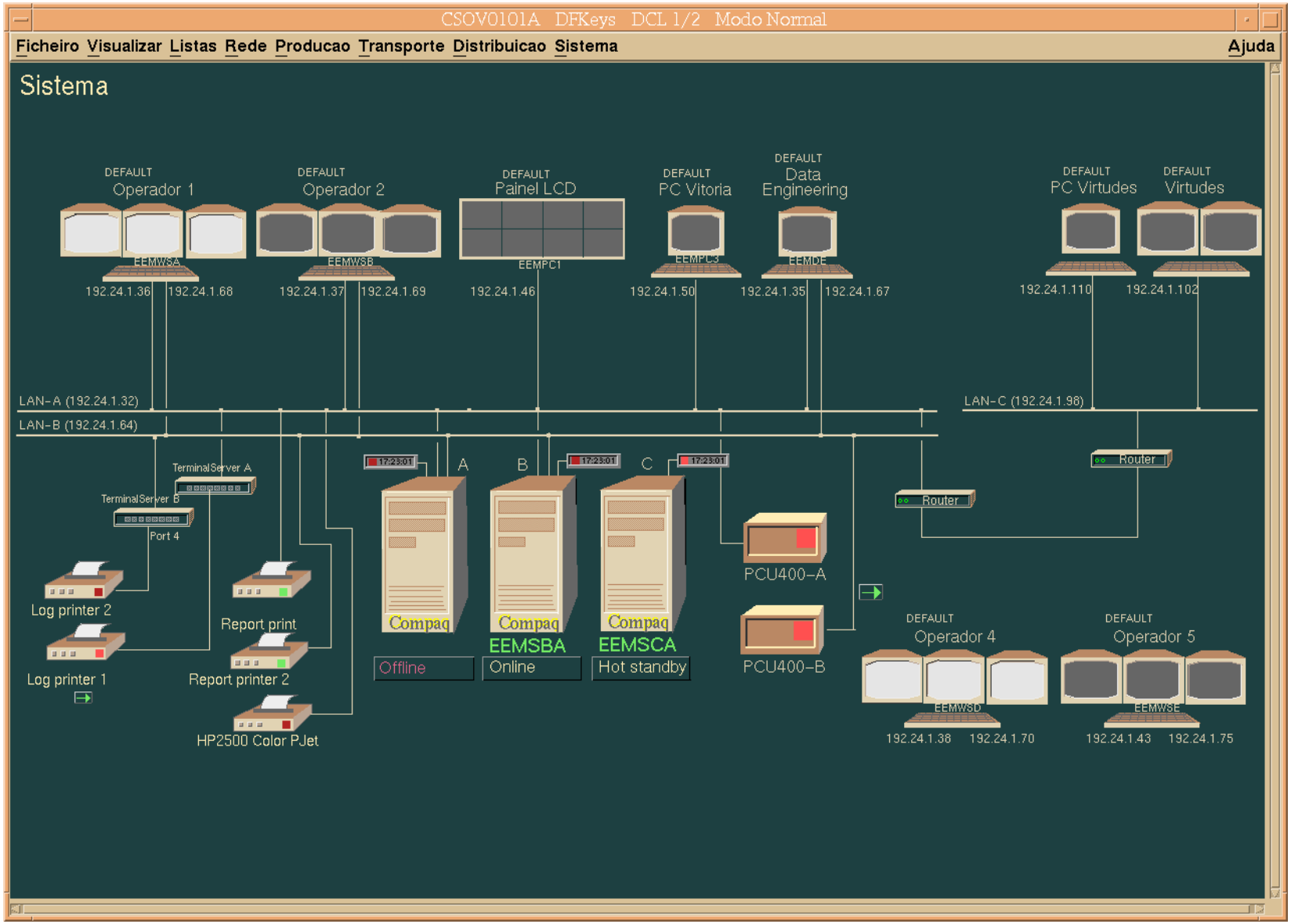
SCADA - Communication

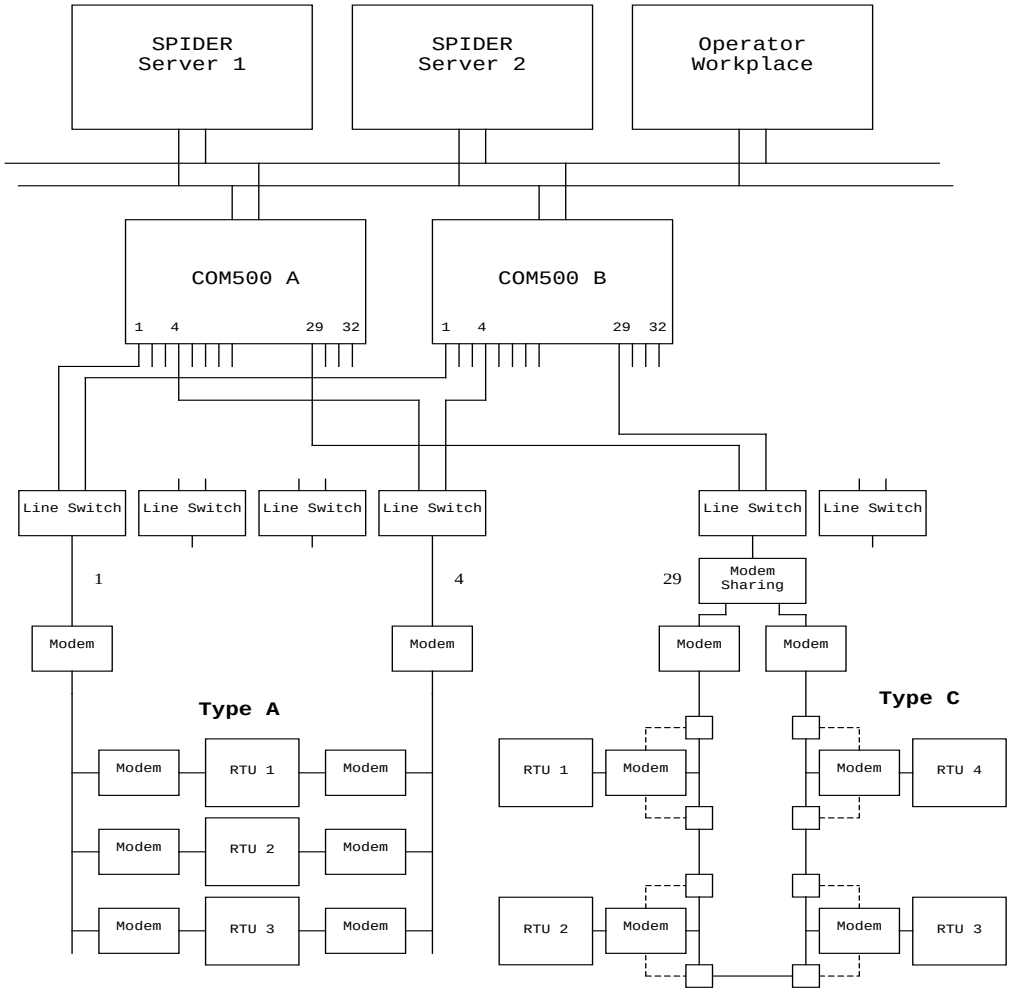
- Protocols, network types:
  - Ethernet ISO 8802.3 (IEEE 802.3) - LAN Communication
  - TCP/IP - LAN und WAN Communication
  - X.25/3 - WAN Communication
  - ICCP - Inter Control Center Communication Protocol
  - IEC 870-5-101, IEC 870-5-104, RP570/571, DNP 3.0 – Protocols in the lower hierarchical part, i.e. substation
- Communication media:
  - Power line carrier
  - Fiber optics
  - Telecommunication: analog/ISDN

Slave Protocols	Master Protocols	Master Protocols cont'd
■ IEC 870-5-101	■ IEC 870-5-101	■ TG709
■ DNP 3.0	■ IEC 870-5-104	■ TG065
■ ADLP180	■ ADLP80	■ USART
■ ADLP80	■ ADLP180	■ SINAUT 8 FW (DPDM)
■ RP570	■ RP570/571	■ Indactic 35
■ Teleconnect III	■ Indactic 33,33/41A	■ WISP
	■ Indactic 2033	■ WISP+
Field Buses	■ Conitel 300	■ Teleconnect III
■ LON	■ MODBUS RTU	■ Netcon 8830
■ SPA-bus	■ TG800	■ HNZ (Q2-02)
■ GCOM	■ DNP 3.0	■ Teleconnect II (Q3-02)
	■ Mobitex	■ ECMA 24
	■ Siemens ST1	

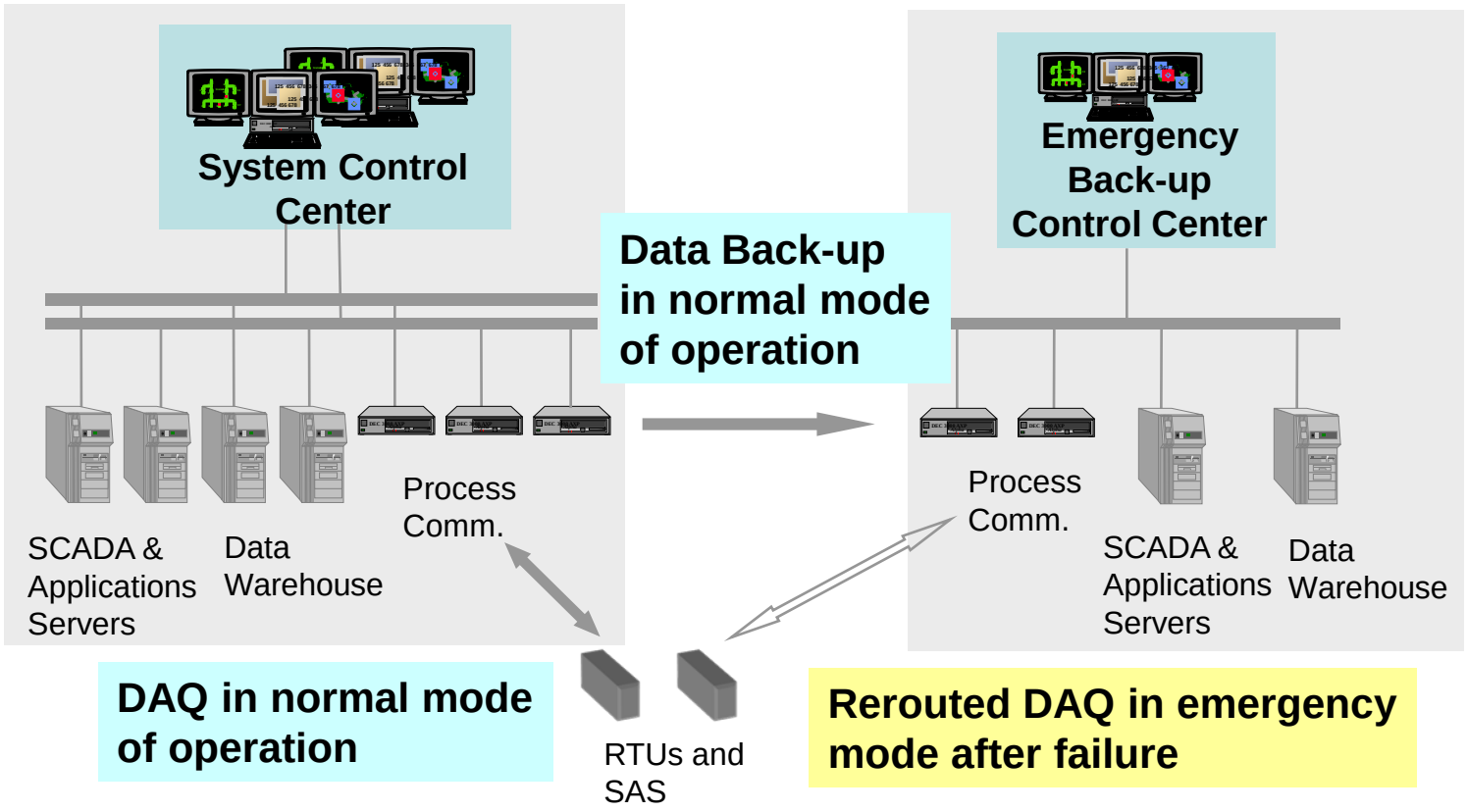
SCADA – Redundancy

- Important SCADA functions have to be available ~100%:
  - Security:
    - Monitoring (Substations -> Network Control Center)
    - Control (Network Control Center -> Substations)
  - Billing
- Redundancy:
  - Definition – outage of a HW or SW component can not lead to an outage of an important SCADA function (this includes also data !)
  - Possible causes:
    - HW outage, SW crash
    - Maintenance, system upgrades
- Solution Concepts:
  - Distributed design:
    - Possibility to distribute applications freely on many servers
  - Multiple components operated in parallel

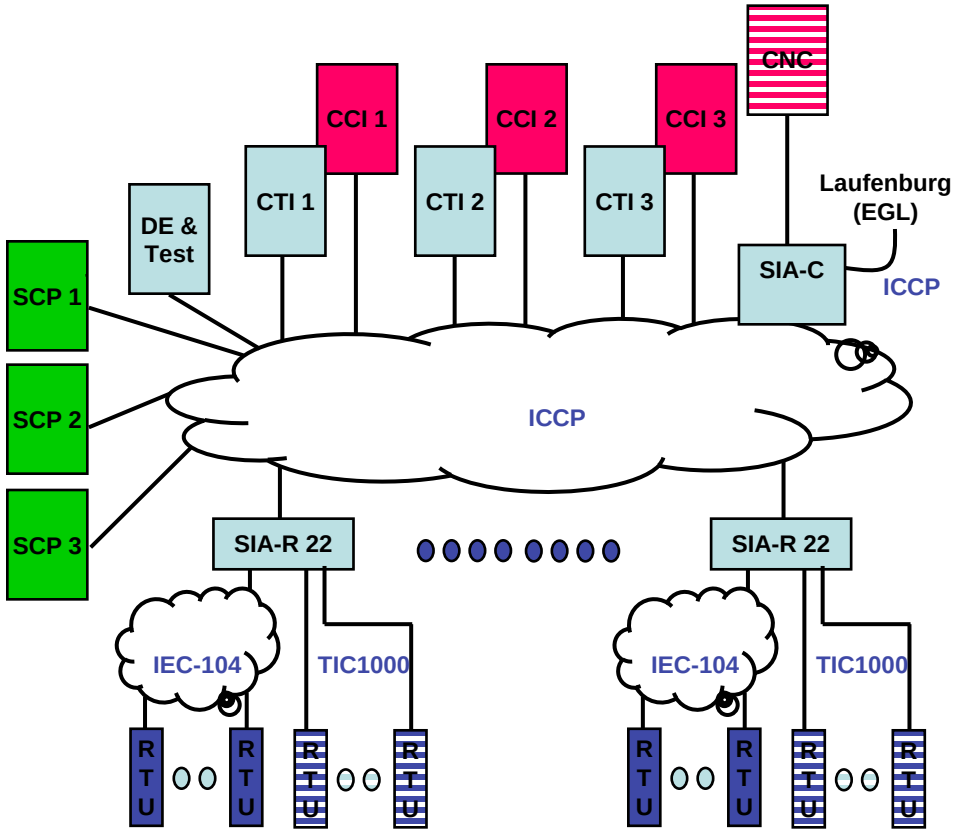

CSOV0101A DFKeys DCL 1/2 Modo Normal
Ficheiro Visualizar Listas Rede Producao Transporte Distribuicao Sistema Ajuda
Sistema
DEFAULT Operador 1
EEMWSA
192.24.1.36
192.24.1.68
DEFAULT Operador 2
EEMWSB
192.24.1.37
192.24.1.69
DEFAULT Painel LCD
EEMPC1
192.24.1.46
DEFAULT PC Vitoria
EEMPC3
192.24.1.50
DEFAULT Data Engineering
EEMDE
192.24.1.35
192.24.1.67
DEFAULT PC Virtudes
192.24.1.110
DEFAULT Virtudes
192.24.1.102
LAN-A (192.24.1.32)
LAN-B (192.24.1.64)
LAN-C (192.24.1.98)
Router
Router
TerminalServer A
TerminalServer B
Port 4
Log printer 2
Log printer 1
Report print
Report printer 2
HP2500 Color PJet
17:23:01
A
B
C
Compaq
Compaq
Compaq
EEMSBA
EEMSCA
Offline
Online
Hot standby
PCU400-A
PCU400-B
DEFAULT Operador 4
EEMWSD
192.24.1.38
192.24.1.70
DEFAULT Operador 5
EEMWSE
192.24.1.43
192.24.1.75


SPIDER Server 1
SPIDER Server 2
Operator Workplace
COM500 A
1 4 29 32
COM500 B
1 4 29 32
Line Switch
Line Switch
Line Switch
Line Switch
Line Switch
Line Switch
1
4
29
Modem Sharing
Modem
Modem
Modem
Modem
Type A
Type C
Modem
RTU 1
Modem
Modem
RTU 2
Modem
Modem
RTU 3
Modem
RTU 1
Modem
Modem
RTU 4
RTU 2
Modem
Modem
RTU 3

Source: ABB


System Control Center
Emergency Back-up Control Center
Data Back-up in normal mode of operation
Process Comm.
SCADA & Applications Servers
Data Warehouse
Process Comm.
SCADA & Applications Servers
Data Warehouse
DAQ in normal mode of operation
RTUs and SAS
Rerouted DAQ in emergency mode after failure

- TERNA: System Owner (CCI)
  - National data acquisition and control infrastructure:
    - ICCP Inter-center communications (IEC TASE.2)
    - 22 communication nodes (SIA-R)
    - 245 new IEC-104 RTUs
    - Interface to 800 existing TIC1000 RTUs
  - 3 Regional Control Centers at Dolo, Rondissone and Bari
  - Centralized data engineering and test system
- GRTN: Independent System Operator (CTI)
  - 3 Regional Control Centers at Scorze, Torino and Pozzuoli
  - Interface to National Control Center (CNC)
- 3 GenCo Control Centers (SCP):
  - ENEL Produzzione, EUROGEN, ELETTROGEN



Source: ABB

EMS

- Energy Management System (EMS)
  - Overall concept of an integration of various computational tools, serving to transmission system operators
- State Estimation
  - Reconstruction of the present system state from measurements
- Power Flow
  - Exploration how an uncontrolled system change (e.g. spontaneous load increase) would affect the system state
- Optimal Power Flow
  - Determination how to properly choose controls' values to achieve a desired system state

EMS

- Goal of EMS is to provide:
  - Decision support to operators
- EMS applications can be divided to categories:
  - Market oriented
  - Security oriented
- EMS characteristics:
  - Flexible (minimal engineering effort related to the particular power system)
  - Scalable
  - Independent software modules
  - Distributed structure (also in Hardware)

EMS

- EMS receives on-line data from State Estimator
- EMS employs within its modules Power Flow and Optimal Power Flow computations

EMS – Security Assessment

- Employment of Security Assessment:
  - Cyclically (automatic regime)
  - On demand (triggered by operator)
- Security Assessment (also referred as Contingency Analysis) structure:
  1. List of all or only selected contingencies
  2. Contingencies screening (static, fast, only approximate – mostly Power Flow based)
  3. Ranking of contingencies
  4. Detailed simulation of highest ranked contingencies (dynamic, detailed)
  5. OPF to compute corrective actions (static)

Contents

- Hierarchical Concept
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- Power Systems Protection

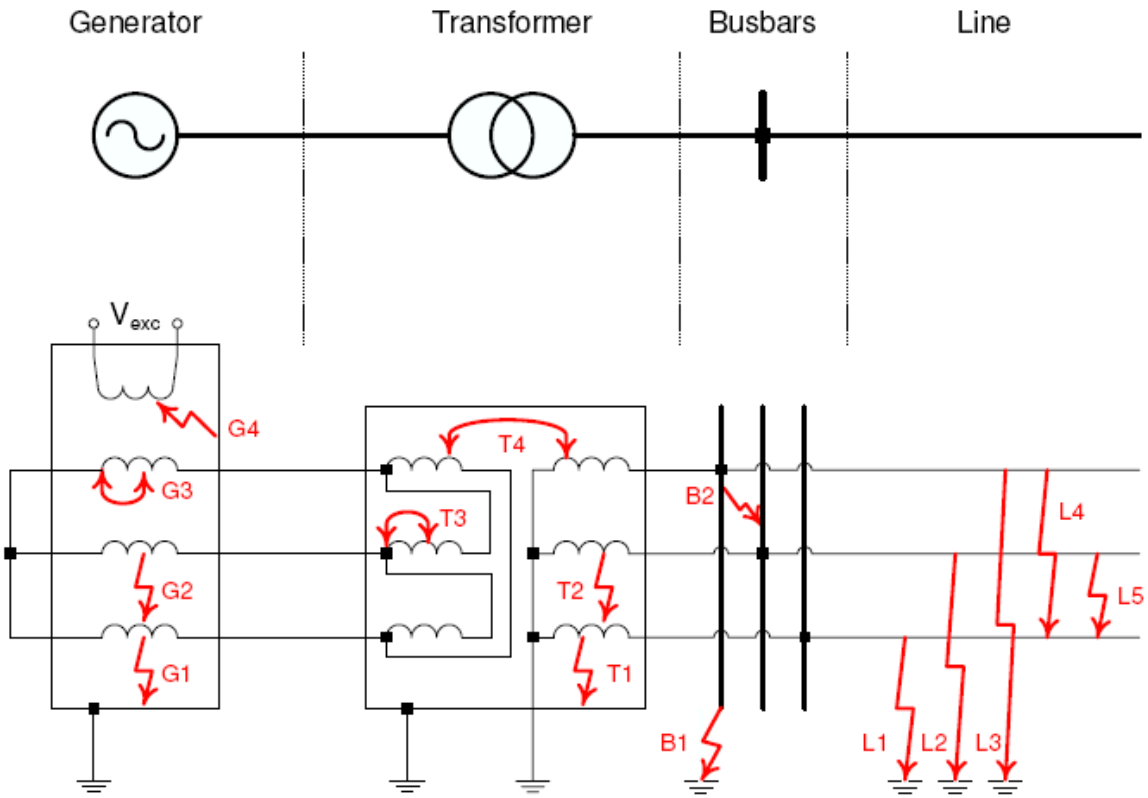
Protection

- To eliminate faults or unacceptable operating conditions for a component and related effects on the network.
- Form of fault elimination is usually isolation of the affected component

Requirements on Protection

- Reliability: assurance the protection will perform correctly
  - Dependability: the degree of certainty that a relay or relay system will operate correctly (sensitivity: ability to determine fault conditions).
  - Security: the degree of certainty that a relay or relay system will not operate incorrectly (selectivity: maximum continuity of service with minimum system disconnection).
- Speed of operation: minimum of fault duration and consequent equipment damage
- Simplicity: minimum protective equipment and associated circuitry to achieve protection objective
- Economics: maximum protection at minimal total costs

Short-circuit Types



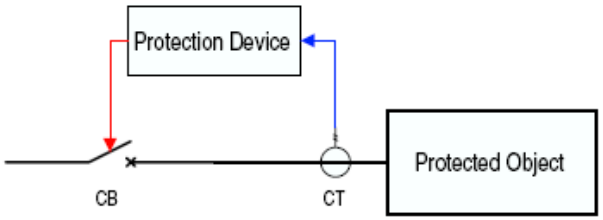
Components Protection

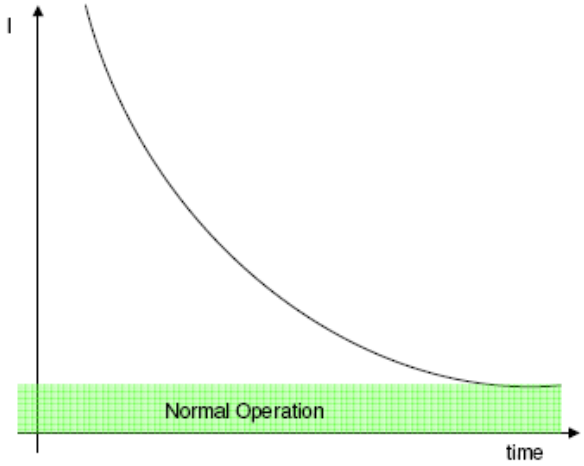
- Focus on the protection of the supervised component
- Usually no consideration of the system wide impact (integrity)
- => disconnection of one component may induce a higher stress on other components thus yielding their overloads and subsequent tripping => cascading spreading

Components Protection

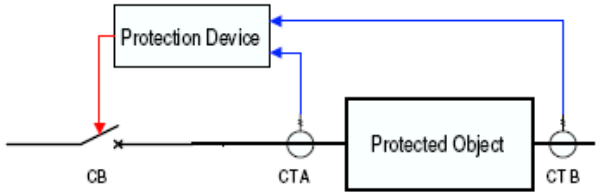
- Distribution, Consumers:
  - Overcurrent protection
- Lines:
  - Overcurrent protection
  - Distance protection
  - Differential protection
  - Fault location
- Busbar:
  - Phase comparison protection
  - Differential protection
- Transformer:
  - Overcurrent protection
  - Differential protection
- Generator

Overcurrent Protection

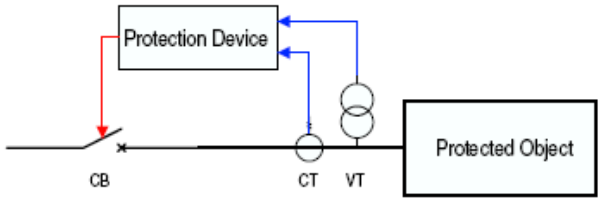




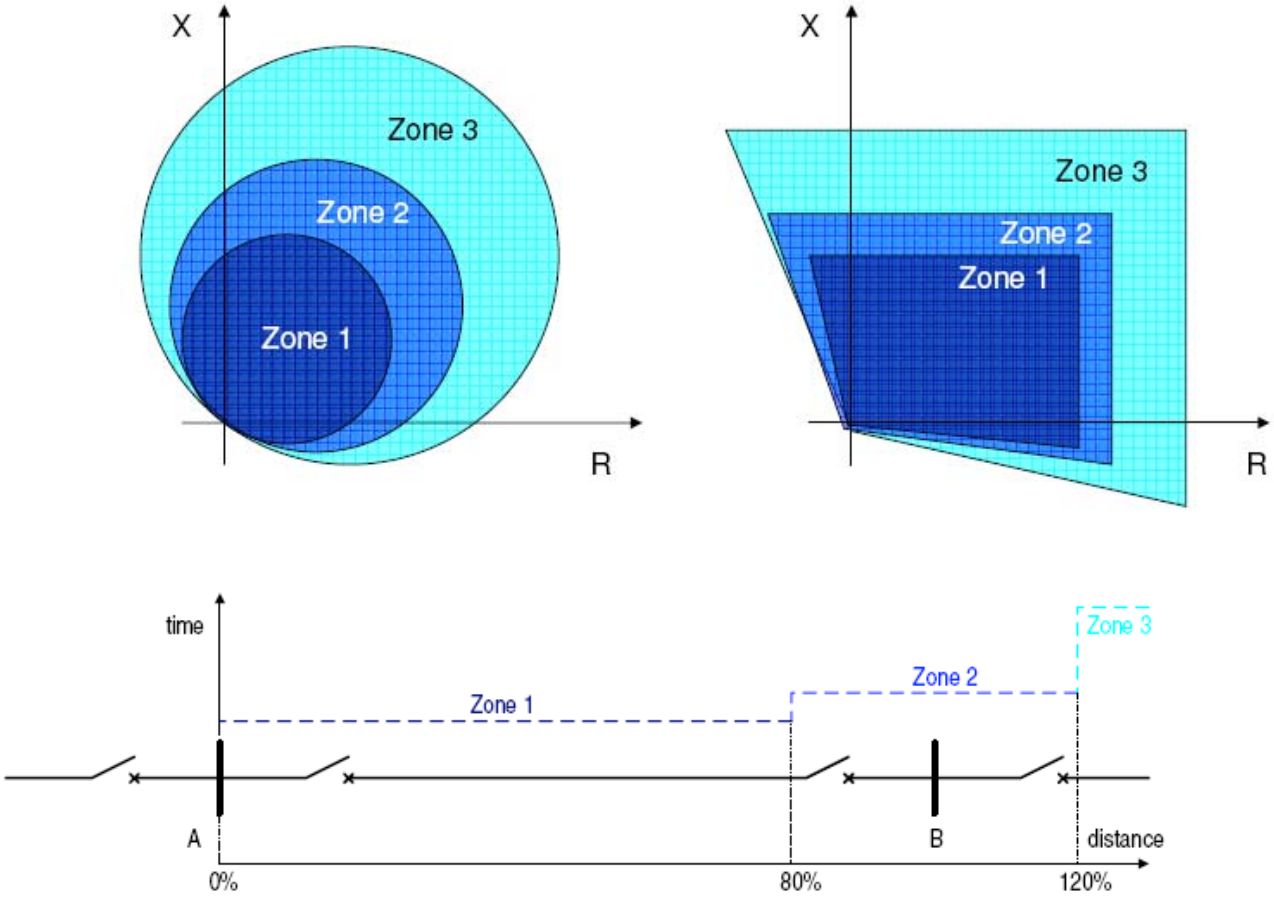
Differential Protection



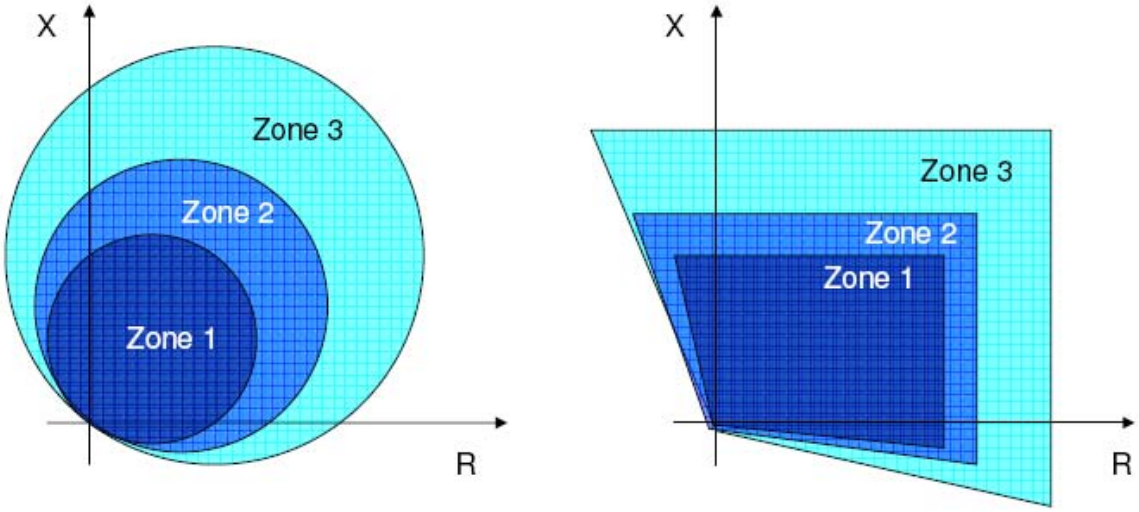
Distance Protection

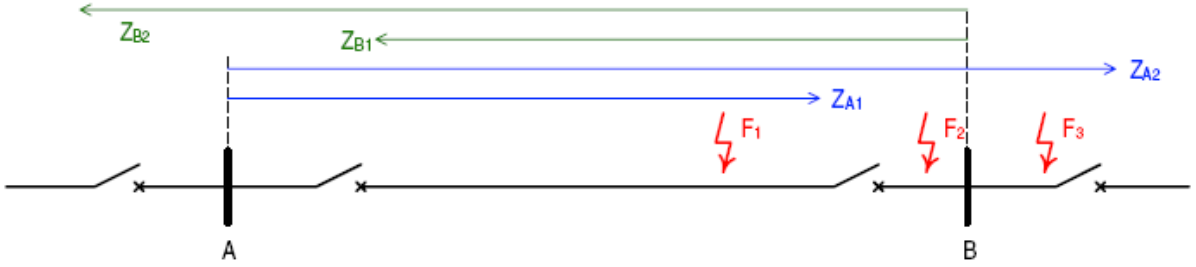


Distance Protection



Permissive Overreaching Scheme





System Protection

- System Protection Schemes (SPS)
- P. M. Anderson, B. K. LeReverend: “Industry Experience with Special Protection Schemes”, IEEE Transactions on Power Systems, Vol. 11, No. 3, August 1996: ***“a protection scheme that is designed to detect a particular system condition that is known to cause unusual stress to the power system and to take some type of predetermined action to counteract the observed condition in a controlled manner. In some cases, SPSs are designed to detect a system condition that is known to cause instability, overload, or voltage collapse.”***

System Protection

- usually a specially designed coordination of the local relays
- off-line simulation to identify the worst scenarios => formulation of the relays operation rules
- usually a topology change driven