SCADA and Central Applications
An introduction

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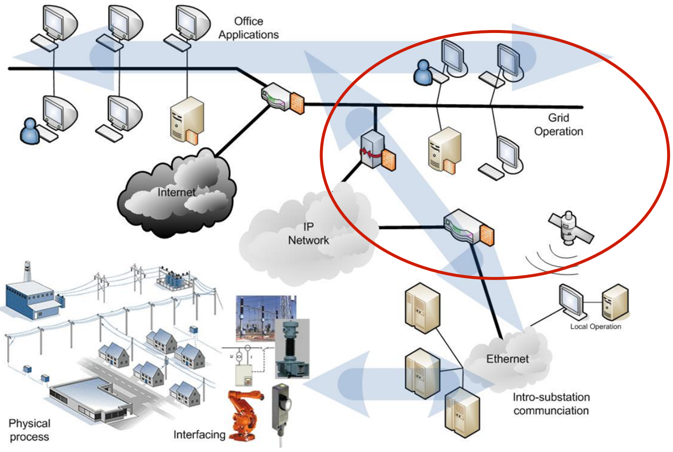
Course map

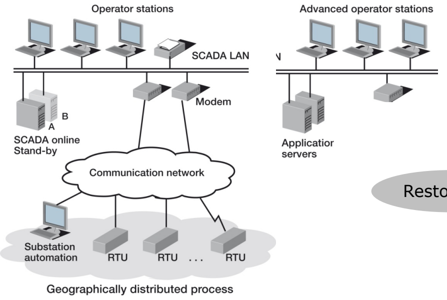


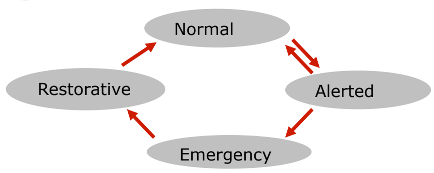
Outline of the lecture

- Power System Operation
  - Centralised Control Applications
- SCADA
  - SCADA architecture & Components
  - SCADA system functions
  - Non functional aspects
- Wide Area Monitoring and Control Systems
  - Architecture & Components
  - Functionality

Power System Operation

- System-wide monitoring, planning & optimisation for reliable and cost efficient operation of the power system
- Time scale: seconds to hours.





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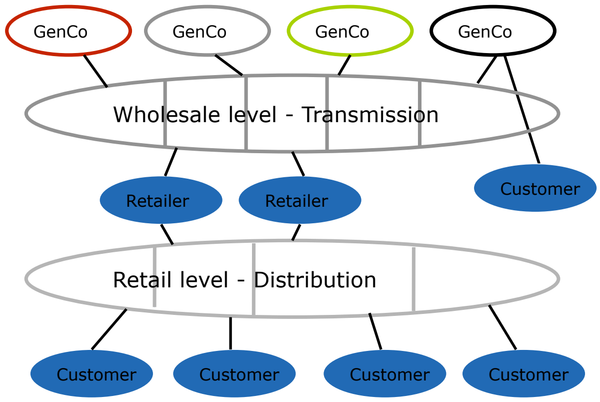
Deregulation– in theory



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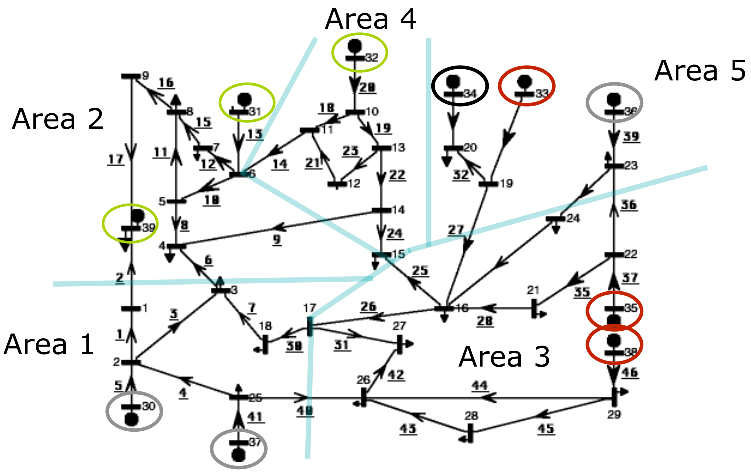
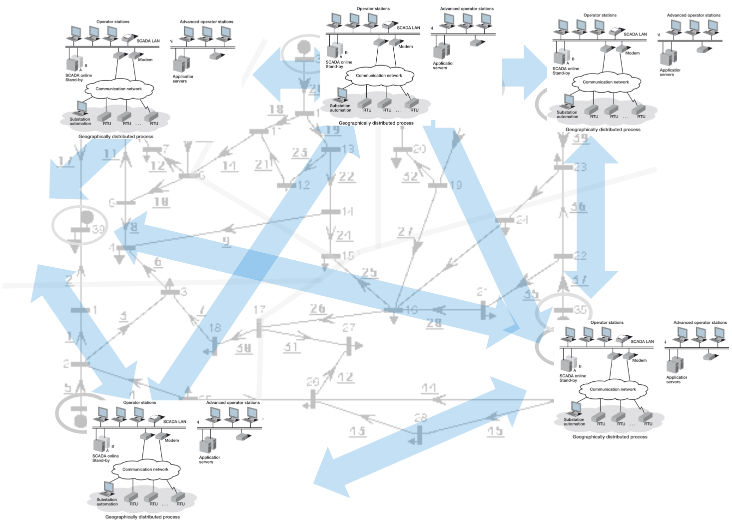
Deregulation – in practice

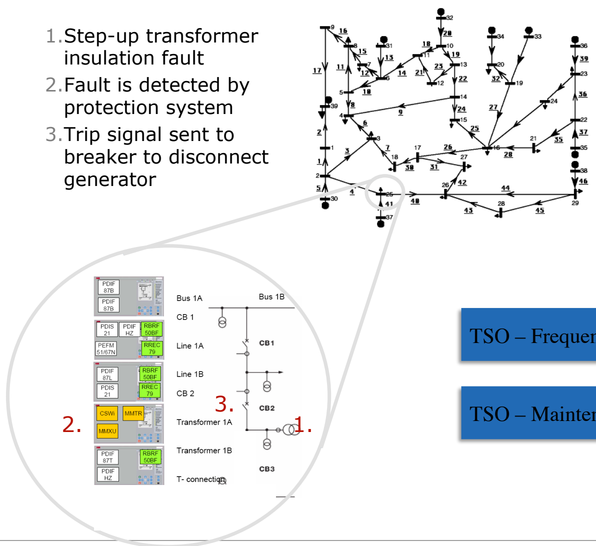


Coordination between actors



Example – root event

1. Step-up transformer insulation fault
2. Fault is detected by protection system
3. Trip signal sent to breaker to disconnect generator



TSO – Frequency control

TSO – Maintenence

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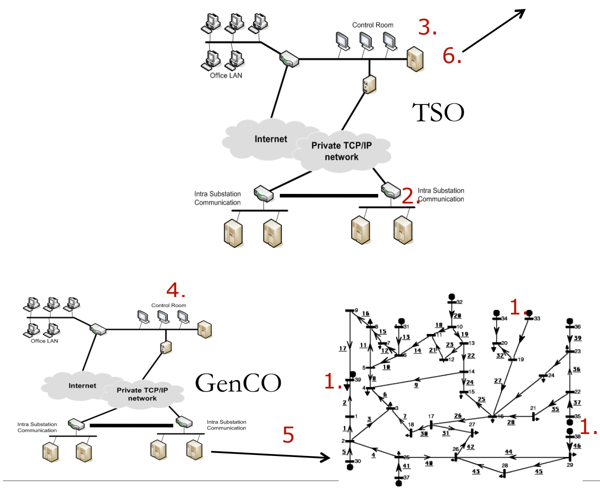
TSO - Frequency Control



1. Frequency dip detected at generators committed to Load Frequency Control leads to automatic increase of output
2. Continuous under-frequency measured are sent to SCADA system using IEC 60870-5-101
3. Control room operator activates secondary reserve by issuing order to GenCo via phone.
4. GenCo orders production increase in secondary reserve.
5. Order for production increase sent to plant from GenCo CC.
6. New measurements sent to neighbouring Grid Utility using ICCP.

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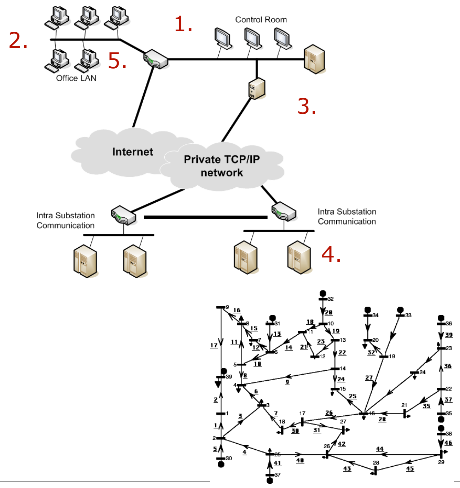
TSO- Repair & Maintenance



1. Fault in transformer sent from SCADA system to work management system using e.g. IEC 61968-4
2. Repair crew sent to site from work dispatch
3. At site, work crew reports to control centre to initiate safe switching sequences
4. Station set to manual control, fault repaired (!) or report initiated for major overhaul.
5. After completed assignment, info on failure stored in maintenance database.

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Central control & coordination

- On the deregulated Power market, all actors
  - Distribution Network Operators
  - Transmission Network Operators
  - Generating companies
- All need some central platform to manage their process
- Enter – the SCADA system

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- SCADA
  - SCADA architecture & components
  - SCADA system functions
  - Non functional aspects
- Wide Area Monitoring and Control Systems
  - Architecture & Components
  - Functionality

Power System Control Center Functionality

- Three groups of functions on SCADA
  - Business Management
  - Energy Management
  - Generation management

What is SCADA?

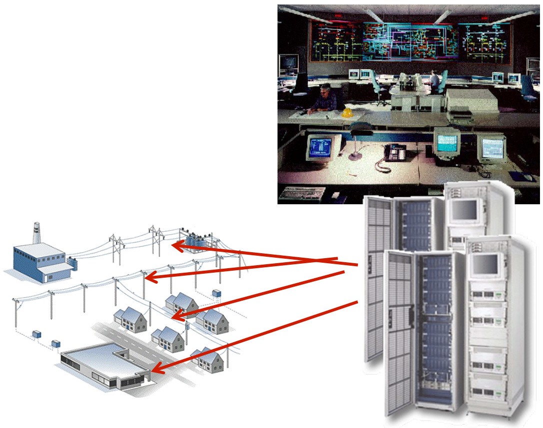
Supervisory **C**ontrol **A**nd **D**ata **A**cquistion
- Collect measurements and status data from the process
- Remotely intervene in the process
- Centralized system platform
- Based on distributed I/O

Applicable Processes
- Oil or Gas prodcution facilities
- Piplelines for gas, oils, chemicals or water.
- Railway/Transportation Process
- Nuclear, Gas, Hyrdo generation plants

The typical control room

What is controlled by SCADA

- Tap changers
- Switching devices
- Shunt capacitor/reactor
- Generator setpoints
  - Excitation & power output
- Sequential control



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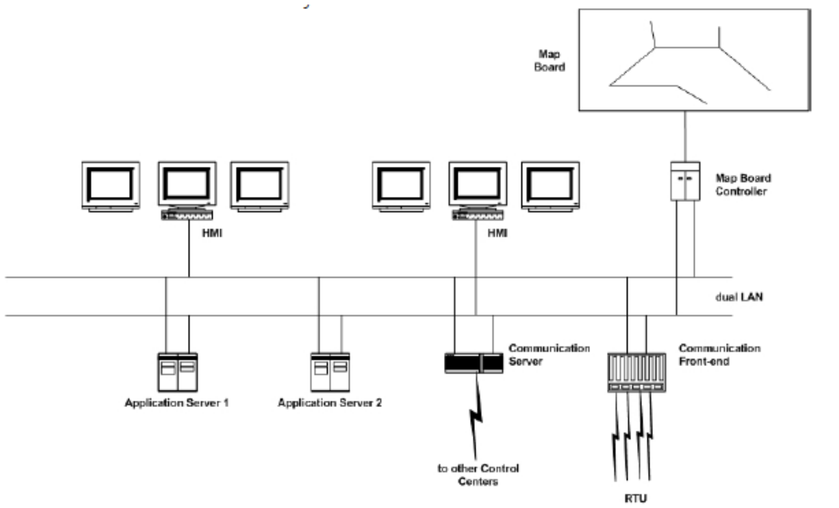
SCADA architecture



Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

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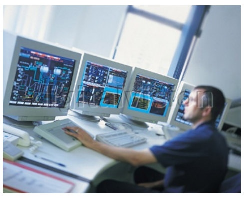
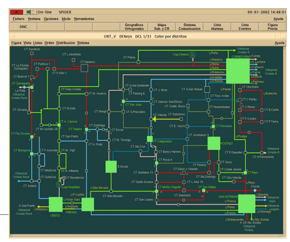
SCADA Components
Human Machine Interface - HMI

- Communication between operator and machine
- Input
  - Mouse, keyboard, touch screen
- Output
  - Screen, audio, print-outs or mimic board
- A weak link
  - Information overload/misinterpretation





SCADA components

Application Servers

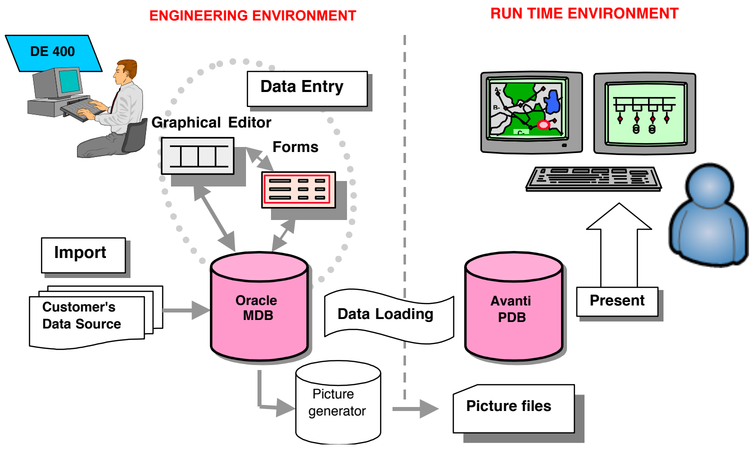
- Application servers provide the computing platform for the SCADA System, included servers are:
  - Real-time database
  - Historical database
  - Energy Management applications
    - State Estimation
    - Optimal/Dispatcher Powerflow
    - Voltage Stability Assessment
    - Etc….
  - Geographic Information Systems
    - Distribution Management

SCADA Components

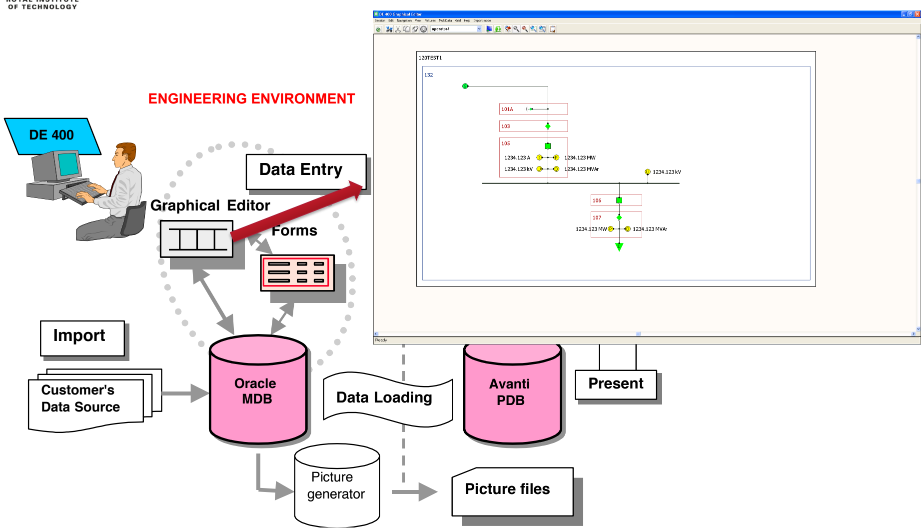
System Configuration Servers

- Allows configuration of the SCADA system environment, typical servers include:
  - Data engineering of the SCADA system providing manual data entry into the SCADA topology database including lidnes, circuitbreakers, stations, …..
  - SubstationdDevice configuration, such as IED configuration tools and databses of IED configuration. Remote access tools for configuration

Data Engineering



Data Engineering



SCADA components
Communication Servers

- Variety of servers for communication
  - Communication to other Control centers using ICCP
  - Communication to office applications

SCADA components
Communication Front End

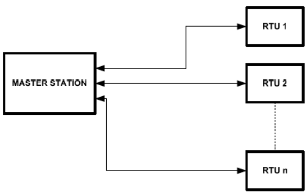
- Manages communication with the field devices
- Supports communication with variety of protocols
- Cyclic polling and event based communication, provides messages queuing

SCADA Components

Remote Terminal Unit - RTU

- A remote terminal unit (RTU) is a microprocessors-controlled electronic device that interfaces objects in the physical world to a distributed control systems or SCADA by transmitting telemetry data to the system, and by using messages from the supervisory system to control connected objects.

Communication Topologies



- Radial serial circuit

- Multi-drop circuit

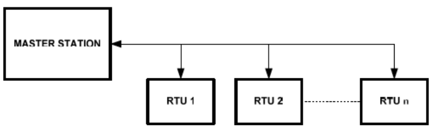
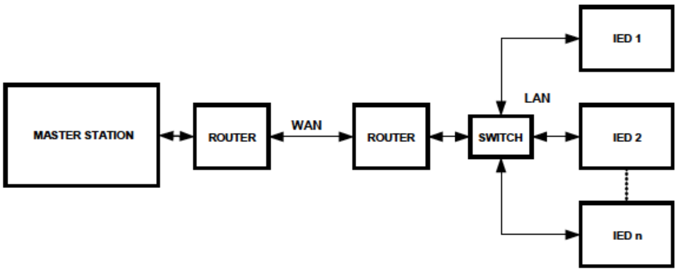


Figure B.3—Single master station, multiple RTU(s) multi-drop circuit

Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

Networked solutions



Communication between Master Station (Front End) is via TCP/IP over a shared Wide Are Network

Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

Communication Principles

- Cyclic Polling
  - Front-End communication server requests data periodically from each RTU.
  - Period times vary from 2-4 up to 10-15 seconds.
  - Real-time?
- Report By Exception
  - Cyclic polling as above
  - RTU only responds if a value has changed
- Balanced protocols
  - The RTU can send a request to be polled by the Front-End

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Communication

- Wide Area Network
  - Analog point to point and multi-point modem networks
  - Frame relay/Cell relay type point to point and multi-point networks
  - Wireless Radio/Satellite networks
  - Fiber-optic based networks

- Protocols
  - Modbus
  - Profibus
  - IEC60870-5-101,104
  - DNP 3
  - IEC61850-90-2
  - IEC60870-6-ICCP (between control centers)

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Distributed Network Protocol (DNP)

- Designed specifically for SCADA systems, i.e. a data acquisition and control communication protocol
- Predominantly a SCADA to RTU/IED or RTU/IED to RTU/IED communication
- Used in Electric automation and prominent in the North and South America, Australia
- Open Standard, not owned or control by a single private organization. All vendors have a say in the design and specification

IEC 60870-5-101/104

- International standards for open transmission of SCADA telemetry and control information
- Provides detailed functional description for telecontrol equipment and systems for controlling geographically widespread processes and specifically intended for electrical industries
- When reference to 60870-5 in the context of SCADA systems is made it is usually for 60870-5-101/104 titled "Companion Standard for basic telecontrol tasks.
- 101 protocol intended for transport of data over serial links
- 104 protocol is a TCP/IP implementation of 101.

101 & 104 message types

<0>	:= not defined	
<1>	:= single-point information	M_SP_NA_1
<2>	:= single-point information with time tag	M_SP_TA_1
<3>	:= double-point information	M_DP_NA_1
<4>	:= double-point information with time tag	M_DP_TA_1
<5>	:= step position information	M_ST_NA_1
<6>	:= step position information with time tag	M_ST_TA_1
<7>	:= bitstring of 32 bit	M_BO_NA_1
<8>	:= bitstring of 32 bit with time tag	M_BO_TA_1
<9>	:= measured value, normalized value	M_ME_NA_1
<10>	:= measured value, normalized value with time tag	M_ME_TA_1
<11>	:= measured value, scaled value	M_ME_NB_1
<12>	:= measured value, scaled value with time tag	M_ME_TB_1
<13>	:= measured value, short floating point number	M_ME_NC_1
<14>	:= measured value, short floating point number with time tag	M_ME_TC_1
<15>	:= integrated totals	M_IT_NA_1
<16>	:= integrated totals with time tag	M_IT_TA_1
<17>	:= event of protection equipment with time tag	M_EP_TA_1
<18>	:= packed start events of protection equipment with time tag	M_EP_TB_1
<19>	:= packed output circuit information of protection equipment with time tag	M_EP_TC_1
<20>	:= packed single-point information with status change detection	M_PS_NA_1
<21>	:= measured value, normalized value without quality descriptor	M_ME_ND_1
<22..29>	:= reserved for further compatible definitions	
<30>	:= single-point information with time tag CP56Time2a	M_SP_TB_1
<31>	:= double-point information with time tag CP56Time2a	M_DP_TB_1
<32>	:= step position information with time tag CP56Time2a	M_ST_TB_1
<33>	:= bitstring of 32 bits with time tag CP56Time2a	M_BO_TB_1
<34>	:= measured value, normalized value with time tag CP56Time2a	M_ME_TD_1
<35>	:= measured value, scaled value with time tag CP56Time2a	M_ME_TE_1

101 & 104 message types - control

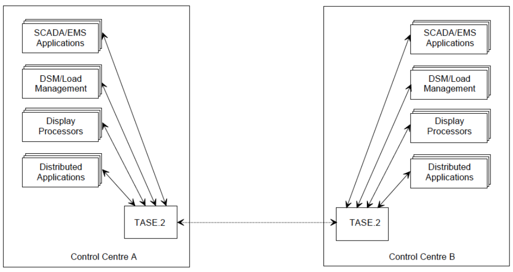
CON	<45>	:=	single command	C_SC_NA_1
CON	<46>	:=	double command	C_DC_NA_1
CON	<47>	:=	regulating step command	C_RC_NA_1
CON	<48>	:=	set point command, normalized value	C_SE_NA_1
CON	<49>	:=	set point command, scaled value	C_SE_NB_1
CON	<50>	:=	set point command, short floating point number	C_SE_NC_1
CON	<51>	:=	bitstring of 32 bits	C_BO_NA_1

TYPE IDENTIFICATION := UI8[1..8]<100..109>

CON	<100>	:=	interrogation command	C_IC_NA_1
CON	<101>	:=	counter interrogation command	C_CI_NA_1
CON	<102>	:=	read command	C_RD_NA_1
CON	<103>	:=	clock synchronization command	C_CS_NA_1
CON	<104>	:=	test command	C_TS_NA_1
CON	<105>	:=	reset process command	C_RP_NA_1
CON	<106>	:=	delay acquisition command	C_CD_NA_1

IEC 60870-6

- Inter Control-center Protocol (ICCP) or TASE.2
- To enable data exchange between control centers of:
  - Measurements
  - Time-tagged data, measurement series
  - Events
- Some variants exist, latest version TASE.2 based on MMS most popular presently.



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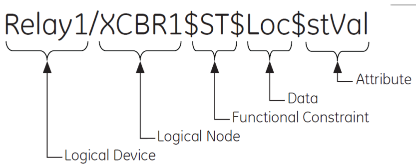
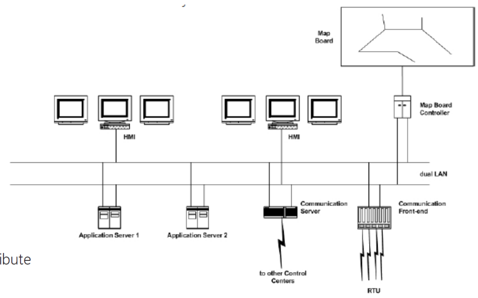
IEC 61850-90-2

- Using Logical Nodes and Attributes from IUEC 61850 also in the SCADA system.
- Data is carried in MMS over TCP/IP





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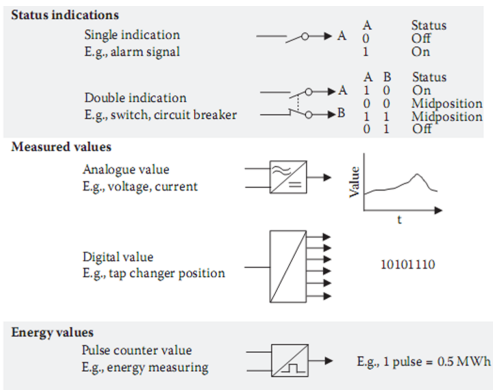
SCADA functions

- Data acquisition
  - Analog and discrete values
- Event and alarm processing
  - Event and alarm
- Control
  - Tap changer
  - Shut capacitor/reactor
  - Switching devices
  - Generator excitation (AGC)
- Data storage, archiving and analysis

Data acquisition

- Points
  - Measured values
- Pseudo points
  - Derived values
- Scan
  - process by which data acquisition system interrogates RTU/IED
- Scanning rate
  - 1 sample/2 seconds
- Time skew
  - elapsed time between the first measurement and the final measurement is taken



Reference: North-Corte Green Control & Automation of Electric Power Distribution Systems

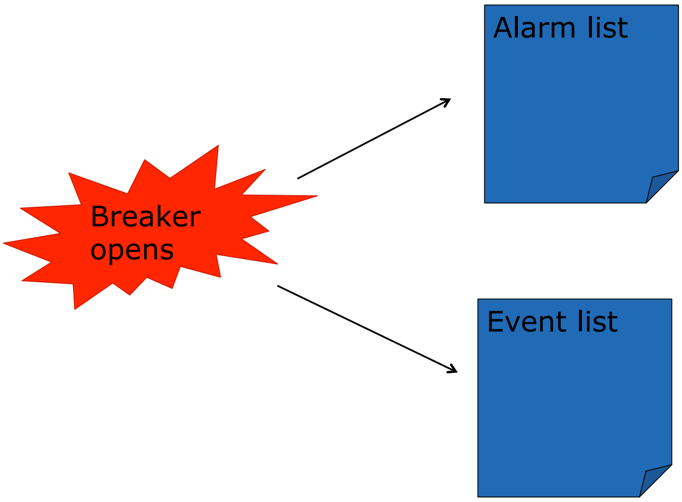
SCADA: Data Acquisition (Cont.)

- Measurements and Status Indications Collected are stored in a Real Time Database.
- The Values are Time tagged in the database.
- As new Values come in from the RTUs/IEDs old values are overwritten (or archived).

Monitoring and Event Processing

- Events
  - Changing positions
    - Breaker / Disconnector opens or closes
    - Value above/below a threshold
  - Equipment activated
    - Reactor or capacitor engaged
  - Automatic changes
    - On load tap changer changes state
- Alarms
  - Critical events
- It is a matter of definition

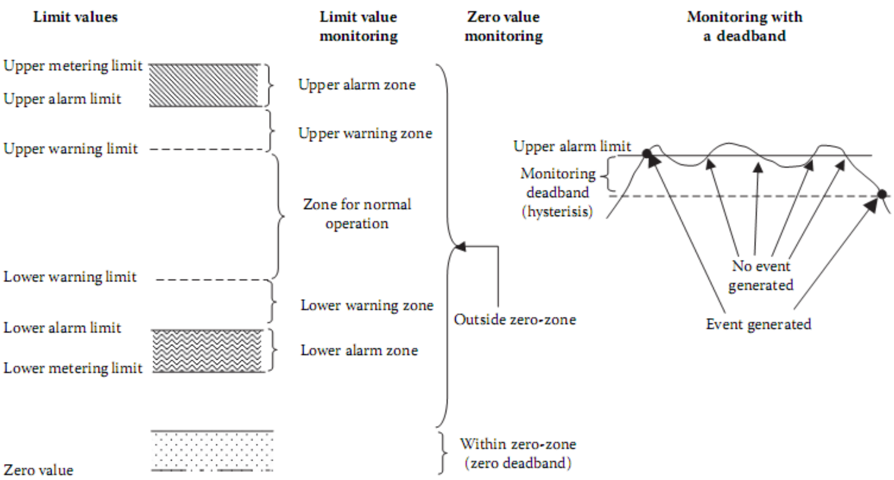
Alarm and Event Management



Event and alarm

- Events
  - Changing positions
    - Breaker/Disconnector opens or closes
    - Value above/below a threshold
  - Equipment activated
    - Reactor or capacitor engaged
  - Automatic changes
    - tap changer changes its position
- Alarms
    - Criticality
    - Sensitivity

Monitoring and Event Processing (cont.)



Reference: North-Corte Green Control & Automation of Electric Power Distribution Systems

Time stamping

- Sequence of events is often important in analysis of chains of events
- Time stamping of Events
  - As close as possible to the source. For example the IED that collected the measurement
  - Requires time synchronisation of distributed devices
  - Additional Time-stamp at Front-End

SCADA: Data Storage, Archiving and Analysis

- Data Collected from the process is sometimes archived, this due to many reasons:
  - Regulations
  - Billing
  - Future Load planning
  - Performance Audits
  - Post Mortem Review, in case of disturbances or interruptions in the process.

  - Changed Values are "archived" at cyclic intervals, the interval depends on the importance of the values. Examples of cyclic intervals are: every scan interval, every 10 seconds or every hour.

Sequence of Events recorders

- Local function implemented in Substation Controller that keeps a record of all events in the substation
- Not all events are sent to the SCADA system
- SER logfiles can be uploaded to the SCADA system to enable analysis

SCADA: Control Functions

- Individual Device Control
  - Direct open/close commands to individual devices
  - **C**heck-**b**ack **b**efore **O**perate function.
- Control Messages to Regulating Equipment
  - E.g. Raising or lowering tap changer taps
- Sequential Control
  - E.g. in the case of a set of sequential switching steps to restore power through predefined backup configuration.
- Automatic Control
  - Triggered by an event of lapse of specific time period that invokes a control actions
  - E.g. automatically changing load tab changer due to voltage set point violation

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Non functional requirements

Functional requirements specifies what is a system suppose to do and **Non functional requirements** specifies how a system should behave.

- Availability
  - the ratio of uptime to the sum of downtime and uptime.
- Maintainability
  - Repairing time for hardware and software
- Scalability
  - How easy the system could be expand
- Security
  - See SCADA security guest lecture
- Interoperability/Openess
  - how easy can the system be integrated with systems from other vendors

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Measurement Service Performance Requirements

	Typical measurement services performance requirements							
Enterprise/function	Example measured elements	Update periodicity (s)	Accuracy (%)	Unavailability (h/mo)	Latency (s)	Resolution (%)	Time skew substation (s)	Time skew SCADA (s)
Tier 1								
Substation operator indications	Voltage, Bus	5	0.3	4	1	0.1	1	1
Switching and tagging	Voltage, Line	5	0.3	4	1	0.1	1	1
End element control	Real and Reactive Power, Line	10	1.0	4	5	0.2	1	1
Low-priority alarm	Real and Reactive Power, Equip	10	1.0	4	5	0.2	1	1
High-priority alarm	Current, Line	5	0.3	4	1	0.1	1	1
System restoration	Current, Equip	5	0.3	4	1	0.1	1	1
	Frequency/Phase Angle	1-5	0.3	4	1	0.1	1	1
	Position, Regulator/valve	10	1.0	4	5	0.2	1	1
	Ancillary value	10	1.0	4	5	0.2	1	1

Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

Status Update Performance Requirements

Enterprise/function	Example measured elements	Update periodicity (s)	Accuracy (%)	Unavailability (h/mo)	Latency (s)	Resolution (%)	Time skew substation (s)	Time skew SCADA (s)
	Typical monitoring services performance requirements							
Tier 1								
Substation operator indications	Breaker trip, fire	2	99.9	4.0	0.5	0.1	0.1	0.1
Switching and tagging	Substation HMI control	2	100	4.0	0.5	0.1	0.1	0.1
End element control		2	99.9	4.0	0.5	0.1	0.1	0.1
Substation algorithm		0.5	99.99	4.0	0.5	0.1	0.1	0.1

Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

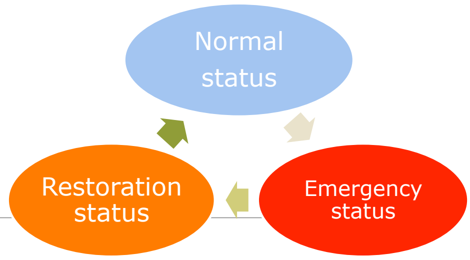
Status Update Performance Requirements

Enterprise/function	Example measured elements	Execution time (s)	Accuracy %	Unavailability (h/mo)	Latency (s)	Single point /multiple point	Feedback sequence
	Typical control services performance requirements						
Tier 1							
Substation operator control	Circuit breaker, capacitor switcher	2	99.99	4.0	1	Single	SBO
Auto-sectionalizing	Substation or field device	2	99.99	4.0	5	Multiple	None
Generation dispatch		2	99.9	4.0	1	Multiple	None
Substation algorithm		0.5	99.99	4.0	Depends	Depends	Depends

Reference: C37.1-2007 IEEE Standard for SCADA and Automation Systems

Non functional requirements - Performance

- Desired response time should be designed for each SCADA function. These response time should comply with power system control and operation procedure.
  - Normal state, quasi-steady-state. Response time should meet the requirements during normal state.
  - Emergency state, when power system operation constraints are violated. SCADA system are engineered to one specific emergency condition without degrading the performance.



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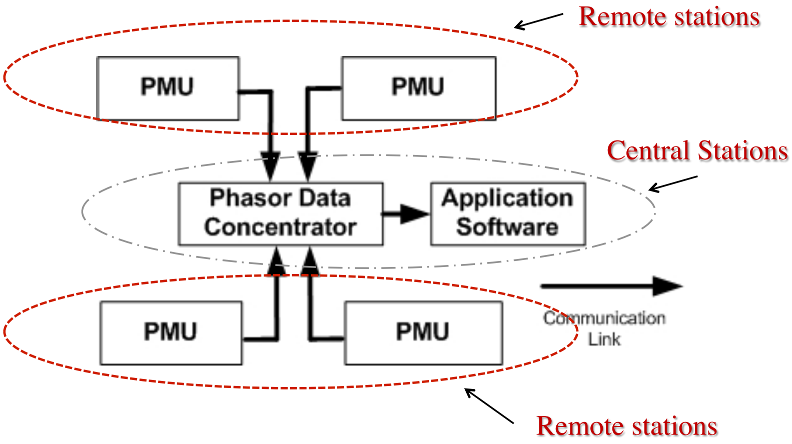
Wide Area Monitoring and Control Systems

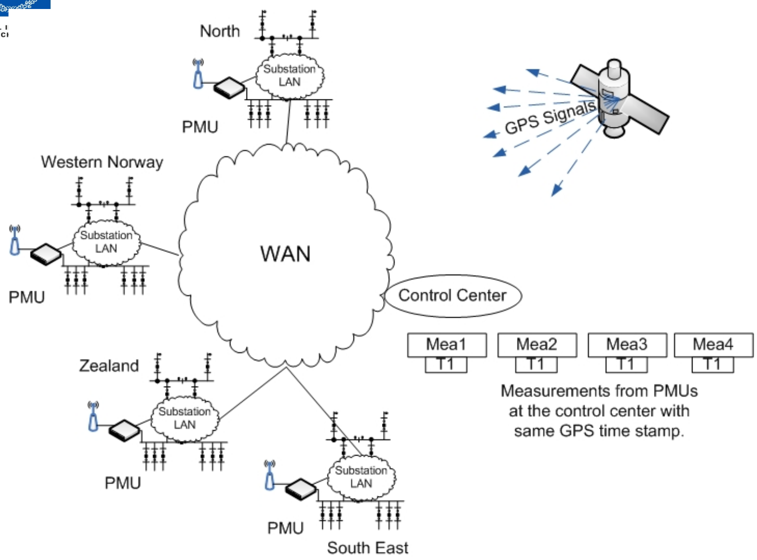
- Based on real time measurements from the grid.
- Makes the model more representative of the actual dynamic process out in the field
- The measurements are of high resolution (e.g. 30 measurement samples per second)
- Less offline analysis, less hypothetical scenarios.
- Most importantly common time reference for measurements (increases accuracy and dependability).
- With advanced applications, enabler of the self healing grid.

Basic Components of a WAMC System



+ Control Functions

The Advent of the PMU



IEEE C37.118

- Protocol specially designed for carrying Phasor Measurements from Phasor Measurement Unit to PDC (Phasor Data concentrator) and from PDC to PDC.
- Contains adress header and a number f phasors including quality checking data.

No.	Field	Size (bytes)	Comment
1	SYNC	2	Sync byte followed by frame type and version number.
2	FRAMESIZE	2	Number of bytes in frame, defined in 6.2.
3	IDCODE	2	Stream source ID number, 16-bit integer, defined in 6.2.
4	SOC	4	SOC time stamp, defined in 6.2, for all measurements in frame.
5	FRACSEC	4	Fraction of Second and Time Quality, defined in 6.2, for all measurements in frame.
6	STAT	2	Bit-mapped flags.
7	PHASORS	4 × PHNMR or 8 × PHNMR	Phasor estimates. May be single phase or 3-phase positive, negative, or zero sequence. Four or 8 bytes each depending on the fixed 16-bit or floating-point format used, as indicated by the FORMAT field in the configuration frame. The number of values is determined by the PHNMR field in configuration 1, 2, and 3 frames.
8	FREQ	2 / 4	Frequency (fixed or floating point).
9	DFREQ	2 / 4	ROCOF (fixed or floating point).
10	ANALOG	2 × ANNMR or 4 × ANNMR	Analog data, 2 or 4 bytes per value depending on fixed or floating-point format used, as indicated by the FORMAT field in configuration 1, 2, and 3 frames. The number of values is determined by the ANNMR field in configuration 1, 2, and 3 frames.
11	DIGITAL	2 × DGNMR	Digital data, usually representing 16 digital status points (channels). The number of values is determined by the DGNMR field in configuration 1, 2, and 3 frames.
	Repeat 6–11		Fields 6–11 are repeated for as many PMUs as in NUM_PMU field in configuration frame.
12+	CHK	2	CRC-CCITT

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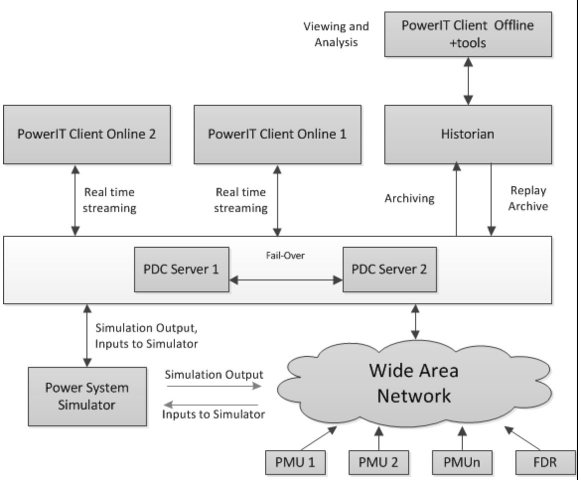
A WAMC test bed and prototype

- KTH's Implementation of a WAMC Platform
- Integrating and utilizing several Open source technologies
- Support many protocols : C37.188, IEEE 1344, FNET, BPA PDCStream.



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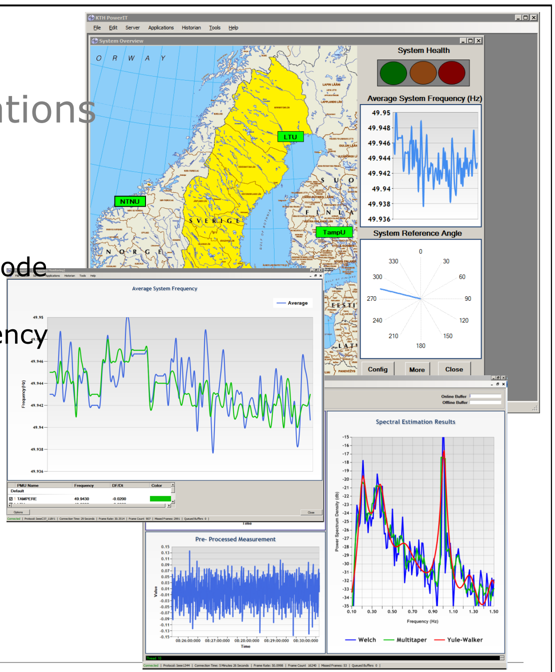
PowerIT Applications

PowerIT

- Implemented a Preliminarly Mode Estimation System
- Implemented standard Frequency Monitoring
- System Overview Monitoring.
- Integrated apps added:
  - Historian Playback
  - Historian Viewer.



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The End