

Hubert Kirrmann  
ABBCH-RD.C1

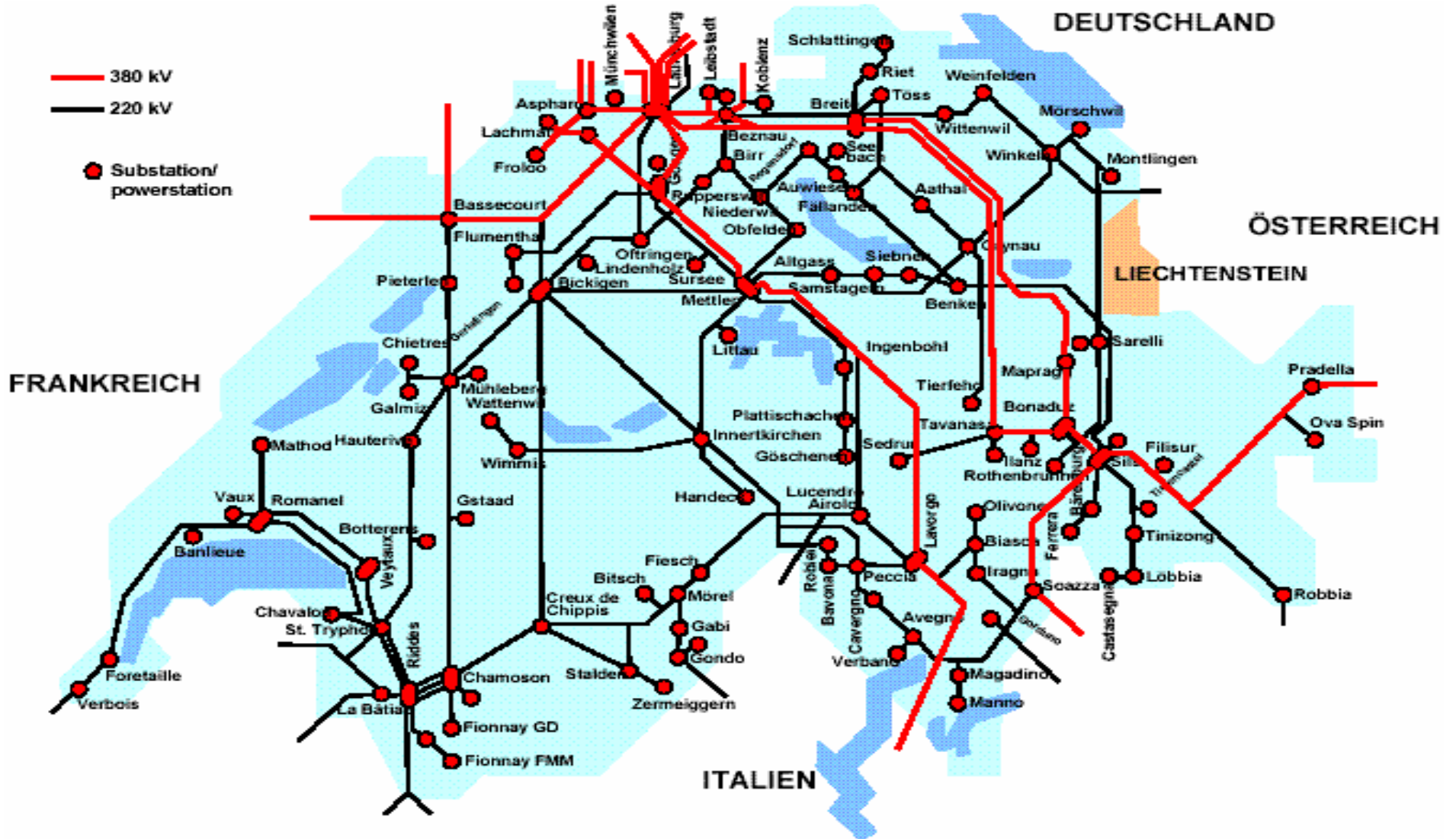
## Introduction to IEC 61850 substation communication standard



communication  
networks and  
systems in  
substations



## Electrical Substations: nodes of the grid



Swiss transmission network

IEC 61850  
MMS Applied

## Air isolated substation



**Station (Unterstation, *Sous-station*)**

- Complete node in the power network (= substation) *or*
- Station buss bar

**Bay (*départ*, Abgang)**

Part of the substation with local functionality, e.g. related to an

- incoming line (“feeder”)
  - connection between the buss bars
- etc.

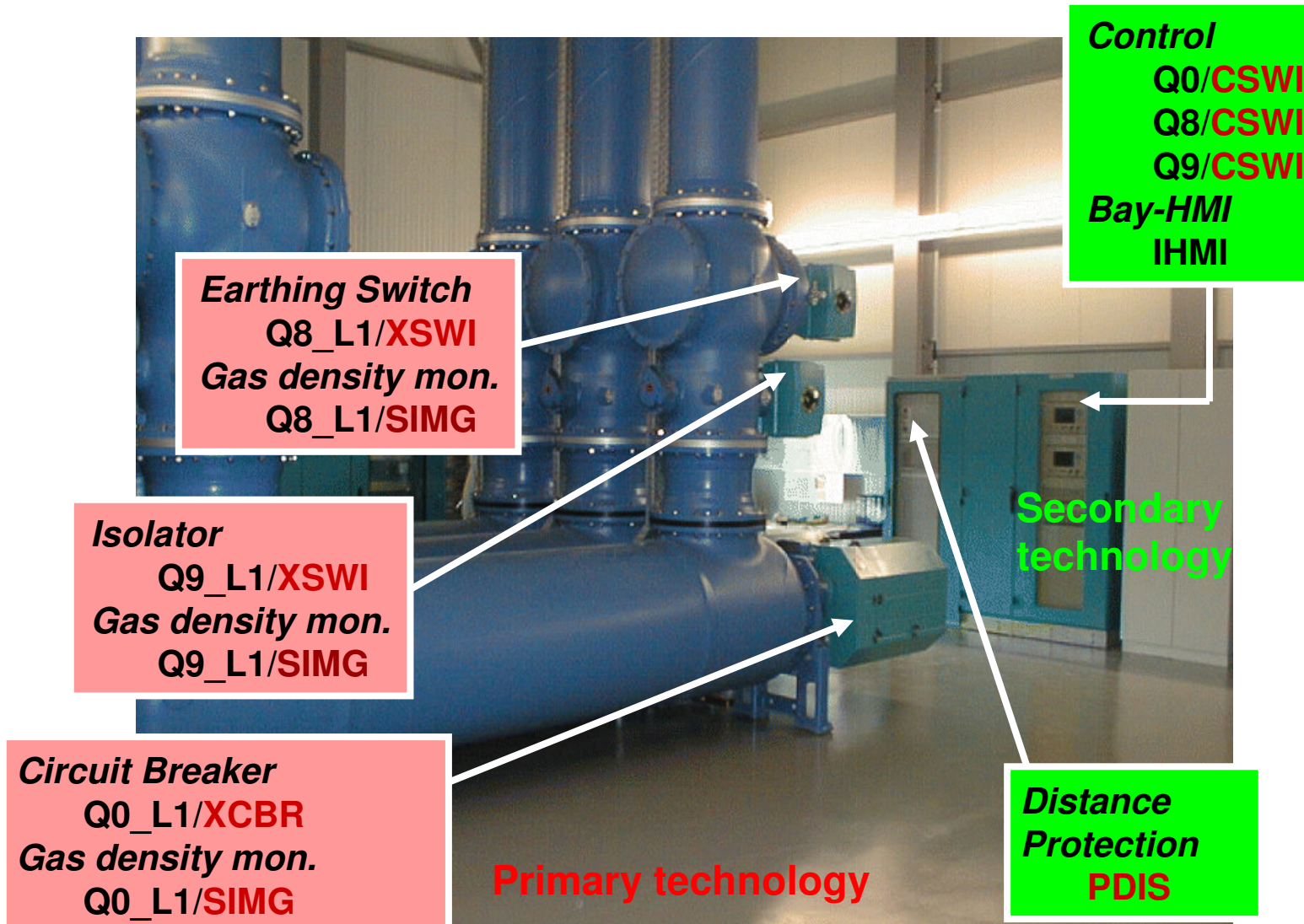
**Process objects (switchyard)**

- breaker
  - transformer
- etc.

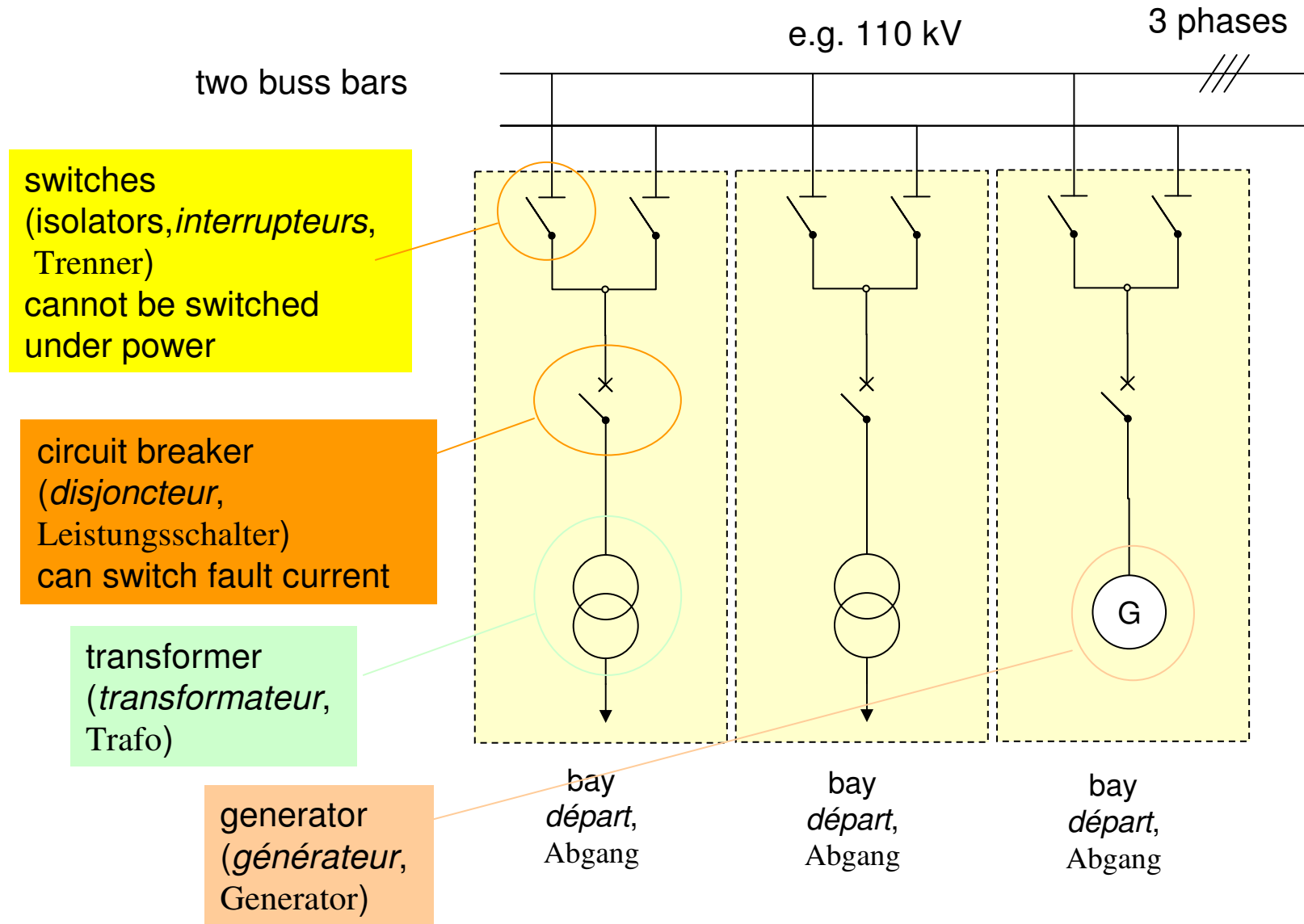
Primary equipment = switchyard hardware

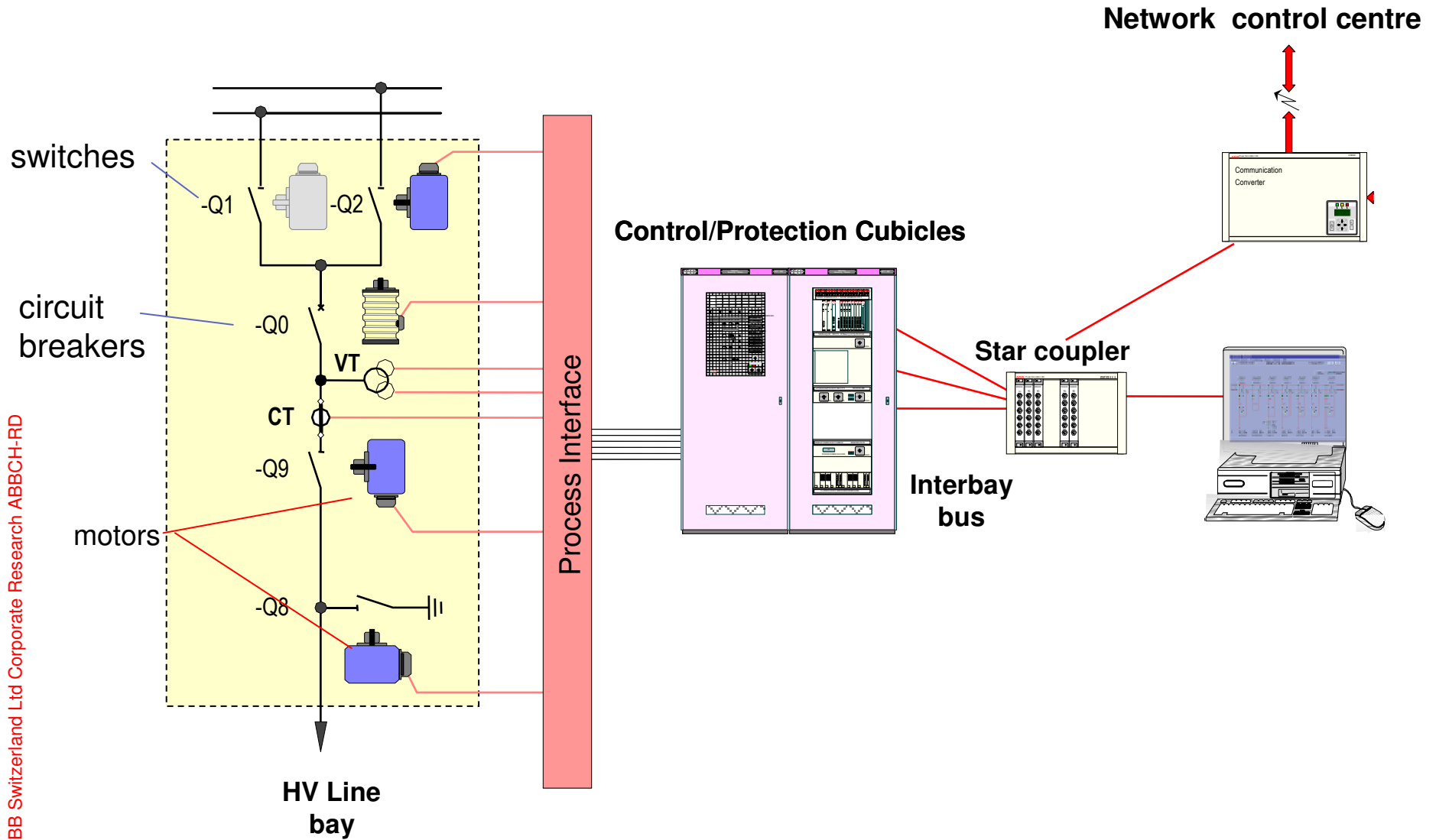
Secondary equipment = control, monitoring and protection devices

# Gas Isolated Substation



# Principle substation: single line diagram





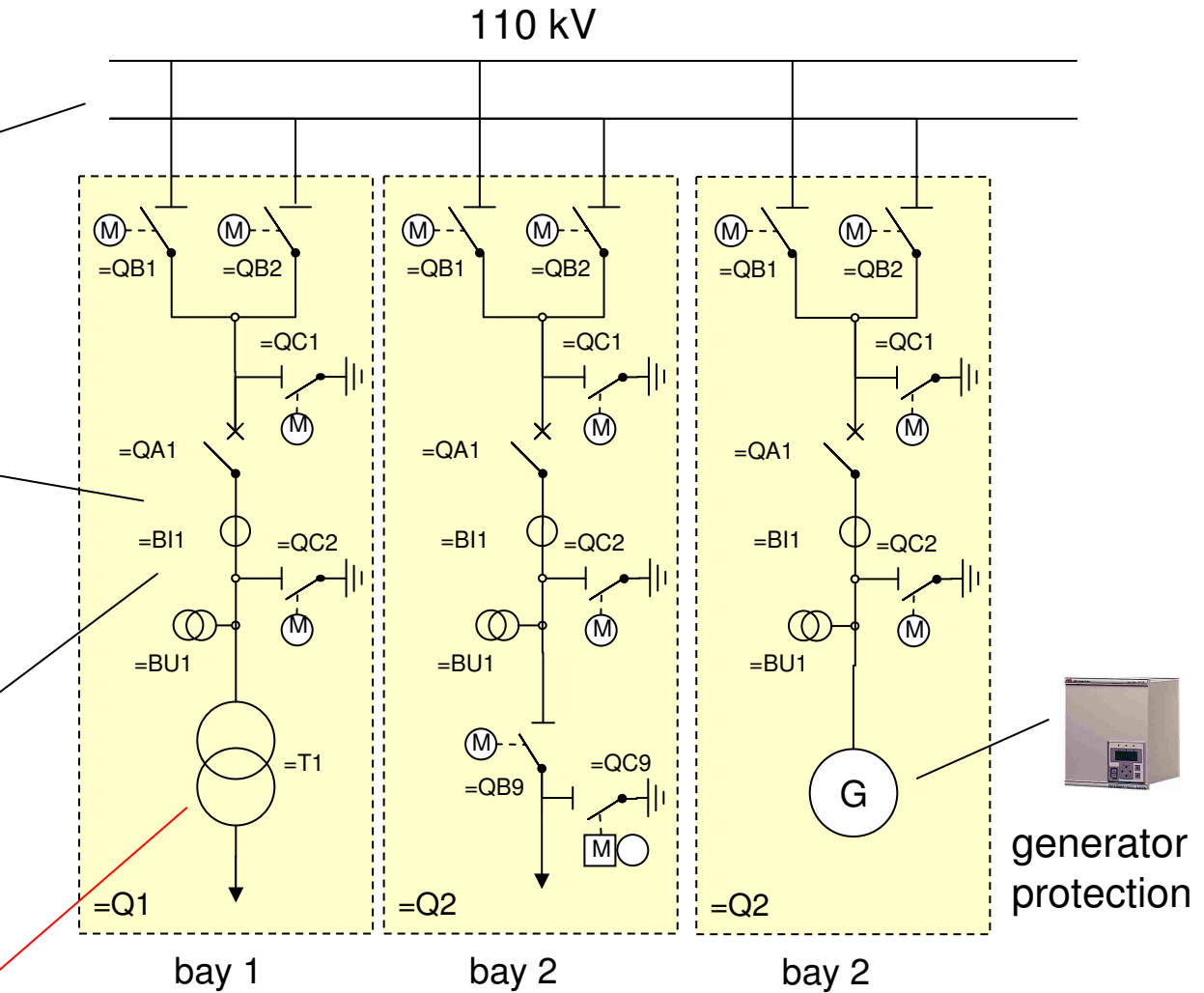
bus-bar  
protection



bay  
protection and control  
back-up bay  
protection and control



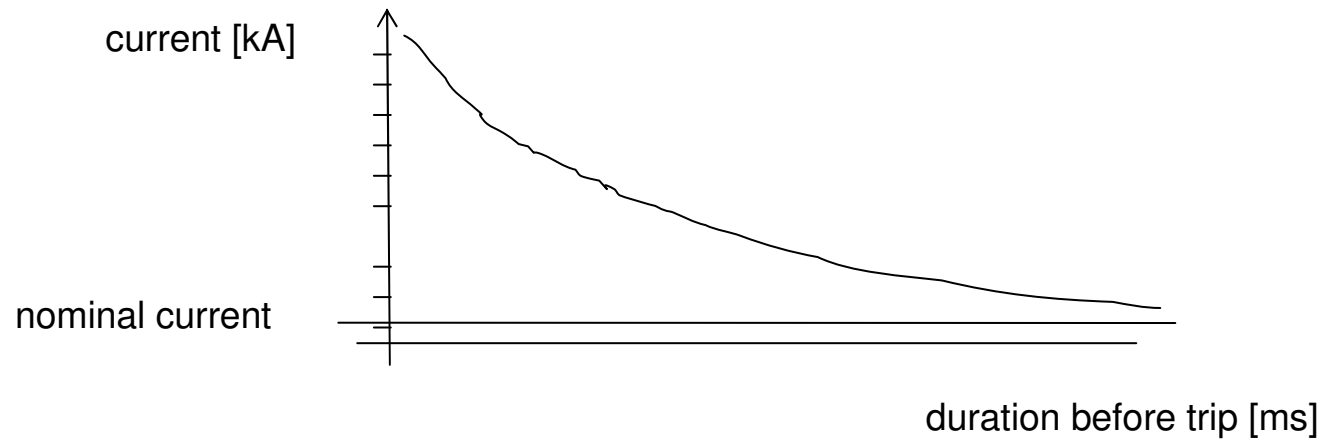
transformer  
protection



Each object is protected by its own protection & control device

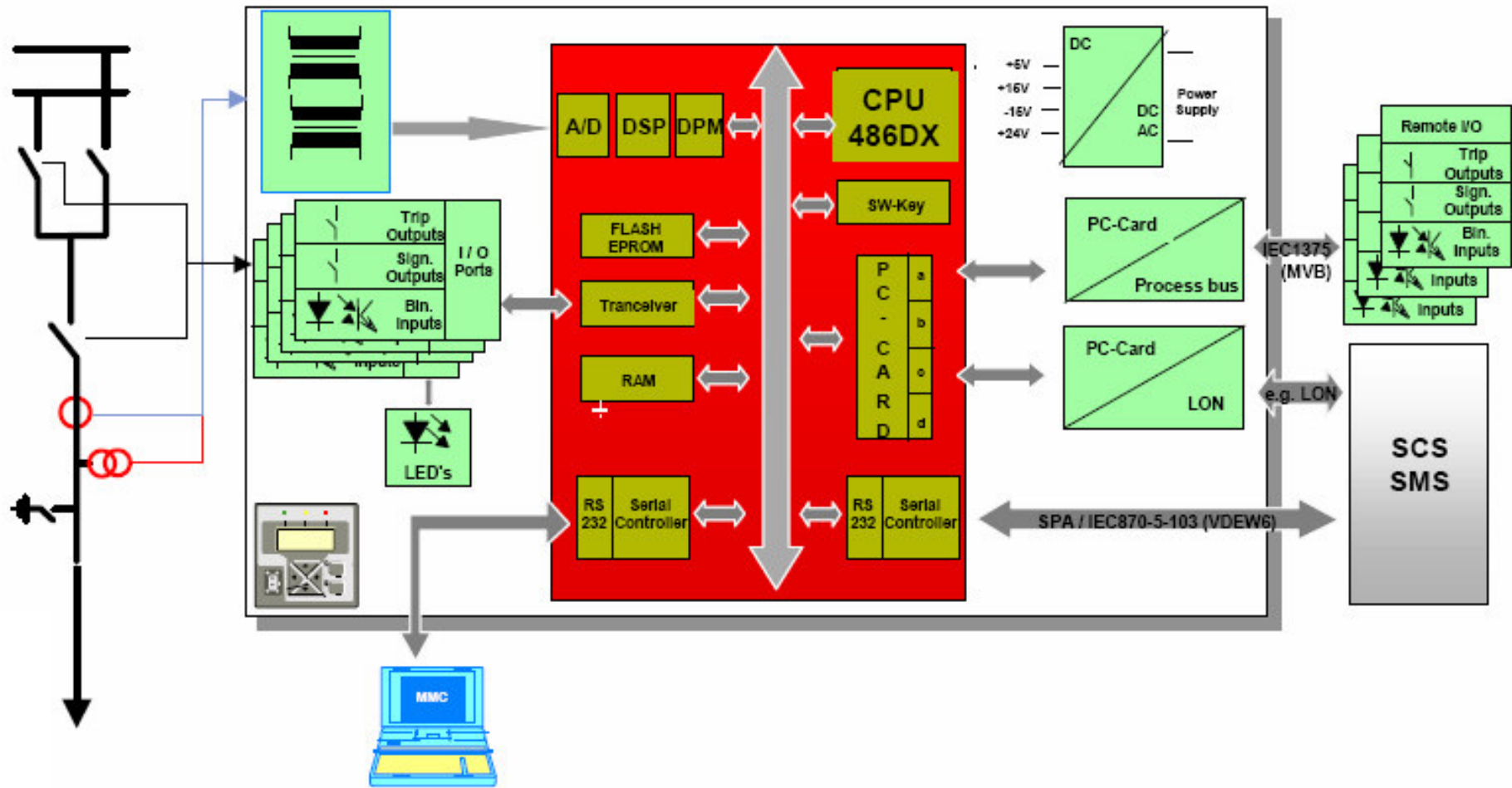


## Example of protection function: overcurrent

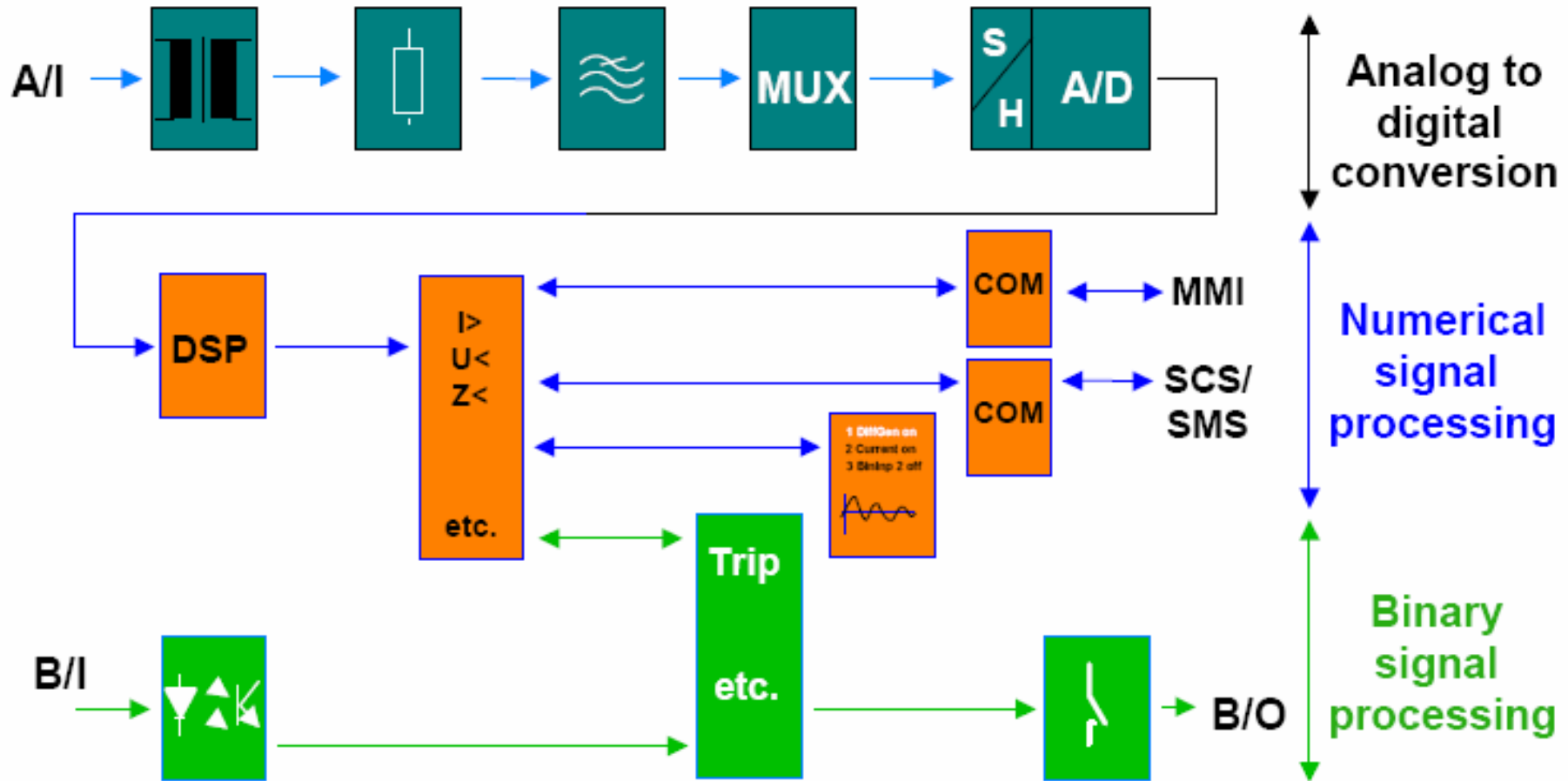


The protection function is adjusted with a number of parameters that are tuned for a specific substation and bay, this is called a *setting*.

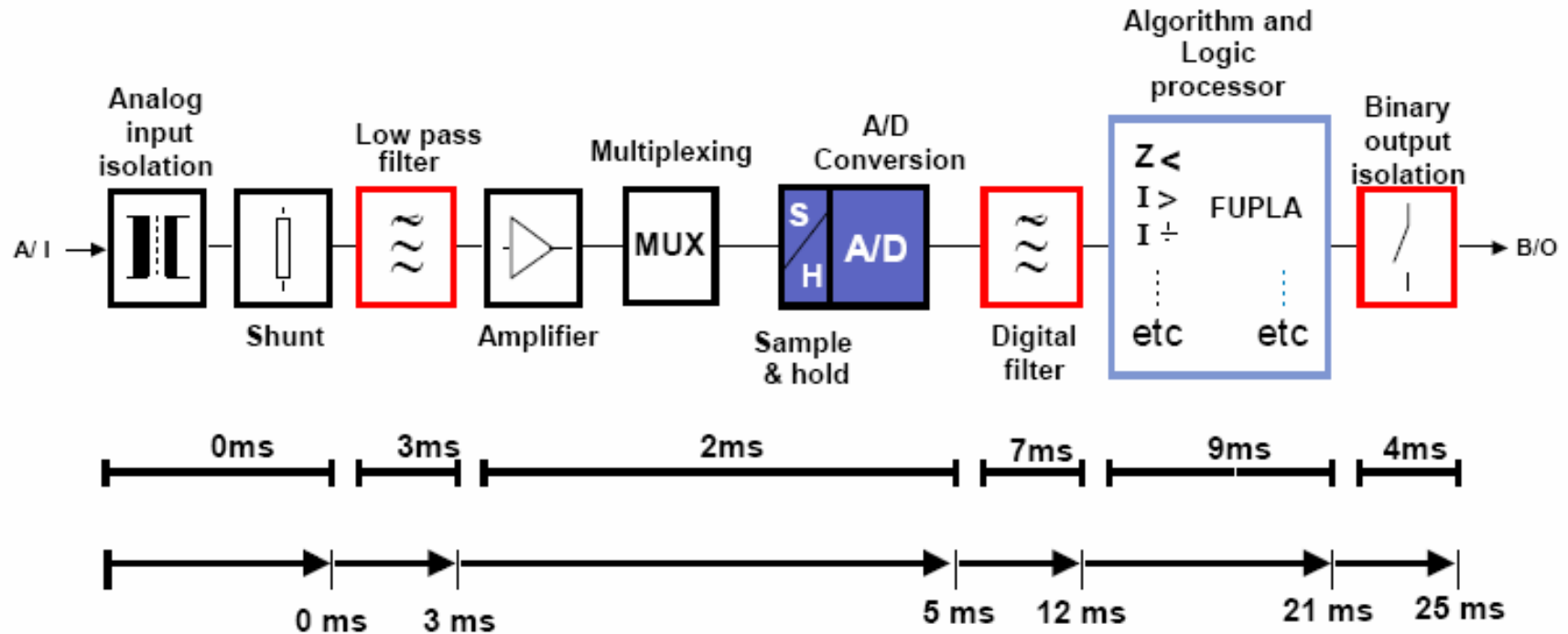
Protection functions have usually different settings, that are used depending on the situation.



### Signal flow in an IED



## Time delays in an IED



### **Protection functions**

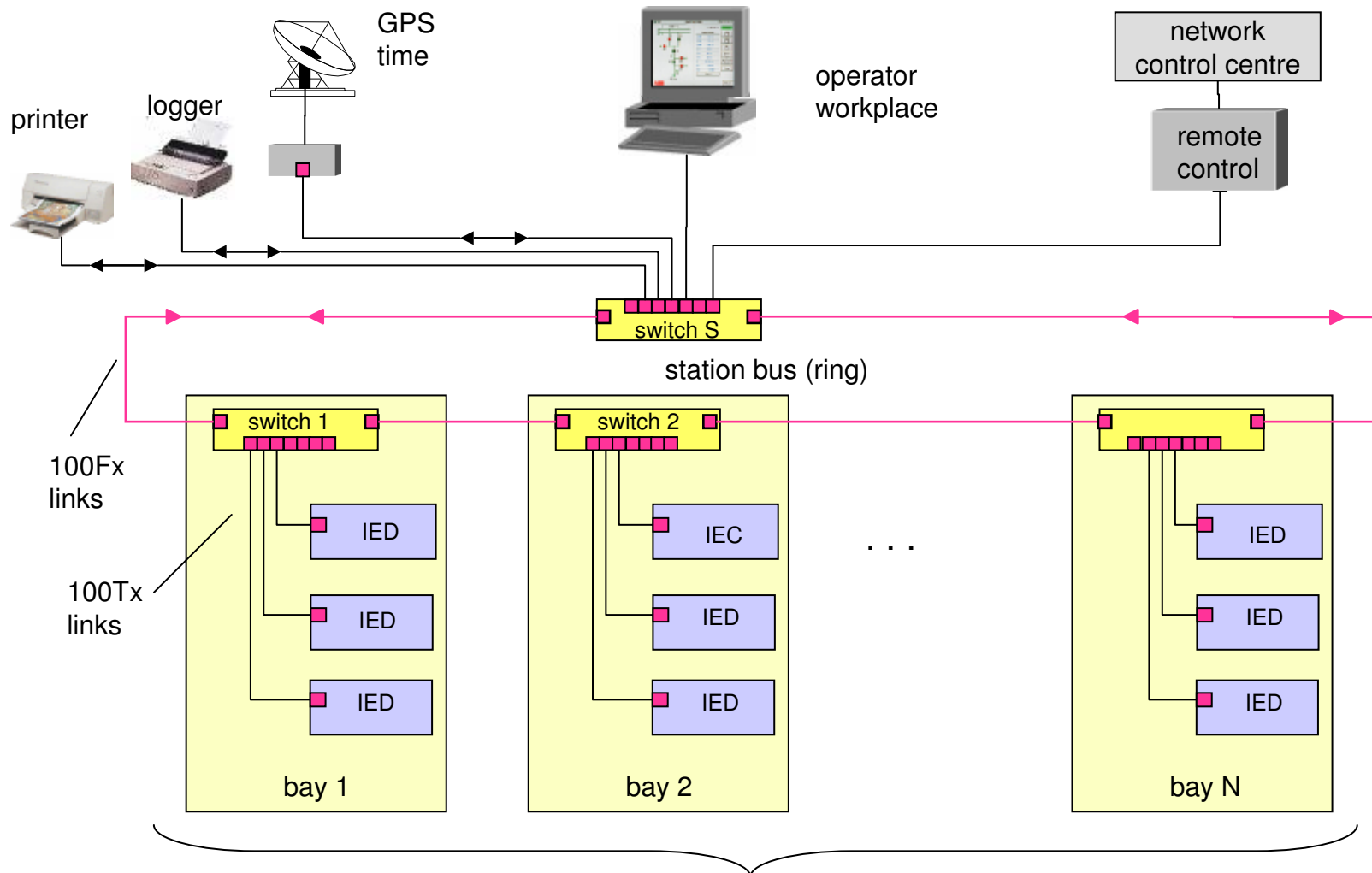
prevent hazard to people, damage to power network components (devices) and breakdown of the power network.  
performed autonomously within some 10 ms .

### **Monitoring functions**

supervise the status of the primary and/or secondary equipment, disturbance recorder, sequence of events with resolution 1 ms

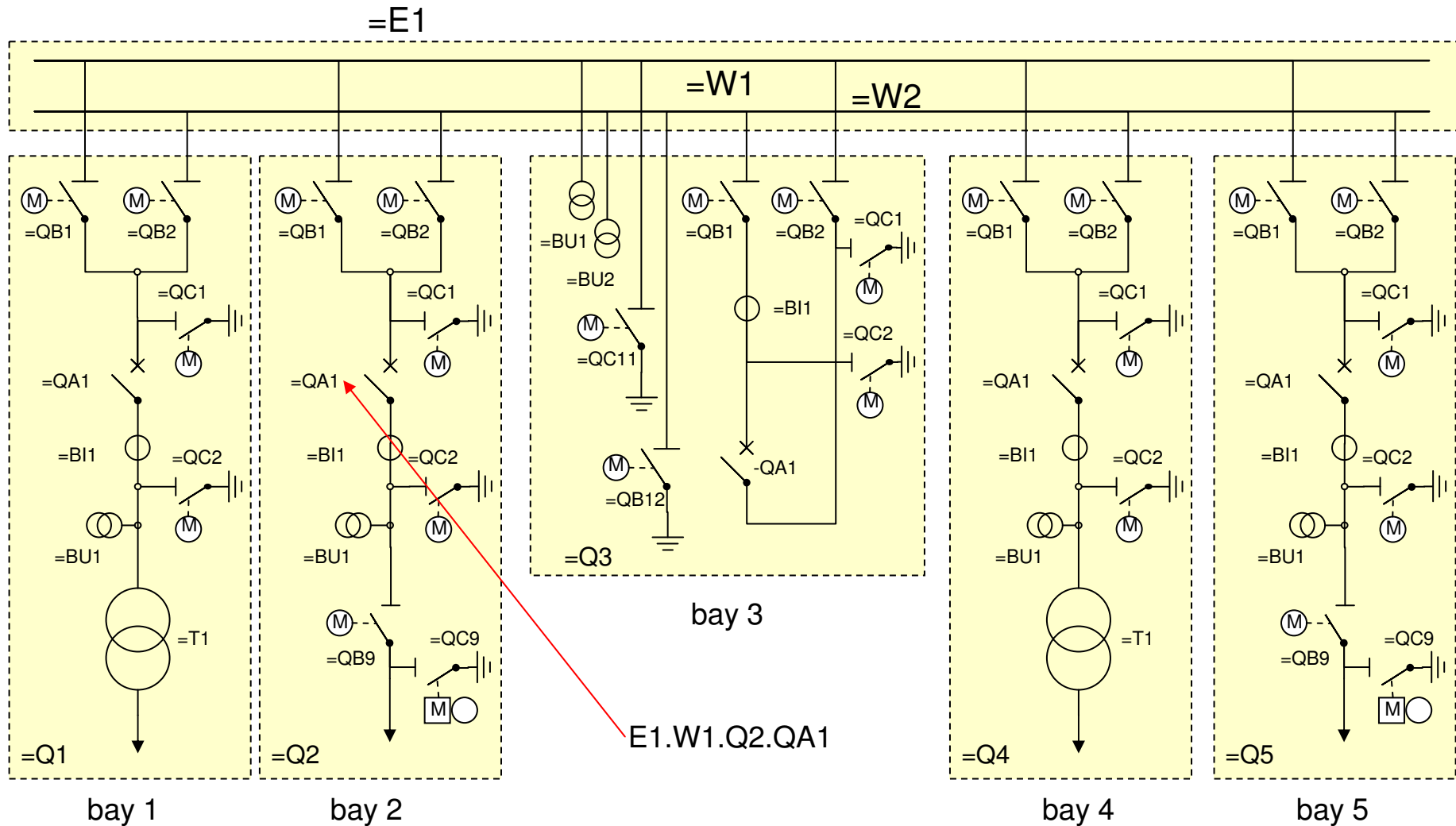
### **Control functions**

allow a local or remote operator to operate the power (response time about of 1 s).  
Automatic sequence functions execute sequence of operations, such as switch from one buss bar to the other ( order of 100 ms)



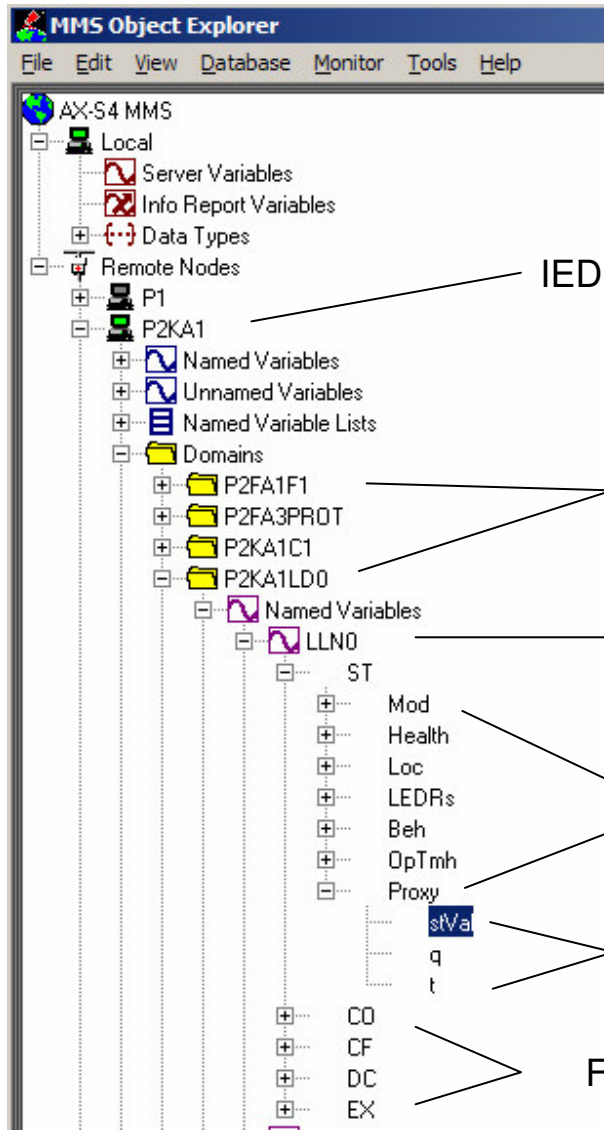
the structure of the network reflects the structure of the substation

Although IEC 61850 is defined as a  
“communication structure for substation and feeder equipment”  
its main contribution is the definition of an object model for all substation objects



The IEC 61346 standard defines how substation elements should be named. Customers define their own names, e.g. Q1 is "City\_Broadway"





When exploring an IED, one finds a hierarchy of branches and leaves

IED

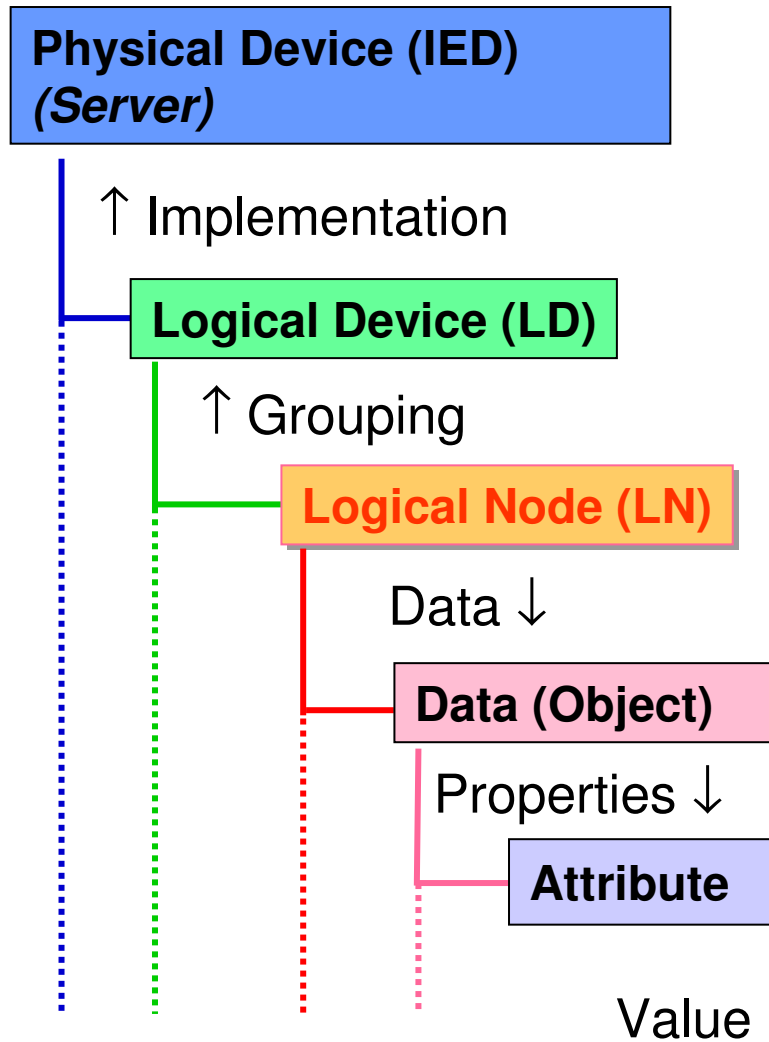
Logical Devices (LD)

Logical Nodes (LN)

Data objects (DATA)

Data Attributes (DA)

Functional Constraints



*example*

*Bay Unit*

*Control*

*CSWI Switch Control*

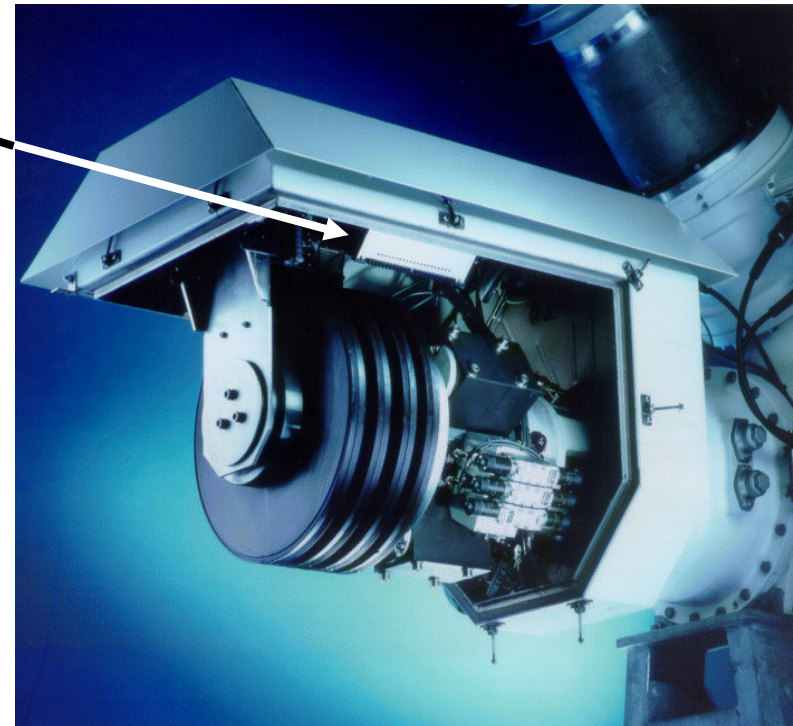
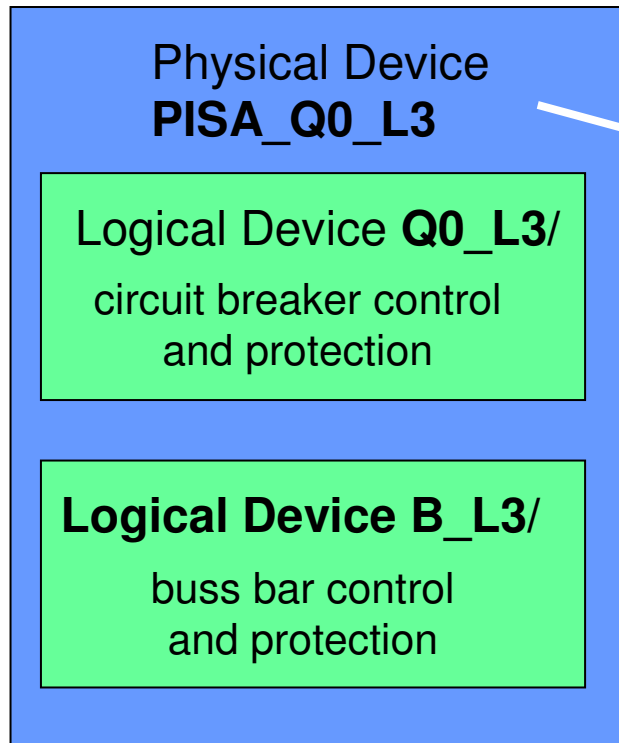
*Position*

*Control Value  
Status Value*

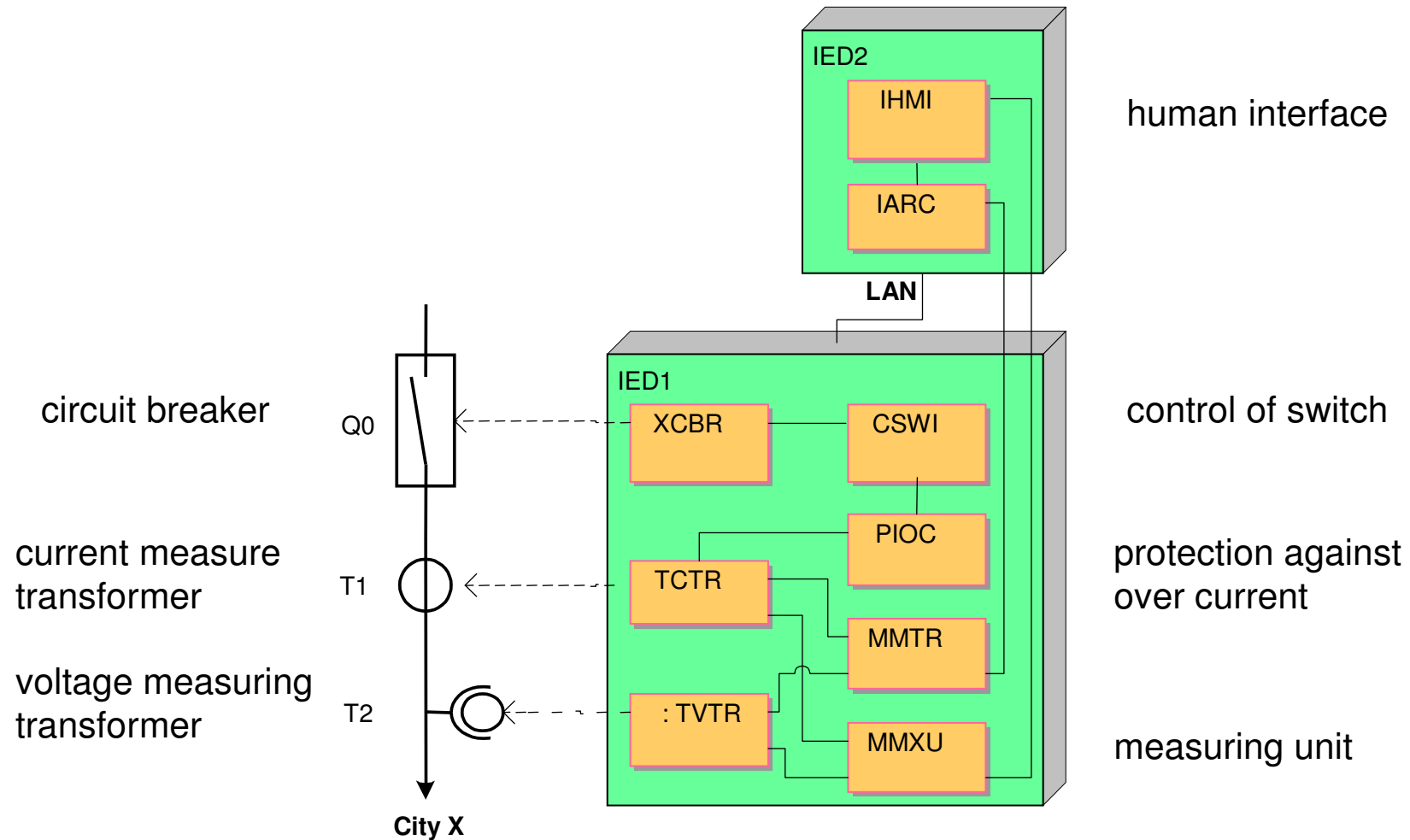
*ON/OFF*

Each physical device (called an IED) can perform functions that was formerly performed by different protection or control devices.

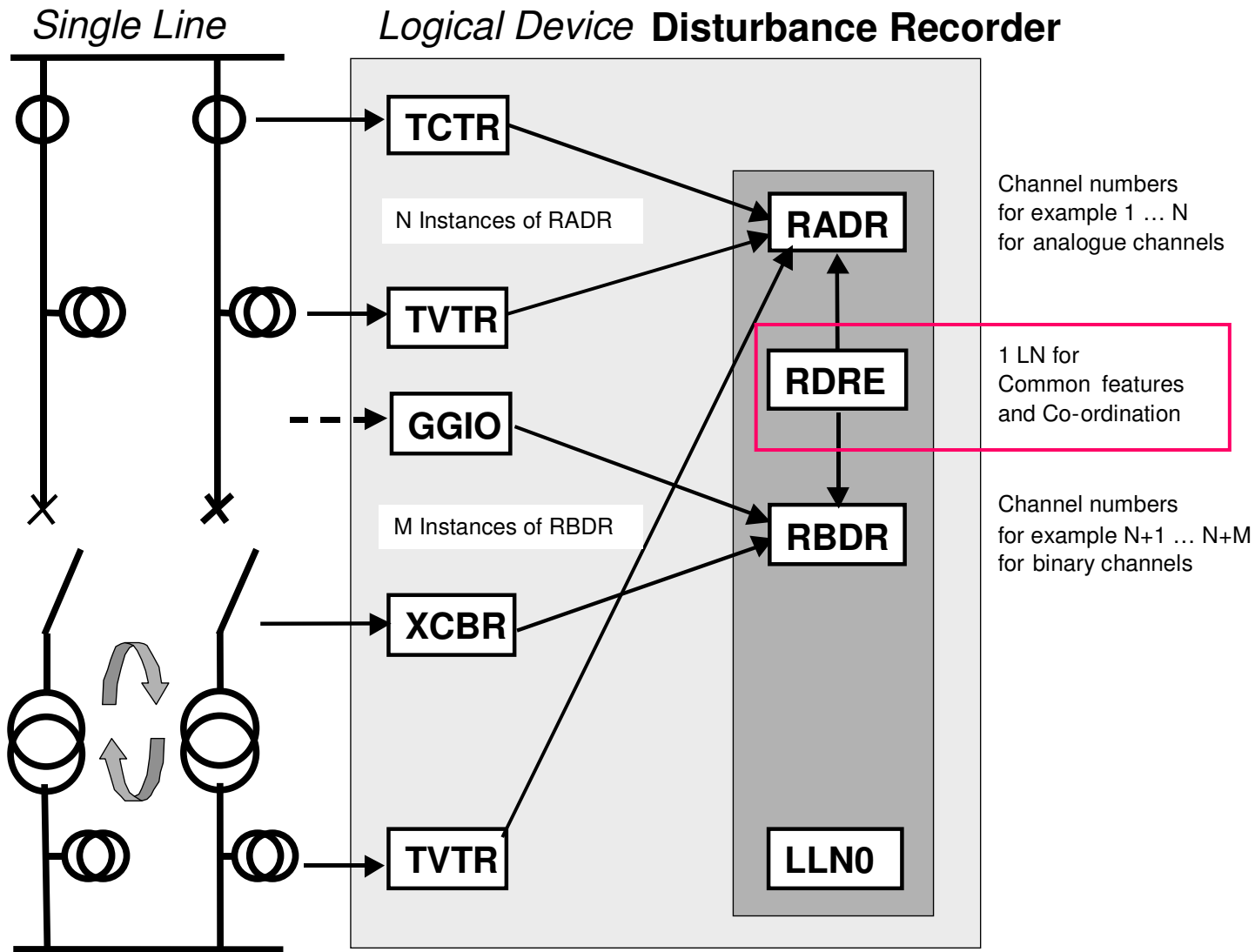
Those former devices are represented by Logical Devices within the physical device.



IEC 61850 assigns to each function within a substation equipment (transformer, circuit breaker, protection function...) a logical node (LN).



## Interaction between logical nodes



The interaction is an application issue, not defined in the standard

IEC 61850-7-4 defines **91** Logical nodes divided into **13** Logical Groups  
The first letter of the Logical Node identifies the group.

Logical Group	Name	Number of Logical Nodes
L	System LN	2
P	Protection	28
R	Protection related	10
C	Control	5
G	Generic	3
I	Interfacing and archiving	4
A	Automatic control	4
M	Metering and measurement	8
S	Sensor and monitoring	4
X	Switchgear	2
T	Instrument transformers	2
Y	Power transformers	4
Z	Further power system equipment	15



LNname	Function	
XCBR	Circuit breaker	a high-power switch capable of switching off or on under full load current (Schalter, Interrupteur)
XSWI	Circuit switch	a switching device capable of electrically isolating a line, but which may only be operated when essentially no current is flowing

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## The P-group, with 28 protection logical nodes

LNname	IEEE protection function(s)	Protection Function
PDIF	87,87P,87L,87N,87T,87B, 87M, 87G	Differential
PDIR	87B	Direction comparison
PDIS	21	Distance protection
PDOP	32	Directional Overpower
PDUP	32,37,40	Directional Underpower
PFRC	81	Rate of change of frequency
PHAR	87T	Harmonic restraint
PHIZ	64	Ground detector
PIOC	50	Instantaneous overcurrent
PMRI	49R,66,48,51LR	Motor restart inhibition
PMSS		Motor starting supervision
POPF	55	Over power factor
PPAM		Phase angle measuring
PSCH	21,85	Protection scheme
PSDE		Sensitive directional earth fault
PTEF		Transient earth fault
PTOC	46,51,60,64R,64S,64W,67,67N,76	Time overcurrent
PTOF	81	Overfrequency
PTOV	47,59,59DC,60	Overvoltage
PTRC		
PTTR	49,49R,49S	Thermal overload
PTUC	37	Undercurrent
PTUV	27	Undervoltage
PTUF		Underfrequency
PUPF	55	Under power factor
PVOC	51V	Voltage controlled time overcurrent
PVPH	24	Volt per Hertz
PZSU	14	Zero speed or underspeed

## (Protection functions standardized by IEEE)

21	Distance protection
24	Volts to Hertz = Overfluxing protection
25AR	Voltage- and synchro-check for autoreclosure
25C	Voltage- and synchro-check for control
49	Thermal overload
49D	Supervision of through current in diameter, current of phase A only
50BF	Breaker fail protection
50EndF	End-fault protection, fast overcurrent for faults between open CB and current-sensor
50GTert	Non-delayed overcurrent in ground connection of the tertiary
50Stub	T-zone protection
	Alternative 1: In case there is no sensor for protection in the feeder, a non-delayed feeder overcurrent function is part of the distance protection. This overcurrent function is released if the feeder disconnecter is open and 21 blocked.
	Alternative 2: In case the feeder is equipped with sensors for protection, a dedicated differential protection is applied (additional zone of REB500)
51	Time overcurrent phase
51G	Ground back-up overcurrent
51N	Overcurrent protection measuring the transformer neutral current
59	Overvoltage
64Tert	Zero-sequence overvoltage as ground protection of an ungrounded tertiary circuit
67G	DEF = directional ground fault with communication to opposite line end
79	Autoreclosure
87B	Busbar Protection
87B1	Protection of bus 1
87B2	Protection of bus 2
87REF	Restricted earth fault, restricted to one winding
87REFMainWdg/ph	Biased differential for main winding, phase-segregated. Used as ground fault protection in case of transformer groups with one tank per phase
87L	Line differential protection
87T	Transformer differential protection
87T	overall Biased differential covering all windings

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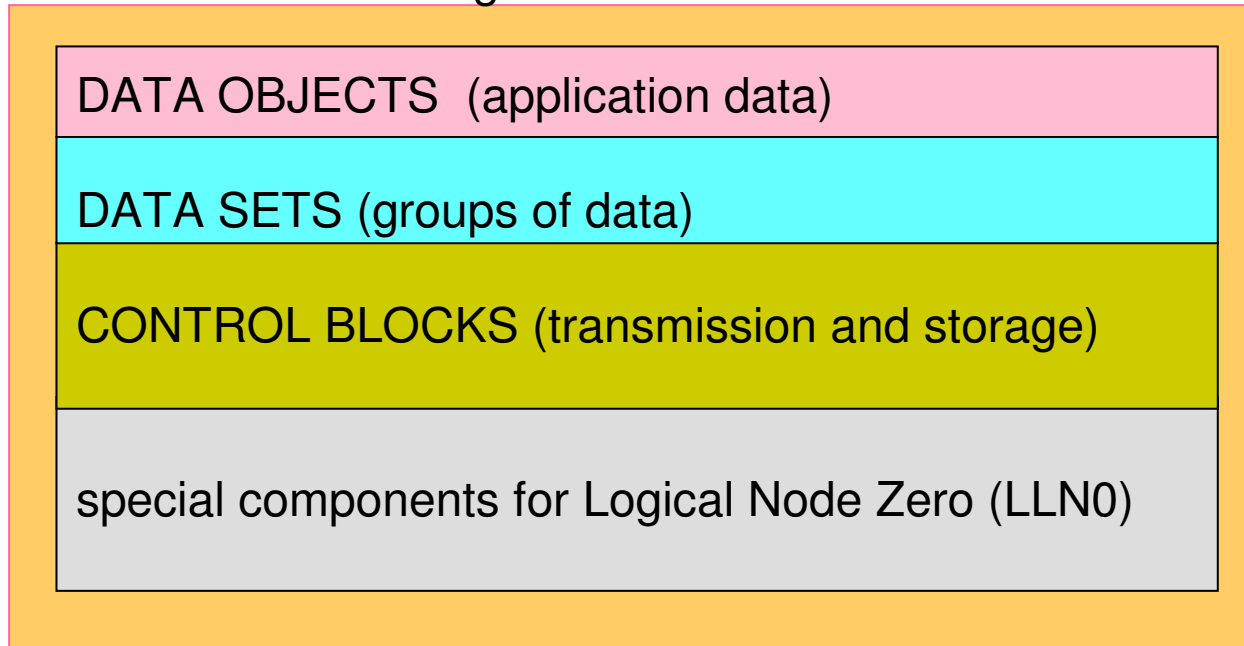
Logical Group	Name	Number of Logical Nodes
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LNname	Function	
<b>LLN0</b>	Logical Node Zero	Special LN that administrates the virtual device it is part of. It defines in particular the communication objects and the log of the virtual device.
<b>LPHD1</b>	Physical Device Logical Node	represents the physical device, and in particular its communication properties, that are identical for all Logical Devices

All logical nodes are constructed according to the template:

Logical-Node class		
Attribute Name	Attribute type	Explanation
LNName	ObjectName	String of characters, e.d XCBR1
LNRef	ObjectReference	Location string, e.g. Q1B1W1/XCBR1
Data [1..n]	DATA	Data Objects, will be detailed
DataSet [0..n]	DATA-SET	Named groups of Data Objects and attributes
BufferedReportControlBlock [0..n]	BRCB	Control block for events
UnbufferedReportControlBlock [0..n]	BRCB	
LogControlBlocks [0..n]	LCB	Control block for history
Only for LLN0		
SettingGroupsControlBlock [0..1]	SGCB	Control block for settings
Log [0..1]	LOG	
GOOSEControlBlock [0..n]	GoCB	
GSSEControlBlock [0..n]	GsCB	
MulticastSampledValues [0..n]	MSVCB	
UnicastSampledValues [0..n]	USVCB	
<b>Services</b>		
GetLogicalNodeDirectory		
GetAllDataValues		

The attributes of logical nodes are divided into:



Let's start with Data Objects

## Modeling the Data Objects (DATA) in the Logical nodes

A logical node contains Data Objects (DATA) that represent application (substation) objects

### Logical Node

- Common logical node information
- information independent from the dedicated function represented by the LN, e.g. name plate, health,....)

- Stati
- represents either the status of the process or of the function of the LN, e.g. switch type, position of a switch)

- Settings
- parameters for the function of a logical node, e.g. first, second and 3rd reclosure time, close pulse time

- Measures
- analog data measured from the process (e.g. line current, voltage, power), or calculated in the LN (e.g. total active power, net energy flow)

- Controls
- data which are changed by commands, e.g. switchgear state (ON-OFF), tap changer position or resetable counters

Example of DATA in a Logical Node: XCBR

XCBR			
Data Object	Explanation	CDC	Mandatory
<i>Basic LN</i>			
Mod	Mode	INC	M
Beh	Behavior	INS	M
Health	Health	INS	M
NamePlt	Name Plate	LPL	
Loc	Local operation, not remote	SPS	
EEHealth	External equipment health	INS	
EENam	External equipment name plate	DPL	
NamPlt	Name Plate	LPL	
OpCnt	Operation counter	INS	M
<i>Controls</i>			
Pos	Switch position	DPC	M
BlkOpn	Block opening	SPC	M
BlkCls	Block closing	SPC	M
ChaMotEna	Charger motor enable	SPC	
<i>Measures</i>			
SumSwARs	Sum of switched amperes, resetable	BCR	
<i>Status</i>			
CBOpCap	Circuit breaker operating capability	INS	M
POWCap	Point on wave switching capability	INS	
MaxOpCap	Operating capability when fully charged	INS	

} common to all logical nodes

➔ Pos is a DATA of Logical Node XCBR





## A Data Object consists of Data Attributes

Each attribute of a DATA consists of a number of Data Attributes, with a Data Attribute Type (DAType) that belong to Functional Constraints (FC)

DATA "Pos"		
Attribute Name	Attribute Type	Functional Constraint
stVal q t	BOOLEAN Quality TimeStamp	Status (ST)
d	Visible String255	Description (DC)
subEna subVal subQ subID	BOOLEAN BOOLEAN Quality Visible String64	Substitution (SV)

CDC =  
DPC

Basic Type

Common data  
attribute type

only needed when  
substitution is  
possible

Many Logical Nodes have Data Objects with the same Data Attributes.

For instance, all binary input variables need the Data Attributes

<status>

<quality>

<timestamp>

<description>

To simplify engineering, IEC 61850 defined standard groups of Data Attributes, called CDC (“Common Data Classes”)

(“Classes” is not related to classes in object-oriented languages, a class is similar to a “struct” in “C”).

**Each Data Object of a logical node belongs to a CDC.**

**Status information (binary, integer):**

SPS: Single Point Status  
 DPS: Double Point Status  
 INS: Integer Status  
 ACT: Protection Activation info  
 ACD: Activation Info Directional Protection  
 SEC: Security Violation Counting  
 BCR: Binary Counter Reading

**Measurand information:**

MV: Measurement Value  
 CMV: Complex Measured Variable  
 SAV: Sampled Value  
 WYE: Phase to Ground  
 DEL: Phase to Phase  
 SEQ: Sequence  
 H MV: Harmonic Value  
 HWYE: Harmonic Value for WYE  
 HDEL: Harmonic Value for DEL

**Controllable status:**

SPC Single Point Control  
 DPC Double Point Control  
 INC Integer Status Control  
 BSC Binary Controlled Step Position Info  
 ISC Integer Controlled Step Position Info

**Controllable Analog:**

APC (fc=SP, set point)

**Status settings:**

SPG Single Point Setting  
 ING (fc = SG, SE or SP)

**Analog settings:**

ASG,  
 CURVE (fc= SG, SE or SP)

**Descriptive information:**

DPL Device Name Plate  
 LPL Logical Node Name Plate  
 CSD Curve Shape Description

These are all the possible types for Data Objects

## CDC: Single Point Setting (SPS)

Single Point Setting (SPS) class					
Attribute	Attribute Type	FC	TrgOp	Value/Value Range	M/O/C
<i>status</i>					
stVal	BOOLEAN	ST	dchg	TRUE   FALSE	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
<i>substitution</i>					
subEna	BOOLEAN	SV		TRUE   FALSE	PICS_SUBST
subVal	BOOLEAN	SV			PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
<i>configuration, description and extension</i>					
d	VISIBLE STRING255	DC	Text		O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

**CDC: Common Measurement Value (CMV)**

Common Measurement Value						
Attribute	Attribute Type	FC	TrgOp	Value/Value Range	M/O/C	
<i>measured attributes</i>						
instCVal	Vector	MX				O
cVal	Vector	MX	dchg			M
range	ENUMERATED	MX	dchg	normal high low high-high low-low ...		O
q	Quality	MX	qchg			M
t	TimeStamp	MX				M
<i>substitution</i>						
subEna	BOOLEAN	SV				PICS_SUBST
subCVal	Vector	SV				PICS_SUBST
subQ	Quality	SV				PICS_SUBST
subID	VISIBLE STRING64	SV				PICS_SUBST
<i>configuration, description and extension</i>						
units	Unit	CF		see Annex A		O
db	INT32U	CF		0 ... 100 000		O
zeroDb	INT32U	CF		0 ... 100 000		O
rangeC	RangeConfig	CF				GC_CON
magSVC	ScaledValueConfig	CF				AC_SCAV
angSVC	ScaledValueConfig	CF				AC_SCAV
angRef	ENUMERATED	CF		V   A   other ...		O
smpRate	INT32U	CF				O
d	VISIBLE STRING255	DC	Text			O
dU	UNICODE STRING255	DC				O
cdcNs	VISIBLE STRING255	EX				AC_DLNDA_M
cdcName	VISIBLE STRING255	EX				AC_DLNDA_M
dataNs	VISIBLE STRING255	EX				AC_DLN_M

**CDC Controllable Double Point CDP (e.g. Pos in XCBR)**

Attribute	Attribute Type	FC	TrgOp	Value/Value Range	M/O/C
<i>control and status</i>					
ctlVal	BOOLEAN	CO		off (FALSE)   on (TRUE)	AC_CO_M
operTm	TimeStamp	CO			AC_CO_O
origin	Originator	CO, ST			AC_CO_O
ctlNum	INT8U	CO, ST		0..255	AC_CO_O
stVal	CODED ENUM	ST	dchg	intermediate   off   on   bad	M
q	Quality	ST	qchg		M
t	TimeStamp	ST			M
stSeld	BOOLEAN	ST	dchg		AC_CO_O
<i>substitution</i>					
subEna	BOOLEAN	SV			PICS_SUBST
subVal	CODED ENUM	SV		intermediate   off   on   bad	PICS_SUBST
subQ	Quality	SV			PICS_SUBST
subID	VISIBLE STRING64	SV			PICS_SUBST
<i>configuration, description and extension</i>					
pulseConfig	PulseConfig	CF			AC_CO_O
ctlModel	CtlModels	CF			M
sboTimeout	INT32U	CF			AC_CO_O
sboClass	SboClasse	CF			AC_CO_O
d	VISIBLE STRING255	DC		Text	O
dU	UNICODE STRING255	DC			O
cdcNs	VISIBLE STRING255	EX			AC_DLNDA_M
cdcName	VISIBLE STRING255	EX			AC_DLNDA_M
dataNs	VISIBLE STRING255	EX			AC_DLN_M

M = mandatory, O = optional, AC\_CO\_M: mandatory when AC\_CO option selected, ....

Data Attributes may be of

- primitive (a simple type, e.g. BOOLEAN)
- composite (constructed, e.g. Vector) in which case they consist of Attributes Components

Vector Type Definition			
Attribute Name	Attribute Type	Value/Value Range	M/O/C
mag	AnalogueValue		M
ang	AnalogueValue		O

AnalogueValue itself is defined as:

AnalogueValue Type Definition			
Attribute Name	Attribute Type	Value/Value Range	M/O/C
l	INT32		integer value GC_1
f	FLOAT32		floating point value GC_1

e.g. **PhaseVoltage.mag.f** is the magnitude of the phase voltage as a floating point number

IEC 61850-7-3.6 defines 12 Common Data Attributes (CDA)

Quality

Analogue value

Configuration of analogue value

Range configuration

Step position with transient indication

Pulse configuration

Originator

Unit definition

Vector definition

Point definition

CtlModels definition

SboClasses definition (Select Before Operate)



Quality type definition			
Attribute name	Attribute type	Value/value range	M/O/C
	PACKED LIST		
validity	CODED ENUM	good   invalid   reserved   questionable	M
detailQual	PACKED LIST		M
overflow	BOOLEAN		M
outOfRange	BOOLEAN		M
badReference	BOOLEAN		M
oscillatory	BOOLEAN		M
failure	BOOLEAN		M
oldData	BOOLEAN		M
inconsistent	BOOLEAN		M
inaccurate	BOOLEAN		M
source	CODED ENUM	process   substituted DEFAULT process	M
test	BOOLEAN	DEFAULT FALSE	M
operatorBlocked	BOOLEAN	DEFAULT FALSE	M

Variables are of different relevance and time criticality.

e.g. the position variable “Pos” of a circuit breaker is of class CDP,  
it contains variables of different urgency:

- the actual position of the switch (XCBR2.StVal) and
- the description (XCBR2.d).

To retrieve information from an IED selectively, each leaf has an associated  
a functional constrain, that becomes part of its name.

The functional constraints apply to each data attribute.

A leaf can belong to more than one Function Constraint, although this occurs  
seldom.

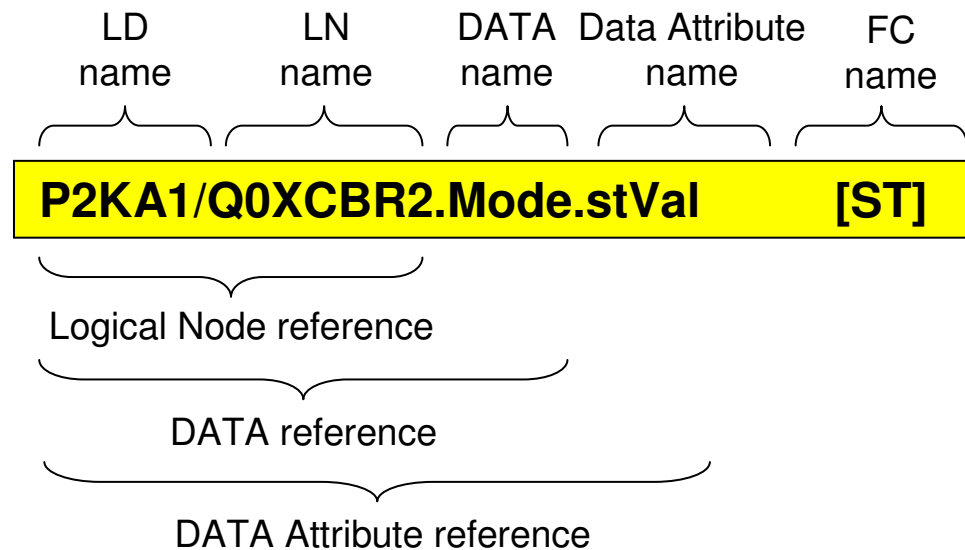
## Functional Constraints

FC	Meaning	Services
ST MX	Process values: Status, Measurand	Read, substitute, report, log
CO SP	Process commands; binary, analog (Set Points)	Operate
SV	Substitution related	Substitute (read, write)
CF DC	Configuration, description	Read, Write (report, log)
SG SE	Parameters, in setting groups (SG: the active, SE: the editable value)	GetSGValue, SetSGValue
CB related	Each CB type	GetxxxCBValues, SetxxxCBValues
SP	Parameter (outside SG)	Read, write
EX	Name space definition	Read

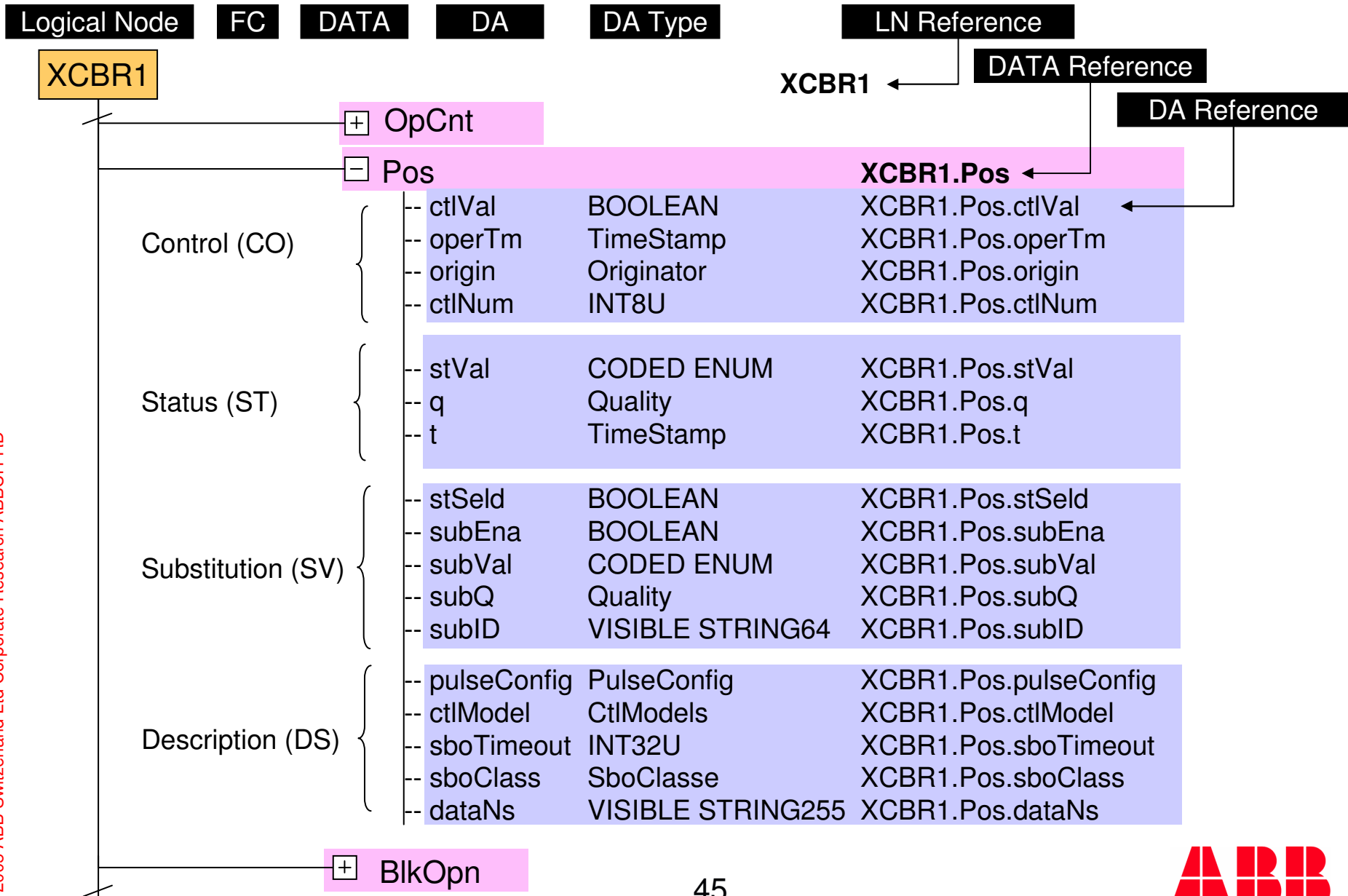
## Naming scheme (LNName and LNRef)

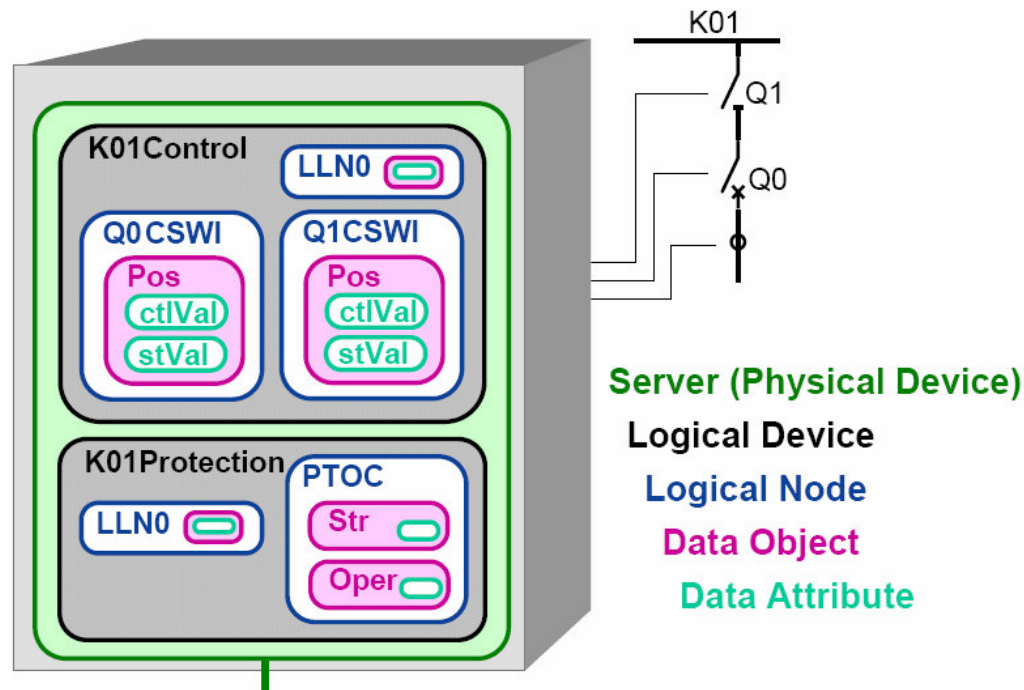
The name of the logical node is that of an instance of the standard logical nodes, unique in the Logical Device e.g. XCBR2

The Object reference is the full path of the object, completed with the Functional Constraint:



# Naming a Data Attribute (“Pos” in an “XCBR”)





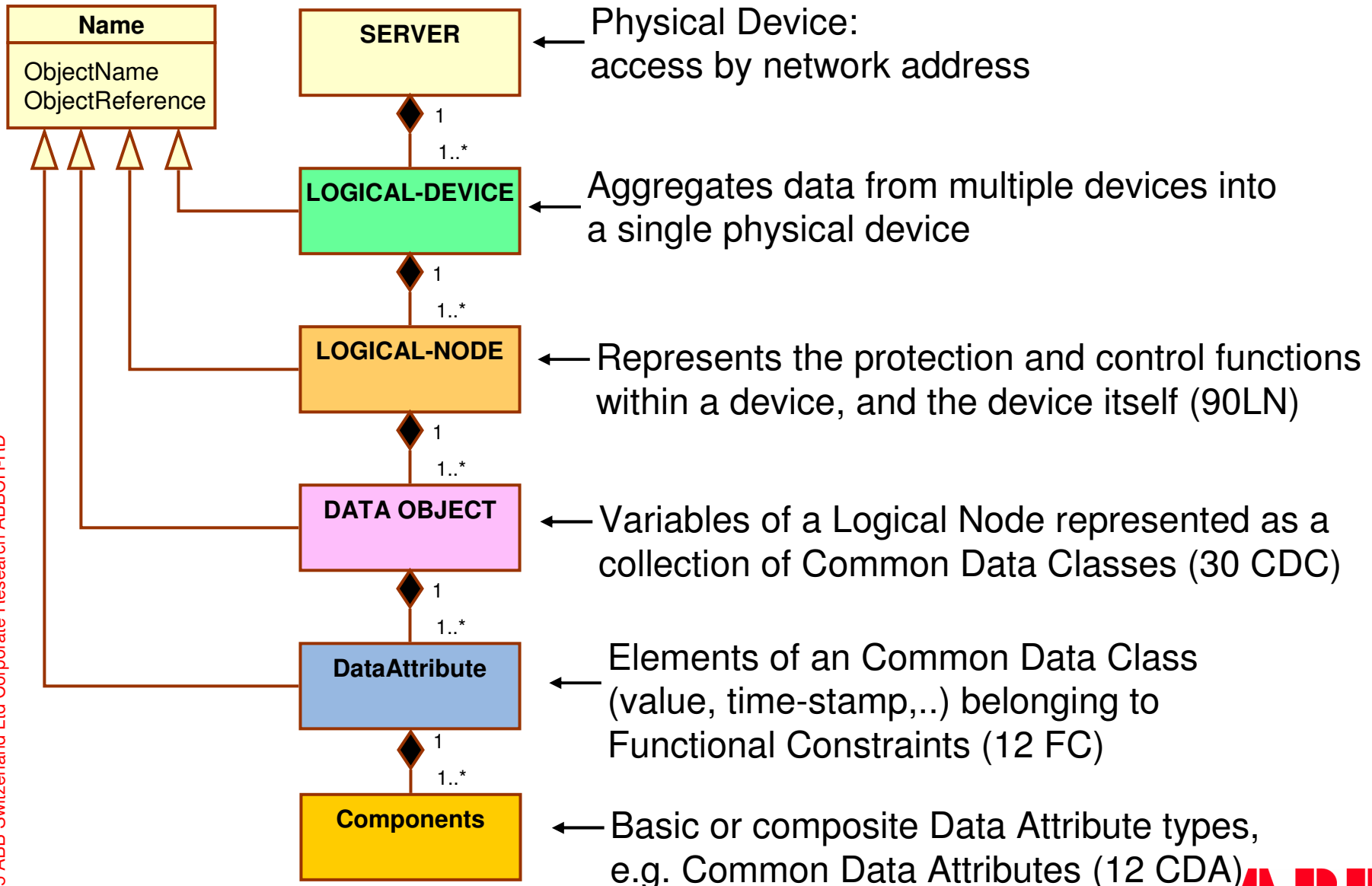
IEC 61850-7-4 defines 90 Logical Nodes, divided into 13 groups (L,P,R,C,G,...)

Each LN consists of Data Object (DATA) grouped in 5 categories  
general, settings, status, command and measure

Each Data Object consists of Data Attributes (DA) that belong to one of 30  
CDC (common data classes) defined in IEC 61850-3.

Each CDC consists of other CDC or of components.

## Simplified IEC 61850 object model



The IEC 61850 supports two kinds of traffic:

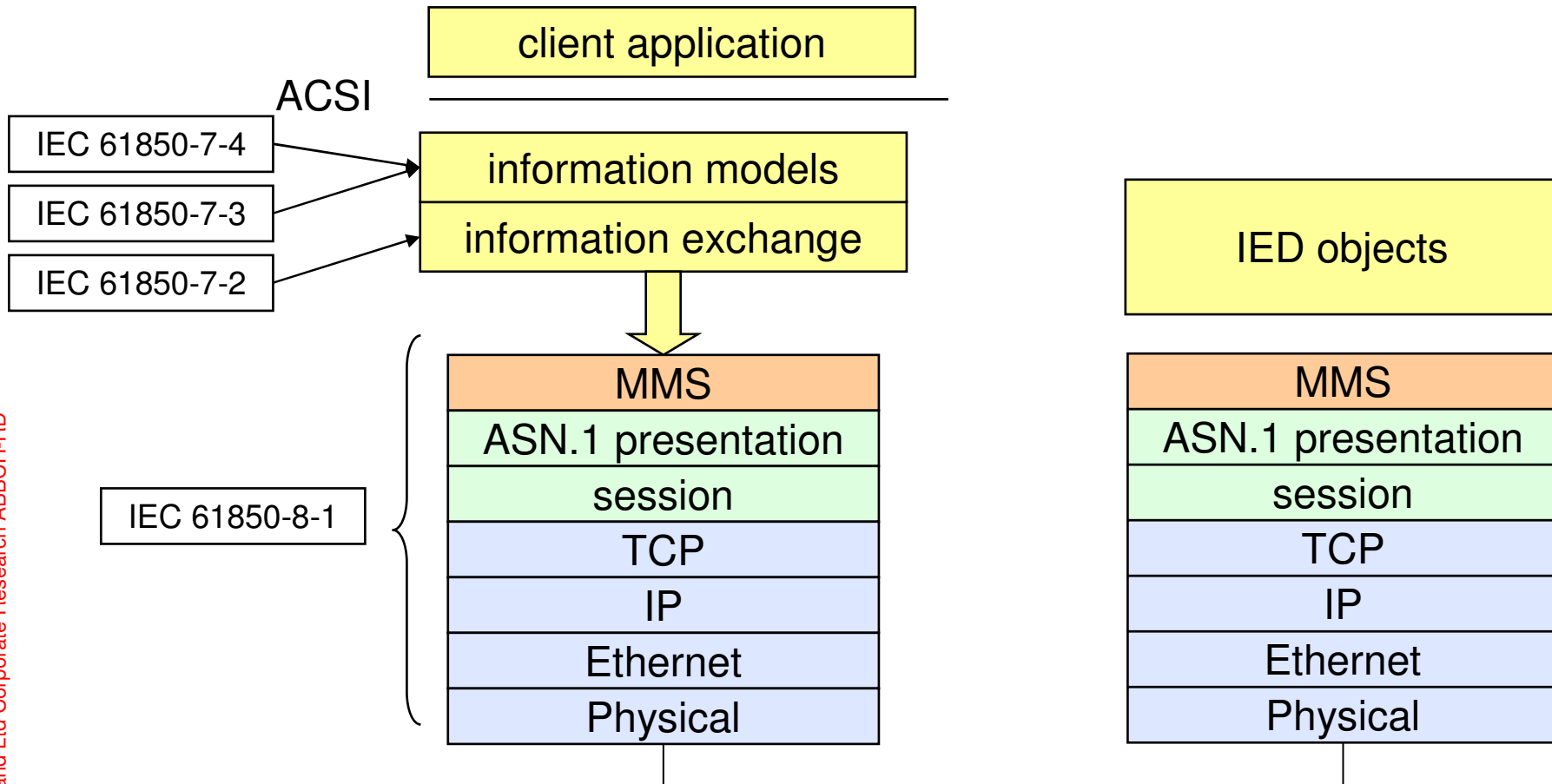
- 1) real-time traffic based directly on communication layer 2, GOOSE or Sampled Values. Encoding of these data is simplified.
- 2) sporadic traffic over TCP/IP – MMS using ASN.1 / BER encoding.
- 3) The sporadic traffic supports the object model described



Datasets are lists of data attributes that are handled as a whole.

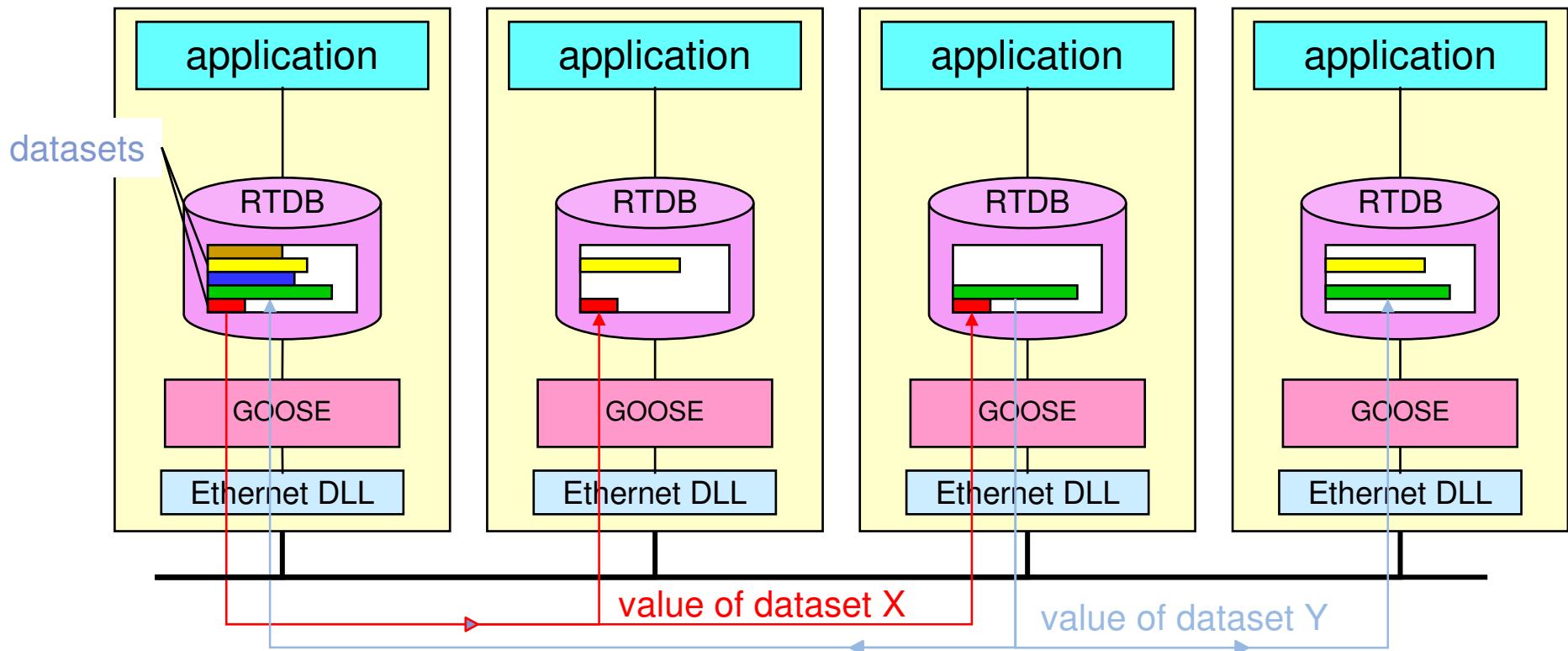
For instance, all Switch positions can be put into a dataset.

A dataset can be defined

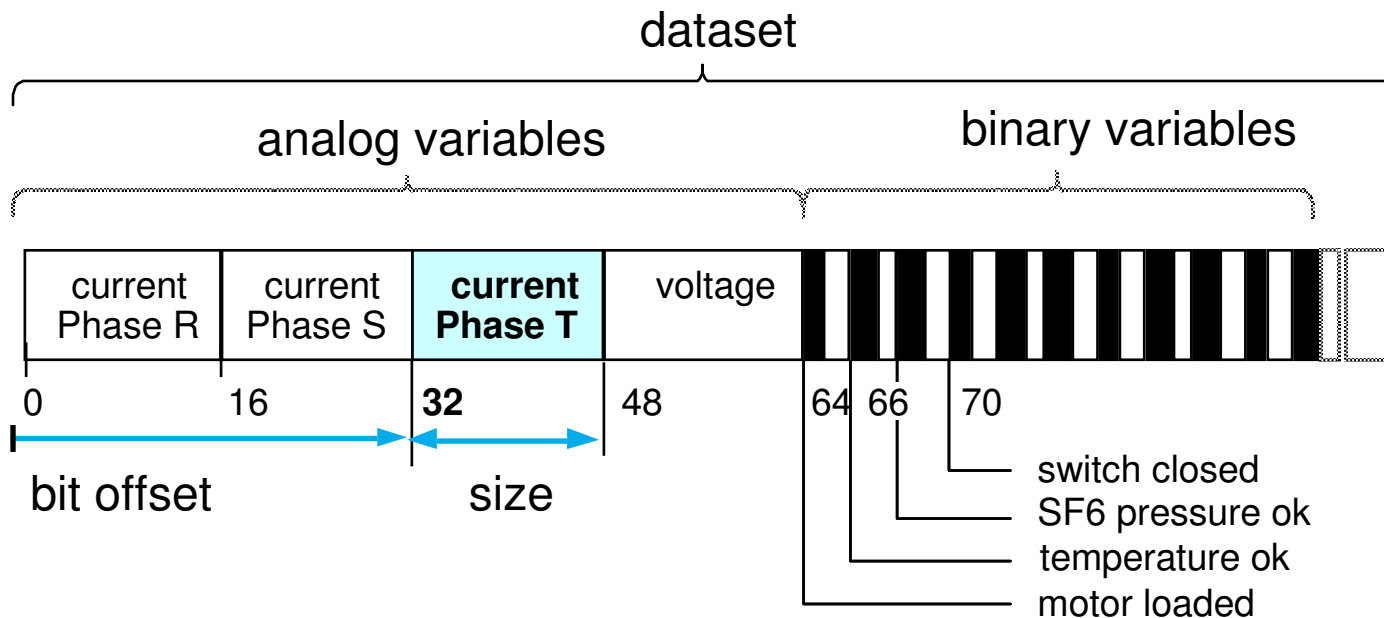


## GOOSE traffic

GOOSE exchanges real-time data on the publisher / subscriber principle:  
An application reads and writes its real-time database, that is organized as datasets.  
Each real-time database contains a subset of all datasets on the network.  
Reading or writing the datasets causes no immediate network traffic.  
The GOOSE protocol refreshes the data bases by broadcasting the dataset values that changed, several times in sequence.



It is economical to transport several variables in the same frame as a dataset.  
 A dataset is treated as a whole for communication and access.  
 A variable is identified within a dataset by its offset and its size  
 Variables may be of different types, types can be mixed.

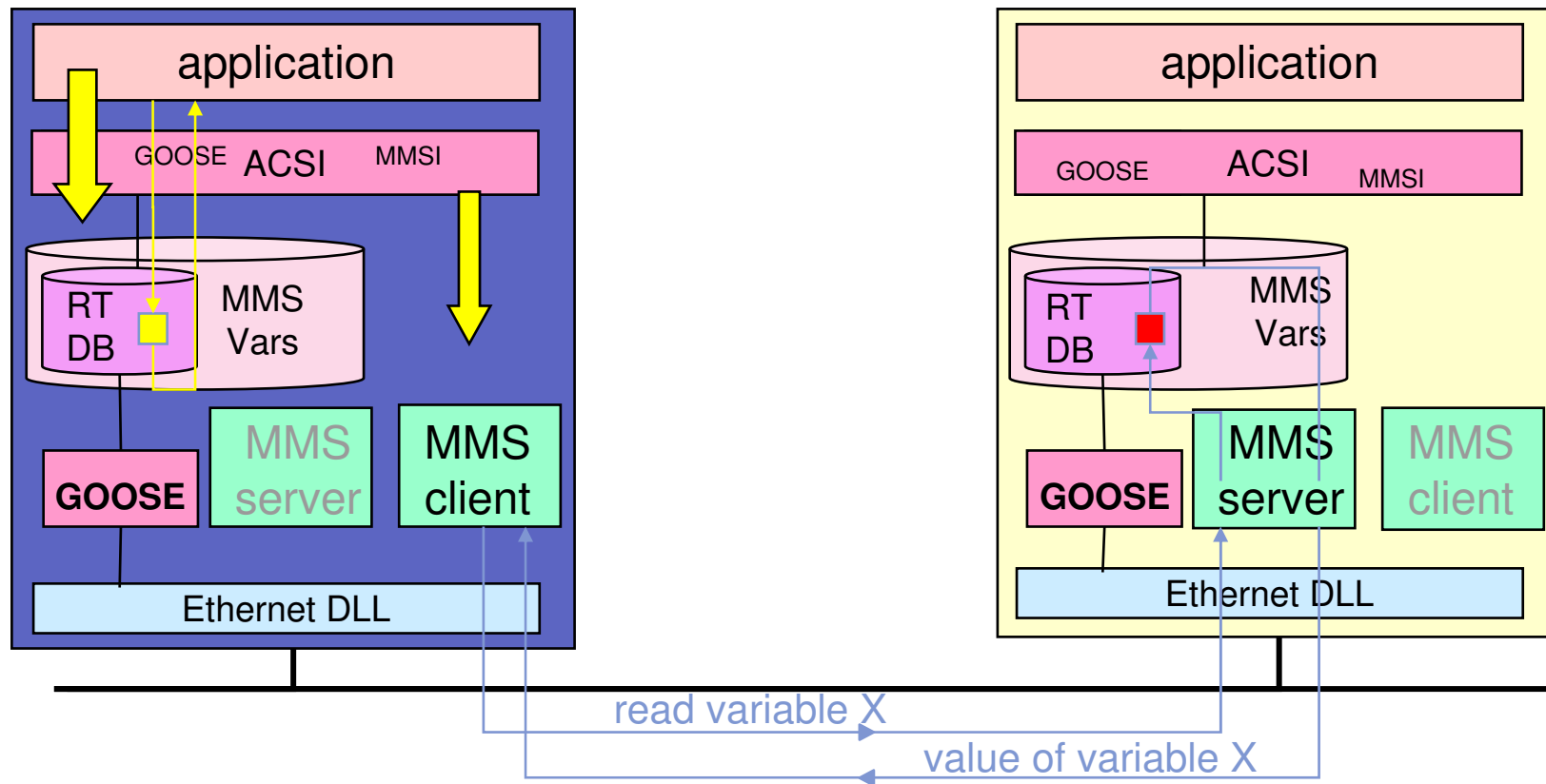


## MMS access to remote variables in 61850

An application can access a remote variable:

- through its MMS client (somewhat slow)
- through its local copy in the GOOSE RTDB.

An application can access a remote GOOSE RTDB only through its MMS client



## MMS services in IEC 61850

IEC 61850 Object	MMS Object	MMS Services
Server	Application Process VMD	Initiate Conclude Abort Reject Cancel Identify
Logical Nodes and Data	Named Variable Objects	Read Write InformationReport GetVariableAccessAttribute GetNameList
Data Sets	Named Variable List Objects	GetNamedVariableListAttributes GetNameList DefineNamedVariableList DeleteNamedVariableList GetNameList Read Write InformationReport
Logs	Journal Objects	ReadJournal InitializeJournal GetNameList
Logical Devices	Domain Objects	GetNameList GetDomainAttributes StoreDomainContents
Files	Files	FileOpen FileRead ObtainFile FileClose FileDirectory FileDelete

Control blocks define, how and when the data is transferred

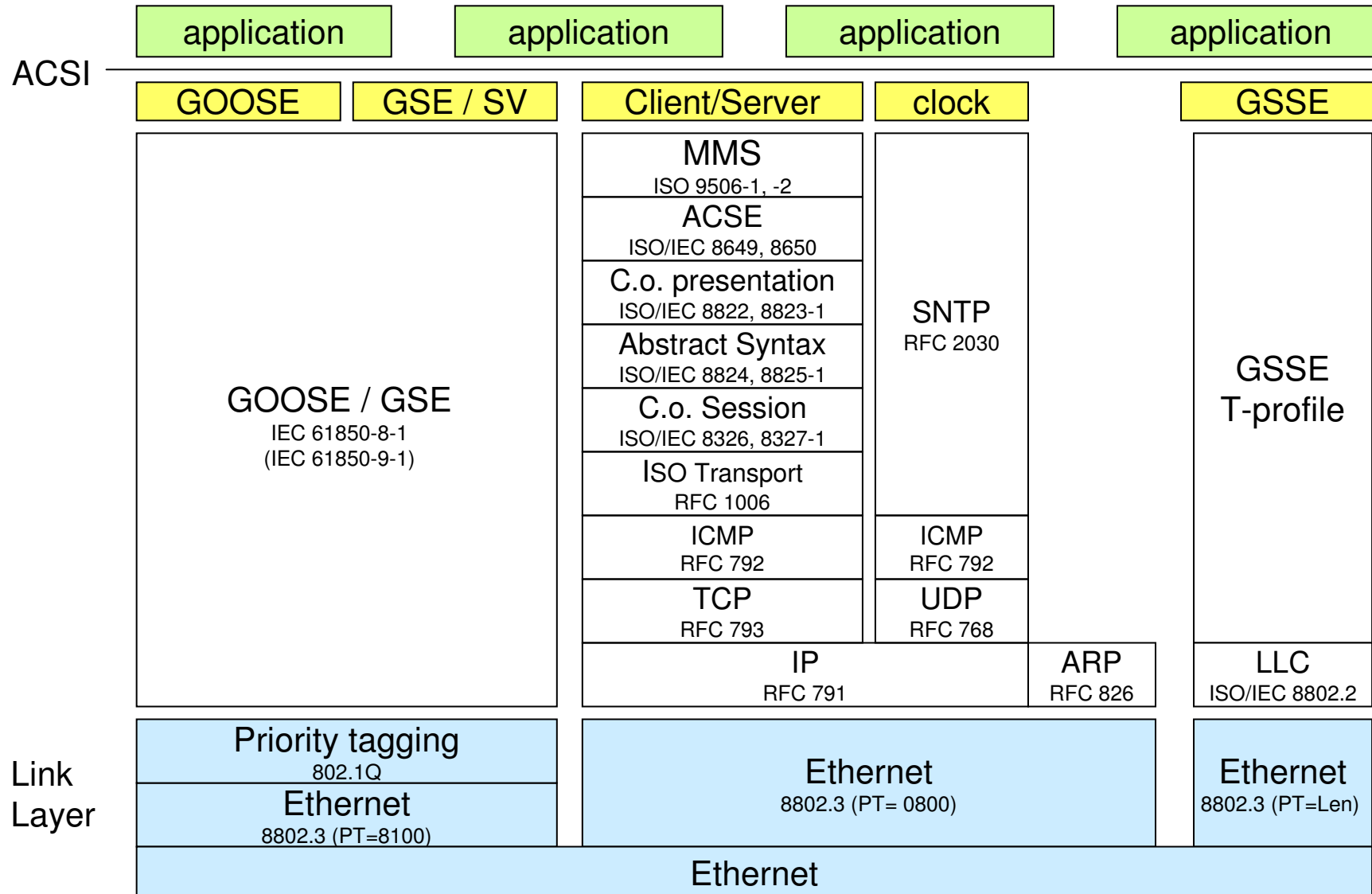
Reports: at data / quality change, changed data only, or periodically

GSE: immediate at some change, else periodically; always whole set

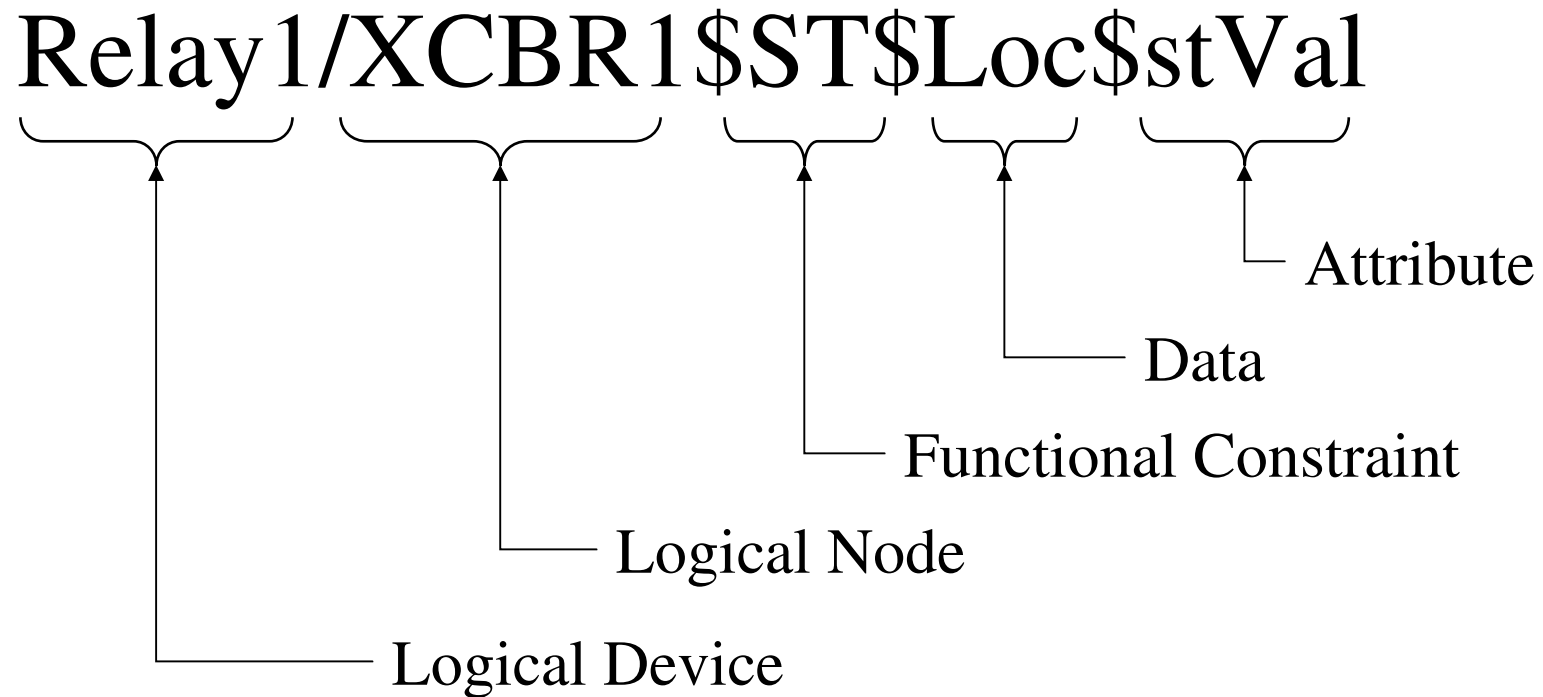
Sampled Values (SV, SMV): periodically

Log: stored at change, changed data only; fetched when needed

IEC 61850 stack (detail)







**K03/Q0CSWI**

**K03/Q0CSWI\$ST**

K03/Q0CSWI\$ST\$Pos

K03/Q0CSWI\$ST\$Pos\$stVal

K03/Q0CSWI\$ST\$Pos\$q

K03/Q0CSWI\$ST\$Pos\$t

K03/Q0CSWI\$ST\$Pos\$origin\$orCat

K03/Q0CSWI\$ST\$Pos\$origin\$orIdent

**K03/Q0CSWI\$SV**

K03/Q0CSWI\$SV\$Pos

K03/Q0CSWI\$SV\$Pos\$subEna

K03/Q0CSWI\$SV\$Pos\$subVal

K03/Q0CSWI\$SV\$Pos\$subQ

K03/Q0CSWI\$SV\$Pos\$subID

**K03/Q0CSWI\$CO**

K03/Q0CSWI\$CO\$Pos

K03/Q0CSWI\$CO\$Pos\$ctlVal

K03/Q0CSWI\$CO\$Pos\$origin\$orCat

K03/Q0CSWI\$CO\$Pos\$origin\$orIdent

K03/Q0CSWI\$CO\$Pos\$T

K03/Q0CSWI\$CO\$Pos\$Test

K03/Q0CSWI\$CO\$Pos\$Check

K03/Q0CSWI\$CO\$Pos\$InvokeID

K03/Q0CSWI\$CO\$Pos\$SID

**K03/Q0CSWI\$CF**

K03/Q0CSWI\$CF\$Pos

K03/Q0CSWI\$CF\$Pos\$ctlModel = sbo-with-enhanced-security

*MMS AA-Specific Named Variable for negative 7-2 control responses*

@/LastApplError

@/LastApplError\$CntrlObj

@/LastApplError\$Error

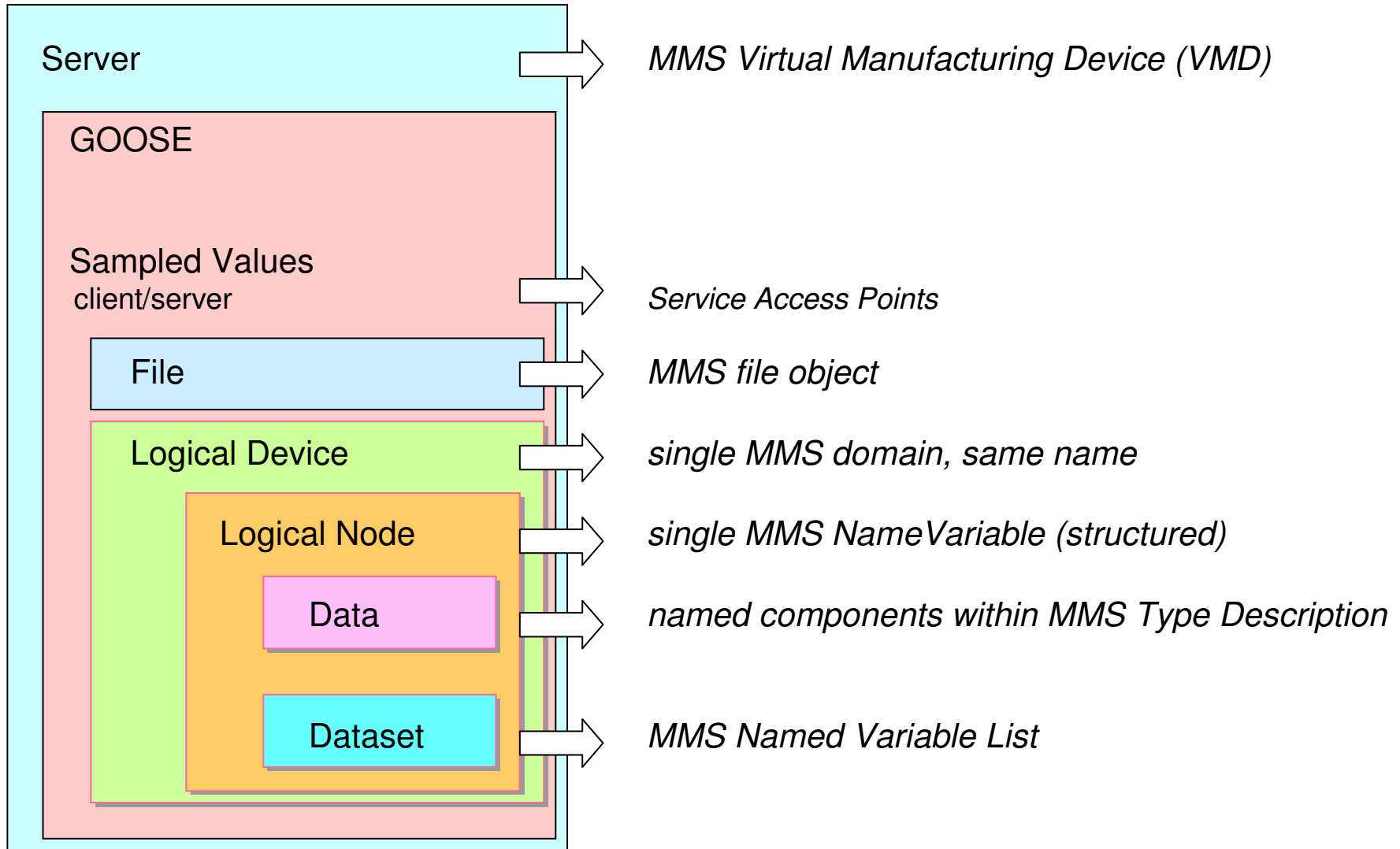
@/LastApplError\$InvokeID

@/LastApplError\$AddCause

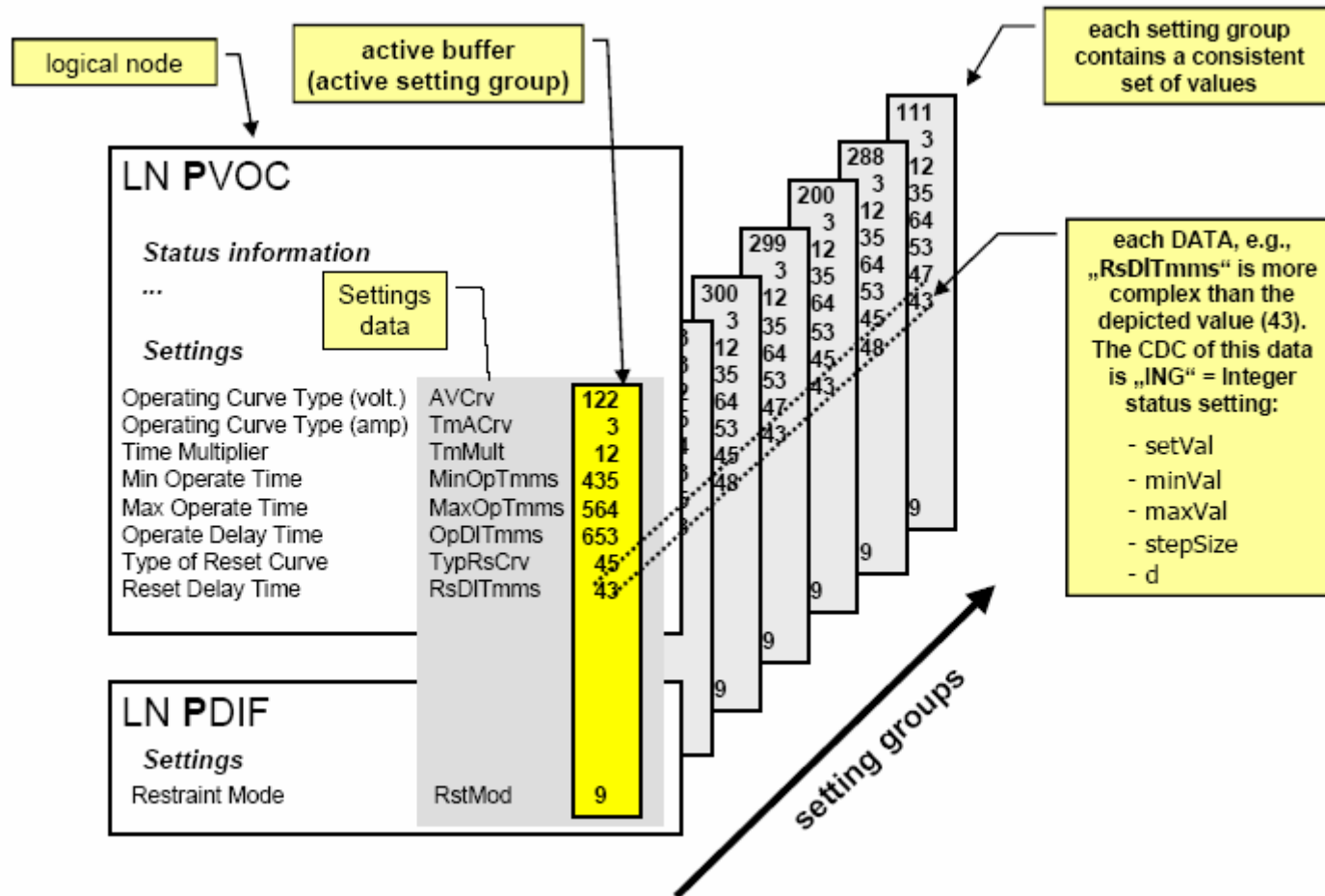
*defined in 7-2*

*defined in 8-1*

*no predefined names*



## Setting groups



A setting group is a set of parameters treated as a whole that can be edited and applied to a logical node.

# Complete Object Model

