

Hubert Kirrmann
ABBCH-RD.C1

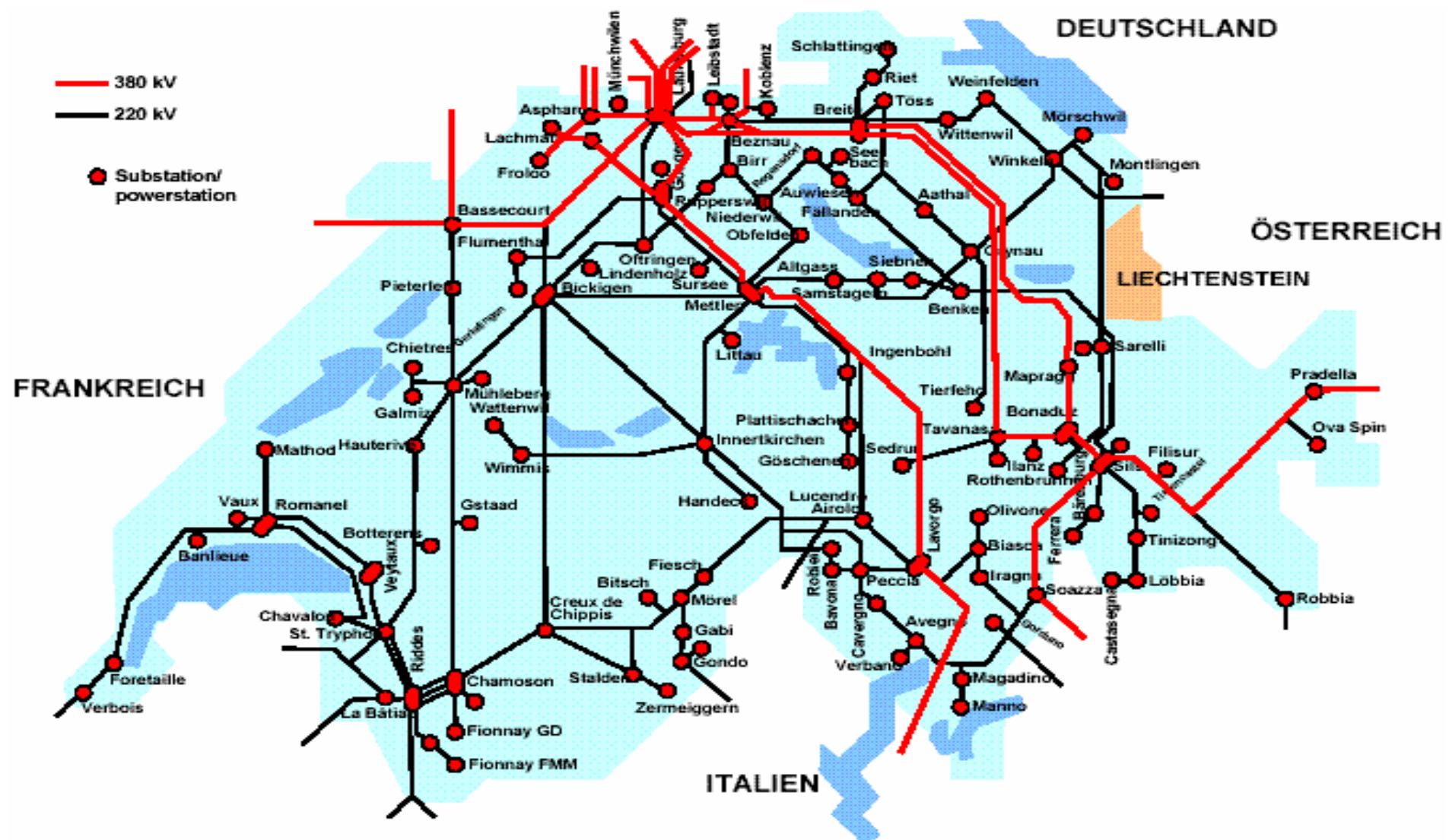
Introduction to IEC 61850 substation communication standard



communication
networks and
systems in
substations



Electrical Substations: nodes of the grid



Swiss transmission network



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

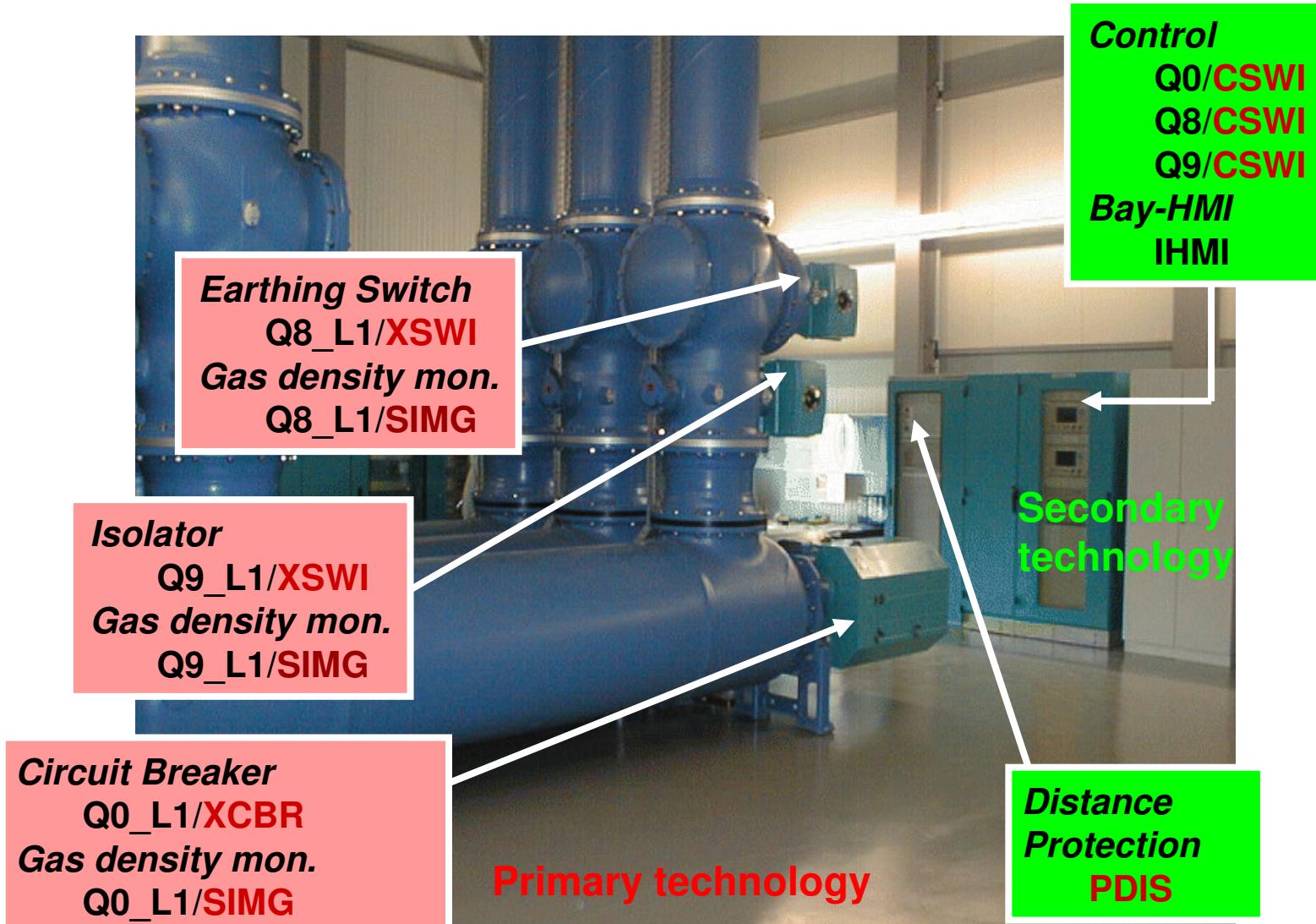
- incoming line (“feeder”)
 - connection between the buss bars
- etc.

Process objects (switchyard)

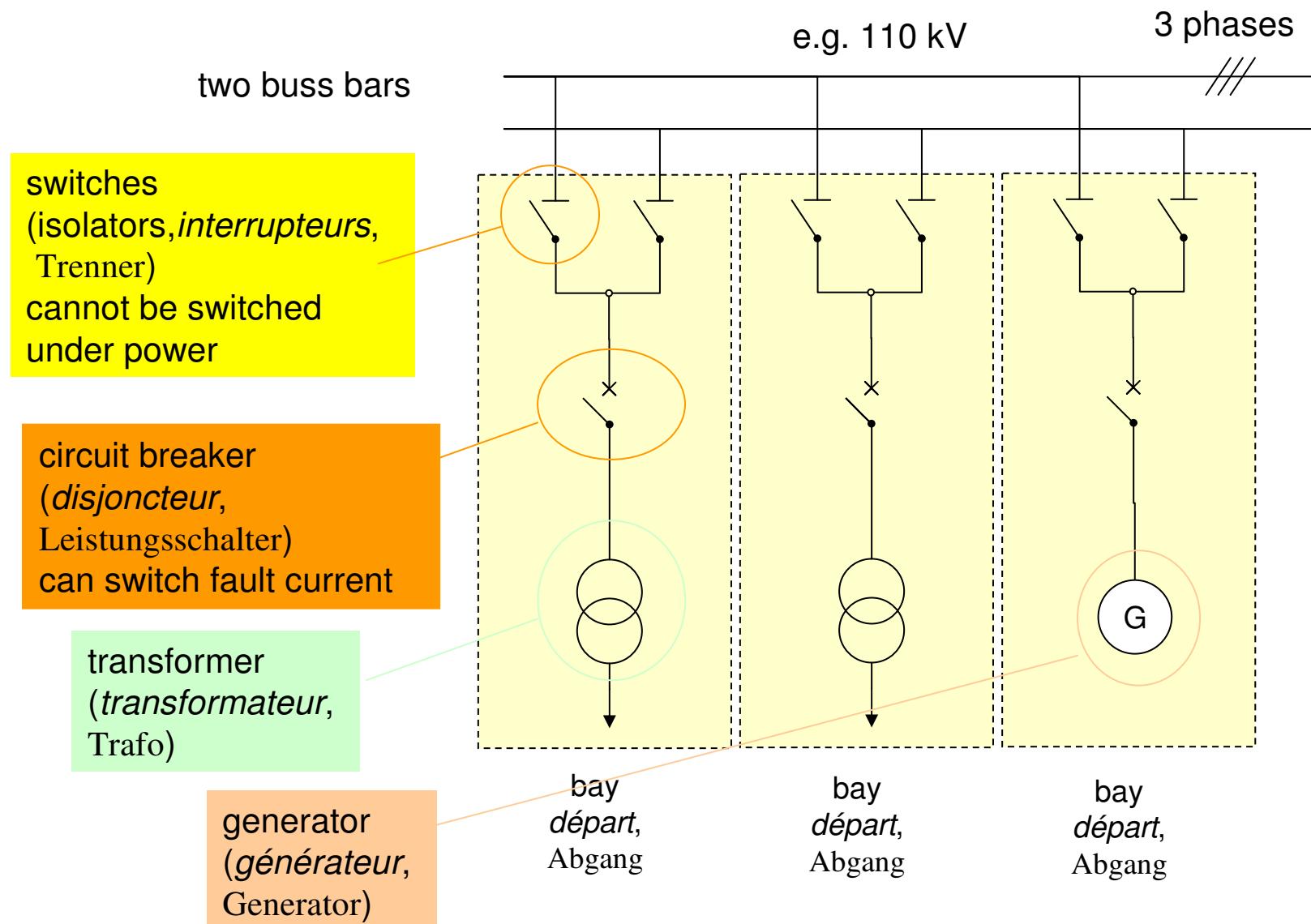
- breaker
 - transformer
- etc.

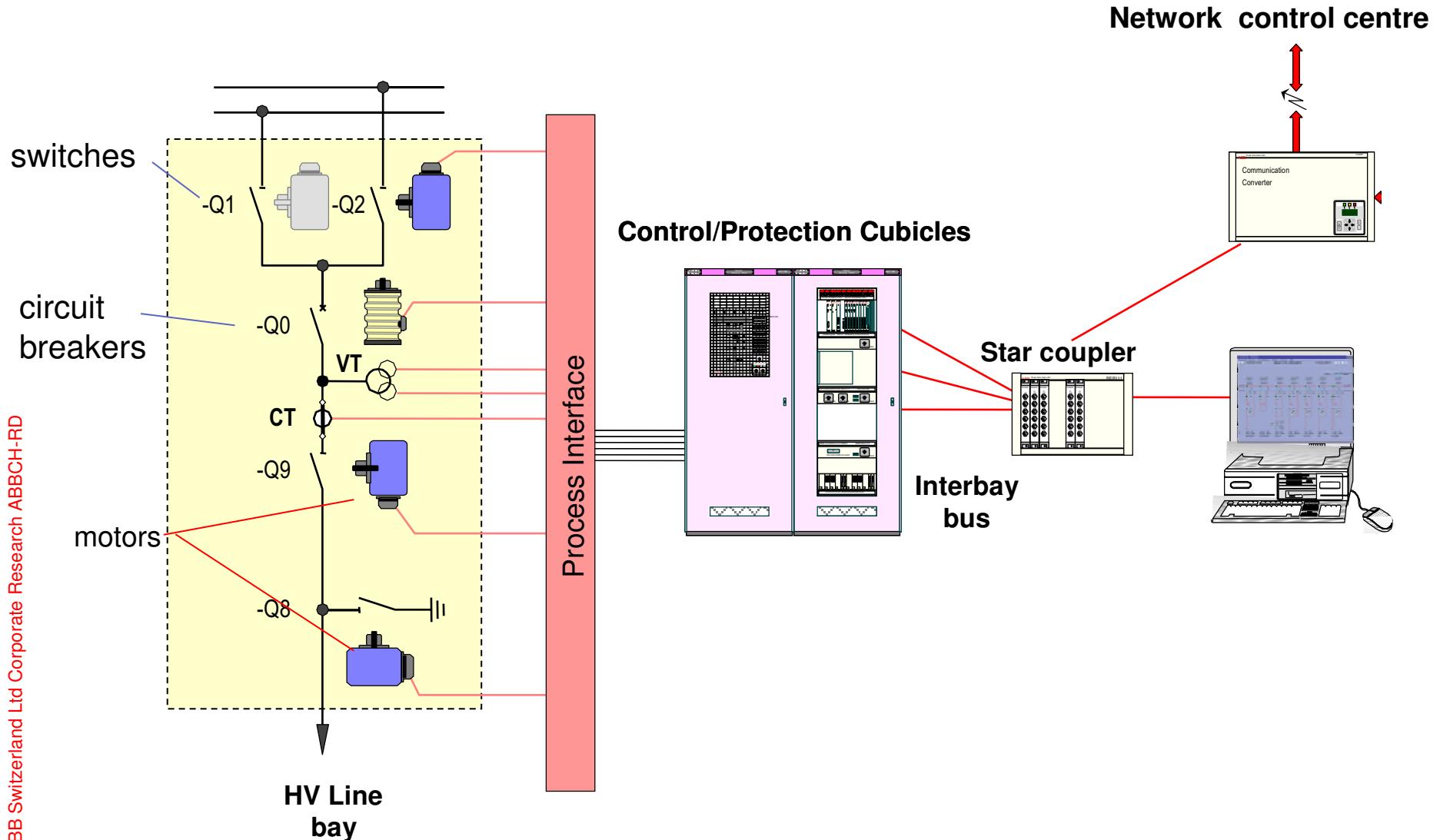
Primary equipment = switchyard hardware

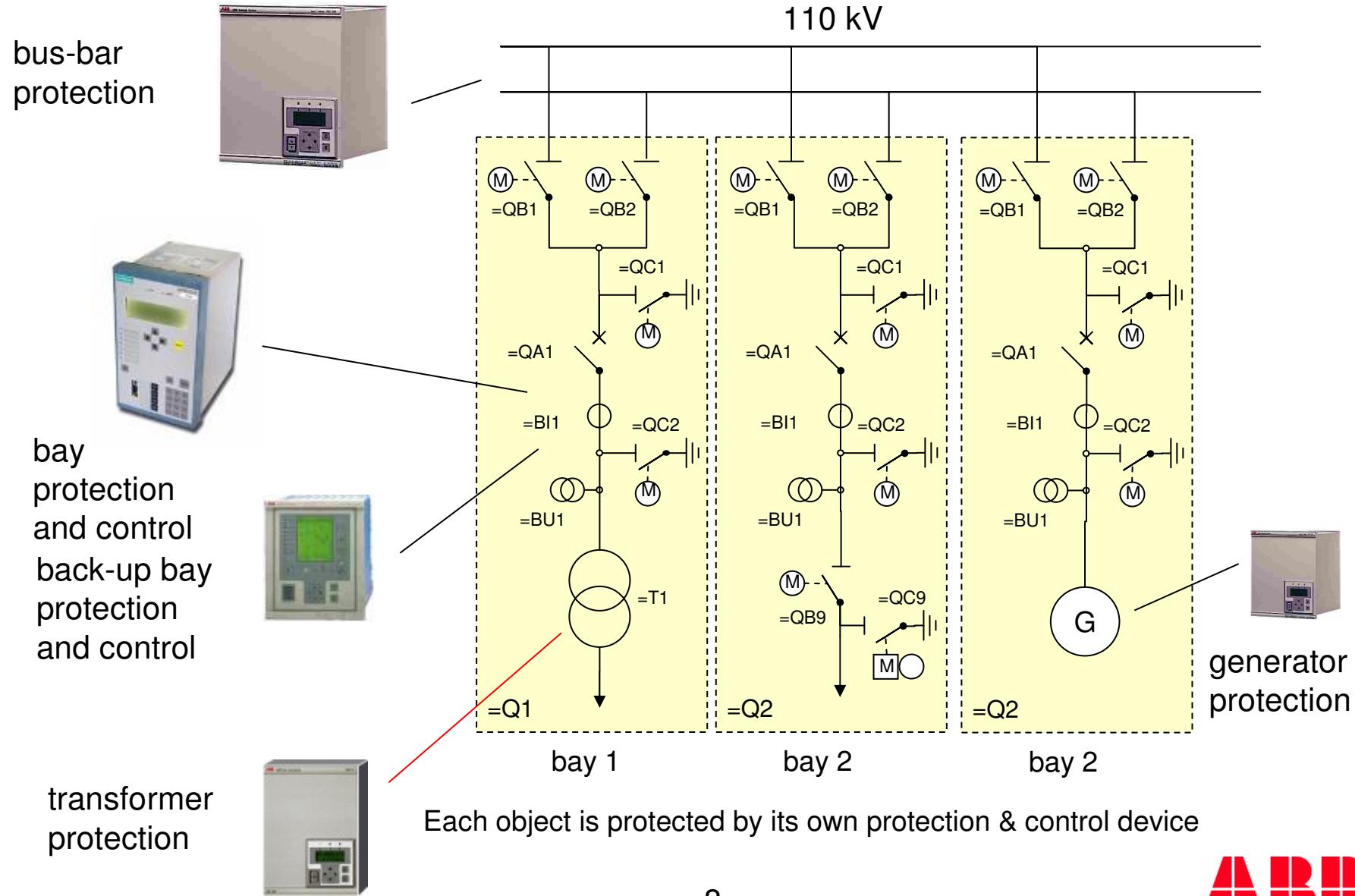
Secondary equipment = control, monitoring and protection devices



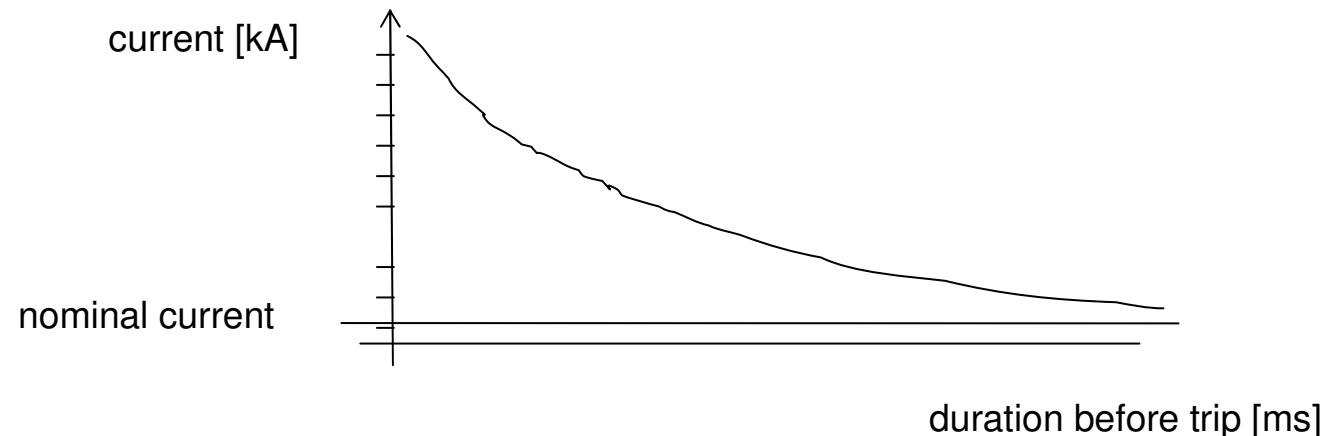
Principle substation: single line diagram





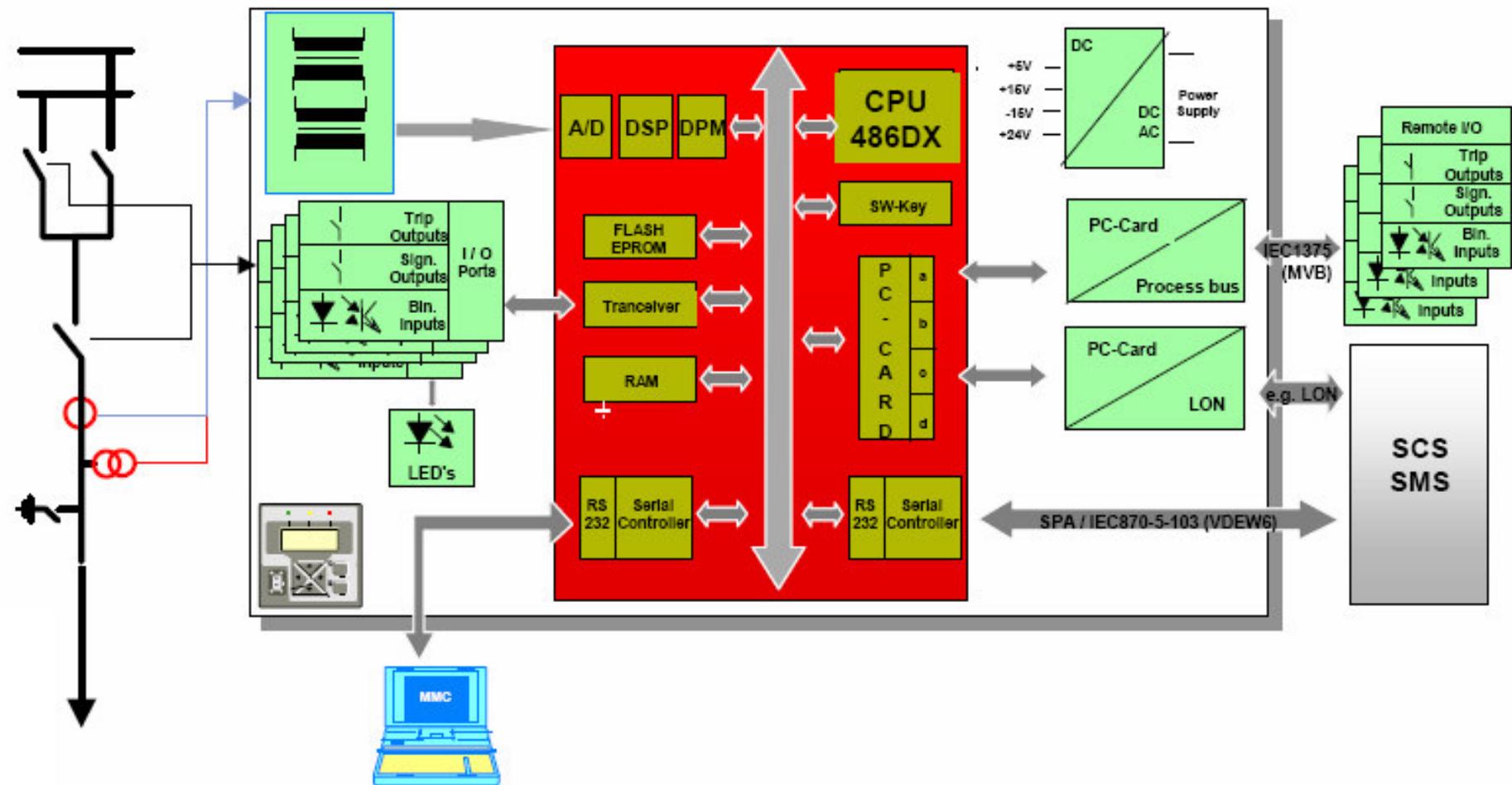


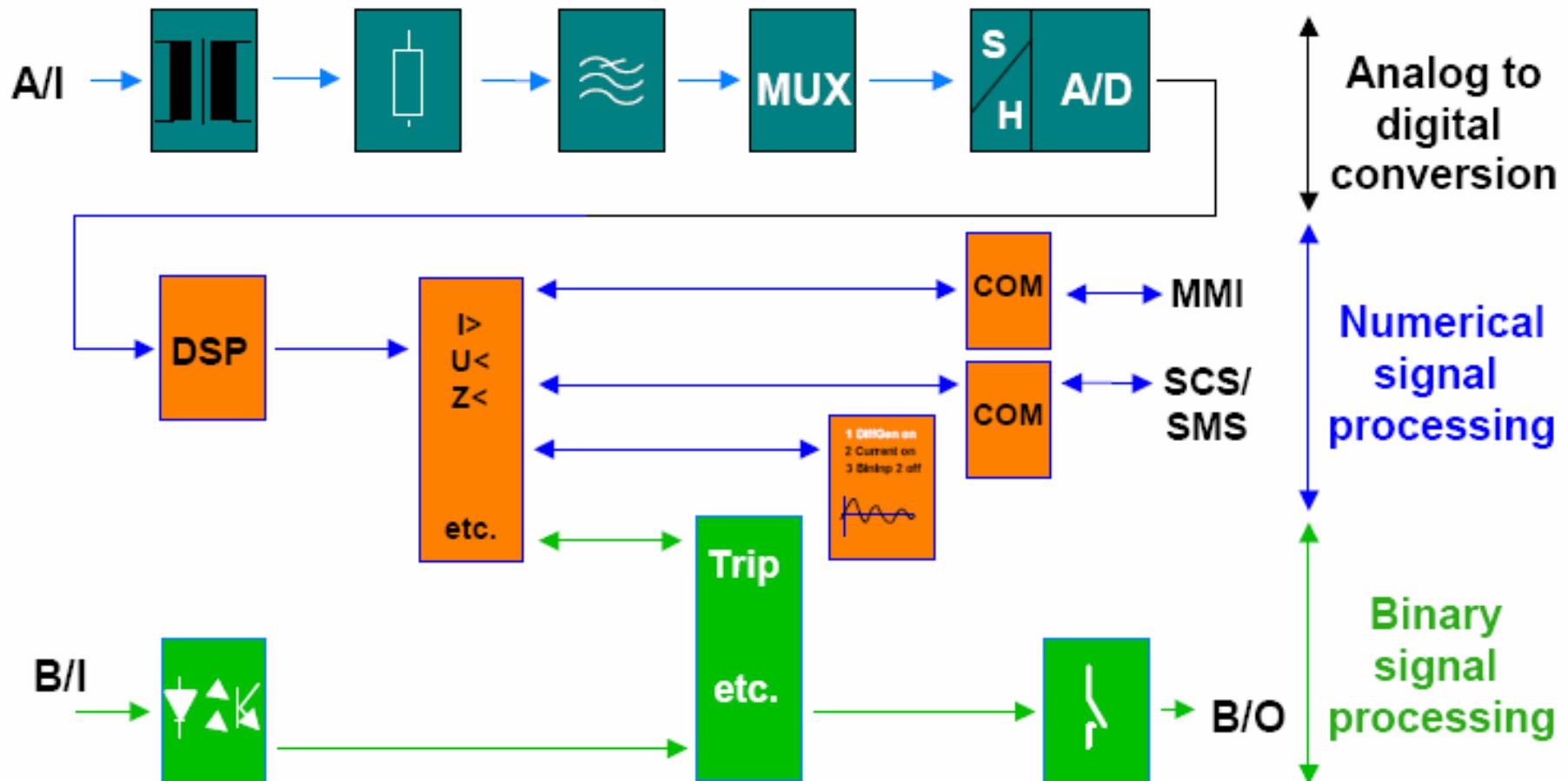
Example of protection function: overcurrent



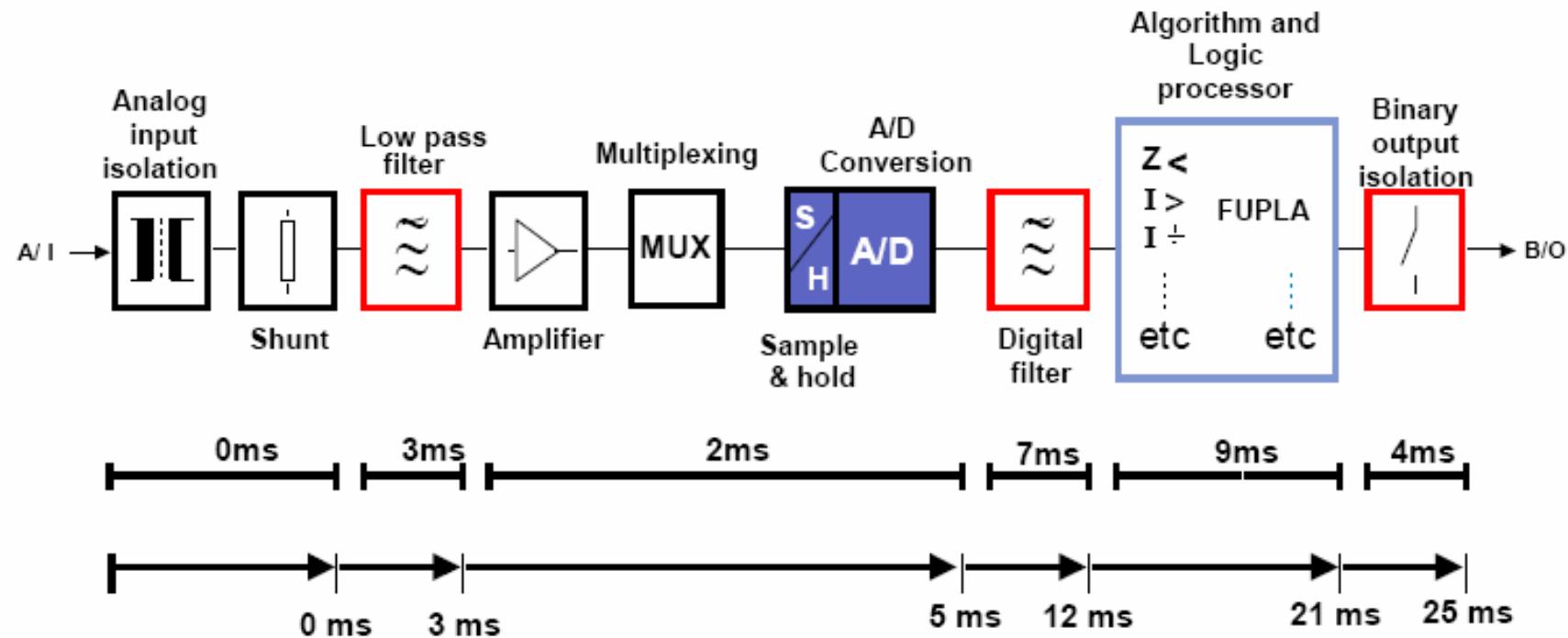
The protection function is adjusted with a number of parameters that are tuned for a specific substation and bay, the is called a *setting*.

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





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

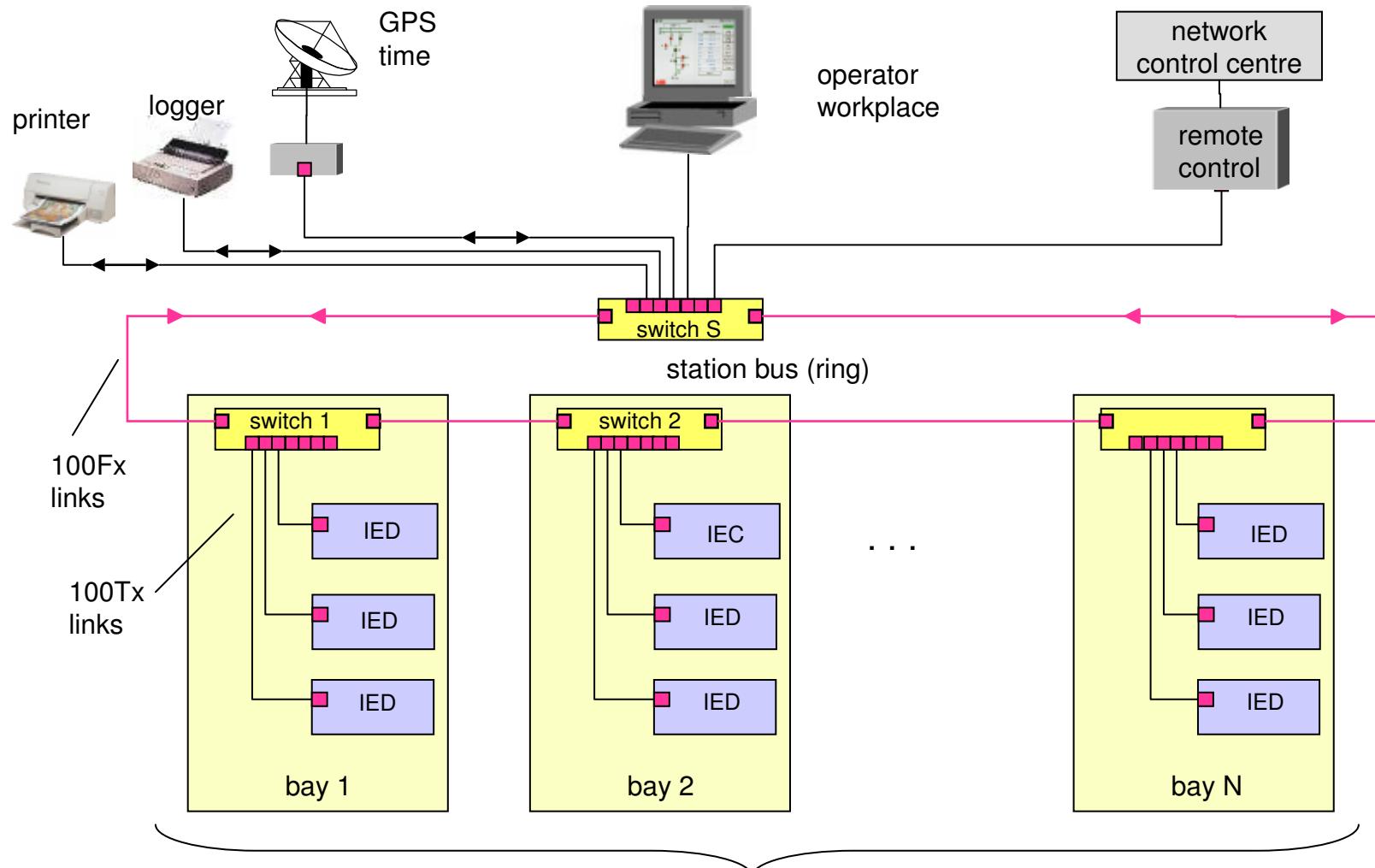
supervise the status of the primary and/or secondary equipment, disturbance recorder, sequence of events with resolution 1 ms

Control functions

allow a local or remote operator to operate the power (response time about of 1 s).

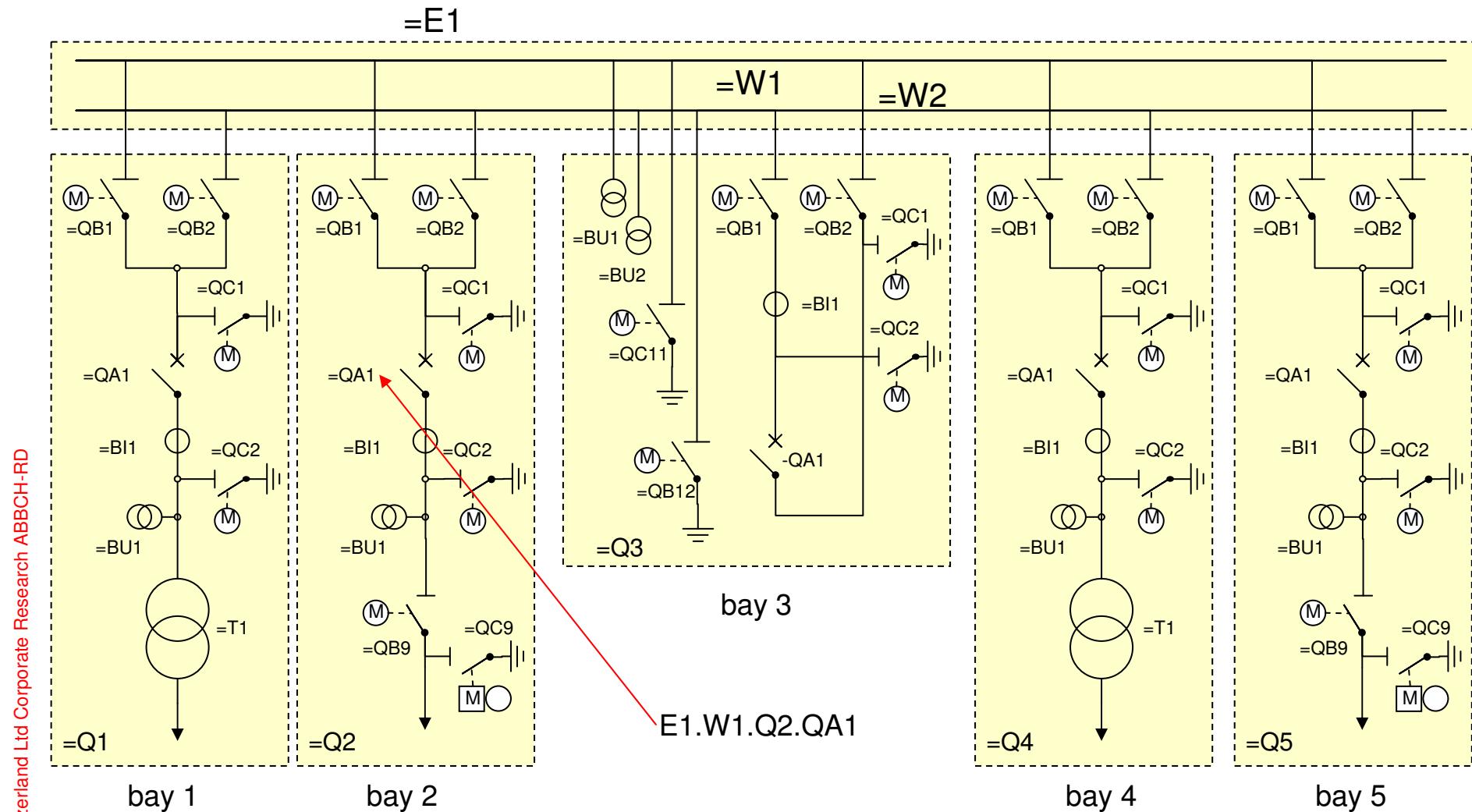
Automatic sequence functions execute sequence of operations, such as switch from one buss bar to the other (order of 100 ms)

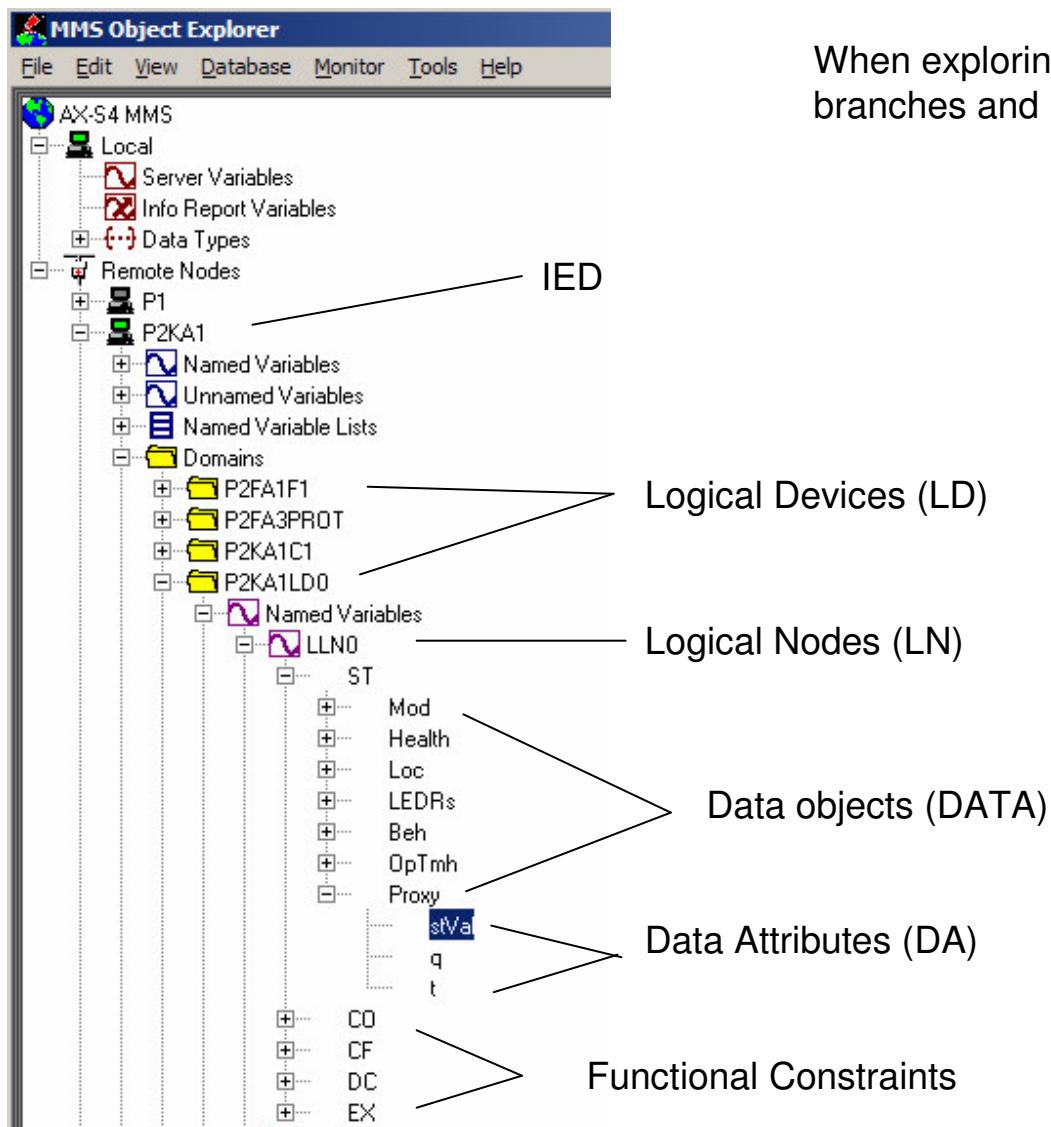
An IEC 61850 network



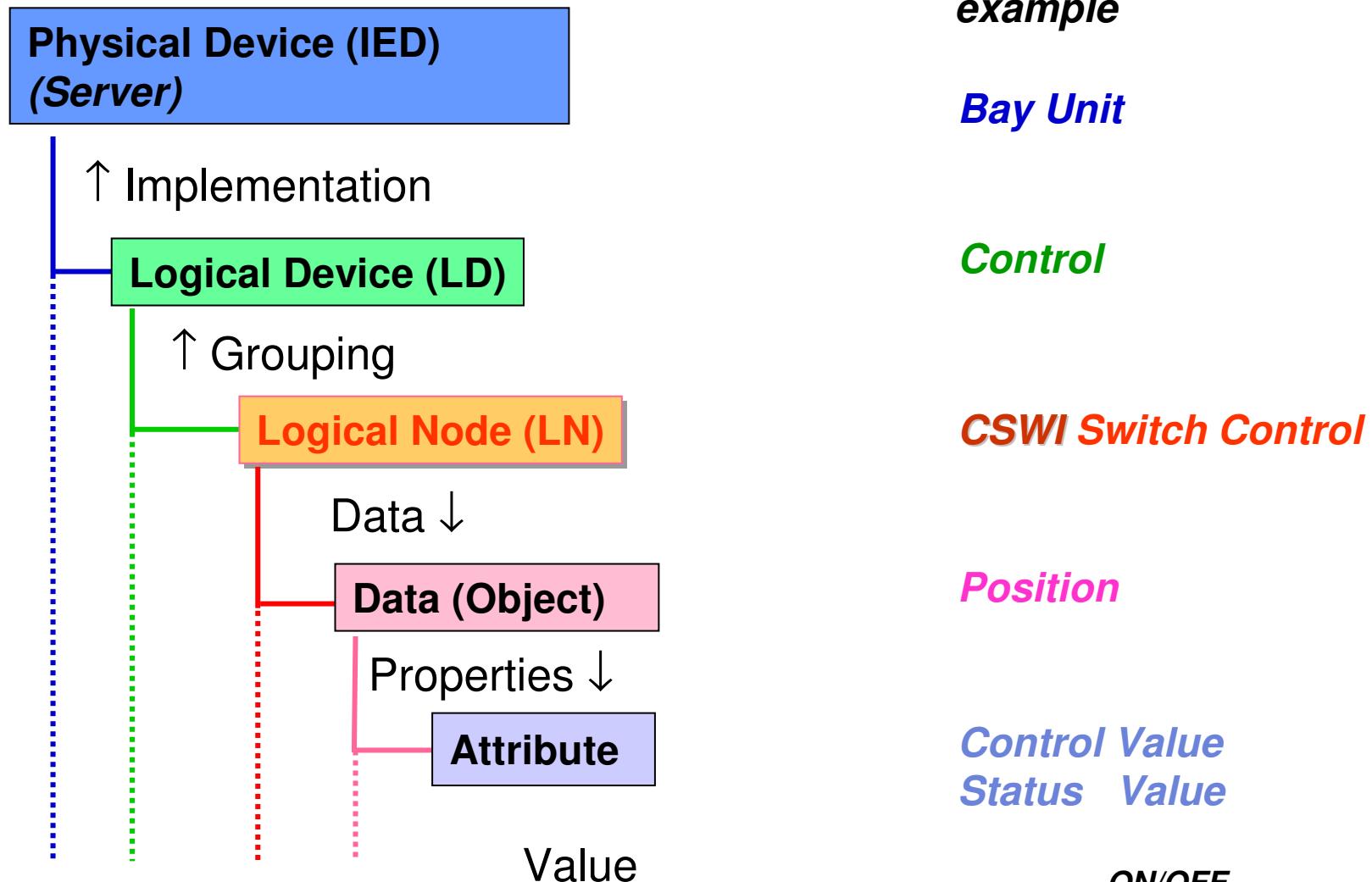
the structure of the network reflects the structure of the substation

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



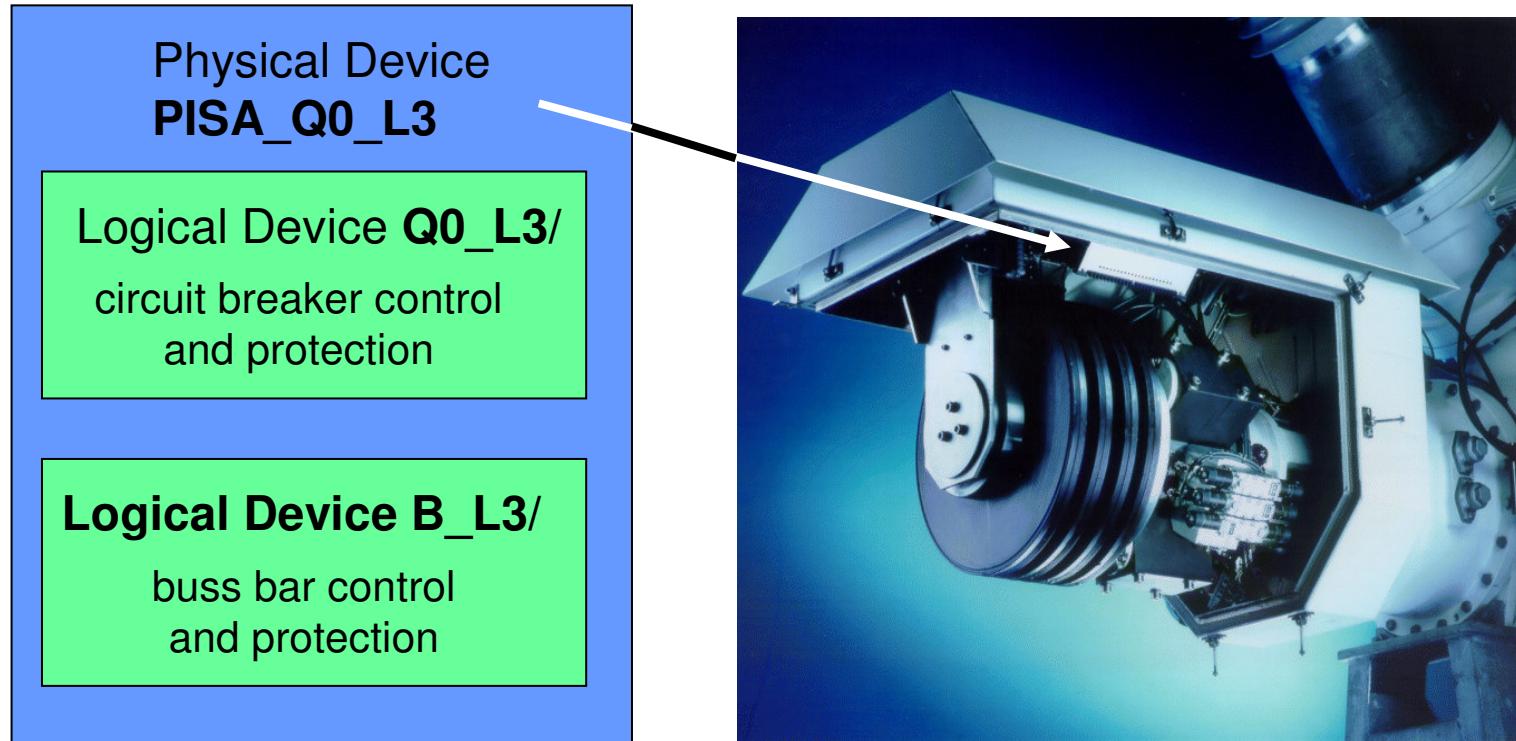


When exploring an IED, one finds a hierarchy of branches and leaves

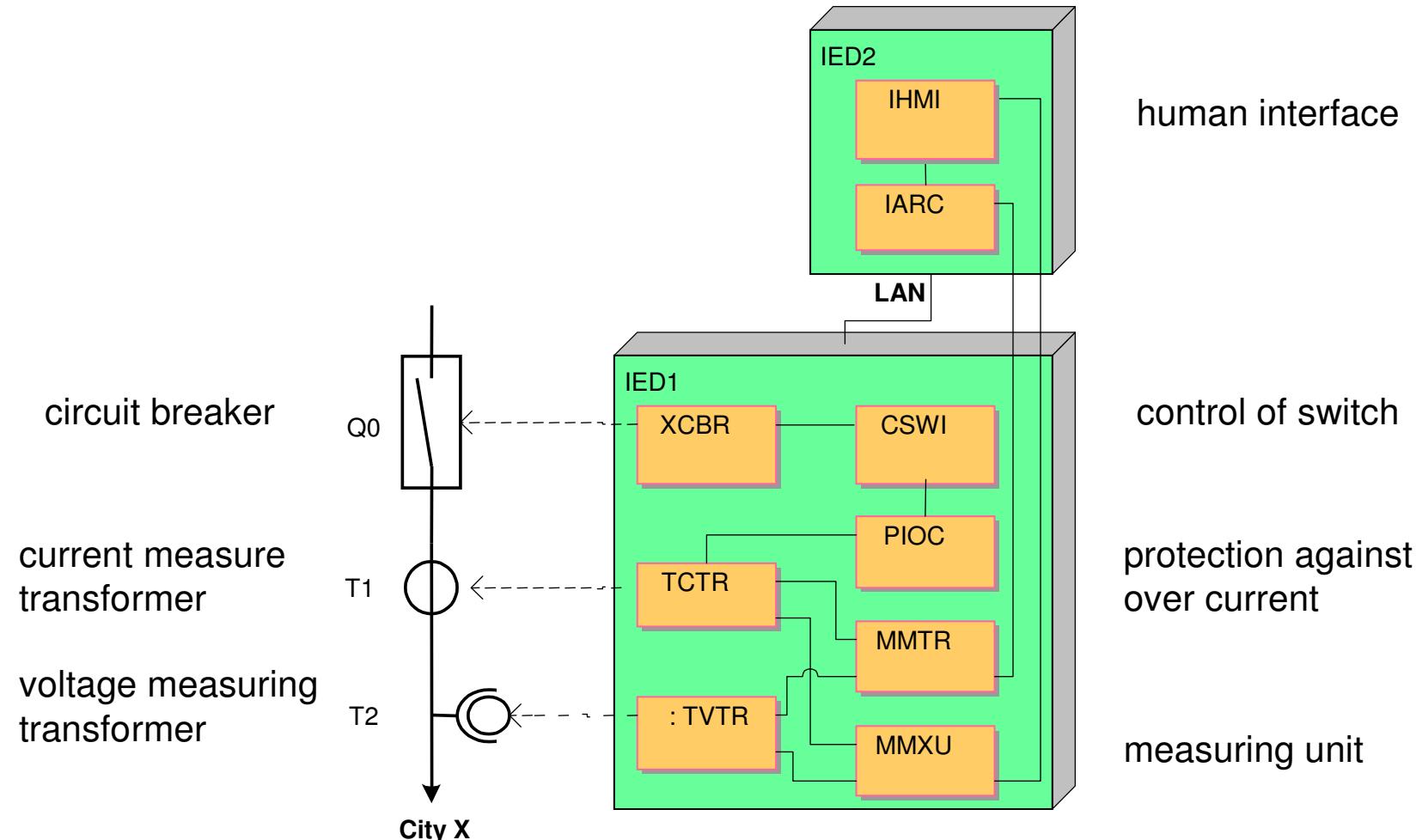


Each physical device (called an IED) can perform functions that was formerly performed by different protection or control devices.

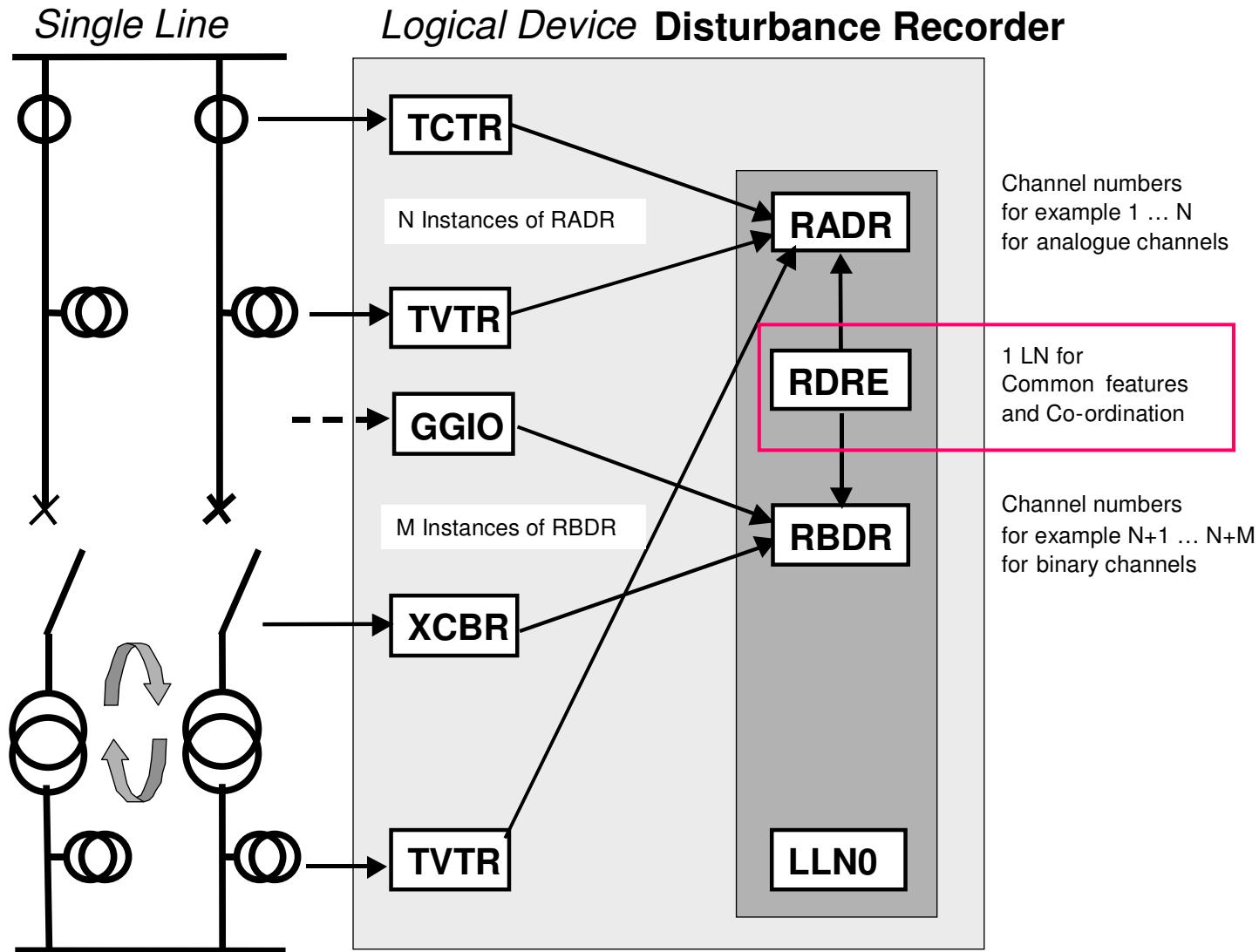
Those former devices are represented by Logical Devices within the physical device.



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

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

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	Oversupply
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

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 disconnector 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	Oversvoltage
64Tert	Zero-sequence oversvoltage 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

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	
LLN0	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.
LPHD1	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] Log [0..1] GOOSEControlBlock [0..n] GSSEControlBlock [0..n] MulticastSampledValues [0..n] UnicastSampledValues [0..n]	SGCB LOG GoCB GsCB MSVCB USVCB	Control block for settings
Services		
GetLogicalNodeDirectory		
GetAllDataValues		

The attributes of logical nodes are divided into:

DATA OBJECTS (application data)

DATA SETS (groups of data)

CONTROL BLOCKS (transmission and storage)

special components for Logical Node Zero (LLN0)

Let's start with Data Objects

Logical Node

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

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		
EEName	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		
POWCap	Point on wave switching capability	INS		
MaxOpCap	Operating capability when fully charged	INS	M	

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)

Basic Type

Common data
attribute type

only needed when
substitution is
possible

CDC =
DPC

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
HMV:	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

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			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_DLND_A_M
cdcName	VISIBLE STRING255	EX			AC_DLND_A_M
dataNs	VISIBLE STRING255	EX			AC_DL_N_M

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_DLNDAM
cdcName	VISIBLE STRING255	EX			AC_DLNDAM
dataNs	VISIBLE STRING255	EX			AC_DLNM

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_DLNDAM
cdcName	VISIBLE STRING255	EX			AC_DLNDAM
dataNs	VISIBLE STRING255	EX			AC_DLNM

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
i	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)

Common Data Attributes: e.g. Quality

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 leave has an associated functional constrain, that becomes part of its name.

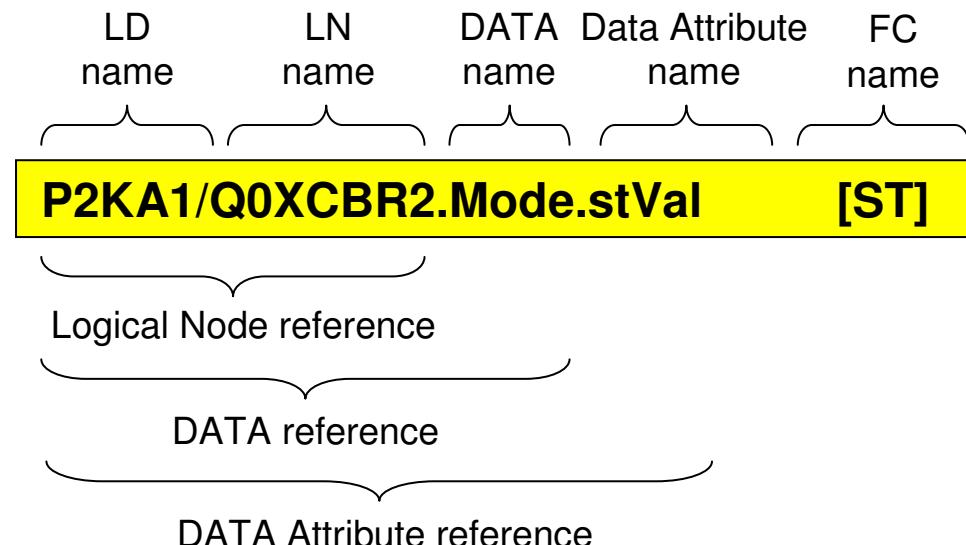
The functional constraints apply to each data attribute.

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

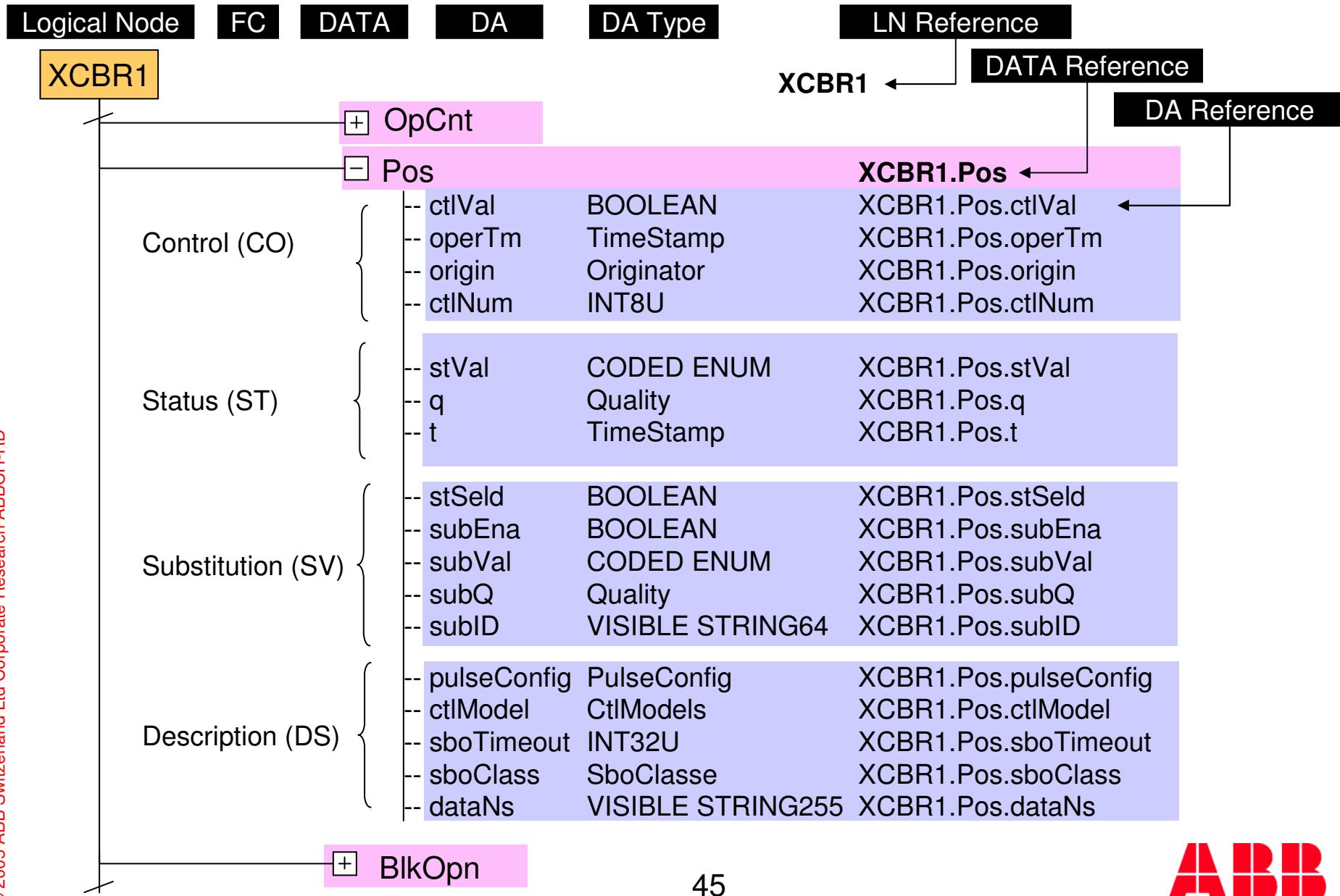
FC	Meaning	Services
ST MX	Process values: Status, Measurand	Read, substitute, report, log
CO SP	Process commands; binary, analog (Set Points)	Operate
SV	Substitution related	Substitute (read, write)
CF DC	Configuration, description	Read, Write (report, log)
SG SE	Parameters, in setting groups (SG: the 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

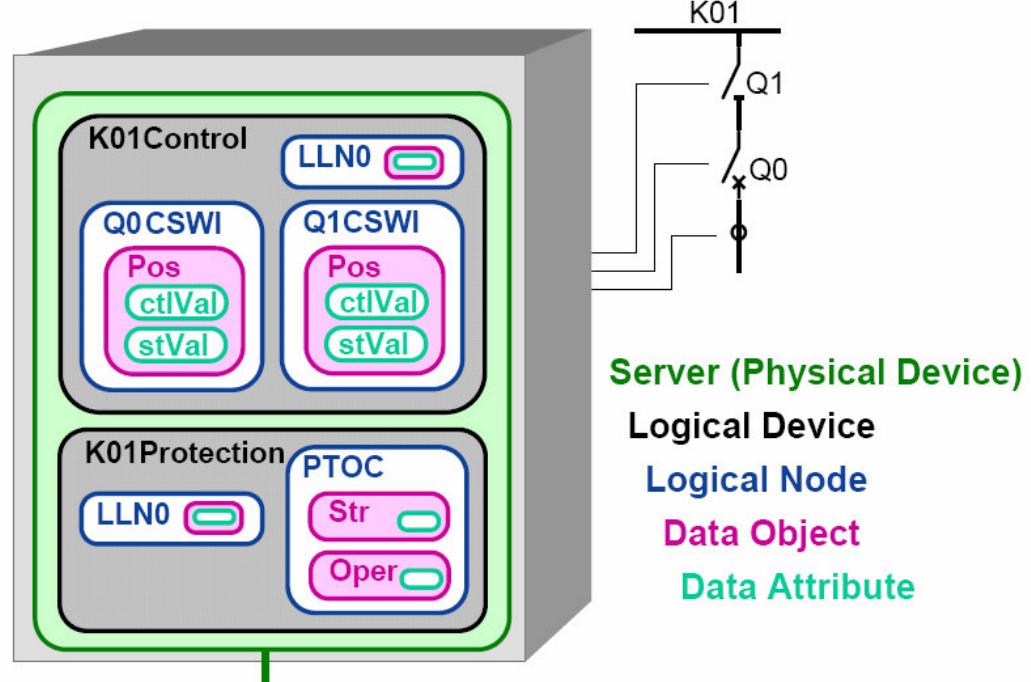
The name of the logical node is that of an instance of the standard logical nodes, unique in the Logical Device e.g. XCBR2

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



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





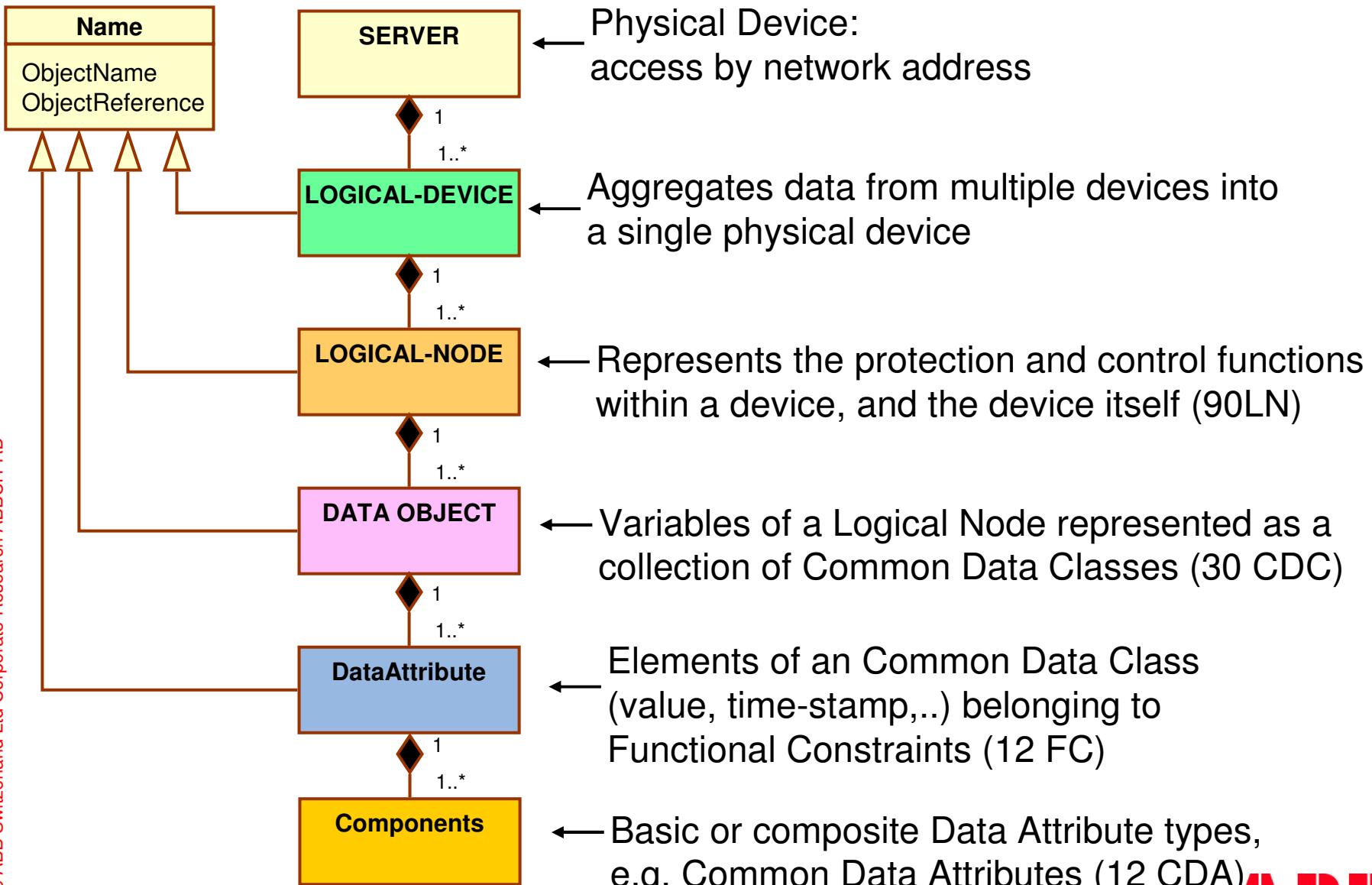
IEC 61850-7-4 defines 90 Logical Nodes, divided into 13 groups (L,P,R,C,G,...)

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



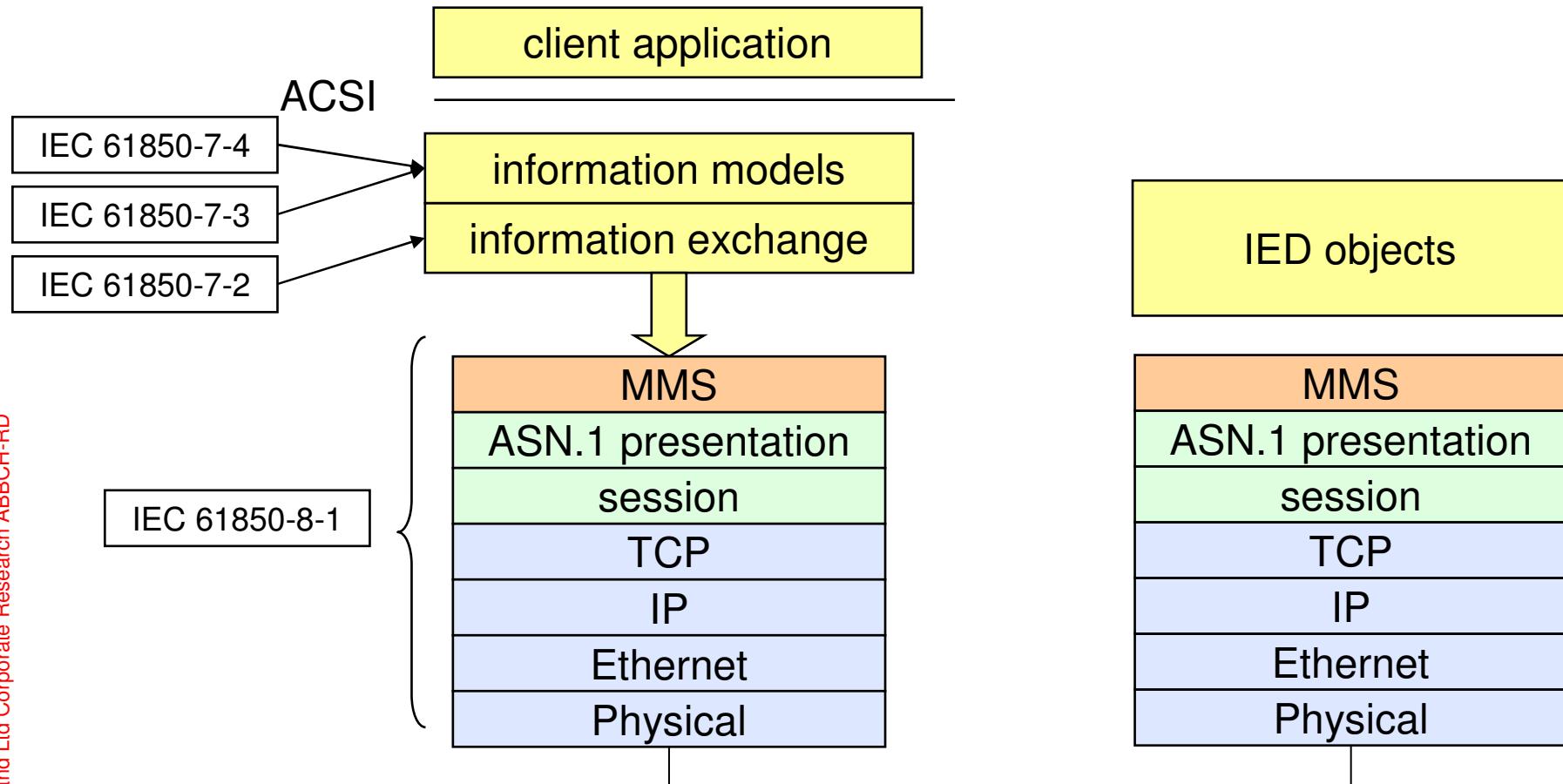
The IEC 61850 supports two kinds of traffic:

- 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

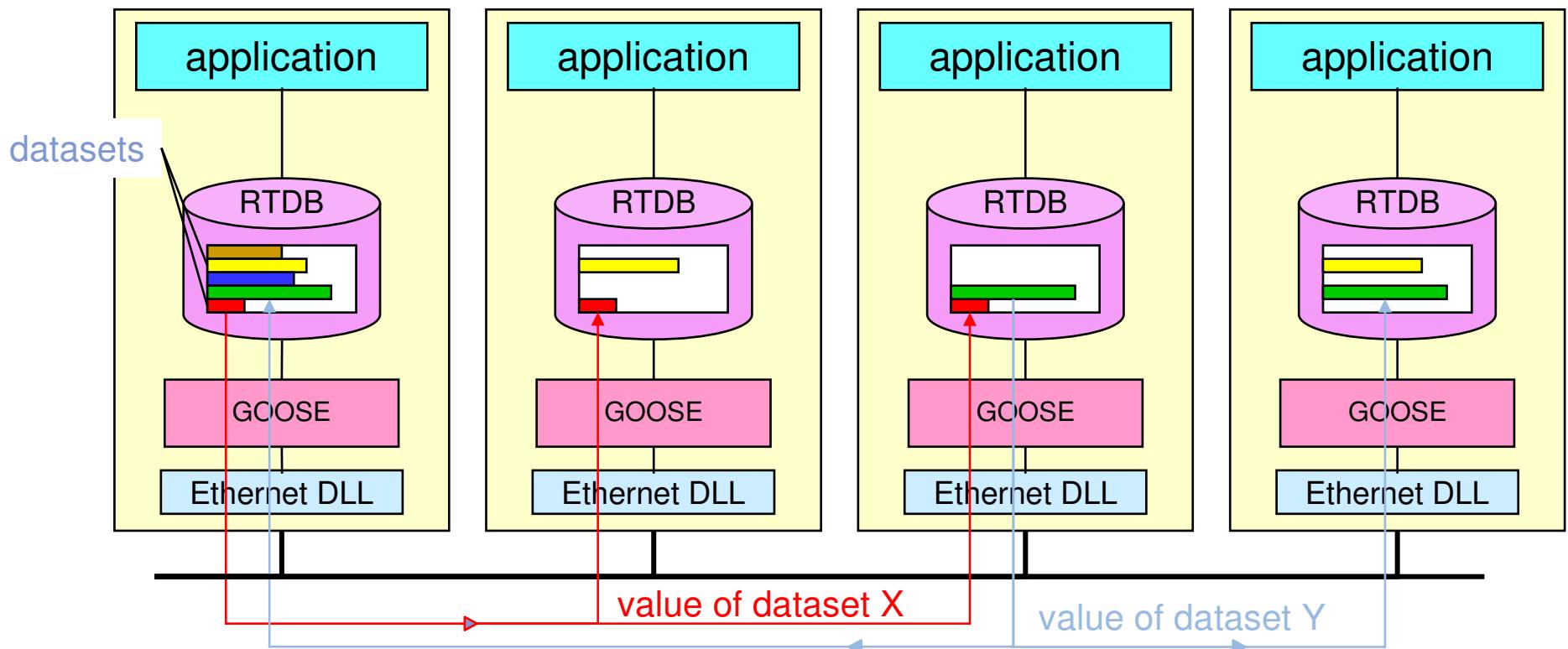
Datasets are lists of data attributes that are handled as a whole.

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

A dataset can be defined



GOOSE 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.

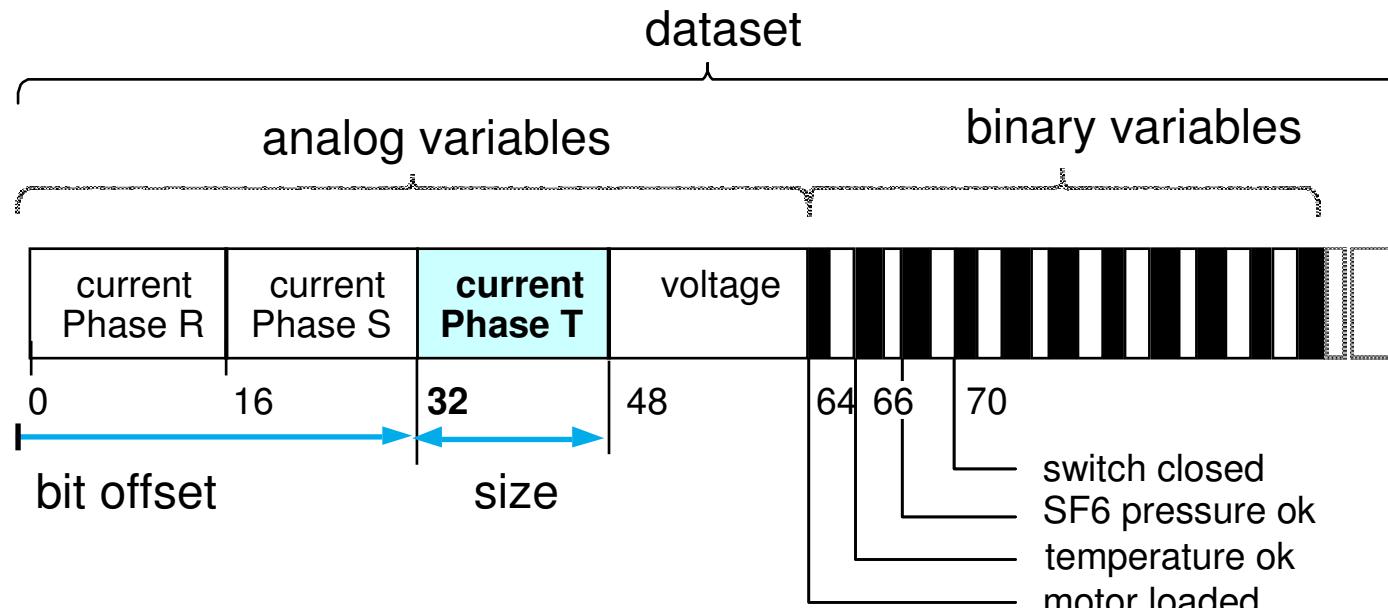


It is economical to transport several variables in the same frame as a dataset.

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.

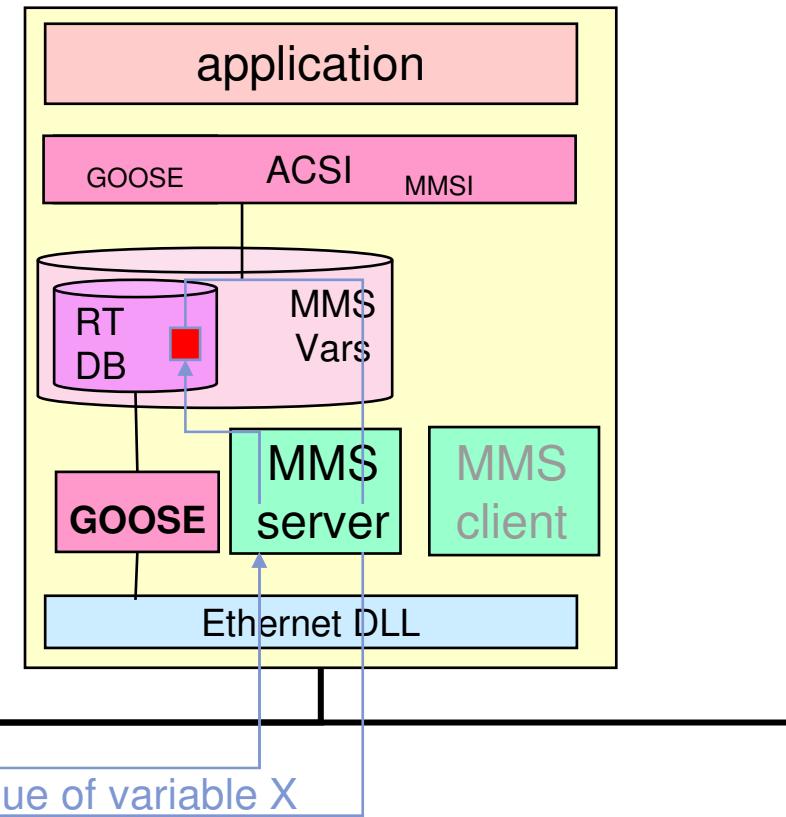
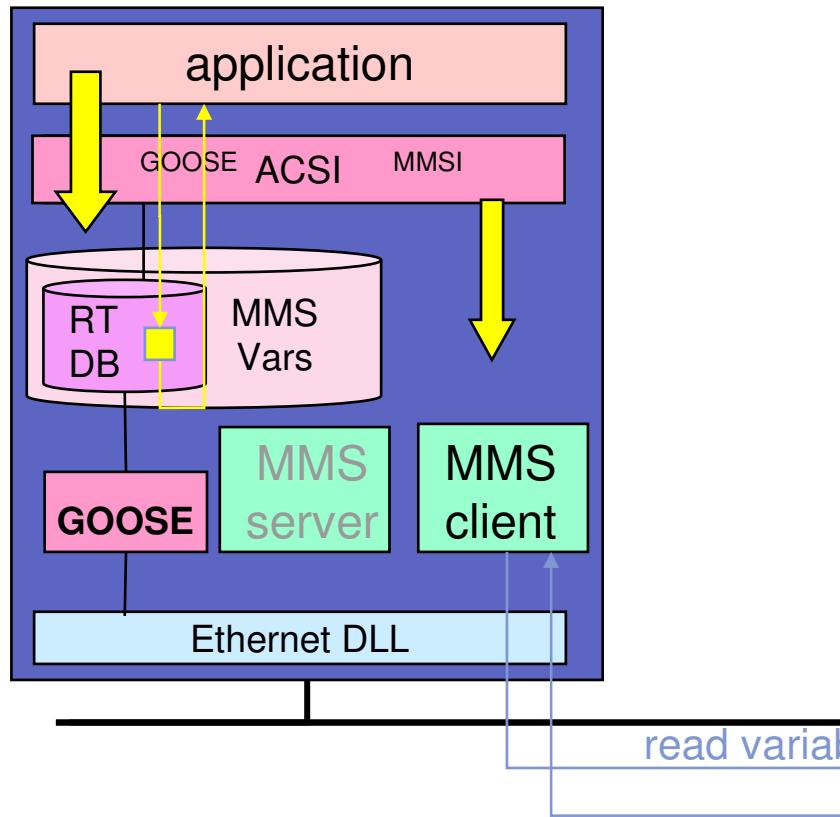


MMS access to remote variables in 61850

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



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

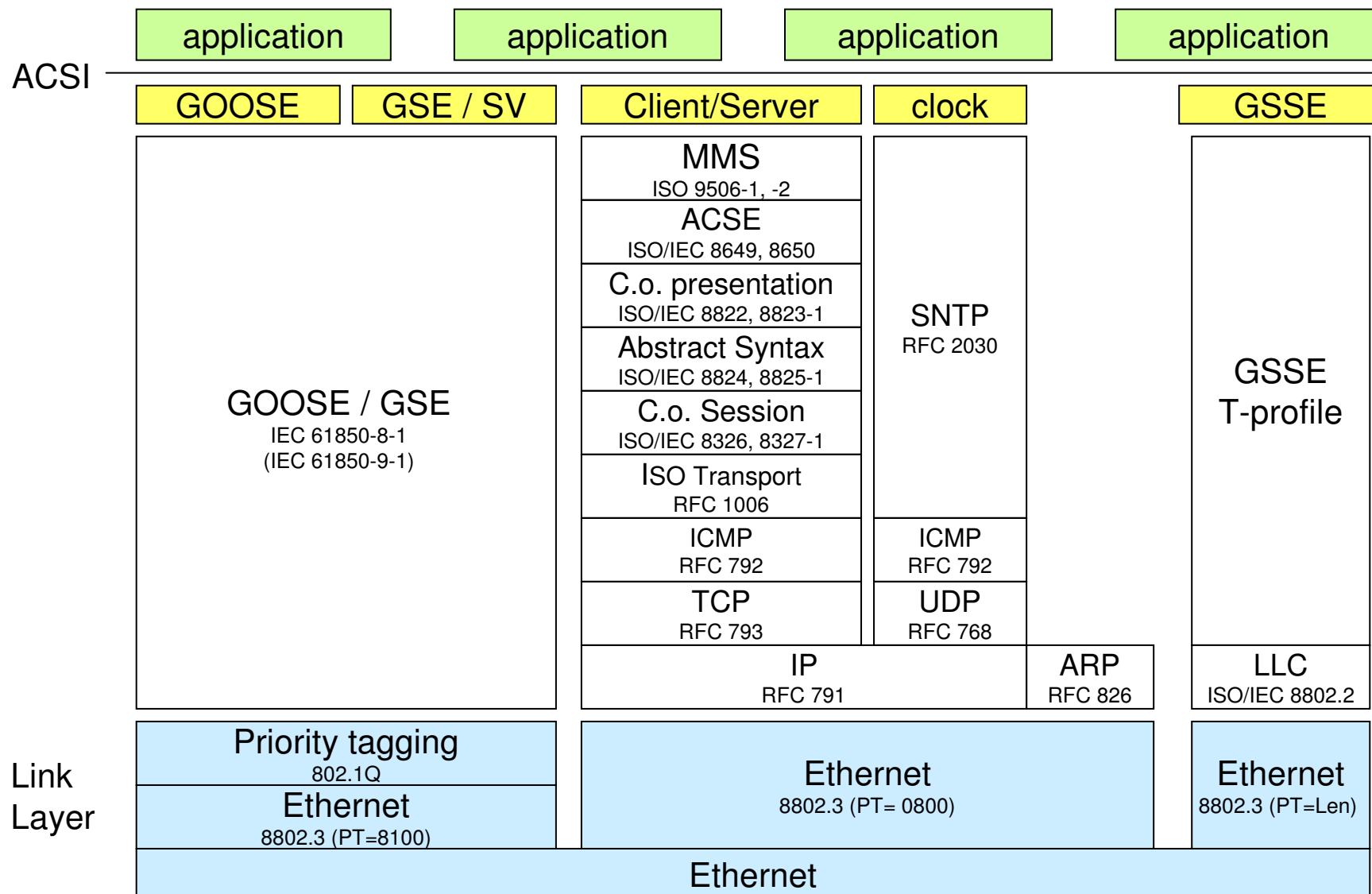
Reports: at data / quality change, changed data only, or periodically

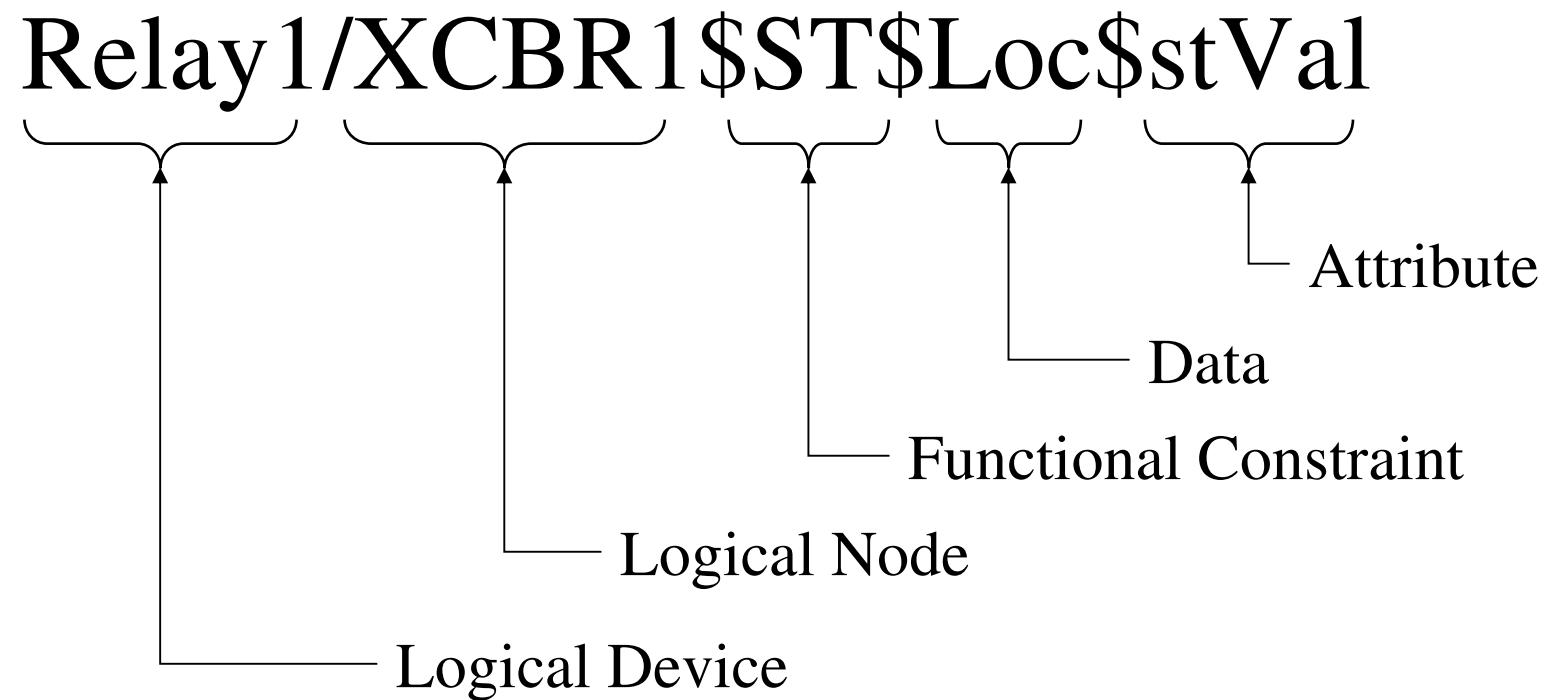
GSE: immediate at some change, else periodically; always whole set

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

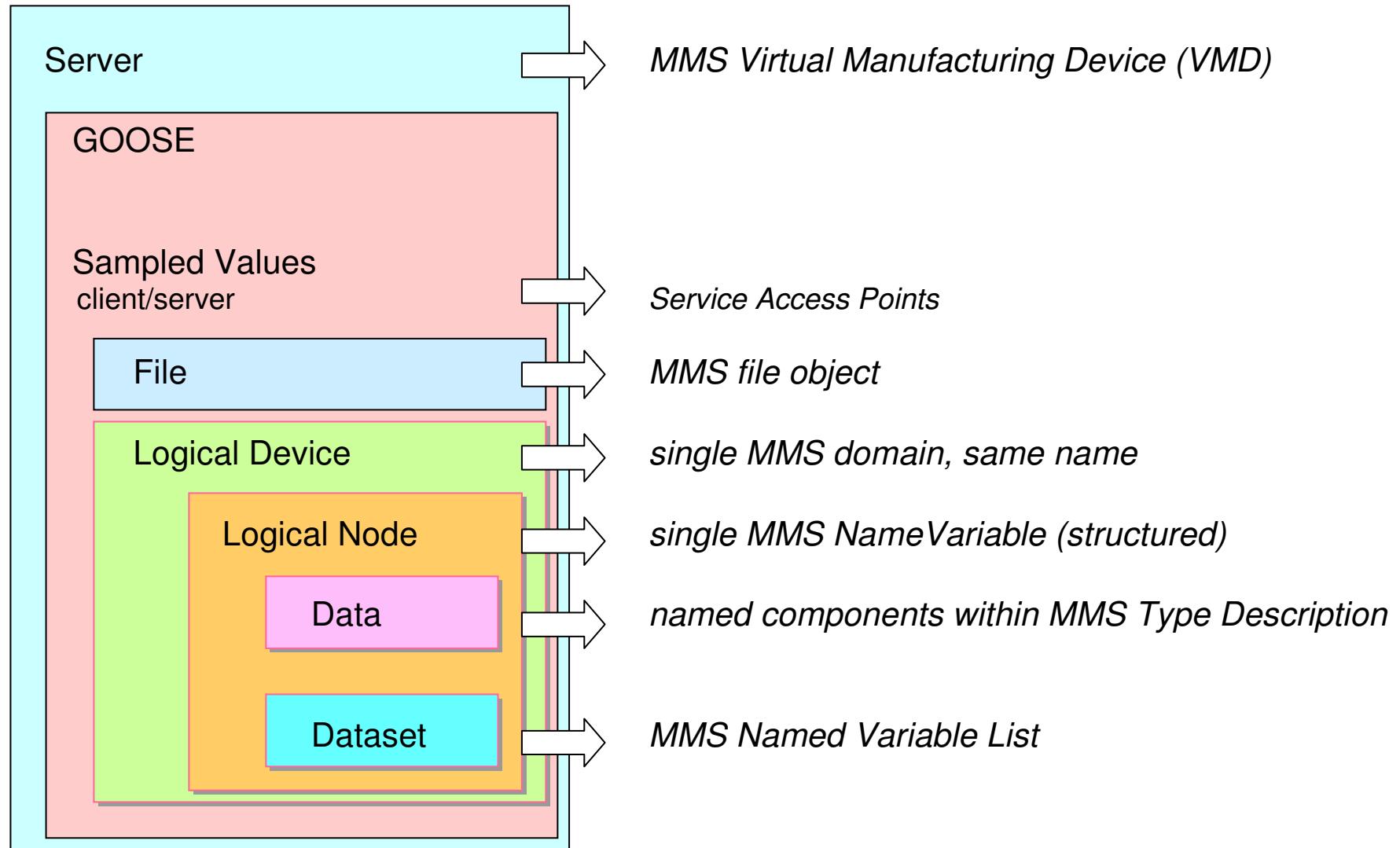
@/LastApplError\$InvokeID

@/LastApplError\$AddCause

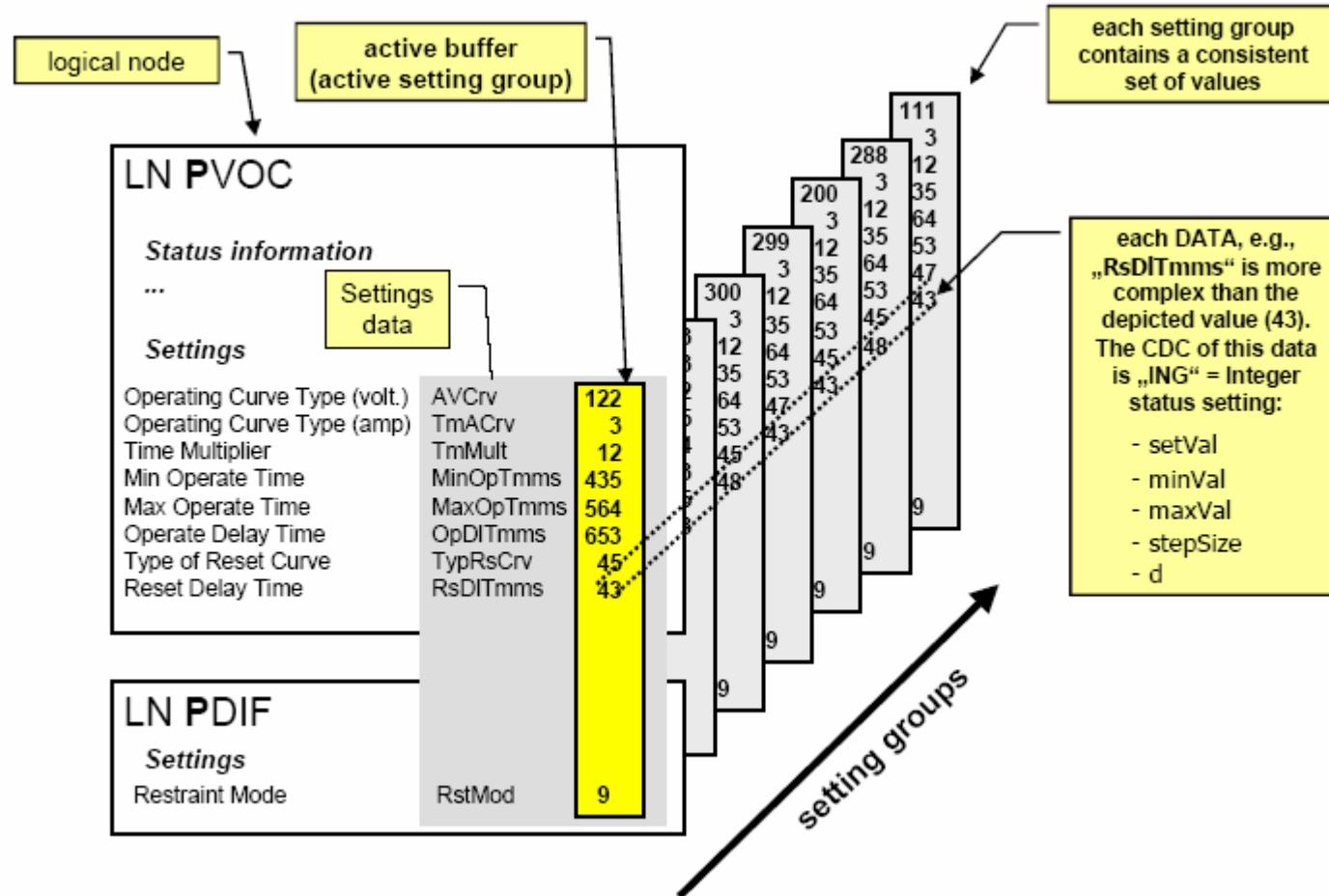
defined in 7-2

defined in 8-1

no predefined names



Setting groups



IEC 938/03

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

