Development of data models according to IEC 61850 for protection, automation and control units of high end

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Abstract — **The main goal of this work is the development of data models for protection, automation and control units of high end, according to the concepts and definitions established by IEC 61850.**

This work tries to present the IEC 61850 standard, explaining the importance of this new standard and trying to point out some advantages towards the standards that preceded it. For better understanding the standard, it's presented a brief explanation of each of the ten parts and a detailed explanation of the themes that compose the standard, which seemed to be more relevant for the outcome of this work, such as the data model, the substation configuration language and the new communication concept introduced by the standard.

In this work it's also presented the data models and at the same time the explanation and justification of the choices made during their preparation. The XML file of the description and configuration of the T500 unit, created during the development of this work, it's also presented.

Keywords — **IEC 61850, protection units, data models, ICD, interoperability.**

I. Standards For Substation Automation Systems

Even though this is not always obvious, nowadays most of the products, processes and services that are available to us are standardized. There are standards for: time, measures, design and performance of products, (whether chemical, electrical, mechanical, etc.), environmental protection, symbols of public information, quality, services and certification.

A standard is a document established by consensus, approved by a recognized body that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at achieving the optimum degree of order.

In the world of protection devices and substations automation systems, the problem was not the lack of rules, but the excess and lack of universality among them. What happens is that the useful life of substation equipment such as circuit breakers, current transformers and voltage transformers is around forty years old, while the protection system does not exceed fifteen or twenty years, due to communication technology. The protection and control functions do not change too much over time, so for a substation's owner, it doesn't make sense to change the protection relays and the Control Unit due to the communication. This reality shows that there is a large variety of protocols. It became obvious and almost a requirement in the utilities of electricity, that an evolution in communication protocols was indispensable, in order to achieve an open standard, to allow the interoperability between all manufacturers. Over the years, manufacturers have been creating various communication protocols. The problem of these protocols is that they only allow direct communication between devices from the same producer.

The resolution for this problem was the creation of an international standard in order to standardize the communication. For the development of this standard, the will and understanding of the major manufacturers was indispensable. This has created the first universal international standard for communication in substations, the IEC 61850: Communication Networks and Systems in Substations.

The system implemented before the IEC 61850, was a system that works, but only with adapters and protocol converters. This system had several limitations such as:

- Interoperability, i.e. the ability of two or more Intelligent Electronic Devices (IED) to exchange information and to use the information that has been exchanged ;
- Free configuration, i.e. the possibility to support different philosophies and to allow a free allocation of functions so that it could be an IED that performs multiple functions or a function that could be performed by multiple IEDs;
- Long-term stability, i.e. the possibility of upgrades, such as the inclusion of new functions or devices in the Substation Automation System (SAS).

The introduction of IEC 61850 has enabled the desired simplicity and consistency in communication, not only horizontally, but also vertically. This led to a new concept of communication, covering all levels of a substation, the IEC 61850 standard.

II. The IEC 61850 Standard

A. *The importance of IEC 61850*

Communication has always played a crucial role in substations and in their operations in real-time. In the sixties when digital communications became a viable option, Data Acquisition Systems (DAS) were installed to collect data from a substation in an automatic way. With the transition to the digital era, thousands of analogue and digital data are available in a single Intelligent Electronic Device and the communication's bandwidth is no longer a constraint. The IED is the key of a communication system, since it is a device with one or more processors, with the ability to receive or send data/controls from or to an external source.

As mentioned above, IEC 61850 is a universal standard that allows a greater and better interoperability between various equipments that constitute a power substation. This standard brings economic benefits because it promotes an open communication's system, allowing the communication between devices from different manufacturers, without the use of protocol converters.

B. Explanation of IEC 61850

The first edition of IEC 61850 was published in 2003. However some limitations were found, leading to the need to create a second and more complete edition, in order to solve some gaps of the first. This second edition is currently being discussed and soon it should be approved.

The IEC 61850 standard has as main goal the standardization of communications in substations and is divided into ten parts [1]:

- IEC 61850-1: Introduction and overview
- IEC 61850-2: Glossary
- IEC 61850-3: General requirements
- IEC 61850-4: System and project management
- IEC 61850-5: Communication requirements for functions and device models
- IEC 61850-6: Substation automation system configuration language
- IEC 61850-7: Basic communication structure for substation and feeder equipment
  - IEC 61850-7-1: Principles and models
  - IEC 61850-7-2: Abstract communication service interface (ACSI)
  - IEC 61850-7-3: Common Data Classes
  - IEC 61850-7-4: Compatible logical node classes and data classes
- IEC 61850-8: Specific communication service mapping (SCSM)
  - IEC 61850-8-1: Mapping to MMS (ISO/IEC 9506 Part 1 and Part 2)
- IEC 61850-9: Specific communication service mapping (SCSM)
  - IEC 61850-9-1: Serial unidirectional multidrop point to point link
  - IEC 61850-9-2: Mapping on a IEEE 802.3 based process bus
- IEC 61850-10: Conformance testing

The first three parts of the standard are purely introductory and informative. The purpose of these three parts is to introduce the topic, explain the structure, scope and purpose of this new standard of communication in substation automation systems.

Parts 4 and 5 focus on the functional requirements for communication in substations. Basic concepts such as: the allocation of functions, the structure of the data model and the communication's process between the devices that are a part of the substation, are introduced in part 5.

Part 6 defines a configuration language for the substation automation system. This language known as Substation Configuration Language (SCL) is based on eXtensible Markup Language (XML) and its main intend is to establish a standard for the configuration attributes, in order to allow the configuration of the IED's with increased security and reliability.

In Part 7 of the standard is presented the basic structure of communication for substations. This part aims to present a general framework for encoding information. Part 7.2 defines the abstract communication service interface (ACSI) for use in the utility application domain that requires real-time cooperation of intelligent electronic devices. The ACSI has been defined in order to be independent of the underlying communication systems. The basic structure presented to mapping data is the Logical Node (LN). All information concerning LN's is defined in part 7.4 of the standard. These LN's are composed by Data Objects that are grouped into classes, or more specifically in Common Data Classes (CDC). All the information related to the CDC is displayed on part 7.3.

Given the data and services abstract definitions, the final step was one of mapping the abstract services into an actual protocol. Section 8.1 defines the mapping of the abstract data object and services onto the Manufacturing Messaging Specification (MMS). Parts 9.1 and 9.2 define the mapping of the Sample Measured Values (unidirectional point-to-point and bi-directional multipoint accordingly) onto an Ethernet data frame.

The last part of the standard focuses on the conformity tests. This section defines the test methodology in order to verify compliance with all the settings and restrictions set forth in the standard.

III. DATA MODELS FOR PROTECTION, AUTOMATION AND CONTROL UNITS

A. Terminal Protection Unit S420

The TPU S420 has been designed as a protection and terminal unit for supervision and control of aerial and underground lines in radial electric networks with isolated, compensated, solid or limiting impedance neutral connection. This equipment also performs a wide range of protection and automation functions. It has an extensive range of user programming options, offering high accuracy regulation in currents, voltages, temporizations and optional characteristics [2].

B. Data Model for TPU S420

To develop the data model according to IEC 61850 for TPU S420 it is necessary to map the variables (data, information, controls) of TPU S420 according to the specifications given in the standard.

So, for example choose the Automatic Reclosing function to illustrate this process.

The main purpose of this function is the service restoration of a line after the elimination of temporary or intermittent faults, common in aerial networks. Reclosing sequence starts with the disconnection of the faulty line, followed by the reclosing command, after the dead time defined for the current cycle. According to the type of cycle configured, the opening command has different sources. In the fast cycle, the opening is done directly by the automatic reclosing automatism, while in the slow cycle the circuit breaker is opened by the protection functions. After the closing command, the automatism waits a configurable time to confirm fault absence. If the fault is still present after the reclosing attempts, a definitive trip signal is generated.

Based on the information accessible on the internal document "TPU-S420 Edição 1 - Manual do Utilizador" and presented in table I and II, it was mapped the LN FUNRREC01 (table III). The LN chosen to map this function was the LN RREC (Autoreclosing) already defined in IEC 61850 standard.

TABLE I
DESCRIPTION OF LOGICAL VARIABLES OF AUTOMATIC RECLOSING FUNCTION [2].

Id	Nome	Descrição
38656	Corrente Religação	Condições de arranque das protecções de máximo de corrente
38657	Disparo Corrente Religação	Condições de disparo das protecções de máximo de corrente
38658	Estado Disjuntor Religação	Imagem do estado do disjuntor
38659	Inicio Religação Automatic	Condição de arranque da função
38660	Fim Religação Automática	Condição de rearme da função
38661	Fecho Disjuntor Religação	Condição para bloqueio da ordem de religação
38662	Religação Automática	Sinalização da função em curso
38663	Religação Rápida	Sinalização de ciclo rápido em curso
38664	Religação Lenta	Sinalização de ciclo lento em curso
38665	Religação Confirmação	Sinalização de função em tempo de confirmação
38666 ... 38670	Religação Ciclo 1 ... Religação Ciclo 5	Sinalização de cada um dos 5 ciclos de religação em curso
38671	Abert Disjuntor Religação	Comando de abertura do disjuntor dado pela Religação
38672	Fecho Disjuntor Religação	Comando de fecho do disjuntor dado pela Religação
38673	Disparo Definitivo Religac	Sinalização de disparo definitivo
38674	Bloqueio Religação MMI	Condições gerais de bloqueio local da função
38675	Bloqueio Religação LAN	Condições gerais de bloqueio remoto da função
38676	Bloqueio Religação	Condições gerais de bloqueio da função
38677	Religação Pronta	Sinalização de religação pronta (activa, em repouso e não bloqueada)

TABLE III
PARAMETERS OF AUTOMATIC RECLOSING FUNCTION [2].

Parâmetro	Gama	Unidade	Valor defeito
Cenário Actual	1..4		1
Estado	OFF / ON		OFF
Num Ciclos	1..5		2
Top Disjuntor	0,05..60	s	0,3
Top Rápida	0..1	s	0,02
Ciclo 1> Operação	RÁPIDA / LENTA		RÁPIDA
Ciclo 1> T Isolamento	0,1..60	s	0,3
Ciclo 1> T Bloqueio	1..60	s	5
Ciclo 2> Operação	RÁPIDA / LENTA		LENTA
Ciclo 2> T Isolamento	0,1..60	s	15
Ciclo 2> T Bloqueio	1..60	s	5
Ciclo 3> Operação	RÁPIDA / LENTA		LENTA
Ciclo 3> T Isolamento	0,1..60	s	15
Ciclo 3> T Bloqueio	1..60	s	5
Ciclo 4> Operação	RÁPIDA / LENTA		LENTA
Ciclo 4> T Isolamento	0,1..60	s	15
Ciclo 4> T Bloqueio	1..60	s	5
Ciclo 5> Operação	RÁPIDA / LENTA		LENTA
Ciclo 5> T Isolamento	0,1..60	s	15
Ciclo 5> T Bloqueio	1..60	s	5

Table III shows the Logical Node corresponding to the Automatic Reclosing function. The extensions made in this LN are highlighted in yellow.

TABLE III
LOGICAL NODE FUNRREC1 FROM AUTOMATIC RECLOSING FUNCTION.

RREC class				
Data Object Name	**CDC**	**Explanation**	**T**	**M/O/E**
FUNRREC1		Automatic reclosing function.		
Data Objects				
Common Logical Node Information				
Mod	ENC	Mode.		M
Beh	ENS	Behavior.		M
Status Information				
Blk	SPS	Dynamical blocking of autoreclosure.		O
RecCyc	INS	Actual reclose cycle.		O
OpCls	ACT	Operation "close switch" issued to close the XCBR.		M
AutoRecSt	ENS	Auto reclosing status. Hypotheses: 1 - ready; 2 – in progress.		M
Settings				
MaxCyc	ING	Parameter for the maximum number of reclose cycles.		O
UseCyc	ING	Parameter for the maximum number of cycles that can be done by the function in sequence.		O
RecTmms1	ING	Parameter for the reclose time (cycle 1).		O
RecTmms2	ING	Parameter for the reclose time (cycle 2).		O
RecTmms3	ING	Parameter for the reclose time (cycle 3).		O
RecTmms4	ING	Parameter for the reclose time (cycle 4).		O
RecTmms5	ING	Parameter for the reclose time (cycle 5).		O
CBTmms	ING	Time that checks the good behaviour of the circuit breaker.		E
OpDlTmms	ING	Time in each cycle that the function has to wait until give an open order to the circuit breaker.		E
CycTyp1	ENG	Indicates the tripping type (single pole or three pole) for cycle 1.		E
CycTyp2	ENG	Indicates the tripping type (single pole or three pole) for cycle 2.		E
CycTyp3	ENG	Indicates the tripping type (single pole or three pole) for cycle 3.		E
CycTyp4	ENG	Indicates the tripping type (single pole or three pole) for cycle 4.		E
CycTyp5	ENG	Indicates the tripping type (single pole or three pole) for cycle 5.		E
BlkTmms1	ING	Parameter that establishes the time that this function have to wait, after an open order for the circuit breaker, to check if the fault has disappeared (for cycle 1).		E
BlkTmms2	ING	Same explanation as the antecedent.		E
BlkTmms3	ING	Same explanation as the antecedent.		E
BlkTmms4	ING	Same explanation as the antecedent.		E
BlkTmms5	ING	Same explanation as the antecedent.		E

Several extensions were necessary, like:

- Data Object "CBTmms" – from "Circuit Breaker Time", belonging to the CDC ING, to map the parameter "Top Disjuntor".
- Data Object "OpDlTmms" – already defined in IEC 61850 library, belonging to the CDC ING, to map the parameter "Top Rápida".
- Data Object "CycTyp1" – from "Cycle Type", belonging to the CDC ENG, to map the parameter "Ciclo n> Operação". This Data Object can be extended from one to n cycles, like described in point 14.4 of 7.1 part of the standard.
- Data Object "BlkTmms1" – from "Block Time", belonging to the CDC ING, to map the parameter "Ciclo n> T Bloqueio". This Data Object can be extended from one to n cycles, like described in point 14.4 of 7.1 part of the standard.

C. Terminal Protection Unit x500

The TPU x500 is the new family of protection and control units produced by Efacec.

This new range, which is currently under development and whose innovations result from the introduction of the new standard IEC 61850: Communication Networks and Systems in Substations, has its marketing planed for the year 2010.

D. Data Model for TPU x500

The creation of this data model is closely linked to the creation of the unit itself, since the process of creating the data model is directly connected to the development of the unit and vice versa. This process differs in many aspects of the data model of TPU S420, previously exposed, and the most important one is the fact that the unit is being developed simultaneously with the data model, thereby allowing more flexibility in building the data model.

The creation of this data model for the TPU x500 is characterized not only by its flexibility, but also by a significant change in the type of variables supported by the internal data model, much more in an IEC 61850 style.

To develop a data model according to IEC 61850 for TPU x500 is necessary to map the internal variables of TPU x500 (data, status information, controls) according to the specifications specified in the standard.

So for example choose the Circuit Breakers Control function to illustrate this process.

This function has, as its name indicates, not only the purpose of controlling the manoeuvres of the circuit breaker but also the purpose of providing a picture of the circuit breaker status.

Based on the information about Circuit Breakers Control function accessible on the internal document "TPU x500, Especificações" and summarily presented in table IV it was created the LN CBCSWI1, which is presented in Table V. The LN chosen to map this function was the LN CSWI (Switch Controller) already defined in IEC 61850 standard.

TABLE IV
SUMMARY OF THE INFORMATION ABOUT CIRCUIT BREAKERS CONTROL FUNCTION [3].

- The command module should accept manual or automatic orders of open or closure switch. The open manoeuvres can be single-phase if the circuit breaker is prepared for them.
- The command module should evaluate the local/remote mode of the different levels and block or not block the orders received according to this. This module should also generate open and close commands directly on the circuit breaker module.
- The closure manoeuvres should consider a maximum waiting time for synchrocheck conditions, which can be different for manual and automatic manoeuvres.
- It shall be provided a picture of the associated circuit breaker status and should also be provided a counter for the open commands to the breaker, which can be resettable to zero.

TABLE V
LOGICAL NODE CBCSWI1 FROM CIRCUIT BREAKERS CONTROL FUNCTION.

CSWI class				
Data Object Name	**CDC**	**Explanation**	**T**	**M/O/E**
CBCSWI1		Switch controller.		
Data Objects				
Mod	ENC	Mode.		M
Beh	ENS	Behavior.		M
Health	ENS	Health.		M
NamPlt	LPL	Name plate.		M
OpCntRs	INC	Resettable operation countable.		O
Controls				
Pos	DPC	Switch general.		M
PosA	DPC	Switch phase A.		O
PosB	DPC	Switch phase B.		O
PosC	DPC	Switch phase C.		O
Status Information				
OpOpn	ACT	Operation "Open Switch" (it can be per phase if the equipment allows).	T	O
OpCls	ACT	Operation "Close Switch".	T	O
SynPrg	SPS	Synchronising in progress.		E

This LN only requires one extension since the other Data Objects defined by the standard for the LN CSWI are enough to map all the information considered necessary. So this LN not only has an operations counter but also control the circuit breaker switch position (general and per phase). The unique extension needed is the setting "SynProg" ("Synchrocheck in progress"), that belongs to the CDC SPS. It is noteworthy that this Data Object is already defined in the IEC 61850 library, more specifically in the LN RSYN.

E. ICD file for TPU T500

To create the IED Capability Description file (.icd) of the protection and control unit TPU T500 the help of the software Automation Studio Designer 1.2.121.0 was very important. This file describes the IED characteristics in terms of communication and data model.

The TPU T500 belongs to the x500 range and is a protection and control unit of transformer for transmission and distribution substations or for other applications, incorporating among others the differential protection of transformer function.

Based on the document that contains the data model of the TPU x500, presented in the previous section, it was created the ICD file to the T500 unit. The work consisted in converting the model previously presented in tables to XML language. In this ICD file it only appears initialized the Data Objects that belong to Status Information and to Measured Values due to the settings that are going to be included in the file depend on the individual needs of each client.

The Automation Studio Designer is a software that allows the configuration of a unit as required by IEC 61850. To prepare the ICD file it is necessary to start by creating a library, presented in Fig. 1, which includes all the Logical Nodes and their Data Objects and Data Attributes that belong to the TPU T500 unit. The name chosen for this library was "Efacec61850Library".

After creating the library, it was created the TPU T500 unit model with the use of three Logical Devices, one for protection functions ("PROTECT"), another for measures ("MEASURES") and finally one for breakers and disconnectors controls ("CONTROL"). To these Logical Devices were added the Logical Nodes created and defined in the library “Efacec61850Library”. Thus, a sample of the result obtained is shown in fig. 2.

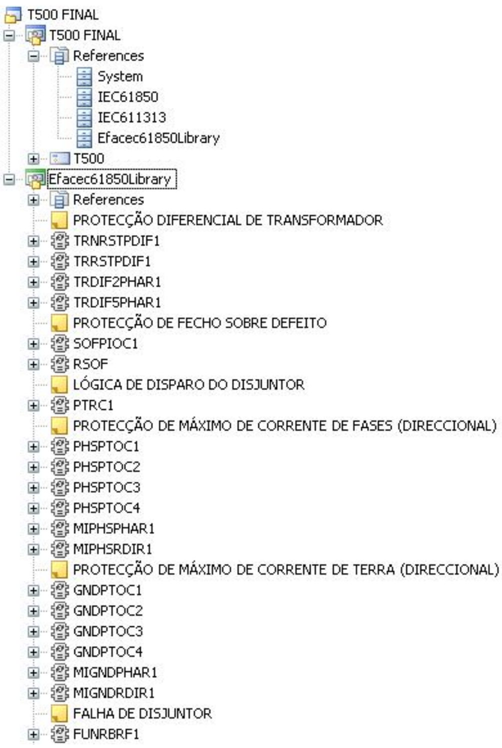

Fig. 1. “Efacec61850Library” library for TPU T500 unit (Automation Studio Designer).

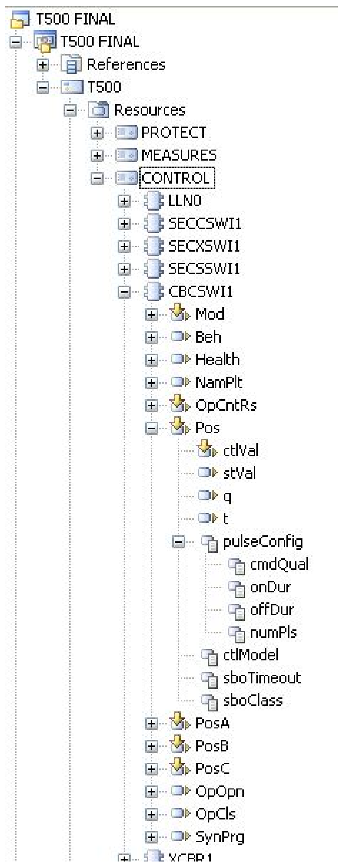

Fig. 2. TPU T500 model (Automation Studio Designer).

After saving and compiling the TPU T500 data model, it was created the .icd file using for this purpose a functionality of the Automation Studio Designer software.

IV. Conclusions

The particularity of the creation of the data model for the TPU x500 is that it is attached to the fact that it is directly linked to the development of the unit itself, since the data model creation is directly conditioned by the development of the functionality of the unit and vice versa.

One of the most significant differences between the process of the creation of the TPU S420 and TPU x500 model comes from the fact that the last one is being developed simultaneously with its data model allowing a larger flexibility in its construction.

Comparing the data model from the TPU S420 with the TPU x500 it’s easily shown that some functions suffered alterations in its internal design and also in its mapping. An example of this is the Circuit Breakers Supervision function, where big changes took place not only in the design but also in the data model, more specifically in what concern to the LN responsible to the modulation of the circuit breaker (XCBR). So, the TPU x500 data model has four Logical Nodes of XCBR type, because this new family of protection devices allows the circuit breaker supervision and control not only general but also per phase, what was not possible in the S420 unit, where the circuit breaker supervision and control was only allowed in the general mode (so one XCBR was enough).

Since not all information on this unit is defined in the standard, one of the biggest challenges of this work was not only to decide to map or not this information, but also how these data would be mapped according to IEC 61850, if the decision would be to include them in the unit’s data model. So, and in the situations that the extension was the choice, the procedure was the one that is established by the standard.

The need for innumerous extensions to the standard made during the creation of the TPU x500 data model shows not only some limitations to the standard as well as the will of the manufacturer (Efacec) to remain in some situations loyal to its philosophy and not sub judging itself to all the suggestions presented by the standard.

The few maturity of this standard is one of its main conclusions that can be drawn from the developed work. The necessity that existed to create a second edition of the standard and also the forthcoming of a third edition it’s the proof that this standard hasn’t reached the desired maturity level.

When all manufactures start to merchandize their protection and control units created according IEC 61850 standard, it will be possible to evaluate more properly the impact of these new solutions brought by the standard and if necessary extend or alter the standard in future editions. A better evaluation of this standard can only happen when a fully equipped substation according to IEC 61850 is created.

Summarizing, this standard allowed not only interoperability allowing the exchange of information between IED’s from different suppliers but also a free configuration that support any philosophy not only from the client but also from the manufacturer. By introducing a virtual data model (Logical Device, Logical Node and CDC) in which every data has a specific name standardized e defined in a context of Power System, associated not only to a standardize configuration language, but also to a communication system vertically and horizontally implemented, the IEC 61850: Communication Networks and Systems in Substations, has everything to turn out to be a long-term standard.

V. References

[1] IEC TC 57, “*IEC 61850-1: Communication Networks and Systems in Substations, Part 1: Introduction and overview*”.

[2] EFACEC, “*TPU-S420 Edição 1 - Manual do Utilizador*”, Outubro 2006.

[3] Jorge, Rui Dias, Manuel Martins, Sara Costa e Rafael Rodrigues, “*TPU x500, Especificações*”, Portugal, Abril 2009.