PROTECTION SCHEME ENSURING INTEROPERABILITY OF PHASOR MEASUREMENT UNITS AND SCADA TECHNOLOGY

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This paper brings forward, from the IEC 61850 series of standards perspective, the interoperability analysis of the Phasor Measurement Units (PMU) and the Intelligent Electronic Device (IED), in order to use them within a communication architecture based on the so-called Scheme of Integrated Protection Systems (SIPS). They represent the hardware support of a new protection function using as trigger criteria the rate of change of both amplitude and phase of current and voltage. The conclusions underline the conditions to be met by the proposed protection function to meet the IEC 61850 series of standards communication requirements, from the subsequent development perspective of its tripping logical.

Keywords: standardization, system integration, synchronized measurements, communication, data integration, phasor measurement unit, SCADA systems.

1. Introduction

The presently deployed IEDs include protection functions able to take a decision in case of power system disturbances, by issuing tripping signals to the primary switching elements. The protection functions are achieved by means of logic and algorithms associated with setting thresholds, as pre-defined by the user.

The present standardization of the protection functions [1] allows us to classify the electric measurements data, so that the protection function name reflects the way it interacts with the process, in case of a disturbance occurred in the protected grid. The criterion underlying the logic evaluation and calculation algorithm is expressed in the protection function name, which has a certain code[3] associated to it, as uniqueness established at the international scientific community level.

The existing IEDs allow designing a number of protection functions by decomposing the underlying algorithms into logical expressions as transposed in gate arrays or code lines, written in specific programming language. The

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categories of such protection functions are to be found in the library of any IED provider, and the classification of such protection functions shall take into consideration their main goal, being easily identified by such the evaluation criteria applied to the measurement information, the underlying protection theory and assumptions and the tripping logic.

An example of large variety of potential IED functionalities is given by the following set [2]: main protection functions, reserve protection functions, control and monitoring functions, interlocking achievement and apparatus control functions, monitoring functions, communication functions at the electric station level and different types of functions used in communication schemes with remotely controlled protection devices.

In order to study a protection function designed as to use PMU reported information with the logic and computation features of an IED, it is necessary to identify the subsequent development benchmark, based on the following standards: IEC 61850 [3], IEEE Std C37.242-2013 [4] and IEEE Std C37.244-2013 [5]. In [6] a solution describing the hardware support necessary to the interoperability of such units is given. The important advantage in using PMUs in data acquisition instead of the IEDs is the high accuracy of the measurements and a very fast rate sampling.

There are several protection functions for which the manufacturers could not find in the existing standardization [1], [7] the required codes to express them as functions included in the IED. For instance, we mention the PSLPSCH function (Power Swing Blocking) or the PPLPHIZ function (Phase Preference Logic) – among others – which do not have an ANSI code. Therefore, the producer considered as being useful to identify certain logic blocks or even independent functions that may represent data platforms relating-interacting with other existing functions inside the IED.

2. Description of protection functions based on evaluating the rate of change of electric current and voltage parameters

The name proposed for the protection function having as criterion the evaluation of the variation speed for the electric current and voltage [8] is *Differential Phasors Overspeeding* (DPO). This name allows easy identification of the mathematical principles underlying the calculation algorithm used in its tripping:

- *Overspeeding*: relates to the electric measurement data variation mode which is assessed and compared to the tripping threshold values. It is about a variation speed, therefore a d/d*t* type variation;
- *Phasors*: represent the characteristic of the DPO protection function, which is associated to the electric measurement data to be evaluated. If

until now the protection functions showed scalar measurements, towards their evaluation (the electric measurement magnitude), within the DPO protection function we simultaneously follow both the magnitude variation speed and the electric measurement argument speed. It will be considered the pure sinusoidal electrical measurement from the three-phase system.

- *Differential*: represents the following mode of the variation speed regarding the monitored electric measurements phasor, associated to the upper protection level of the system element.

  Based on the classic formula used for differential protection function:

  - Tripping current:

$$I_{dif} = \left|\underline{I}_1 + \underline{I}_2\right| \quad (2.1)$$

  - Restraint current:

$$I_{stab} = \left|\underline{I}_1\right| + \left|\underline{I}_2\right| \quad (2.2)$$

$\underline{I}_1$ and $\underline{I}_2$ are the vectors corresponding to each terminal (H1, respectively H2) of the protected system element. DPO uses the amplitudes and angles of the voltages and currents to compare rate of change of the measured values with settings.

Thus, it is created a new evaluation method based on rate of change of these values, in accordance with the formula below:

$$\text{IAngOsPhsA/B/C-H1/H2} = d(\phi_A/\phi_B/\phi_C\text{-H1/H2}) / dt \quad (2.3)$$

where *IAngOsPhsA/B/C-H1/H2* represents the rate of change of current vector angle for phase A (B or C) in terminal H1 (or H2), calculated from the formula $d\phi/dt$.

In this case, the rate of change of the angle for currents (phase A or B or C) acquired form overhead line 1 or 2 is calculated.

Therefore, it is possible to build a functional block (as an integral part of a protection function) which, at this moment, has not an American National Standards Institute (ANSI) associated code, according to the criteria indicated in [1], [7]. Of course, if the DPO protection function is accepted by the international scientific community, its framing may be subsequently done in the protection functions list, as worldwide used to protect a power system.

A series of requirements regarding the protection functions, mainly for the devices and protection functions models encompassing, are the ones regarding the interoperability achieved by means of communication networks and the communication with other protection systems in the electric stations [3]. In this case, the IEC 61850 series of standards offers the possibility to verify if a protection function is qualified and meets the requirements regarding the communication of the protection function, the calculation block of the protection function according to ranked values and criteria, pre-defined concepts and categories which are generally valid.

For this reason, we consider essential to indicate the way in which the DPO protection function meets these criteria and requirements in order to prove its role and existence within IEC 61850 [3].

The interoperability among the devices forming the DPO protection function is the key for having it coexist with the present protection functions. From the action mode point of view, we notice a double dual character of the DPO function:

- As regards the tripping mode to protect a system element, both at the bay level and at the protected system element level, the DPO protection function may use electric measurements data processed both locally and remotely (transmitted by means of PMUs and PDCs) in order to compare and to take a unique decision for both electric bays of the protected system element;
- As regards the tripping mode as interface and support of the monitored information by means of PMU and PDC units, the DPO protection function may allow the PDC unit to allocate calculation resources in order to evaluate, at the system element level, some of the measurement data, which further build tripping criteria of such system element and, from the Dispatching Center management point of view, a first order criterion for the WAMPAC integrated system to take action on other emergent system elements (connections to / disconnections from electric lines, the acting of on-load devices, changes in the reactive power circulation etc.).

3. Implementation of the logical functions concept

The logical nodes concept is shown in the description of any protection functions. They facilitate the way in which the protection function obtains input information / data, processes them, evaluates them according to the mathematical criteria and algorithms in order to finally offer other process information underlying the following functions or equipment actions. The description of the protection function is accompanied by the presentation of the connection between the logical nodes in its architecture, the indication of the physical equipment the previously described processes take place, as well as by the indication of connections between those functions (Fig. 1).

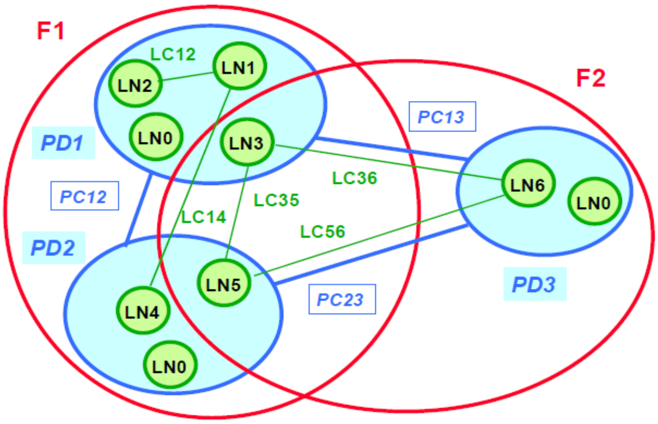

Fig. 1. Standardization concept for logical nodes and connections between them

Fig. 2 represents the division of the DPO protection function at the level of a system element. It is thus identifiable the dual character of the DPO protection function, both at the level of an bay and at the level of a system element. The representation of the logical node concept for the DPO protection function at the system element level (for instance, the ALPHA – BETA overhead line) includes elements from both ends of the electric line and also the common part at the communication level with the Dispatching Center.

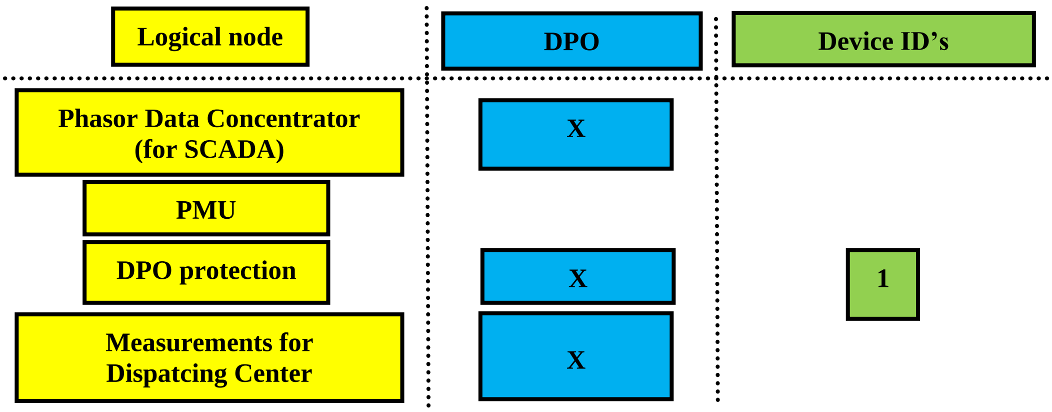

Fig. 2. The division of the DPO function at the level of a system element based on the logical nodes concept

In what regards the interoperability of the DPO protection function, the concept shown in Fig. 1 is applicable while specifying the way in which the defining elements such as logical node, physical devices, physical connections and logical connections are defined.

Therefore, we may subsequently specify the interaction mode of the DPO protection function with other protection functions or other devices forming a system or a information process structure.

The protection functions need to be divided into logical nodes in order to indicate the relation between the logical node, functions and physical devices contained herein.

Similar to the representation of logical nodes at the level of system element, the division of the DPO protection function is shown at the level of a bay. Fig. 3 presents the division of the DPO protection function done in order to fulfill the interoperability at the electric bay level (the example below shows the bay ALPHA from ALPHA – BETA overhead line).

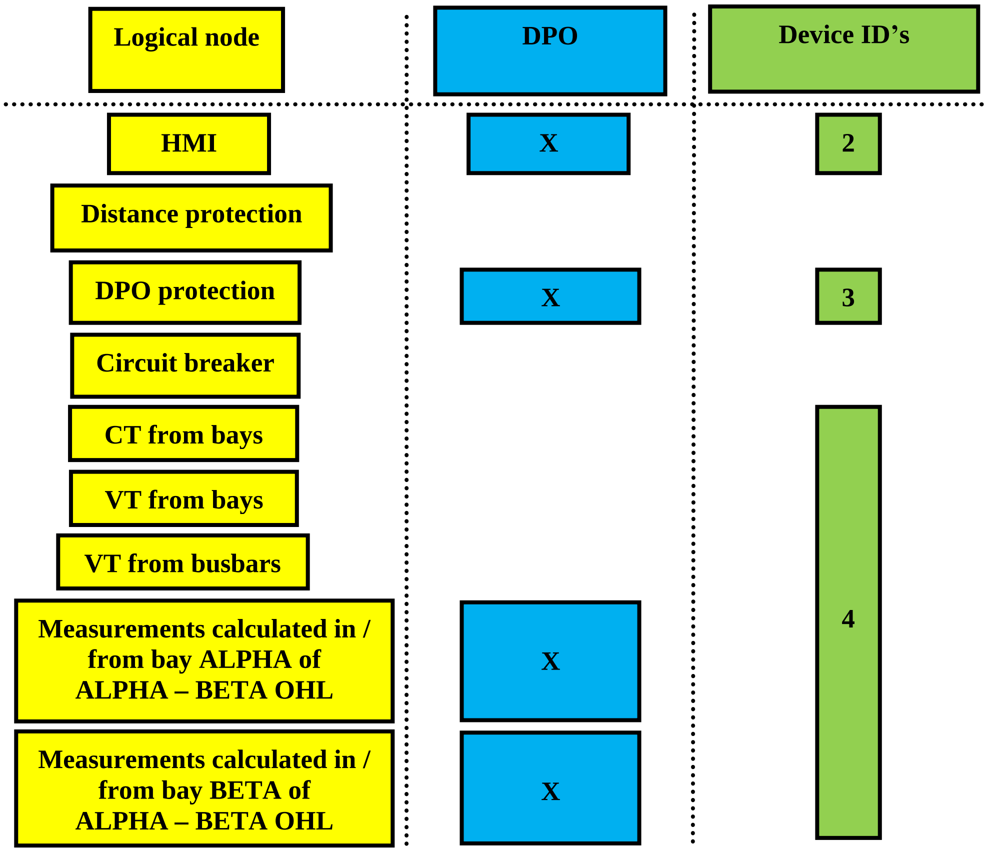

Fig. 3. The division of the DPO function at the electric bay level based on the logical nodes concept

The physical devices are represented in Figs. 2 and 3 by considering the presently industrial IED models. For this reason, the following trends in the IED evolution shall be envisaged:

- to include certain measurement facilities for the PMU type electric measurements in the present protection numerical terminals of some well known producers (Siemens, SEL);
- to develop and interconnect on PMU type integrated platforms in the Energy Management System – Supervisory Control and Data Acquisition (EMS-SCADA) and trends to Power Management System – Supervisory Control and Data Acquisition (PMS-SCADA);
- to develop the Smart Grid facilities within the IEDs, as combined with the protection functions logic.

Taking into account the above-mentioned allegations, for the DPO protection function, the practical achievement concept supposes the interoperability between the following physical devices:

- the physical device number 1: Human Machine Interface (HMI). This device may be either an external device or it can be included in the physical device number 2;
- the physical device number 2: a IED including all the calculation functions and logical evaluation, being necessary to fulfill the DPO protection algorithms. It is a device which interfaces with the PMU, undertaking the data obtained by it.
- the physical device number 3: a PMU, used in order to obtain data to be transmitted to the physical device number 2 (IED) and to the physical device number 4.
- the physical device number 4: a PDC containing calculation algorithms, logical processing functions at a system element level in order to achieve the DPO protection function at this level and to interface with the Dispatching Center. The proposed PDC is a modified PDC present device, meaning that it fulfills both the present function, already associated with PMUs, and the new calculation and transmission function, between the ends of the monitored system element, for the information specific to the DPO function.

4. Definition of the functional areas for the DPO protection function

According to [9], the DPO protection function is part of the entire functional system including the functional areas presented within the IEC 61850-5 Standard. The integration of the DPO protection function can be realized by following the sequences described below:

- to create a model of the system created by:
    - organizing the DPO protection function, by indicating the functional logic modes;
    - standardized information;

    - describing the information transfer performance;
    - framing of information in a standardized medium;
    - having access to data, process data setting.
- to create a configuration format and the possibility to exchange data and certain engineering instruments by:
    - describing the used devices capability;
    - specifying the possibilities to configure devices;
    - configuring the entire protection function system;
    - defining the circulation of information, structure and used model.

The DPO function is included in the considered area according to the following functional areas:

- exchange of data specific to the synchrophasors type systems (PMU and PDC);
- communications between substations;
- permissions of configuration instruments, exchange of data and advanced engineering (due to the data processing on a IED specific platform);
- data synchronization using, for example, GPS-enabled modules;
- functions' organization by means of logical nodes;
- map and standardized information parameterization;
- access to process data setting;
- use in every electric energy domains (transport, distribution, energy stocking, generation, etc.).

5. Definition of the applicable SCL model

From the hardware point of view, the IED containing the DPO protection function shall be organized according to the IEC-61850 series of standards, by using the XML format for the exchange of information with other systems and devices. By means of a standard Structured Control Language (SCL) model [3], any producer may undertake the information contained in the IED containing the DPO protection function (fig. 4). Thus, the interchangeability among IEDs is allowed and developed by means of a configuration menu of the existing protection function, which is also including the DPO protection function.

It is not necessary that DPO function should be developed on a separate IED platform: instead, it may be within a IED having other protection functions included. Based on the capacity to process information, each manufacturer may define and set the location of the DPO function. However, this asks for changes of the presently in use IED platforms or, if a separate IED platform is considered, it will be necessary to reshape the communication modules between the IEDs. It should be mentioned that in the EU the symbols are accordingly with IEC 60617 Graphical Symbols for Diagrams [10].

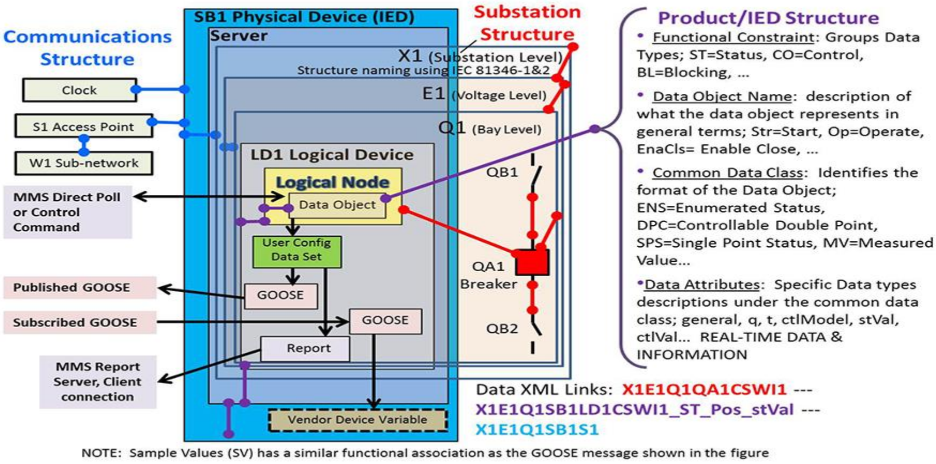

Fig. 4. The SCL model of the IEC-61850 Standard [3]

Irrespective of the choice made by the IED producers (either including the DPO protection function in the existing IEDs also containing other protection functions – distance protection, overcurrent protection etc. – or considering a separate IED in the newly designed architecture of the command, control, protection and automation system of an substation), the SCL model should be observed and defined according to the one described by [3] and presented in Fig. 5.

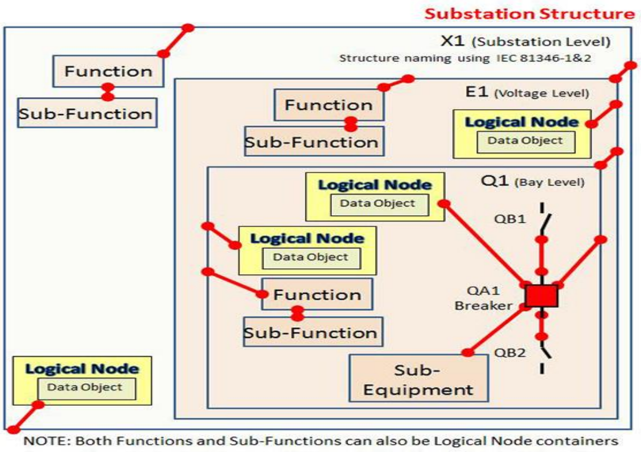

Fig. 5. The SCL model of the IEC-61850 Standard applied to electric station [3]

Fig. 6 presents the SCL model of the DPO protection function, associated to the network element it protects. We notice that, in this way, the protection is capable to access a upper level by including the DPO function in certain PDCs type IEDs fulfilling at the system level a relationship data structure.

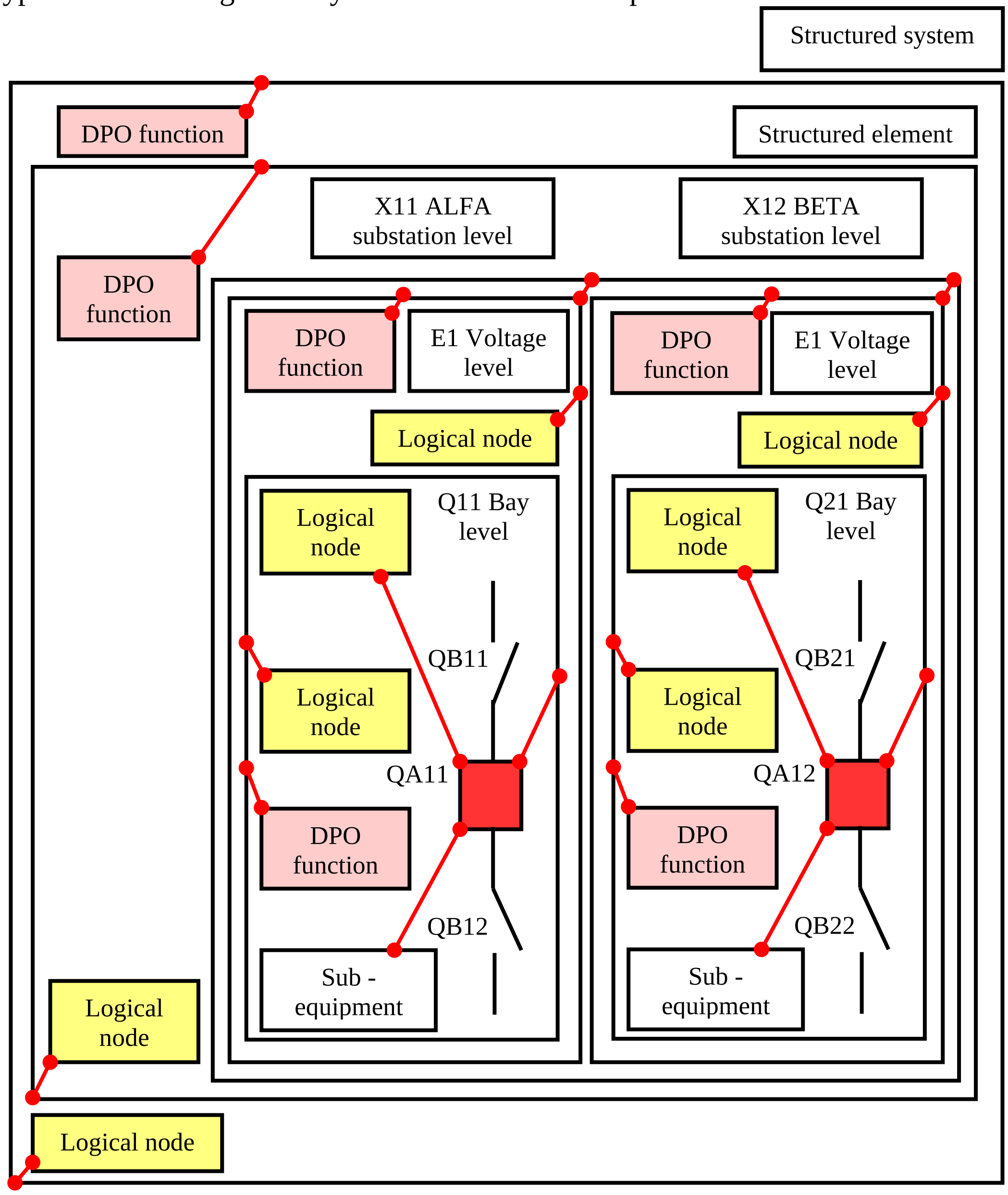

Fig. 6. The SCL model of the DPO protection function at the network element level

Also, the DPO protection function should be framed for each above-mentioned development perspectives, according to the SCL model, corresponding to an electric station [9], as presented in Fig. 5.

The dual character of the DPO function (both at the bay level and at the system element level) implies to complete the above presented models by the IEC 61850 Standard, following the presentation of the SCL model at the system element level.

Practically, the answer of the DPO protection function is complex: on one hand, it is not specific to a bay level (like in the case of a classic protection function – except PDB), but serves the two bays of a system element (electric line, electric transformer / autotransformer). On the other hand, the protection of the system element (as a whole, therefore for both bays simultaneously) takes place at the upper level of the equipment fulfilling PMU type functions, by area corresponding PDC devices.

Consequently, the approach given by the interpretation made by [11] by indicating the allocation mode of a protection function to a process given by any protection function, should be modified in order to include the entire complex acting mode of the DPO function at the 2 switches level (for instance, from both OHL ends) and at the protected system element level. Thus, the two protection relays, each one being located in both OHL ends, and which access PDC, at their turn, simultaneously during the process, should be mentioned in the complex mode the process takes place.

6. Conclusions and perspectives

As a result of this study, we draw the following conclusions:

- the SCL model proposed for the DPO protection function contains the elements necessary to be included in the present requirements of the IEC 61850 series of standards [3];
- the IED and PMU devices are the main hardware elements forming the hardware support necessary to the DPO protection function at one bay level;
- the SCL model proposed for the DPO protection function at the network element level has an extension feature, able to provide the full control of the protected system zone;
- the interface between the PMU and IED from one end of a system element with the similar devices situated at the other end of the same system element is represented by a PDC;
- the physical devices forming the DPO protection function at the whole system element level provide the dual character of the DPO function, being possible to ensure the protection of the system element while also transmits specific information to the PMU for the EMS-SCADA platform;

- in order to increase the interoperability between the PMU and IED containing the necessary elements for the DPO protection function it is advisable to implement the IEC-61850-9-2 standard [12];
- the future implementation of the DPO protection function represents a serious challenge for the manufacturers of the present IED, PMU and PDC devices in order to meet the operational requirements within SIPS and WAMPAC.

R E F E R E N C E S

[1]. IEEE Std C37.2 IEEE Standard Electrical Power System Device Function Numbers, Acronyms and Contact Designation, 2008
[2]. www.abb.com: 1MRK500118-UEN – 670 series 2.0 IEC Operation Manual
[3]. IEC 61850 ”Communication networks and systems in substations” - Part 5 ”Communication requirements for functions and device models”, 2013
[4]. IEEE Std C37.242-2013 ”IEEE Guide for Synchronization, Calibration, Testing and Installation of Phasor Measurement Units (PMUs) for Power System Protection and Control”. 2013
[5]. IEEE Std C37.244-2013 ”IEEE Guide for Phasor Data Concentrator Requirements for Power System Protection, Control and Monitoring”, 2013
[6]. *H. Nicorescu, M. Albu, M. Eremia* ”Achieving Interoperability of power system protection using SCADA and PMU information”, Modern Power System Conference, Cluj, 2019
[7]. www.GEDigitalEnergy.com: ANSI Standard Device Numbers & Common Acronyms
[8]. *H. Nicorescu* ”A new protection function based on the rate of change of voltage and current phasors variation”, PhD Report no. 5, Politehnica University of Bucharest, April, 2019
[9]. IEEE Power and Energy Society: Std 2030-2017 ”IEEE Recommended Practice for Implementing an IEC 61850-Based Substation Communications, Protection, Monitoring and Control System”
[10]. IEC60617 Graphical Symbols for Diagrams
[11]. *M. Adamiak, D. Baigent, R. Mackiewicz* ”IEC 61850 Communication Networks and Systems in Substations”, Monterrey, Mexic, 2004
[12]. IEC61850-9-2 Communication networks and systems for power utility automation – Part 9-2: Specific communication service mapping – sampled values over ISO/IEC 8802-3