# RECENT TRENDS REGARDING DISTANCE PROTECTION A REVIEW

MESZAROS R.G., KILYENI ST., BARBULESCU C., MIHALCEA M.
Politehnica University Timisoara,
Power Systems Department, Power Systems Analysis and Optimization Research Center
robert.meszaros@upt.ro, stefan.kilyeni@upt.ro, constantin.barbulescu@upt.ro, maria.mihalcea@upt.ro

**Abstract - This paper is structured in six parts and aims to present actual trends regarding distance protection. In the first part is determined the importance of the topic and the requirement of using protections. In the second part is presented the evolution of the protection and automation systems. In part three is presented the distance protection with its past and present, with its principles. In part four are given examples of how the pickup characteristics of the the distance protection have evolved. Part five presents how actual protection functions are implemented and related to the distance protection which functions are new. Part six is dedicated to present the conclusions related to this paper.**

**Keywords:** protection functions, distance protection, tripping characteristic, impedance, fault.

## 1. INTRODUCTION

An important factor of the economical development of a country is represented by the state and the capacity of the country's power system to sustain the energy consumption and the need for electricity. Therefore, an electric power system has two major requirements: safety in operation and continuity in the supply of electricity to consumers.

Considering those two requirements is very important for the system to be protected against the destructive effects of the electric arch due to a fault in the system [1]. Protecting the system and ensuring the continuity of electricity supply to consumers is carried out through the protection and automation systems.

## 2. EVOLUTION OF PROTECTION AND AUTOMATION SYSTEMS

With the development of technology, protection and automation systems have been developed too [2], [3]. The first protection and automation systems were composed of a huge number of elements. There is a distinct element for each function of the protection and automation system. So in order to achieve a complex protection like the distance protection a large number of interconnected elements are used, leading to very complex schemes and also to higher decision and tripping time [1].

Actual trends are based on the realization of the protection functions in numerical technology including more functions in the same equipment. Thus, it is ensured a much greater swiftness in the detection, assessment and removal of a fault, as well as a simplification of protection schemes [1], [2], [3], [4].

## 3. DISTANCE PROTECTION

Overhead power lines (OHL) are the most wide-spread elements of an electrical power system, they are not concentrated in a relatively small area of a substation as bus bars or transformers/autotransformers. Given the fact that lines are spread across extended areas, they are subject to risks and frequency of occurrence of faults rather than other power system elements.

220 kV OHL's basic protection is the distance protection, one of the protections which suffered the biggest changes with the development of numerical technique.

Whether we are talking about the classical protection, or that we are talking about the ones made in the numerical technique, the operating principle of distance protection uses one of the most basic laws of electrotechnics, Ohm's law [4], [5], [6], [7].

This measures the impedance (distance) between the place of mounting protection (CT's and VT's) and the fault location [6], [8], [9], [10]. The calculation of the distance is made on the basis of the measured values of current and voltage [6], [11]. The electrical distance is directly proportional to the physical distance on the condition that the line does not have a longitudinal compensation [5], [10], [12], [13], [14]. The closer the fault, the faster the protection will command the trip of the circuit breaker. So the tripping characteristic of the protection is one in increasing steps with the increasing impedance. In figure 1 the tripping characteristic of the distance protection is shown [15], [16].

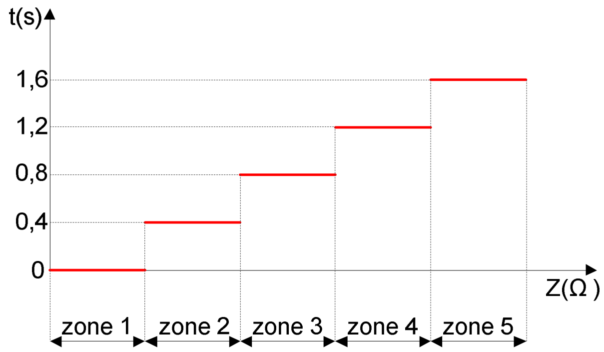


**Fig. 1. Tripping characteristic of the distance protection**

The main reason for the fact that this protection measures the distance to the fault is to enclose the fault in a given distance zone and not to provide an approximate location of it!

## 4. EVOLUTION OF PICKUP AND TRIPPING CHARACTERISTICS

In terms of pickup and tripping characteristics of the classic distance protection and the numeric one, they differ very much [16].

If the classic distance protections had a pickup characteristic and measurement characteristic commonly represented by continuous sealed type circular curves or ellipse type to the numerical protections they have changed radically. The distance protection function from the numerical terminals uses interrupted characteristics obtaining the form of polygonal characteristics, increasing the sensibility of the protection. These characteristics are represented in the complex plan of the impedance by setting the value of the real component – resistance and the imaginary one – reactance.

Electrical parameters of power and network in case of faults and abnormal operating states of the system differ from case to case. So depending on the type of the fault, the occurrence or not of the electrical arch, or operation in overload, impedance suffers major changes, with the possibility of having wrong tripping decisions of the distance protection [17].

In the case of a metallic short circuit, the impedance vector will shrink, entering the tripping zone. In this case the angle between the vector of complex impedance and resistance will remain unchanged.

The situation changes however in case of a short circuit through the electrical arch. The electrical arch is purely ohmic, so to the fault impedance it adds the arch resistance, reactance being zero. In this case the angle between the total fault impedance and resistance decreases, but not very much. In figure 2 and 3 are presented the two types of behaviour of the impedance vector in the given cases [14].

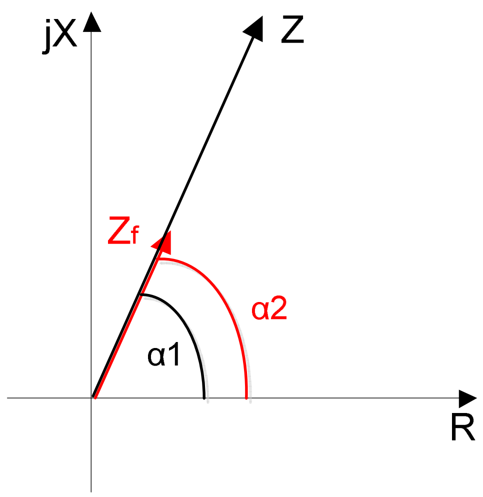


**Fig. 2. Impedance vector behaviour in case of fault without electric arch**

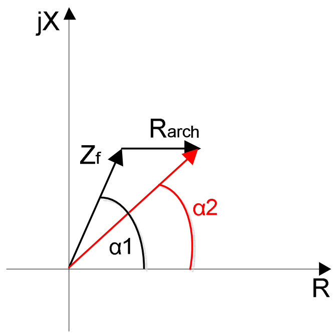


**Fig. 3. Impedance vector behaviour in case of fault with electric arch**

In case of overloads, the impedance vector decreases not as much as in case of a fault, but the impedance vector can enter the tripping area because the angle between this vector and the resistance decreases very much (figure 4).

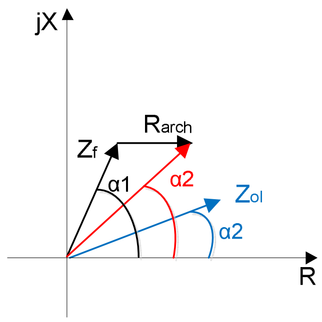


**Fig. 4. Impedance vector behaviour in case of overload**

Taking into account these behaviors of impedance in different situations, there have been developed more types of pickup characteristics. The simplest such pickup characteristic is the impedance characteristic, which is represented by a circle with center in the origin. This characteristic is shown in figure 5.

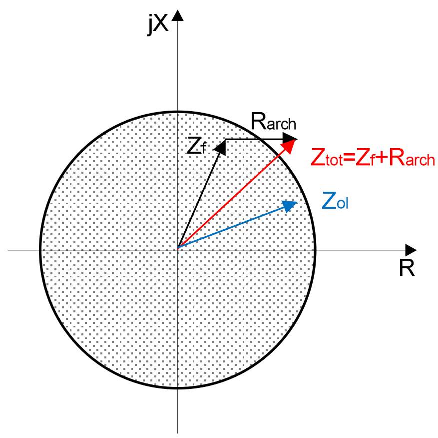


**Fig. 5. Impedance characteristic**

For this characteristic we notice that is doesn't perform very well in case of faults with large arch resistance, even in case of more pronounced overloads there is a risk of a wrong pickup and trip of the relay [14].

To solve the problem of the electrical arch influence, there were developed the so called generalized resistance characteristic. This characteristic is represented by a circle given the center moved along the axis R and it is presented in the next figure.

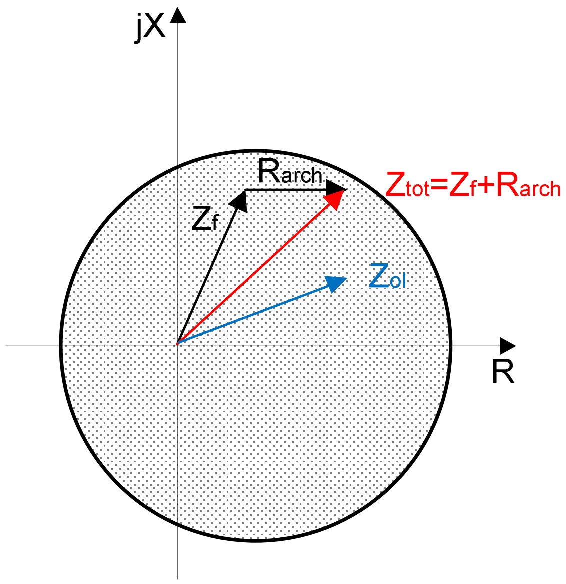


**Fig. 6. Generalized resistance characteristic**

This characteristic, having the circle's center moved along the axis R, performs very well at high current electrical arch resistance. The major disadvantage is the behavior to overloads, these are practically undetectable [14].

For a better framing of the fault in case of electrical power lines fault and the attempt to detect overloads there were created mixed admittance relays (mho). These relays have a circular characteristic, the center of the circle being offset by both the axis R and the axis jX. The radius of the circle forms a straight segment between the origin and the center of the circle, which is inclined 45° to the axles. Characteristic of the mixed admittance relay is presented in figure 7.

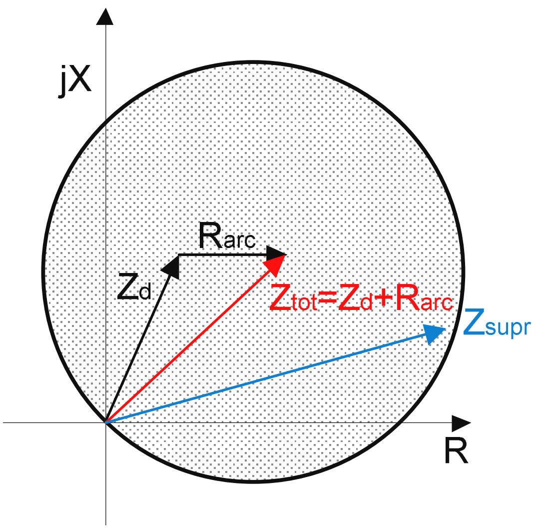


**Fig. 7. Mixed admittance relay characteristic**

These characteristics have an excellent behavior in case of short circuits with or without an electric arch, but the detection and classification of the overload state in a system depends very much on how the angle between the complex impedance and R axis decreases [14].

As the time passed, there has been found a solution to this problem by introducing ellipse type characteristics. These ellipses are thus positioned in the complex plan, so between the major axis and the R axis will be formed an angle equal to the short circuit angle of the protected line (figure 8).

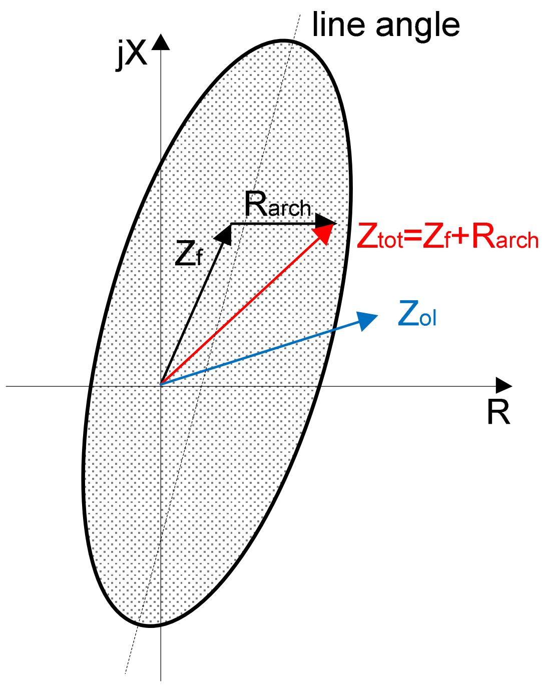


**Fig. 8. Ellipse type characteristic**

This kind of characteristic has a great behaviour in both cases, the electric arch influence and the case of overloads [14].

The current trends in terms of achieving operating characteristics using numerical technique resulted in obtaining the characteristics of polygonal type which are very similar to the elliptical characteristics (figure 9).

Therefore actual equipment are using polygonal type of characteristics like the one presented in figure 10.

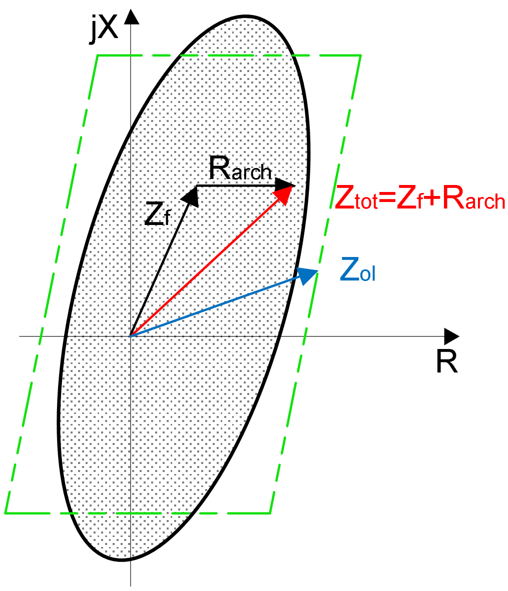


**Fig. 9. Comparison of the elliptical and polygonal characteristics**

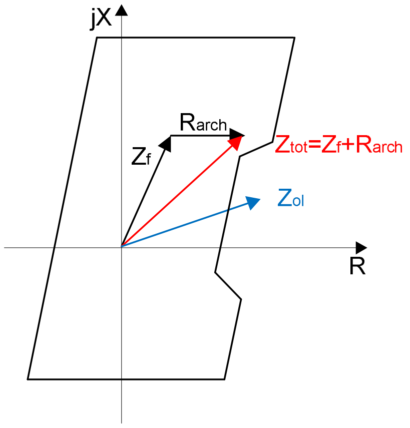


**Fig. 10 – Actual polygonal type characteristics**

Distance protection is a protection targeted for using both power parameters such as voltage values and current values. Related to these aspects, in both cases, the classic protection and the numeric protection, at the disappearance of the secondary voltage the distance protection function must be blocked [7], [11].

For the classic relays this has been done with specific relays, while in the case of numerical relays this is done through the auxiliary normally closed contacts of MCB located in the secondary voltage circuits [11].

Another issue related to the operation of the distance protection is the dependence of the abnormal state of power swings. Power swings causes quick changes of the impedance vector by changing the power direction [18], [19]. These swings can also cause tripps so the distance protection must be blocked [20], [21], [22].

Detection of the power swing is based on the measuring of the decreasing speed of the complex measured impedance and her passing speed between the distance zones [20]. I mention that if during blocking protection as a result of power swing detection a fault occurs, the blockage must be canceled, the protection ordering the circuit breaker tripping in the detected zone [17], [20], [21].

## 5. THE CONSTRUCTIVE PRINCIPLES OF DISTANCE PROTECTION

As we stated before, classic protections were made through a number of items for each function. Currently the protections made in the numerical technique include several protection functions within the same terminal equipment called numerical protection equipment [3].

Distance protection called generically is a numerical protection terminal given as basic protection function in the terminal is the distance protection, this terminal have other functions [23], [24]:

- fuse failure protection;
- power swing blocking;
- auto reclosure function;
- overcurrent functions;
- teleprotection;
- high current switch on to fault function – SOTF/TOR.

This last function is a new function that is not included within classic protections and that uses different principles of operation. Perhaps of all the protection functions this is the only one that can be improved, and there are a few cases of wrong actions in operation.

The function is basically a high speed overcurrent protection which activates only in case of a manual close command of the circuit breaker [3], [23].

A major difference between the classic protection systems and the new ones is the ability of communication between these devices [25], [26], [27]. Communication is carried out via fiber optic support and it's using the IEC 61850 communication protocol, which is a substation protocol [22], [27], [28].

## 6. RECENT TRENDS USING NUMERICAL PROTECTION

This section deals with the recent trends regarding the evolution of the protection systems. The synthesis is developed using 35 papers from international conferences regarding power systems protection (mainly the distance protection).

a) aspects regarding secondary circuits [1], [2], [3], [4], [27], [31]:
- secondary circuits influence on power system behavior;
- internal supervision of the protection equipment;
- relay testing considering primary equipment position;
- relay configuration study;
- communication improvement between transformers and protection equipments;
- secondary circuits simulation.

b) distance protection behavior in presence of line compensation [5], [6], [10], [12]:
- distance protection optimization considering line compensation;
- distance zones parametrization considering line compensation;
- distance protection behavior using SVC systems.

c) influence on distance zones [7], [8], [9], [11], [13], [15]:
- faulted phase selection;
- STATCOM systems impact on distance zones;
- frequency deviation impact on distance protection;
- transformers influence on voltage and current values;
- wind farms influence on distance zones;
- parallel power line influence on the first distance zone.

d) distance protection behavior during power swing and electric arc [14], [17], [18], [19], [20], [21]:
- electric arch influence on measured impedance;
- distance protection behavior during power swing;
- distance protection blocking during power swing;
- power swing detection;
- renewable energy impact on distance protection.

e) protection devices using numerical technology [16], [22], [24]:
- tripping time analysis;
- fault location using numerical information;
- numerical equipment behaviour during system restoration.

f) fiber optic communication between protection devices

[25], [26], [28], [29]:
- substation modernization using IEC61850 protocol;
- equipment communication using IEC61850 protocol;
- protection and automation system implementation using IEC61850 protocol;
- human-machine communication.

g) importance of backup protection functions [23], [30], [32], [33], [34], [35]:
- usage of directional backup overcurrent function;
- control and backup protection insurance in power system operation;
- false tripping due to improper configuration;
- line differential protection;
- power line protection using electrical power parameter information during fault.

## 7. CONCLUSION

In the past two decades, by the development of the computing technique, the protection functions have been implemented in the numerical technology, including several protection functions in the same equipment. Through this jump and through the use of numerical technology there were solved two of the three main conditions which must be satisfied by a protection equipment: speed and sensibility.

Taking into account the two major requirements that the power system and the actual trends of realizing protection and automation equipment has to accomplish, I consider that there are functions that can be optimized.

Most of these functions are based on laws and theorems in electrical engineering and studies of the behaviour of electrical energy parameters in different situations.

I think that some new protection functions can be optimized and that new ones may arise, but for that to happen, there must be a solid and open collaboration between electrical and IT engineers.

Also, a research on the protection and automation systems must include some variables such as the state at a certain moment of some equipment and not to rely only on what type of system element should be protected and neither on the specific protection of this element.

By studying how to implement the protection's logics on the basis of laws and theorems in electrical engineering, by implementing them into a mathematical model and through the use of variables that represent the status of the system at a certain time, you can get very good results regarding the selectivity and the optimization of the protection and automation equipment's functioning.

## REFERENCES


[1] E.L. Kokorin, S.A. Dmitriev, A.I. Khalyasmaa, Electrical network reliability assessment with consideration of the secondary circuits effect, 57th International Scientific Conference on Power and Electrical Engineering of Riga Technical University (RTUCON), 2016. pp. 1-6

[2] Y.T.Y.H. Jia Liu, Improved analytic model to detect hidden failure of protection relays, IEEE International Conference on Probabilistic Methods Applied to Power Systems (PMAPS), 2016, pp. 1-6

[3] B. Vandiver, Why testing digital relays are becoming so difficult. Part 3: Advanced feeder protection, 69th Annual Conference for Protective Relay Engineers (CPRE), 2016, pp. 637-642

[4] W. An, M.Y. Zhao, J.S. Li, H.Y. Zhou, Z.H. Chen, J. Yu, L. Li, S.J. Chen, Z.D. Bi, Y.H. Xia, Q.Y. Yu, Online evaluation and verification of protection relay settings – Design and field experience, 12th IET International Conference on Developments in Power System Protection (DPSP), 2014, pp. 19-22

[5] X.G. Magagula, D.V. Nicolae, A.A. Yusuff, The performance of distance protection relays on series compensated line under fault conditions, IEEE International Conference Africon, 2015, pp. 1-6

[6] S. Roy, P.S. Babu, Power swing protection of series compensated transmission line with novel fault detection technique, International Conference on Green Computing Communication and Electrical Engineering (ICGCCEE), 2014, pp. 1-6

[7] T. Utsumi, T. Nakatsuka, H. Takani, H. Amoh, F. Kawano, P. Beaumont, Faulted phase selection function based upon impedance comparison in a distance protection relay, International Conference on Advanced Power System Automation and Protection (APAP), 2011, p. 314-319

[8] M. Allehyani, H. Samkari, B.K. Johnson, Modeling and simulation of the impacts of STATCOM control schemes on distance elements, North American Power Symposium (NAPS), 2016, pp. 1-6

[9] C.L. Silva, G. Cardoso Jr., A.P. de Morais, G. Marchesan, F.G.K. Guarda, A continually online trained impedance estimation algorithm for transmission line distance protection tolerant to system frequency deviation, Electric Power Systems Research, 147 (2017), pp. 73-80

[10] A.R. Singh, Sanjay S. Dambhare, Adaptive distance protection of transmission line in presence of SVC, Electrical Power and Energy Systems, 53 (2013), pp. 78–84

[11] [Ghor2015] A. Ghorbani, An adaptive distance protection scheme in the presence of phase shifting transformer, Electric Power Systems Research, 129 (2015), pp. 170-177

[12] H. Abdollahzadeh, B. Mozafari, M. Jazaeri, Realistic insights into impedance seen by distance relays of a SSSC-compensated transmission line incorporating shunt capacitance of line, Electrical Power and Energy Systems, 65 (2015), pp. 394-407

[13] L.A.T. Guajardo, A.C. Enríquez, Z. Leonowicz, Error compensation in distance relays caused by wind power plants in the power grid, Electric Power Systems Research, 106 (2014), pp. 109-119

[14] M.C.R. Paz, R.C. Leborgne, A.S. Bretas, Adaptive ground distance protection for UPFC compensated transmission lines: A formulation considering the fault resistance effect, Electrical Power and Energy Systems, 73 (2015), pp. 124-131

[15] M.R. Araújo, C. Pereira, A practical first-zone distance relaying algorithm for long parallel transmission lines, Electric Power Systems Research, 146 (2017), pp. 17-24

[16] M. Lukowicz, J. Magott, P. Skrobanek, Selection of minimal tripping times for distance protection using fault trees with time dependencies, Electric Power Systems Research, 81 (2011), pp. 1556-1571

[17] R. Dubey, S.R. Samantaray, B.K. Panigrahi, V.G. Venkoparao, Data-mining model based adaptive protection scheme to enhance distance relay performance during power swing, Electrical Power and Energy Systems, 81 (2016), pp. 361-370

[18] V. Azbe, R. Mihalic, J. Jaeger, A direct method for assessing distance-protection behavior during power swings, Electrical Power and Energy Systems, 90 (2017), pp. 94-102

[19] G. Benmouyal, D. Hou, D. Tziouvaras, Zero setting power swing blocking protection, 3rd IEEE International Conference on Reliability of Transmission and Distribution Networks (RTDN), 2005 pp. 249-254

[20] M.K. Gunasegaran, C.K. Tan, A.H.A. Bakar, H. Mokhlis, H.A. Illias, Progress on power swing blocking schemes and

the impact of renewable energy on power swing characteristics: A review, Renewable and Sustainable Energy Review, 52 (2015), pp. 280-288

[21] J. Mooney, N. Fischer, Application Guidelines for Power Swing Detection on Transmission Systems, Power Systems Conference on Advanced Metering, Protection, Control, Communication, and Distributed Resources, 2006, pp. 1-6

[22] M. Lattner, W. Carr, C. Benner, Improved fault location on distribution circuits using advanced inputs, 69th Annual Conference on Protective Relay Engineers (CPRE), 2016, pp. 1-8

[23] J.Z. Castro, J.M. Lopez-Lezama, Optimal coordination of directional overcurrent relays operating as backup protection in electrical power system, IEEE Central America and Panama Convention (CONCAPAN XXXIV), 2014, pp. 1-6

[24] M. Jaworski, J. Jaeger, Protection relay behaviour during power system restoration – a boundary based state classification approach, 13th International Conference on Development in Power System Protection (DPSP), 2016, pp. 1-6

[25] [Chen2015] X. Cheng, W.J. Lee, X. Pan, Electrical substation automation system modernization through the adoption of IEC 61850, IEEE/IAS Industrial & Commercial Power Systems Technical Conference (I&CPS), 2015, pp. 1-7

[26] X. Cheng, W.J. Lee, X. Pan, Modernizing substation automation systems: Adopting IEC standard 61850 for modelling and communication, IEEE Industry Applications Magazine, 23/1, 2017, pp. 42-49

[27] D.V. Topolskiy, N.D. Topolskiy, E.V. Solomin, Development of algorithms of interaction between electronic instrument transformer and substation automation system, International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), 2016, pp. 1-6

[28] B. Adhikary, S. Rao, S.R. Balasani, Implementation aspects of substation automation systems based on IEC 61850, 2nd International Conference on Control, Instrumentation, Energy & Communication (CIEC), 2016, pp. 442-445

[29] [Stoc2016] M. Stockton, J. Kelly, M. Mohemmed, Optimization of protection IED user interaction and implementing self-monitoring protection schemes, 13th International Conference on Development in Power System Protection (DPSP), 2016, pp. 6-6

[30] [Gao2016] S. Gao, Q. Liu, G. Song, Current differential protection principle of HDVC transmission system, IET Generation, Transmission& Distribution, 11/5 (2917), pp.1286-1292

[31] [Pepp2016] J. Peppanen, S. Grijalva, M.J. Reno, R.J. Broderick, Secondary circuit modelcreation and validation with AMI and transformers measurements, North American Power Symposium (NAPS), 2016, pp. 1-6

[32] [Babu2016] K.N.D. Babu, U. Sivakumar, A. Kathiresh, J. Gupta, J.P. Joseph, Case study on analysis of busbar protection relay tripping due to improper logic configuration, IEEE 6th International Conference on Power Systems (ICPS), 2016, pp. 1-4

[33] [Jena2017] M.K. Jena, S.R. Samantaray, B.K. Panigrahi, Supervisory control based wide area backup protection scheme for power transmission network, National Power Systems Conference (NPSC), 2016, pp. 1-5

[34] [Alme2017] M.L.S. Almeida, K.M. Silva, Transmission lines differential protection based on an alternative incremental complex power alpha plane, IET Generation, Transmission & Distribution, 11/1 (2017), pp. 10-17

[35] [Bola2014] T.G. Bolandi, H. Seyedi, S.M. Hashemi, Protection of transmission lines using fault component integrated power, IET Generation, Transmission & Distribution 8/12 (2014), pp. 2163-1172