Computer relaying for smart grid protection

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Abstract:- In order to improve reliability and availability in upcoming smart grids, a number of effective actions based on new digital protection systems are suggested. The functions of new generation digital protections are presented and discussed, and operating solutions in designing smart grid protection plans are illustrated. As a matter of fact, smart grids are crucial, complex systems that must ensure a very high quality of the electric power delivered. In order to increase the distribution system reliability, also protection backup systems are identified and discussed. The main digital functions investigated are overcurrent code, directional overcurrent code and undervoltage code. Considerations on the selectivity plan and apparatus setting are also made. Finally, comments and suggestions are reported about the reconfiguration and restoration of the power system after a fault clearance.

Key-Words: - Power system protection, Smart grids, Digital protections, Power quality.

1 Introduction

Digital protections can offer a number of advantages, the main of which are: multi-functionality, compatibility with DGI (Digitally Integrated Systems), remarkable sensitivity and selectivity, high reliability level, high speed, adaptive protection, reduced load on current and voltage transformers, maintenance-free and low cost. Digital protections involve also Information and Communication Technologies (ICT) using advanced systems, such as microprocessors, satellites, optical fibers, wireless networks, etc. [1-7], [9], [15].

Since protection actions activate a disconnection of system elements, in order to improve the continuity level of a smart grid it is very important to provide operations for an automatic, fast system restoration. The main functions to be implemented are surely reclosing operations and subsequent grid reconfiguration, automatic synchronization, automatic transfer of power flows and automatic relocation to alternative power supplies.

An improper design of the protection system can actually cause important blackouts involving loss of service in large areas, hazard for human life and relevant economic losses.

When compared with transmission systems, smart grids are more complex due to their ramified nature, the presence of massive, intermittent distributed generation and the possibility to operate in islanded mode, which indeed makes it difficult to adequately protect the network in the presence of a fault [8], [11-12], [14], [16]. In addition, when an overcurrent fault occurs all distributed generators are usually disconnected to clear the fault, and therefore it becomes very difficult to remove only the single faulted line-segment. Other problems that may arise in distributed generation are false tripping, protection blinding, increasing and decreasing short circuit currents.

For typical short circuits in distribution systems statistical investigations give the following quota: single-phase-ground, 70-80%; phase-phase-ground, 17-10%; phase-phase, 10-8%; three-phase, 3-2%.

The main principles of distribution line protection are: overcurrent (50, 51, 50N, 51N), directional overcurrent (67, 67N) and undervoltage (27D and 27S).

2 The general architecture of a digital protection system

A digital protection consists of subsystems with well-defined functions. The block diagram in Fig. 1 shows the main subsystems of a digital protection, and it can easily be seen that this architecture is very similar to that of a measuring system with programmable logic.

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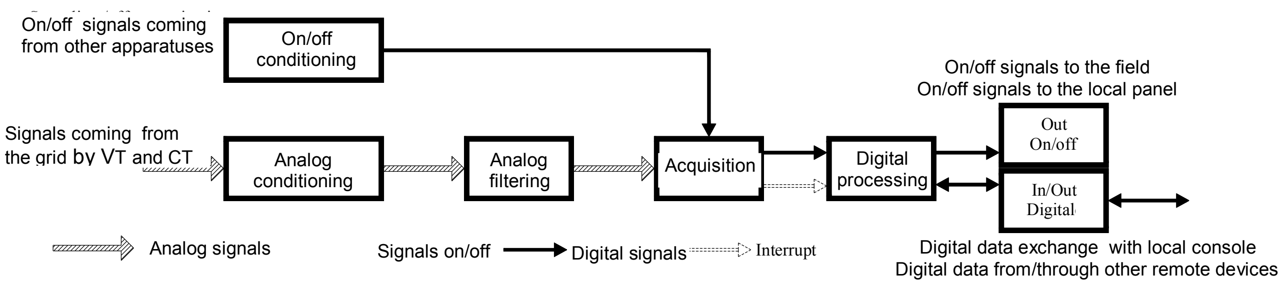

Fig. 1 – General diagram of a digital protection.

In this scheme, the computational processor is central, since it is responsible for processing, storing and sharing data with peripheral interfaces.

Usually, the relay inputs are the signals of voltages and currents, often acquired from current and voltage transformers that must be properly conditioned and digitalized by suitable analog/digital converters.

In the following, the main functions implemented in digital protections are presented and commented with the aim to correct set them for an effective smart grid protection.

2 The overcurrent function (relays 50-51)

The overcurrent function is available in four models, furtherly subdivided into two banks, each available in two groups, named *Group A* and *Group B* respectively. These groups can be arranged in two different modalities through an appropriate configuration of specific parameters. The three-phase overcurrent function is activated if one, two or three of the phase-currents exceed the trigger threshold. This protection, which is of the time-delayed type, can be delay-dependent or delay-independent and can be devised so as to enable the construction of 14 different operation curves. Fig. 2 shows the conceptual scheme and the operation diagram of the function presented.

The above-mentioned time-delayed curves are detailed in Table 1, which is very simple to read since only the basic time *Ts* and the regulated current *Is* (e.g. *30A*, *0.8s*) must be known. As an example, to find the protection trip time for a current equal to *4Is*, the first column of the table 1 must be read where the number *4* appears, and in that row the value of the selected curve (e.g. VIT, Very Inverse Time) can be found. The tripping time t_A is equal to KT_S. A practical method to set this protection is as follows.

First of all, it is necessary to define the value of the rated load current. At this point, also the current I_S will be known, since: $Is = In$. In order to calculate the time *Ts*, it is necessary to know the maximum current of the downstream protection and its operation time (I_B, T_B). Consider the point (I_B, $T_B+\Delta t$) on the *I-T* plane. Once a characteristic is selected, it is possible to intercept the I_B/Is point on the first column of Table 1 and then verify the *K* value.

Finally, the setting time can be calculated using the following relationship:

$$T_s = \frac{T_B}{K}$$

3 The maximum ground overcurrent (51N)

The maximum earth current function is characterized by two thresholds. The function is unipolar and is energized if the ground current reaches the operation threshold. The protection function includes a second harmonic restraint that ensures greater stability during the transformer energization [10], [13]. This restraint locks the intervention, whatever the value of the fundamental current. In this protection as well, operation is possible in either time-independent or dependent modality with the same features as previously described. Fig. 3 shows the block diagram of the 51N function.

4 The under voltage functions (27D and 27S)

In this case, two functions are available, and are standardized as 27D and 27S. The former triggers if the direct voltage component V_d of the three-phase system is lower than the threshold calibration V_{sd}.

The latter is triggered instead if one of the phase voltages is below that of the threshold.

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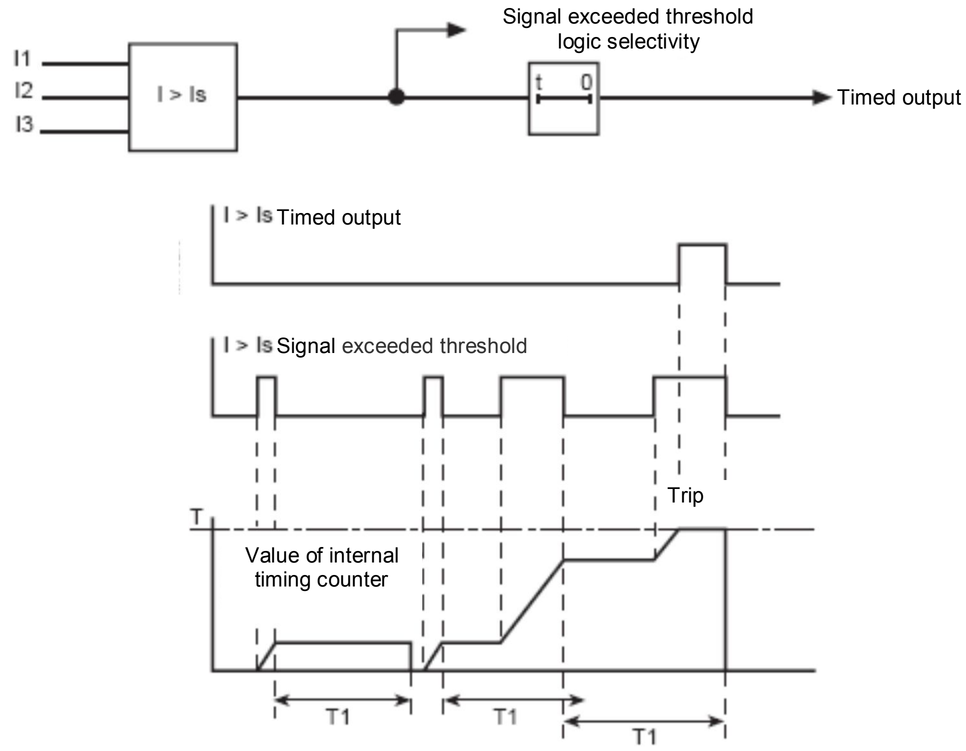

Fig. 2 - Conceptual scheme and operation diagram of the overcurrent function.

I/Is	SIT e CEI/A	VIT, LTI e CEI/B	EIT e CEI/C	UIT	RI	IEEE MI (CEI/D)	IEEE VI (CEI/E)	IEEE EI (CEI/F)	IAC I	IAC VI	IAC EI
1,0	—	—	—	—	3.062	—	—	—	62.005	62.272	200.226
1,1	24,700(1)	90,000(1)	471,429(1)	—	2,534	22,461	136,228	330,606	19,033	45,678	122,172
1,2	12,901	45,000	225,000	545,905	2,216	11,777	65,390	157,946	9,413	34,628	82,899
1,5	5,788	18,000	79,200	179,548	1,736	5,336	23,479	55,791	3,891	17,539	36,687
2,0	3,376	9,000	33,000	67,691	1,427	3,152	10,199	23,421	2,524	7,932	16,178
2,5	2,548	6,000	18,857	35,490	1,290	2,402	6,133	13,512	2,056	4,676	9,566
3,0	2,121	4,500	12,375	21,608	1,212	2,016	4,270	8,970	1,792	3,249	6,541
3,5	1,858	3,600	8,800	14,382	1,161	1,777	3,242	6,465	1,617	2,509	4,872
4,0	1,676	3,000	6,600	10,169	1,126	1,613	2,610	4,924	1,491	2,076	3,839
4,5	1,543	2,571	5,143	7,513	1,101	1,492	2,191	3,903	1,396	1,800	3,146
5,0	1,441	2,250	4,125	5,742	1,081	1,399	1,898	3,190	1,321	1,610	2,653
5,5	1,359	2,000	3,385	4,507	1,065	1,325	1,686	2,671	1,261	1,473	2,288
6,0	1,292	1,800	2,829	3,616	1,053	1,264	1,526	2,281	1,211	1,370	2,007
6,5	1,236	1,636	2,400	2,954	1,042	1,213	1,402	1,981	1,170	1,289	1,786
7,0	1,188	1,500	2,063	2,450	1,033	1,170	1,305	1,744	1,135	1,224	1,607
7,5	1,146	1,385	1,792	2,060	1,026	1,132	1,228	1,555	1,105	1,171	1,460
8,0	1,110	1,286	1,571	1,751	1,019	1,099	1,164	1,400	1,078	1,126	1,337
8,5	1,078	1,200	1,390	1,504	1,013	1,070	1,112	1,273	1,055	1,087	1,233
9,0	1,049	1,125	1,238	1,303	1,008	1,044	1,068	1,166	1,035	1,054	1,144
9,5	1,023	1,059	1,109	1,137	1,004	1,021	1,031	1,077	1,016	1,026	1,067
10,0	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000	1,000
10,5	0,979	0,947	0,906	0,885	0,996	0,981	0,973	0,934	0,985	0,977	0,941
11,0	0,959	0,900	0,825	0,787	0,993	0,963	0,950	0,877	0,972	0,957	0,888
11,5	0,941	0,857	0,754	0,704	0,990	0,947	0,929	0,828	0,960	0,939	0,841
12,0	0,925	0,818	0,692	0,633	0,988	0,932	0,912	0,784	0,949	0,922	0,799
12,5	0,910	0,783	0,638	0,572	0,985	0,918	0,896	0,746	0,938	0,907	0,761
13,0	0,895	0,750	0,589	0,518	0,983	0,905	0,882	0,712	0,929	0,893	0,727
13,5	0,882	0,720	0,546	0,471	0,981	0,893	0,870	0,682	0,920	0,880	0,695
14,0	0,870	0,692	0,508	0,430	0,979	0,882	0,858	0,655	0,912	0,868	0,667
14,5	0,858	0,667	0,473	0,394	0,977	0,871	0,849	0,631	0,905	0,857	0,641
15,0	0,847	0,643	0,442	0,362	0,976	0,861	0,840	0,609	0,898	0,846	0,616
15,5	0,836	0,621	0,414	0,334	0,974	0,852	0,831	0,589	0,891	0,837	0,594
16,0	0,827	0,600	0,388	0,308	0,973	0,843	0,824	0,571	0,885	0,828	0,573
16,5	0,817	0,581	0,365	0,285	0,971	0,834	0,817	0,555	0,879	0,819	0,554
17,0	0,808	0,563	0,344	0,265	0,970	0,826	0,811	0,540	0,874	0,811	0,536
17,5	0,800	0,545	0,324	0,246	0,969	0,819	0,806	0,527	0,869	0,804	0,519
18,0	0,792	0,529	0,307	0,229	0,968	0,812	0,801	0,514	0,864	0,797	0,504
18,5	0,784	0,514	0,290	0,214	0,967	0,805	0,796	0,503	0,860	0,790	0,489
19,0	0,777	0,500	0,275	0,200	0,966	0,798	0,792	0,492	0,855	0,784	0,475
19,5	0,770	0,486	0,261	0,188	0,965	0,792	0,788	0,482	0,851	0,778	0,463
20,0	0,763	0,474	0,248	0,176	0,964	0,786	0,784	0,473	0,848	0,772	0,450

Table 1 – Data used to set the inverse time tripping curves.

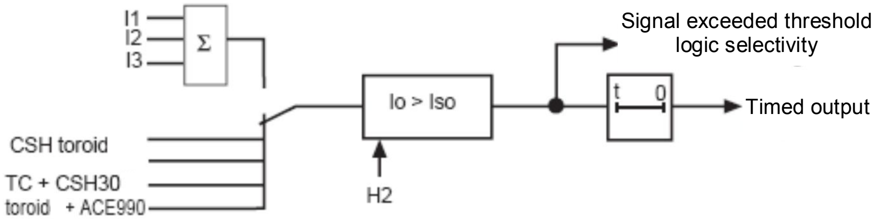

Fig. 3 - Block diagram of the 51N function.

5 Ground directional overcurrent (67N)

This function has two settings banks, each available in two models, and there are three types of operations. Type 1 determines the projection of the I_0 residual current on the characteristic straight line whose position can be fixed by adjusting the θ_0 characteristic angle with respect to the residual voltage. This projection is compared with the threshold I_{s0}. The timing is always time-independent.

Fig. 4 shows the block diagram for the type-1 modality.

The Type 2 function acts as an overcurrent protection to which the concept of direction was added. It is useful for single-ring configurations or with grounded neutral.

Fig. 5 shows the block diagram for the type-2 modality.

The protection also allows to set a release time T_1, as shown in Fig. 6.

Finally, Fig. 7 shows that Type-3 modality acts as a zero-sequence overcurrent protection to which a criterion of angular direction was added.

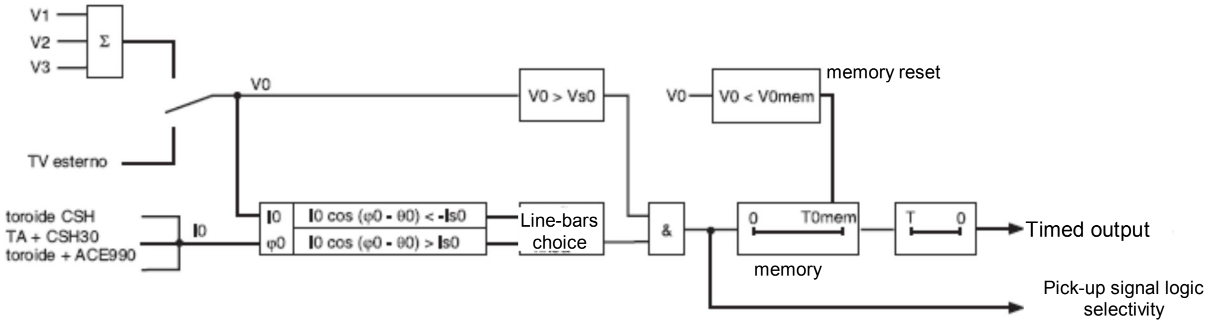

Fig. 4 - Block diagram for the *Type 1* modality.

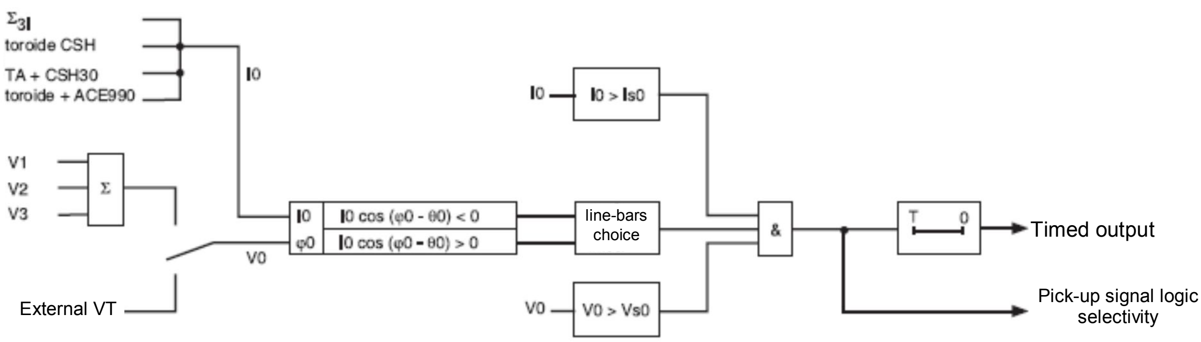

Fig. 5 - Block diagram for the *Type 2* modality.

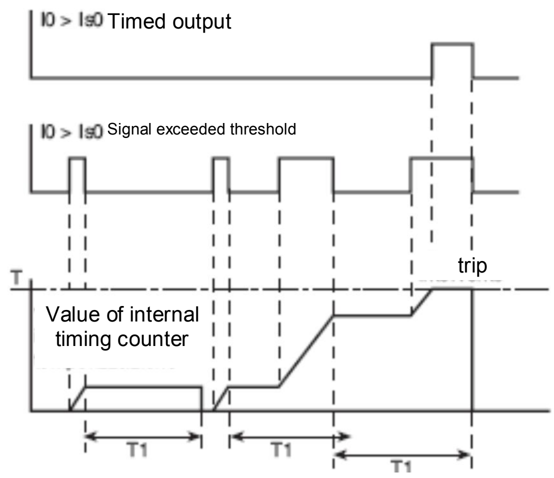

Fig. 6 – Operation diagram for the *Type 2* modality.

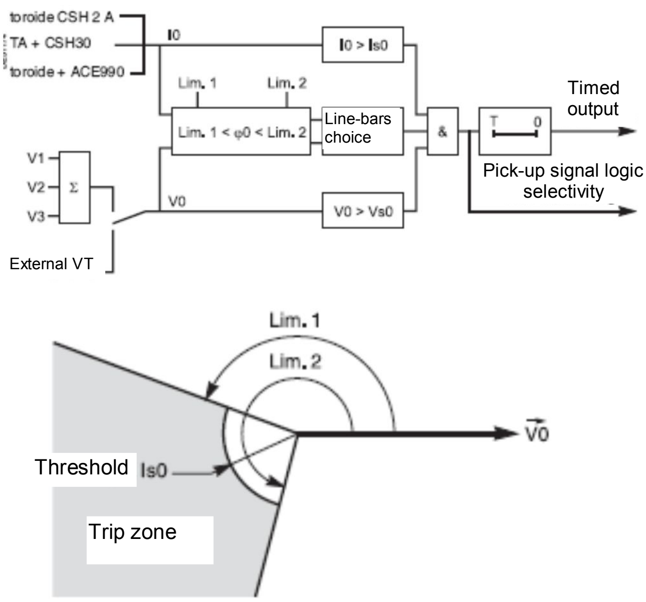

Fig. 7 – Operation diagram of *Type* 3 modality.

6 Remarks

When designing a smart grid, it is necessary to find a balance between the level of reliability to be achieved and the costs involved. Although it is impossible to eliminate the occurrence of faults and other abnormal operating conditions that may cause severe disturbances in smart grids, an effective protection system can actually enact important corrective and preventive actions. The first stage of protection is aimed at the individual components of the system, with the purpose to isolate the single faulted element and avoid therefore more extended inefficiencies and damage to the electrical system. As a rule, modern electrical systems work close to safety limits, since it is necessary to minimize costs to comply with economic and competition policies.

For the same reasons, if the protection system disconnects grid elements it is advisable to install an automatic mechanism to reconfigure and restore the power system in very short time.

7 Conclusions

The paper analyses the issue of distribution system protection, involving nowadays new targets to be reached and new challenges to be faced in order to ensure the needs of upcoming smart grids. A number of different functions of new digital relays are presented and discussed, and information on the architecture of protection systems is also supplied. Moreover, some issues connected to selectivity, backup protection and apparatus setting are addressed. The digital protections proposed can improve the reliability, power quality, safety and stability of developing smart grids. Furthermore, the reclosing feature is presented as an additional procedure that can substantially improve system reliability and availability.

References:

[1] G. Fazio, V. Lauropoli, F. Muzi, G. Sacerdoti, Variable-window algorithm for ultra-high-speed distance protection, *IEEE Transactions on Power Delivery* - Vol. 18, N. 2, April 2003.

[2] F. Muzi, A filtering procedure based on least squares and Kalman algorithm for parameter estimate in distance protection, *International Journal of Circuits, Systems and Signal Processing*, Issue 1, Vol. 1, 2007.

[3] F. Muzi, L. Passacantando, A real-time monitoring and diagnostic procedure for electrical distribution networks, *International Journal of Energy*, ISSN: 1998-4316, Issue 2, Vol. 1, 2007

[4] F. Muzi, Real-time Voltage Control to Improve Automation and Quality in Power Distribution, *WSEAS Transactions on Circuits and Systems*, Issue 4, Volume 7, April 2008.

[5] F. Muzi, F. D'Innocenzo, Implementation of a new control system for low voltage switchboards, *IEEE International Symposium on Industrial Electronics - ISIE 2010*, Bari, Italy, 4-7 July 2010.

[6] F. Muzi, A. De Sanctis, P. Palumbo, Distance protection for smart grids with massive generation from renewable sources, *The 6th IASME/WSEAS International Conference on Energy & Environment (EE'11)*, Cambridge (UK), 2011.

[7] F. Muzi, A. De Sanctis, P. Palumbo, A new algorithm for smart grid protection based on synchronized sampling, *International Journal of Energy and Environment*, Issue 4, Volume 5, 2011.

[8] C. Buccella, C. A. Canizares, C. Cecati, F. Muzi, P. Siano, Guest Editorial for the Special Section on Methods and Systems for Smart Grids Optimization, *IEEE Transactions on Industrial Electronics*, Vol. 58, Number 10, ITED6, October 2011.

[9] F. Muzi, Distance relays in conjunction with a new control algorithm of inverters for smart grid protection, *2011 CIGRE International Symposium*, Bologna, Italy, 2011.

[10] M. Gong, X. Zhang, Z. Gong, W. Xia; J. Wu, C. Lv, Study on a new method to identify inrush current of transformer based on wavelet neural network, *Electrical and Control Engineering (ICECE)*, 2011.

[11] F. Muzi, M. Barbati, A real-time harmonic monitoring aimed at improving smart grid power quality, *2011 IEEE International Conference on Smart Measurements for Future Grids (SMFG)*, Bologna, Italy, Nov. 14-16, 2011.

[12] G. Houlei, P. Qingle, A. Yanqiu, Z. Baoguang, Q. Xiaosheng, W. Yuanbo. T. Chun, New type of protection and control method for smart distribution grid, *Developments in Power Systems Protection, 2012, 11th International Conference on Digital Object Identifier*, 2012.

[13] F. Muzi, R. Dercosi Persichini, An analysis of overvoltages in large MV-Cable installation, *15th IEEE-ICHQP International Conference*, Hong Kong, 17-20 June 2012.

[14] M. Khederzadeh, Wide-area protection in smart grids, *Developments in Power Systems Protection, 11th International Conference on Digital Object Identifier*, 2012.

[15] Schneider Electric, *Sepam* user-manual – 2012.

[16] F. Muzi, The transformer inrush currents in large MV-cable installations, *12th WSEAS International Conference on Electric Power Systems, High Voltages, Electric Machines (POWER '12)*, Prague, Czech Republic, September 24-26, 2012.