NUMERICAL OVERCURRENT PROTECTIVE RELAY USING THE RMS CALCULATION BASED ON THE QUADRATURE SAMPLING METHOD

Mohammed LATROCH[1], Djelloul RAHIEL[2], Mounir KHIAT[3]

In this paper, a model of a numerical overcurrent protective relay is proposed, tested in simulation and validated. The simulation of the model is performed using the Matlab simulating software package. The purpose of the simulation is to assess the performances of the model. In the SCAMRE laboratory and using the Schneider Electric Sepam MD2ADSEP pedagogical platform equipped with a Schneider Electric Sepam series 80 numerical protection relay, the model is validated. The proposed model has several advantages; one of them that is based on the quadrature sampling method, this method is rather precise and fast in the calculation of the root mean square values of a periodic signal. Another advantage that distinguishes the model is its easy implementation on all the types of the programmable electronic boards. Also, the proposed model supports the three tripping characteristics of the overcurrent protection: Instantaneous, definite time and inverse definite minimum time.

Keywords: Numerical relay, overcurrent model, simulation, validation, IDMT

1. Introduction

A protective relay is the device, which gives instruction to disconnect a faulty part of the system. This action ensures that the remaining system is still fed with power and protects the system from further damage due to the fault. Hence, use of protective apparatus is very necessary in the electrical systems, which are expected to generate, transmit and distribute power with least interruptions and restoration time [1].

The power system fault is inevitable, so accurate and rapid intelligent analysis [2]. Numerical relays are capable of meeting the fundamental protective requirements such as reliability, sensitivity, selectivity and speed. Therefore, the use of numerical relays will soon replace previous relays' technology such as static relays [3].

[1] SCAMRE LABORATORY, Department of Electrical Engineering, National polytechnic school of Oran (ENPO-MA), Oran, Algeria. e-mail: latroch_mohammed@hotmail.com
[2] Prof. Department of Electrical Engineering, National polytechnic school of Oran (ENPO-MA), Oran, Algeria. e-mail: rahiel_djelloul@yahoo.fr
[3] Prof. Department of Electrical Engineering, National polytechnic school of Oran (ENPO-MA), Oran, Algeria. e-mail: khiat2_2000@yahoo.fr

Overcurrent protection is one of the basic protective relaying principles [4]. The overcurrent protection operates when the current exceeds the pickup value [5] (The threshold value). The time curves of overcurrent relays are appropriate for equipment protection because they allow temporary overload conditions [6].

This article aims to present a model of a numerical overcurrent protective relay. The model is based on the quadrature sampling method; this method makes it possible to calculate more precisely and more quickly the root mean square (RMS) value of a periodic signal.

The idea behind the use of this method is to present it as a calculator of the RMS value of the current; it uses the discrete time domain which facilitates its implementation in a numerical protective relay.

Using the MATLAB software package, the model performances are tested. The validation of the results obtained during the implementation for simulation of the model is required to confirm its reliability, for this purpose a comparison with a numerical overcurrent protective relay is performed within the SCAMRE laboratory. The numerical protective relay used for the validation of the proposed model is a Schneider Electric Sepam series 80 (S80), the S80 protective relay is introduced into a Schneider Electric Sepam MD2ADSEP pedagogical platform, this platform and by using the switches: inputs and to the built-in current, voltage and frequency generators makes it possible to carry out tests on the protection relays.

The proposed model is numerical, it can be implemented on the programmable electronic boards namely: FPGA, DSPIC, DSP Kit ... etc. it can be easily practically realized.

The numerical overcurrent protective relay presented in this article supports the three tripping characteristics of the overcurrent protection: Instantaneous, definite time (DT), and inverse definite minimum time (IDMT). For the IDMT, the model has the features of the three inverse characteristics curves according to IEC60255 standards: standard inverse (SI), very inverse (VI) and extremely inverse (EI).

2. Numerical relays

All numerical relays utilize so-called sampling technique of the input current and voltage signals. Typically 12 to 32 samples per fundamental power system cycle are used depending on the particular relay design.

From these samples numerical relays calculates root-mean-square values of the input quantities by using different type of digital filters. These RMS values are then typically processed by different protective functions [7].

The decisions of numerical relays are based on algorithms which manipulate the digitalized measuring signals mathematically.

The performance of the relays therefore depends very much on the ingenuity of the measuring algorithm [8].

Numerical relays may have preference to select various characteristic curves based on different standards [9]. Fig. 1 shows a simplified functional block diagram for a numerical protective relay.

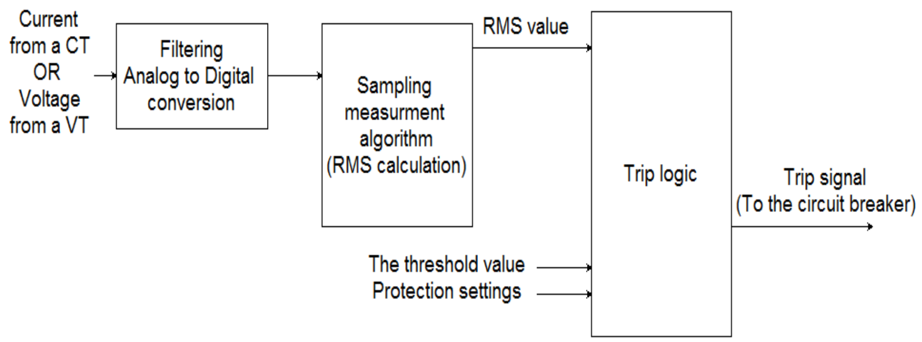


Fig.1. Simplified functional block diagram for a numerical protective relay

3. Overcurrent relays

An overcurrent relay is a type of protective relay which provides protection against over currents; it operates when the load current exceeds a preset value. This relay uses the current transformer (CT) and is calibrated to operate at or above a specific current level by comparing the measured values with preset values [10].

For the overcurrent protection, the relay operates with or without an intended time delay and trips the associated circuit breakers [11].

There are three types normally based on their operation time: instantaneous Overcurrent Relay, Definite Time overcurrent relay and inverse definite minimum time (IDMT) overcurrent relay [12].

The instantaneous overcurrent will operate instantaneously if the input current is larger than the setting value [13].

For the definite time overcurrent relay, the operating time is independent of current where relay closest to the fault has shortest operating time [14].

IDMT overcurrent relays in which a Time Dial Setting (TDS) is provided on the relays instead of exact time delay setting. In these relays after meeting the first condition, the time delay is not a constant value, but it varies by varying the fault current amplitude in an inverse way, i.e. the higher the fault current amplitude, the lower will be the time delay [15].

The characteristics of IDMT overcurrent relays can be varied according to the required time needed for tripping. For this purpose, IEC 60255 standard for

electric relays defined and standardized a number of characteristics as follows [16]:
Standard Inverse (SI).
Very Inverse (VI).
Extremely Inverse (EI).

IEC standard defines a formula, with different constant values, The formula is as follows:

$$t = TDS \frac{k}{\left(\frac{I_{RMS}}{I_s}\right) - 1} \tag{1}$$

Where t is the operating time of relay. TDS is time dial setting and I_S is a threshold value, which if exceeded; the relay will operate [17].

I_{RMS} is the RMS value of the actual current seen by the relay. Table 1 below shows the values for k and α corresponding to each characteristic curve according to the IEC standard.

Table 1

Different types of inverse time characteristics curves and the constant values

Characteristic curve	*k*	*α*
SI	*0.14*	*0.02*
VI	*13.5*	*1*
EI	*80*	*2*

4. The current RMS calculation based on quadrature sampling method

The one phase current $i(k)$ of the electrical supply network is given by:

$$i(t) = I\cos(wt - \alpha) \tag{2}$$

w is the frequency, α is the phase between the current and the voltage, I is the magnitude current value.

The current can be represented in the sampled time domain as follows:

$$i(k) = I\cos(wkT_S - \alpha) \tag{3}$$

Where T_S is the sampling period.

Similar to the conventional methods, the quadrature method calculates the RMS value based on the sampled time domain. However, it uses only two samples per a half cycle with 90 degrees ($\frac{\pi}{2}$ radians) distance between them [18].

i'(k) is a current formula shifted with 90 degrees compared to *i'(k)*, it is presented as follows:

$$i^{'}(k) = I\,cos(wkT_S - \alpha + \frac{\pi}{2}) \tag{4}$$

Using this relation from the trigonometry: $cos(\theta + \frac{\pi}{2}) = -sin\,\theta$ equation (4) gives:

$$i^{'}(k) = -I\,sin(wkT_S - \alpha) \tag{5}$$

$$i(k)^2 + i^{'}(k)^2 = I^2\,[cos^2(wkT_S - \alpha) + sin^2(wkT_S - \alpha)] \tag{6}$$

In the trigonometry $cos^2(wkT_S - \alpha) + sin^2(wkT_S - \alpha) = 1$ so equation (6) gives:

$$i(k)^2 + i^{'}(k)^2 = I^2 \tag{7}$$

The magnitude of the current can be calculated as follows for each sample *k*:

$$I = \sqrt{i(k)^2 + i^{'}(k)^2} \tag{8}$$

Therefore, the RMS value of the current *I* is:

$$I_{RMS} = \frac{I}{\sqrt{2}} = \frac{\sqrt{i(k)^2 + i^{'}(k)^2}}{\sqrt{2}} \tag{9}$$

5. Modeling and implementation for simulation

The proposed model of the numerical overcurrent protective relay is composed of a blocks-assembly, each block has a definite function. Fig. 2 shows a block diagram for the proposed model.

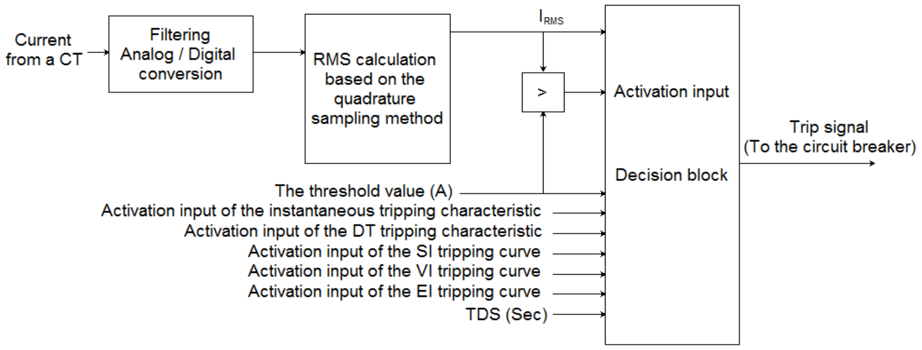


Fig. 2. Block diagram for the proposed model of the numerical protective relay

The filtering and digitizing block receives directly the measurement signal delivered by a CT. This block ensures the elimination of the noise from the measurement signal and its conversion to the digital.

The measurement signal after the filtering and the digitization is injected into a block where the algorithm of the quadrature sampling method is implemented, this block calculates for each sample *k* the RMS value of the measurement signal. Fig. 3 shows the quadrature sampling algorithm.

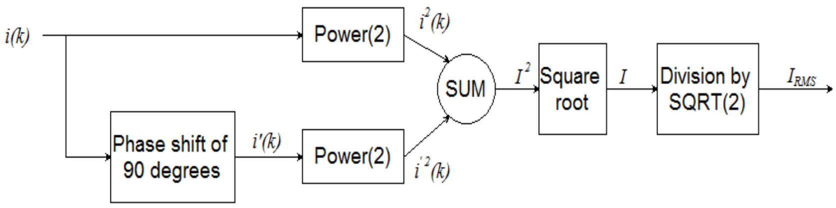


Fig. 3. The implemented quadrature sampling algorithm in the proposed model

For each sample *k*, the calculated RMS value of the measurement signal is compared to a threshold, if the RMS value exceeds the threshold, the decision block becomes active.

The decision block and according to the selected tripping characteristic of the overcurrent protection (Instantaneous or DT or IDMT) sends a trip signal to the circuit breaker.

The operation of this block is provided by an implemented algorithm shown in Fig. 4. Inputs on the decision block allow the choice of the desired tripping characteristic, the operating times for the DT characteristic and the TDS values for the IDMT characteristic curves.

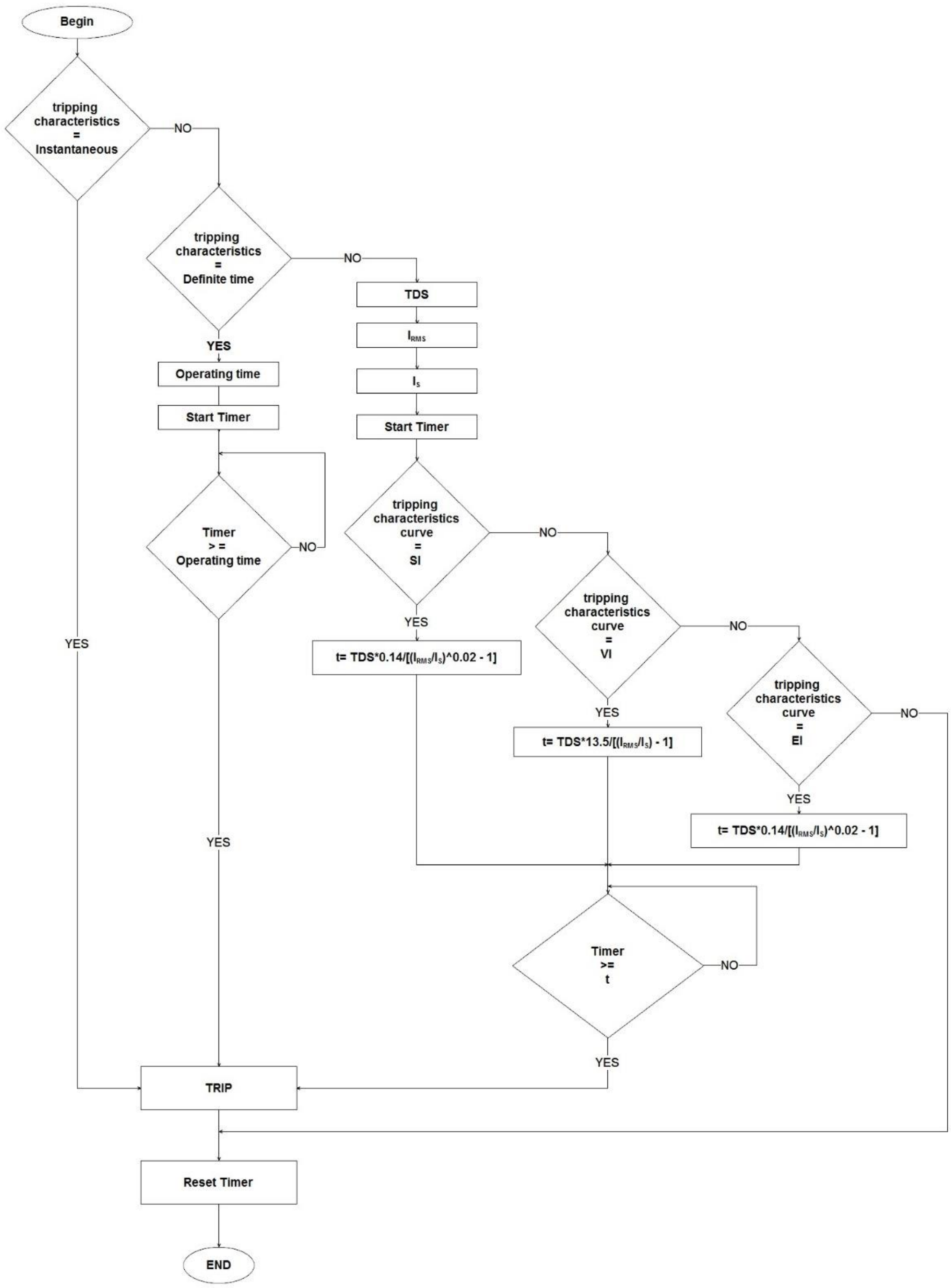


Fig. 4. The implemented algorithm in the decision block

The performances of the proposed model were tested by its implementation for simulation using the Matlab simulation software package. During all the simulation steps, the model was used to detect the overcurrents in a simple radial power system developed on the Simulink/Matlab and composed of:

A power source 400 V, 1200 KVA, 50 Hz
A circuit breaker (C.B)
A transmission line (Pi section of 100 m)
Two busbars (B1 and B2)
A load of 800 KW, 600 KVAR

The simple radial power system is shown in Fig. 5 with the model of the numerical overcurrent protective relay connected.

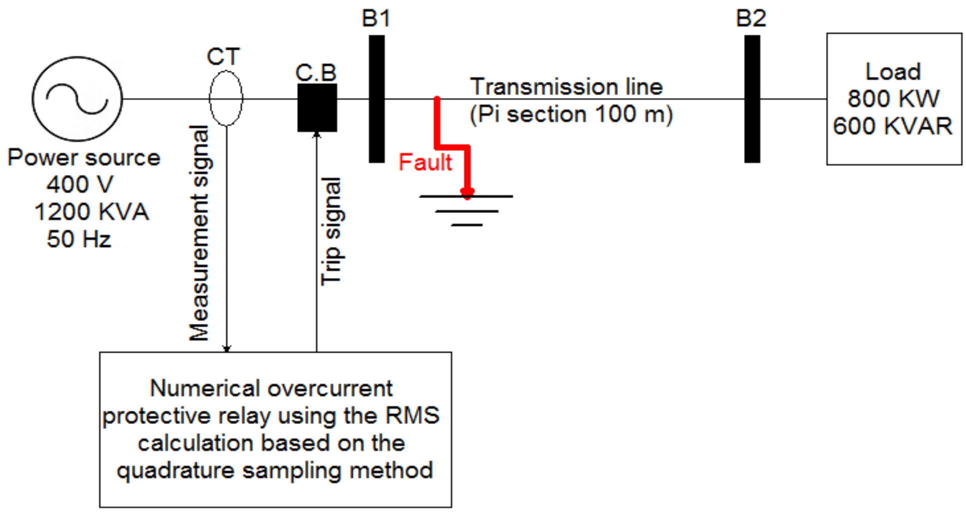


Fig. 5. The simple radial power system with the model of the numerical overcurrent protective relay connected.

The performances of the proposed model of the numerical overcurrent protective relay were tested in simulation through three steps as follows:

Step one: in this step the model was tested by activating the instantaneous tripping characteristic of the overcurrent protection and for different instants of faults in the radial power system (0.100 Sec, 0.300 Sec, 0.500 Sec and 0.700 Sec). For each instant a three-phase to ground fault was caused.

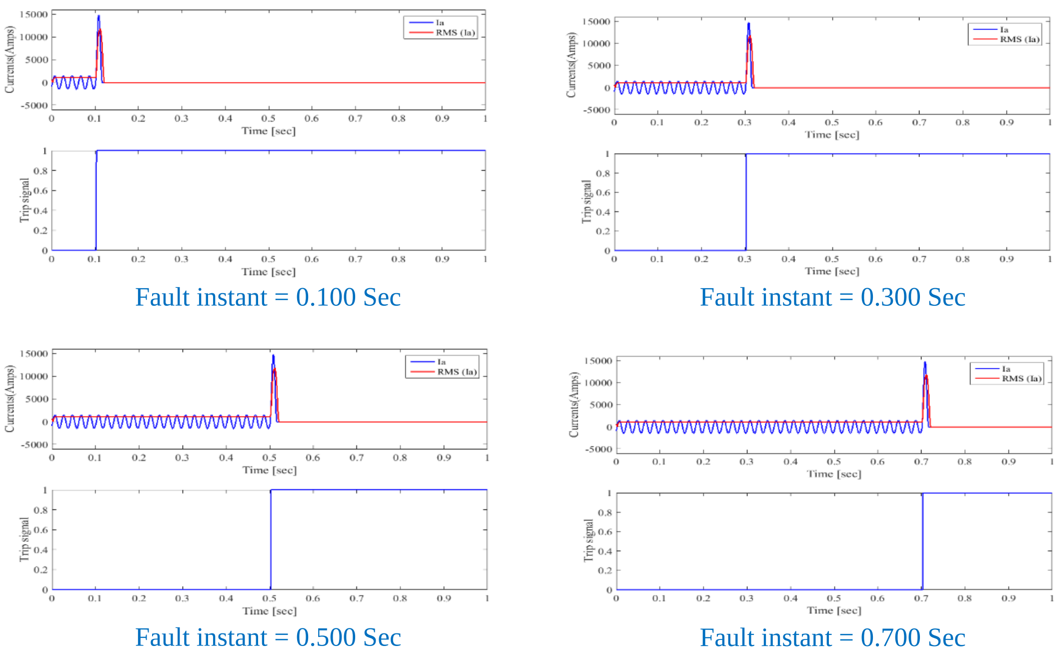
Step two: this step was devoted to test the performances of the proposed model by activating the defined time tripping characteristic of the overcurrent protection and by choosing different operating times (0.020 Sec, 0.050 Sec, 0.100 Sec and 0.200 Sec). During this entire step the same instant of the three-phase to ground fault was chosen (0.200 Sec).

Step three: this step was performed to test the performances of the proposed model by independently enabling one of the three characteristic curves (SI, VI and EI) of the IDMT characteristic of the overcurrent protection and by choosing for each curve different values for the TDS (0.010 Sec, 0.020 Sec, 0.030 Sec and 0.050 Sec). During this entire step, the same instant of the three-phase to ground fault was chosen (0.200 Sec).

A value of (2080 A) was chosen as a threshold during all three steps of the implementation for simulation of the proposed model. The chosen value of the threshold is equal to (1.2) multiplied by the nominal current (1734 Amps) of the power source inserted into the radial power system used for the simulation. This choice is the most adopted in the setting of the overcurrent protection for the real cases.

All the results obtained during the implementation for simulation of the proposed relay model are presented by graphs in Fig. 6, Fig. 7, Fig. 8, Fig. 9 and Fig. 10 recorded from the MATLAB simulating software package.

The graphs show the results for a single phase (Phase A), as it’s a case of symmetrical fault and the other two phases will be phase shifted by 120 degrees [19].



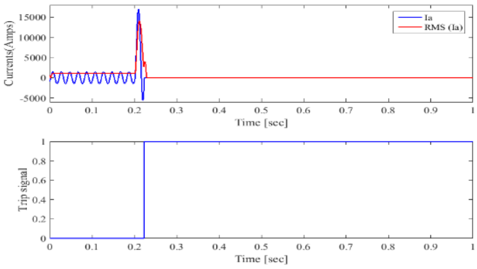
Fault instant = 0.100 Sec

Fault instant = 0.300 Sec

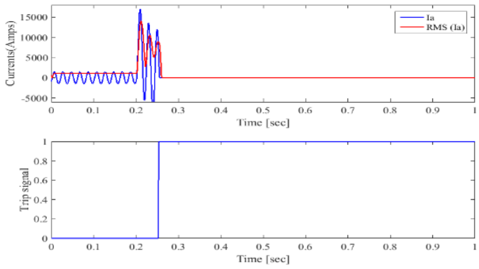
Fault instant = 0.500 Sec

Fault instant = 0.700 Sec

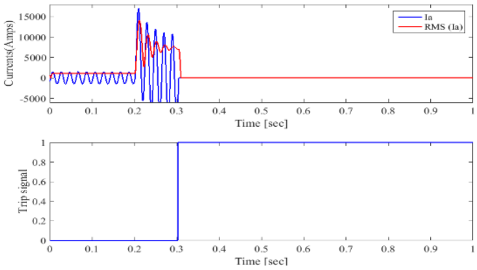
Fig.6. The results of the implementation for simulation by activating the instantaneous tripping characteristic



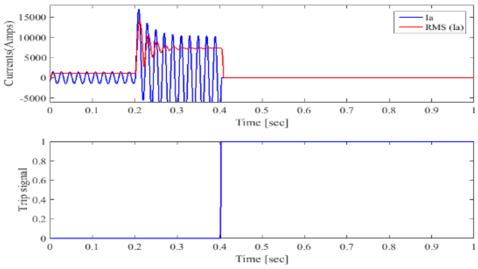
Operating time = 0.020 Sec



Operating time = 0.050 Sec

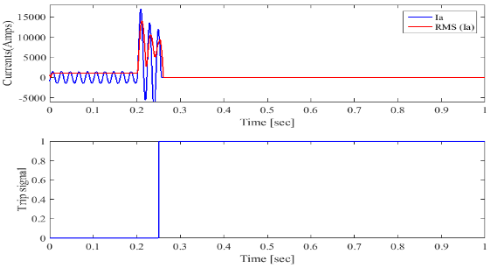


Operating time = 0.100 Sec

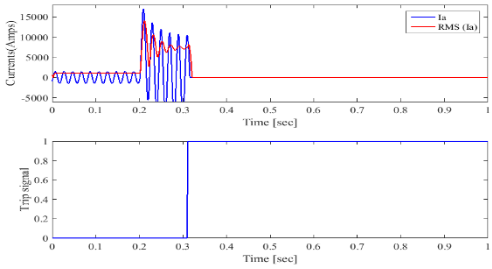


Operating time = 0.200 Sec

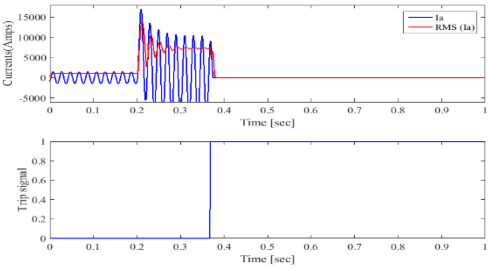
Fig.7. The results of the implementation the simulation by activating the definite time tripping characteristic



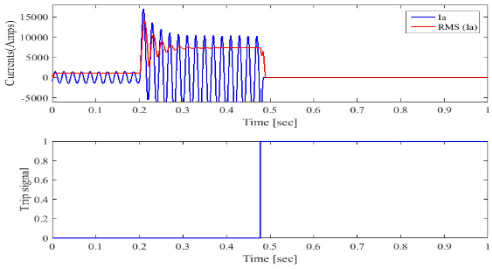
TDS = 0.010



TDS = 0.020



TDS = 0.030



TDS = 0.050

Fig.8. The results of the implementation for simulation by activating the SI characteristic curve

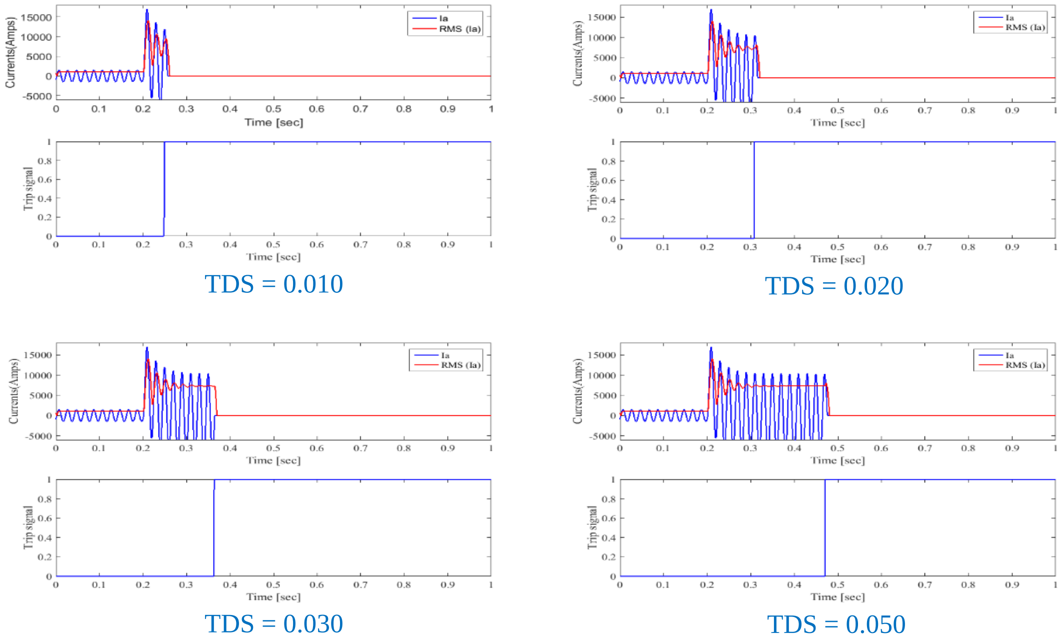


Fig.9. The results of the implementation for simulation by activating the VI characteristic curve

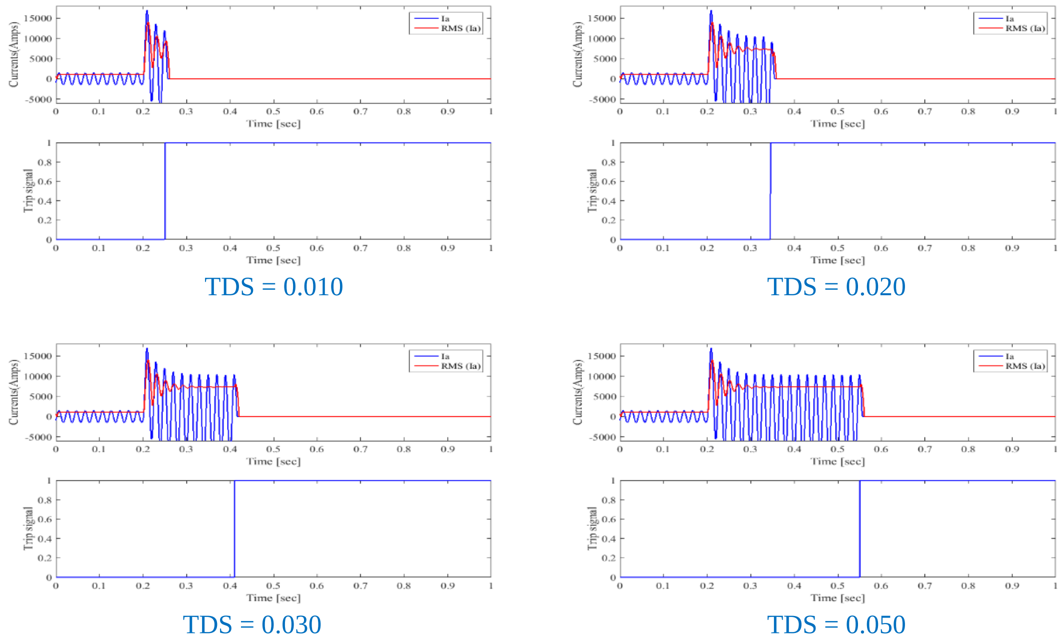


Fig.10. The results of the implementation for simulation by activating the EI characteristic curve

Tables 2, 3 and 4 below summarize the results of all the tests carried out during the implementation for simulation of the proposed numerical overcurrent protective relay.

Table 2

Instantaneous tripping characteristic activated

Fault instant (Sec)	Overcurrent detection instant (Sec)	Tripping instant (Sec)	Δt (Sec)
0.100	0.102	0.102	0.000
0.300	0.302	0.302	0.000
0.500	0.502	0.502	0.000
0.700	0.702	0.702	0.000

Table 3

Definite time tripping characteristic activated

Fault instant (Sec)	Overcurrent detection instant (Sec)	Operating time (Sec)	Tripping instant (Sec)	Δt (Sec)
0.200	0.202	0.020	0.222	0.020
0.200	0.202	0.050	0.250	0.050
0.200	0.202	0.100	0.302	0.100
0.200	0.202	0.200	0.402	0.200

Table 4

IDMT tripping characteristic activated

Fault instant (Sec)	Overcurrent detection instant (Sec)	TDS (Sec)	IDMT characteristic curve	Tripping instant (Sec)	Δt (Sec)
0.200	0.202	0.010	SI	0.250	0.048
0.200	0.202	0.020	SI	0.310	0.108
0.200	0.202	0.030	SI	0.367	0.165
0.200	0.202	0.050	SI	0.477	0.277
0.200	0.202	0.010	VI	0.248	0.046
0.200	0.202	0.020	VI	0.308	0.106
0.200	0.202	0.030	VI	0.363	0.161
0.200	0.202	0.050	VI	0.470	0.268
0.200	0.202	0.010	EI	0.250	0.048
0.200	0.202	0.020	EI	0.345	0.143
0.200	0.202	0.030	EI	0.410	0.208
0.200	0.202	0.050	EI	0.550	0.348

By analyzing the results obtained during the simulation tests, it is clearly remarkable that the proposed model has provided the function of an overcurrent protection device. The model detected that the current was exceeded the chosen threshold in phase A and therefore sent a trip signal to the circuit breaker instantaneously for cases or after a delay for other cases. The implementation for simulation of the proposed model showed its sensitivity to overcurrents, the model was able to detect the overcurrents for all the performed tests. In a next step, the validation of the delays (Δt) between the overcurrents detection instants and the tripping instants is necessary to confirm the reliability of the mode.

6. The model validation

To decide on the reliability of the proposed model, a validation is required. The relay model can be verified by comparing the modeling results to the physical relay testing results [20].

In the laboratory SCAMRE the model was compared with a physical numerical protective relay, the S80 was chosen.

The S80 was introduced into a Schneider Electric Sepam MD2ADSEP pedagogical platform. By using the switches on the MD2ADSEP: inputs and to the built-in current, voltage and frequency generators makes it easy the manipulation of the S80 to perform the validation tests. Fig. 11 presents the MD2ADSEP with the S80 numerical overcurrent protective relay introduced.

Similar tests to those performed during the implementation for simulation of the proposed model of the numerical overcurrent protective relay were again performed on the S80. The same tripping characteristics and the same parameters (operating time, TDS and current threshold) were chosen for a second time.

A workstation on which the SFT2841 software is installed was used for the communication with the S80 via the universal serial bus (USB) and its configuration, this workstation makes it possible to load the protection parameters on the memory of the S80 in a very easy way as well as their modifications.

Fig. 12 shows the MD2ADSEP pedagogical platform and the SFT2841 workstation.

Fig. 11. The MD2ADSEP pedagogical platform with the S80 numerical overcurrent protective relay introduced

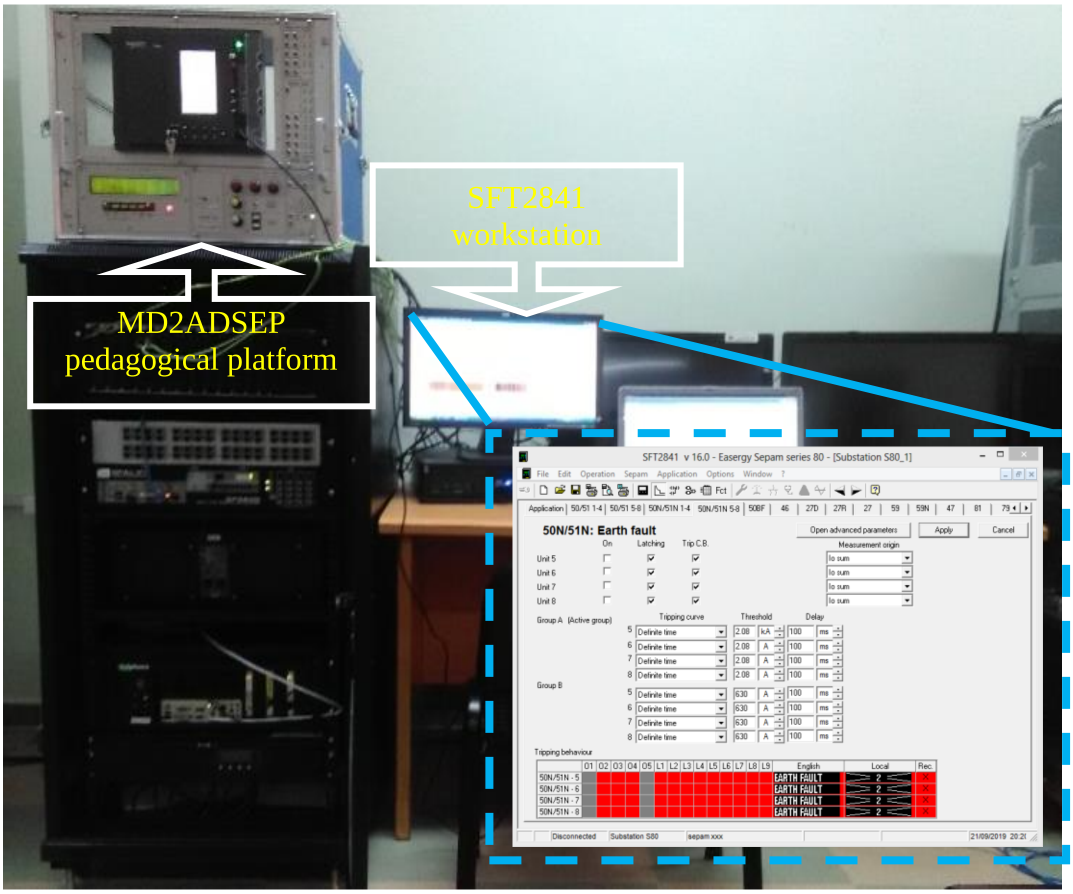


Fig. 12. The MD2ADSEP pedagogical platform with the SFT2841 workstation connected (In the SCAMRE LABORATORY)

The MD2ADSE pedagogical platform is equipped with an injection control automation (Fig. 13) used to launch the tests and to visualize the delays (Δt) necessary for tripping.

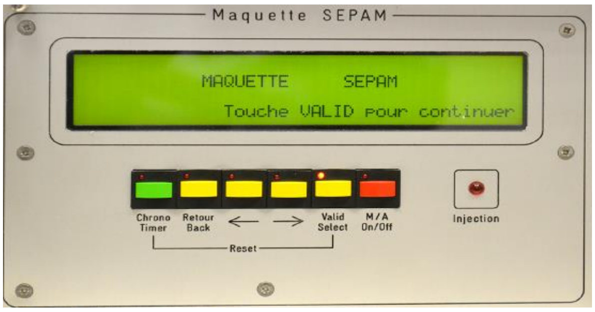


Fig. 13. The injection control automation on the MD2ADSE pedagogical platform

Table 5 shows a comparison between the required delays for the tripping during the simulation tests and during the validation tests.

Table 5

Comparison between the required delays for the tripping during the simulation tests and during the validation tests

Tests	Δt (Sec) in simulation	Δt (Sec) in validation
Instantaneous tripping characteristic activated	0.000	0.001
	0.000	0.000
	0.000	0.002
	0.000	0.001
Definite time tripping characteristic activated results	0.020	0.020
	0.050	0.052
	0.100	0.101
	0.200	0.202
SI characteristic curve activated	0.048	0.048
	0.108	0.108
	0.165	0.165
	0.277	0.278
VI characteristic curve activated	0.046	0.046
	0.106	0.106
	0.161	0.161
	0.268	0.268
EI characteristic curve activated	0.048	0.050
	0.143	0.146
	0.208	0.209
	0.348	0.348

As it can be seen from Table 5 [21]. The delays required for tripping obtained during the implementation for simulation of the proposed model and the results obtained during the validation using the MD2ADSEP pedagogical platform are the same for the majority of cases and very close for the remainder of the cases, which confirm the reliability of the proposed model.

Infinitesimal errors of (0.001 Sec) to (0.003 Sec) were found. These errors are due to both causes: The first is that MATLAB software package gives results equal to the ideal calculations. The second is that the injection control automation on the MD2ADSE pedagogical platform uses a microcontroller in the calculations but the simulation was carried out on a workstation equipped with a microprocessor with a clock frequency of 2.2 Ghz.

The proposed model of the numerical overcurrent protective relay is clearly capable to protect electrical equipment according to the different tripping characteristics of the overcurrent protection (Instantaneous, DT and IDMT).

7. Conclusion

In this article a model of a numerical overcurrent protective relay model was proposed. The model uses the quadrature sampling method for the calculation of the RMS value of the measurement signal delivered by a CT for each sample of time.

The model was implemented for simulation using the Matlab simulating software package. In the simulation the model was able to detect the overcurrents and to generate tripping signals for all tests that had proved its sensitivity.

In the SCAMRE laboratory and using MD2ADSEP pedagogical platform the proposed model was validated, The delays required for tripping obtained during the simulation and during the validation were the same for the majority of cases and very close for the remainder of the cases, the model had shown its reliability.

The simulation results can be implemented on a real system. By mastering a type of the programmable electronic card as: FPGA, DSPIC, DSP Kit also the way of its programming, the implementation on a real system of the simulation results will be easily done. When implementing the simulation results on a real system, it is very essential to validate this implementation. Having a validation tool like the real-time digital simulation platforms is very important. On these platforms, a real hardware can be connected and subjected to the tests. This operation is called hardware-in-the-loop (HIL).

Several features will be added to the model namely the location and classification of the faults, all this will be reported in future publications.

REFERENCES

[1] Hewitson, Leslie, Brown, Mark, et Balakrishnan, Ramesh. (Practical power system protection). Elsevier, 2004.

[2] Cai, Xiao Ling, Zhang, Ji Fen, Lin, ChuanWei, et al. “Design and implementation of relay protection fault information intelligent analysis system in Smart Grid”. In : 2011 International Conference on Advanced Power System Automation and Protection. IEEE, 2011. pp. 1625-1630.

[3] Abdel-Salam, Mazen, Kamel, Rashad, Sayed, Khairy, et al. “Design and implementation of a multifunction DSP-based-numerical relay”. Electric Power Systems Research, 2017, vol. 143, pp. 32-43.

[4] Sharaf, Hebatallah Mohamed, Zeineldin, H. H., Ibrahim, Doaa Khalil, et al. “A proposed coordination strategy for meshed distribution systems with DG considering user-defined characteristics of directional inverse time overcurrent relays”. International Journal of Electrical Power & Energy Systems, 2015, vol. 65, pp. 49-58.

[5] Wang, Yifan et Dinavahi, Venkata. "Real-time digital multi-function protection system on reconfigurable hardware". IET Generation, Transmission & Distribution, 2016, vol. 10, no 10, pp. 2295-2305.
[6] Soria, O. Arreola, Enriquez, A. Conde, et Guajardo, La Trujillo. "Overcurrent relay with unconventional curves and its application in industrial power systems". Electric Power Systems Research, 2014, vol. 110, pp. 113-121.
[7] GAJIĆ, Zoran, HILLSTRÖM, Birger, et MEKIĆ, Fahrudin. "HV shunt reactor secrets for protection engineers". In : 30th Western Protective Relaying Conference, Washington. 2003.
[8] Jakominich, D., Krebs, R., Retzmann, D., et al. "Real time digital power system simulator design considerations and relay performance evaluation". IEEE transactions on power delivery, 1999, vol. 14, no 3, pp. 773-781.
[9] Rajput, Vipul n. et Pandya, Kartik S. "A hybrid improved harmony search algorithm-nonlinear programming approach for optimal coordination of directional overcurrent relays including characteristic selection". International Journal of Power and Energy Conversion, 2018, vol. 9, no 3, pp. 228-253.
[10] Yacine, Ayachi Amor, Noureddine, Ayachi Amor, Hamid, Bentarzi, et al. "Implementation of a Numerical Over-current Relay Using LabVIEW and Acquisition Card". In : 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM). IEEE, 2018. pp. 1-5.
[11] Goh, Yin Lee, Ramasamy, Agileswari K., Nagi, Farrukh Hafiz, et al. "Evaluation of DSP based numerical relay for overcurrent protection". International Journal of Systems Applications, Engineering and Development, 2011, vol. 5, pp. 396-403.
[12] Liu, Z., Høidalen, H.K.: "An adaptive inverse time over-current relay model implementation for real time simulation and hardware-in-the-loop testing". 13th Int. Conf. Development in Power System Protection 2016 (DPSP), Edinburgh, Scotland, United Kingdom, 7–10 March 2016, pp. 1–6.
[13] Hairi, Mohd Hendra, Aras, Mohd Shahrieel Mohd, Hanaffi, Farhan, et al. "Performance Evaluation of Overcurrent Protection Relay Based on Relay Operation Time (ROT) ". International Journal of Electrical Engineering and Applied Sciences (IJEEAS), 2018, vol. 1, no 1, pp. 1-8.
[14] Hussin, Nur Hazwani, Idris, Muhd Hafizi, Amirruddin, Melaty, et al. "Modeling and simulation of inverse time overcurrent relay using Matlab/Simulink". In : 2016 IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS) ". IEEE, 2016. pp. 40-44.
[15] Ojaghi, Mansour et Ghahremani, Robab. "Piece–wise linear characteristic for coordinating numerical overcurrent relays". IEEE Transactions on Power Delivery, 2016, vol. 32, no 1, pp. 145-151.
[16] Abdolkhalig, Ahmed et Zivanovic, Rastko. "Simulation and testing of the over-current protection system based on IEC 61850 Process-Buses and dynamic estimator". Sustainable Energy, Grids and Networks, 2015, vol. 2, pp. 41-50.
[17] Mahari, Arash et Seyedi, Heresh. "An analytic approach for optimal coordination of overcurrent relays". IET Generation, Transmission & Distribution, 2013, vol. 7, no 7, pp. 674-680.
[18] Zaro, F. R., Abido, M. A., Ameenuddin, S., et al. "Characterization of short-duration voltage events". In : 2012 IEEE International Conference on Power and Energy (PECon). IEEE, 2012. pp. 650-654.
[19] Almas, Muhammad Shoaib, Leelaruji, Rujiroj, et Vanfretti, Luigi. "Over-current relay model implementation for real time simulation & Hardware-in-the-Loop (HIL) validation". In : IECON 2012-38th Annual Conference on IEEE Industrial Electronics Society. IEEE, 2012. pp. 4789-4796.

[20] Kezunovic, M. et Chen, Q. “A novel approach for interactive protection system simulation”. In Proceedings of 1996 Transmission and Distribution Conference and Exposition. IEEE, 1998. pp. 458-464.
[21] Ahmadi, S. A., Karami, H., Sanjari, M. J., et al. “Application of hyper-spherical search algorithm for optimal coordination of overcurrent relays considering different relay characteristics”. International Journal of Electrical Power & Energy Systems, 2016, vol. 83, pp. 443-449.