Modelling and performance testing of a digital over-current relay enhanced designed model

Introduction. The over-current relay is widely used to protect distribution and transmission electrical systems against excessive currents occurring due to short circuit or overload conditions. Many works have been carried out in the field of models simulation design of digital over-current relays in the literature, but unfortunately many of them are more complex design models, have very slow execution time and only work in simple faults cases. Purpose. The purpose of this work is to present the performance of a modified and improved model of a digital over-current relay designed in Simulink/MATLAB environment with more simplified design, faster execution time, and able to operate under more complex fault conditions. Methodology. Before starting tests, modelling of over-current relay is presented in details, of which the basic logics of the proposed model to implement inverse and instantaneous characteristics are well explained. Afterwards, various tests are carried out for the performance analysis of the enhanced designed relay model in terms of: operating speed for eliminating faults that has arisen, ability to distinguish between a fault current and load starting current, capacity distinguish between real and temporary fault currents, the way to manage variable faults over time, and the degree of harmony between primary protection relay and back-up protection relay. Originality. The originality of our proposed work consists in the development and improvement of a digital over-current relay model designed in Simulink/MATLAB environment in such way that it becomes able to operate under new harsh test conditions. This developed designed model is implemented and applied in a 400V radial distribution power system with a load that causes a starting current. Results. The obtained values of simulation are compared with the theoretically calculated values and known existing models. The obtained results after various tests validate the good performance of our enhanced designed model. References 18, tables 3, figures 18.

Key words: digital over-current relay, inverse and instantaneous characteristics, load starting current, primary protection, back-up protection.

Introduction. According to the International Electrotechnical Commission (IEC), the protection of electrical networks is the set of monitoring devices intended for the detection of faults and abnormal situations such as short-circuits, variation in voltage, machine faults, etc. and ensuring the stability of an electrical network with the aim of ensuring an uninterrupted power supply and avoids the destruction of expensive equipment. Generally, this protection is provided by relays which are devices that continuously compare electrical variables such as: current, voltage, frequency, etc. with predetermined values, and when the monitored value exceeds the threshold they automatically give opening orders to its associated circuit breakers [1]. Many types of relays have been employed by electric power utilities such as over- and under-voltage, over- and under-frequency and over-current relays (OCR), etc. However, this latter is the most commonly used, and they can be applied in any zone in the power system for both primary and back-up protection [2, 3].

Currently, in view of growing demand for precise, selective and reliable OCR due to the increasing complexity and capacity of power systems on the one hand, and the development of logic, communication, information storage and processing capacities of modern microprocessors on the other hand, traditional electromechanical and solid state relays are replaced by digital relays which are faster, more compact, more reliable in operation, ensuring minimal power outage in case of fault and has advantages in terms of data logging and adaptive functionality, etc. [2, 4, 5].

The goal of the paper is to present the performance of a modified and improved model of a digital over-current relay designed in Simulink/MATLAB environment for some new cases.

The performance of the proposed digital OCR is sought and tested on a line between two buses of a 400 V radial distribution power system where the objectives of
this work are summarized in testing the following characteristics: operating speed, ability to distinguish between a fault current and load pickup current, capacity to distinguish between real and temporary fault currents, the way to manage variable faults, degree of harmony between primary protection and back-up protection.

The remainder of the paper is organized as follows. First, the current-time characteristic of an OCR is explained. Then, the OCR modelling is presented on details. Next, the enhanced designed digital OCR is implemented in a 400 V radial network to carry out a different test. Finally, we conclude our paper with some remarks, and a prospect.

**Current-time characteristic of an OCR.** OCR has the function of detecting single-phase, two-phase or three-phase over-currents. The protection can be time-delayed and will only be activated if one, two or three phases of the monitored current exceed the specified setting threshold for a period at least equal to the selected time delay also called «operating time», and is calculated based on the protection algorithm incorporated in the relay microprocessor [1, 6]. According to this delay the current-time characteristic of a typical OCR shown in Fig. 1 can be one of two as follows.

![Fig. 1. Current-time characteristic of an OCR](image)

**Inverse characteristic.** This characteristic means that the operating time of the relay is inversely proportional to the fault current i.e. the higher the current, the shorter the operating time (see curve AB in Fig. 1). This characteristic is used for the protection of electrical installations against excessive fault currents below severe fault levels but able enough that they will damage such installations if maintained for a certain period [2, 6, 7].

On the other hand, inverse characteristic of a relay may have to be modified depending on the characteristics and the required operating time of other protection devices used in the electrical network. This is why IEC defines several types of inverse delay protection which are distinguished by the gradient of their curves: Standard Inverse (SI), Very Inverse (VI), Extremely Inverse (EI) and Long Inverse (LI) [7, 8].

The operating time in inverse characteristic of OCR (noted 7) is depicted as per IEEE standard by the following general expression [3]:

\[
T = \frac{K}{(I_f/I_p)^n - 1},
\]

where \(K\) is the constant for relay characteristic; \(I_f\) is the actual fault current; \(I_p\) is the pre-set current setting threshold; \(n\) is the constant representing inverse-time type.

By selecting suitable values of \(n\) and \(K\) any desired relay curve can be obtained. Equation (1) can be modified in terms of actual faults as:

\[
T = \frac{K}{I_f^n},
\]

with \(I_p < I_f < I_n\), where \(I_n\) is the short circuit current.

It is important to note that the fault current \(I_f\) detected by the relay is implicitly assumed constant. Otherwise, during a transient or a variable fault current this will lead to an inaccurate operating time by the relay.

**Instantaneous characteristic.** This characteristic (shown in curve BCD of Fig. 1) means that the relay operates in the fastest possible time i.e. as soon as the fault current becomes greater than the value of the short circuit current \(I_n\). In this case the operating time is only of the order of a few milliseconds:

\[
T = T_s,
\]

with \(I_f > I_n\), where \(T_s\) is the instantaneous operating time.

Relays with instantaneous characteristic are graded by a time interval of Definite Time (DT sec) between them, e.g. the relay \(R_3\) imposed at the end of the network of Fig. 2 is set to operate as fast as possible with an instantaneous operating time \(T_{S3}\), while its upstream relay \(R_2\) is set to a higher independent operating time \((T_{S2}=T_{S3}+DT)\). The instantaneous operating times of the remaining relays increase sequentially at DT sec on each section, moving back up to the source [9].

![Fig. 2. Graded relays in radial network](image)

**Modelling of OCR.** Digital relays also called «programmable relays» based on microprocessors are of great importance in the protection field, especially in industry in view of their ability to protect against various faults (over-currents, over-voltages, thermal overloads, etc.) [10, 11]. The general functional diagram of a microprocessor-based OCR implemented in a power system is shown in Fig. 3.

![Fig. 3. General block diagram of a microprocessor-based OCR implemented in a power system](image)

The digital relay operation is based on continuous data sampling [10]. Firstly, it takes the signal during run
time via an analog-to-digital converter. Then, the digital signal is filtered from any harmonics which can cause the relay to malfunction as well as to avoid the operating time reduction of the relay which causes coordination problems [12]. After that, the relay calculates the peak value of the measured fault current \( I_f \) (also noted \( I_f \)), then the data \( (I_f, I_p, I_t) \) entered into the relay logic (μ-processor) which finally gives the opening (0) or closing (1) order to its associated circuit breaker (CB).

The global output of the digital OCR is the logical multiplication (AND) of the outputs of inverse and instantaneous characteristics elements [13].

**Modelling of inverse characteristic.** The basic logic for implementing the inverse characteristic is summarized as follows.

Measuring fault current peak value \( I_f \). To detect the fault current, it must firstly compare the alternating current value \( I \) of frequency \( f \) entering the OCR with the pre-set current constant value of the latter. For this, it is mandatory to convert the fundamental sinusoidal current into DC form \([14, 15]\), and to measure its slope \( S \). From (8), frequency is determined by:

\[
    f = \frac{1}{T} = \frac{1}{2} - \frac{T_2}{T_1 - T_2}. \tag{9}
\]

Figure 5 depicts the frequency measurement block designed in Simulink. Firstly, the signal enters the «Hit Crossing» block which transmits it only at its zero crossings to the «If» block, and the latter sends the value of the ramp signal at that instant to the output. The duration of the generated ramp can be calculated and saved in a variable «A».

As long as \( I_f \geq I_p \), the value of \( I_f \) is raised to an appropriate power \( n \) to reach the desired relay curve, then integrated in the «Integrator» block [2].

If the fault current is permanent and has a constant level, the value of \( I_f^n \) will also remain constant and therefore the output of the integrator will be:

\[
    C_M = \int_0^T I_f^n dt = I_f^n. \tag{10}
\]

Equation (10) is the equation of a straight line with slope \( I_f^n \). On the other hand, the greater the fault current magnitude, the greater the rate of rise of integrator output and therefore a shorter time to reach the value of the constant \( K \).

**Modelling of instantaneous characteristic.** As mentioned previously, when \( I_f \) is greater than short-circuit current \( I_s \), OCR operates in instantaneous characteristic mode and sends a «0» trip signal to its associated circuit breaker after a shorter fixed delay of «Ts» seconds. The logic for implementing the instantaneous characteristic is shown in Fig. 6 below.
**Simulation and performance testing.** In order to test the performances of the enhanced digital OCR model, the considered power system is a radial distribution network (see Fig. 7), with a load causing a starting current. It is worth to mention that the considered network is supposed without losses. Further, the electrical network parameters are summarized in Table 1, where $U$ is the network voltage; $P$ is the active power; $Q$ is the reactive power; $P_f$ is the power factor; $T_{acc}$ is the accelerating period of the load; $I_{isc}$ is the initial starting current; $I_r$ is the nominal (rated) current.

**Parameters calculation and relays settings choice.** In this sub-section, before starting to carry out the tests, it is firstly essential to calculate some necessary parameters and to make an adequate choice for relay setting of primary protection as well as for relay of backup protection. This choice is based on the parameters given in previous Table 1 and those calculated.

**Calculation of the rated current at full load and the initial starting current.** The rated current $I_r$ at full load is calculated as follows:

$$I_r(rms) = \frac{P}{\sqrt{3} \cdot U \cdot \cos \phi} = \frac{100 \cdot 10^3}{\sqrt{3} \cdot 400 \cdot 0.85} \approx 169.81 \text{ A}. \quad (11)$$

From (11), the peak value of $I_r$ is:

$$I_p = \sqrt{2} \cdot I_r \approx 240.15 \text{ A}. \quad (12)$$

From Table 1 the initial starting current is $I_{isc}$:

$$I_{isc}(rms) = 3 \cdot I_r \approx 509.43 \text{ A}. \quad (13)$$

![Fig. 6. Block diagram for implementing instantaneous characteristics of a digital OCR](image)

![Fig. 7. Single line diagram of the proposed radial power network with coordination of relays (primary and backup protection)](image)

![Fig. 8. Overall developed simulation model of the two OCRs implemented in the power system](image)

The peak value of $I_{isc}$ is:

$$\hat{I}_{isc} = \sqrt{2} \cdot I_{isc} \approx 720.44 \text{ A}. \quad (14)$$

**Relays settings choice.** The pickup current $I_p$ (peak value) must be set to a value greater than the rated current $I_r$. We therefore choose a value somewhat close ($I_p = 250 \text{ A}$) and similar for both primary ($R_2$) and emergency ($R_1$) protection relays. On the other hand, severe fault current setting $I_{f}$ (as a peak value) must be greater than the initial starting current ($I_{isc} \approx 720.44 \text{ A}$).

Consequently, a relatively close value ($I_p = 800 \text{ A}$) is chosen for the relay $R_2$. In addition, the instantaneous operating time is chosen as $T_{acc} = 0.1 \text{ s}$, and the constant $K$ is selected such that it does not cause false tripping during start-up and transient conditions ($K_{RT} = 900$).

Furthermore, for a good relays coordination, $R_1$ must have a higher setting of $I_r$, $K$ and $T_s$ than that of $R_2$. Therefore, the setting of these parameters is maintained as: $I_{RT} = 1000 \text{ A}$, $K_{RT} = 1000$ and $T_{RT} = 0.2 \text{ s}$. The parameters settings of $R_1$ and $R_2$ relays chosen in this subsection are collected and tabulated in Table 2.

Moreover, in this work the constant representing inverse-time type is chosen as $n = 0.9$, the total simulation time is $t = 10 \text{ s}$ and the contact operating time of circuit breakers is assumed to be zero.

| Selected parameters settings of R1 and R2 relays |
|-----------------------------------------------|
| $I_p$, A (peak) | $I_r$, A (peak) | $K$ | $T_s$, s |
| $R_2$ | 250 | 800 | 900 | 0.1 |
| $R_1$ | 250 | 1000 | 1000 | 0.2 |

**Test 1: Start-up, temporary fault and permanent fault test.** To see and verify the enhanced designed relay behavior, it is considered three different situations: starting period [0-2 s], temporary fault period [3-4 s] and permanent fault period [5-end] whose fault current value is $I_f = 400 \text{ A}$. The models of [2], [16], [17] and [18] were invested so that the inverse characteristic was added to the last three models and the first model was developed and improved and then the four models were combined to obtain a final modified and improved model that illustrated in Fig. 8 to be able to operate under hard conditions tests.

**Start-up period.** From Fig. 9 below, during the acceleration period, the initial starting current $I_{isc}$ (peak value) is greater than the pickup current $I_p$ of $R_2$, which increases the output of its integrator. At $t = 2 \text{ s}$, when $I_{isc} < I_p$, the integrator output being less than $K$ setting and drops to zero, and $R_2$ is reset.
The R2’s \( K \) value is deliberately set above its maximum integrator output during the acceleration period to avoid any false tripping of relays R1 and R2.

On the other hand, it can be seen also that the line representing R2 integrator output in the load acceleration period is not straight seeing that the starting current is nonlinear (decreasing current). It is noted that if we drawing slopes in some points of this line (see Fig. 9) we notice that a large amplitude of the starting current (beginning of the current) results in a higher rate of rise of the integrator output and therefore a shorter time to reach the value of the constant \( K \). Consequently, this remark applies to all other fault currents.

**Temporary fault period.** In this case, it is clear from Fig. 9 above, that the R2 integrator output is straight-shaped seeing that the fault current in this case is constant during this period.

As the fault is of a short duration (1 s in the interval [3-4 s]), this can’t allow the output of the rising integrator of R2 to reach the value of \( K = 900 \); so it goes back to zero. Relay R2 stops counting its inverse characteristic operating time:

\[
T = \frac{K}{I_f^p} = \frac{900}{400^{0.9}} \approx 4.1 \text{ s}.
\]  (15)

As the fault time (1 s) is less than R2 relay operating time (4.1 s), the latter therefore does not send any trip signal to its associated CB and ensures continuity of service at rated current \( I_r \).

**Permanent fault period.** Contrary to the previous case, R2 relay integrator output in this situation has sufficient time to reach the value of \( K = 900 \) after the same operating time of inverse characteristic calculated in (15) \((T = 4.1 \text{ s})\) counted from instant \( t = 5 \text{ s} \).

Relay R2 therefore sends its trip signal to its associated CB at the instant: \( t = 5 \text{ s} + 4.1 \text{ s} = 9.1 \text{ s} \), while the backup protection relay R1 remains inactive, as shown in Fig. 10, 11.

**Test 2: Variable fault test.** In this 2nd test, we will create a variable fault current for a relatively long duration of 3 s in the interval [3-6 s]. The considered variable fault current starts from \( I_f = 270 \text{ A} \) at \( t = 3 \text{ s} \) until \( I_f = 960 \text{ A} \) at \( t = 6 \text{ s} \). From Fig. 12, it can be seen that unlike the falling starting current whose rising integrator output has the convex parabola shape, the rising variable fault current is also having a rising integrator output but in a concave parabola form. In addition, it is clear from the Figure that before the R2 relay integrator output reaches the predefined value \( K = 900 \) (fixed only at 694.4 at \( t = 5.35 \text{ s} \) so that R2 gives its tripping order in order to eliminate the fault current which is located in its inverse operating zone, the fault current reaches the severe current level \( I_f = 810.5 \text{ A} > I_s = 800 \text{ A} \) despite the long fault duration and enter in the instantaneous operating zone at \( t = 5.25 \text{ s} \). Therefore, R2 relay switches from inverse mode to instantaneous mode and interrupts the fault current after the pre-set instantaneous delay \( T_s = 0.1 \text{ s} \), i.e. at \( t = 5.35 \text{ s} \) (see Fig. 13). On the other hand, R1 backup protection relay remains inactive because there is no reason to make it work (the same of Fig. 11).

The conclusion of this test is that the relay R2 has eliminated the variable fault in instantaneous operating mode \((T_s = 0.1 \text{ s}, [5.25-5.35 \text{ s}])\), but after a certain period of inverse operating time \((T_{inv} = 2.25 \text{ s} [3-5.25 \text{ s}])\), so after a total time of \( T = 2.35 \text{ s} \).
Test 3: Testing of a fault during the acceleration period. In this 3rd test, a permanent fault current of constant value $I_f = 780$ A is considered, appeared at the instant $t = 1$ s during the acceleration period [0-2 s]. In the normal state, theoretical operating time of $R_2$ in inverse characteristic is:

$$T = \frac{K}{I_f^\alpha} = \frac{900}{780^{0.9}} \approx 2.25 \text{ s}.$$  

Hence, the fault theoretical interruption instant counting from their appearance instant ($t = 1$ s) is: 

$$1 \text{ s} + 2.25 \text{ s} = 3.25 \text{ s}$$

Accordinng to Fig. 14, it can be seen that the fault is eliminated in advance at $t = 2.44$ s, i.e. 0.81 s ahead. This is explained by the fact that $R_2$ integrator output began to rising from the initial start-up instant ($t = 0$ s), and at the fault appearance instant ($t = 1$ s) it has reached the value 319.25; therefore, it needs only a little time to reach the pre-set value $K = 900$. It should be noted that $R_2$ integrator output in this case is a line composed of two parts of which the first is a convex parabola in the interval [0-1 s] due to the starting current, and the second is a straight line in the interval [1-2.44 s] due to the constant value of the fault current.

The status of $R_1$ and $R_2$ are shown respectively in Fig. 11 (the same status of previous cases) and Fig. 15. The performance presented by the relay according to this test resides in that it has the ability to distinguish between starting current which must let it to pass and fault current which must eliminate it.

Test 4: Fault test with broken down primary protection. In this test, it is assumed that $R_2$ relay of primary protection is broken down (cannot give its tripping order to its associated CB). At $t = 3$ s, a fault current which exceeds the severe current threshold of $R_2$ ($I_f = 840$ A $> I_{L_2} = 800$ A) is appeared. Thus, it was supposed that $R_2$ must eliminate this fault after an instantaneous operating time ($T = 0.1$ s), but in view of it is in break-down, the fault current still remains present. Consequently, the back-up protection is activated to operate through the $R_1$ relay; and since ($I_p < I_f < I_{L2}$) the fault current is therefore in the inverse operating zone of $R_1$, whose the operating time is:

$$T = \frac{K}{I_f^\alpha} = \frac{1000}{840^{0.9}} \approx 2.33 \text{ s}.$$  

According to Fig. 16-18, it appears that $R_1$ relay gives its tripping order at $t = 5.33$ s counted from the fault.
appearance instant ($t = 3$ s) i.e. after 2.33 s; it is exactly the theoretically calculated value in (17).

On the other hand, some numerical data on improving operating speed (operating time $T$) of inverse characteristic of OCRs used for eliminating faults that has arisen are provided in Table 3.

Through the comparison table above, it is clear that the operating time value obtained in our test 4 is exactly the theoretically calculated value, as well as the higher accuracy of the inverse characteristic of our modified model compared to the results of other models.

From this test, it appears the service continuity performance guaranteed by both relays: $R_2$ of primary protection at the receiving end of the network, and $R_1$ of backup protection at the sending end to avoid any break-down problem and ensure a good protection of the power system.

**Conclusions.**

In this paper, an enhanced designed model in Simulink/MATLAB of a digital over-current relay used as a primary protection and backup protection is presented in details. The proposed model is tested in a radial 400 V distribution network to carry out a various tests under new harsh test conditions. The simulation results proves the good and the high performance of the improved designed over-current relay on terms of: operating speed (time) for eliminating faults that has arisen, ability to distinguish between a fault current and load starting current, capacity distinguish between a real (permanent) and a temporary fault currents, the way to manage variable faults over time, and the degree of harmony (coordination) between primary relay and back-up relay.

Finally, the enhanced designed digital over-current relay can be extended to design a directional over-current relay for a possible work in the future.

**Conflict of interest.** The authors declare that they have no conflicts of interest.

### REFERENCES

1. Prévě C. Protection of Electrical Networks. ISTE Publ., 2006. 508 p. doi: https://doi.org/10.1002/9780470612224.
2. Aman M.M., Khan M.Q.A., Qazi S.A., Digital Directional and Non-Directional Over-Current Relays (Modeling and Performance Analysis), *NED University Journal of Research*, 2011, vol. VIII, no. 2, pp. 70-85. Available at: https://www.neduet.edu.pk/NED-Journal/previous_vol/pdf/11vol2paper7.pdf (Accessed 12 March 2021).
3. Jhanwar V., Pradhan A.K. Accurate Overcurrent Relay Algorithm using Fundamental Component. 2008 Joint International Conference on Power System Technology and IEEE Power India Conference, 2008 pp. 1-4. doi: https://doi.org/10.1109/IPST.2008.4745367.

4. Siddhu T.S., Sachdev M.S., Wood H.C. Design of a microprocessor-based overcurrent relay. [Proceedings] WESCANEY, 91, 1991, pp. 41-46. doi: https://doi.org/10.1109/WESCANEY.1991.160517.

5. Shah K.R., Detjen E.D., Phadke A.G. Feasibility of adaptive distribution protection system using computer overcurrent relaying concept. IEEE Transactions on Industry Applications, 1988, vol. 24, no. 5, pp. 792-797. doi: https://doi.org/10.1109/28.8981.

6. Almas M.S., Leelaruji R., Vanfretti L. Over-current relay model implementation for real time simulation & Hardware-in-the-Loop (HIL) validation. IECON 2012 - 38th Annual Conference on IEEE Industrial Electronics Society, 2012, pp. 4789-4796. doi: https://doi.org/10.1109/IECON.2012.6389585.

7. Yacine A.A., Noureddine A.A., Hamid B., Farid H. Implementation of a Numerical Over-current Relay Using LabVIEW and Acquisition Card. 2018 International Conference on Electrical Sciences and Technologies in Maghreb (CISTEM), 2018. pp. 1-5. doi: https://doi.org/10.1109/CISTEM.2018.8613455.

8. Alstom Grid. Network Protection & Automation Guide. May 2011. 508 p. Available at: rpa.energy.mn/wp-content/uploads/2016/07/network-protection-and-automation-guidebook.pdf (Accessed 12 March 2021).

9. Aliwa O.S.E. Practical Power System and Protective Relays Commissioning. Elsevier, Academic Press, 2019. 398 p. doi: https://doi.org/10.1016/C2018-0-00911-1.

10. Saleem A., Iqbal A., Mehmood K., Samad M.A., Hayat M.A., Manzoor U. Modelling and Implementation of Microprocessor Based Numerical Relay for Protection Against Over/Under Current, Over/Under Voltage. Journal of Computational and Theoretical Nanoscience, 2020, vol. 17, no. 2, pp. 1332-1338. doi: https://doi.org/10.1166/jcnt.2020.8809.

11. Verzosa Q., Lee W.A. Testing Microprocessor-Based Numerical Transformer Differential Protection. IEEE Transactions on Industry Applications, 2017, vol. 53, no. 1, pp. 56-64. doi: https://doi.org/10.1109/TIA.2016.2609402.

12. Donohue P.M., Islam S. The Effect of Non-Sinusoidal Current Waveforms on Electro-Mechanical & Solid State Overcurrent Relay Operation. 2009 IEEE Industry Applications Society Annual Meeting, 2009, pp. 1-6. doi: https://doi.org/10.1109/IAS.2009.5324811.

13. Naga Sujatha K., DurgaRao R., Shalini V.B. Performance analysis of digital over current relays under different fault conditions in radial and parallel feeders. International Journal of Science and Technology, 2017, vol. 3, no. 1, pp. 146-158. doi: https://doi.org/10.20319/Mijst.2017.s3.146158.

14. Suliman M.Y., Ghazal M. Design and Implementation of Overcurrent Protection Relay. Journal of Electrical Engineering & Technology, 2020, vol. 15, no. 4, pp. 1595-1605. doi: https://doi.org/10.1007/s42835-020-00447-0.

15. Pan Y., Steurer M., Baldwin T.L., McLaren P.G. Impact of Waveform Distorting Fault Current Limiters on Previously Installed Overcurrent Relays. IEEE Transactions on Power Delivery, 2008, vol. 23, no. 3, pp. 1310-1318. doi: https://doi.org/10.1109/TPWRD.2008.919170.

16. Maje P., Ghosh G. Designing Over-Current Relay Logic in MATLAB. International Journal of Scientific & Engineering Research, 2017, vol. 8, no. 3, pp. 40-43. Available at: https://www.ijser.org/researchpaper/Designing-Over-Current-Relay-Logic-in-MATLAB.pdf (Accessed 12 March 2021).

17. Idris M.H., Adzman M.R., Tajuddin M.F.N., Amirruddin M., Ismail M.A. Auto-reclose Relay Simulation for Research and Education. 2018 4th International Conference on Electrical, Electronics and System Engineering (ICEESE), 2018, pp. 29-33. doi: https://doi.org/10.1109/ICEESE.2018.8703542.

18. Ibrahim M.A., Ibrahim W.K., Hamoodi A.N. Design and Implementation of Overcurrent Relay to Protect the Transmission Line. International Journal of Engineering Research and Technology, 2020, vol. 13, no. 11, pp. 3783-3789. doi: https://doi.org/10.37624/IJERT/13.11.2020.3783-3789.

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