



RESEARCH ARTICLE - ENGINEERING

Design and Implementation of Multifunction Relay Based on Microcontroller

Ali Abdulsattar Hameed^{1,3}, Ahmed Jasim Sultan¹, Mehdi F. Booneya²

¹ Electrical Power Engineering Techniques Dept., Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.

² Kut Technical Institute, Middle Technical University, Baghdad, Iraq.

³ Industrial Development & Research, Ministry of Science & Technology, Iraq.

* Corresponding author E-mail: aliepe1988@gmail.com

Article Info.	Abstract
<p><i>Article history:</i></p> <p>Received 26 June 2021</p> <p>Accepted 13 August 2021</p> <p>Publishing 30 September 2021</p>	<p>The power systems are exposed to many abnormal conditions, so an advanced protection system must be provided to stand up to these challenges. Protection devices evolved continuously with the development of power systems. The accuracy, high response, reliability, and speed of fault detection are required in the operating mode of multi-function protective relays. A Multifunction Relay has been designed and implemented, which consists of three types of relays: over current relay OCR, over/under voltage relay OVR/UVR, and differential relay DFR. The relays OCR, OVR/UVR, and DFR are designed according to the standards IEC 60255, IEEE 1159, and IEEE C37.91, respectively, based on Arduino MEGA. The multi-function relay was implemented to work on a single phase.</p> <p>The setting of the multi-function relay configuration done using a new design based on the MATLAB GUI environment. Furthermore, the results obtained after each test appear on it and LCD screen. The multi-function relay which is designed can work as (OCR, OVR/UVR, DFR) in the case of a single-phase source.</p> <p>The experiential results show that the proposed multi-function relay is accurate, fast response, reliable, selective, good performance, low cost, and sensitivity when used to protect the power system equipment under different operating conditions.</p>

2019 Middle Technical University. All rights reserved

Keywords: Multifunction Relay; Overcurrent Relay; Arduino MEGA; PZEM004-T Sensor; Extremely Inverse; Temporary

1. Introduction

The rapid development in the production of electric power and the accompanying development in equipment, transmission lines, transmission, and distribution stations contributed to the development of the protection systems. Protection devices are an essential part of the electric power system and an important part of modern advanced protection systems [1]. A strong protection system is necessary to stand firmly in front of these challenges. There are several protection methods in the power system to prevent any change in electrical values that occurs suddenly [2]. Protection relays are developed to match the growth and development of the complex power system. The biggest revolution in protection systems was the invention of a microprocessor in 1971 when a microprocessor-based relay was developed after a short period of this invention [2]. The modern protection relay depending on the microprocessor. The microprocessor relay is one of the software devices that is based on numerical measurement [3].

There are several types of protection relay classified according to the nature of the need and the work. The first type of protection relay is overcurrent. The overcurrent Relay (OCR) is widely used in transmission and distribution systems to protect the ring and radial system [4]. The overcurrent relay is mainly used in power systems as backup protection in power systems [2]. The directional overcurrent (DOR) differs from the Overcurrent (OCR) by one point is the DOR measure the value of the current in addition to the angle, while the OCR measures the current value only [5].

Nomenclature

MFR Multifunction Relay
 OCR Overcurrent Relay
 OVR Overvoltage Relay
 DFR Differential Relay

CT Current Transformer
 PT Potential Transformer
 TFT Thin-Film-Transistor
 TFT Thin-Film-Transistor

The principle work of OCR is if the flowing current through the system exceeds the set value in a relay, the relay directly disconnects the current to provide the required protection.

There are some types of Overcurrent relay [1-2]:

- 1- Instantaneous Overcurrent Relay.
- 2- Definite Time Overcurrent Relay.
- 3- Inverse Time Overcurrent Relay.
- 4- Vary Inverse Overcurrent Relay.
- 5- Extremely Inverse Overcurrent Relay.

The second type is the overvoltage relay. The over/under voltage is an abnormal voltage that occurs as a result of special, unusual conditions in the power system. This voltage formed as a result of excessive voltage in the transformer, generator which leads to a failure in the equipment that must be protected [6]. Most electrical equipment, such as transformers or generators, is designed on voltages that can withstand up and down in voltage. In the event of overvoltage, devices are designed to work on a voltage between (105-110%) of the normal voltage, Whereas, in the case of the voltage drop, the devices are designed to work on voltages in the range) 90% (of the normal voltage. For these reasons, devices that sense the rise and fall of voltage are designed to send a signal to the circuit breaker when such situations occur, called over / under voltage Relay. The third type of protection relay is the Differential relay. Differential protection is a unit that provides instantaneous protection used to protect specific equipment such as the generator, transformer, motor, etc., but is more used in transformers [7]. The function of the differential protection Relay is comparing the incoming and outgoing currents of the element to be protected; if the difference between two values exceeds a certain value, this means that a fault occurs inside the transformer. As a result, a signal is sent from DFR to the circuit breaker to disconnect the current from the element to protect it from breakdown [5-7]. In any electrical power system, an inrush current (magnetizing current) is generated from an energized transformer [8]. The value of the Inrush current is between 1-2% of the rated current value when the transformer in the steady state, while the Inrush current value is more than 8-30 times the rated current when the transformer is energized [2]. The design of the protection digital relay consists of some inputs such as voltage, current, etc. The Current is measured by the current transformer while voltage is measured by the potential transformer [9]. Any electrical power system must contain a set of protection systems such as Over-current, Over and under voltage, differential protection, etc. [1-5]. The MFR contains several self-operating relays when exceeding the values passing through the power system, the values stored inside the relay, the relay sends a signal at high response speed to the circuit breaker to perform the protection function assigned to it. The fault in the power system usually occurs but not continuously. One of the basics of the multi-function relay is to distinguish faults between acceptable conditions and unacceptable conditions, and these conditions include increased current, high and low voltage, change impedance, frequency, etc. [10].

This work aims to design a multi-functional relay that contains the main requirements for the electrical network. The MFR includes several protection devices such as (overcurrent relay, over/under voltage relay m differential relay, etc.).

1.1. Literature Review

In 2017, Deshmukh et al. [11] implemented a differential relay to protect the transformer using fuzzy logic to distinguish between fault state and normal states using MATLAB software by selecting an appropriate slope for the differential protection of 25% .The practical part was implemented using two current transducers and a microcontroller from type dsPIC33E, operating as a part of the fuzzy logic controller. The result did not base on IEEE standardized; also, the researcher did not perform all the tests on the transformer.

In 2018, Majumder et al. [12] implemented an overcurrent relay from type inverse definite minimum time (IDMT). The protection system was tested on three-phase transmission lines, depending on the signal conversion method from analog to digital. The current value is sensed using a hall effect sensor (ACS712). The researchers did not implement all overcurrent relay types such as (vary inverse, extremely inverse). Also, the hall effect sensor was used inaccurately to measure currents.

In 2018, Kotb et al. [13] designed and implemented of over / under voltage relay for the protection of the solid-state transformer using the microcontroller Arduino from type UNO. The system is built using the proteus program. The transformer chosen consider a branch of future renewable electric energy delivery and management. The results showed inaccurate sensors to measure voltage compare to the modern sensors. Also, the researchers did not implement all overvoltage relay types according to IEEE standards.

In 2019, Kotb et al. [14] designed and implemented an overcurrent relay using Arduino from UNO type as a microcontroller. The author used the proteus program to build the schemes. The relay is used to protect the Future Renewable Electric Energy Delivery and Management from any increase in current value as backup protection. The design is depending on standardized IEC 60255-151 to implement three types of OCR which are (normally inverse, very inverse, and Extremely inverse) for different TDS values. The researchers did not implement all overcurrent relay types according to IEEE standards such as (vary inverse, extremely inverse) in real-time.

In 2020, Rahebi et al. [15] designed and implemented a model for a multi-function relay using a three-phase transmission line system. Different type of multi-function relay was implemented such as (over/under voltage, over current, and over/ under frequency). The MFR design is built using MATLAB SIMULINK. The prototype used different tests such as (overload, change the voltage value, and change the frequency) to

make fault in the system. The researchers did not design the proposed model in real-time. Also, the researchers did not implement all protection relay types according to IEEE standards.

This work aims to design a multi-functional relay to implement the protection requirements of the electrical power system. The MFR contains more than one relay. Each relay works according to characteristics. The MFR consists of three types of the relay (overcurrent relay, over/under voltage relay, differential relay).

This paper consists of (MFR problem, Overcurrent relay, Inverse definite minimum time, extremely inverse, Very inverse, Over/under voltage relay, differential relay, the proposed MFR, the experiential results and conclusion).

2. MFR Problem

Protection relay devices in power systems monitor the flow of power continuously to ensure the continuity of electricity and ensuring the least damage to electrical equipment [16]. The proposed MFR is one of the essential parts of a modern power system. The MFR interface is designed by using MATLAB GUI software. The MFR consists of several protection relays that are used according to protection degree, such as (OCR, OVR, UVR, and DFR).

2.1. Overcurrent relay

The development of power systems is important to provide electric energy with high quality to consumers and to keep up with demand increasing. Over-current protection was evolved many years ago [3]. It is one of the simplest, cheapest, and most popular protection systems in the world. The working principle of Overcurrent Relay is when a fault occurs in the power system, the value of the current measured by the OCR increases, the relay compares the measured value with the setting value if the measured value is greater than the setting value and continues for a period of time, the relay directly sends a trip signal to separate the current from the part to be protected, three types of overcurrent can be classified according to delay time [12]:

- 1- Inverse definite minimum time
- 2- Vary Inverse Overcurrent Relay
- 3- Extremely Inverse Overcurrent Relay.

2.1.1. Inverse definite minimum time

The disadvantage of inverse time-current is the operating time is not specified for the higher fault current; hence it is difficult to obtain good coordination between relays. To avoid this problem, we can adjust the relay to get an operation time at a definite minimum have a PSM (Plug setting multiplier) value. Therefore, the relay characteristic becomes an inverse relationship between the time and the current values that are less than PSM, and a straight line with values above PSM. In this type of relay, the operating time of the relays connected to different zones of the feeders is set even at the minimum operating time of the relays to make true separation when a fault occurs. The process adjustment of a relay is called time setting. It is implemented in steps starting from 10% of the maximum operating time to design a specific plug setting that has a value that varies between 10% to 100%. These steps are regulated under the term time multiplier setting (TMS) can be expressed as (1) [16].

$$TMS = \frac{\text{actual operation time of relay}}{\text{standardized operating time for a special PSM}} \quad (1)$$

Inverse definite minimum time (IDMT) characteristics can be represented by a group of curves between PSM and the operation time. Each curve corresponds to a certain value of the Time multiplier setting (TMS).

For standard overcurrent relay relationship of type Inverse Definite Minimum Time (IDMT) As per IEC 60255 standard can be expressed as (2) [17]:

$$t = TMS * \frac{0.14}{(I_r^{0.02} - 1)} \quad (2)$$

Where: $I_r = \frac{I}{I_s}$

Where: I = the measured current

I_s= the setting current

t = operation time of relay.

2.1.2. Extremely inverse

The properties of this type of OCR is the time value of the operation is inversely proportional to the square of the current passing through the relay, This makes it convenient and practical to protect the distribution feeders in the event that the distribution circuit is exposed to the peak current at the switching moment [17].

The mathematical expression for the Extremely inverse current as per IEC 60255 standard can be expressed as Eq. (3) [12]:

$$t = TMS * \frac{80}{(I_r^2 - 1)} \quad (3)$$

2.1.3. Very inverse

Vary inverse current relay is especially used for faults that are a long distance from the power source and have a lower value of the fault current, which means an increase in the fault impedance [17].

Vary inverse has a characteristic that the operation time is doubled to reduce setting current from 4 to 7 times setting current. This makes it convenient to use the same TMS for more than one relay connected in series. The mathematical expression for the vary inverse current As per IEC 60255 standard can be expressed as (4) [17].

$$t = TMS * \frac{13.5}{(Ir-1)} \tag{4}$$

The characteristics of Inverse relay compared to a different type of relay (Inverse definite minimum time, extremely inverse relay) are shown in Fig. 1.

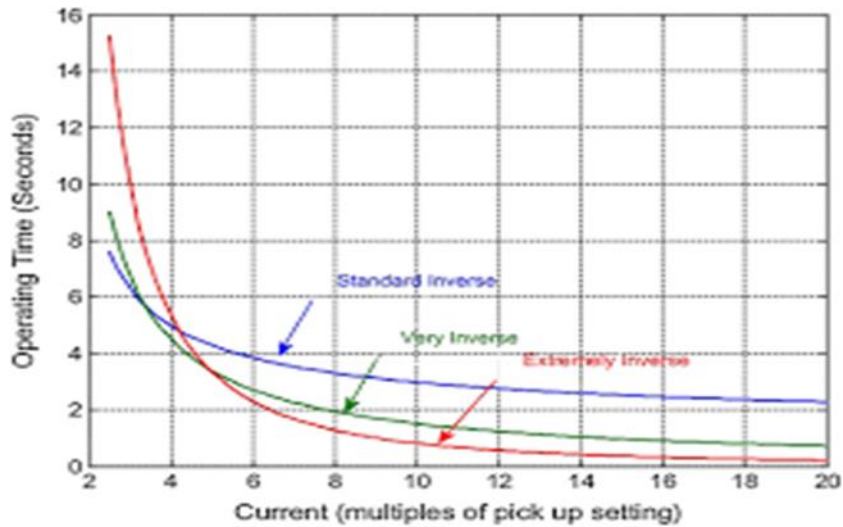


Fig. 1 Curves of various Inverses relay

The flow chart of Overcurrent Relay in Fig. 2.

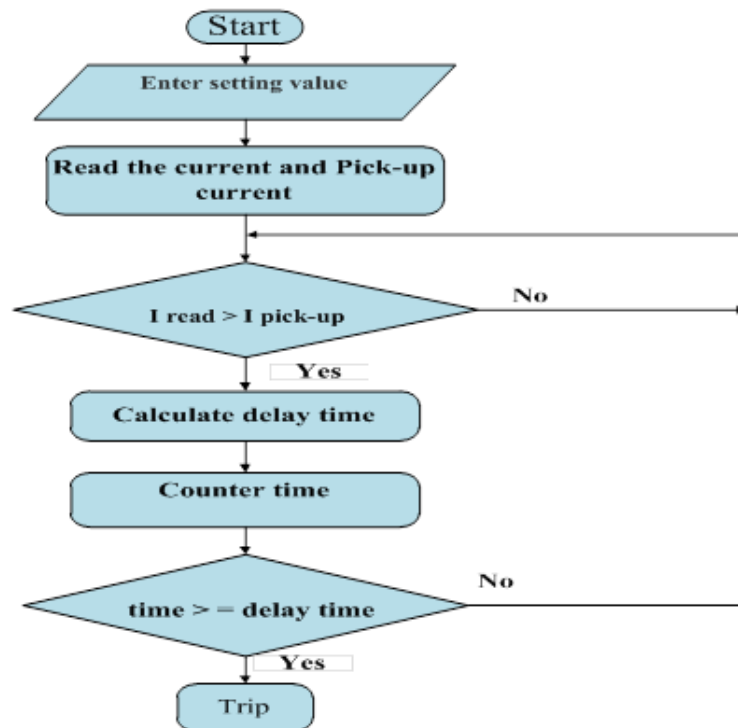


Fig. 2 The flowchart of OCR

2.2. Over/under voltage relay

The electrical energy supplied to the consumer must have a powerful and developed protection system to detect faults by the protection relays and send a trip signal to protect the equipment inside the power system. The relays protect all parts of the power system from generation to distribution through the transmission line. Protection relays are available in several types, Such as electromechanical, digital, etc. One of the most important protection devices necessary in the power system for protection against high and low voltage is over voltage / under voltage Relay. Electronic appliances and electrical equipment are greatly affected by voltage variation [18]. There are two types of voltage protection devices.

2.2.1. OVR

Overvoltage occurs because the voltage is increased to 110% times the applied voltage more than the permissible limits. Overvoltage is less common than under-voltage, but it also causes faults in the system [19]. The principle work of this type is when the voltage Increase to a certain value above the set value defined by the user and continues for a certain time. The relay sends a signal to the circuit breaker to isolate the voltage source from equipment and protect it from failure after the end of this time [20]. The principle work of this type of protection compares the reference voltage with measured voltage as follow:

The overvoltage can be classified according to IEEE 1159 standard [21]:

- 1- Instantaneous: The standard duration between (0.5 s- 30 cycles) and the standard voltage magnitude between (1.1 P.U-1.8 P.U).
- 2- Momentary: The standard duration between (30 cycles- 3 sec) and the standard voltage magnitude between (1.1 P.U-1.4 P.U).
- 3- Temporary, The standard duration between (3 sec – 1 min), and the standard voltage magnitude between (1.1 P.U-1.2 P.U) .

2.2.2. UVR

Under voltage occurs when a high load is suddenly connected to the power system, the current draw at this moment start in high value, this resulting decrease in voltage suddenly [22]. Under voltage is reduced value to 90% of the applied voltage for a period of time more than the certain time. The Under-voltage state occurs at the Switching moment.

The principal work of this type is when the voltage Decrease to a certain value below 90 % of the setting value defined by the user and continue for a period more than the delay time according to the equation of IDMT. After the end of time, the relay sends a signal to the circuit breaker to isolate the voltage source from equipment to protect it. The principle work of this type of protection is comparing the reference voltage with measured voltage as follow:

The under-voltage can be classified according to IEEE 1159 standard [21]:

- 1- Instantaneous, The standard duration between (0.5 s- 30 cycles), and the standard voltage magnitude between (0.1 P.U-0.9P.U).
- 2- Momentary: The standard duration between (30 cycles- 3 sec) and the standard voltage magnitude between (0.1 P.U-0.9P.U).
- 3- Temporary: The standard duration between (3 sec – 1 min), and the standard voltage magnitude between (0.1 P.U-0.9P.U).

The flow chart of the overvoltage relay according to IEEE 1159 is shown in Fig. 3.

2.3. Differential relay

The differential protection is characterized by the ability to distinguish both internal and external faults [18]. The DFR sometimes is known as unit protection because it is responsible for protecting one unit, such as a transformer, generator, etc. The unit may be a transformer or maybe generator and perhaps both transformer and generator together. In all cases, differential Relay does not work unless the fault occurs inside the zone (internal fault) to be protected, but not operate when the fault occurs out the zone [24]. In the following Fig. 4, a single line diagram is shown representing the differential protection system [25].

The principle of differential relay protection work is based on the results from the primary and secondary currents. The primary and secondary conductors connect to the current transformer CT to bring the current from the transformer to the differential relay. The result of the two currents is almost approximately equal to zero in the pre-fault cases, while in the case of the event faults, the difference values are greater than the pickup value, as shown in Fig. 5. This fault leads to the operation of the differential relay and sends a signal to the circuit breaker to start the separation process [2].

The differential relay can be used to detect internal faults in the transformer. While internal faults with lower values, it is difficult to use the same method. To avoid this problem, the percentage differential protection was used. The differential protection compares two factors, the restraining and operation current [26]. The operation current (differential current) I_{op} for ideal condition equal to zero and it can be calculated as follow:

$$I_{op} = |I_p + I_s| \quad (5)$$

Where

I_p, I_s are the primary and secondary current.

The restrain current I_{rt} can be found in this way.

$$I_{rt} = K|I_p - I_s| \quad (6)$$

$$I_{rt} = K(|I_p| + |I_s|) \quad (7)$$

Where k is constant equal (1 or 0.5)

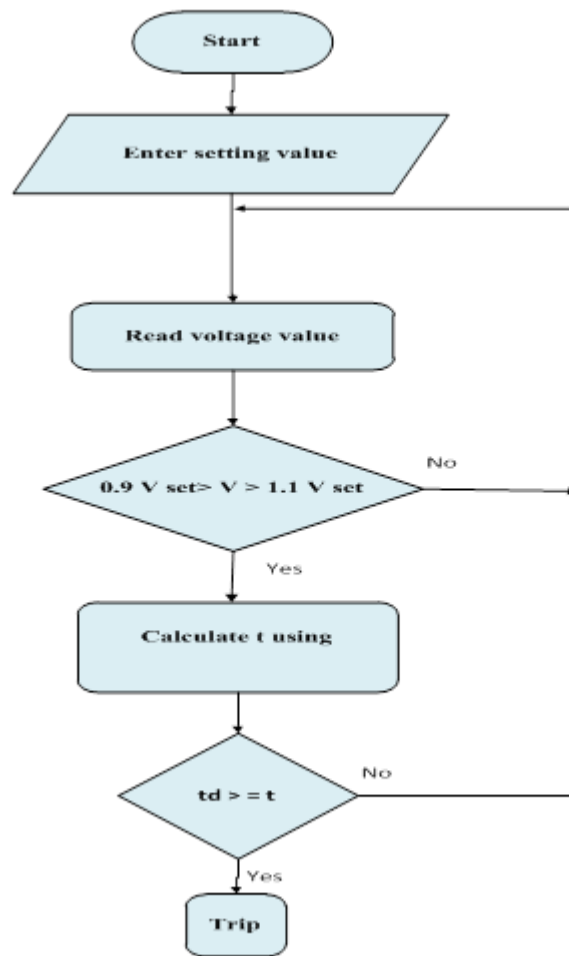


Fig. 3 The flowchart of OVR/UVR

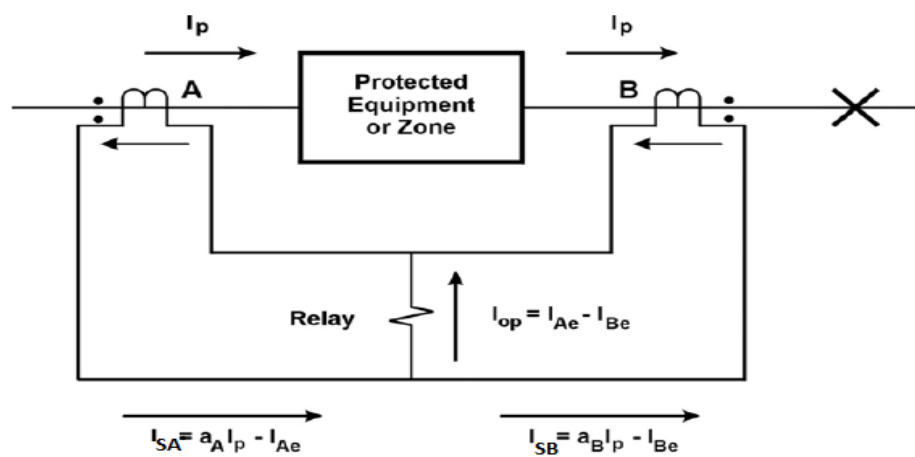


Fig. 4 The basic of Differential Relay under External fault or normal state

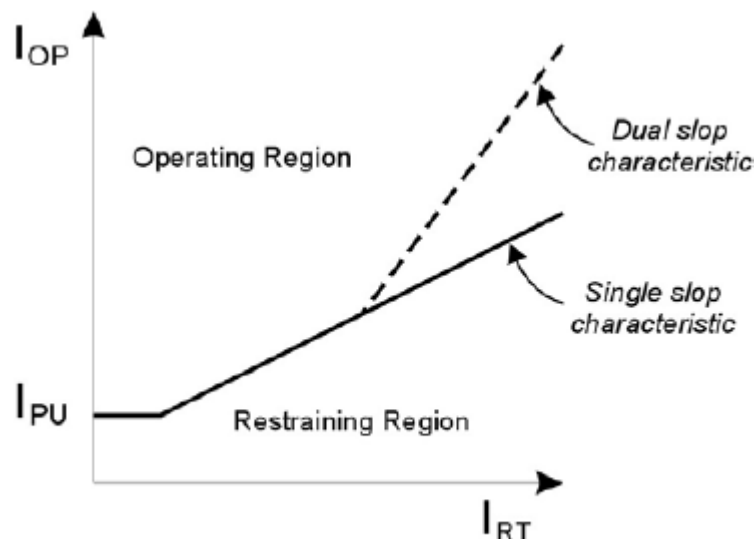


Fig.5 The differential relay characteristics

The differential relay characteristics are shown in fig. 5, the restraint current I_{rt} located at the x-axis and operation current located on the y-axis. The characteristics having two lines the straight line represent the pickup current and the slop (SLP). The straight line divided the Figure into two regions: the lower region represents the operation part of the relay while the upper region represents the restraint part of the relay. The choice of the slope value depends on the value of the current. In light currents, the slope is small to sense the value of the fault current at the lowest value. While at higher value currents, the slope is high. The Differential relay sends a signal to the circuit breaker if the operation current is greater than the percentage restraining current, and at some time, the operation current is larger than the pickup current.

$$I_{op} > SLP * I_{rt} , \quad (8)$$

Where

SLP_i : The slop of differential relay.

The flowchart of DFR can be seen in Fig. 6.

3. The Proposed MFR

The proposed MFR is one of the essential parts of a modern power system. The MFR interface is designed by using MATLAB GUI software. The MFR consists of several protection relays that are used according to protection degree, such as (OCR, OVR, UVR, and DFR). The MFR window contains types of the relay, the setting value that must be entering it according to each type, and the table to of result, etc., as shown in Fig. 7.

The MATLAB program was used to input setting data for current and time values etc. When any fault occurs, results are obtained to know the fault current and the time delay.

The proposed OCR & OVR consists of the following parts:

- 1- Arduino Mega
- 2- Current and voltage sensors
- 3- Relay
- 4- Dc source 12v &5V
- 5- LCD
- 6- Switch
- 7- Load
- 8- Variac

The practical component of single-phase relay as shown in Fig. 8.

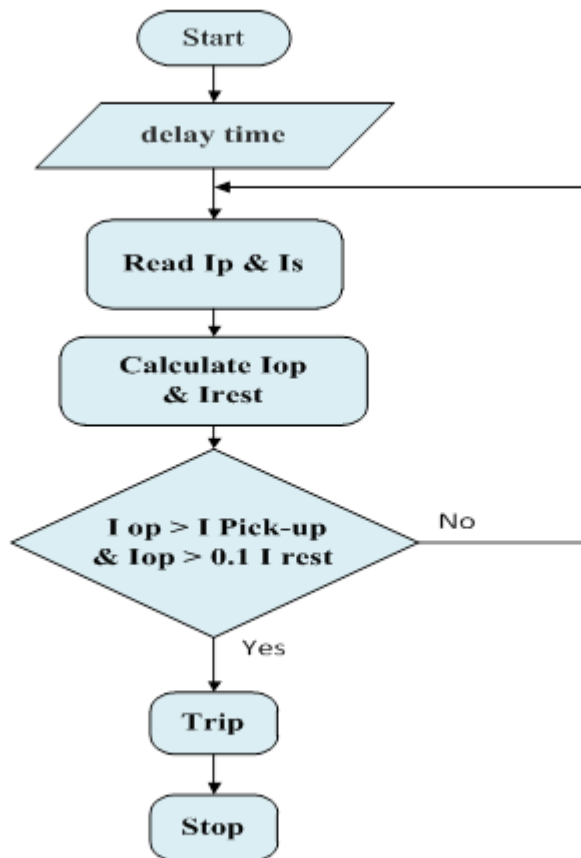


Fig. 6 The flowchart of DFR

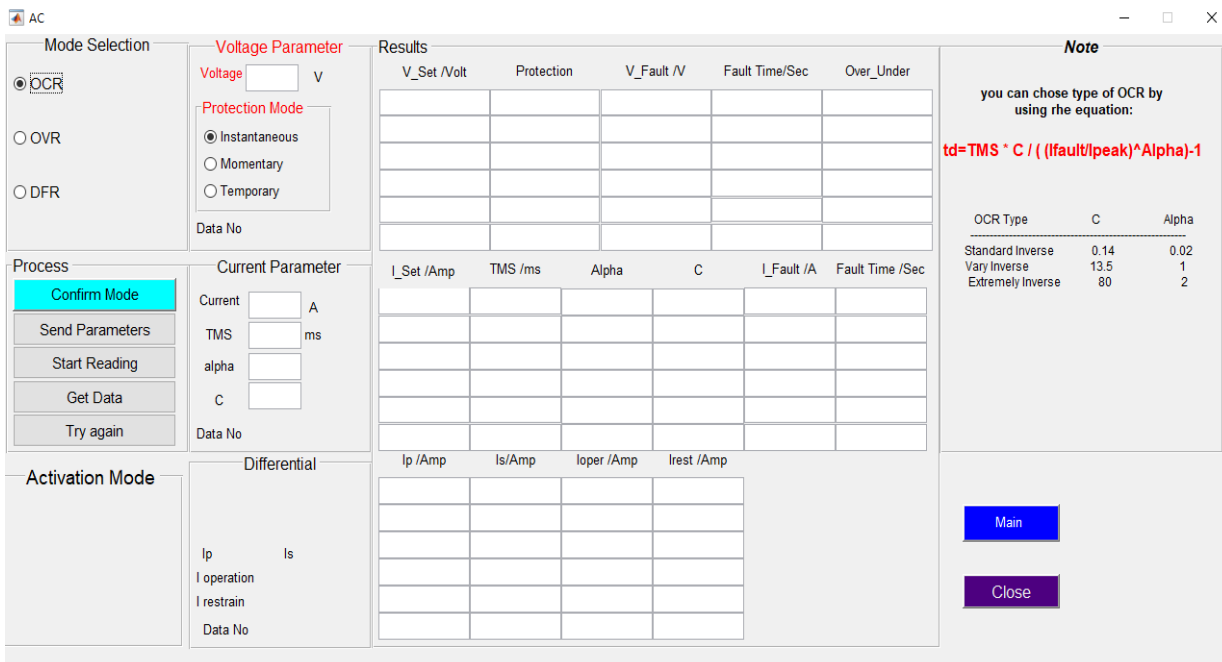


Fig. 7 The MATLAB GUI window for MFR

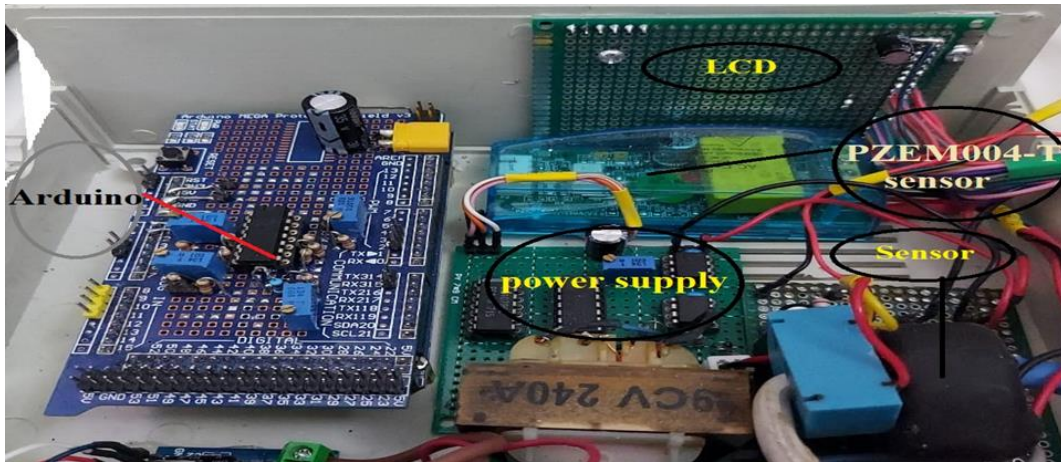


Fig. 8 The proposed OCR and OVR

The proposed design of DFR can be seen as shown in Fig. 9.

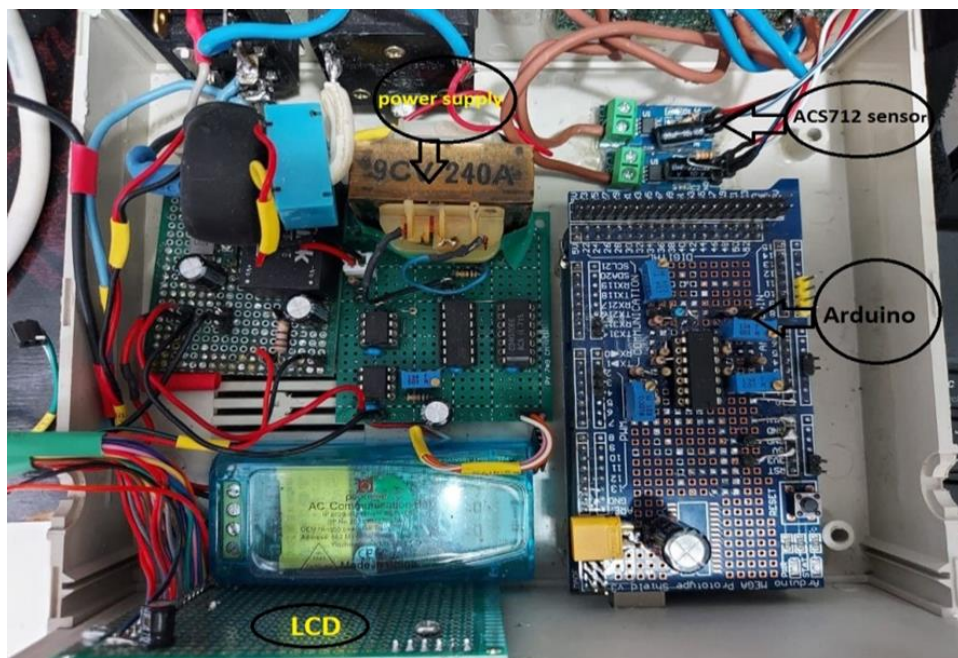


Fig. 9 The practical circuit of DFR

While the practical circuit of MFR can be seen as shown in Fig. 10.

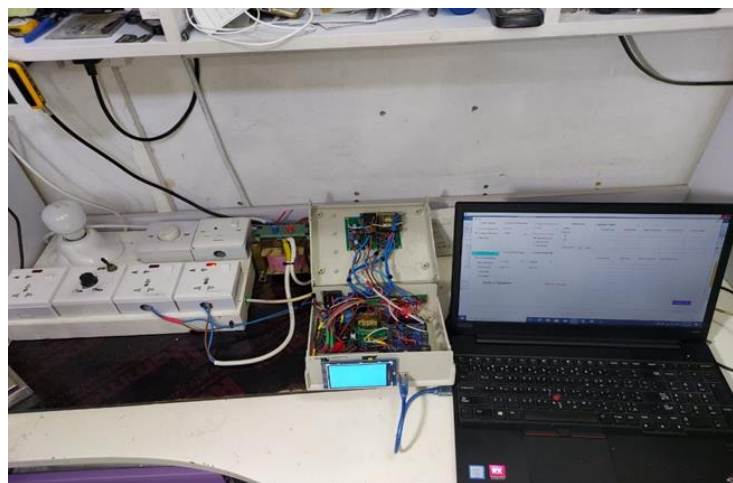


Fig. 10 The practical circuit of MFR

4. The Experiential Results

The new MFR is an essential part of the modern power system because of its high ability to detect and predict fault. The MFR consist of a number protection relay device.

4.1. OCR

4.1.1. Case 1 Standard Inverse (TMS=100ms)

The first type of overcurrent relay is standard inverse. The setting value as follows entered: $C=0.14$, $\text{Alpha}=0.02$, $I_{\text{set}}=1\text{A}$ and $\text{TMS}=100\text{ms}$

After entering the settings and sending the data from the computer to the Arduino, we got the following results as shown in Table 1.

Table 1 The result of overcurrent Relay when Relay work as Standard Inverse

(IF) (A)	I pickup (A)	Time Delay (s)	Theoretical time (s)	The difference	State
1	1.25	-	-	-	No Trip
1.1	1.25	-	-	-	No Trip
2.15	1.25	1.31	1.28	0.03	Trip
1.69	1.25	2.93	2.31	0.62	Trip
1.93	1.25	1.62	1.6	0.01	Trip
2.15	1.25	1.3	1.28	0.02	Trip
8.84	1.25	0.42	0.35	0.07	Trip
6.48	1.25	0.5	0.42	0.08	Trip

4.1.2. Case 2 Very Inverse OCR (TMS=100ms)

The Second type of OCR is very inverse, the setting value of this type entered as following:

$C=13.5$, $\text{Alpha}=1$ $I_{\text{set}}=1\text{A}$ and $\text{TMS}=100\text{ms}$

After entering the setting value and sending the data from the MATLAB program to the Arduino. The operation order is executed by clicking on the start reading button in MATLAB GUI, we get the following results as shown in Table 2.

Table 2 The result of overcurrent relay very inverse type when TMS = 100ms

(IF) (A)	I pickup (A)	Time Delay (s)	Theoretical time (s)	The difference	State
0.7	1.25	-	-	-	No Trip
1.54	1.25	6.53	5.82	0.7	Trip
.216	1.25	1.96	1.85	0.11	Trip
1.92	1.25	0.261	2.52	0.09	Trip
1.71	1.25	3.92	3	0.16	Trip
3.77	1.25	0.74	0.67	0.07	Trip
8.17	1.25	0.33	0.24	0.09	Trip
1.5	1.25	5	6.75	-	No Trip

4.1.3. Case 3 Extremely Inverse (TMS=100ms)

The last type of OCR is extremely inverse. The setting value of this type is set as follows: $C=80$, $\text{Alpha}=2$ $I_{\text{set}}=1\text{A}$ and $\text{TMS}=100\text{ms}$

After completing enter the data and sending it to the OCR device by clicking on Send data, give the start operation command in the MATLAB GUI; we get the following results as shown in Table 3.

Table 3 The result of OCR extremely inverse type when TMS = 100ms

(IF) (A)	I pickup (A)	Time Delay (s)	Theoretical time (s)	The difference	State
0.9	1.25	-	-	-	No Trip
.156	1.25	14.53	14.34	0.19	Trip
1.97	1.25	5.38	5.38	0.00	Trip
2.58	1.25	2.47	2.45	0.02	Trip
2.35	1.25	3.28	3.15	0.13	Trip
.278	1.25	2.04	2.02	0.02	Trip
3.18	1.25	1.65	1.46	0.19	Trip
.24	1.25	1	2.98	-	No Trip

4.2. OVR/UV

4.2.1. Case 1 Instantaneous

The results obtained after performing the tests as shown in Table 4.

Table 4 The Instantaneous OVR/UVR

The reading voltage (V)	The setting voltage (V)	Delay time (s)	State
235	220	-	No Trip
248.6	220	0.5	Trip
259.1	220	0.56	Trip
194.9	220	0.64	Trip
196.8	220	0.64	Trip
197.3	220	0.64	Trip
194	220	0.64	Trip
230	220	-	No Trip

4.2.2. Case 2 Momentary

The results obtained after performing the tests as shown in Table 5.

Table 5 The Momentary OVR/UVR

The reading voltage (V)	The setting voltage (V)	Delay time (s)	State
210	200	-	No Trip
233.8	200	2.04	Trip
235.2	200	2.04	Trip
226.4	200	2.04	Trip
174.8	200	2.02	Trip
195	200	-	No Trip
173.5	200	2.01	Trip
221	200	2.03	Trip

4.2.3. Case 3 Temporary

The results obtained after performing the tests as shown in Table 6.

Table 6 The Temporary OVR/UVR

The reading voltage (V)	The setting voltage (V)	Delay time (s)	State
205	200	-	No Trip
227.8	200	10.06	Trip
234.6	200	10.1	Trip
239.7	200	10.02	Trip
192	200	-	No Trip
172.4	200	10.03	Trip
161	200	10.04	Trip
232	200	10.03	Trip

4.3. DFR

4.3.1. Case 1: fault in the primary side

The result obtained is:

$$I_{\text{primary}} (I_1) = 2.98\text{A}$$

$$I_{\text{secondary}} (I_2) = 0.11\text{A}$$

$$I_{\text{operation}} (I_{\text{op}}) = 2.88$$

$$I_{\text{restrain}} (I_{\text{RES}}) = 1.55\text{A}$$

To clarify how to obtain practical results, we perform theoretical calculations as follows :

$$I_{\text{op}} = I_1 - I_2$$

$$= 2.98 - 0.11$$

$$= 2.88\text{A}$$

$$I_{\text{rest}} = \frac{I_1 + I_2}{2}$$

$$I_{\text{rest}} = \frac{2.98 + 0.11}{2}$$

$$I_{\text{rest}} = 1.55\text{A}$$

4.3.2. Case 2: fault in secondary side

The result obtained:

$$I_{\text{primary}} (I_1) = 0.77\text{ A}$$

$$I_{\text{secondary}} (I_2) = 0.10\text{A}$$

$$I_{\text{operation}} (I_{\text{op}}) = 0.67\text{A}$$

I restrain (IRES)=0.43 A

To clarify how to obtain practical results, we perform theoretical calculations as follows :

$$I_{OP} = I_1 - I_2$$

$$= 0.77 - 0.10$$

$$= 0.67A$$

$$I_{rest} = \frac{I_1 + I_2}{2}$$

$$I_{rest} = \frac{0.77 + 0.10}{2}$$

I rest=0.43 A

4.3.3. Case 3: fault out of the zone

I primary (I1) = 0.13 A

I secondary (I2) = 0.17A

I operation (Iop) =0.04A

I restrain (IRES)=0.15 A

To clarify how to obtain practical results, we perform theoretical calculations as follows:

$$I_{OP} = I_1 - I_2$$

$$= 0.17 - 0.13$$

$$= 0.04A$$

$$I_{rest} = (I_1 + I_2) / 2$$

$$I_{rest} = (0.13 + 0.17) / 2$$

I rest=0.15 A

After each test, the result show in the TFT screen contains the type of the relay and information about the fault, as shown in Fig. 11.

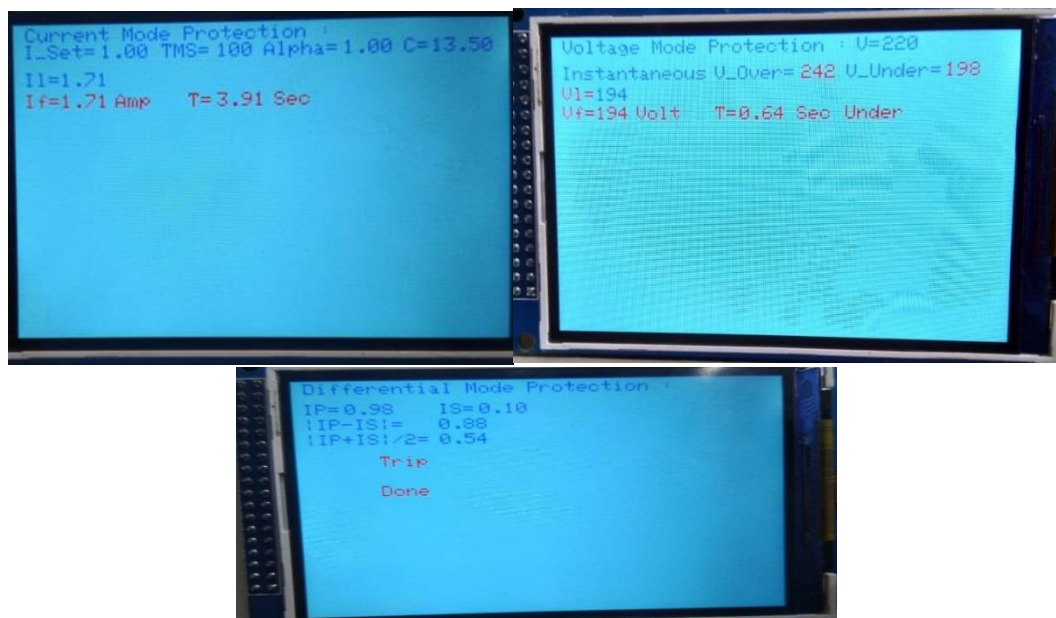


Fig. 11 The TFT screen of MFR

5. Conclusions

The multi-function relay is a smart relay for easy adjustment of the control signals, with multi-functions (Over Current relay, Over Voltage /Under Voltage Relay, and Differential Relay) and multi-voltage input built-in. Multifunction relay offers high functionality on a small footprint. The new design of MFR was built using Arduino from type (MEGA) to work single-phase source that consists of the following types (OCR, OVR/UVR, DFR). The settings are tuned through the MATLAB GUI environment of the proposed configurations. After each fault, the results will appear on the MATLAB GUI interface and TFT screen. These features enable result acquisition and setting-control more flexibly.

References

- [1] J.C. Das. "Power Systems Protective Relaying," Georgia, USA, 2018.
- [2] PAITHANKAR, Yeshwant G.; BHIDE, S. R. Fundamentals of power system protection, India, 2010.

- [3] Sachdev, Mohindar S. "Understanding microprocessor-based technology applied to relaying" Report of Working Group I-01 of the Relaying Practices Subcommittee ,2009
- [4] Birla, Dinesh, Rudra Prakash Maheshwari, and Hari Om Gupta. "Time-overcurrent relay coordination: A review." *International Journal of Emerging Electric Power Systems*, Vol 2,2, 2005.
- [5] Gan, Zhijun, S. Elangovan, and A. C. Liew. "Microcontroller based overcurrent relay and directional overcurrent relay with ground fault protection." *Electric power systems research* Vol38,1, pp.11-17, 1996.
- [6] Torres, Francisco, Yofre Jacome, and Charles Henville. "Application of overvoltage protection to the Peruvian power system." ,506-512, 2008.
- [7] Miss. Nidhi Reddiwar, and Prof. Pratik Ghutke. "Design and Results of Differential Relay Settings for Power Transformers 80MVA, 40MVA and 100MVA." *Int. J. Sci. Eng. Technol. Res* 2, Vol 8, pp 32-34, 2019.
- [8] Y. L. Goh, A. K. Ramasamy, A. A. Z. Abidin, and F. H. Nagi, "Design of Digital Differential Relay for Protection of Power Transformer", *International Journal of Emerging Technologies in Science, Technology and Management*, Vol 2: Issue 3. 2017
- [9] Mozina, Charles, and Michael Young. "Multi-function digital relay commissioning and maintenance testing." *IEEE Industry Applications Magazine* Vol 11, pp50-58,2005.
- [10] Kezunovic, Mladen, Jinfeng Ren, and Saeed Lotfifard. " Design, Modeling and evaluation of protective relays for power systems. ". Switzerland: Springer International Publishing, 2016
- [11] Deshmukh, M. S., & Barhate, V. T. "Microcontroller based differential relay using fuzzy logic for transformer protection". In 2017 *International Conference on Intelligent Computing and Control Systems (ICICCS)*, pp. 712-717. IEEE, 2017.
- [12] Majumder, R., Dolui, S., Agasti, D., & Biswas, S. "Micro-controller-based overcurrent relay using Hall Effect current sensor". In 2018 *Emerging Trends in Electronic Devices and Computational Techniques (EDCT)*, pp. 1-4. IEEE, 2018.
- [13] Kotb, Mohamed Fawzi, Magdi M. El-Saadawi, and Eman H. El-Desouky. "Design of Over/Under Voltage Protection Relay using Arduino Uno for FREEDM System". *European Journal of Electrical Engineering and Computer Science*, vol. 2, Issue. 7,2018.
- [14] Kotb, Mohamed F., Magdi El-Saadawi, and Eman H. El-Desouky. "Overcurrent protection relay-based Arduino Uno for FREEDM system". *International Transactions on Electrical Energy Systems*, vol. 29, Issue. 6,2019.
- [15] Rahebi, Javad, and Muhanned Mahmood Shakir Al-Shalah. "Design, Modeling and Implementation of Multi-Function Protective Relay with Digital Logic Algorithm". *Avrupa Bilim ve Teknoloji Dergisi*, vol. 19, pp. 549-565, 2020.
- [16] Chen, Zejian. "Advanced microprocessor based intelligent relay for multi-function protection system. ". Diss. Victoria University of Technology, 1995.
- [17] Alstom Grid, "Network Protection and automation guide, protective Relay, Measurement & control May,2013.
- [18] Paul, Manish, Barnali Talukdar, and Banani Baishya. "Simulation of Overvoltage and Under-Voltage Protection in PSIM." *International Journal of Engineering Research & Technology (IJERT)*, Vol 3, Issue 11, pp 1005-1008, 2014.
- [19] Bhosale, G., Vakhare, A., Kaystha, A., Aher, A., & Pansare, V., "Overvoltage undervoltage protection of electrical equipment". *International Research Journal of Engineering and Technology (IRJET)*, Vol 5, Issue 2, p,p 29-32., 2018.
- [20] Sleva, Anthony M. " Protective relay principles". CRC Press, New york,USA , 2018.
- [21] IEEE Power & Energy Society, "IEEE Recommended Practice for Monitoring Electric Power Quality", IEEE Standardd 1159, New York, June 2009.
- [22] Kumar, N., PrakashVerma, V., Singh, V. K., Nandi, S., & Ventrui, V. Double relay-based sag, swell, over and under voltage protection and detection scheme. In 2013 *International Conference on Communication and Signal Processing*. IEEE, pp.1008-1012, 2013.
- [23] Tripathy, Manoj, Rudra Prakash Maheshwari, and H. K. Verma. "Power transformer differential protection based on optimal probabilistic neural network." *IEEE transactions on power Delivery* Vol 25, Issue 1, pp 102-112, 2009.
- [24] Kumar, S. D., Raja, P., & Moorthi, S." Self-adaptive differential relaying for power transformers using FPGA". In 2015 *International Conference on Condition Assessment Techniques in Electrical Systems (CATCON)* IEEE pp. 121-126, 2015.
- [25] Perez, Sandro Gianni Aquiles. "Modeling relays for power system protection studies". Diss. University of Saskatchewan, 2006.
- [26] Al-Khalifah, A. K., & El-Saadany, E. F., Investigation of magnetizing inrush current in a single-phase transformer. In 2006 *Large Engineering Systems Conference on Power Engineering*, IEEE, pp. 165-171, 2006.