Real-Time Implementation of a New Multifunction Relay

Ali AbdulSattar Hameed1,3, Ahmed Jasim Sultan1, Mehdi F. Booneya2 and Tahseen Ali Abd Almunhasen 1,4
1 Electrical Power Engineering Techniques Dept., Electrical Engineering Technical College, Middle Technical University, Baghdad, Iraq.
2 Kut Technical Institute, Middle Technical University, Wasit, Iraq.
3 Industrial Development & Research, Ministry of Science & Technology, Iraq
4 General Company of Electricity Transmission/Middle Region, Ministry of Electricity, Baghdad, Iraq

Abstract. This paper aims to design and building a New Multifunction Relay (MFR) by using the Arduino MEGA. It is used to provide protection against many abnormal conditions that may occur in the power system. The MFR contains two functions: firstly, are designing an inverse Overcurrent relay, and the other is an Over/Under voltage Relay based on the IEC 60255-151 standard and IEEE 1159 standard respectively. The GUI is designed by using the MATLAB environment to provide a platform of the relay. The proposed MFR showed accuracy results, Low costs, fast response, and very small error rate.

Keywords: MFR, OCR, OVR, UVR, Arduino MEGA, PZEM004-T

1. Introduction
The optimum power system should contain devices that protect the system and the other tools from the faults that may occur in the power system suddenly during the operation [1]. Therefore, most of the power stations cannot operate without an integrated protection system that can identify any abnormal conditions that may occur in the system, these abnormal conditions include over/under voltage, over current. To meet all these situations, different types of protection have been designed, each according to its use, including Over current, over / under voltage, distance Relay, etc. [2-4]. The protection unit consists of a current transformer (CT), a voltage transformer (PT), and a circuit breaker (CB) [2]. Most protection systems consist of two devices. The first is used to convert high current values, and high voltage values are a few values that the relay can deal with, as well as provide high isolation between the power system and tools on one side and the relay on the other side[5-6]. If the current or voltage value is greater than the setting value entering on the relay, the relay sends the electrical signal to CB to disconnect the electrical energy from the source and isolate all the parts required to be protected [3-10]. The development in the technology of protection systems made the new types of relay depend on the base of the microprocessor. These types are called a numerical relay [6]. The numerical relay, like the electrostatic wave, receives the voltage and current signal and deals with it, but at a higher speed [5-7].

The protection devices have great interest from previous researchers in the field of developing devices from the Previous style to devices that depend on digital methods, because of the advantages of digital methods in terms of speed in performance and accuracy in detecting faults and speed of identification.
The digital relay is more useful than other older types due to reliability, better performance, efficiency, and quick response in the face of any faults [5-10]. The multi-function relay performs several functions at the same time. It monitors both the high and low voltage and the current rise under various conditions [9-10]. The multifunction relay consists of two protection type, the first type is OCR used to monitor an increase of the current, the relay has been chosen from the type Inverse Definite Minimum Time (1.D.M.T) and the result is depending according to IEC 60255 [2]. The second function is OVR/UVR used to monitor and follow up the Increase and decrease of the voltage according to the IEEE standard 1159 [11].

2. Multifunction Relay Problem
The multifunction Relay (MFR) is important in protection devices, because of the ability to choose between more than one type of relay in the same equipment. The MFR prototype consists of two types of the relay, one is over current and the other is over / under voltage, the protected type is chosen based on the protection requirements and the system to be protected. The multifunction relay is designed to perform these tasks, see Figure 1. The proposed design consists of two parts, a practical part, and a programmatic part. The practical side consists of several tools, including LCD as display value, current sensor and voltage sensor (CT & PT) to convert the current and voltage to a small value For Arduino to be able to deal with it without burning because it is necessary to convert it to small values to not exceed 5V see Figure 2. The current and voltage can be sensed value by using Multifunction power sensor (PZEM-004T). The OV/UV we can control it by changing the voltage by using the voltage controller (VARIAC), As for the current, we can control it by changing the loads until the fault is reached. In all cases of reaching the fault, a signal is sent to the CB to cut off the source, thus protecting the system from failure and collapse. The programmatic part was written in C language and was uploaded to the Arduino Mega by USB cable.

2.1. Overcurrent Relay
The purpose of using this type of protection (OCR) is to reduce the risks arising from a sudden increase in the value of the current that may damage electrical equipment. When the current increases to a high value as a result of abnormal conditions occurring in the electrical system, (OCR) sends a signal to (C.B) to isolate the equipment to be protected. In this type, the current is entered to the relay, if the reading current exceeds the pick-up current value of the relay, a signal is sent from the relay to (C.B) to disconnect the equipment to be protected.

2.1.1. Instantaneous Overcurrent Relay.
In this type of (Over Current) devices, the disconnection state occurs, if the current exceeds a certain value Without any delay, the relay Disconnects immediately after 100 ms [16-17].
2.1.2. Time delay Overcurrent Relay
The second type of Overcurrent device is a time delay overcurrent relay, if the current passes through MFR exceeds a specified value (pick-up value) and at the same time the delay time exceeds time setting value, a signal is sent from the relay to the circuit breaker after the time delay has passed. The principle operation of the MFR depends on two factors: the value of the current and delay time \(t_d\). The relay is activated and the signal is sent to the circuit breaker if the two factors occur together. The time delay can be classified into two parts: the first section definite time and the second type of inverse time. In the first section, the time is fixed, this type is used as support for distance relay when protecting transmission lines, and to support differential relay when protects the transformer.

**Figure 1.** The proposed Multifunction Relay.

**Figure 2.** The principle of an MFR
The second type (inverse time delay) The delay time is variable according to the current value entering to MFR. The relationship between the fault current value and the delay time is an inverse. Based on the above, the inverse time types were divided into three parts: extremely inverse, very inverse, standard inverse [2].

Extremely inverse:

\[ t_d = TMS \times \frac{80}{P_{SM^2-1}} \]  \hspace{1cm} (1)

Vary inverse:

\[ t_d = TMS \times \frac{13.5}{P_{SM-1}} \]  \hspace{1cm} (2)

Standard inverse:

\[ t_d = TMS \times \frac{0.14}{P_{SM^{0.02}-1}} \]  \hspace{1cm} (3)

\[ PSM = \frac{I_f}{I_{peak}} \]

Where:

\( t \) =the time delay if the current \( (I_f) \) passes through it \( (s) \)

\( TMS \) =the time dial setting or the time multiplier setting \( (s) \)

\( PSM \) = the ratio of the fault current to the pick-up current

Figure 3 showed the relation between the setting current \( (I_s) \) and delay time \( (t_d) \) for a different type of Inverse Overcurrent Relay. If the current value is reached the pick-up value, it results in a fault, and at the same time the delay time starts to calculate according to OCR type.
reaches its specified value, the MFR will send an electrical signal to the CB to disconnect the current passing and provide protection.

2.2. Over / under voltage Relay

Loads and multiple power sources can be subjected to abnormal conditions that affect voltage values. As a result of changing loads or faults that occur on the electrical power transmission system, the voltage may increase or decrease suddenly, which may affect the performance of the devices and thus the failure of these devices [12]. This type of OVR/UVR is designed according to IEEE 1159 standard. The over voltage and under voltage can be classified according to the length of the duration long or short. If the relay work as Overvoltage (swell) / under voltage (sag), For short duration, the time delay for both type (OVR, UVR) can be classified into three parts [12]: Instantaneous (0.5 second -0.6 second), Momentary (0.6 second – 3 second) and Temporary (3 second- 1 minute), and For short duration swell the Overvoltage (swell) magnitude can be classified: Instantaneous (1.1 per unit – 1.8 per unit), Momentary (1.1perunit–1.4perunit) Temporary (1.1 per unit – 1.2 per unit). Also, for short duration sag the under-voltage (sag) magnitude can be classified: Instantaneous (0.1 per unit – 0.9 per unit), Momentary (0.1 per unit – 0.9 per unit), and Temporary (0.1 per unit – 0.9 per unit).

3. MFR Design

The proposed design for a multifunction relay consists of two parts, the first part is the design of overcurrent relay from Inverse Overcurrent Relay type, This type is designed according to IEC 60255-1 standard. The sensor reads the current in continuously, If the current passes through the MFR exceeds the pick-up current value, the MFR start calculated the time delay (\( t_d \)) according to the equation type of OCR. If the time calculated is exceeded the delay time (\( t_d \)), the MFR directly disconnects the current via the circuit breaker. The setting current is entered by using the MATLAB program.

The second type of Multifunction Relay type is Over / Under Voltage. Under voltage is more common than Overvoltage, but both of them cause faults in the system [12]. This type of OVR/UVR is designed according to the IEEE 1159 standard can be classified into three types Instantaneous, Momentary and Temporary. The selective between the three types is made by the MATLAB program. The selected type is sent from the computer to the Arduino via a USB cable. In case of choice instantaneous, the condition of activation this type is: If the Over voltage value is reached from (110% -180%) or the Under voltage value between (10% -90%), the circuit disconnects after 0.55 seconds without any added period. In the case of choosing Momentary, the condition of this type is: if the Over voltage value reaches between (110% -140%) or the Under voltage value between (10% -90%), the relay sends a signal to the circuit breaker after passing 2 seconds, in case of chose Temporary, the condition of this type is: if the Over voltage value reaches between (110% -120%) or the Under voltage value between (10% -90%), the relay sends a signal to the circuit breaker after passing 10 seconds. The new design consists of several parts, including Arduino Mega and Multifunction sensor that senses both voltage and current, as well as a circuit breaker, LCD, DC voltage sources, and a switch. The proposed design consist of two parts software parts and hardware parts.

3.1. Software Section

It is intended to connect all the equipment (the Arduino Mega, the sensor, the circuit breaker and other tolls) and implement what is required to provide protect the power system from any sudden increase in current value, increase, or decrease in voltage. The C language is used to write and build the program by using a computer program (ARDUINO 1.8.9). And it was uploaded to the Arduino Mega by using
USP cable. The step programming for both Relay over current and over/under voltage can be seen in figure (4,5).

3.1.1 Overcurrent Relay.
The procedure of operation Overcurrent Relay is:
1) Enter the Current setting by using the MATLAB program.
2) Send the setting value from MATLAB to the Arduino by pressing the send parameter.
3) Start reed current value by pressing start reading in MATLAB program.
4) Change the current by changing the load used for several values.
5) In the state of the current is more than the Pick-up value of current which is set to 125% Of Current. The setting, it sends a signal from the Arduino signal to the C.B.
6) The LCD and MATLAB show the values of fault current and delay time.
7) We can Repeat the experiment by pressing the reset button in MATLAB program.

Figure 4. The flow chart of MFR
3.1.2 Over/under voltage Relay.
The procedure of operation Over /Under voltage Relay is:
1) The Over / Under Voltage type is selected according to standard IEEE 1159 Instantaneous or Momentary and Temporary by using the MATLAB program.
2) Enter the voltage setting by using the MATLAB program.
3) Send the setting value from MATLAB to the Arduino by pressing the send parameter.
4) Start read voltage value by pressing start reading in MATLAB program.
5) Change the voltage value with VARIAC.
6) If the voltage exceeds the specified value ±10%, The Arduino sends a signal to the circuit breaker to disconnect the source from the load after the end of the delay time.
7) The display shows the values of fault voltage and delay time in LCD and MATLAB.
8) We can repeat the experiment by pressing the Repeat button in MATLAB program.

![Flow Chart](image)

**Figure 5.** The flow chart of under voltage relay type according to IEEE 1159

3.2. Hardware section
The second part of the proposed MFR is a hardware device, it means connecting all the hardware components such as the Arduino Mega, the LCD screen, then switch to the power sources and processing them. Connecting the hardware part is like connecting the software part to produce a Multifunctional Relay.
The following is a summary of the most important parts in the hardware section:
3.2.1. The Relay
The Relay is an electrical switch used to control high-voltage electronic devices. The Relay is used to control high-voltage electrical appliances of 220 volts with a small input voltage of 5 volts. When dealing with a relay, the voltage must be taken into account. The relay operates at a voltage of 5 volts, which can be supplied from the Arduino, but if the relay operates at a voltage of 12 volts, it can be supplied from an external source. The relay properties used in this intelligent relay are 250VAC and 12VDC.

3.2.2 The Multifunction Sensor (PZEM-004T)
In the proposed relay, the sensor used in this paper from type (PZEM-004T) was used because of its unique ability to sense several variables at the same time, including current, voltage, real power, power factor [13], [15]. The properties of this sensor are high accuracy, good speed, and very little error. The multifunction sensor is based on a new method of communication module TTL [14]. The connection method of the multifunction sensor to the Arduino Shown in Figure 6.

![Figure 6. The practical connection of current sensor AC80](image)

3.2.3 Liquid Crystal Display
The liquid Crystal Display (LCD) is an electronic display screen that is widely used in various electronic applications. The LCD is used to display the value of both voltage and current, if the current and voltage values exceed the setting values, a message appears on the screen that contains information that contains the values of the fault current and the delay time in the case of OCR and the values of over or under voltage and the delay time in the case of OV / UV.

3.2.4 Microcontroller (Arduino MEGA)
The microcontroller (Arduino Mega) is an electronic board that consists of an open-source electronic circuit. The language that the Arduino deals with it (C language). The Arduino contains analog ports (16 port), digital ports (54 port), serial ports (4 port), and power outlets, USB port. The Arduino needs a voltage source to start working, ranging from (7-12) volts can be supplied from an external source or a USB port. The sensor converts the input current and voltage values into values that the Arduino can deal with it, then the Arduino compares the input values and sitting value current and voltage.
4. The Practical Part
The final practical part consists of several parts showed in Figure 7 (1) Arduino Mega (2) Multifunctional Sensor (PZEM-004T), (3) Circuit Breaker, (4) loads, (5) Liquid Crystal Display, (6) DC source, (7) Switch, (8) voltage variable. The practical side consists of two parts: the first section is overcurrent and the second section is over voltage, / under voltage. Initially, the Arduino Mega is supplied from an alternating current source after converting it to a DC source for the Arduino to work, because the Arduino needs a voltage of 7-12 volts. The Multifunction Sensor, LCD and Arduino are supplied from the power source.

![Figure 7. The practical circuit of Multifunction Relay](image)

A computer is used to transfer the data to the Arduino using a USB cable so that the smart relay starts working. After sending the data, the relay starts to work and begin reading the current and the voltage value, in the event of any fault occurs, the signal is sent to the circuit breaker and at the same time the Arduino sends the data to the computer. This data is the time delay, the value of the fault current and the fault voltage see Figure 8.

![Figure 8. The MFR circuit and experiential test Board](image)
5. RESULTS & DISCUSSIONS
Case 1: IDMT OCR.
The results obtained from several tests showed the accuracy and fast response of the new design for different fault currents. The results demonstrated the relationship between time delay and fault current. The fault current must be exceeded the Pickup current to start MFR separate process. The pick-up value is set to 125% of the setting current. The Results obtained is calculated according to standard IEC 60255-151. The results obtained appeared in the LCD as well as in the MATLAB program and can be seen in Figure 9.
The results obtained are shown prove the accuracy of the components, with a low error rate (10 ms), fast response, and a separation time that is close to theoretical calculations.

Table 1. IDMT OCR

| Fault current (A) | I pick-up (A) | Time delay (s) | Theoretical time | The difference | State |
|-------------------|---------------|----------------|------------------|----------------|-------|
| 1.51              | 2.5           | -              | -                | -              | No Trip |
| 2                 | 2.5           | -              | -                | -              | No Trip |
| 3.01              | 2.5           | 3.75           | 3.74             | 0.01           | Trip   |
| 3.29              | 2.5           | 2.55           | 2.54             | 0.01           | Trip   |
| 3.26              | 2.5           | 1.89           | 1.88             | 0.01           | Trip   |
| 3.7               | 2.5           | 1.83           | 1.78             | 0.05           | Trip   |

The result in overcurrent case can be shown in LCD as in Figure 10. The result also can be seen in MATLAB program as in Figure 10.

Figure 9. The result on LCD in overcurrent relay
Figure 10. The result obtained from the MATLAB program

Case 2: Over / under voltage relay.

The experiential result shows the accuracy of separation decision-making for different types of over / under voltage according to IEEE 1159 standard, the result obtained from the MATLAB program can be seen in Figure 11. The three types of over / under voltage relay were tested for different voltage value. The results obtained showed the accuracy of the sensor in detecting any voltage value rise or fall, and a separation time determined according to the IEEE 1159 standard Over/Under voltage type (Instantaneous, Momentary, Temporary).

1- Instantaneous

Table 2. The Instantaneous over/under voltage relay

| The reading voltage (V) | The setting voltage (V) | The delay time (s) | State   |
|-------------------------|-------------------------|--------------------|---------|
| 230                     | 220                     | -                  | No Trip |
| 240                     | 220                     | 0.55               | Trip    |
| 255                     | 220                     | 0.55               | Trip    |
| 192                     | 220                     | 0.55               | Trip    |
| 205                     | 220                     | -                  | No Trip |

2- Momentary

Table 3. The Momentary over/under voltage relay

| The reading voltage (V) | The setting voltage (V) | The delay time (s) | State |
|-------------------------|-------------------------|--------------------|-------|
| 230                     | 220                     | -                  | No Trip |
| 247                     | 220                     | 2                  | Trip  |
| 255                     | 220                     | 2                  | Trip  |
| 210                     | 220                     | -                  | No Trip |
| 192                     | 220                     | 2                  | Trip  |
3- Temporary

**Table 4. The Temporary over/under voltage relay**

| The reading voltage (V) | The setting voltage (V) | The delay time (s) | State |
|-------------------------|-------------------------|-------------------|-------|
| 230                     | 220                     | -                 | No Trip |
| 243                     | 220                     | 10.02             | Trip   |
| 256                     | 220                     | 10.02             | Trip   |
| 210                     | 220                     | 10.02             | Trip   |
| 180                     | 220                     | -                 | No Trip |

The result in overvoltage case can be shown in the LCD as in Figure 11.

**Figure 11.** The result on LCD in overvoltage mode

The result also can be shown in the MATLAB program as Figure 12

**Figure 12.** The result obtained from the MATLAB program
6. Conclusion

The Multifunction Relay (MFR) performs with an Arduino type Mega as a microcontroller. The experimental results prove that the accurate MFR under various conditions. When the current passing through the MFR exceeded the pickup current and the time taken exceeded the delay time calculated based on with the standard IEC 60255-151, the signal is sent from the Arduino to the C.B. The current setting is entered and sent by using MATLAB program (GUI). In the other case, there are three types of Over/Under voltage Relay based on the standard IEEE1159 (Instantaneous, Momentary and temporary). The Overvoltage and Undervoltage Relay type and the voltage setting value are chosen by using MATLAB program. After fault occurs the voltage and current value is sent from MFR to the computer by using USB cable. The new design was distinguished by the cheapness of the components, the accuracy, the speed of response to fault that occurs in the system.

7. Reference
[1] Ahmed, A. H., & Sultan, A. J. (2018). Intelligent power transformer protection relay based fuzzy logic. International Journal of Engineering & Technology, vol 7, no 4, pp 5882-5886.
[2] ALSTOM . (2002). Network protection & automation guide., protective Relay , Measurement & control . Alstom.
[3] Das, J.C.(2017). power system protection relaying.CRC Press
[4] Glover, J. D., Sarma, M. S., & Overbye, T. (2012). Power system analysis & design, SI version. Cengage Learning G.
[5] Sleva, F. Anthony (2009). Protective Relay Principles. CRC PRESS.
[6] Horowitz, S. H., & Phadke, A. G. (2008). Power system relaying (Vol. 22). John Wiley & Sons.
[7] Blackburn, J. L., & Domin, T. J. (2015). Protective relaying: principles and applications. CRC press.
[8] Jagdale, K., & Rao, A. S. (2017). Overcurrent protection of transmission lines using GSM and Arduino. International Journal of Engg. Trends & Technology, vol 50, no 1.
[9] Abdel-Salam, M., Kamel, R., Sayed, K., & Khalaf, M. (2017). Design and implementation of a multifunction DSP-based-numerical relay. Electric Power Systems Research, vol 143, pp 32-43.
[10] Harlow, J. H. (1990). A multifunction protective relay for the cogeneration industry. IEEE Computer Applications in Power, vol 3, no4, pp 25-30.
[11] IEEE Recommended Practice for Monitoring Electric Power Quality, IEEE Standard.
[12] Kumar, N., PrakashVerma, V., Singh, V. K., Nandi, S., & Ventru, V. (2013, April). Double relay-based sag, swell, over and Undervoltage protection, and detection scheme. In 2013 International Conference on Communication and Signal Processing (pp. 1008-1012). IEEE.
[13] Bhosale, G., Vakhare, A., Kaystha, A., Ahir, A., & Pansare, V. (2018). Overvoltage, Undervoltage protection of electrical equipment. International Research Journal of Engineering and Technology (IRJET), vol 5,no2, pp 29-32.
[14] Harahap, P., Pasaribu, F. I., & Adam, M. (2020). Prototype Measuring Device for Electric Load in Households Using the Pzem-004T Sensor. Budapest International Research in Exact Sciences (BirEx) Journal, vol 2, no 3, pp 347-361.
[15] Krishan, M. M., Younes, T. M., & Al-Taweel, F. M. (2019). The new design of socket modules for smart home applications. Int. J. Eng. Res. Technol, vol 12, no 2, pp 151-156.
[16] HAMEED, Ali Abdulsattar; SULTAN, Ahmed Jasim; BONNEYA, Mehdi F. Design, and Implementation a New Real-Time Overcurrent Relay Based on Arduino. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020. p.p 012005.
[17] HAMEED, Ali Abdulsattar; SULTAN, Ahmed Jasim; BOONEYA, Mehdi F. Design, and Implementation a New Real-Time Overcurrent Relay Based on Arduino MEGA. In: IOP Conference Series: Materials Science and Engineering. IOP Publishing, 2020. p.p 012142.