An Intelligent Method to Adapt the Distance Relay in Power System Fault Detection with Electric Vehicles Presence

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Keywords

Electric Vehicles, ANN, Distance relay, Smart System, Faults Detection

Abstract

In this research paper, the effect of electric vehicles integration on performance of distance relay in the distribution system was studied. The number of electric vehicles integrated into the distribution system has been increased, and its effect on distance protection has been demonstrated using the MATLAB / Simulink software. The results showed that integrating these vehicles led to poor performance, due to the occurrence of over-reach in distance protection and the difficulty of fault location. To obtain distance protection that could be adapted to the condition of the system, smart adaptive distance protection was proposed based on artificial intelligence. Artificial neural networks were used to detect the faults and to issue a trip signal with an accuracy of 99.9%. Meanwhile, fuzzy logic was used to locate the fault with an error rate of 0.00036 when 30 electric vehicles were added. Thus, smart distance protection was obtained that was able to adapt its characteristics to the number of added vehicles and to detect and locate a fault with high accuracy.

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1. INTRODUCTION

Environmental pollution, which the world is suffering from today, has become a monumental problem due to emissions from the transportation and power generation sectors, factories, etc., which are the main sources of these emissions. Their dependence on fossil fuels as well as the high cost of these fuels have given rise to many of the problems that the world is witnessing today. It is necessary to turn to new policies to reduce the use of fossil fuels, and thus, reduce emissions resulting from their use (Habib, Kamran & Rashid, 2015). Electric vehicles are considered as one of the important solutions as the electrification of the transportation sector will lead to a reduction of emissions from internal combustion engines (Rezaee, Farjah & Khorramdel, 2013). Despite the advantages of electric vehicles, they have negative effects on the distribution system, and many researchers have conducted studies and literature reviews to investigate these negative effects. A literature review was carried out by(Nour, Chaves-Ávila, Magdy & Sánchez-Miralles, 2020) on the effects of electric

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vehicle charging stations on the parameters of the distribution system in terms of voltage stability, losses, power factor and power quality, where the researchers concluded that adding these stations will reduce stability and the power factor, and increase losses in the system. Meanwhile, the research by (Utakrue & Hongesombut, 2018) deal with the effect of the addition of electric vehicle charging stations on power transformers and their life span. The effect on the level of failure following the addition of charging stations was studied by (Kumar & Saxena, 2019), who concluded that the addition of charging stations will lead to an increase in the faults level (short circuit level) and the demand for reactive power. The negative effects caused by the integration of electric vehicles will also negatively impact the protection system in the electric network because of the harmonics that these vehicles inject into the electric system. In (Etezadi-Amoli, Choma & Stefani, 2010) investigated the effects of the fast-charging (FC) of electric vehicles on the distribution system without compensation and in several different locations by studying the power flow and analyzing the faults, as well as the use of the necessary protection to protect the transformer from various fault currents. In (Gong, Ma, Zhang, Ding, Li, Yang & Liu, 2017) studied the effects of integrated electric vehicle charging stations (EVCSs) on the coordination and accuracy of protection relays in distribution networks, and developed the necessary solutions to avoid the effects of adding these stations. In (Goodarzi, sadat Nouprvar, Safaei & Mozaffari, 2019) the researchers employed the genetic algorithm to improve the coordination of the overcurrent relay in the event of the integration of electric vehicle charging stations, where the aforementioned algorithm can be used to select the optimal trip time for the overcurrent relay. By modelling and simulating a distribution system consisting of 33 buses using the MATLAB/Simulink program, the researchers found that the increased integration of electric vehicles (EVs) into the system will lead to an increase in short circuit levels and trip time.
In this paper, the effect of integrating fast-charging stations (FCS) into the distribution system on the performance of distance protection was investigated using MATLAB/Simulink software, after which, adaptive protection was designed using artificial intelligence (AI). This paper is divided into seven sections. The first section gives the introduction, the second section is on the electric vehicle charger model, the third section is concerning the effect of the charging station on distance protection, the forth present research method , the fifth is on artificial neural networks (ANN) ,the sixth section presents the simulation results, and the seventh section presents the conclusions.

2. ELECTRIC VEHICLE CHARGER MODEL

Before presenting the details on the protection of the distribution system, the type of charger used in the research should first be mentioned. When charging the batteries of electric vehicles, it is necessary for the alternating current to be converted to a direct current. Many technologies are available for charging the batteries of electric vehicles, such as conductive charging, wireless charging, and battery swapping. The charger can also be a single-phase or three-phase charger (Khudher, Aris, Mailah & Sahbudin, 2017), or it can be classified according to the direction of the power flow from and to the battery. In other words, the charger can be bidirectional or unidirectional (Nour et al., 2020). The charger used in this research paper was a six-pulse three-phase charger (as shown in Figure 1.) with a closed loop control using thyristors.

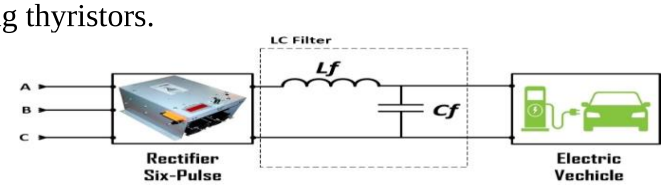

Figure 1. A six-pulse three-phase charger for charging an electric vehicle

Meanwhile, Figure 2. shows the control circuit of the three-phase charger, which controlled the operation of the thyristor by changing the firing angles so that the output remained constant to obtain a stable charge and a fast-charging process. As such, the proposed circuit provided charging at a constant current and voltage.

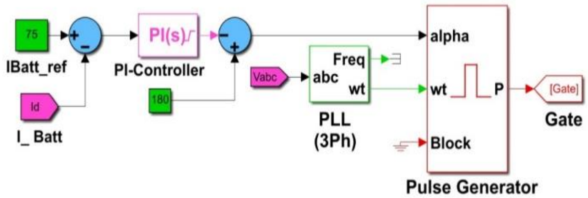

Figure 2. Control circuit of three-phase charger

3. EFFECT OF THE CHARGING STATION ON THE PERFORMANCE OF THE DISTANCE RELAY

The main objective of the distance relay is to protect the transmission lines and thus, protect and ensure the safety of the electrical system (Nasser & Arkan, 2019). The functioning of the distance protection depends on the measured impedance at the moment a fault occurs. Both the voltage and current signal are entered continuously into the distance protection, which works uninterruptedly to measure the impedance. When a fault occurs, the impedance that is seen by the distance protection will be less than the setting impedance, and thus the distance protection works to issue an trip signal to the circuit breaker to Isolate the faulty part from the network (Alsammak & Abdulhameed, 2018; Electric, 2017). However, there are other factors that affect the operation of the distance element, such as fault resistance, and flexible alternating current transmission systems (FACTS) (Alsammak & Janderma, 2019). The loads connected to the electrical network are divided into two types, linear and non-linear loads. Electric vehicle charging stations are considered non-linear loads since they work to convert the alternating current into a direct current using power electronic devices, as a result of the closing and opening operations of the power electronics switches, it leads to the generation of harmonics and thus distortion of current and voltage waves. In addition to reducing the power factor, reducing the voltage, increasing the losses in the system and increasing the load (Alsammak & Janderma, 2019; Khraiwish, Alshamasin, Kassasbeh, shiboul, Al-Qudah & Al-Busoul, 2009; Nour et al., 2020). The process of adding charging stations to the distribution system leads to an increase in harmonics, and consequently these harmonics lead to the wrong operation of the protection devices (Khraiwish et al., 2009).The impedance seen by the distance protection is greatly affected by the harmonics in the current and voltage, and this will result in poor performance and Maloperation of the distance protection. The current and voltage that determine the perceived impedance can be calculated in the normal case and at the moment of failure, as shown in the equations (1,2,3).
To calculate the seen impedance by the distance protection, the equation (1,2,3) is used:

$$|V_{rms}| = \sqrt{V_1^2 + (|V_i||_{h=5})^2 + (|V_i||_{h=7})^2 + ..} \quad (1)$$

$$|I_{rms}| = \sqrt{I_1^2 + (|I_i||_{h=5})^2 + (|I_i||_{h=7})^2 + ..} \quad (2)$$

In order to calculate the seen impedance by the distance protection, the equation (3) is used.

$$Z_{relar} = \frac{|V_{rms}|\angle\theta}{|I_{rms}|\angle\varphi} \quad (3)$$

where V_rms and I_rms, represent the voltage and current, respectively, including the existing harmonics, and Z_relay represents the impedance observed by the distance protection. As a result of the injection of these harmonics into the distribution system, an over reach of the distance protection occurs as the number of vehicles is increased.

4. RESEARCH METHOD

The network model shown in Figure 3. was proposed to show the effect of adding electric vehicles into the distribution system in two different scenarios. Artificial neural networks were used to detect the faults, while fuzzy logic was used to locate the faults.

1- For the system in a normal case without the addition of electric vehicles, the fault resistance values were 0Ω, 5Ω, 10Ω, and 15Ω, the fault location value was changed by 5% to 80%, the fault procedure was phased with the ground (single line to ground), while the resistance (R) and inductance will (X) were recorded.

2- The first scenario was applied with the addition of 30 electric vehicles.

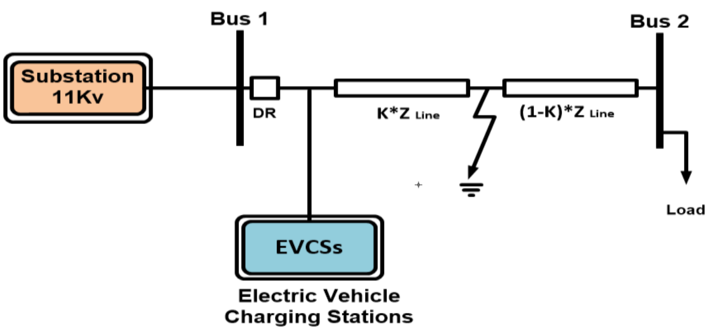

Figure 3. Model of proposed network for the study

Table 1. Data of the proposed system for the study

Element	Data
Substation	3 Phase, $V_{ph-ph} = 11Kv$, f=50 Hz
EV capacity	Charging current=75 A,V Battery=450 V , Pin=34 Kw
Transmission Line	R_1 [Ω/Km]= 0.0474, R_0=[Ω/Km]= 0.3073, L_1[H/Km]= 0.001011047, L_0[H/Km]= 0.003476, C_1[F/Km]=11.3 $* 10^{-9}$, C_0[F/Km]=8.14 $* 10^{-9}$, Line Length = 58.8 Km
Load	3 phase Yg , $V_{ph-ph} = 11Kv$, f=50 Hz S=11.2 KVA, PF=0.8944 lag

A- Case one

In this case, Fig.3 was represented in MATLAB. The fault (A-G) was applied for a period (t) of 1.3 seconds without the addition of any electric vehicle. This was the normal case of the system. The value of K was changed by 5% to 80% for variations in the value of the fault resistance (0Ω, 5Ω, 10Ω, 15Ω). All the readings that were obtained for the resistance (R/Ohm) and inductance (X/Ohm) were recorded, and then, the distance protection characteristics were plotted using the obtained resistance and inductance values. Figure 4 shows the characteristics of the distance protection in the normal case.

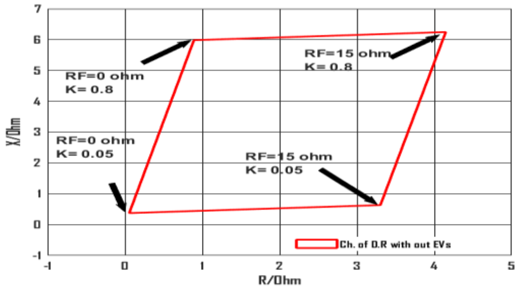

Figure 4. Characteristics of the distance protection in the normal case

B- *Case two*

30 electric vehicles were added to the distribution system, and the same scenario was repeated as in the first case. Figure 5**.** shows the distance protection characteristics in the second case, and the effect of adding 30 electric vehicles compared to the first case.

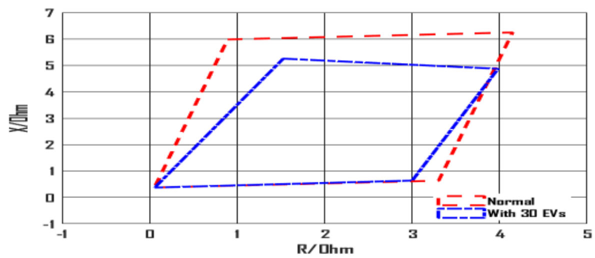

Figure 5. Characteristics of the distance protection with the addition of 30 vehicles compared to the normal condition

Figure 5. shows that the addition of 30 electric vehicles led to the occurrence of over-reach in the distance relay, that is, the apparent impedance in the case of the addition of electric vehicles was less than the impedance in the normal case, and this resulted in poor performance and problems in the selectivity of the circuit breakers that had to be separated At the moment of failure, the same applied to the location of the fault, which was difficult to determine as the process depended mainly on the value of the impedance.

5. ARTIFICIAL NEURAL NETWORKS (ANN)

One of the techniques of artificial neural networks (ANNs) is the feed forward neural network (FNN), which can be represented by equation (4):

$$Y = F(\sum_{i=1}^{n} I_i * w_i) \tag{4}$$

where Y represents the output of the feed-forward neural network; I_i, the number of entries for the network; and w_i, the bias weights of the neural network cells (Alnaib, Alsammak & Sabry, 2022). The previously mentioned cases were used to obtain the data for the training process to develop a model of the neural network that was responsible for issuing the trip signal, and another that was responsible for locating the fault using fuzzy logic. Given below is the training that was conducted on the data extracted from each of the cases.

A- *Case One*

The characteristics of the distance relay in Figure 4 were converted into a set of data, as shown in Figure 6, and this data was entered into the neural network as the training set. Thus, this data was ready to train the artificial neural networks. Figure 6 shows the characteristics of the relay in the form of points, in the normal case.

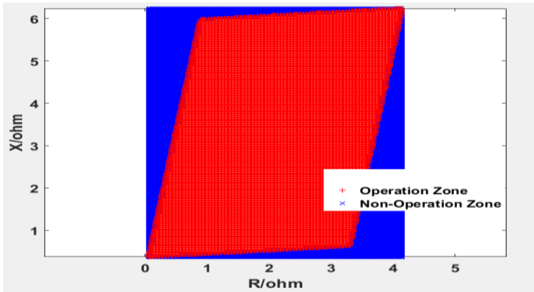

Figure 6. Characteristics of the distance relay, in the form of points, in the normal case.

After the training group had been obtained using MATLAB, the neural networks were trained using a classification algorithm, and the following training results were obtained by using the scaled conjugate gradient algorithm. as shown below in Table 2.

Table 2. describes the best training of the neural network for fault detection in the normal case

Number of hidden neurons	Training algorithm	Cross-entropy Error	Error	Epoch
40	Scaled conjugate gradient	0.0046	0.0009	364

B- Case Two

In the same way as in the first case, Figure 5 shows the characteristics that were obtained when 30 compounds were added into the system. These characteristics were also converted into data to be trained on the neural network, after which, the specifications of the neural network were as shown below in Table 3.

Table 3. describes the best training of the neural network for fault detection in the case of the addition of 30 vehicles

Number of hidden neurons	Training algorithm	Cross-entropy Error	Error	Epoch
20	Scaled conjugate gradient	0.0042	9.6e-4	408

6. FUZZY LOGIC

Fuzzy logic can be used in many modern applications. In this research, it was used as part of the proposed distance relay to locate faults, as the location of a fault is affected by the addition of electric vehicles. Fuzzy logic consists of four parts: Fuzzifier, Rules, Inference, and Defuzzifier (Alsammak & Janderma, 2019), as shown in Figure 7.

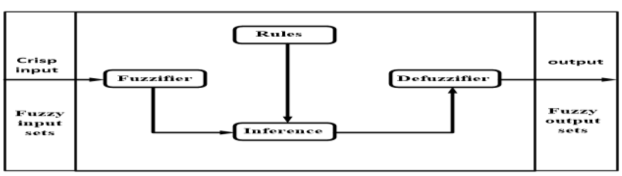

Figure 7. Basic structure of fuzzy logic

Fuzzy logic is trained using artificial neural network (ANN) algorithms. For this research, a hybrid algorithm, containing two types of training algorithms, namely, a back propagation and least square algorithm, was used. This adaptive neuro-fuzzy inference system used the Takagi-Sugeno type of inference mechanism (Alnaib, Alsammak & Sabry, 2022), where the inputs to the fuzzy logic were the impedance and angle of the protected line at the moment of failure. Below are the training results for the data obtained previously. The data obtained from the normal condition without the addition of electric vehicles was entered at the moment of failure. There were two entries, namely, the value of the impedance (Z) and the angle. The fuzzy logic was trained using the system of attempts to obtain the lowest error rate. Table 5. shows the specifications of the fuzzy logic to obtain the lowest error rate, Figure 8. represents a three-dimensional form of the fuzzy logic model. An illustration of the fuzzy logic model used to locate the fault is given in Figure 9.

Table 5. Fuzzy logic specifications for locating the fault in the normal state

Input membership function type	No. of input membership function	Output membership function type	RMSE
Triangular	5	constant	0.00129

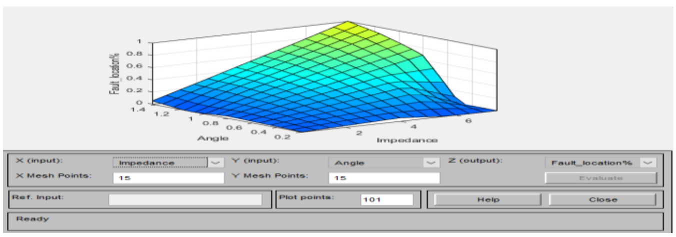

Figure 8. Three-dimensional figure showing the relationship between input and output

Figure 9. Illustration of the input and output of the fuzzy logic

30 electric vehicles were added to the distance phase, and, as shown in Figure 5, it occurred beyond the range of the phase and distance, and affected the accuracy of the fault location. Therefore, this effect was treated using fuzzy logic, as in the first case. The data was entered into the fuzzy logic, and in the same way, the specifications of the fuzzy logic model, which gave the lowest error rate, were obtained. Table 6. shows the specifications of the fuzzy logic for this case.

Table 6. Specifications of the fuzzy logic for the location of faults in the case of the addition of 30 vehicles

Input membership function type	**No. of input membership function**	**Output membership function type**	**RMSE**
Triangular	6	constant	0.00075

The distance relay was adapted to suit the condition of the system in the normal case and considering the presence of 30 electric vehicles. The addition of electric vehicles led to an increase in the total harmonic distortion (THD), and from the measurement of the harmonic distortion, it could be determined if these vehicles were connected to the system. Thus, the characteristics of the distance relay were chosen to suit the condition of the system, and it worked correctly in issuing the trip signal, in addition to determining the location of the fault with high accuracy. Figure 10 shows the structure of the proposed distance relay.

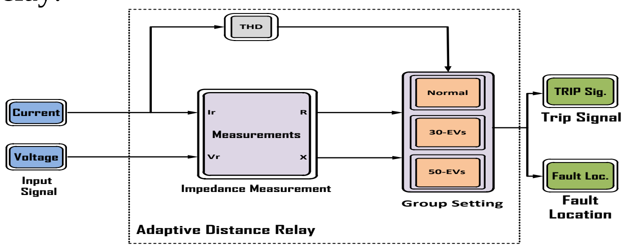

Figure 10. Structure of the proposed distance relay

7. SIMULATION RESULTS

On completion of the training of the neural networks on the training sets for each of the previously mentioned cases, and after obtaining the best specifications for the neural networks, the distance relay in the event of a ground fault (SLG) was tested regarding the issuing of the trip signal, as well as in determining the location of the faults for all the studied cases. The results were divided according to the two cases, namely, the normal condition and the addition of 30 vehicles. Each of the cases included displaying the condition of the ground fault (SLG) in terms of the status of the voltage, current and fault detection time, respectively, together with a table showing the fault locations that were predicted by the proposed distance relay and the error rate for each fault location. The ground fault (SLG) for the normal condition without the addition of any electric vehicle was achieved at a fault resistance of 7Ω, fault location of 70%, and time of 1.3 seconds. Figure 11. shows the ground fault current and the response of the distance relay in the release of the trip signal.

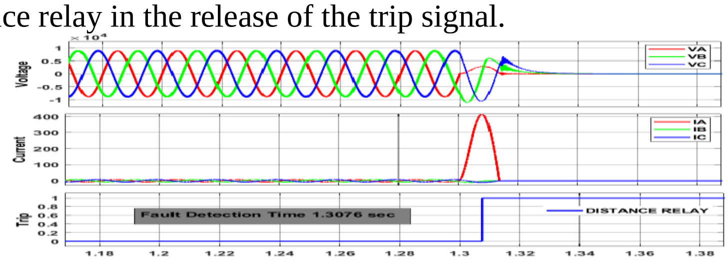

Figure 11. Ground fault phase at 1.3 sec

It was noted in Fig. 11 that the ground fault of the first phase occurred at 1.3 seconds, and the protection relay issued an trip signal to the circuit breaker for 7.6 msec to isolate the faulty part of the system. In the same manner as in the first case, the ground fault was applied, and the results, as presented below in Figure 12 , show the earth fault current and relay response with the addition of 30 electric vehicles.

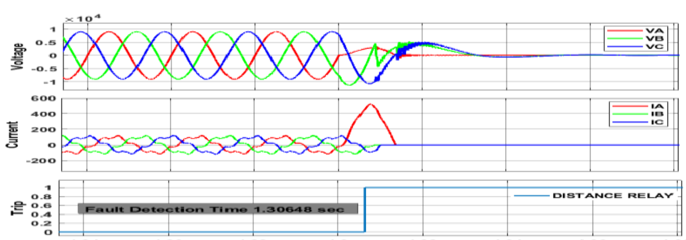

Figure 12. Ground fault phase at 1.3 sec with the addition of 30 vehicles

It was noted in Figure 12, that the ground fault of the first phase occurred at 1.3 seconds, and that the fault current was greater than the fault current in the first case.

It was also noted that the protection relay issued a trip signal to the circuit breaker for 6.48 m-sec to isolate the faulty part of the system. The larger the number of vehicles connected to the system, the greater the fault current. To determine the location of the fault, tables were presented for locating the faults for the two states (normal condition and addition of 30 EVs), at different locations and with a fault resistance of 5Ω. The error rate for a different set of fault locations when the fault resistance is (5 Ω) was from (3.02945e-6 to 114480292|) and the actual fault locations was (5%-80%) by 5% step and their predicted at the moment the faults occurred was (0.04999997 -0.798855197) .It can be seen from the result that the trained fuzzy logic model was able to predict the fault locations with high accuracy and at a very low error rate of less than 5%.

8. CONCLUSION

In this paper, the effect of the electric vehicle charging station on the performance of distance protection in the distribution system was studied, where a three-phase charger with a six-pulse controller was used. From the results, it was clear that the addition of electric vehicles led to increases in the fault current, current drawn from the system, and the harmonics in the drawn current. Also, the increase in the number of electric vehicles led to poor performance of the distance relay, where the value of the impedance apparent at the distance relay was less compared to the normal case, and this was known as over-reach that occurred for the distance relay. This resulted in a change in the characteristics of the distance relay as the number of electric vehicles increased. In this research, the relay was designed based on two cases (normal condition and addition of 30 vehicles. The error rate at the fault location (5%) was 3.02945e-06% in the normal case and 2.85874e-06% for the same location with the addition of 30 vehicles. While the accuracy of the artificial neural network model for fault detection was 99.9%.

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Conflict of Interest

Authors declare that there is no conflict of interest.

Authors Contributions

The authors involved in this study are Wisam Mohamed Najem, Dr.Shaker M.Khudher, Dr.Omar Sh. Al-Yozbaky; contributed to all aspects of the study. All authors contributed to the idea, design, inspection,resources, data collection, literature review, critical review and analysis and interpretation sections of the study.

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