International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 08 | Aug 2019 www.irjet.net p-ISSN: 2395-0072

Design a Fuzzy Distance Relay Including STATCOM Effects

Dr. Ahmed Nasser Alsammak, Mr. Sarmad Arkan Janderma

[1]Assistance Professor, Dept. of Electrical Engineering, University of Mosul, Mosul-Iraq.
[2]Assistance Lecturer, Dept. of Electrical Engineering, University of Mosul, Mosul-Iraq.

Abstract - *Distance relay is one of the most important elements used in the protection of transmission lines, but it suffers from some obstacles in the detection of the faults due to the presence of factors that affecting the characteristics of their work such as: fault resistance (Rf), power flow and presence of Flexible Alternating Current Transmission System (FACTS) such as STATic synchronous COMpensator (STATCOM) which causes the insufficiency of the performance of the relay. This paper, MATLAB/PSAT was used to investigate the presence of STATCOM in the sample power system (IEEE-9 Bus) that protected by the distance relay. The effect of the STATCOM and its location in the middle and the end of the transmission line. The effects of the characteristics of the location of the relay were observed. The line fault of different fault resistance and various locations of the line are simulated. A new fuzzy relay was built depend on the new characteristics of the relay to overcome the effects of compensation on the performance of the relay such as under-reach and overreach conditions.*

Key words: Protection of Power System, Distance Relay, STATCOM, Fuzzy Logic, MATLAB/PSAT.

1. INTRODUCTION

Overhead transmission lines are considered as one of the main parts of power systems. They are often exposed to ambient conditions and the probability of faults on these lines is higher than the main parts of the power system. When the fault occurs on the electric transmission line, it is necessary to detect and locate it so as to separate the faults and restore the power system to normal condition as soon as possible. Because the time needed to calculate the location of the fault along the transmission line will affect the quality of the power distribution. Therefore, the speed of locating the fault is a necessary requirement for permanent faults as well as transient faults in order to ensure that the power distribution of consumers is not interrupted. Hence the need to the distance relay, which is considered as one of the most important types of protection, used in high voltage transmission lines [1]. But the distance relay may be exposed during the work of some of the effects that may play a negative role in their performance, therefore, researchers have been constantly improving the performance and development of the distance relay to detect faults and increase the speed of work as well as sensitivity and change the characteristics of the relay to suit the prevailing conditions of the system [2]. The impact of STATCOM on the measured impedance has been discussed and studied in [3] where the effect of the STATCOM on the characteristics of the distance relay negatively reflects on the performance of the relay, it causes under-reach and over-reach to the distance relay. Also the effect of the equivalent circuit was studied for the compensator, it was first considered as a voltage source then found the high difference between the real value of the impedance and the apparent value. In the case of being considered an ideal current source, the difference was small. The performance of the distance relay in compensated transmission lines by FACTS devices that Connected in parallel as the STATCOM was studied in Ref. [4] where the MATLAB was used to determine the type and location of the faults by constructing a logical circuit to find the type of fault, then found that the fault location to the compensator and the operating modes of the compensator may cause a over-reach and under reach problems of the distance relay. Ref. [5] presented the study of the effects of STATCOM on the distance relay of a parallel-line power system by analysing the power frequency where found that the seen apparent impedance by the relay in the presence of a single-line to ground fault will affected by the reactive power injected from the STATCOM which may lead to a new case either over-reach or under-reach of the distance relay. In this paper, the effect of the STATCOM on the distance relay was included on the fuzzy rules to avoid the under-reach and over-reach due to the presence of compensator.

2. FACTS DEVICES (STATCOM)

The STATCOM is a parallel device of the FACTS family of devices. Self-commutated devices such as the Insulated Gate Bipolar Transistors (IGBT) can be used to control all variables in the system including voltage and reactive power. The integration of FACTS devices increases transport flexibility of power and makes it economically viable. This helps to improve the power transfer because it provides a quick way to dampen oscillations in power system and also responds to sudden changes in loads, and support load during cutting in transmission lines or distribution lines and corrects voltages loads for quick control of reactive power and finally allow generators to work balanced with load in the system [4]. The basic voltage-sourced converter scheme for reactive power generation is shown schematically, in the form of a single-line diagram, in Fig.1. From a DC input voltage source, provided by the charged capacitor C_S, the converter produces a set of controllable three-phase output voltages with the frequency of the AC power system. Each output voltage is in phase with, and coupled to the corresponding AC system voltage via a relatively small reactance (which in practice is provided by the per phase leakage inductance of the coupling transformer) [6]. By varying the amplitude of the output voltages produced, the reactive power exchange between the converter and the AC system can be controlled in a manner similar to that of the rotating synchronous machine. That is, if the amplitude of the output voltage increases above that of the AC system voltage, then the current will flows through the tie reactance from the converter to the AC system and the converter generates reactive (capacitive) power for the AC system [7]. If the amplitude of the output voltage decreases below that of the AC system, then the reactive current will flows from the AC system to the converter and the converter absorbs reactive (inductive) power. If the amplitude of the output voltage is equal to that of the AC system voltage, the reactive power exchange is zero. As shown in equation (1).

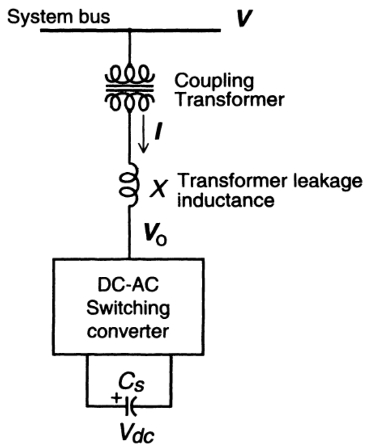

Fig-1: Reactive Power Generation by a Voltage Sourced Switching Converter.

$$Q = V(V - V_O)/X \qquad (1)$$

Where:

Q: The reactive power generated by STATCOM.

V: The AC system voltage.

V_O: The amplitude of the output voltage of STATCOM.

It is clear from Fig.1 that STATCOM is actually used for the voltage sourced converter. But in fact the STATCOM found in two types STATCOM can be based as a voltage-sourced converter and current-sourced converter [7]. The equivalent circuit of the STATCOM also consists of two forms: STATCOM can be modelled as a shunt branch consisting of impedance, due to the coupling transformer, and a voltage source as shown in Fig.2. So will act as a source of voltage in phase with the system voltage at the point of connection and the consumption or generation of reactive power will depend on the system voltage as illustrated in Equation (1) [8]. STATCOM can be modelled as a shunt branch which is an ideal current source [8], without internal impedance. The current source phase angle is perpendicular to its connection point voltage phase angle; therefore, it only injects or absorbs the reactive power as shown in Fig.3.

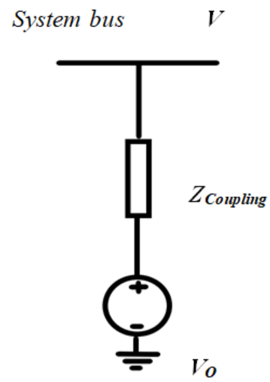

Fig-2: Equivalent circuit of STATCOM as voltage source.

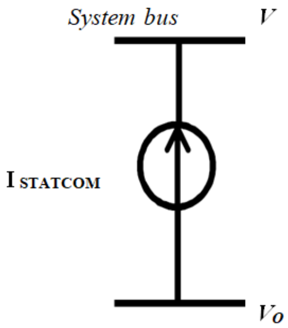

Fig-3: Equivalent circuit of STATCOM as ideal current source in capacitive mode.

In this paper, the STATCOM from MATLAB/PSAT library was used to connect it at midpoint and endpoint of transmission line between bus7 and bus5 in the IEEE-9 Bus sample system, then studied the impact of STATCOM of the distance relay characteristics then included in fuzzy system.

3. DISTANCE RELAY

Distance relay protection in simplest form is a system of protection and unity. The main goal of the distance relay is to protect the transmission lines and thus ensure the safety of the equipment in the power system such as generators; transformers, etc. were called the distance relay because the principle of its work depends on the distance between the relay site and the point of fault [9].

The basic principle of the distance relay depends on the local measurements of the voltages and the current at the relay position, through which the line impedance is calculated continuously throughout the working period. If the measured impedance is less than the line impedance in the natural state, The relay will give a signal to the circuit breaker tell him the existence of a fault and ordered him to separate the part of the disruption of the proper part of the system, If the measured impedance is equal to or greater than the impedance of the line, then the relay does not produce a trip signal . This condition expresses the normal state of work in the electric power system [10]. But it suffers from some obstacles in the detection of the faults due to the presence of factors affecting the characteristics of their work such as: fault resistance (R_F), power flow and presence of FACTS such as STATCOM which causes the insufficiency of the performance of the relay.

This paper will investigate the presence of Static Synchronous Compensator (STATCOM) in the (IEEE-9 Bus) power system line protected by the distance relay by using MATLAB/PSAT by taking the effect of the Static Synchronous Compensator (STATCOM) location in the transmission line (the middle and the end of the transmission line).

4. RESULTS AND THEIR DISCUSSION

4.1 STATCOM at Mid-Point of the transmission line

STATCOM is often connected at the middle of the transmission line to control the power flow or to increase the transmission possibility [11] and [12], IEEE-9 bus sample system was modelled by MATLAB / PSAT with STATCOM at the middle of the line (7-5) was used in this paper due to its weak lines in this system [13].

The selection of the compensator location was based on previous research it was found bus 5 to be a weakest voltage bus. Therefore, the bus 5 was taken as a study center in this research. As shown in Fig.4

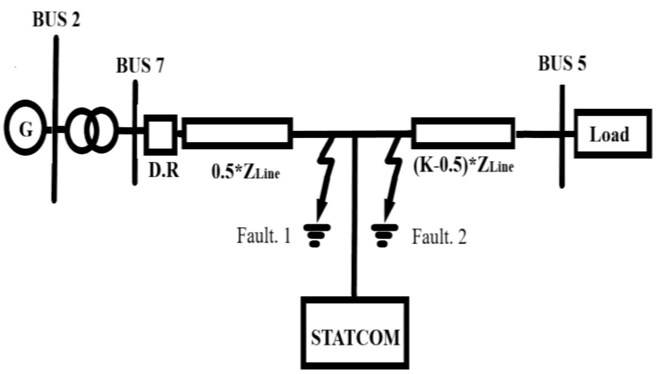

Fig-4: Power system with STATCOM Installed at the Midpoint.

Where:

G is the generator

K is fault location on the line in per unit of line length.

D.R is the distance relay

Z_{Line} Transmission line impedance in ohm.

Fig. 4 illustrates when the fault locate between 0<*k*<0.5 (Fault. 1) the measured impedance by the relay is not affected by the compensation since fault happens before the STATCOM is installed in place (out of fault loop). But when the fault locate between 0.5<*k*≤1 (Fault. 2) the measured impedance by the relay will affect by the compensation because the STATCOM place within fault loop and will therefore affect the equivalent impedance seen by the distance relay. So the maximum effect of the STATCOM on the characteristics of the distance relay when located at the middle of the line and within the fault loop [12]. Fig.5 shows the impedance trajectory in the case of the STATCOM in the middle of the line, which proves the theoretical speech above. Since the impedance trajectory does not place within the characteristics of the work of the relay and therefore the relay does not produce a trip signal despite the fault and as a result suffer from a under-reach.

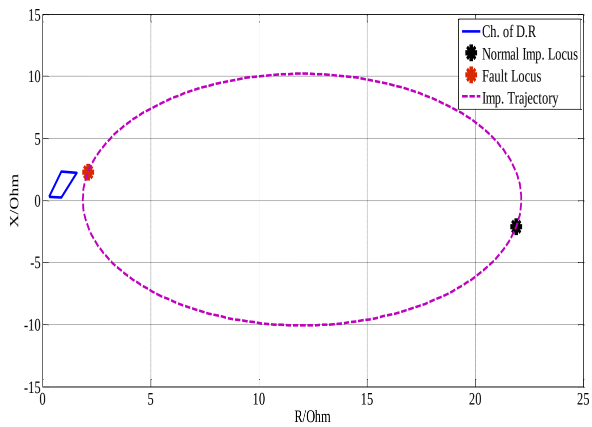

Fig-5: Impedance trajectory in the case of the STATCOM in the middle of the line.

4.2 STATCOM at End-point of the transmission line

Often put static compensator at the end of the transmission line to improve the stability of electric power system (Voltage Stability) [12].As shown in Fig.6. When the STATCOM is at the end of the transmission line, in all cases of fault it will be outside the loop of the fault and therefore will have a slight effect on the characteristics of the relay compared to the case of the STATCOM in the middle of the transmission line.

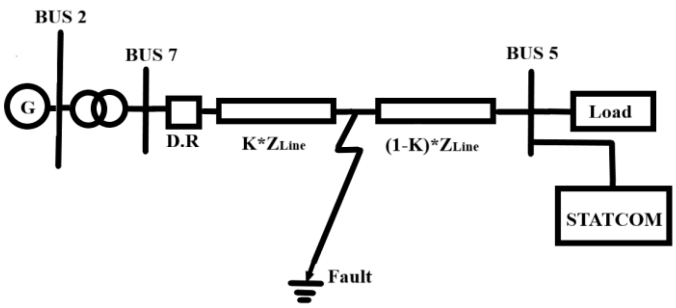

Fig-6: Power system with STATCOM Installed at the Endpoint.

Fig.7 shows the impedance trajectory in the case of the STATCOM in the end of the line, Here, the relay will suffer from a under reach situation, but with a lower rate than the compensator in the midpoint of the line.

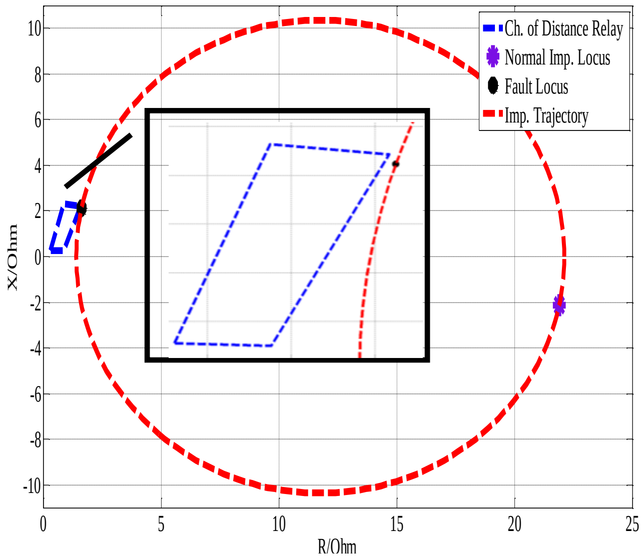

Fig-7: Impedance trajectory in the case of the STATCOM in the end of the line.

After observing the effect of a STATCOM on the performance of the distance relay where it causes a under-reach or over-reach depends on mode of operation of STATCOM (inductive, capacitive). Finally, the fuzzy relay characteristics were adapted to overcome the fault with and without STATCOM in the system.

4.3 Adjusting the characteristics of the distance relay to avoid the effect of the STATCOM using Fuzzy Logic.

Fuzzy Logic was used to adapt the characteristics of the distance relay, Where the fuzzy logic uses a Takagi-Sugeno type to give the proper tripping signal in the case of presence of STATCOM at mid and end point. Fig.8 shows the Fuzzy logic construction.

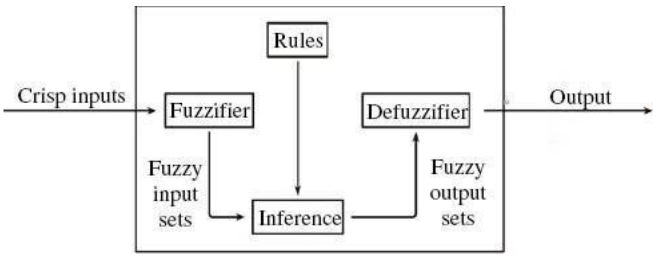

Fig-8: the basic structure of Fuzzy Logic.

The input set data for the both cases of presence of STATCOM are the apparent resistance (R) and reactance (X) seen by the Simulink block diagram, which represent the circuit of impedance calculation of the transmission line by the distance relay as shown in Fig. 9.

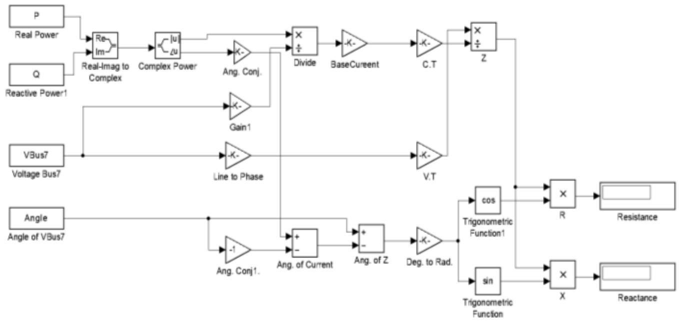

Fig-9: the representation of the circuit used in the line impedance calculation.

4.3 Adjusting the characteristics of the distance relay in the case of presence of STATCOM at midpoint

The membership functions of the input group in the case of presence of STATCOM at midpoint of transmission line are selected to be as shown in Fig. 10 and Fig.11

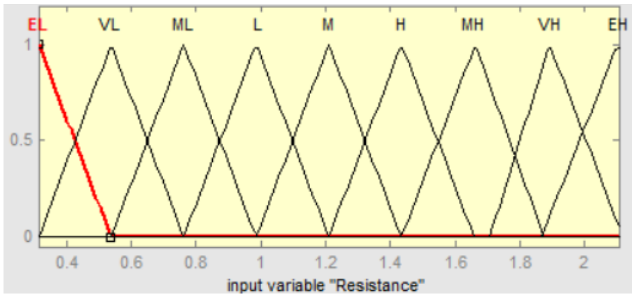

Fig-10: Fuzzy input membership function for Resistance (R) in case of STATCOM at midpoint.

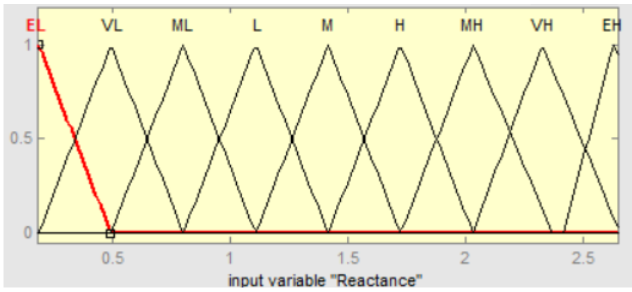

Fig-11: Fuzzy input membership function for Reactance (X) in case of STATCOM at midpoint.

Triangular membership functions have been chosen because the change is linear and thus the output will be accurate with minimum error. Then fuzzy logic trained to be the relay as in the Fig.12 and have three dimensional output (trip) characteristics as in Fig.13

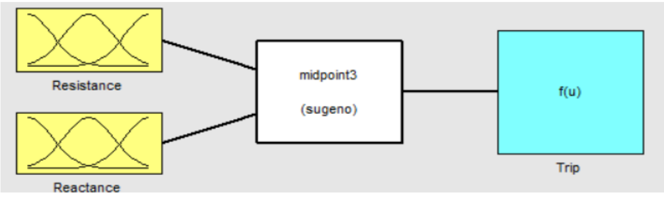

Fig-12: Fuzzy logic of Distance Relay with STATCOM at midpoint.

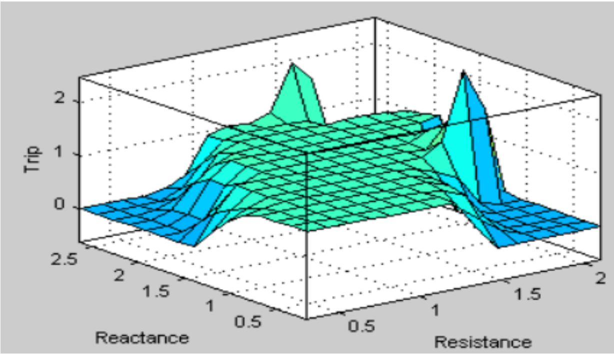

Fig-13: Three dimensions input, output characteristics of the fuzzy logic distance relay in case of presence of STATCOM at midpoint.

4.4 Adjusting the characteristics of the distance relay in the case of presence of STATCOM at endpoint.

The membership functions of the input group in the case of presence of STATCOM at endpoint of transmission line are selected to be as shown in Fig.14 and Fig.15

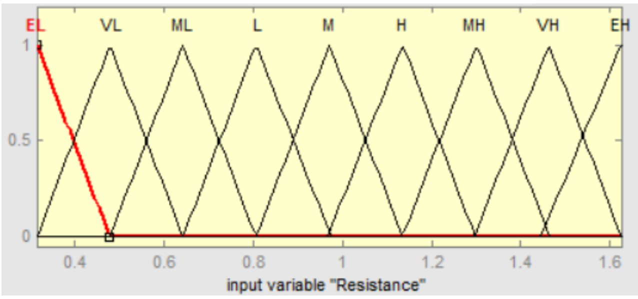

Fig-14: Fuzzy input membership functions for Resistance (R) in case of STATCOM at endpoint.

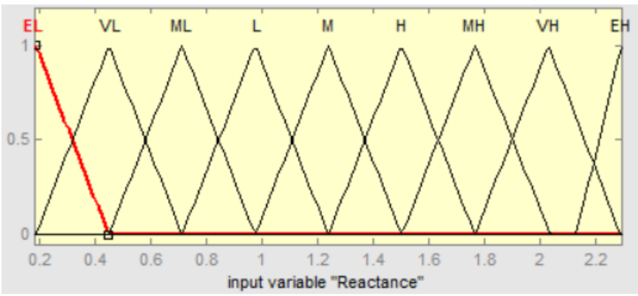

Fig-15: Fuzzy input membership function for Reactance (X) in case of STATCOM at endpoint

As it is clear from the Fig.14 and Fig.15 also triangular membership functions have been chosen because the change is linear and thus the output will be accurate with minimum error. Then the fuzzy logic trained to be the relay as in the Fig.16 and have three dimensional output (trip) characteristics as in Fig.17.

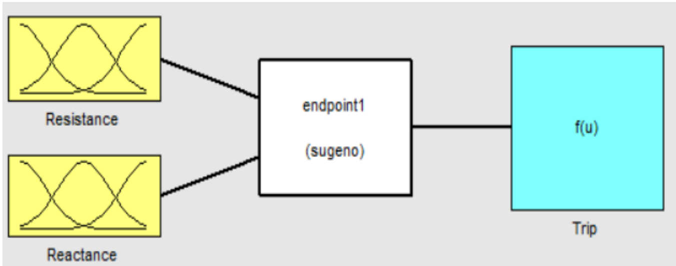

Fig-17: Fuzzy logic of Distance Relay with STATCOM at endpoint.

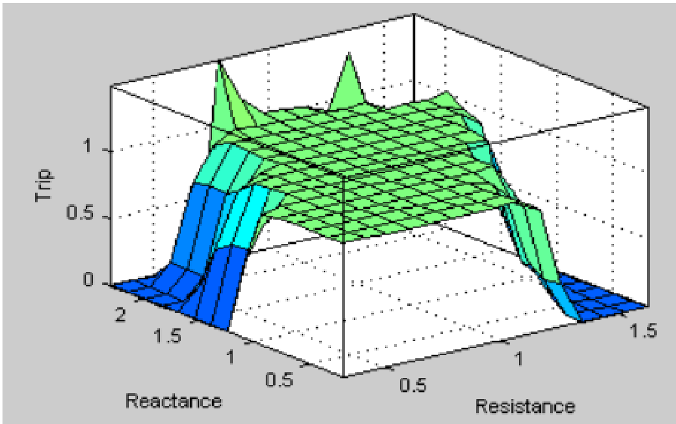

Fig-18: Three dimensions input, output characteristics of the fuzzy logic distance relay in case of presence of STATCOM at end point.

Finally from the figures above by using the fuzzy logic the characteristics of the distance relay were adapted to the new ones for both the existence of the static compensator location to be as shown in Fig.19, Fig.20, Fig.21 and Fig.22.

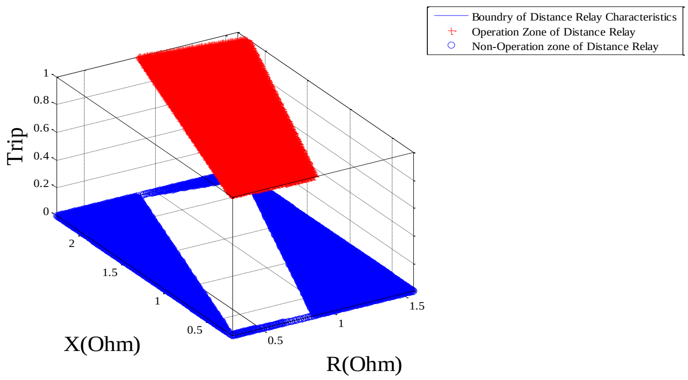

Fig-19: Three dimension trip characteristics without STATCOM.

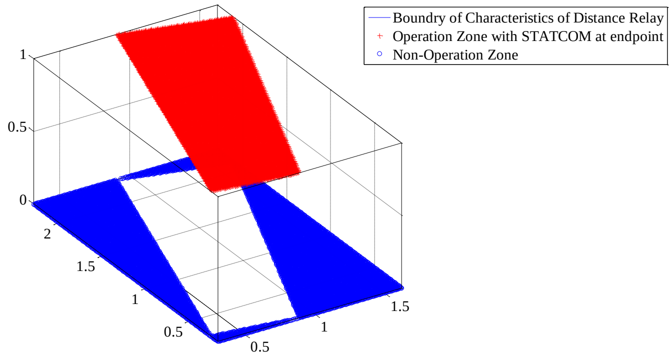

Fig-20: Trip characteristics with STATCOM at endpoint.

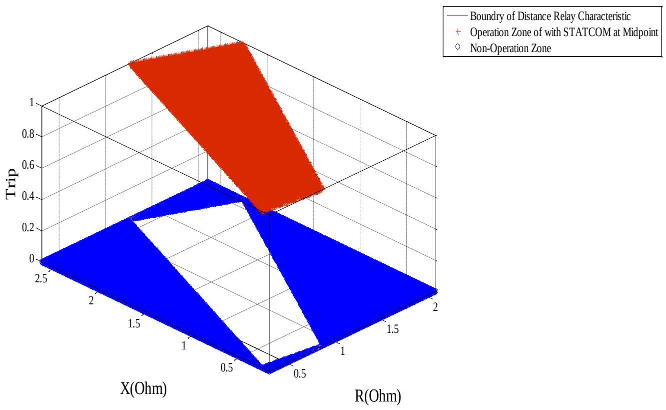

Fig-21: Trip characteristics with STATCOM at midpoint.

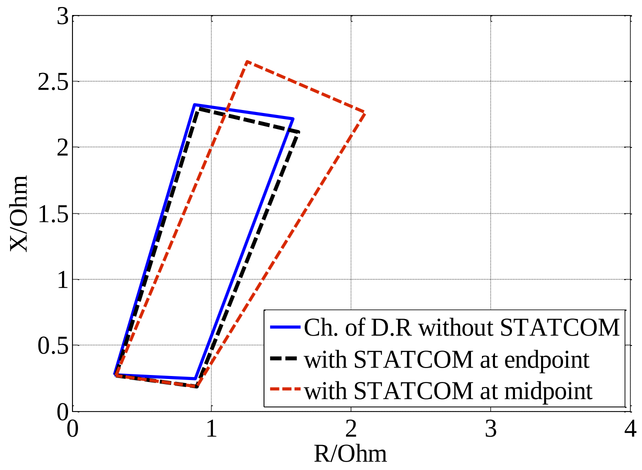

Fig-22: Characteristics of work adapted by fuzzy logic.

5. CONCLUSIONS

This study investigated the effect of the presence of a STATCOM on a distance relay on the sample IEEE-9 Bus system and solves this problem by building a new Fuzzy relay. The conclusion can be summarized as follows:

1 - The rate of compensation by the STATCOM depends on:

1.1- Increasing fault resistance lead to increased compensation rate, where reduce fault resistance, the compensation rate was reduced.

1.2 - The location of the fault (K) effects on compensation rate where the increasing K (the distant fault) increases the compensation rate and the reason for that the fault current will be determined by the high line impedance.

2- The STATCOM used to improve the operation and stability of the power system. The characteristics of the distance relay will be affected and suffer from under-reach or over-reach in different rates depend on the position of the STATCOM.

3- When the STATCOM located in the middle of a transmission line will have the greatest effect on the working characteristics of the distance relay, result in the case of greatest under-reach occurs when the fault location between (1> k>0.5) from the line.

4- When a STATCOM is present at the endpoint of a transmission line, it will have a slight effect on the characteristics of the work of the distance relay compared to its presence in the midpoint of the transmission line, because the STATCOM will be out of the fault loop, It will also cause under- reach but only a small percentage compared to the condition at midpoint of the line.

5- The use of a fuzzy relay improve the process of adopting characteristics of the distance relay, where by using fuzzy logic gives possibility to choose the characteristics of the appropriate work according to the location of the existence of the STATCOM. So as a result, the accurate tripping signal will generate by suggesting fuzzy relay when the fault occurs.

APPENDIX

System Data:

The Transmission line lengths= 178 Km

Transmission line Impedance = 0.032+ j60.7 p.u.

System Voltage = 230 kV

System frequency = 60 Hz

STATCOM rating = ± 100 Mvar

ACKNOWLEDGEMENT

Our thanks to all our colleagues who supported this work.

REFERENCES

[1] C. Chen, C. Liu, and J. A. Jiang, “Application of combined adaptive fourier technique and fault detector to fast distance protection” IEEE. Trans. On power delivery , pp. 1–8, 2006

[2] G. B. Abande, M. Satarkar, M.H. Rawoot, "Impact of STATCOM on Distance Relay", International Conference on Circuit, Power and Computing Technologies [ICCPCT], 2014.

[3] S. Jamali, et al, "Measured impedance by distance relay for inter phase faults in presence of STATCOM", in Power and Energy Society .General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, IEEE,, pp. 1-6, 2008.

[4] Ahmed Albehadili, Ikhlas Abdul-Qader,"Analysis of distance relay performance on shunt FACTS-compensated transmission lines", IEEE International Conference on Electro/Information Technology (EIT), 2015.

[5] X.Y Zhou, H.F Wang, R.K Aggarwal, P.Beaumont, "THE IMPACT OF STATCOM ON DISTANCE RELAY",15th PSCC, Liege, Session 19, Paper 4,2005

[6] A. Arulampalam, J. B. Ekanayake, and N. Jenkins, "Application study of a STATCOM with energy storage," Generation, Transmission and Distribution, IEE Proceedings, Vol.150, No.3, pp.373-384, 13 May 2003.

[7] R. Mohan Mathur, and Rajiv K. Varma. Thyristor-Based FACTS Controllers for Electrical Transmission Systems. John Wiley & Sons, Inc. publication, 2002.

[8] Khalil El-Arroudi, Geza Joos, and Donald. T. McGillis, "Operation of impedance protection relays with the STATCOM", IEEE Trans. Power Delivery, vol. 17, no. 2, pp. 381-387, April 2002

[9] Semaa.M.Y.Altae,"Adaptive Distance Relaying using Artificial Neural Networks" ,M.Sc. Thesis university of Mosul ,college of Electrical Engineering, ,2007

[10] Muhamed Nashwan Amjed Alkaleajie, "Design and Implementation distance Relay using Fuzzy logic' " M.Sc.Thesis university of Mosul, college of Electrical Engineering, 2015.

[11] Ali Abdolkhani, PeymanS.Bandaghiri, FarzadA. Rocky, "Impact of STATCOM on Distance Relay Operation for Various Types of Faults", International Journal of Advanced Research in Electrical Electronics and Instrumentation Engineering Vol. 2, Issue 10, October 2013.

[12] Wen-Hao Zhang, Seung-Jae Lee and Myeon-Song Choi," Setting Considerations of Distance Relay for Transmission Line withSTATCOM", Journal of Electrical Engineering & Technology Vol. 5,No.4,pp.522~529,2010.

[13] Ahmed Nasser Alsammak, and Abdulrazaq Ahmed M.AlNuaimy, "Transient Stability Improvement of Multi-machine Power System Using Modern energy storge systems", International Journal of Engineering and Innovative Technology (IJEIT), Volume 7, Issue 1, July 2017.

BIOGRAPHIES

Dr. Ahmed B. Al-Sammak, Received the BSc, MSc and PhD degrees in electrical engineering (Power and Machine) from University of Mosul, Mosul-Iraq in 1997, 1999 and 2007, respectively. He worked on a design and implementation in numerous engineering projects. He is an IEEE member- IEEE Power & Energy. Currently, he works as an assistant professor in EE Department-College of Engineering University of Mosul. He has 15 publications and his interests include electrical power systems and machines, power system stability, modeling, simulation, fuzzy controller, nonlinear circuit and system theory as related to electrical power and machine systems.

Mr. Sarmad Arkan Janderma Received the BSc, MSc degrees in electrical engineering (Power and Machine) from University of Mosul, Mosul-Iraq in 2012, 2019 respectively.