Detection of Fault and Load Increase for Distance Relay Operation Using FFT

Nor Massita Binti Sukirman
Faculty of Electrical Engineering
Universiti Teknologi MARA Malaysia
40450 Shah Alam, Selangor, Malaysia
e-mail: massita.sukirman@yahoo.com

Abstract— **Undesirable operation of distance relays is due to occurrence of load increase but not because of fault. That operation has contributed to voltage collapses worldwide and it has played a part in many major blackouts. This problem occurred because of distance relay failed to differentiate between fault occurrence and load increase in power distribution system. This research presents a new approach to improve the identification of fault occurrence and load increase to prevent distance relay mal-operation. The main objective of this research presented in this thesis is basically focuses on how to differentiate between fault occurrence and load increase in transmission lines. Besides, the other objective is to study the characteristics of fault and load increase and their effects in transmission lines and also to develop the method that can clearly distinguish between fault occurrence and load increase by developing and simulating the IEEE 9 bus test system using PSCAD Software. The analyses of voltage have been done at the corresponding buses of the simulation system. The study on Fast Fourier Transform (FFT) has shown the different of voltage profile between fault and load increase.**

Keywords – Distance relay; fault; load increase

I. Introduction

The relay criterion is to be chosen that it should trip only under fault condition which the relay is designed to protect the power system. Distance relay is one of the types of relay and it also known as impedance relay. Distance relays usually use the ratio between voltage and current (which in turn produces impedance) as the principle of ratio comparison, where the impedance is proportional to the distance in transmission lines [1]. These relays are widely used as the main protection scheme for long extra-high-voltage transmission lines transmitting power at 132 kV, 220 kV and 400kV. For 60 kV transmission lines and 11 kV distribution lines, distance protection would not be economically viable and hence overcurrent relays are used. This also because of overcurrent principle cannot easily deal with the change in the direction of power flowed. [1, 2]

However, the relay operating criteria becomes complicated as the relay should operate in faulty conditions and it should not operate when there is no fault. As what was happened on November 4th, 2006, any tripping events that occurred on line loading during significant system is also known as distance relays. In North Germany, a distance relay on the Wehrendorf end of the Wehrendorf-Landesbergen 380kV transmission line is operated on load when the largest disturbances is occured in Europe. It was concluded that the distance protection operated as designed and might have prevented an even more severe blackout. [2]

In order to prevent the distance relay mal-operation, it is important to study how to improve the reliability of distance relay performance. This can be done by identify the characteristics of fault and load increase. Analysis of voltage through simulations of IEEE 9 bus system using PSCAD is used to achieve the objectives.

II. Theoretical Background

Backup coverage is one of the important notions associated to the zone selection and allocation. The multiple zones of protection are typically used for different sections of the transmission line. The distance relay operates in three different operating zones. Each zone of protection will be set to cover the transmission line according to specific length [3]. Zone 1 is used as a primary protection because it will trip instantaneously for faults occurred along the transmission line. If there is fault occurs within the Zone 1 coverage, the relay will immediately sends the tripping signal to the breaker. This zone will cover the protection line about 80 – 90% of the transmission line. The distance relay of Zone 2 is delayed to allow Zone 1 relays to operate first. It will protect the remaining part of a transmission line not reached by Zone 1 and extends into neighboring transmission line. While the times of Zone 3 allow the corresponding relays either in the Zone 1 or Zone 2 which is closer to the fault to operate first. Figure 1 shows the selection of the overlapping zones for transmission line protection. [4, 5]

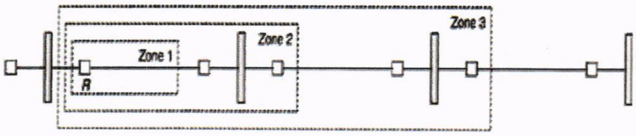

Figure 1. Selections of the overlapping zones for transmission line protection.

These zones of protection can be selected by locating a relay at a line terminal. As mentioned above, the length that corresponds to the relay coverage is determined in the percentage of the line length between the relay terminal and neighboring relay terminals.

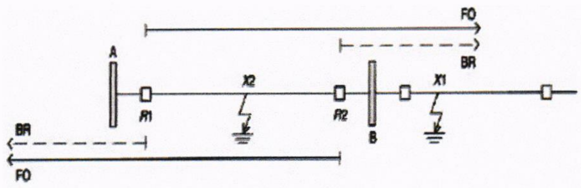

Figure 2. The blocking principle of relaying with fault directionality discrimination.

For example of the relaying scheme operation, Figure 2 shows the implementation of blocking principle where the relaying zones are used. Each relay operates with two operations which are forward overreaching (FO) and backward reverse (BR).

For FO operation, the setting selected to the relay is in forward direction, occurrence of fault can be "seen" from the relay position toward the neighboring line terminal and beyond. While the BR setting is operate in backward direction so that the fault occurrence behind the relay can be "seen". In this case, it may cause the power flowing in the reverse direction.

As shown in Figure 2, the relay R1 which is located at A has "seen" the fault X1 in the FO zone. However, the relay R1 has been blocked by relay R2 which has "seen" the fault X1 in the BR zone. Hence, the relay R2 send the blocking signal to the relay R1 so that it will not operates.

Another case shown in the Figure 2 is fault X2 occurred in between relay R1 and relay R2. Both relays operate instantaneously since both of the relays are in zone FO. [5, 6]

III. METHODOLOGY

To illustrate the effectiveness in distinguishing between fault occurrence and load increase condition, the proposed method is shown in Figure 3.

Firstly, the apparent impedance (Z_a) has been monitored continuously either it enter the tripping zone or not. Once the apparent impedance enters one of the tripping zones, there are two possibility conditions that may be occurred, either fault or load increase. In order to distinguish between these two conditions, the difference value of magnitude is obtained. In this case, the difference between magnitude 2 and magnitude 3 have been calculated for the analysis.

A. Flowchart

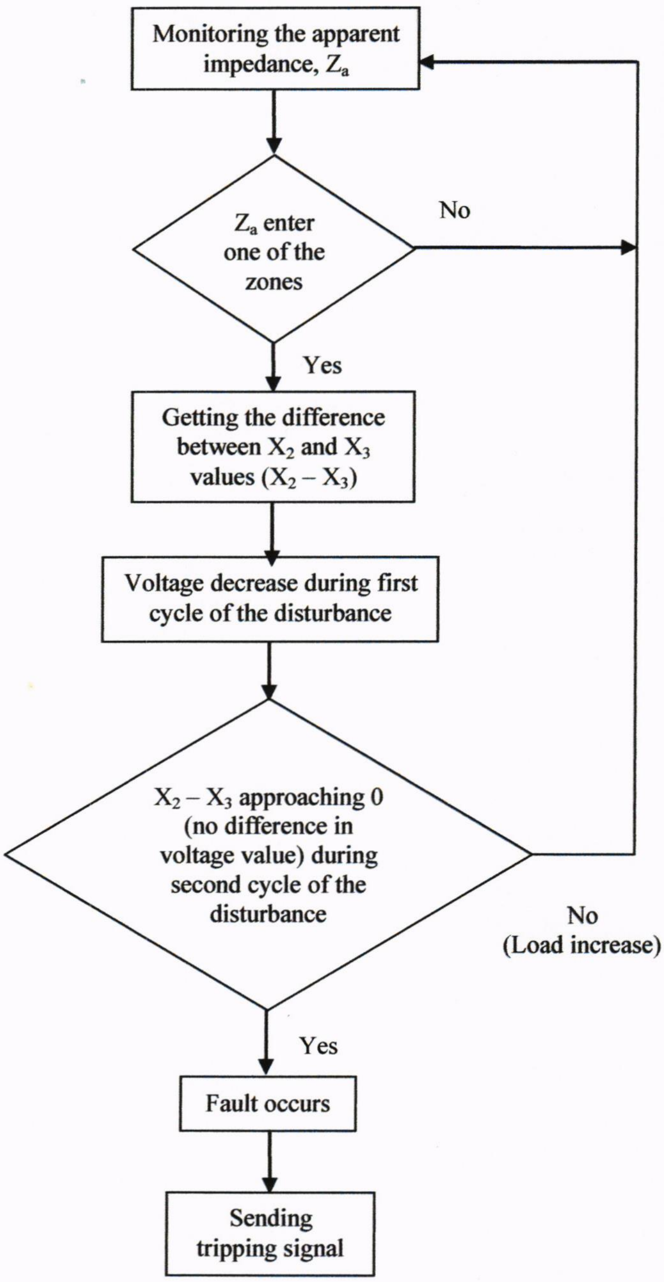

Figure 3. Flowchart of the proposed method.

B. System Simulation

As a solution for this study, the IEEE 9 bus test system is simulated to obtain the difference between fault and load increase [7]. The recommended method to prevent distance relay operates during load increase is by analyzing the voltage on the corresponding buses. Figure 4 shows the test system that has been used for this simulation. There are three generation buses which are located at bus 1, 2 and 3. Bus 5, 7 and 9 are the load buses.

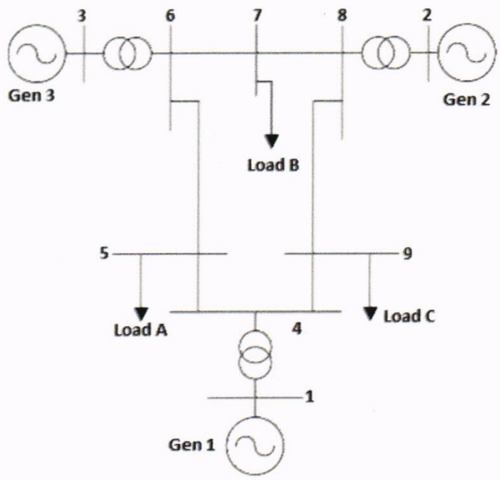

Figure 4. IEEE 9 bus test system

C. Procedure of the Simulation Test

i) IEEE 9 bus system has been designed by using PSCAD Software.

ii) The occurrence of fault is created at several different buses. Fault is applied to the bus at time, t = 5 sec and the duration of fault occurred is 0.1 sec.

iii) At the load buses, which locate at bus 5, 7 and 9, loads are set to be increased. For the bus 5 and 7, the loads increase 4 and 5 times respectively in order to get better performances to illustrate the load increase condition. Load increase at bus 9 is used the same value.

iv) The breaker operation is set at time, t = 8 sec, so the load increase is occurred at that time.

v) Thus, the RMS voltage drops during fault and load increase are fed into an online Fast Fourier Transform (FFT), so that the magnitude and phases of the harmonics present can be determined.

vi) The circuit has been simulated and the results show the difference between fault and load increase.

vii) The data obtained are plotted in Microsoft Excel and have been analyzed.

IV. Result and Discussion

The instantaneous voltage sinusoidal waveforms of fault and load increase condition are shown below in Figure 5 and Figure 6 respectively.

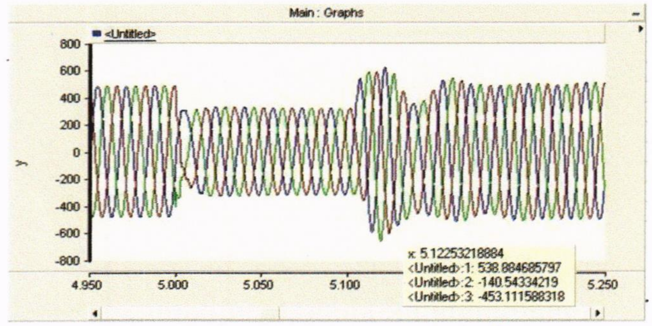

Figure 5. Instantaneous voltage, V waveform of fault.

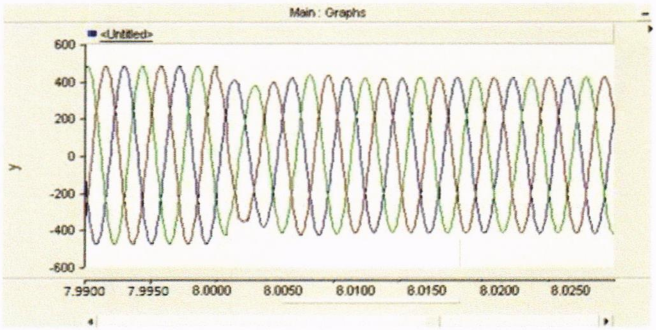

Figure 6. Instantaneous voltage, V waveform of load increase.

From Figure 5 and Figure 6 above, the Fast Fourier Transform (FFT) is used to obtain the magnitudes of the voltage. Figure 7 shows the magnitudes of voltage obtained during fault condition while Figure 8 shows the magnitudes during load increase condition. The "X_2" and "X_3" at the magnitude bars indicate the value taken to calculate the difference of magnitude's value. The calculation will be discussed later.

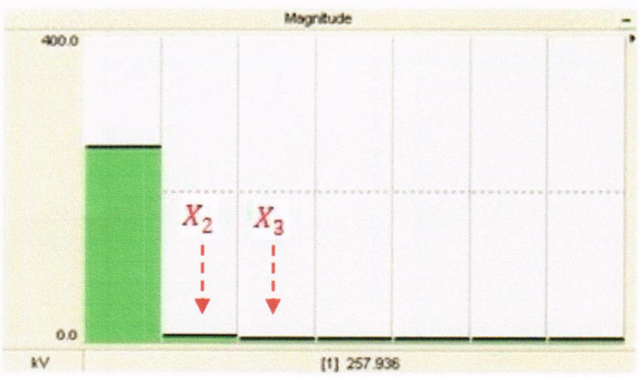

Figure 7. Magnitude of fault.

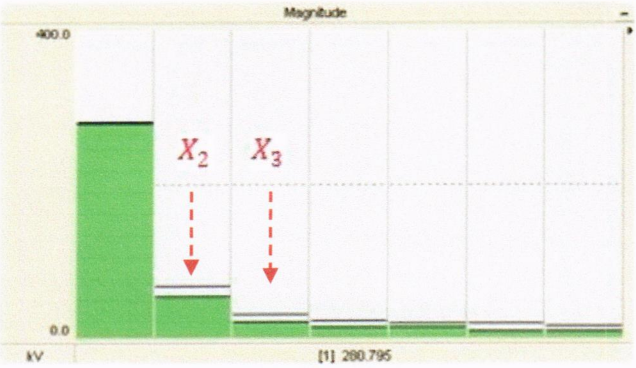

Figure 8. Magnitude of load increase.

Figure 9 shows the harmonic magnitude during fault occurrence while Figure 10 shows the harmonic magnitude of load increase condition. These two conditions have been simulated at several buses so that various results can be observed.

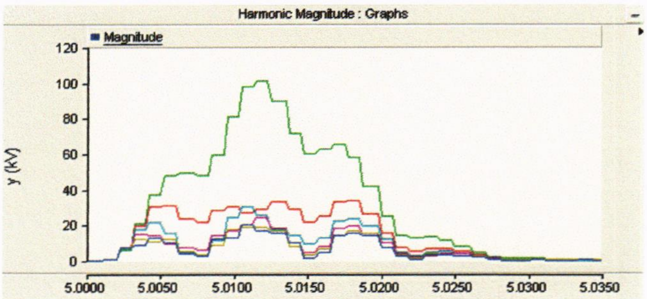

Figure 9. The magnitude of fault shown in FFT.

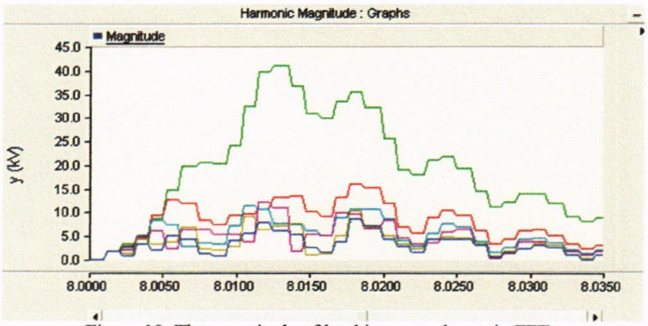

Figure 10. The magnitude of load increase shown in FFT.

After the result has been analyzed, it is shows that there is no different during the first cycle of the disturbance, either in fault occurrence or load increase condition. It is noticed that the values of voltage for both conditions were dropped significantly during the first cycle after the disturbance occurred. The differences of the profile only can be seen at the second cycle of the disturbance. The study will be discussed later on.

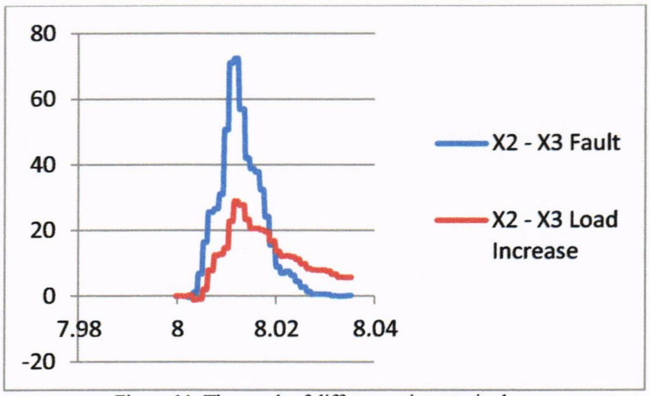

Figure 11. The graph of differences in magnitudes.

The difference in magnitude value, Δ is calculated from following equation:

$$\Delta = X_2 - X_3 \qquad (1)$$

Where,

Δ : The difference in magnitude voltage.
X_2 : The second magnitude from fault and load increase magnitude bars.
X_3 : The third magnitude from fault and load increase magnitude bars.

Therefore, the difference in magnitude value, Δ is identified as an indicator to differentiate between fault and load increase. The graph has been plotted as shown in Figure 11 to illustrate the difference between two of them. The data are tabulated as shown in Table I until Table V.

TABLE I. FAULT AT BUS 6, LOAD INCREASE AT BUS 5

Location of FFT Measured	Difference in magnitude voltage, Δ	
	Fault	***Load Increase***
Bus 5	0.376738448	7.890216045
Bus 7	0.571309371	7.780933665

TABLE II. FAULT AT BUS 4, LOAD INCREASE AT BUS 5

Location of FFT Measured	Difference in magnitude voltage, Δ	
	Fault	***Load Increase***
Bus 1	0.560279739	3.087014546
Bus 5	1.786127363	7.864259514
Bus 9	1.714095854	7.452640564

TABLE III. FAULT AT BUS 6, LOAD INCREASE AT BUS 7

Location of FFT Measured	Difference in magnitude voltage, Δ	
	Fault	***Load Increase***
Bus 5	0.376753824	8.400753874
Bus 7	0.571298755	7.933231489

TABLE IV. FAULT AT BUS 7, LOAD INCREASE AT BUS 5

Location of FFT Measured	Difference in magnitude voltage, Δ	
	Fault	***Load Increase***
Bus 8	0.93104776	7.146756516
Bus 6	1.197712949	8.20722996
Bus 4	0.84319844	7.339478924
Bus 9	0.907530923	7.467833442

TABLE V. FAULT AT BUS 5, LOAD INCREASE AT BUS 7

Location of FFT Measured	Difference in magnitude voltage, Δ	
	Fault	***Load Increase***
Bus 8	0.93104776	7.146756516
Bus 6	1.197712949	8.20722996
Bus 4	0.84319844	7.339478924
Bus 9	0.907530923	7.467833442

As mentioned earlier, the difference characteristic of fault and load increase have been clearly identified during the second cycle of the disturbance. From the proposed method of $X_2 - X_3$, results tabulated at table above show the difference of magnitude in fault condition tend to decrease towards zero. The range of difference in magnitude voltage, Δ during fault condition is from 0 and not more than 2. As shown in tables above, the smallest value of Δ during this condition is 0.376738448 and the largest value is 1.786127363.

Different in the load increase condition, it still shows the substantial difference in Δ. The range of Δ in this condition is from 3 and not more than 9. Tables above show the smallest value of Δ in load increase condition is 3.087014546 and the largest is 8.400753874. Although the smallest value is 3.087014546, the range of Δ is significantly can be seen not less than 7 for most data obtained.

Since the method proposed can not distinguish the different between fault occurrence and load increase during the first cycle of the disturbance, it means the method is not appropriate to used for Zone 1 of the protection zone. This is because Zone 1 has to send the trip signal instantaneously. This method is applicable to Zone 2 and Zone 3 since they have time delay setting.

CONCLUSION

In order to avoid the false trip signal sent undesirably by the distance relay, it is important to study the differences characteristic between fault and load increase. The proposed method for this paper is by differentiating the fault occurrence and load increase by using (1). From the simulation result, it can be concluded that the proposed method gives clear differentiation between these two conditions during the second cycle of the disturbance. However, the drawback of the method as it only can be operating for Zone 2 and Zone 3.

ACKNOWLEDGMENT

Firstly, praise be to Allah for giving me ideas and good health during the completion of the Final Year Project. My special thank goes to very helpful supervisor, Dr. Ahmad Farid Bin Abidin @ Bharun for his guidance, encouragement, ideas and his time spent for me. The supervision and support that he gave truly help the progression of this project. I owe many thanks to all my friends and people who have willingly helped me out with their abilities in completion of this project.

REFERENCES

[1] Book of Bhuvanesh A Oza, Nirmal-Kumar C Nair, Radesh P Mehta and Vijay H Makwana, "Power System Protection And Switchgear"

[2] Working group D4, "Application of Overreaching Distance Relays," Internet: http://pscal.ece.gatech.edu/FDAPRC/files/PRC%20Website%20material/D4_Application_of_Overreaching_Distance_Relays.pdf [2nd December 2012]

[3] Working group D6, "Transmission Line Protective Systems Loadability," Internet: http://www.pes-psrc.org/Reports/D6_Loadability.pdf [2nd December 2012]

[4] Ahmad Farid Abidin, Azah Mohamed and Afida Ayob, "A New Method to Prevent Undesirable Distance Relay Tripping During Voltage Collapse" European Journal of Scientific Research, ISSN 1450-216X Vol.31 No.1 (2009), pp. 59-71.

[5] Mladen Kezunovic, "Fundamentals of Power System Protection"

[6] Mattias Jonsson, Student Member, IEEE, and Jaap E. Daalder, "An Adaptive Scheme to Prevent Undesirable Distance Protection Operation During Voltage Instability" Ieee Transactions On Power Delivery, Vol. 18, No. 4, October 2003

[7] Ahmad Farid Abidin and Azah Mohamed, "On The Use of Voltage Stability Index to Prevent Undesirable Distance Relay Operation during Voltage Instability" Environment and Electrical Engineering (EEEIC), 2010 9th International Conference, 16-19 May 2010,pp. 384- 387