

Fault current Characterization Based on Fuzzy Algorithm for DOCR Application

Luly Susilo, J.C. Gu, S.K. Huang

Electrical Engineering Department, National Taiwan University of Science and Technology.
Email: lulysusilo@gmail.com

Received January, 2013

ABSTRACT

Penetration of distribution generation (DG) into power system might disturb the existing fault diagnosis system. The detection of fault, fault classification, and random changes of direction of fault current cannot always be monitored and determined via on-line by conventional fault diagnosis system due to DG penetration. In this paper, a fault current characterization which based on fuzzy logic algorithm (FLA) is proposed. Fault detection, fault classification, and fault current direction are extracted after processing the measurement result of three-phase line current. The ability of fault current characterization based on FLA is reflected in directional overcurrent relay (DOCR) model. The proposed DOCR model has been validated in microgrid test system simulation in Matlab environment. The simulation result showed accurate result for different fault location and type. The proposed DOCR model can operate as common protection device (PD) unit as well as unit to improve the effectiveness of existing fault diagnosis system when DG is present.

Keywords: Fault Current Characterization; Fuzzy Logic Algorithm; DOCR; Distributed Generation

1. Introduction

Penetration of DG that concentrated closer to customer side can improve the efficiency of electric power delivery. In the contrary, multi-source power system scheme as result of penetration of DG both in radial and ring power system might produce bi-directional power flow as well as fault current. The fault current may be in forward or reverse direction, and this will change rapidly depends on system requirement. It is inevitable; however, existing fault diagnosis system based on radial scheme with focusing only on single source can be no effective anymore. In conventional fault diagnosis system, after obtaining information operation status of protection device (PD) during/after fault event, then the information will be matched with table database in SCADA. Dispatcher will locate the fault section as soon as possible according to diagnosis result [1]. One aim of this work is to improve effectiveness of fault diagnosis system; PD will send its operating status to SCADA as well as the fault current characteristic information. Furthermore, dispatcher not only can locate the faulted section, but also accurately determine fault source and decide appropriate action in advance.

Sample of analog signal of line current will be processed in Digital Fourier Transform (DFT) module. Magnitude of phase line current, positive sequence current and zero sequence current as well as angle of positive

sequence current will be taking into fuzzification input, from fuzzy interference system (FIS) that already constructed before, the membership value will be generated after comparing the input and membership function. Then from defuzzification process will decide the relationship of all input line current with related fault characterization information. Many publications already presented concept regarding fault detection, fault classification, and fault current direction which based on various intelligence control approaches (Wavelet, Neural Network, and FLA) [2,4,7,8]. Unfortunately, none of them clearly provided a complete concept fault characterization through a single approach. In this work, this solution is addressed. In part II, elaboration of FLA for fault characterization is provided in detail and systematic. The proposed microgrid test system as well as the DOCR and its control model in Matlab environment are shown in part III. Next part, brief discussion about simulation result is conducted before closing by conclusion part.

2. Fuzzy logic algorithm (FLA) for fault current characterization

The nature form of fault current characterization problem is not including complex mathematical expression. FLA is preferably to be implemented since this algorithm is simple and not involve any complex computation. Major procedures in this work are shown in **Figure 1**.

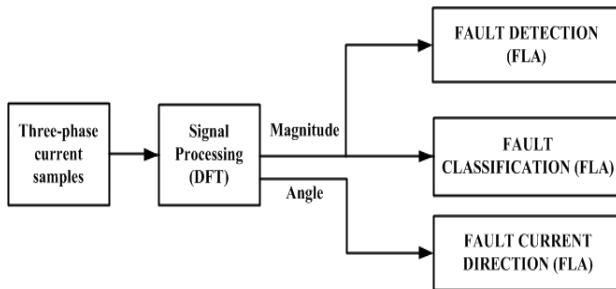


Figure 1. Fault current characterization block diagram.

2.1. Fault Detection and Fault Classification

Occurrence of shunt fault on power system create very low impedance path so very high fault current will appear and be delivered by power sources. Fault detection is important part in work in order to distinguish real fault current from transient/inrush current.

Transient/inrush period will generate significant amount of current, but it will decrease very fast. Conventional DFT module is utilized to extract the magnitude of line current, magnitude of zero sequence current and angle of positive sequence current. Fault detection module will sense and record the current data both before and after 1 cycle at point where high current detected. If high current still remain within and after 1 cycle, it means fault is detected. Fault detection is denoted as δ_0 .

$$\delta_0 = 1 \text{ (fault), if } I \geq I_{\text{ref.}}$$

$$\delta_0 = 0 \text{ (no-fault), else}$$

where: I is measured line current and $I_{\text{ref.}}$ is nominal line current.

The characteristic features of different types of fault are described in terms of δ_1 , δ_2 , δ_3 , and δ_4 which are calculated as described below.

$$\delta_1 = \frac{I_a - I_b}{\max(I_a, I_b, I_c)}; \delta_2 = \frac{I_b - I_c}{\max(I_a, I_b, I_c)};$$

$$\delta_3 = \frac{I_c - I_a}{\max(I_a, I_b, I_c)}; \delta_4 = \frac{I_0}{I_1}$$

where

I_a, I_b, I_c are magnitudes of three phase current

I_0 is zero sequence current

I_1 is positive sequence current

Variation in fault location, power angle, fault inception angle and fault resistance are very important in order to study value of δ_1 , δ_2 , δ_3 , and δ_4 for any kind of fault condition [2]. Hence two-bus power system as shown in **Figure 2** is built to study the fault current characteristic features.

Line length AB is 60 km, two sources 11.4 kV, frequency 60 Hz and with next following sequence impedance as tabulated in **Table 1**.

Fault location at 25% and 75% of line length; power angle for 10° and 30° ; fault inception angle at 0° and 90° fault resistance 0.001Ω and 100Ω ; All these variations are considered in order to determine the fault current characteristic features (δ_1 , δ_2 , δ_3 , and δ_4) of the different types of fault. The result can be shown in **Table 2** and summarized as following:

For δ_1 , δ_2 and δ_3 , “high” means a value between 0.1 and 1, “medium” means a value between -0.15 and 0.4, “low” means a value between -0.1 and -1. For δ_4 , “high” means a value between 0.1 and 1, “low” means a value between 0.01 and 0.015. The triangular membership function of δ_0 , δ_1 , δ_2 , δ_3 , and δ_4 are shown from **Figure 3** to **Figure 5**.

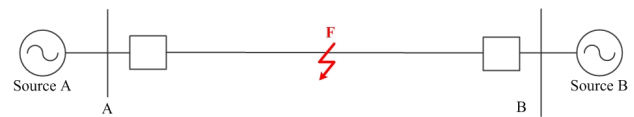


Figure 2. Two-bus power system.

Table 1. Impedance data of two-bus power system

Sequence	R (Ω/km)	L (mH/km)	C ($\mu\text{F}/\text{km}$)
Zero	0.38640	4.1264	7.751
Positive	0.01273	0.9337	12.74

Table 2. Fuzzy rule of fault classification.

Input	δ_1	δ_2	δ_3	δ_4	δ_0
Fault Type	δ_1	δ_2	δ_3	δ_4	δ_0
a-g	high	medium	low	high	fault
b-g	low	high	medium	high	fault
c-g	medium	low	high	high	fault
a-b	medium	high	low	low	fault
b-c	low	medium	high	low	fault
c-a	high	low	medium	low	fault
a-b-g	medium	high	low	high	fault
b-c-g	low	medium	high	high	fault
c-a-g	high	low	medium	high	fault
a-b-c	medium	medium	medium	low	fault

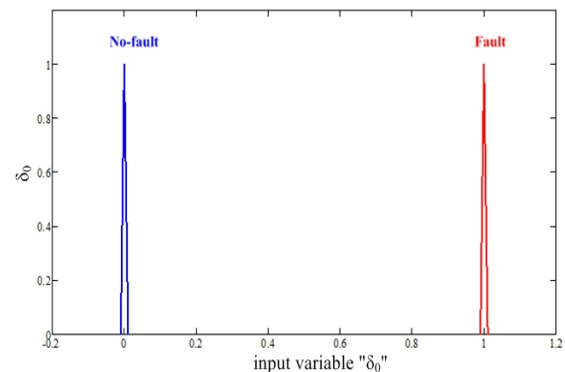


Figure 3. Fault detection triangular membership function.

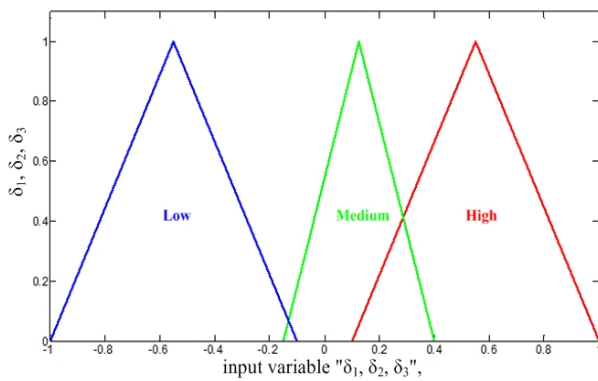


Figure 4. Fault classification triangular membership function for δ_1 , δ_2 , and δ_3 .

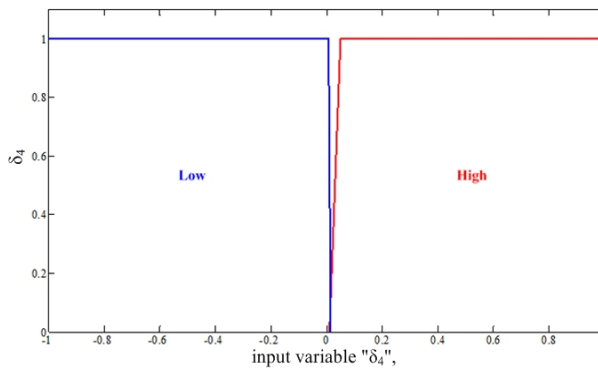


Figure 5. Fault classification triangular membership function for δ_4 .

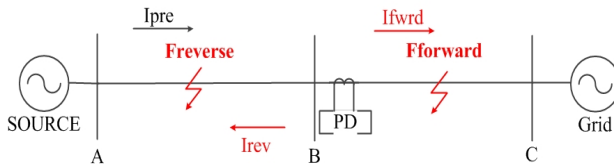


Figure 6. Forward fault and reverse fault.

2.2. Fault Current Direction

The original concept of fault current direction estimation can be found in reference [3,4,5,6,9,10]. The difference in angle of positive sequence between fault current and pre-fault current can be used to estimate the fault direction [3]. The pre-fault current is flow from source to grid as shown in Figure 6.

When fault forward occurs, the total fault current seen by PD is accumulation both pre-fault current and forward fault current. On the opposite, when fault reverse occurs, the total fault current seen by PD is subtraction between pre-fault current and reverse fault current. It is concluded that if the phase angle change value is negative that means forward fault occurs. On the contrary, if the phase angle change value is positive that means reverse fault occurs. The characteristic feature of fault direction is

determined in terms of δ_5 , which calculated as following.

$$\delta_5 = \theta_{I_{\text{postfault}}} - \theta_{I_{\text{prefault}}}$$

where:

$\theta_{I_{\text{postfault}}}$ is angle of postfault current

$\theta_{I_{\text{prefault}}}$ is angle of prefault current

As in previous section, the features for fault direction have been determined in terms of δ_0 and δ_5 .

The fuzzy rule of fault current direction is determined as below:

If δ_0 is "1" (fault) and δ_5 is positive, it is reverse fault

If δ_0 is "1" (fault) and δ_5 is negative, it is forward fault

For δ_5 , "positive" means a value between 0° and 180° , "negative" means a value between 0° and -180° . If the angle value is more than 180° , it shall be normalized with subtracting it with 360° . And if it less than -180° , it shall be normalized with adding it with 360° [3]. The triangular membership function can be seen in Figure 7.

3. Test System and Directional Overcurrent Relay (DOCR) Model

The proposed approach is validated on test system which shown in Figure 8. It consists of multisource power system including utility and several distributed generation sources, non-critical and critical load, and charging station. The system parameter of system in Figure 8 is tabulated in Table 3.

3.1. DOCR Model in Matlab Environment

As shown in Figure 9, the DFT module will extract the magnitude of three phase line current, magnitude of positive sequence and zero sequence current and angle of positive sequence current. These values will be used as inputs for fault characterization module in order to compute the features characteristic ($\delta_1 \sim \delta_5$) of fuzzy logic module.

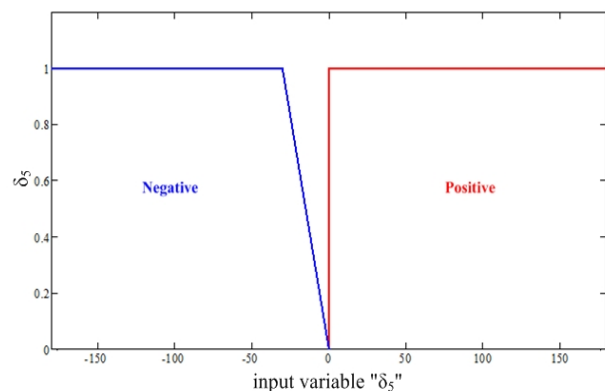


Figure 7. Fault current direction triangular membership function for δ_5 .



Utility	MVA _{sc} =2500MVA , X/R=20%		
Transformer	T1	50 MVA	161 kV/11.4 kV Z=11.4%
	T2	300 kVA	11.4 kV/380 V Z=3.4%
	T3	3 MVA	2.4 kV/11.4 kV Z=6%
	T4	500 kVA	11.4 kV/380 V Z=3.4%
	T5	12 MVA	4.8 kV/11.4 kV Z=9.6%
#Line	1	3KM	R ₁ =0.01273 Ω/km R ₀ =0.38640 Ω/km L ₁ =0.9337×10 ⁻³ H/km L ₀ =4.1264×10 ⁻³ H/km C ₁ =12.740×10 ⁻⁶ F/km C ₀ =7.751×10 ⁻⁶ F/km
	2	5KM	
Distributed Generation (DG)	1	Diesel Engine	3.125 MVA 4.8kV
	2	PV	150 kVA 380V
	3	Energy Storage	500 kVA 380V
Load	Load1	Uncritical	1 MW
	Load2	Critical	6 MW
	Load3	Uncritical	300 kW
	Load4	Critical	100 kW
	Charging Station (CS1)	Uncritical	60 kW×8
		Critical	60 kW×4
	Charging Station (CS2)	Uncritical	60 kW×2
		Critical	60 kW×1

tained at 1 cycle after fault occurs. The detail DOCR module can be seen in **Figure 10**.

For testing performance and accuracy of proposed approach, simulation was done in two fault locations in test system. They are marked as F1 and F2. Final results of fault characterization simulation of test system are tabulated in **Table 4** and **Table 5**. Information regarding fault classification and fault current detection can be obtained accurately from this approach. Later, the information can be transferred through communication channel to SCADA for further fault diagnosis analysis. The proposed method in [2] use two different fuzzy rule base instead of combining become one fuzzy rule base as proposed in this work both for phase fault and ground fault. Therefore, the proposed approach can work more effective.

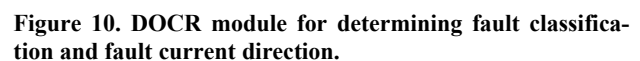


Table 4. Simulation result for fault location at F1 (PD3 and PD7).

Fault type	Protection Device No.	Fault information seen by PD						
		Fault type		Fault direction		Current Angle (degree)		
		A-B-G	B-C	A-B-C	Forward	Reverse	Pre-fault	Fault
A-B-G	PD3	✓	-	-	-	✓	26.7	131.7
	PD7	✓	-	-	✓	-	28.1	-56.8
B-C	PD3	-	✓	-	-	✓	26.7	128.2
	PD7	-	✓	-	✓	-	28.1	-57.9
A-B-C	PD3	-	-	✓	-	✓	26.7	138.3
	PD7	-	-	✓	✓	-	28.1	-58.4

Table 5. Simulation result for fault location at F2 (PD13 and PD16).

Fault type	Protection Device No.	Fault information seen by PD						
		Fault type		Fault direction		Current Angle (degree)		
		B-G	B-C	A-B-C	Forward	Reverse	Pre-fault	Fault
B-G	PD13	✓	-	-	✓	-	25.9	-46.4
	PD16	✓	-	-	-	✓	28.9	158.3
B-C	PD13	-	✓	-	✓	-	25.9	-52.6
	PD16	-	✓	-	-	✓	28.9	164.6
A-B-C	PD13	-	-	✓	✓	-	25.9	-52.8
	PD16	-	-	✓	-	✓	28.9	171.4

To detect the ground fault existence in system, the zero sequence current value has been considered. The detection of ground fault is denoted as δ_4 in the proposed fuzzy logic scheme. The performance of proposed approach has also been studied for variation of operating conditions. The characteristic features value can be vary according to system parameter change and configuration. Any significant change can affect the fault current direction decision. Therefore, load flow study shall be performed at first in order to determine the normal current flow direction for pre-fault current reference.

5. Conclusions

An approach applying fuzzy logic algorithm (FLA) for fault current characterization was presented. The DOCR model based on this approach is developed in Matlab

environment. DOCR model can operate and perform fault current characterization within 1 cycle after fault occurring. In addition to the FLA ability, not only fault detection was conducted; fault classification and fault current direction were also determined. Due to FLA has property to make decision in parallel, the whole process of fault current characterization take a very short time. The proposed DOCR model was applied to test power system and show accurate result as expected. Moreover, the proposed DOCR model can improve effectiveness of existing fault diagnosis system with delivering both its operating status and the fault current character information.

REFERENCES

- [1] Y. Sekine, *et al.*, "Fault Diagnosis of Power Systems," *Proceedings of the IEEE*, Vol. 80, No. 5, May 1992, pp. 673-683. [doi:10.1109/5.137222](https://doi.org/10.1109/5.137222)
- [2] R. N. Mahanty and P. B. Gupta Dutta, "A Fuzzy Logic Based Fault Classification Approach Using Current Samples Only," *Electric Power Systems Research*, 77, 2007, pp. 501-507. [doi:10.1016/j.epsr.2006.04.009](https://doi.org/10.1016/j.epsr.2006.04.009)
- [3] A. K. Pradhan, A. Routray and M. S. Gudipalli, "Fault Direction Estimation in Radial Distribution System Using Phase Change in Sequence Current," *IEEE Transactions On Power Delivery*, Vol. 22, No. 4, 2007, pp. 2065-2071.
- [4] A. Ukil, B. Deck and V. H. Shah, "Current-Only Directional Overcurrent Relay," *IEEE Sensor Journal*, Vol. 11, No. 6, 2011, pp. 1403-1404. [doi:10.1109/JSEN.2010.2094186](https://doi.org/10.1109/JSEN.2010.2094186)
- [5] A. K. Pradhan and P. Jena, "Solution to Close-in Fault Problem in Directional Relaying," *IEEE Transactions On Power Delivery*, Vol. 23, No. 3, 2008, pp. 1690-1692. [doi:10.1109/TPWRD.2008.923149](https://doi.org/10.1109/TPWRD.2008.923149)
- [6] A. Ukil, B. Deck and V. H. Shah, "Smart Distribution Protection Using Current-only Directional Overcurrent Relay," *IEEE PES Conference Innovative Smart Grid Technology*, 2010, pp. 1-7.
- [7] O. A. S. Youssef, "Fault Classification Based on Wavelet Transforms," *IEEE PES T&D Conference and Exposition*, 2001, pp. 531-536.
- [8] S. A. Gafoor and P. V. R. Rao, "Wavelet Based Fault Detection, Classification and Location in Transmission Lines," *First International Power and Energy Conference- PECon*, November 2006, pp. 114-118.
- [9] S. Das, N. Karnik and S. Santoso, "Distribution Fault-Locating Algorithms Using Current Only," *IEEE Trans. On Power Delivery*, Vol. 27, No. 3, 2012, pp. 1144-1153. [doi:10.1109/TPWRD.2012.2191422](https://doi.org/10.1109/TPWRD.2012.2191422)
- [10] A. Ukil, B. Deck and V. H. Shah, "Current-Only Directional Overcurrent Protection for Distribution Automation: Challenges and Solutions," *IEEE Transactions on Smart Grid*, Vol. PP, No. 99, August 2012, pp. 1-8.