OVERCURRENT PROTECTION OF DISTRIBUTION SYSTEM WITH DISTRIBUTED GENERATION

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Abstract: This paper presents the digital protection technique based on combined d-q transform and Wavelet singular entropy to detect short circuit faults in distribution system with distributed generation. The direct axis and quadrature axis transformation is applied to three phase current signal and the resulting d-q current is analysed through Wavelet Packet Transform. Due to the increased size of current vector, their analysis is more complicated and time consuming. The Singular value decomposition and Shannon entropy is applied to wavelet packet coefficients to decrease vector size of the current. This technique provides enough information to identify and discriminate fault, islanding and grid reconnected condition. This method requires less sampling rate and hence it is simple and requires less hardware and computation time. This method is immune to fault inception angle and fault location. This method is tested in distribution system with distributed generation. To test the proposed method, faults are numerically simulated in MATLAB/SIMULINK and it is compared with recent technique.

Key words: Digital protective relays, d-q axis components, singular value decomposition, fault, wavelet packet transform, entropy.

1. Introduction

Distributed generation is widely employed nowadays due to the increasing demand of electrical energy. Chengshan et al [1] investigated that protection issues are increasing in Distribution system due to the incorporation of Distributed generation.

During islanding, the fault current measured by relays is less than the fault current in grid connection. This is one of the major problems in over current protection [2]. Short-circuit faults cause many harmful effects on the electrical distribution systems and devices. Hence, these faults should be detected as quickly as possible.

In current scenario, several methods are proposed for protection of distribution system with distributed generation. In [3], islanding detection is done by using sandia frequency shift in inverter based distributed generators. In [4], passive islanding detection scheme is employed in photovoltaic units. Mohammad et al [5], used self healing perspective to detect islanding in active distribution network. In [6], Artificial Neural Network is employed for Anti-Islanding protection of distributed generators

Direct axis –quadrature axis (d-q) transformation is applied as the pre-processing technique for transforming the three phase current signal to single signal. This technique is usually applied to differentiate the fault signal from non-fault signal. In [7], Saleh et al applied this transformation to the microgrid protection. In the proposed method also, this transformation is employed as a pre-processing technique.

A wavelet-based signal processing technique is usually employed in power system transient analysis [8-9]. The wavelet transform retains the time information which is an excellent advantage compared to Fourier analysis. It provides time location and frequency information. Wavelet Packet Transform (WPT)-based digital based protective relays provides better performance compared to other techniques. In [10], WPT is employed for islanding detection in grid connected photovoltaic system.

Entropy technique is combined with WPT to decrease the size of feature vector. In [11], Dehghani et al applied wavelet singular entropy (WSE) to detect and classify faults in distribution lines in the presence of distributed generations. This method uses positive sequence component for WSE calculation and it uses haar wavelet.

The proposed method detects the fault both in islanded and grid connected condition. It does not detect the grid reconnected condition as fault. In this method, the d-q current is used for WSE calculation. Since, for fault detection, Daubechies 4 db4 wavelet is suitable and it is employed here.

This paper is organized as follows. Section 2 explains d-q WSE technique. Section 3 describes the results and discussion. The conclusion is given in section 4.

2. d-q WSE technique

The fault signal has more amplitude than normal signal and it is a high frequency transient signal. The grid reconnected signal i.e. non fault signal also has more

amplitude and transient nature. The relay should not trip during this grid reconnected condition. In islanded condition, the fault current magnitude is less than fault current in grid connected condition. Here, there is a possibility that the relay for not detecting the fault. The dq transformation is helpful in shifting the frequencies of non fault signal to lower frequencies and fault signal to high frequencies. In this way, the protective relay effectively discriminates fault and non fault signal

This method is the combination of d-q transform, WPT, Singular value decomposition (SVD) and Shannon entropy. The three phase current signals are converted into single d-q current signal $I_{dq}[t]$. The resulting signal is converted in to discrete signal.

Third level WPT is applied to the d-q current signal. This transform splits the current signal into low and high frequency signal. Low frequency signal is known as Approximation. High frequency signal is Detail. The resulting signal has eight level of sub band frequencies. Each sub band coefficients is formed as a row of matrix X.

SVD is applied to this matrix X, the singular values are taken from diagonal matrix. From the singular values, probability is calculated. Shannon entropy is calculated from probability. The process is explained in flowchart as shown in figure 1.

The 0dq components from park transformation matrix T are obtained as

$$\begin{bmatrix} I_d(t) \\ I_q(t) \\ I_0(t) \end{bmatrix} = T \begin{bmatrix} I_a(t) \\ I_b(t) \\ I_c(t) \end{bmatrix} \qquad (1)$$

$$I_{dq}[t] = (I_d[t])^2 + \left(I_q[t]\right)^2 \qquad (2)$$

Approximation is calculated by

$$A_{dq}[n] = \sum_{k=0}^{M-1} g[k]I_{dq}[n-k] \qquad (3)$$

Detail is calculated by

$$D_{dq}[n] = \sum_{k=0}^{M-1} h[k]I_{dq}[n-k] \qquad (4)$$

By singular value decomposition

$$X = UDV^T \qquad (5)$$

$$Q = diag[D] = [\lambda_1 \ \lambda_2 \ \cdots \ \lambda_r] \qquad (6)$$

The probability is

$$P_i = \frac{\lambda_i}{\sum_{j=1}^{r} \lambda_j} \qquad (7)$$

The entropy is given by

$$WSE = -10 \sum_{i=1}^{r} (P_i * \ln P_i) \qquad (8)$$

where:

I_d, I_q, I_0 are dq0 current components
I_a, I_b, I_c are Three phase currents
$I_d[t]$ is direct axis current
$I_q[t]$ is quadrature axis current
$A_{dq}[n]$ is low frequency sub band of dq WPT
$D_{dq}[n]$ is high frequency sub band of dq WPT
n, k is sample index

g[k] is low pass filter coefficients
h[k] is high pass filter coefficients
λ_i is singular values
D is diagonal matrix
U, V, Q, X are matrices
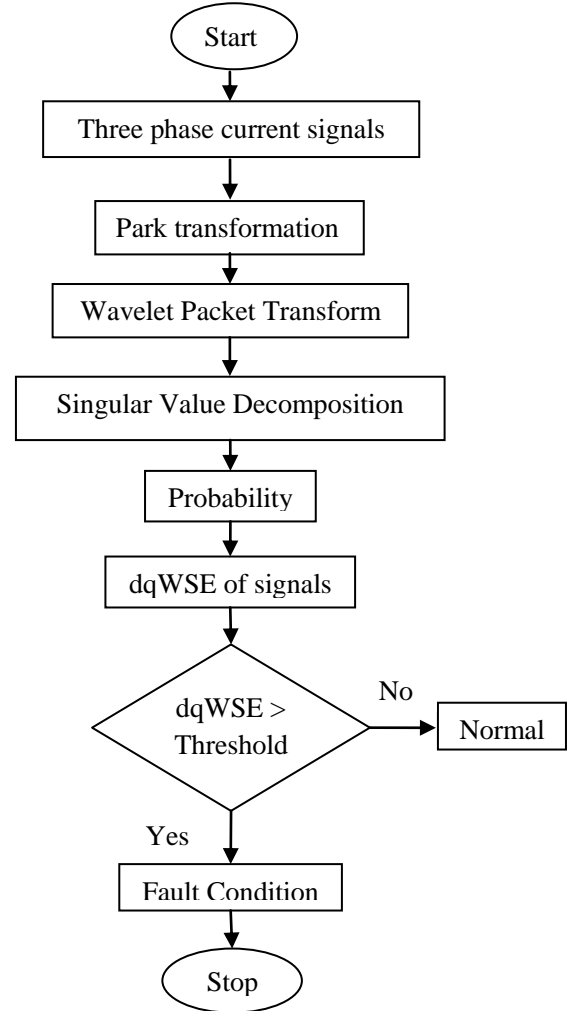P_i is Probability
WSE is wavelet singular entropy

Figure 1. Flowchart for fault detection process

3. Results and Discussions

The distribution system with distributed generation is taken from pukar et al [10] and it is shown in figure 2.
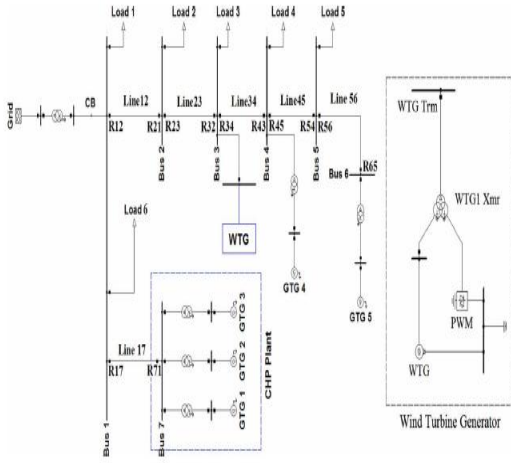
Figure 2. Distribution system with distributed generation

The three phase current measurements are taken from bus 1. Single phase to ground (A-G) fault is applied at the middle end of line 17 at 0.4 s. The sampling frequency is 3.6 kHz. For every 5 ms, dq WSE value is calculated. The figure 3 shows the dq current and entropy values during fault condition. The threshold is taken for 110% of maximum current. The entropy value during normal condition is less than threshold and it is greater than threshold during fault condition.
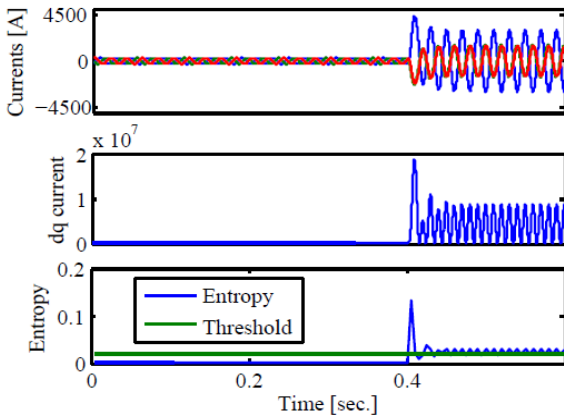

Figure 3. Three phase currents, dq current and Entropy during single phase fault

3.1 Islanded condition

The CHP plant is disconnected from the grid at 0.4 s. The figure 4 shows the three phase current, dq current and entropy values during this condition. The magnitude of fault current is less during islanding than that in grid connection. The entropy value is more than threshold during fault. Hence, the proposed method effectively identifies the fault even in islanded condition.
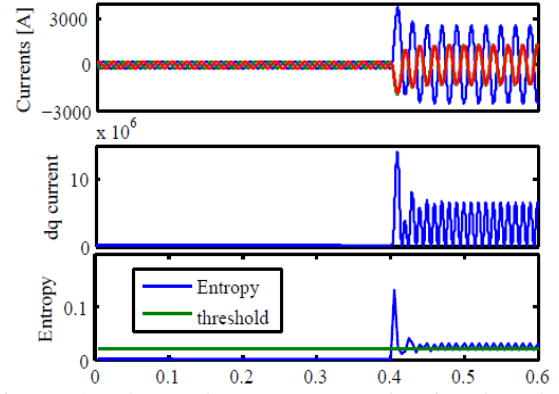

Figure 4. Three phase currents, dq signal and Entropy during single phase fault in islanded condition

3.2 Grid reconnected condition

The islanded CHP plant is reconnected to the grid at 0.4s. During this period, the magnitude of current increases. The protective relay should not distinguish this condition as fault. The figure 5 shows that the entropy value slightly increases during grid reconnected instant but it is less than threshold. Hence, the proposed method does not detect grid reconnected condition as fault.
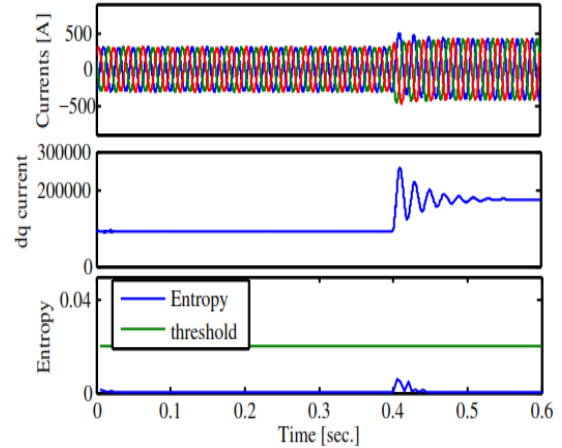

Figure 5. Three phase currents, dq current and Entropy during grid connected condition

3.3 Comparison of fault detection time

The fault detection time for various faults is compared with the recent technique and the results are tabulated in table 1. The results shows that the proposed method is fast compared to WSE method.

Table 1
Comparison of fault detection time

Types of fault	Fault detection time in ms	
	WSE Method	dq WSE method
Single line to ground	6	4
Double line to ground	7	4
Symmetrical fault	8	4

4. Conclusion

The proposed method effectively detects the fault during grid connected and in islanded condition. During grid reconnected condition i.e., non fault condition, the relay does not operate. This method is simple and it uses less sampling frequency. Due to the usage of single dq signal and entropy technique, the hardware complexity reduces. This method is able to detect all types of fault for various fault inception angle, fault distance. This method provides fast fault detection with the fault detection time of quarter power cycle.

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