Electric Power Systems Research 152 (2017) 401–410

Contents lists available at ScienceDirect

Electric Power Systems Research

journal homepage: www.elsevier.com/locate/epsr

Microgrid fault detection based on wavelet transformation and Park's vector approach☆

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ARTICLE INFO

Article history:
Received 17 April 2017
Received in revised form 1 July 2017
Accepted 26 July 2017

Keywords:
Microgrids
Signal processing
Wavelet transformation
dq0 transformation

ABSTRACT

This paper presents a new algorithm for fault detection in microgrids application. This algorithm is used in real time by applying the dq0 and wavelet transformation over local measurements. This approach consists of transforming three-phase voltage or current signals into dq0 components to analyze its behavior during faults in order to then recognize patterns that indicate the start of a fault. By filtering one of the dq0 components through the wavelet transformation, and by isolating band frequencies of interest, faults can be detected using the finite difference between samples of the filtered signal. In order to demonstrate the algorithm's performance, we have performed an experiment on a scaled microgrid and worked with the data obtained from this simulation. This algorithm will likely impact the development of new microgrid architectures with fewer resources directed to power monitoring.

1. Introduction

Over the last years, microgrids have evolved and become an economically viable alternative for the environmental issues related to burning fossil fuels when using renewable energy systems. A microgrid is defined as a group of all loads and low power generation units (micro energy sources) operating as an independent controllable system from the macro-grid providing both power and heat to a local area as explained in Ref. [1]. As a general description of the system, a microgrid is composed of one or more distributed generation (DG) units, energy storage if necessary, controlled and uncontrolled loads, and a control power electronic system [2].

Since microgrids are composed of DG units, they are also affected by the faults or disturbances of the DG systems. There are many types of electrical faults; however, this work is focused on symmetrical and asymmetrical faults that are described in Ref. [3]. To maintain the correct functioning of the microgrid, it is necessary to detect these faults in the shortest period of time, in order to make contingence and maintenance protocols to protect the system and correct the fault. The correct detection is very important to determine the exact time when the fault-like phenomena began.

The wavelet transformation (WT) is a mathematical tool that allows the analysis of a signal in time and frequency simultaneously, and it is used in detection of high impedance due to its sensitivity to abrupt changes. The WT allows analysis in multiple frequency bands of a signal, where the levels of resolution are considered frequency bands. The WT corresponds to the decomposition of a continuous function $f(t) \in L^2(R)$ in a family of scaled and translated functions $\psi_{m,n}(t)$, and they are generated from the mother wavelet $\psi(t)$; however, for a function to be classified as wavelet, it needs to be square integrable and must satisfy the admissibility condition.

Algorithms exist to detect faults, in microgrids, the algorithm presented in Ref. [4] is based on wavelet transformation, where the wavelet index is used in order to detect faults when its value surpasses a determined threshold. This analysis is done over the three phases of the power system, and allows classification of the type of fault. In Ref. [5] a method for fault detection in microgrid is proposed using wavelet transformation in order to obtain the coefficients in three levels of resolution, and obtain the wavelet energy on each level, this information about wavelet energy and wavelet coefficients is then provided to a fuzzy logic neural network to classify and detect faults, this has a response time of 2 ms.

In Ref. [6], a method is proposed for detection and location of faults in microgrids, using wavelets and Park transformation, how-

☆ Financial support for this work was provided by the 2014–2015 MIT – Peru – Universidad de Ingenieria y Tecnologia Seed Fund part of the MISTI Global Seed Funds and by the Cooperative Agreement between Masdar Institute of Science and Technology (Masdar Institute), Abu Dhabi, UAE and the MIT—Reference 02/MI/MIT/CP/11/07633/GEN/G/00.

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http://dx.doi.org/10.1016/j.epsr.2017.07.028
0378-7796/

ever, this method requires the analysis of data from five monitoring stations in order to locate and detect the faults.

Rapid changes in state circuits can create electromagnetic transient behavior in the system parameters; this transient behavior contains frequency components besides the fundamental frequency that characterize the phenomena that generate this behavior; in particular, faults can cause system currents to increase. The proposed solution in this article is based on the reconstruction of Park's vector modulus (PVM) [7] of current, using the wavelet transformation, and obtaining the DC component of the PVM which should be constant unless there is an electromagnetic transient. The mother wavelet and scale function chosen to complete this task were the Haar wavelets and their respective scale functions. The Haar wavelet will sharpen the edges of the reconstructed signal so that an increase in the DC component of PVM will be detected as a transient.

To test the algorithm's performance, an experiment at MIT's electromagnetic and electronic system laboratory (LEES) [8–10] was performed. The experiment was done over a scaled-size micro-grid, properly named nanogrid, where two types of fault were simulated [11]. The algorithm's design and testing have been performed in Peru [12,13].

2. dq0-wavelet based analysis of a three-phase signal

2.1. Park transformation

This transformation is normally applied to electrical motors to represent 3-phase stator current into a stationary reference frame, it allows a coordinate change from a three-phase system to the rotating coordinate system on axes dq0 [7]. This method can also be applied to 3-phase current in a power system to help identify and clear faults in micro-grids due to its unique property of eliminating all time varying inductances from the voltage equations of the three-phase ac machines due to motor spinning. Eq. (2) represents the Park's vector modulus (PVM).

$$\begin{bmatrix} f_d \\ f_q \\ f_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \cos(\omega t) & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ -\sin(\omega t) & -\sin\left(\omega t - \frac{2\pi}{3}\right) & -\sin\left(\omega t + \frac{2\pi}{3}\right) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \begin{bmatrix} f_a \\ f_b \\ f_c \end{bmatrix} \quad (1)$$

$$f_{dq} = \sqrt{f_d^2 + f_q^2} \quad (2)$$

The time t is calculated in real time by starting a counter k with zero in the moment that the A phase axis of the rotor is aligned to the A phase axis of the stator. In other words, when the voltage in phase A is 0 and its derivative is positive.

2.2. Dyadic wavelet transform

The dyadic wavelet transform of a signal $f(t)$ can be represented as shown in Eq. (3), where j and k are integers and the indices for scaling and translation, respectively.

$$Wf(j,k) = 2^{-\frac{j}{2}} \int_{-\infty}^{\infty} f(t)\,\psi\left(2^{-j}t - k\right) dt \quad (3)$$

In Eq. (1) the translation parameter determines the location of the wavelet in the time domain, whereas the dilation parameter determines the location of the wavelet in the frequency domain.

The wavelet decomposition allows to decompose any signal into its contribution in different regions of time-frequency space, by projecting it on the corresponding wavelet basis. In order to fast

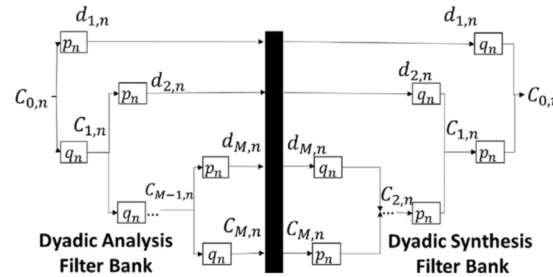

Fig. 1. Scheme of the wavelet reconstruction.

compute the wavelet decomposition, the projection of the signal on the corresponding basis will be based on a filtering operation as shown in Eq. (4), where $c_{j,n}$ is the discrete approximation and $d_{j,n}$ is the discrete detail, and $q(k)$ and $p(k)$ are the low-pass filter and the high-pass filter respectively .

$$c_{j,n} = \sum_{k=-\infty}^{\infty} q(k)\,c_{j-1,n}$$
$$d_{j,n} = \sum_{k=-\infty}^{\infty} p(k)\,d_{j-1,n} \quad (4)$$

The original signal is considered to be the scaling function coefficients at the finest level of resolution. Eq. (5) shows the reconstruction of the signal from its wavelet decomposition. Thus the decomposition and reconstruction of a signal can be represented schematically by Fig. 1.

$$c_{j-1,n} = \sum_k q(k)\,d_{j-1,n} + \sum_k p(k)\,c_{j-1,n} \quad (5)$$

3. Basic ideas and proposed algorithm

When a transient occurs in transmission lines, a signal appears in addition to the original waveform of the voltage as shown in Eq. (6), where $f_a(t)$, $f_b(t)$ and $f_c(t)$ represent the electromagnetic transient in the signal.

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \begin{bmatrix} V_{ma}\cos(wt) + f_a(t) \\ V_{mb}\cos\left(wt - 2\pi/3\right) + f_b(t) \\ V_{mc}\cos\left(wt + 2\pi/3\right) + f_c(t) \end{bmatrix} \quad (6)$$

These changes in voltage waveform generate changes in the current waveform, since the objective of the research shown in this paper is to detect faults (which can be represented as electromagnetic transients), it is important to develop an algorithm capable of differentiating between non-failed events and faults. When analyzing the current and voltage signals in the dq0 reference frame, during conditions of normal behavior, these signals can be represented as constant functions as shown in Eq. (7), where θ is the starting angle, which is set to 0 for practical uses and V_m is the amplitude of the signal.

$$v_0 = 0$$
$$v_d = \frac{\sqrt{6}}{2} V_m \cos(\theta) \quad (7)$$
$$v_q = -\frac{\sqrt{6}}{2} V_m \sin(\theta)$$

Using Eq. (2) over the components of Eq. (7) it is clearly seen that in normal conditions, the Park's vector modulus is going to be a constant, however when a fault occurs, a waveform signal appears both in voltage and current PVM. The analysis of the PVM of a signal