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Rapid Transient Detection of Switching With the Aim of Improving Power Quality Using Wavelet Transform

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Extended Abstract

Today due to the increasing consumption of electrical energy and the use of non-linear loads that create transient regime states in distribution networks, analysis of power quality for energy sustainability in power networks has become more important. Transients are often created by energy injection through switching or lightning and make changes in voltage and nominal current. Sudden increase or decrease in voltage or current makes characteristics of the transient regime. This paper investigates and identifies capacitor bank switching, which is one of the causes of oscillatory transient regime states in distribution network, using wavelet transform. By identifying the switching current of capacitor bank and the internal fault current of the transformer to prevent the unnecessary outage of differential relay, it will propose a new smart method. The accurate performance of this method is shown by simulation in EMTP and MATLAB

Introduction

It is important to study power system stability, and power engineers try to make the system better and more sustainable. In this regard, studying power systems in the stationary and transient states is very important. Sudden decrease or increase in voltage or current makes the transient characteristics of the regime. Transient regime is a part of a variable changes that disappears during the transition from a steady condition to another. Generally transients are divided into two categories: impact and oscillatory. The dominant cause of oscillatory transient is switching and the dominant cause of impact transient is lightning. The use of parallel capacitor banks in the network is inevitable according to a variety of applications including reducing power dissipation, voltage control, and increasing system capacity. However, when connecting to the network, parallel capacitor banks create a transient state in the system which can reduce power quality if the transient is not properly detected [1].

Studying transient states in power systems is one of factors that can help figure out how to protect power transformers and other network equipment and how to insulate them and design relevant insulation equipment. The parallel capacitor bank switching is one of the most important factors that cause transient states in distribution networks. If this capacitor bank switching occurs at the voltage moment of 90 degrees, it leads to excess current of the second transformer which can lead to failure to detect this current by the differential relay, and differential relay identifies this current as an internal fault and commands to cut the breakers at both ends of the transformer and causes unwanted outage in the distribution system. This affects the power quality and reliability of the network. Thus it is necessary to separate and detect the time and location of this type of transients in order to avoid

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unnecessary outage of the differential relay and contribute to the network stability and reliability [2]. In [3], a method is used based on calculating the disturbance energy caused by capacitor bank switching in a time period. The disadvantage of this method is the use of three-phase voltage and current to calculate disturbance energy. [4] Using the Kalman filter, the location and excess increase of the voltage of capacitor bank switching are identified. In [5, 6], a method is suggested based on the identification and classification of power disturbances using fuzzy logic and genetic algorithm. Its disadvantage is the long duration of calculation. In [7], a method is proposed based on the classification of power disturbances using neural network. Its disadvantage is that it requires training data and the network training is time-consuming. Recently wavelet transform was used to detect the time, location and disturbance classification of power quality. In [8], a method is provided that combines wavelet transform and neural network. In [9], a combination of wavelet transform and fuzzy logic is used for the identification and classification of the power quality of disturbances. Their benefit is the use of wavelet transform to reduce data and computing time compared to the previous methods. In this paper, we investigate and determine the switching capacitor bank that was one of the causes of making the states of isolation transient in distribution networks by using wavelet transform, identify switching capacitor banks and internal fault current of transformer we present a new and intelligent algorithm to prevent cutting the differential relay. Finally, we simulate this algorithm in IEEE standard 14 base system and we show results by using MATLAB and EMTP software's.

I. WAVELET TRANSFORM

A multi-scale feature makes wavelet and signal able to transform and analyze to a number of features. We can use this feature to separate the internal fault of Trans from capacitor switching bank [9]. The process of multi-resolution analyzing of signal $X[n]$ is illustrated in figure 1. Each stage includes two digital filters and two sampling rate reducer. The first filter g[.] is a main discrete wavelet which is originally overpass and the second one h[.] is symmetry of the first one and low past. The outputs of these filters create the component D1 and estimation A1, respectively. Estimation A1 analyzes again and proceed as figure 1. All wavelet transformations can be distracted by low pass filter h which comply the condition of standard symmetric filter.

$$H(z)H\left(z^{-1}\right)+H(-z)H\left(-z^{-1}\right)=1$$

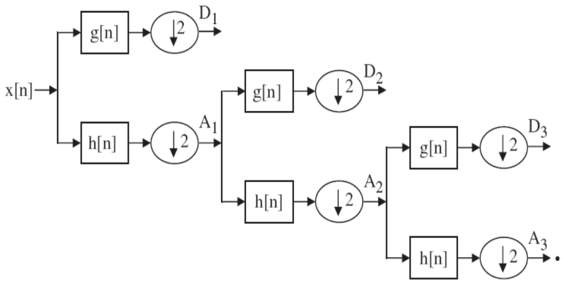

Figure 1. Analyzing the band of discrete wavelet transformation, g[n] is overpass filter and h[n] is a low pass filter.

H(z) is the z transformation of filter h. The complement of its overpass filter is defined as follows:

$$G(z)=zH\left(-z^{-1}\right)$$

By increasing the length (I Indices) a sequence of filters is concluded as follows:

$$H_{i+1}(z)=H\left(z^{2^{i}}\right)H_{i}(z)$$

$$G_{i+1}(z)=G\left(z^{2^{i}}\right)H_{i}(z),\quad i=0,\ldots,I-1$$

Using the basic condition $H_0(z)=1$ it can be converted to following double-scale relation:

$$h_{i+1}(k)=[h]_{\uparrow 2^{i}}*h_{i}(k)$$

$$G_{i+1}(k)=[g]_{\uparrow 2^{i}}*h_{i}(k)$$

Indices m shows the sampling rate increasing with factor m and k has been sampled equally in a discrete time. The wavelet is normalized and scale functions $\varphi_{i,l}(k)$ and $\psi_{i,l}(k)$ are defined as follows:

$$\varphi_{i,l}(k)=2^{i/2}h_{i}\left(k-2^{i}l\right),\quad \psi_{i,l}(k)=2^{i/2}g_{i}\left(k-2^{i}l\right)$$

The factor $2^{1/2}$ is the inner product of normalization. i and 1 are scale parameter and reverse parameter, respectively. Analyzing of discrete wavelet transformation is shown in relation (6):

$$a_{(i)}(l)=x(k)*\varphi_{i,l}(k),\quad d_{(i)}(l)=x(k)*\psi_{i,l}(k)$$

$a_{(i)}(l)$ and $d_{(i)}(l)$ are the estimation coefficients and partial coefficients, respectively

II. PROPOSED ALGORITHM

Since the differential relay is used for protecting internal fault of Trans, it should only protect the Trans against internal fault and do not react into other faults which are temporary, such as transients caused by capacitor bank switching. Therefore, separation of these two is essential for stability and power quality. It has been shown in [10, 13, 14] that the family of db are appropriate in using the analysis of electronic signals by wavelet transformation. Indeed, because of the proximity of Switching current slope and internal current of Trans, wavelet db1 is able to separate them from each other. In this article using two following principles we investigate and analyze the differential current of Trans:

To find the starting point of switching we use level D1, as we can observe the fastest changes and frequencies in this level.

To separate the internal current from the capacitor bank switching current, we use level D5 because of slowness of frequency changes and more clarity of signal components.

According to figures 1-3 and 2-3, we realize that the internal fault current with less slope and more time is increasing compared with the capacitive switching current. Hence, it is expected that the internal fault current of Trans has less frequency and domain than capacitive switching current. On the other hand, at the moment of switching, because of the more slope of capacitive switching current in comparison with internal fault of Trans, more frequency and domain are expected. [11, 12].

In this article, according to the fact that the capacitive switching current has a high slope at the moment of switching, we use db1 because of sensitivity of main wavelet to sharp changes.

Figure 3-3 illustrates the signal of internal fault of Trans which is taken from 5 levels of decomposed wavelet alteration.

In figure 4-3 five levels of the decomposed wavelets alternation are taken from the signal of capacitor bank switching.

The process is as follows, according to two started principles, first we analyze the signal of differential current of trains in all three phases with db1 in level D1 and A5. We use level D1 to distinguish the moment of fault occurrence or switching capacitor and then investigate the first two peaks from this point. Even if in one phase the first peak named X is less than the second peak named Y, the internal fault current and relay commands breakers to cut the current and if it was more than Y, relay doesn’t command to cut the current. The algorithm of this process is shown in figure 6-3.

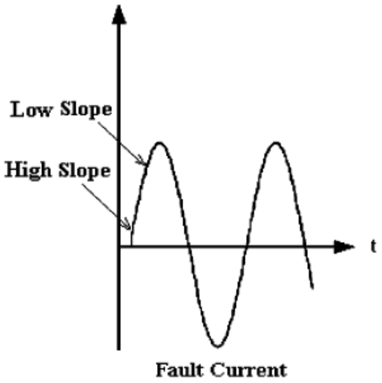

Figure 3-1. :Differential current of internal fault of Trans.

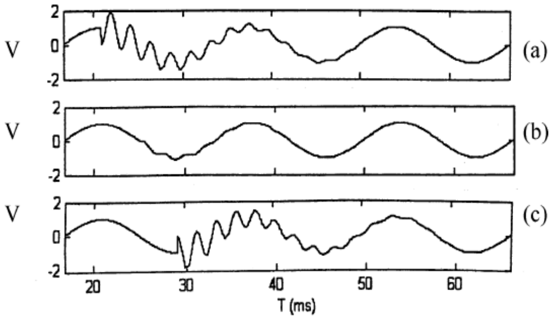

Figure 3-1. :Transient caused by capacitor switching bank.

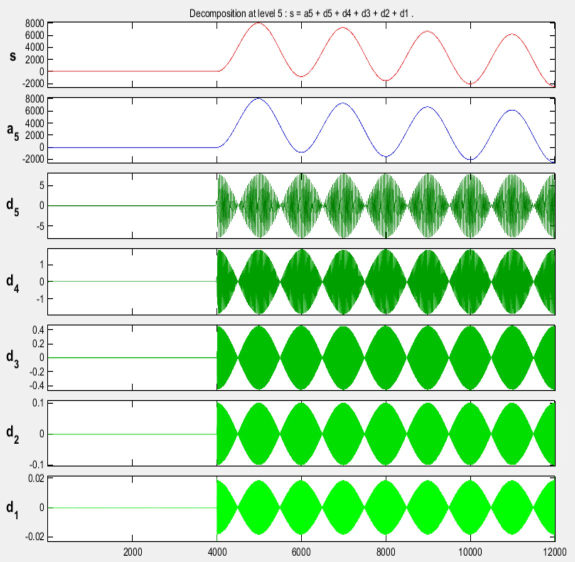

Figure 3-3. :Transformation of discrete wavelet of internal fault signal of Trans at 0.04 second.

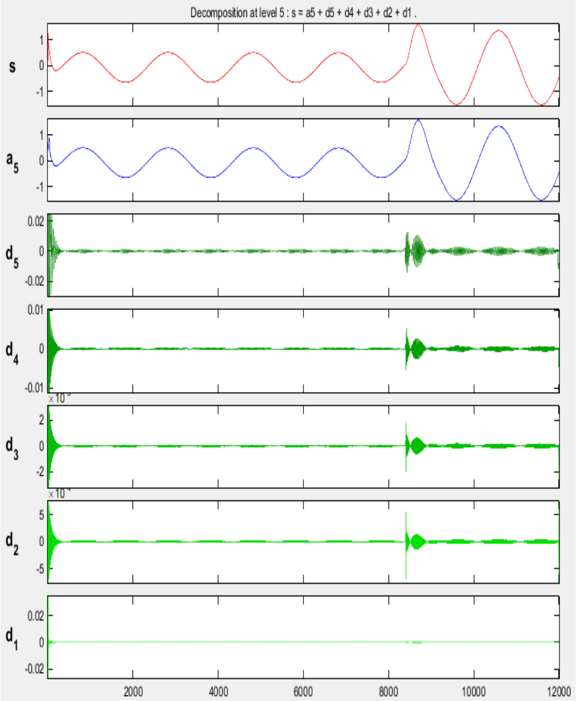

Figure 3-4:. Transformation of discrete wavelet taken from switching current signal at 0.84 second.

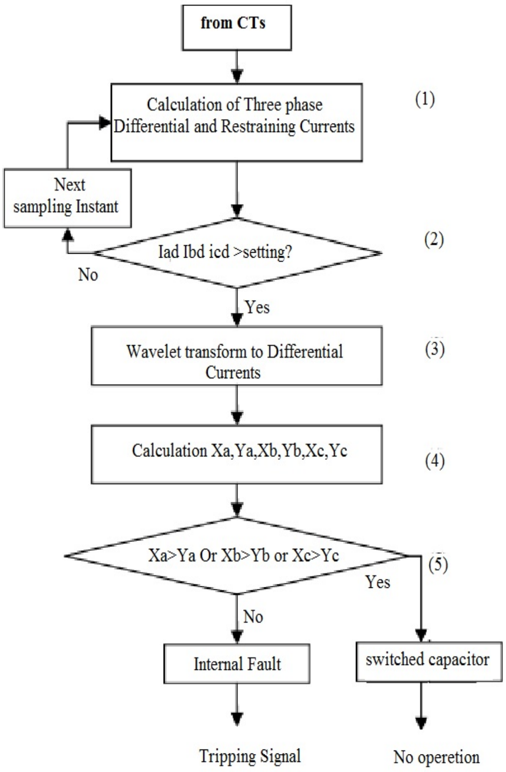

Figure 3-6.: Current chart of distinction of internal fault from capacitor switching bank.

III. SIMULATION

To obtain the information needed for the proposed algorithm, the power system of figure 1-4 which includes a voltage source, a distribution Trans, current trances, three loads and three capacitors for power factor correction, and is simulated in two software's EMTP and MATLAB is used. The values related to each element are listed in Appendix A. To achieve the validity of proposed algorithm, we studied five type of current faults in power system in part 4 and proved the validity of algorithm in all types.

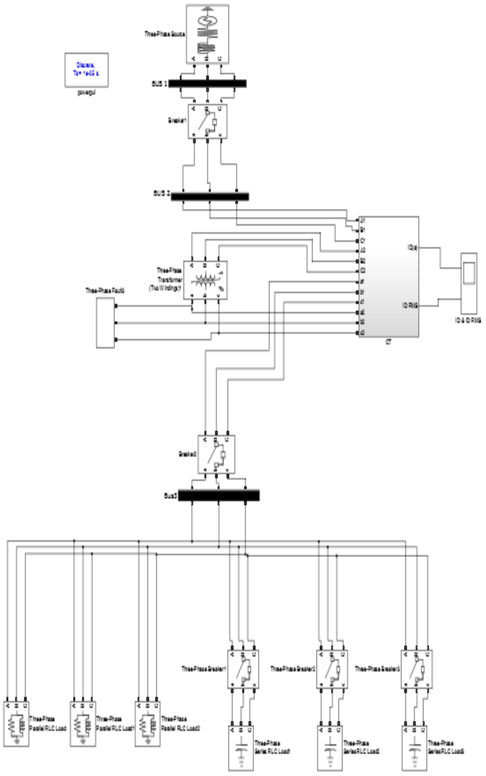

Figure 4-1.: A sample of assimilated orbit.

A. The additional current caused by capacitive switching bank

To investigate the proposed algorithm we generate an additional current caused by capacitive bank switching in stimulated orbit in 0.840 seconds, which is the peak of voltage of phase a (figure 1-1-4). At the time of 0.840 when changes are at level D1 we check it again. In figure (2-1-4) magnifying at level D5 we realize, which is according to the algorithm, a current caused by capacitive bank switching and relay doesn`t command to cut the current.

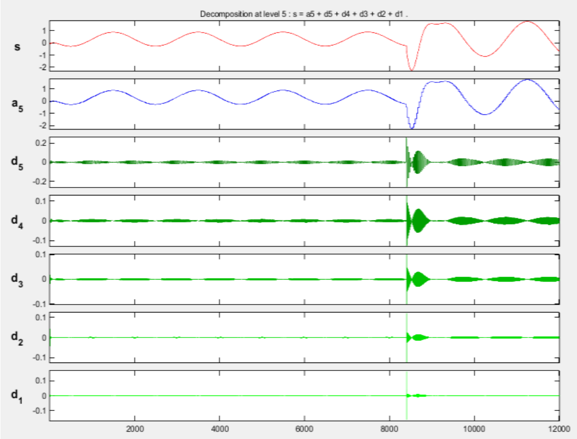

Figure 4-1-1.: Additional current caused by capacitor switching bank of phase a.

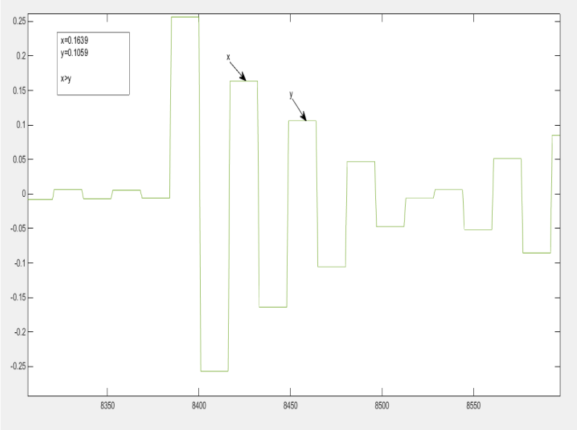

Figure 4-1-2:. Magnifying the current caused by capacitor switching bank at the moment of 0.04 second.

B. Internal fault of signal phase to ground

To investigate algorithm, fault of one phase on the ground was tested. In this part we study an fault at the moment of zero voltage in phase a, as the most amount of short circuit is accrued at this moment. Fault current and wavelet transformation of ingle-phase fault on the ground is shown in figure 1-2-4. Using level D1the time of beginning of fault determined. As we can see in the future, at 0.04 second, a quick change in wave shape is occurred. In figure 2-2-4, magnifying in 0.04 second at D5 we call the first two peaks by X and Y. According to the algorithm, it can be attained that. Therefore, this transient is a transient caused by internal fault and relay commands to cut the current.

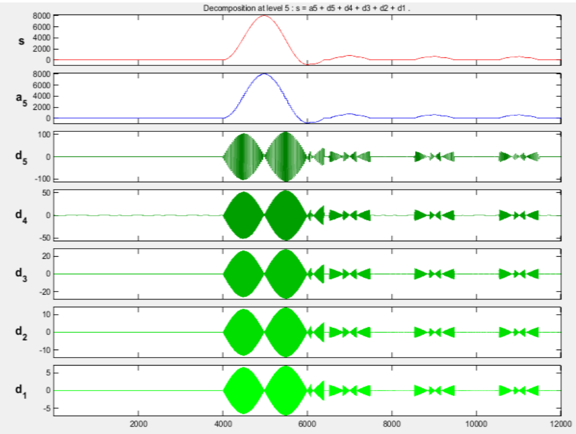

Figure 4-2-1. :Wavelet transformation of fault of phase a.

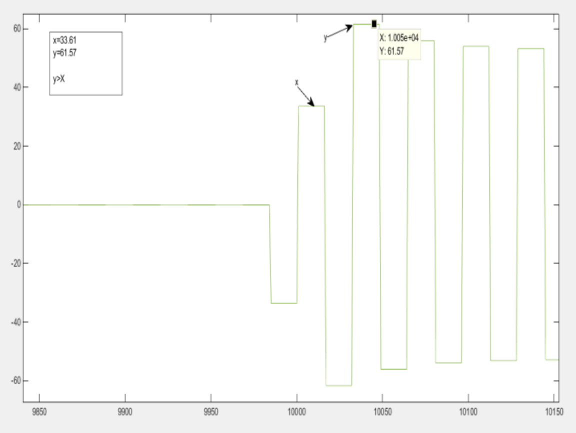

Figure 4-2-2. :Internal fault magnification

C. Internal fault of Two-phase

To investigate algorithm, internal fault of two phases on the ground was tested. In this part we study on fault at the moment of zero voltage in phase a and b, as the most amount of short circuit is occurred at this moment. Fault current and wavelet transformation of two-phase fault on the ground is shown in figure (1-3-4). Using a level D1 the time of beginning of fault is determined. In figure (3-2-4), magnifying in 0.04 second at D5 we call the first two peaks by X and Y. According to the algorithm, it can be attained that. Therefore, this transient is a transient caused by internal fault and relay commands to cut the current.

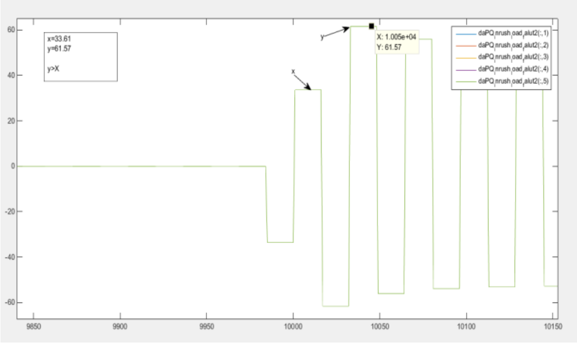

Figure 4-2-1. :Wavelet transformation of fault of two-phase.

D. Fault of two-phase to ground

To investigate algorithm, fault of one phase was tested on the ground. In this part we study on fault at the moment of zero voltage in phase a. Fault current and wavelet transformation of single-phase fault on the ground is shown in figure (4-4-1). Using the level D5 the time of beginning of fault is determined. As we can see in figure, at 0.04 second, a quick change in wave shape is occurred. In figure (4-4-1) we call the first two peaks by X and Y. According to the algorithm, it can be observed that $X < Y$ which caused by internal fault.

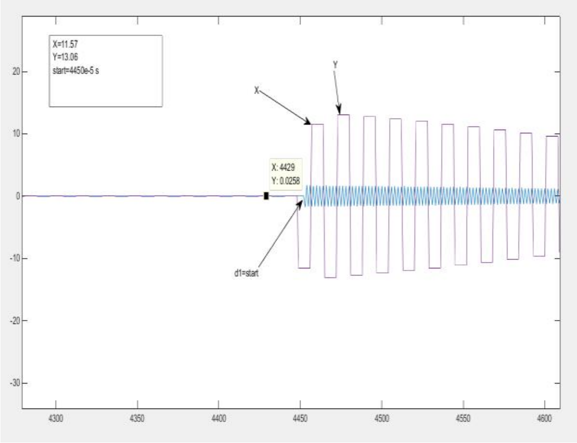

Figure 4-4-1. :Wavelet transformation of two-phase internal fault current to ground.

E. Fault of Three -phase

To investigate algorithm the fault of one phase was tested on the ground. In this part we study the fault at the moment of zero voltage in phase a and at the moment of 120 in phase b and c. Fault current and wavelet transformation of single-phase on the ground is shown in figure 4-5-1. Using level D1 we can determine the time of beginning of fault. As we can observe in figure, at 0.04 second, a quick change in wave shape is occurred. In figure (4-5-1) in part D5 we call the first two peaks by X and Y which can be found out that $X < Y$ according to algorithm. Hence, this transient is caused by internal fault and relay commands to cut the current.

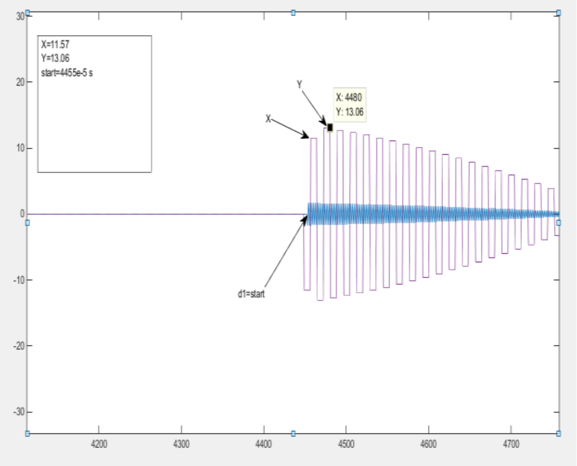

Figure 4-5-1. :Wavelet transformation of internal fault current of three-phase

F. Fault of Three-phase to ground

To investigate algorithm, fault of three phase on the ground was tested. In this part on fault at the moment of zero voltage was studied in phase a. Fault current and wavelet transformation of single-phase fault on the ground is shown in figure (4-6-1). Using level D1 the time of beginning of fault can be determined. As we can see in figure (4-6-1), at 0.04 second, a quick change in wave phase is occurred. In figure (4-6-1) at D5 we call the first two peaks by $X < Y$. Hence, this transient caused by internal fault and relay commands to cut the current.

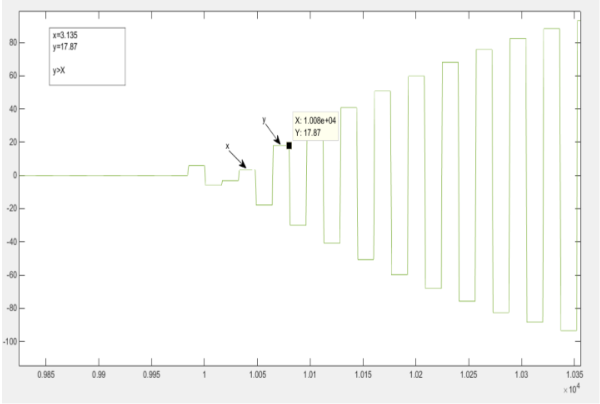

Figure 4-6-1.: Wavelet transformation of three-phase internal fault current to ground.

G. Investigating the proposed algorithm in network IEEE 14 bas

In order to ensure the validity of our proposed algorithm, the algorithm was tested and studied in standard network IEEE 14 bas and in all types, the fault and current of switching was checked. The results of using the algorithm in al cases of internal fault and transient caused by capacitor bank switching, are listed in table 4-7.

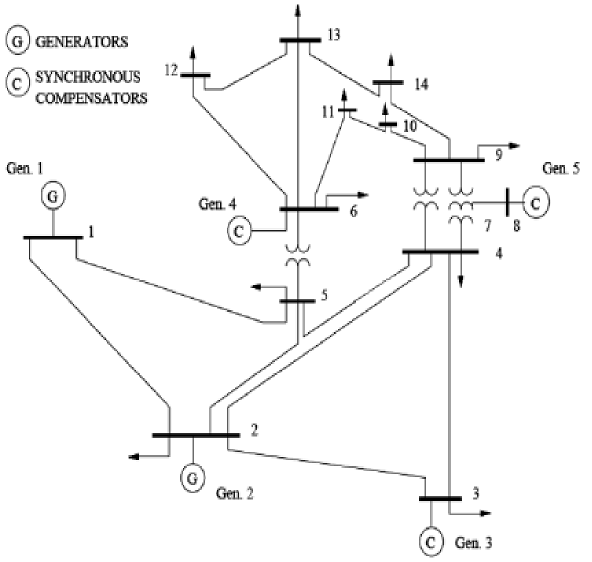

Figure 4-7. :Standard network IEEE 14 bas.

Table 4-7.: Results related to testing the algorithm in 14 bas network.

Type inrush current	phase	Fault time	X value	Y value	Test algorithm	Result
capacitor banks Switching	A	۹۰	۰.۰۰۱۳۸	۰.۰۰۰۲۸۱	X>Y	NO Fault
	B	۲۱۰	۰.۰۰۱۵۹	۴.۶۳۶E-۵	X>Y	
	C	-۲۱۰	۰.۰۰۱۳۸	۰.۰۰۰۲۸۳	X>Y	
One phase-to-ground fault	A	۰	۰.۰۳۱۵۱	۰.۰۳۸۳۶	X<Y	Fault
	B	-	-	-	-	
	C	-	-	-	-	
Two phase	A	۰	۰.۰۱۲۸۵	۰.۰۱۴۴۱	X<Y	Fault
	B	۱۲۰	۰.۰۱۲۹۴	۰.۰۱۴۴۸	X<Y	
	C	-	-	-	-	
TWO phase-to-ground fault	A	۰	۰.۰۱۴۸۶	۰.۰۱۶۶۶	X<Y	Fault
	B	۱۲۰	۰.۰۴۲۴۸	۰.۰۴۲۱۲	X>Y	
	C	-۱۲۰	-	-	-	
Tree phase	A	۰	۰.۰۰۷۳۲	۰.۰۰۵۰۶۹	X>Y	Fault
	B	۱۲۰	۰.۰۳۳۱۱	۰.۰۳۳۹۵	X<Y	
	C	-۱۲۰	۰.۰۴۰۴۳	۰.۰۳۹۰۲	X<Y	
Tree phase-to-ground fault	A	۰	۰.۰۱۴۸۶	۰.۰۱۶۶۵	X<Y	Fault
	B	۱۲۰	۰.۰۴۲۴۸	۰.۰۴۲۱۵	X>Y	
	C	-۱۲۰	۰.۰۴۰۴۸	۰.۰۳۹۰۶	X>Y	

Conclusion

In this paper, using wavelet transformation we proposed an approach based on the difference between the slope of internal fault current of trans and invasion current of capacitor bank switching which is able to distinguish the cycle of internal fault current from invasion current of capacitor bank switching. The result concluded from the simulated information show that the proposed algorithm is a precise algorithm to provide diffential protecting. Moreover, in all cases the time of fault occurrence was distinguished in less than quarter of time which shows it`s high rate. These days due to the overdevelopment and emerging of new technologies and sensitive tools, and also introducing new discussions of Privatization, necessity of more precise surveying of these transient is unavoidable. In this paper, the problem issued from capacitor bank switching was studied from the view of protecting tools and power quality problems and some new and quick approaches were proposed to conquest of problems using wavelet transformation.

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