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Proposed Suitable Methods to Detect Transient Regime Switching to Improve Power Quality with Wavelet Transform

Javad Safaee Kuchaksaraee*, Soodabeh Soleymani, Babak Mozafari

Department of Electrical Engineering, Science and Research
Branch, Islamic Azad University, Tehran, Iran

Study Area: Tehran, Iran

Coordinates: 35.6892° N, 51.3890° E

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Abstract

The increasing consumption of electrical energy and the use of non-linear loads that create transient regime states in distribution networks is increasing day by day. This is the only reason due to which the 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 shed some lights on the capacitor bank switching, which is one of the main causes for oscillatory transient regime states in the distribution network, using wavelet transform. The identification of the switching current of capacitor bank and the internal fault current of the transformer to prevent the unnecessary outage of the differential relay, it propose a new smart method. The accurate performance of this method is shown by simulation in EMTP and MATLAB (matrix laboratory) software.

Introduction:

It is important to study power system stability, and thus constant efforts are applying 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 regime characteristics. The Transient regime is a part of a variable change that disappears during the transition from a steady condition to another. Generally, transients are divided into two categories: impact and oscillatory. The main cause of oscillatory transient is switching whereas the lightning is the main cause for impact transient. 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, as per report of the IEEE (1992) 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.

Studying transient states in power systems is one of the factors that can help to figure out that how to protect power transformers and other network equipment and

how to insulate them and/or design other 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. Further, the differential relay identifies this current as an internal fault and commands to cut the breakers at both ends of the transformer and causes the 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 such unnecessary outage of the differential relay and contribute to the network stability and reliability (Soodabeh & Soleymani, 2014).

The transient states of a power system are the non-periodic signals. It is notable that the Fourier transform is defined for the periodic signals. Therefore, the Fourier transform is not a suitable method for analyzing the transient states of a power system. In other words, the Fourier transform is usually used for the steady states of a power system.

*Corresponding Author: j_safaee@yahoo.com

A method is also in use which is based on calculating the disturbance energy caused by capacitor bank switching in a time period (Parsons *et al.*, 2000). The disadvantage of this method is the use of three-phase voltage and current to calculate disturbance energy. Using the Kalman filter, the location and the excess increase of the voltage of capacitor bank switching could be identified (Kim *et al.*, 2002). A method based on the identification and classification of power disturbances using fuzzy logic and the genetic algorithm has also been forwarded (Boris & Peter, 2006; Wang & Tseng, 2011). Its disadvantage is to require a long duration of calculation. A method was also proposed by Abu-Elanien & Salama (2009) based on the classification of power disturbances using the neural network. However, it requires training data and the network training is time-consuming due to which it disqualify. Recently, wavelet transform has also been used to detect the time, location and disturbance classification of power quality. Mohammadi *et al.*, 2013a forwarded a method that combines wavelet transform and neural network. A combination of wavelet transform and fuzzy logic is used for the identification and classification of the power quality of disturbances (Karthik *et al.*, 2011). Their benefit is to use of wavelet transform to reduce data and computing time compared to the previous methods.

In the present study, we investigate and determined the switching capacitor bank which is 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 the transformer. We have tried to present a new and intelligent algorithm to prevent cutting the differential relay. We simulated this algorithm in IEEE standard 14 base system and found results by using MATLAB and EMTP softwares.

Wavelet Transform (a):

A multi-scale feature makes wavelet and signals able to transform and analyze the number of features. We could use such features to separate the internal fault of Trans from capacitor switching bank (Karthik *et al.*, 2011). The process of multi-resolution analyzing of a signal is illustrated in fig.: 1. Each stage includes two digital filters and two sampling rate reducer. The first filter $g[\cdot]$ is a main discrete wavelet which is originally overpass and the second one $h[\cdot]$ is the symmetry of the first one with low past. The outputs of these filters create the component D_1

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

and estimation A_1 , respectively. Estimated A_1 analyzes again and proceed as fig.: 1. All wavelet transformations can be distracted by low pass filter h which complies the condition of the standard symmetric filter.

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

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

$$(2) \quad G(z) = zH(-z^{-1}) = 1$$

By increasing the length (1 Indice) a sequence of filters is concluded as follows:

$$H_{i+1}(z) = H(z^2) = H_i(z)$$

$$(3) \quad G_{i+1}(z) = G(z^2) = H_i(z), \quad i=0, \dots, I-1$$

Using the basic condition it can be converted to following double-scale relation:

$$(4) \quad h_{i+1}(k) = [h] \uparrow 2^i * h_1(k); \quad G_{i+1}(k) = [g] \uparrow 2^i * h_1(k)$$

Indice 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 $\phi_{i,1}(k)$ and $\psi_{i,1}(k)$ are defined as follows:

$$(5) \quad \phi_{i,1}(k) = 2^{-i/2} h_1(k-2^i); \quad \psi_{i,1}(k) = 2^{-i/2} g_1(k-2^i)$$

The factor $\cdot$ 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):

$$(6) \quad a_{(i)}(l) = x(k) * \phi_{i,1}(k); \quad d_{(i)}(l) = x(k) * \psi_{i,1}(k);$$

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

Proposed Algorithm (b):

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 reported by Mohammadi *et al.* (2013b) that the family of db is 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 investigated and analyze the differential current of Trans:

1. To find the starting point of switching, we used level D_1 , as we can observe the fastest changes and frequencies in this level.
2. To separate the internal current from the capacitor bank switching current, we used level D_5 because of the slowness of frequency changes and more clarity of signal components.

According to figures 1 & a-3, we realized 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. Inspite of it, at the moment of switching, due to more slope of capacitive switching current in comparison with an internal fault of Trans, more frequency and domain are expected (Guzman *et al.*, 2001; Kanitpanyacharoen & Premrudeepreechacharn, 2004).

As per the situation that is the capacitive switching current

has a high slope at the moment of switching, in this article we used db1 because of the sensitivity of main wavelet to sharp changes. Fig.:b-3 illustrates the signal of an internal fault of Trans which is taken from 5 levels of decomposed wavelet alteration.

In fig.: c-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 analyzed the signal of differential current of trains in all three phases with db1 in level D1 and A5. We used 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

Figure:b-i. Differential current Figure:b-ii. Transient caused by of internal fault of Trans. capacitorswitching bank.

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

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

Figure:b-i. Transient caused by capacitorswitching bank.

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 fig.:e-3.

Simulation (c):

In order to gaining the information required 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 softwares EMTP and MATLAB (matrix laboratory) 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: c-i. A sample of assimilated orbit.

The additional current caused by capacitive switching bank (c-i): to investigate the proposed algorithm we generated 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 checked it again. In figure (2-1-4) by magnifying at level D5 we realized, that according to the algorithm, a current caused by capacitive bank switching and relay doesn't command to cut the current.

Internal fault of signal phase to ground (c-ii): to investigate algorithm, the fault of one phase on the ground was tested. In this

Figure:c-i-i.Additional current caused by capacitor switching bank of phase a.

Figure:c-i-i.Additional current caused by capacitor switching bank of phase a.

part, we studied a fault at the moment of zero voltage in phase a, as the most amount of short circuit occurred during the same moment. Fault current and wavelet transformation of single-phase fault on the ground is shown in figure 1-2-4. Using level D1 the time of beginning of fault determined. As we could see in the future, at 0.04 second, a quick change in wave shape occurs. In figure 2-2-4, magnifying in 0.04 second at D5 we called the first two peaks by X and Y. According to the algorithm, it could be attained that the same. Thus such transient is known to cause by internal fault and relay commands to cut the current.

Internal fault of Two-phase (c-iii)

To investigate algorithm, internal fault of two phases on the ground was tested. In this part we studied on fault at the moment of zero voltage in phase 'a' and 'b', as the most amount of short circuit was occurred at that 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 was determined. In figure (3-2-4), magnifying in 0.04 second at D5 we found the first two peaks by X and Y. According to the algorithm, it could be attained that the same. the transient is a transient caused by internal fault and relay commands to cut the current.

Fault of two-phase to ground (c-iv):

To investigate algorithm, the fault of one phase was tested on the ground. In this part, we studied on the 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 (c-iv-i). Using the level D5 the time of the beginning of fault is determined. As we can see in the figure, at 0.04 second, a quick change in wave shape occurs. In figure (c-iv-i) we saw the first two peaks by 'X' and 'Y'. According to the algorithm, it could be observed that $X < Y$ which caused by an internal fault.

Fault of Three-phase (c-v):

To investigate algorithm the fault of one phase was tested on the ground. In this part, we studied 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 could determine

Figure:c-ii-i. Wavelet transformation of fault of phase a.

Figure:c-ii-ii. Internal fault magnification

Figure:c-ii-i. Wavelet transformation of fault of two-phase.

Figure:c-iv-i.Wavelet transformation of two-phase internal fault current to ground.

Figure:c-v-i.Wavelet transformation of internal fault current of three-phase.

the time of beginning of fault. As we can observe in the figure, at 0.04 second, a quick change in wave shape occurs. In figure (4-5-1) in part D5 we saw the first two peaks by 'X' and 'Y' which can be found out that according to an algorithm. Hence, this transient is caused by internal fault and relay commands to cut the current.

Fault of Three-phase to ground (c-vi):

To investigate algorithm, fault of three phase on the ground was tested. In this part of 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 (c-vi-i). Using level D1 the time of the beginning of fault could be determined. As we can see in figure (c-vi-i), at 0.04 second, a quick change in wave phase occurs. In figure (4-6-1) at D5 we saw the first two peaks by 'X' and 'Y'. Hence, this transient caused by internal fault and relay commands to cut the current.

Investigating the proposed algorithm in network IEEE 14 bus standard (c-vii): in order to ensure the validity of our proposed algorithm, the algorithm was tested and studied in standard network IEEE 14 bus standard and in all types, the fault and current of switching were checked. The results of using the algorithm in all cases of internal fault and transient caused by capacitor bank switching are listed in table 1.

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Figure:c-vi-i.Wavelet transformation of three-phase internal faultcurrent to ground. Figure:c-vii.Standard network IEEE 14 bas.

Table:1- Results related to testing the algorithm in 14 bas network.

Type inrush current	phase	Fault time	Xvalue	Y value	Test algo- rithm
Capacitor banks Switching	A	90	0.00138	0.000281	X>Y
	B	210	0.00159	4.636E-5	X>Y
	C	-210	0.00138	0.000283	X>Y
One phase-to- ground fault	A	0	0.03151	0.03836	X<Y
	B	-	-	-	-
	C	-	-	-	-
Two phase	A	0	0.01285	0.01441	X<Y
	B	120	0.01294	0.01448	X<Y
	C	-	-	-	-
TWO phase-to- ground fault	A	0	0.01486	0.01666	X<Y
	B	120	0.04248	0.04212	X>Y
	C	-120	-	-	-
Tree phase	A	0	0.00732	0.005069	X>Y
	B	120	0.03311	0.03395	X<Y
	C	-120	0.04043	0.03902	X<Y
Tree phase-to- ground fault	A	0	0.01486	0.01665	X<Y
	B	120	0.04248	0.04215	X>Y
	C	-120	0.04048	0.03906	X>Y

Conclusion and recommendations:

On this paper by 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. Conclusively, simulated information revealed that the proposed algorithm is a precise algorithm to provide differential 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 over development and emerging of new technologies and sensitive tools, and also introducing new discussions of Privatization, necessity of more precise surveying of this 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 a conquest of problems using wavelet transformation.

Given the problems caused by new requirements electrical energy is good quality, less research has been done that could be a new topic for further research. In this paper, the problems caused by the launch of the induction motor overcurrent relay examined. The effect of the following on the relays could be the subject of further research.

- No time switching lines
- Capacitor switching, both as single and back-to-back
- Capacitor switching, both as single and back-to-back.

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