IMPROVING THE PERFORMANCE OF A PROTECTIVE RELAY BASED ON DFT METHOD

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Abstract. *The real time application which controls in fact a protective relay working has to meet critical performance conditions provided by hard structure and software as well. As a software instrument, the Discrete Fourier Transform (DFT) was already successfully used by many designers. In spite of its excellent filtering qualities, DFT is not however recommended for high speed protection due to voltage and current transients existing during a short-circuit which corrupt in an unpredictable mode the periodic components detected by this method. A way to prevent this is to modify the DFT algorithm itself so the decaying d.c. component is rejected. The authors do propose a different solution based on supplementary digital filtering, inserted in the computational process previous to a standard DFT application, so that the undesired, nocive influence of transients is removed. This filter is a digital of high-pass type.*

Keywords**: protective relay, digital filter, discrete Fourier transform.**

1. Introduction

The input signals of a protective relay are subject of various steady and transient noise effects which can trouble the correct function of the device or lead to an unacceptable delay in the parameters system involved in the state estimation which are used to take the appropriate decision. Among these noises we can mention the inherent inductive/resistive behavior of the power system which produces transients in the post-fault regime. These transients have a significant effect in the current waveform and a much lesser influence in the voltage signals. Other particular properties of the power system (shunt capacitance of the feeders, capacitive series compensation) and analog part of the data acquisition system (nonlinearities of the instrument transformers and time response of the analog input filters) are also responsible for noise effects but they often are of lower importance.

Solving such problems reclaims the insertion of some appropriate filters. In many references such as [1], [2] and [3] the problems mentioned above are treated. The general way followed consists in preventing noises by filtering signals acquired by the relay system.

Referring to the digital filters it must be mentioned that these are subject to the general constraint that the amount of calculus has to be correlated with the hard device speed so that the relay can take the correct decision in an imposed time after the fault produced in the protected area of the power system.

2. Basic filters

In a digital protective relay there are two main categories of filters: analogue antialiasing filters and digital filters. The first has to reject or attenuate in a sufficient amount the components whose frequency is twice as the sampling frequency used by the analogue-digital converter. The second must rebuild the analogue information on the base of the samples acquired.

Generally speaking, the quality of a relay filter can be evaluated from different points of view such as:

- time response
- immunity to the power system frequency shift
- immunity to the dc offset of the measuring system
- immunity to the harmonics beyond a certain limit
- immunity to the exponentially decaying dc offset

Some of these performances are related one to each other so that optimizing one has benefits on the overall behavior.

This paper is focusing on the process of digital filtering.

Input data for a digital filter consists in a set of samples x_J, j=1...N covering a measuring window. Number N defines the length of the filter. The output for a finite impulse response filter (FIR) y at the discrete time n is:

$$y_n = \sum_{j=0}^{N-1} a_j x_{n-j} \qquad (1)$$

where a_j are the filter coefficients and the moment n is a multiple kT_s of the sampling period T_s.

In the case of an infinite impulse response filter (IIR) the output depends not only of the input samples but also of some previous output values:

$$y_n = \sum_{j=0}^{N-1} a_j x_{n-j} + \sum_{j=1}^{M} b_j y_{n-j} \qquad (2)$$

In the classic full-cycle Fourier algorithm, which is in fact a FIR filter, the coefficients are two series of sine and cosine values having arguments related to the sampling rate. So, for the fundamental having the period $T_0 = NT_s$ included in a wave, one can compute two rectangular components:

$$Y_c^{(n)} = \frac{2}{N} \sum_{j=0}^{N-1} x_{n-j} \cos \frac{2\pi}{\mathrm{N}} j \qquad (3)$$

$$Y_s^{(n)} = \frac{2}{N} \sum_{j=0}^{N-1} x_{n-j} \sin \frac{2\pi}{\mathrm{N}} j \qquad (4)$$

These permit to define amplitude and the phase of the representative fasor for the analog input sampled:

$$\left|Y^{(n)}\right| = \sqrt{\left(Y_c^{(n)}\right)^2 + \left(Y_s^{(n)}\right)^2} \qquad (5)$$

$$\varphi^{(n)} = \arctan \frac{Y_s^{(n)}}{Y_c^{(n)}} \qquad (6)$$

Similar relations are available for the harmonic components whose frequency is a multiple of the fundamental. So, in (2) and (3) for the k harmonic the arguments of the sine and cosine is multiplied by k.

The DFT is an efficient instrument for an accurate detecting of sinusoidal components contained in a wave. For this, the sampling frequency must be adapted to the actual frequency of the power system and the measured waves must be in steady-state (normal or fault regime). The first condition is most often implicitly assured by the power system automation which maintains the frequency values in a narrow band. In special situations the first above condition can be fulfilled by an adaptive system included in the relay which controls the network frequency and modifies accordingly the sampling rate. Taking into account the second condition is more difficult. The simplest solution is the least performant: waiting for the transients become unsignificant some periods after the fault occurs.

For protective relays which have to work in a high speed manner such a waiting state is not acceptable. This is the case of a distance relay whose first tripping stage has not to be delayed. Anyway, if not transients are present, the fastest decision based on DFT method can be derived only after a period elapsed from the fault moment. In other words, the moment of the fault has to be outside the measuring window.

Following the above reasons, results that, in spite of its filtering qualities, DFT alone is not however recommended for high speed protection due to voltage and current transients existing during a short-circuit which corrupt in an unpredictable mode the periodic component detected by this method. A way to prevent this is to modify the DFT algorithm itself so the d.c. component is to be rejected.

3. Main assumptions

We will consider a continuous signal containing a sinusoidal component of constant amplitude and an aperiodic one:

$$x(t) = X \sin(\omega_0 t + \varphi) + A \exp(-t/\tau) \qquad (7)$$

which represents the short-circuit current after a fault produced at t=0. The time constant τ is related to the inductance and resistance of the faulted network and is 1.5 times the period T_0 of the permanent sinusoidal component. In order to have a more relevant results the worst case will be taken into account, i.e. the fault occurs when the phase between the voltage and the current is $\pi/2$. In this condition the initial value of the aperiodic component has a maximum.

We will assume that the sampling rate is perfectly adapted to the period of the sinusoidal component so that $T_0=NT_s$. For N usual values of 20 and 40 will be considered, which means a sampling frequency of 1kHz and 2kHz respectively.

It must be noted that adding in (7) a set of harmonics of the fundamental does not affect the essential of the transient process.

Implicitly the antialiasing analogue filter is supposed to reject the sinusoidal components having frequency above the half of the sampling frequency. In fact, the usual cut-off frequency of the antialiasing filter is about five or seven times the power system frequency, i.e. 250 or 350Hz.

4. Testing DFT filter

The results presented here and in the next sections were obtained with a MATLAB program.

Fig.1 illustrates the transient of the short-circuit current in the particular case of a no load before fault.

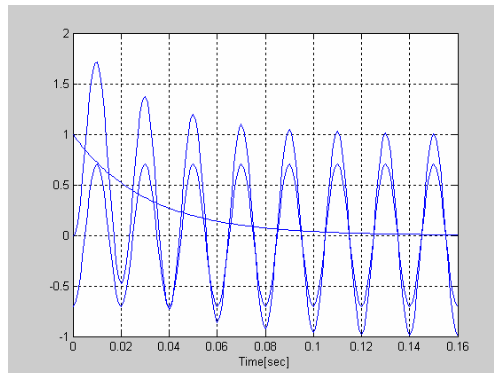

Fig. 1. Short-circuit current with a d.c. decaying component

Applying the standard full-cycle DFT algorithm leads to the permanent component amplitude presented in Fig.2.

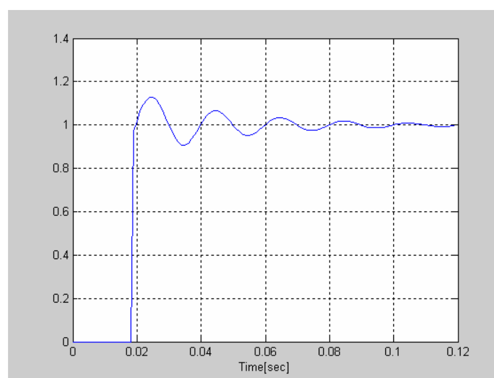

Fig. 2. Fundamental amplitude computed by DFT algorithm

It is obvious that the amplitude is seriously affected by the d.c. decaying component. At the inherent delay of 0.02s an extra-time has to elapse till a decision could be taken. This pattern will be considered as a term of comparison for the results obtained with an enhanced system of digital filtering studied below.

5. Improving filtering

The idea of improving the rejection property of the DFT is to insert a supplementary digital filter responsible with the eliminating the d.c. decaying component (Fig.3).

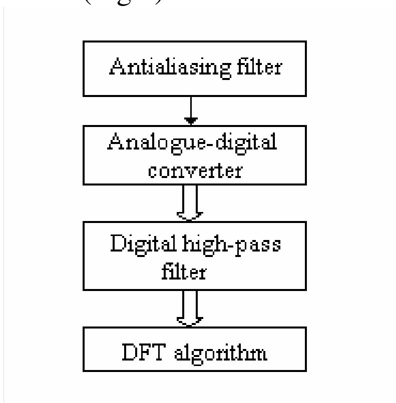

Fig.3. The enhanced filtering system

The distorting component being a d.c. one it results that the supplementary digital filter must be of high-pass type.

Theoretically, digital filtering can assure any required performances. For this, one must take into account a sufficient large amount of samples. In an on-line system, such a protective relay, the number of samples involved in the digital filtering process is restricted by the time performance itself.

In so doing, the design of the digital filter must be a trade-off between the rejection properties and the number of samples used, which has a direct equivalent in time performance.

As was mentioned above, there are two basic types of digital filters: IIR and FIR. The first is a digitized solution which follows the designing methods used with the analogue filters. The second is a way specific to digital filter implementation. We have investigated the both solutions for a high-pass filter.

A major inconvenient in solving the problem is that, from the point of view of a filter, the zero frequency of the d.c. component which is to be removed is very close to fundamental frequency (50 Hz). In fact, the basic structure of the filters were tried successively in order to find the best fitted parameters.

Here are some results obtained with two kind of high-pass filter.

As a FIR filter was selected a Blackman window sinc filter with the length of 18. The diagram in Fig.4 shows a good damping of oscillations. The delay is about two periods after the fault inception.

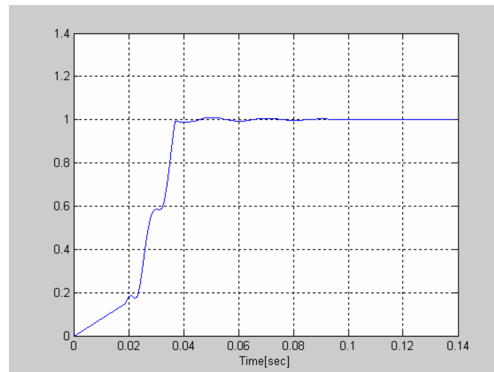

Fig.3. The amplitude detected by a Blackman window sinc filter and DFT algorithm

As a IIR filter was selected a Cebishev recursive filter with two poles and an imposed pass-band ripple of 4%. The diagram in Fig.5 shows a better damping of oscillations than that assured by the FIR filter. More important, the delay is about one period after the fault inception which is the minimum value in a DFT algorithm.

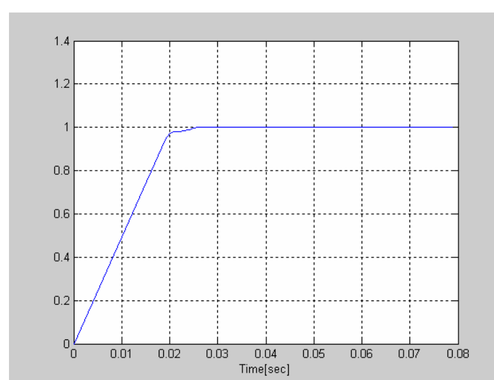

Fig.3. The amplitude detected by a Cebishev recursive filter and DFT algorithm

6. Conclusions

The simulation tests proved the efficiency of a supplementary digital filter which prepare a cleaner wave for the DFT method. This filter remove the d.c. decaying component present in the short-circuit current wave which can not be managed in a satisfactory manner by the DFT alone. Especially the recursive filter leads to a response near the limit involved by the DFT algorithm, i.e. a delay of about one period after the fault moment. This time performance could be considered sufficient for a high speed protective relay. To the outstanding performance assured by the Cebishev recursive filter must be added the little amount of arithmetic operations involved.

References

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