Algorithm for Elimination of DC Component from Fault Current

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Abstract. This paper describes a new algorithm for elimination of DC component in the current which appears during the fault condition in power system. The algorithm is very simple and convenient for implementation in numerical protection systems without rigid requirements on the speed of operation (medium voltage level feeder protections). This algorithm is described, the area of its possible application is emphasized, and the results of simulation conducted in MATLAB are given.

1 Introduction

The electric power system (EPS) becomes more complex each day. The requirements on the availability, as well as the stability of voltage and frequency which EPS system must comply become more rigid. The cost of undelivered kWh of electric power becomes significant asset [1]. In accordance to these facts, a special attention is being paid to control and guidance of EPS. From the point of control and guidance, the heaviest conditions are average regimes caused by short circuits. Wrong and delayed reaction to these conditions can cause system break down [2].
Important component of EPS are protection systems, which first react to the disturbances in the network. Their proper respond is of crucial importance. The protection systems are requested to discriminate the fault condition from temporal disturbance, not to react to changes caused by overload or switching of the load, transformers etc., but, at the same time, to quickly and selectively switch off the fault [3]. The existing systems of protection functions use various methods to determine parameters necessary to react (currents and/or voltages). The specific problems for proper operation of protection systems represent the transient processes [3],[4]. The transient process which appears in case of fault is usually followed by appearance of direct current component (DC), as a consequence of fast change in the network structure, as well as of existence of elements which accumulate energy (inductance, capacitance) in the network. Without further analysis of transient processes, it will be implied that two dominant types of components make up the current in case of fault: direct current component, and sinusoidal components [4]. The direct current possesses exponential shape with amplitude being dominant in the moment of fault, and tending to decline

with time constant τ. The time constant τ has values between 10ms to 100ms for high voltage networks [3] and from 10ms to 5s for medium voltage networks with isolated star junction [5]. It depends on the characteristics of the network, and the impedance of the fault. The time constant for transient process represents a variable and unknown parameter in principle. Sinusoidal components represent stationary current of fault and their higher harmonics, which arise as consequence of the existence of nonlinear elements in the network, so they are of importance to determine the necessary values for operation of protection systems. The existence of exponential component would produce an error in standard algorithms, which can cause a nonselective operation [4]. Therefore, the newer implementations of overcurrent protection devices use time delays of about 200ms even for I>>, what enables a considerable settling of transient process, and correct determination of amplitude and direction as well. If it is desirable to have proper information on fault current in time shorter than 200ms, it is necessary to suppress the direct current component in the fault current.

2 Description of the Algorithm

If line is represented by R,L elements, according to Fig.1., then the current i(t), which flows in the moment of fault can be defined according to the (1) [4]:

$$i(t) = A_0 e^{-\frac{t}{\tau}} + \sum_{k=1}^{N} A_k \sin(k\omega t + \beta_k) = i_e(t) + i_s(t) \qquad (1)$$

where $\tau = \frac{L}{R}$ represents the time constant of the line, $A_k = \frac{V_m}{\sqrt{R^2 + (k\omega L)^2}}$ amplitudes of harmonics in the fault current and $\beta_k = \alpha - \arctan(\frac{k\omega t}{R})$ the angle of harmonic components in the current in the moment of fault.

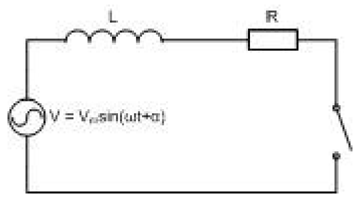

Figure 1. The model of line

The shape of the total current i(t), exponential component $i_e(t)$ and stationary current of fault $i_s(t)$, in case that the component $i_s(t)$ contains only fundamental frequency cycle, is shown in Fig. 2.

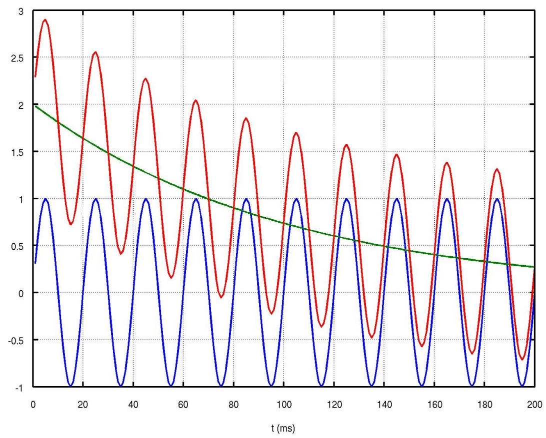

Figure 2. The components of current of fault with exponential component

In order to determine the direct current, we can use the fact that stationary current of fault represents a sum of sinusoidal components, with mean value on basic period T_0 equal to zero. The mean value of signal of fault current on the basic period T_0 can be represented as:

$$\overline{i(t)} = \frac{1}{T_0}\int_{t-T_0}^{t} i(t)dt \qquad (2)$$

If we multiply the (2) by the period of the fundamental frequency cycle (T_0), and substitute the expression for fault current from (1), we have:

$$T_0 \cdot \overline{i(t)} = \int_{t-T_0}^{t} i(t)dt = \int_{t-T_0}^{t} (i_s(t)+i_e(t))dt = \sum_{k=1}^{N}\left(\int_{t-T_0}^{t} A_k \sin\left(\frac{2k\pi}{T}t\right)dt\right) + \int_{t-T_0}^{t} A_0 e^{-\frac{t}{\tau}}dt.$$

The first part of the expression above equals to zero, so only the second part remains.

$$T_0 \cdot \overline{i(t)} = A_0 \int_{t-T_0}^{t} e^{-\frac{t}{\tau}}dt = A_0(-\tau)e^{-\frac{t}{\tau}}\Big|_{t-T_0}^{t} = -A_0\tau\left(e^{-\frac{t}{\tau}} - e^{-\frac{t-T_0}{\tau}}\right) = A_0\tau e^{-\frac{t}{\tau}}\left(e^{\frac{T_0}{\tau}} - 1\right)$$

Follows:

$$T_0 \cdot \overline{i(t)} = A_0 e^{-\frac{t}{\tau}}\left(\tau\left(e^{\frac{T_0}{\tau}} - 1\right)\right) = i_e(t)\cdot\tau\left(e^{\frac{T_0}{\tau}} - 1\right)$$

The value of exponential component in the fault current can be determined from the expression:

$$i_e(t) = \frac{T_0 \cdot \overline{i(t)}}{\tau\left(e^{\frac{T_0}{\tau}} - 1\right)} = C \cdot \overline{i(t)} \qquad (3)$$

where C represents a no dimensional parameter, which depends on the time constant for the line τ, and which is given in the (4).

$$C = \frac{T_0}{\tau\left(e^{\frac{T_0}{\tau}} - 1\right)} \tag{4}$$

Depending on the variation of the time constant τ, the value of the parameter C varies from 0.9 (for the time constant value τ=0.1 sec) to 1 (for the time constant value τ>5 sec).

According to the (3), the value of exponential component can be calculated, knowing the value of time constant. Knowing the exponential component, it is possible to extract the fault current from the input signal:

$$i_s(t) = i(t) - i_e(t) = i(t) - C \cdot \overline{i(t)} \tag{5}$$

Since the time constant represents the unknown and variable parameter in principle, and since C represents a function of this constant, it is necessary to estimate C from the signal after the fault.

If C=1 was taken which represents the limit value for very big time constant (Fig. 3), then the mean value of signal on the period T_0 could be taken as value of the exponential component in the moment t_2 (Fig. 4). Since the mean value of sinusoidal signal on the period T_0 equals to zero, the calculated mean value of signal in this point corresponds to the mean value of the exponential signal at the interval (t_1,t_2), which in fact is equal to the period T_0.

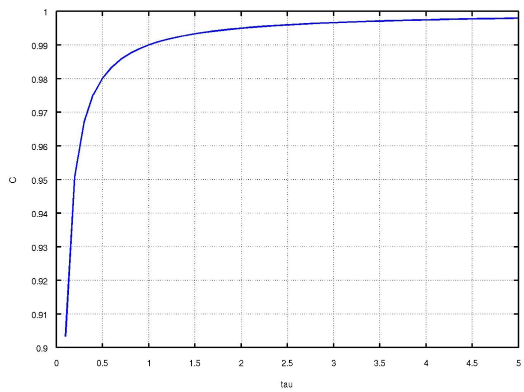

Figure 3. The dependence of parameter *C* on time constant of the line

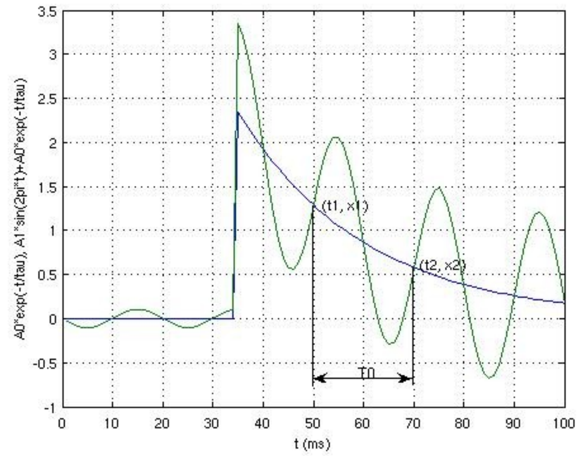

Figure 4. Determination of parameter *C*

If we approximate the exponential signal at the interval (t_1,t_2) by linear function, then the calculated mean value in the moment t corresponds to the value of approximated exponential component in the moment which for a half or the period (T_0) precedes the moment of calculation (t). Since the mean value of the signal in the moment t-T_0/2 is known, by calculating the difference between these two values the value of error of calculation of the exponential component can be determined.

Finally, the expression for exponential component with the mentioned linear approximation can be given as:

$$i_e(t) = \overline{i(t)} - ((\overline{i(t - T_0/2)} - \overline{i(t)}) = 2 \cdot \overline{i(t)} - \overline{i(t - T_0/2)} \quad (6)$$

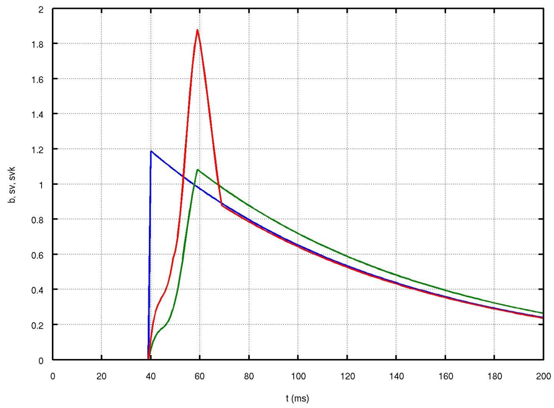

Figure 5. The results of calculation of the exponential component according to the (3) (*C*=1, green) and according to the (6) (with correction, red)

Fig. 5. shows the calculated exponential component with correction ($C \in (0.9;1)$) and without correction (C=1). It can be noticed from the figure that the calculation of the exponential component lasts 20ms without correction and 30ms with correction.

3 Numeric Model

By discretization of the input signal with N samples per period, the following equation can be used for calculation of the signal of fault current with elimination of exponential component:

$$\begin{aligned}
&\overline{i(n)} = \frac{1}{N}(\overline{i(n-1)} + i(n) - i(n-N)) \\
&i_e(n) = 2 \cdot \overline{i(n)} - \overline{i(n-N/2)} \\
&i_s(n) = i(n) - i_e(n).
\end{aligned} \tag{7}$$

The presented discrete system uses recursive form for calculating the mean values [6], and discrete forms of the previously given (3) and (6). The system is presented by the block structure given in Fig. 6.

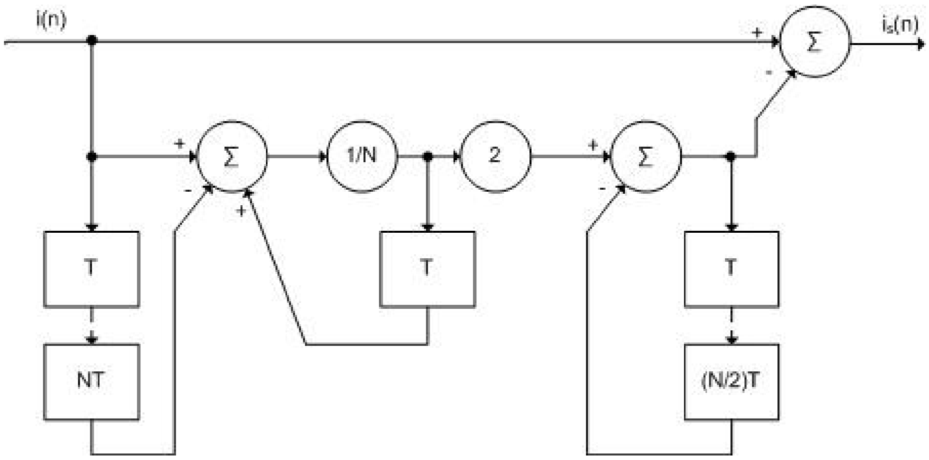

Figure 6. Block-structure of discrete system

T in Fig. 6 represents the delay block, which corresponds to the sampling period $T=T_0/N$.

4 Simulation Results

For N=20 samples taken per period, and with the time constant τ equal to 1s, the following results can be acquired (Fig. 7). It can be noticed that the system needs 30 ms after the moment of fault t_k=35ms in order to completely eliminate the exponential component.

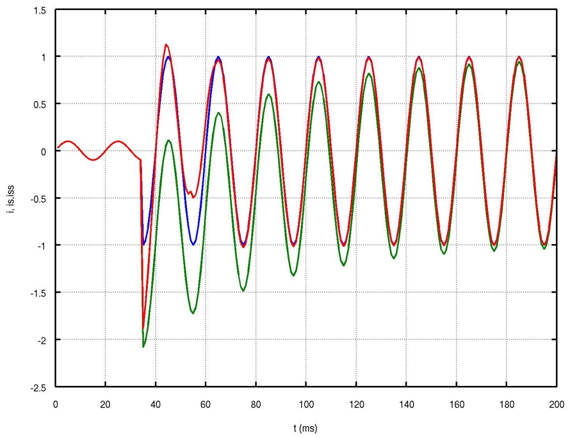

Figure 7. The simulation results for the algorithm

In order to show the efficiency of the presented algorithm, the measurement of the amplitude of the input signal from the figure above was conducted, using the Fourier band-pass filter [7] with and without elimination of the direct current component. Twenty samples per period were used. The acquired results are shown in Fig. 8.

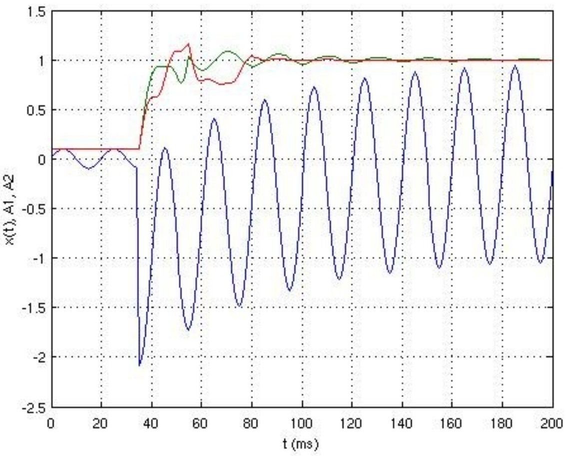

Figure 8. Comparison of the results of application of Fourier band-pass filter with (red) and without (green) elimination of the exponential component

The lower curve represents the input signal, with the amplitude of fault (I_k=1In). The fault with strong exponential component present happens at the moment t=35ms. It can be noticed from the figure that even t=170ms after the moment of fault the input signal did not reach the stationary state. The upper two curves show the amplitude calculated using the Fourier band-pass filter, where the red curve represents the case with elimination of the exponential component, while the green curve represents the case without elimination of the exponential component. It can be noticed that the curve for the case with elimination of the direct current component achieves the exact amplitude as early as t=50ms after the moment of fault, while in the second case the error is present till the transient process settles down.

5 Conclusion

The discussed algorithm is very easy for application. Only 30 ms after the fault it efficiently removes the exponential component from the fault current.
In respect to the time needed to eliminate the exponential component, it is convenient for application in protection systems for medium voltage, with the minimal switch-off times equal to 100 ms.
The Fourier filter, which produces the considerable error in presence of direct current component, with use of this algorithm, gives the correct amplitude 50ms after the appearance of the fault.

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