TRANSIENTS ANALYSIS IN RESONANT GROUNDED POWER DISTRIBUTION SYSTEMS

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Abstract

Earth fault currents in resonant grounded power distribution systems are characterized by important and significant transients.
This paper presents the Prony's method and the recursive wavelet transform. Both methods are well suited techniques for the analysis of non stationary earth fault currents. They are applied to a fault current generated by an EMTP simulation.
A comparison is made between these methods and analytical relations are established between Prony's parameters and wavelet coefficients.

Key Words

Power Distribution System, Resonant Grounding, Earth Faults, Transients, Prony's Method, Wavelets.

1. INTRODUCTION

One prominent part of digital relays in power distribution systems is to reduce the consequences of faults by fast detection and localization. Efficient algorithms are thus essential to better analyse and categorize power signals. Unfortunately, most of the time, the protection function of a digital relay is designed as an adaptation for a microprocessor-based device of a conventional algorithm used in analog relays. Such an adaptation often implies that power signal analysis tools currently used in digital relays are based on power system steady state signal analysis. Among several techniques used in conventional algorithms, the Fast Fourier Transform (FFT), the least square method and the Finite Impulse Response filtering can be mentioned [1] [2].
However these techniques are very poor to analyse the transient following a fault or any kind of operation on power networks. It is why the trip is sometimes delayed in order to avoid any unwanted trip during operation transients. One of the advantages of digital relays could be to analyse the transient itself, and not only the steady state, in order to increase the speed and the precision of some protection devices. Such an analysis of transient signals requires the use of digital techniques dedicated to the analysis of non stationary signals.
It must also be noticed that a transient analysis is not necessary for every protection device. First of all, the use of a transient analysis can decrease the fault clearance time only if the breakers associated with the relay itself are fast enough, compared to the tripping time of the algorithm. Secondly, it is worth analysing the transients especially if the network configuration may lead to significant transient signals after a fault. For instance, in case of an earth fault, the transients depend on the neutral impedance. They are very important in resonant grounded power systems but very weak in the case of a resistive grounded system.
This paper presents two efficient methods, Prony's method [3] [4] and wavelets [5] [6], for the analysis of earth fault signals in a resonant grounded power distribution system. Prony's method extracts the dominating modals of the signal. It is a clean representation with only few parameters. The wavelet transform is a time-frequency representation. A "mother wavelet" allows a recursive and continuous computation of wavelet coefficients. So, it may involve a real time analysis of fault signals.
These two methods are well suited to the analysis of transient signals. They may be useful for power distribution system relaying.

2. RESONANT GROUNDED SYSTEM

In a compensated distribution network, a Petersen coil is connected between the neutral of the power system and the ground. The reactance of the Petersen coil is tuned for resonance with the capacitance of the system to ground.

One of the advantages of this kind of grounding system is to eliminate arcing faults [7] [8].
An example of radial power distribution network is described in Fig. 1. This 20 kV resonant grounded system can be simulated with EMTP (ElectroMagnetic Transients Program). A single phase fault is simulated and is used in this paper as an example to illustrate the Prony analysis and the wavelet analysis and to show how these methods can be useful for power system relaying.

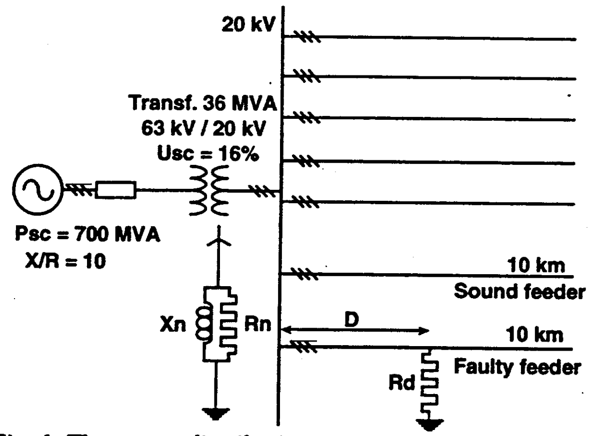

Fig. 1. The power distribution resonant grounded system.

The resonant grounding improves the extinguishing conditions of arcing faults. It reduces insulator troubles and leads to limited earth fault currents. This kind of grounding system is particularly efficient in case of very high capacitive currents in the network (very long or underground feeders). In fact, in compensated networks, the fundamental system frequency component of the zero sequence current is very weak. On the one hand, the fact that the fault current be very small is an advantage because the consequences of the fault are limited, but on the other hand, it makes the detection and localization of the fault very hard to perform. Nevertheless, it is important to note that the grounding inductance is tuned with the zero-sequence capacitance of the network for only one frequency : 50 Hz or 60 Hz. Even if the fundamental component of the current (50 Hz or 60 Hz) is very small, transients are thus generally very important and contain meaningful and useful information. Fig.3 shows an example of such a fault current. Moreover, earth faults often consist in intermittent arc faults which are a series of transient short duration self extinguishing faults. For all these reasons, a transients analysis of signals may improve protective system performances.
Let us assume that nonlinear dynamics in the power system described in Fig. 1, are negligible. The earth fault signals (zero sequence currents and busbar zero sequence voltage) are given by a linear system response to a sinusoidal excitation. An earth fault signal $s(t)$ is thus the sum of aperiodics and exponentially damped and pure sinusoids.The pure sinusoid is the system fondamental frequency steady state forced term. The transient term contains especially two damped sinusoids. The highest frequency one is due to the discharge of the faulty feeder's capacitance, whereas the second is due to the charge of the sound feeders' capacitance [9].

3. PRONY'S METHOD

Prony's method is an autoregressive modeling based technique that estimates the frequency, damping, magnitude, and initial phase of the modal components present in a time dependent signal $s(t)$. This method decomposes the signal $s(t)$ as follows:

$$s(t) = \tilde{s}(t) + b(t) \qquad (1)$$

where $b(t)$ is a noise and $\tilde{s}(t)$ is the sum of exponentially damped and pure sinusoids.

$$\tilde{s}(t) = \sum_{i=1}^{q} A_i e^{-\alpha_i t} \cos(2\pi f_i t + \theta_i) \qquad (2)$$

where q is the number of elementary functions, A_i is a magnitude, α_i is a damping factor, f_i is a frequency in hertz, and θ_i is a phase in radians. For damped exponentials we have $f_i=0$ and $\theta_i=0$ or π , and for pure sinusoids $\alpha_i=0$. We suppose that $s(t)$ is formed by q_1 purely damped exponentials and q_2 sinusoids, damped or not, ($q= q_1 + q_2$).
Let $s(t)$ consist of N equally spaced samples $s_0, \dots s_{N-1}$. ($s_n=s(n\Delta t)$), where Δt is the sampling period. Then, the discrete-time function corresponding to (2) is:

$$\tilde{s}_n = \sum_{i=1}^{p} \beta_i z_i^n \quad n=0,1,\dots,N-1 \qquad (3)$$

with $p = q_1 + 2q_2$, and the complex constants β_i (complex amplitude) and z_i (complex frequency) are defined by:

$$\begin{cases} \beta_i = A_i e^{j\theta_i} & \text{for purely damped exponentials} \\ \beta_i = 1/2\, A_i e^{j\theta_i} & \text{for pure and damped sinusoids} \\ z_i = e^{(-\alpha_i + j2\pi f_i)\Delta t} & \end{cases} \qquad (4)$$

There are three basic steps for obtaining a Prony analysis.

Step 1. Determination of the linear prediction parameters "$(a_i)_{i=1\dots L}$":
The expression (3) involves that the sampled signal $\tilde{s}_n$ can be described by the backward recursive difference equations:

$$\tilde{s}_n = -\sum_{i=1}^{p} \tilde{a}_i \tilde{s}_{n+i} \qquad (5)$$

On account of (1), the equations (5) lead to:

$$s_n + \sum_{i=1}^{p} \tilde{a}_i s_{n+i} = b_n + \sum_{i=1}^{p} \tilde{a}_i b_{n+i} \qquad (6)$$

The expression (6) represents an ARMA model (AutoRegressive Moving Average) with identical AR and MA parameters. This model may be approached by a high order (L) AR model. Therefore, the actual samples s_n comply with the following backward recursive difference equations:

$$s_n = -\sum_{i=1}^{L} a_i s_{n+i} \qquad (7)$$

where the a_i's are the linear prediction parameters.
The expression (6) can be considered as a set of linear equations whose unknown coefficients are $(a_i)_{i=1\dots L}$. They can be expressed in the next matrix form:

$$X.a = -x \qquad (8)$$

where

$$X = \begin{bmatrix} s_1 & \cdots & s_L \\ \vdots & \ddots & \vdots \\ s_{N-L} & \cdots & s_{N-1} \end{bmatrix},\ a = \begin{bmatrix} a_1 \\ \vdots \\ a_L \end{bmatrix}, \text{and } x = \begin{bmatrix} s_0 \\ \vdots \\ s_{N-L-1} \end{bmatrix}.$$

The solution is:

$$a = -\sum_{i=1}^{p} \frac{1}{(\eta_i^2 - \mu^2)} \left[v_i^T X^T x \right] v_i \tag{9}$$

where T stands for the transposition et $(\eta_i)_{i=1...p}$ are the highest eigenvalues of X, μ is the mean of the $(L\text{-}p)$ lowest eigenvalues, $(\eta_i)_{i=p+1...L}$, of X, and $(v_i)_{i=1..L}$ are the eigenvectors of $X^T X$.

Step 2. Determination of the complex frequencies "$(z_i)_{i=1..p}$":

The "a_i's" are the coefficients of the characteristic polynomial:

$$\Psi_L(z) = \prod_{i=1}^{L}(1 - z_i^{-1} z^{-1}) = 1 + \sum_{i=1}^{L} a_i z^{-i} \tag{10}$$

$(z_i^{-1})_{i=1..L}$ are determined by the polynomial rooting. The p signal zeros $(z_i^{-1})_{i=1..p}$ fall outside the unit circle whereas the $(L\text{-}p)$ extraneous zeros fall inside the unit circle [19].

The complex frequencies $(z_i)_{i=1..p}$ yield the estimates of the damping factors α_i and the sinusoidal frequencies f_i:

$$\begin{cases} \alpha_i = -\log(|z_i|) \big/ \Delta t \\ f_i = \text{angle}(z_i) \big/ (2\pi\Delta t) \end{cases} \tag{11}$$

Step 3. Determination of the complex magnitudes "$(\beta_i)_{i=1..p}$":

Once the set of equations (3) is expressed in the matrix form, the least squares method provides the well known solution:

$$x = V.\beta \tag{12}$$

with $\beta = \begin{bmatrix} \beta_1 \\ \vdots \\ \beta_p \end{bmatrix}$ and $V = \begin{bmatrix} 1 & 1 & \cdots & 1 \\ z_1 & z_2 & \cdots & z_p \\ \vdots & \vdots & & \vdots \\ z_1^{N-1} & z_2^{N-1} & \cdots & z_p^{N-1} \end{bmatrix}$.

The complex magnitudes $(\beta_i)_{i=1..p}$ yield the estimates of the initial phase θ_i and the magnitude A_i:

$$\begin{cases} A_i = |\beta_i| & \text{if aperiodic} \\ A_i = 2\,|\beta_i| & \text{else} \\ \theta_i = \text{angle}(\beta_i) \end{cases} \tag{13}$$

So, Prony's method allows to decompose $s(t)$ into elementary functions (exponentially damped sinusoids) and, consequently, to find the four real parameters, $[A_i, \alpha_i, f_i, \theta_i]_{i=1...q}$, of each elementary function.

4. WAVELETS

The wavelet transform of a time dependent signal, $s(t)$, consists in finding a set of coefficients $W_s(\tau,\varepsilon)$. These coefficients measure the similarity between the signal $s(t)$ and a set of functions $\psi_{\tau,\varepsilon}(t)$, named analysing wavelets. All the wavelets, $\psi_{\tau,\varepsilon}(t)$, are derived from a chosen "mother wavelet" $\psi(t)$ as follows:

$$\psi_{\tau,\varepsilon}(t) = \frac{1}{\sqrt{\varepsilon}}\, \psi\!\left(\frac{t-\tau}{\varepsilon}\right) \tag{14}$$

The "mother wavelet" $\psi(t)$ is an oscillating and damped function. It is well located both in the time and the frequency domains. Each wavelet, $\psi_{\tau,\varepsilon}(t)$, is a scaled (compressed or dilated) and translated (shifted) version of the same original function $\psi(t)$. "ε" represents a time dilation and "τ" a time translation. "$1/\sqrt{\varepsilon}$" is an energy normalization factor, that keeps the energy of the scaled wavelets, $\psi_{\tau,\varepsilon}(t)$, equal to the energy of the "mother wavelet" $\psi(t)$.

The coefficients $W_s(\tau,\varepsilon)$ are defined by the follwing inner product:

$$W_s(\tau,\varepsilon) = \int_{-\infty}^{+\infty} s(t).\, \overline{\psi}_{\tau,\varepsilon}(t).\, dt \tag{15}$$

The bar stands for complex conjugate. The wavelet coefficients (15) are the convolutions of the signal with a family of wavelets. Therefore, the wavelet transform may be interpreted as a projection of the signal onto functions that are simultaneously located in time and scale.

Since the convolution (15) is equivalent to a recurrent difference equation when $\psi(t)$ has a rational function z-transform in z^{-1}, We propose the following "mother wavelet" [6]:

$$\psi(t) = \left(1 + \sigma|t| + \frac{\sigma^2}{2} t^2\right) e^{-\sigma|t|}\, e^{i\omega_0 t} \tag{16}$$

We choose $\omega_0 = 2\pi$ in order that $1/\varepsilon$ be equal to a frequency f. We set $\sigma = 2\pi/\sqrt{3}$ such that

$$\hat{\psi}(0) = \int_{-\infty}^{+\infty} \psi(t)\, dt = 0 \tag{17}$$

In fact, a finite energy function $\psi(t)$, must meet the "admissibility" condition, to be a "mother wavelet". The wavelet defined in (16) is then admissible. It is shown in Fig. 2 at the frequency 50 Hz.

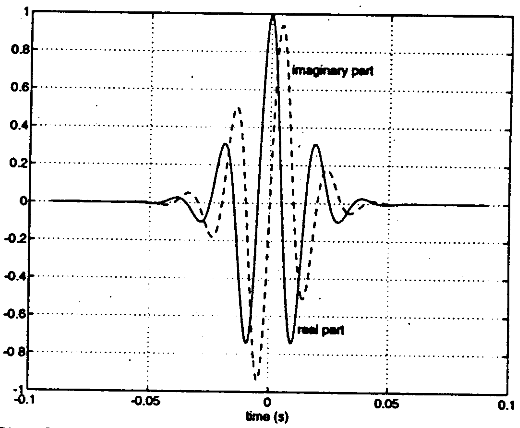

Fig. 2. The Complex Recursive "Mother Wavelet"

Moreover, the wavelet (16) is considered as progressive. So, the phase of the corresponding wavelet transform possesses many good properties.

Finally, this "mother wavelet" leads to a fast recursive implementation of the wavelet transform. The wavelet transform yields a time frequency representation of the signal $s(t)$ and allows the knowledge and the extraction of the prevailing modal components.

The wavelet coefficient corresponding to a frequency "f" and a location "$k\Delta t$" is reckoned as follows:

$$W_s(k\Delta T,f)=\Delta T\sqrt{f}\left[W_s^+(k\Delta T,f)+W_s^-(k\Delta T,f)\right] \quad (18)$$

with the constant coefficient linear difference equations described by:

$$\begin{aligned}W_s^+(k\Delta T,f)&=s(k\Delta T)+\delta_1 s[(k-1)\Delta T]\\&+\delta_2 s[(k-2)\Delta T]-\lambda_1 W_s^+[(k-1)\Delta T,f]\\&-\lambda_2 W_s^+[(k-2)\Delta T,f]-\lambda_3 W_s^+[(k-3)\Delta T,f]\end{aligned}$$

and

$$\begin{aligned}W_s^-(k\Delta T,f)&=(\bar{\delta}_1-\bar{\lambda}_1)s[(k+1)\Delta T]\\&+(\bar{\delta}_2-\bar{\lambda}_2)s[(k+2)\Delta T]+(\bar{\delta}_3-\bar{\lambda}_3)s[(k+3)\Delta T]\\&-\bar{\lambda}_1 W^-[(k+1)\Delta T,f]-\bar{\lambda}_2 W^-[(k+2)\Delta T,f]\\&-\bar{\lambda}_3 W^-[(k+3)\Delta T,f]\end{aligned}$$

where

$$\lambda_1=-3e^{-fT(\sigma-i\omega_0)};\ \delta_1=\left(\tfrac{1}{2}(\sigma fT)^2+\sigma fT-2\right)e^{-fT(\sigma-i\omega_0)}$$

$$\lambda_2=3e^{-2fT(\sigma-i\omega_0)};\ \delta_2=\left(\tfrac{1}{2}(\sigma fT)^2-\sigma fT+1\right)e^{-2fT(\sigma-i\omega_0)}$$

$$\lambda_3=-e^{-3fT(\sigma-i\omega_0)}$$

5. COMPARISON OF BOTH METHODS

5.1. Fault current analysis

Prony's method and the recursive wavelet transform have been applied on several earth fault signals as generated by the simulations with EMTP or corresponding to actual records. In this paper a fault current (Fig. 3) is used as an example to illustrate the efficiency of both methods and to make some comparisons.

The fault current presented in Fig. 3 is the residual current in the faulted feeder of the distribution network (Fig. 1). It is supposed that a single phase earth fault occurs at the time origin. The fault resistance is Rd = 1 Ω, the distance between the fault and the busbar is D = 4 km, and the total length of the feeders is 105 km.

The table 1 shows the Prony's parameters of this earth fault current. There are four elementary functions EDS1, EDS2 (exponentially damped sinusoids), DE (damped exponential) and PS (permanent sinusoid).

The recursive wavelet transform of the signal consists in a two-dimensional (time-frequency) complex matrix formed by the complex wavelet coefficients (18). Two time-frequency three-dimensional graphs are, thus, used to show the phase and the magnitude of the wavelet decomposition. The figures 4 and 5 show respectively, with level curves, the magnitude and the phase of the fault current wavelet transform.

The magnitude plan (Fig. 4) and the phase plan (Fig. 5) show clearly the existence of the damped sinusoids (EDS1 and EDS2) and the sinusoid PS. In the neighbourhood of 50 Hz, 180 Hz, or 750 Hz, we can notice that the phase lines (Fig. 5) are parallel and their densities are different. We can also notice that there are two magnitude local maxima (Fig. 4) corresponding to 180 Hz and 750 Hz, and an almost constant magnitude corresponding to the 50 Hz permanent sinusoid.

The wavelet transform yields a good representation of oscillating elementary functions. However, it is not designed to analyse aperiodics (frequency equal to zero).

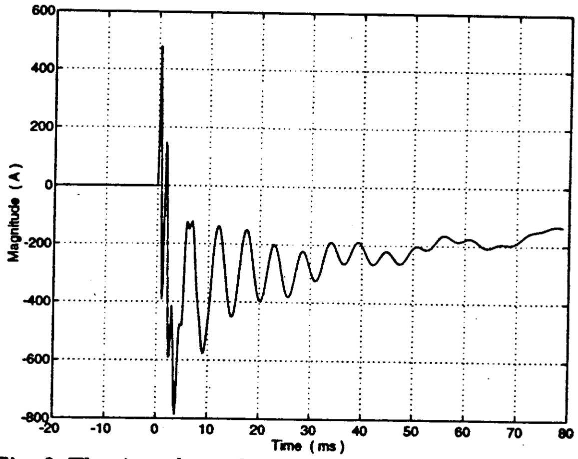

Fig. 3. The time-dependent residual current in the faulted feeder. The earth fault occurs at the time origin.

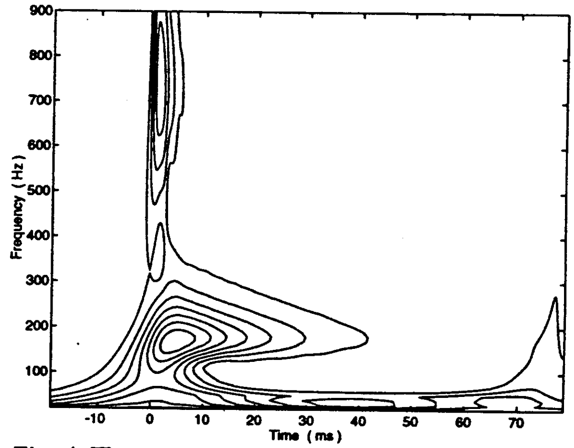

Fig. 4. The magnitude (level curves) of the wavelet transform of the fault current presented in Fig. 3.

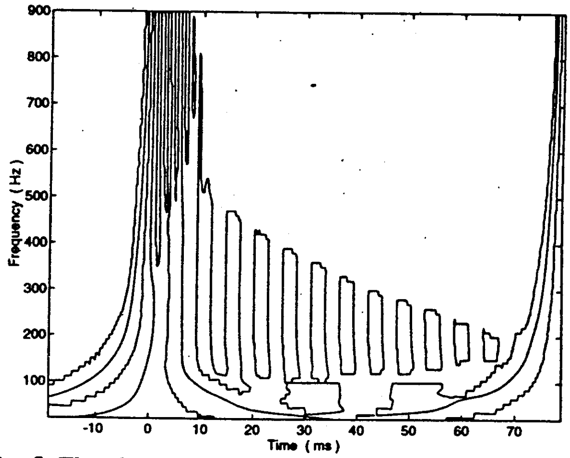

Fig. 5. The phase (level curves) of the wavelet transform of the fault current presented in Fig. 3.

Table 1. Prony's Parameters of the earth fault current presented in figure 3.

	f_k (Hz)	α_k (s^{-1})	A_k (A)	θ_k (rd)
EDS1	750	443	586	-0.93
EDS2	182	60	374	-0.90
DE	0	11	369	π
PS	50	0	23	1.1

Nevertheless, the wavelet transform may consider an aperiodic as a very low frequency signal. So there is an indication, in time-frequency plans, about the occurrency of aperiodics in the neighbourhood of low frequencies.

5.2. Analytical relations

The aim of this paragraph is to establish quasi analytical relations between the wavelet coefficients and the Prony's parameters. For this purpose, let us consider the positive time oscillating Prony's elementary function:

$$s_e(t) = A_e\, e^{-\alpha_e t} \cos(2\pi f_e t + \theta_e) \qquad (19)$$

where the magnitude A_e, the damping factor α_e, the frequency f_e, and the phase θ_e are the parameters of the elementary function $s_e(t)$.

The signal (19) may be expressed as the sum of a positive frequency function and a negative frequency one as follows:

$$s_e(t) = s_e^+(t) + s_e^-(t) \qquad (20)$$

where

$$\begin{cases} s_e^+(t) = \dfrac{A_e}{2}\, e^{(-\alpha_e + i2\pi f_e)t + i\theta_e} \\ s_e^-(t) = \dfrac{A_e}{2}\, e^{(-\alpha_e - i2\pi f_e)t - i\theta_e} \end{cases} \qquad (21)$$

So, as the elementary function $s_e(t)$ is null before the origin, the wavelet coefficient given by (15) becomes:

$$W_{s_e}(\tau, \varepsilon) = \int_0^{+\infty} s_e^+(t).\, \overline{\psi}_{\tau,\varepsilon}(t).\, dt + \int_0^{+\infty} s_e^-(t).\, \overline{\psi}_{\tau,\varepsilon}(t).\, dt$$

Since the proposed recursive wavelet (16) is considered as progressive because its Fourier transform is negligible for negative frequencies, the expression of the wavelet coefficient is:

$$W_{s_e}(\tau, \varepsilon) = \int_0^{+\infty} s_e^+(t).\, \overline{\psi}_{\tau,\varepsilon}(t).\, dt \qquad (22)$$

Therefore, when $1/\varepsilon$ (or the frequency f) is equal (or in the neighbourhood) to f_e, we obtain the following expressions, for negative time and positive time, of the wavelet coefficients:

$$\begin{aligned} W_{s_e}(\tau \le 0, f_e) = {} & e^{i(2\pi f_e \tau + \theta_e)}\ 1/2\sqrt{f_e}\ A_e\, e^{\sigma f_e \tau} \\ & \Big(\frac{1}{(\sigma f_e + \alpha_e)} + \frac{\sigma f_e}{(\sigma f_e + \alpha_e)^2} + \frac{(\sigma f_e)^2}{(\sigma f_e + \alpha_e)^3} \\ & - \Big(\frac{\sigma f_e}{(\sigma f_e + \alpha_e)} + \frac{(\sigma f_e)^2}{(\sigma f_e + \alpha_e)^2}\Big)\tau + \Big(\frac{(\sigma f_e)^2}{2(\sigma f_e + \alpha_e)}\Big)\tau^2\Big) \end{aligned} \qquad (23)$$

and

$$\begin{aligned} W_{s_e}(\tau \ge 0, f_e) = {} & e^{i(2\pi f_e \tau + \theta_e)}\ 1/2\sqrt{f_e}\ A_e \\ & \Big[e^{-\alpha_e \tau}\Big(\frac{1}{(\sigma f_e + \alpha_e)} + \frac{\sigma f_e}{(\sigma f_e + \alpha_e)^2} + \frac{(\sigma f_e)^2}{(\sigma f_e + \alpha_e)^3} \\ & + \frac{1}{(\sigma f_e - \alpha_e)} + \frac{\sigma f_e}{(\sigma f_e - \alpha_e)^2} + \frac{(\sigma f_e)^2}{(\sigma f_e - \alpha_e)^3}\Big) \\ & - e^{-\sigma f_e \tau}\Big(\frac{1}{(\sigma f_e - \alpha_e)} + \frac{\sigma f_e}{(\sigma f_e - \alpha_e)^2} + \frac{(\sigma f_e)^2}{(\sigma f_e - \alpha_e)^3} \\ & + \Big(\frac{\sigma f_e}{(\sigma f_e - \alpha_e)} + \frac{(\sigma f_e)^2}{(\sigma f_e - \alpha_e)^2}\Big)\tau + \Big(\frac{(\sigma f_e)^2}{2(\sigma f_e - \alpha_e)}\Big)\tau^2\Big)\Big] \end{aligned} \qquad (24)$$

In the neighbourhood of f_e, the dominating wavelet coefficients of the signal $s(t)$ are due to $s_e(t)$ as it is shown in the following. Fig. 6 presents two sections, made on the fault current wavelet transform amplitude, for the frequencies 180 Hz and 750 Hz. These curves fit the wavelet transform magnitude computed with the expressions (23) and (24) for f_e=180 Hz and f_e=750 Hz. The phase of the wavelet coefficient is the same in (23) and (24). It involves that the phase (modulo 2π) at f_e, is periodic in time and its frequency is f_e. Fig. 7 (resp. Fig. 8) presents a section, made on the fault current wavelet transform phase, for 180 Hz

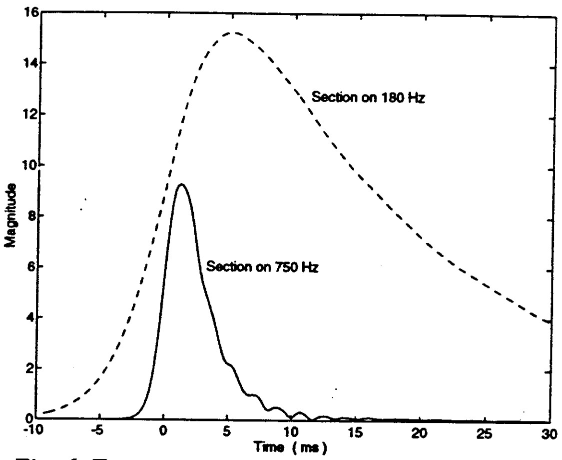

Fig. 6. Two sections on the time-frequency plane, presented in Fig. 4, on 180 Hz and 750 Hz.

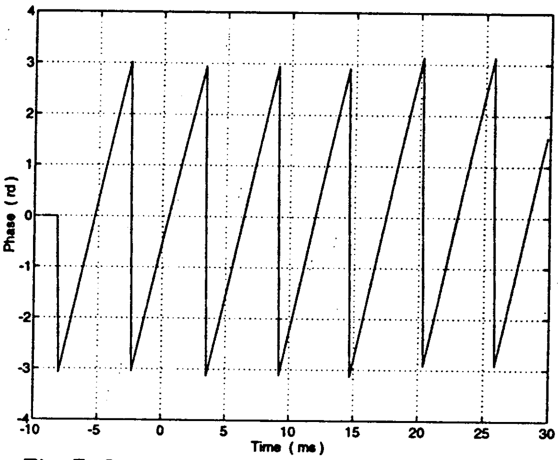

Fig. 7. One section on the time-frequency plane, presented in Fig. 5, on 180 Hz.

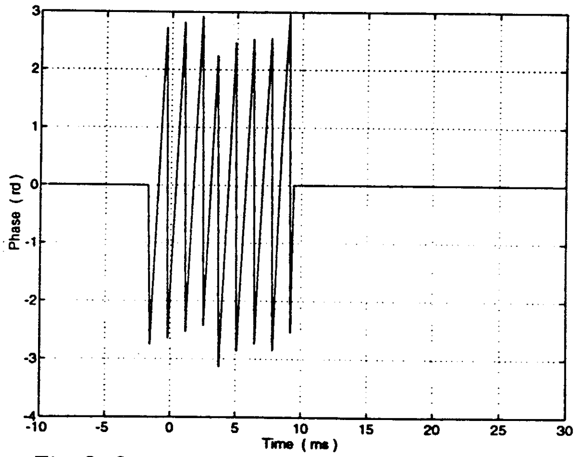

Fig. 8. One section on the time-frequency plane, presented in Fig. 5, on 750 Hz.

(resp. 750 Hz). One can see that the phase is periodic and its frequency is 180 Hz (resp. 750 Hz). Moreover, the phase expression in (23) or (24) imply that the phase at the origin of time is nothing else than θ_e the initial phase of the Prony's elementary function. This is illustrated by the figures 7 and 8.

5.3. Advantages and drawbacks

Prony's method is an appropriate analysing method for the analysis of fault currents in a compensated network. It decomposes a signal into a sum of elementary functions which are very suitable for modeling earth fault currents. Prony's method leads to the best representation of fault currents with the minimal number of parameters. These Prony's parameters (magnitudes A_i, damping factors α_i, frequencies f_i, and initial phases θ_i) have a heavy signification and are tightly related to the faulted network's characteristics [4].
The Prony's analysis gives important and precise informations and it is easier to interprete than the wavelet transform. In fact, the wavelet representation may seem less explicit, but it is more robust than Prony's method. It gives good results even when the noise increases whereas Prony's method requires a relatively high signal-to-noise-ratio in order to yield good results.
Prony's method is an efficient tool for analysing records. Since it extracts the few parameters corresponding to the modal components of fault signals, it may be useful for the inexpensive storage of a great number of fault signals. Therefore, Prony's parameters may be used, in the generation of fault signals, instead of EMTP's simulations for protection tests.
On the other hand, the wavelet transform may also be employed for analysing records. Furthermore, it may be employed in real time operation for protection devices. In fact the recursive aspect of the wavelet transform leads to a fast computation of the wavelet coefficients. Wavelets are more efficient than Prony's method for real time relaying operation. There is not yet algorithms that allow a fast implementation of Prony's method. It is difficult to compute the Prony's parameters in real time to use them in a fast digital relay.
Finally, this paper shows that the swiftly computed wavelet coefficients are closely related to the significant Prony's parameters $[A_i, \alpha_i, f_i, \theta_i]_{i=1..q}$. This is illustrated by clear and obvious analytical relations between wavelet coefficients and Prony's parameters.

6. CONCLUSION

One aim of the resonant grounding system is to eliminate arcing grounds. However, earth fault currents, corresponding to this kind of neutral grounding, are characterized by important transients.
Generally, current relays are based on only one system frequency analysis and they don't take benefit from the transients.
In this paper the Prony's method and the recursive wavelet transform have been described. They are new efficient tools for earth fault signal transient analysis.
All the information contained in an earth fault signal is reflected by only a small number of Prony's parameters. The Prony's meaningful parameters are closely connected to the swiftly reckoned recursive wavelet coefficients.
Prony's method is well suited for earth fault signal storage and record analysis; and recursive wavelets are compatible with relaying real time implementation.

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