Accurate Measurement of Mean Frequency During Power Swing

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Abstract: This paper presents an algorithm for measuring mean frequency in two machine system during power swings, which applies to sampled current signals in transmission lines with two sinusoidal components. Modulation of voltage and current signals with low-frequency components during power swing creates difficulty in accurate measurement of the frequency. The algorithm is based on rigorous mathematical deducing and recombines itself with Taylor series expansions. Computation requirements are modest and technique has been implemented on the test signal. The method is tested on two bus system using MATLAB. As an application of this method, the accurate frequency is used for the finding out the accurate frequency during three phase fault.

***IndexTerms* – Distance relay, power swing, unbalance fault, frequency measurement**

1. INTRODUCTION

Frequency is an important operating parameter for power systems, which should be maintained constant. Over the last couple of decades, a lot of literature is available on the frequency measurement techniques for power system applications. Various signal processing technique techniques are used for frequency measurements of power system, such as discrete Fourier transforms, least square error technique, Kalman filtering, recursive Newton-type algorithm, adaptive notch filters, iterative algorithm, etc [1]. Distance relays with remote backup protection zones have been successfully used for many years as the most common type of protection in the transmission lines. Undesirable operation of the distance relays affects the power system security, when the system is operating in a stressed condition [2].

The measured frequency, which is estimated from single-frequency signals, is used for power system protection and control applications, e.g., frequency relay for load shedding and load-frequency controller, so the estimated frequency should be sufficiently accurate. The calculation of mean frequency with two frequency components serves for the transmission line protection by providing accurate parameters, so that the performance of the relaying device can be improved. Therefore, needed accuracy of the frequency measurement is lower than that of normal single-frequency signals. At the same time, the difficulty in measuring the mean frequency with two frequency components increases because of additional unknown parameters in sampled signals. The measured mean frequency has at least several functions. First, it can be used for eliminating the unbalanced current of negative sequence. Second, current fault components can be extracted accurately, thus, preventing directional relay based on fault components from mal-operating.

In this paper accurate mean frequency estimation technique is proposed for power swing conditions, considering fundamental and modulating frequency information. This method estimates both the frequencies of current signals. Proposed method is tested for current signal using MATLAB simulink software.

2. PROPOSED METHOD

A. Mean frequency of power system

The modulated current waveform during the power swing for a two-machine equivalent power system can be modeled as follows [3]

$$i(t) = I_1 \sin(2\pi f_1 t + \varphi_1) + I_2 \sin(2\pi f_2 t + \varphi_2)$$

Where

I_1 , I_2 Amplitudes of two current signals

f_1 f_2 Two unknown frequencies

φ_1 φ_2 Initial phase angles.

In general case, current I_1 is equal to I_2. So we can assume that I_1=I_2=I. so finally the current signal written as

$$i(t) = 2I.cos[\pi.t(f_1 - f_2) + \theta_1].sin[2\pi.t(f_1 + f_2)/2 + \theta_2]$$

Where

$|f_1 - f_2|$ Frequency of the current envelope

$(f_1 + f_2)/2$ Mean frequency of the sampled current.

B. Sampling Technique for Current Signals

In process of the calculation, the amplitudes of the two components can be assumed constant and two frequencies cannot change quickly. The current is sampled at the interval of K. let a1 and b1 is the initial phases of the (p-2)th sample. Thus the (p-4)th, (p-3)th, (p-2)th, (p-1)th and (p)th samples can be given in the following manner.

$$i_{p-4} = I_m \sin(-2\omega_1 K + a_1) + I_n \sin(-2\omega_2 K + b_1) \quad (1)$$
$$i_{p-3} = I_m \sin(-\omega_1 K + a_1) + I_n \sin(-\omega_2 K + b_1) \quad (2)$$
$$i_{p-2} = I_m \sin(a_1) + I_n \sin(b_1) \quad (3)$$
$$i_{p-1} = I_m \sin(\omega_1 K + a_1) + I_n \sin(\omega_2 K + b_1) \quad (4)$$
$$i_p = I_m \sin(2\omega_1 K + a_1) + I_n \sin(2\omega_2 K + b_1) \quad (5)$$

C. Estimation of Frequency during power swing

Equation (3) can be expressed as

$$M_1 + N_1 = i_{p-2} \quad (6)$$

Where $M_1 = I_m \sin(a_1), N_1 = I_m \sin(b_1)$

By adding (2) to (4)

$$M_1.\cos(\omega_1 K) + N_1 \cos(\omega_2 K) = \frac{1}{2}(i_{p-3} + i_{p-1}) \quad (7)$$

According to (1), (3), (5), it follows that

$$M_1.\cos^2(\omega_1 K) + N_1.\cos^2(\omega_2 K) = \frac{1}{4}(i_{k-4} + 2i_{k-2} + i_k) \quad (8)$$

Similarly, let a_1 and b_1 be initial phases of the (p+q-2)th sample. We get

$$M_2 + N_2 = i_{p+q-2} \quad (9)$$
$$M_2.\cos(\omega_1 K) + N_2.\cos(\omega_2 K) = \frac{1}{2}(i_{p+q-3} + i_{p+q-1}) \quad (10)$$
$$M_{2.}cos^2(\omega_1 K) + N_2 cos^2(\omega_2 K) = \frac{1}{4}(i_{p+q-4} + 2i_{p+q-2} + i_{p+q}) \quad (11)$$

Where $M_2 = I_m \sin(a_2), N_2 = I_n \sin(b_2)$
From (6) to (11), the following equation can be obtained

$$\cos(\omega_1 K) + \cos(\omega_2 K) = \frac{x_3.y_1 - x_1.y_3}{x_2.y_1 - x_1.y_2} \quad (12)$$

$$\cos(\omega_1 K).\cos(\omega_2 K) = \frac{x_3.y_2 - x_2.y_3}{x_2.y_1 - x_1.y_2} \quad (13)$$

Where
$x_1 = i_{p-2}$
$x_2 = (i_{p-3} + i_{p-1})/2$
$x_3 = (i_{p-4} + 2i_{p-2} + i_p)/4$
$y_1 = i_{p+q-2}$
$y_2 = (i_{p+q-3} + i_{p+q-1})/2$
$y_3 = (i_{p+q-4} + 2i_{p+q-2} + i_{p+q})/4$

Define

$$R = \frac{x_3.y_1 - x_1.y_3}{x_2.y_1 - x_1.y_2} \qquad S = \frac{x_3.y_2 - x_2.y_3}{x_2.y_1 - x_1.y_2}$$

The combination of (12) and (13) defines

$\cos[(\omega_1 + \omega_2).K] = S - \sqrt{1 - R^2 + 2S + S^2}$

In above equation, $\omega_1 + \omega_2 = 4\pi f$. Here f is the mean frequency to be estimated. Then equation (14) can be written as

$$\cos(4\pi f) = S - \sqrt{1 - R^2 + 2S + S^2} \qquad (14)$$

R and S have the same denominator. According to (6), (7), and (10) the denominator can be expressed as

$$x_2.y_1 - x_1.y_2 = (M_1N_2 - M_2N_1).[\cos(\omega_1 K) - \cos(\omega_2 K) \qquad (15)$$

The sampling rate used here is 400Hz. Therefore, the sampling K is 1/400s. R and S can be obtained on-line. Lwt the right-hand side of (14) be w, the value of $\sqrt{1 - R^2 + 2S + S^2}$ be z. then

z= $\sqrt{1 - R^2 + 2S + S^2}$

w=S-z

$$\cos(4\pi f K) = w. \qquad (16)$$

The value of w is obtained, and the measurement frequency is

$f = \cos^{-1}(w)\,/(4\pi K)$.

Using the Taylor series expansion of $\cos^{-1}(w)$ can be expanded. The series contains infinite terms and is given in (17)

$$f = f_0 + \sum_{n=1}^{\infty} \frac{1}{n!} f_0^{(n)} (w - w_0)^n \qquad (17)$$

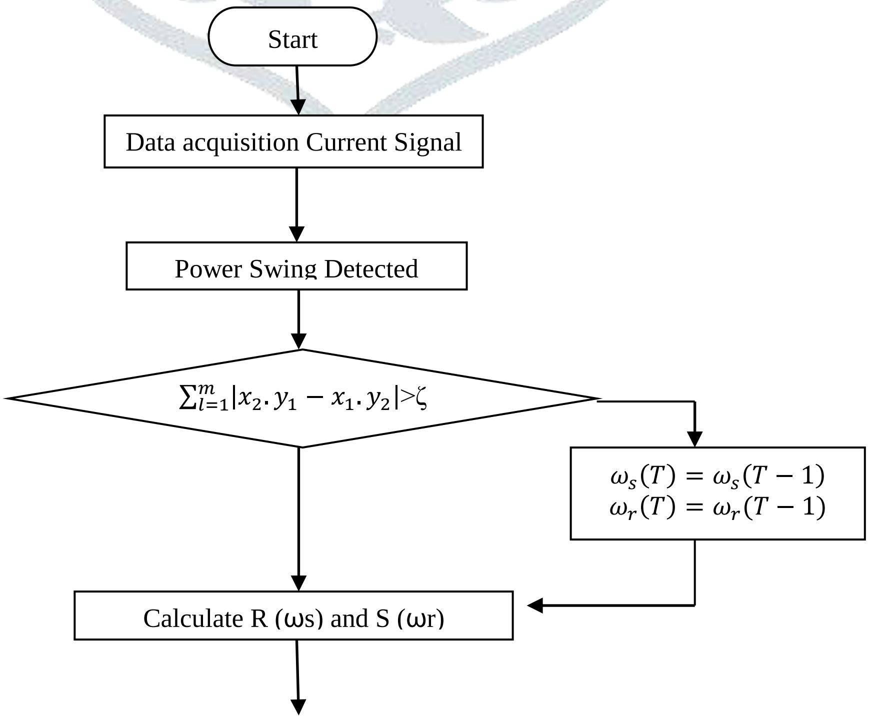
Using first three terms of the series, the measured frequency can be calculated by

$$f = 50.000 - 31.8310w - 5.3052w^3$$

3. CRITICAL PARAMETERS OF THE METHOD AND NECESSITY OF THRESHOLD

The method, which estimates the mean frequency from sampled line currents, has been developed in the last section. This method is affected by many factors such as the interval between the (p-2)th and (p+q-2)th samples, iteration of the Taylor series expansion , parameter q, sampling rate. Accurate parameter selections could give the right estimation of the frequency. The q can be chosen among many positive integers, and there is no obvious reason for selecting its value. The lasger parameter q is, the larger the measurement window needed. Offline computations that, when q=2, the accuracy of this algorithm is higher than when any other values of q are used.

Very small values of $\sum_{l=1}^{m} |x_2.y_1 - x_1.y_2|$ in this equation will give rise to great errors of the estimates under two conditions. The sampled current envelope passes zero. Many consecutive samples are small. The relative errors of the sampled data will increase greatly. Thus great errors will be bought about to the estimates. During power swings, the phases of the current signals are continuously charging, and the current envelope is close to zero only for very short period of time. The two situations should be distinguished by setting a threshold for the denominator in above equation. With the threshold, the measurement errors can be reduced.



Calculate Mean Frequency as per (17)

Fig.1.Flow diagram of method

4. RESULTS AND TEST SAMPLE FOR THE POWER SWING CASE WITH A SYNTHESIZES SIGNAL

For the testing of this method, two machine systems are utilized. The sampling frequency if the system is 480Hz: 8 samples per cycle in 60Hz system. Sample data were obtained from the simulator. For the two machine systems when three phase fault is happened both side of current values will be affected. During the fault both the sides of current samples will be taken from the simulator. Power swing is a phenomenon of oscillation in machine rotor angle often caused by disturbances, such as tripping of the transmission line, loss of generation, and disconnection of large block of load.

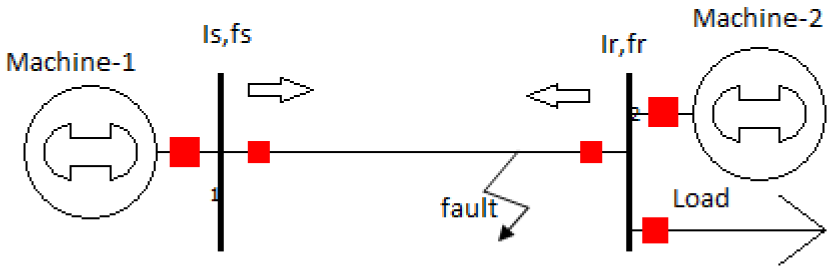


Fig: 2 Two Machine System

In order to verify the performance of the proposed method, a test signal as (18) is generated with I_s = 1.5A, I_r =1A, f_s = 64Hz and f_r = 56Hz

$$i_a(t) = I_s \sin(2\pi f_s t + \pi/6) + I_r \sin(2\pi f_r t - \pi/6) \qquad (18)$$

The signal is sampled with the rate of 480Hz. Frequency of the current signal are estimated using (12) and (13), and the tested sample is depicted in fig 3which frequency would be estimated. And the results are shown in fig.4. The frequency estimation technique provides correct values (f_s = 64Hz and f_r=56Hz).

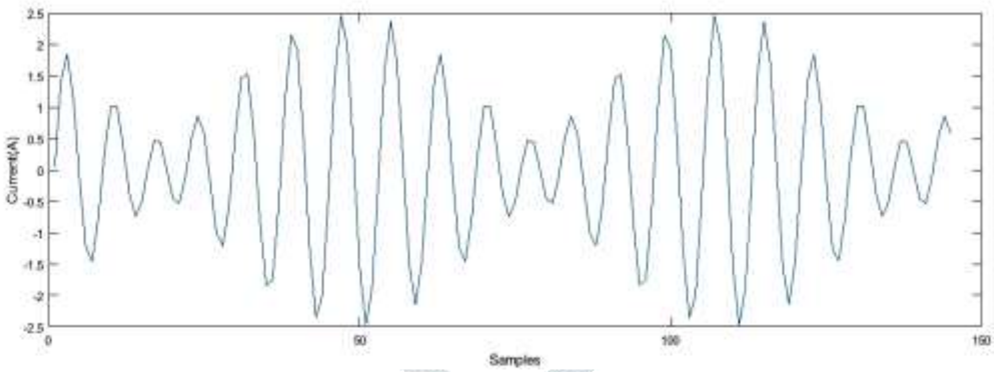


Fig.3: Sample Current

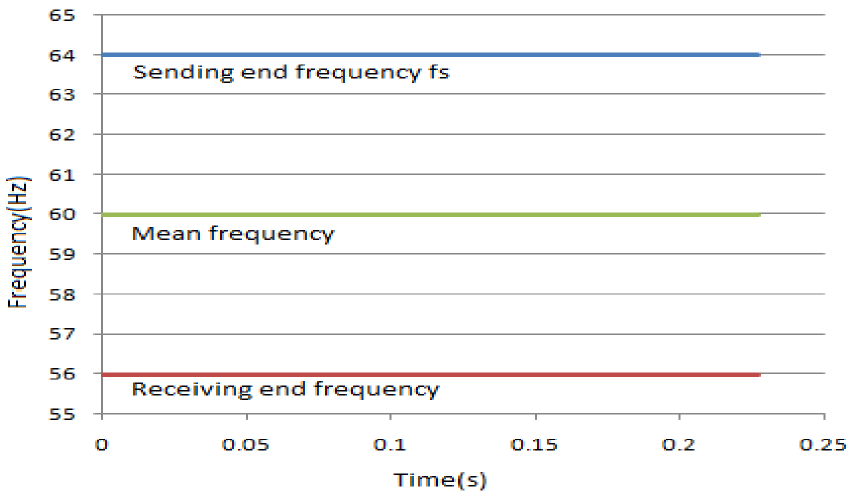


Fig: 4 Estimated Mean Frequency

5. CONCLUSION

A new algorithm of measuring of mean frequency of two machine system during power swing is presented in this paper. The algorithm is developed through rigorous mathematics, adopts Newton iterative technique and Taylor series. Adding the absolute values of the numerator and denominator can eliminate the influence of zero-point of denominator and can weaken the interference of noise. Simulation show that the maximum measurement error will not exceed 1Hz.which is allowable for transmission line protection.

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