

for loop. The voltage regulator affects the dynamic response of the SVC in a number of ways. First, when a severe disturbance occurs and the SVC bus voltage dips, a positive error signal is generated and the SVC voltage regulator increases $x(t)$ to boost the SVC bus voltage. An increased $x(t)$ raises the $-\delta$ curve of the system. Second, when the SVC bus voltage exceeds the reference voltage, a negative error signal is generated and causes $x(t)$ to decrease; a decreased $x(t)$ lowers the $-\delta$ curve of the system. The controller design for a SVC involves the same type of difficulties as those of the AVR of a generator. A real case where the difficulties to meet the objectives of rapid voltage regulation as well as maintaining stability margins in the worst situation was encountered recently and recorded for the Chester, Maine SVC project in the USA.

Conclusions: From the analysis given in the preceding section, the following novel conclusions are made:

- The maximum power transfer, P_{max} , for line compensation by FACTS controllers can be written in the general form of $P_{max} = P_{uncomp}(1-k)$ where P_{uncomp} is the maximum power transfer for the uncompensated line and k is the degree of compensation.
- For a SVC of the same rating, the effectiveness of the SVC for stability enhancement is *increased* if the transmission line length is *increased*.

Note that for a TCSC of the same rating, however, the effectiveness of the TCSC for transient stability enhancement is *reduced* if the transmission line is *increased*.

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Labview Implementation of Speed Detection for Mains-Fed Motors Using Motor Current Signature Analysis

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Abstract: The speed of an induction motor (IM) can be extracted from the motor currents of an induction motor with a Labview implementation of Motor Current Signature Analysis (MCSA). The implementation is applied to an IM driven by the 60 Hz mains. The estimation system consists of data acquisition, demodulation and FFT spectrum analyses. The above estimation algorithms are implemented in Labview for Windows, with the Labview output being compared to measurements from a tachometer, with acceptable results.

Introduction: Motor current signature analysis (MCSA) is an electric machinery monitoring technology developed by the Oak Ridge National Laboratory (ORNL) [1, 2, 3]. It has been used as a test method to improve motor bearing wear assessment for inaccessible motors during plant operation. MCSA can be implemented using time domain or frequency domain analyses. The contribution in this paper is a real-time Labview implementation for speed detection. The actual speed of a machine can be determined at the motor control center, remote from the machine. This may be subsequently used for speed control or protection.

The fundamental principle of MCSA is based on the recognition that a conventional electric motor powering a machine also acts as an efficient and permanently connected transducer, detecting small time-dependent motor load variations generated within the mechanical system and converting them into electric current signals that flow along the cable supplying power to the motor. To obtain rotor speed, frequency-domain analysis is chosen. Motor current signals can be obtained from the outputs of current transducers which are placed nonintrusively on one of the power leads. The resulting raw current signals are acquired by computers after they go through conditioning circuits and data interfaces. The signals are processed by Labview in the computer after acquisition.

Labview Implementation: Labview is a program development application, which uses a graphical programming language, G, to create programs in block diagram form. It uses terminology, icons, and ideas familiar to researchers and relies on graphic symbols rather than textual language to describe programming actions. Labview has extensive libraries of functions and subroutines for most programming tasks and also contains application-specific libraries for data acquisition, analysis, presentation and storage. Labview programs are called virtual instruments (VIs) because their appearance and operation imitate actual instruments. VIs have both an interactive user interface and a source code equivalent and accept parameters from higher level VIs. These three VI features are discussed below.

Demodulation of Current Signals: Regardless of thermal noise, the stator current signals are

$$i(t) = k_0 + k_1 \cos(2\pi f_1 t) + k_2 \cos(2\pi f_2 t) + \dots + k_n \cos(2\pi f_n t) \cos(2\pi f_0 t) \quad (1)$$

Where k_i are constants, f_i are frequencies, which depend on the mechanical and electrical systems. f_0 is 60 Hz, which is the frequency of the ac power supply. (1) is rewritten as

$$i(t) = m(t) \cos(2\pi f_0 t) \quad (2)$$

where $m(t)$ is the amplitude of the stator current. Compared with (1), $m(t)$ is

$$m(t) = k_0 + k_1 \cos(2\pi f_1 t) + k_2 \cos(2\pi f_2 t) + \dots + k_n \cos(2\pi f_n t) \quad (3)$$

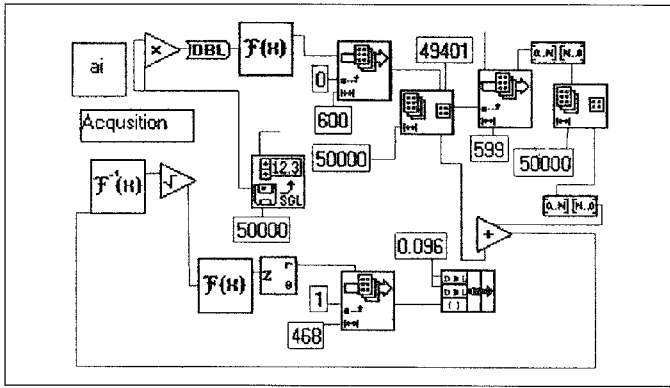


Figure 1. G program of MCSA

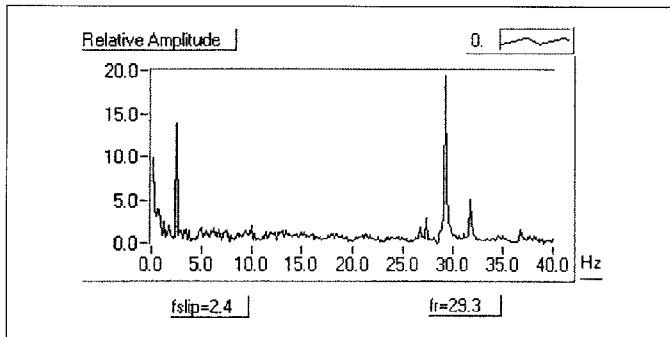


Figure 2. Panel of the G program in Figure 1; spectrum indicates: $f_r = 29.3$, $f_{slip} = 2.4$

the frequency of each term in (3) is lower than f_0 .

In order to detect the frequency components of currents, the stator current signal, as expressed in (1), is first squared to yield

$$i(t) \times i(t) = m(t)^2 \cos^2(2\pi f_0 t) \quad (4)$$

Rewriting (4)

$$(i(t))^2 = \frac{1}{2} m(t)^2 + \frac{1}{2} \cos(2 \times 2\pi f_0 t) m(t)^2 \quad (5)$$

The current signal $i(t)$ is sent to a multiplier to multiply by itself and then $i(t)^2$ is obtained. Since the frequency of each component in $m(t)$ is lower than f_0 , a lowpass filter can be used to filter the second term of (5). $m(t)$ is extracted after $i(t)^2$ goes through a lowpass filter and then a square-root operator. The cutoff frequency of the lowpass filter must be lower than $2f_0$ in order to filter components with frequency of $2f_0$. Both the square operation and square-root operator are implemented using Labview functions. Finally, amplitude information is separated from the current signal after $m(t)^2$ is square rooted.

Speed estimation of motor: In the previous section, the method for extracting the amplitude information from current signals have been developed. To find the motor speed, the speed spectrum must be searched in the range of (f_s to $2f_s/p$), where p is the number of poles and $2f_s/p$ is the synchronous mechanical speed. $2f_s/p$ is the upper limit of the rotor speed. f_k can be determined by

$$f_k = 2 \frac{f_0}{p} \left(1 - \frac{R_s}{(R_s^2 + (X_s + X_r)^2)^{0.5}} \right) \quad (6)$$

Where R_s is rotor resistance, R_r is stator resistance, X_s is stator leakage reactance, and X_r is rotor leakage reactance. The component with the maximum amplitude value in that range corresponds to the rotor speed. f_k corresponds to the slip frequency at maximum torque, below which the motor is unable to operate.

The FFT subroutine outputs the Fourier transform of $m(t)$. It is a complex array and is converted to a polar array by the Complex to Polar function. The Subset function picks up a range for searching. The Max & Min function finds the component with the maximum value and gives its position in the range. Subsequently, its position in the Fourier transform array is found and f_r is obtained by using its position multiplied by the resolution of frequency, i.e.

$$f_r = i \times \Delta f \quad (7)$$

where i is the position of the component associated with f_r .

A model to implement MCSA is shown in Figure 1, which includes acquisition, demodulation and FFT of $m(t)$. A spectrum of $m(t)$ is drawn in Figure 2. The spectrum shows that the rotor speed is 29.3 Hz and the slip frequency is 2.4 Hz.

Conclusions: This paper has developed a Labview implementation of motor current signature analysis. A key feature is the method to demodulate the fundamental component so that the components of interest can be detected with greater ease. While the technique can be applied to a range of problems associated with condition monitoring, particular attention was paid to the detection of the speed signal for closing the speed loop.

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