SENSORLESS SPEED PREDICTION OF INDUCTION MACHINES BY USING FLUCTUATION OF ZERO CROSSINGS OF MOTOR CURRENT

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ABSTRACT

The purpose of this study is to implement of sensorless speed detection in induction machines by using fluctuation of three phase supply current zero crossings only. These fluctuations are sensed by µC, and transferred to a PC for speed prediction using Fast Fourier Transformation algorithms. This method is not only suitable to convert it to the online speed measurement system using cascaded digital bandpass filters but it may also be possible to use as a feedback signal. The most important of the features is being sensorless, and does not require any additional sensor.

I. INTRODUCTION

Nowadays the accuracy and resolution are two critical issue required for speed measurement of induction motor drives. For this purpose an encoder, resolver or tachogenerator are used. Due to the high installation cost, calibration, requirements of frequent maintenance and additional cables, sensorless alternatives are become more viable solution. Several works have been done to detect motor speed without tachometers, encoders and resolvers [1-5]. However, current methods have already used complex and heavy computation algorithms. Sometimes it is essential to use sensorless speed measurement for explosive environment and for conditions that unable to connect cable [6].

In this study, sensorless speed measurement of induction motors using stator current zero crossings is implemented. It is enough to use current transformers already installed in the system for remote applications.

The advantages of the system are being simple, cheap, not require complex computations, and sampling process is not affected by large amplitude of supply frequency in the spectrum.

In addition, electrical and mechanical faults of motor and driven pumps can be diagnosed using this signal. It is possible to extend the application areas.

II. OBTAINING SPEED PARAMETER (ZCT SIGNAL)

There are six zero crossings in three phase sinusoidal supply currents for one period as one phase currents for one period as one phase current has two zero crossing per period (for 50 Hz supply frequency). For 50Hz supply frequency there are totally 300 times zero crossings of motor current signal. It is the final limit of sampling rate. For ideal 50Hz supply frequency the time value of adjacent two crossings is equal 3333 µs. The current value of ZCT is described as following equation $ZCT_i=T_i-T_{i-1}-T_{60^o}$ where ZCT_i current value ZCT_{i-1} is the previous value, and T_{60^o} is the time length for between two adjacent zero crossings which is 3333 µs. Due to unsymmetrical stator windings, change on supply and motor load, the value of ZCT signal is not zero. It is in the range of 1-3333 µsec. This corresponds to –70dB dynamic range for signal analysis [6-7].

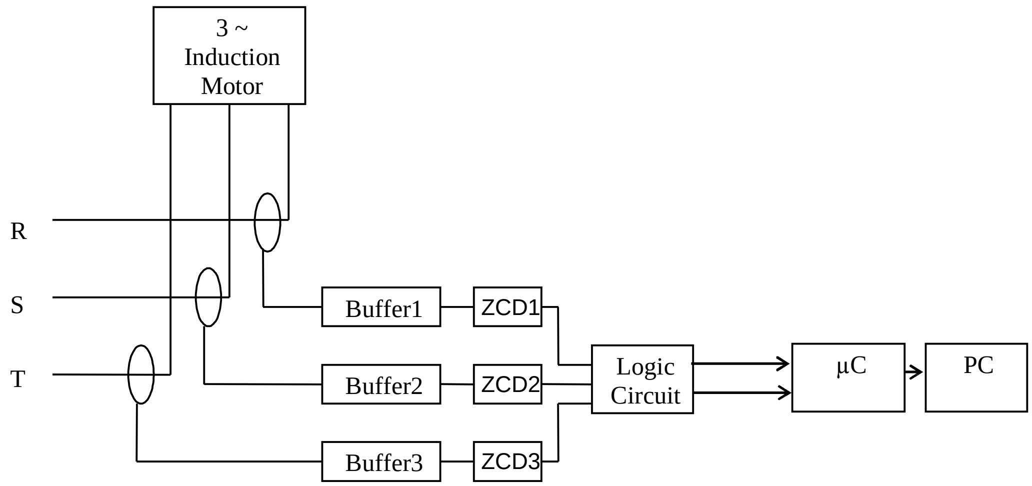

Figure 1 Block diagram of the ZCT data acquisition circuit for sensorless speed measurement

III. OBTAINING OF ZERO CROSSING FLUCTUATIONS FROM MOTOR CURRENT

Decreased value of stator current using three Hall Effect current transducers for each phase is converted to one square ware by logic gates as shown figure l. For ideal conditions pulse width of this square waveform is equal to 3333 μs [8, 12]. When induction motor is fed (controlled) by an invertor, it is obligation to use of a lowpass filter at 1 kHz cut off frequency before applied ZCT to detectors. Thus, the high switching frequency is minimized. Pulse width of this square wave is calculated by 16 bit timers in AT89C52 microcontroller, and sequentially transmitted to a PC using serial communication. Speed related frequency components and other diagnostic frequencies are determined by frequency domain transformation of ZCT signal in Matlab signal processing toolbox software [13, 15].

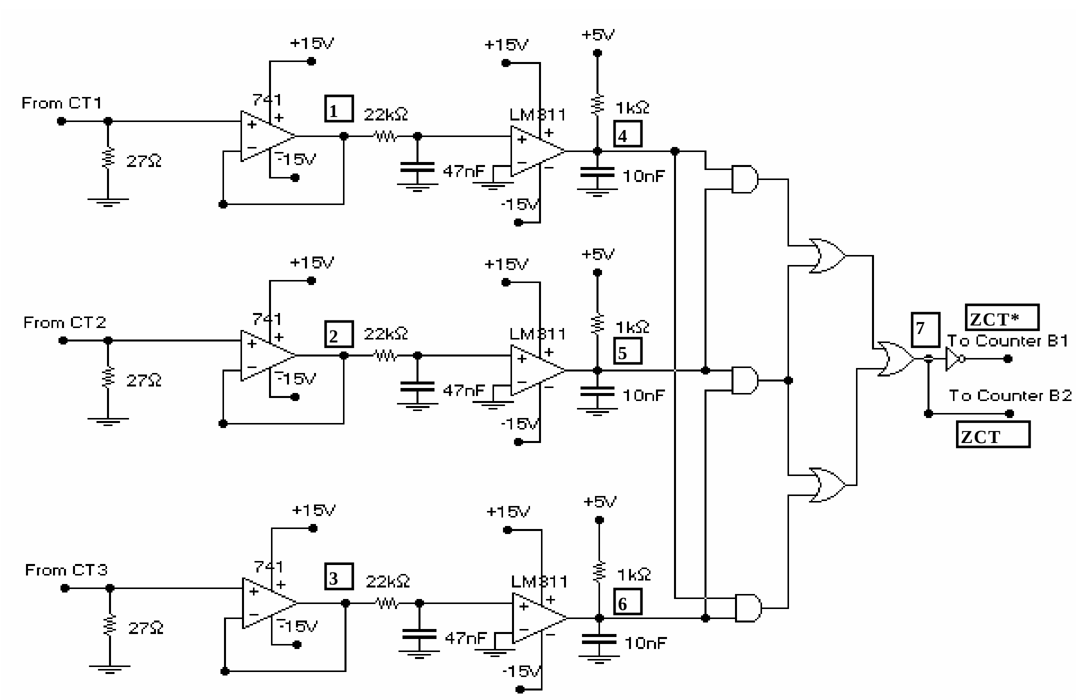

Figure 2 The motor current zero crossing detection circuit

Current transducer, supplied by 15V symmetrical sources having 1/1000 ratio and its output amplitude, produces 5V instantaneous value. In Figure 2, three LM311 voltage comparators, 7408 and logic IC, 74132 are used to obtain

ZCT signal [9-10]. It is sampled at 300Hz constant sampling frequency. The result is discrete sequence related fault frequency components as shown in Figure 3.

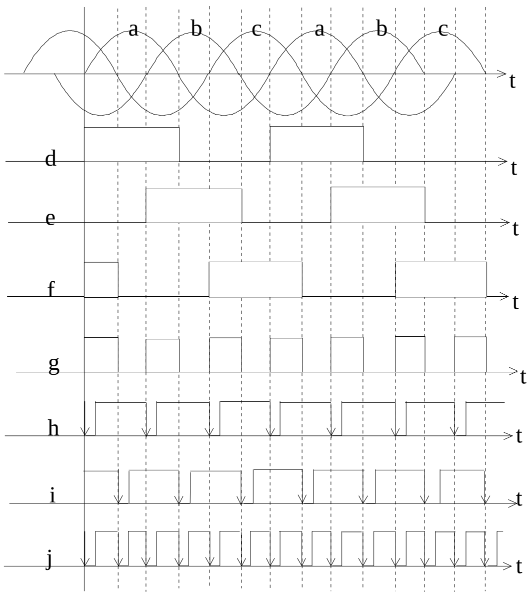

Figure 3 ZCT Discrete Signal

Two 16 bits timers in 8 bits micro controller are used to calculate time difference between each adjacent zero crossings. Each timer is interrupted either on positive rising edge or negative falling edge of the signal. For online speed detection it is required to use only one interrupt. Therefore, 4047B monostable multivibrator is used to convert to one adjustable interrupt [11]. Between µC and PC, MAX232 signal level converter is used to convert TTL output of µC to the RS232 level of computer [11]. For serial transmissions transmit data pin TXD, receive data RXD and ground pins are used.

IV. OFF-LINE SPEED PREDICTION

C language is used to read ZCT signal and write in a file as text format in PC side. For signal processing Matlab/Signal processing toolbox functions such as pwelch or psd are used [13].

For four-pole squirrel cage induction motor, rotor speed is around 23 and 25 Hz depend on motor loading conditions. To get sufficient frequency resolutions sampling interval of ZCT signal is changed. For instance for 300 Hz constant sampling frequency if sampling period is 10 seconds frequency resolutions becomes 0,1 Hz. If necessary doubling the sampling period, provides 0.05 Hz frequency resolution. Figure 4 indicates that the motor speed is obtained at f_r=24.9 Hz in ZCT signal spectrum after post processing

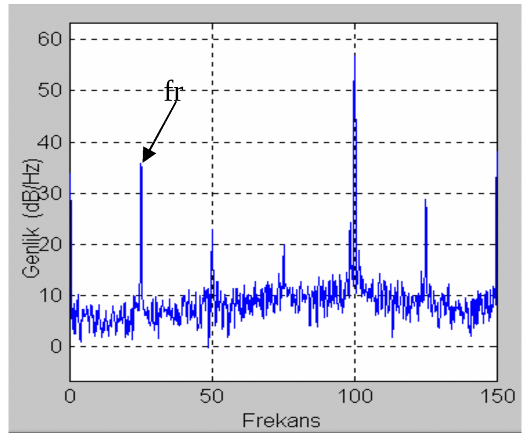

Figure 4 ZCT spectrum of 4 pole 4 kW 1499d/d, 380V motor,

Table 1 Comparison of Speed Measurements

Motor	Tachometer		ZCT	
Supply (V)	rpm.	Rotor Speed (Hz)	Fr (Hz)	Error %
380	1499	24,98	24,90	0,33
160	1487	24,78	24,76	0,09
100	1470	24,50	24,46	0,16
75	1454	24,23	24,18	0,22
50	1445	24,08	24,00	0,35
50	1432	23,87	23,80	0,28

For constant, balanced sinusoidal supplied three phase four pole squirrel cage induction motor speed is measured with ZCT method compared with speed sensor results. The experimental results shown in Table 1 indicate that the motor speed is measured with 0.35 % error percentage. It is shown that there is good correlation between measurement methods.

Figure 5 shows that f_r speed indicator component is moving left when load changes.

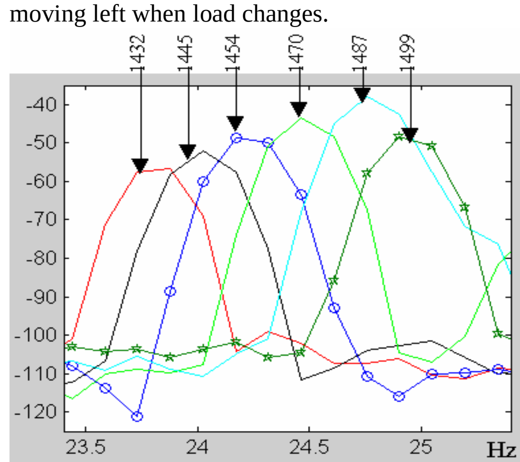

Figure 5 ZCT spectrums for various speed conditions (Same motor)

V. ON-LINE SPEED PREDICTION

The frequency resolution in off-line speed measurement is proportional with the sampling number. If a frequency resolution of 0.05 Hz is desired, ZCT data must be collected for 20 seconds. This requires 6000 sampled values to be stored for a 50 Hz supply frequency. This is obviously not suitable for online speed measurement. In addition any change in speed causes distortion in spectrum during sampling period. The spectral peaks are smeared out and reduced in amplitude may be hard to observe. To overcome this problem bandpass filter with a very narrow width is used as shown in Figure 6.

Figure 6 Block diagram of online speed measurement system

ZCT data are passed through a 14 th order Butterworth (having flat passband characteristic) type digital bandpass filter with bandwidth of 2 Hz, from 23Hz to 25Hz. It eliminates the time consuming FFT process. It consists of seven 2nd order sections, which connected in cascaded, with the output from one filter block forming the input to the next. The effect is same as the high order filter but without the instability, at the expense of slightly more computation. It should be pointed out that this bandpass filter is IIR filter [14].

Instead of processing the data in frequency domain the frequency of the speed component is measured by timing an exact numbers of cycles and by determination its zero crossing points in time domain. Filtered ZCT signal period is measured and speed component f_r is obtained by inverting the period. It may be displayed as a moving average while sampling is going on.

VI. DETERMINATION OF MOTOR SPEED

Motor speed information can be extracted by timing an exact number of cycles by observing their zero crossing points in time domain as shown in Figure 7.

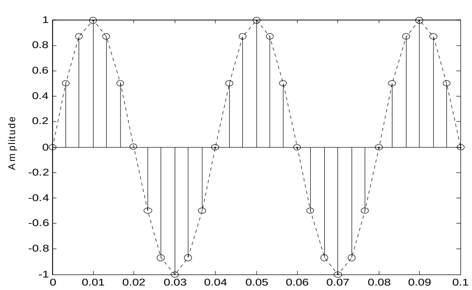

Figure 7 Bandpass filtered ZCT signal

Suppose N zero crossings of filtered data are detected, there must be $\frac{n-1}{2}$ cycles within those data. The numbers of the ZCT data are counted as P and sample period of data is $\frac{1}{6 f_{Supply}}$ the time length for $\frac{n-1}{2}$ cycles filtered data is then $(p-1)\times\frac{1}{6 f_{Supply}}$.

Motor speed component f_r is obtained using following equation [6, 8].

$$f_r = \frac{\frac{n-1}{2}}{(p-1)\times\frac{1}{6\cdot f_{Supply}}} = \frac{n-1}{p-1}\times 3 f_{Supply}$$

In online determination of motor speed above equation is used after ZCT data filtered through 7 stage cascaded 2nd order Butterworth bandpass filter with passband 23-25Hz for 4 pole motor. Due to P in most cases is not integer their frequency component f_r is displayed after moving average.

VII. FEATURES OF ON-LINE SPEED MONITORING

Speed determination by the ZCT method has high-speed accuracy 0.35% with no need-complicated modeling and temperature compensation. The motor speed f_r will closely follow $\frac{f_s}{\mathrm{P}}$ where f_s supply frequency P pole pair. When variable speed drive is used a switchable cascaded bandpass filters are required. The bandpass filter is selected automatically by software to cover whole range such as 0 to 50 Hz interval.

VIII. CONCLUSIONS

ZCT method for induction motor speed determination can be used off-line and on-line. It has advantages of high-speed accuracy 0.35% with no need any compensation. ZCT method is not influenced by an unbalanced supply. For stand alone application of this method requires three anti-alias filters to reduce harmonic components of current signal. Processing by DFT to obtain speed component makes it unsuitable to use as control signal for close loop speed control [8, 12].

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