Stator Fault Detector for AC Motors Based on the TMS320F243 DSP Controller

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I. Introduction

Stator faults, such as the inter-turn, inter-phase, and phase-to-ground short circuits, or a broken connection in one or more phases, constitute the most common cause of failure of three-phase ac motors. In many instances, especially these involving critical drives, an early warning of the impending drive stoppage is crucial, allowing task re-scheduling to avoid costly process interruptions. Although serious faults usually result in immediate tripping of the motor, some of them may spread slowly, so that the motor can still run for certain amount of time. The challenge is to catch a fault as early as possible, utilizing only the stator current and voltage signals [1],[2].

This paper describes the principle of operation and realization of a stator fault detector based on the Texas Instruments' TMS320F243 DSP controller. The detector is primarily designated for uncontrolled motors, which still dominate in the industrial drives.

II. Operating Principles of the Detector

The phase-to-ground short circuit is easy to detect by checking if stator currents in all three phases of stator add up to zero. Other short and open circuits do not affect the zero sum of these currents, but they cause impedance changes in the affected windings. In an ideal motor supplied from an ideal three-phase source, the total power, which is the sum of instantaneous powers of all phases, is constant, that is

$$p_{\mathrm{tot},0} = p_A + p_B + p_C = v_A i_A + v_B i_B + v_C i_C = P_0 \tag{1}$$

where $p_{\mathrm{tot},0}$, p_A, p_B, and p_C denote the total power and powers in phases A, B, and C, v_A, v_B, and v_C are individual phase voltages, i_A, i_B, and i_C are individual phase currents, and P_0 is the dc component of the total power, that is, the average real power consumed by the motor.

An ac component (ripple), p_{ac}, of the total power, at a double value of the supply frequency, indicates non-ideal operating conditions of the motor. Distorted supply voltage, such as that shown in Figure 1, is a common cause of the power ripple. As seen in Figure 2, the voltage waveform contains substantial odd harmonics. Similar harmonics will appear in the stator current, so that the instantaneous power, a product of voltage and current, would acquire, among others, a harmonic at twice the supply frequency. Therefore, low-pass filtering of the measured voltages and currents must be employed.

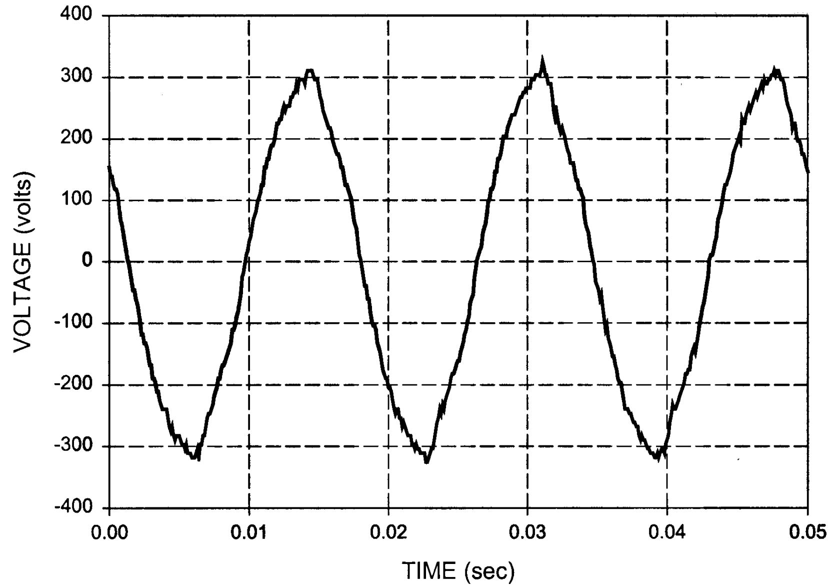


Fig. 1. Example voltage waveform (Reno, NV, 7/3/00, 2:43 PM).

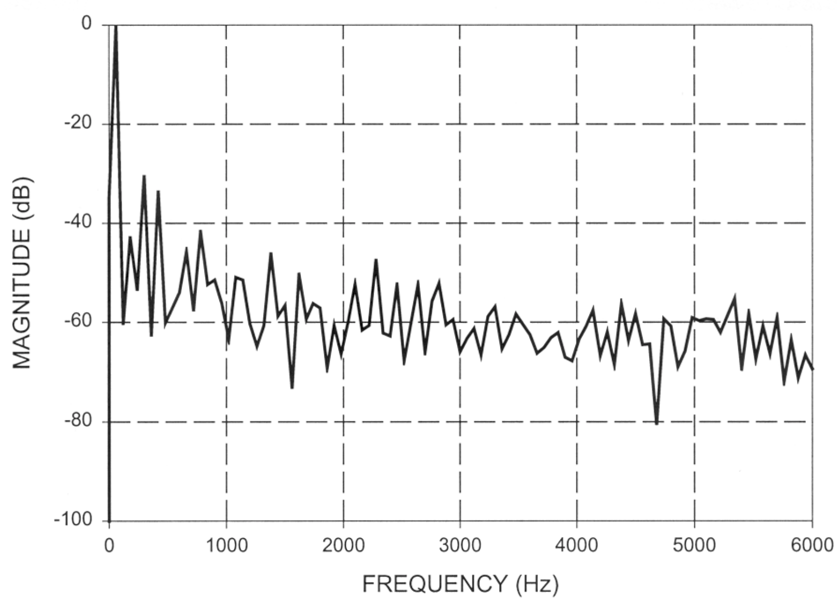


Fig. 2. Spectrum of the voltage waveform in Fig. 1.

With the voltage and current filtered, the ripple of instantaneous power at twice the supply frequency indicates unbalanced conditions of individual stator phases. These are: (1) voltage imbalance, (2) constructional imbalance, consisting in non-identical phase impedances in a healthy motor, and (3) stator fault. In order to compensate for conditions (1) and (2), contributions of individual phases to the total power must be properly corrected. Specifically, the total power is now calculated as

$$p_{tot} = k_{VA}k_{IA}p_A + k_{VB}k_{IB}p_B + k_{VC}k_{IC}p_C = P_0 + p_{ac} \quad (2)$$

where p_{ac} denotes the power ripple. Because of patent issues, algorithms for determination of correction coefficients, k_{VA} through k_{IC}, cannot be disclosed at this time.

In the last stage of the operating algorithm, the ripple of the total instantaneous power given by (2) is evaluated by comparing the minimum, $p_{tot,min}$, and maximum, $p_{tot,max}$, values of p_{tot} within a cycle of this ripple. As a measure of severity of the stator fault, a fault coefficient, k_f, taken as the ratio of peak-to-peak amplitude of the power ripple to the average value of the power,

$$k_f = (p_{tot,max} - p_{tot,min})/ P_0 \quad (3)$$

can be employed.

III. IMPLEMENTATION

The stator fault detector described has been realized using the Texas Instruments' TMS320F243 evaluation module (EVM). Computation of the instantaneous stator power is illustrated in Fig. 3. The DSP controller operates with the sampling frequency of 2 kHz, computation of the correcting coefficients performed within consecutive cycles of the stator voltage. In the output module (not shown), the average value of the fault coefficient is determined every minute, and the frequency of blinking of a warning light is made proportional to that value. In this way, the blinking frequency and its changes indicate to the plant personnel the occurrence and rate of spread of a stator fault.

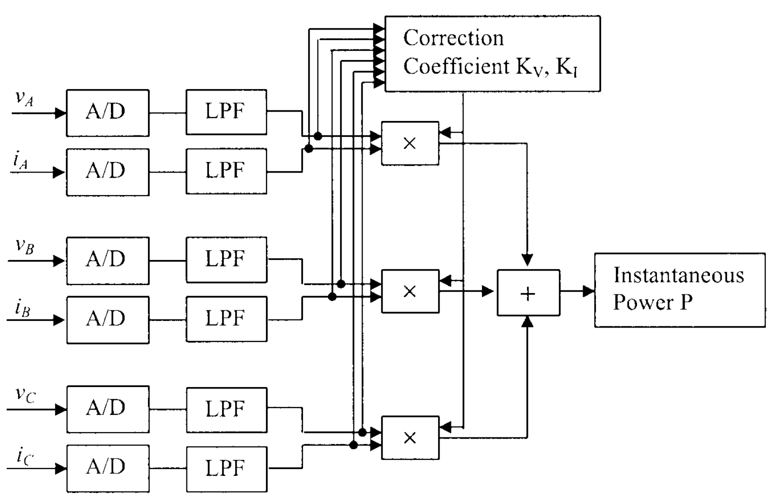


Fig. 3. Computation the instantaneous stator power in the stator fault monitor.

IV. Experimental Setup and Results

The setup used for development of the stator fault monitor and laboratory experiments is shown in Fig. 4. A commercial power inverter (Danfoss 3004), with a customized control board, is employed as a source of adjustable three-phase voltage for the monitored induction motor (IM), loaded by a dc generator. The 230-V, 5-hp motor has the stator resistance of 0.8 Ω/ph. The inverter, controlled from the TMS320F243 EVM, allows setting a desired degree of voltage imbalance. External high-current, low-resistance resistors connected in series with stator terminals allow easy simulation of the constructional imbalance and inter-turn short circuits. Note that such a short circuit affects not only the phase resistance but also, and to a greater extent, the phase reactance. Therefore, with respect to real stator faults, the monitor can be expected to be even more sensitive.

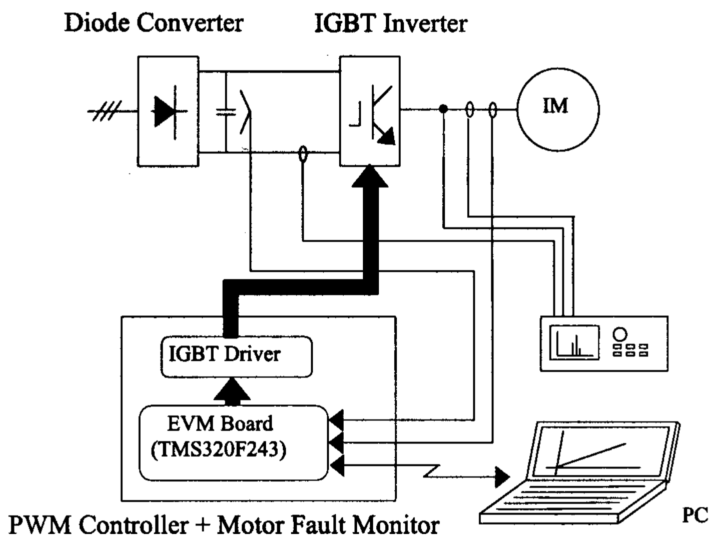


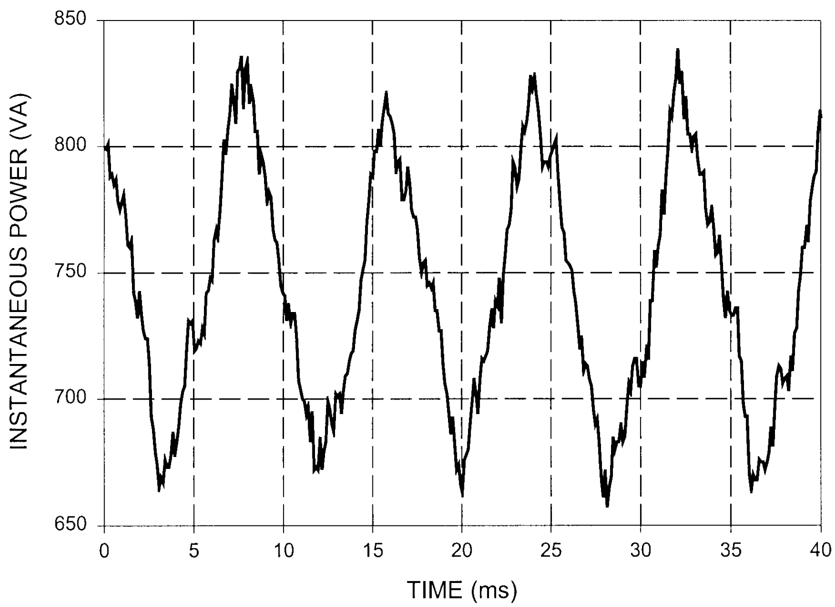
Fig. 4. Experimental setup.

Selected experimental results for the motor on a light load are illustrated in Figs. 5 to 7. An oscillogram of uncorrected total instantaneous power with unbalanced phase voltages is shown in Fig. 5. The 120-Hz component is quite strong. As depicted in Fig. 6, when the correction coefficients are applied to each phase power, the ac component is almost eliminated. If stator resistance in one phase is now reduced by 0.05 Ω, that is, by about 6%, the power ripple, shown in Fig. 7, increases significantly (notice a different magnitude scale than that in Fig. 5). With the average power, P_0, of 750 W, the fault coefficient, k_f, is about 0.015.

V. Conclusion

The stator fault monitor described is simple and inexpensive, but effective. It can be used in both controlled and uncontrolled drives (the low-pass filtering removes the high-frequency component of voltages and currents, typical for inverter-fed motors). Placed in a visible location, the monitor will alert the personnel by a simple means of a red light blinking with the frequency related to the severity of the perceived fault. This is expected to reduce unplanned process interruptions and improve the productivity of industrial plants.

Fig. 5. Uncorrected total instantaneous power with stator voltage imbalance.



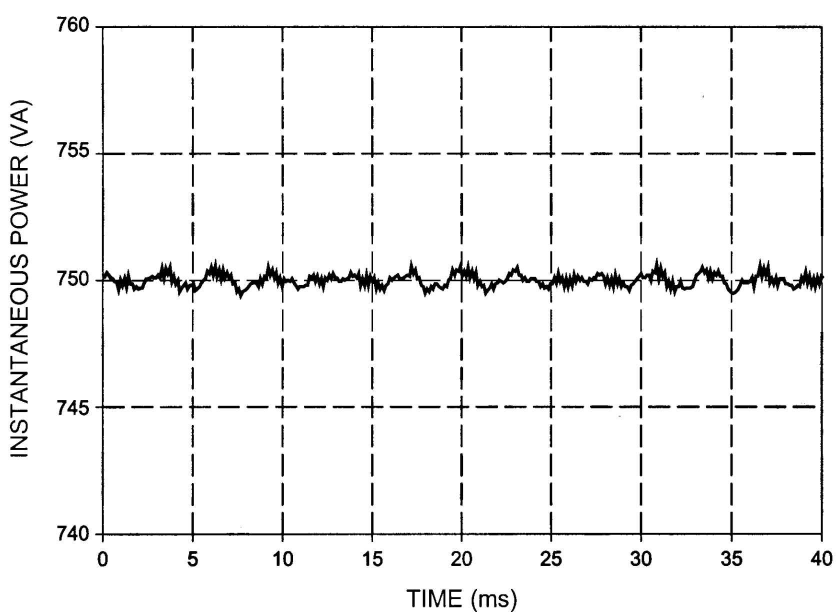


Fig. 6. Corrected total instantaneous power.

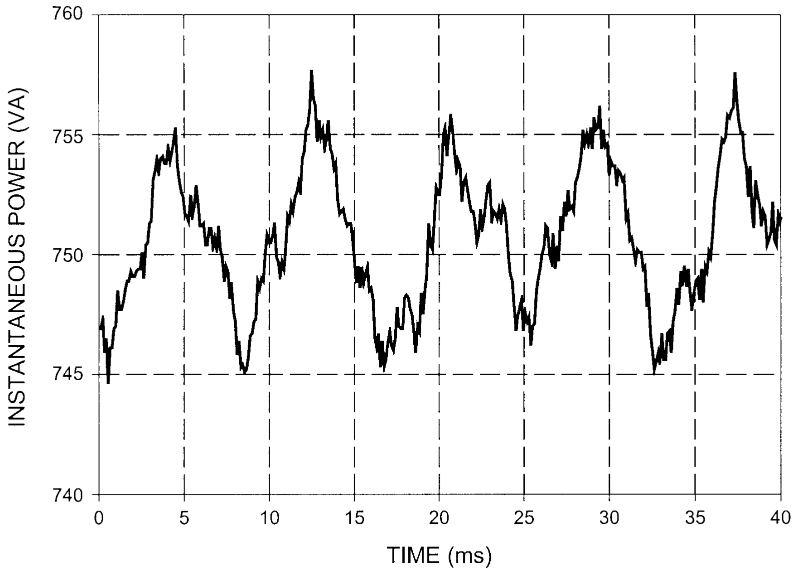


Fig. 7. Instantaneous power with a simulated inter-turn short circuit.

It is worth mentioning, that the instantaneous power constitutes an attractive medium for diagnosis of mechanical abnormalities in induction motor drives. This has been demonstrated in [3], with respect to broken rotor bars, rotor imbalance, and lateral vibration.

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