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Analysis of field-oriented controlled induction motor drives under sensor faults and an overview of sensorless schemes

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ABSTRACT

To obtain high dynamic performance on induction motor drives (IMD), variable voltage and variable frequency operation has to be performed by measuring speed of rotation and stator currents through sensors and fed back them to the controllers. When the sensors are undergone a fault, the stability of control system, may be designed for an industrial process, is disturbed. This paper studies the negative effects on a 12.5 hp induction motor drives when the field oriented control system is subjected to sensor faults. To illustrate the importance of this study mine hoist load diagram is considered as shaft load of the tested machine. The methods to recover the system from sensor faults are discussed. In addition, the various speed sensorless schemes are reviewed comprehensively.

1. Introduction

The induction motors consume major parts of electrical energy in any process industries. Control system employed in these motors plays a vital role in such industries where the speed has to be varied as per the requirements. The rotor speed of the induction motor can be varied by the following three ways [1–5]:

(a) By changing the number of poles,
(b) by changing the stator supply voltage with fixed frequency (VVFF), suitable to fan and pump loads, and
(c) by changing the stator supply voltage with variable frequency (VVVF), suitable to all types of industrial loads

The first one is achieved by designing the motor in such a way that it works on two speed levels and this motor is called Pole-Amplitude-Modulated Induction motor [1,5]. It does not require the frequency converters and it can be easily implemented cost-effectively. However, this method is operated at two speeds of certain speed ratio and requires more care in the winding design.

The second method is based on varying the supply voltage to IMD. In 1960s, when thyristors was invented [6] and suggested various topologies like a back to back thyristor configuration in each phase, control of output voltage from a constant source was achieved by delaying the conduction angle of thyristors. A pair of thyristors connected back to back in each phases of a star connected stator induction motor produce an acceptable steady state performance (with energy conservation) for fan and pump types of loads. But the use of same topology in delta connected induction machine produced average torque per rms value of stator current an inferior value [7]. Also the third order harmonics generated by the motor gets circulated in the windings and causes heating effect. As a result, parameter variations occurred in the motor which leads to more heating effect. Furthermore, the variable voltage applied to the machine is non-sinusoidal in nature which produces time-harmonic currents, increases the heating effect of the machine. Hence the variable voltage is normally applied to low and medium capacity pumps of power range 5–150 hp in which torque is proportional to the square of the motor speed [7].

The third method is based on varying the supply frequency. For the variable voltage and variable frequency operation, a pulse width modulation (PWM) technique should be used for the motion control of electrical drives. The modulation techniques can be of sinusoidal pulse width modulation (SPWM) or space vector modulation for generating the PWM Pulses in digital form. Microcontrollers or digital signal processors (DSPs) or field programmable gate array (FPGA) or dSPACE can be used to generate triggering pulses based on the algorithms designed. These pulse signals are compatible to power electronic switches present in the PWM inverter. The PWM inverter is connected to the stator

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terminals of the induction motor. By varying the modulation index (amplitude of reference wave to its corresponding carrier wave) the pulses are varied to get variable frequency.

The main contribution of this paper is to analyze the performance of vector controlled IMD under sensor faults with the consideration of mine hoist load diagram. And then the paper reviews comprehensively the sensorless schemes including position estimation, stator current estimation, and fault detection and isolation techniques. In addition, stator current reconstruction from DC link current is also discussed whereas Ref. [27] (published recently in this area) reviewed speed estimation techniques only. The paper is organized as follows: Section 2 discusses the different methods of speed control of Induction motor drives, Section 3 analyzes the IMD under sensor faults, Section 4 reviews speed sensorless schemes, Section 5 discusses the current sensor fault detection and isolation (FDI) techniques, Section 6 reviews phase current reconstruction techniques from DC link current and finally the paper concludes at Section 7.

2. Speed control techniques for induction motor drives

As discussed earlier, the speed control techniques of IMD can be broadly classified into constant frequency drives and variable frequency drives with further classifications as shown in Fig. 1. Variable frequency drives usually offer good dynamic performance which can be broadly classified into two: (i) scalar control and (ii) vector control.

2.1. Scalar control method

The air gap flux is kept constant by varying the corresponding voltage in proportional to the frequency (keeping their ratio constant for torque constant) as given by the linear relationship [1,2,9]

$$E_g = 4.44 K_w N \Phi_{ag} f \quad (1)$$

where K_w is windage factor, N is the number of stator turns, Φ_{ag} is the air gap flux, E_g is the induced emf, f is the supply frequency, K_w and N are constants. Eq. (1) can be rewritten as follows:

$$\frac{E_g}{K_g f} = \Phi_{ag} \quad (2)$$

where $K_g = 4.44 K_w N$ is a constant.

From Eq. (2), it is clear that the supply frequency can be varied in linear proportion to the induced emf to maintain air gap flux as constant [10]. When the load varies from no load to full load, the air gap flux has to be varied in linear proportion of voltage and frequency. It is possible up to the rated voltage as winding insulation deteriorated at over-voltages. There are two types of conventional scalar control methods depending on control loops i.e. open loop V/f control and closed loop V/f control.

(i). Open loop V/f control:
The open loop V/f control is shown in Fig. 2. A variable frequency PWM inverter is connected to the stator circuit of the motor. The control variables are voltage and the frequency. In Fig. 2, reference voltage is generated from the frequency command value G so that the V/f ratio is maintained constant. These voltage and variable frequencies are generated by neglecting the stator voltage drop. However at low frequency operation the stator resistance drop cannot be neglected since, most of the stator voltage is absorbed by the stator winding resistances. This voltage drop has to be compensated by a boost voltage [3] and its value should be high at the time of starting and can be reduced to a lower value once the motor

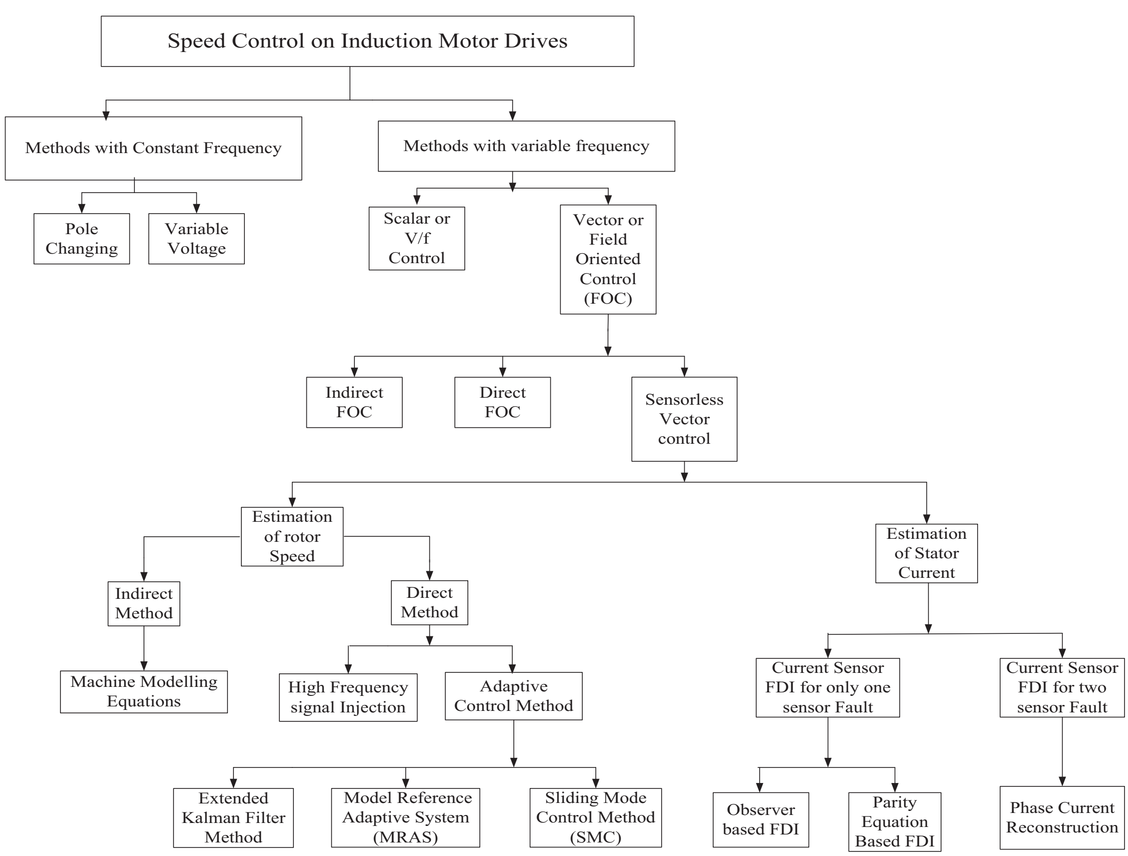

Fig. 1. General classification of speed control of induction motor drives and its estimation techniques.

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