Analysis & Simulation of Variable Frequency Measurement for Induction Motor

Vrajesh Bhandari
Sayajiganj,Vadodara, India

Abstract— Induction motors and Variable Frequency Drives (VFDs) are widely used in industry to drive machinery trains. However, some mechanical trains driven by VFD motor systems have encountered torsional vibration problems. This vibration can induce large stresses on shafts and couplings, and reduce the lifetime of these mechanical parts. Long before the designed lifetime, the mechanical train may encounter failure. This thesis focuses on VFDs with voltage source rectifiers for squirrel-cage induction motors of open-loop Volts/Hertz and closed-loop Field Oriented Control (FOC). Induction motor loss segregation and efficiency measurement requires loading dynamometers and other equipment such as a variable voltage sinusoidal power supply. These are expensive and not often available even when a loading device is accessible. Variable frequency drives are now widely used for operating induction machines and are more widely available and less expensive.

Key words: Pulse Generator, Sinusoidal Supply, Fundamental Component

I. Introduction

Nowadays, in industry a lot of mechanical systems are driven by induction motors (asynchronous motors). For easy speed control in wide speed range and energy efficiency, most induction motors are controlled by Variable Frequency Drives (VFDs). VFDs are electrical drives using power electronics techniques. The induction motor and its VFD compose the electrical drive system. Thus for a complete motion train, the electrical and mechanical systems are coupled together. However, in practice, some mechanical trains driven by VFD-motor systems have encountered torsional vibration problem. From the paper written by Fees (Engineering Dynamics Incorporated) and Max field (Tesoro Refining & Marketing Company) [1] [3] these torsional vibration problems are identified as the result of using VFDs. This torsional vibration induced by VFDs can bring great damage to the mechanical train component, like failure of coupling or shaft. This thesis will focus and analyze on the VFD system of voltage source and squirrel cage induction motor. Two VFD control methods will be studied and analyzed, including the open-loop Volts/Hertz control and the closed- loop Field Oriented Control (FOC).[12][9] The complete machinery train system combining electrical and mechanical parts will be modeled and simulated. To achieve this object, a complete simulation method to model the electrical system and mechanical system Together is developed .Induction motor driven mechanical transmission systems are widely utilized in many applications across numerous sectors including industry, power generation and transportation. They are however subject to common failure modes primarily associated with faults in the driven mechanical components. Notably, gearboxes, couplings and bearings can cause significant defects in both the electrical and mechanical systems. Condition monitoring (CM) undertakes a key role in the detection of potential defects in the early development stages and in turn avoiding catastrophic operational and financial consequences caused by unplanned breakdowns. Meanwhile, variable speed drives (VSDs) have been increasingly deployed in recent years to achieve accurate speed control and higher operational efficiency. [10]Among the different speed control designs, senseless VSDs deliver improved dynamic performance and obviate speed measurement devices. This solution however results in heightened noise levels and continual changes in the power supply parameters that potentially impede the detection of minute fault features [11]

II. Previous Work

Review Early in 2015s, the torsional vibration problem induced by VFD has been considered. M.C. Trigg [5] discussed this kind of problem in the cement industry. His paper described the general conception of torsional vibration in mechanical trains. And a general VFD machinery train structure was given. The whole system was divided into four parts - electrical supply system, drive motors, mechanical system and load system. The excitation sources from each part were generally described. Then, several types of cement industry drives and potential resonant frequencies were discussed based on experience. In Vikas Shrivastava [1] gave an outline of analysis and also provided a general conception about the performance effects of system components of soft switching In his paper, the concepts of torsional natural frequency, excitation and interface diagram were introduced. These discussions offered an analysis direction for VFD machinery trains. As the induction motors and VFDs become widely used in the industry, the torsional vibration problem due to VFDs is greatly concerned. [4][8]

III. Theory & Background of Induction Motor

A. Construction

The induction machine has two parts - stator and rotor. The stator carries a distributed 3-phase winding. The stator winding is the input/output winding and is the armature of the machine. The lab machine has a squirrel cage rotor. A squirrel cage rotor has solid bars in the slots and they are shorted together at the ends.

B. Operation

When a balanced 3-phase voltage is supplied to the armature, a rotating magnetic field is produced (just as in a synchronous machine). The speed of rotation is the synchronous speed given by

$$\omega_s = \frac{4\pi f_1}{p} \quad \text{rad / s}$$

or

$$n_s = \frac{120 f_1}{p} \quad \text{rpm,}$$

Where p is the number of poles of the armature winding and f_1 is the line frequency. However, the rotor rotates at a speed less than the synchronous speed. We will designate the angular speed of the rotor in rad/s and the speed in rev/min (rpm) by n. The slip speed is speed of the rotor relative to the field, i.e.

$$\text{Slip speed} = \omega_s - \omega \text{ (rad/s)}$$

$$= n_s - n \text{ rpm}$$

The per-unit slip, or, simply slip, is defined as

$$s = \frac{\omega_s - \omega}{\omega_s} = \frac{n_s - n}{n_s}$$

The magnitude and frequency of the rotor induced voltage depends on the speed of the relative motion (between rotor and field), which is

$$\text{slip speed} = \omega_s - \omega = s\,\omega_s.$$

The rotor frequency is, thus,

$$f_2 = sf_1$$

The voltage induced (and thereby the current) in the squirrel cage rotor is balanced three-phase with the same number of poles as in the armature. The balanced 3-phase current at the frequency of f_2 causes a rotating magnetic field that rotates at the slip speed with respect to the rotor, which means at synchronous speed with respect to the stator. The two rotating fields (stator field and rotor field) rotate at the same (synchronous) speed and maintain a certain angular relationship with each other in steady state. Useful for measure the frequency of variable frequency control of an induction motor drive.[2]

IV. PROPOSED MODEL

MATLAB design to calculate variable frequency measurement of induction motor for various application MATLAB is powerful software for engineering model and simulation. It provides modelling and simulating software's for systems in specified engineering areas, i.e. electrical power system, mechanical system, electronic system, aerodynamic system, hydraulic power and control system. Best of all, all of these software's for different specific areas can be combined and simulated together in Simulink environment in MATLAB. This gives a way to model the machinery driven by VFDs with coupled electrical and mechanical systems. Convert the input to the data type and scaling of the output.

The conversion has two possible goals. One goal is to have the Real World Values of the input and the output be equal. The other goal is to have the Stored Integer Values of the input and the output be equal. Overflows and quantization errors can prevent the goal from being fully achieved. Output pulses:

if (t >= PhaseDelay) && Pulse is on
Y(t) = Amplitude
else
Y(t) = 0

Pulse type determines the computational technique used. Time-based is recommended for use with a variable step solver, while Sample-based is recommended for use with a fixed step solver or within a discrete portion of a model using a variable step solver.

V. MODELLING THE CONTROL CIRCUIT

The Control Circuit consists of a PWM Generator. The PWM signals are obtained by comparing a sine wave with a pulse train and modulating the pulse width accordingly. As can be seen the pulse train is integrated and then compared to the sinusoidal signal In VSD the definition of the voltage measurement techniques and instrumentation is one of the most interesting topics. Both AC and DC voltage measurements can be required, according to the features of the power electronics devices adopted in the VSD. A digital instrument for AC voltage measurement embodies two main blocks, a voltage conditioner and a low voltage measuring system.

VI. MEASUREMENT VOLTAGE & FREQUENCY

To select the right instrument, different parameters must be analyzed. The nominal voltage root mean square (RMS) value, usually 115/230 V for one-phase and 200/400 V for three-phase configurations, firstly influences the choice of the voltage conditioner, respectively, even if higher voltage amplitudes can be used for high power VSD. A voltage attenuation stage must be provided to supply the right signal level to the electronic measuring system. Moreover, insulation is frequently required. To measure AC voltage accurately both voltage conditioner and digital instrument must have a suitable bandwidth. For a sine wave, it must be at least as large as the sine frequency. Nevertheless, considering the usual definition of bandwidth, a signal with a frequency near this value will be decreased by 3 dB, so an even wider bandwidth is desirable for a better measurement. In some VSD applications the voltage nominal frequency, usually 50–60 Hz, cannot be considered because, using both voltage waveform Pulse Width Modulation (PWM) and six-step techniques,

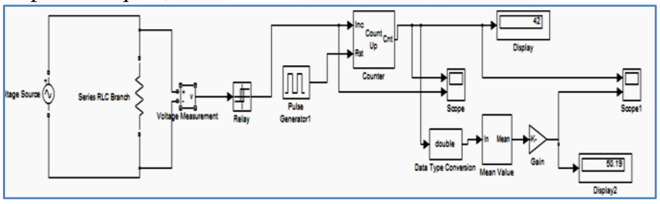

Fig. 1: Proposed Model of Frequency Measurement

The AC supply from the mains is supplied to a rectifier which converts into DC and this is fed to the PWM Inverter. The PWM Inverter varies the frequency of the supply and the voltage is varied accordingly to keep the ratio constant. The electromagnetic torque is directly proportional to the flux produced by the stator which is in turn directly proportional to the ratio of the terminal voltage and the supply frequency. Hence by varying the magnitudes of V and f while keeping the V/f ratio constant, the flux and hence the torque can be kept constant throughout the speed range. A MATLAB code was developed which asked the user to input different frequencies and then varied the voltage to keep the V/f ratio constant. The different synchronous speeds corresponding to the different frequencies were calculated and the torque characteristics were plotted as the rotor speed was incremented from zero to the synchronous speed in each case. The resulting Torque vs Speed graph was plotted.

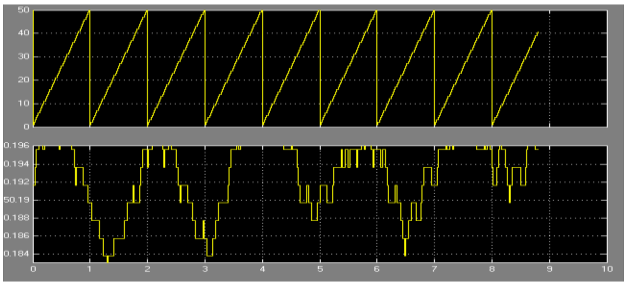

Fig. 2: Current & Voltage Signals Comparison at Full Speed

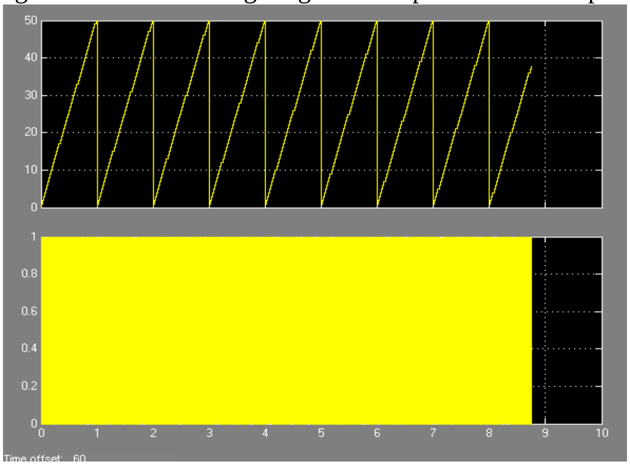

Fig. 3: Time Domain Graph with Fully Load

VII. CONCLUSION

This paper discusses efficiency and frequency measurement of induction motor using VFD power source as equivalent variable voltage sinusoidal supply. The difference in power measurement due to different power analyser setting is demonstrated. Induction motor loss segregation and efficiency measurement requires loading dynamometers and other equipment such as a variable voltage sinusoidal power supply. These are expensive and not often available even when a loading device is accessible. Variable frequency drives are now widely used for operating induction machines and are more widely available and less expensive.

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