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Squirrel cage induction motor scalar control constant V/F analysis

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Abstract

In constant V/f control technique it is assume that the stator resistance and leakage inductance drops are negligible, especially at high speed and small load. In other words, the back emf is comparatively large at high speed and hence these voltage drops can be neglected. By maintaining constant V/f, constant Eg/f and hence constant air-gap flux is assumed. This assumption is however invalid at low speeds since a significant voltage drop appears across the stator impedance. The terminal voltage, V no longer approximates Φ ag. By using MATLAB Simulink, the open-loop constant V/f is simulated. It is shown that the performance of the drive deteriorates at low speeds. The improvement in the performance by applying voltage boost is shown and discussed.

Keywords: *induction machine, induction motor, motor scalar control, open loop V/f control, slip compensation, squirrel cage*

1. Introduction

The operation of induction motors in the constant volts per hertz (V/f) mode has been known for many decades, and its principle is well understood [1-4]. With the introduction of solid-state inverters, the constant V/f control emerged and the great majority of variable speed drives in operation today are of this type. Its practical application at low frequency is still challenging, due to the influence of the stator resistance and the necessary rotor slip to produce torque [5-7].

The simplest stator resistance compensation method consists of boosting the stator voltage by the magnitude of the current–resistance (*IR*) drop. Andrew Smith et al. study on the improved method for a scalar control scheme was proposed [8]. In this scheme, the flux magnitude is derived from the current estimation. Using the dc-link voltage and current, both flux and torque loops are introduced. Its use at low frequency is limited by the flux estimation. Also, the slip compensation was based on a linear torque–speed assumption which led to large steady-state errors in speed for high load torques.

2. Scalar Control

In this technique, the supply voltage magnitude is varied by maintaining the E_g/f ratio constant. For small value of slip, s and constant air-gap flux, Φ_{ag}, it can be shown that the relationship between the torque and slip speed is linear. To ensure that Φ_{ag} is at its rated value, when the voltage is changed, the frequency has to change as well as given by (1).

$$E_g = k\, f\, \Phi_{ag} \tag{1}$$

To ensure maximum torque capability at all time, it is therefore necessary to maintain the magnetic flux at its rated value at any frequency. From the steady-state induction motor

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equivalent circuit shown in Figure 1, this is equivalent to maintaining the magnetizing current at its rated value. At high speed, where the induced back emf is large, the drop across the stator leakage and resistance is negligibly small. Therefore, E_g/f is maintained constant by maintaining V/f constant as shown by (2).

$$\frac{E_g}{f} \approx \frac{V_s}{f} \tag{2}$$

By applying a 3-phase supply to a 3-phase sinusoidal distributed winding of the stator produces a rotating mmf force and rotating magnetic flux. Rotating magnetic flux will induce emf on the rotor circuit and it is shorted for squirrel cage rotor. Rotor current will flow and interacts with rotating flux and then producing torque.

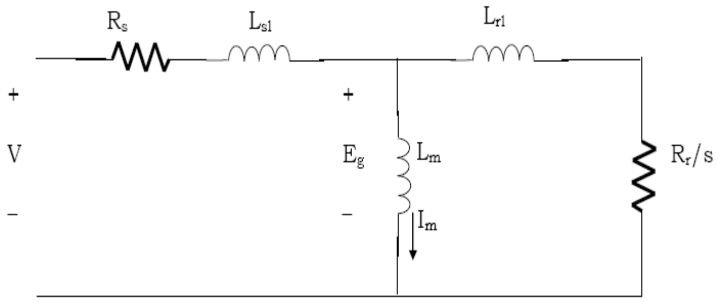

Figure 1. Induction machine equivalent circuit

The torque can be in maximum mode as the magnetic flux is maintained on its rated value at any frequency. By referring to Figure 1, we can see that maintaining magnetic flux is the same like maintaining magnetizing current as we have already obtained the induction machine equivalent circuit.

The magnetic flux can be controlled by maintaining the ratio Eg/f constant. During the high speed mode, the back emf is large and the ration Eg/f is maintained constant by maintaining the ratio value of V/f constant [9]. This is shown in Figure 2. The situation is different at low speed where the back emf is low and the drop is significant. The flux decreases below the rated value and causes the torque to go down.

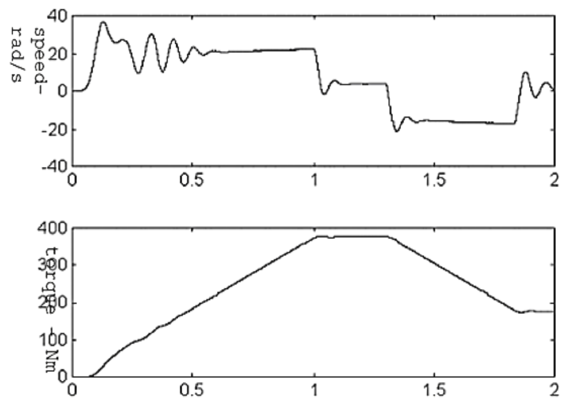

Figure 2. Graphs of speed and torque when V/f is constant

Nevertheless, the main drawback of the constant V/f procedure consists in the effects of the stator-voltage drop, which cause difficulties especially at low speed operation. The voltage drop at low frequencies has the same order of magnitude with the computed voltage and it makes the method inadequate for low speed region.

There are two methods to improve the performance of the system i.e. by:

a. Boosting the voltage when in low frequency/low speed
b. Controlling the stator current

In this paper, we will only figure out how can by boosting the voltage will improve the performance of the induction motor.

3. Open Loop V/f Control

Open loop constant V/f is being used for the low cost and performance drive. In this control type system, the rotor speed will be less than the synchronous speed because of the slip speed. Referring to the Figure 3 *w** will differ from the actual speed because of the presence of the slip speed.

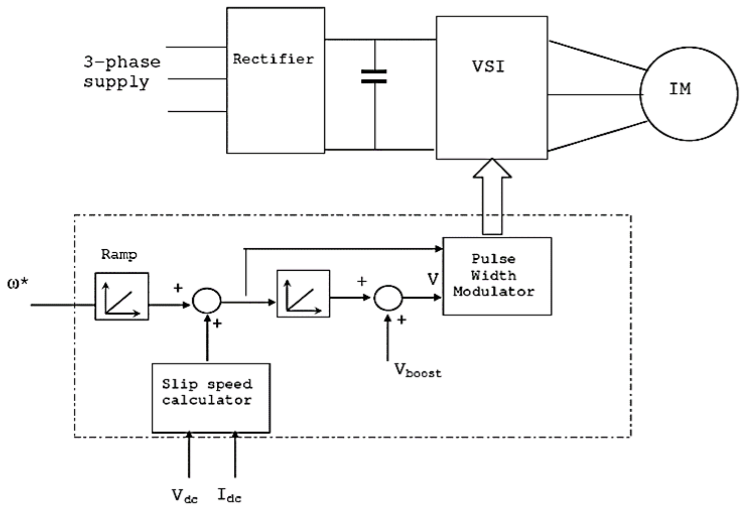

Figure 3. Open loop V/f control system

The slip frequency depends on the torque, so we need to estimate the slip frequency by estimating the torque. The slip speed on the other hand depends on load torque. This relation is shown in Figure 4.

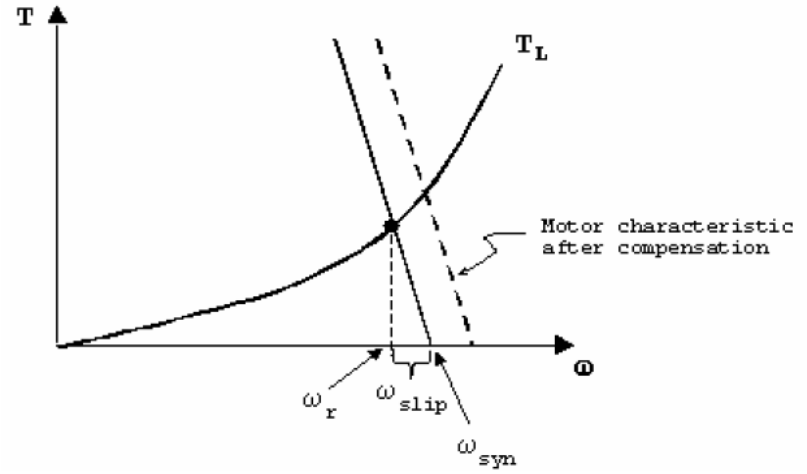

Figure 4. Slip frequency which depends on load torque

3.1. Change in Steady State Speed

By using the m-file in the MATLAB, we firstly view the steady-state torque-speed characteristics with frequencies 10 Hz, 30 Hz and 50 Hz and make the load torque value at 0 Nm. The graph is plotted as shown in Figure 5 above. The same graph is used throughout. We then add the load torque value from 0 Nm to 200 Nm but there occured a problem in which the system cannot control the load torque value of 200 Nm at a frequency of 10 Hz. Due to this case, we need to the boost the voltage for about 20 V or 8.35% from the rated voltage. The simulation results obtained by the simulation are shown and discussed later part.

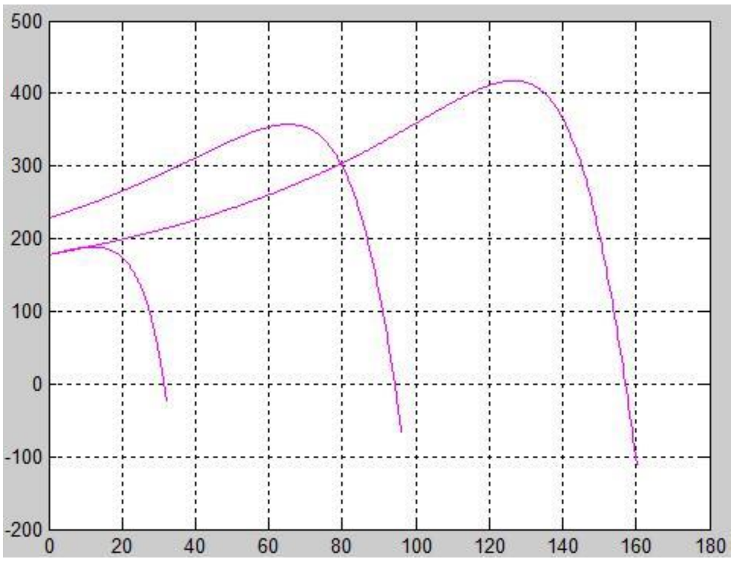

Figure 5: Torque versus speed characteristics

3.2. Open Loop Constant V/f Simulations

By using MATLAB Simulink, an open-loop constant V/f induction motor/machine drive simulation diagram as in Figure 6 is simulated. The defaults for the induction motor are:

3-phase
1.5kW
4 poles
50 Hz

with the parameters used as follow:

240V
50Hz
4 poles
$R_r = 0.2\Omega$
$R_s = 0.25\Omega$
L_r=L_s= 0.0971H
L_m = 0.0955H

We simulated the above open loop V/f control system by controlling the speed in the induction machine to avoid it from collapse. To maintain the V/f on its rated value, the load torque of the induction machine must be incremented from zero with a small perturbation during the starting time. When operating in low frequency, the voltage drops. By calculating the voltage drop value, the voltage boost value is obtained, which is then used to recover back the value of the voltage drop. The graph of the voltage boost is shown in Figure 7.

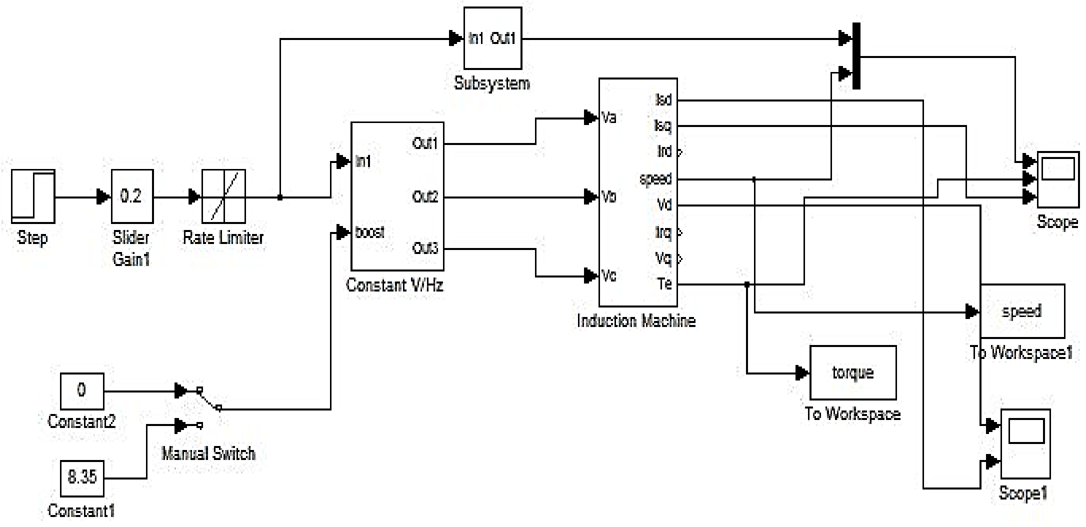

Figure 6. Induction machine in MATLAB simulation

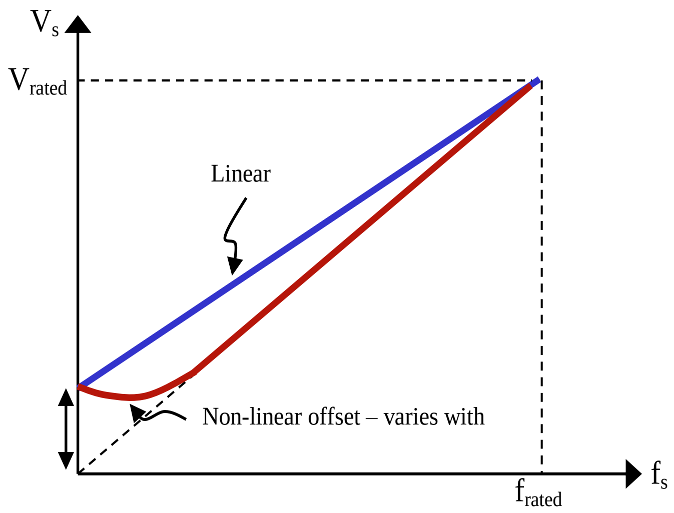

Figure 7. The voltage boost recovered back the voltage drop in the low frequency

4. Result and Discussion

For starting, the supply voltage is set to 240 V with no load torque. The frequency of 50 Hz with no load torque is applied as the steady-state is reached. The load torque is then increased to 50 Nm, 100 Nm and finally 200 Nm at 0.52 s, 0.75 s and 1.1 s respectively. The increase of the load torque will cause the induction machine speed to decrease. The results are as shown in Figure 8.

Then the frequency is changed by reducing it to 30 Hz and finally 10 Hz as the load remains at 200 Nm. At 10 Hz mode, the motor collapsed at 1.4 s. Due to this, voltage boost is connected to the system at 1.6s and the system recovered back by oscillating around a steady-state value. To obtain the transient torque-speed characteristics curve, torque is plotted versus speed on the same graph of the steady-state characteristics.

Figure 9 shows the steady-state (black) and transient (green) torque-speed characteristics curves with 50Nm load torque of the induction machine. We can see that the machine can be maintained in steady-state condition although there is change in frequency. We can say that the induction machine is in stable condition because the transient torque-speed characteristics spin on a point on the steady-state torque-speed characteristics.

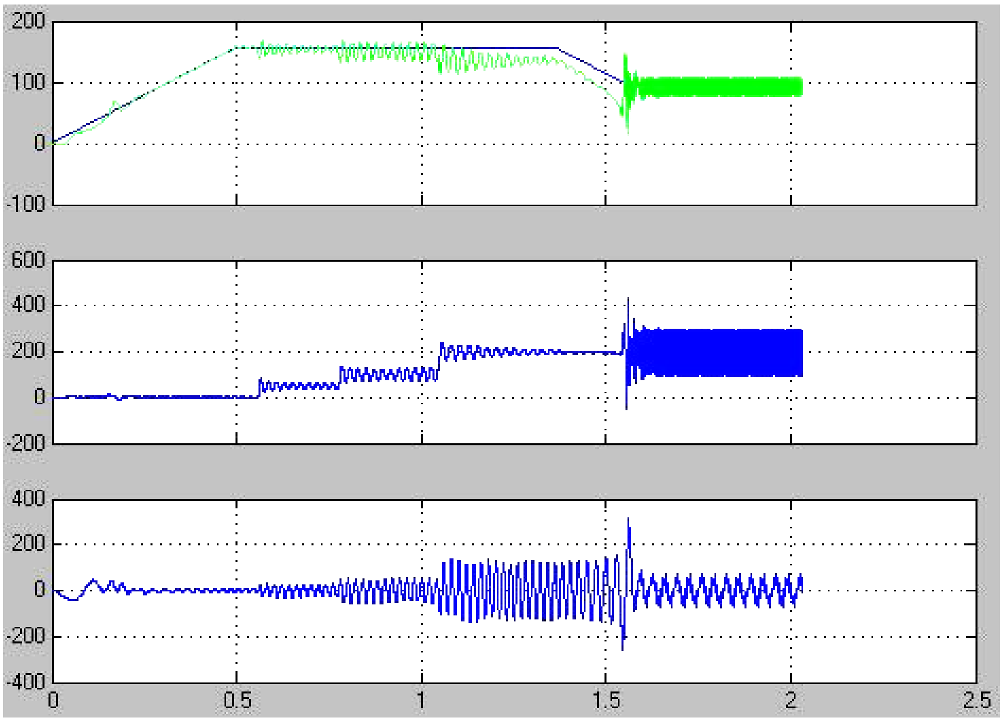

Figure 8. Speed, load torque and current characteristics at \50 Hz

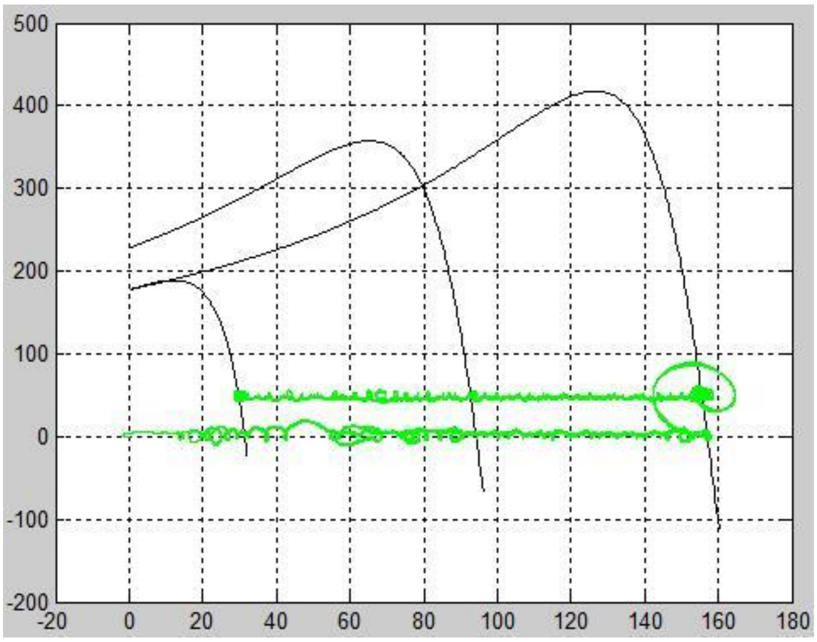

Figure 9. Steady-state and transient torque-speed characteristics with 50 Nm load torque

When the load torque is increased to 200 Nm, V/f control cannot maintain its speed when the operating frequency is decreased. The transient characteristic is spinning around a point on the steady-state speed-torque characteristic curves for the 50 Hz and 30 Hz of operating frequencies. Instead, on the 10Hz frequency, the transient characteristic has been took away. It has been exposed to unstable condition because it exceeded the maximum torque capability at 10 Hz. This has been shown in Figure 10.

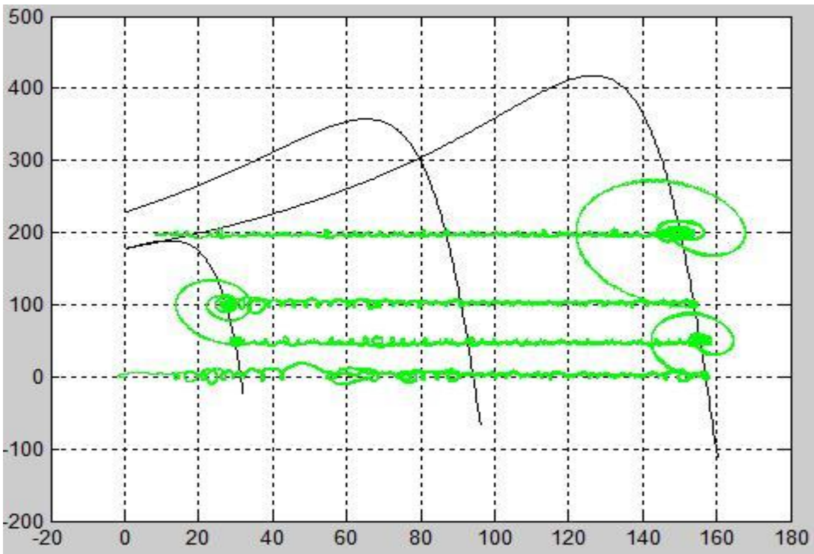

Figure 10. Steady-state and transient torque-speed characteristics with 200 Nm load torque

Due to the unstable condition shown in Figure 10, we need to apply the voltage boost. Upon the application of the voltage boost, the unstable transient characteristic recovers back to steady-state characteristic as we can see Figure 11. The unstable condition can be brought back to stable condition by applying voltage boost.

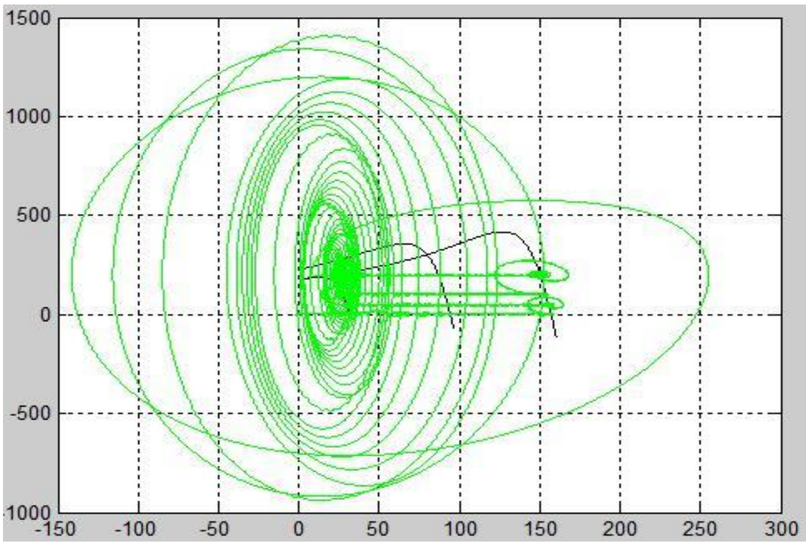

Figure 11. Steady-state and transient torque-speed with voltage boost characteristics

5. Conclusion

The performance of the drive can be improved at low speed by applying the voltage boost. At high speed, where the induced back emf is large, the drop across the stator leakage and resistance is negligibly small. Therefore E_g/f is maintained constant by maintaining V/f constant. However at low speed, the back emf is low and the voltage drop is significant. Thus the flux and torque capability are reduced below rated value. Voltage boost is obtained from stator current (d component) and the impedance of stator resistance and stator inductance. With voltage boost, the slip will reduce and resulted in increase of torque at low speed. This reduction of slip will improve a lot in the performance of induction motor drive at low speed. Any variation of parameters due to temperature (resistances) and magnetic saturation (inductances) may lead to serious stability problems. This is the main reason why V/f control method, though simple, is to be used only with light load start applications.

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