A Closed Loop Controller for Elevator Application Using VVVF Induction Motor Drive

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Abstract

The V/f control method is one of speed control methods for induction motors. We have proposed an auto-boost voltage method to compensate the voltage drop of stator impedance and a slip frequency compensation method to decrease the speed error caused by the change of load. Torque-speed characteristics and transient responses of proposed system are presented by PSCAD/EMTDC simulations. Compared with the constant V/f control method, speed accuracy of proposed method is improved in various speeds and loads.At last an evaluation of response power quality and losses is presented by evaluating THD of applied current of the motor.

1. Introduction

The V/f control method is one of variable-speed control methods for induction motors (IM). Unfortunately, the motor performance deteriorates at low frequencies when the airgap flux decreases, because of the voltage drop across the stator leakage impedance. In addition, a rotor slip of IM is requisite for producing torque. This slip causes the error between the actual and desired speeds, and cannot be ignored in many cases. Therefore, some common problems have appeared as the applications of
V/f control method for general-purpose inverters. One problem is that the starting torque is limited. Another is that the speed control accuracy becomes worse with load increase or frequency decrease. On the other hand, speed
sensorless vector control of IM allows high performance control of speed and torque. But the application of speed sensorless vector control has also some problems. One problem is the system stability under the influence of parameter variation. Another is that the control system is relatively complicated. For general application of variable-speed drive system, the V/f control method is also attractive if the drive system does not need a fast dynamic response. The study on V/f control has been reported to improve the performance. To realize an advanced V/f control, we propose an auto-boost voltage method to compensate the voltage drop across the stator leakage impedance and a slip frequency compensation method to decrease the speed error. By detecting stator currents, the voltage drop across the stator leakage impedance can be instantly calculated and added to the voltage command automatically when the load varies. The slip frequency related the load variation can be also calculated by the detected currents and added to the supply frequency command to compensate the motor speed reduction caused by the necessary torque producing slip. For stabilizing the system, two first-order lags are introduced in the feedback loops of voltage drop and slip frequency compensators. A linear model of the proposed system at a steady-state operation is derived and the system stability is analyzed.Simulation results of the proposed compensation method are presented. Compared with the constant V/f method, the speed accuracy is remarkably improved by the proposed method in various speeds and loads. The effectiveness of the proposed system has been verified by simulation .As PSCAD/EMTDC software package prepares a graphical environment and makes good undestanding of system performance it is used here .

2. Proposed Method

Compensation of Stator Leakage Impedance
Fig.1 shows the steady-state equivalent circuit of induction motor. From Fig.1, Fig.2 shows a phasor diagram defined by a d-q reference frame with respect to Vs. According to the principle of constant vector control, E0 in Fig. 1 must be proportional to the supply frequency for keeping rotor flux constant. Generally, E0 is considered to be approximately equal to the input voltage Vs at high frequencies because Vs is greater than the voltage drop across the stator leakage impedance.

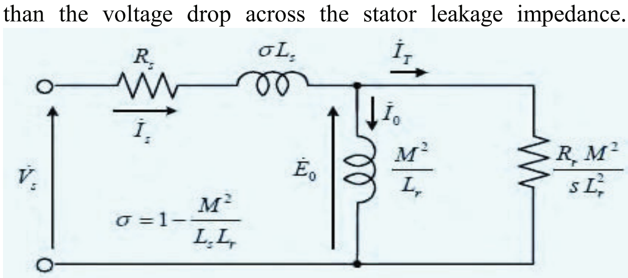

Fig. 1. Equivalent circuit of induction motor

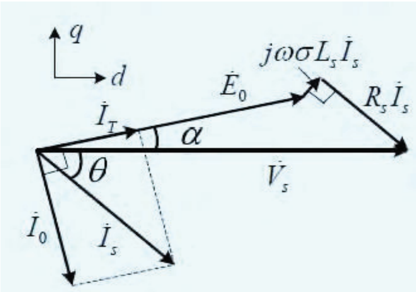

Fig. 2.Phasor diagram and definition of d-q reference frame.

But it is not valid at low frequencies or with heavy load, because this voltage drop becomes greater relatively and cannot be ignored. Therefore, the influence of voltage drop must be considered. The d-q currents can be written as follows: (1)

$$\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} = \sqrt{2}\begin{bmatrix} \sin(\theta^* - \frac{\pi}{6}) & -\cos\theta^* \\ \cos(\theta^* - \frac{\pi}{6}) & \sin\theta^* \end{bmatrix}\begin{bmatrix} i_{sa} \\ i_{sb} \end{bmatrix} = \sqrt{3}I_s\begin{bmatrix} \cos\theta \\ -\sin\theta \end{bmatrix}$$

where θ is phase difference between the phase voltage and the phase current. Defining Xs =ωσL s, the following equations can be obtained from Fig. 2.(2)

$$V_s = E_0\cos\alpha + \frac{1}{\sqrt{3}}\left(R_s i_{sd} - X_s i_{sq}\right)$$
$$\sin\alpha = -\frac{1}{\sqrt{3}E_0}\left(X_s i_{sd} + R_s i_{sq}\right) \quad (2)$$

E0 is proportional to the supply frequency. The magnitude of the auto-boost voltage can be calculated by (3)

$$V_b' = V_s - E_0 \quad (3)$$

Because of the inherently positive feedback characteristic of the auto-boost voltage, it is necessary to stabilize the system by introducing a first-lag in the feedback loop. The actual auto-boost voltage command is obtained by (4);

$$V_b = \frac{1}{1+\tau p}V_b' \quad (4)$$

The phase voltage command is given by (5)

$$V_s^* = E_0 + V_b \quad (5)$$

Compensation of Slip Frequency

This slip causes an error between the actual and desired speeds, and cannot be ignored in many cases, for example, at low frequency operation or at the heavy load operation.

From Fig. 1, the magnetizing current I0 and the torque current IT are obtained as follows:(6)

$$I_0 = \frac{L_r E_0}{\omega M^2}$$
$$I_T = \frac{sE_0 L_r^2}{R_r M^2} \quad (6)$$

Then, the slip frequency f sl ′ is obtained by (7)

$$f_{sl}' = \frac{R_r}{2\pi L_r}\frac{I_T}{I_0} \quad (7)$$

I0 and IT shown in Fig. 2 are expressed as(8)

$$\begin{bmatrix} I_0 \\ I_T \end{bmatrix} = \frac{1}{\sqrt{3}}\begin{bmatrix} \sin\alpha & -\cos\alpha \\ \cos\alpha & \sin\alpha \end{bmatrix}\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix} \quad (8)$$

In order to stabilize the system, a first-lag in the feedback loop is introduced as follow:(9)

$$f_{sl} = \frac{1}{1+\tau p}f_{sl}' \quad (9)$$

The actual supply frequency f **can be calculated by(10)

$$f^{**} = f^* + f_{sl} \quad (10)$$

where f * is the frequency corresponding to speed command. Fig. 3 shows the block diagram of proposed system. The output voltage error of PWM inverter caused by dead-time and voltage drop of IGBT is considered and the voltage commands are well pre-processed with a compensating algorithm.

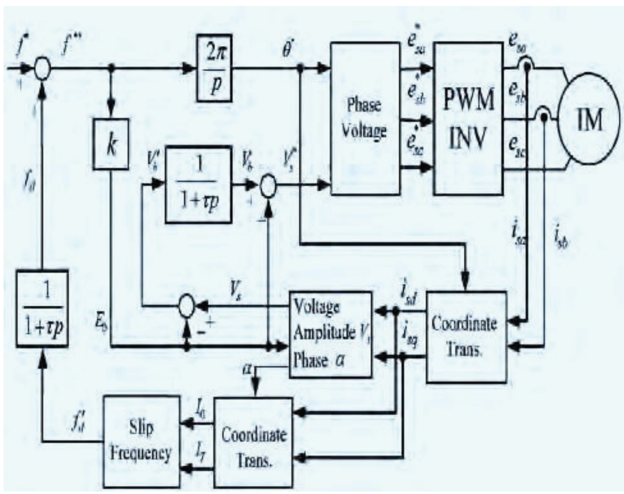

Fig. 3. Block diagram of proposed method

3. Simulation Results

Motor parameters to simulate are as below:
Rated RMS phase voltage=0.127[kv] ;
voltage rating [V]
HP=10.0 ; Horsepower rating [hp]
Base angular frequency =376.991 [rad/s]
Other Machine parameters are considered as Typical data.
fo=60 ; Base frequency (Hz)
wo=2*pi*fo ; Base frequency (rad/s)

Here is the simulated circuit in PSCAD/EMTDC:
The inverter side of simulation

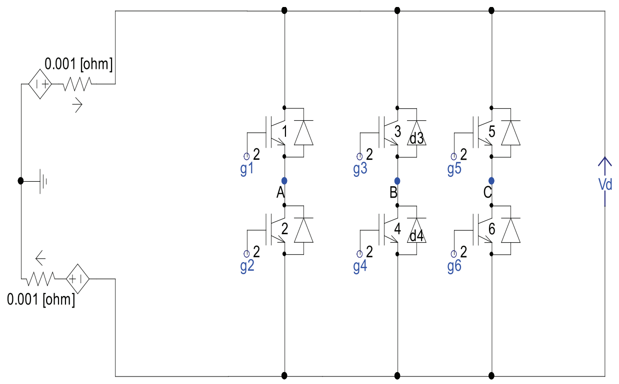

Fig. 4. Inverter side of simulation

As shown in figure below, the inverter side is connected to the motor side:

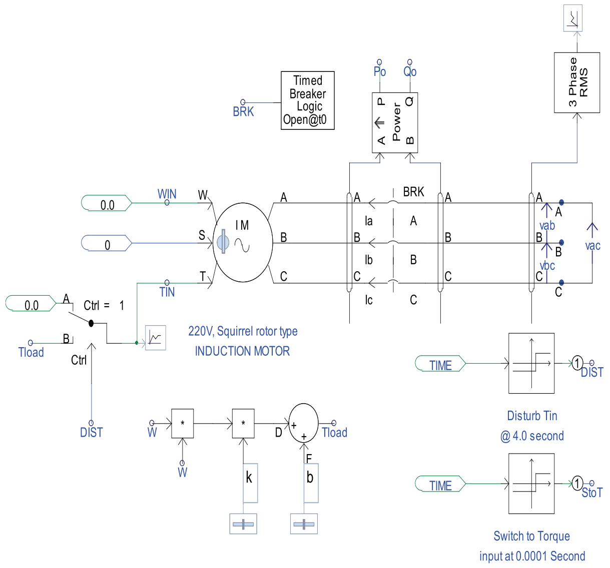

Fig. 5. Motor side of the simulation

The diagrams below show the blocks to generate control signals,firing angels in order to have a closed loop VVVF control:

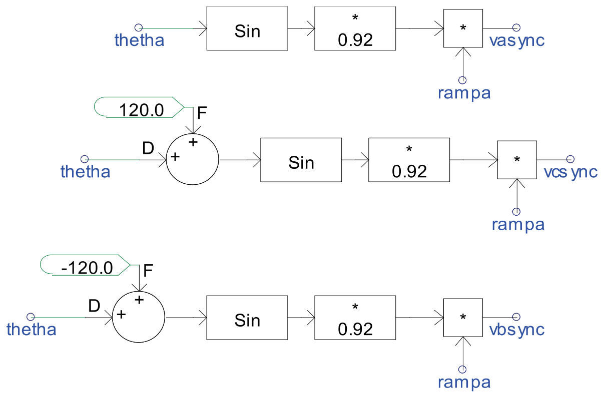

Fig. 6. generating control signals,firing angels

Finally firing pulses are produced:

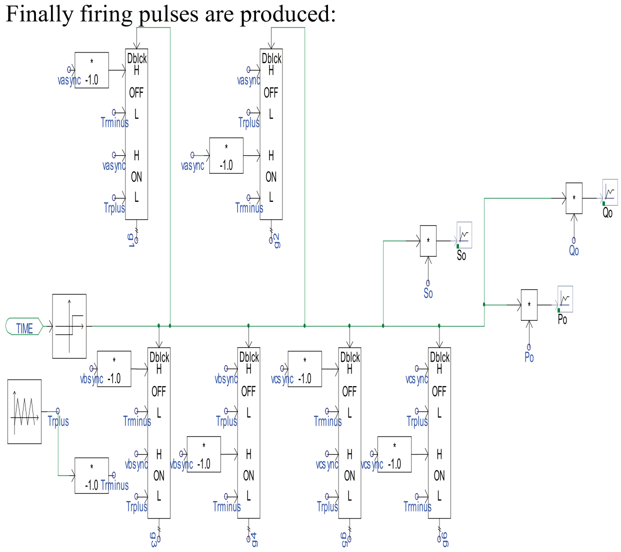

Fig. 7. generating control signals,firing angels

Here is the inverter control blocks: to control frequency of ac voltage, a sinewave generator is used:By using this controller with any variation in motor frequency ,new voltages for the above control circuit is generated.

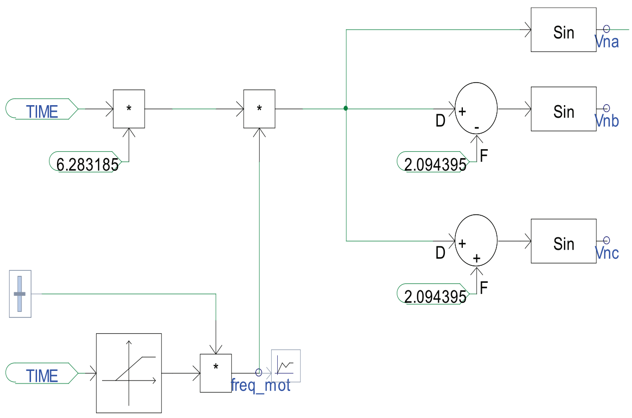

Fig. 8. inverter control blocks

Here are all results obtained from PSCAD simulations and THD values of currents::

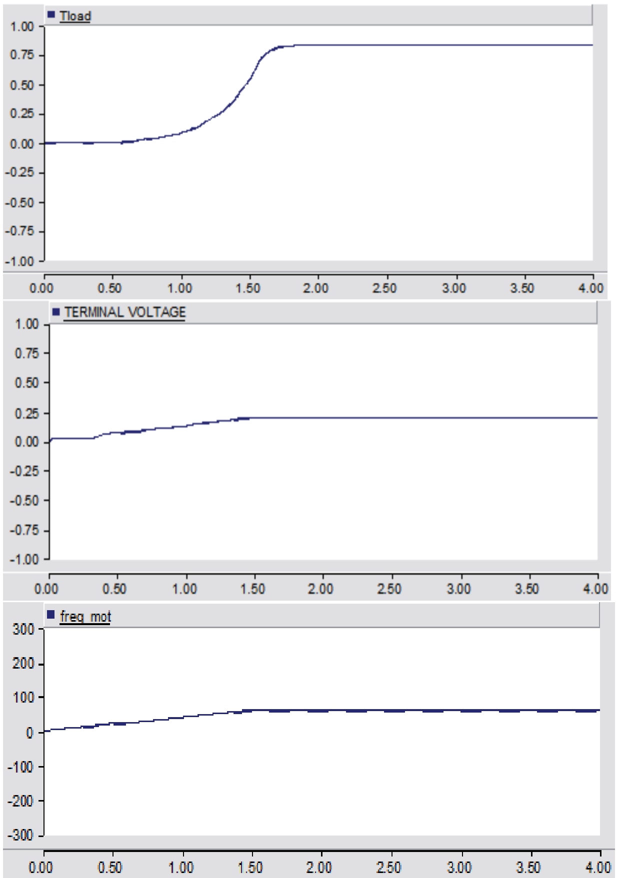

Fig. 9. Tload, terminal voltage of the motor and motor frequency

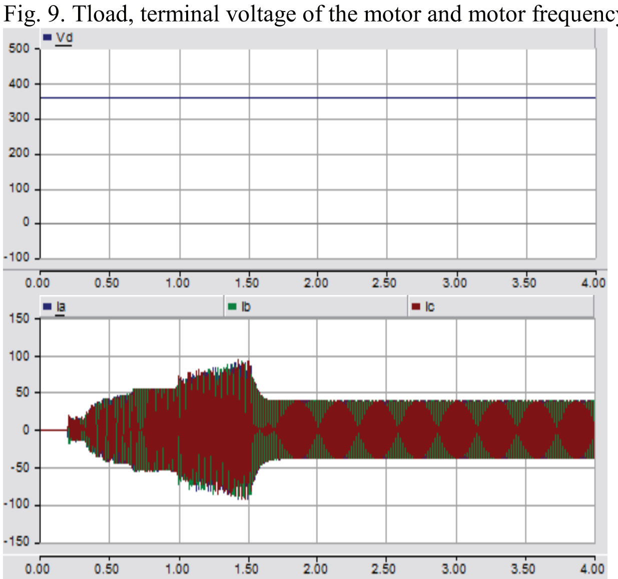

Fig. 10. DC voltage inverter is fed,motor phase currents

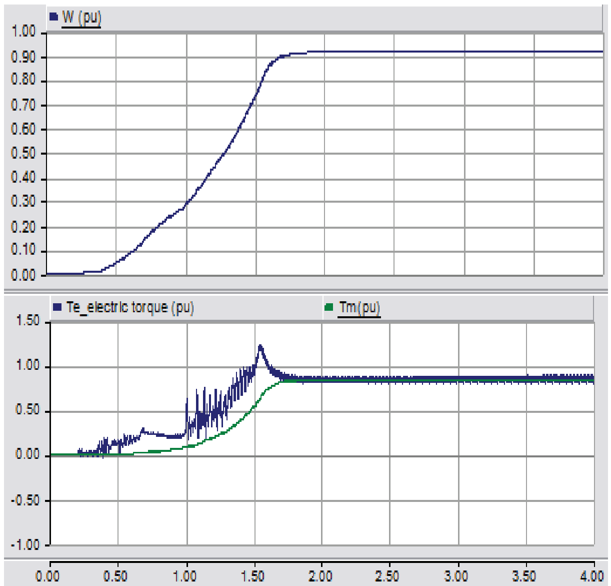

Fig. 12. Output speed(pu),electric and mechanical torque(pu):

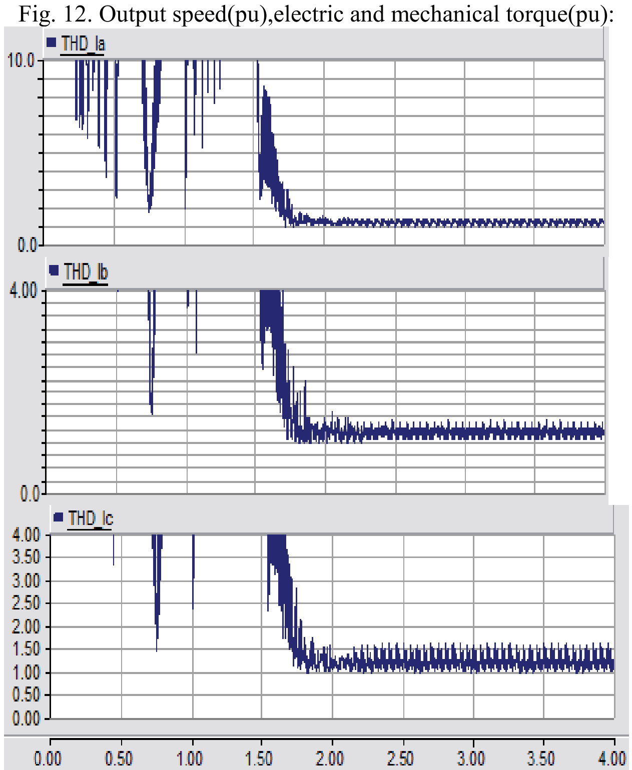

Fig. 13. Evaluated THD of motor phase currents

As shown in above figures the THD is about 1% and has a small value.

4. Conclusions

In this paper a V/f control method has been presented. By calculating the d-q currents of IM, auto-boost voltage compensation for the voltage drop across stator leakage impedance and the slip frequency compensation are realized. When the constant V/f method is used, the motor cannot be operated at very low speed. On the other hand, the proposed method can realize the speed control at very low frequency operation, such as 30 rpm, from no load to the rated load. Simulation results show that good speed control accuracy can be achieved by the proposed method. This method can be easily applied to existing V/f drives. Compared to sensorless vector control system, the mentioned method does not need any PI controllers for current control, speed control and speed estimation.

5. References

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