Minimum Current Control for PWM Inverter-Mounted Drive System

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Abstract

This paper describes minimum current control method for size reduction and performances improvement at unified inverter-induction motor system. This control method is based on V/f without speed sensor. Through the use of mimimum stator current points at required torque during V/f operation it is possible to minimize the size of heat-sink related with the losses of power circuit and to improve overall efficiency compared to conventional V/f control. Using this proposed scheme, it is so much more useful to apply to some fields such as electric vehicles, air conditioning system and textile mills where the limited space is given and required low cost.

I. Introduction

PWM Inverter systems have been widely used for adjusting the speed of the induction motor. Recently, inverter system has emerged as a very important technology with module, asic, and unified inverter-motor system for size reduction and performances improvement in the recent trend of industrial automation[1-2].

The unified inverter system mounted on induction motor(hereafter the system of this structure is called PIMD system) among them has the advantages as follows :

- it can be designed mutual complement in the aspects of performances and space.
- it is possible to remove needless power line between inverter and motor.

These is results in the prevention of over-design, cost down, and the increase of reliability[3].

Therefore, in cases of unified system or PWM inverter-mounted system, the inverter should be considered in the selection of control scheme for compact size. Also because it is applied to the same space with motor, it is required the removal of sensors in the poor environment conditions.

In this paper, for proper control scheme of these requirements it is proposed to drive by minimum current control which is possible to minimize the size of heat-sink related with the losses of power circuit, to realize no sensors, and relatively the cost could be reduced.

For these realizations, the simulation tools of the ACSL is used to design PWM inverter - mounted drive(PIMD) system, and then to develop the matching techniques and control algorithm. Also the TMS370C756 single-chip microcomputer is used for whole controller implementation. The prototype system of 1-Hp, three-phase, 4-pole induction motor and three-phase output PWM inverter is made and tested at various load conditions of all frequency ranges.

II. Minimum current control

The choice of control strategy is important problem in determining the characteristics and performance of drive system. The criteria, such as simplicity, cost effectiveness, loss minimization, good performance should be considered in the selection of control scheme for compact drive system. V/f control is an good choice in many variable frequency drives because of its simplicity and cost effectiveness. The minimum current control method is based on V/f control.

For V/f control of induction motor, the airgap flux must be sustained to be constant at all frequencies. According to steady state equivalent circuit, a constant airgap flux is obtained when the ratio E_1/f_1 is constant. As the stator resistance R_1 and leakage reactance X_1 are considerably small. E_1 can be regarded as the input voltage V_1. Consequently airgap flux is nearly constant when the ratio V_1/f_1 is fixed.

But the conventional schemes for V/f contol is not sufficient at PIMD system. That is, constant V/f control is driven to induction motor by constant flux pattern, and which is reduced to efficiency and power factor at various load conditions of all frequency ranges. Also in case of optimal efficiency control that attempt to maintain operation of adjustable speed drives at the maximum efficiency, it is required to find the slip points for motor maximum efficiency. Therefore this control method is require an accurate knowledge of the motor parameters and/or additional implementation such as speed/position sensors.

In PIMD system, it is very important to improve the efficiency of the overall system itself including inverter and induction motor. Especially, because the size of heat-sink is closely related with losses. Therefore it is important that the load current of system minimizes at various load conditions. To meet this purpose, the operation at maximum torque per current is more effective than any other optimal control scheme.

For a three-phase induction motor, torque and stator current relation is given as

$$T = \frac{3 \cdot I_1^2 \cdot X_m^2 \cdot \frac{R_2}{S}}{\omega_1 \cdot \left[\left(\frac{R_2}{S}\right)^2 + X_2^2 + X_m^2 + 2 \cdot X_2 \cdot X_m\right]} \qquad (1)$$

where T : mechanical torque, I_1 : stator current
ω_1 : synchronous angular velocity, S : slip
R_2: rotor resistance, X_m : magnetizing reactance
X_2 : rotor leakage reactance

In order to maximize torque per ampere, the motor is operated at the particular slip which develops the required torque with minimum stator current. The particular slip, at which stator current is a minimum, can be obtained as (2) by $\partial T / \partial S = 0$

$$S_{min} = \frac{R_2}{X_m + X_2} \qquad (2)$$

When adjustable frequncy operation, slip frequency for minimum current can be defined as follows [4]:

$$f_{2,min} = f_1 \cdot S_{min} = \frac{R_2}{L_m + L_2} \qquad (3)$$

Therefore, it is possible to be obtained to the operation of the current minimization control at the various load conditions of all frequency ranges.

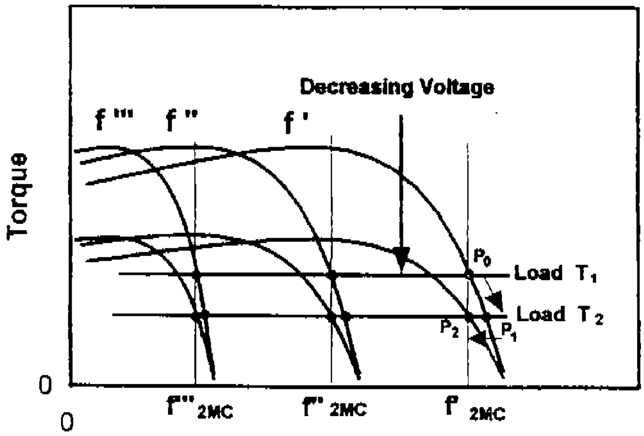

Fig. 1. Induction motor speed-torque characteristics by V/f variation

Minimum current control by V/f variation at induction motor speed-torque characteristics is shown in Fig. 1. For this, it must be sustained constant slip frequency which is current minimization point P0(=P2) by supplied voltage control at various load conditions of all frequency ranges. However, practically because motor parameters are varied due to temperature, it is difficult to apply without any compensation. Also it is needed speed/positon sensors for constant slip frequency.

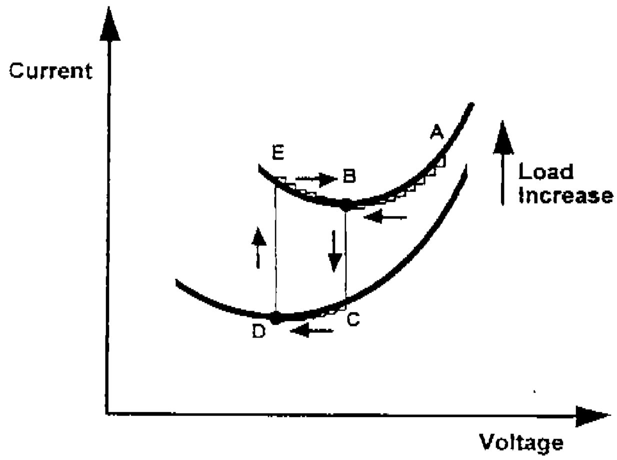

Fig. 2. Minimum current control.

In this paper, to solve these problems, the magnitude of input stator current is minimized by reducing or increasing voltage level near the operating point. Fig. 2 shows the tracking course of V-I characteristic and current minimization according to load variation. In any load conditon, that is, V/f value moves A to B for current minimization point. In case of load decrease, the operating point move B to C. And then, transfer D point. In case of load increase, the operating point move D to E and is stabilized B point by control of V/f value.

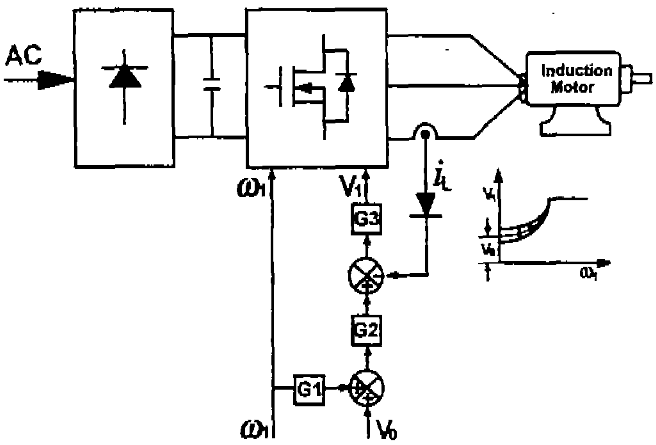

Fig. 3. Block diagram by minimum current scheme.

Fig. 3 is the block diagram for the realization of Fig. 2. It is tracking minimum current point by the comparison between former and present current level which is sensed at the output terminal of power circuit.

Fig. 4 shows the proposed minimum current control algorithm. The new V/f value for minimum current drive is provided by $\Delta V/f$ which is calculated using former and present stator current level at various frequency conditions.

III. Test Results and Discussion

The proposed inverter is composed of power MOSFETs, freewheeling diodes and electrolytic capacitor, including the dynamic braking circuit.

Fig. 5 gives the relations between the stator current and supplied voltage at 100[%] load condition. This figure shows the existence of minimum stator current point by experimentation. Using the characteristics of Fig. 5, it can be obtained the current minimization operation of the proposed system.

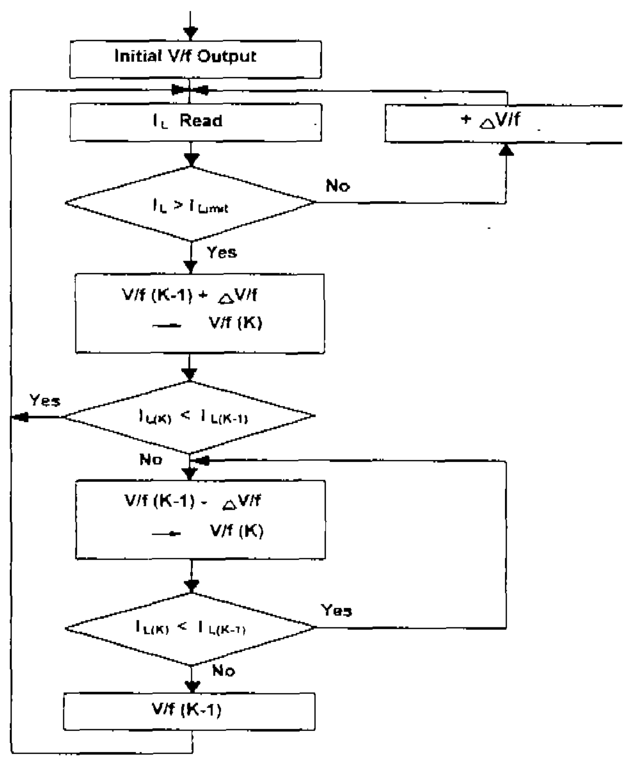

Fig. 4. Flow chart of the current minmization technique.

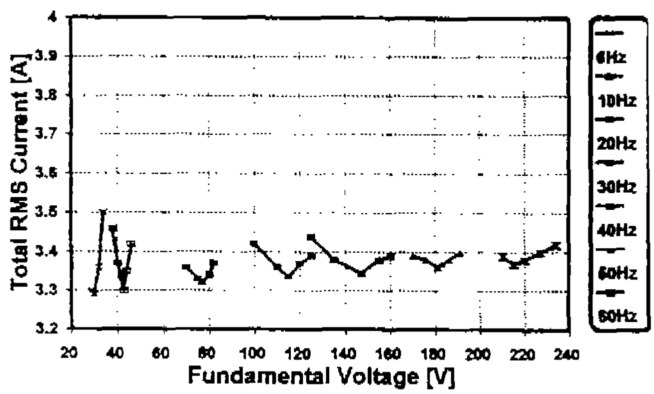

Fig. 5. Current characteristics according to V/f ratio variation. (100[%] load)

Fig. 6 shows the reference voltage signal by single-chip microcomputer and the response of stator current at the operating condition of 30[Hz] when the load is varied from 100 to 50[%].

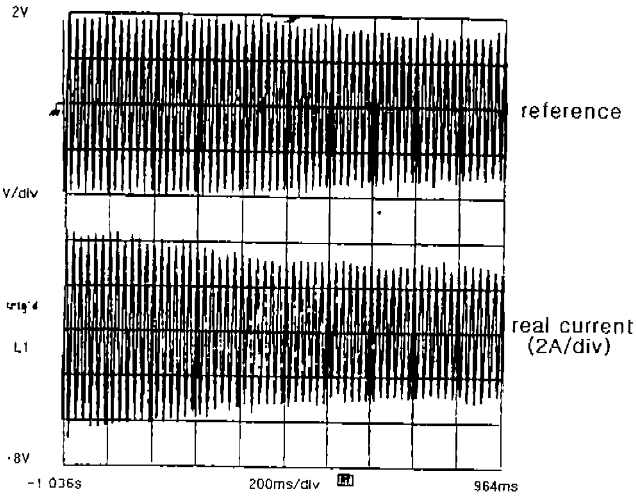

Fig. 6. Reference voltage signal and real current as minimum current control (30[Hz], 100→50[%] load).

Also, Fig. 7 shows the stator current and PWM inverter output voltage comparing minimum current control with constant *V/f* control, which show that the stator current is heavily reduced at the operating condition of 6[Hz], 50[%] load, and switching frequency 13[kHz].

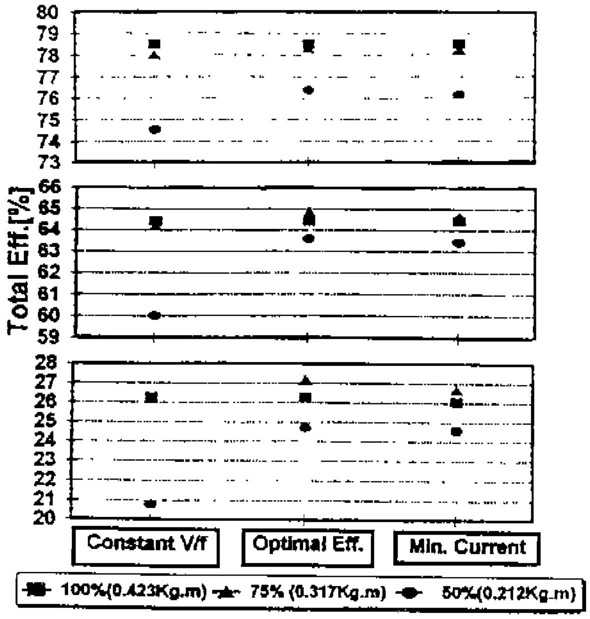

Fig. 8. Overall efficiency of system.
(a)60[Hz] (b) 30[Hz] (c) 6[Hz]

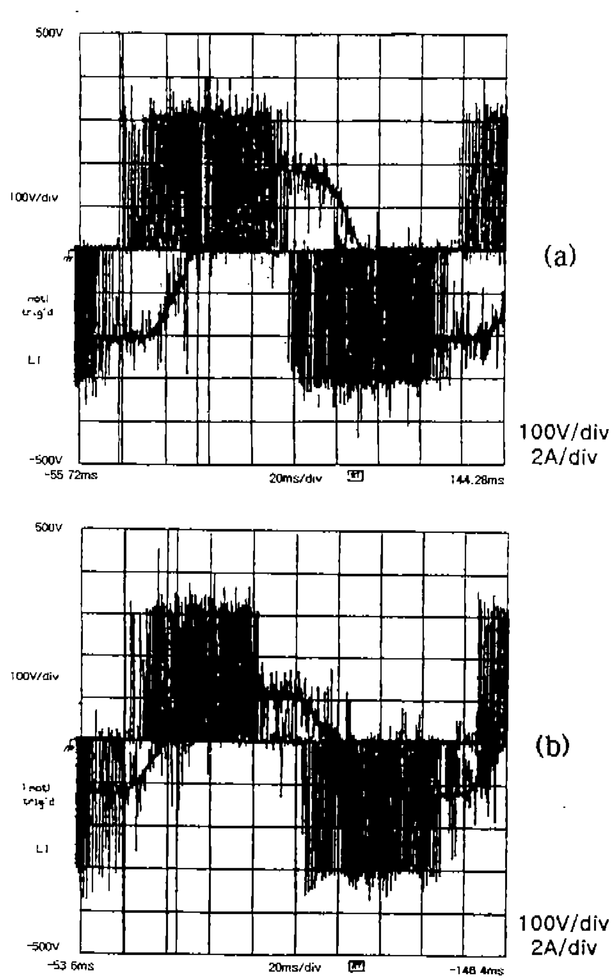

Fig. 7. Current and voltage waveforms(6[Hz], 50[%]load)
(a) constant V/f control (b) minimum current control

The overall efficiency including inverter circuit and induction motor is shown in Fig. 8, where it can be known that the proposed minimum current control method is nearly equal to the optimal efficiency control method.

This paper describes minimum current control method of PIMD system. The proposed scheme's validity is experimentally verified at various frequency and load conditions. Through current minimization control during *V/f* operation it is possible to minimize the size of heat-sink related with the losses of power circuit. And this can improve the overall efficiency to nearly optimal value without sensors.

As results, PIMD system using this technique expects to be applied so much more useful some fields such as electric vehicles, air conditioning system and textile mills where the limited space is given and required low cost.

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