A Rule-Based Acceleration Control Scheme for an Induction Motor

K. L. Shi, T. F. Chan, *Member, IEEE*, Y. K. Wong, *Senior Member, IEEE*, and S. L. Ho

***Abstract*—This paper presents a rule-based acceleration control scheme that aims to give an inverter-fed induction motor excellent dynamic performance. In every time interval of the control process, the acceleration increments produced by two different voltage vectors are compared, yielding one optimum stator voltage vector which is selected and retained. The online inference control is built using a rule-based system and some heuristic knowledge about the relationship between the motor voltage and acceleration. Because evaluation of integrals is not required and the motor parameters are not involved, the new controller has no accumulation error due to the integrals as in the conventional vector control schemes and the same controller can be used for different motors without modification.**

***Index Terms*—Acceleration control, induction motor drives, intelligent control, knowledge based systems, simulation.**

NOMENCLATURE

a	Rotor acceleration in square radians per second.
a^*	Rotor acceleration command in square radians per second.
i_s	Stator current vector in amperes.
J_M	Moment of inertia of the rotor in kilograms per square meter.
J_L	Moment of inertia of the load in kilograms per square meter.
R_s	Stator resistance in ohms per ph.
T_e	Electromagnetic torque in nanometers.
T_L	Load torque in nanometers.
V_s	Stator voltage vector in volts.
$V_s^{(n)}$	Stator voltage vector for nth switch state of inverter in volts.
γ	Normalized mechanical time constant.
λ_s	Primary flux vector in webers.
ω_o	Rotor speed in radians per second.
ω_o^*	Rotor speed command in radians per second.
ε	Threshold of acceleration error in square radians per second.

I. INTRODUCTION

ALTHOUGH conventional vector control of the induction motor has largely been successful [1], it suffers from sensitivity to parameter variations and error accumulation when evaluating the definite integrals. In addition, the control must be continuous and the calculation must begin from an initial state. If the control time is long, degradation in the steady state and transient responses will result due to drift in parameter values and excessive error accumulation. Due to the complexities existing in induction motor control problems, not all of them can be well represented, solved and implemented by the traditional mathematical methodologies and tools. Consequently, the applications of artificial intelligence in design and performance of induction motor control have been an attractive research area. In this paper, the rule-based system principle [2], [3] is employed to control the rotor acceleration of an induction motor, which aims to overcome the drawbacks of common vector control schemes.

Based on the relationship between stator voltage and rotor acceleration, a method that involves voltage comparison and voltage retaining is proposed to control the rotor acceleration. This method uses a trial-and-error strategy to determine the best of seven voltage vectors in every interval of the control process, which is then selected and retained. To decrease the number of voltage vectors to be compared, the production knowledge base is continuously updated by tracking the angle of the stator current vector. After using the heuristic knowledge, the number of voltage vectors compared is decreased to two, and the influence of sub-optimal voltages is reduced to a minimum.

Manuscript received November 19, 1999; revised February 26, 2002. This work was supported by Hong Kong Polytechnic University Research Grant V157.

The authors are with the Department of Electrical Engineering, Hong Kong Polytechnic University, Hunghom, Kowloon, Hong Kong.

Publisher Item Identifier S 0885-8969(02)05403-7.

II. RELATIONSHIP BETWEEN THE STATOR VOLTAGE AND ROTOR ACCELERATION

The rotor acceleration can be expressed as

$$a = \frac{d\omega_o}{dt} = \frac{1}{\gamma}\left(\lambda_\mu^s \times i_s^s - T_L\right). \tag{1}$$

The increment of stator flux can be calculated by

$$\Delta\lambda_\mu^s = \left(V_s^{(n)} - R_s i_s^s\right)\Delta t \tag{2}$$

where $V_s^{(n)}(\mathrm{mod}(n) = 7)$ denotes one of the seven voltage vectors and determines the increment of the stator flux, $\Delta\lambda_\mu^s$.

The incremental acceleration $\Delta a(n)$ can be derived from (1) and (2) as follows:

$$\Delta a(n) = \frac{1}{\gamma}\left[\left(V_s^{(n)} - R_s i_s^s\right)\Delta t \times i_s^s + \lambda_\mu^s \times \Delta i_s^s - \Delta T_L\right]. \tag{3}$$

Because $i_s^s \times i_s^s = 0$, (3) becomes

$$\Delta a(n) = \frac{1}{\gamma}\left[\left(V_s^{(n)} \times i_s^s\right)\Delta t + \lambda_\mu^s \times \Delta i_s^s - \Delta T_L\right]. \tag{4}$$

Equation (4) shows that the stator voltage $V_s^{(n)}$ determines the incremental accelerations of the rotor. An example of the incremental accelerations that result from the six stator voltages is illustrated in Fig. 1.

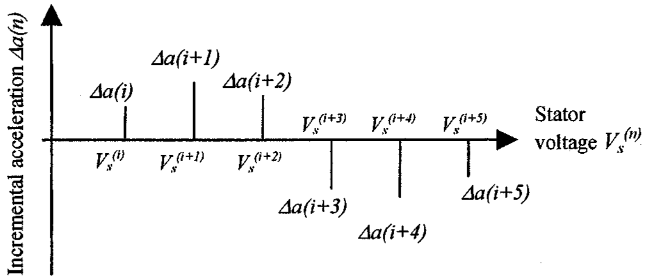

Fig. 1. Acceleration increments produced by stator voltages.

Two important results are obtained from (4).

1) The incremental acceleration is determined by the stator voltage.
2) If $\Delta a(j) < 0$, there is at least one number m such that $\Delta a(j+m) > 0$. If $\Delta a(j) > 0$, there is at least one number l such that $\Delta a(j+l) < 0$.

Because there is no direct relationship between the acceleration and the stator voltage, the optimum voltage has to be selected by comparing the incremental acceleration produced by every voltage vector. Based on these two results, a controller may be designed using a voltage comparison and retaining method.

III. Control Strategy of Voltage Comparison and Retaining

In the proposed control method, the time is divided into many small intervals each consisting of a voltage comparison period and a voltage retaining period. In the comparison period, several voltages are supplied to the induction motor in proper order, and the incremental acceleration of each voltage is recorded. At the end of the comparison period, the optimum voltage that produces a larger incremental acceleration is selected for the retaining stage. In the latter stage, the controller retains this optimum voltage to the motor. If the acceleration is above or below a certain threshold during the voltage-retaining period, zero voltage is supplied. A cycle of the control process for the induction motor is illustrated in Fig. 2.

Three problems need to be addressed before the proposed method can be applied successfully to control an induction motor. The first problem is how to assign the comparison time and retaining time, which will affect the results of control for the induction motor. The second problem is how to select heuristically the voltage vectors to be compared and retained, because too many voltage comparisons will degrade the performance of the induction motor. The third problem is how to compare the acceleration, because the voltage that produces maximum acceleration may not be the optimum voltage. The optimum voltage vector should produce a large acceleration, and at the same time should maintain the appropriate current amplitude.

A. Assignment of the Comparison Time and Retaining Time

Because there are six nonzero voltages supplied during a revolution and the stator voltage rotation is faster than the rotor by

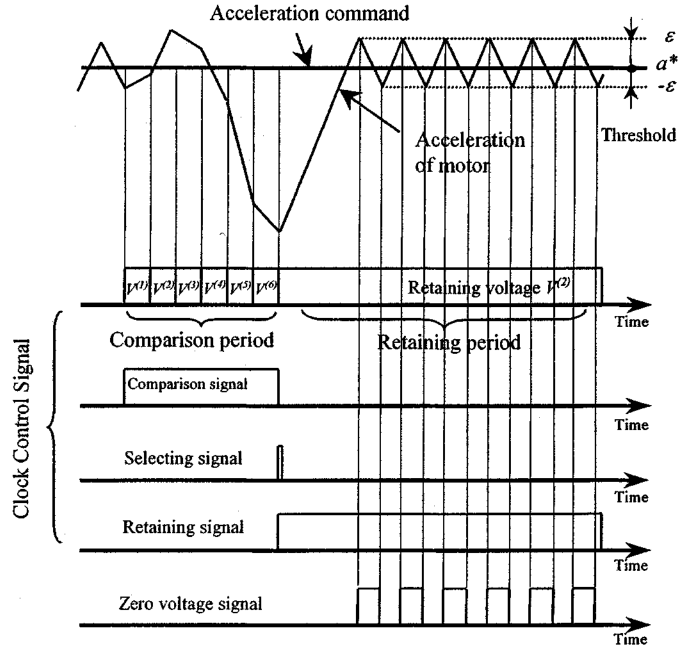

Fig. 2. Cycle of voltage comparison and voltage retaining.

the induction motor principle, the cycle time should be much shorter than the time for the rotor to rotate through $1/6$ of a revolution. The cycle time should thus be shorter when the speed of rotor is higher.

B. Selection of the Voltage Vectors to be Compared and Retained

In order to decrease the number of voltage vectors to be compared, a method of selecting these voltages heuristically is used by tracking the angle of the stator current vector. From (1)

$$\frac{d\omega_o}{dt} = \frac{1}{\gamma}\left(|\lambda_\mu^s||i_s^s|\sin\varphi_i - T_L\right) \tag{5}$$

when $(d\omega_o/dt) = 0$

$$\varphi_i \bigg|_{\frac{d\omega}{dt}=0} = \arcsin\left\{\frac{T_L}{|\lambda_\mu^s|\,|i_s^s|}\right\} = \varphi_0 \tag{6}$$

when

$$\frac{d\omega_o}{dt} > 0, \varphi_0 < \varphi_i < \pi - \varphi_0 \tag{7}$$

when

$$\frac{d\omega_o}{dt} \le 0, -\pi - \varphi_0 \le \varphi_i \le \varphi_0. \tag{8}$$

After the actual acceleration has been known, the angle range between the stator current and the flux vector may be determined from (7) and (8). Once the actual angle of the stator current vector is detected, the flux angle range may be estimated. Because the estimated angle range of the flux vector should not exceed π, the incremental acceleration can be determined by comparing only two voltage vectors.

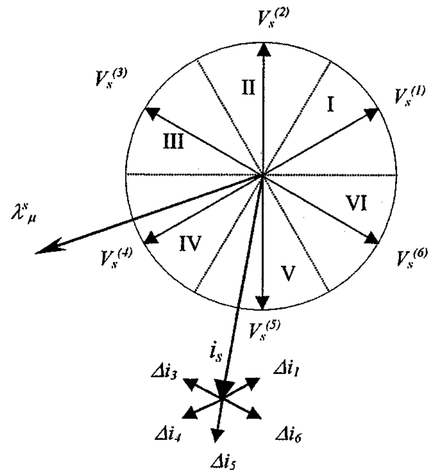

Fig. 3. Illustrating the selection of voltage vectors to be compared.

An example of voltage comparison based on the position of the stator current vector is shown in Fig. 3. When the acceleration is larger than zero and the stator current vector is in area V, the fluxes λ_μ^s may be in area II, III, or IV according to (7). From a predictive (optimal) principle of current control [4], [5], the incremental current $\Delta i_1, \Delta i_4, \Delta i_5$, and Δi_6 are as shown in Fig. 3.

From (4) and Fig. 3, six rules may be established as follows.

1) If $V_s(5)$ is chosen, then the current amplitude and the acceleration will be increased.
2) If $V_s(6)$ is chosen, then the current amplitude will be maintained and the acceleration will be increased.
3) If $V_s(1)$ is chosen, then the current amplitude will be decreased and the acceleration will be increased.
4) If $V_s(3)$ is chosen, then the current amplitude will be decreased and the acceleration will be decreased.
5) If $V_s(4)$ is chosen, then the current amplitude will be maintained and the acceleration will be decreased.
6) If $V_s(0)$ is chosen, then the current amplitude and the acceleration will be decreased.

The selection pattern of compared voltages can be derived from the above six rules. When the acceleration command is larger than zero, the supply current should be maintained at a larger value. Hence, the compared voltage vectors should be $V_s(5)$ and $V_s(6)$ and the voltage vectors $V_s(1), V_s(2), V_s(3)$, and $V_s(4)$ are discarded. When the acceleration command is less than zero, the supply current should be maintained at a larger value. Hence, the compared voltage vectors should be $V_s(5)$ and $V_s(4)$ and the voltage vectors $V_s(1), V_s(2), V_s(3)$, and $V_s(6)$ are discarded. When the acceleration command is equal to zero, the supply current should be maintained at a smaller value. Hence, the compared voltage vectors should be $V_s(5)$ and $V_s(1)$ or $V_s(3)$ and the voltage vectors $V_s(6), V_s(2)$, and $V_s(4)$ are discarded. These selection patterns are summarized in Table I.

Let the neighborhood of $V_s^{(n)}$ be n. The selection of the voltage vectors to be compared can be summarized as follows.

TABLE I
SELECTION OF THE VOLTAGE VECTORS TO BE COMPARED ACCORDING TO ACCELERATION AND SPEED COMMANDS

a^* $\omega_0{}^*$	Voltages compared						Retained Voltage
	$V_s^{(1)}$	$V_s^{(2)}$	$V_s^{(3)}$	$V_s^{(4)}$	$V_s^{(5)}$	$V_s^{(6)}$	$V_s^{(0)}$
$a^*>0$					✓	✓	✓
$a^*<0$				✓	✓		✓
$a^*=0$ $\omega_0{}^*>0$	✓				✓		✓
$a^*=0$ $\omega_0{}^*<0$			✓		✓		✓

1) If $a^* > 0$, and stator current vector is in area n, the compared voltages are $V_s^{(n)}$ and $V_s^{(n+1)}$, and the retained voltage is $V_s^{(0)}$.
2) If $a^* < 0$, and stator current vector is in area n, the compared voltages are $V_s^{(n)}$ and $V_s^{(n-1)}$, and the retained voltage is $V_s^{(0)}$.
3) If $a^* = 0, \omega_0^* > 0$, and stator current vector is in area n, the compared voltages are $V_s^{(n)}$ and $V_s^{(n+2)}$, and the retained voltage is $V_s^{(0)}$.
4) If $a^* = 0, \omega_0^* < 0$, and stator current vector is in area n, the compared voltages are $V_s^{(n)}$ and $V_s^{(n-2)}$, and the retained voltage is $V_s^{(0)}$.

C. Acceleration Comparison Strategy

When the stator current vector is in area n, the amplitude increment of stator current produced by $V_s^{(n)}$ is larger than $V_s^{(n+1)}, V_s^{(n+2)}, V_s^{(n-1)}$, or $V_s^{(n-2)}$. In order to maintain the amplitude of stator current, once the acceleration produced by $V_s^{(n+1)}$ or $V_s^{(n+2)}$ is larger than zero (for the case "$a^* > 0$" or "$a^* = 0$ and $\omega_o^* < 0$"), or, $V_s^{(n-1)}$, or $V_s^{(n-2)}$ is less than zero (for the case "$a^* < 0$" or "$a^* = 0$ and $\omega_o^* < 0$"), they should preferentially be selected as the retained voltage rather than $V_s^{(n)}$. The acceleration comparison strategy can be summarized as shown at the bottom of the next page.

η is a preferential parameter that is larger than 1 to implement the preferential selection. A satisfactory value of η is 500 from the results of computer simulation. V_s^R is the optimum voltage that will be supplied in the retaining stage of the control process.

The rule-based system is a very suitable tool for implementing the above voltage comparison and voltage retaining control strategies.

IV. RULE-BASED ACCELERATION CONTROL FOR AN INDUCTION MOTOR

The rule-based acceleration controller consists of a rule base, an inference engine, an input interface, and an output interface. The rule base contains production rules of the type: "**if** premise **then** conclusion (action)." The premise is the fact or the goal of the database and the conclusion results in an action. The inference engine is designed to emulate the human's decision-making process to operate the rules to arrive at the conclusion or to satisfy the goals. The input interface implements the numerical and linguistic coding of electrical signals. The output interface implements the transformation from the numerical values and linguistic commands to electrical signals. In this way, the rule-based acceleration controller is capable of choosing the most appropriate strategy to control the induction motor.

The acceleration control rule base can be represented as fourteen rules with the following symbol definitions:

a, a^*	actual acceleration and acceleration command;
Δa	increment of acceleration $\Delta a = a(t + \Delta t) - a(t)$;
i	denotes area in which the stator current vector lies;
n	number which denotes a stator voltage vector;
m	temporary register of the stator voltage vector;
t, t_h	time counter and retaining time;
A_1	$a^* > 0$;
A_2	$a^* = 0$;
A_3	$a^* < 0$;
B_1	$\Delta a(V_s(n)) > \eta \Delta a(V_s(n+1))$;
B_2	$\Delta a(V_s(n)) \leq \eta \Delta a(V_s(n+1))$;
B_3	$\Delta a(V_s(n)) > \eta \Delta a(V_s(n+2))$;
B_4	$\Delta a(V_s(n)) \leq \eta \Delta a(V_s(n+2))$;
B_5	$\Delta a(V_s(n)) < \eta \Delta a(V_s(n-1))$;
B_6	$\Delta a(V_s(n)) \geq \eta \Delta a(V_s(n-1))$;
B_7	$\Delta a(V_s(n)) < \eta \Delta a(V_s(n-2))$;
B_8	$\Delta a(V_s(n)) \geq \eta \Delta a(V_s(n-2))$;
C_1	$n = 0$ number of zero voltage;
C_2	$n \neq 0$ nth number of nonzero voltage;
D_1	$a \geq a^* + \varepsilon$;
D_2	$a^* - \varepsilon < a < a^* + \varepsilon$;
D_3	$a \leq a^* - \varepsilon$;
E	$t > t_h$ (comparison stage);
$\neg E$	$0 < t < t_h$ (retaining stage);
F	$\omega_o^* > 0$;
$\neg F$	$\omega_o^* < 0$;
H	X_1, X_2 or X_3 has been performed when $t > t_h$;
$\neg H$	X_1, X_2 or X_3 has not been performed when $t > t_h$;
S	$(a^* = 0) \wedge (\omega_o = 0)$;
$V_s(k)$	stator voltage supplied to induction motor;
X_1	supply $V_s(n)$ and $V_s(n+1)$ to motor in succession;
X_2	supply$V_s(n)$ and $V_s(n+2)$ to motor in succession;
X_3	supply$V_s(n)$ and $V_s(n-1)$ to motor in succession;
ω_o	actual rotor speed;
ε	threshold of acceleration error;
η	preferential parameter.

The rule-based system consists of the set of rules shown at the bottom of the next page.

A typical sequence of the rule-based acceleration control is illustrated in Table II.

TABLE II
TYPICAL ACCELERATION CONTROL SEQUENCE

Iteration No.	Working memory	Conflict Set	Rule fired	Remarks
i	$A_1 \wedge \neg E \wedge D_1 \wedge C_2$	11	11	Modify base: $m=k, k=0$
$i+1$	$\neg E \wedge D_2$	12	12	Retaining voltage
$i+2$	$A_1 \wedge \neg E \wedge D_3 \wedge C_1$	13	13	Modify base: $k=m$
$i+3$	$E \wedge \neg H$	1,2,3,4	1	Modify base: $n=i$
$i+4$	$E \wedge A_1 \wedge \neg H$	2	2	Input comparing voltages
$i+5$	$E \wedge A_1 \wedge H \wedge B_1$	6	6	Modify base
$i+6$	$A_1 \wedge \neg E \wedge D_3 \wedge C_2$	14	14	Keep voltage
$i+7$	$\neg E \wedge D_2$	12	12	Retaining voltage
$i+8$	$A_1 \wedge \neg E \wedge D_1 \wedge C_2$	11	11	Modify base: $m=k, k=0$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$i+k$	S	$\varnothing$	Halt	Motor stops

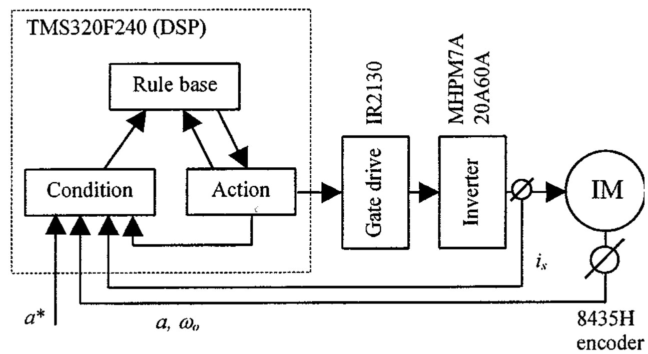

Fig. 4. Rule-based acceleration control system for an induction motor.

A rule-based acceleration control system for an induction motor may be constructed as shown in Fig. 4. For different induction motors, the corresponding inverter will be used, but the rule-based acceleration controller is the same.

Experimental hardware of the rule-based acceleration control system may consist of the MCK240 board with the Texas Instruments TMS320F240 (DSP), the International Rectifier IR2130 (gate drive), the Motorola power module MHPM7A20A60A (inverter), a current sensor, the Gurley Model 8435H (encoder) and an induction motor. The TMS320F240 is capable of executing 20 million instructions/s (MIPS). The module MHPM7A20A60A integrates a three-phase input rectifier bridge, a three-phase output inverter, a brake transistor/diode, and a temperature sensor in a single convenient package. The Gurley Model 8435H hollow-shaft optical encoder (an incremental encoder with a resolution up to 900 000 counts/revolution) implements the speed measurement, which can meet the experimental requirements of the expert-system acceleration controller.

$$
\begin{aligned}
\Delta a\left(V_s^R\right) &= \max\left\{\Delta a\left(V_s^n\right), \eta \Delta a\left(V_s^{n+1}\right)\right\}, \quad \text{when } a^* > 0\\
\Delta a\left(V_s^R\right) &= \min\left\{\Delta a\left(V_s^n\right), \eta \Delta a\left(V_s^{n-1}\right)\right\}, \quad \text{when } a^* < 0\\
\Delta a\left(V_s^R\right) &= \max\left\{\Delta a\left(V_s^n\right), \eta \Delta a\left(V_s^{n+2}\right)\right\}, \quad \text{when } a^* = 0, \omega_o^* > 0\\
\Delta a\left(V_s^R\right) &= \min\left\{\Delta a\left(V_s^n\right), \eta \Delta a\left(V_s^{n-2}\right)\right\}, \quad \text{when } a^* = 0, \omega_o^* < 0
\end{aligned}
$$

V. Computer Simulation and Comparison

Three computer simulation examples are presented to prove the feasibility of rule-based acceleration control. In the first example, the performance of an inverter-fed induction motor driving a constant torque load is investigated. The simulation results of direct self control (DSC) [6], [7] and the proposed rule-based controller are compared. The second example compares the robustness of the two controllers. The third example verifies that the rule-based controller has exchangeability, i.e., the same controller can be used for different induction motors. The simulation is implemented using Matlab/Simulink software.

A. First Simulation Example

This is a comparison of DSC and the rule-based controller in respect of speed, acceleration, torque, stator current, and primary flux. The induction motor chosen for the simulation studies has the following parameters:

Type: three-phase, 7.5 kW, 220 V, 60 Hz, 6-pole, squirrel-cage

$$\begin{aligned} &R_s = 0.291\ \Omega/\text{ph}, \quad L_s = 0.0422\ \Omega/\text{ph} \\ &R_r = 0.158\ \Omega/\text{ph} \\ &L_r = 0.0416\ \Omega/\text{ph}, \quad L_m = 0.042\ \text{H/ph} \\ &J_M = 0.4\ \text{kg} \cdot \text{m}^2 \\ &J_L = 0.4\ \text{kg} \cdot \text{m}^2, \quad T_L = 20\ \text{N} \cdot \text{m}. \end{aligned}$$

Speed commands

$$\begin{aligned} &\omega_o^* = 40\ \text{(rad/s)} \quad 0\ \text{s} \le t < 0.4\ \text{s} \\ &\omega_o^* = -40\ \text{(rad/s)} \quad 0.4\ \text{s} \le t < 1\ \text{s}. \end{aligned}$$

Acceleration commands

$$\begin{aligned} &a^* = 300\ (\text{rad/s}^2) \quad (\omega_o^* = 40) \wedge (\omega_o < 40) \\ &a^* = 0\ (\text{rad/s}^2) \quad (\omega_o^* = 40) \wedge (\omega_o = 40) \\ &a^* = -300\ (\text{rad/s}^2) \quad (t \ge 0.4\ \text{s}) \wedge (\omega_o > 40) \\ &a^* = 0\ (\text{rad/s}^2) \quad (\omega_o^* = -40) \wedge (\omega_o = -40). \end{aligned}$$

Fig. 5 shows the simulation results for the rule-based controller and the DSC controller. The responses of speed, torque and acceleration of the two controllers are almost the same.

B. Second Simulation Example

In order to verify the robustness of the new controller to load changes and noise, an oscillating load is applied to the motor and a drift noise (nonzero mean value) is added to the current.

Fig. 6 shows that the rule-based controller has good noise immunity and effective control is obtained over a long period of time. On the other hand, DSC is sensitive to the noise and the load. At $t = 2$ s, the motor speed drops to zero and the controller fails [Fig. 6(b)].

C. Third Simulation Example

In this investigation, the controller in the first simulation example is used for the control of a different induction motor. The new motor has the following parameters:

Type: three-phase, 220 V, 0.75 kW, 60 Hz, 4-pole, squirrel-cage

$$\begin{aligned} &R_s = 3.35\ \Omega/\text{ph}, \quad R_r = 1.99\ \Omega/\text{ph} \\ &L_s = 0.18\ \text{H/ph}, \quad L_r = 0.17\ \text{H/ph} \\ &L_m = 0.16\ \text{H/ph}, \quad J_M = 0.05\ \text{kg m}^2 \\ &J_L = 0.05\ \text{kg} \cdot \text{m}^2, \quad T_L = 2\text{N} \cdot \text{m}. \end{aligned}$$

The speed commands and the acceleration commands are the same as those in the first simulation example.

Fig. 7 shows that the responses of the motor are almost the same as those obtained in the first simulation example.

VI. Conclusion

This paper has presented a rule-based acceleration control scheme for an inverter-fed induction motor. From the relationship between the stator voltage and rotor acceleration, a control strategy that involves voltage comparison and voltage retaining

Rule# Condition Action

1. $E \wedge \neg H \rightarrow n = i$
2. $E \wedge A_1 \wedge \neg H \rightarrow X_1$
3. $E \wedge A_2 \wedge \neg H \rightarrow X_2$
4. $E \wedge A_3 \wedge \neg H \rightarrow X_3$
5. $(E \wedge A_1 \wedge H \wedge B_1) \vee (E \wedge A_2 \wedge H \wedge B_3) \vee (E \wedge A_3 \wedge H \wedge B_5)$ $\vee (E \wedge A_2 \wedge H \wedge B_7) \rightarrow k = n, \quad t = 0$
6. $E \wedge A_1 \wedge H \wedge B_2 \rightarrow k = n + 1, \quad t = 0$
7. $E \wedge A_2 \wedge F \wedge H \wedge B_4 \rightarrow k = n + 2, \quad t = 0$
8. $E \wedge A_2 \wedge \neg F \wedge H \wedge B_8 \rightarrow k = n - 2, \quad t = 0$
9. $E \wedge A_3 \wedge H \wedge B_6 \rightarrow k = n - 1, \quad t = 0$
10. $(A_1 \wedge \neg E \wedge D_1 \wedge C_1) \vee (A_3 \wedge \neg E \wedge D_3 \wedge C_1) \rightarrow V_s(k)$
11. $(A_1 \wedge \neg E \wedge D_1 \wedge C_2) \vee (A_3 \wedge \neg E \wedge D_3 \wedge C_2) \rightarrow m = k, \quad k = 0, V_s(k)$
12. $\neg E \wedge D_2 \rightarrow V_s(k)$
13. $(A_1 \wedge \neg E \wedge D_3 \wedge C_1) \vee (A_3 \wedge \neg E \wedge D_1 \wedge C_1) \rightarrow k = m, V_s(k)$
14. $(A_1 \wedge \neg E \wedge D_3 \wedge C_2) \vee (A_3 \wedge \neg E \wedge D_1 \wedge C_2) \rightarrow V_s(k)$

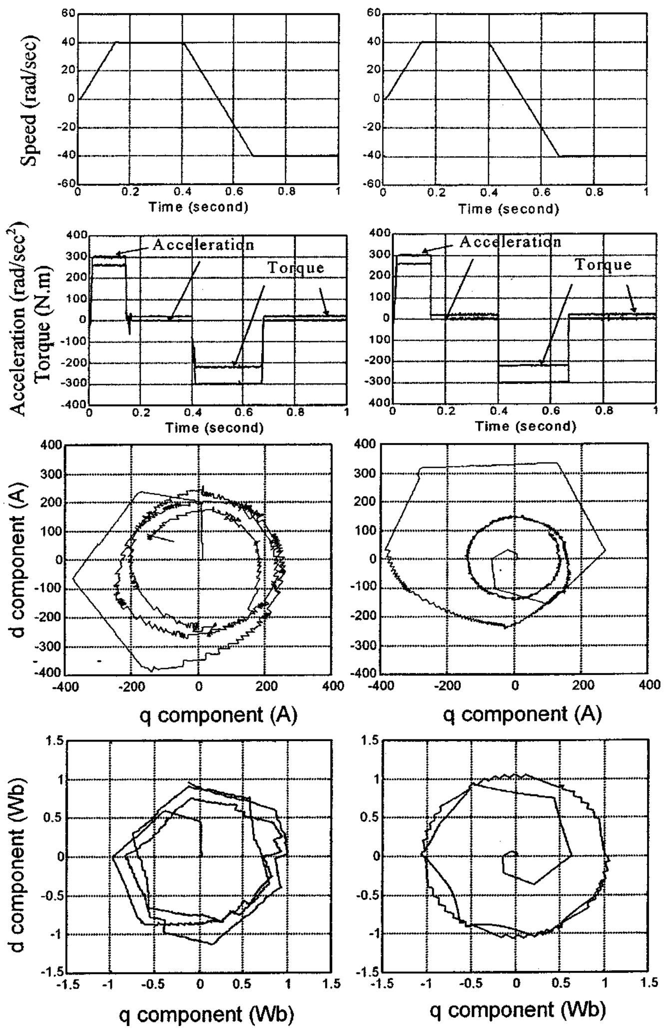

Fig. 5. Responses of speed, torque, acceleration, stator current vector, and primary flux vector.

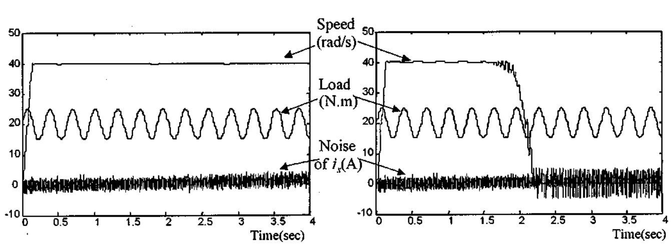

Fig. 6. Effects of drift noise and oscillating load.

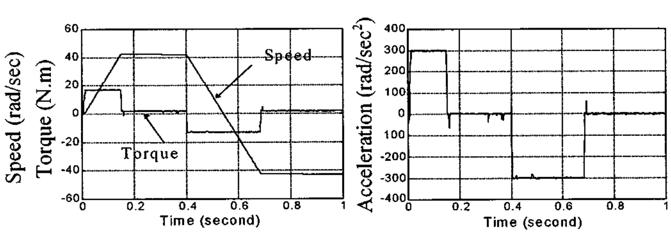

Fig. 7. Speed, torque, and acceleration of 0.75 kW induction motor with rule-based controller.

is proposed. The principle of acceleration control and construction of the rule base are presented in detail.

The rule-based acceleration control scheme is quite different from the usual vector control schemes. Due to the use of inference instead of algebraic calculations, the rule-based controller has a small control error but no cumulative error. Since the controller is independent of the parameters of the induction motor, the same controller can be used for different machines without modification. Results of computer simulation confirm the feasibility of the proposed control scheme.

REFERENCES

[1] K. S. Rajashekara, A. Kawamura, and K. Matsuse, "Speed sensorless control of induction motors," in *Sensorless Control of AC Motor Drives*. New York: IEEE Press, 1996, pp. 1–19.

[2] B. Buchanan and E. H. Shortliffe, *Rule-Based Expert Systems*. Reading, MA: Addison-Wesley, 1984.

[3] K. M. Passino and A. D. Lunardhi, "Qualitative analysis of expert control systems," in *Intelligent Control Systems: Theory and Applications*. New York: IEEE Press, 1996.

[4] A. Nabae, S. Ogasawara, and H. Akagi, "A novel control scheme for current-controlled PWM inverters," *IEEE Trans. Ind. Applicat.*, vol. 22, pp. 697–701, July/Aug. 1986.

[5] B. K. Bose, *Power Electronics and Variable Frequency Drives*. New York: IEEE Press, 1997, p. 248.

[6] I. Takahashi and T. Noguchi, "A new quick-response and high-efficiency control strategy of an induction motor," *IEEE Trans. Ind. Applicat.*, vol. 22, pp. 820–827, Sept./Oct. 1986.

[7] M. Depenbrock, "Direct self control (DSC) of inverter-fed induction machines," *IEEE Trans. Power Electron.*, vol. 3, pp. 420–429, July 1988.

K. L. Shi received the B.Sc. degree from Chengdu University of Science and Technology, China, in 1983, the M.Sc. degree from the Harbin Institute of Technology, China, in 1989, and is currently pursuing the Ph.D. degree at the Department of Electrical Engineering, Hong Kong Polytechnic University.

His current research interests include intelligent control of induction motor, pattern recognition, parameter identification, and state estimation.

T. F. Chan (M'95) received the B.Sc. and M.Phil. degrees in electrical engineering from the University of Hong Kong, in 1974 and 1980, respectively.

Since 1978, he has been with the Department of Electrical Engineering, the Hong Kong Polytechnic University, where he is now an Associate Professor. His current research interests are self-excited ac generators, brushless ac generators, and computer-aided design of electrical machines.

Y. K. Wong (SM'95) received the B.Sc. and M.Sc. degrees from London University, London, U.K., the M.Soc.Sc. degree from the University of Hong Kong, the M.Phil. degree from the Chinese University of Hong Kong, and the Ph.D. degree from Heriot-Watt University, U.K.

He joined the Hong Kong Polytechnic University in 1980. His current research interests include linear systems, modeling, simulation, and intelligent control.

Dr. Wong is a member of the IEE and a Fellow of both the Institute of Mathematics and its Applications and the Royal Statistical Society.

S. L. Ho received the B.Sc. (with first class honors) and Ph.D. degrees in electrical engineering from the University of Warwick, U.K., in 1976 and 1979, respectively.

He joined the Department of Electrical Engineering, Hong Kong Polytechnic University in 1979 and is currently an Associate Professor. He is very active in the areas of machine design, phantom loading of motors, condition monitoring of electrical machines, and traction engineering. He has published more than 60 papers in international journals and conferences.