Sensorless Vector Control for Induction Motor Drive using Modified Tabu Search Algorithm

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Abstract: The design of speed controller for induction motor using tabu search is studied. The proposed sensorless vector control for Induction Motor is composed of two parts. The first part is for optimizing the initial parameters of input-output. The second part is for real time changing parameters of input-output using tabu search. Proposed tabu search is improved by neighbor solution creation using Gaussian random distribution. In order to show the usefulness of the proposed method, we apply the proposed controller to the sensorless speed control of an actual AC induction Motor System. The performance of this approach is verified through simulation.

Keywords: Tabu search, sensorless vector, speed estimation.

1. INTRODUCTION

Research interest in induction motor (IM) sensorless drives has grown significantly over the past few years due to some of their advantages, such as mechanical robustness, simple construction, and maintenance. So, Induction motors have been used more in the industrial variable speed drive system with the development of the vector control technology. This method requires a speed sensor such as shaft encoder for speed control. However, a speed sensor cannot be mounted in some cases such as motor drives in a hostile environment and high-speed drives. In addition, it requires careful cabling arrangements with attention to electrical noise. Moreover, it causes to become expensive in the system price and bulky in the motor size. In other words, it has some demerits in both mechanical and economical aspects. Thus current research efforts are focused on the so called “sensorless” vector control problem, in which rotor speed measurements are not available, to reduce cost and to increase reliability. The performance at the high speed region is satisfactory [1],[2], but it’s performance at very low speed is poor. In many research, most of the methods are estimation of rotor flux angle and parameter tuning in field oriented vector control. Among these the most commonly used is the PI controller. The PI controller is easily implemented and can approach desired system response. However, if the controlled electrical drives require high performance, i.e., steady state and dynamic tracking ability to set point changes and the ability to recover from system variations then a conventional PI controller for such drives cannot lead to good tracking and regulating performance simultaneously. If we select a PI speed control structure, the control parameter are open constant, which is designed by the given control conditions. When varying system parameters occur, the system’s response using PI controller is easily affected. Thus, ensuring specified dynamic response independent of system parameter variation requires the development of an adaptive speed control. In this paper, we applied tabu search algorithm to cope with this problems. We employed a modified tabu search algorithm based on the allied control strategy to the conventional PI controllers. The approach having ability for global optimization and with good robustness is expected to overcome some weakness of conventional approaches and to be more acceptable for industrial practices. The feasibility of the proposed algorithm is verified by simulation.

2. SPEED ESTIMATION

The field oriented equations of induction motor are as follows

$$v_d = R_s i_d + L_s^* \frac{di_d}{dt} + (L_s' - L_s^*)\frac{di_m}{dt} - \omega_{dq} L_s^* i_q \quad (1)$$

$$v_q = R_s i_q + L_s^* \frac{di_q}{dt} + (L_s' - L_s^*)\omega_{dq} i_m + \omega_d L_s^* i_d \quad (2)$$

$$\frac{L_r'}{R_r}\frac{di_m}{dt} + i_m = i_d \quad (3)$$

$$\omega_{dq} = \omega + \frac{R_r i_q}{L_r' i_m} \quad (4)$$

$$\tau_e = (L_s^* - L_s')i_m i_q \quad (5)$$

The system is constituted by five equations. First two determine d-axis and q-axis components of the stator voltage. The third and fourth are associated with the rotor circuits, and fifth equation determines the electrical torque.

where

i_d, i_q	d-axis and q-axis current
i_m	Modified magnetization current
v_d, v_q	d-axis and q-axis voltage
R_s, R_r	Stator, Rotor resistance
L_s^*, L_s', L_r'	Inductance parameters
τ_e	Electrical torque
ω_{dq}	Speed of the dq frame
ω	Motor speed

From equation (4), we can know that Slip Speed ω_{slip} as follows:

$$\omega_{slip} = \frac{R_r i_q}{L_r' i_m} \quad (6)$$

A block diagram of control system shown in Fig.1.

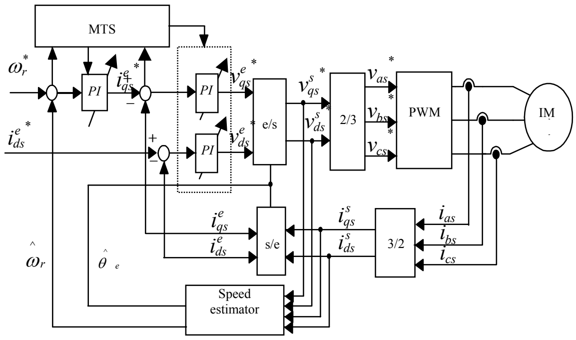

Fig. 1 Control Block Diagram

The speed estimator estimates the field speed ω_{dq} and the speed of induction motor ω based only on the q-axis components of the voltage and current, The field speed is used to carry out the coordinate transformations while the estimated speed is compared in the control block with the target speed to determine the target current i_d^* and i_q^* that, once transformed into the block “2/3” are sent to the inverter closing the control loop[3].
The speed estimator is built under the fundamental assumption that the modified magnetization current i_m, remains constant in the nominal value i_m^*. Thus equation (3) is reduced to the equality:

$$i_d = i_m \quad \text{with } i_m = i_m^* = \text{ constant} \tag{7}$$

That indicates that i_m constant maintain, it is also necessary that i_d stays constant. This fact will be design premise of control block. Equation (2) is also simplified as follows:

$$v_q = R_s i_q + L_s^* \frac{di_q}{dt} + \omega_{dq} L_s' i_m^* \tag{8}$$

finding the field speed

$$\omega_{dq} = \frac{1}{L_s' i_m^*}\left[v_q - R_s i_q - L_s^* \frac{di_q}{dt} \right] \tag{9}$$

Rotor speed is determined substituting equation (9) in equation (4):

$$\omega = \frac{1}{L_s' i_m^*}\left[v_q - R_s i_q - L_s^* \frac{di_q}{dt} \right] - \frac{R_r}{L_s' i_m^*} i_q \tag{10}$$

that can be written as

$$\omega = K_v v_q - K_R i_q - K_L \frac{di_q}{dt} \tag{11}$$

where

$$K_v = \frac{1}{L_s' i_m^*}; K_R = \frac{R_s}{L_s' i_m^*} + \frac{R_r}{L_s' i_m^*}; K_L = \frac{L_S^*}{L_s' i_m^*} \tag{12}$$

The expression (11) permits to estimate the rotor speed knowing only the q-axis components of the motor voltage and current. The resistive parameters of the motor(R_s and R_r) only take part in speed estimator through the constant K_R .

3. TABU SEARCH

The tabu search(TS) is a general improvement heuristic procedure which has been very efficient for solving many combinatorial optimization problems. A detailed description of TS is provided in a recent paper of Glover, Taillard and de Werra[4].
TS is easier to use the knowledge of the corresponding problem than the conventional optimization algorithms such as genetic algorithm and simulated annealing. The conventional optimization algorithms have high complexity of the corresponding problem and cost high computation time in converging to the best solution in case that the search region is wide. TS also has simple search method. Fig. 2 shows basic tabu search method[5].

Step 1 : S ∈ X → determine initial value S_0

Step 2 : Generate the Subset, N(s) of solution in N(i).
Step 3 : N(s) → Find a best s' in N(S)
(i.e. such that (f(s') ≤ f(s*), s* ∈ N(s))

Step 4 : if f(s') ≥ f(s) then stop, else s:=s',
Go to Step 2, until stop condition

Fig. 2 Basic Tabu search method

TS starts with a initial solution created by a random number generator. Next, we create a set of neighborhoods from the near region of an initial solution and belief space. And setting the best solution of the evaluated values in the neighbor solution generated in Step 2 as a trial solution. If the trial solution is not included with tabu list, set it as the current solution of the next search. Finally the tabu search process is stopped when a given criterion is satisfied[6],[7].
Generally, TS performance is depended on definition of N(S) and search strategy. Fig. 3 shows general method for generating neighborhood solution.

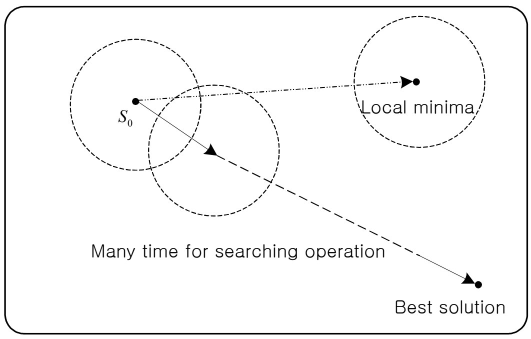

Fig. 3 General method for generating neighborhood

From Fig.3 if best solution is far from S_0, in order to obtain best solution, we take many time for searching operation. and if searching direction is not near to best solution, solution can be trapped in local minima.

To solve this problem, it needs to extend the range of neighborhood solution. When we extend neighborhood solution, there is big possibility of getting the best solution in the near initial solution S_0 and there is small possibility of it is far from S_0. Thus we make neighborhood solutions distributed the like patten of Gaussian random distribution.

Let $f(x)$ is function of x which have Gaussian random distribution. Then $f(x)$ is described as bellow.

$$f(x) = \frac{1}{\sqrt{2\pi\sigma_x^2}} e^{-(x-a_x^2)/2\sigma_x^2} \tag{13}$$

where a_x is center of Gaussian random distribution, σ_x is standard deviation. Fig.4 shows the Gaussian random distribution.

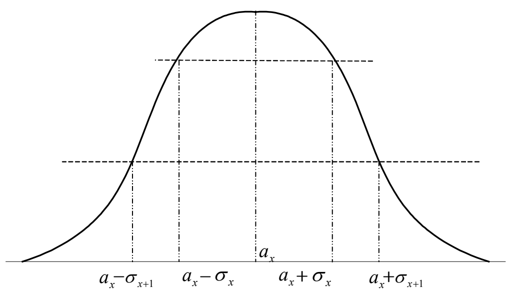

Fig. 4 Gaussian random distribution

From Fig. 4 the density of neighborhood is high near a_x, otherwise it is low. In other words, it is affected by standard deviation σ_x. If σ_x is big, it can be searched in wide range of solution.

Supposing that " R "(0≤ R ≤1) is entire searching range of best solution and " d " is range of neighborhood solution, where range of neighborhood solution " d " is σ_x. It can be find the best solution by control " d " during tabu search.

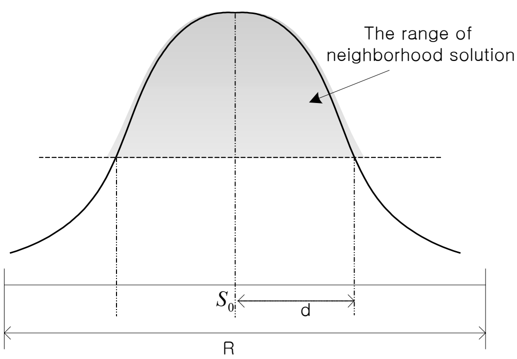

Fig. 5 The range of neighborhood solution, according to σ_x

4. DESIGN OF CONTROLLER USING MODIFIED TABU SEARCH.

The flow chart of proposed algorithm using Tabu search is shown in Fig. 6

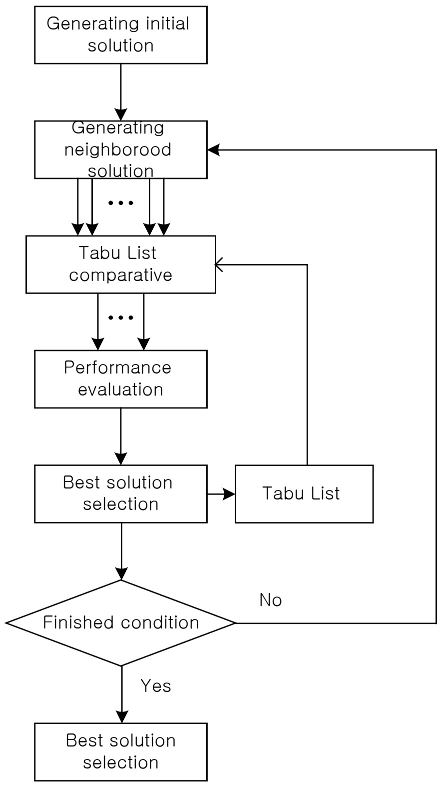

Fig. 6 Flow chat of tabu search

1) Generating the initial solution

Generating the initial solution like (13) such that constraint of the given problem is satisfied, and than setting it as the current Solution.

$$S_{0,} = \{init1, init2, init3\} \tag{14}$$

2) Generating neighborhood solution

Generating neighborhood solution for current best solution according to search strategy and object within the search region. and it is compared with the tabu list. If the solution is included with tabu list, the solution is excluded neighborhood solution.

3) Evaluation

New neighborhood solution N(S), from above 2), is evaluated by object function O_j set like (15)

$$O_j = Minimize \sum_{k=1}^{n} E(k) \tag{15}$$

where n : number of data acquired during specified time.

During evaluation, it is calculated Performance Index(PI)

According to PI, Range of (Ns) is increased or decreased.

5. SIMULATION RESULTS

This section presents some simulation result to evaluate the proposed control scheme in the Fig1. Using modified tabu search controllers, simulation of a sensorless vector control for, induction motor, rating of 2.2KW was carried out.
The parameters used for simulations are listed on Table 1

Table 1. Simulation parameters

Stator Resistance	Rs	0.921Ω
Rotor Resistance	Rr	0.583Ω
Stator Inductance	Ls	67.1mH
Rotor Inductance	Lr	67.1mH
Magnetizing inductance	Lm	65 mH

According to the parameters value mentioned above, a series of comparison curve of the speed control response between the conventional PI controller and the proposed controllers are shown in Fig .7 to 8.
Fig.7 and Fig.8 show the variation of the speed in the same system.
In Fig.7, the curves are corresponding to the starting response of command speed 500rpm caused by the PI and the new proposed controllers.
In Fig. 8, the curves are corresponding to the starting response of command speed 1000rpm caused by the PI and the new proposed controllers. In Fig. 9, it is shown error of speed.
The simulation curves show that the setting time is shorter by using proposed controller.
In Fig.10, the curves are corresponding to the transient response in change of the speed reference. The speed reference is changed from 800rpm→1600rpm→800rpm under no load condition.
In Fig.11, the curves are corresponding to the transient response in change of the load(from 0% to 100%) caused by the PI and the new proposed controllers. The speed reference is 800rpm, the rated torque is applied, and then after 0.5 sec, the load is removed in this system.
The simulation curve shows that system with new proposed controllers is insensitive to the load disturbance.
As the simulation results, the proposed controller has a better speed response for the system.

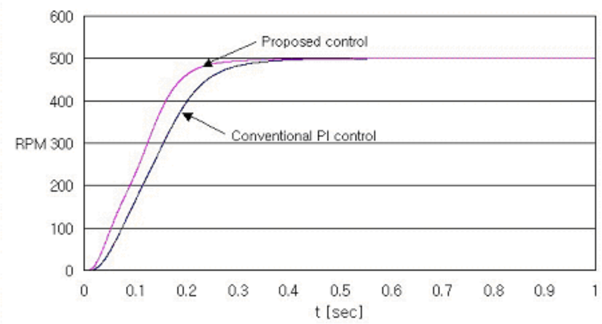

Fig. 7 Speed step response (500rpm)

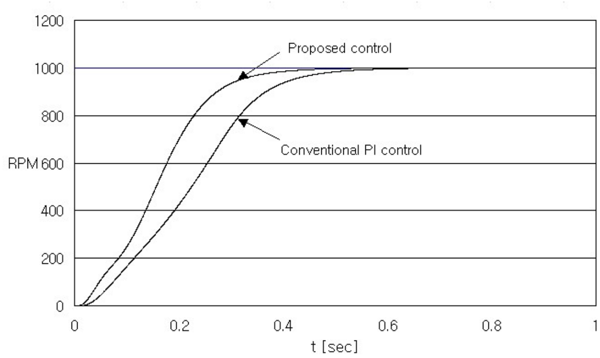

Fig. 8 Speed step response (1000rpm)

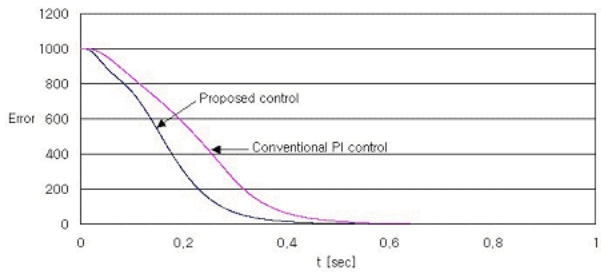

Fig. 9 Error of speed (1000RPM)

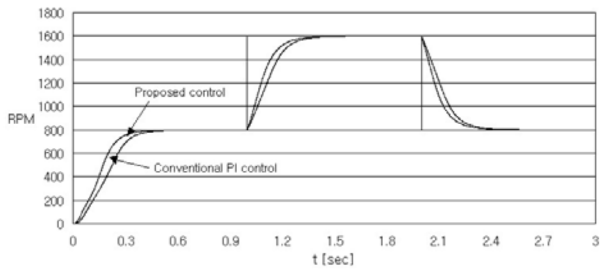

Fig. 10 Speed step response (800rpm→1600rpm→800rpm)

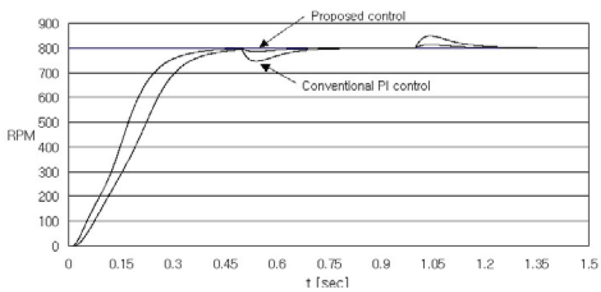

Fig. 11 Speed Regulation against load variation.
(800rpm, no load→rated load→ no load)

6. CONCLUSION

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A new approach for sensorless vector control of induction motor using modified tabu search has been presented.

Some important advantages of proposed controllers are summarized as follows.

1. Precision and Robustness : The controller gives small errors and it has been roust when wide variations in the resistive parameters of the motor occur.
2. Efficiency : the calculation simplicity permits to exercise a greater number of control actions per second, what permits to guide the control in motor strict way.
3. Good dynamical behavior : in transient state the speed follows very close the target one. The sharp torque changes, even in transient periods, are absorbed easily with low cost and size that can be sold integrated with the inverter.

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