Intelligent Control for Permanent Magnet Synchronous Motor with Improved Particle Swarm Optimization

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Abstract: This paper presents a new intelligent controller for a permanent-magnet synchronous machine in a HEV (hybrid-electric vehicle) application. IPSO (Improved Particle Swarm Optimization) will be used to optimize three proportional parameters \( k_a \), \( k_b \), \( k_c \) of FLC (Fuzzy Logical Controller) online increasing the robustness of overall system. Finally, the overall system will be simulated under various operating conditions. The use of IPSO as an optimization algorithm makes the drive robust, with faster dynamic response, higher accuracy and intensive to load variation. The system is tested using a step change signal of load. The simulation results show good dynamic response with fast recovery time.

Key-Words: IPSO; PMSM; FLC; Robustness; HEV; Optimization

1 Introduction

Important advantages, such as lowered emissions and fuel consumption, as compared to standard internal combustion engines (ICEs), have made hybrid electric vehicles (HEVs) interesting from a global perspective [1]. Compared to standard vehicles equipped with ICEs, the drive-line topology in any HEV is indeed considerably more complex, containing additional components, such as battery fuel cells, electric machines and power electronics. In order for the HEV concept to be competitive on the market, each part has to be carefully designed so that emissions and fuel consumption really are reduced down to economically competitive levels.

A key component in any HEV is the electric machine(s), controlled by power electronics. The permanent-magnet synchronous machine (PMSM) has, due to its high efficiency, power density, and torque-to-inertia ratio, become a common choice in several HEV concepts: examples are [2].

It is important for a PMSM used in HEV to provide an adequate torque. Thus, it is necessary to make full use of reluctance torque of PMSM. However, an inaccurate d-axes current can result in torque vibration [3]. Some papers have presented some adaptive FLC (Fuzzy Logic Controller) by regulating fuzzy rules on-line [4-7], but regulating fuzzy rule is very complex and can not get the most optimization results without optimization for proportional parameters of FLC. So this paper presents an intelligent FLC using IPSO (Improved Particle Swarm Optimization) algorithm to optimize the scaling factors instead of the traditional trail and error method. Because the drive system plays an important role to meet the other requirements, it should enable the drive to follow any reference speed taking into account the effects of load impact, saturation, and parameter variation. Simulation results are completed with MATLAB.

2 Mathematics Model of PMSM

A space vector diagram of PMSM is shown in Fig.1. The voltage equations in d-q reference frame are

\[
\begin{align*}
\begin{bmatrix}
    u_d \\
    u_q
\end{bmatrix} &=
\begin{bmatrix}
    r_s & 0 \\
    0 & r_s
\end{bmatrix}
\begin{bmatrix}
    i_d \\
    i_q
\end{bmatrix} +
\begin{bmatrix}
    p & o \\
    -o & p
\end{bmatrix}
\begin{bmatrix}
    \psi_d \\
    \psi_q
\end{bmatrix} \\
\end{align*}
\]

(1)

The flux linkages are defined as,

\[
\begin{align*}
\begin{bmatrix}
    \psi_d \\
    \psi_q
\end{bmatrix} &=
\begin{bmatrix}
    L_d & 0 \\
    0 & L_q
\end{bmatrix}
\begin{bmatrix}
    i_d \\
    i_q
\end{bmatrix} +
\begin{bmatrix}
    \psi_m \\
    0
\end{bmatrix}
\end{align*}
\]

(2)

3 Particle Swarm Optimization

Particle swarm optimization (PSO) was firstly introduced by Eberhart and Kennedy [8]. It is a semi-global optimization algorithm that simulates the movement of birds, insects and fish swarm while...
searching for food. The total swarm proceeds in the direction of the swarm member with the best fitness. That member with the best position remains the leader of the swarm. At another member finds a location better than their former best “position” it becomes the new leader. This continues till the swarm collapses to the location with the global best fitness.

PSO is a simple optimization technique without heavy computation. It doesn't need training with heuristic data. The original PSO formulate define each particle current position in D-dimensional space, with particle $k$ represented as:

$$X_k = (X_{k1}, X_{k2}, \ldots, X_{kD}).$$

Also, each particle maintains a memory of its previous best position as:

$$P_k = (P_{k1}, P_{k2}, \ldots, P_{kD}).$$

And velocity along each dimension represented as:

$$V_k = (V_{k1}, V_{k2}, \ldots, V_{kD}).$$

At each iteration, the particle is subjected to limit constrains in each particle subjected to limit constrains in the local neighborhood, designated $P_g$, and the particle is then used to compute a new position for the particle as follow [8]:

$$w = w_{max} \cdot k \cdot \frac{W_{max} - W_{min}}{k_{max}}$$

where $w_{min}$, $w_{max}$ and $k_{max}$ are minimum, maximum values of $w$ and pre-specified maximum number of iteration cycles, respectively.

## 5 Adaptive Fuzzy Controller Using IPSO

Fig.2 shows the framework of normal fuzzy controller for PMSM.

The FLC inputs are the speed error $e(T)$ and change in speed error $ce(T)$ defined by:

$$e(T) = \omega_{ref}^* (T) - \omega(T)$$

$$ce(T) = e(T) - e(T-1)$$

Where $\omega_{ref}^* (T)$ is speed reference signal; $k_a$, $k_b$, $k_c$ are fixed proportional parameters; $\omega(T)$ is speed backfeed signal; $u(T)$ is the change in quadrature reference current.

The forms of the membership functions are chosen to be triangular, except on the extremities of the universes of discourse where open and ordinary trapezes are used for the input and output variables respectively. Defining an overlap of 50% between membership functions, there will be a minimum of 1 and a maximum of 4 rules fired at each sampling instant.

However, fixed proportional parameters can not satisfy different operation conditions, then the whole system can not get the optimization. Here, IPSO is used to optimize $k_a$, $k_b$, $k_c$ dynamically showed as fig.3. Detail procedures are follows:

a) Initialization

Firstly, divide the solution space into five areas. In every area, let

$$X_i(0) = [k_{a1}(0), k_{b1}(0), k_{c1}(0)]$$

of $k$th particle, where $k_{a1}(0)$, $k_{b1}(0)$, $k_{c1}(0)$ are the components (FLC gains) of each particle subjected to limit constrains in a population of size $n$ ($k=1$ to $n$).

Similarly, generate randomly initial velocities of all particles

$$V_i(0) = [v_{k_{a1}(0)}, v_{k_{b1}(0)}, v_{k_{c1}(0)}]$$

are subjected to limit constrains.

b) Updating

Each particle in the initial population is evaluated using the fitness function, $f(X_i)$, and updates position, velocity
and inertia weight of particle in light of formulations.

3) Stopping criteria

For each particle, the objective function $J$ is $e(T) \leq 0.0001$. If $J$ is satisfied, then stop; else go to b) until the number of iterations reaches maximum iterations $N$. Then the responding values of $k_a$, $k_b$, $k_u$ are most optimal results.

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**6 Simulation Results**

Fig. 4 shows the simulation framework about vector control with IPSO-Fuzzy controller. External loop is speed loop with speed command of 1000 r/s. Speed error $e$ is produced by (9) and putted into IPSO to optimize $k_a$, $k_b$, $k_u$. Inner loop is current loop which produced through SVPWM (Space Vector Pulse Width Modulation). Control strategy is vector control and $i_d = 0$

In the simulation process, speed reference is set as 100 r/s firstly, and load torque changes from 2N.m to 10N.m. Fig. 5, Fig. 6 and Fig. 7 shows the speed, a phase current and torque curves when motor starts. It can be seen that the fluctuation is very small when load torque changes suddenly. In order to test the performances of system when PMSM is running at high speed, we set the speed command as 1000r/s, fig. 8, fig. 9, fig. 10 show the responding simulation results. So whole control system has a sound robustness ability.

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**Fig. 2 Normal fuzzy control of PMSM**

**Fig. 3 Adaptive fuzzy control of PMSM using IPSO**

**Fig. 4 Simulation of fuzzy control for PMSM using IPSO**
Fig. 5: Rotor speed curve at 100 r/s

Fig. 6: A phase current curve at 100 r/s

Fig. 7: Load torque curve at 100 r/s

Fig. 8: Rotor speed curve at 1000 r/s

Fig. 9: A phase current curve at 1000 r/s

Fig. 10: Load torque curve at 1000 r/s
7 Conclusion
This paper presents a fuzzy controller using IPSO for a permanent-magnet synchronous machine in a HEV (hybrid-electric vehicle) application. IPSO is used to optimize three proportional parameters $k_a$, $k_b$, $k_c$ of FLC (Fuzzy Logical Controller) online. From simulation results, it can be known that the use of IPSO as an optimization algorithm makes the drive more robust, with faster dynamic response, higher accuracy and insensitive to load variation.

References: