CHAPTER 6
CONCLUSIONS

In this dissertation, some new torque control strategies for IPMSM drives are proposed to fully exploit the reluctance torque as well as preserve the merit of the simple linear torque control scheme. A novel linear torque control strategy is proposed for IPMSM drives such that the resulting torque is proportional to the line current magnitude. A sufficient condition for the existence of the linear torque control is derived and the corresponding torque constant is also maximized. In addition, a closed form relation between the i_{ds} and i_{qs} is also derived. It turns out that the proposed torque control strategy can not only fully exploit the reluctance torque but also can preserve the simple linear torque control characteristic. In addition, for a well designed IPMSM, the constant torque operation region can be extended greatly, say up to 197% as compared to that of $i_{ds} = 0$ control strategy from the aforementioned example. Naturally, much better performance can thus be obtained at higher speed region by using the proposed LTC strategy.

Based on the proposed LTC strategy, the constant torque limit speed range can be extended considerably wider than that of $i_{ds} = 0$ control strategy. However, when the motor is operated beyond the base speed that is commonly called the field weakening region, the maximum torque capability of an IPMSM is decreased with the increase of the motor speed. But there is still considerable torque capability available in this higher speed region. Thus, an integrated linear torque control strategy is proposed to achieve wide speed operation range for IPMSM drives. Also, for the first time, the theoretical basis of the proposed field weakening control is proposed and the corresponding analytical forms are derived. Basically, the operation modes of the drive system can be divided into three regions according to different motor speeds. However, there require only two types of controls. Furthermore, when the motor is operated in the field weakening region, in order to fully use the maximum torque capability to achieve fast response, a variable line current magnitude limiter is proposed. From the experimental results, one can see that the proposed integrated linear torque control strategy is effective over the field weakening range.

For a high performance motor drive system, operation under high drive efficiency is also desirable. The extension of the existing maximum torque per ampere control in the constant torque limit region up to the field weakening region by using the proposed LTC strategy is therefore proposed. The theoretical basis of the proposed control strategy has been described in detail and some analytical forms are also provided for reference. Furthermore, within the operable region, the steady state current vector command is proven to have minimum magnitude in both the constant torque limit control mode and the field weakening control mode. Therefore, the proposed control can achieve minimum copper loss over the entire speed range. From the results of the experimental comparison of dynamic and steady state performances between the proposed LTC and the proposed LMTPA control, one can see that the enhancement of the dynamic response (i.e. the accelerating time period) by the proposed LMTPA control is about 2.3% and the reduction of the copper loss (i.e. the line current magnitude) by the proposed LMTPA control is about 3.5%.

Because the q-axis effective air-gap length is smaller than the d-axis effective air-gap length. Hence, the q-axis flux linkage tends to saturate under the operation conditions of large q-axis current. On the other hand, the corresponding d-axis flux linkage shows a relatively linear magnetic characteristic with respect to the d-axis current. A new saturated model for the q-axis flux linkage is proposed and the corresponding LMTPA control strategy is derived. Then the effects of the magnetic saturation on the dynamic and the steady state performances for the tested IPMSM drive system are examined via some experimental tests. For implementation, the control programs in the digital signal processor are modified to implement the proposed control. The experimental results have shown that the transient performance can be enhanced by at least 3.4% and the corresponding copper loss can also be reduced by averagely about 2.7% while considering the magnetic saturation effect.

Finally, several other research topics not covered in this dissertation are recommended in the following for future studies:

1. Advanced control theories can be applied to IPMSM drives to achieve robustness by using the proposed linear torque control strategy.
2. Apply the proposed LMTPA control strategy to a practical drive system, such as the fuel cell vehicle drive, the hybrid vehicle drive, and the renewable energy conversion system where energy management issue is also an important consideration.
3. Apply the proposed LMTPA control strategy to a new class of IPM machine whose permanent magnet flux linkage is smaller as well as the winding maximum current limit is large. This kind of IPM machine is usually applied in the integrated starter and generator (ISG) in hybrid vehicle drive system.
4. The performance of the decoupled current controller in the high speed field weakening region can be further improved by the other over-modulation strategies.