# Chapter 6

# Summary and Future Perspectives

In this short chapter, we summarize the work done in the thesis by pointing out the main attributes as well as limitations. We also elaborate on possible future investigations.

## 6.1 Research Summary

Conventional switched reluctance motors (SRMs) face a problem of low torque and power density. With the development of double-stator SRMs (DSSRMs), the torque and power density are improved significantly. The further add-on of single-tooth winding configuration increases the compactness, fault-tolerance capability, copper loss and speed range. However, these motor still have the problem of high torque ripple. Research should be focused to reduce the torque ripple together with some further improvements.

The geometry and design concepts of single-tooth winding radial flux DSSRM are discussed in Chapter 2. The torque equation is derived for this motor topology. The arc angles of stator poles and rotor segments are derived for high aligned and low unaligned inductances to increase the output torque. Based on this, the selection procedure of slot/segment combination is discussed. It is observed that 12/10 pole combination has torque and power density compared to the other variants. The influences of winding polarities are also investigated. It is observed that subtracting flux winding polarity has slightly better torque density over aiding flux winding polarity for 12/10 DSSRM for the rated operation. It is also observed that this motor possesses a high torque ripple, which should be mitigated.

A schematic for torque ripple reduction in SRMs is discussed in Chapter 3. In this schematic, it is expected that if some design modifications are done in the DSSRM in such a way that torque generation of the incoming phase increases near the unaligned position, torque ripple in the commutation region can reduce. The effect of rotor segments shift as well as stator and rotor surface shift are investigated to reduce the torque ripple in 12/10 pole DSSRM. The static and dynamic simulation results conclude that shifting of alternate rotor segments in the direction of rotation can effectively reduce the torque ripple. The optimal shift angle is calculated through parametric analysis. Likewise, the shifting of stator and rotor surfaces are also investigated. Shifting the rotor surfaces in the direction of rotation and stator surfaces opposite to the direction of rotation effectively reduce the torque ripple. It is observed that shifting of both stator surfaces is dominant to minimize the torque ripple compared to other shifts.

In Chapter 4, the effects of the segment and surface shift on the performance of the motor are discussed. The electromagnetic performance of an electrical machine depends on the distributions of the fluxes in different parts of the machine. The influence of the segment and surface shift on the radial force of the rotor segments is investigated by calculating the normal and tangential components of the air-gap flux densities in the inner and outer air-gaps of the motor. It is observed that a small unbalance condition is created on the rotor of 12/10 pole DSSRM due to the segments shift. This is because of the occurrence of unequal radial force densities in the air gaps of the diametrically opposite sides of the rotor after the segments shift. However, this unbalance condition is inherently omitted in the case of 24/20 pole DSSRM because of the equal radial force densities at the opposite sides of the rotor. For the case of surface shift, the rotor possesses a balance condition in each case. With the shift of segment and surface, the peak radial force on a rotor segment increases. The effect of segment and surface shift on the output torque in the commutaion region is studied. It is observed that the tangential force density increases in this region, in the case of segment or surface shift. This increases the output torque and reduces torque ripple in this region. The influences of the segment and surface shift on other performances of the motor are also studied. The increment in the shift angle increases the maximum core flux density, core loss and unaligned inductance of the motor; furthermore, it reduces air-gap flux density, aligned inductance and output torque. For the higher value of shift angle, the reduction in output torque is considerable, which reduces the efficiency of the motor.

In Chapter 5, the design of a new DSSRM is discussed, which has a significantly low torque ripple at a higher operating speed. In the proposed motor, the outer stator is shifted by half of the stroke angle with respect to the inner stator. The phase windings of the inner and outer stator are excited parallelly with the same phase shift. Each rotor segment is divided into two halves, and a wide non-magnetic isolator is inserted between them. Modifications are done in outer stator poles and outer half rotor segments after this insertion. The proposed motor shows a significantly reduced torque ripple near the rated speed.

## 6.2 Limitations and Future Investigations

As is common in all designs, the proposed design also has some limitations and shortcomings, and there exists scope for further improvements. These issues and future work can be pointed out as:

- DSSRMs improve the torque and power density; however, such topology increases some design complexity and production cost as compared to the conventional SRMs.

- In the presented work, the torque ripple reduction techniques are proposed and investigated through the shift of rotor segments as well as stator/rotor surfaces. However, these methods require modified structures, which can only be implemented by developing new motors.

- The method of segment or surface shift can reduce torque ripple effectively when current chopping control mode is active. This region occurs for the lower back EMF condition. When the speed of the motor increases considerably, the back EMF increases and this method becomes less significant.

- In the presented work, the torque ripple is reduced via segment and surface shift on the cost of some increase in the radial force of the rotor segments. In 12/10 pole motor, a small unbalance condition occurs on the rotor due to the segments shift. Therefore, future research can be carried out to reduce the radial force and unbalance force which is the primary cause of noise and vibration in the motor.

- The motor discussed in Chapter 5 requires the excitation of the inner and outer stator windings parallelly with the phase shift. This will increase the number of devices, complexity and cost of the inverter circuit. Moreover, the rotor, which includes the half rotor segments will increase complexity and cost during production.

- The works presented here are based on FEM studies. The experimental verification is still scope as future work for its validation check.