Undoubtedly, the three-phase machines are today the natural choice for electrical drives. However, for high power ratings and/or for high-reliability drives requiring fault-tolerant operation, the multiphase solutions (number of phases higher than three) have become a valid alternative. The main benefit of adopting a multiphase machine is the reduction of the phase current without the increase of the rated voltage, by splitting the power current on a higher number of phases. This feature is particularly convenient in high-power/high current applications, such as ship propulsion, hybrid propulsion for aircrafts, high power electrified powertrains for trucks and sport cars, wind power generation, high power industrial drives, where the per-phase current rating is reduced compared to the three-phase solution by keeping the same power ratings.

Although the literature reports many different multiphase drive solutions, the industry adopted at large scale the multi-three-phase drive topologies. Therefore, this dissertation focuses on multiphase machines with a modular topology adopting multithree-phase units with isolated neutral points. They represent the natural extension of the traditional three-phase machine, and they permit the exploitation of conventional and well-established three-phase power converter units. Additionally, the control techniques developed for three-phase machines can be applied to control each unit of the multi-three-phase machine, thus obtaining a modular control solution. This is the reason why industry adopted the multi-three-phase solution.

An increased reliability of the drive can be achieved when both the multiphase machine and the power converter units adopt a modular topology. By dividing the N machine phases in multiple M-phase units ($M < N$), a modular machine topology is realized. Thus, every unit can be fed independently by a M-phase power converter and, in case of a fault event involving a phase of a unit, an easy reconfiguration can be performed, guaranteeing the reliability of the whole drive.

In order to fully exploit the drive modularity, modular torque control solutions capable of independently regulating the torque produced by each unit of the multithree-phase machine have been investigated. The existing literature about modular torque control for multiphase machines does not exploit the latest flux-based control strategies proposed for three-phase machines.

Therefore, the thesis focused on controllers for multi-three-phase machines featuring modular torque control capabilities exploiting the regulation of the machine’s flux vectors. In detail, the controllers must guarantee that the torque production of the multi-three-phase machine is the sum of the torque contributions of each three-phase unit independently controlled from the others.

To validate the developed modular torque control solutions, a multi-three-phase synchronous machine has been adopted because it is superior in efficiency and torque density to its induction counterpart. Specifically, an interior permanent magnet (IPM) synchronous machine has been selected. It features rotor anisotropy and saturation phenomena, which affects machine modelling and torque control development. Despite the increased complexity, the IPM is the state-of-the-art design in the automotive field, where the proposed torque controllers aim to be applied.

The dissertation starts by reviewing multiphase applications, available multiphase configurations, and the main control techniques reported in the literature for multiphase machines. It also proposes a brief review of fault-tolerant operation.

Consequently, different electromagnetic models of the IPM machine under study are proposed adopting the machine modelling approaches currently available in the literature: the multi-stator (MS) modelling approach, the vector space decomposition (VSD) modelling approach and the decoupled-multi-stator (DMS) modelling approach.

Therefore, two different multi-three-phase modular torque controllers are proposed by adopting the MS modelling approach. They extend two torque-control strategies developed for three-phase machines: the direct flux vector control (DFVC) scheme and the flux polar control (FPC) scheme.

The DFVC solution regulates the torque delivered from a three-phase unit by controlling the unit's stator flux amplitude and the torque-producing current component. Accordingly, the modular DFVC scheme applied to the multi-three-phase machine independently regulates the torque delivered from each three-phase unit by controlling its stator flux amplitude and torque-producing current component. However, the need for a complex decoupling algorithm to implement the modular DFVC scheme pushed for pursuing a more straightforward modular control solution.

The FPC has been identified as the optimal control solution to implement a modular control, solving all the coupling issues. The adoption of the FPC for the modular control of a multi-three-phase machine represents the main novelty proposed by this thesis. The FPC solution regulates the torque delivered from a three-phase unit by controlling the polar components, i.e., amplitude and phase, of the unit's stator flux vector. Therefore, the modular FPC scheme applied to the multi-three-phase machine independently regulates the torque delivered from each three-phase unit by controlling its stator flux polar components. The state-space variables adopted to implement the FPC ensure its exclusive feature of being the only formulation of a self-decoupled multi-three-phase torque control solution, thus not requiring decoupling actions. Therefore, the main benefit of the modular FPC scheme is that it enables the establishment of a modular torque control solution, overcoming all the complexities resulting from the modular architecture and ensuring the independent and decoupled control of the torque delivered from each winding set.

Finally, the performance of the modular DFVC and the modular FPC have been validated through experimental tests carried out on a quadruple three-phase IPM synchronous machine prototype. Several tests have been performed on the multi-three-phase IPM under analysis, including dynamic tests proving the torque response, torque-sharing tests validating the capability of independently controlling the torque production of every unit, unit switch-off testing the fault-ride-trough capability, and torque profiles in the speed-range of the drive proving the control performance in delivering the peak-torque and performing the flux weakening operation. The experimental results demonstrate the modular torque control capability of the modular DFVC and the modular FPC in the different testing conditions.