Nested-Loop Neural Network Vector Control of Permanent Magnet Synchronous Motors
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ABSTRACT
Permanent Magnet Synchronous Motors (PMSMs) are at the top of AC motors in high performance drive systems for Electric Drive Vehicles (EDVs). Traditionally, a PMSM is controlled with standard decoupled d-q vector control methods. However, recent studies indicate that such mechanisms show limitations. This paper investigates how to mitigate such problems using a nested-loop neural network architecture to control a PMSM. The neural network implements a dynamic programming algorithm and is trained using backpropagation through time. The performance of the neural controller is studied for typical vector control conditions and compared with conventional vector control methods, which demonstrates the neural vector control strategy proposed in this paper is effective. Even in a dynamic and switching environment, the neural vector controller shows strong ability to track rapidly changing reference commands, tolerate system disturbances, and satisfy control requirements for complex EDV drive needs.

CONVENTIONAL CONTROL METHODS
- Each of the d- and q-axis control loops has a cascaded structure.
- A fast inner current loop combined with an outer slower loop for speed and air gap magnetic field controls.
- The speed reference is generated during the operation of the vehicle.
- The speed and magnetic field control is converted into decoupled d-q current control.
- The current-loop controller implements the final control function by applying a stator voltage control signal to the voltage-source PWM converter.
- The control of the d- and q-axis current loops has a competing control nature.
- Relies primarily on the compensation terms rather than the PI loops.
- Those compensation terms are not contributed in the feedback principle.
- May result in malfunctions of the overall system.

PM MOTOR IN ELECTRIC VEHICLE
A PMSM is an ac electric motor that uses permanent magnets to produce the air gap magnetic field rather than using electromagnets.
- Rotors: driven by the stators, via a synchronous rotational field generated by the three-phase currents passing through the stator windings.
- Stator: connected to the dc bus through a standard three-leg voltage-source PWM converter.
- Converter: converts dc to three-phase ac in the PMSM drive mode or converts three-phase ac to dc in the regenerating mode.
- Drive mode: power flows from the dc bus to the PMSM to drive the vehicle.
- Regenerating mode: power flows from the PMSM to the dc bus to charge the battery.

PERFORMANCE EVALUATION
- Nested-loop NN vector controller
- Performance under variable parameters of PM motor System
- Comparison with conventional standard vector control method
- Power converter switching condition

NEURAL NETWORK CONTROLLER
- Current-loop controller
- Continuous system model:
- Discrete equivalent model:
- Network input:
- Control action:
- Predict input:
- Speed-loop controller
- Continuous system model:
- Discrete equivalent model:
- Network input:
- Predict motor speed:
- Control action:
- Control action with stabilization matrix:
- Control action with stabilization matrix:

CONCLUSIONS
- This Paper presents a nested-loop NN vector control method, and describes how dynamic-programming methods are employed to train the current- and speed-loop NN controllers through a BPTT algorithm.
- The current-loop NN controller can track the reference d- and q-axes currents effectively.
- The speed-loop NN controller is able to follow the reference speed excellently.
- Compared to conventional standard vector control methods, the NN vector control approach produces the fastest response time, low overshoot, and, in general, the best performance.
- The neural networks are trained under variable system parameters. Thus, the nested-loop NN controller has an attractive performance when the system parameters are hard to be identified.
- In switching environment, the NN vector controller demonstrates strong capability in tracking reference commands while maintaining a high power quality.

REFERENCE