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A Study on Electrical Efficiency Improvement and Heating Control via Induced Inefficiencies of an Electric Compressor for EV Energy Consumption Improvement

- Electrical Efficiency Improvement of Motor/Inverter and Loss-Based Heating Control for Cold Operation -

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Improving driving range in electric vehicles (EVs) requires reducing auxiliary power consumption, especially for heating and air-conditioning in cold conditions. In heat-pump-based thermal systems, the electric compressor is a major high-voltage load; therefore, its electrical efficiency directly affects vehicle energy consumption. This paper presents an integrated approach to (i) improve compressor electrical efficiency (motor + inverter) and (ii) enable a controllable loss-based heating mode to expand cold-temperature operability by intentionally inducing additional electrical losses.

For motor efficiency improvement, key stator and rotor geometric parameters were selected and optimized using the Taguchi method, targeting the dominant operating condition around 8500 rpm and 7 Nm. Stator parameters (e.g., tooth width and slot-related dimensions) were screened to identify dominant contributors while maintaining feasible winding specifications. Rotor parameters (e.g., barrier/bridge-related dimensions, outer diameter, air gap) were optimized to improve torque capability and flux distribution while considering mechanical constraints; additionally, a higher residual-flux-density magnet and a thinner, lower-loss electrical steel were adopted to reduce high-frequency core loss.

On the inverter and control side, refined maximum-torque-per-ampere (MTPA) maps were generated using a simulation model and validated by dynamometer testing, improving current vector accuracy at representative compressor operating points. To reduce switching loss and extend the feasible high-speed region, discontinuous PWM (DPWM) with overmodulation was applied, with the DPWM variant selected to provide lower switching loss in both MTPA and field-weakening regions. Furthermore, a SiC MOSFET-based inverter was evaluated to quantify loss benefits; circuit-level countermeasures (e.g., bootstrap/snubber and clamp-related measures) were incorporated to suppress self turn-on associated with low gate-threshold behavior.

Dynamometer validation showed that the optimized motor improved efficiency from 91.5% to 93.5% at 8500 rpm and 7 Nm (about +2.0%p), corresponding to approximately 145 W loss reduction at the targeted operating point. Additional reductions were achieved by control and hardware measures: MTPA map refinement reduced loss by about 15.4 W at 4500 rpm and 5 Nm, DPWM reduced switching loss by about 16 W compared to SVPWM, and the SiC MOSFET inverter reduced loss by up to 32 W at 8000 rpm and 4 Nm (about 20 W on average across the evaluated region). The combined electrical loss reduction was approximately 208.4 W; using an internal conversion factor of 0.25% vehicle energy-consumption improvement per 10 W auxiliary reduction, this corresponds to an estimated 5.21% improvement in EV energy consumption.

Impact of Electrical Load Reduction (10 W) on Fuel/Energy Efficiency (Avg.)		
	Compact / Mid-size	Full-size
EV (km/kWh)	0.25% (0.22–0.30%)	0.18% (0.16–0.20%)
HEV (km/L)	0.14% (0.13–0.15%)	0.11%
ICE (km/L)	0.12% (0.11–0.12%)	0.10% (0.09–0.11%)

Load Reduction by Efficiency Improvement Technology					
	Motor Design	MTPA	DPWM	SiC MOSFET	Total
Reduced Load	145 W	15.4 W	16 W	32 W	208.4 W
Efficiency Improvement	3.625%	0.385%	0.40%	0.80%	5.21%

Fig.1 Effect of load reduction on fuel economy and EV energy consumption.

To enhance heat-pump operation under extremely cold ambient conditions, a loss-based heating control was investigated by intentionally shifting the current vector phase angle away from MTPA to increase copper and core losses and utilize the additional electrical input as heat. At 4500 rpm and 3 Nm, efficiency decreased from 92.043% (MTPA, 8°) to 73.45% (heating mode, 66.8°), creating approximately 390 W additional electrical input. Vehicle-level testing demonstrated up to 7.7°C higher refrigerant discharge temperature and an expanded operating range through refrigerant-system operating-point shifts. These results indicate that electrical-efficiency improvements can reduce steady-state energy consumption, while the proposed controllable inefficiency mode can provide supplementary heating capability without additional dedicated heating components, thereby improving cold-weather operability of EV heat-pump systems.