Modeling of Arc Discharge during Ground Faults in Motor Drive Systems and Prediction of Discharge Energy Losses

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Introduction

In recent years, the automotive industry has accelerated the transition from internal combustion to electric vehicles as part of global climate change mitigation. With increasing motor output, battery voltages have risen, and some systems now operate above 800 V. Automotive electric compressors are also adopting high-voltage operation; however, under high-temperature and high-pressure conditions, arc discharges during short circuits may induce refrigerant self-decomposition. The HFO refrigerant R-1132(E), offering both low global warming potential (GWP) and high cooling performance, therefore requires careful safety evaluation [1].

Since physical short-circuit testing is costly and time-consuming, this study develops a simulation-based methodology. The motor drive system of an automotive electric compressor is modeled as an equivalent circuit incorporating measured parameters and overcurrent protection (OCP) behavior. A short-circuit model is introduced to reproduce arc discharge events and calculate discharge energy, and the validity of the approach is confirmed through comparison with experimental results.

Proposed Method

Figure 1 shows the measured and simulated current and voltage waveforms obtained when the Motor w-phase of a stationary electric compressor was short-circuited to ground. The interval labeled T_{arc} corresponds to the duration of the arc discharge, during which a large current is observed. To reproduce these waveforms, a short-circuit model Z_{arc}, as illustrated in Figure 2, was constructed and simulated. The short-circuiting process can be divided into three distinct stages.

·Phase1 (From t_{arc} to t_1)

By closing SW1 to the arc position and SW2, the inductor current gradually increases, reducing the w-phase–ground voltage.

·Phase2 (From t_1 to t_2)

Subsequently, by opening SW2 and short-circuiting SW3, the voltage arising after the occurrence of arc discharge is reproduced.

·Phase3 (From t_2 to t_{Fin})

Finally, the overcurrent protection is activated, dissipating the energy stored in the inductors and thereby reducing the current.

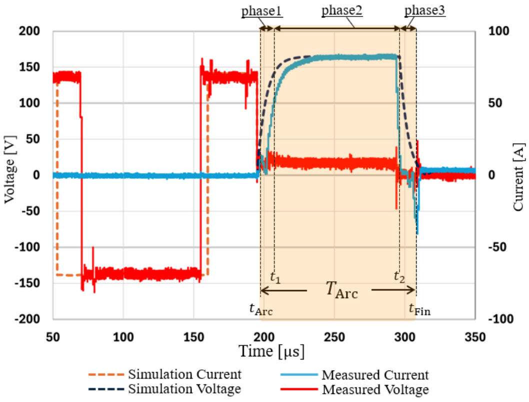

Fig.1 Arc Discharge during Ground Faults

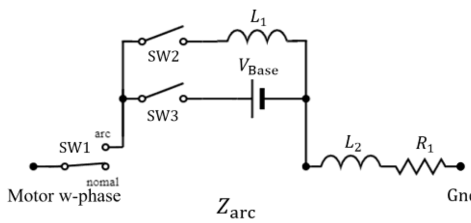

Fig.2 Short Circuit

Conclusion

This study models the arc discharge occurring during short circuits in automotive electric compressors and evaluates the associated energy losses. A system model and a short-circuit model are constructed based on component parameters obtained through disassembly and measurement of the actual device, and loss simulations are performed to demonstrate the effectiveness of the proposed approach.

References

[1] Kengo Nagai, Yota Omizu, Kensuke Shibuya, Takashi Usui, Yasutaka Negishi, Tomoyuki Goto, Koichi Shigematsu, Jun Imaoka, Masayoshi Yamamoto: Modeling of Arc- Discharge Phenomenon for Refrigerants in Motor-Driven Systems, Proceedings of the JSAE Annual Congress (Autumn), No.116-24, pp.1-6, 2024.