Starting Current Reduction of Single-phase Induction Motor for Ultra-low Temperature Freezer

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***Abstract*—This paper proposes a starting current control algorithm of single-phase induction motor (SPIM) for ultra-low temperature freezer. In general, there are different methods to start the SPIM, which are a Split-Phase, Capacitor-Start, Permanent-Split Capacitor (PSC), Capacitor-Start Capacitor-Run (CSCR), and Shaded-Pole (SP). And these starting methods basically cannot control the magnitude of the starting current because of the fixed system structures. As a result, a novel soft starting algorithm based on the proportional resonant (PR) control with a variable and constant frequency is used to adjust the inrush current without changing the CSCR starting method. In addition, the transition algorithm for operation modes is described to generate a constant voltage and constant frequency (CVCF). The validity and effectiveness of the proposed starting and transition algorithm is verified through the several experimental results**

Keywords—Starting current control, SPIM, PR control, Operation mode transition

I. INTRODUCTION

In general, the single-phase induction motors (SPIMs) are widely used in home appliances such as washing machines, dishwashers, refrigerators, pumps, fans, and compressors. Basically, the SPIMs are robust, easy to maintain and low in cost [1]-[7]. However, the single-phase induction motors cannot produce their own starting torque unlike a three-phase winding system. Instead, the magnetic field generated by a single phase remains stationary in position and pulsates with time. Since, there is no rotating magnetic field and a SPIM cannot run without any modification. As a result, the most common type in order to start a SPIM is the Split-Phase, Capacitor-Start, Permanent-Split Capacitor (PSC), Capacitor-Start Capacitor-Run (CSCR), and Shaded-Pole (SP) [1]-[3]. In this paper, the ultra-low temperature freezer uses a Capacitor-Start Capacitor-Run method with a positive temperature coefficient (PTC) starter and overload protector as shown in Fig. 1. The starting current under the CSCR method can be around 500 ~ 700% of the motor full-load current [4]. It causes an abnormal operation to electrical systems and mechanical systems. Therefore, the inrush current when starting the SPIM must be improved. This paper proposes a starting current control algorithm using a proportional resonant (PR) with a variable and constant resonant frequency controller to reduce the inrush current and the transition algorithm also presents to control a constant voltage and constant frequency at steady state. The usefulness and effectiveness of the proposed algorithms is verified through several experiments.

II. CONTROL STRATEGIES FOR SOFT STARTING AND OPERATION MODE TRANSITION

A. Configuration of CSCR-PTC for SPIM

Fig. 1 shows the configuration of CSCR-PTC for starting a SPIM in order to control the ultra-low temperature freezer. The motor is composed of two stator windings which are main winding and an auxiliary winding, with a PTC starter as shown in Fig. 1.

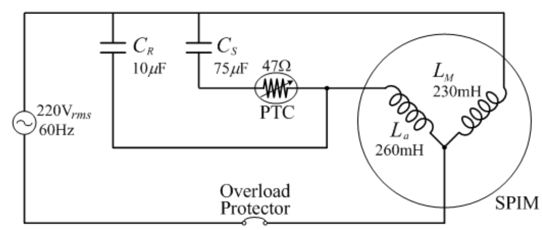

Fig. 1. Configuration of CSCR-PTC for starting SPIM.

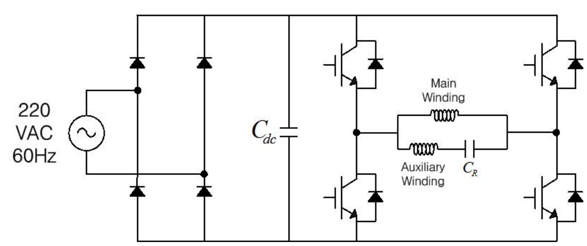

Fig. 2. Single-phase PWM inverter for soft starting.

B. Soft Starting Control

In the circuit shown in Fig. 2, a full-bridge diode rectifier and a full-bridge PWM inverter are used. This topology is easy to control soft starting of SPIM by a current control. As a result, the motor starting current is significantly reduced by

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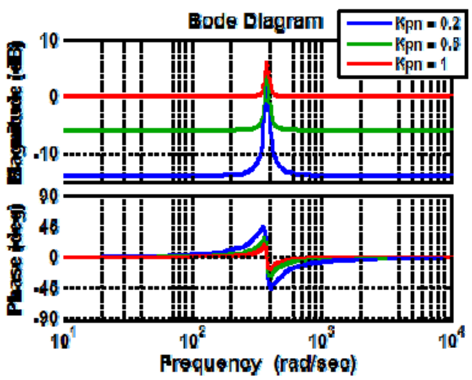
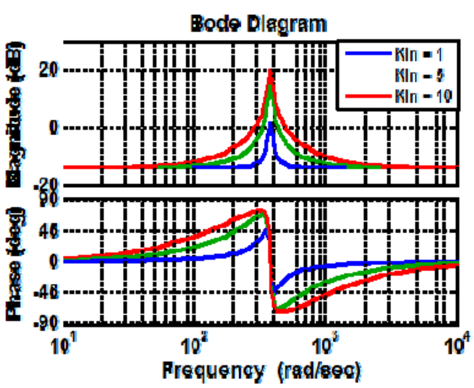
using the proposed algorithm. The transfer function of practical PR controller can be computed as

$$G_{PR\_prac}(s)=K_{pn}+\frac{2K_{in}\omega_c s}{s^2+2\omega_c s+\omega_o^2} \quad (1)$$

where ω_c is the bandwidth at the cutoff frequency.



(a)



(b)

Fig. 3. Bode plot of practical PR controller according to parameter variation. (a) Kpn. (b) Kin.

Fig. 3 shows the bode plot of the practical PR controller. According to the variation of the used gains depends on the magnitude and phase of the used systems. Finally, the control block diagram of the proposed soft starting algorithm is shown in Fig. 4.

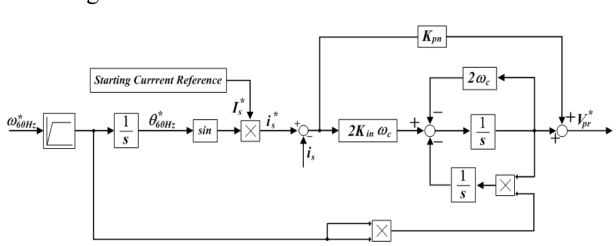


Fig. 4. Control block diagram of the proposed soft starting algorithm.

C. Mode Transition Algorithm Between Soft Starting and CVCF

The used ultra-low temperature freezer basically runs at a constant speed which is 50 [Hz] or 60[Hz]. Therefore, the SPIM have to operate at constant voltage and constant frequency (CVCF) after starting operation. That is why the mode transition algorithm is necessary between soft staring and CVCF. Fig. 5 shows the overall block diagram of the SPIM including the soft starting control and mode transition control, respectively.

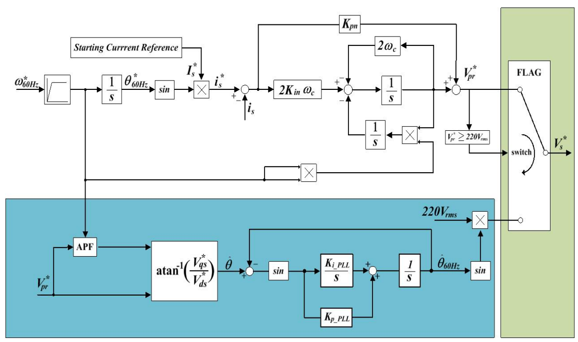


Fig. 5. Overall block diagram of SPIM control system.

III. EXPERIMENTAL RESULTS

Fig. 6 represents the photograph of the SPIM, which includes the ultra-low temperature freezer, power converter systems, and a control board. As shown in Fig. 6, the SPIM used in the experiments is based on the Capacitor-Start Capacitor-Run starting method. The full-bridge PWM inverter is implemented by the IGBT modules with a switching frequency of 5 kHz. The control algorithm is performed by a digital signal processor (DSP) control system. Fig. 7 shows the experimental results of the SPIM when applying the proposed soft starting algorithm. When running the initial startup, the room temperature is -60 [°C]. The variable and constant resonant frequencies are used to verify the proposed algorithm. Each algorithm is tracking well with the starting current command as shown in Fig. 7. Fig. 8 demonstrates the experimental waveforms according to the variation of the room temperature from -60 [°C] to -40 [°C] without/with the starting and mode transition algorithms. The proposed starting and mode transition algorithms are steadily tracking as shown in Fig. 8.

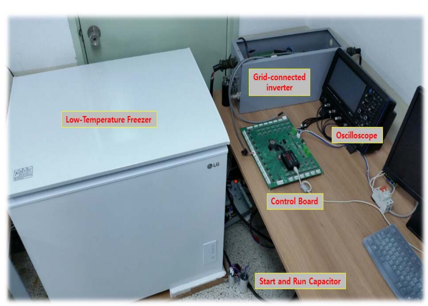
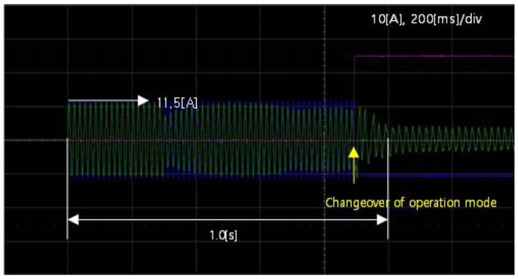
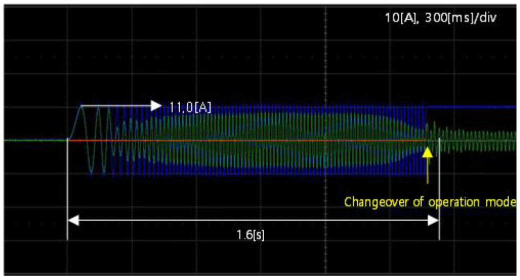


Fig. 6. Photograph of SPIM driving system.

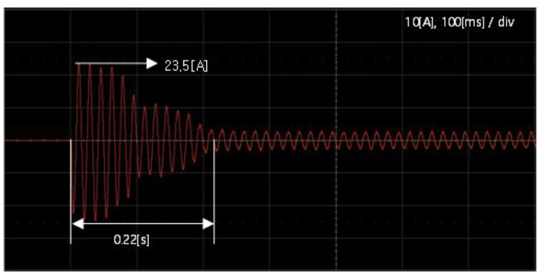


(a)

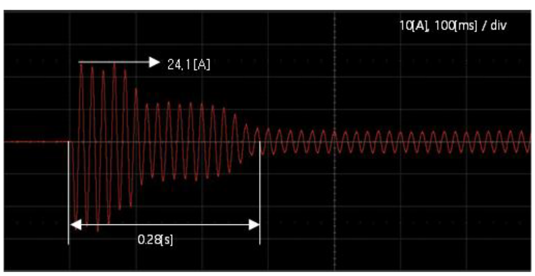


(b)

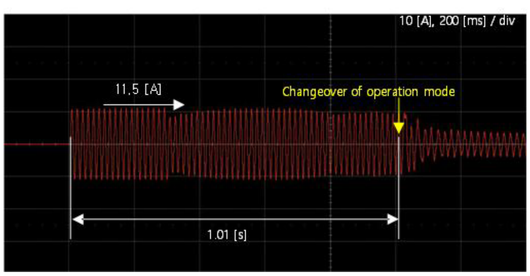
Fig. 7. Experimental results of SPIM. (a) with CFPR control. (b) with VFPR control.



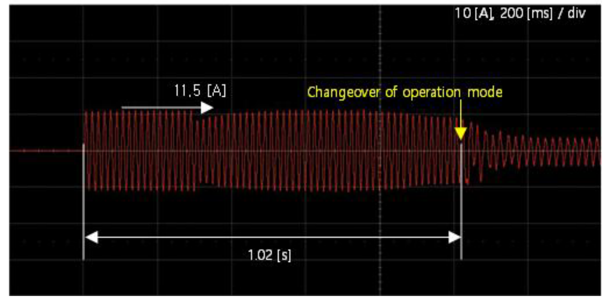
(a)



(b)



(c)



(d)

Fig. 8. Experimental results of SPIM. (a) without soft starting(RT:-60°C). (b) without soft starting(RT:-40°C). (c) with soft starting(RT:-60°C). (d) with soft starting(RT:-40°C).

IV. Conclusions

This paper presents a new soft starting algorithm based PR current controller for ultra-low temperature freezer. In addition, the mode transition algorithm is proposed to generate a constant voltage and constant frequency (CVCF). In order to verify and realize the SPIM system, a ultra-low temperature freezer has been built and its control system is proposed. A constant frequency proportional resonant (CFPR) and variable frequency proportional resonant (VFPR) current controller was applied for the starting reduction of the SPIM. The effectiveness of the proposed control system is verified by the experimental results used in the SPIM.

Acknowledgment

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