Soft Starting Control of Single-Phase Induction Motor Using PWM AC Chopper Control Technique

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Abstract — This paper presents a soft starting control scheme of a capacitor start and run type single-phase induction motor(SPIM) using a PWM AC Chopper control technique to control an amplitude of the motor starting current. The actual current of the motor during start up is used as a feedback signal for comparing with a setting value. The error, then, is sent to a PI controller. The output of the PI controller is compared with a carrier to generate a PWM signal. The MATLAB/Simulink is used for simulations. The results of the simulations are the amplitude of the motor starting current in accordance with the setting value which is around 150-200% of the rated motor current, the energy consumption during the start up and the ripples in the electromagnetic torque. It is found that the control scheme proposed in this paper is effective and can be considered as an alternative in a starting method for SPIM.

I. INTRODUCTION

Single-phase induction motors (SPIMs) are widely used for driving mechanical loads in many industrial and manufacturing processes. Usually, when a SPIM is started by a direct on-line starting method, the motor starting current can be around 500-700% of the motor full-load current, which can cause an abnormal operation to electrical systems and mechanical systems. An auto-transformer is used for reducing a voltage magnitude which is supplied to a single phase induction motor as one of motor starting methods to limit a starting current [1]. However, there are a number of limits in auto-transformer starting method such as costs and sizes. In some of industrial processes or applications, reduced-voltage starters, or the so-called soft starters, are employed as effective and low-cost means of reducing high starting currents through the use of thyristor-based voltage control or phase control technique[1,2]. However, this technique affects the output voltage and current waveforms due to high distortion and low power factor. Currently, a PWM AC chopper technique has become interesting for researchers as an alternative since the technique can overcome those problems associated with the conventional thyristor-based voltage control [3].

In this paper, the simulations of a single phase induction motor operation with a PWM AC chopper using MATLAB/Simulink are given. The main power circuit, shown in Fig.1, consists of two bidirectional switches. The advantage of this topology is easy to control due to less count of switches compared with other topologies. A soft-starting control of the capacitor start and run type SPIM using the PWM AC chopper control technique by a close-loop current control is discussed. The motor starting current is limited at 150-200% of rated current. The scheme proposed in this paper is called "With Starting Current Control (WSCC)", and the comparison of performances with two widely used techniques which are "Without Starting Current Control (WOSCC)" and "Direct On-line Control (DOC)" are shown respectively.

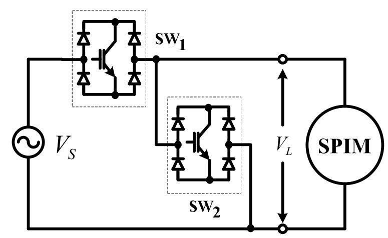

Fig. 1. A main power circuit of a PWM AC chopper for a soft-starting control.

II. THE CHARACTERISTIC OF SPIMS

A capacitor start and run type SPIM is also called two-value capacitor motor. The motor consists of two stator windings which are a main winding and an auxiliary winding, with a centrifugal switch as shown in Fig.2

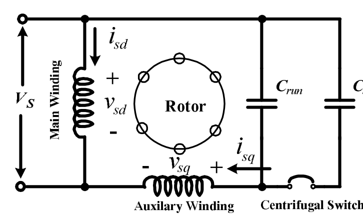

Fig. 2. A Schematic diagram of a capacitor start and run type SPIM.

The capacitor-start is connected in series with the centrifugal switch and the auxiliary winding. The function of capacitor-start is to build-up the motor staring torque. When the motor speed reaches to 75% of synchronous speed, the capacitor-start is disconnected by the centrifugal switch. The function of capacitor-run is to build-up the motor running torque and to improve the performance of a SPIM. The

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instantaneous electromagnetic torque produced by a SPIM is then given by [4]:

$$T_e = \frac{P}{2}\frac{L_{mq}}{L_r}\left(\lambda_{rd} \cdot i_{sq} - \lambda_{rq} \cdot i_{sd}\right) \qquad (1)$$

where, P, L_{mq} and L_r are the machine poles, the stator mutual inductance and the rotor self inductance, respectively. λ_{rd} and λ_{rq} are d-q axis of rotor fluxes. i_{sd} and i_{sq} are d-q axis of stator currents in the stator reference frame.

The torque-speed characteristics of SPIMs with variable voltages as shown in Fig.3 to find that the starting current and the staring torque are decreased. Therefore, the soft-starting control is aimed at varying the voltage supplied to the motor.

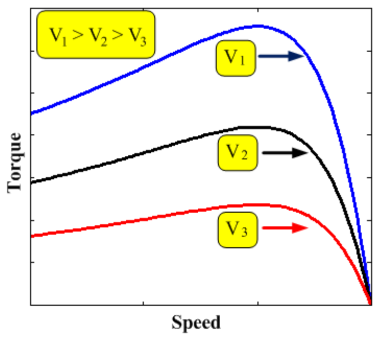

Fig. 3. Torque-speed characteristics of SPIMs with variable voltage.

III. THE CONCEPTS OF SOFT STARTING CONTROL.

The bidirectional SW_1 and SW_2 as shown in Fig.1 are controlled by T_{on} and T_{off}. A duty ratio (D) can be expressed as (2). Then, the fundamental voltage supplied to the motor can be derived as (3) [3].

$$D = \frac{T_{on}}{T_s} = \frac{T_{on}}{T_{on} + T_{off}} \qquad (2)$$

$$V_{L_1}(t) = D \bullet V_m \, Sin(\omega t) \qquad (3)$$

The motor voltage can be varied by controlling the duty ratio of a PWM signals to turn-on and turn-off bidirectional SW_1 and SW_2. Both switches is alternately operated.

The generating scheme of the PWM signals without a close-loop signal from the motor starting current is shown in Fig.4. This is called "Without Starting Current Control (WOSCC)" technique.

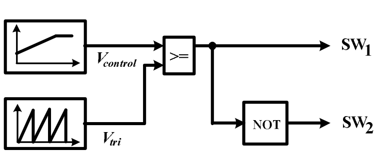

Fig. 4. The generating scheme of the PWM signals using WOSCC technique.

The duty ratio (D) is controlled by a voltage control signal ($V_{control}$) to follow the ramp time which is compared with a carrier (V_{tri}) to generate the PWM signals to control bidirectional switches as shown in Fig.5. In the initial condition, the width of SW_1 signal is narrow. After that, when the value of $V_{control}$ increases, the width of SW_1 signal increases too. Therefore, the voltage supplied to the motor and the motor current is gradually increased.

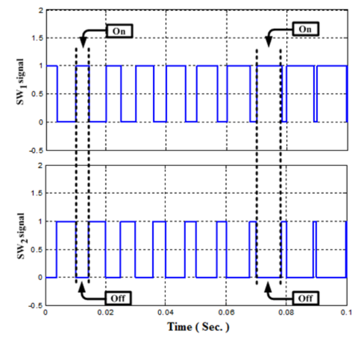

Fig. 5. PWM signals for control SW_1 and SW_2.

For the control scheme proposed in this paper, the actual current of the motor during a start up process is used as a feedback signal to be compared with the current reference or the setting value. Then, the error is sent to a PI controller. The output of the PI controller is compared with the carrier to generate the PWM signals. The motor starting current is limited at 150-200% of the motor rated current, this technique is called "With Starting Current Control (WSCC)"

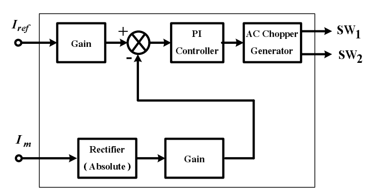

Fig. 6. The generating scheme of PWM AC Chopper with starting current control.

IV. SIMULATION CIRCUITS

In this paper, a capacitor start and run type SPIM with 220 V, 50 Hz, 2 poles,4 HP , 10.4 A , 1,450 rpm , Cstart = 150 μF, Crun = 21.5 μF is used in simulations. A switching frequency in the PWM AC Chopper control technique is set at the value of 2 kHz. The simulation circuits are constructed on MATLAB/Simulink as shown in Figs. 7 and 8.

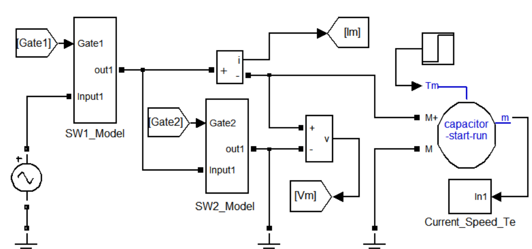

Fig. 7. The simulation block of the main circuit.

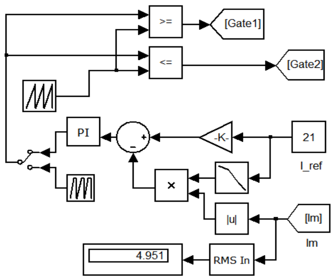

Fig. 8. The simulation block of the proposed feedback control circuit.

V. Simulation Results

When the motor is operated at a no-load condition, the results from simulations are shown in Figs.9-11. The motor starting current using the DOC technique is very high about to 70 A. of a peak value, but when using the WOSCC technique, the current is gradually increased and lower than DOC technique. While, the starting currents using the WSCC technique are limited in accordance with the setting values (150% and 200% of the motor rated current). The current is lower than those of the DOC and of the WOSCC technique as shown in Fig.9. The ripple of electromagnetic torques using the WOSCC and the WSCC technique are decreased as shown in Fig. 10.

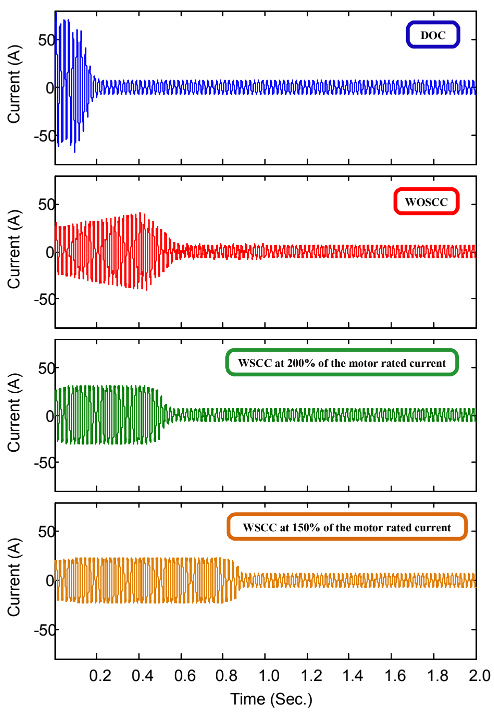

Fig. 9. The comparison of the motor current using DOC, WOSCC and WSCC technique.

It is also found that WSCC technique can have an effect in reducing the energy consumption of the motor during the starting up process. The comparison of the energy consumed among the WOSCC, the WSCC and the DOC techniques are as shown in Fig. 11. It is found that the setting value employed in the WSCC technique has an effect in energy consumption of the motor. The WSCC technique with a setting value of 150% of the rated current draws less energy that that due to the setting value of 200% of the rated current. The WSCC technique with the setting value of 200% of the rated current also gives the higher energy consumption that the energy drawn by WOSCC technique. It is, Taken into account for the WSCC technique to designate a proper setting value in term of the energy consumption reduction.

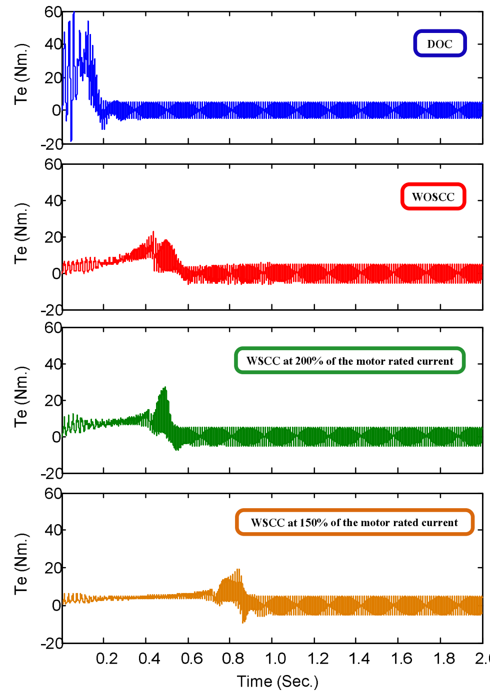

Fig. 10. The comparison of the electromagnetic torques using DOC, WOSCC and WSCC technique.

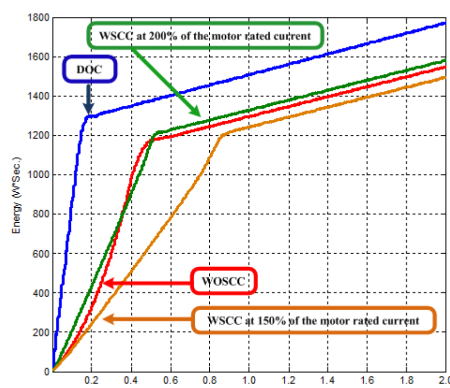

Fig. 11. The comparison of the energy used for starting the motor using DOC, WOSCC and WSCC technique.

It is also, important to consider the on-load condition of the motor during the starting up process. When the motor operates at 2 Nm on-load condition, the results in terms of starting current, energy consumption and torque ripples are shown in Figs. 12-14. It is found that the motor takes the starting up time longer than that required in the no-load condition. The WOSCC technique is still able to keep the amplitude of the starting current depending on the setting values. However, the energy drawn by the motor is changed due to the variation in the starting up time. As a result, the load must be considered into the WOSCC scheme so that the most appropriate setting value can be determined.

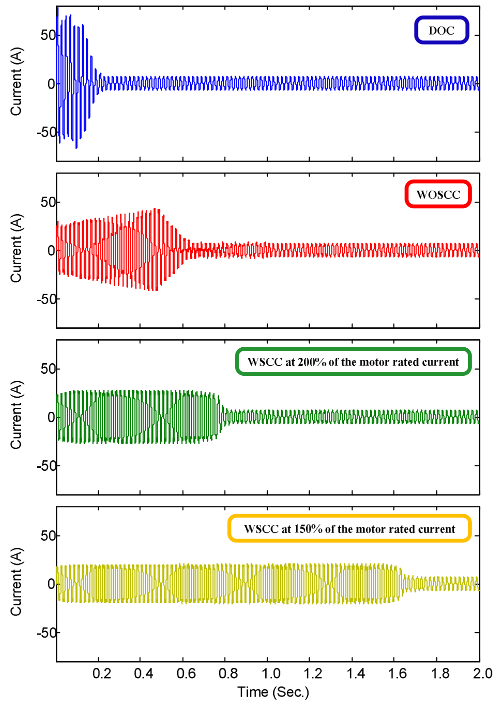

Fig. 12. The comparison of the motor current using the DOC, WOSCC and WSCC technique (load torque 2 Nm).

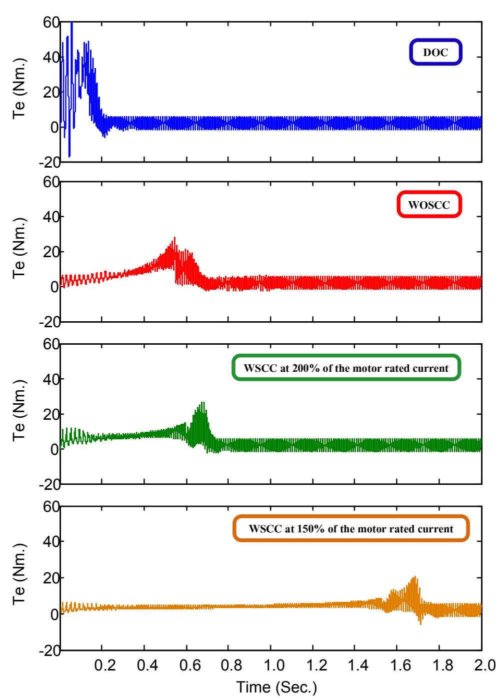

Fig. 13. The comparison of the electromagnetic torque using DOC, WOSCC and WSCC technique (load torque 2 Nm).

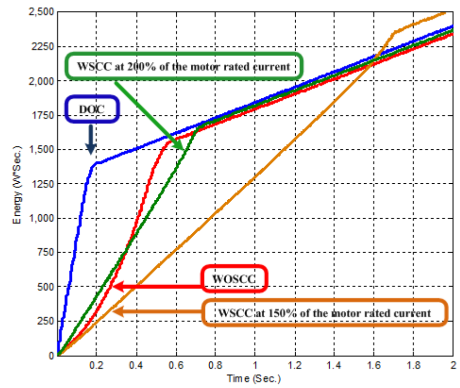

Fig. 14. The comparison of the energy used for starting the motor using DOC, WOSCC and WSCC technique (load torque 2 Nm).

VI. Conclusions

The scheme which is called "With Starting Current Control (WSCC)" employed in a soft staring with PWM AC Chopper control for a single phase induction motor has been presented. The technique is to adjust the duty ratio for control bidirectional switches in order to control the amplitude of the motor starting current with a feedback signal. Computer models have been constructed and implemented on MATLAB/Simulink to illustrate the capability of the WSCC technique. It has been found that the WSCC technique is able to control the starting current of the motor depending on the setting values. Comparing with the WOSCC technique, the WSCC scheme with a proper selection of the setting value is able to reduce the maximum amplitude of the motor starting current. In addition, the WSCC technique has shown that the energy consumed by the motor during the starting process with no-load condition is less comparing with the direct online starting method. The hardware control on the basis of a microcontroller board is being developed, so that experimental results will be obtained in order to verify the WSCC technique.

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