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Modular Cascade Inverter Techniques for an Induction Motor with Speed Sensorless Start-Up Method

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Abstract: *A modular multilevel cascade inverter based on double star chopper cells (MMCI-DSCC) has been expected as one of the next generation medium voltage multilevel pulse width modulation (PWM) inverters for such motor drives. For the sake of simplicity, the MMCI-DSCC is referred to as the "DSCC" in this paper. Each leg of the DSCC consists of two positive and negative arms and a center tapped inductor sitting between the two arms. Each arm consists of multiple bidirectional dc/dc choppers called as "chopper cells." The low voltage sides of the chopper cells are connected in cascade, while the electrically floating high-voltage sides of chopper cells are equipped with a dc capacitor and a voltage sensor. A synergy effect of lower voltage steps and phase shifted PWM leads to lower harmonic voltage and current, as well as lower EMI emission, as the count of cascaded chopper cells per leg increases. The power conversion circuit of the DSCC is so flexible in design that any count of cascaded chopper cells is theoretically possible.*

When a DSCC is applied to an ac motor drive, the DSCC would suffer from ac voltage fluctuations in the dc capacitor voltages of each chopper cell in a low speed range, because the ac voltage fluctuation gets more serious as a stator current frequency gets lower. Hence, the fluctuation should be attenuated satisfactorily to achieve stable low speed and start up performance. Several papers have exclusively discussed startup methods for DSCC based induction motor drives.

Keywords: *Total Harmonic Distortion, Medium voltage induction motor drives, minimal stator current, modular multilevel cascade inverters, speed sensorless startup method.*

1. INTRODUCTION

Induction motors are the most widely used electrical motors due to their reliability, low cost and robustness. However, induction motors do not inherently have the capability of variable speed operation. Due to this reason, earlier dc motors were applied in most of the electrical drives. But the recent developments in speed control methods of the induction motor have led to their large scale use in almost all electrical drives. The importance of multilevel inverters has been increased since last few decades. These new types of inverters are suitable for high voltage and high power application due to their ability to synthesize waveforms with better harmonic spectrum and with less Total Harmonic Distortion (THD). Numerous topologies have been introduced and widely studied for utility of non-conventional sources and also for drive applications.

Cascade Multilevel Inverter (CMLI) is more recent and popular type of power electronic converter that synthesizes a desired output voltage from several levels of dc voltages as inputs. If satisfactory number of dc sources is used, a nearly sinusoidal voltage waveform can be synthesized. CMLI offers several advantages such as, its capabilities to operate at high voltage with lower dv/dt per switching, high efficiency and low electromagnetic interference [EMI].The Proposed system is a MMCI (modular multilevel cascaded inverter) –DSCC (double star chopper cell) based induction motor drive, in which the motor starts rotating from standstill to middle speed with a ramp change. This motor drive is suitable, particularly for an application to a fan or blower-like load. This proposed motor-speed control of an induction motor is similar to the conventional "volts-per-hertz" and "slip-frequency" control techniques, but different in terms of combining the two control techniques together. The motor-speed control is based on "feedback" control of the stator current, which is the same as that in the slip-frequency control, whereas the commands for the amplitude and frequency of the stator current are based on "feed forward" control in consideration of a speed-versus-load-torque characteristic. Thus in this system, speed sensor is not required. Also, this motor-speed control technique can be applied to any inverter with current sensors at the ac terminals. The idea is to design and develop a Simulink model of a capacitor voltage control system to verify that it can be useful to eliminate ac-voltage fluctuation in all the frequency range.

2. PROPOSED SYSTEM

2.1 Overall control block diagram for the start-up method

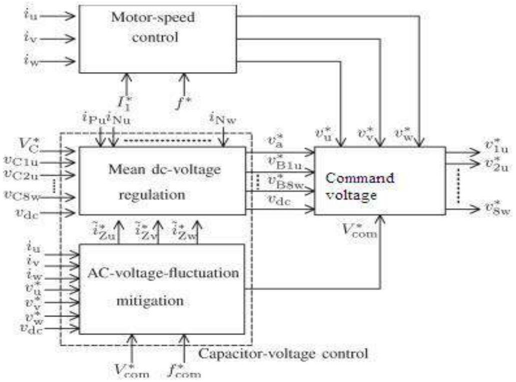


Fig .1. *Overall control block diagram*

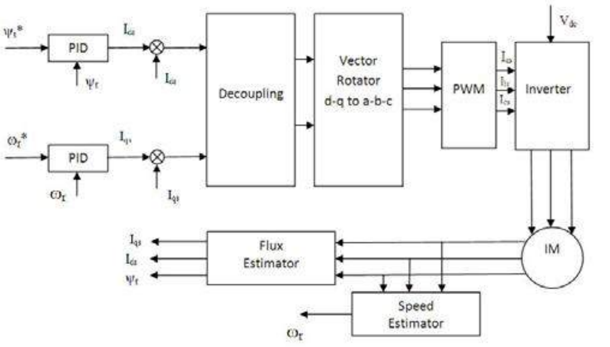


Fig 2: *Basic block diagram of sensorless control of induction motor*

2.2. Capacitor-Voltage Control

The proposed sysem two kinds of existing capacitor-voltage ontrol techniques for regulating the mean dcvoltage of each dc capacitor and for mitigating th ac-voltage fluctuation at the stator-current freqency. Fig. 3.1 shows the overall control block dagram of the start-up method. The 24 dc-capacitor voltages V_{Cjuvw}, the dc-link voltage v_{dc}, and the six arm currents i_{Puvw} and i_{Nuvw} are detected and they are input signals for the block diagram. Note that the three stator currents i_{uvw} are calculated from the detected arm currents. The mean dc-voltage regulation can be achieved by using the "arm" balancing control applied to the six arms and the "individual" balancing control applied to the one arm at the same time. The ac-voltage fluctuation can be mitigated by the sophisticated control discussed. This control interact the common-mode voltage v_{com}, which is injected to three centre-tap terminals of the DSCC with the ac components of the three circulating currents $\tilde{i}_{Zuvw}$. This can mitigate the ac voltage fluctuation at the stator-current frequency, thus leading to start up from standstill. As a result, the remaining ac-voltage fluctuations are independent of the time-varying frequencies of the stator current, but dependent on a fixed frequency of the injected common-mode voltage (50 Hz in this experiment). The circulating-current feedback control included in the mean dc voltage regulation block yields a command voltage of V_-^*.Finally command u-phase voltages for each chopper cell

(i.e. v_{ju}^*) are given as follows:

$$v_{ju}^* = v_a^* + v_{Bju}^* - \frac{v_u^* + v_{com}^*}{4} + \frac{v_{dc}}{8} \, (j = 1 - 4)$$

$$v_{ju}^* = v_a^* + v_{Bju}^* + \frac{v_u^* + v_{com}^*}{4} + \frac{v_{dc}}{8} \, (j = 5 - 8)$$

Here, V_a^* and V^*_{Bju} are used to regulate the mean dc voltage, V^*_u is the command motor voltage, V^*_{com} is the command common-mode voltage, and V_{dc} is the dc-link voltage used as feed-forward control. The command rms value of the common-mode voltage V^*_{com} should be set as high as possible to reduce the amplitude of each ac circulating current, because it is inversely proportional to V_{com}. Moreover, there is no relationship between common-mode voltage and power rating of the motor. In proposed system, switches over the two capacitor-voltage control techniques according to the stator-current frequency as follows.

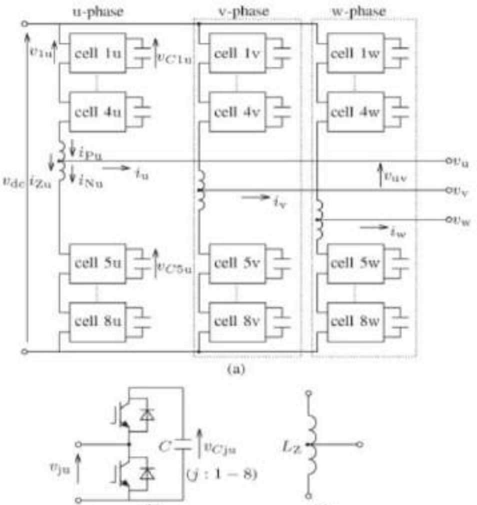
- In a low-speed range of f≤12Hz, the rms value of the common-mode voltage V_{com} and the ac circulating currents $\tilde{i}_{Zuvw}$ are controlled actively to mitigate the ac voltage fluctuation of each dc-capacitor voltage.
- When f≥20 Hz, neither V_{com} nor $\tilde{i}_{Zuvw}$ is superimposed, during a frequency range of 12≤f≤20Hz, v_{com}, and $\tilde{i}^*_{Zuvw}$ decrease linearly in their amplitude.

Note that the dc circulating current is used to regulate the mean dc voltage of each dc capacitor through all frequency range.

2.2 Circuit configuration for MMCI-DSCC

In this section we are going to discuss about configuration of proposed system, Fig. 2 (a) shows the main circuit configuration of the DSCC, Each leg consists of eight cascaded bidirectional chopper cells shown in Fig. 2 (b) and a centre tapped inductor per phase, as shown in Fig.2 (c). The centre tap of each inductor is connected directly to each of the stator terminals of an induction motor, where i_u is the u-phase stator current. The centre-tapped inductor is more cost effective than two non-coupled inductors per leg, because the centre tapped inductor presents inductance L_Z only to the circulating current i_Z and no inductance to the stator current i_u. It brings significant reductions in size, weight, and cost of the magnetic core. These advantages in the centre-tapped inductor are mostly welcomed, particularly applications to motor drives, in which no ac inductors are required between the motor and the inverter. In Fig.3.2 (a) instantaneous currents i_{Pu} and i_{Nu} are the u phase positive and negative-arm currents, respectively, and i_{Zu} is the u-phase circulating current defined as follows:

$$i_{Zu} == \underline{\Delta} \frac{1}{2} (i_{Pu} + i_{Nu})$$



Note that i_{Zu} includes dc and ac components to be used for the capacitor-voltage control. The dc component flows from the common dc link to each leg, while the ac component circulates among the three legs. The individual ac components included in the three-phase circulating currents $\tilde{i}_{Zu}$, $\tilde{i}_{Zv}$, and $\tilde{i}_{Zw}$ cancel each other out, so that no ac component appears in either motor current or d c-link current.

The arm currents i_{Pu} (positive phase current) and i_{Nu} (Negative phase current) can be expressed as linear functions of two independent variables i_u and i_{Zu} as follows:

$$iP_u = \frac{i_u}{2} + iz_u$$

$$iN_u = -\frac{i_u}{2} + iz_u$$

The dc-capacitor voltage in each chopper cell consists of dc and ac components causing an AC-voltage fluctuation. When neither common-mode voltage nor ac circulating current is superimposed, the peak-to-peak ac-voltage fluctuation ΔV_{Cju} is approximated as follows

$$\Delta vc_{ju} = \frac{\sqrt{2} I_1}{4\pi f C}$$

Where I_1 is the rms value of the stator current, f is the frequency of the stator current, and C is the capacitance value of each dc capacitor. According to, Δv_{Cju} is inversely proportional to f and proportional to I_1. Hence, Δv_{Cju} increases as the stator-current frequency decreases. Increasing the ac-voltage fluctuation is undesirable due to the following reasons,

- It affects the voltage rating of insulated-gate bipolar transistors.
- It causes over-modulation to each chopper cell.
- It makes the system unstable because the ac-voltage fluctuation can be considered as a disturbance to the control system.

Therefore, the ac-voltage fluctuation should be mitigated to an acceptable level.

2.3 Motor-Speed Control

This section describes a motor-speed control forming a feedback loop of three-phase stator currents for achieving a stable start-up of an induction motor. First, the motor-speed control is discussed in terms of a form and function. Second, it is compared with conventional motor-speed control techniques, i.e., "volts-per-hertz" and "slip-frequency" control techniques.

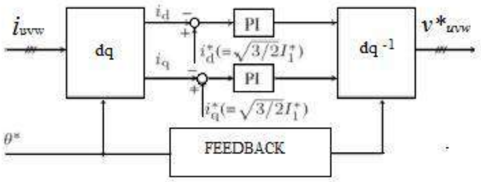


Fig.3. *Block diagram for the motor-speed control*

3. COMPARISON OF THREE MOTEOR SPEED CONTROL TECHNIQUE

Comparisons among the three motor speed control techniques, with a focus on similarity and difference. The"volts-per-hertz" control or shortly "V/f" control has two independent variables V_1 and f, in which V_1 is the stator voltage and f is the stator frequency. On the other hand, the two dependent variables are the stator current I_1 and the slip frequency f_s. The V/f control is a straightforward speed control requiring no speed sensor, which is based on feed-forward control of V_1 and f. However, both motor and DSCC may suffer from an over current during the start-up or when a rapid change in torque occurs. The slip-frequency control has two independent variables I_1 and f_s and the two dependent variables are V_1 and f. Here, the commands for I_1 and f_s are determined by a feedback loop of the motor mechanical speed, thus requiring a speed sensor attached to the motor shaft. The slip-frequency control can provide a faster torque response than the V/f control because of the existence of a feedback control for the motor mechanical speed. The motor-speed control proposed for the DSCC-based induction motor drive has two independent variables I_1 and f, and the two dependent variables are V_1 and f_s. Unlike the slip frequency control, the motor-speed control requires no speed sensor because the commands for I_1 and f, i.e., I_1^* and f^* are given not by feedback control, but by feed-forward control, as done in the V/f control. This implies that the motor speed control proposed system is inferior to the slip frequency control, in terms of torque controllability. However, it is applicable to a fan- or blower-like load, where the load torque is changing relatively slow and predictable Moreover, no over current occurs during the start-up, or when a rapid change in torque occurs, because of the existence of a feedback control loop of the stator current.

Table .1. *Comparisons motor-speed control technique*

	Volt-per-hrertz control	Slip frequency control	Propos Ed Motor Speed Control
Independ Ent Variables	$V_1$and f	I_1 and f_s	I_1 and f
Depende Nt Variables	I_1 and f_s	V_1 and f	V_1 and F
Voltage Control	Feedforward	-	-
Current Control	-	Feedback	Feedba Ck
Speed Sensor	NO	YES	NO

An energy saving during a start-up does not make a significant contribution to total energy saving performance from a practical point of view because the motor power in a low speed range is negligible in applications such as fan- or blower-like loads. This means that a comparison of the three methods, in terms of energy saving performance during a

start-up, does not make sense when fan- or blower-like loads are considered. Moreover, current stresses of the conventional motor-speed control techniques, the V/f and slip-frequency control, and the proposed motor-speed control technique are the same, at least, in a steady-state condition when a magnetizing current is set to the same value in all speed range.

3.1. Sensorless Speed Control

The schematic diagram of control strategy of induction motor with sensorless control is shown in simulink model. Sensor less control induction motor drive essentially means vector control without any speed sensor. The inherent coupling of motor is eliminated by controlling the motor by vector control, like in the case of as a separately excited motor. The inverter provides switching pulses for the control of the motor. The flux and speed estimators are used to estimate the flux and speed respectively. These signals then compared with reference values and controlled by using the PI controller**.** An incremental speed signal for an induction motor is essential for closed-loop speed control of scalar or vector drives. The signal is also needed for indirect vector control, and direct vector control if speed control is necessary from zero speed. A physical speed encoder mounted on the shaft adds cost and reliability problems to the drive, in addition to the need for a shaft extension for mounting it. In modern speed sensorless vector control, precision speed estimation from the machine terminavoltages and currents with the help of DSP is an important topic of research. The machine stationary frame (d-q) equations.

Torque and flux error is obtained, from which drive can decide either flux has to increase or decrease, also torque has to increase, decrease or remains constant. From the stator flux angle, sector will decided. gate pulses creates required signal which decouples the torque and flux from stator currents.

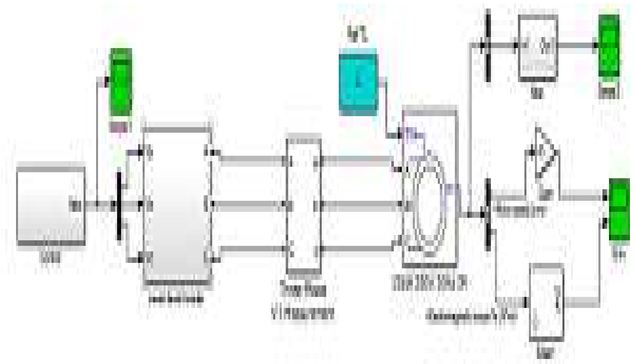
3.2. With Sensorspeed Control

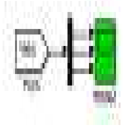
If we use speed sensor then time required to set the steady speed will be less shown in results compared in next part of report. But if we use speed sensor in hostile environment like effects of radiation, underwater operation, vacuum operation, and extremely high and low temperatures then there is discontinuity of work and other things so in hostile environment we should prefer this proposed scheme with speed sensor and decoder use having some drawbacks for hostile environment

- Requirement of shaft extension
- Reduction of mechanical robustness of motor drive
- Reduce the drive reliability

4. SIMULINK MODEL

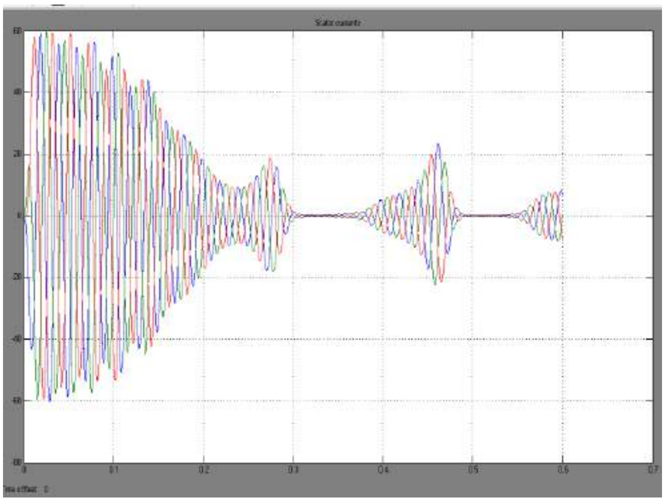
4.1. Speed Control without Sensor



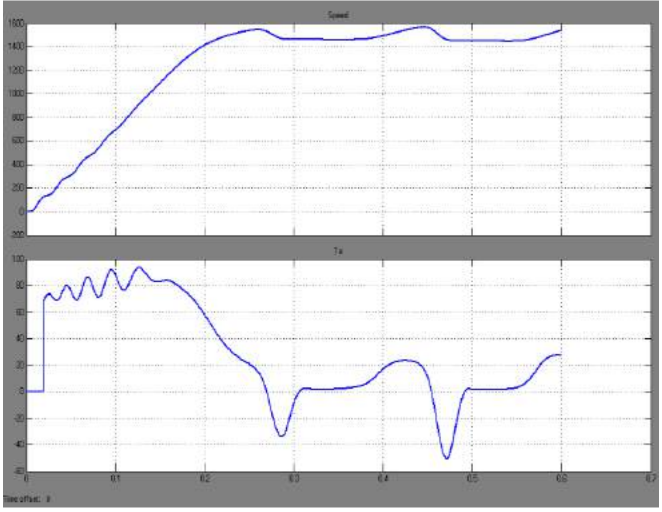


5. RESULTS

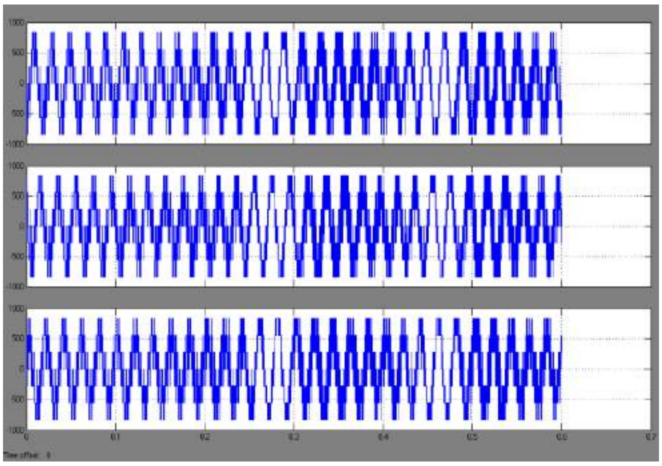
Stater Current



Speed and Torque



Inverter



6. CONCLUSION

The proposed start-up method for DSCC of an induction motor drive without speed sensor is from standstill to middle speed. This start-up method is characterized by combining capacitor-voltage control and motor-speed control. The motor-speed control with the minimal stator current under a load torque is based on the combination of feedback control of the three-phase stator currents with feed forward control of their amplitude and frequency. The arm-current amplitudes and ac-voltage fluctuations across each of the dc capacitors can be reduced to acceptable levels.This method is suitable particularly for adjustable-speed motor drives of large-capacity fans, blowers, and compressors for energy savings.

The main objective of MMCI for starting of I.M is to study per unit rise in the speed from standstill to middle speed in the without sensor. On the other hand using the sensor there is an overshoot to the rated speed in the first quarter of the response and it is not check in the staring performance.

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