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High Power Medium Voltage Applications With CSI-FED Induction Motor Drive

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Abstract: *This review introduces a new topology for Silicon Controlled Rectifier (SCR) -based current source inverter powered induction motor drives (CSIs) suitable for medium voltage (MV) drive applications. The requirement for forced commutation circuits was a major drawback of SCR-based CSI powered induction motor drives. The proposed drive uses an induction motor with an auxiliary low voltage winding isolated on the stator. The SCR converter is connected to the main winding of a medium voltage level motor. A small rated voltage source inverter (VSI) connected to the auxiliary winding injects the voltage required to ensure safe commutation of the SCR inverter. This allows the drive to operate over the full speed range without the need for additional external rectifier circuits. VSI also compensates for low frequency torque harmonics due to quasi-square wave CSI currents, ensuring a low ripple torque profile. The proposed drive has been experimentally validated using a 37.5kW, 1.65kV laboratory prototype with 400V auxiliary windings. In this highly active area, different converter topologies are being developed for different drive applications in the industry. This topic is extensively covered and is therefore divided into two parts. Multi-level voltage source and current source converter topology. This white paper focuses on Part 2 and describes current source inverter technologies such as pulse width modulated current source inverters (CSIs) and load commutation inverters. In addition, this article describes the current status of cycloconverters, also known as cycloconverters (CCVs). This white paper focuses on the latest CSI and CCV technologies and provides an overview of commonly used modulation schemes. It also introduces the latest technological advances and future trends for large drives with CSI and CCV.*

Keywords: (CSI) Current Source Inverter, VSI (Voltage Source Inverter), SCR (Silicon Controlled Rectifier) etc..

I. INTRODUCTION

Current Source Inverter (CSI) fed drives are well suited for high-power, medium voltage industrial drive applications. Inherent regeneration capability, greater reliability, motor friendly waveforms and the absence of voltage doubling effects in long cable applications are some of their important advantages [1]–[4]. CSI fed drives currently employed in industry can be generally classified into two types depending on the type of switching device used.

PWM-CSI fed drives employing devices with gate turn-off capability like IGCTs or

SGCTs are mostly used in conjunction with induction motors. Silicon Controlled Rectifier (SCR) based Load Commutated Inverter (LCI) drives are typically used with synchronous

motors. Despite the rapid advancements in the field of power devices, the SCR based LCI fed synchronous motor drive is still one of the most popular options for large power drives,

especially in fan and pump type applications. This is mainly due to the greater simplicity, ruggedness, efficiency and low cost features of the SCR converter [5]. But the LCI requires

a leading power factor at its terminals for reliable operation, and hence it is conventionally used only in synchronous motor drives. However, considering the better ruggedness and lower cost features of induction motors compared to synchronous motors, several topologies for SCR converter based induction motor drives have been reported in literature.

The use of forced commutation circuits that use additional capacitors and auxiliary thyristors [6]–[8] to realise SCR inverter based induction motor drives have long lost their popularity, due to the reduced reliability. SCR inverter fed induction motor drives using shunt capacitor banks to obtain an overall leading power factor operation so as to enable load commutation have been reported in literature [9]–[11].

Though these drives work well for low power drives, the requirement of large bulky capacitors are a major disadvantage at higher power and medium-voltage levels. Also, the capacitors can introduce unwanted resonant oscillations in association with the machine inductances.

Current source inverter (CSI) based drive is widely used in high power applications due to its high reliability, inherent short circuit protection and regenerative capability. CSI employs two-quadrant switching devices with bidirectional voltage blocking capability. Silicon controlled rectifier (SCR) of thyristor family is the most preferred choice for high power CSI-fed drives due to its rugged nature and for its availability in high voltage and current ratings. But SCR being a semi-controlled device, it requires forced commutation circuit for its turn OFF in most of the applications.

When operated at leading power factor SCRs in CSI can be turned OFF through load commutation. Hence, SCR based CSI is very popular in synchronous motor drive as the load commutation can be performed by operating the synchronous motor at leading power factor through over-excitation. This configuration has a strong presence in high power applications ranging (>10 MW) few megawatts to hundreds of megawatts, due to its advantages like high efficiency and easy four quadrant operation [1]–[4]. However, low speed operation of load commutated CSI fed synchronous motor is still a challenge as the motor back EMF would be insufficient for its natural commutation [5]. So it is a practice in the industry to operate the SCR based CSI in pulsed mode at low speeds, but it results in large torque pulsations [6].

II. LITERATURE SURVEY

In [2011], CSI-equipped drives currently being deployed The industry can be broadly divided into two types based on the type of switching device used. PWM CSI drive drives that use devices with gate turn-off capabilities such as IGCT and SGCT are primarily used in combination with induction motors. Load rectifying inverter (LCI) drives based on Silicon Controlled Rectifiers (SCRs) are typically used in synchronous motors. Despite rapid advances in the field of power devices, SCR-based LCI powered synchronous motor drives remain one of the most popular options for large power drives, especially in fan and pump applications. This is primarily due to the higher simplicity, robustness, efficiency, and lower cost features of the SCR converter.

In [2015], indirect converters can be divided into voltage source and current source topologies, depending on the energy storage component of the intermediate circuit. Voltage source converters typically use DC capacitors in DC intermediate circuits, while current source converters use DC inductors (choke) in DC circuits. Current Source Inverter (CSI) technology is ideal for high power propulsion.

In [2016], CSI can be broadly divided into pulse width modulation (PWM) CSI and load commutation inverter (LCI). The former uses a symmetric gate turn-off (GTO) or integrated gate-commutated thyristor (IGCT) as the switching device, and the latter inverter uses a silicon controlled rectifier (SCR) device. In general, current source converters have a simple converter structure, a small number of switches, low switching dv / dt, and reliable overcurrent / short circuit protection, as summarized in Table I. The main drawback is the limited dynamic performance due to the use of large DC chokes. High power CSI drives in the megawatt range are widely used in the industry. In recent years, it is estimated that at least 700 large CSI drive drives are produced each year worldwide.

In [1999-2005], multi-level current source inverters can significantly improve the quality of motor current and reduce torque pulsation. In addition, multi-layer configurations can improve system reliability by reducing device rated current requirements and introducing redundancy.

In [2017], induction motors (IMs) are the industry favorite due to their high reliability, robustness, and low cost. However, thus load commutation SCR-based CSI cannot be used for induction motor drives because the motor operates with a delayed mpower factor (PF). Various schemes have been proposed in the literature to achieve load commutation in CSI-driven induction motor drives. Some of them are hybrids that use SCR-based CSI with a voltage source inverter (VSI).

III. MODELLING AND ALGORITHM

A new topology for SCR-based CSI powered AC drives with an inducer with two stator windings, an MV rated main winding, and an additional small auxiliary low voltage winding on the stator. A low voltage, low power VSI is

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connected to the auxiliary winding. The SCR-CSI is connected to the main winding terminal and operates in 6 pulse mode. The function of VSI is to support SCR rectification by applying the selected active vector.

Connect to the auxiliary winding during a short SCR turn-off time to ensure proper rectified voltage is induced between the main winding terminals. The main features of the proposed drive are listed below.

1. Since SCR commutation does not depend on leading power factor operation, the proposed method of CSI can supply both real and reactive power to the drive.
2. The VSI connected to the LV auxiliary winding does not supply active or reactive power to the drive, so the VSI's power rating is very low.
3. The VSI can inject harmonic currents to compensate for some of the low frequency torque ripple caused by the CSI, resulting in a smoother torque profile.

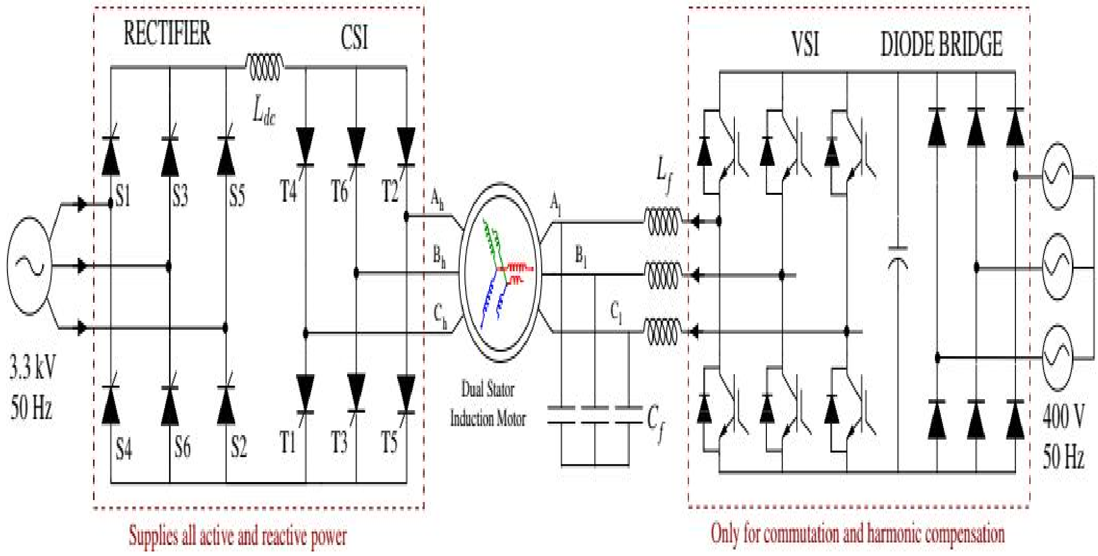

Fig . 3.1 Power topology of the proposed drive

Figure 3.1 shows the power structure of the proposed drive. Ah, Bh, Ch indicate the main winding terminal of the machine's MV rating. These are supplied by a medium voltage based SCR

CSI operates in 6 pulse mode. The input DC power to the CSI is obtained using another SCR-based 6-pulse converter that acts as a rectifier with an output DC link inductance. DC

The link inductance helps to provide the CSI with a low ripple input current. Both converters are built using converter quality SCR equipment with the appropriate RC snubbers. Al, Bl, Cl. It is a terminal of the low voltage auxiliary stator winding. These are powered by a low power IGBT-based VSI with a front-end diode bridge rectifier connected to a low voltage delivery. An output LC filter with the corresponding passive or active damping [22], [23] is connected to the output of the VSI. The LC filter removes the switching frequency harmonics from the VSI output and provides a nearly sinusoidal voltage to both winding terminals of the machine.

Space phasor equivalent circuit in the stationary frame:

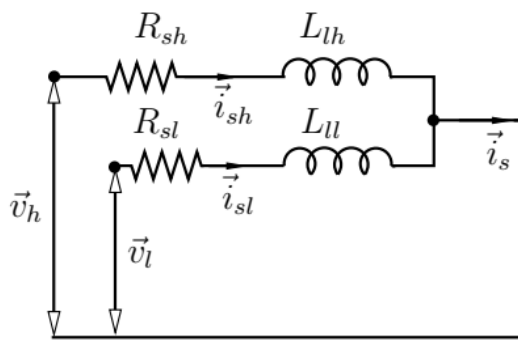

Fig. 3.2 Space phasor equivalent circuit in the stationary frame

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Figure 3.2 above shows a spatial vector equivalent circuit model of a machine in a quiescent frame with all NS winding sizes relative to HV windings. This model will help you analyze the proposed rectification scheme described in the next subsection. The rotor circuit of the model is the same as the rotor circuit of the conventional induction motor model.
On the stator side, Rsh and Rsl indicate stator resistance, and Llh and Lll indicate the self-leakage inductance of the HV and auxiliary LV windings, respectively. Llm represents the mutual leakage inductance between the HV winding and the LV winding, Rr and Llr represent the rotor resistance and leakage inductance, and Lm represents the magnetization inductance. ~ Yr indicates the rotor flux vector, and w indicates the rotor velocity. In the high frequency equivalent circuit diagram in Figure 3.3, the resistors Rsh, Rsl, Rr, and main inductance Lm are negligible.

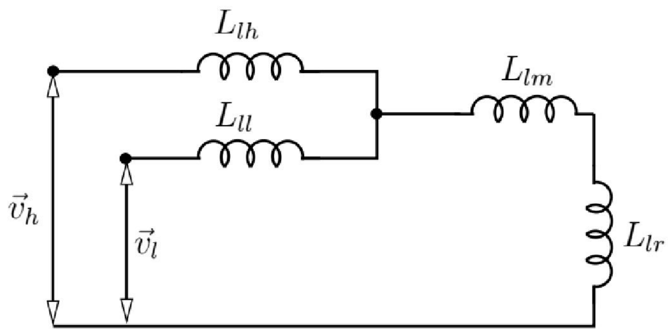

Fig.3.3 High frequency equivalent circuit

The equivalent commutation inductance Lc can then be written as

$Lc = Llh + (Lll\backslash\backslash(Llm + Llr))$ (1)

Also, for an applied voltage ~vl at the LV winding, the induced voltage at the HV winding is obtained as,

$$\vec{v}_h = \frac{L_{lm} + L_{lr}}{L_{ll} + L_{lm} + L_{lr}} \vec{v}_l = k\vec{v}_l \quad (2)$$

The self leakage inductance Lll is usually much smaller than Llm +Llr such that value of k is usually greater than 0.8. To understand the active vector based commutation technique.

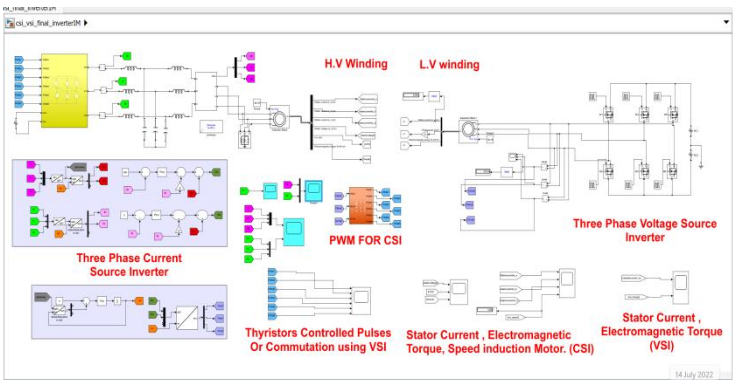

Fig. 3.4 Complete control simulation diagram of the proposed drive topology

The proposed drive is controlled using a rotor-flux oriented vector control technique. The control architecture is developed

$$\begin{aligned} i_{hd} + i_{ld} &= i_{mr} + \tau_r \frac{di_{mr}}{dt} \\ \omega_{slip} &= \frac{i_{hq} + i_{lq}}{\tau_r i_{mr}} \\ M_d &= \frac{P}{2}\frac{L_m^2}{L_r} i_{mr}(i_{hq} + i_{lq}) \end{aligned}$$

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whereihd, ihq and ild, ilq are the d and q axes current components of the HV and LV windings respectively. Imr denotes the rotor flux magnetising current. tr and Lr are the rotor time constant and rotor inductance respectively. Md is the developed electromagnetic torque, P denotes the number of poles and wslip denotes the electrical slip speed.

IV. RESULT ANALYSIS

Simulation results of frequency converter rated speed operation at maximum rated load using VSI used for active switching and harmonic compensation. It can be observed that the peak current is drawn from the VSI during active switching. The phase voltage waveform is almost sinusoidal on both windings. It can be seen that the CSI's R-phase current lags behind the R-phase voltage, in contrast to the main power factor operation of traditional thyristor-based LCI powered drives. The LV winding current is also distorted and spiked due to the low harmonics injected by the VSI for compensation and active vector commutation techniques.

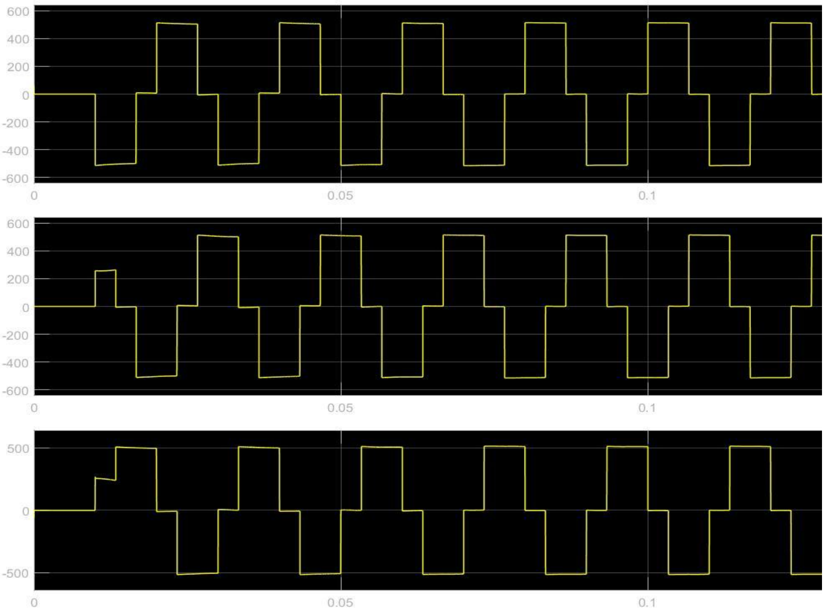

Fig. 4.1 Thyristors Controlled Pulses Or Commutation using VSI

The ability to commutate the SCRsat will using the VSI provides the self-starting capability to the drive, which is usually absent in conventional loadcommutated drives. The profile of the CSI current waveformis typical of a vector controlled drive with initial rated currentwhich settles to the steady state value as the speed settles. Theauxiliary winding current is mostly the harmonic componentsin addition to a current spike during each commutation.

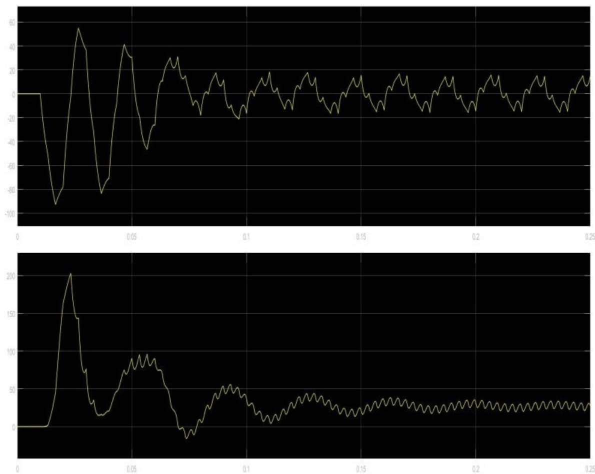

Fig 4.2 Stator Current , Electromagnetic Torque (VSI)

Dynamics of d-axis and q-axis currents at start-up

The drive diagram is shown in Figure 4.3 and Figure 4.4. The rotor magnetic flux is first accumulated at start-up and reaches the set value. The d-axis current of the HV winding has low frequency ripple due to the quasi-rectangular waveform. The d-axis current of the LV winding also shows ripple due to harmonic compensation and active vector switching, but the mean value remains zero because the VSI does not provide reactive power. The q-axis CSI current initially rises to provide the maximum rated starting torque and then subsides when the speed leveled off. The generated electromagnetic torque follows the same pattern as the rotor flux is kept constant. The q-axis current of the LV winding has harmonic currents and ripples due to active switching, but the average value is zero because this winding is not actually powered.

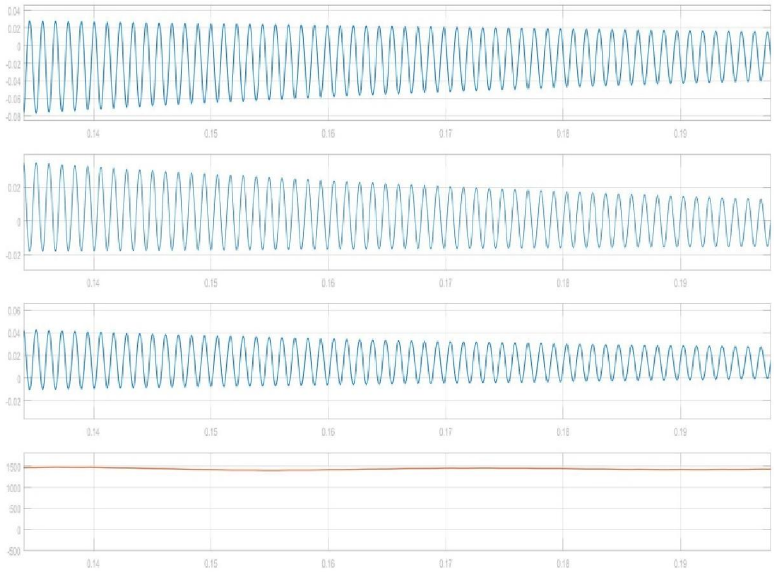

Fig. 4.3 Stator Current , Electromagnetic Torque, Speed induction Motor. (CSI)

Fig. 4.3 shows the steady state operation of the drive at 1500 rpm. The proposed method results in safe commutation even at such low speeds.

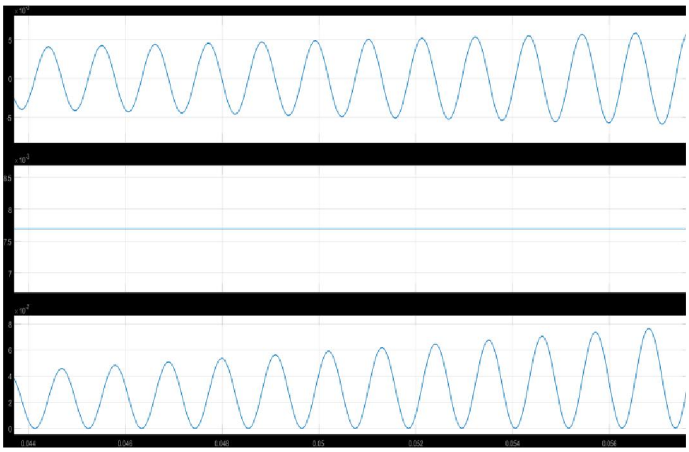

Fig.4.4 Stator Voltage, Inductance Lm, Electromagnetic Torque across Voltage source Inverter (VSI)

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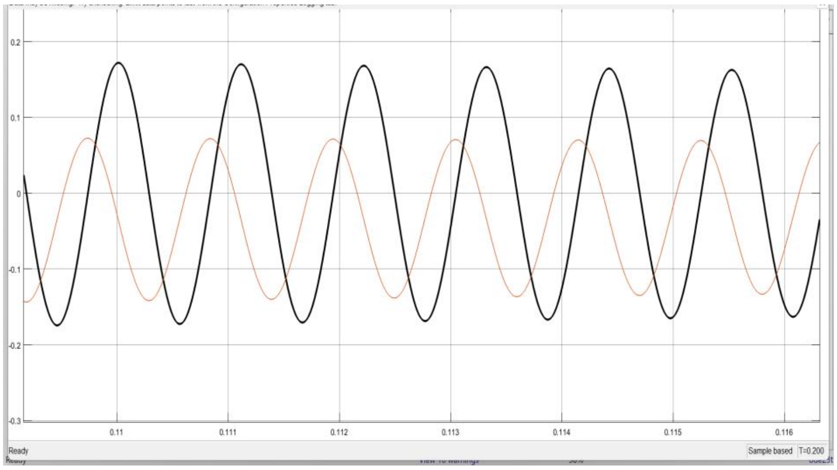

Fig.4.5 Inverter Voltage across the R phase and Current through the R phase.

VI. CONCLUSION

A new topology for csi powered induction motor drives with Scr converters for MS drive applications without the use of complex external forced commutation circuits. Effective commutation is achieved by using a small low voltage vsi connected to the low voltage and low power auxiliary windings of the stator. This drive also offers the benefit of reducing torque ripple by using vsi for harmonic torque compensation. Because the induced voltage at the csi terminal causes commutation, this drive combines the low cost and high efficiency benefits of a spontaneous commutation SCR converter with the robustness of an induction motor.

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