Performance of Multilevel Inverter Topologies for Closed Loop v/f Controlled Technology

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Abstract- **This study investigates the closed-loop control of an induction motor drive using a multilevel inverter and constant V/f method. Multilevel inverters generate stepped sinusoidal voltages with lower harmonic content as the number of levels increases. A five-level inverter is developed using Sinusoidal Pulse Width Modulation (SPWM) for both the traditional VSI and cascaded MLI. The inverter output, having minimal THD, is filtered to improve the quality of the sine wave.The induction motor is modeled using a step-by-step mathematical approach after receiving this filtered voltage. The speed of the motor is controlled by maintaining a constant V/f ratio, and a PI controller is used to ensure that the motor speed follows the reference value. The closed-loop system is tested under different speed references and varying load conditions. A performance comparison is carried out between MLI and VSI-based induction motor drives, analyzing factors like transient response, steady-state behavior, efficiency, and cost. MATLAB/SIMULINK is used for simulation and result validation..**

Key Words: **Multilevel Inverter, Closed-loop V/f Control, PWM, Speed Control, PID, Induction Motor, Motor Feedback**

INTRODUCTION

An electrical drive is a system that converts electrical energy into mechanical motion. These drives are essential in modern industries for precise control and energy savings. Induction motors are widely used due to their robustness and low cost. However, without a drive, maintaining stable speed under load changes becomes difficult. Drives help regulate motor speed and improve performance. Induction motors can be controlled using different methods, mainly classified into scalar and vector control. Scalar control adjusts only the magnitude of electrical quantities and is simpler to implement. It includes techniques like voltage control, frequency control, and V/f control. Among these, the V/f control method is most commonly used because it is easy to implement and suitable for many industrial applications. Control systems can be open-loop or closed-loop. Closed-loop systems are preferred because they provide better accuracy under changing loads. Induction motors typically receive power from inverters like Voltage Source Inverters (VSI) or Multilevel Inverters (MLI). While VSI produces a quasi-square wave output that includes harmonics, MLIs provide a more stepped and sinusoidal waveform with fewer harmonics. As the number of levels (m) in an MLI increases, harmonic content (h) decreases.

MLIs are mainly of three types: Cascaded H-Bridge, Diode Clamped, and Flying Capacitor. This research focuses on using a cascaded MLI for variable-speed industrial applications.

1. CASCADE MLI FED INDUCTION MOTOR

The induction motor speed control is achieved by adjusting the slip speed while maintaining a constant voltage-to-frequency (V/f) ratio. A Proportional-Integral (PI) controller is used to maintain the motor speed at a specified reference level. This closed-loop control strategy is evaluated under various reference speeds and dynamic load disturbances. A comparative analysis is carried out between multilevel inverter (MLI) and voltage source inverter (VSI)-fed induction motor drives in terms of transient response, steady-state behavior, system efficiency, and cost-effectiveness. The entire system is simulated using MATLAB/SIMULINK to verify the effectiveness of the proposed control method.

The three-phase induction motor, which requires a three-phase AC supply, is driven through a simplified cascaded multilevel inverter to limit starting current. This inverter operates with DC input voltages and uses power electronic switches—primarily IGBTs due to their superior performance—to generate AC output voltages. In the case of a five-level Cascaded H-Bridge Multilevel Inverter (CHBMLI), the output waveform consists of five discrete voltage levels: +2Vdc, +Vdc, 0, -Vdc, and -2Vdc. A basic diagram of this configuration is illustrated in Fig. 1.

To summarize, the number of output voltage levels from a multilevel inverter can be determined using the formula:

$m = (2 \times i) + 1,$

where i represents the number of independent DC voltage sources. Pulse Width Modulation (PWM) plays a critical role in the functioning of the circuit by precisely switching the IGBT devices at the correct times to generate the desired output.

Multiple PWM techniques are available for this purpose, including Space Vector Modulation (SVM), Selective Harmonic Elimination (SHE) — which often involves complex calculations — and Carrier-based PWM (CB-PWM). For applications where circuit compactness is a priority, CB-PWM is often the preferred method. In this approach, a reference sine wave is compared with a high-frequency triangular carrier signal to determine the switching states.. For m-leveled MLI, carriers must be (m-1)]. The different CB-PWMs are Phase disposition (PD), Phase Opposition Disposition (POD), and Alternate Phase Opposition Disposition (APOD).

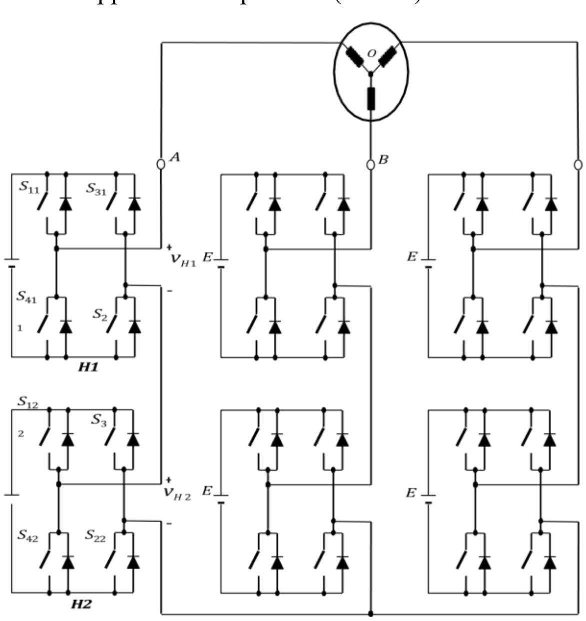


Fig. 1. Five level cascaded MLI

Closed control of MLI fed induction motor using V/f scheme

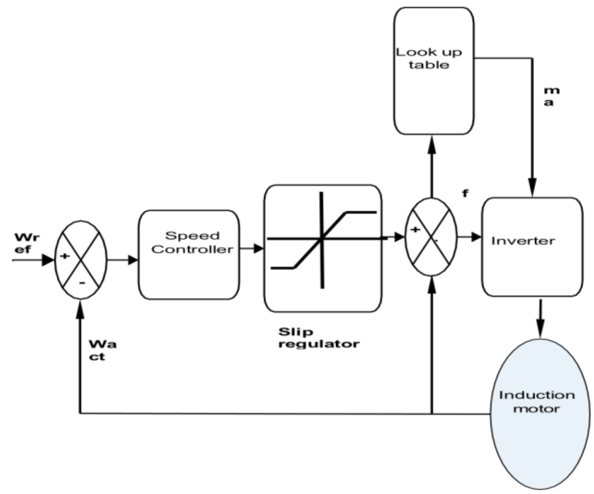


Fig. 4. Induction Motor closed loop speed control

The synchronous speed of an induction motor is given by the formula,

$Ns=(120*f)/p$

where represents the supply frequency and denotes the number of pole pairs. An increase in supply frequency or a reduction in the number of poles results in a higher synchronous speed. Conversely, lowering the frequency reduces the speed but leads to an increase in magnetic flux, which may cause core saturation and a rise in magnetizing current—ultimately leading to a drop in the power factor.

In the modeled system, the induction motor (IM) is represented using the reference frame and is powered by the AC output of either a Voltage Source Inverter (VSI) or a Multilevel Inverter (MLI), which is connected through a passive filter (L = 1.001 mH, C = 1000 μF). The motor's mechanical speed, denoted as , is monitored as the actual speed. A Proportional-Integral (PI) controller is employed in a closed-loop configuration, receiving the desired reference speed . The speed error, calculated as the difference between and , is processed through the proportional and integrator components. Careful tuning of the gains and is crucial, as inappropriate values can degrade control performance.

The controller output is directed to a slip regulator, which adjusts the slip to maintain stator current and torque within safe operating limits. This regulated slip is then added to the actual speed to determine the required frequency command. A pre-defined lookup table is used to convert this frequency into a corresponding voltage value by mapping it to a suitable modulation index, thereby modifying the amplitude of the reference waveform. This voltage signal is finally used to control the MLI-fed induction motor.

Expected Simulation results and analysis

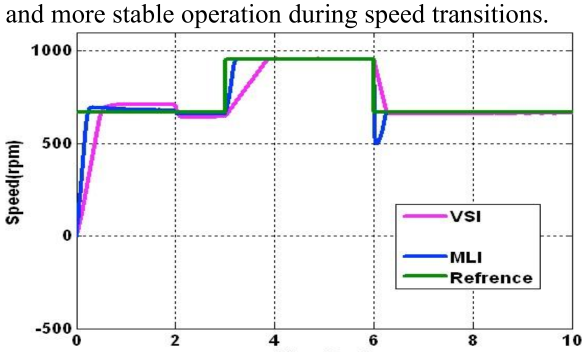
The closed-loop control system for the induction motor driven by a multilevel inverter (MLI) has been implemented and tested under two distinct operating scenarios:

1. Variable speed with constant torque
2. Constant torque with variable speed

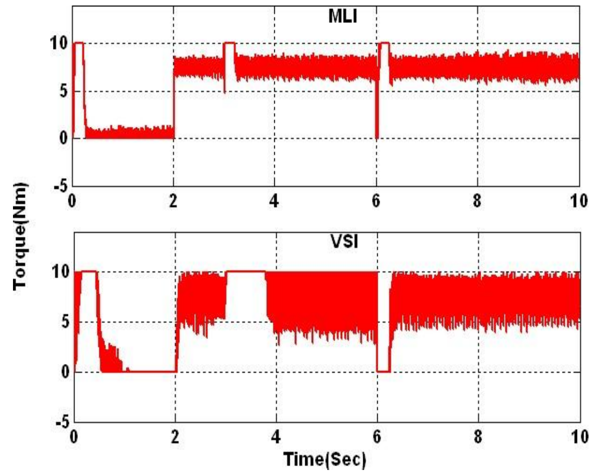
Reference Speed Variation

In this scenario, the induction motor operates under a constant load torque of 7.5 Nm. A step change is introduced in the reference speed from 670 rpm to 955 rpm at 4 seconds, followed by a return to 670 rpm at 6 seconds. The dynamic performance of the system is analyzed by observing the speed, torque, and stator current responses for both MLI and traditional VSI-fed drive systems, as shown in Figure 5.

From the simulation outcomes, it is observed that the MLI-fed drive exhibits enhanced performance over the conventional VSI-fed system. Notably, the MLI-based drive demonstrates a significant reduction in both torque and current ripples, indicating smoother and more stable operation during speed transitions.



a)



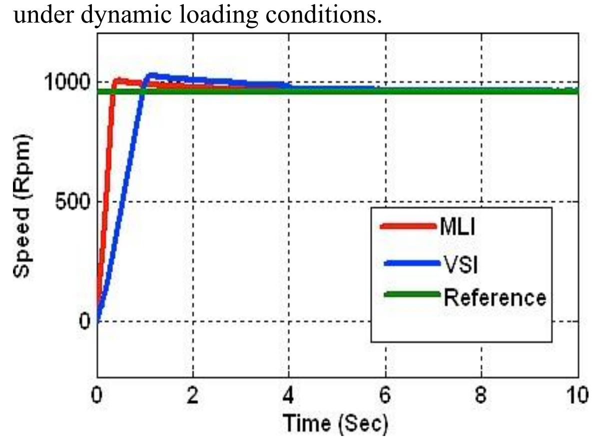
b)

Fig. 5. MLI and VSI fed drive responses for change in speed (a) Speed (b) Torque

Trapezoidal Load Torque Variation

In this test case, the induction motor is maintained at a constant speed while the load torque is varied in a trapezoidal pattern, ranging from 0 Nm up to 5 Nm. Figure 7 illustrates the resulting waveforms for speed, torque, and stator current for both MLI and VSI-based drive configurations.

The simulation results clearly highlight the advantages of the MLI-fed drive system. Compared to the traditional VSI-fed drive, the multilevel inverter approach offers improved performance, with noticeable reductions in both torque and current ripples. This leads to more stable motor operation under dynamic loading conditions.



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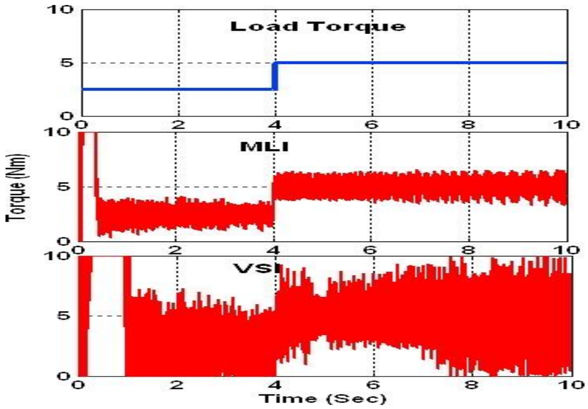

b)

Fig. 6. MLI and VSI fed drive responses for step change in load torque (a) Speed (b) Torque

CONCLUSION

A closed-loop V/f control system for an induction motor was successfully built using MATLAB/ SIMULINK. Traditionally, Voltage Source Inverter (VSI)-based drives are used in many commercial systems. However, they have some drawbacks like high torque and current ripples. To overcome these issues, a Multilevel Inverter (MLI)-based drive was developed with the same V/f control strategy. Both VSI and MLI-based drive systems were tested under various conditions, such as sudden changes in load and speed. The performance of both systems was carefully studied and compared. Results show that the MLI-fed drive performs better than the VSI-fed drive. In the MLI-based system, torque and current ripples are significantly lower, and the system reaches its stable operating point faster.

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