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Common-mode five-leg inverter using space vector pulse width modulation for dual-motor drives: a review of topology, switching strategies, and control performance

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ABSTRACT

A common-mode five-leg inverter (CM-FLI) is a reduced-switch-count power converter designed to supply two three-phase motors through a shared inverter leg. Compared with two independent three-leg inverters, this configuration reduces the number of power switches while retaining the possibility of independent motor-speed regulation. However, the shared leg introduces additional control challenges, particularly current interaction, unequal voltage utilization, switching coordination, and harmonic distortion. Space vector pulse width modulation (SVPWM) provides a systematic approach to generating the required voltage references and coordinating switching states for both machines. This review examines the operating principles of CM-FLI systems, the role of the common leg, and the development of SVPWM-based switching strategies for dual-motor applications. It also discusses direct torque control (DTC), vector control, predictive methods, discontinuous modulation, and simplified SVPWM algorithms. The comparison emphasizes DC-link utilization, common-leg current, total harmonic distortion, switching losses, dynamic response, and implementation complexity. The literature indicates that SVPWM can improve voltage utilization and switching coordination, although performance depends on reference-vector synthesis and load interaction. Further research should prioritize experimentally validated modulation methods, common-leg current limitation, and robust independent motor control.

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1. INTRODUCTION

Multi-motor drive systems are used in industrial machinery, electric vehicles, traction systems, textile production, and other applications requiring coordinated mechanical operation. Conventional systems generally employ two separate three-phase voltage-source inverters to control two three-phase motors independently. Although this arrangement provides straightforward control, it requires six inverter legs and associated semiconductor switches, gate drivers, and supporting circuitry. Reducing the number of power-electronic components without sacrificing acceptable motor performance is therefore an important design objective [1]–[4].

A five-leg voltage-source inverter (FLI) addresses this objective by using one inverter leg in common between two three-phase motor connections. The resulting configuration contains four independent legs and one shared leg, reducing the hardware requirement compared with two conventional three-leg inverters. In the literature considered here, the term common-mode five-leg inverter (CM-FLI) is associated with the common-leg operating arrangement rather than a conventional common-mode voltage-control method. This distinction is important because the shared leg carries the combined electrical interaction of the two motor systems and influences the switching and current-control strategy [2], [4], [5].

Despite its reduced component count, the CM-FLI creates several control challenges. The voltage references of both motors must be synthesized while respecting the switching states available from the shared

leg. Differences in motor speed, load torque, and electrical phase can increase common-leg current and affect the voltage available to each machine. This review examines the use of space vector pulse width modulation (SVPWM) to address these challenges and evaluates its relationship with alternative control strategies [6]–[9].

2. CM-FLI TOPOLOGY AND OPERATING PRINCIPLES

The CM-FLI topology connects two three-phase machines to a single five-leg inverter by sharing one phase leg. Each motor has two dedicated inverter legs, while the fifth leg supplies the common connection between their remaining phases. This arrangement reduces the number of inverter legs from six to five and can reduce the semiconductor and gate-driver requirements. However, the electrical behavior of the shared leg must be considered when designing the motor-current and voltage-control loops [2], [3], [10].

The two motors can be operated at identical or different speeds depending on the application and control architecture. Independent operation requires the controller to generate suitable voltage references for both machines while maintaining acceptable current through the common leg. When the motor operating points differ significantly, the common leg may experience higher current demand and additional conduction losses. Consequently, the benefits of reducing the switch count should be evaluated together with current-sharing capability and the operating limits of the shared semiconductor devices [5], [8], [11].

The basic CM-FLI configuration can be used with induction motors and permanent-magnet synchronous motors, although the motor-control algorithms differ. Induction-motor systems may employ direct torque control (DTC) or field-oriented control, whereas PMSM systems commonly use rotor-position-oriented current regulation. The inverter topology does not itself guarantee independent motor control, because the modulation and feedback algorithms determine how effectively the two machine references are coordinated. Therefore, topology selection and control design must be treated as interconnected engineering decisions [9], [12], [13].

3. ROLE OF SVPWM IN CM-FLI

SVPWM generates inverter switching signals by representing the desired output voltage as a reference vector and synthesizing it from available switching states. Its principal advantages include effective DC-link voltage utilization, flexible switching-sequence selection, and suitability for digital implementation. For a CM-FLI, however, the modulation process is more complicated than for a conventional three-leg inverter because two three-phase voltage systems must be supplied through a shared switching leg. The modulation strategy must therefore coordinate the voltage references and switching intervals of both motor systems [7], [14], [15].

A conventional three-phase SVPWM algorithm cannot simply be duplicated for each motor without considering the shared-leg constraint. Switching decisions that are appropriate for one motor may conflict with the voltage requirements of the other motor. The controller must establish compatible switching states and allocate the available DC-link voltage between the two outputs. This coordination is essential for maintaining motor-current quality and avoiding excessive common-leg loading [2], [4], [15].

Kondratenko and Lewicki proposed a simplified SVPWM technique for a five-leg inverter with dual three-phase output in 2023. Their approach aimed to reduce the computational complexity of the modulation process and bring its execution requirements closer to those of carrier-based PWM methods. This work is particularly relevant because it directly addresses SVPWM implementation for the five-leg dual-output structure. It also indicates that computational efficiency is an important consideration when translating modulation concepts into practical embedded controllers [15].

4. SWITCHING STRATEGIES AND MOTOR-CONTROL INTEGRATION

The choice of switching strategy affects the quality of the output voltage, switching losses, and common-leg current. Conventional carrier-based PWM offers a relatively straightforward implementation, while SVPWM provides additional flexibility in voltage-vector selection and switching-sequence design. Jones et al. demonstrated a five-leg inverter PWM method for two-motor constant-power applications, emphasizing the importance of DC-link voltage allocation and switching-frequency distribution. Their work provides an important foundation for understanding the practical modulation constraints of reduced-switch-count dual-motor drives [2].

DTC can be integrated with a five-leg inverter to regulate the electromagnetic torque of induction motors. The switching decisions produced by DTC must nevertheless be translated into compatible five-leg inverter states. Sabarad and Kulkarni presented a CM-FLI dual-motor control approach combining DTC and SVPWM, with simulation results examining motor-speed regulation and harmonic performance. Their study

is a direct reference for the specific CM-FLI configuration considered in this review, although further experimental evidence is needed to establish its performance under a wider range of operating conditions [9].

Alternative approaches include field-oriented control, model predictive control, and duty-cycle-regulated PWM. Lim et al. investigated predictive control of a two-motor drive supplied by a five-leg inverter, while later studies examined advanced speed-control and priority-based predictive methods. These approaches provide alternative ways to manage motor interaction and switching constraints. Their practical value depends on computational requirements, parameter sensitivity, current limits, and the ability to maintain stable operation during load or speed transitions [6], [8], [12], [13].

5. COMMON-LEG CURRENT AND VOLTAGE UTILIZATION

Common-leg current is one of the most important constraints in a CM-FLI system. Since the shared leg participates in the electrical supply of both motors, its current is influenced by the instantaneous phase-current demands of the two machines. Depending on their relative electrical operating conditions, these currents may partially reinforce or oppose each other. The resulting current profile can increase semiconductor stress and conduction losses if the control strategy does not account for the interaction [5], [8], [16].

Voltage utilization is another major design consideration because the available DC-link voltage must support two motor outputs. The allocation of voltage between the machines becomes especially important when they operate at different speeds or require different torque levels. Research on rotor-angle control and mutual-flux-angle regulation has investigated methods for improving voltage utilization and reducing losses in the common leg. These approaches suggest that motor coordination can provide benefits beyond the modulation algorithm alone [16], [17].

The common-leg constraint also affects protection and fault management. An open-circuit or short-circuit failure in an independent leg may affect one motor differently from a failure in the shared leg, which can influence both motor outputs. A robust design should therefore include current monitoring, overcurrent protection, fault detection, and safe shutdown or degraded-operation strategies. These requirements are particularly important in traction and industrial applications where an inverter fault may affect the availability of the overall drive system [10], [18], [19].

6. COMPARATIVE ASSESSMENT OF CM-FLI CONTROL STRATEGIES

Table 1 summarizes the principal modulation and control approaches relevant to CM-FLI systems. The comparison highlights their respective contributions to switching coordination, voltage utilization, and independent motor operation. It also shows that SVPWM is not the only possible solution, because carrier-based PWM and predictive control can address different implementation priorities. The most suitable approach depends on the required dynamic performance, available processing resources, and acceptable common-leg current.

Table 1. Comparison of modulation and control strategies for CM-FLI dual-motor drives

Strategy	Main operating principle	Main advantages	Main limitations
Carrier-based PWM	Generates switching signals from carrier and reference comparisons	Simple implementation and low computational demand	Switching coordination and DC-link utilization require careful design
Conventional SVPWM	Synthesizes reference voltage vectors from inverter switching states	Flexible switching sequences and effective DC-link utilization	More complex with a shared leg
Simplified SVPWM	Reduces vector-location and switching-time calculations	Lower computational burden	Requires validation across operating conditions
Discontinuous PWM	Reduces switching transitions through selected clamping intervals	Potential reduction in switching losses	May affect harmonic distribution and current ripple
Direct torque control with SVPWM	Combines torque regulation with vector-based voltage synthesis	Fast torque control and flexible switching	Requires coordination of both motor voltage references
Model predictive control	Selects switching states by evaluating predicted system behavior	Can incorporate current and switching constraints	Model dependence and computational demand
Mutual-flux-angle control	Coordinates the electrical relationship between the two machines	Can reduce common-leg losses under suitable operation	Requires additional estimation and control loops

The comparison in Table 1 indicates that simplified SVPWM is a promising option when both switching quality and computational efficiency are important. Conventional SVPWM provides a flexible framework, but its implementation must account for the restricted switching combinations of the five-leg structure. Predictive control may provide more direct handling of operating constraints, although its

computational burden can be higher. Discontinuous PWM can reduce switching transitions, but its harmonic and current effects must be assessed for the actual motor operating range [6], [10], [13], [15], [20]–[22].

7. RESEARCH CHALLENGES AND FUTURE DIRECTIONS

A major research gap concerns the limited number of studies that directly evaluate CM-FLI using SVPWM under comprehensive experimental conditions. Some published work focuses on simulation, while other studies investigate five-leg inverter operation using related PWM or predictive-control approaches. These results provide useful design foundations, but they do not establish universal performance improvements across different motor ratings, speed combinations, and load conditions. Future research should therefore include experimental comparisons with conventional dual-inverter systems under clearly defined operating conditions [8], [9], [15].

The development of robust SVPWM algorithms should also address unequal motor speeds, changing torque demands, and DC-link voltage variations. The controller should maintain acceptable voltage utilization while preventing excessive current through the shared leg. Adaptive switching sequences and predictive current constraints may provide useful solutions, particularly when the motors operate under different dynamic conditions. Their effectiveness should be evaluated using common-leg current, output-current THD, switching losses, torque response, and computational execution time [12], [13], [16], [17].

Further work is needed on hardware implementation and fault-tolerant operation. Digital controllers must execute the modulation algorithm within the available sampling interval while accounting for dead time, device delays, current-sensor errors, and switching constraints. Experimental evaluation using digital signal processors or field-programmable gate arrays would help establish the practical feasibility of simplified SVPWM. Such studies should also quantify the trade-off between reduced semiconductor count and the additional control and protection requirements introduced by the common leg [10], [14], [18].

8. CONCLUSION

The CM-FLI provides a reduced-switch-count solution for supplying two three-phase motors from a single voltage-source inverter. Its principal advantage is the reduction from six inverter legs to five while retaining the possibility of independently regulating the two motor drives. However, the shared leg introduces additional constraints involving current interaction, switching coordination, voltage utilization, and fault management. SVPWM offers a flexible method for synthesizing the required motor voltages, but its implementation must explicitly account for the shared-leg structure. The reviewed literature indicates that simplified SVPWM, DTC-based switching, predictive control, and coordinated motor-control strategies offer complementary approaches to improving CM-FLI performance. The most important design objective is not merely reducing the number of switches, but achieving reliable dual-motor operation without excessive common-leg current or unacceptable harmonic distortion. Future development should emphasize experimental benchmarking, adaptive voltage allocation, common-leg protection, and low-complexity real-time modulation. These improvements are necessary to establish CM-FLI as a practical alternative to conventional dual-inverter systems in industrial and transportation applications.

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