5.2 Multilevel Converter with Reduced Switch Count Structures

Multilevel converters are power electronic devices that can generate an output with multiple voltage levels, providing smoother waveforms and reduced harmonic distortion compared to traditional two-level inverters. However, a common challenge with multilevel converters is the large number of power electronic switches required to generate these multiple voltage levels. This results in increased complexity, cost, and switching losses.

To address this challenge, researchers and engineers have developed various **reduced switch count structures** for multilevel converters. These structures aim to generate the same number of voltage levels with fewer switches, which can improve the efficiency and reduce the overall size and cost of the inverter.

Working Principles of Multilevel Inverters with Reduced Switch Count:

To understand how reduced switch count MLIs work, let's break down the principles behind common topologies that achieve this goal:

1. **Diode-Clamped Multilevel Inverter (DCMLI)**
   - **Principle**: A DCMLI uses diodes and capacitors to generate multiple voltage levels. The diodes clamp the voltage between each capacitor level, allowing for a step-like voltage waveform. The reduced switch count can be achieved by simplifying the number of diodes and capacitors needed for higher levels.

- **Working**: For a 3-level DCMLI, two capacitors create three voltage levels (positive, zero, and negative). A set of switches is used to select between these levels. As the number of levels increases, the capacitor voltage balancing and diode clamping are key to reducing switch count while still producing a high-quality waveform.

2. **Flying Capacitor Multilevel Inverter (FCMLI)**
   - **Principle**: In FCMLI, capacitors are used to create intermediate voltage levels. These capacitors "fly" between levels and are switched in such a way that each capacitor maintains a balanced voltage. With fewer capacitors, more voltage levels can be synthesized, achieving reduced switch count.
   - **Working**: Capacitors are charged and discharged by appropriately switching the power devices (e.g., IGBTs) to step the output voltage up or down. A typical 3-level FCMLI uses 2 capacitors and 3 switches, and the switching pattern determines how the levels are achieved.

3. **Cascade H-Bridge Multilevel Inverter (CHB)**
   - **Principle**: This topology uses multiple H-Bridge inverter cells connected in series, each producing a different voltage level. By shifting the phase of each H-Bridge cell, more voltage levels can be created.
   - **Working**: Each H-Bridge cell has 4 switches, and for a 3-level inverter, two H-Bridge cells are used. In a reduced switch count

design, advanced switching patterns and phase shifting reduce the number of switches per level. For example, **modular designs** like the **phase-shifted PWM** can optimize the performance.

4. **Asymmetrical Multilevel Inverter**
   - **Principle**: The voltage sources are not equal in this topology, which leads to more voltage levels with fewer switches. By using unequal DC sources, it is possible to generate a higher number of voltage levels without increasing the switch count as much as in symmetrical MLIs.
   - **Working**: In asymmetrical topologies, different voltage sources are used for each phase or level, and the switches are controlled to step up or down between these levels.

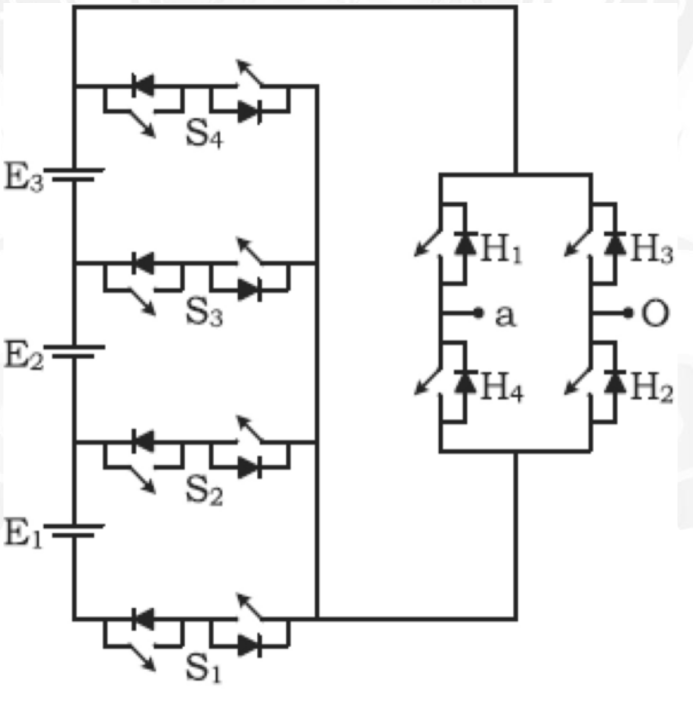

Figure 5.2.3 Multilevel inverters with reduced switch count

[Source: "Multilevel Converters for Industrial Applications" Page: 214]

Types of Reduced Switch Count Multilevel Converter Structures

1. **Reduced Switch Count Diode-Clamped Multilevel Inverter (DCMLI)**
   - The **Diode-Clamped Multilevel Inverter (DCMLI)** is one of the most common topologies for multilevel converters. In a typical DCMLI, each level requires a separate switch and diode.
   - **Reduced Switch Count**: Various modifications of DCMLI aim to reduce the number of switches by using fewer clamping diodes and sharing switches between multiple levels. For example, a modified DCMLI uses fewer clamping diodes, thereby reducing the number of required switches while maintaining the voltage levels.
   - **Benefits**: The reduced switch count improves the system's efficiency and reduces the cost, especially for higher power applications.
2. **Flying Capacitor Multilevel Inverter (FCMLI) with Reduced Switch Count**
   - The **Flying Capacitor Multilevel Inverter (FCMLI)** is another popular topology where the intermediate voltage levels are created by capacitors, and the inverter switches between these capacitors to produce the required output voltage levels.
   - **Reduced Switch Count**: To reduce the switch count in FCMLI, different methods such as using shared capacitors or fewer capacitors are employed, reducing the number of switches and

maintaining the required voltage levels. Some advanced FCMLI structures may use multi-phase techniques or optimizations to further minimize the switch count.

- **Benefits**: Reduced switch count in FCMLI leads to more compact designs, lower cost, and improved system reliability due to fewer switching devices.

3. **Cascaded H-Bridge Multilevel Inverter (CHBMLI) with Reduced Switch Count**
    - **Cascaded H-Bridge Multilevel Inverters (CHBMLI)** are one of the most widely used multilevel inverter structures. In a standard CHBMLI, each H-Bridge is responsible for generating a different voltage level, and these H-Bridges are connected in series.
    - **Reduced Switch Count**: The reduced switch count in CHBMLI is achieved by utilizing a modified arrangement where fewer H-Bridge units are used to achieve the same voltage levels. For example, multi-level CHB topologies use fewer H-Bridge cells while still creating multiple voltage levels through specific switching techniques, such as **hybrid cascaded topologies**.

In hybrid cascaded topologies, some of the H-Bridge units generate voltage levels using a standard setup, while others use modified techniques like the **symmetrical cascade** or **asymmetrical cascade**, resulting in fewer switches while maintaining the desired voltage levels.

Benefits: Reduced switch count in CHBMLI results in lower complexity and reduced cost compared to conventional designs.

4. **Multilevel Inverter with Reduced Switches via Transformer**
   - Another innovative approach to reducing switch count in multilevel inverters is the **use of transformers**. These transformers can help step up or step down voltage levels, thus allowing for a reduced number of switches in the inverter circuit.
   - **Reduced Switch Count**: In this approach, the transformer-based multilevel inverter uses a smaller number of switches because the transformer can perform the voltage division, reducing the complexity of the switching network. The voltage levels can still be created by switching between different taps or windings on the transformer.
   - **Benefits**: This technique is particularly useful in systems where reducing the number of power electronic devices is critical, such as in high-voltage applications. Transformer-based topologies also improve the system's isolation and safety.
5. **Hybrid Multilevel Inverter Structures (Switch Sharing)**
   - Hybrid multilevel inverters combine different types of multilevel converter topologies (such as DCMLI, FCMLI, or CHBMLI) to achieve the desired voltage levels with fewer switches.

- **Switch Sharing**: In some hybrid structures, switches are shared between multiple voltage levels. For instance, in certain configurations, switches can be shared between adjacent levels or between different phases, allowing for significant reductions in the total number of switches.
- **Benefits**: Hybrid inverters can achieve the same voltage levels as traditional topologies while using fewer switches. This leads to simpler control strategies, lower cost, and higher reliability.

Key Benefits of Reduced Switch Count Structures

- **Reduced System Cost**: By reducing the number of switches, the overall cost of the inverter is significantly lowered, which is beneficial for large-scale industrial and renewable energy applications.
- **Improved Reliability**: Fewer switches mean fewer failure points, enhancing the overall reliability and lifespan of the inverter system.
- **Lower Switching Losses**: With fewer switches, the switching losses (which occur every time a switch transitions between on/off states) are reduced, improving the overall efficiency of the inverter.
- **Simpler Control**: Reduced switch count simplifies the control strategies required for operation, leading to easier and more efficient system management.

Conclusion

Reduced switch count multilevel converters represent an important evolution in the design of power electronic systems. By using innovative techniques such as hybrid configurations, transformer-based designs, and optimized switching strategies, engineers can achieve the benefits of multilevel conversion (e.g., high-quality output waveforms and low harmonic distortion) with fewer switches.