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Capacitor Voltage Regulation of a Single Dc Source 5-Level Cascaded H-Bridge Multilevel Inverter Fed Induction Motor Drive with Energy Storage

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ABSTRACT: This paper presents a new control technique to regulate the capacitor voltage in cascaded multilevel inverters. Without requiring transformers, the scheme proposed here allows the use of a single dc power source with the remaining $n - 1$ dc sources being capacitors. This paper focuses mainly to achieve an effective capacitor voltage regulation with the Phase shift modulation and energy storage using Ultra-capacitors as they have higher power density, higher efficiency, longer life and greater cycling capability in cascaded multilevel inverters. It shows hope to reduce the voltage ripple of the capacitors, which leads to higher power conversion efficiency with equal power distribution, reduces the initial cost, and complexity hence it is apt for industrial applications. In this paper a 5-level cascaded multilevel inverter with induction motor drive is considered. Finally, the simulation results validate the concept of this topology.

KEYWORDS: Hybrid cascaded multilevel converter, Energy storage, power distribution, Ultra-capacitors, motor drive.

I.INTRODUCTION

Numerous industrial applications have begun to require high power apparatus in recent years. Multilevel inverters have become more popular over the years in industrial propel applications and high power applications with the promise of less disturbances, smaller common-mode voltage, the possibility to function at lower switching frequencies, and good potential for further developments than ordinary two-level inverters. In multilevel inverters the Cascaded H-Bridge (CHB) configuration has recently become very popular in high-power AC supplies and adjustable-speed drive applications. A cascade multilevel inverter consists of a series of H-bridge (single-phase full bridge) inverter units in each of its three phases. The cascaded multilevel inverter was invented for use in medium to high power applications. The traditional cascaded multilevel inverter interfaces DC energy sources.
The advantages of cascaded multilevel inverters are:

- Requires less number of components per level.
- Modularized structure without clamping components.
- Simple voltage balancing modulation.

Hybrid cascaded multilevel converters provide an attractive option for high power and high performance motor drive applications. Traditional H-bridge HCMC use multiple dc sources, but recently, energy storage elements have been used to replace some of the dc sources, mainly to provide reactive power compensation. Most of the research that has been conducted on the use of energy storage for motor drive applications is based on the use of converter for interface between the ultra-capacitors (UC) and the induction motor.
In most applications, a power converter needs to transfer real power from ac to dc (rectifier operation) or dc to ac (inverter operation). When operating at unity power factor, the charging time for rectifier operation (or discharging time for inverter operation) for each capacitor is different. Such a capacitor charging profile repeats every half cycle, and the result is unbalanced capacitor voltages between different levels. The voltage unbalance problem in a multilevel

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converter can be solved by several approaches, such as replacing capacitors by a controlled constant dc voltage source such as pulse-width modulation (PWM) voltage regulators or batteries. The use of a controlled dc voltage will result in system complexity and cost penalties. With the high power nature of utility power systems, the converter switching frequency must be kept to a minimum to avoid switching losses and electromagnetic interference (EMI) problems. When operating at zero power factors, however, the capacitor voltages can be balanced by equal charge and discharge in one-half cycle. This indicates that the converter can transfer pure reactive power without the voltage unbalance problem.

II. PROPOSED TOPOLOGY

In this paper, the proposed multilevel inverter not only has the modularity feature of cascaded topologies but also consists of single dc source and the remaining are of capacitors. Proposed topology is not only used to regulate the voltage across the capacitors and also used for energy storage purpose with the use of ultra capacitors.

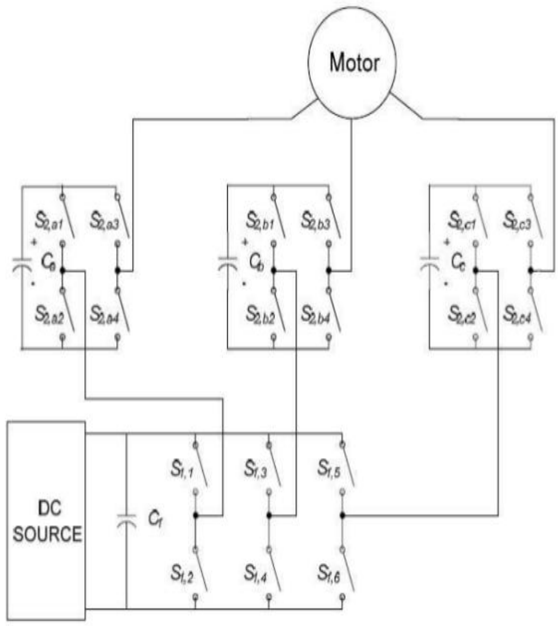

Figure.1: Topology for the five-level H-bridge cascaded multilevel converter fed induction motor drive.

In this topology, each leg of a standard three-leg converter is connected in series with an H-bridge converter. The three-leg converter is powered by a dc source while each of the three H-bridges is supplied by a capacitor. While the this topology has the advantage of utilizing only a single dc power supply.

III. CAPACITOR VOLTAGE REGULATION

The most important factors causing the voltage imbalance among these DC capacitors are the difference in the power stage losses and the component tolerances. The internal losses may be differently influenced by the switching and conduction activity and the component tolerances. To achieve steady-state, balanced voltages, these DC capacitors must have the same amount of real power utilization in a given period of time. Due to sharing the same output current, the differences in the capacitor currents are caused by the different duty cycles, because a capacitor current is a product of a duty cycle and an output current. Therefore, the average switching functions or duty cycles in these H-bridge converters must be identical.

The imbalance of DC capacitor voltages will degrade the quality of the voltage output. In severe cases, this could lead to the complete collapse of the power conversion system. Moreover, it will cause excessive voltages across the devices

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and an imbalance of switching losses. An adequate control strategy for avoiding the imbalance of DC capacitor voltages must meet the following requirements.

1) The impact on voltage quality should be as small as possible.
2) It can balance voltages when components of H-bridges have parameter variations.
3) It can balance voltages when H-bridges switch with different switching patterns.

In the proposed topology, the capacitor voltage regulation is obtained by using a new technique called phase shift modulation. The principle of operation is explained by the following figure.2 shown below.

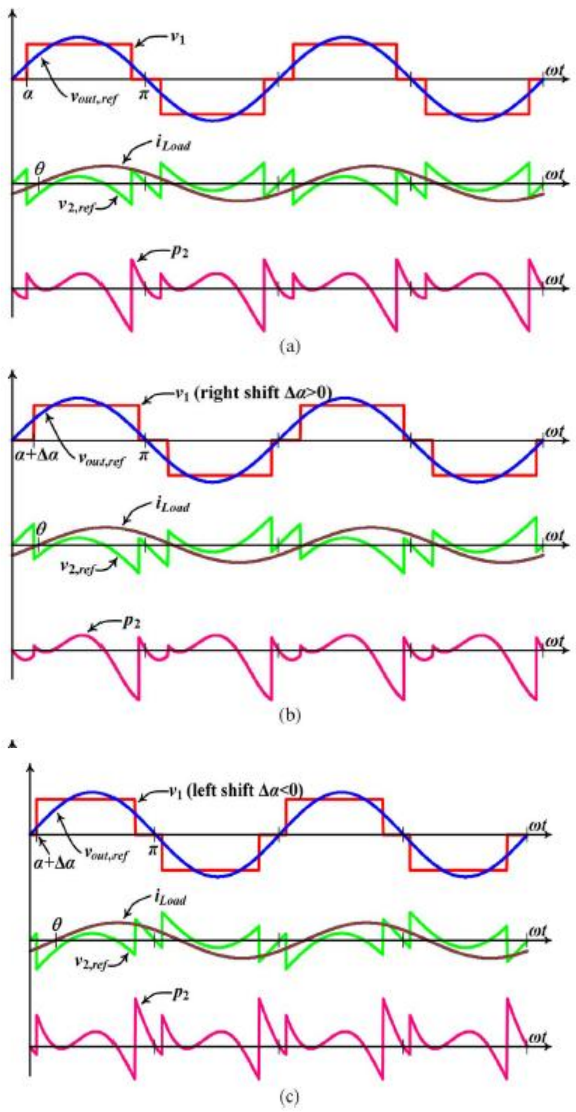

Fig.2 Impact of a phase shift in *v*1 on the power supplied by the auxiliary cell. (a) No phase shift. (b) Shift to the right. (c) Shift to the left.

The operation of the capacitor voltage regulation using phase shift modulation is clearly explained as, when the capacitor is charging, the generated active power in the main cell will be greater than the power transferred to the load and the remaining power is used charge the capacitor of the auxiliary cell. While when the capacitor is discharging, the main cell will not supply as much power. Consequently, the capacitor in the auxiliary cell will be discharged. When no

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phase shifting is applied, the average power that the harmonics send out during a cycle is zero, which therefore does not contribute to the output power of the cell. Therefore, by controlling $\Delta\alpha$ we can charge or discharge the capacitor to regulate its voltage at the desired value. By this principle explained above, clearly shows that capacitor voltage regulation is effectively achieved by phase shift modulation.

IV. ENERGY STORAGE

Electrical energy storage is emerging as a key technology with applications in areas such as improved reliability and power quality in the utility sector and other non-stationary power applications, integration of renewable sources into distributed generation systems, improved energy efficiency and productivity in conventional power generation plants, and regenerative motor drive systems. Energy storage systems can be characterized by their specific requirements such as power levels, energy storage capacity, and response time (determined by storage times or discharge times). The ultra-capacitor as an energy storage device dedicated for power conversion applications. In comparison to state of the art electrochemical batteries, the ultra-capacitors have higher power density, higher efficiency, longer lifetime and greater cycling capability. In comparison to the state of the art electrolytic capacitors, the ultra-capacitors have higher energy density. All these advantages make the ultra-capacitors good candidate for many power conversion applications. In the proposed topology the cascaded multilevel inverter consists of single dc source, and the remaining are of capacitors, these capacitors are replaced by the ultra capacitors which are very efficient for energy storage.

V. EXPERIMENTAL RESULTS

Matlab simulations are employed to validate the proposed method. The experimental results show that the proposed method can effectively eliminate the specific harmonics, and the output voltage waveforms have low total harmonic distortion (THD). The output phase voltage of cascaded multilevel inverter for 7-levels is shown in Fig.3.

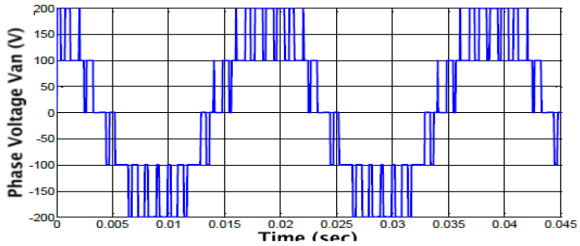

Fig.3 Output phase voltage waveform of a five level inverter.

The effective capacitor voltage regulation obtained by using phase shift modulation is shown in figure.4 Below.

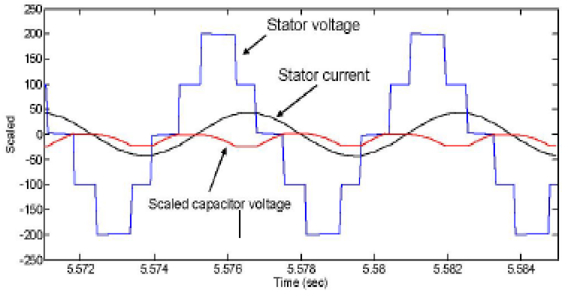

Fig.4 capacitor voltage (V), stator current (A), and stator voltage vs time.

The proposed topology of induction motor drive parameters are shown in the below figure.

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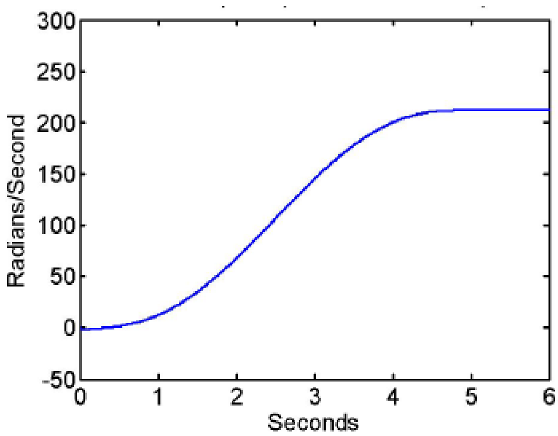

Fig.5 Rotor speed of induction motor.

By this simulation results, we can observe that the capacitor voltage regulation is achieved effectively by using phase shift modulation.

VI. CONCLUSION

A single-dc-source cascaded H-bridge multilevel converter has been analyzed. A new control method, phase-shift modulation, is used to regulate the voltage of the capacitors replacing the independent dc sources by capacitors. The proposed method offers an effective regulation of the capacitor voltage and the energy storage using ultra-capacitors as they have higher power density, higher efficiency, longer life and greater cycling capability with hybrid cascaded multilevel inverter topologies for high performance motor drive applications. The experimental results show the effectiveness of this method of regulating the capacitor and reduce the voltage ripple of the capacitors, which leads to higher power conversion efficiency with equal power distribution, reduces the initial cost, and complexity hence it is apt for industrial applications.

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