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Implementation of BESS on Micro grids for Isolated Modular Multilevel High Step-Up/Down DC-DC Converter fed Induction motor drive

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Abstract: *In this project Battery Energy Storage System is implemented for microgrid for Isolated Modular Multilevel High Step-Up/Down DC-DC Converter with Induction motor drive. Battery Energy Storage System (BESS) is used for primary frequency regulation. As developments in batteries progress, advancement in applications of BESS including the implementation in high power penetration is expected. Load shedding is one of frequency control methods during stand-alone operation, and the performance of frequency control improves in combination with BESS.A modular multilevel structure is adopted as switching valves to sustain medium voltages to achieve modular design and high reliability. Only one high-frequency transformer is used in the proposed converter, which significantly simplifies the circuit and galvanic insulation design. The efficiency of a modular converter to share the voltage and current among its modules for a given power rating. A drive system is typically composed of three components: a dc-dc converter that converts low dc voltages to a required high dc voltage, an inverter that converts the high dc voltage to a single- or three-phase ac voltage a digital controller that controls the converter inverter operation. A transformer is used to both isolate the converter and to further increase the step-up/down ratio. The system performance can be analyzed by using MATLAB/SIMULINK software.*

Key Words: Modular Multilevel Converter (MMC), Battery Energy Storage System, High Step-Up/Down DC-DC Converter, Induction motor drive.

I. INTRODUCTION

With the increasing share of electrical power from renewable sources, investments in a stronger national grid may become necessary to level out differences in local power-in feed across the country [1]. Battery energy storage systems can help to reduce this effort by buffering the energy in the region where the power fluctuations occur [2]. To allow for a high power output per deployed unit, these systems need to connect directly to the medium voltage distribution grid.

State-of-the-art solutions are based on conventional multilevel power converters that have a limited output voltage and therefore require bulky line-transformers to connect to the medium-voltage grid. Going to a higher number of voltage levels (and thus a higher output voltage) would come at the cost of a gradually increasing complexity.

In contrast to that, the modular multilevel converter [3] presents a new approach, which allows for the realization of a high number of output voltage levels by connecting multiple identical power electronic modules in series. Additional modules can easily be added to the design to provide redundancy, which increases the reliability of the entire system. The high number of output voltage levels makes for an excellent output current quality at minimal filtering effort and allows the converter to be deployed in the medium-voltage distribution grid without the need for a line transformer.

In [4], it is has been proposed to use the MMC converter for ultra-fast charging of electric vehicles and [5] describes an MMC converter based on H-bridge cells as a stand-alone high-power battery energy storage systems based on split batteries (BESS). In [6] an MMC converter is proposed as a grid-tie inverter with integrated split battery storage capability, but no comprehensive design methodology has been given.

The main objective of this paper is to develop a modular high-efficiency high step-up boost converter with a forward energy-delivering circuit integrated voltage-doubler as an interface for dc-microgrid system applications. In the proposed topology, the inherent energy self-resetting capability of auxiliary transformer can be achieved without any resetting winding [7-10]. Moreover, advantages of the proposed converter module such as low switcher voltage stress, lower duty ratio, and higher voltage transfer ratio features are obtained. Steady-state analyses are also made to show the merits of the proposed converter topology [11]. For further understanding the dynamic characteristic, small-signal models of the proposed converter are derived by using state-space averaging technique [12-13]. For higher power applications, modules of the high step-up converters are paralleled to further reduce the input and output ripples.

This paper presents an optimal design procedure for the MMC converter used in a high-power BESS. In contrast to [14], the system can operate without a dc-link or a dc-link capacitor, which makes the control structure different to that of the classical MMC.

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II. SYSTEM CONFIGARATION

The overall system is shown in Fig.1. It has a set of parallel- and series-connected batteries as an input, a bidirectional high step-up/down isolated MMC converter, and a three phase bidirectional dc-ac inverter. Depending on the load condition, the high step-up/down can boost, or buck the voltage. In other words, the MMC can charge the batteries in battery charging mode, and it can operate as a step-up converter during discharging mode. The UPS is controlled based on the droop method.

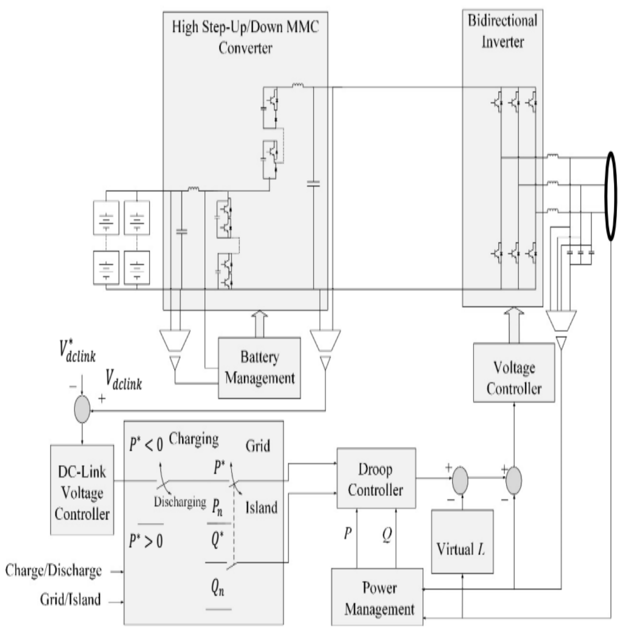

Fig.1 The overall control system with proposed converter

III. CONVERTER DESIGN

The topology that is described in [15] is for a transformerless modular multilevel converter where the transformerless MMC circuit system consists of an upper and lower set of capacitor-transistor cells, where the number of upper capacitor-transistor cells is N and the number of the lower capacitor-transistor cells is M [15], as shown in Fig.2. Phase shift pulse width modulation (PSPWM) with a high duty cycle is used with the proposed MMC. This high duty cycle ensures that all except one of the capacitors are connected at any given time. This means that at any instance the pulse-width modulation method ensures all of the upper and lower capacitors (except one of them) are in series with the high side inductor and capacitor. However, for isolation purposes, a transformer is placed between the upper and lower cells. The transformer ensures that there is no direct connection between the input and the output. In addition, the transformer can provide some additional voltage increase on the output. Fig.3 shows an isolated high step-up modular multilevel converter.

For a transformerless MMC, the voltage and current conversion ratio equations are written in [15] as:

$$\frac{v_H}{v_L} = \frac{N}{1-d} \tag{1}$$

The current for this converter design is then derived [16]

$$I_L = \frac{v_H}{v_L} I_o \tag{2}$$

Wherev_H is the output voltage, v_L is the input voltage, $d$isthe duty cycle,I_L is the input current, and I_O is the outputcurrent. From (2), the voltage conversion ratio depends onboth the number of the upper cells, N, and the duty cycle d.To have a 1:10 conversion ratio, the number of the upper cells sets to be 4, and the duty cycle 0.6. Both equations (1) and (2) have the same expression for an isolated MMC. The only difference is that the turns ratio for the transformer should be included in the voltage and current conversion ratio equations. In other words, the voltage and current conversion ratio for an isolated topology can be written as:

$$\frac{v_H}{v_L} = \left(\frac{N_s}{N_p}\right)\frac{N}{1-d} \tag{3}$$

$$I_L = \left(\frac{N_p}{N_s}\right)\frac{N}{1-d} I_o \tag{4}$$

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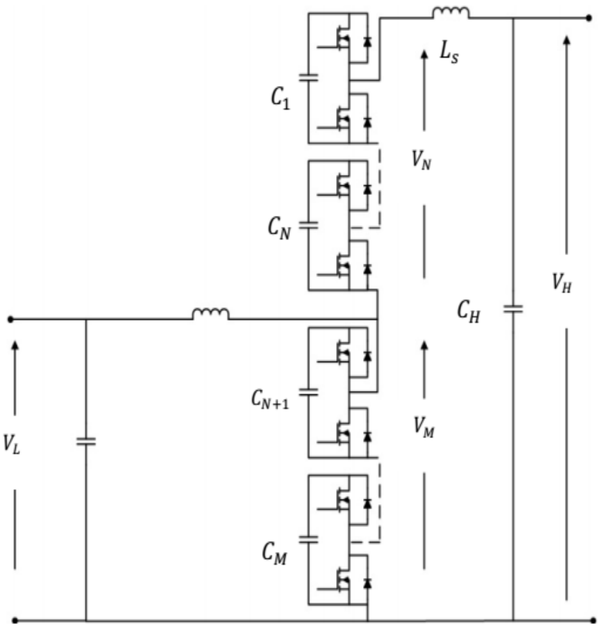

Fig.2 A high step-up modular multilevel converter [15].

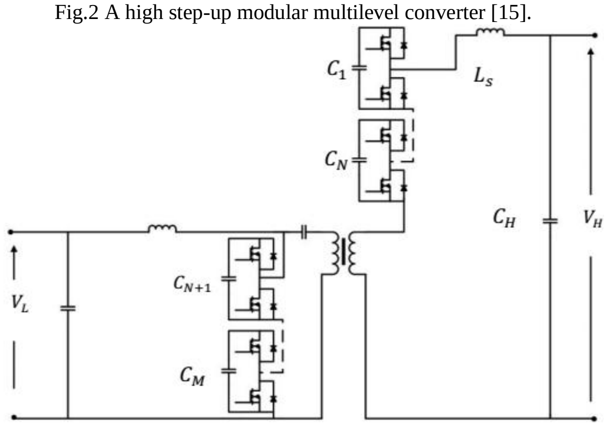

Fig.3 The proposed isolated modular multilevel converter

WhereN_p and N_s are the number of the turns in theprimary and secondary winding of the transformer, respectively. As mentioned earlier, the transformerless MMC can achieve 1:10 conversion ratio. However, the conversion ratio could be increased to 1:15 by using a transformer.

IV. BATTERY ENERGY STORAGE SYSTEMS (BESS)

In recent years much of the focus on the development of electric storage technology has been on battery storage which is the main emphasis of this paper. There is a wide variety of battery types serving various purposes which would be examined in this paper.

In a chemical battery, charging causes reactions in electrochemical compounds to store energy from a generator in a chemical form. Upon demand, reverse chemical reactions cause electricity to flow out of the battery and back to the grid. The first commercially available battery was the flooded lead-acid battery which was used for fixed, centralized applications. The valve-regulated lead-acid (VRLA) battery is the latest commercially available option. The VRLA battery is low-maintenance, spill- and leak-proof, and relatively compact. Zinc/bromine is a newer battery storage technology that has not yet reached the commercial market. Other lithium-based batteries are under development. Batteries are manufactured in a wide variety of capacities ranging from less than 100 watts to modular configurations of several megawatts. As a result, batteries can be used for various utility applications in the areas of generation, T&D, and customer service. Batteries currently have the widest range of applications as compared to other energy storage technologies. The type and the number of battery storage applications are constantly expanding mainly in the areas of electric and electric hybrid vehicles, electric utility energy storage, portable electronics, and storage of electric energy produced by renewable resources such as wind and solar generators.

They are also used for a variety of applications such as: power quality assurance, transmission and distribution (T&D) facility deferral, voltage regulation, spinning reserve, load leveling, peak shaving, and integration with renewable energy generation plants. Battery systems appear to offer the most benefits for utilities when providing power management support and when responding to instant voltage spikes or sags and outages.

Operation

Electric batteries are devices that store electric energy in electrochemical form and deliver direct (dc) electricity. Electrode plates, typically consisting of chemically reactive materials, are placed in an electrolyte which facilitates transfer of ions within the battery. The negative electrode, or anode, “gives up” electrons during discharge via the oxidation part of the oxidation-reduction electrochemical process. Those electrons flow through the electric load connected to the battery, giving up energy. Electrons are then transported to the positive electrode, or cathode, for electrochemical reduction. The process is reversed during charging. Battery systems consist of cells, which have a characteristic operating voltage and maximum current capability, configured in various series/parallel arrays to create the desired voltage and current. Typically a BESS consists of a power conditioning system (PCS) that processes electricity from the battery and makes it suitable for alternating current (ac) loads. This includes (a) adjusting current and voltage to maximize power output, (b) converting DC power to

AC power, (c) matching the converted AC electricity to a utility's AC electrical network, and (d) halting current flow from the system into the grid during utility outages to safeguard utility personnel. The conversion from DC to AC power in the PCS is achieved by an inverter, which is a set of electronic switches that change DC voltage from battery to AC voltage in order to serve an AC load.

V. INDUCTION MOTOR

An asynchronous motor type of an induction motor is an AC electric motor in which the electric current in the rotor needed to produce torque is obtained by electromagnetic induction from the magnetic field of the stator winding. An induction motor can therefore be made without electrical connections to the rotor as are found in universal, DC and synchronous motors. An asynchronous motor's rotor can be either wound type or squirrel-cage type.

Three-phase squirrel-cage asynchronous motors are widely used in industrial drives because they are rugged, reliable and economical. Single-phase induction motors are used extensively for smaller loads, such as household appliances like fans. Although traditionally used in fixed-speed service, induction motors are increasingly being used with variable-frequency drives (VFDs) in variable-speed service. VFDs offer especially important energy savings opportunities for existing and prospective induction motors in variable-torque centrifugal fan, pump and compressor load applications. Squirrel cage induction motors are very widely used in both fixed-speed and variable-frequency drive (VFD) applications. Variable voltage and variable frequency drives are also used in variable-speed service.

In both induction and synchronous motors, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. Whereas a synchronous motor's rotor turns at the same rate as the stator field, an induction motor's rotor rotates at a slower speed than the stator field. The induction motor stator's magnetic field is therefore changing or rotating relative to the rotor. This induces an opposing current in the induction motor's rotor, in effect the motor's secondary winding, when the latter is short-circuited or closed through external impedance. The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary winding(s). The currents in the rotor windings in turn create magnetic fields in the rotor that react against the stator field. Due to Lenz's Law, the direction of the magnetic field created will be such as to oppose the change in current through the rotor windings. The cause of induced current in the rotor windings is the rotating stator magnetic field, so to oppose the change in rotor-winding currents the rotor will start to rotate in the direction of the rotating stator magnetic field. The rotor accelerates until the magnitude of induced rotor current and torque balances the applied load. Since rotation at synchronous speed would result in no induced rotor current, an induction motor always operates slower than synchronous speed. The difference, or "slip," between actual and synchronous speed varies from about 0.5 to 5.0% for standard Design B torque curve induction motors. The induction machine's essential character is that it is created solely by induction instead of being separately excited as in synchronous or DC machines or being self-magnetized as in permanent magnet motors.

For rotor currents to be induced the speed of the physical rotor must be lower than that of the stator's rotating magnetic field (n_s); otherwise the magnetic field would not be moving relative to the rotor conductors and no currents would be induced. As the speed of the rotor drops below synchronous speed, the rotation rate of the magnetic field in the rotor increases, inducing more current in the windings and creating more torque. The ratio between the rotation rate of the magnetic field induced in the rotor and the rotation rate of the stator's rotating field is called slip. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. For this reason, induction motors are sometimes referred to as asynchronous motors. An induction motor can be used as an induction generator, or it can be unrolled to form a linear induction motor which can directly generate linear motion.

Synchronous Speed:

The rotational speed of the rotating magnetic field is called as synchronous speed.

$$Ns = \frac{120 \text{ x } f}{P} \quad (RPM) \tag{5}$$

Where, f = frequency of the supply

P = number of poles

Slip:

Rotor tries to catch up the synchronous speed of the stator field, and hence it rotates. But in practice, rotor never succeeds in catching up. If rotor catches up the stator speed, there won't be any relative speed between the stator flux and the rotor, hence no induced rotor current and no torque production to maintain the rotation. However, this won't stop the motor, the rotor will slow down due to lost of torque, and the torque will again be exerted due to relative speed. That is why the rotor rotates at speed which is always less the synchronous speed.

The difference between the synchronous speed (Ns) and actual speed (N) of the rotor is called as slip.

$$\% \text{ slip} \quad s = \frac{Ns - N}{Ns} \text{ x } 100 \tag{6}$$

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VI. MATLAB/SIMULINK RESULTS

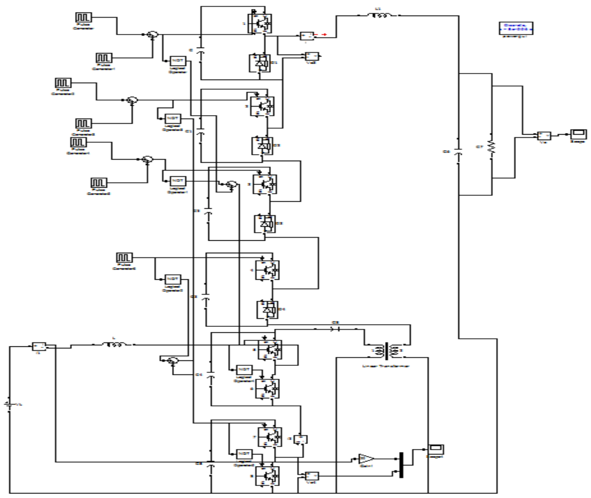


Fig.4 Matlab/Simulink model of modular multilevel converter.

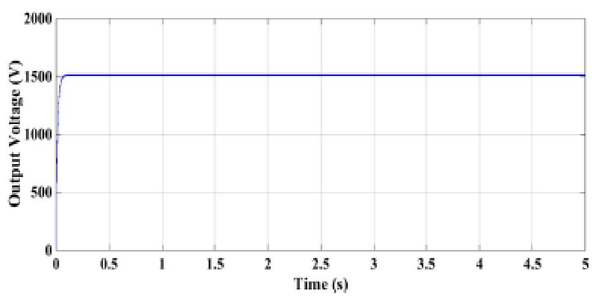


Fig.5 Output voltage of the proposed MMC when the input voltage is 100 V.

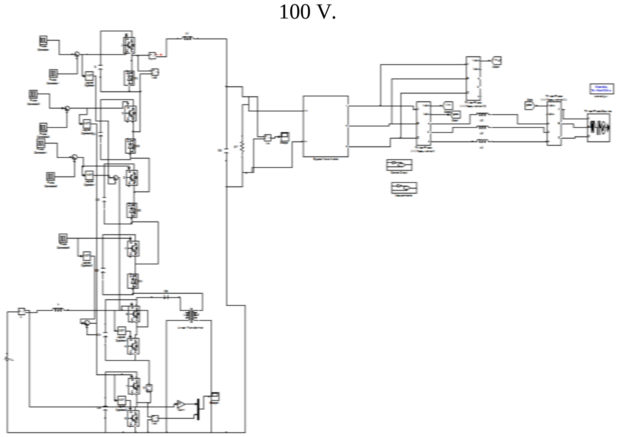
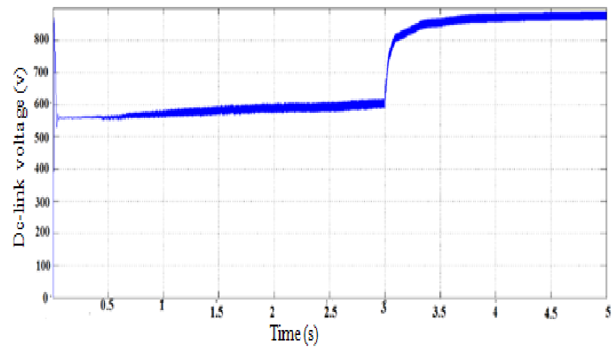
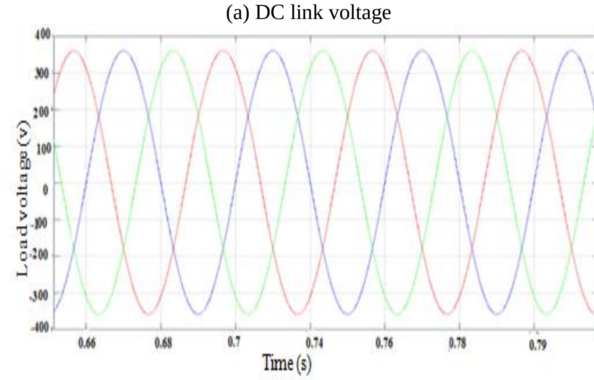


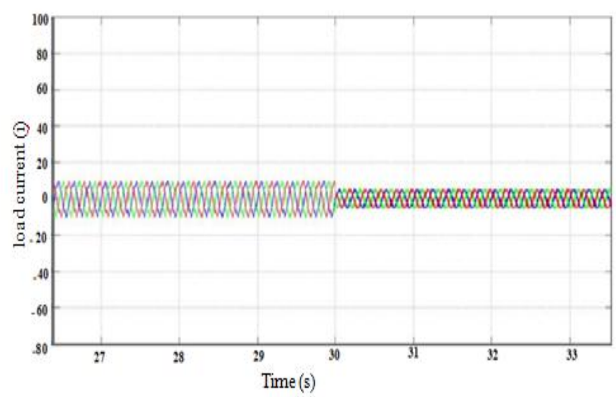
Fig.6 Matlab/Simulink model of high step-up modular multilevel converter.



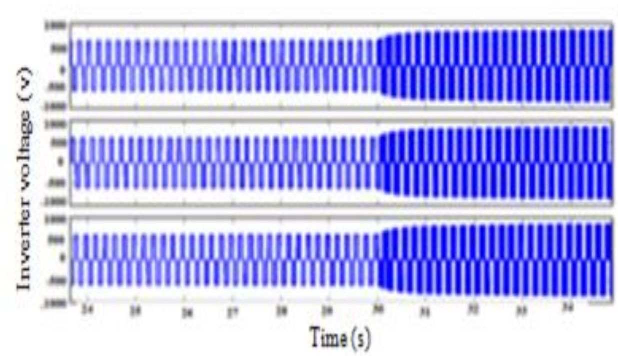
(a) DC link voltage



(b) Source voltage

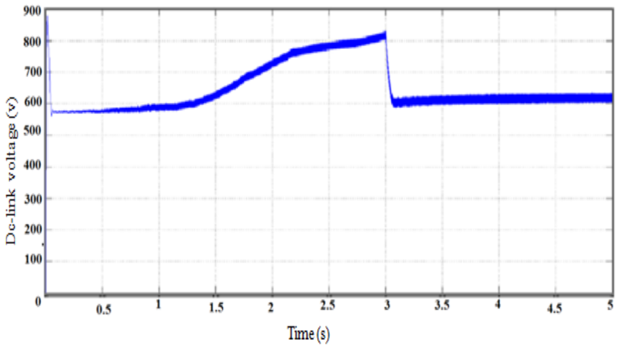


(c) Source current

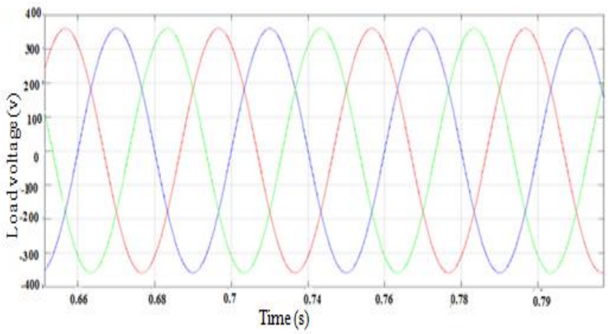


(d) Inverter Voltage

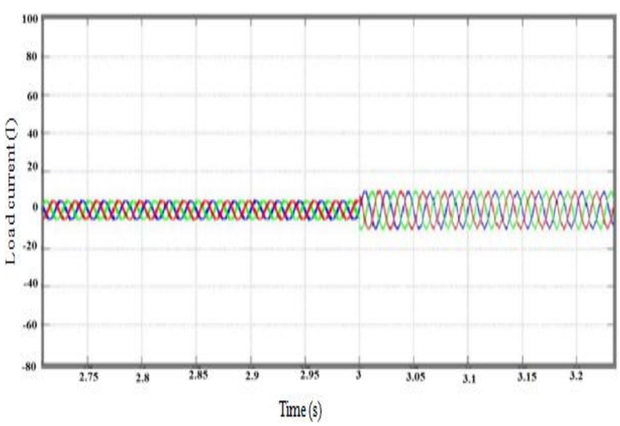
Fig.7. Transient from discharging to charging mode.



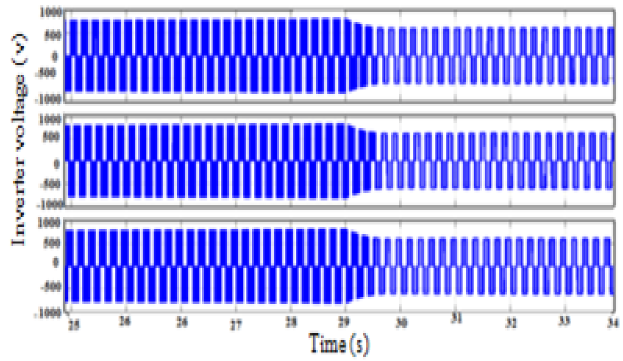
(a) DC link voltage



(b) Source voltage



(c) Source current



(d) Inverter Voltage

Fig.8. Transient from charging to discharging mode.

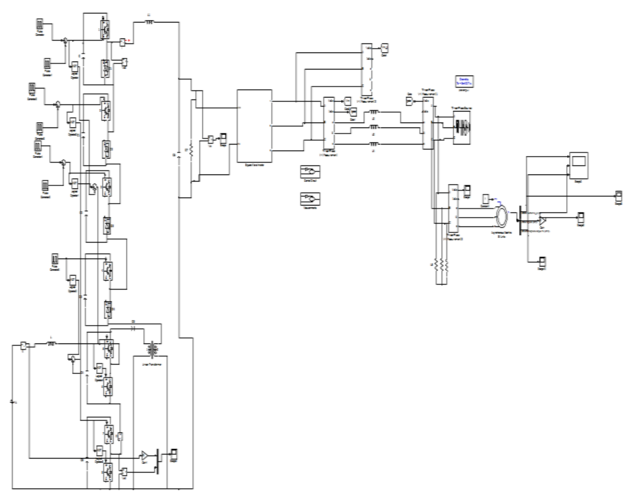


Fig.9 Matlab/Simulink model of High Step-Up Modular Multilevel Converter connected with Induction Motor.

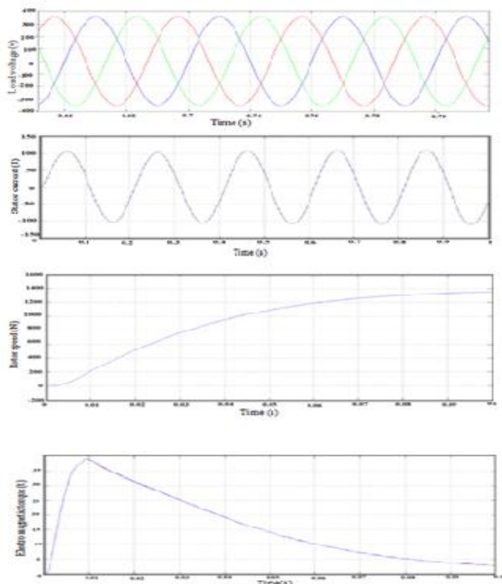


Fig.10 Three-voltage, stator current, rotor speed, electromagnetic torque characteristics of the Induction Motor

V. CONCLUSION

In this paper, the fundamental verification of the control strategy for a high step up/down converter which applies the modular multilevel converter (MMC) was presented. The proposed converter has successfully implemented an efficient high step-up/down conversion through the voltage multiplier module. The interleaved structure reduces the input current ripple and distributes the current through each component. In addition, the lossless passive clamp function recycles the leakage energy and constrains a large voltage spike across the power switch. The analysis of high step-up/down DC-DC converter integrated with bidirectional converter feeding an induction motor drive is carried out and simulation results are presented.

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