



High Gain Efficient Interleaved Dc-Dc Converter for Induction Motor Applications

Narsingoju Mounika

M-tech Student Scholar Department of Electrical & Electronics Engineering,
NARSIMHA REDDY ENGINEERING College of Engineering, R.R(Dt); Telangana, India.

R. Kumarswamy

Associate Professor Department of Electrical & Electronics Engineering,
NARSIMHA REDDY ENGINEERING College of Engineering R.R (Dt); Telanana, India.

Abstract—

Large electric drives and utility applications require advanced power electronics converter to meet the high power demands. In order to meet the required load demand, it is better to integrate the renewable energy sources with the application of drive connected scheme by using inverter module. A novel interleaved high step-up converter with voltage multiplier cell is proposed in this paper to avoid the extremely narrow turn-off period and to reduce the current ripple. The voltage multiplier cell is composed of the secondary windings of the coupled inductors, a series capacitor, and two diodes. Furthermore, the switch voltage stress is reduced due to the transformer function of the coupled inductors, which makes low-voltage-rated MOSFETs available to reduce the conduction losses. Additional active device is not required in the proposed converter fed induction motor drive using inverter module, which makes the presented circuit easy to design and control. The simulations results are conferred using Matlab/Simulink platform.

Keywords: Photovoltaic Systems (PV, Step-Up DC/DC Converter; High Voltage Gain; Boost-Fly Back Converter; Voltage Multiplier Module; Induction Motor Drive

I INTRODUCTION

Renewable energy sources play an important role in rural areas where the power transmission from conventional energy sources is difficult. Other advantages of renewable energy sources are clean, light and does not pollute

atmosphere. As a result, power converter structure has been introduced as an alternative in high power and medium voltage situations using RES. The recent trends in small scale power generation using the with the increased concerns on environment and cost of energy, the power industry is experiencing fundamental changes with more renewable energy sources (RESs) or micro sources such as photovoltaic cells, small wind turbines, and microturbines being integrated into the power grid in the form of distributed generation (DG) [1]. The fuel cells are electrochemical devices that convert chemical energy directly into electrical energy by the reaction of hydrogen from fuel and oxygen from the air without regard to climate conditions, unlike hydro or wind turbines and photovoltaic array. Fuel cells are different from batteries in that they require a constant source of fuel and oxygen to run, but they can produce electricity continually for as long as these inputs are supplied. This can be accomplished mainly by resorting to wind and photovoltaic generation, which, however, introduces several problems in electric systems management due to the inherent nature of these kinds of RESs [2]. In fact, they are both characterized by poorly predictable energy production profiles, together with highly variable rates. As a consequence, the electric system cannot manage these intermittent power sources beyond certain limits, resulting in RES generation curtailments and, hence, in RES penetration levels lower than expected. Power electronic converters, especially dc/ac PWM inverters have been extending their range of use in industry because they provide reduced energy consumption, better system efficiency, improved quality of product, good maintenance, and so on [3]-[7].

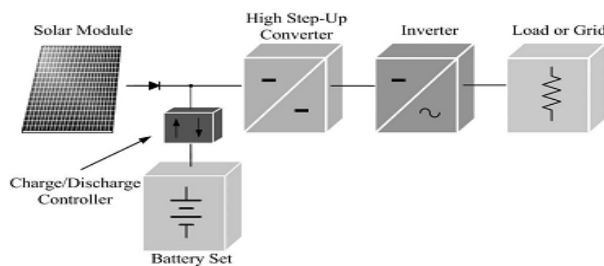


Fig. 1 Typical Photovoltaic System

Nowadays, photovoltaic (PV) energy has attracted interest as a next generation energy source capable of solving the problems of global warming and energy exhaustion caused by increasing energy consumption. PV energy avoids unnecessary fuel expenses and there is no air pollution or waste. Also, there are no mechanical vibrations or noises because the components of power generation based on PV energy use semiconductors. The life cycle of the solar cell is more than 20 years, and it can minimize maintenance and management expenses. The output power of the solar cell is easily changed by the surrounding conditions such as irradiation and temperature, and also its efficiency is low. Thus high efficiency is required for the power conditioning system (PCS), which transmits power from the PV array to the load.

Power converters have required improvement in the power efficiency as well as reduction of size and weight especially in mobile information/communication devices, traction converters, power control units for electric/hybrid vehicle, etc. Passive components and cooling devices usually occupy a much larger space than semiconductor devices in power electronics building block. It is well known that when many DGs are connected to utility grids, they can cause problems such as voltage rise and protection problem in the utility grid. To solve these problems, new concepts of electric power systems are proposed. Resonant converters eliminate most of the switching losses encountered in Pulse Width Modulation converters. The active device is switched with either Zero Current Switching or Zero Voltage Switching at its terminals. When current through the switch is made zero, it is turned on /off, it is known as zero current switching and when voltage across the switch is made zero, it is turned on / off, it is known as zero voltage switching [8]-[12].

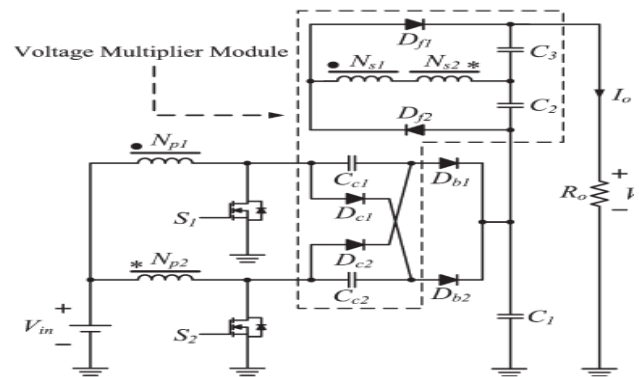


Fig. 2. Proposed high step-up converter.

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-doublers as an interface for high power applications. In the proposed topology, the inherent energy self-resetting capability of auxiliary transformer can be achieved without any resetting winding. Moreover, advantages of the proposed converter module such as low switcher voltage stress, lower duty ratio, and higher voltage transfer ratio features are obtained.

Despite these advances, high step-up single-switch converters are unsuitable to operate at heavy load given a large input current ripple, which increases conduction losses. The conventional interleaved boost converter is an excellent candidate for high-power applications and power factor correction. Unfortunately, the step-up gain is limited, and the voltage stresses on semiconductor components are equal to output voltage. Hence, based on the aforementioned considerations, modifying a conventional interleaved boost converter for high step-up and high-power application is a suitable approach [13]. The DC-DC Converter has low switching power losses and high power efficiency. The use of single transformers gives a low-profile design for the step-up DC-DC converter for low-DC renewable energy sources like photovoltaic module and fuel cell. The proposed converter is a conventional interleaved boost converter integrated with a voltage multiplier module, and the voltage multiplier module is composed of switched capacitors and coupled inductors. The coupled inductors can be designed to extend step-up gain, and the switched capacitors offer extra voltage conversion ratio. In addition, when one of the switches turns off, the

energy stored in the magnetizing inductor will transfer via three respective paths; thus, the current distribution not only decreases the conduction losses by lower effective current but also makes currents through some diodes decrease to zero before they turn off, which alleviate diode reverse recovery losses.

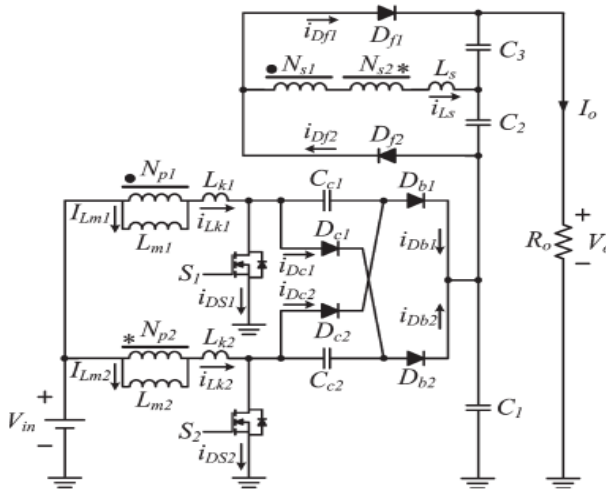


Fig. 3. Equivalent circuit of the proposed converter.

II. OPERATING MODES OF PRAPOSED CONVERTER

The proposed high step-up interleaved converter with a voltage multiplier module is shown in Fig. 2. The voltage multiplier module is composed of two coupled inductors and two switched capacitors and is inserted between a conventional interleaved boost converter to form a modified boost-fly back-forward interleaved structure. When the switches turn off by turn, the phase whose switch is in OFF state performs as a fly back converter, and the other phase whose switch is in ON state performs as a forward converter. Primary windings of the coupled inductors with N_p turns are employed to decrease input current ripple, and secondary windings of the coupled inductors with N_s turns are connected in series to extend voltage gain. The turn ratios of the coupled inductors are the same. The coupling references of the inductors are denoted by “.” and “*”

In the circuit analysis, the proposed converter operates in continuous conduction mode (CCM), and the duty cycles of the power switches during steady operation are greater than 0.5 and are interleaved with a 180° phase shift [14]-[18]. The key steady waveform

in one switching period of the proposed converter contains six modes, which are depicted in Fig. 4, and Fig. 5 shows the topological stages of the circuit.

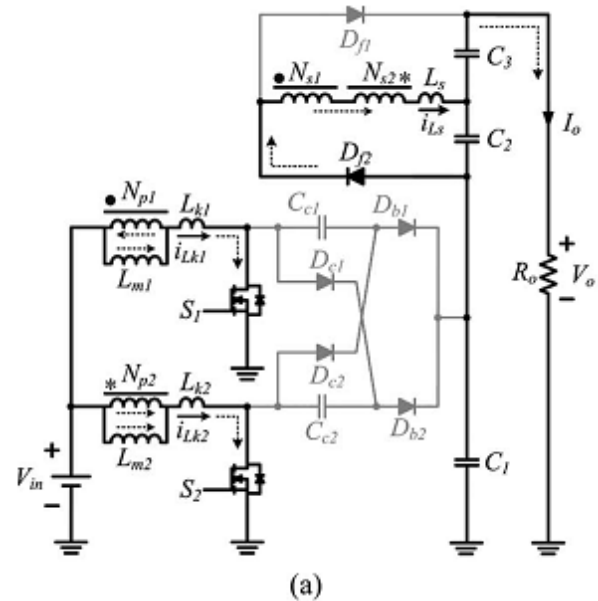
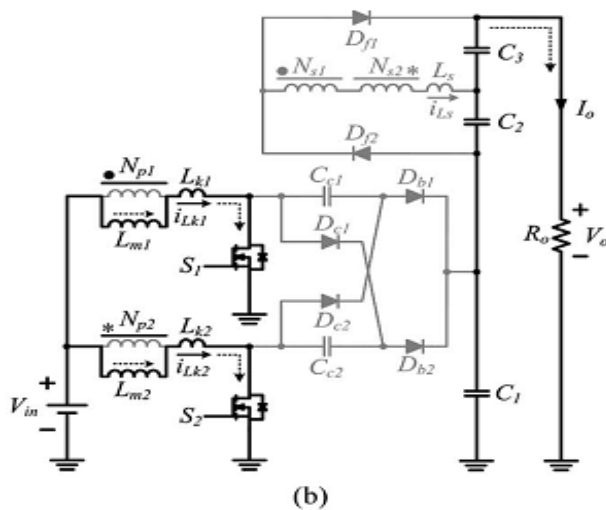


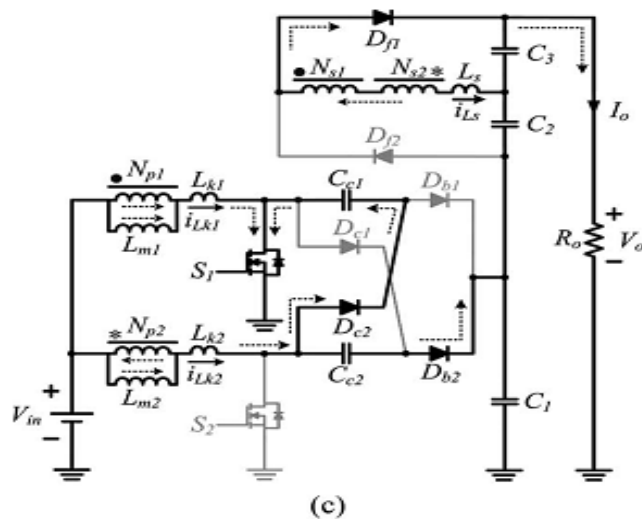
Fig 4 (a) Mode I $[t_0, t_1]$.

Mode I $[t_0, t_1]$: At $t=t_0$, the power switch S_2 remains in ON state, and the other power switch S_1 begins to turn on. The diodes D_{c1} , D_{c2} , D_{b1} , D_{b2} , and D_{f1} are reversed biased, as shown in Fig. 5(a). The series leakage inductors L_s quickly release the stored energy to the output terminal via fly back-forward diode D_{f2} , and the current through series leakage inductors L_s decreases to zero. Thus, the magnetizing inductor L_{m1} still transfers energy to the secondary side of coupled inductors. The current through leakage inductor L_{k1} increases linearly, and the other current through leakage inductor L_{k2} decreases linearly.

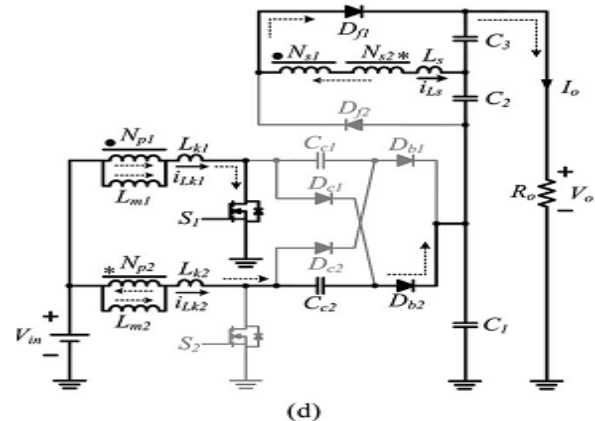
Mode II $[t_1, t_2]$: At $t=t_1$, both of the power switches S_1 and S_2 remain in ON state, and all diodes are reversed biased, as shown in Fig. 5(b). Both currents through leakage inductors L_{k1} and L_{k2} are increased linearly due to charging by input voltage source V_{in} .

Fig 5.(b) Mode II $[t_1, t_2]$.

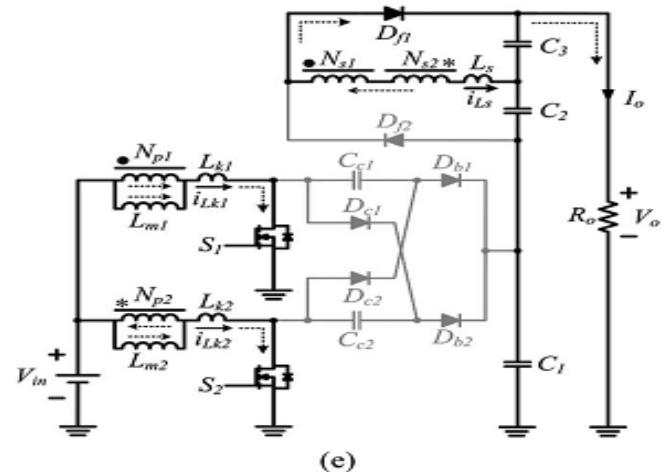
Mode III $[t_2, t_3]$: At $t=t_2$, the power switch S_1 remains in ON state, and the other power switch S_2 begins to turn off. The diodes D_{c1} , D_{b1} , and D_{f2} are reversed biased, as shown in Fig. 5(c). The energy stored in magnetizing inductor L_{m2} transfers to the secondary side of coupled inductors L_s flows to output capacitor C_3 via fly back-forward diode D_{f1} . The voltage stress on power switch S_2 is clamped by clamp capacitor C_{c1} which equals the output voltage of the boost converter. The input voltage source, magnetizing inductor L_{m2} , leakage inductor L_{k2} , and clamp capacitor C_{c2} release energy to the output terminal; thus, V_{C1} obtains a double output voltage of the boost converter.

Fig 6.(c) Mode III $[t_2, t_3]$.

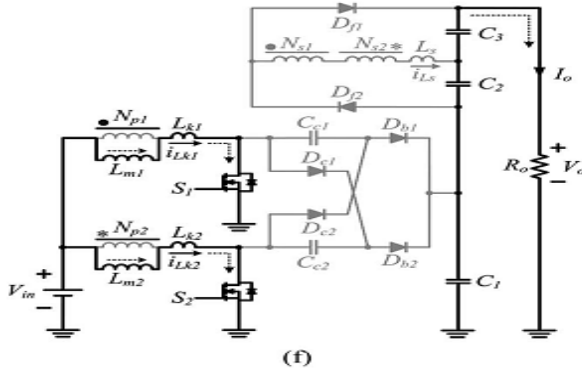
Mode IV $[t_3, t_4]$: At $t=t_3$, the current i_{Dc2} has naturally decreased to zero due to the magnetizing current distribution, and hence, diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous states except the clamp diode D_{c2} , as shown in Fig. 5(d).

Fig 7 (d) Mode IV $[t_3, t_4]$.

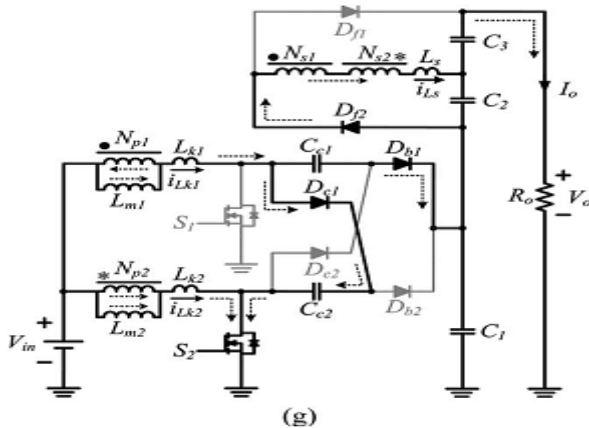
Mode V $[t_4, t_5]$: At $t=t_4$, the power switch S_1 remains in ON state, and the other power switch S_2 begins to turn on. The diodes D_{c1} , D_{c2} , D_{b1} , D_{b2} , and D_{f2} are reversed biased, as shown in Fig. 5(e). The series leakage inductors L_s quickly release the stored energy to the output terminal via fly back-forward diode D_{f1} , and the current through series leakage inductors decreases to zero. Thus, the magnetizing inductor L_{m2} still transfers energy to the secondary side of coupled inductors. The current through leakage inductor L_{k2} increases linearly, and the other current through leakage inductor L_{k1} decreases linearly.

Fig 8 (e) Mode V $[t_4, t_5]$

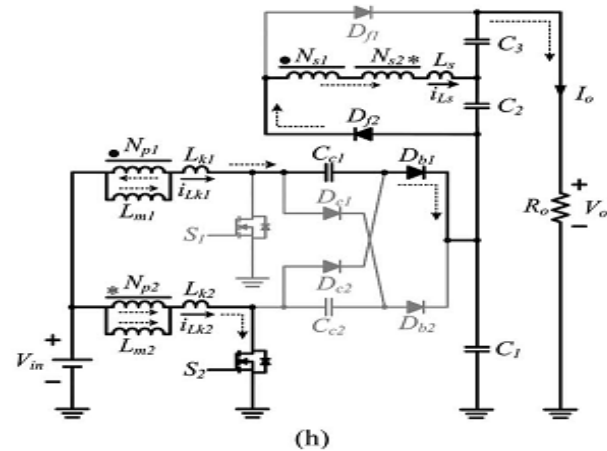
Mode VI [t_5, t_6]: At $t=t_5$, both of the power switches S_1 and S_2 remain in ON state, and all diodes are reversed biased, as shown in Fig. 5(f). Both currents through leakage inductors L_{k1} and L_{k2} are increased linearly due to charging by input voltage source V_{in} .

Fig 9 (f) Mode VI [t_5, t_6].

Mode VII [t_6, t_7]: At $t=t_6$, the power switch S_2 remains in ON state, and the other power switch S_1 begins to turn off. The diodes D_{c2}, D_{b2} , and D_{f1} are reversed biased, as shown in Fig. 5(g). The energy stored in magnetizing inductor L_{m1} transfers to the secondary side of coupled inductors, and the current through series leakage inductors flows to output capacitor C_2 via fly back–forward diode D_{f2} . The voltage stress on power switch S_1 is clamped by clamp capacitor C_{c1} which equals the output voltage of the boost converter. The input voltage source, magnetizing inductor L_{m1} , leakage inductor L , and clamp capacitor C_{c1} release energy to the output terminal; thus, V_{C1} obtains double output voltage of the boost converter.

Fig 10 (g) Mode VII [t_6, t_7].

Mode VIII [t_7, t_8]: At $t=t_7$, the current i_{Dc1} has naturally decreased to zero due to the magnetizing current distribution, and hence, diode reverse recovery losses are alleviated and conduction losses are decreased. Both power switches and all diodes remain in previous states except the clamp diode D_{c1} , as shown in Fig. 5(h).

Fig 11 (h) Mode VIII [t_7, t_8].

III. STEADY-STATE ANALYSIS

The transient characteristics of circuitry are disregarded to simplify the circuit performance analysis of the proposed converter in CCM, and some formulated assumptions are as follows.

- 1) All of the components in the proposed converter are ideal.
- 2) Leakage inductors L_{k1}, L_{k2} , and L_s are neglected.
- 3) Voltages on all capacitors are considered to be constant because of infinitely large capacitance.
- 4) Due to the completely symmetrical interleaved structure, the related components are defined as the corresponding symbols such as D_{c1} and D_{c2} defined as D_c .

A. Step-Up Gain

The voltage on clamp capacitor C_c can be regarded as an output voltage of the boost converter; thus, voltage V_{Cc} can be derived from

$$V_{Cc} = \frac{1}{1-D} V_{in}. \quad (1)$$

When one of the switches turns off, voltage V_{C1} can obtain a double output voltage of the boost converter derived from

$$V_{C1} = \frac{1}{1-D} V_{in} + V_{Cc} = \frac{2}{1-D} V_{in}. \quad (2)$$

The output filter capacitors C_2 and C_3 are charged by energy transformation from the primary side. When S_2 is in ON state and S_1 is in OFF state, V_{C2} is equal to the induced voltage of N_{s1} plus the induced voltage of N_{s2} , and when S_1 is in ON state and S_2 is in OFF state, V_{C3} is also equal to the induced voltage of N_{s1} plus the induced voltage of N_{s2} . Thus, voltages V_{C2} and V_{C3} can be derived from

$$V_{C2} = V_{C3} = n \cdot V_{in} \left(1 + \frac{D}{1-D} \right) = \frac{n}{1-D} V_{in} \quad (3)$$

The output voltage can be derived from

$$V_o = V_{C1} + V_{C2} + V_{C3} = \frac{2n+2}{1-D} V_{in}. \quad (4)$$

In addition, the voltage gain of the proposed converter is

$$\frac{V_o}{V_{in}} = \frac{2n+2}{1-D}. \quad (5)$$

Equation (5) confirms that the proposed converter has a high step-up voltage gain without an extreme duty cycle. The curve of the voltage gain related to turn ratio and duty cycle is shown in Fig. 6. When the duty cycle is merely 0.6, the voltage gain reaches ten at a turn ratio of one; the voltage gain reaches 30 at a turn ratio of five.

B. Voltage Stress on Semiconductor Component The voltage ripples on the capacitors are ignored to simplify the voltage stress analysis of the components of the proposed converter. The voltage stress on power switch S is clamped and derived from

$$V_{S1} = V_{S2} = \frac{2}{1-D} V_{in} = \frac{1}{2n+2} V_o. \quad (6)$$

Equation (6) confirms that low-voltage-rated MOSFET with low $R_{DS(ON)}$ can be adopted for the proposed converter to reduce conduction losses and costs. The voltage stress on the power switch S accounts for a fourth of output voltage V_o , even if turn ratio is one. This feature makes the proposed converter suitable for high step-up and high-power applications.

The voltage stress on diode D_c is equal to V_{C1} , and the voltage stress on diode D_b is voltage V_{C1} minus voltage V_{Cc} .

These voltage stresses can be derived from

$$V_{Dc1} = V_{Dc2} = \frac{2}{1-D} V_{in} = \frac{1}{n+1} V_o \quad (7)$$

$$V_{Db1} = V_{Db2} = V_{C1} - V_{Cc} = \frac{1}{1-D} V_{in} = \frac{1}{2n+2} V_o. \quad (8)$$

The voltage stress on diode D_b is close to the voltage stress on power switch S . Although the voltage stress on diode D_c is

larger, it accounts for only half of output voltage V_o at a turn ratio of one. The voltage stresses on the diodes are lower as the voltage gain is extended by increasing turn ratio. The voltage stress on diode D_f equals the V_{C2} plus V_{C3} ,

which can be derived from

$$V_{Df1} = V_{Df2} = \frac{2n}{1-D} V_{in} = \frac{n}{n+1} V_o. \quad (9)$$

Although the voltage stress on the diode D_f increases as the turn ratio n increases, the voltage stress on the diodes D_f is always lower than the output voltage.

IV. CLOSED LOOP SYSTEM

Sometimes, we may use the output of the control system to adjust the input signal. This is called feedback. Feedback is a special feature of a closed loop control system. A closed loop control system compares the output with the expected result or command status, and then it takes appropriate control actions to adjust the input signal. Therefore, a closed loop system is always equipped with a sensor, which is used to monitor the output and compare it with the expected result. Fig. 12 shows a simple closed loop system. The output signal is fed back to the input to produce a new output. A well-designed feedback system can often increase the accuracy of the output [19]-[20].

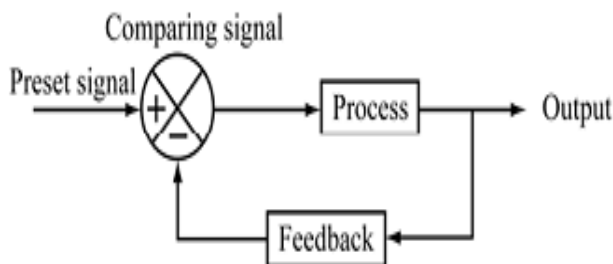


Fig. 12 Block diagram of a closed loop control system

Feedback can be divided into positive feedback and negative feedback. Positive feedback causes the new output to deviate from the present command status. For example, an amplifier is put next to a microphone, so the input volume will keep increasing, resulting in a very high output volume. Negative feedback directs the new output towards the present command status, so as to allow more sophisticated control. For example, a driver has to steer continuously to keep his car on the right track. Most modern appliances and machinery are equipped with closed loop control systems. Examples include air conditioners, refrigerators, automatic rice cookers, automatic ticketing machines, etc. One advantage of using the closed loop control system is that it is able to adjust its output automatically by feeding the output signal back to the input. When the load changes, the error signals generated by the system will adjust the output. However, closed loop control systems are generally more complicated and thus more expensive to make.

A. Operation of a Closed-Loop Control System

Most people may not think about control systems in their day to day activities. Control systems are used millions of times a day. Control systems are found in cars, home electronics, power plants, and cities worldwide. The most common type of control system is a closed loop system. The closed loop system consists of five essential processes. The processes are carried out in each basic part of a control system and they are: input transducer, summing junction, controller, plant or process, and the output transducer.

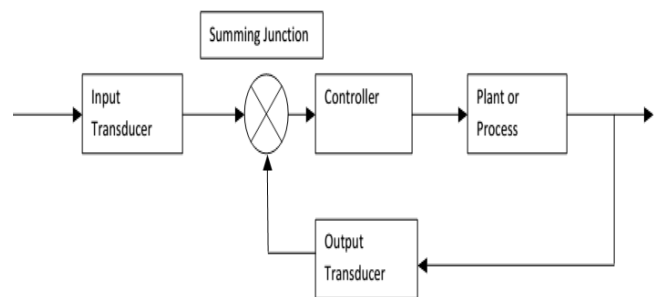


Fig. 13 Diagram of a Closed-loop Control System

The Proportional-Integral (P-I) controller is one of the conventional controllers and it has been widely used. The major features of the P-I controller are its ability to maintain a zero steady-state error to a step change in reference. A PI Controller (proportional-integral controller) is a special case of the PID controller in which the derivative (D) of the error is not used. The controller output is given by

$$K_p \Delta + K_i \int \Delta dt$$

V.SIMULATION RESULTS

Here the simulation carried by two different cases they are 1) High Step-Up Interleaved Converter with a Voltage Multiplier Module 2) High Step-Up Interleaved Converter with a Voltage Multiplier Module with Induction Machine Drive Connected System Using RES system.

Case-1 High Step-Up Interleaved Converter with a Voltage Multiplier Module

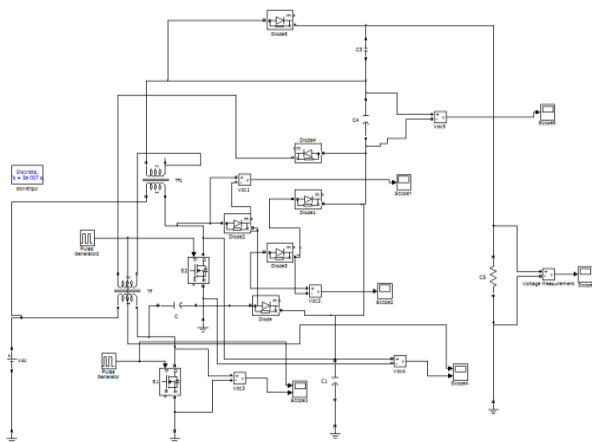


Fig.14 Simulink Model of High Step-Up Interleaved Converter with a Voltage Multiplier Module

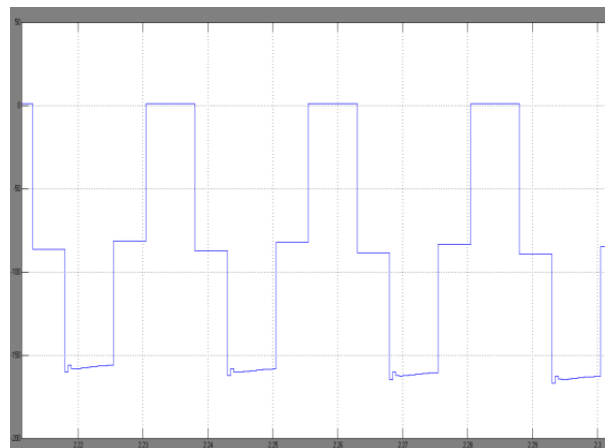


Fig.17 Shows the Simulated Output Waveform Voltage across Switched Capacitor

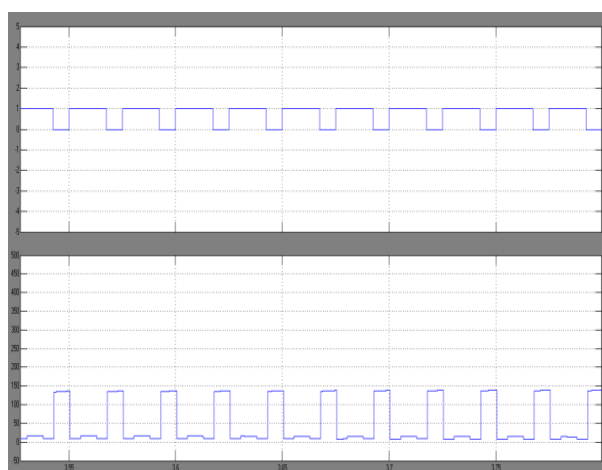


Fig.15 Power Switch S1 Gating Pulse and Output Voltage

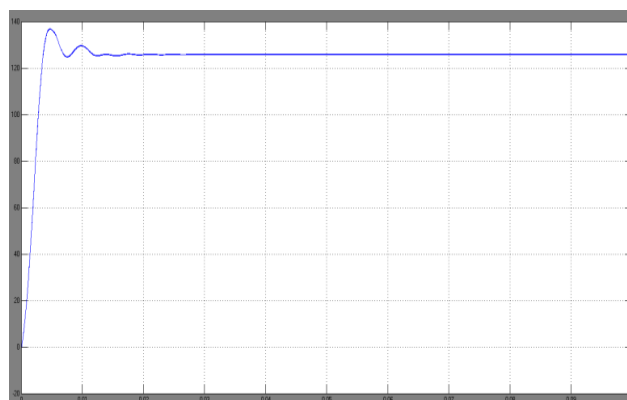


Fig.18 Output Voltage of Clamp Diode

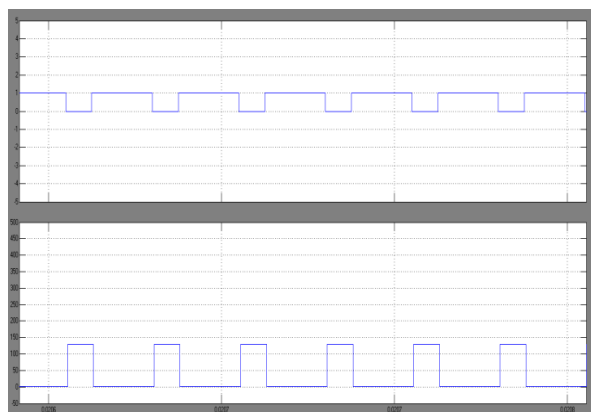


Fig.16 Power Switch S2 Gating Pulse and Output Voltage

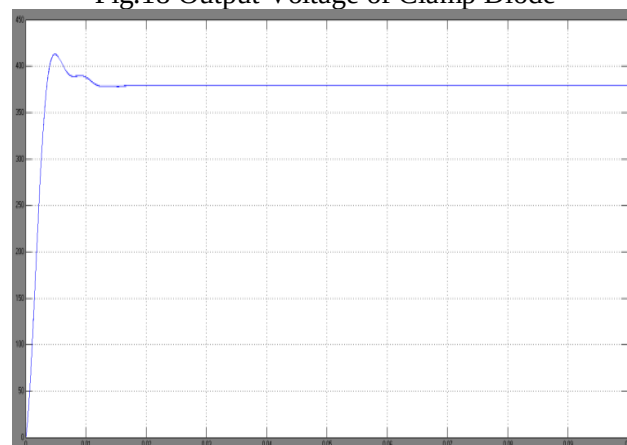


Fig.19 Shows the Output Voltage of High Step-Up Interleaved Converter operated under Open Loop condition.

Case 2: High Step-Up Interleaved Converter with a Voltage Multiplier Module with Induction Machine

Drive Connected System Using RES system

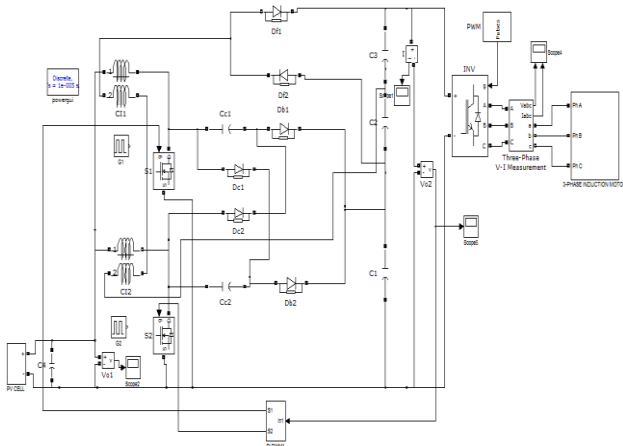


Fig.14 Simulink Model of High Step-Up Interleaved Converter with a Voltage Multiplier Module with Induction Machine Drive System using RES system



Fig.15 Output Voltage & Current

Fig.15 shows the Output Voltage & Current of High Step-Up Interleaved Converter with a Voltage Multiplier Module with Induction Machine Drive System.

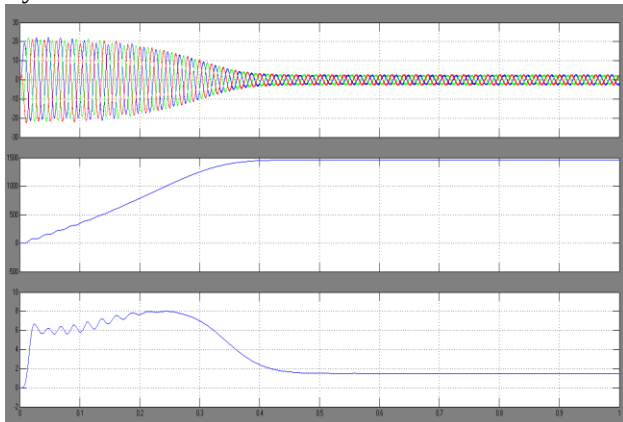


Fig.16 Stator Current, Speed, Electromagnetic Torque
Fig.16 shows the Stator Current, Speed, and Electromagnetic Torque of High Step-Up Interleaved

Converter with a Voltage Multiplier Module with Induction Machine Drive System for updating the drive characteristics.

VI. CONCLUSION

However, the extensive use of power electronics based equipment with pulse width modulated variable speed drives are increasingly applied in many new industrial applications that require superior performance. This paper has presented the simulation analysis of steady state value related consideration, for the proposed converter operated under open-loop & closed loop manner. The proposed converter has successfully implemented an efficient high step-up 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. Meanwhile, the voltage stress on the power switch is restricted and much lower than the output voltage (380 V). Furthermore, the full-load efficiency is improved at $P_o = 1000$ W, and the highest efficiency is nearly 97.1% at $P_o = 400$ W. Thus, the proposed converter is suitable for high-power or renewable energy applications that need high step-up conversion with efficient operation.

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