High Voltage Gain DC-DC Boost Converter based Photovoltaic System Using Multilevel Inverter fed Induction Motor

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Abstract— Solar energy is the most low cost, competition free, universal source of energy as sun shines throughout. This energy can be converted into useful electrical energy using photovoltaic technology. The effective operation of Induction motor is based on the choice of suitable converter-inverter system that is fed to Induction Motor. Converters like Buck, Boost and Buck-Boost converters are popularly used for photovoltaic systems. This review is mainly focused on high efficiency step-up DC/DC converters with high voltage gain. To obtain optimum motor performance and to reduce total harmonic distortion of the inverter output waveform, we employed sinusoidal pulse width modulation (SPWM) technique based multilevel inverter for switching of inverter power circuit. In order to maximize the power output the system components of the photovoltaic system should be optimized. Maximum power point tracking algorithm (Perturb & Observe) is used to extract maximum power from photovoltaic panel. The proposed inverter can be replaced with multilevel inverter and is implemented MATLAB/SIMULATION software for better control of motor.

Index Terms— DC–DC Power Conversion, Capacitor Modules, Interleaved Methodology, PI Controller.

I. INTRODUCTION

Renewable-energy-based micro-grids have appeared to be a better way of exploiting renewable energy and reducing the environmental risks of fossil fuels. In the view of the fact that most renewable energy sources (RES), such as photovoltaic (PV), fuel cell (FC) and variable speed wind power systems, generate either DC or variable frequency/voltage AC power, a power–electronics interface is an indispensable element for the grid integration [1, 2]. In addition, modern electronic loads such as computers, plug-in hybrid electric vehicles and even traditional AC loads such as induction motors, when driven by a variables speed drive require DC power. The multilevel inverters have been considered as a key element in such grid-connected systems. Producing an acceptable sinusoidal voltage waveform at the output and boosting the output voltage are two challenging issues. Using a transformer in the boost multilevel inverter increases the size and cost and decreases the efficiency of the system due to its bulky inductors. Multilevel Inverters (MLI) began with the neutral point clamped inverter topology proposed by Nabae et al. [3]. Recently, multilevel inverters have become more attractive for researchers due to their advantages over conventional three-level pulse width-modulated (PWM) inverters. MLI has two main advantages compared with the conventional H-bridge inverters, the higher voltage capability and the reduced harmonic content in the output waveform due to the multiple dc levels. MLI is now preferred in high power medium voltage applications due to the reduced voltage stresses on the devices.

The dc–dc boost converter can achieve a high step up voltage gain with an extremely high duty ratio. However, in practice, the step-up voltage gain is limited due to the effect of power switches, rectifier diodes, and the equivalent series resistance (ESR) of inductors and capacitors. Moreover, the extremely high duty-ratio operation will result in a serious reverse-recovery problem. A dc–dc fly back converter is a very simple structure with a high step-up voltage gain and an electrical isolation, but the active switch of this converter will suffer a high voltage stress due to the leakage inductance of the transformer. For recycling the energy of the leakage inductance and minimizing the voltage stress on the active switch, some energy-regeneration techniques have been proposed to clamp the voltage stress on the active switch and to recycle the leakage-ductance energy [4–6]. The coupled-inductor techniques provide solutions to achieve a high voltage gain, a low voltage stress on the active switch, and a high efficiency without the penalty of high duty ratio [7].

In general, a conventional boost converter can be adopted to provide a high step-up voltage gain with a large duty ratio. However, the conversion efficiency and the step-up voltage gain are limited due to the constraints of the losses of power switches and diodes, the equivalent series resistance of inductors and capacitors and the reverse recovery problem of diodes. However, the active switch of these converters will suffer very high voltage stress and...
high power dissipation due to the leakage inductance of the transformer. Although this configuration is useful in terms of system monitoring and repair, the partial shading, module mismatch, and dc connection cable losses are inevitable problems and lead to significantly reduced system energy yields [8]–[10]. The ac module, which has been proposed to improve these problems, consists of a single PV panel and a micro-inverter. The micro-inverter receives the low dc voltage from the PV panel and transforms it to ac voltage, then delivers it to the load or main electricity as would a small scale conventional PV inverter.

Fig.1 shows the energy of a single PV panel through the micro-inverter output to the main electricity; this is a general configuration of inverter with induction motor drive. The micro-inverter is inlaid in the rear bezel of the PV panel and outputs the ac current to the load or to the main electricity; this alternative solution not only immunizes the yield loss by shadow effect, but also provides flexible installation options according to the user’s budget [11]–[12]. Fig. 2 shows that the maximum power point (MPP) voltage range is from 15 V to 40 V with various power capacities of about 100 W to 300 W for a single commercial PV panel. When a wide input voltage range is essential for the single stage micro-inverter, high efficiency is difficult to achieve [13]. However, the dual-stage micro-inverter, which combines a high step-up dc/dc converter and dc/ac inverter, is able to achieve efficiency as high as the conventional PV string-type inverter [14]. Fig.1 also shows that the micro-inverter integrates a high step-up dc/dc converter and dc/ac inverter. The typical Zeta converter provides either a step-up or a step-down function to the output, in a manner similar to that of the buck-boost or SEPIHC converter topologies. The conventional Zeta converter is configured of two inductors, a series capacitor and a diode.

However, leakage inductance issues that relate to the voltage spike and the efficiency remain significant. An integrated boost-fly back converter [15] based on a coupled inductor with high efficiency and high step-up voltage gain has been presented. The energy stored in the leakage inductor is recycled into the output during the switch off period. Thus, the efficiency can be increased and the voltage stress on the active switch can be suppressed. Many step-up converters, which use an output voltage stacking to increase the voltage gain, are presented.

II. PROPOSED CONVERTER TOPOLOGY

The simplified circuit model of the proposed converter is shown in Fig. 3. The coupled inductor T1 includes a magnetizing inductor Lm, primary and secondary leakage inductors L4 and L4, and an ideal transformer primary winding N1 and secondary winding N2. To simplify the circuit analysis of the proposed converter, the following assumptions are made.

1) All components are ideal, except for the leakage inductance of coupled inductor T1. The ON-state resistance RDS (ON) and all parasitic capacitances of the main switch S1 are neglected, as are the forward voltage drops of the diodes D1–D4.
2) The capacitors C1–C3 are sufficiently large that the voltages across them are considered to be constant.
3) The ESR of capacitors C1–C3 and the parasitic resistance of coupled-inductor T1 are neglected.
4) The turn’s ratio n of the coupled inductor T1 winding is equal to N2/N1.

The operating principles for continuous-conduction mode (CCM) are now presented in detail. Fig. 4 shows the typical waveform of several major components during one switching period. The five operating modes are described as follows.

A. CCM Operation

Mode I[t1–t]: In this transition interval, the secondary leakage inductor L4 is continuously releasing its energy to capacitor C2. The current flow path is shown in Fig. 5(a);
as shown, switch $S_1$ and diodes $D_2$ are conducting. The current $i_{Lm}$ is descending because source voltage $V_{in}$ is applied on magnetizing inductor $L_m$ and primary leakage inductor $L_{k1}$; meanwhile, $L_m$ is also releasing its energy to the secondary winding, as well as charging capacitor $C_2$ along with the decrease in energy, the charging current $i_{D2}$ and $i_{C2}$ are also decreasing. The secondary leakage inductor current $i_{Lk2}$ is declining according to $i_{Lm}/n$. Once the increasing $i_{Lk1}$ equals the decreasing $i_{Lm}$ at $t=t_1$, this mode ends

$$i_{Lm}^I(t) = i_{DS}^I(t) = i_{Lk1}^I(t) (1)$$
$$\frac{di_{Lm}^I(t)}{dt} = \frac{v_{Lm}}{L_m} (2)$$
$$\frac{di_{Lk1}^I(t)}{dt} = \frac{V_{in} - v_{Lm}}{L_{k1}} (3)$$
$$i_{Lk2}^I(t) = \frac{i_{Lm}^I(t) - i_{Lk1}^I(t)}{n} (4)$$

Mode II[$t_1,t_2$]: During this interval, source energy $V_{in}$ is series connected with $C_1,C_2$, secondary winding $N_2$, and $L_{k2}$ to charge output capacitor $C_3$ and load $R$; meanwhile, magnetizing inductor $L_m$ is also receiving energy from $V_{in}$. The current flow path is shown in Fig. 4(b); as illustrated, switch $S_1$ remains on, and only diode $D_3$ is conducting. The $i_{Lm}$, $i_{Lk1}$, and $i_{D3}$ are increasing because the $V_{in}$ is crossing $L_{k1},L_m$ and primary winding $N_1:L_m$ and $L_{k1}$ are storing energy from $V_{in}$; meanwhile, $V_{in}$ is also in series with $N_2$ of coupled inductor $T_1$, and capacitors $C_1$ and $C_2$ are discharging their energy to capacitor $C_3$ and load $R$, which leads to increases in $i_{Lm}$, $i_{Lk1}$, $i_{D3}$, and $i_{D3}$. 

Fig. 3. Typical waveforms of the proposed converter at CCM operation.
This mode ends when switch S₁ is turned off at t=t₂

\[ i_{Lm}^{II}(t) = i_{Lk2}^{II}(t) = 0 \]

\[ \frac{di_{Lm}^{II}(t)}{dt} = \frac{V_{in}}{L_{m}} \]

\[ i_{Lm}^{III}(t) = i_{Lk1}^{III}(t) - ni_{Lk2}^{III}(t) \]

\[ \frac{di_{Lk2}^{III}(t)}{dt} = \frac{di_{Dk2}^{III}(t)}{dt} = \frac{nV_{Lm} + V_{C2} - V_{O}}{L_{k2}} \]  

Mode IV [t₃, t₄]: During this transition interval, the energy stored in magnetizing inductor Lₘ releases simultaneously to C₁ and C₂. The current flow path is shown in Fig. 4(d). Only diodes D₁ and D₂ are conducting. Currents iₖ₁ and iₖ₂ are persistently decreased because leakage energy still flows through diode D₁ and continues charging capacitor C₁. The Lₘ is delivering its energy through T₁ and D₂ to charge capacitor C₂. The energy stored in capacitors C₃ is constantly discharged to the load R. The voltage across S₁ is the same as previous mode. Currents L₁ and iₘ are decreasing, but i₄₂ is increasing. This mode ends when current iₖ₁ is zero at t=t₄

\[ i_{Lm}^{IV}(t) = i_{Lk1}^{IV}(t) - ni_{Lk2}^{IV}(t) \]

\[ \frac{di_{Lk1}^{IV}(t)}{dt} = -\frac{V_{C1} - V_{Lm}}{L_{k1}} \]

\[ \frac{di_{Lk2}^{IV}(t)}{dt} = \frac{V_{C2} + nV_{Lm}}{L_{k2}} \]

Mode V [t₄, t₅]: During this interval, magnetizing inductor Lₘ is constantly transferring energy to C₂. The current flow path is shown in Fig. 5(e), and only diode D₂ is conducting. The iₘ is decreasing due to the magnetizing inductor energy flowing continuously through the coupled inductor T₁ to secondary winding N₂ and D₂ to charge capacitor C₂. The energy stored in capacitors C₃ is constantly discharged to the load R. The voltage across S₁ is the summation of Vₐ and Vₗₐₘ. This mode ends when switch S₁ is turned on at the beginning of the next switching period

\[ \frac{di_{Lm}^{V}(t)}{dt} = \frac{V_{Lm}}{L_{m}} \]

\[ i_{Lk1}^{V}(t) = 0 \]

\[ \frac{di_{Lk2}^{V}(t)}{dt} = \frac{nV_{Lm} + V_{C2}}{L_{k2}} \]

III. MULTILEVEL INVERTER

The modified single phase five-level inverter uses a full bridge configuration and an auxiliary circuit. The circuit diagram is shown in Fig. 5.
IV. INDUCTION DRIVE

The ac power inverted by the multilevel inverter is fed to an induction drive. An induction or asynchronous motor is an AC electric motor in which the electric current in the rotor needed to produce torque is induced by electromagnetic induction from the magnetic field of the stator winding. An induction motor therefore does not require mechanical commutation, separate-excitation or self-excitation for all or part of the energy transferred from stator to rotor, as in universal, DC and large synchronous motors. An induction motor's rotor can be either wound type or squirrel-cage type. In induction, the AC power supplied to the motor's stator creates a magnetic field that rotates in time with the AC oscillations. The rotating magnetic flux induces currents in the windings of the rotor; in a manner similar to currents induced in a transformer's secondary windings. 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. Under load, the speed drops and the slip increases enough to create sufficient torque to turn the load. 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.

V. MATLAB MODELING AND SIMULATION RESULTS

Here the simulation is carried out by two cases, in that 1. Proposed DC/DC Converter, 2. Proposed DC/DC Converter with PV system and Induction motor.

Case 1: Proposed DC/DC Converter

![Matlab Simulink Model of Proposed DC/DC Converter Operating Under Open Loop Condition](image1)

Fig.6. shows the Matlab/Simulink Model of Proposed DC/DC Converter Operating Under Open Loop Condition using Matlab/Simulink Tool.

![Output Voltage](image2)

Fig.7. shows the Output Voltage of Proposed DC/DC Converter Operating under Open Loop Condition, due to non-presence of feedback system attains low stable operation, attains 0.02 sec for fast response.
Fig. 8. Output Power
Fig. 8. shows the Output Power of Proposed DC/DC Converter.

Fig. 9. Switching States, Vds, Ids
Fig. 9. shows the Switching States, Vds, Ids of Proposed DC/DC Converter Operating under Open Loop Condition.

Case 2: Proposed DC/DC Converter Operating with PV system and Induction motor.

Fig. 10. Matlab/Simulink Model of Proposed DC/DC Converter Operating with PV system and induction motor.
Fig. 10. shows the Matlab/Simulink Model of Proposed DC/DC Converter Operating with PV system and induction motor using Matlab/Simulink Tool.

Fig. 11. inverter output voltage without filter.
Fig. 11. shows the Output Voltage of five level inverter each phase output voltage without filter (a, b, c).

Fig. 12. inverter voltage with filter.
Fig. 12 shows the five level inverter output voltage with filter.

Fig. 13. Simulation results for stator current, speed and electromagnetic torque of the motor.

VI. CONCLUSION
The high step up dc–dc converters are usually used as the front-end converters to step from low voltage to high voltage which are required to have a large conversion ratio, high efficiency, and small volume. The proposed converter employs the turns ratio of the coupled inductor to achieve high step-up voltage gain; based on the floating switch structure of the boost converter, this design successfully isolates the energy from the PV panel when the converter is non-operational, which helps to prevent
injury to humans or damage to facilities. Also this technique features easy implementation and more importantly, minimum harmonic content in the inverter output voltage and current of the Induction Motor Load. The simulation with multilevel converter with induction motor has been done and the output is verified.

REFERENCES


