RESEARCH ARTICLE

Cascade Multilevel Inverter for Grid-Connected Hybrid Solar and Wind Energy Systems

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ABSTRACT

In today's global energy landscape, power generation from renewable energy sources is becoming increasingly important. The primary reasons for this are the scarcity of fossil fuels and the environmental risks connected with existing energy producing technologies. The most popular grid-connected renewable energy systems are solar photovoltaic and moreover wind energy systems. This research provides a new system design for a hybrid solar and wind energy system that is grid-connected. This strategy enables these renewable energy sources to deliver the load simultaneously or separately, depending on availability. The suggested architecture employs a reformed five level inverter topology to convert DC voltage provided by renewable energy sources to AC voltage at 50 Hz. The use of a five-level inverter drops the level of total harmonic distortion (THD) in output voltage and assists in eliminating the need for bulk filters on the output side. A simulation study of the suggested technique has been carried out using MATLAB Simulink, and the outcomes of simulation have been presented.

Keywords: Total Harmonic Distortion, Wind energy system, Photovoltaic system, Renewable energy system.

INTRODUCTION

Because of the scarcity of fossil fuels and the greenhouse impact, demand for renewable energy has skyrocketed in recent years. Solar and wind energy, among other renewable energy sources, have grown in popularity and demand as power electronics techniques have advanced. Photovoltaic sources are now widely used in a variety of applications because to their low maintenance and pollution-free nature. Over the last 20 years, solar-electric-energy consumption has grown at a constant rate of 20%-25% per year, owing primarily to lower costs and prices. The rising energy demand, higher expenses, the short-term availability of fossil fuels, and worldwide environmental pollution have sparked intense interest about renewable energy options. Aside from hydroelectric electricity, wind and solar are the predominant and efficient energy sources for fulfilling our power needs. Wind energy can provide massive amounts of power, but its availability is inconsistent. Solar electricity is accessible throughout the day, even though solar irradiance levels fluctuate due to incessant variations in the sun's shadows and intensity generated by many kinds of factors. In general, wind and sun power complement each other. Based on this, the hybrid photovoltaic and wind energy system delivers more consistent power than either system alone. Another advantage of the hybrid system is that it requires less battery storage because it operates more reliably than independent systems. This study also discusses the most important control and modulation methods established for this type of converter: multilevel sinusoidal PWM, selective elimination of harmonic in multilevel, and SVM. Special emphasis is given to the most recent and relevant uses of these converters, such as laminators, conveyor belts, and unified power-flow controllers. The need for an active front end on the input side of inverters supplying regenerative loads is also examined, as are the circuit layout alternatives. Finally, [1] addresses peripherally emerging sectors such as high-voltage, high-power devices and optical sensors, as well as other potential future development opportunities.

A review of various multilevel topologies and their applicability of grid connected solar systems. Several transformer-less photovoltaic systems with multilayer converters are examined in terms of component count and stress, system energy rating, and the impact of photovoltaic array earth capacitance [2]. Various topologies used for inverters are given, contrasted, and evaluated in terms of demand, longevity, component rating, and cost. Finally, various topologies are identified as the most promising for either single or multiple PV module applications [3]. Photovoltaic power is generated using solar panels made up of a number of solar cells containing photovoltaic material. Multilevel inverter architectures have been designed to address inadequacies in solid-state switching device ratings, allowing them to be used in high voltage electrical systems. The multilayer voltage source inverter's unique structure enables them to achieve high voltages with low harmonics without the usage of transformers. This results in unique power electronics topologies that are appropriate for Flexible AC Transmission Systems and specialized power applications [4]. A unique way for connecting renewable energy sources to the electric grid. Due to the rising power capability of available generation systems, a three-level three-phase neutral-point-clamped voltage-source inverter is chosen as the heart of the interface system [5]. The regulator employs a multivariable control law due to the system's inherent multivariable structure. To validate the suggested approach's good performance, a current source (playing the role of a generic renewable energy source) is connected to the grid via a three-level inverter [6].
A single-phase, five-level PV inverter designed for grid-connected installations, with a revolutionary PWM control technique. The switches' PWM signals were generated using two similar reference signals offset by the amplitude of the triangle carrier signal. The proposed system is validated through modeling and implemented as a prototype, and the experimental results are compared to those of a standard single-phase three-level grid-connected PWM inverter [7]. This arrangement enables the two sources to serve the load separately or concurrently, depending on the availability of the energy sources. This cuk-SEPIC fused converter's intrinsic design eliminates the need for extra input filters to filter out high frequency harmonics. This project discusses the closed loop mechanism of the CUK and SEPIC converters, and the simulation results are shown in [8].

IMPLEMENTATION OF PROPOSED TECHNIQUE

DC-DC Converter

The converter of DC-DC with a large step-up voltage gain is utilized in a variety of applications, including high-intensity discharge lamp ballasts for automobile headlamps, fuel cell energy conversion systems, solar cell energy conversion systems, and battery backup systems for uninterruptable power supplies. In theory, a DC-DC Boost Converter can achieve a large step-up voltage gain while maintaining an exceptionally high duty ratio. In practice, the step-up voltage gain is restricted by power switches, rectifier diodes, and the equivalent resistance of capacitors and inductors. Fig. 1 depicts a high step-up DC-DC converter equipped with an filter for reduction of common mode electromagnetic interference and integrated coupling inductor. Here, a converter of step- up-flyback with a linked inductor and output voltage stacking is created. A high step-up converter with a connected inductor and a doubler of voltage approach on the stacking of output voltage is introduced. A boost converter with high step-up with numerous connected inductors at the output V_0.

Boost Converter

The principle of a Boost Converter consists of two distinct states:

- In the On-state, the switch S closes, increasing the inductor current.
- In the Off-state, the switch S is open, leaving just the flyback diode D, capacitor C, and load R_L for the inductor current to flow through it and Fig. 2 depicts the boost converter.

Continuous mode

When a boost converter functions in continuous mode, and also the current through the inductor I_L never reaches zero. Fig. 3 depicts typical waveforms of currents and voltages in a converter operating in this mode. The output voltage is computed as follows in the case of an ideal converter, which uses components with perfect behavior during steady-state operation.

During the On-state, the switch S is closed, causing the input voltage Vi to appear across the inductor, resulting in a change in current IL flowing through the inductor during a time period t as defined by the formula:

$$\frac{\Delta I_L}{\Delta t} = \frac{V_i}{L}$$

The increase of I_L at the end of the On-state is

$$\Delta I_{Lon} = \frac{1}{L}\int_0^{DT} V_i dt = \frac{DT}{L} V_i$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is ON. Therefore D ranges between 0 i.e., Switch is never on and 1 i.e., S is always on.

During the off-state, switch S is open, allowing inductor current to pass through the load. If we consider zero voltage drops in the diode and capacitor large enough to keep the voltage constant, the flow of I_L is:

$$V_i - V_0 = L\frac{dI_L}{dt}$$

Therefore, the variation of I_L during the Off-period is

$$\Delta I_{Loff} = \int_{DT}^{T} \frac{(V_i - V_0)dt}{L} = \frac{(V_i - V_0)(1-D)T}{L}$$

the duty cycle to be

$$D = 1 - \frac{V_i}{V_0}$$

The above expression demonstrates that the output voltage is always greater than the input voltage as the duty cycle progresses from 0 to 1, and that it grows with D, theoretically reaching infinity as D approaches 1. This converter is also named as a step-up converter.

Discontinuous mode

If the ripple content of the current is too large, the inductor may be entirely discharged before the end of the commutation cycle. This is usual with light loads. In this situation, the current through the inductor drops to zero for

a portion of the period, as depicted in Fig.4. Although the change is modest, it has a more significant impact on the output voltage equation.
the gain of the output voltage can be expressed as follows:

$$\frac{V_o}{V_i} = 1 + \frac{V_i D^2 T}{2L\, I_o}$$

Cascaded H-Bridge Multilevel Inverter

Cascaded H-Bridge arrangement has lately gained popularity in high-power AC supply. A cascaded multilevel inverter consists of a sequence of H-bridge, or single-phase full bridge inverter units, in each of its three phases, as illustrated in Fig. 5. The ac terminal voltages of different level inverters are linked in series using various arrangements of the four switches, S1-S4. Each converter level can provide three different voltage outputs, namely +Vdc, -Vdc, and 0. The AC outputs of various full-bridge converters in the identical phase are linked in series, resulting in a synthetic voltage waveform which is the total of the converter outputs. The output-phase voltage levels numbering is determined differently than for other converters, such as diode clamped and flying capacitor. In this structure, the sum of output-phase voltage levels is denoted by m = 2N+1, where quantity of DC sources is N. A seven-level cascaded converter, for example, has three DC sources and three full bridge converters. Controlling the conducting angles at various converter levels can help to achieve the lowest harmonic distortion. Each H-bridge unit generates a quasi-square waveform by altering the positive and negative phase legs' switching timings. Five-level cascaded inverters will include two SDCS and two full-bridge cells. The sequence of switching of five-level cascaded inverter is deliberated in Table 1. Two complete Bridges are used and cascaded to each other. Switches S1, S2, S3, & S4 are from the upper H-bridge, while S5, S6, S7, and S8 are from the lower H-bridge. We can acquire five voltage levels by incorporating the suitable switching strategy. The switching table below shows how to get 5 levels using a symmetrical DC source.

PV/WIND BASED MULTILEVEL INVERTER FOR GRID CONNECTED SYSTEM

The maintenance of output voltage is constant, this study uses a boost converter in a solar photovoltaic system and a buck converter in a wind energy system. It enables battery charging with a steady voltage. A five-level inverter converts the battery's dc voltage to ac voltage and connects it to the grid. Multilevel inverters generate the necessary voltage by combining different levels of direct current voltages as inputs. As the number of levels increases, so does the output waveform, which transforms into a staircase wave with increasing steps. Thus, the output voltage approaches the ideal sinusoidal waveform. The precise significant benefits of employing multilayer inverter technique are lower power ratings for power devices and lower costs.. The main idea behind a multilayer converter is to increase the operating voltage by connecting power semiconductor switches with significantly lower voltage ratings than those used in a normal two-level inverter. These power switches are programmed such that a extreme number of voltage levels are generated at the output from numerous dc sources. A multilayer inverter has the advantage of being able to generate output voltages with extremely low THD, draw input current with low distortion, and work over the switching frequencies are a wide range from nominal reference frequency to utmost extreme frequency. The most common topologies of multilevel inverter are flying capacitor, diode clamped and cascaded H-bridge multilevel inverters. This paper proposes a redesigned multilayer inverter with fewer input DC switches and sources.

Proposed System Architecture

In order to confirm the battery charges smoothly, the voltage in the input should be constant. So the solar panel's output is sent through a boost converter to maintaining a consistent voltage. The wind generator employed here is a 230V AC induction generator. A rectifier converts the wind generator's output to DC, which is then supplied via a buck converter to maintain a steady output voltage. So the battery will be charged with both solar and wind energy. The battery output is supplied into a five-level multilevel inverter, which transforms it to alternating current (ac). Fig. 6 shows a block diagram of the proposed architecture. The voltage in between the each DC capacitor is VDC / 2. The suggested inverter generates five levels of output voltage: VDC, VDC/2, 0, -VDC/2, and -VDC. An auxiliary circuit of four diodes and a switch is used to generate five voltage levels at the output. The proper switching sequence in this modified circuit produces five levels of output voltage.

RESULTS AND DISCUSSIONS

The MATLAB SIMULINK has been used to verifying the proposed inverter simulations. Table 1 illustrates the PWM switching approach employed in this paper. It is composed of reference signals and a triangle carrier signal. Both the reference signals are compared to the triangle carrier signal and PWM switching signals are generated for the inverter circuit's switches S1 through S5. It is worth noticing that one leg of the inverter switches at a fast rate equal to the frequency of the carrier signal, while the other leg switches at the fundamental frequency (50 Hz). The switch in auxiliary circuit S1 operates at the same frequency as the carrier signal. As previously stated, the modulation index M determines the form of the inverter output voltage Vinv and grid current Ig. Fig.'s 7-9 depict Vinv and Ig for various values of M. To inject current into the grid, set the dc-bus voltage to 400 V (greater than √2Vg, in this example, Vg =240 V). Figure 9 shows that Vinv is less than √2Vg since M is less than 0.5. The inverter should not operate at this condition because the current will be injected from the grid into the inverter, rather than the PV system injecting the current into the grid, as shown in Fig. 8. Over modulation condition, which happens when *M* >1.0, is shown in Fig. 10. It has a flat top at the peak of the positive and negative cycles because both the reference signals exceed the maximum amplitude of the carrier signal. This will cause *Ig* to have a flat portion at the peak of the sine waveform, as shown in Fig. 11. To optimize the power transferred from PV arrays to the grid, it is recommended to operate at 0.5< *M* < 1.0. *V*inv and *Ig* for optimal operating condition. As shown in fig.8,9. *Ig* is almost a pure sine wave, the THD can be reduced compared with that below of other values of *M*. The performance of the PI current control scheme has analyzed, a sudden step change is applied to the simulation process. This step change is similar to real-time environment condition (for example, the sun is emerging from the clouds). The Table 2 show the comparison of THD values.

CONCLUSION

This study describes the modeling and simulation of a five-level inverter driven by renewable energy sources. There are two sources of electricity: solar and wind. A boost converter for a solar photovoltaic system and a buck converter for a wind energy system maintain a steady output voltage. A five-level inverter converts the battery's dc voltage to ac power and connects it to the grid. The use of a five-level inverter decreases THD in output voltage and helps to eliminate the need for bulk filters on the output side. With an increase in the number of levels, the resulting output waveform becomes a staircase wave with more steps, approaching the required sinusoidal waveform. The proposed five-level inverter topology has less number of switches and input DC sources in comparison with conventional cascaded H-bridge configuration.

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Table 1: The Switching Sequence

S_1	S_2	S_3	S_4	S_5	V_{inv}
0	1	0	0	1	V_{dc}
1	0	0	0	1	$V_{dc}/2$
0	1	0	1	0	0
0	0	1	0	1	
1	0	0	1	0	$-V_{dc}/2$
0	0	1	1	0	$-V_{dc}$

Table 2: The Comparison of THD Values

level	THD
5-level	48.56%
7-level	26.41%

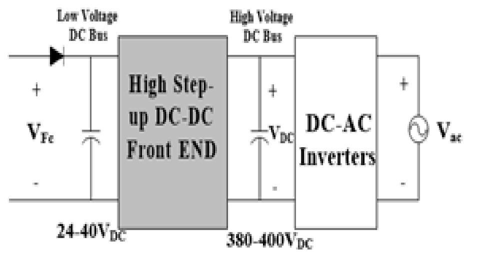

Fig. 1: General Power generation system with a high step-up converter

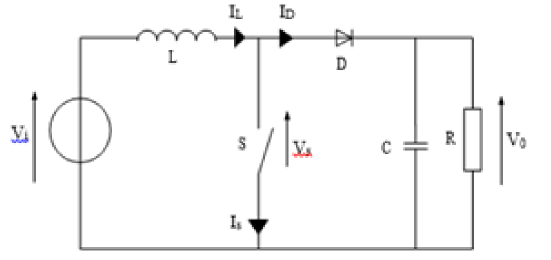

Fig. 2: Overall diagram of Boost Converter

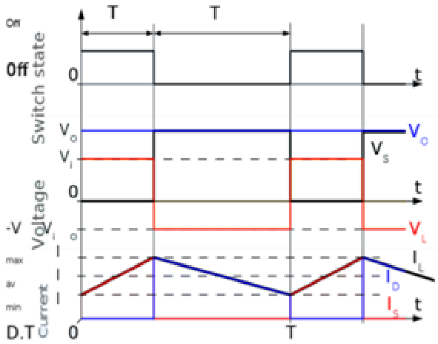

Fig. 3: Waveforms of current and voltage in a boost converter operating in continuous mode

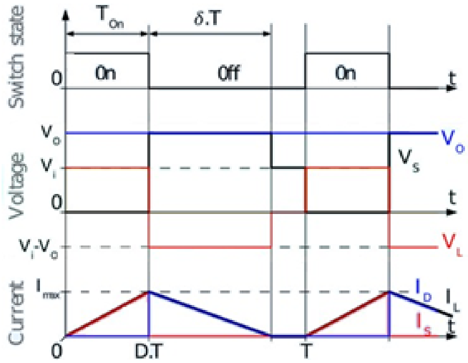

Fig. 4: Waveforms of current and voltage in a boost converter operating in discontinuous mode

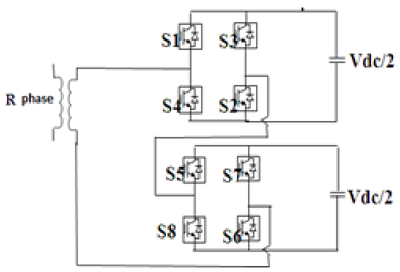

Fig. 5: Symmetrical Cascaded H-Bridge Inverter with five level

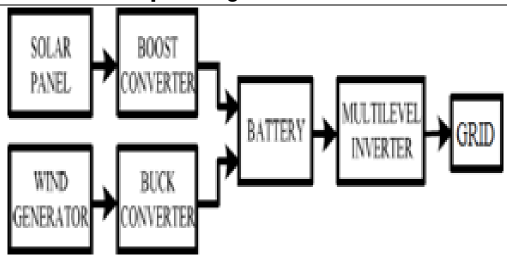

Fig. 6: The Architecture of Proposed System

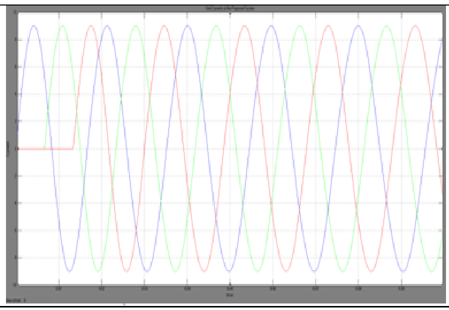

Fig. 7: Output Voltage Waveform of the Proposed System

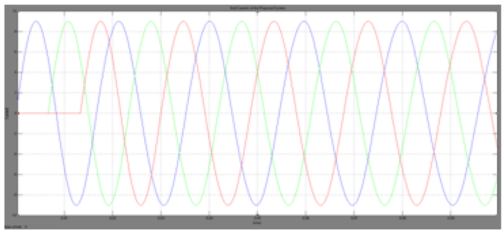

Fig. 8: Grid Currents of the Proposed System

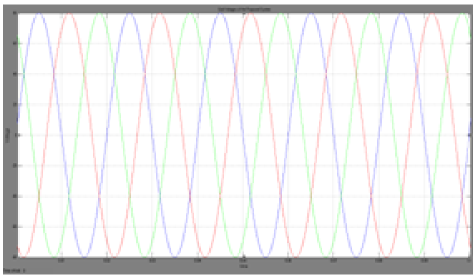

Fig. 9: Grid Voltages of the Proposed System

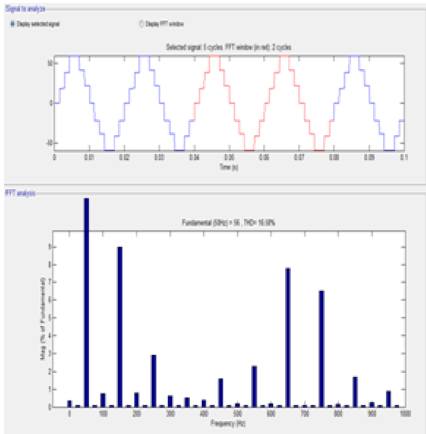

Fig. 10: THD for a Five Level Inverter

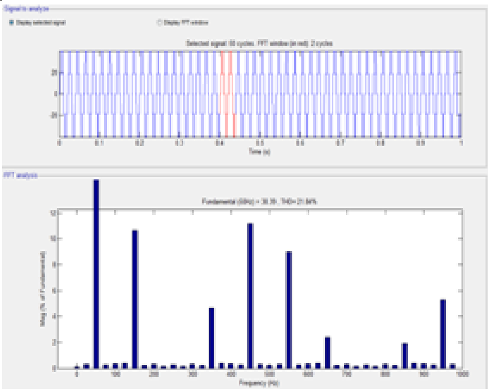

Fig. 11: THD for a Seven Level Inverter