# A Single Phase Multistring Multi level Inverter Topology for Distributed Energy Resources using Space Vector Modulation

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**Abstract- The objective of this paper is to study a seven level multi string inverter topology for DERs based DC/AC conversion system using SVM. In the micro grid system, the distributed energy resources (DER) based single-phase inverter is usually adopted. In order to reduce conversion losses in the system, the key is to save costs and size by removing any kind of transformer as well as reducing the power devices.**

**In this study, a high step-up converter is introduced as a front-end stage to improve the conversion efficiency of conventional boost converters and to stabilize the output DC voltage of various DERs such as PV and fuel cell modules for use with the simplified multilevel inverter. The simplified multilevel inverter requires only six active switches instead of the eight required in the conventional cascaded Hbridge (CCHB) multilevel inverter. In addition, two active switches are operated under line frequency. The studied multi string inverter topology offers strong advantages such as improved output waveforms, smaller filter size. Simulation and experimental results show the effectiveness of the proposed solution.**

Index terms – multi level converters, dc/dc converters, space vector modulation.

## INTRODUCTION

With increasing concern of global warming and the depletion of fossil fuel reserves, many are looking at sustainable energy solutions to preserve the earth for the future generations. Other than hydro power, photovoltaic energy holds the most potential to meet our energy demands. Alone, solar energy is capable of supplying large amounts of power but its presence is highly unpredictable as it can be here one moment and gone in another. Similarly, solar energy is present throughout the day but the solar irradiation levels vary due to sun intensity and unpredictable shadows cast by clouds, birds, trees, etc. Fuel Cell converts the chemical energy to electrical energy with higher efficiency.

The common inherent drawback of photovoltaic systems is their intermittent natures that make them unreliable. However, by combining these two intermittent sources and by incorporating maximum power point tracking (MPPT) algorithms, the system's power transfer efficiency and reliability can be improved significantly. The integration of renewable energy sources and energy-storage systems has been one of the new trends in power-electronic technology. The increasing number of renewable energy sources and distributed generators requires new strategies for their operations in order to maintain or improve the power-supply stability and quality. Combining multiple renewable resources via a common dc bus of a power converter has been prevalent because of convenience in integrated monitoring and control and consistency in the structure of controllers as compared with a common ac type. Dynamic performance of Fuel cell and solar system is analyzed. A system model was developed and compared with a real system. Several methodologies for optimal design or unit sizing.

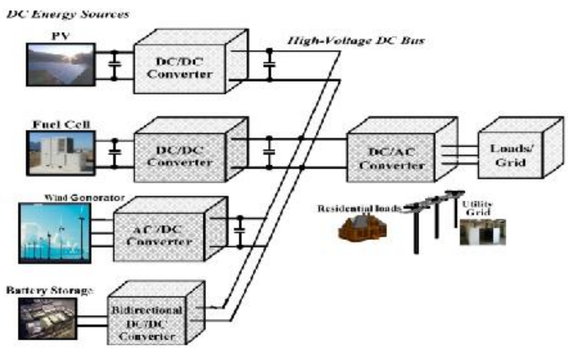



Fig 1: General Hybrid System

Most applications are for stand-alone operation, where the main control target is to balance local loads. A few grid-connected systems consider the grid as just a back-up means to use when there is insufficient supply from renewable sources.Such hybrid systems, focusing on providing sustainable power to their loads, do not care much about the quality or flexibility of power delivered to the grid. From the perspective of utility, however, a hybrid system with less fluctuating power injection or with the capability of flexibly regulating its power is more desirable. In addition, users will prefer a system that can provide multiple options for power transfer since it will be favorable in system operation and management. Control strategies of such a hybrid system should be quite different from those of conventional systems.

This project addresses dynamic modeling and control of a grid-connected Fuel Cell– PV–battery hybrid system with versatile power transfer. The hybrid system, unlike conventional systems, considers the stability and dispatch-ability of its power injection into the grid. The hybrid system can operate in three different modes, which include normal operation without use of battery, dispatch operation, and averaging operation.

The concept and principle of the hybrid system and its supervisory control are described. Classical techniques of maximum power tracking are applied in PV array control. Dynamic modeling and simulations were based on Power System Computer Aided Design with MATLAB/SIMULINK. The program was based on Dommel's algorithm, specifically developed for the simulation of high-voltage direct current systems and efficient for the transient simulation of power system under power-electronic control.

## SYSTEM CONFIGURATION OF OPERATION PRINCIPLES

A general overview of different types of photovoltaic (PV) modules or fuel cell inverters is given in figure. This paper presents a multistring multilevel inverter for DERs application. The multistring inverter shown in Fig. 1 is a further development of the string inverter, whereby several strings are interfaced with their own DC/DC converter to a common inverter. This centralized system is beneficial because each string can be controlled individually. Further enlargements are easily achieved because a new string with a DC/DC converter can be plugged into the existing platform, enabling a flexible design with high efficiency. This topology configuration consists of two high step-up DC/DC converters connected to their individual DC bus capacitor and a simplified multilevel inverter. The studied simplified five-level inverter is used instead of a conventional phase disposition (PD) pulse width modulated (PWM) inverter because it offers strong advantages such as improved output waveforms, smaller filter size, and lower electromagnetic interference and THD. It should be noted that, by using the independent voltage regulation control of the individual high step-up converter, voltage balance control for the two bus capacitors *Cbus1*, *Cbus2* can be achieved naturally.

## A. High Step-Up Converter Stage

In this study, high step-up converter topology is introduced to boost and stabilize the output DC voltage of various DERs such as PV and fuel cell modules for employment of the proposed simplified multilevel inverter. The architecture of a high step-up converter initially introduced from figure, depicted in Fig. 2, and is composed of different converter topologies: boost, flyback, and a chargepump circuit.

The coupled inductor of the high step-up converter in Fig. 2 can be modeled as an ideal transformer, a magnetizing inductor, and a leakage inductor. According to the voltage seconds balance condition of the magnetizing inductor, the voltage of the primary winding can be derived as

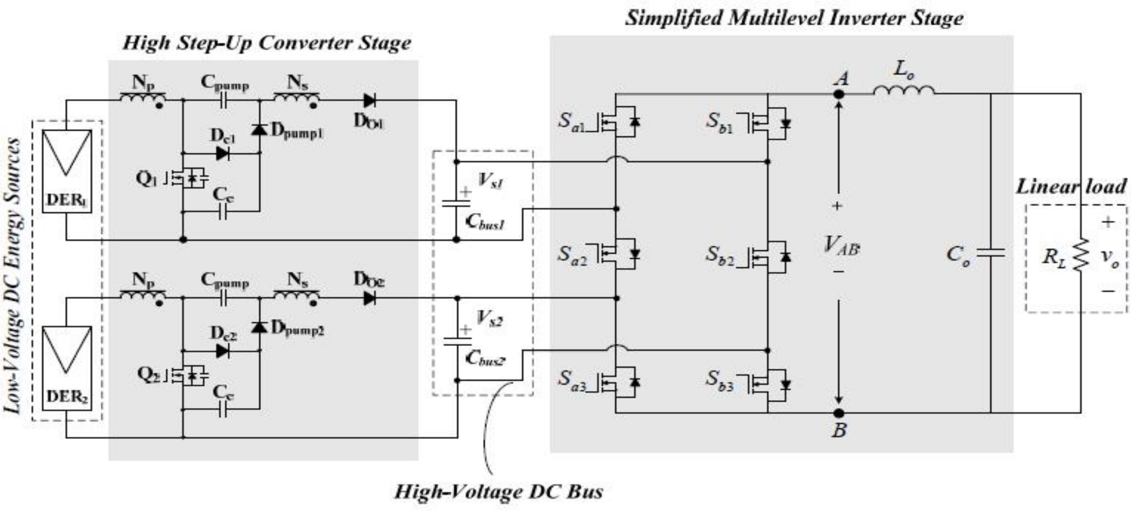



Fig. 2 Single-phase multistring five-level inverter topology

$$v_{pri} = V_{in} \cdot D/(1-D)$$ ………………(1)

Where *Vin* represents each the low-voltage DC energy input sources, and voltage of the secondary winding is

$$v_{sec} = N_s/N_p \cdot v_{pri} = N_s/N_p \cdot V_{in} \cdot D/(1-D)$$ ..……………(2)

Similar to that of the boost converter, the voltage of the charge-pump capacitor *Cpump* and clamp capacitor *Cc* can be expressed as $$v_{Cp} = v_{Cc} = V_{in} \cdot 1/(1-D)$$ ..…………..….(3)

Hence, the voltage conversion ratio of the high step-up converter, named input voltage to bus voltage ratio, can be derived as

$$\frac{V_{si}}{V_{in}} = \left(2 + \frac{N_s}{N_p} \cdot D\right) \Big/ (1-D) \Big|_{i=1,2}$$ ….……………(4)

## B. Simplified Multilevel Inverter Stage

To assist in solving problems caused by cumbersome power stages and complex control circuits for conventional multilevel inverters, this work reports a new single-phase multistring topology, presented as a new basic circuitry in Fig. 3.

Referring to Fig. 2, it should be assumed that, in this configuration the two capacitors in the capacitive voltage divider are connected directly across the DC bus, and all switching combinations are activated in an output cycle. The dynamic voltage balance between the two capacitors is automatically controlled by the preceding high step-up converter stage. Then, we can assume *Vs1=Vs2=Vs*.

This topology includes six power switches—two fewer than the CCHB inverter with eight power switches—which drastically reduces the power circuit complexity and simplifies modulator circuit design and implementation. The SVM control scheme is introduced to generate switching signals and to produce seven output-voltage levels.

For convenient illustration, the switching function of the switch in Fig. 3 is defined as follows:

$$S_{aj} = \begin{cases} 1, & S_{aj}\ ON \\ 0, & S_{aj}\ OFF \end{cases}, \quad j = 1, 2, 3$$ …………..(5)

$$S_{bj} = \begin{cases} 1, & S_{bj}\ ON \\ 0, & S_{bj}\ OFF \end{cases}, \quad j = 1, 2, 3$$ …..………..(6)

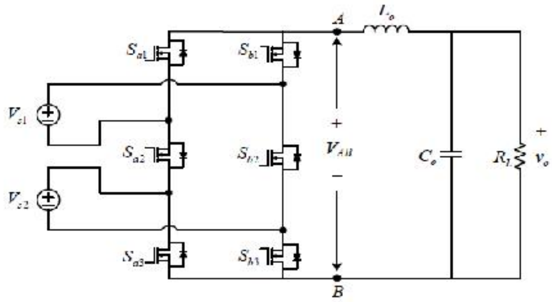
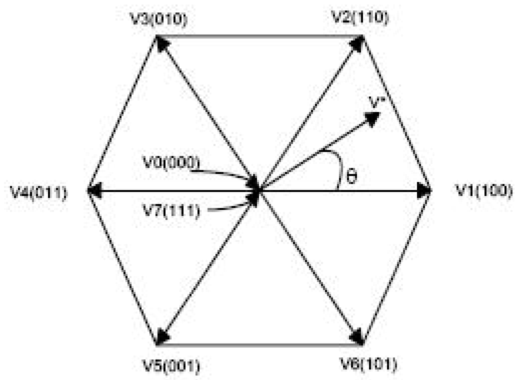


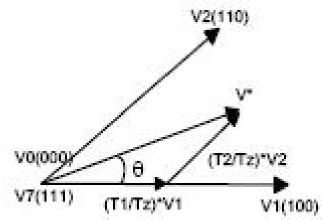
Fig. 3

Basic five-level inverter circuitry.

Table I. lists switching combinations that generate the required seven output levels. The corresponding operation modes of the multilevel inverter stage are described clearly as follows:




(a)




(b)

Fig. 4 Modulation strategy: (a) space vector signals; (b) Switching times.

TABLE I.
SWITCHING COMBINATIONS

| $S_{a1}$ | $S_{a2}$ | $S_{a3}$ | $S_{b1}$ | $S_{b2}$ | $S_{b3}$ | $V_{AB}$ |
|---|---|---|---|---|---|---|
| 0 | 1 | 0 | 1 | 0 | 1 | $2V_S$ |
| 0 | 1 | 1 | 1 | 0 | 0 | $V_S$ |
| 1 | 1 | 0 | 0 | 0 | 1 | $V_S$ |
| 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 0 | 0 | 1 | 1 | $-V_S$ |
| 0 | 0 | 1 | 1 | 1 | 0 | $-V_S$ |
| 1 | 0 | 1 | 0 | 1 | 0 | $-2V_S$ |

To verify the feasibility of the single-phase seven-level inverter, a widely used software program PSIM is applied to simulate the circuit according to the previously mentioned operation principle. The control signal is shown in Fig. 4.

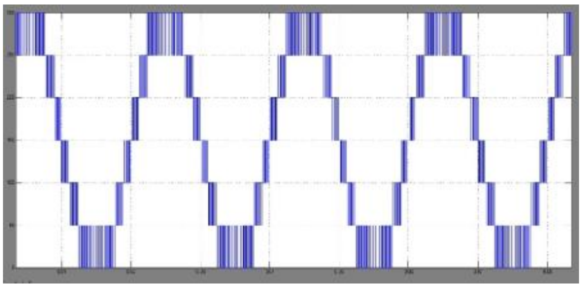


Fig. 5 Simulated waveforms of phase voltage *VAB* of inverter stage [Scale: 100V/div]

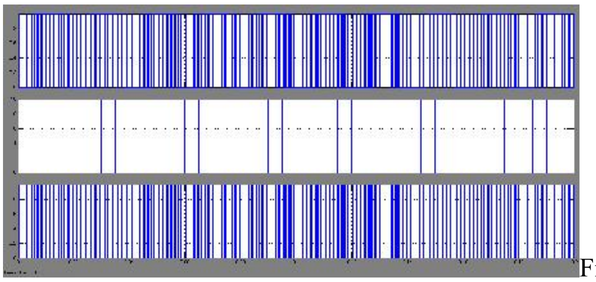


Fig. 6 Simulated waveforms of switch voltage for inverter stage within a line period. [Scale: 100V/div]

## C. Comparison with CCHB inverter

The average switching power loss *Ps* in the switch caused by these transitions can be defined as

$$P_S = 0.5V_{DS}I_o f_s\left[t_{c(on)} + t_{c(off)}\right] \qquad \text{…………(7)}$$

Where *tc(on)* and *tc(off)* are the turn-on and turn-off crossover intervals, respectively; *VDS* is the voltage across the switch; VDS and *Io* is the entire current which flows through the switch.

Similarly, the switching power loss of the proposed single-phase five-level inverter due to six switches can also be obtained as

$$P_{s,proposed} \propto 4V_s f_s + 2(2V_s) f_m \propto 4V_s(f_s + f_m) \qquad \text{………(10)}$$

Because switches Sa2, Sb2 can only be activated twice in a line period (60Hz) and the switching frequency is larger than the line frequency (*fs*>>*fm*), the switching losses of the proposed circuit is approximated to 4*Vsfs* . Obviously, the switching power loss is nearly half that of the CCHB inverter.

Compared with the CCHB circuit topology as shown in Fig. 7, the voltage stresses of the eight switches of the CCHB inverter are all equal to *Vs*.

For simplification, both the proposed circuit and CCHB inverter are operated at the same turn-on and turn-off crossover intervals and at the same load *Io*. Then, the average switching power loss *Ps* is proportional to *VDS* and *fs* as

$$P_S \propto V_{DS} f_S \qquad \text{..…………(8)}$$

According to Eq. (8) and Table IV, the switching losses of the CCHB inverter from eight switches can be obtained as

$$P_{S,H-bridge} \propto 8V_S f_S$$

…………….(9)

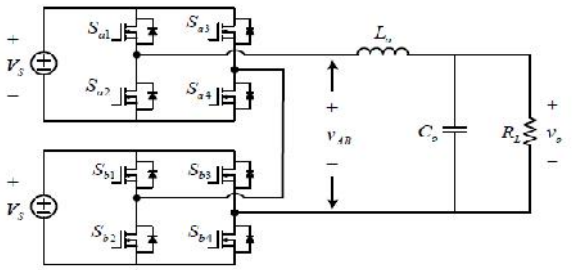



Fig. 7 seven level inverter topologies of CCHB inverter

TABLE II.
Harmonics of $V_{AB}$ for CCHB Inverter

| h | $m_a$=0.7 | $m_a$=0.8 |
|---|---|---|
| Fundamental 1 | 128.866V | 150.984V |
| 3 | 2.810V | 2.780V |
| 5 | 1.632V | 1.604V |
| 7 | 0.915V | 0.981V |
| 9 | 0.493V | 0.573V |
| 11 | 0.307V | 0.301V |
| %THD $V_{AB}$ | 0.433 | 0.401 |
| %THD $v_o$ | 0.020 | 0.018 |

*Note: $m_a$ is the modulation index; h is the harmonic order*

TABLE III.
Harmonics of $V_{AB}$ for New Multilevel Inverter

| h | $m_a$=0.7 | $m_a$=0.8 |
|---|---|---|
| Fundamental 1 | 133.491V | 155.605V |
| 3 | 1.193V | 1.250V |
| 5 | 0.400V | 0.492V |
| 7 | 0.029V | 0.131V |
| 9 | 0.193V | 0.076V |
| 11 | 0.278V | 0.169V |
| %THD $V_{AB}$ | 0.279 | 0.169 |
| %THD $v_o$ | 0.009 | 0.008 |

TABLE IV
COMPARISONS OF TWO MULTILEVEL INVERTERS

| Inverter Type | CCHB Inverter | Studied Multilevel Inverter |
|---|---|---|
| Switch Numbers | 8 | 6 |
| Voltage Stress | $S_{a1} \sim S_{a4} : V_S$<br>$S_{b1} \sim S_{b4} : V_S$ | $S_{a1}, S_{a3}, S_{b1}, S_{b3} : V_S$<br>$S_{a2}, S_{b2} : 2V_S$ |
| Switching Loss | $P_{s,H-bridge} \propto 8V_S f_S$ | $P_{s,proposed} \propto 4V_S f_S$ |
| NOTES | (1) *CCHB Inverter:*<br>All switches are operated with high frequency<br>(2) *New Multilevel Inverter:*<br>$S_{a2}$, $S_{b2}$ are operated under line frequency. | |

## EXPERIMENTAL RESULTS

To facilitate understanding of the operating principle and as verification, a prototype system with a high step-up DC/DC converter stage and the simplified multilevel DC/AC stage are built with the corresponding parameters listed in Table V.

The specifications of the two preceding high step-up DC/DC converters are (a) input voltage 30V; (b) controlled output voltage 100V; and (c) switching frequency 85kHz. The corresponding specifications of the simplified multilevel DC/AC inverter stage are (1) output power, *Po*=230W; (2) input voltage, *Vs*=100V; (3) output voltage, *vo*=110Vrms; (4) line frequency, *fm*=60Hz; (5) switching frequency, *fs*=40kHz; and (6) peak modulation index, *mpeak*=0.76.

For better understanding, the guidelines and considerations of the DC-link capacitance and the use of an L-C output filter at the output are described as follows.

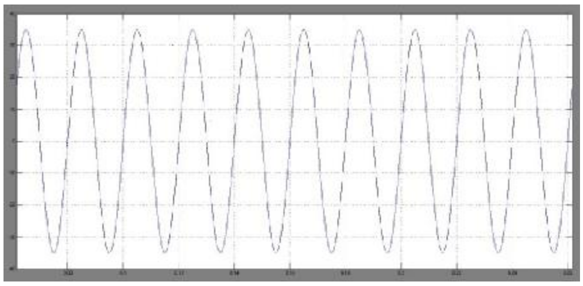


Fig. 8 Measured waveforms of grid voltage for inverter stage. [Scale: 10V/div, Time: 5ms/div]

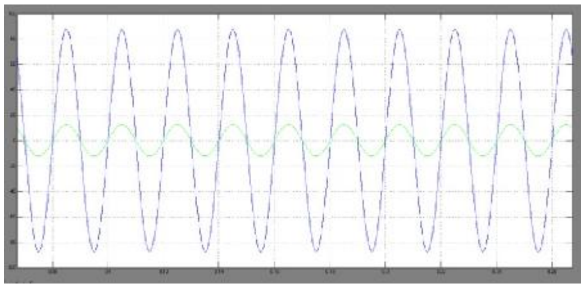


Fig. 10 Measured waveforms of output voltage *vo*, output current *io*, and voltage applied to L-C filter terminal *VAB*. [Time: 5ms/div]

TABLE V.
COMPONENT PARAMETERS OF THE PROTOTYPE

| *High Step DC/DC Converter Stage* | | |
|---|---|---|
| Components | Symbol | Value/Part no. |
| Coupling inductor | $L_m$, $N_P$:$N_S$ | 24μH, ETD 39<br>$N_P$:$N_S$ = 1.5 |
| Power switches | $Q_1$, $Q_2$ | FDB3632<br>(100V, 9mΩ) |
| Charge-pump diodes | $D_{pump1}$, $D_{pump2}$ | STPS10AH100<br>(100V, 10A) |
| Clamping diodes | $D_{c1}$, $D_{c2}$ | STPS10AH100<br>(100V, 10A) |
| Output diodes | $D_{O1}$, $D_{O2}$ | 15ETH06S<br>(600V, 12A) |
| Charge-pump caps | $C_{pump}$ | 2×4.7μF/630V |
| Bus capacitors | $C_{bus1}$, $C_{bus2}$ | 2000uF/400V |
| *Simplified Multilevel DC/AC stage* | | |
| Power switches | $S_{a1}$, $S_{a2}$, $S_{a3}$<br>$S_{b1}$, $S_{b2}$, $S_{b3}$ | FDB2710<br>(250V, 2.5mΩ) |
| Output inductor | $L_o$ | 1mH |
| Output capacitor | $C_o$ | 4.7μF/630V |

## CONCLUSION

The proposed system illustrates Renewable & Sustainable power generation strategies of a grid system with versatile power transfer. This grid system allows maximum utilization of freely available renewable energy sources like fuel cell and photovoltaic energies. For this, an adaptive MPPT algorithm along with standard perturbs and observes (P&O) method will be used for the PV & Fuel system with DC/AC Power Converter with SVM Technique.

Also, this configuration allows the sources to supply the load separately or simultaneously depending on the availability of the energy sources. Renewable energy resources like Fuel cell and Solar cell power generated are interconnected to DC Link.

The inverter converts the DC output from non-conventional energy into useful AC power for the connected load (Industrial & Commercial Loads). This Grid system operates under normal conditions which include normal room temperature or At Any atmospheric Condition. The simulation results are analyzed to illustrate the operating principle, feasibility and reliability of this proposed grid systems.

This work reports a modified single phase multi string multilevel inverter topology that produces a significant reduction in the number of power devices required to implement multilevel output for DERs. The studied inverter topology with SVM Technique offer strong advantages such as improved output waveforms, smaller filter size, and lower EMI and THD. Simulation results show the effectiveness of the proposed solution.

## REFERENCES


1. S.K. Kim, J.H Jeon, C.H. Cho, J.B. Ahn, and S.H. Kwon, “Dynamic Modeling and Control of a Grid-Connected Hybrid Generation System with Versatile Power Transfer,” IEEE Transactions on Industrial Electronics, vol. 55, pp. 1677-1688, April 2008
2. N. A. Ahmed, M. Miyatake, and A. K. Al-Othman, “Power fluctuations suppression of stand-alone hybrid generation combining solar photovoltaic/wind turbine and fuel cell systems,” in Proc. Of Energy Conversion and Management, Vol. 49, pp. 2711-2719, October 2008.
3. Y.M. Chen, Y.C. Liu, S.C. Hung, and C.S. Cheng, “Multi-Input Inverter for Grid-Connected Hybrid PV/Wind Power System,” IEEE Transactions on Power Electronics, vol. 22, May 2007.
4. S. Jain, and V. Agarwal, “An Integrated Hybrid Power Supply for Distributed Generation Applications Fed by Nonconventional Energy Sources,” IEEE Transactions on Energy Conversion, vol. 23, June 2008.
5. N. Mohan, T. Undeland, and W Robbins, “Power Electronics: Converters, Applications, and Design,” John Wiley & Sons, Inc., 2003.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[1] Korea, 2011, pp. 2658–2662.

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