

# Cascaded H-bridge multilevel inverter for renewable energy generation

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**Abstract.** In this paper cascaded H-bridge multilevel inverter (CHBMLI) has been investigated for the application of renewable energy generation. Energy sources like solar, wind, hydro, biomass or combination of these can be manipulated to obtain alternative sources for renewable energy generation. These renewable energy sources have different electrical characteristics like DC or AC level so it is challenging to use generated power by connecting to grid or load directly. The renewable energy source require specific power electronics converter as an interface for conditioning generated power. The multilevel inverter can be utilized for renewable energy sources in two different modes, the power generation mode (stand-alone mode), and compensator mode (statcom). The performance of the multilevel inverter has been compared with two level inverter. In power generation mode CHBMLI supplies the active and reactive power required by the different loads. For operation in compensator mode the indirect current control based on synchronous reference frame theory (SRFT) ensures the grid operating in unity power factor and compensate harmonics and reactive power.

## 1. Introduction

Renewable energy sources like solar, hydro, wind, and biomass can be used for electrical power generation. Energy conversion of renewable energy sources with current technology in [1][2] that would offer dependable and efficient electricity facility. In recent years renewable energy system has become significant alternative of conventional electrical energy generation due to increase in fuel prices, limited reserves and environmental issues. The concern stood by conventional energy sources like non availability of fuels and climate change has been addressed in many countries and aiming to increase the development in the renewable energy system [3]. Energy generated by the renewable sources can feed local loads and the surplus power can be transferred to the grid with the use of power electronics converter [4][5]. The quality of electrical power transfer between renewable energy sources and grid depends on the quality of voltage/current [6]. The voltage and current fed by the converter should be synchronized to grid with Harmonics level defined by IEEE and IEC standard. The integration of renewable source requires proper power control that plays important role for system efficiency and required output of the system. The available power from these renewable energy sources can be optimize and maximize by significant control of the system. Some renewable energy system may require power tracking control to track the maximum power point as in case of PV (Photovoltaic), wind power generating units. The system design requires the proper control, suitable converters, optimum cost considering all ecological factors.



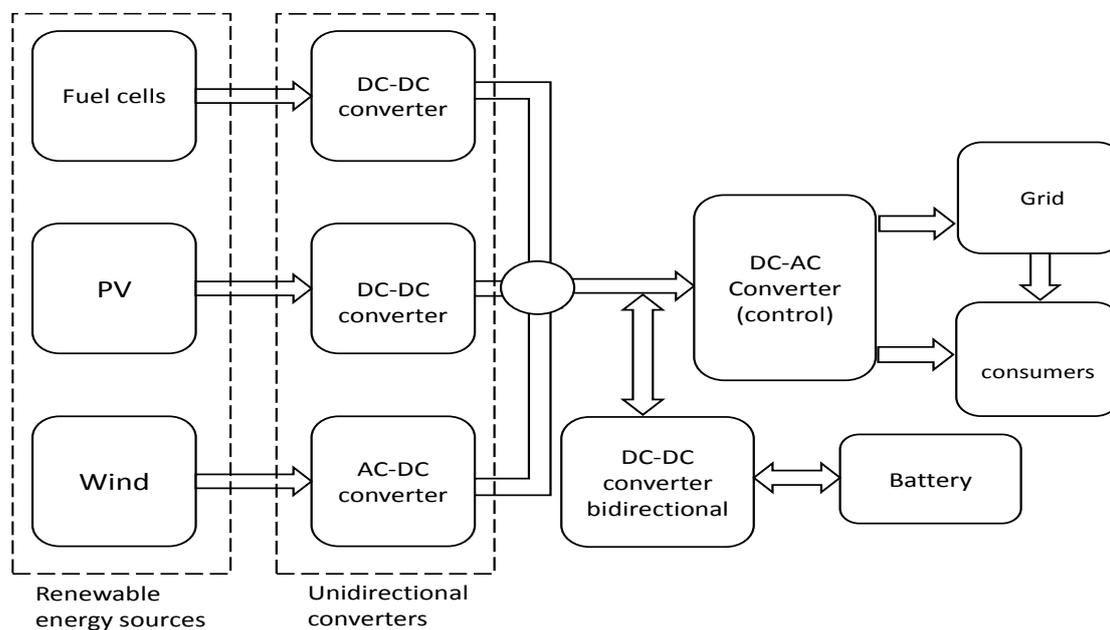


Fig.1 Topology of renewable energy generation system

The connection and significance of power electronics converters for renewable energy system consist of Fuel, PV and wind as distributed power generating unit is represented as block diagram in Fig.1. To obtain significant improvement in power quality the two level PWM (Pulse width modulation) converters are extended to multilevel inverters [7][8]. Multilevel inverter for DC-AC conversion generates synthesized output voltage by chopping the DC voltage in to different levels [9]. The multilevel inverter was designed in the earlier stage for generation of three level output voltage waveform ( $+V_{dc}, 0, -V_{dc}$ ). The inverter topology is extended to various new topologies. Three measure classification of multilevel inverter topologies are (i) Diode clamped MLI [10] (ii) capacitor clamped MLI [11] (iii) cascaded H-bridge multilevel inverter (CHBMLI) [12]. The CHBMLI is more suitable for application of renewable energy system due to its modular structure and requirement of distributed DC sources. The efficiency of CHBMLI is better due to enhanced harmonics profile of stepped output wave with less component required in comparison to other MLIs. It is having other advantages like less  $dv/dt$  stress on load and less electromagnetic interference which make these type of power converters more appropriate [13].

In this paper integration of renewable energy system considered as DC source is investigated in which dc-ac conversion with respect to CHBMLI for stand-alone and grid connected mode is done. The CHBMLI is used with equal DC voltage source. The performance of multilevel inverter is compared and analyzed with respect to conventional two level inverter considering power quality of the system. The effectiveness of the multilevel topology is tested under power generation mode and in compensator mode for modelled and simulated in MATLAB/SIMULINK using power system tool box.

## 2. Cascaded H-bridge Multi level inverter

CHBMLI was introduced for motor drive application at initial stage. But in high voltage application due to the limited power rating of electronics switches, the conventional converters became very lossy and inefficient. So CHBMLI become significant for renewable energy system integration to electrical power grid for medium and high power application. The Cascaded H-bridge multilevel inverter provides lower cost, less electromagnetic interference, higher performance i.e. lower THD (Total harmonic distortion), and higher efficiency for grid voltage or current conditioning application in both shunt and series compensation. Each H-bridge of symmetrical CHBMLI requires a separate DC source of equal

value so integration of different renewable energy sources is less complex in comparison with other multilevel inverter topology. The generated voltage through three phase symmetrical structure of CHBMLI is closer to sinusoidal waveform having reduced THD level in respect of conventional inverter. The quality of the output waveform depends upon the synthesized levelled output. So performance of CHBMLI can be improved by increasing number of H-bridge. The relation of number of H-bridges (n) and levelled output per phase (m) is  $m=2n+1$ . Due to limitation of switches and losses in the system, the number of levels can be increased according to the system requirement and application.

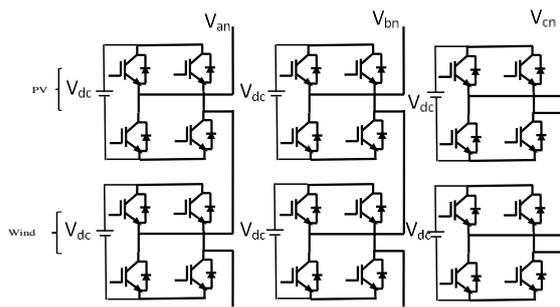


Fig.2 CHBMLI topology

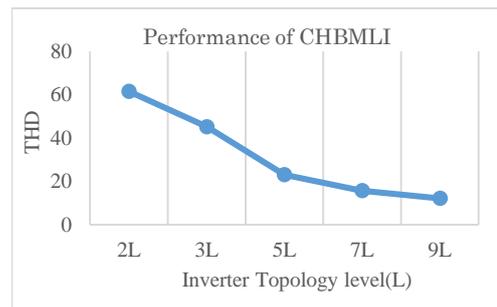


Fig.3 THD of MLIs

### 3. Performance of CHBMLI in Power generation mode

The performance of the CHBMLI for renewable energy sources is investigated for the linear load of 40 KVA 0.8 pf lagging connected to conventional two level and three level, five level, seven level cascaded h-bridge inverters. THD level for The output voltage waveform is illustrated as a graph in Fig.3 for above mentioned different level of inverter. The synthesized levelled output voltage and load current for corresponding 3,5 and 7 level inverter is shown in Fig.4, Fig5, Fig6. The load current for conventional two level of inverter is shown in Fig.7. On each bridge a separate DC source are used to supply 415 V (line to line) three phase load. It is observed that voltage levels are divided between 340 V (peak) and zero for 240 V rms voltage per phase. For three level inverter the voltage levels are -340V, 0V, 340V, for five level inverter the voltage levels are -340V, -170V, 0V, 170V, 340V, for seven level inverter the voltage levels are -340V, -170V, -85V, 0V, 85V, 170V, 340V.

It is observed that load is connected to different inverters are having same system parameter and performance is enhanced due to effect of multilevel topology. The output power of the inverter can be increased by integration of different small renewable energy sources which generate DC. This is one of the advantage of multilevel inverter which operates on distributed DC source system.

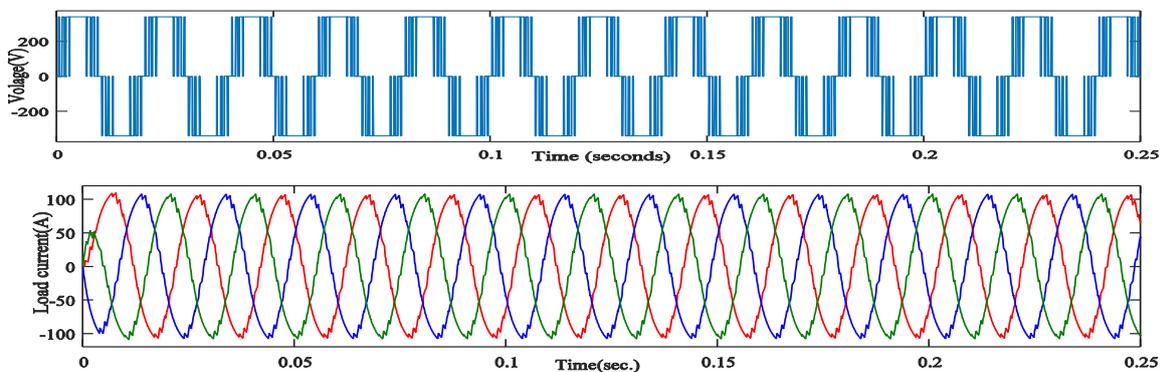


Fig.4 Three level inverter load voltage (phase a) and load current

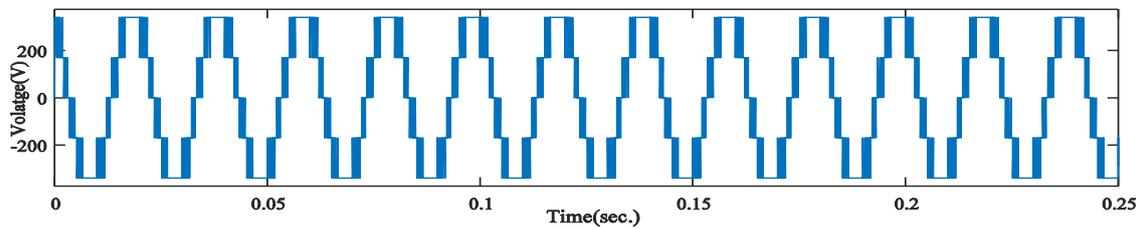


Fig.5 Five level inverter load voltage (phase a) and load current

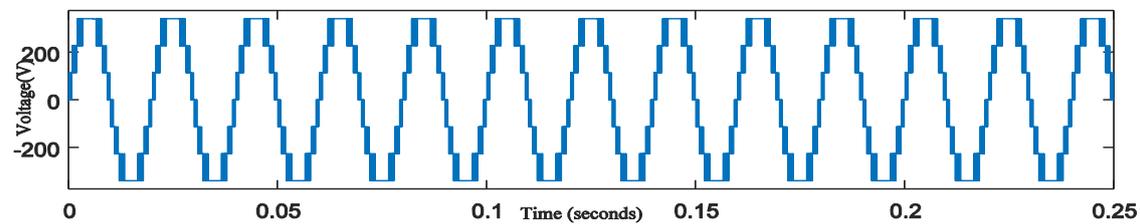


Fig.6 Seven level inverter load voltage (phase a) and load current

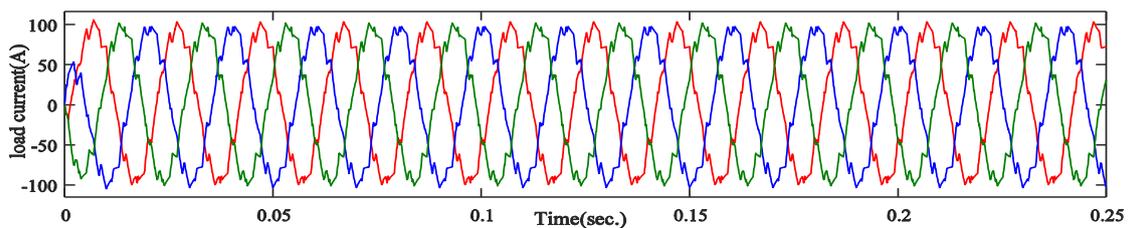


Fig.7 Conventional inverter load current

The output voltage and load current is showing improved waveforms with multilevel inverter and it can be observed in above illustrated waveforms. The THD of the output voltages and load current is significantly reduced with multilevel inverter even with less line inductance, small size of ripple filter interfacing the inverter and load as compared to conventional two level inverter. The THD of load current are 6.2%, 3.5%, 1.57%, 0.82%, for conventional two level, three level, five level, seven level inverters respectively under same load conditions.

#### 4. Performance of CHBMLI in compensator mode

The integration of renewable energy sources using CHBMLI to grid can ensure the role of compensator as well as back-up of power. The power quality improvement is possible by compensating harmonics component injected by the load using suitable power control algorithm. The fundamental approach of control algorithm applied for renewable power system is to supply load reactive power and to compensate harmonics injected by load [14].The reference current generation is one of the measure aspect for compensator design and control and grid integrated renewable energy system with generalized control shown in Fig.8.

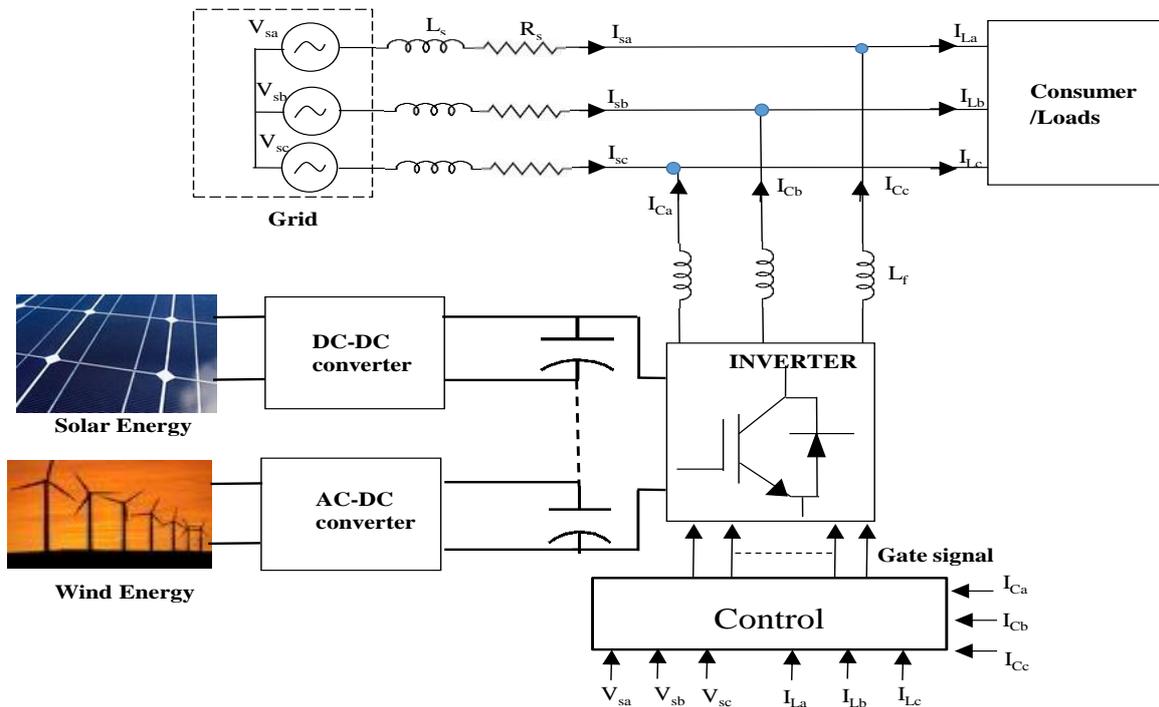


Fig.8 Grid integration of Renewable energy sources

At the consumer side, load is variant and could have different characteristics such as low power factor, Nonlinear. As a compensator the role of CHBMLI based renewable energy system is to reduce the reactive power supplied by the grid and harmonics injected by load up to its capacity to improve the operating power factor of the grid. Grid integrated renewable energy source analysed for linear load of 25 KVA at 0.8 pf and diode rectifier load of  $(10+7.45)\Omega$  under compensation mode is assumed for performance evaluation of the system. The Control block in Fig.8 is responsible for synchronization of power generated from renewable system and grid using Phase locked loop(PLL) and multilevel inverter comprises of additional switching devices in comparison to conventional inverter. So sinusoidal pulse width modulation(SPWM) used for conventional inverter is extended for switching of multilevel inverter[15]. In this paper PSPWM (Phase shift pulse width modulation) is used to control the multilevel inverter requires hierarchal switching scheme[16]. For compensator reference current generation, algorithms like synchronous reference frame theory (SRFT), power balance theory, Instantaneous Power theory is introduced in [17]. In this paper the SRFT based control is implemented for generation of reference current . The result shown in Fig.9 shows the impact of compensator to the grid current and

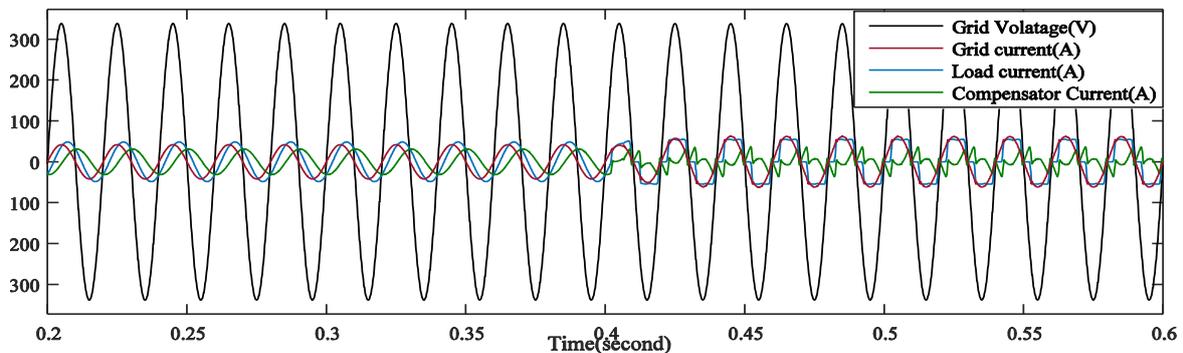


Fig.9 Grid voltage, current connected to linear load, non-linear load with compensator

voltage while load is not ideal (low p.f. and nonlinear) at the consumer end. At  $t=0$  sec. the linear load was in operation with the system and at  $t=0.4$  second it is switched to the non-linear load. The grid is operating under unity power factor linear for linear load condition as renewable system is able to supply reactive power of the load and also power factor is improved under nonlinear load condition. The load current THD for non-linear load is 24.6% and grid current THD is maintained at 3.58 %.

## 5. Conclusion

The CHBMLI topology is investigated and simulated for the renewable energy sources connected to three phase electrical power grid and power generation mode. The system is operating well and load current THD is maintained well within the standard limits for multilevel inverter and is significantly improved in comparison to two level inverter. In compensation mode, the grid power factor has been successfully improved for linear and non-linear load condition. The CHBMLI topology is working satisfactorily and suitable for integration of different renewable energy sources to grid.

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