7-level cascaded H-bridge inverter using selective harmonic elimination

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ABSTRACT

A multilevel inverter utilizes multiple DC sources to synthesize a stepped waveform. The power drawn from the different voltage sources vary as a function of modulation index, output voltage levels and load power factor. This may result in unsteady and, at times, unstable DC voltage levels. Hence the DC sources deliver unequal power. As a result, different DC sources would have different lifetimes. When multiple input DC sources are used, it is desirable that these sources maintain a balanced state of charge or, in other words, exhibit equal load sharing.

An algorithm is proposed for equal load sharing which is applicable for PWM as well as SHE modulation technique. According to the algorithm load draws equal power from all the DC sources. The algorithm is generalized for N-level MLI. This can also be used for other topologies of MLI family. The performance of the developed algorithm is analyzed in Matlab/Simulink environment and experimentally verified in the laboratory.

Key words

1 Distributed Generation

Distributed energy resources (DER) are small, modular, decentralized, grid connected or off grid energy system located in or near the place where the energy is used. They are integrated system that can include effective means of power generation, energy storage and delivery.

Distributed generation takes place on two-levels: the local level and the end-point level. Local level power generation plants often include renewable energy technologies that are site specific, such as wind turbines, geothermal energy production, solar systems (photovoltaic and combustion), and some hydro-thermal plants. These plants tend to be smaller and less centralized than the traditional model plants. They also are frequently more energy and cost efficient and more reliable [3]. Since these local level DG producers often take into account the local context, the usually produce less environmentally damaging or disrupting energy than the larger central model plants.

At the end-point level the individual energy consumer can apply many of these same technologies with similar effects. One Distributed generation technology frequently employed by end-point users is the modular internal combustion engine. These modular internal combustion engines can also be used to backup homes. As many of these familiar examples show DG technologies can operate as isolated "islands" of electric energy production or they can serve as small contributors to the power grid.

1.1 TYPES OF DISTRIBUTED ENERGY RESOURCES

Reciprocating engines: This technology uses compressed air and fuel. The mixture is ignited by a spark to move a piston. The mechanical energy is then converted into electrical energy. Reciprocating engines are a mature technology and largely spread thanks to their low capital investment requirement, fast start-up capabilities and high energy efficiency when combined with heat recovery systems.

Gas turbines: Gas turbines are widely used for electricity generation thanks to the regulatory incentives induced to favour fuel diversification towards natural gas and thanks to their low emission levels. Conversely to reciprocating engines, gas turbines ordered over the period covered by the survey were widely used as continuous generators (58%), 18% were used as standby generators and 24% as peaking generators. Gas turbines are widely used in cogeneration.

Micro turbines: Micro turbines are built with the same characteristics than gas turbines but with lower capacities and higher operating speed.

Fuel cells: Instead of converting mechanical energy into electrical energy, fuel cells are built to convert chemical energy of a fuel into electricity. The fuel used is generally natural gas or hydrogen. Fuel cells are a major field of research and significant effort is put in reducing capital costs and increasing efficiency which are the two main drawback of this technology .

Renewable sources: Renewable technologies have been used as a way to produce distributed energy. Renewable sources ranges from photovoltaic technologies, wind energy, thermal energy etc. These sources qualify as distributed generation only if they meet the criteria of the definition which is not always the case. Distributed generation is therefore clearly distinct from renewable energy.

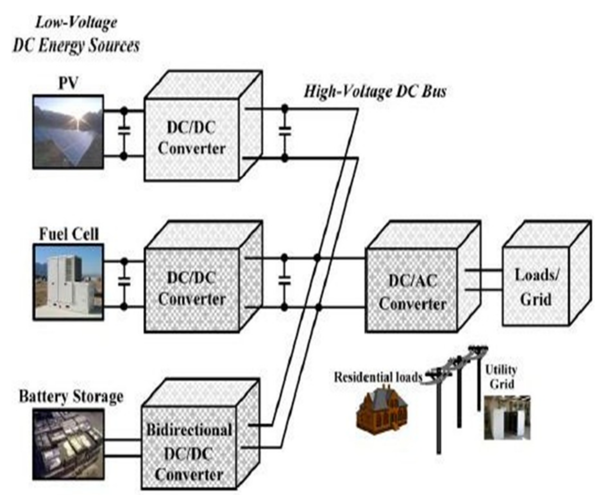

Fig 1 Configuration of multistring inverter for various DER's application

2 *MULTILEVEL CARRIER-BASED PWM*

Multilevel carrier-based PWM uses several triangular carrier signals, which can be modified in phase and/or vertical position in order to reduce the output voltage harmonic content. There are two common carrier modifications applied to these multilevel inverters.

1) Level-shifted PWM is widely used in NPC inverters and can also be used in cascaded inverters. It is shown that this modulation technique is applied to a five-level inverter. This modulation technique produces an uneven distribution of power among cells, such as that in Fig. 2.1, which produces a high harmonic content in the input current.

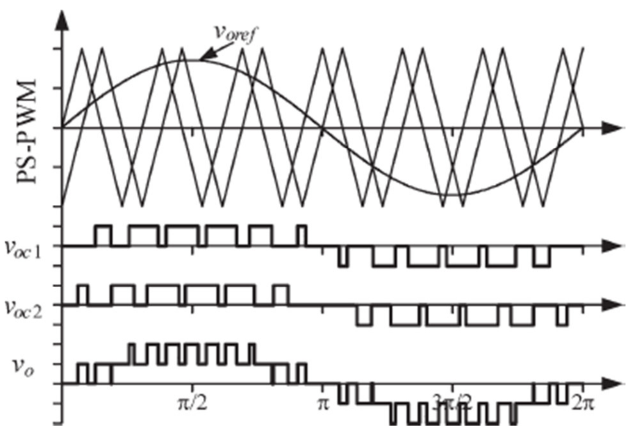

Fig. 2 Multilevel level-shifted carrier-based techniques

2) Phase-shifted PWM is the most commonly used modulation technique for cascaded multilevel inverters because it offers an evenly power distribution among cells and it is very easy to implement independently of the number of inverters. This modulation shifts the phase of each carrier in a proper angle to reduce the harmonic content of the output voltage, as shown in Fig.2.2

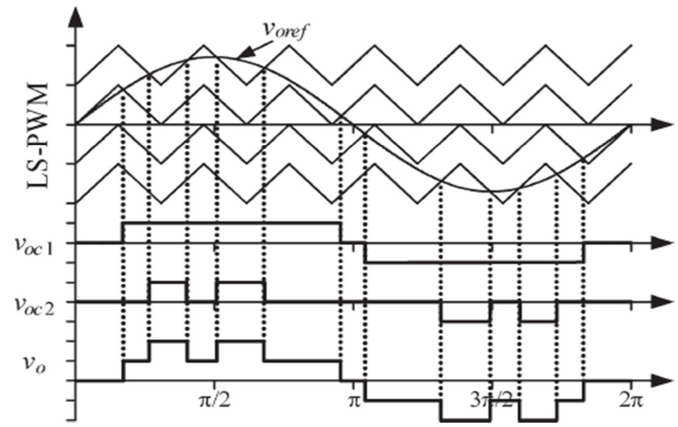

Fig. 3 Multilevel phase-shift carrier-based technique

3 POWER BALANCING

A multilevel inverter utilizes multiple DC sources to synthesize a stepped waveform. The power drawn from the different voltage sources vary as a function of modulation index, output voltage levels and load power factor. This may result in unsteady and, at times, unstable DC voltage levels. Hence the DC sources deliver unequal power. As a result, different DC sources would have different lifetimes. The DC sources balancing in multilevel inverters depend on the duty cycle of each level that is synthesizing the desired output waveforms. When multiple input DC sources are used, it is desirable that these sources maintain a balanced state of charge or, in other words, exhibit equal load sharing. Minimum two input DC sources are required for charge balance control. Charge balance control can be achieved if 'N' DC sources are utilized alternately in alternate cycles of the output waveform and thus balancing would be achieved in 'N' cycles .

3.1 ALGORITHM FOR EQUAL LOAD SHARING AMONGST INPUT SOURCES

The algorithm is explained with the help of 7-level cascaded H-bridge inverter using selective harmonic elimination (SHE) modulation technique. The figure 4.1 shows the circuit diagram of 7-level cascaded H-bridge inverter where three full bridge inverters are connected in series with R-L load. Each full bridge inverter has separate DC source of same magnitude.

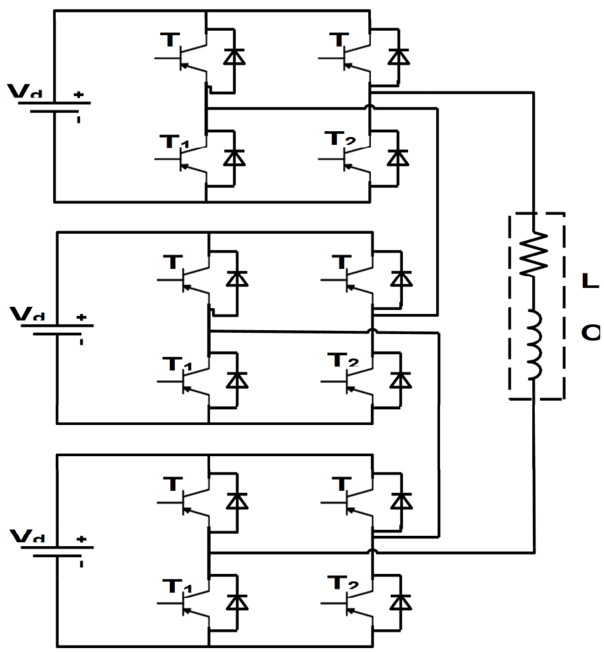

Fig 4 Circuit diagram of 7-level cascaded H-bridge

3.2 FIVE-LEVEL CHB USING MULTICARRIER PWM

In a multicarrier PWM scheme, carrier signals are compared with the reference signal and the pulses so obtained are used for switching of devices corresponding to the respective voltage levels. Four triangular waveforms of 900 Hz frequency each are used as carriers. A sinusoidal waveform of 50 Hz frequency is the reference signal. Carrier signals above the time-axis are designated as C_p , {p = 1, 2} and those below the time axis are designated as C_q , {q = 3,4} as shown in fig 3.1. In this scheme, if the reference is greater than carrier C_p , the comparator gives '1' otherwise '0'. If the reference is greater than carrier C_q , the comparator gives '0', otherwise '-1'.

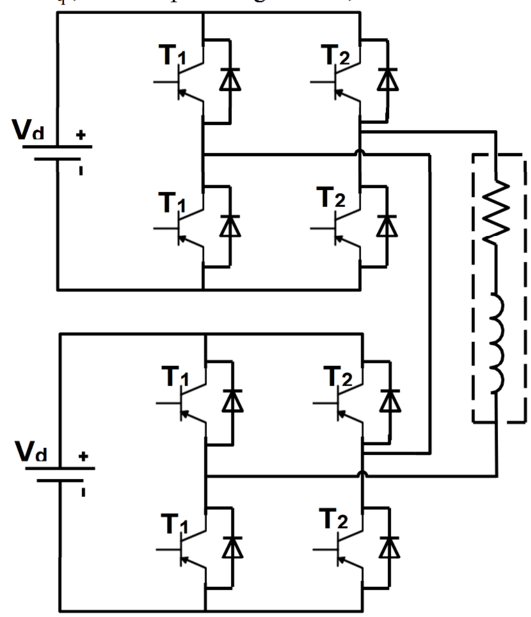

Fig 5 Five-level cascaded H-bridge inverter

4. SIMULATION RESULTS OF NINE-LEVEL CHB USING SELECTIVE HARMONIC ELIMINATION (SHE) MODULATION TECHNIQUE

Similarly to examine the performance of nine-level CHB inverter, a simulation model is developed in MATLAB/Simulink environment. Four DC sources with equal magnitude V_{DC1}= V_{DC2}= V_{DC3}= V_{DC4}= 100 V are used to obtain an output voltage of 400 V. The load is considered to be RL load (R=2Ω, L=15 mH) so as to observe the charge and discharge patterns of the DC sources. The modulation technique is used for the inverter is selective harmonic elimination in which four appropriate angles are compared with the reference wave. The frequency of reference wave is 50 Hz.

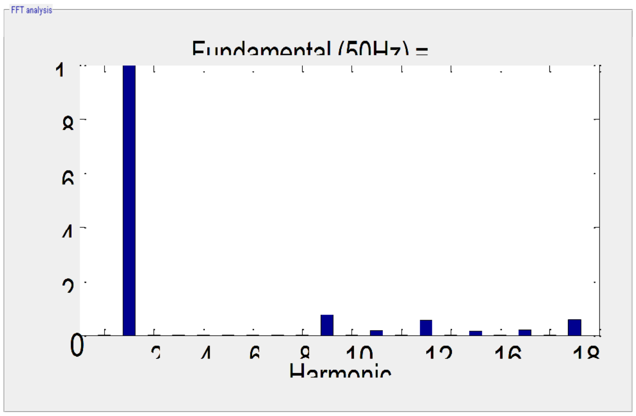

Fig 6 Harmonic spectrum of 9-level voltage output

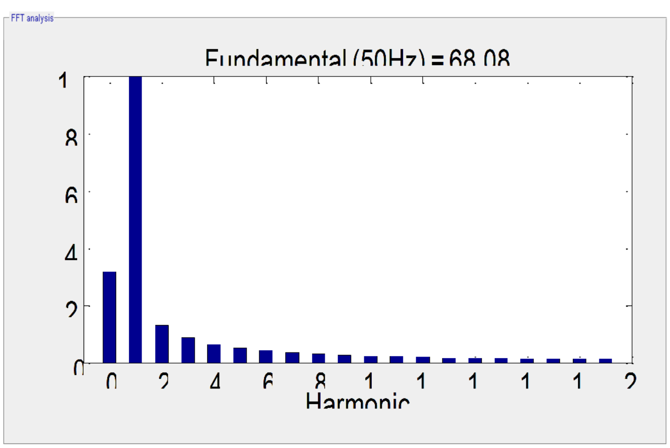

Fig 7 Harmonic spectrum of 9-level load current

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