LITERATURE REVIEW OF POWER GENERATION USING Z SOURCE INVERTERS FOR PHOTOVOLTAIC MODULES

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ABSTRACT:

Photovoltaic (PV) power generation is becoming more promising since the introduction of the thin film PV technology due to its lower cost, excellent high temperature Performance, low weight, flexibility, and glass-free easy installation. However, there are still two primary factors limiting the widespread application of PV power systems. The first is the cost of the solar cell/module and the interface converter system; the second is the variability of the output (diurnal and seasonal) of the PV cells. A PV cell’s voltage varies widely with temperature and irradiation, but the traditional voltage source inverter (VSI) cannot deal with this wide range without over-rating of the inverter, because the VSI is a buck converter whose input dc voltage must be greater than the peak ac output voltage. Because of this, a transformer and/or a dc/dc converter is usually used in PV applications, in order to cope with the range of the PV voltage ,reduce inverter ratings, and produce a desired voltage for the load or connection to the utility. This leads to a higher component count and low efficiency, Hence a Z-source inverter (ZSI) can be proposed suitable for residential PV system because of the capability of voltage boost and inversion in a single stage.

KEYWORDS: PV Technology, Solar Systems, Inverter, VSI, NPC.

INTRODUCTION:

It is generally known that the output voltage of PV array varies widely under different irradiance and environment temperature, the typical ratio of the maximum output voltage and the minimum is 2:1, and even bigger. Thus in order to get steady ac voltage, grid-connected PV system should have the ability to buck/boost voltage. What’s more, to enhance the efficiency of PV array, grid-connected PV system also should have the ability to make PV array output maximum power. A model-based control algorithm can be used to control a switching matrix that connects a solar adaptive bank to a fixed part of the PV array. Similarly, dynamic electrical array reconfiguration can be used to improve the PV energy production during partial shadowing conditions. A controllable switching matrix can also be used between the PV generator and the central inverter to allow electrical reconnection of the available PV modules so that the maximum energy efficiency can be achieved.

LITERATURE SURVEY

1. CASCADED H-BRIDGE MULTILEVEL CONVERTER MULTISTRING TOPOLOGY FOR LARGE SCALE PHOTOVOLTAIC SYSTEMS

Grid connected solar photovoltaic energy conversion systems are the fastest growing renewable energy source in installed capacity in the last 5 years. In fact, it has increased an annual average of 60% per year between 2004 and 2009 (7 GW installed in 2009 only, with a total of 21 GW installed capacity world wide) [1]. Large-scale PV utility plants range from 200 kW up to almost 100 MW in total capacity (the largest is of 97 MW in Sarnia, ON, Canada). Currently there are more than 150 utility-scale PV plants over 10 MW [2]. There is a clear global trend to increase the capacity and quantity of utility-scale PV plants.

Currently large-scale PV plants are interfaced by two type of power converter configurations: the centralized topology and the multi string topology [3]. The centralized topology is characterized by a large amount of PV modules in series to reach the desired PV string voltage. Several of these strings are then paralleled to reach the total power level of the PV system.

The dc power is interfaced to the utility by a centralized grid tied inverter, most likely a three-phase 2-level voltage source inverter. Isolation, if required, is usually provided by a low frequency transformer at the ac side. The advantage of this configuration is the simplicity of the structure and control (only one converter) and reduced cost. The main disadvantage is the lower power output due to a single maximum power point tracking (MPPT) for the whole plant, which is affected by module mismatch and partial shading. On the other hand, the multistring concept [4] also uses a centralized grid tied inverter, but has a distributed dc-bus in which each string is connected through a dc-dc converter.

Commonly these are boost converters, if isolation is provided at the ac side, or a high frequency isolated dc-dc converters (like a flyback or push-pull converter), if isolation is required at dc side [5]. The main advantage of the multistring concept is the increased modularity, allowing to combine different types of modules and even dc-dc string converters. It also decouples the grid converter control from the PV string control, which allows independent MPPT tracking of each string, increasing the power output. The main disadvantage is the higher cost and topology complexity of having additional power converters, sensors, and control systems. Nevertheless, the higher conversion efficiency has proven to be a superior advantage in long term operation, hence it is considered the state of the art configuration today.

Both configurations commonly operate with the centralized inverter at low voltage (690 V), which given current limitations of semiconductors, allows a power rating of up to 0.7 MW without paralleling devices or converters. This imposes a severe limitation for large scale PV plants (in the megawatt range), where several centralized converters are needed to interface the power. The converters can be used as separate centralized topologies dividing the PV plant in subsystems, or connected in parallel as a single one to handle all the power of the PV plant.

The trend of megawatt range PV plants will demand higher power ratings for the central grid tied converter, and traditional two level voltage source converters (2L-VSC) topologies will not be able to fulfill power rating, power quality and efficiency requirements. Moreover, more demanding grid codes could apply to these systems as happens today with wind energy conversion systems [6], pushing further the limits of the 2LVSC. The use of several 2-level converters also means more power electronics, control systems, sensors, filters, size and cost compared to using a single medium-voltage high-power converter.

Medium voltage converters have been proposed recently for grid connected PV systems. Most of these proposals are based on the 3-level NPC multilevel converter, and the single-phase cascaded H-bridge multilevel converter. The NPC topology can be commercially found up to several tens of megawatt (up to 40MVA) and typically connected to 3.3kV and 4.16kV grids [16]. To fully use the power rating of an NPC converter too many modules need to be connected in series to reach medium voltage, and several more in parallel to reach desired power levels. This issue comes back to the same problem of the centralized topology. An improvement has been made with an NPC multistring approach [15], where the dc-dc stage can help boosting the voltage reducing the number of modules in series. In addition parallel connection is performed with individual strings and their respective dc-dc converters with all the advantages of the multistring concept.

The CHB has particular advantages for PV systems: it provides several dc-links to which connect PV strings, each one with independent MPPT, and it easily reaches medium voltage. Nevertheless, since each H-bridge cell has its independent PV system with its own power point, there is an inherent power imbalance between the cells. If this imbalance is not taken into consideration in the control system or modulation, the dc-link voltages will drift. The dc-link voltage imbalance degrades the power quality introducing voltage distortion at the grid side, and more importantly, represents a hazard for the converter if voltage limits of the capacitors are exceeded. This has been addressed in several ways for single phase systems. To reach higher capacity for large scale plants, three-phase configurations are needed. However, the three-phase CHB for PV system introduces an additional challenge, which is the inherent imbalance between the three phases, since each cell has its own MPPT. This will lead to unbalanced currents, which is not allowed by grid codes.

This paper proposes a compensation method in the modulation stage of the three-phase CHB converter to deal with this imbalance, by shifting the neutral of the reference voltages in such a way the currents are balanced. This is achieved through a weighted zero sequence injection, in which each phase voltage reference is inversely compensated according to the respective imbalance ratio. This acts as a feed forward mechanism correcting the undesired behavior. In addition, to increase the power capacity of the total PV system, the multistring concept is introduced to each dc-link of the CHB.

This enables to connect several strings in parallel to each Hbridge cell, each with its independent MPPT. In this way, very large PV plants can be concentrated into a single CHB, with the benefits of: high power quality, increased efficiency, one control system, one set of sensors, one line filter, etc. The proposed configuration and control system is simulated for a three-phase 7-level CHB (3 cells), which in practice reaches medium voltage level of 3.3kV for current semiconductor limits. Nevertheless, the configuration and control method can be directly extended for CHBs of any number of levels.

A new medium voltage converter interface for large scale PV energy conversion systems is presented. It is based on a three-phase CHB multilevel multistring topology. The multistring converter structure composed of isolated dc-dc and a grid tied dc-ac converter, effectively decouples the grid side control form the PV strings control requirements. This allows independent MPPT control of each string without affecting the dc-link voltages of each cell. The main challenges related to the proposed configuration are the possible existence of two types of power imbalance: between the power cell of one phase of the converter and between the phases of the converter. These challenges are solved by including two simple feedforward compensations: one applied to the reference voltage of each phase by means of a power ratio and a min-max zero sequence, and another by adjusting the modulation index of the different references of each cell used in the phase-shifted modulation of a phase of the converter. The proposed compensation methods can work even under combined power imbalances.

The three-phase CHB multistring topology with the proposed control and imbalance compensation methods, enables to concentrate in a single medium voltage converter a large scale PV plant of up to 120 MVA. Additional advantages are the inherent superior power quality of the CHB (compatible with current grid codes), low switching frequency (higher efficiency), medium voltage grid connection and possible fault tolerant operation.

2. Z-SOURCE INVERTER

This paper presents an impedance-source (or impedance-fed) power converter (abbreviated as Z-source converter) and its control method for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be obtained in the traditional voltage-source (or voltage-fed) and current-source (or current-fed) converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter (abbreviated as V-source converter) and current-source converter (abbreviated as I-source converter) and provides a novel power conversion concept. The Z-source concept can be applied to all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. To describe the operating principle and control, this paper focuses on an example: a Z-source inverter for dc-ac power conversion needed in fuel cell applications. Simulation and experimental results will be presented to demonstrate the new features.

There exist two traditional converters: voltage-source (or voltage-fed) and current-source (or current-fed) converters (or inverters depending on power flow directions). A dc voltage source supported by a relatively large capacitor feeds the main converter circuit, a three-phase bridge. The dc voltage source can be a battery, fuel-cell stack, diode rectifier, and/or capacitor. Six switches are used in the main circuit; each is traditionally composed of a power transistor and an antiparallel (or freewheeling) diode to provide bidirectional current flow and unidirectional voltage blocking capability. The V-source converter is widely used. It, however, has the following conceptual and theoretical barriers and limitations.

- The ac output voltage is limited below and cannot exceed the dc-rail voltage or the dc-rail voltage has to be greater than the ac input voltage. Therefore, the V-source inverter is a buck (step-down) inverter for dc-to-ac power conversion and the V-source converter is a boost (step-up) rectifier (or boost converter) for ac-to-dc power conver sion. For applications where over drive is desirable and the available dc voltage is limited, an additional dc-dc boost converter is needed to obtain a desired ac output. The additional power converter stage increases system cost and lowers efficiency.
- The upper and lower devices of each phase leg cannot be gated on simultaneously either by purpose or by EMI noise. Otherwise, a shoot-through would occur and destroy the devices. The shoot-through problem by electromagnetic interference (EMI) noise's misgating-on is a major killer to the converter's reliability. Dead time to block both upper and lower devices has to be provided in the V-source converter, which causes waveform distortion, etc.
- An output LC filter is needed for providing a sinusoidal voltage compared with the current-source inverter, which causes additional power loss and control complexity.

A dc current source feeds the main converter circuit, a three-phase bridge. The dc current source can be a relatively large dc inductor fed by a voltage source such as a battery, fuel-cell stack, diode rectifier, or thyristor converter. Six switches are used in the main circuit, each is traditionally composed of a semiconductor switching device with reverse block capability such as a gate-turn-off thyristor (GTO) and SCR or a power transistor with a series diode to provide unidirectional current flow and bidirectional voltage blocking. However, the I-source converter has the following conceptual and theoretical barriers and limitations.

- The ac output voltage has to be greater than the original dc voltage that feeds the dc inductor or the dc voltage produced is always smaller than the ac input voltage. Therefore, the I-source inverter is a boost inverter for dc-to-ac power conversion and the I-source converter is a buck rectifier (or buck converter) for ac-to-dc power conversion. For applications where a wide voltage range is desirable, an additional dc–dc buck (or boost) converter is needed.

The additional power conversion stage increases system cost and lowers efficiency.

- At least one of the upper devices and one of the lower devices have to be gated on and maintained on at any time. Otherwise, an open circuit of the dc inductor would occur and destroy the devices. The open-circuit problem by EMI noise's misgating-off is a major concern of the converter's reliability. Overlap time for safe current commutation is needed in the I-source converter, which also causes waveform distortion, etc.
- The main switches of the I-source converter have to block reverse voltage that requires a series diode to be used in combination with high-speed and high-performance transistors such as insulated gate bipolar transistors (IGBTs). This prevents the direct use of low-cost and high-performance IGBT modules and intelligent power modules (IPMs). In addition, both the V-source converter and the I-source converter have the following common problems.
- They are either a boost or a buck converter and cannot be a buck–boost converter. That is, their obtainable output voltage range is limited to either greater or smaller than the input voltage.
- Their main circuits cannot be interchangeable. In other words, neither the V-source converter main circuit can be used for the I-source converter, nor vice versa.
- They are vulnerable to EMI noise in terms of reliability.

This paper has presented an impedance-source power converter for implementing dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion. The Z-source converter employs a unique impedance network (or circuit) to couple the converter main circuit to the power source, thus providing unique features that cannot be observed in the traditional voltage-source and current-source converters where a capacitor and inductor are used, respectively. The Z-source converter overcomes the conceptual and theoretical barriers and limitations of the traditional voltage-source converter and current-source converter and provides a novel power conversion concept. The Z-source concept can be applied to almost all dc-to-ac, ac-to-dc, ac-to-ac, and dc-to-dc power conversion.

This paper focused on an example a Z-source inverter for fuel-cell applications. Through the example, the paper described the operating principle, analyzed the circuit characteristics, and demonstrated its concept and superiority. Analytical, simulation, and experimental results have been presented. The Z-source inverter can boost–buck voltage, minimize component count, increase efficiency, and reduce cost.

3. MAXIMUM BOOST CONTROL OF THE Z-SOURCE INVERTER

Many pulse-width modulation (PWM) control methods have been developed and used for the traditional three-phase voltage-source (V-source) inverter. The traditional V-source inverter has six active vectors (or switching states) when the dc voltage is impressed across the load and two zero vectors when the load terminals are shorted through either the lower or upper three devices. These total eight switching states and their combinations have spawn many PWM control schemes.

The recently presented Z source inverter shown has additional zero vectors: shoot-through switching states that are forbidden in the traditional V-source inverter. For the traditional V-source inverter, both switches of any phase leg can never be gated on at the same time or a short circuit (shoot through) would occur and destroy the inverter. The new Z-source inverter advantageously utilizes the shoot through states to boost the dc bus voltage by gating on both upper and lower switches of a phase leg. Therefore the Z-source inverter can boost voltage and produce a desired output voltage that is greater than the available dc bus voltage. In addition, the reliability of the inverter is greatly improved because the shoot through due to mis-gating can no longer destroy the circuit.

Thus it provides a low-cost, reliable, and high efficiency single stage structure for buck and boost power conversion. In [1], the main circuit of the Z-source inverter and the operation principle have been described in detail. In this paper, we will examine the relationship of voltage boost and modulation index, present two control methods to achieve maximum voltage boost, namely maximum boost control. The voltage boost and voltage stress on the devices will be investigated. The maximum boost control method, and its theoretical relationship of voltage gain versus modulation index will be presented.

A simple boost control method was used to control the shoot-through duty ratio. The Z-source inverter maintains the six active states unchanged as the traditional carrier based PWM control. For this simple boost control, the obtainable shoot-through duty ratio decreases with the increase of M . The maximum shoot-through duty ratio of the simple boost control is limited to (1-M) , thus reaching zero at a modulation index of one. The maximum obtainable voltage gain, M' B versus M , which indicates no voltage boost and no voltage gain at M=1. The shaded area is the possible operation region under the simple control. In order to produce an output voltage that requires a high voltage gain, a small modulation index has to be used. However, small modulation indexes result in greater voltage stress on the devices.

This paper presented two control methods to obtain maximum voltage gain of the Z-source inverter. The method maximizes the shoot through period without effecting the active states by turning all zero states into the shoot through zero state, thus maximum output voltage can be obtained for a given modulation index. In turn, maximum modulation index can be used to obtain any desired output voltage, thus, minimizing the voltage stress across the switches. Third harmonic injection can also be used to extend the modulation index range. The relationship of the voltage gain versus modulation index was analyzed, and the relationship between minimum voltage stress of the switches and voltage gain was given. Simulation and experiments were conducted to verify the control methods and analysis.

4. Z-SOURCE INVERTER FOR RESIDENTIAL PHOTOVOLTAIC SYSTEMS

It is believed that the distributed generation market will be between US $10 and 30 billion by the year 2010. Due to environmental concerns, more effort is now being put into clean distributed power like geothermal, wind power, fuel cells, and photovoltaic (PV) that directly uses the energy from the sun to generate electricity. The worldwide grid-connected PV system grows at a rate of 25% every year. As the energy from the sun is free, the major cost of photovoltaic generation is the installation cost, which is mainly composed of the costs of solar modules and the interface converter system, also called the power conditioning system (PCS). With the development of solar cell technology, the price of solar modules has dropped dramatically. A recent worldwide survey shows that in the last three years, the retail price of solar modules has dropped 16.95%. However, at the same time, the prices for the PCSs almost remain the same. Furthermore, compared with converters used in drive systems, the prices for the converters used in PV systems are still up to 50% higher. To lower the cost of the PCSs has become a very urgent issue of grid connected PV systems [1].

PCS is required to convert the dc output from PV to grid synchronized 50- or 60-Hz ac. This paper proposes a -source inverter based PCS, which connects the PV arrays for residential systems that are 60-Hz, 120/240-V split phase ac in the United States. By utilizing the -source inverter, the number of switching components and the total volume of the system can be minimized. Thus, the cost of the PCS is minimized.

5. BASICS OF PCS FOR RESIDENTIAL USE

In order to transfer energy from PV arrays into utility grids, PCS converter systems have to fulfill the following three requirements:

1) To convert the dc voltage into ac voltage;

2) To boost the voltage, if the PV array voltage is lower than the grid voltage;

3) To insure maximum power utilization of the PV modular.

Usually, a line frequency transformer is associated with huge size, loud acoustic noise, and high cost. In addition, the inverter has to be oversized to cope with the wide PV array voltage change. The KVA rating of the inverter is doubled if the PV voltage varies at a 1 2 range. So in order to eliminate the transformer and to minimize the required KVA rating of the inverter, in many applications, a high frequency dc-dc converter is used to boost the voltage to a constant value as shown. Unfortunately, the switch in the dc–dc converter becomes the cost and efficiency killer of the system.

Another option is to use a single-stage inverter for direct dc–ac conversion as shown. For the split-phase system used in United States' residential power, two 120-V ac outputs with same ground and 180 phase difference are required. For this purpose, there are two circuit choices for the dc–ac inverters in the PCS: four-switch inverter and six-switch inverter.

This paper presented a new PV power conditioning system based on -source inverter. The proposed system realizes the boost and inversion with maximum power tracking in one single power stage, thus minimizing the number of switching devices. All the advantages of the Z -sources inverter and the six-switch split-phase inverter are inherited and integrated together to create a highly reliable PCS system with minimized volume and cost.

6. THE PWM STRATEGIES OF GRID-CONNECTED DISTRIBUTED GENERATION ACTIVE NPC INVERTERS

The Neutral Point Clamped topology due to high efficiency, low leakage current and EMI, its integration is widely used in the distributed generation (DG) systems. However the main disadvantage of the NPC inverter is given by an unequal distribution of the losses in the semiconductor devices, which leads to an unequal distribution of temperature. By using the Active NPC topology, the power losses distribution problem is alleviated. The modulation strategy is a key issue for losses distribution in this topology. In this paper two known strategies are discussed and a new proposed PWM strategy, namely the Adjustable Losses Distribution (ALD) PWM strategy is proposed for better losses distribution in the Active NPC (ANPC) topology. Simulations using Simulink and the PLECS toolbox have been done for evaluating efficiency of different NPC topologies and some experimental results are presented in this paper to validate the operation of the different strategies.

With the renewable power increasing, the grid-connected photovoltaic (PV) systems, in particular low power single phase systems (from 1kW to 10kW), are becoming one of the most important parts in the DG (Distributed Generation) system. Meanwhile the low power PV systems are usually private systems, which need to give the users maximum profitability through high efficiency, long life time, low prices, small volume and safety.

In order to improve the efficiency of PV inverters and lower the system prices, the grid isolation transformers are usually eliminated (they are usually used for providing personal protection and avoiding leakage currents between the PV system and the ground). Thereby, many transformerless applications were proposed [1] including HERIC topology [2], FB with DC Bypass topology [3], H5 topology [4], conventional Neutral Point Clamped (NPC) topology, Conergy NPC topology and Active NPC topology.

The NPC topology was introduced by Nabae, Takahashi and Akagi in 1981 [5], it was one of the inverter topologies connecting to the grid without using any transformer. Compared with the traditional 2-level full bridge PWM inverters, the NPC topology also can produce lower switch losses, harmonics and common mode current which significantly improve the efficiency of the inverters and make it appealing for photovoltaic application. Meanwhile the main disadvantage of the NPC inverter is given by an unequal distribution of the losses in the semiconductor devices, which leads to an unequal distribution of temperature and limits the output power of the inverter. In order to overcome this drawback, the conventional NPC topology was extended to the Active NPC structure.

The Active NPC has more degrees of freedom and can be controlled by different PWM strategies. Compared to the conventional NPC topology, the total losses in 3L-ANPC converter are not smaller, but a better balancing of losses is obtained. Lots of different Active NPC PWM strategies have been presented in [6] [7], but the losses distribution was not ideal because conduction loss distribution is not equal and will be influenced by the work mode. In this paper, two known PWM strategies for ANPC are shown and a new PWM strategy named Adjustable Losses Distribution (ALD) for better losses distribution is proposed. This PWM strategy could get loss balanced by adjusting the switching losses distribution. The comparison and control strategies of different strategies are also discussed. After showing some simulation and experimental results, a conclusion is given which proves that the proposed strategy has better losses distribution performance.

The conventional NPC topology is the most popular 3- level topology. It is also very versatile and can be used in both single phase (full-bridge or half-bridge) and three- phase inverters. As presented the NPC half bridge is composed by four switches and two clamp diodes. The main concept is that zero voltage can be achieved by “clamping” the output to the grounded “middle point” of the dc bus using D+ or D- depending on the sign of the output current.

The switching losses of a 5kW NPC topology inverter at different switching frequencies which presents the losses distribution is unbalance. This figure points out that the stresses due to switching losses on the outer switches S1 and S4 is higher than on the inner switches, especially at higher frequency. As the switching frequency increases, the uneven losses distribution in the NPC inverter gets even worse.

The NPC topology showed very high performances both in the experimental and the simulation tests conducted in this work, which make them very suitable for transformer-less PV applications due to their high efficiency and low leakage current and EMI. Whereas the main disadvantage of the NPC inverter is given by an unequal distribution of the losses in the semiconductor devices, which leads to an unequal distribution of temperature and limits the output power of the inverter. In order to overcome this drawback, the conventional NPC topology was extended to the Active NPC structure.

The ANPC topology, which uses different modulation strategies, has a better power losses distribution. Thus, the ANPC topology is suitable for the high power transformer less PV system applications. The modulation strategy is a key issue in this topology. As S1 and S5, S4 and S6, S2 and S3 (active states) could not be ON at the same time, the dead time setting needs to be carefully considered.

In this paper, a new ANPC strategy named Adjustable Losses Distribution (ALD) is proposed. This strategy combines the losses distribution advantages of classical and DF-ANPC strategies. Depending on the different M and PF (which means different conduction losses distribution between inner and outer switches), this strategy can choose the most suitable Stress In/Stress Out mode rate to balance the total losses distribution between inner and outer switches, where the switching losses distribution is controlled by the Stress In/Stress Out mode rate. This strategy is validated by experiments that the efficiency is not lower compared with other ANPC strategies. The simulation results show that whatever the M and PF value are, the losses distribution could get balanced without adding any components. The NPC topology is currently used by Danfoss Solar Inverters in a three-phase configuration with multi-string boost converter. With the power rate of DG systems increasing, Active NPC topology and ALD strategy might be widely used in particular high power systems.

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