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An Integrated High Gain Boost Resonant Converter for PV System

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Abstract – The Effective photovoltaic power conditioning requires well-organized power conversion and accurate maximum power point tracking to neutralize the effects of panel mismatch, shading, and variation in power output during a daily cycle. This paper presents a unique method for widening the input range of pulse width modulation of integrated resonant converters and it maintains high conversion efficiency. The technique primarily unites constant-on, constant off, and fixed-frequency control depending on the required duty cycle. With hybrid-frequency control, the circuit also retains zero current switching for the output diodes, minimizes the switching loss, and eliminates circulating energy at the transformer across the entire operating range. The Z-source inverter (ZSI) is widely used in low-voltage input applications such as photovoltaic, fuel cells, motor drivers due to its outstanding compared with the traditional voltage source inverter (VSI). Worst of all, the boost ability is too small. Several control strategies are provided to overcome these disadvantages of the classic ZSI, but they still have limits to avoid the discontinuous input current, as well as reduce the voltage stress. More importantly, the stronger boost ability is achieved, the larger shoot-through duty ratio should be used, which will result in a poor output voltage profile and low voltage-conversion ratio. Thus, the control strategies are not efficient to improve the boost ability.

Index Terms – Photovoltaic - PV, Pulse Width Modulation - PWM, Voltage Source Inverter – VSI, Z-Source Inverter – ZSI.

1. INTRODUCTION

The Z-source inverter (ZSI) is widely used in low voltage input applications such as photovoltaic, fuel cells, motor drivers due to that the ZSI is compared with traditional voltage source inverter. Worst of all, the boost ability is too small. Several control strategies are provided to overcome these disadvantages of the classic ZSI, To reducing greenhouse gas emissions, renewable energy's other benefits include employment creation, reduced use of non-renewable resources, reduced atmospheric pollution such as: sulphur oxides, nitrogen oxides, mercury, and a range of other toxins and water based acid mine drainage, and to increased energy security through diversification and improved national balance of payments [1]. For most countries, increased energy security, improved trade balance and reduced dependence on imported fossil fuels are the main drivers for use of renewable energy, although environmental aims, especially greenhouse gas reduction, also play a role. During the last decades, significant changes occurred in the electricity grid. After the oil crisis, many governments supported research into alternatives for oil based energy systems. Concerning the electricity network, this led to a strong increase in electricity generation based on renewable energy sources such as: wind, sun, tidal and wave energy [2].

In order to limit the use of oil as a primary energy source for generating electricity, power plants based on coal, natural gas or nuclear fission strongly gained popularity. Comparing the present primary energy source usage (2008) with the one, one can see that nuclear energy really emerged as a new important source for electricity production. Also, the use of natural gas strongly increased, whereas coal approximately maintained its relative market share and remains the most important primary energy source for electricity production [3|. The renewable energy sources (RES) still represent a very small percentage of the total electricity production in the world. However, several types of renewable energy sources have significantly increased their degree of grid penetration during the last decade and forecasts project an ongoing positive trend for the years to come [4]. Also, several political treaties and protocols regarding the use of renewable energy resources for electricity generation have been agreed upon, resulting in well defined targets for the deployment of generators using renewable as the primary energy source. It has some additional benefits to large scale centralized renewable in that it can help defer network augmentation, reduce line losses and, being smaller, is more modular and so can be gradually installed as required [4], [5].

The ZSI has attracted wide attention over the others mainly because it continues to employ a conventional VSI as the power converter, yet with a modified DC link stage. As a research in power electronics, the Z-source topology as shown has been greatly explored from various aspects. Due to the obvious advantages of ZSI, it have been adopted for various applications such as ac motor drives, fuel cell vehicles, uninterruptible power supplies, residential photovoltaic systems, electronic loads, wind power conversion and distributed generation [6].

2. RELATED WORK

The multilevel converters have been under research and development for more than three decades and have found successful industrial application. However, this is still a technology under development, and many new contributions and new commercial topologies have been reported in the last few years. The review of these recent contributions, in order to establish the current state of the art and trends of the technology, to provide readers with a comprehensive and insightful review of where multilevel converter technology stands and is heading [7], [8]. This presents a brief overview of well established multilevel converters strongly oriented to their current state in industrial applications to then center the discussion on the new converters that have made their way into the industry. In addition, new promising topologies are discussed. Recent advances made in modulation and control of multilevel converters is also addressed. A great part of this work is devoted to show nontraditional applications powered by multilevel converters and how multilevel converters are becoming an enabling technology in many industrial sectors [9], [10].

The power electronic converters, especially DC/AC sinusoidal pulse width modulation inverters have been extending their range of use in industry because of their numerous advantages. They typically synthesize the stair–case voltage waveform from several DC sources, which has reduced harmonic content [11]. The extend knowledge about the performance of five level Cascaded H-Bridge MLI topology with DC/DC Boost Converter using SPWM for fixed DC Source. The output voltage is the sum of the voltage that is generated by each bridge [12]. The switching angles can be chosen in such a way that the total harmonic distortion is minimized. This topology incorporates boost converter in the input side which magnifies the fundamental output voltage with reduction in total harmonic distortion. It also incorporates LC filter and hence output is drawn near the sine wave because of more levels. The performance of the SPWM strategy in terms of output voltage and THD has studied successfully [13], [14].

An extended switched inductor quasi-Z-source inverter (ESL-qZSI) with high boost voltage inversion ability is presented which combines the SL-qZSI with the traditional boost converter, as well as improves the switched inductor cell. Compared with the classic qZSI topologies, that topology have reduces voltage stresses of capacitors, power devices and diodes for the same input and output voltage. Furthermore, the conversion efficiency is improved. The Operation principle of the topology is analyzed in details, which is followed by the comparison between the three topologies [15],

The Z-source inverter (ZSI) with battery operation can balance the stochastic fluctuations of photovoltaic (PV) power injected to the grid/load, but the topology has a power limitation due to the wide range of discontinuous conduction mode during battery discharge. This proposes a new topology of the energy stored ZSI to overcome this disadvantage. The two strategies of the related design principles to control the new energy stored ZSI when applied to the PV power system. They can control the inverter output power track the PV panel maximum power. The voltage boost, inversion, and energy storage are integrated in a single stage inverter [16].

3. QUASI-Z-SOURCE INVERTER

A control strategy for the quasi-Z-source inverter (qZSI) with a battery based photovoltaic power conversion system was presented. A battery assisted qZSI can buck/boost PV panel voltage by introducing shoot-through states, and make full use of PV power by the energy stored battery paralleled to the quasi-Z-source capacitor. A dynamic small signal model of the battery assisted qZSI is established to design a closed loop controller for regulating shoot-through duty ratio and managing the battery's energy storage [17]. A modified space vector modulation (SVM) technique for the qZSI is applied to achieve low harmonics, high voltage utilization, and high efficiency. A P-Q decoupled grid-tie power injection is fulfilled with the maximum power capture from PV panels and the unity power factor. The results showing the efficient method for energy stored PV power generation. In either system, the DC–DC stage implements local MPPT optimization, while the second stage attempts to regulate the DC-link voltage by sending power to the utility grid. In the distributed PV PCS, the isolated DC–DC stage must operate efficiently at full power, while maintaining high performance at light load, across a range of PV voltages. In order to maintain high efficiency under low power conditions, it is necessary to minimize the amount of circulating energy in the system. An alternate definition of this characteristic would be producing a system with a high power factor at the isolation transformer. Also critical to light load efficiency is mitigating the device [18], [19].

They are simple to implement, but have defects of high switching frequency and additional switching operations, resulting in the incremental losses. Therefore, the traditional space vector modulation (SVM) has been modified and applied. A traditional energy storage system usually requires an extra bidirectional DC–DC Converter, which increases the system cost, volume, and control complication [20].

The grid connected PV power system designs focus on converting as much irradiant power as possible into real power and current flowing into the grid in phase with the utility-defined voltage. The solar inverter is a critical component in a solar energy system. It performs the conversion of the variable DC output of the solar panel. The different families of power converters have been designed to interface the renewable resources for different applications [21]. The traditional power electronic inverters are VSI and current source inverter (CSI). In VSI two switches of the same leg can never be gated ON at same time because it causes a short circuit, which would destroy the inverter. The maximum output voltage is obtained by interfacing boost converter system with inverter system which leads to additional task to the controller circuits and this voltage can never exceed the bus voltage. These limitations can be overcome by the proposed maximum boost ZSI system. Considering also only multistage solutions allows for increased interoperability between distributed AC and DC systems while permitting the removal of electrolytic capacitors, which have limited lifetime from the system design [22], [23].

In the system, the DC–DC stage implements local MPPT optimization, while the second stage attempts to regulate the DC-link voltage by sending power to the utility grid. The block diagrams showing the Z-source inverter system structures are provided in Figure 1. It is this combination of high CEC efficiency, galvanic isolation, and a localized distributed approach to energy conversion that has prompted the proceeding technical development.

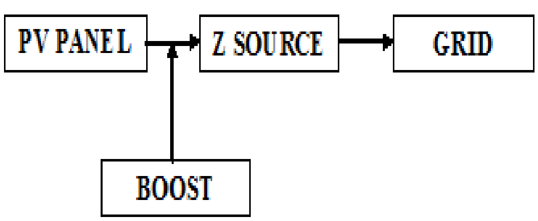

Figure 1: Block Diagram of PV Power Generation

4. PHOTOVOLTAIC CELL

The Photovoltaic power generation has an important role to play due to the fact that it is a green source. The only emissions associated with PV power generation are those from the production of its components. After the installation it can generate electricity from the solar irradiation without emitting greenhouse gases. In the 25 years of lifetime, PV panels produce more energy than that for their manufacturing. Also they can be installed in places with no other use, such as roofs and deserts, or they can produce electricity for remote locations, where there is no electricity network [24].

The latter type of installations is known as off-grid facilities and sometimes it is the most economical alternative to provide electricity in isolated areas. However, most of the PV power generation comes from grid-connected installations, where the power is fed in the electricity network. In fact, it is a growing business in developed countries such as Germany, which in 2010, is by far the leading in PV power generation followed by Spain, Japan, USA and Italy. On the other hand, due to the equipment required, PV power generation is more expensive than other resources [25].

The government is promoting it with subsidies or feed-in tariffs, expecting the development of the technology so that in the near future it will become competitive. Increasing the efficiency in PV plants so the power generated increases is a key aspect, as it will increase the incomes, reducing consequently the cost of the power generated so it will approach the cost of the power produced from other sources [26].

The efficiency of a PV plant is affected mainly by three factors: the efficiency of the PV panel, the efficiency of the inverter (95-98 %) and the efficiency of the maximum power point tracking (MPPT) algorithm (which is over 98%). Improving the efficiency of the PV panel and the inverter is not easy as it depends on the technology available, it may require better components, which can increase drastically the cost of the installation. The MPPT algorithm has also certain limitations in increasing the efficiency of the solar power generation [27]. The Figure 2 shows the equivalent circuit of photovoltaic cell.

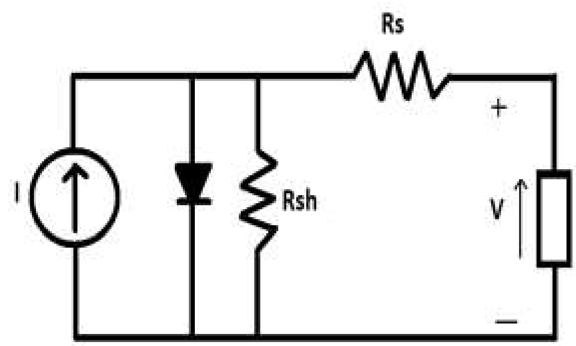

Figure 2: Equivalent Circuit of PV Cell

The one with MPPT control algorithm is used to extract the maximum power from the PV arrays. The other one, equipped with a voltage regulation control method, is required to regulate the power between the PV arrays and loads and to generate a constant output voltage for supplying power to the DC loads. Since the one with the MPPT control algorithm uses PV arrays as its power source, its controller, which is a microcontroller is divided into two control units: MPPT unit and power management unit. The MPPT one can track the maximum power point (MPP) of the PV arrays. Its control method adopts the perturb and observe method, which is described [28].

The solar cell naturally exhibits nonlinear characteristics of I-V and P-V curve that varies with solar irradiance and temperature [6]. The Characteristics of I-V and P-V curve of the solar cell are shown in Figure 3.

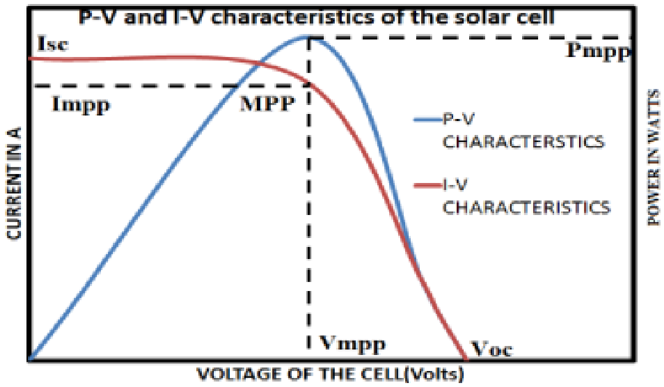

Figure 3: Characteristics of Solar Cell

The power management one can separately regulate the output voltage of DC converters with MPPT control algorithm and with the voltage regulation control method, according to the relationships between the maximum power of the PV arrays and the load power P_L by signals M1 and SP. Moreover, the PWM IC unit is adopted to control the DC-DC converter by the voltage regulation control method to obtain a constant output voltage. Regulation of the output power by control signal SP is also required. All of the protections are implemented by the microcontroller. The protections include over current and temperature protections of two DC-DC converters and battery undercharge. Therefore, the proposed PV power system can achieve the optimal utility rate of PV arrays [29].

5. PULSE WIDTH MODULATION

Mainly the power electronic converters are operated in the "switched mode". Which means the switches within the converter are always in either one of the two states; turned off (no current flows), or turned on (saturated with only a small voltage drop across the switch). Any operation in the linear region, other than for the unavoidable transition from conducting to non-conducting, incurs an undesirable loss of efficiency and an unbearable rise in switch power dissipation. To control the flow of power in the converter, the switches alternate between these two states (i.e. on and off). This happens rapidly enough that the inductors and capacitors at the input and output nodes of the converter average or filter the switched signal. The switched component is attenuated and the desired DC or low frequency AC component is retained. This process is called Pulse Width Modulation (PWM), since the desired average value is controlled by modulating the width of the pulses [30], [31] .

For maximum attenuation of the switching component, the switch frequency f_c should be high, many times the frequency of the desired fundamental AC component f_1 seen at the input or output terminals. In large converters, this is in conflict with an upper limit placed on switch frequency by switching losses. For GTO converters, the ratio of switch frequency to fundamental frequency f_c/f_1=N, the pulse number may be as low as unity, which is known as square wave switching.

Another application where the pulse number may be low is in converters which are better described as amplifiers whose upper output fundamental frequency may be relatively high. These high power switch-mode amplifiers find application in active power filtering test signal generation servo and audio amplifiers. These low pulse numbers place the greatest demands on effective modulation to reduce the distortion as much as possible. The low pulse numbers place the greatest demands on effective modulation to reduce the distortion as much as possible. In these circumstances, multi-level converters can reduce the distortion substantially, by staggering the switching instants of the multiple switches and increasing the apparent pulse number of the overall converter [32],

6. SIMULATION RESULTS

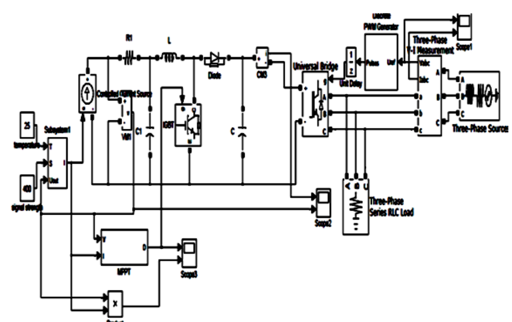

Figure 4: Simulation Diagram

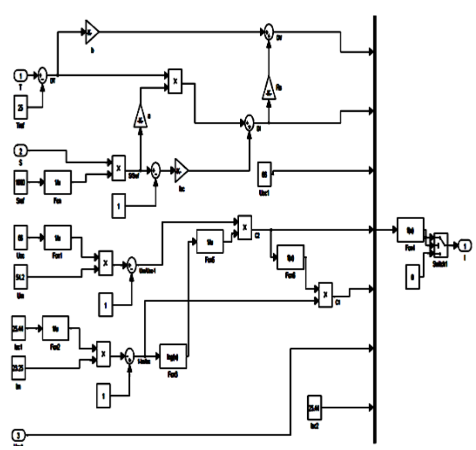

Figure 5: Solar Subsystem

In Figure 4 shows the simulation model of resonant converter and Figure 5 shows the simulation model of Solar Subsystem of the resonant converter. In that model the MOSFET is used as a switch for the best performance of voltage control, fast switching and low losses. When the MOSFET switch is closed supply voltage is connected to inductor and the inductor current starts to increase and store the energy. When the MOSFET switch is opened the inductor current starts to decrease. The Figure 6 (a) and 6 (b) show the simulation results of inverter voltage and load of the resonant converter.

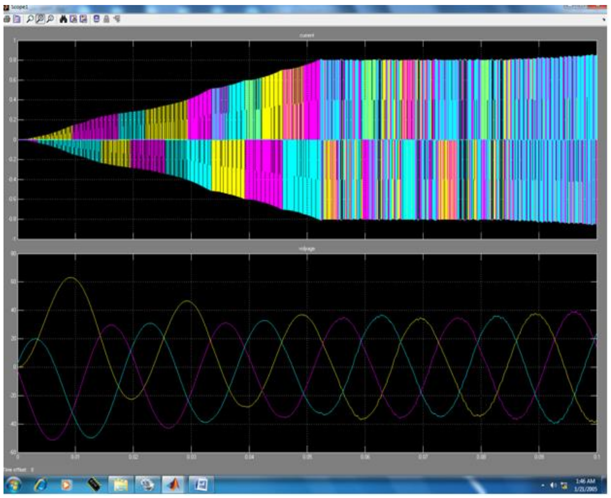

Figure 6: Simulation Diagram

7. CONCLUSION

This paper has proposed by combining traditional SL-qZSI with boost converter as well as applying an improved SL cell. Compared with the original qZSIs, the proposed qZSI has the following main characteristics such as: obtains high boost ability with continuous input current; offers lower voltage stress across capacitor, switching devices as well as diodes for the same input and output voltage. Furthermore, the proposed topology will be able to achieve higher conversion efficiency. The Effectiveness of the analysis for the proposed qZSI is verified by MATLAB/SIMULINK simulations under both simple boost and maximum constant boost control methods. According to above, it can be concluded that the proposed qZSI is more applicable for the distributed generation applications with low voltage sources, such as fuel cells, photovoltaic and so on.

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