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A Single Stage Power Conditioning Unit for Photovoltaic Energy System Using Z Source Inverter

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Abstract: **World is facing a great energy crisis and in this situation, photovoltaic energy systems are good option because of their clean, never ending and non-polluting nature. Solar power is obtained at load side after passing solar energy through Power Conditioning Unit (PCU). This PCU is used to convert energy obtained from sun into usable form. PCU basically contains inverters. In this paper, a new approach has been used by incorporating ZSI into PCU. ZSI provides single stage power conversion. Although, ZSI can be used without MPPT and had been using since a long time in the same way but in the proposed model, a MPPT block has also been used along with ZSI. To provide gating control signals for ZSI, simple boost control has been utilized. Addition of MPPT block makes system complex up to a level, yet it decreases THD of the system, increases its efficiency and also the gain. Design approach to the proposed circuit has been mentioned in section III. Section IV provides the simulated model of proposed circuit and section V shows and explains the results of the system.**

Keywords: **Power Conditioning Unit, THD (Total Harmonic Distortion), Photovoltaic system, Z source inverter, MPPT (maximum power point tracking).**

1. INTRODUCTION

Increasing global demand of power and scarcity of fossil fuels on the earth has forced us to think upon new solution to fulfill worldwide energy demand. Humankind has wasted fossil fuels as much as their capacity was. Now, the time has come when decreasing reserves of energy are teasing us and reminding us of the power we have wasted. We were busy in creating one by one new scientific inventions. We have enough of inventions to make our life easy but probably we will not be capable to operate them and take their advantages. A new challenge has risen before us to solve energy crisis and come up with such a solution that will not decrease or deteriorate with time. Answer to this challenge is renewable, non-conventional energy resources. The main importance of these renewable resources is they are non- polluting, clean, never ending, cheaper source of energy. They have been in use as energy resources since ages and again the time has come when humankind is getting to depend upon non- conventional resources for energy leaving behind a lot of conventional resources that it had searched after working over an era.

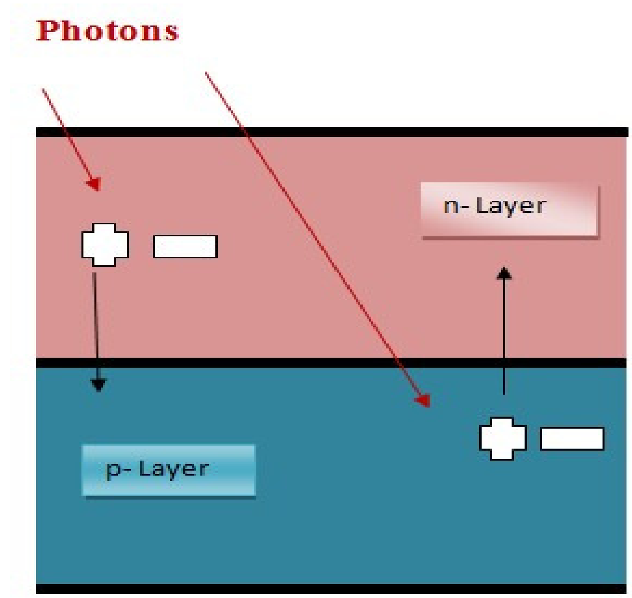

Figure 1. Photovoltaic cell

We have a number of non- conventional energy resources before us. Now it has to be decided that which resource will fulfill the energy demand along with their side effects in a better way. As options, there are hydro power, ocean energy, tidal energy, solar energy, wind energy etc. Among these, sun is found to be most promising energy resource. The energy obtained from sun is called photovoltaic energy as there are photovoltaic cells that convert solar energy to electrical energy.

Photovoltaic energy is being used since a long time but with the passage of time, there increases a demand to make it more powerful and more efficient. After converting solar energy through photovoltaic cells, it is passed to power conditioning unit before going to load. So, all the time, this power conditioning unit is needed to b improved. Power conditioning unit basically contains inverters and as inverters and their role are changed, efficiency changes [6]. Since, long time traditional voltage source inverters and current source inverters are in use for power conditioning unit. There are many flaws in their use. So, we will be using a impedance source inverter in power conditioning unit.

2. REVIEW OF CONVENTIONAL INVERTERS AND Z SOURCE INVERTER

The conventional inverters are of basically two types:

1. Voltage source inverters

2., Current source inverter

2.1 Voltage Source Inverter

The voltage source inverters are limited in their use because:

- Voltage source inverters behave as step down/ buck converter for dc-ac conversion while as step up/ boost for ac-dc conversion. They cannot be used as buck or boost with same circuit configuration.
- Both the power switching device of the same phase leg cannot be gated on simultaneously. It will lead to shoot through switching state and will destroy the inverter circuitry. Due to EMI noises, there can be misgating on and circuit will destroy [5].

An additional LC filter is needed to get sinusoidal output at load.

2.2 Current Source Inverter

At the same time, current source inverters face following limitations:

- Current source inverters are boost /step up converters for dc-ac conversion and buck /step down converters for ac-dc conversion but they cannot be both step up and step down simultaneously.
- In current source inverters, both the power switching devices of the same phase leg cannot be switched off simultaneously. At a time, one device is needed to be switched on necessarily. But due to EMI noises and other problems in the circuit, there can be misgating off that will make the inverter circuit to come in shoot through state and circuit will be destructed [5].

2.3 Z Source Inverter

Z source inverters are impedance source inverters, which employ a unique impedance network and so called Z source inverters. The impedance network of Z source inverter has two inductors connected in split phase or separately and two capacitors in X shape [1]. The following features of Z source network increases the efficiency of the system where it is used:

- Z source inverters can be used as either buck converter or boost converter simultaneously.
- The same circuit of Z source inverter can be employed for dc-dc, dc-ac, ac-ac and ac-dc i.e. in all type of conversions.
- Z source inverters provide single stage conversion.
- Using shoot through states, voltage can be boosted up.
- Z source inverter uses a different SVPWM (state vector pulse width modulation) technique for its control [5].
- Due to modulation used for control, ZSI gets a unique buck-boost feature with boost factor depending on the modulation index.
- ZSI can also be used in MPPT (maximum power point tracking) of solar energy.
- It has minimized number of switches, switching losses and also THD of the inverter system.
- For the same voltage and current ratings of inductors and capacitors, their values are less when used in ZSI.

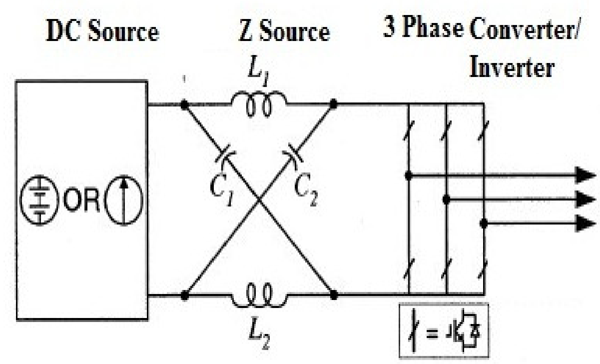

Figure 2. ZSI

The impedance network is used here with a suitable combination of modified switching scheme that allows a proper voltage boost without adding an extra converter stage. In Z source inverter; there are only passive components in the voltage boost configuration that will reduce extra switching losses from the inverter side configuration. Although, the whole inverter system is composed of two parts; Z source network and three phase inverter configuration, still they are considered as a single system and cannot be operated separately with the gating control provided to it. Both the parts of the system are taken as a single stage of conversion. Here comes the advantageous unique feature of Z source inverter. In all the traditional inverters, shoot through states are strictly

3. CONTROL AND OPERATION PRINCIPLE

In simple boost method shoot through states are inserted in all the conventional zero states of a switching cycle. Rest, the active states remains unchanged as in case of conventional inverters and modulation schemes. Two straight lines are used to get shoot through duty cycle ratio where one line is equal to amplitude of three reference sinusoidal waveforms and other being negative of the first one [3,4].

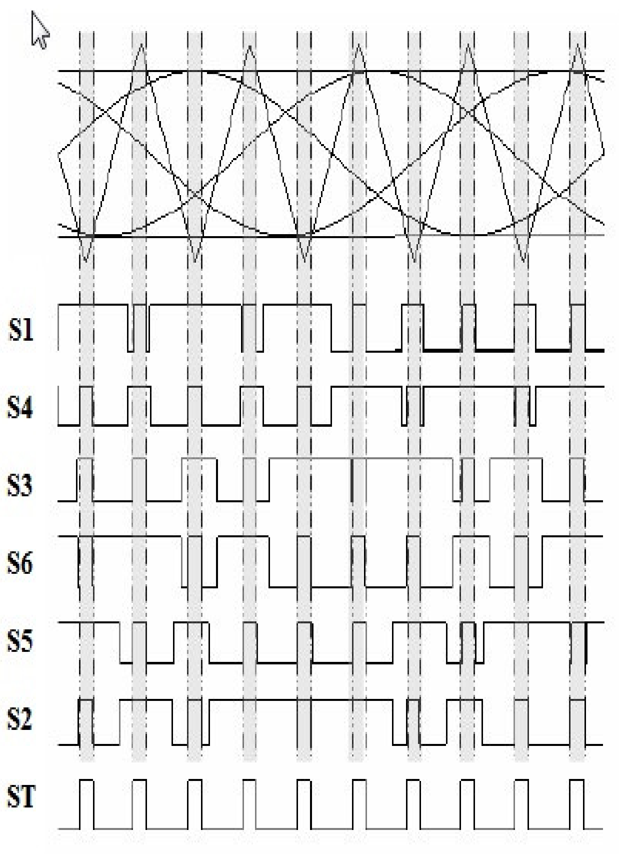

Figure 3. Simple Boost Control

In SPWM (sinusoidal pulse width modulation) scheme, gate pulses are obtained by comparison of triangular carrier signal with three phase sinusoidal carrier signals. In one cycle of operation, two zero states come in addition to six active states. So, it cannot be used in output voltage control. The shoot through states must be inserted into two zero states to boost the output voltage. In inverter switching cycle, zero states are obtained when all the three sinusoidal signals are greater than or lesser than the reference carrier signal. Therefore, for the insertion of shoot through states in zero switching states, two steady state signals namely V_P and V_N respectively having amplitude equal to that of sinusoidal signal, being equal in magnitude and opposite in polarity are compared with reference carrier signal.

Voltage gain of Z source inverter can be expressed as:

$$\frac{\hat{V}_{ac}}{V_{pv/2}} = MB$$

$\square_{ac}$ is the peak output phase value, V_{pv} is input dc voltage, M is modulation index and B is boost factor. If BM product is replaced with gain G then

$$\hat{V}_{ac} = G\frac{V_{pv}}{2}$$

The modulation index is given as:

$$B = \frac{T}{T_1 - T_0} = \frac{1}{1 - (\frac{2T_0}{T})}$$

Where T_0 is shoot through time interval in a whole switching cycle of duration T. so T_0/T becomes the shoot through duty ratio.

Fig.3 describes simple boost control method in which two straight envelope lines V_P and V_N are used. When triangular carrier signal is greater than upper shoot through envelope V_P , then or lesser than lower shoot through $V_{N,}$ then the inverter gets entrusted to shoot through state. In between shoot through states, active states come as in traditional inverters. As the modulation index increases, shoot through duty ratio decreases. The maximum value of shoot through duty ratio of the simple boost control method can be (1-M) and finally reaching to null at modulation index of one [5]. Here, we see that voltage gain is already proportional to shoot through duty ratio and duty ratio is inversely proportional to the modulation index, hence our output voltage gain is inversely proportional to the modulation index. In simple words, if higher output voltage gain is desired then modulation index should be lower [5].

$$G = MB = \frac{M}{1 - 2D_0}$$

Since, $D_0 = 1 - M$.

$$G = \frac{M}{1 - 2D_0} = \frac{M}{1 - 2(1 - M)} = \frac{M}{2M - 1}$$

$$\hat{V}_{ac} = M\frac{BV_{pv}}{2}$$

Here BV_{pv} should be dc input voltage at voltage source inverter but when it comes about Z source inverter, it is input to inverter bridge. From fig 3.8, it is clear that it will be voltage stress on the inverter components that can be given by

$V_{inv} = BV_{pv}$

$$V_{inv} = \frac{1}{2M-1} V_{pv} = (2G-1)V_{pv}$$

Here voltage stress on switches increases as output voltage gain increases. So, a higher gain cannot be obtained employing this control method.

4. DESIGN APPROACH OF THE PROPOSED CIRCUIT

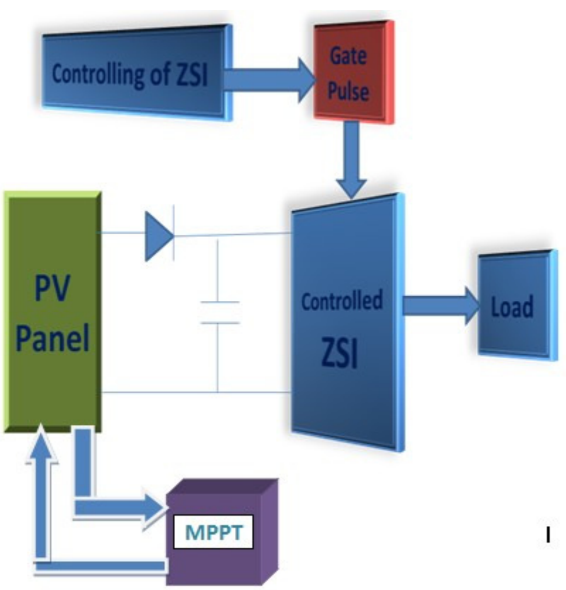

Figure 4. Block Diagram of Proposed Circuit

Usually all power conditioning units contain two stage approach for their proper operation of the circuitry. According to ZSI based PCU design approach, we don't need an extra circuitry of DC-DC regulator to perform the regulation of the output to provide the efficient output because of ZSI. Although, a better THD reduction and efficient output is obtained with conventional ZSI based PCUs but it can be improved more. Improvement can be done in many ways. In this paper, we have proposed to add MPPT block in the PCU to extract maximum power from sun.

In this single stage PCU, MPPT works in parallel manner. We need only single stage for entire operation of the circuit.

Its block diagram representation is described in fig.4.

5. SIMULATION RESULTS

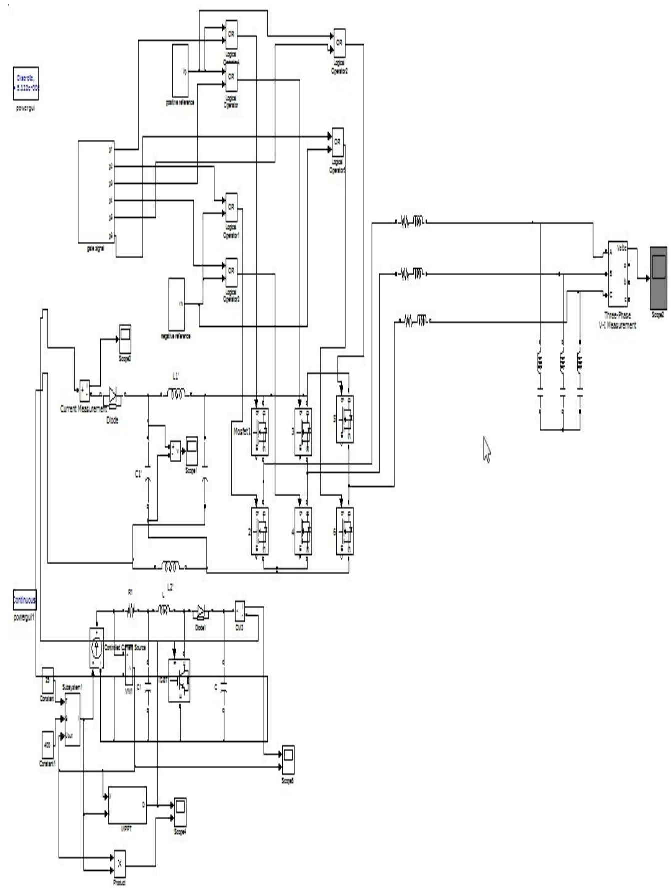

Figure 5. Simulink Model of Proposed PCU

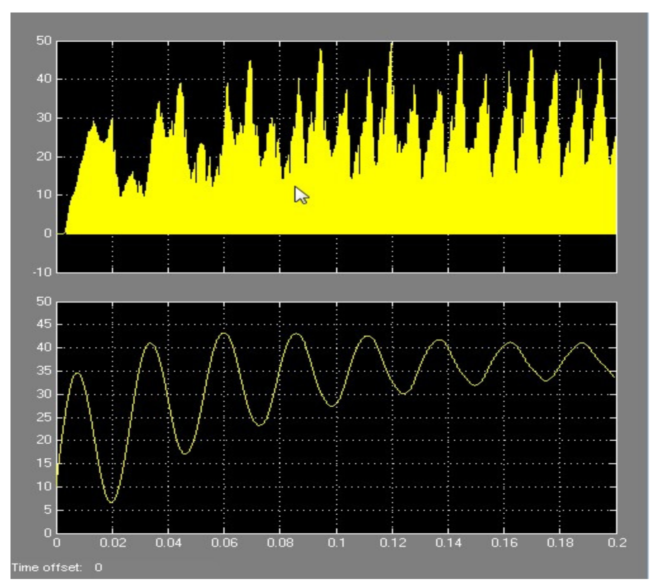

Figure 6. Output current and voltage waveform of PCU without using MPPT

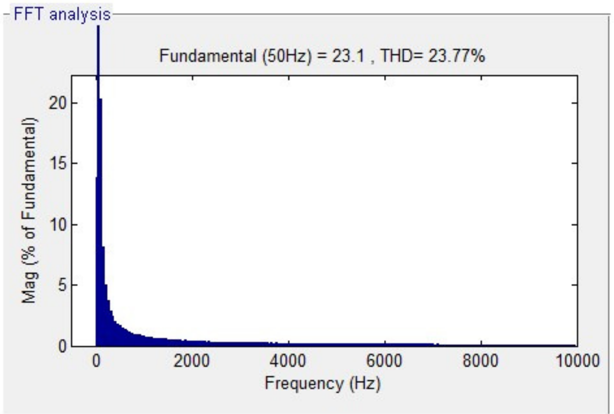

Figure 8. FFT analysis of the PCU without MPPT

A single stage MPPT associated Power Conditioning Unit for photovoltaic system is proposed and fully tested. Simulink model of the proposed circuit is shown in fig.5. The observed waveform of output current and output voltage of the conventional ZSI based PCU without using MPPT is shown in fig. 6 and output voltage and current waveforms of the proposed ZSI based PCU incorporated with MPPT are shown in fig. 7. Thus we find that for the same solar panel used at same operating conditions, for PCUs without adding MPPT, we get 42V at output while Proposed PCU incorporated with MPPT gives 440V at output. THD of this proposed circuit is 23.30% while that of PCU without MPPT is almost 23.77%.

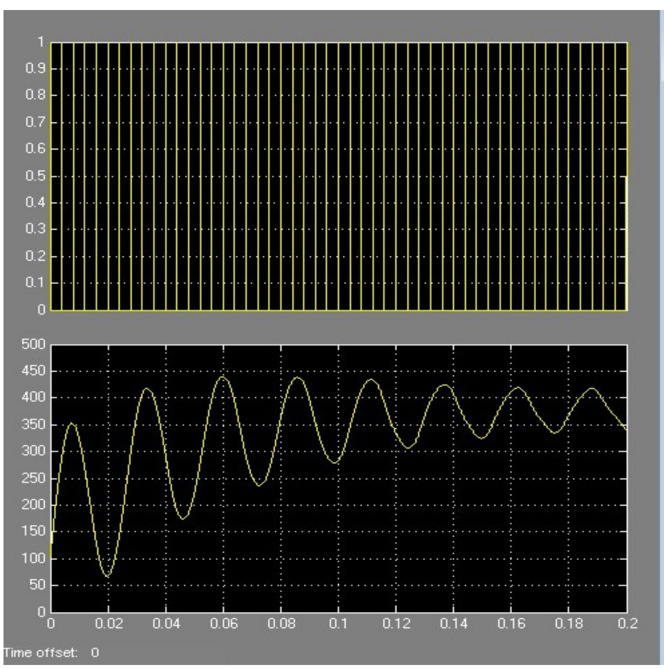

Figure 7. Output current and voltage waveform of proposed PCU using MPPT

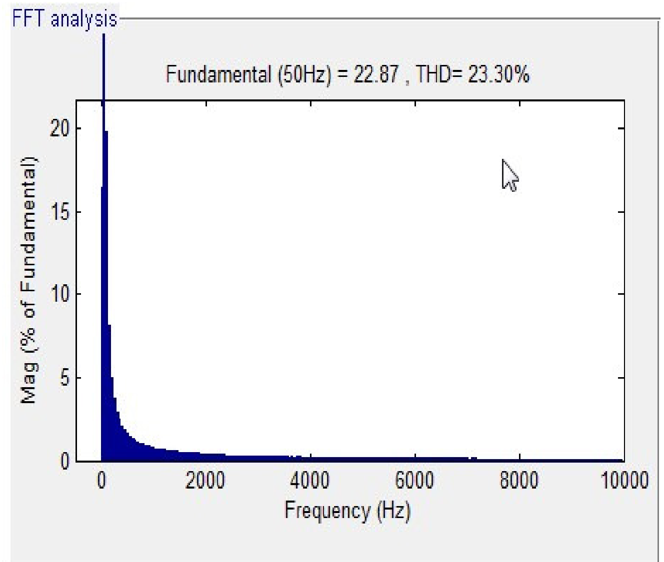

Figure 9. THD of the proposed PCU

6. ACKNOWLEDGEMENTS

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