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Comparison of Photovoltaic (PV) Panels and Soft Switching Boost Converters for PV Power Generation Systems

P. Manimekalai *[1], R. Harikumar [+], and S. Raghavan [#]

Abstract – *In this paper comparison of monocrystalline and polycrystalline PV arrays based on output voltage and power was carried out. The comparison of Zero Voltage Switching (ZVS) interleaved converter, Zero Current Switching (ZCS) interleaved converter and soft switching (resonance) interleaved converter was carried out using MATLAB/SIMULINK simulation. The simulation results were compared based on efficiency, harmonic distortion and settling time. Perturb and Observe MPPT (maximum power point tracking) control is used for simulating the model. The hardware performance of interleaved soft switching converter was compared with simulation results. A fault tolerant circuit was introduced to protect the converter from switching circuit faults and device faults.*

Keywords *– Comparison of PV panels, design of interleaved boost converters, fault tolerant circuit,performance analysis of interleaved boost converters, photovoltaic power generation.*

1. INTRODUCTION

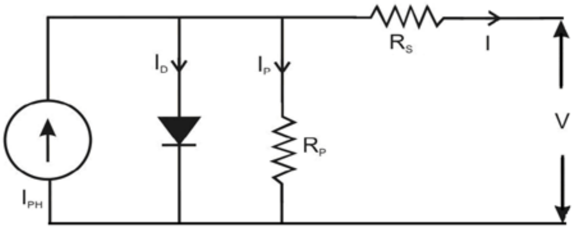
The increasing energy need is demanding us to think about other energy sources instead of conventional energy sources. But the global energy requirement will be doubled by 2050 [1]. To fight against the global warming and other problems associated with fossil fuels such as depletion of energy sources like oil and coal by the end of this century is another reason to go for non conventional energy sources [2].

To supply power to remote areas such as hill stations and forest areas conventional method of power distribution requires long transmission lines. The transmission line losses will also be high. To reduce transmission line cost and transmission losses standalone hybrid power systems using non conventional energy sources such as wind, solar and biogas will be a suitable approach [3].

Among many renewable energy sources solar energy is mostly used due to its non-polluting, highly reliable and non exhaustible nature. India is in the sunny belt of the world. In a year, India gets almost 300 sunshine days. Electricity of 500,000 terrawatt-hour (Twh) can be generated from the solar energy received by India using PV modules having an energy conversion efficiency of 10%. [4]. According to International Energy Agency, in 2050 PV power generation will satisfy around 45% of the energy needs of the world [5]. PV panels absorb energy from solar radiation and have a maximum operating point, at this operating point maximum energy will be extracted from solar insolation. But this point varies with variation of solar irradiation, temperature and environmental conditions. The efficiency of the PV array will be maximum at the maximum power point. So to transfer power from the PV array to load a high efficiency power conditioning system is necessary. The power conditioning system consists of a DC-DC boost converter to boost the output of PV array using maximum power point tracking technique and a DC-AC inverter to provide ac output to the load [6].

2. PV EQUIVALENT CIRCUIT

A solar cell basically is a p-n semiconductor junction. When exposed to light, a dc current is generated. The generated current varies linearly with the solar irradiance. The standard equivalent circuit of the PV cell is shown in Figure 1 [2].



I_{PH} is the light generated current (A).
Io is the diode saturation current.
q is the charge of electron = $1.6x10^{-19}$ (coulomb)
K is the Boltzmann constant (J/K).
T is the cell temperature (K).
Rp, Rs are cell series and shunt resistance (ohms).
V is the cell output voltage (V).

Fig. 1. Equivalent circuit of PV solar cell.

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3. TYPES OF PV PANELS

There are three types of commercially available solar panels namely thin film type or amorphous silicon, Polycrystalline type and Monocrystalline type. Thin film panel is used solar powered calculator or watch. For Power generation purposes mono or polycrystalline panels are used. The sunlight to electrical efficiency of monocrystalline cells are from 10%-15%, Polycrystalline 9%-12% and thin film 9% [7].

4. COMPARISON OF PV PANELS

Monocrystalline and polycrystalline panels of same specification as in Table 1 were taken and their I-V and P-V characteristics were obtained by taking readings under same test conditions as in Table 2.

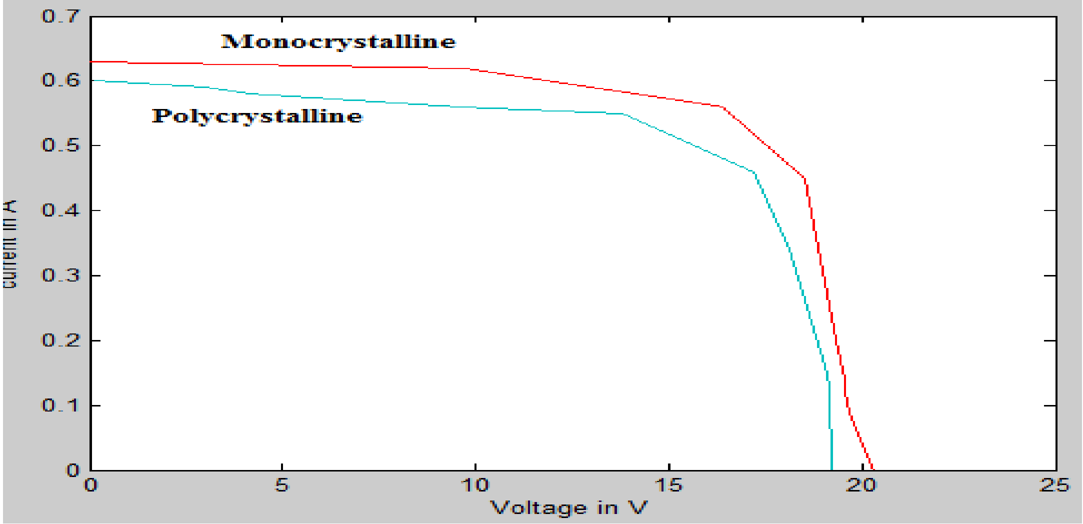

Fig. 2. I-V characteristics of PV arrays.

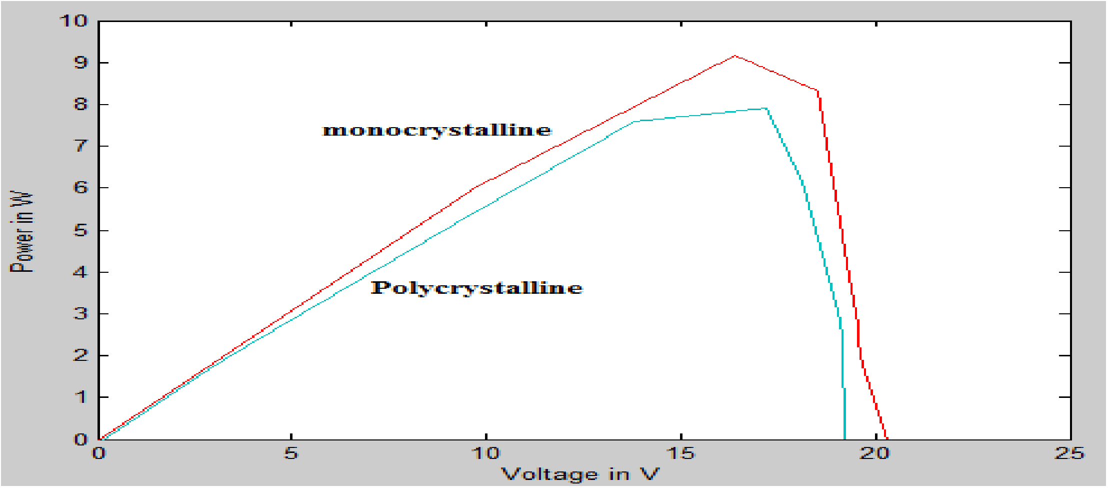

Fig. 3. P-V characteristics of PV arrays.

Table 1. PV panel specifications.

Monocyrstalline		Polycrystalline	
Pmax	10W	Pmax	10W
Imp	.59A	Imp	.59A
Vmp	17V	Vmp	17V
Voc	21V	Voc	21V
Isc	.62A	Isc	.62A
Tolerance	5%	Tolerance	5%

5. EXPERIMENTAL SET UP

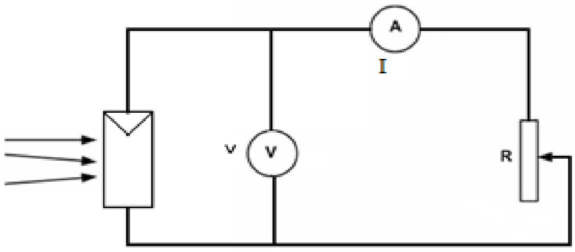

Fig. 4. Circuit diagram for V-I measurement.

6. CHARACTERISTICS OF PV PANELS

From the characteristics it can be seen that the output voltage and output power of monocyrstalline array is higher than that of polycrystalline array for the same specifications and same atmospheric conditions.

The I-V characteristic gives two important values, the short circuit current (Isc) which is the maximum current at zero voltage and the open circuit voltage (Voc) which is the maximum voltage at zero current. For each point on the I-V curve the power output is obtained by finding the product of current and voltage. The maximum power point (P_m) is the point where the product of I and V is maximum on the I-V curve [8]. The increase in temperature causes some increase in short circuit current and decrease in cell voltage of 2.2mv per degree rise of temperature [9]. The output voltage, current and power variation for monocrystalline and polycrystalline arrays under the same environmental conditions are given in Table 2.

Table 2. Comparison of monocrystalline and polycrystalline arrays performance on voltage and power basis.

S. no	Monocrystalline array			Polycrystalline array		
	Voltage in V	Current in A	Power in W	Voltage in V	Current in A	Power in W
1	00.00	0.63	0.000	00.00	0.62	0.000
2	09.70	0.62	6.014	02.94	0.59	1.735
3	16.36	0.56	9.167	04.11	0.58	2.384
4	18.50	0.45	8.325	09.58	0.56	5.365
5	19.03	0.29	5.519	13.80	0.55	7.590
6	19.34	0.20	3.868	17.18	0.46	7.903
7	19.54	0.14	2.736	18.13	0.34	6.164
8	19.58	0.12	2.350	19.06	0.16	3.050
9	19.70	0.09	1.773	19.17	0.13	2.493
10	20.32	0.00	0.000	19.23	0.00	0.000
11						

7. BOOST CONVERTERS

DC-DC boost converters are used at the output of the PV array with MPPT control to provide power to the load through dc-ac inverter. Boost converter have simple topology, high power density, fast transient response and continuous input current. Therefore, boost converters are usually used in different power electronics applications such as active PFC, photovoltaic power systems and fuel cells.

Boost converter is a step up converter as in Figure 5, consists of a boost inductor, switching device, boost diode and boost output capacitor. During the conduction of the switch, the input current flows through the inductor and switch and the inductor stores the energy during this period. When the switch is off, the inductor current cannot reduce immediately and this current is forced to flow through the diode and the load during this off period.

The decrease of current reverse the polarity of the emf induced in the boost inductor. Thus the voltage across the load is the sum of supply voltage and inductor voltage and it is greater than the supply voltage [10], [11]. To provide high output voltage, dc- dc converter need to be operated at extreme duty cycle which subjects the switching devices to short pulse, high amplitude current which leads to reverse recovery and EMI (Electro Magnetic Interference) problems and the extreme duty cycle leads to poor dynamic response for line and load variations.

Converters with coupled inductor can provide a high output voltage, less switching voltage stress without extreme duty cycle. But the leakage energy losses in the coupled inductor reduce efficiency of the converter [12]. Resonant or quasi resonant converters can be used as dc-dc converters. The voltage stress in the switching devices is high for high input dc voltage applications is the drawback.

To overcome these difficulties and to improve the performance of the boost converter interleaving technique can be used [9].

8. INTERLEAVED CONVERTERS

Interleaved operation (the parallel connection of switching converters) of two or more boost converters has been proposed to increase the output power and to reduce the output ripple. The interleaved converter consists of identical boost converters connected in parallel for which the switching signal of same frequency with the phase shift is provided by the interleaving method.

Cancellation of the ripple, both in the input-output voltage waveforms and reduced current peak values are the benefits of interleaving technique shown in Figure 6. Further the volume of the inductor can be reduced by a factor of four and current rating of the semi conductors can be reduced by half for two phase interleaved structure compared to conventional boost converters [13].

The hard switching interleaved converters have low conduction losses and high switching losses. The switching losses cause a significant amount of power dissipation in high power applications. High switching frequency operation is necessary to achieve small size of the converter.

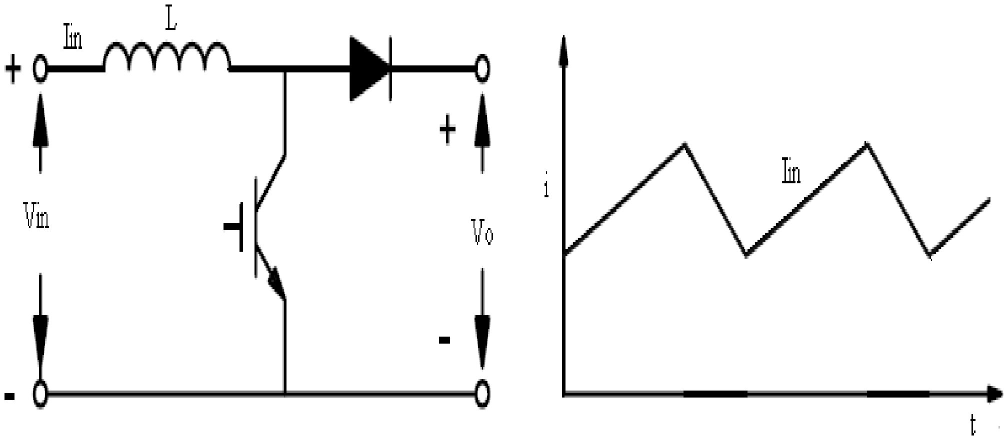

Fig. 5. Conventional boost converter.

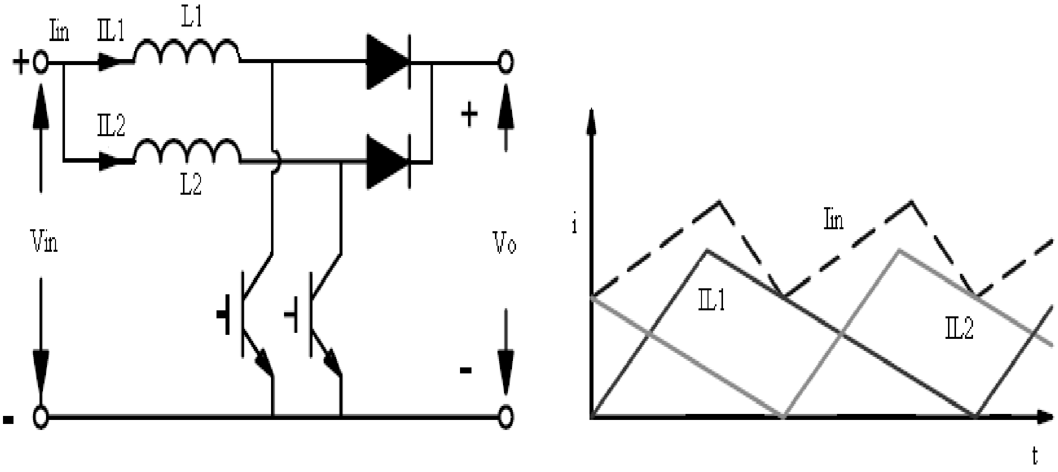

Fig. 6. Interleaved boost converter.

In order to minimize the switching losses soft switching techniques such as ZVS and ZCS can be used. Interleaved converters operating in continuous current mode have better utilization of power devices, lower conduction losses and lower input peak currents. This mode is suitable for high power applications [12].

9. DESIGN OF COMPONENT VALUES FOR INTERLEAVED BOOST CONVERTERS

9.1 Boosting Ratio

Boosting ratio is given by the equation:

$$\frac{V_0}{V_i} = \frac{1}{1-D} \quad (1)$$

where V_0 is the output voltage, V_i is the input voltage and D is the duty ratio. This is similar to conventional boost converter.

The duty ratio is:

$$D_{(min)}=1-(V_{imax}/v_{omax}) \quad (2)$$

$$D_{(max)}=1-(V_{imin}/v_{omax}) \quad (3)$$

9.2 Calculation of Inductor and Capacitor Values

In the operation of interleaved boost converter, the inductor is used to transform the energy from the input voltage to the inductor current and to convert the inductor current to the output voltage.

The value of the inductor can be calculated using the formula:

$$L = \frac{V_s D}{\Delta I_L . f} \tag{4}$$

The value of the capacitor can be calculated using the formula:

$$C = \frac{V_0 D f}{R \Delta V_0} \tag{5}$$

where Vs is the source voltage and ΔI_L is the inductor current ripple, D is the duty ratio, Vo is the output voltage (V), f is the switching frequency, R is the resistance and ΔVo is the change in the output voltage (V) [14].

9.3 Selection of the Number of Phases

As the number of phases increases the ripple content decreases. The ripple content reduces by 9% in a two phase interleaved boost converter than that of conventional boost converter. If the number of phases increases without restriction, the number of components increases and hence the cost increases without much reduction in ripple. In all the phases the number of components, type of components and the ratings of the components should be the same [14].

9.4 Choice of active devices

The device used for interleaved boost converter is power MOSFET which have high commutation speed and efficiency at low voltages. The IGBT, an isolated gate device can be used for high power applications [14].

10. SOFT SWITCHING CONVERTER TYPES

10.1 Zero Voltage Soft Switching Converters

In this converter the active power switches S1 and S2 are turned on at zero voltage to reduce the switching losses and to increase the conversion efficiency. Efficiency of the module will be as high as 95.1% [15] - [18], [22].

10.2 Zero Current Switching Converters

Interleaved zero current switching converter is suitable for high power applications where IGBT is used as a switching device. The IGBT is turned on at zero current. This zero current turn on is useful for the elimination of tailing current losses. Efficiency of the ZCS converter will be 96.6% [17], [18], [21], [22].

10.3 Interleaved Soft Switching Boost Converters

Two single phase boost converters are connected in parallel to form an interleaved boost converter as in Figure 9. The phase difference between the two PWM signals is 180 degrees. The switches are turned off at zero voltage and turned on at zero current to ensure the maximum efficiency by reducing the switching losses.

The total current is the sum of the inductor currents L_1 and L_2. This leads to the reduction in the size of the inductor. Efficiency of the converter will be 98.5%. [19]-[22].

11. FAULT TOLERANT TOPOLOGY

While working with isolated power generation systems, the major factors to be considered are safety, reliability and power quality. If there is a sudden failure in the driving circuit or switching devices detection and compensation of the fault at a short time will help to maintain the performance and prevent the unscheduled shut down.

The fault tolerant circuit which was highlighted can work within 5-10 microseconds and regain the normal operation. The components named fault 1 and fault 2 were used to create fault for simulation purposes after time of .02s to .03s and .05s to .07s. [23].

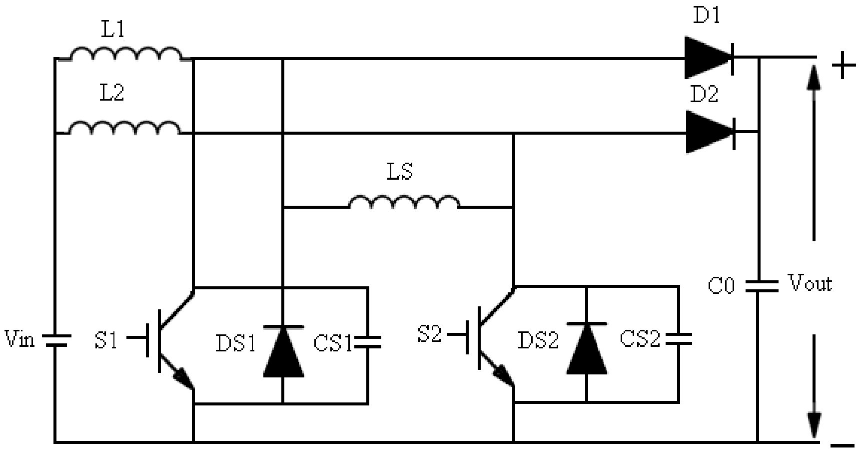

Fig. 7. Interleaved ZVS boost converter.

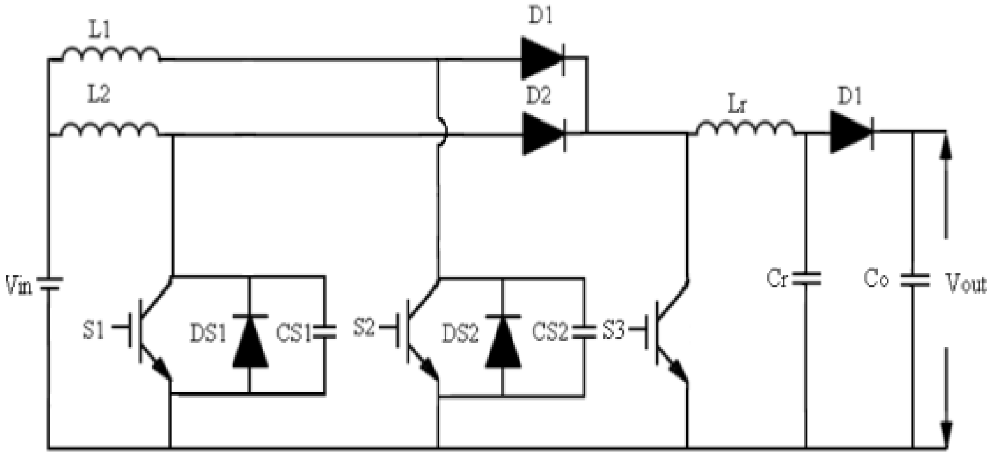

Fig. 8. Interleaved ZCS boost converter.

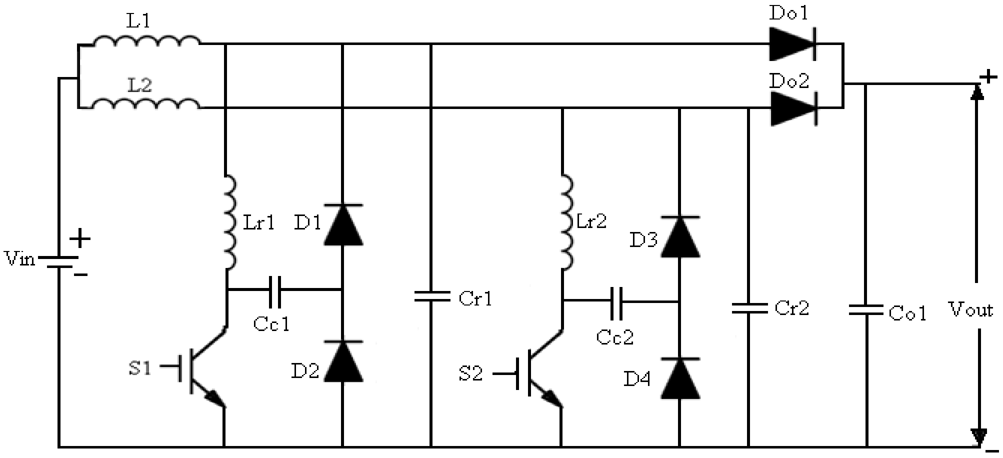

Fig. 9. Interleaved soft switching converter.

Fig.10. Hardware set up for resonant converter.

12. SIMULATION RESULTS

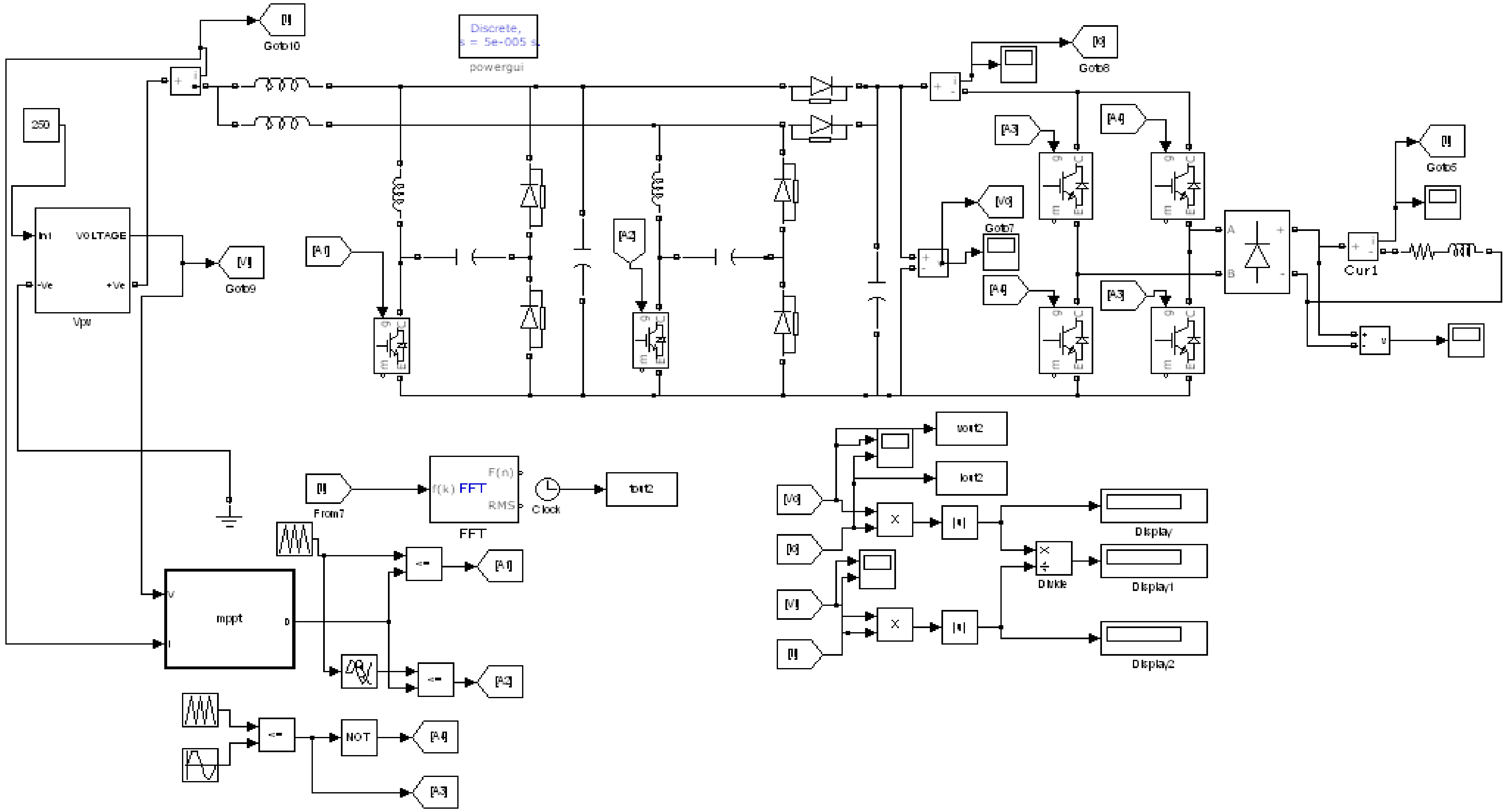

Fig. 11. Interleaved soft switching converter simulation model.

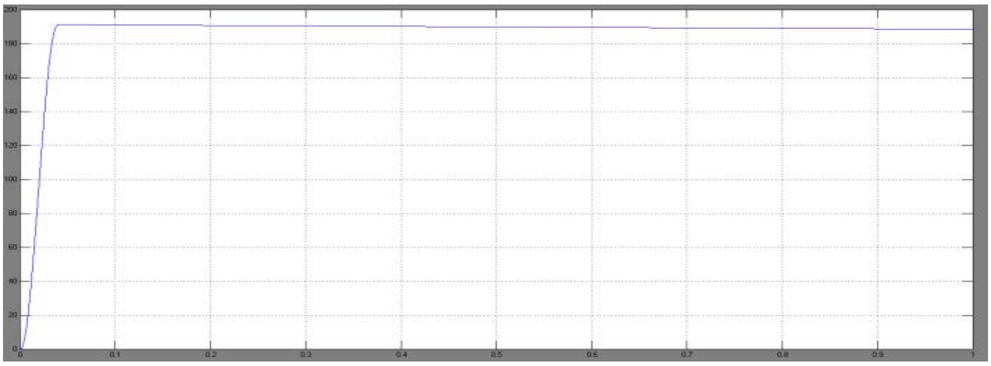

Fig.12. a ZCS converter output.

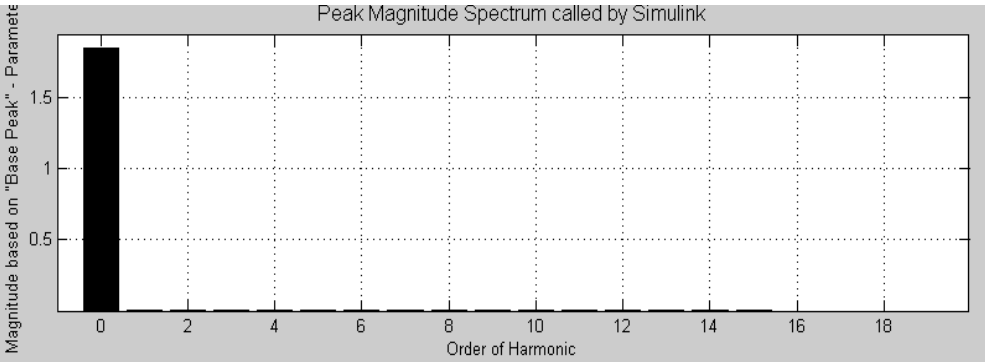

Fig.12.b FFT analysis of ZCS

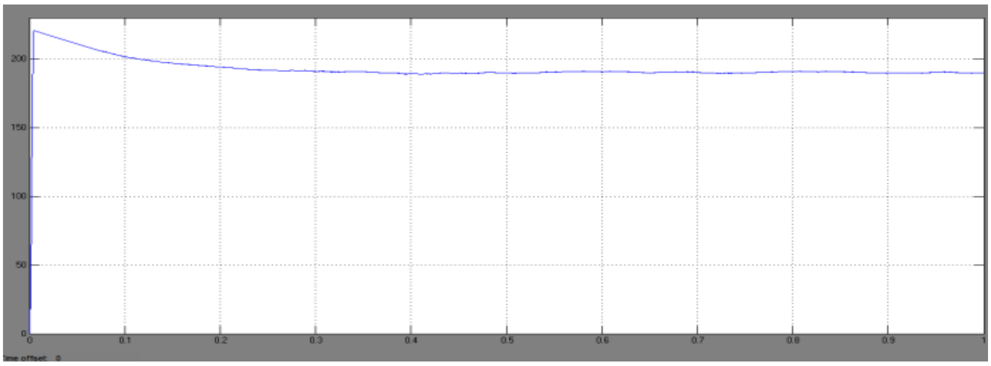

Fig.13.a ZVS converter output.

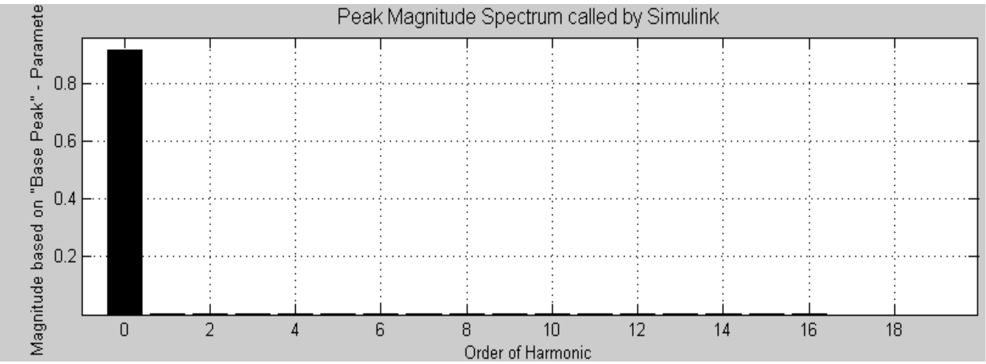

Fig. 13.b FFT analysis of ZVS.

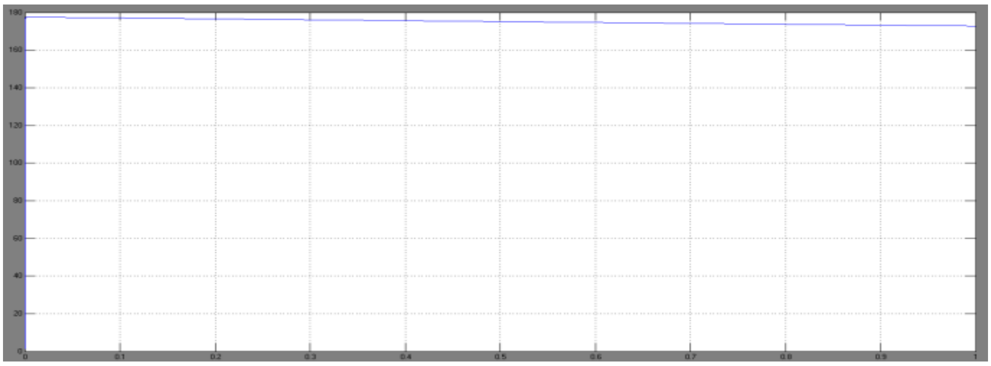

Fig.14.a Interleaved soft switching converter output.

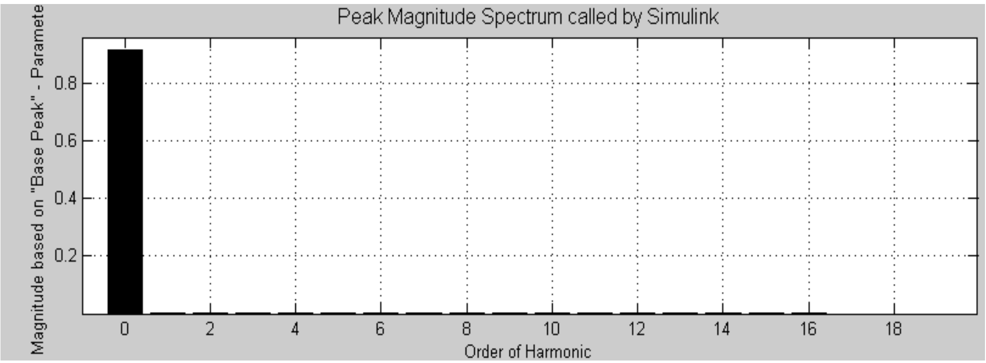

Fig .14.b FFT analysis of soft switching converter.

Table 3. Comparison of simulation results .

s. no	type	Efficiency in %	settling time(sec)	Fundamental magnitude(units)
1	ZVS	95.1	0.10 sec	2.10
2	ZCS	96.6	0.04 sec	2.05
3	Soft Switching	98.5	0.08 sec	2.20

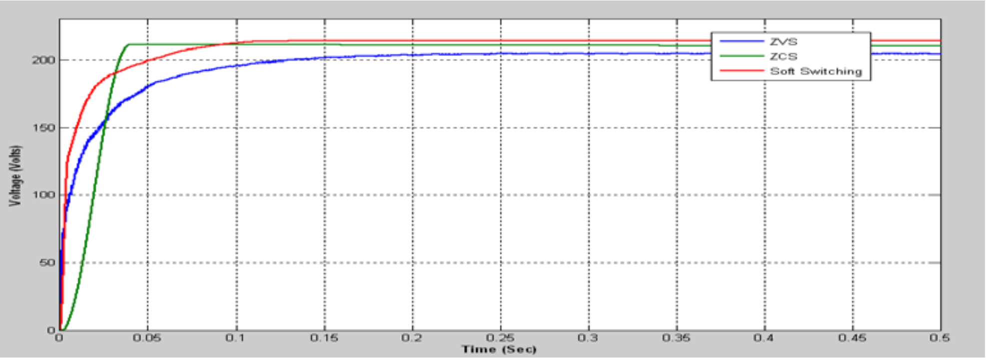

Fig. 15. Comparison of ZCS, ZVS and soft switching converter output waveforms.

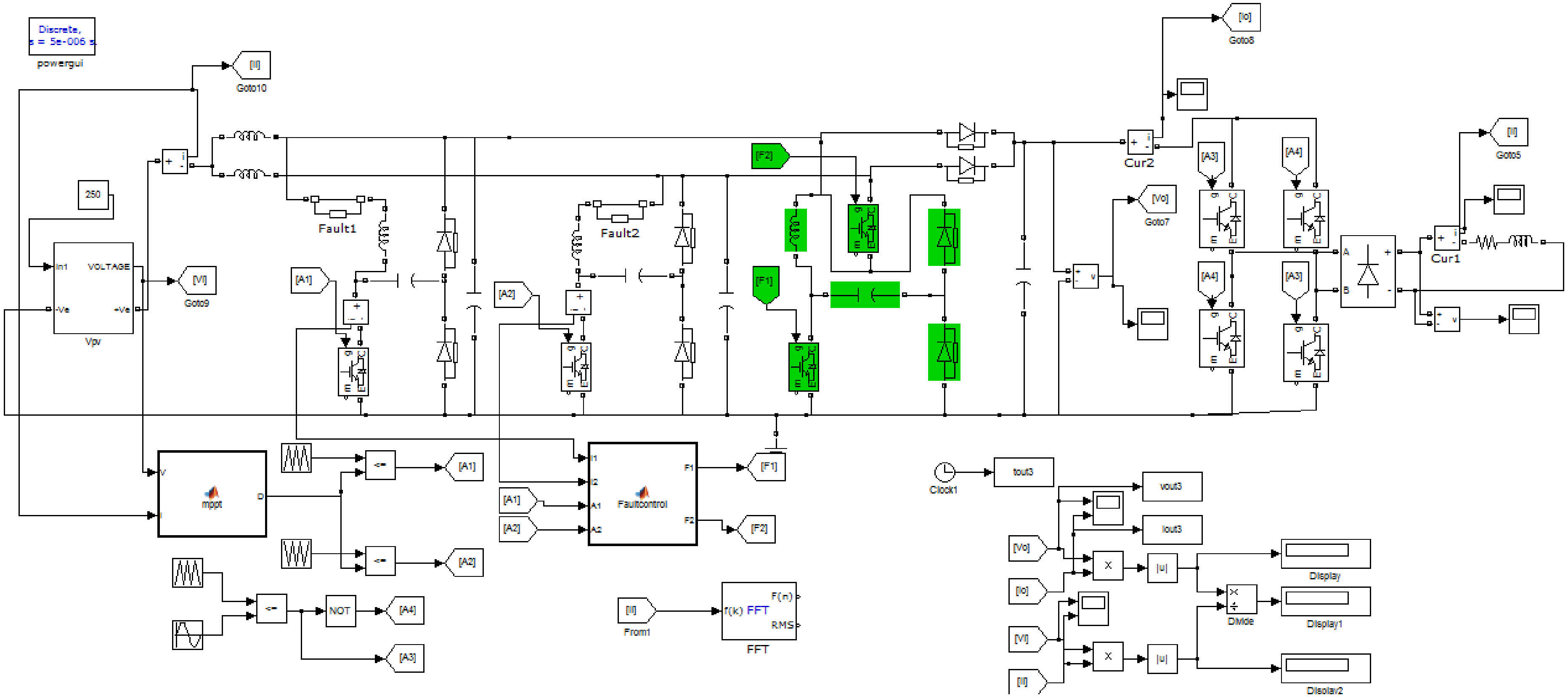

Fig. 15. Interleaved soft switching converter with fault tolerant circuit.

16. CONCLUSIONS

The monocrystalline array generated high output power than polycrystalline array under the same environmental conditions and specifications. The performance comparison of ZVS, ZCS and Soft Switching converters were carried out using MATLAB Simulation. Based on Simulation results Soft Switching interleaved converter had highest efficiency and medium settling time with minimum harmonics and maximum output amplitude. The ZCS had a faster settling time and moderate efficiency. The ZVS output magnitude was less compared to ZCS and soft switching. For simulation Perturb and Observe MPPT technique was used. Full bridge inverter was used to convert DC to AC. Active load was connected for analyzing Harmonic distribution. The efficiency of resonant converter by simulation was 98.5% but from the hardware set up it was found to be 86.7%. The fault tolerant part can be included for safety operation.

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