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An Efficient Photo Voltaic System for Onboard Ship Applications

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ABSTRACT
In this paper a high efficient photovoltaic system is proposed for onboard ship applications which convert the lower voltage obtained from solar modules to higher voltage required by the ship service loads. In a typical photovoltaic system only step-up /boost converter is used due to which the converter has to operate in extreme duty ratio, resulting in increase of switching losses and thus decreasing the overall efficiency. But in this paper the conventional boost converter is used with interleaved inductors and capacitors. The poposed system stores the energy in inductors and thus reduces the stress in the switches (Without allowing the total voltage to appear across the switch). The simulation is designed using MATLAB/Simulink with an Input voltage of 40-V to achieve a output voltage of 300-380 V. The developed simulation results are compared for output powers of 500W and 1kW

Keywords **-** Photovoltaic system, renewable energy sources, interleaved boost converter, voltage multiplier module.

I. INTRODUCTION

Currently, the diesel engines, is considered has the most viable and reliable option for ship propulsion and auxillary power generation. But the complication with the extensive usage of this technology is emmision of gases like CO_2, NO_x, SO_x and other organic chemicals. The shipping industry is estimated to produce 3% of global emmission of CO_2, this includes the mechant ships, combat ship and cruise ships [7][8]. As a solution to this, extensive research is being carried out world wide in implementation of renewable energy sources for Ship propulsion and other Ship service loads. The renewable energy, primarily solar and wind energy sources can be considered as an alternative energy source for main propulsion and auxillary power requirements of a ship though there are some inherent limitations for these renewable energies due to their intermittent nature [4].

The electrical load on board ship can be classified into propulsion loads and service loads. With the present day solar technology and with the typical characteristics of propulsion drives, the solar energy has a primary source of energy may not be a feasibile option for medium or large ships but can be used for small size ships. For large size ships, the solar energy can be used to cater only the selected laods so as to mainatin the continuity of electrical supply. The solar energy on board ship can be connected to the vital loads viz. Combat systems, mobility systems, fire systems etc [1]. Fig. 1 shows a typical photovoltaic system catering the service loads of the ship which consists of a solar module, a step-up converter, a controller, a battery set, and an inverter.

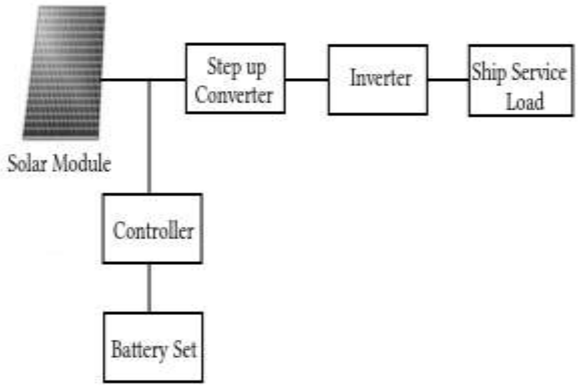

Fig. 1 Typical photovoltaic system Theoretically, the conventional step-up converters, such as the boost converter and fly-back

converters, cannot achieve a high step-up conversion and high efficiency because of the resistance of the elements or leakage inductance [2]-[4]. The answer to this problem a modified boost–fly-back converter is proposed in this paper.

As compared to the conventional circuit, losses are less in an asymmetrical interleaved converter for a high step-up and high-power application. But the asymmetrical interleaved converter circuit is complicated. One of the simplest approaches to achieve high step-up gain is by using the Modified boost–fly-back converter as shown in Fig. 2(a). Here the gain is realized by using a coupled inductor. The performance of the converter is similar to an active-clamped fly-back converter in which the leakage energy is recovered to the output terminal [5][6]. An interleaved boost converter with a voltage-lift capacitor is shown in Fig. 2(b). It is similar to the conventional interleaved type converter. It obtains extra voltage gain through the voltage-lift capacitor, and reduces the input current ripple, which is suitable for power factor correction (PFC) and high-power applications.

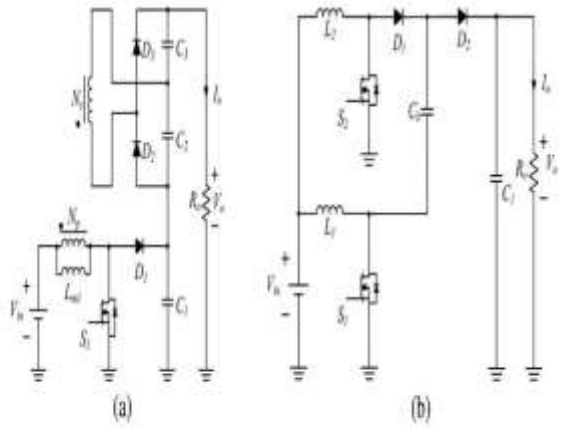

Fig. 2 (a) integrated fly-back–boost converter structure.(b) Interleaved boost converter with a voltage-lift capacitor structure.

In this paper, an asymmetrical interleaved high step-up converter is proposed with PV system having voltage multiplier module. The turns ratio of coupled inductors are designed to extend the voltage gain, and a voltage-lift capacitor is used to offer an extra voltage conversion ratio. The system designed here stores the energy in inductors and thus reduces the stress in the switches (Without allowing the total voltage to appear across the switch).

II. OPERATING PRINCIPLE

The proposed high step-up interleaved inductor capacitor converter with voltage multiplier module is shown in Fig. 3. A boost converter withinterleaved capacitor and inductor makes the system asymmetrical. Number of winding in primary is N_p and that of secondary is N_s.

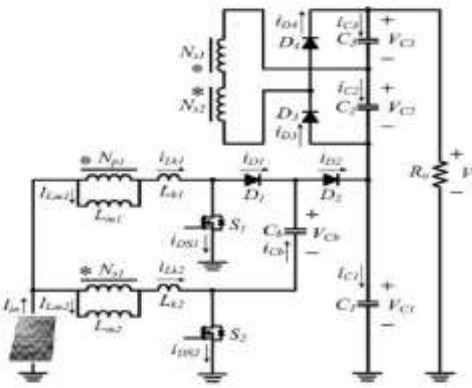

Fig. 3 The proposed converter.

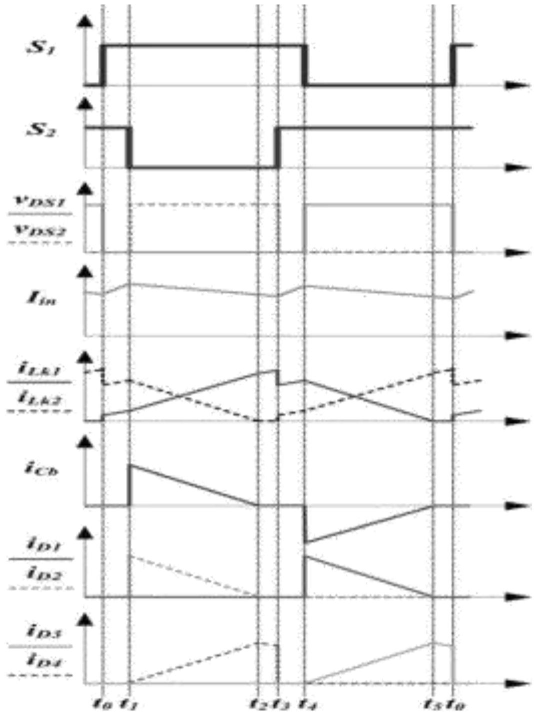

Fig. 4 Waveforms for the proposed converter .

Primary windings of the coupled inductors are employed to decrease the input current ripple, and that of secondary windings are used for extend voltage gain. The turn's ratios of the coupled inductors are the same .In the circuit L_{m1} and L_{m2} are the magnetizing inductors, L_{k1} and L_{k2} represent the leakage inductors, S_1 and S_2 denote the power switches, C_b is the voltage-lift capacitor, and n is defined as a turn's ratio equal to N_s /N_p.

The proposed system operates in continuous conduction mode (CCM).The power switches during the steady state operation are interleaved with a 180◦ phase shift; the duty cycles are greater than 0.5.

The steady state waveforms in one switching period of the proposed converter have six modes, which are depicted in Fig. 4, and the different modes of operations are explained in detail in Fig. 5. In the circuit the PV system is represented by a DC voltage source.

2.1 Mode 1 [t_0, t_1]: In mode 1, when $t=t_0$ both the switches S_1 and S_2 are turned ON. So voltage drop across the switches V_{DS1} and V_{DS2} are zero. Diodes D_1 to D_4 are reverse biased. Hence capacitors are not charged. But the magnetizing inductors L_{m1} and L_{m2} as well as leakage inductors L_{k1} and L_{k2} are linearly charged by the input voltage source V_{in}. Therefore current flowing through the i_{Lk1} and i_{Lk2} starts increasing. The operation is described in fig 5 (a).

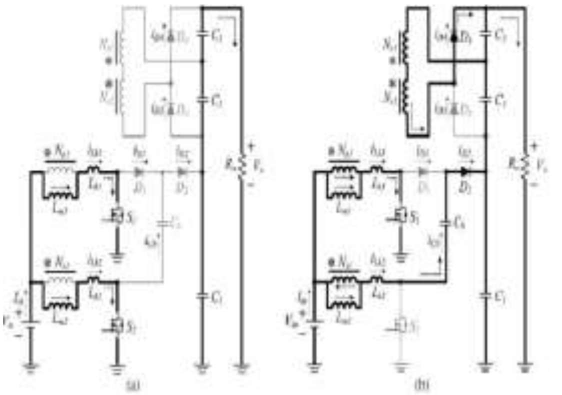

Fig.5 Operating modes (a) Mode 1 (b) Mode 2

2.2 Mode 2 [t_1, t_2]: When t=t_1, the power switch S_2 is switched OFF, thereby diodes D_2 and D_4 are forward biases. The energy stored in the magnetizing inductor L_{m2} now transferred to the capacitor C_b. In this mode i_{Lk1} is increasing since the power switch S_1 is on. Also C_2 is charging through D_2 and C_3 is charging through D_4.The current flowing through the magnetizing inductor L_{m2}, leakage inductor L_{k2}, and then voltage-lift capacitor C_b releases the energy to
the output capacitor C_1 through the diode D_2, there by extending the voltage on C_1.

2.3 Mode 3 [t_2, t_3]: At the end of t_2 the capacitor C_b discharges completely and diode D_2 is reverse biased automatically. Hence current through that capacitor i_{cb} is zero. In mode 3, the power switch S_2 is switched OFF, S_1 is ON as in the previous mode. In this mode of operation, C_1 is charged completely using the energy released from the C_b through D_2.Since D_2 is reverse biased capacitor C_2 also discharges completely. Magnetizing inductor L_{m2} transfers energy to the secondary side charging the output filter capacitor C_3 through the diode D_4 until t_3.

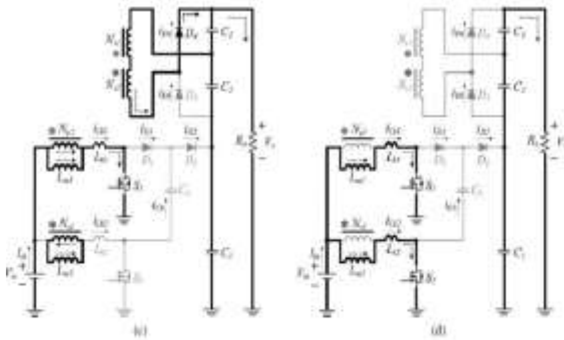

Fig 5: (c) Mode 3. (d) Mode 4

2.4 Mode 4 [t_3, t_4]: At time t=t_3, the power switch S_2 is switched ON and all the diodes are reverse biased. The operation of mode 4 is similar to that of mode 1. Diodes D_1 to D_4 are reverse biased. But the magnetizing inductors L_{m1} and L_{m2} as well as leakage inductors L_{k1} and L_{k2} are linearly charged by the input voltage source V_{in}. Fig 5 (c) and (d) explains the mode 3 and 4.

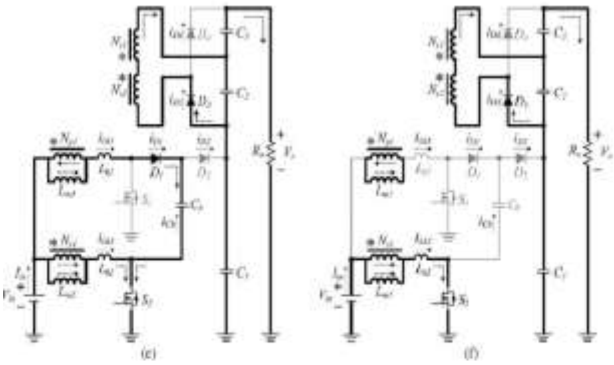

Fig 5: (e) Mode 5. (f) Mode 6

2.5 Mode 5 [t_4, t_5]: At t=t_4, the power switch S_1 is switched OFF, which forward biases the diodes D_1 and D_3. D_3 is on due to the fully charged C_1 capacitor. The capacitor C_2 is charging from the fully charged capacitor C_1. The input voltage source and magnetizing inductor L_{m1} release energy to voltage-lift capacitor C_b through diode D_1, which stores extra energy in C_b. Since the C_b is charging through D_1 the polarity is changed. Hence the i_{cb} direction is reversed.

2.6 Mode 6 [t_5, t_0]: At t=t_5, the diode D_1 is automatically turned OFF because the total energy of leakage inductor L_{k1} has been completely released to voltage-lift capacitor C_b. Magnetizing inductor L_{m1} transfers energy to the secondary side charging the output filter capacitor C_2 via diode D_3 until t_0.

III. STEADY-STATE ANALYSIS

The transient characteristics of circuitry are disregarded to simplify the circuit performance analysis of the proposed converter in CCM and some formula and assumptions are as follows:
1. All the components are ideal.
2. Leakage inductors L_{k1} and L_{k2} are neglected.
3. Voltage V_{Cb},V_{C1},V_{C2}, and V_{C3} are considered to be constant because of infinitely large capacitance.

3.1 Voltage Gain and other voltage equations:

$$V_{Cb} = \frac{1}{1-D} V_{\text{in}}. \quad (1)$$

$$V_{C1} = \frac{1}{1-D} V_{\text{in}} + V_{Cb} = \frac{2}{1-D} V_{\text{in}}. \quad (2)$$

$$V_{C2} = V_{C3} = n \cdot V_{\text{in}} \left(1 + \frac{D}{1-D}\right) = \frac{n}{1-D} V_{\text{in}}. \quad (3)$$

$$V_o = V_{C1} + V_{C2} + V_{C3} = \frac{2n+2}{1-D} V_{\text{in}}. \quad (4)$$

$$\frac{V_o}{V_{\text{in}}} = \frac{2n+2}{1-D}. \quad (5)$$

3.2 Voltage stresses on semiconductor components:

$$V_{S1} = V_{S2} = \frac{1}{1-D} V_{\text{in}}. \quad (6)$$

$$V_{S1} = V_{S2} = V_o - \frac{2n+1}{1-D} V_{\text{in}}. \quad (7)$$

$$V_{D1} = V_{C1} = \frac{2}{1-D} V_{\text{in}} \quad (8)$$

$$V_{D2} = V_{C1} - V_{Cb} = \frac{1}{1-D} V_{\text{in}}. \quad (9)$$

$$V_{D1} = V_o - \frac{2n}{1-D} V_{\text{in}} \quad (10)$$

$$V_{D2} = V_o - \frac{2n+1}{1-D} V_{\text{in}}. \quad (11)$$

$$V_{D3} = V_{D4} = \frac{2n}{1-D} V_{\text{in}}. \quad (12)$$

$$V_{D3} = V_{D4} = V_o - \frac{2}{1-D} V_{\text{in}}. \quad (13)$$

IV. SIMULATION RESULTS OF THE PROPOSED CONVERTER

Fig 6 shows the simulation circuit of high step up converter with voltage multiplier. Simulation is done using MATLAB simulink.

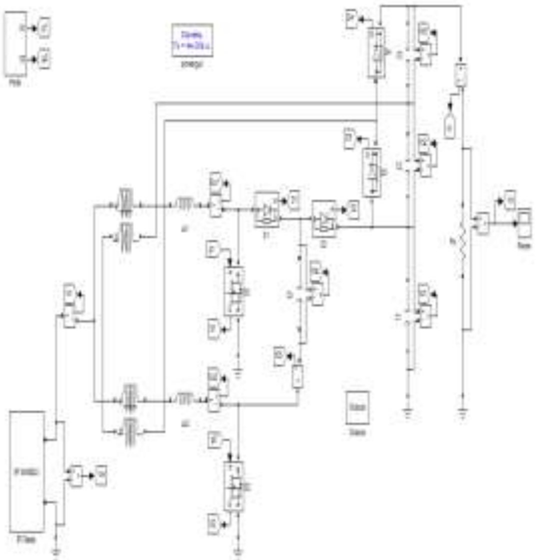

Fig 6 simulation circuit of high step-up converter with a voltage multiplier module with PV

The input voltage is taken from a PV panel and the power switches S_{w1} and S_{w2} are Power MOSFETS. The converter components used and parameter values are give in TABLE 1.

Parameters	Notations	Values
Magnetizing inductances	L_{m1},L_{m2}	133µH
Leakage inductances	L_{k1}, L_{k2}	1.6µH
Turns ratio	N_s/N_p	1
Capacitors	C_b,C_2,C_3	220 µF
Capacitors	C_1	470µF

TABLE 1: Converter parameters

Fig 7 shows the gate pulses G_1 and G_2, voltage across the power switches S_{w1} and $S_{w2.}$ Switch S_{w1} is ON during Mode 1 to 4. Mode 5 and 6 S_{w1} is OFF. During mode 2 and 3the switch S_{w2} is off, and in other modes it is turned ON. Fig 7 shows the gate pulses and voltage across the switches for 0.5 kW and fig 8 gives the same response for 1kW.

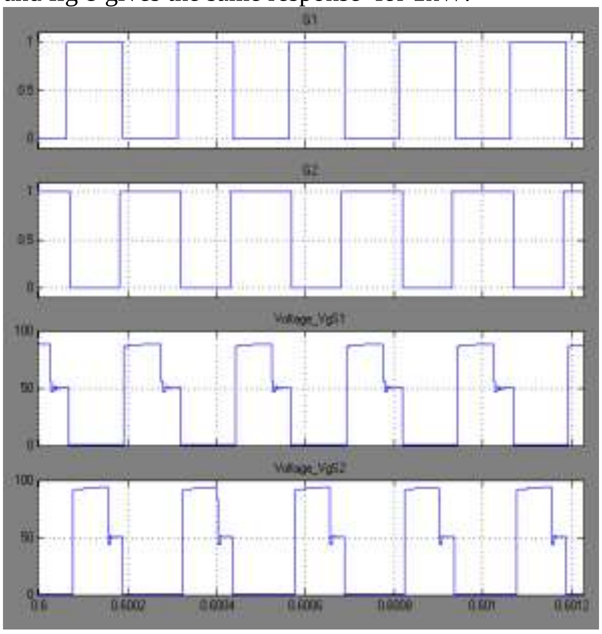

Fig 7 gate pulses & voltages across the switches S_{w1}& S_{w2} for 0.5kw power

In Fig 9 the measured input current, different leakage input current and capacitor current for 0.5kW are shown. When the switch S_{w1} s on, i_{Lk1} is increasing from zero and when t=t_3 it i_{Lk1} is maximum, after that it starts to decreases and when t=t_5, current flowing through the leakage inductor i_{Lk1} again reaches zero.

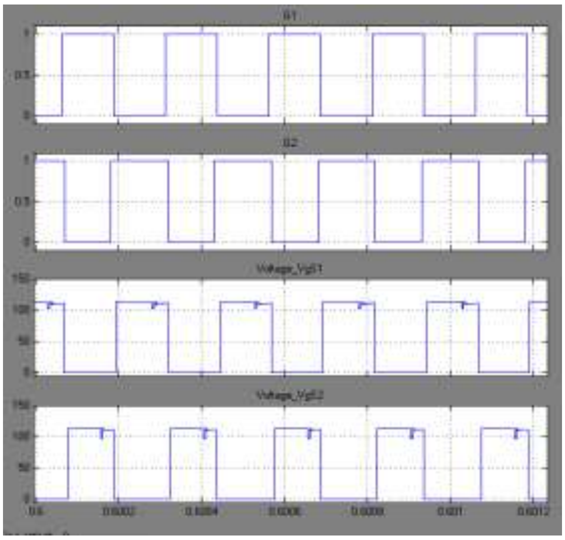

Fig 8 gate pulses & voltages across the switches S_{w1}& S_{w2} for 1kw power.

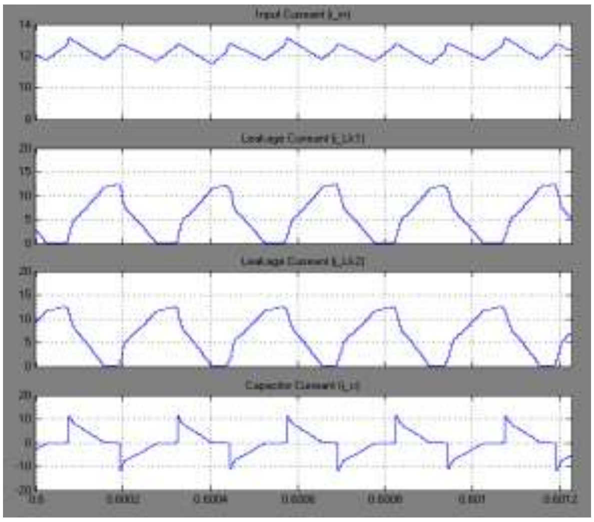

Fig 9 Measured waveforms of Iin, ILK1, ILK2 and Ic for 0.5kw power

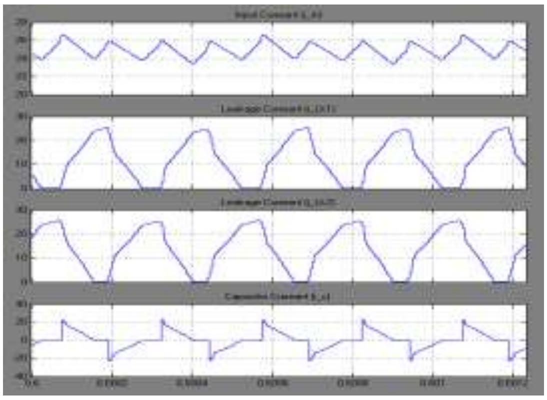

Fig 10 Measured waveforms of I_{in}, I_{LK1}, I_{LK2} and I_c for 1kw power

In Fig 10 leakage current and measured input current, different leakage input current and capacitor current for 1kW. When the switch S_{w2} s on, i_{Lk2} is increasing from zero and when $t=t_0$ it i_{Lk2} is maximum, after that it starts to decreases and when $t=t_3$, current flowing through the leakage inductor i_{Lk2} again reaches zero. t.

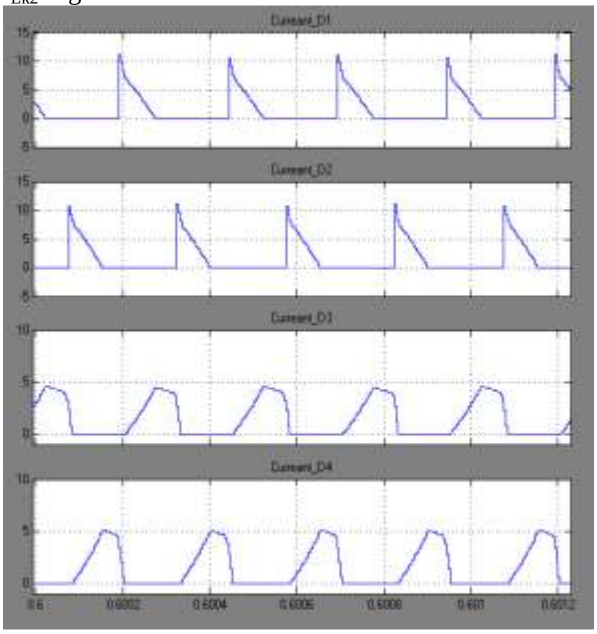

Fig 11. Measured waveforms of D_1, D_2, D_3 and D_4 for 0.5kw power

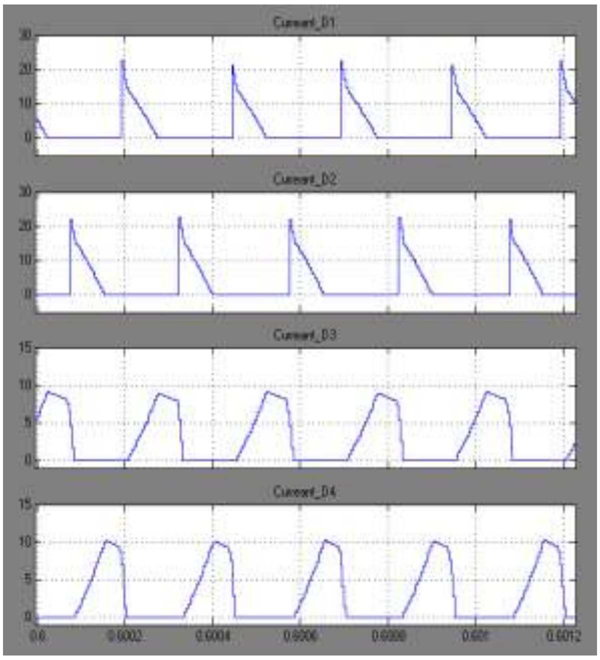

Fig 12 Measured waveforms of D_1, D_2, D_3 and D_4 for 1kw power

Fig 11 shows measured current waveforms of D_1,D_2,D_3,D_4 for 0.5kW.In mode 1 all are reverse biased ,hence no current flows through the circui

In Fig 12 it shows the different diode current at 1kW.In mode 2 D_2,D_4 are on where as in mode 3 and mode 4 D_4 is on the rest is off. In mode 5 D_1 and D_3 are on where as in last mode D_3 is On.

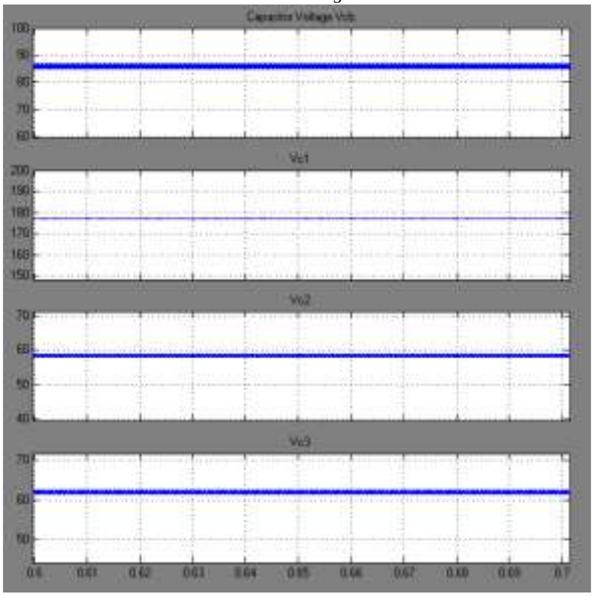

Fig 13 Waveforms of V_{cb}, V_{c1}, V_{c2} and V_{c3} for 0.5kw power

Fig 13 and 14 represents the voltage across different capacitors. In mode 2, each capacitor starts to charging, and C_b starts to discharge. At $t=t_3$, C_b and C_2 are fully discharge and again when $t=t_4$, capacitors C_2 and C_b will again start to charge.

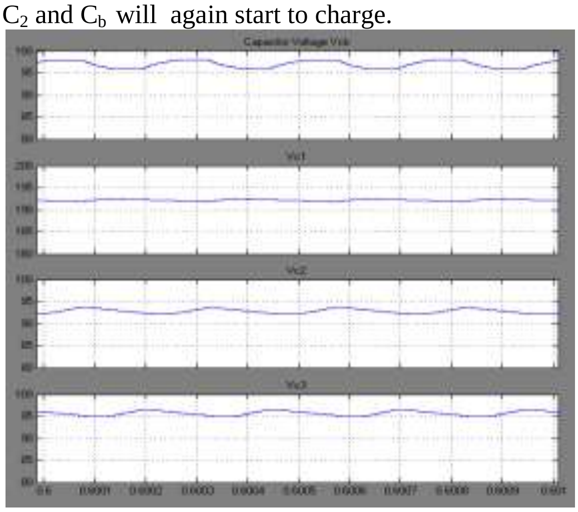

Fig 14 Waveforms of V_{cb}, V_{c1}, V_{c2} and V_{c3} for 1kw power

In Fig 14 gives the different capacitor current at 1kW power. Fig 15 and 16 compares the input, output power at 0.5 kW and 1kW.The voltage stress over the power switches are restricted and are much lower than the output voltage. These switches of low on-state resistance MOSFET, can be selected. The full-load efficiency at P_o = 1000 W is 96.1%, and the efficiency at P_o = 500 W is 96.8%.

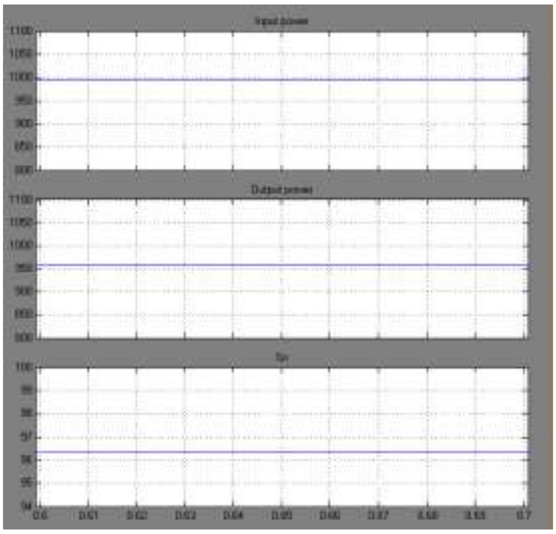

Fig 15 Waveforms of Pin, Po and %n for 1kw power

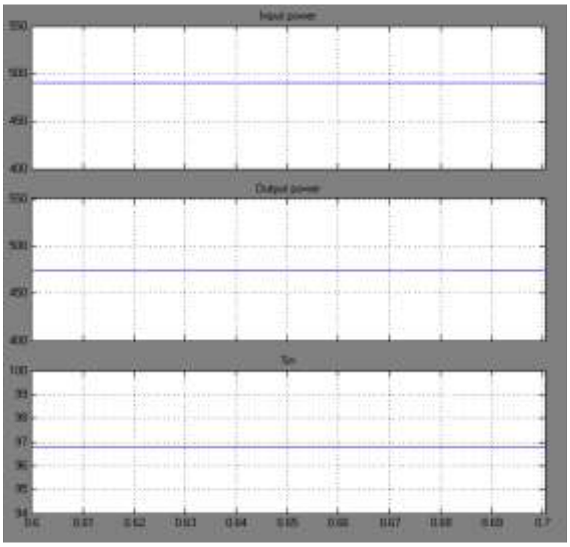

Fig 16 Waveforms of Pin, Po and %n for 0.5kw power

V. CONCLUSION

This paper has presented the topological principles, steady-state analysis, for a designing an efficient photovoltaic system that can be used for onboard ship applications. The converter proposed in this paper provides a efficient high step-up conversion through the voltage multiplier module and voltage clamp feature. Due to the low conduction losses and high efficiency, the proposed converter is suitable for onboard ship high power applications like blasting compressors, assault systems, radar communications etc.

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