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DESIGN AND IMPLEMENTATION OF PV BASED LUO- CONVERTER FED BLDC MOTOR

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Abstract - ***This paper work is aimed at design and analysis of PV based Luo Converter Fed BLDC Motor. The super-lift Luo converter uses a voltage lift technique to improve performance. Unlike traditional converters that increase voltage in an arithmetic progression, the super-lift converter does so geometrically, enhancing power transfer gain. This design effectively boosts voltage for lower input levels, making it suitable for driving BLDC motors. Compared to classical buck converters, which generate significant output voltage ripples and parasitic effects, the Luo converter integrates additional filter elements, such as inductors and capacitors, tosmooth out the output and reduce ripples. By varying the duty cycle, the Luo converter can function as both a buck and boost converter, making it a versatile choice for BLDC motor drives.***

Key Words: **Luo-converter, BLDC motor, Pulse Width Modulation, Variable Load, DC-DC Converter, DC-AC Converter, H-Bridge Multilevel Inverter, Photo Voltaic, Matlab, Simulink**

1. INTRODUCTION

In recent days the use of renewable energy is widely increasing day by day. Among them, Solar Energy is considered as one of the important energy sources since these are environmental friendly and produces electric power without causing pollution. Therefore, Solar Photo Voltaic (PV) panels are preferred that are readily available. In comparison to other renewable resources, the PV system is quiet, stationary, devoid of mechanical parts, and has minimal production and operating expenses. There is a growing tendency in the global sector and in the operation of different industrial facilities for the use of photovoltaic as a source of electrical energy. Numerous variables, including the decline in the cost of producing photovoltaic power per kW, the increase in the price of fossil fuels, and the advancement of efficient photovoltaic energy conversion technologies, are driving this trend [1]-[4].

The photovoltaic cells generate electrical energy using the sunlight. A PV panel is formed of PV cells connected in series, parallel or series-parallel that is working commonly with a DC-DC converter and stores electrical energy in a battery array. DC-DC converters are electronic devices that are used to change DC electrical power efficiently from one voltage level to another. The control of voltage is done by controlling the duty ratio of the switch [5]. Switches used are MOSFET's, transistors, GTO's, IGBT's depending upon the circuit or the power transfer capability. The control of output voltage to a constant magnitude is achieved by the help of a feedback. The use of one or more switches for the purpose of power conversion can be regarded as a SMPS [6]-[10].

In recent trends, in various industries, DC-DC conversion plays a significant role for various applications and there are various types of DC-DC conversion techniques to improve the voltage gain as well as efficiency. In DC-DC conversion step-up chopper boosts the output voltage whereas step down chopper bucks the output voltage [11]-[14]. Due to a lot of research in DC-DC conversion more topologies developed, generally, these topologies are categorized into with and without transformer. The transformer-less DC-DC conversion has led to a reduction in the size, weight, costand losses. There are many voltage building techniques adopted in conversion stages, namely, voltage lift technique and super- lift technique in the case of Luo DC – DC converters [15]-[18].

Luo converters developed from the fundamental DC – DC converter has a simple and cheap topology as well provide high voltage gain, better efficiency and lowest ripple at the output. In the voltage lift technique, the output voltage is increased step by step in arithmetic progression. However, in the super-lift technique, the output voltage increases geometrically. Two types of super- lift techniques are Positive Output Super-lift Luo Converter (POSLC) and Negative Output Super- lift Luo Converter (NOSLC) [19]-[20]. Luo converters are DC-DC Switching Mode Boost converters. A boost converter (step-up converter) is power converter with an output dc voltage greater than its inputdc voltage. Luo converters are a class of converters providing a high gain with relatively lesser number of components. Although Luo converters provide a high gain, when cascaded, the gain increases stage by stage only in Arithmetic Progression i.e. these converters uses the voltage lift (VL) technique [21].

In order to solve this discrepancy in the Classical Luo Converters, another class of converters called Super-lift Luo Converters was developed. While the positive aspects of the Classical Luo Converters are retained in Super-lift

converters, Super-lift converters also have the advantage that the gain in this converter increases in geometric progression, stage by stage [22].

2. CIRCUIT SCHEME

The study outlines the design of a Luo converter specifically engineered to provide a boosted voltage for driving a BLDC motor, especially when input voltages are low. Unlike traditional converters, that often struggle with excessive voltage ripples and parasitic effects in BLDC motor applications, the Luo converter is more effective. Its output stage, featuring an inductor and capacitor, inherentlyacts as a filter, efficiently storing and delivering energy to the load. This results in a smooth and stable output voltage. The Luo converter's ability to function both as a buck and a boost converter by varying the duty cycle makes it well-suited for the BLDC motor drive application.

Additionally, a BLDC motor drive with a PI controller scheme necessitates a constant DC supply for the voltage source inverter (VSI) using a Pulse Width Modulated (PWM) technique for speed control. The motor's speed is influenced by the DC voltage at the inverter's front end, allowing variable speed operation by adjusting the DC link voltage with fundamental frequency switching. A PI controller-based speed control loop is employed to regulate the DC voltage in accordance with the desired speed, ensuring precise control and efficient operation of the BLDC motor.

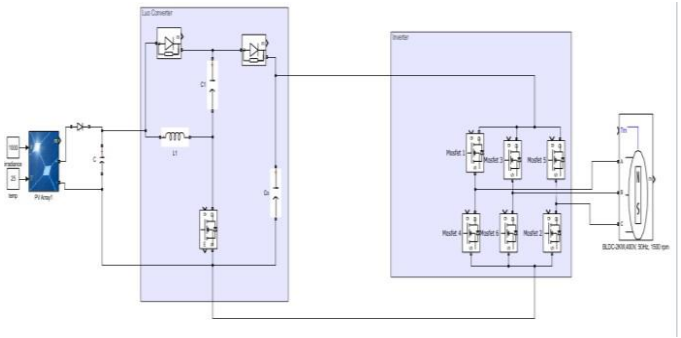

Figure 1: Circuit Schematic of the Proposed System

The luo converter operates based on the speed controller consists of two loops, speed control loop senses the reference speed and measured speed and the error is provided for PI controller generates voltage reference is provided to voltage control loop generates duty ratio based on the error in voltage of reference and converter output voltage. The generated duty ratio is provided for PWM pulse generation for the luo converter. The output of the luo converter is provided to the inverter operates based on the pulses generated using hall signals. The inverter output is provided to the BLDC motor of 400V, 50 Hz, 2KVA, 1500 rpm.

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical current is drawn from the dc link capacitor for 120◦ and placed symmetrically at the center of each phase. AHall-effect position sensor is used to sense the rotor position on a span of 60◦, is required for the electronic commutation of the BLDC motor. A line current i_{ab} is drawn from the dc link capacitor whose magnitude depends on the applied dc link voltage (V_{dc}), back electromotive forces (EMFs), resistances (R_a and R_b), and self inductance and mutual inductance (L_a, L_b, and M) of the stator windings.

3. MODE OF OPERATION OF LUO CONVERTER

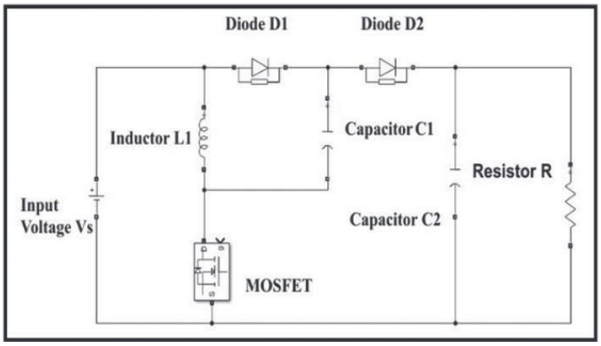

Figure 2: Circuit Diagram of Luo Converter

The circuit consists of a MOSFET switch S, Inductor L1, Diodes D1 and D2, capacitors C1 and C2, and a load resistance R. Figure 2.3 shows the circuit diagram of Positive Output Super-Lift Luo Converter (POSLC).
Analysis of the POSLC begins by making these assumptions:

- The circuit is operating in steady state
- The inductor current is continuous (always positive)
- The capacitor is very large, and the output voltage is held constant at voltage V_o
- The switching period is K; the switch is closed for time DK and open for time (1-D)K.
- The components are ideal.

Mode 1: During mode 1 operation, the switch S is considered to be in ON state thereby, capacitor C_1 gets charged to V_s. The current i_{L1} flowing through inductor increases with voltage V_s. The input current is will be equal to $i_{L1} + i_{c1}$. The mode 1 operation is depicted clearly through Figure 3. When the switch is closed, the diode D1 is forward biasedand diode D2 is in the OFF state.

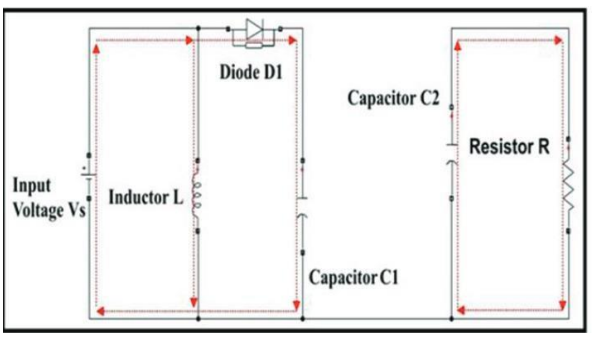

Figure 3: Equivalent Circuit of Luo Converter When Switch Is Turned ON

Mode 2: Figure 4 clearly shows the mode 2 operation of positive output super-lift Luo converter. During mode 2 operation, switch S is considered to be in OFF state, diode D1 is reversed biased and D2 becomes forward biased. During mode 2 operation, input current will be equal to i_{L1} (=i_{co}).

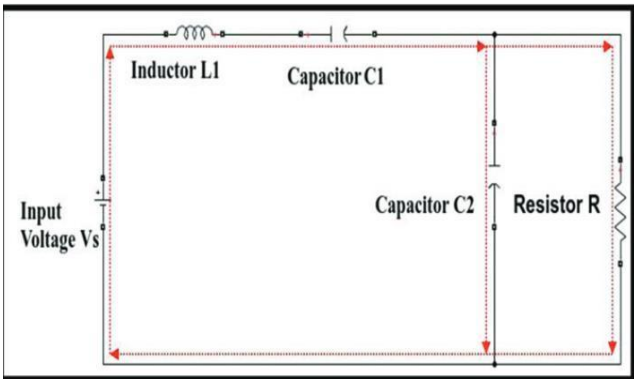

Figure 4: Equivalent Circuit of Luo Converter When Switch Is Turned OFF

The voltage across the capacitor C1 is charged to V_{in}. The current i_{L1} flowing through inductor L1 increases with voltage V_{in} during switching- ON period KT and decrease with voltage (V_o-2V_{in}) during switching- OFF period (1-K)T. Therefore, the ripple of the inductor current is i_{L1}. The input current i_{in} is equal to (i_{L1}+i_{C1}) during switching-on, and only equal to i_{L1} during switching-off. Capacitor current i_{C1} is equal to i_{L1} during switching-off. In steady-state, the average charge across capacitor C1 should not change.

4. DESIGN OF LUO CONVERTER

The Table 1 gives the information about the inputand output parameters required for the design of the PV based Luo converter fed BLDC motor.

Table 1: Design Specifications

PV Array	Module	Apollo Solar Energy ASEC-300G6M (Polycrystalline Module)
	Parallel Connected Modules	7 No's
	Total Power Output	2100 W
	Voltage at MPP	35.5 V
	Short Circuit Current	59.15 A
Luo Converter	Input Voltage	24 V
	Output Voltage	400 V
	Switching Frequency	2 kHz
	Power	2 kW
	Output Current	5 A
	Resistance	75 Ω
BLDC Motor	Power	2 kW
	Voltage	400 V
	Frequency	50 Hz
	Speed	1500 rpm

The duty cycle, D for proposed converter, is calculated as

$$D = \frac{V_o - 2Vin}{Vo - Vin} \quad (1)$$

Where, V_o= Output Voltage
V_{In}= Input Voltage

$$D = \frac{400 - 48}{400 - 24}$$
$$D = 0.93$$

The calculation of ripple current of boost inductance is performed by the following relation:

$$\Delta I_l = 0.2 \times \frac{V_o}{V_{in}} \times I_o \quad (2)$$

Where, I_o= Output Current

$$\Delta I_l = 0.2 \times \frac{400}{24} \times 5$$
$$\Delta I_l = 16.67\ A$$

The calculation of inductance is performed by the following relation:

$$L = \frac{D(1-D)^2 * R}{2(2-D) * Fs * \Delta I_L} \quad (3)$$

Where, R= Resistance
F_S= Switching Frequency

$$L = \frac{0.93(1 - 0.93)^2 \times 75}{2(2 - 0.93) \times 2 \times 10^3 \times 16.67}$$

$$L = 4.77\ \mu H$$

The switching time period, T_s is calculated from the switching frequency as shown below:

$$T_S = \frac{1}{F_S} \quad (4)$$

$$T_S = \frac{1}{2K}$$
$$T_S = 0.5\ msec$$

The capacitance value at the load side is provided by the following relation:

$$C_{out} = \frac{I_o * D}{\Delta V_o * F_S} \quad (5)$$

$$C_{out} = 581 \mu F$$

The ripple output voltage is calculated with the following equation:

$$\Delta V_o = 2\%\ of V_o \quad (6)$$

$$\Delta V_o = 4\ V$$

The coupling capacitance value of Luo converter is provided by the following relation:

$$C_1 = \frac{(1-D)V_O}{F_S \Delta V_O R} \quad (7)$$

$$C_1 = \frac{(1-0.93)400}{2000 \times 4 \times 75}$$

$$C_1 = 4.77 \mu F$$

Table 2: Luo Converter Design Parameters

SYMBOL	PARAMETERS	DESIGN VALUE
D	Duty Ratio	0.93
ΔI_L	Input Inductor Current	16.67 A
T_S	Switching Time Period	0.5 msec
L_M	Input Inductor	0.36 mH
L	Inductor	4.77 µH
C_1	Coupling Capacitor	4.77 µF
C_{out}	Output Capacitor	581 µF

BLDC MOTOR TORQUE CALCULATION

Voltage,

$$V_{max} = \frac{V_{rms} \times \sqrt{2}}{\sqrt{3}} \quad (8)$$

$$V_{max} = \frac{1.414 \times 400}{1.732} = 326.54\ V$$

T_a= Gross mechanical torque (or) motor torque

T_{lost}= loss torque due to friction, windage and iron losses

T_{sh} or T_l= Load torque

$$T_a = T_{lost} + T_{sh} \quad (9)$$

$$Power, P_{out} = T_{sh} \times W \quad (10)$$

$$T_{sh} = \frac{P_{out}}{W}$$

$$W = \frac{2\pi N}{60} \quad (11)$$

$$W = \frac{2 \times \pi \times 1500}{60} = 157$$

$$T_{sh} = \frac{2000}{157} = 12$$

$$T_{sh} = 12\ \frac{Tsh}{2} = 6\ \frac{Tsh}{4} = 3$$

5. SIMULATION RESULTS

The PV panel is providing voltage of 35V and power 2KW to the Luo converter. The luo converter operates based on the speed controller consists of two loops, speed control loop senses the reference speed and measured speed and the error is provided for PI controller generates voltage reference is provided to voltage control loop generates duty ratio based on the error in voltage of reference and converter output voltage. The generated duty ratio is providedfor PWM pulse generation for the luo converter. The output of the luo converter is provided to the inverter operates based on the pulses generated using hall signals. The inverter output is provided to the BLDC motor of 400V, 50 Hz, 2KVA, 1500 rpm. Figure 5, shows the simulation circuit of the proposed system.

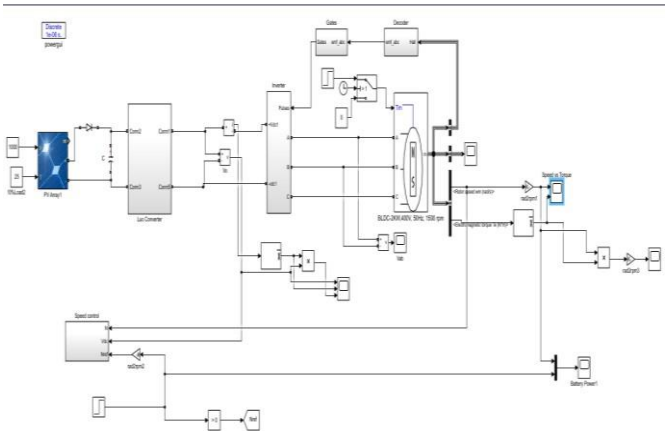

Fig5: Simulation Circuit

Figure 6, shows Luo converter output voltage, current and power waveform. The voltage is around 80V from t=0 to 0.5s (500 rpm) and increased to 250Vfrom t=0.5s (1500rpm). The current is nearly zero from t=0 to 1s (No load) and increased to 3A from t=1s to 2s (25% load) and again increased to 12A at t=2s (Full load)

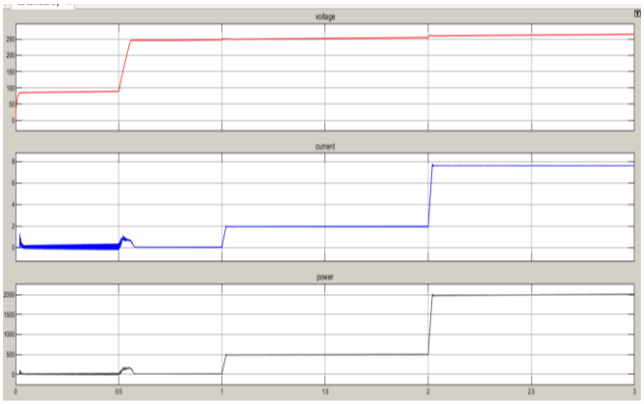

Figure 6: Luo Converter Output Voltage, Current and Power Waveform

Figure 7, shows the speed torque waveforms of the BLDC motor. Initially the speed reference is 500 rpm and changed to 1500 rpm at t=0.5s. Also the motor operates under no load condition from t=0 to 1s and the torque increases to 3Nm (25% load) at t=1s and again increased to 12Nm (Full load) at t=2s.

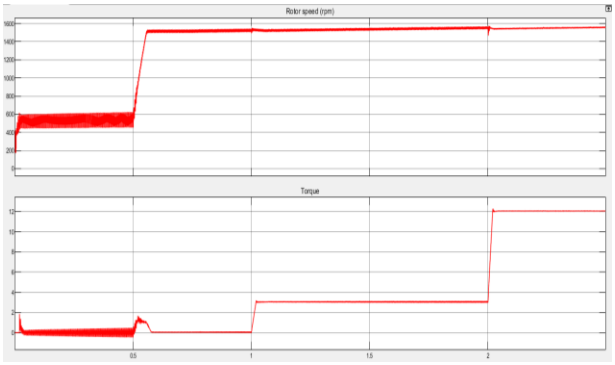

Figure 7: Speed and Torque Waveforms of BLDC Motor

Similar to dc current, the stator current also varies due to the load changes applied to the BLDC motor load. Figure 8, shows the stator current waveforms of BLDC motor.

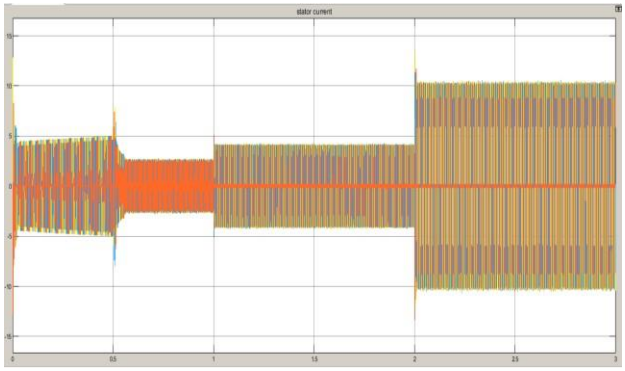

Figure 8: Stator Current Waveform of BLDC Motor

Figure 9, shows the three phase inverter line output voltage waveform. Similar to converter output voltage, the inverter voltage increase from 80V to 250V at t=0.5s due to increase in reference speed

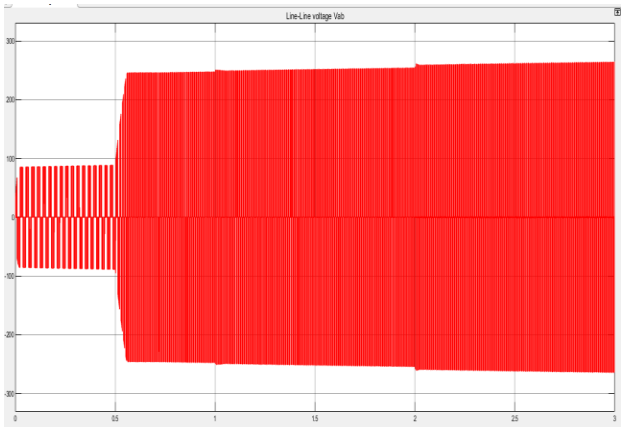

Figure 9: Inverter Phase A Output Voltage Waveform

6. HARDWARE SPECIFICATION

The system and control parameters used in the hardware model are given in table 3. The hardware topology is tested.

Table 3: Parameters of the PV based Luo converter Circuit considered for the Hardware

	PARAMETER	MODEL/ VALUE
Single Phase AC Supply	Voltage	230 V
	Frequency	50 Hz
Luo Converter	Input Voltage	12V
	Output Voltage	36V
	Step-down Transformer	12-0-12V, 3A
	MOSFET	IRFP250
	Capacitor	4700µF,63V, & 100µF, 100V
	Diode	MUR1560
Three Phase Inverter	Input Voltage	36V
	Output Voltage	36V
	MOSFET	IRFP250
Driver Circuit	Step-down Transformer	0-12 V, 1 A
	Diode Rectifier	S1WB60
	Buffer IC	CD4050UBC
	Driver	TLP250
	Diode	1N4007
	Capacitor	1000 µF, 25 V
	Resistor	100 Ω
BLDC Motor	Motor KV (RPM/V)	1000
	No-Load Current	500mA
	Maximum Efficiency	80%

7. HARDWARE CIRCUIT

The hardware circuit of PV based Luo converter fed BLDC motor is shown in figure 10. 230 Volts single phase AC supply is provided as input to step-down transformer of 230/12V, 3A, is then fed to the Positive Output Super-Lift Luo Converter via rectifier. The Luo Converter gives an output voltage of 36 volts that is further connected to three phase inverter. The output of three phase inverter is connected to a 1000KV BLDC motor.

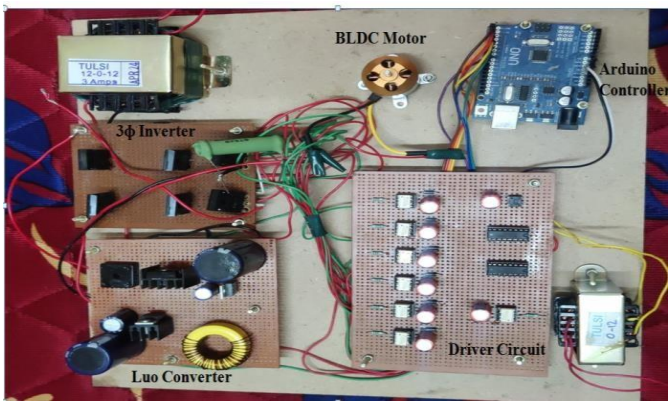

Figure 10: Hardware Circuit Top View

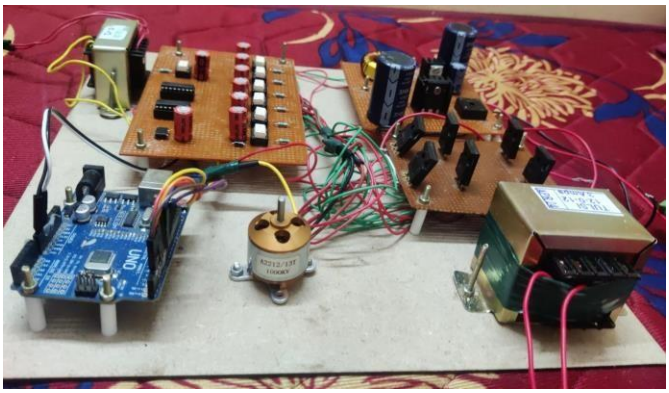

Figure 11: Hardware Circuit Side View

8. HARDWARE RESULTS

Figure 12, shows the gate pulse waveform generatedfrom the driver circuit. The pulse is viewed in the Cathode ray oscilloscope (CRO).

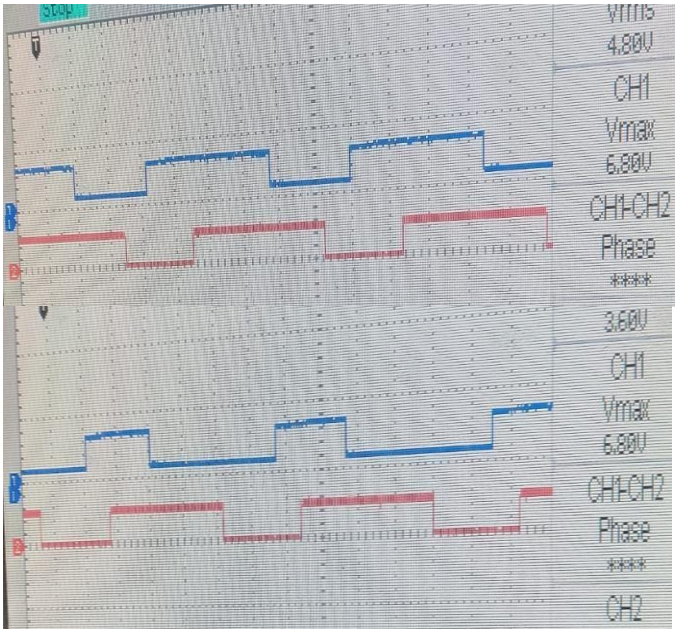

Figure 12: Gate Pulse Waveforms.

The input rms voltage of the luo converter is around 10 V, is shown in figure 13.

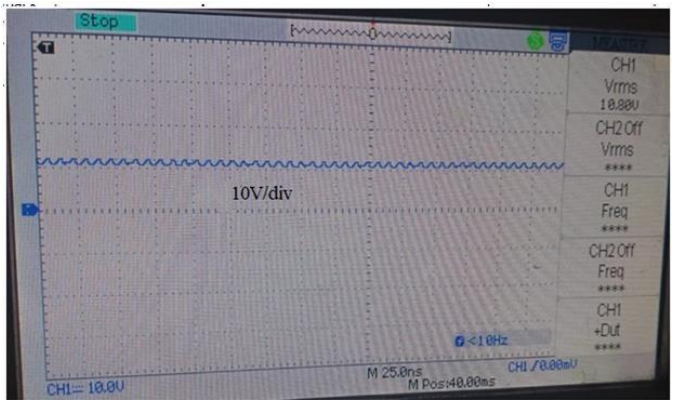

Figure 13: Luo Converter Input Voltage

The output voltage of the luo converter is around 34.6 V. Figure 14, shows the output voltage of the Luo converter.

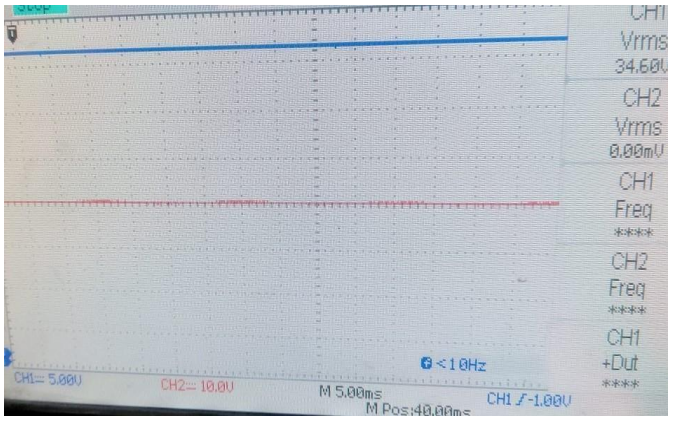

Figure 14: Luo Converter Output Voltage Waveform

The output voltage of luo converter is applied to three phase inverter and the output voltage waveforms of the three phase inverter is shown in figure 15.

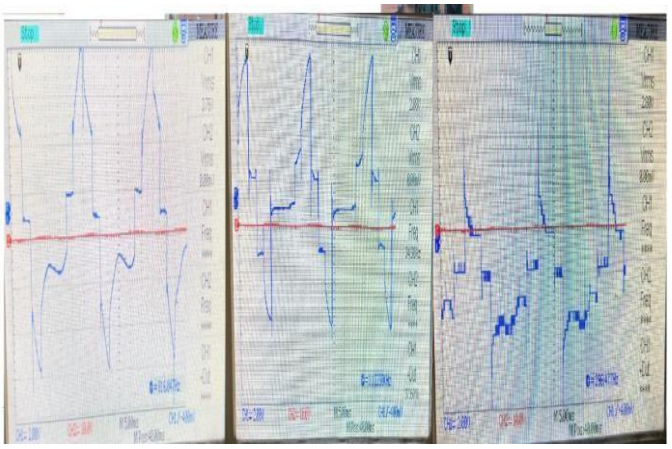

Figure 15: Inverter Voltage Waveforms

9. CONCLUSION

In this paper, designing and implementation of PV Based Luo converter Fed BLDC Motor was proposed. A Luo converter (LC) using Super-Lift Technique is a powerful DC-DC converter where the voltage is converted from positive source voltage to positive load voltage as it produces positive voltages of comparatively higher ranges and produces less ripples than those of conventional types. The modeling of proposed system was carried out on the PV module of total capacity of 2100W to obtain improved efficient power extraction and minimal performance loss. The simulationwas carried out in MATLAB/Simulink software. The hardware prototype of the proposed work for 230 V single-phase AC supply producing and 36 V DC output to run the BLDC motor was implemented and the results were analysed.

From the simulation results, it was observed that the output power of the Luo converter is 2000 W and high voltage gain of 240 Volts from 35.5 Volts PV input supply was obtained. The BLDC motor runs at its rated speed irrespective of the load variation. The hardware was implemented for smaller rating and was connected to a BLDC motor of 1000 KV.

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