COMPARATIVE ANALYSIS OF LUO CONVERTER AND ZETA CONVERTER FOR SPV POWERED BLDC MOTOR DRIVE

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Abstract - *In recent days, the continuous use of conventional energy sources has resulted in global energy crisis and created in need of an alternative energy source. Solar energy with the features of being clean, reliable, sustainable, environment friendly, abundant is considered as a substitute for alternative energy source. The selection of appropriate machine drive plays a vital role in reliable and enhanced performance of the system. Conventional DC-DC converters were used with the solar photovoltaic(SPV)panel to provide a stable power to the load. Main drawback of such converters is that the output current is pulsating in nature and require current handling capability. The use of advanced DC-DC converters such as Luo and Zeta converter can eliminate such issues. This paper presents the design and performance analysis of SPV array powered Luo/Zeta converter fed BLDC motor driven model. The Luo and Zeta converters extort the maximum power from the SPV panel through incremental conductance algorithm that results in effective performance of BLDC motor. The proposed converter topology also enables soft starting of BLDC motor. The proposed SPV powered Zeta and Luo converter fed BLDC driven models are simulated using MATLAB/Simulink environment and simulation results are presented.*

***Key Words*: Incremental conductance, SPV array, Luo converter, Zeta converter, Brushless DC (BLDC) motor.**

1. INTRODUCTION

The continuous use of non-renewable energy sources results in global energy crisis and creates in need of an alternative energy source. Clean energy policies and competitive renewable energy markets are the driving factors in the selection of an alternative energy source. A drastic reduction in the cost of power electronic devices and SPV array encourages the researchers and the industries to utilize the solar PV array generated power as an alternative energy source for different applications. Solar energy is an ideal form of energy with the features of being clean, reliable,environment friendly, abundant and substitute of dwindling energy sources.

The selection of appropriate machine drive plays a vital role in reliable and enhanced performance of the system. The researches carried out in the area of SPV array, combining various advanced DC-DC converters such as Zeta and Luo converters in association with permanent magnet brushless DC(BLDC) motor drive possess very good conversion efficiency, very low output voltage ripple and a higher voltage gain as compared to conventional DC-DC converters. The features of high operating efficiency, brushless construction and increasing awareness about energy conservation resulted in demand of BLDC motor for SPV technology.

The working includes the operation of an Luo and Zeta converter through incremental conductance algorithm as a intermediate converter between a solar PV array and voltage source inverter(VSI) in order to achieve the maximum efficiency of SPV array and the proposed model also helps in soft starting of BLDC motor drive and there by controlling the speed of BLDC motor drive without any additional control.

The performance characteristics of Luo and Zeta converters such as output voltage, output current are observed and compared. The results determined from the comparative analysis helps to choose the best suited system for SPV fed BLDC motor drive. The solar based BLDC driven models using Luo and Zeta converter are simulated and executed in the MATLAB/Simulink environment.

2. LITERATURE REVIEW

A brief review of various converters used for BLDC motor drive is discussed and the theoretical aspects of different DC – DC converters are discussed [1-2]. The design and simulation analysis of various Luo converter topologies for BLDC motor drive is implemented. The comparison is made between Luo converter topologies and the results show that P/O Luo converter is efficient than N/O and D/O Luo converter [3-4].

The performance analysis of solar powered BLDC Motor Drive using Luo Converter is carried out and the results show that Luoconverters are a series of new DC-DC step-up converters, that provide an overall output voltage lift with less ripple, as a MPPT tracker that results in increment in system efficiency [5-8].

The simulation analysis of SPV array Zeta converter fed for BLDC drive is carried out. The results show that Zeta converter offers several advantages such as it results in non-inverted output, improved power factor, low distortion of input current, low ripple output current and wide operating range[9-11].

3. METHODOLOGY

3.1 Proposed Methodology

The structure of proposed SPV array-fed BLDC motor driven model employing Luo and Zeta converters are discussed. The proposed system consists of an SPV array, a Zeta converter, a VSI, a BLDC motor. The BLDC motor contains an inbuilt encoder. The pulse generator is used to operate the Zeta converter.

The fig-1 and fig-2 represents the basic diagrams of SPV powered Luo and Zeta converter fed models.

The SPV array generates the electrical power as per the requirements of BLDC motor. The electrical power is fed to the motor via Zeta converter and a voltage source inverter (VSI). The SPV array appears as a power source for the Zeta converter shown in fig-1. The same amount of power is delivered to the output of Zeta converter and it appears as an input source for VSI. The pulse generator generates, switching pulses for insulated gate bipolar transistor (IGBT) switch of the Zeta converter through incremental conductance algorithm and also it generates actual switching pulse by comparing the duty cycle with a high-frequency carrier wave. In this way, the maximum power extraction and the efficiency optimization of the SPV array is accomplished. The VSI converts DC output from a Zeta converter into AC, feeds the BLDC motor drive. The VSI is operated in fundamental frequency switching through an electronic commutator of BLDC motor and it is assisted by its built-in encoder. The high frequency switching losses are eliminated, contributing in an increased efficiency of proposed system.

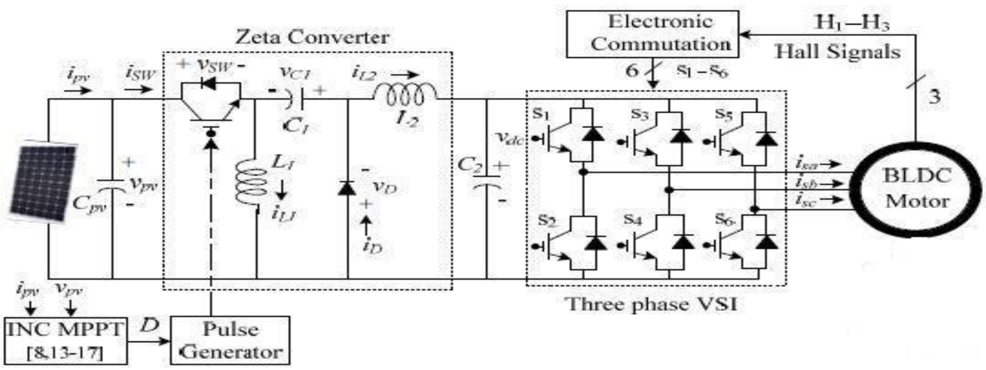

Fig - 1: SPV array Zeta Converter fed BLDC Motor Driven Model

The model of SPV powered Luo converter fed BLDC driven model is shown in fig-2. Luo converter is used to extract maximum power from the solar PV array and for the safe starting of BLDC motor. The optimum value of duty cycle for the IGBT switch of Luo converter is generated through an incremental conductance algorithm. A elementary Luo converter is used to obtain a maximum power output from a solar PV array. A small value of ripple filter is used at the input to reduce the input current ripple. Output of the Luo converter feeds the voltage source inverter and it drives the BLDC motor. Switching sequences of voltage source inverter is provided by the process of electronic commutation motor and it is assisted by its built-in encoder.

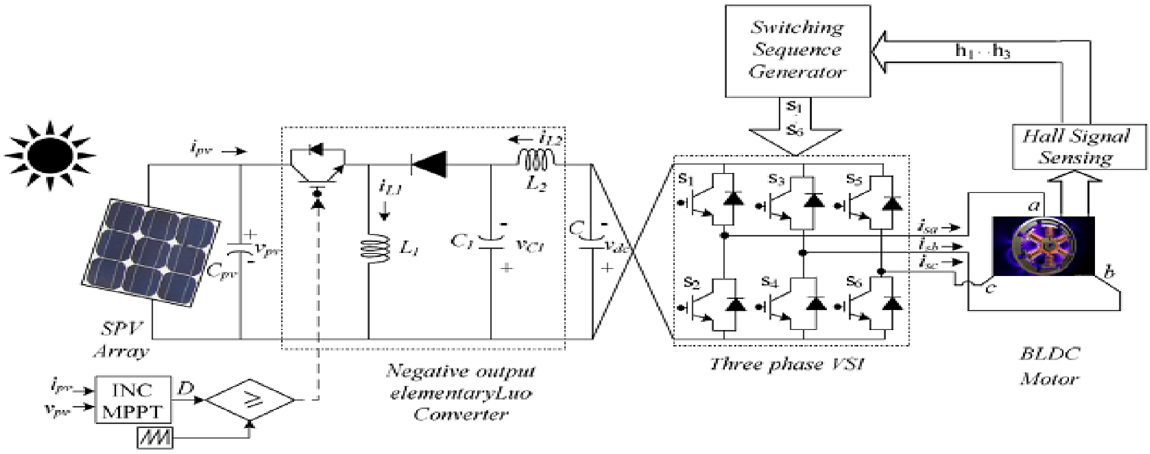

Fig - 2: SPV array Luo Converter fed BLDC Motor Driven Model

4. SPECIFICATIONS AND DESIGN DETAILS

4.1 Specifications of SPV array

Table 1 shows the specification of peak power Pm(W), open circuit voltage Voc(V) and voltage at MPP Vm(V), short circuit current Isc(A), current at MPP Im(A).

Table 1: Specifications of a solar panel

Peak power, Pm (W)	280
Open circuit voltage, Voc (V)	39.5
Voltage at MPP, Vm (V)	31.2
Short circuit current, Isc(A)	9.71
Current at MPP, Im (A)	9.07

4.2 Design of SPV array

The detailed designs of various power conversion stages such as SPV array, Zeta converter, Luo converter is implemented in a following manner[7]

A BLDC motor of 2.89-kW power rating and an SPV array of 3.4 kW peak power capacity under standard test conditions (STC:1000W/m2,25 degree celsius) are selected for designing the proposed system.

- Number of modules required to connect in series/parallel are estimated by

selecting the voltage of SPV array at MPP under STC as Vmpp= 187.2V.

- The current of SPV array at MPP Impp is estimated as

$$I_{mpp} = \frac{P_{mpp}}{V_{mpp}} = \frac{3400}{187.2} = 18.16A$$

- The number of modules required to connect in series are as follows:

$$N_s = V_{mpp}/V_m = 187.2/31.2 = 6$$

- The number of modules required to connect in parallel are as follows:

$$N_p = \frac{I_{mpp}}{I_m} = \frac{18.16}{9.07} = 2$$

- Connecting six modules in series, having two strings in parallel, an SPV array of required size is designed for the proposed system.

4.3 Design of Zeta Converter and Luo Converter

The design of various passive components of Zeta converter and Luo Converter is calculated using given system specifications and is tabulated in table 2 [6].

Table 2: Design of Zeta Converter and Luo Converter

Sl No	Parameter	Expression	Design data	Calculated value
1	L_1	$\frac{DV_{mpp}}{f_{sw}\Delta I_{L1}}$ $D = \frac{V_{dc}}{V_{dc} + V_{mpp}}$	$D = \frac{200}{200 + 187.2} = 0.52$ $V_{mpp} = 187.2V$ f_{sw} =20kHz $\Delta I_{L1} = 6\%\ of\ I_{L1}$ = 0.06*18.16 = 1.0896A	5mH
2	L_2	$\frac{(1-D)V_{dc}}{f_{sw}\Delta I_{L2}}$	D =0.52 $V_{dc} = 200V$ f_{sw} =20kHz $\Delta I_{L2} = 6\%\ of\ I_{L2}$ =0.06*17 =1.02A	5mH
3	C_1	$\frac{DI_{dc}}{f_{sw}\Delta V_{C1}}$ $I_{dc} = P_{mpp}/V_{dc}$	D =0.52 I_{dc} = 3400/200 = 17A f_{sw} =20kHz $\Delta V_{C1} = 10\%\ of\ V_{C1}$ =0.1*200 =20V	$22uF$
4	C_2	$\frac{I_{dc}}{6 * \omega_{min} * \Delta V_{dc}}$ $\omega_{min} = 2\pi \frac{NP}{120}$	$I_{dc} = \frac{P_{mpp}}{V_{dc}} = 17A$ $\omega_{min} = 2\pi \frac{1100 * 6}{120} = \frac{345.57\text{rad}}{\text{sec}}$ $\Delta V_{dc} = 10\%\ of\ V_{C1}$ = 0.1*200 = 20V	$500uF$

4.4 Incremental Conductance MPPT Algorithm

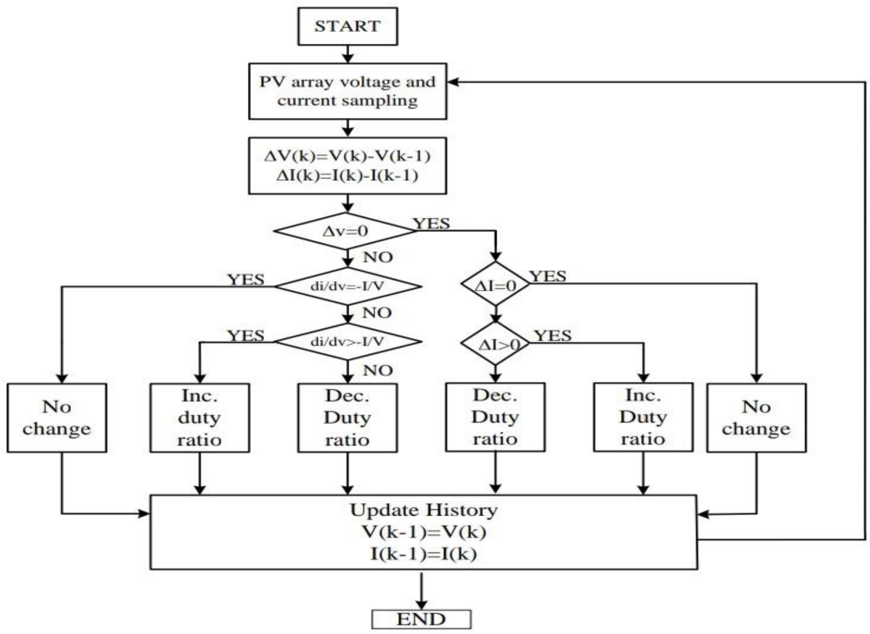

Fig - 3: Incremental Conductance MPPT Algorithm

Incremental Conductance method uses the information of source voltage and current to find the desired operating point. Below equation is the condition to achieve the maximum power point, if variance of the output conductance is equal to the negative of the output conductance, the module will work at the maximum power point [11].

$$\left(\frac{dI}{dV}\right) MPP = -\frac{I}{V}$$

5. SIMULATION APPROACH AND PERFORMANCE ANALYSIS

5.1 MATLAB code for Incremental Conductance Algorithm

```
function y=MPPT(u, i, u0, i0, D)
%test
m = 0;
du = u-u0;
di = i-i0;
if du == 0
    if di == 0
        m = D;
    elseif di > 0
         m = D-0.01;
    else
            m = D + 0.01;
    end


elseif di/du == -(i/u)
        m=D;
else
        if di/du > -(i/u)
            m = D-0.01;
        else
            m = D+0.01;
        end
end
    y=m;
end
```

Fig - 4: MATLAB code for Incremental Conductance Algorithm

5.2 Performance of SPV array

A solar PV array of 3.4 kW peak power capacity, somewhat more than required by the motor, is selected so that the performance of the system is not affected by the losses associated with the converters and the motor. The corresponding V-I and P-V characteristics of SPV array are observed and are shown in fig-5, which indicate that the SPV array is able to operate at maximum power point of 3.4 kW.

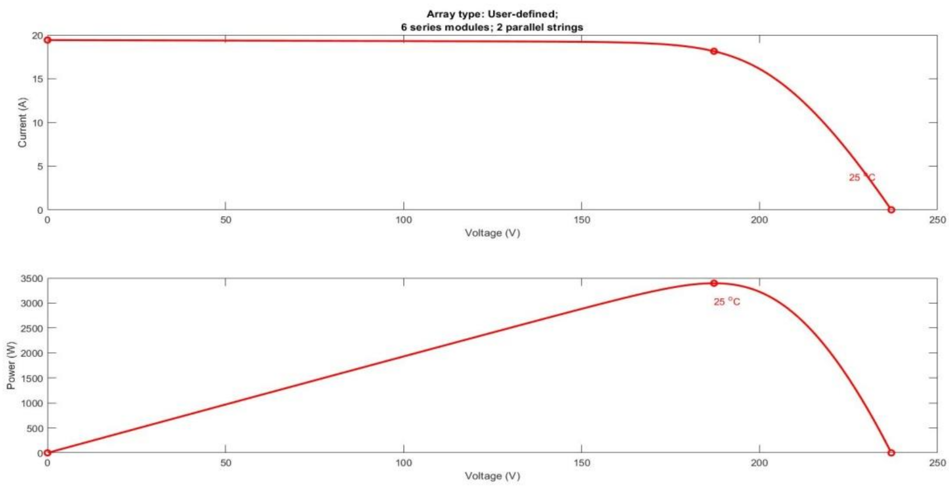

Fig - 5 : V-I and P-V characteristics of a solar panel

5.3 Performance of Zeta Converter

The steady-state performance of Zeta converter at 1000 W/m2 is carried out. The input inductor current IL1, intermediate capacitor voltage Vc1, output inductor current IL2, voltage stress on IGBT switch Vsw, current stress on MOSFET switch Isw, blocking voltage of the diode Vd, current through diode Id and dc-link voltage Vdc are presented. The Zeta converter is operated in CCM. The operation of converter in this mode reduces the stress on power devices and components. The converter indices such as IL1, Vc1, IL2, and Vdc follow the variation in the weather condition and vary in proportion to the solar irradiance level. The Zeta converter automatically changes its mode of operation from buck mode to boost mode and vice-versa according to the irradiance level to optimize the output power of SPV array. A small amount of ripple in the Zeta converter is observed and it is caused by permitting the ripples up to an extent to optimize the size of the components**.** The simulated view of block diagram and the corresponding performance curves are shown in fig-6, fig-7 and fig-8.

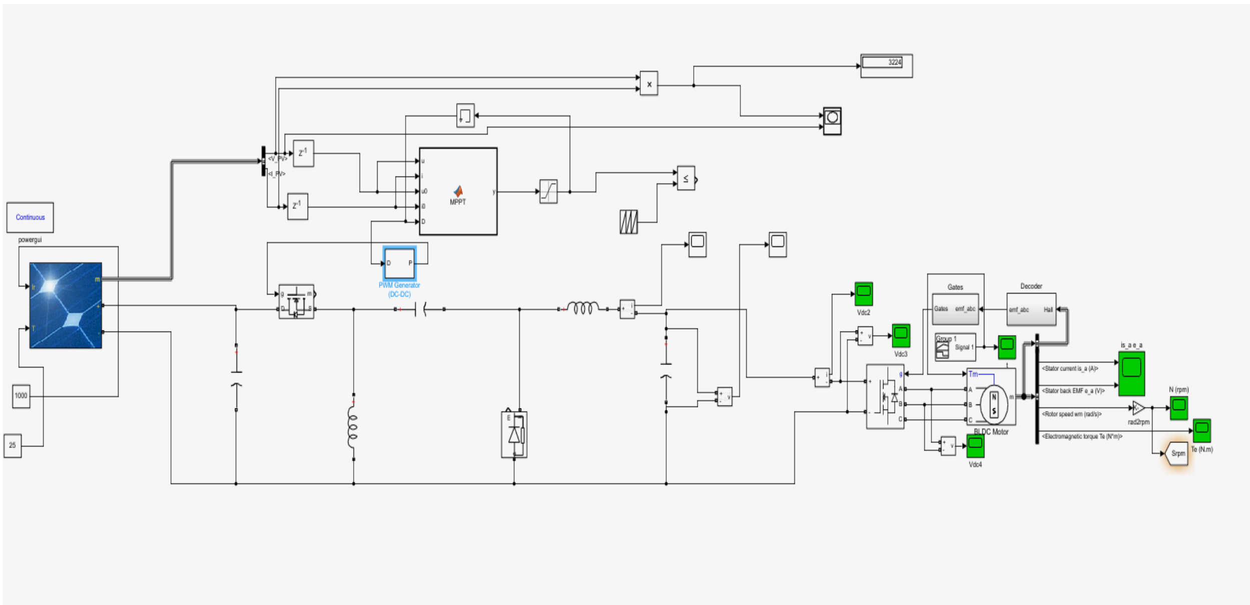

Fig - 6 : Simulation diagram for proposed SPV powered Zeta converter fed BLDC driven model

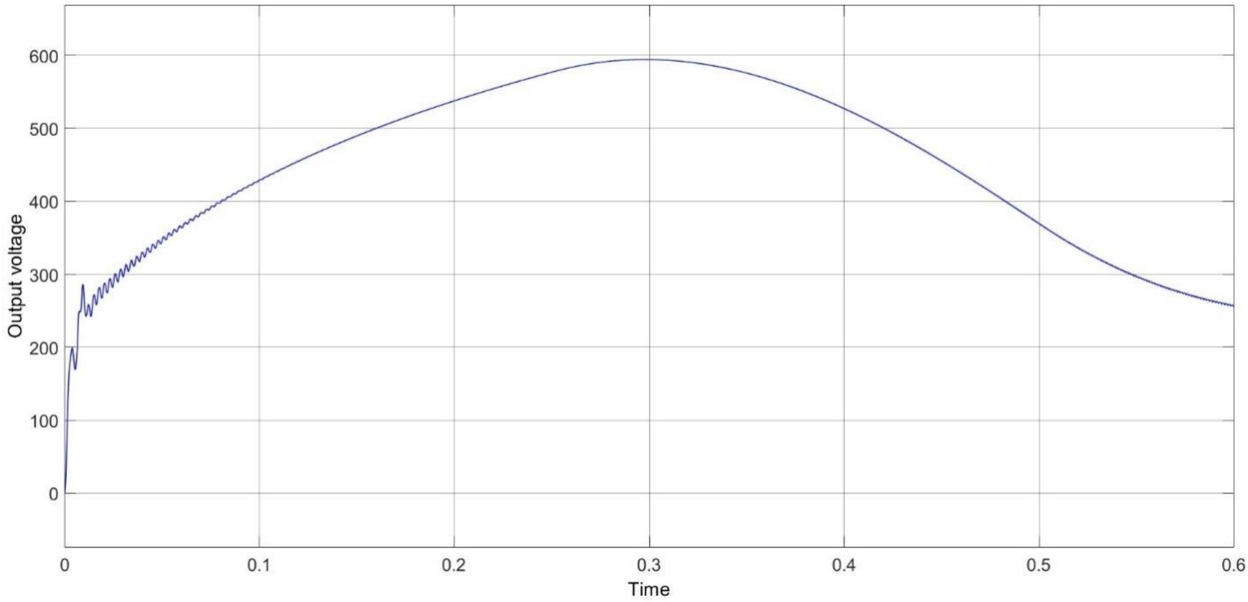

Fig - 7: Output voltage of Zeta converter vs time

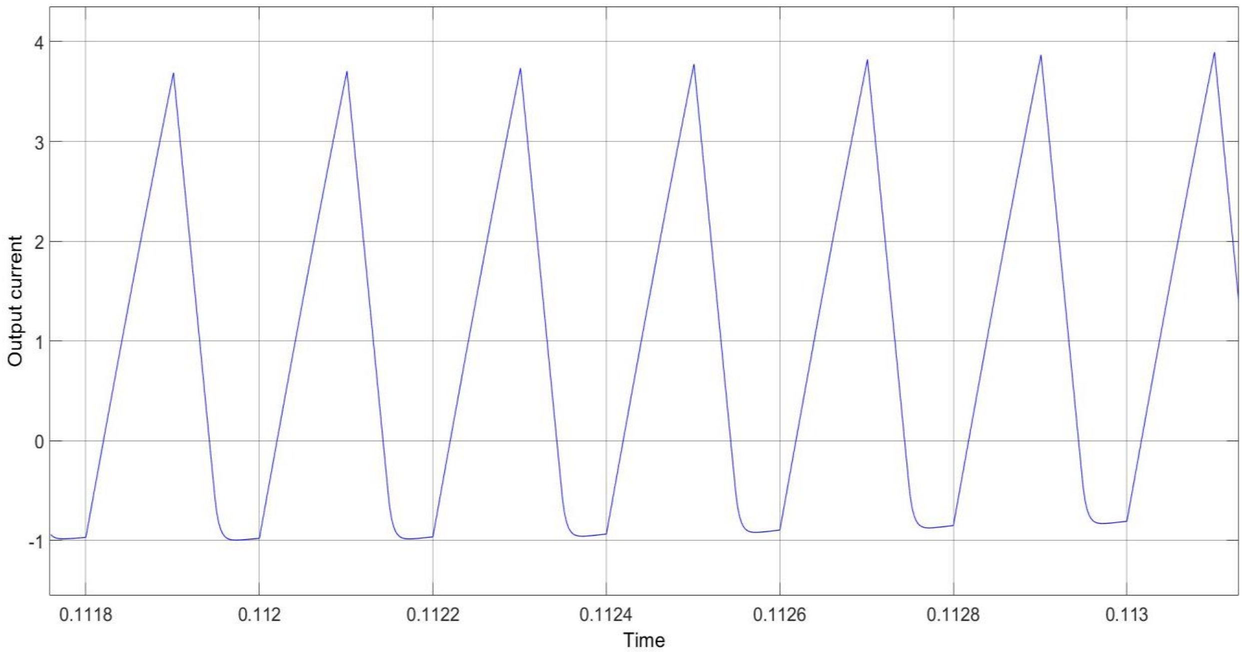

Fig - 8: Output current of Zeta converter vs time

5.4 Performance of Luo Converter

The steady-state performance of Luo converter at 1000 W/m2 is carried out. The input inductor current IL1, intermediate capacitor voltage Vc1, output inductor current IL2, voltage stress on IGBT switch Vsw, current stress on MOSFET switch Isw, blocking voltage of the diode Vd, current through diode Id and dc-link voltage Vdc are presented. The Luo converter is operated in CCM. The operation of converter in continuous conduction mode reduces the stress on power devices and components. The Luo converter automatically changes its mode of operation from buck mode to boost mode and vice-versa according to the irradiance level to optimize the output power of SPV array. A large amount of ripple in Luo converter is observed and it is caused by permitting the ripples up to an extent to optimize the size of the components. The simulated view of block diagram and the corresponding performance curves are shown in fig-9, fig-10 and fig-11.

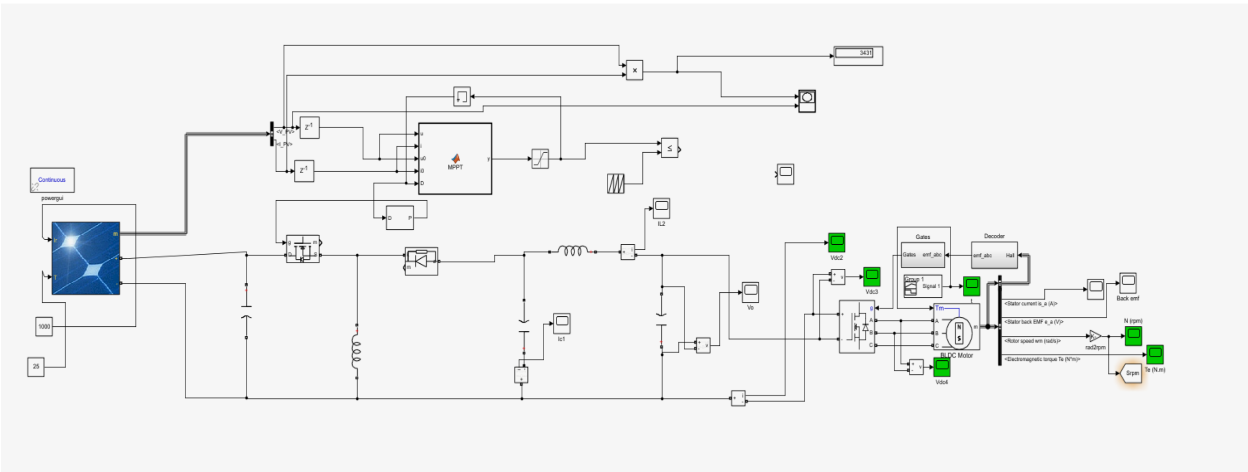

Fig - 9: Simulation diagram for proposed SPV powered Luo converter fed BLDC driven model

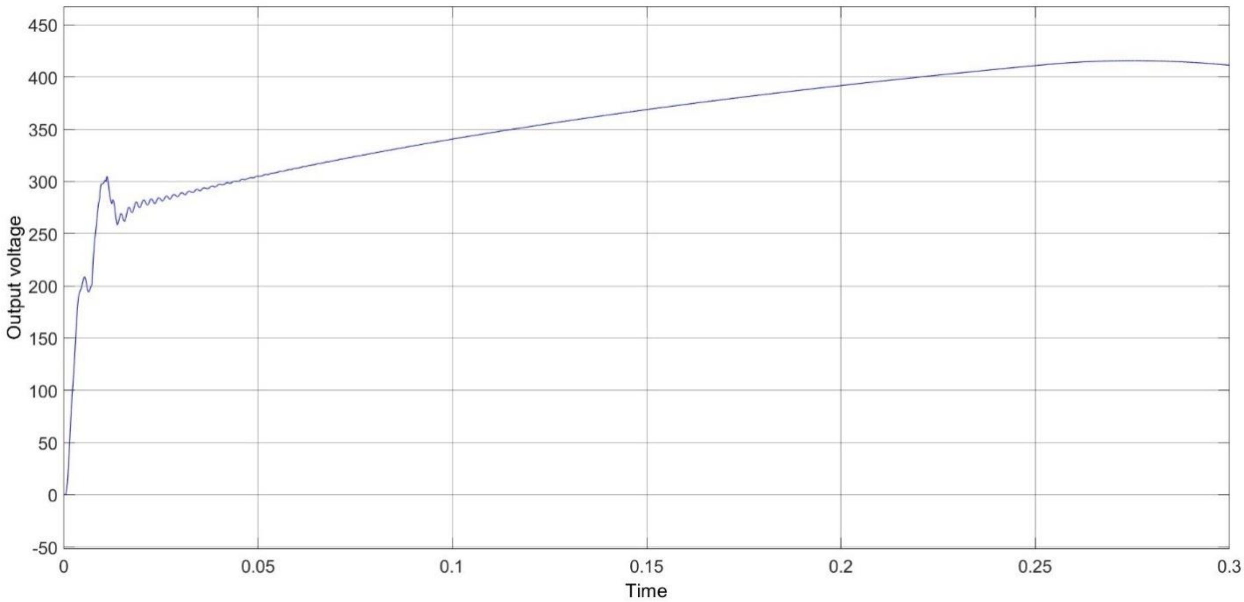

Fig - 10: Output voltage of Luo converter vs time

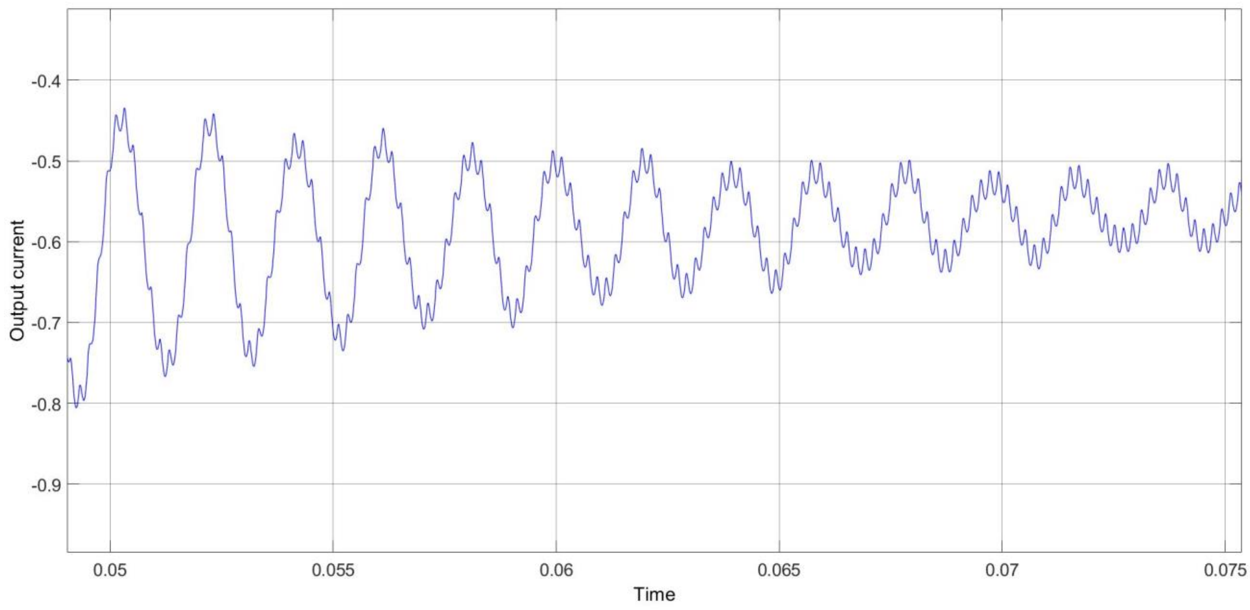

Fig - 11: Output current of Luo converter vs time

5.5 Performance of BLDC Motor

As the solar insolation level alters, the various BLDC motor indices such as the back EMF, Ea, the stator current, Isa, the speed(N), the electro-magnetic torque developed, Te and the load torque, TL vary in proportion to the solar insolation level. Two important facts are observed from the simulated results. First, the stator current, Isa at the start is controlled such that it takes some time to reach its steady state value and hence the BLDC motor develops a soft starting. Secondly, the BLDC motor develops the electromagnetic torque, Te equal to the torque required to drive the load, TL under all variations in solar insolation level ensuring the stable operation of the proposed system regardless of the weather condition. However, a small pulsation in electromagnetic torque Teis observed from the electronic commutation of the BLDC motor. Besides, the BLDC motor attains a speed higher than the rated speed that is able to drive the load regardless of the solar insolation level. The various performance curves of BLDC motor are shown in fig-12, fig-13, fig-14, fig-15.

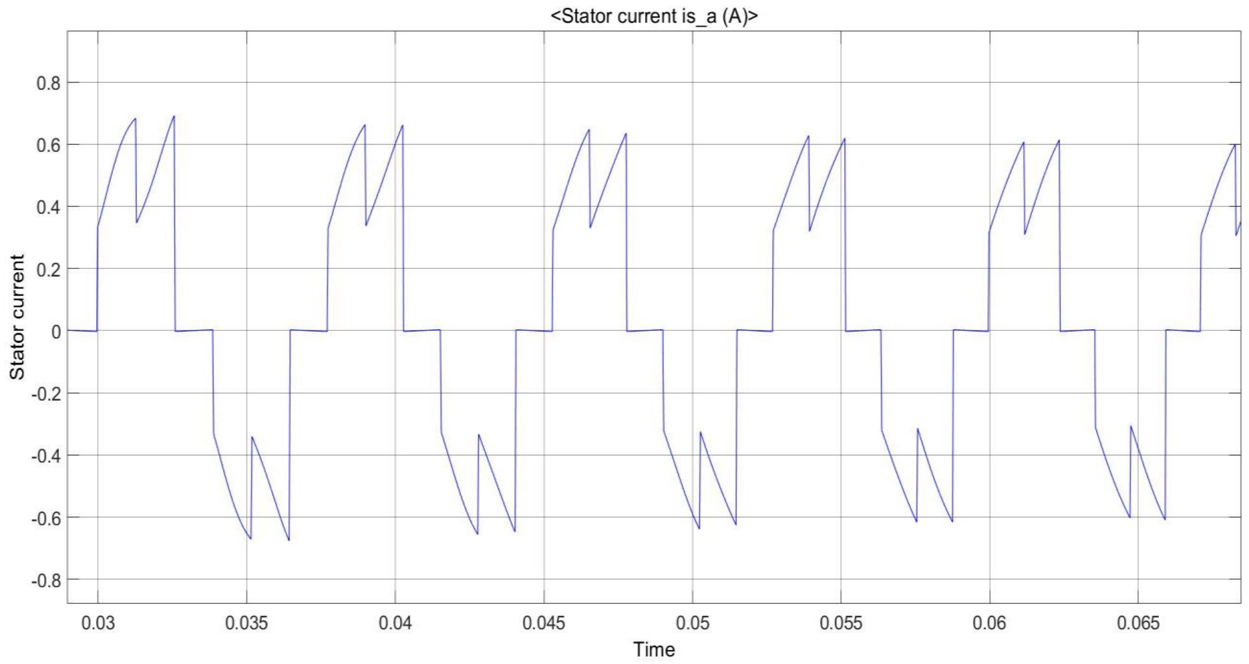

Fig - 12: Stator current of BLDC motor vs time

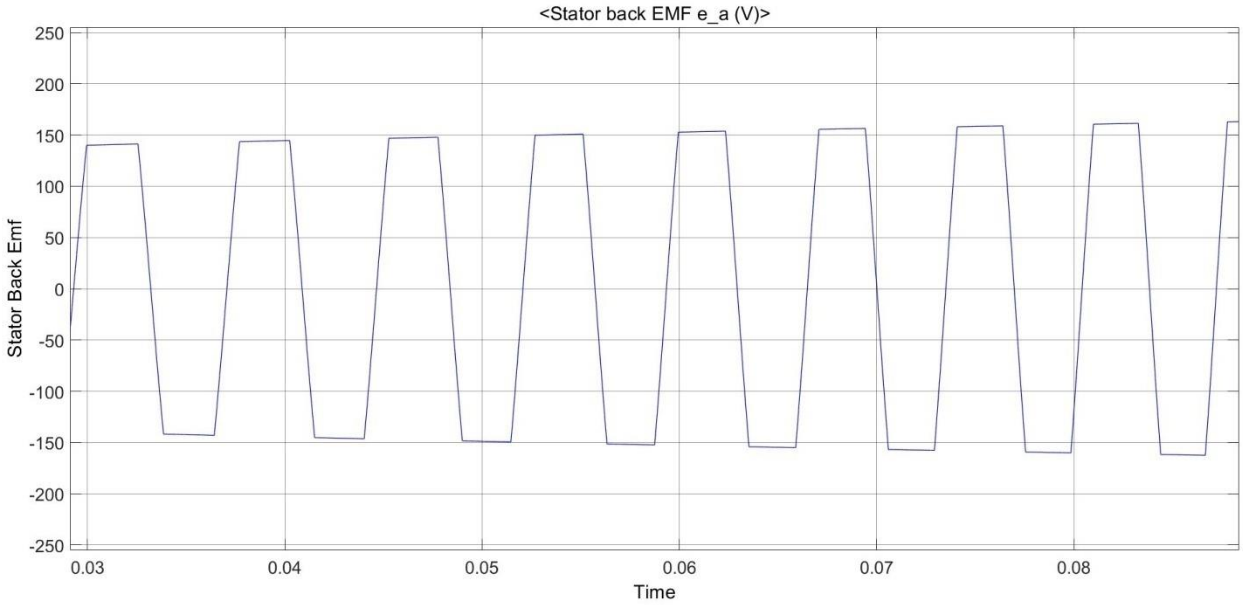

Fig - 13: Stator Back emf of BLDC motor vs time

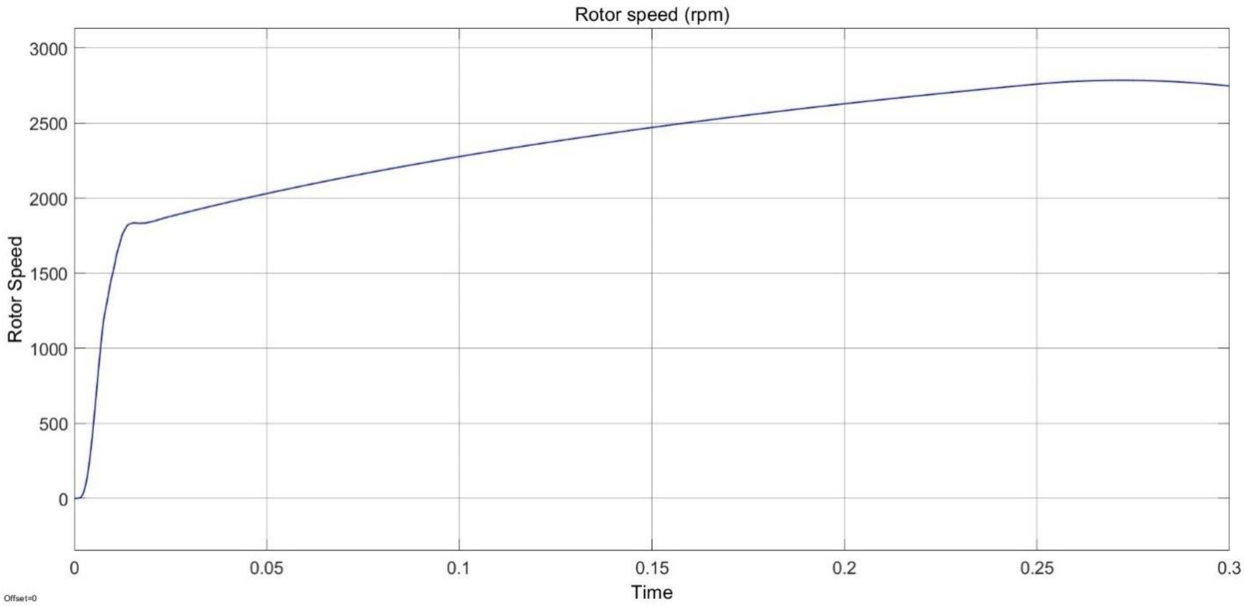

Fig - 14: Rotor speed of BLDC motor vs time

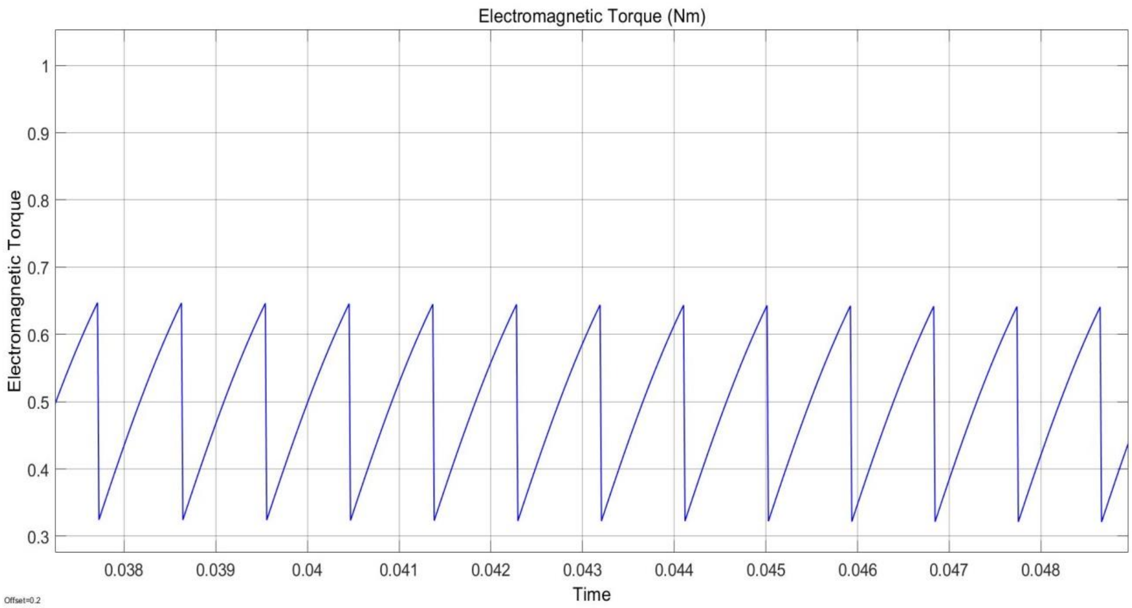

Fig - 15: Electromagnetic torque of BLDC motor vs time

6. RESULTS AND DISCUSSION

From the simulation the corresponding results are obtained. Table 3 indicates the simulated measured values of performance parameters of Luo and Zeta converters.

Table 3: Simulated measured values of performance parameters of Luo and Zeta converters

Types of converters	Switching frequency(kHz)	Output voltage ripple(mV)
Luo Converter	20	24.12
Zeta Converter	20	17.23

Table 4: Simulated measured values of performance parameters of Luo and Zeta converters

Types of converters	Input voltage(V)	Input current(A)	Output voltage(V)	Output current(A)	Efficiency(%)
Luo Converter	187.2	18.14	200	9.67	57
Zeta Converter	187.2	18.14	200	13.58	80

From table 3 and table 4, the corresponding conclusions are drawn.

Table 5: Comparison between Zeta and Luo Converters

Zeta Converter	Luo Converter
Voltage gain is more	Voltage gain is less
Output voltage ripple is less	Output voltage ripple is more
Conversion efficiency is more	Conversion efficiency is less

7. CONCLUSIONS

The SPV array fed Zeta and Luo converter fed BLDC motor driven models are simulated and executed using MATLAB/Simulink environment. Based on the simulation results the corresponding conclusions are drawn.

- The performance curves of Zeta converter, Luo converter, BLDC motor are observed.
- The output voltage ripple of Zeta converter is less by 7mV as compared to Luo converter.

- The efficiency of Zeta converter is 23% higher than Luo converter.
- The use of Zeta converter for SPV fed BLDC driven model helps in maximum power extraction of SPV array and soft starting of BLDC motor.

REFERENCES

[1] G. G. Gadhave and S. B. Patil, "Implementation of PF Improvement of Brushless DC Motor Drives using Zeta Converter," IEEE International Conference on Communication and Signal Processing, Chennai, India, pp. 1006-1010, Sep-2020.

[2] Aryaraj B K, Tony George, "Review of various converters fed BLDC motor used in water pumping system," International Research Journal of Modernization in Engineering Technology and Science, Kerala, India Volume:02, Issue02,pp. 1286- 1292, 07/July -2020.

[3] R.Saravanan, N.Chandrasekara, "Design and Simulation Analysis of Various Luo Converter Topologies fed BLDC Drive for Solar PV Applications," 6th International Conference on Advanced Computing and Communication Systems, Coimbatore, India, pp. 1120-1123, April–2020.

[4] Ardra Ravindran Dr. Binoj Kumar A. C, "Solar Powered BLDC Motor Drive using LUO Converter,"IEEE International Conference on Power, Control, Signals and Instrumentation Engineering,Chennai, India, pp. 1030-1035, Jun 2018.

[5] Emelda V BeulinJayarama Pradeep, "Design of Ultra-Lift Luo Converter for Pumping Applications,"International Conference on Power, Energy, Control and Transmission Systems, Chennai, India. pp. 201-207, Nov-2018.

[6] Anjali UddhavraoSelokar, V.B. Waghmare, "Solar photovoltaic array and Zeta converter based water pumping system based on BLDC motor with torque ripple compensation,"International Conference on Emerging Trends in Information Technology and Engineering, Vellore, India. pp. 1-4, Apr-2020.

[7] Ranjan Kumar, Bhim Singh, "BLDC Motor Driven Solar PV Array Fed Water Pumping System Employing Zeta Converter,"IEEE 6th India Intenational Conference on Power Electronics, Kurukshetra India, pp 111-117, 01 June 2015.

[8] N. Mohan, T. M. Undeland and W. P. Robbins, "Power Electronics: Converters, Applications and Design," pp no.162-198, John Wiley and Sons Inc., USA, 1995.

[9] Daniel W. Hart, "Power Electronics",pp.196-260, Published by McGraw-Hill,2011.

[10] M. H. Rashid, Power Electronics: Circuits, Devices and Applications, pp no.180-223, third edition (2013).

[11] Dhananjay Choudhary, Anmol Ratna Saxena,"Incremental Conductance MPPT Algorithm for PV System Implemented Using DC-DC Buck and Boost Converter," 2014 International Journal of Engineering Research and Applications,Vellore, India, vol. 4, Issue 8, pp.123-132, August 2014.