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Solar Photovoltaic Panel Fed SEPIC Converter Based BLDC Motor Drive With MPPT

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***Abstract*---In the past decade solar energy is contributing major part of Renewable energy sources. The paper constitutes of solar photovoltaic (SPV) panel fed permanent magnet brushless DC (BLDC) motor drive with an intermediate single-ended primary-inductor converter (SEPIC) for DC-DC conversion followed by three phase voltage source inverter (VSI) operating at 120^o conduction mode.The negative output elementary Luo converter is employed as SEPIC to pull out maximum power from SPV panel and for harmless start of BLDC motor. Incremental conductance (INC) method of maximum power point tracking (MPPT) is used. The SEPIC used is having less number of energy storing elements, that has inbuilt characteristics of reducing ripples of output current. The output of Luo converter is given as input to voltage source inverter (VSI), which feeds three phase power to BLDC motor. The switches of the VSI are operated at fundamental frequency to avoid high frequency switching losses results in greater efficiency. SPV panel at rated power supplies DC voltage to the BLDC drive at which maximum switch utilization is achieved for Luo converter. The drive performances at different operating conditions are plotted and analyzed using MATLAB Simulink model. Realization of prototype is done by dsPIC30F4011[10].**

***Keywords*— SPV panel; SEPIC; Luo converter; BLDC motor/drive; INC; VSI; MPPT; CCM.**

1. INTRODUCTION

Over the last two decades using of fossil fuels has been at it's peak, leading to severe environmental disorders. Burning of fossil fuels releases greenhouse gases into atmosphere. Results in global warming, ozone layer depletion and shortage of fossil fuels for next generations etc.., campaigns are running everywhere to create awareness among citizens to go for renewable energy sources such as wind, solar, tidal and geothermal etc.., in tropical regions like India solar energy can be highly reliable. It is necessary to operate solar photovoltaic at high efficiency irrespective of operating conditions and obstacles. The efficiency is enhanced by MPPT algorithm. Different kinds of DC-DC converters are implemented in tracking of MPPT. But still some converters are unexplored. Luo converter is a kind of it. In Luo converter various topologies like elementary, self-lift circuit, re-lift circuit, triple-lift circuit and quadruple-lift circuit voltage lift techniques[1] are present. But to provide high voltage transfer gain requires different kinds of components and switching devices which is not economical.

The basic negative output elementary Luo converter is used to obtain the maximum power of solar photovoltaic panel. This converter allows BLDC motor to start at low starting current than usual operation. As the converter is operated in continuous conduction mode, the maximum utilization of switch is also achieved. Unless like buck-boost converter it has a smooth, ripple free current.

BLDC motor is selected for electrical drive application. The impeccable suitability of BLDC motor is the reason behind it's employment to drive application. The inverter is operated at fundamental switching frequency to reduce switching losses.

The adoptability of this solar photovoltaic panel fed BLDC motor drive is observed under several operating and environmental conditions and displayed by the satisfactory simulated results using MATLAB Simulink model[2].

2. STRUCTURE OF PROPOS-ED SYSTEM

The structure of proposed SPV panel fed BLDC motor drive employing Luo converter, 120^0 conduction mode operating VSI and load to motor is centrifugal pump is presented in Fig.1. The proposed system consists of SPV panel fed BLDC drive with an intermediate SEPIC converter for MPPT, a VSI supplying three phase power to the BLDC drive. The BLDC motor having an inbuilt encoder for electronic commutation through Hall signal sensing and a centrifugal pump is selected[5] and connected as a load to the BLDC drive. The INC-MPPT algorithm executes the pulse generation. Optimum value of duty ratio is generated by INC-MPPT algorithm at MPP. Further the duty ratio is converted by comparing with high frequency saw-tooth signal, into a switching pulses for IGBT of SEPIC converter. The various stages of system Design, control and operation are discussed briefly in the fallowing sections.

3. DESIGN OF PROPOSED SYSTEM

Irrespective of the operating conditions the designed proposed system consisting of SPV panel, SEPIC converter and BLDC drive should be of satisfactory, reliable and efficient. Each stage is designed at standard test conditions (1000 W/m^2, 25^0C). A BLDC motor ratings of 5.18KW, 310V DC and 3000rpm is considered. The aptable rating SPV panel of 6KW is employed. A higher rated SPV panel is selected considering the losses at different converting stages and mechanical losses of BLDC motor. The designing structure of various stages of proposed is discussed section wise.

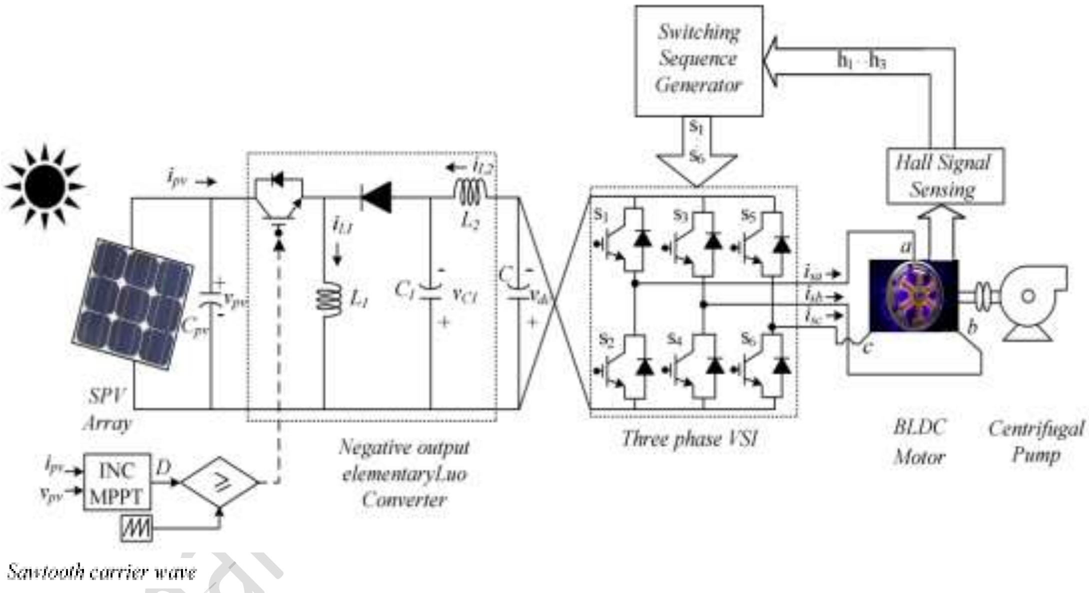

Fig.1. Configaration of proposed SPV panel-Luo converter fed BLDC motor drive

3.1. DESIGN OF SPV PANEL

The SPV panel with P_{mpp}=6KW is employed considering all the losses for the BLDC drive application. Solar world make SPV panel, Sunmodule® SW 50 Poly RMA [11] is selected to realize a PV panel of required size. Calculation of MPP voltage, V_{mpp} prepares the initiation of SPV panel. Electrical quantity proposal of this module are listed in the Table.1. As the SEPIC converter belongs to the family of buck-boost converter, the maximum switch utilization occurs at 0.5 duty ratio. From the above mentioned condition input and output voltages of SEPIC converter are equal. The output voltage of SEPIC converter is 310V which is the DC link voltage of VSI as well as DC voltage rating of BLDC motor. The duty ratio of 0.5 is achieved by operating SPV panel at INC-MPPT and at mentioned test conditions and hence the maximum switch utilization of SEPIC converter, it is incumbent to go for V_{mpp}. So the input voltage of Luo converter is 310V. The SPV panel ratings of 6KW, 310V DC required to calculate I_{mpp} at MPP condition is,

$$I_{mpp}=P_{mpp}/V_{mpp}=6000/310=19.35A \quad (1)$$

Journal of Engineering Sciences
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After all this, it is easier to evaluate number of series/parallel modules of SPV panel. Number of series modules equals to,

$N_s = V_{mpp}/V_m = 310/18.2 = 17$ (2)

Number of parllel modules are,

$N_p = I_{mpp}/I_m = 19.35/2.75 = 7$ (3)

As per the design of proposed system, connecting 17 modules in series and 7 modules in parallel completes the formation of SPV panel. The ratings of SPV panel are mentioned in Appendix- A.

TABLE.1 Electrical specifications of Sunmodule® SW 50 POLY RMA SPV PANEL

Peak power, P_m (Watt)	50
Open circuit voltage, V_0 (V)	22.1
Short circuit current, I_s (A)	2.95
Voltage at MPP, V_m (V)	18.2
Current at MPP, I_m (A)	2.75
Number of cells connected in series, N_{ss}	36

3.2. IMPLEMENTING OF INC

As the design is completed implementation of MPPT is the next job to do. Many of MPPTs available, the suitable MPPT for this system is Incremental Conductance Method[4] (INC). The SEPIC converter has a bound less region of MPPT in INC method. The INC method computes MPP by comparing i/v = di/dv of PV panel.
i/v – Instantaneous conductance

di/dv – Incremental conductance

When the two voltages are same i.e., MPP Voltage = Output Voltage of the Controller, maintains the same voltage until the irradiation changes and the process is repeated. The INC method is based on the following observation

$dp/dv = 0$ (4)

$dp/dv = d(vi)/dv = i(dv/dv) + v(di/dv)$

$di/dv = -i/v$ (5)

Based on PV curve obtained from Simulink model the fallowing observations are made

(a) $dp/dv > 0$ then $V_m < V_{mpp}$ (6)

(b) $dp/dv = 0$ then $V_m = V_{mpp}$ (7)

(c) $dp/dv < 0$ then $V_m > V_{mpp}$ (8)

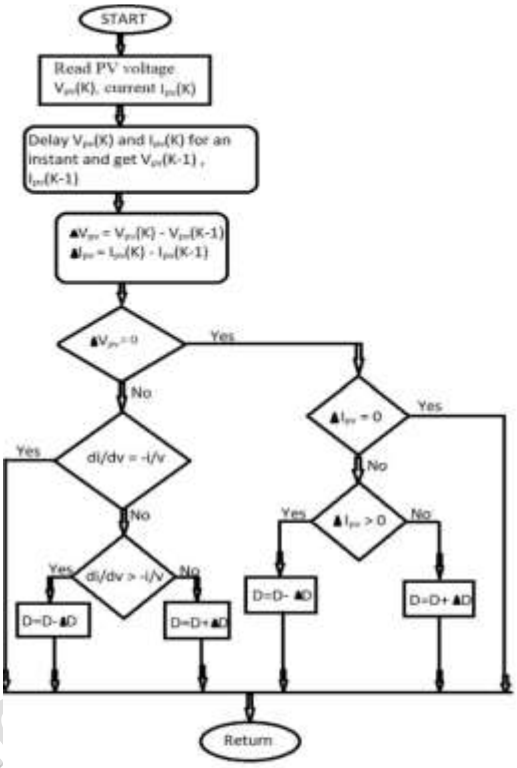

Fig.2. Flowchart of INC MPPT

3.3. DESIGN OF LUO CONVERTER

While designing SPV panel the maximum switch utilization of Luo Converter[7] is considered. The elements of Luo Converter are always operated at a duty ratio of D = 0.5, so that the continuous conduction mode is achieved. The elements of the converter are input inductor, L_1, intermediate capacitor, C_1, output inductor, L_2 and output capacitor, C_2. A great value of switching frequency, fsw = 20 kHz is implemented in order to get the compact value of converter elements. The DC link current of VSI i.e., the output current of Luo converter, *Idc* is equal to *Impp* i.e. the input current of Luo converter as the power and voltage level are identical at both the input and output stage of converter. Input inductor, L_1 is estimated as[3],

$$L1 = \frac{DV_{mpp}}{\text{fsw}\Delta I_{L1}} = \frac{0.5*310}{20000*(19.35+19.35)*0.04} = 5mH$$
(9)

where ΔI_{L1} is amount of ripple permitted in the current flowing through L_1, addition of input and output current of Luo converter. Output inductor, L_2 is estimated as,

Vol 11, Issue 10,OCT /2020

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$$L2 = \frac{(1-D)V_{dc}}{f_{sw}\Delta I_{L2}} = \frac{(1-0.5)*310}{20000*19.35*0.08} 5mH \quad (10)$$

where ΔI_{L2} is amount of ripple permitted in the current flowing through L_2, equal to the output current of Luo converter.

To estimate DC link capacitor, C, the fundamental output voltage frequencies of the VSI corresponding to the rated speed of BLDC motor, ω_{rated} and the minimum speed of BLDC motor essentially required to pump the water (N = 1100 rpm), ω_{min} are taken into account which are estimated as,

$$\omega_{rated} = 2\pi f_{rated} = 2\pi \frac{Nrated}{120} = 2\pi * \frac{3000*6}{120} = 942\text{rad/sec.} \quad (11)$$

$$\omega_{min} = 2\pi f_{min} = 2\pi \frac{NP}{120} = 2\pi * \frac{1100*6}{120} = 345.57 \text{ rad/sec} \quad (12)$$

where f_{rated} and f_{min} are the frequencies corresponding to ω_{rated} and ω_{min} respectively, in Hz; N_{rated} is rated speed of BLDC motor; P is the numbers of poles in BLDC motor.

Since 6th harmonic component of ac voltage is reflected from the motor on the DC link of VSI as a dominant harmonic, two values of C are estimated corresponding to ω_{rated} and ω_{min} as,

$$C_{rated} = \frac{I_{dc}}{6 * \omega_{rated} * \Delta V_{dc}} = \frac{19.35}{6 * 942 * 310 * 0.06} = 184\mu F \quad (13)$$

$$C_{min} = \frac{I_{dc}}{6*\omega_{min}*\Delta V_{dc}} = \frac{19.35}{6*345.57*310*0.06} = 500\mu F \quad (14)$$

where ΔVdc is the amount of permitted ripple in the voltage across C.

Finally, $C = Cmin = 500$ μF is selected as DC link capacitor (larger one out of the two estimated values to ensure satisfactory performance of proposed system irrespective of the operating conditions). Thence, $C1$ is also selected as 500μF to avoid the oscillations in the various indices of Luo converter. Estimated values of elements of SEPIC converter repeated in Appendix B.

3.4. DESIGN OF INVERTER

A 120^0 mode conduction angle suitable VSI topology is designed from the study of[6], which is operating at fundamental frequency to avoid high frequency switching losses.Switch TLP250[8] of IGBT or MOSFET can be recruited for optimum operation of VSI. The output current of SEPIC Converter, which is ripple free is given as input to VSI. The hall sensors of BLDC motor helps in generating gate pulses by feedback path for the operation.

3.5. DESIGN OF BLDC MOTOR

BLDC motor of model-23.2TC[12] of Tachometric Controls is selected. The ratings mentioned as in Appendix C is employed for better operation of drive considering all the pre losses. The 3-phase AC input is flowing to the motor from the VSI. As the ripples are already mitigated in SEPIC,motor runs smoothly at rated torque and speed.
The proportionality constant of BLDC motor is

$$K = \frac{TL}{\omega_r^2} = \frac{16.5}{\left(2\pi*\frac{3000}{60}\right)^2} = 1.67*10^{-4} \quad (15)$$

where TL is equal to the rated torque of BLDC motor, $Trated$ under steady state and ωr is rated speed of BLDC motor in rad/sec.

4. CONTROL OF PROPOSED SYSTEM

The proposed system is to be controlled at two stages. They are described in brief as follows.

4.1.INCREMENTAL CONDUCTAN-CE MPPT

Fig.2 depicts the flowchart of INC-MPPT algorithm through which MPPT is achieved for every solar insolation level. In reality, the Luo converter is controlled by the accomplishment of INC-MPPT algorithm to reach the MPP of SPV array. Proper selection of perturbation size enables reduced current starting of BLDC motor, eluding the detrimental effect of high starting current in motor windings.

4.2. ELECTRONIC COMMUNICA-TION OF BLDC MOTOR

Motor Power Company make model-23.2TC of Tachometric Controls BLDC motor [12] is selected for the proposed SPV array fed BLDC motor drive. Electronic commutation of BLDC motor is executed by operating three phase VSI in 120° conduction mode using six switching pulses generated according to the rotor position. The inbuilt encoder senses the rotor position on each 60° span, generates a specific set of three Hall effect signals and consequently the switching sequence for VSI is generated. Fundamental frequen-cy switching of VSI is conquered by the electronic commu-tation of BLDC motor. Detailed data of selected BLDC motor are given in Appendix C.

5. RESULTS AND DISCUSSI-ON

The configuration of proposed SPV array BLDC drive shown in Fig. 1 is designed,modeled and simulated using MATLAB Simulink and its simpower-system toolboxes. Various starting, dynamic and steady state performances of the system are subjected to uncertain operating conditions are illustrated in Figs. 2-4. To demonstrate the dynamic behavior, solar insolation level is considered to be of varying nature as indicated in Table II. Various performances of each stages viz. SPV array, Luo converter and BLDC motor-pump are described separately in following sub-sections.

5.1.PERFORMANCE OF SPV ARRAY AND INC-MPPT ALGORITHM

Fig.3 depicts the various SPV array indices viz. solar insolation level, *S*, SPV array voltage, *vpv* and SPV array power, *Ppv*. At the starting, MPPT algorithm takes time to reach the operation of SPV array at MPP under steady state in view of the reduced current starting of BLDC motor.

It is clearly visible that the MPPT technique is capable of optimizing the SPV array power under dynamically changing atmospheric condition. Since the proposed system is designed considering the standard value of *S*, SPV array indices reach their rated value at 1000 W/m2.

TABLE.2 VARIOUS SOLAR INSOL-ATION LEVEL

Solar insolation level, S(W/M^2)	Duration(Sec)
200	0.0 – 0.2
400	0.2 – 0.4
600	0.4 – 0.6
800	0.6 – 0.8
1000	0.8 – 1.0

The PV & IV characteristics of SPV panel are obtained and depicted in Fig.3 and Fig.4

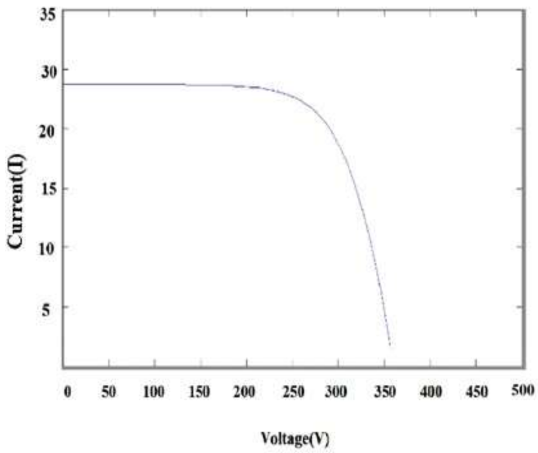

Fig.3. IV characteristics

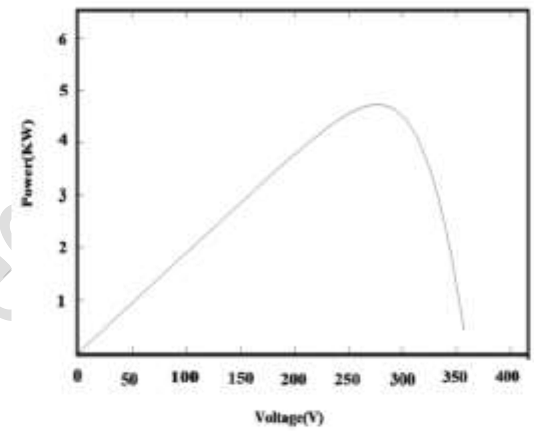

Fig.4. PV characteristics

5.2.PERFORMANCE OF LUO CONVERTER

Various performance indices of Luo converter viz. ouput current flowing, output voltage, voltage across the DC link of VSI, *vdc* are illustrated in Fig.4. All these indices instantly follow the variation in *S*. Fig.4 clearly demonstrates the operation of Luo converter in continuous conduction mode (CCM). High frequency switching avoids the ripple contents in various indices.

5.3. PERFORMANCE OF BLDC MOTOR DRIVE

Fig.6 depicts the torque and speed characteristics of BLDC motor-pump system exposed to a swiftly changing solar insolation level. As the DC link voltage varies, various motor indices viz. the stator current, *isa*, the electromagnetic torque, *Te*, and the rotor speed, *N* vary accordingly. It is clear from the waveform of *isa* that the high starting current of BLDC motor is hindered and its safe starting is achieved. The BLDC motor-pump indices reach their rated values at 1000 W/m^2 under steady state condition. The motor always attains the speed of more than 1100 rpm even at the lowest solar insolation level of 200 W/m^2. Small pulsation in *Te* is observed because of electronic commutation of BLDC motor. *Te* as an evidence of stable operation of motor-load system.

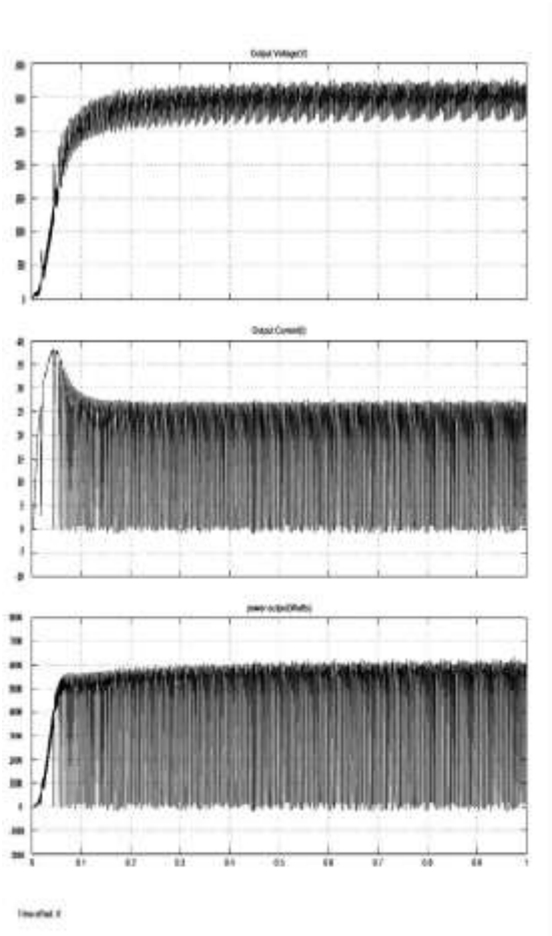

Fig.5. Output characteristics of Luo converter

5.4. REALIZATION OF HARDWA-RE

Fig.7 shows the implementation of Hardware. The Hardware is realized[7] using dsPIC30F4011 according to the Simulink model. MOSFET IRF840[9] are employed as switches of Luo converter. TOSHIBA TLP-250 are the switches of Inverter. Tachometric 23.2-TC BLDC motor is considered filtering all the losses and ratings.

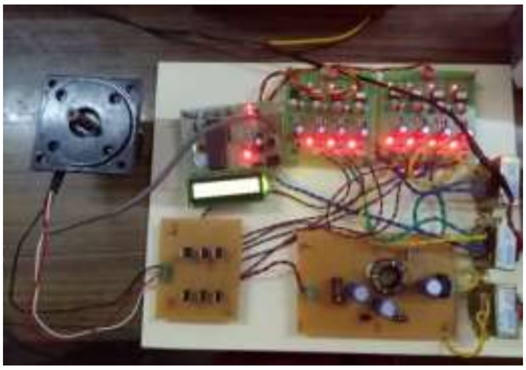

Fig.7. Prototype of BLDC motor drive

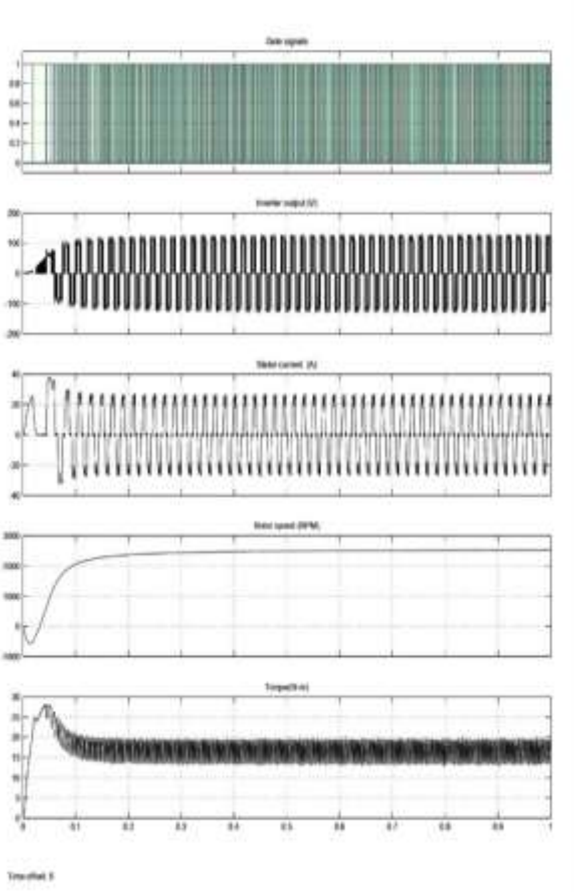

Fig.6. Bldc motor drive output characteristics

6. CONCLUSION

A Solar photovoltaic panel fed Luo converter based BLDC motor drive has been implemented using MATLAB Simulink model and different parameters of model are analyzed under various conditions. The suitability of this model under practical conditions is observed by the realization of hardware. The Luo converter is operated to limit the starting current to stator of BLDC motor as it cannot withstand higher currents and helps in

MPPT. Luo converter is operated in CCM to achieve maximum switch utilization and minimize stress on other power devices. A 120^0 conduction mode inverter is operated at fundamental frequency to avoid higher order frequency losses. The safe starting and stable operating conditions BLDC motor drive are obtained.

Appendix A

Parameters of solar PV panel:
Open circuit voltage, *Voc*=375.7 V;
Short circuit current, *Isc*=20.65A; Maximum power, *Pmpp*= 6 kW; Voltage at MPP, *Vmpp* = 310 V;
Current at *MPP*, *Impp*= 19.35 A;
Numbers of cells connected in series in a module, *Nss*= 36; Numbers of modules connected in series, *Ns*= 17; Numbers of modules connected in parallel, *Np* = 7.

Appendix B

Parameters for Luo converter: Switching frequency, *fsw*=20kHz;
Input inductor, *L1* = Output inductor, *L2*=5mH; Intermediate capacitor, *C1* = DC link Capacitor, *C* = 500 µF.

Appendix C

Parameters for BLDC Motor: Stator phase/phaseresistance, *Rs*=0.41Ω;Stator phase/phase inductance, *Ls*=2.13mH;
Torque constant, *Kt* = 0.74 Nm/Apeak; Voltageconstant, *Ke*=78VpeakLL/krpm; Rated current, *Israted* = 22.15A; Rated torque, *Trated* = 16.5 Nm; Rated speed, *Nrated* = 3000rpm @ 310 V DC; Rated power, *Prated* = 5.18 kW; No.of poles, *P* = 6.

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