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Research paper

Comparison of BLDC Motor Control with Fuzzy Tuning by Solar Power Input and Zeta Converter

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Abstract

The importance of brushless DC (BLDC) motor along with its control is enhancing in present days due to its wide applications in sophisticated equipments. In this paper various parameters of the BLDC Motor was observed using open loop and closed feedback loop with Fuzzy and PI control. With the help of observed parameters, better controlling techniques are applied to BLDC Motor control. Solar power is used with Zeta converter in boost mode to give the power supply to the Motor. Using DC Generator the electrical loading is applied on BLDC Motor. The effect of closed loop control on Zeta converter was also analyzed. In present days the BLDC Motor drives are widely using in aviation, defense, etc due to absence of commutator sparks. So high priority for better control of BLDC Motor in coordination with embedded designs is given due to its increasing utilization.

Keywords: *BLDC, Hall sensor signal,solarcell ,Torque, zeta converter*

1. Introduction

The BLDC Motor is preferred to DC machine due to absence of commutator and sparks. Solar device is used to give the DC supply. Compared to the wind energy, solar energy generation needs large storage battery due to the partial shading or full shading [1] during monsoon season. Wind energy almost available during all weather seasons. Generally Solar power generation is well suitable in low rainfall areas and near to desert areas. In rain fall areas solar power generation may be available continuously in summer season only. In this season solar power interruption is less but efficient generation is real challenge and it has to be done with necessary arrangements. The battery and ultra capacitors together can also store the regenerative energy of the BLDC Motor. BLDC Motor can operate in all four quadrants. Zeta converter can be used for DC-DC level conversion and it can also be used for (MPPT) maximum power point tracking [2]. The MPPT control is using incremental conductance method . BLDC Motor will be controlled by using Hall sensor signal or by using speed sensor. For 3-phase BLDC , three hall signals are generated and each signal will conduct for 1/2f by giving phase difference of 120^0. Fuzzy tuned PI control yields better inverter pulse width decision on BLDC Motor control. Fuzzy control not only used for better Torque control, it can also be used for speed control with practical embedded control algorithm.BLDC Motor can be modeled in different manners. In both 1-phase and 3-phase BLDC models, either the armature or the poles act as a rotor. The poles are generally made with permanent magnets to avoid the DC source excitation. The force of attraction or repulsion will act between stator and rotor for generating the torque .

2 BLDC motor controls in open loop

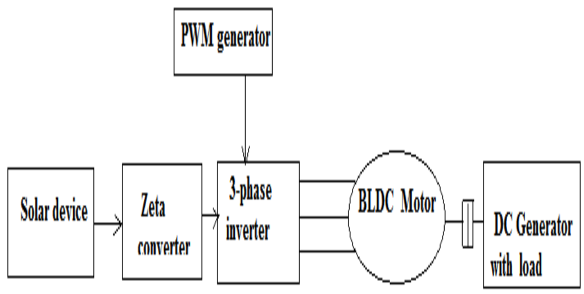


Fig1 : BLDC Motor in open loop

In the above Figure. 1, the solar device is generating 60v with each cell of 0.6v. The PWM generator is using carrier frequency of 1350 Hz and the modulation index of 0.8.

2.1. 3-phase BLDC motor

Each phase of the 3-phase BLDC motor can be modeled by the equation as [3]

$$[L-M]\ (SI_{ph}) + R_a I_{ph}\ (s) = V\ (s) - E\ (s) \qquad (1)$$

L= self inductance

M= Mutual inductance
R_a= armature resistance of each phase
V= applied Voltage of each phase
E= Back EMF of each phase
P= $E_aI_a + E_bI_b + E_cI_c$
$T_e\,\omega = P$
$T_e = f(I_{ph})$, $\omega = f(E)$
$T_{LM} - T_{GE} = J\,d\omega/dt + B\,\omega$
T_{LM} = Motor load torque
T_{GE} = Generator electric torque
J,B are inertia and friction constants of generator.
The BLDC motor can operate in all four quadrants as shown in Figure.2. Generally under no load or light load conditions, The Motor will operate in 2 quadrant [4-5].

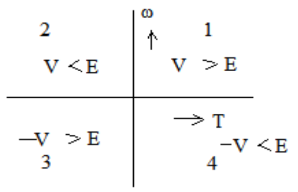


Fig2 : Four Quadrant operation

Voltage source inverter should be preferred for allowing regenerative breaking using feedback diodes. Generally the regenerative power is used to charge the battery and ultra capacitors. Of course the feedback diodes are also useful for flow of reverse currents during lagging and leading loads.

2.2 Solar cell and Zeta converter

Practically Solar cell not always operate at its maximum power point . MPPT has been used to obtain the maximum power point . From VI characteristics of the solar device the MPPT will control the voltage and current to the device maximum point.The zeta converter in the Figure 1 is used as boost converter. It can also be used for maximum power point tracking by varying its duty ratio. For a constant load supplied by only solar source, precaution has to be taken against shadings,partial shadings, partial cell damages. Under partial shading or partial cell damages , the constant loading may cause solar cell to operate beyond its short circuit capacity and leads to further damaging of cells . This problem can be avoided either by connecting the solar cell device to common grid along with the battery or by reducing the load . Maximum power point can be obtained by using incremental conductance method. At the maximum power point [6]

$$\partial p/\partial v = \partial(iv)/\partial v = i + v^* \partial i/\partial v \qquad (2)$$

At this maximum power point dp/dv =0, $\partial i/\partial v = -i/v$.
Because of negative v-i characteristics, power raises up to maximum point and then it starts decreasing due to sharp current fall.

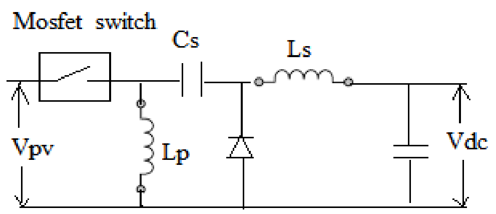


Fig 3 : Zeta Converter

The main differences of Zeta converter compared to the other converters are its continuity of current and dc insulation. Series inductor size should be more to maintain in the continuous current mode. In Figure.3, series inductor L_S value will depend up on switching frequency f_{sw} and DC link voltage V_{dc}. Series capacitor C_S size depends up on DC link current and duty ratio D[6].

$$V_{dc} / V_{pv} = D/1\text{-}D = I_{pv} / I_{dc} \qquad (3)$$

$$L_S\, f_{sw}\, dI = D\, V_{pv} \qquad (4)$$

$$C_S\, f_{sw}\, dV = (1\text{-}D)\, I_{pv} \qquad (5)$$

Capacitor C_S charging during on period and discharges during off period of the switch. Minimum current should be above zero in continuous current mode by proper selection of inductance value.

2.3 BLDC motor in open Loop

In open loop control the BLDC Motor runs without any feedback control. The voltage from the Zeta converter is applied through the inverter to the Motor. The Motor is loaded with DC Generator and electrical load. In open loop, the oscillations in the parameters of zeta converter were observed due to ripples in the BLDC Motor Torque.

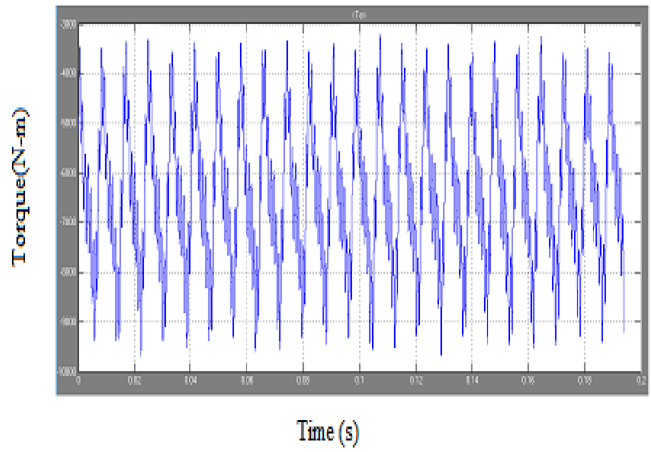


Fig 4: BLDC Motor Torque

The Hall signals of the Motor are shown in Figure. 5

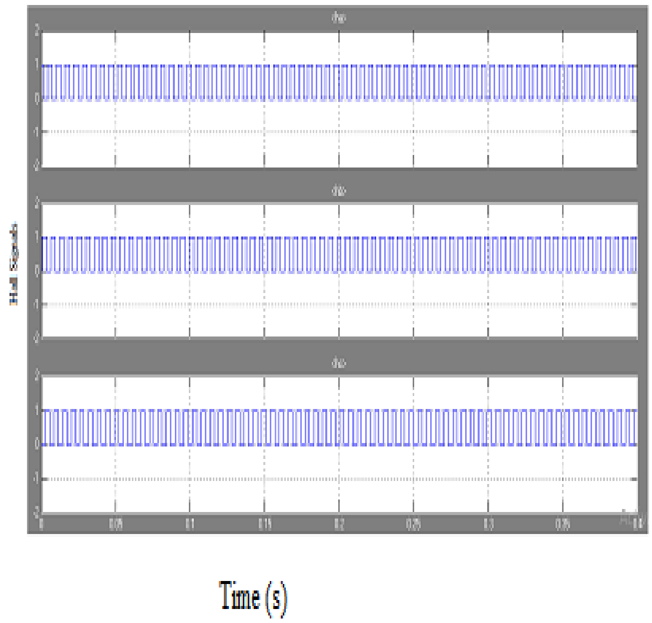


Fig 5: Hall signals of BLDC Motor

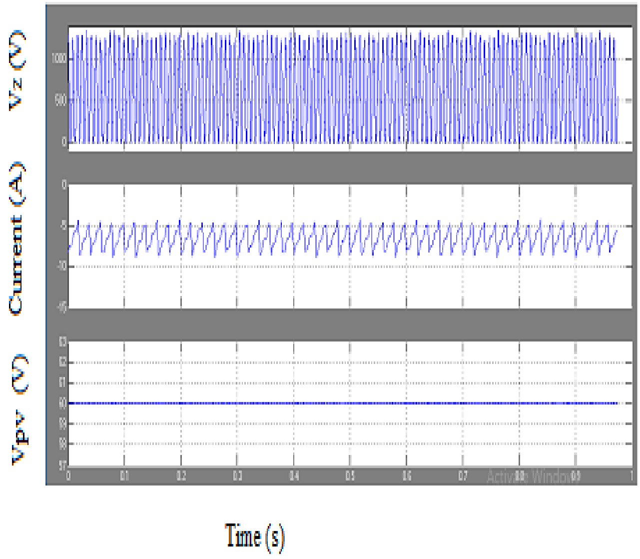


Fig 6: Zeta converter parameters in open loop

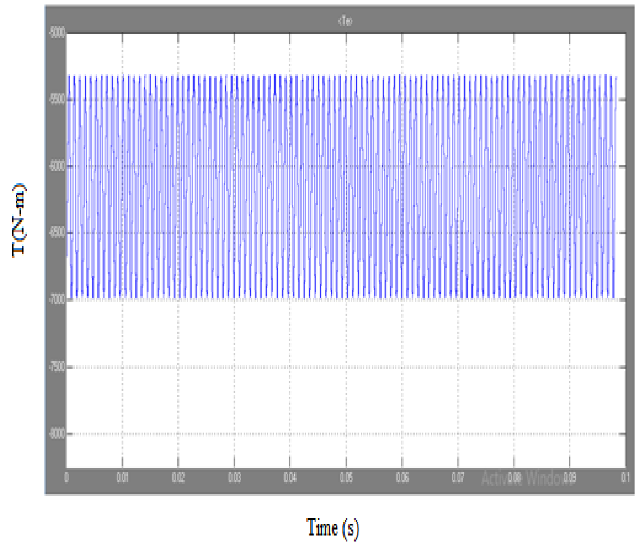


Fig 8: BLDC Torque in PI control

The current of the zeta converter varies with the PWM variation and also with duty ratio of Zeta converter. BLDC Motor stator voltages are trapezoidal .The rms voltage across Ls gives more oscillatory than the mean voltage Vz across Zeta converter output .In open loop ,the zeta converter voltages like V_{LS} , V_Z are oscillating along with torque oscillations. In addition to that there are more harmonics in BLDC input voltage. Table 1 shows the variation of Zeta converter voltages with duty ratio.

Table 1: Zeta Converter Parameters in Open Loop

Duty Ratio percentage	Mean value of V_Z (kV)	RMS Value of V_{LS} (kV)
30	0.65	1.250
50	0.65	1.500
70	0.65	1.750
90	0.65	1.875

3. Bldc motor control in closed loop

Closed loop control of BLDC motor [7] is more effective than open loop due to ripples and oscillations of the various parameters.

3.1 Feedback control with PI

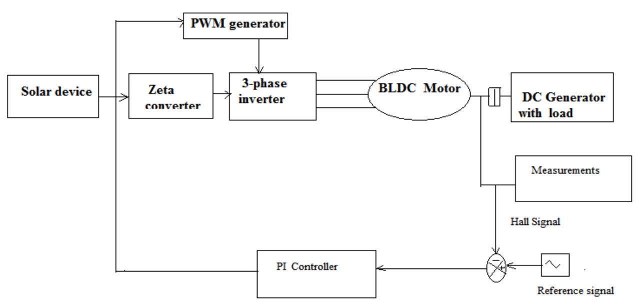


Fig 7: BLDC Motor with PI control

$$\text{PWM Input} = (K_p + Ki/s)\, e(s) \quad (6)$$

In PI control of Fig.7, the BLDC Motor Torque ripples are reduced compared to the open loop control. Ripples in V_Z mean value and in V_{LS} rms value of the Zeta converter are also reduced. At K_p= 10 , K_i =1 , BLDC Motor Torque variation is shown in Fig.ure8.

3.2 Feedback control with PI and fuzzy rule view

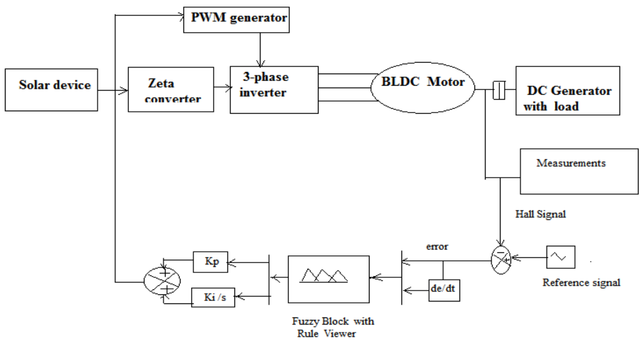


Fig 9: BLDC Motor with Fuzzy and PI control

In this control ,Fuzzy logic controller[8-10] will take error and derivative of the error at its input as in Figure.9. Based on the rule view the output K_P , K_i values are changed dynamically until the reference setting is reached. In this control, the ripples in the Torque are reduced. Simultaneously variations in the zeta converter parameters V_{LS} rms, V_Z mean are also reduced. V_Z mean value settling time is more in this control. Table 2 shows the variation of Zeta converter voltages with duty ratio.

Table 2: Zeta Converter Parameters In Closed Loop

Duty Ratio percentage	Mean value of V_Z (kV)	RMS Value of V_{LS} (kV)
30	2.3	1.250
50	3.75	2
70	4.8	2.65
90	5.7	3.12

The Zeta parameter variations as a graph are shown in Figure. 10

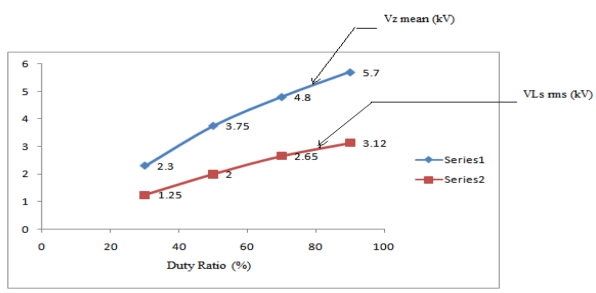
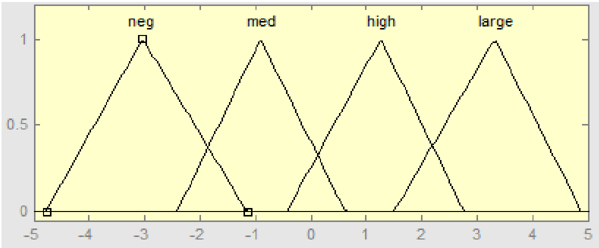


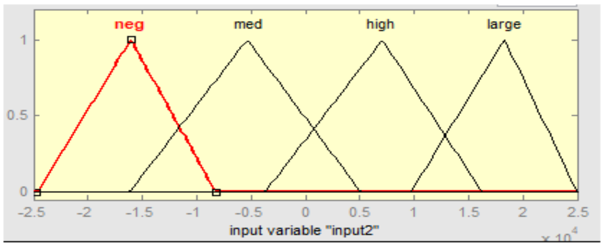
Fig 10: Zeta parameter variations

The member ship functions of error and derivative error are shown in Figure.11 and Figure .12 respectively.



input error membership function

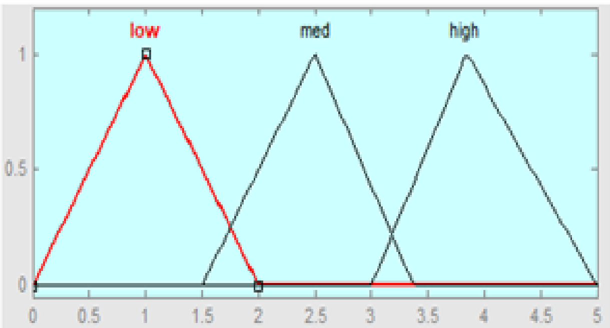
Fig. 11: Input error Member function



input membership function for derivative error

Fig. 12: Input derivative error Member function

The output member ship function for K_P and K_i is shown in Figure .13



output membership function for kp and Ki

Fig13: Out put Membership function

The following Table 3 shows Mamdani rule viewer for K_p, K_i at different error and derivative error member variables

Table 3: Rule Viewer For K_p And K_i

de \ e	NEG	MED	HIGH	LARGE
NEG	HIGH	HIGH	HIGH	HIGH
MED	HIGH	HIGH	HIGH	HIGH
LARGE	LOW	LOW	LOW	LOW
HIGH	MEDIUM	MEDIUM	MEDIUM	MEDIUM

K_i parameter influences the steady state error and settling time. The parameter K_P influences the peak overshoot.These parameters behaviour will differ at different locations and with different combinations inclusively in closed loop control. The BLDC Motor torque with closed loop fuzzy control is shown in Figure. 14. The V_Z mean and V_{LS} rms voltages with fuzzy control are shown in Figure. 15 and Figure.16.

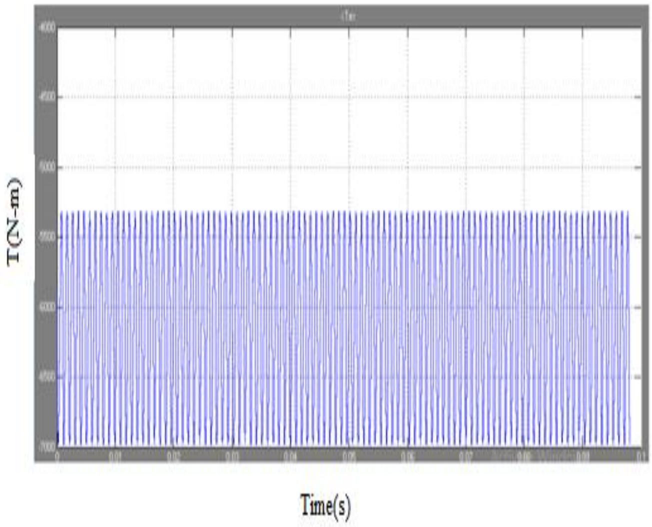


Fig. 14: BLDC Motor Torque with Fuzzy control

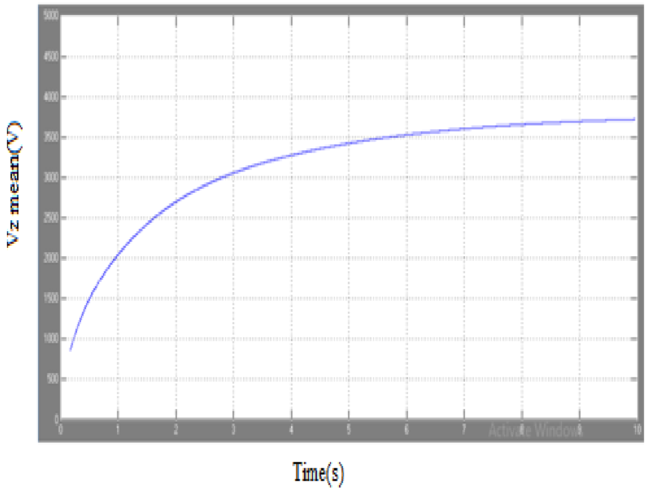


Fig.15: Zeta converter mean output voltage

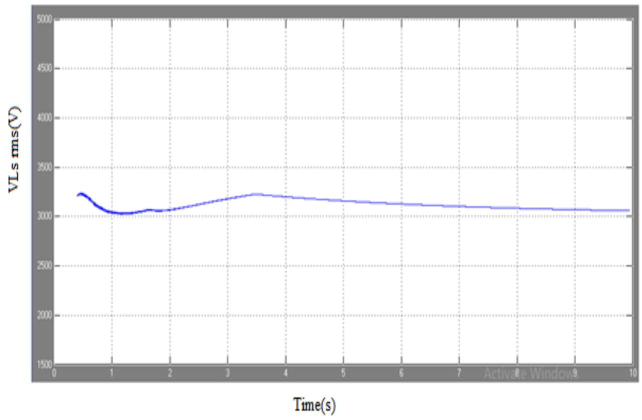


Fig .16: RMS voltage of V_{LS} in Fuzzy control

4. Conclusions

The closed loop control of BLDC Motor is more effective than open loop control. The ripples and pulsations in the torque as well as in the zeta converter parameters are reduced by the closed loop fuzzy and PI feedback control. The hall signals are used and compared for feedback control. The speed control also can be realized by setting full load speed as a reference using embedded control algorithm. Using speed control the power can be saved under light load or no load conditions. BLDC Motor is using in many applications. The closed loop controlling improves the performance and gives the better results. In addition to that, the controlling techniques are also enhancing the further utilization capacity of the Motor.

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Annexure

Specifications of the different components

A.1 Solar cell

Total number of cells: 10
Each cell open circuit voltage: 0.6v
Each cell short circuit current: 8A

A.2 Zeta Converter

Rin = 10k, Cin = 0.22 f
L_p= 3.2 mH, Cs = 2μ f, Ls = 2.8 H
Cout = 700 μ f, Rout =10K

A.3 BLDC Motor

R_s = 3.58 Ω , Ls = 9.13 mH

A.4 DC Generator with Load

Generator specifications: 10 hp, 500V, 1750 rpm
Field voltage = 300V
R_a = 4.712Ω, L_a= 0.052H
R_f = 180 Ω
P_{out} = 1000W