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Comparative analysis of PID and Fuzzy Based Control of SEPIC Fed Multilevel Inverter Scheme with Reduced Torque Ripple Content

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Abstract: ***This work compares the PID and Fuzzy based controllers for two SEPIC based multilevel inverters connected with a reduction in torque ripple content. The switches of SEPIC converter realized using PID or fuzzy logic controllers while that of multilevel inverter uses Hall Effect sensor for the generation of switching pulses. The proposed PID and Fuzzy based controllers achieved a reduced torque ripple of 31.2% and 18.75 % respectively compared to the existing control method with a torque ripple content of 36.4%[1].***

Keywords: ***Single-Ended Primary-Inductor Converter, Hall Effect Sensor, Neutral-Point-Clamped, Brushless DC motor.***

I. INTRODUCTION

Brushless Direct Current Motors are preferred in industrial applications due to its features including less maintenance and noise capability, high efficiency and they are capable of operating at low voltages. Due to the influence of stator winding inductance, current and thus, torque ripples are produced in the BLDC motor [2]. Proposed two stage converters including SEPIC converter and three level inverters whose switches operated based on the gate pulses generated using PID controller.

The SEPIC converter forms the first stage while the second stage consists of the NPC multilevel inverter realized using Hall effect sensor. The SEPIC converter used at the input stage to reduce the current and torque ripples in BLDC motor which occur due to the influence of stator winding inductance. Figure 1 represents the schematic block diagram of the proposed multilevel inverter scheme with two-stages incorporating both the control schemes. Series-Parallel switched multilevel DC-Link inverter can be used to reduce the number of components while maintaining the number of levels [3]. Space vector control strategy used for the reduction of torque and current ripple during the steady state and transient conditions [4]. In BLDC motors, 120° and 180° conduction modes are used for low speed and high-speed range respectively [5].

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SEPIC converter has an added advantage of producing non-inverting output voltage compared to other DC-DC converter topologies [6]. SEPIC converter also used for balancing the power between the battery and Photovoltaic System efficiently and has better MPP characteristics compared to other boost converter topologies [7], [8]. The Resonant based SEPIC converter has the capability of achieving maximum efficiency over a wide input and output voltage range by neglecting the load disturbances [9].

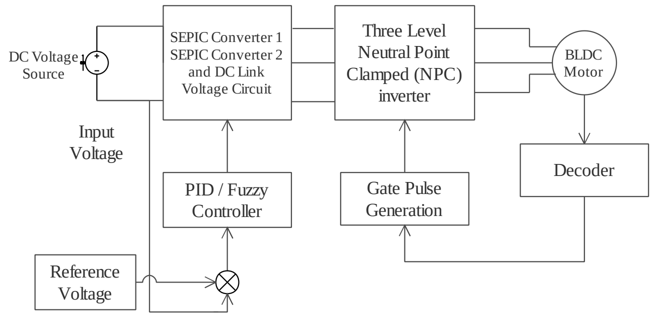

Fig.1 Block diagram of the Proposed NPC based three-level inverter

Two SEPIC converters are connected to the supply voltage of 200V. The input supply voltage is compared with the reference voltage for the generation of an error signal which in turn fed to the PID controller for the generation of gate signals to the switches of SEPIC converter. The parameters such as Stator current, Stator back emf, rotor speed and the electromagnetic torque are obtained from the BLDC motor using Hall Sensor for the generation of the Gate pulses to the switching devices of Three-Level inverter scheme. Replacing the boost converter with the SEPIC converter at the input stage also improves the efficiency and reduces the harmonic content of NPC Multilevel inverter [10]. The optimization and artificial intelligence techniques not only improves the output power gain but also reduces the oscillations around a certain range and reduces system response time [11].

2. Implementation of Proposed System using PID and Fuzzy Logic Control

The proposed system simulation diagram is shown in Figure 2. The subsystem implements the two-SEPIC based converter as shown in Figure 3 that forms the first stage [1], [12]. This converter output is connected to the Neutral Point Clamped Three-level Inverter as in Figure 4 which forms the second stage.

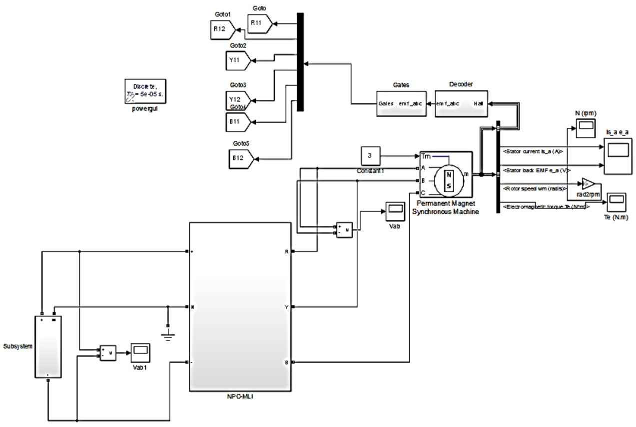

Fig.2 Simulation diagram of the Proposed Two Stage converter scheme for BLDC Motor

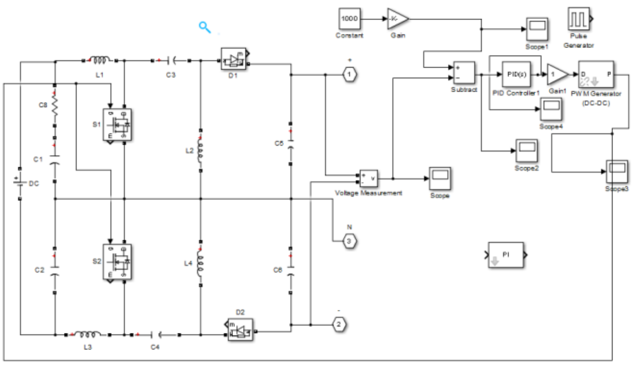

Fig.3 Implementation of Two-SEPIC based converter

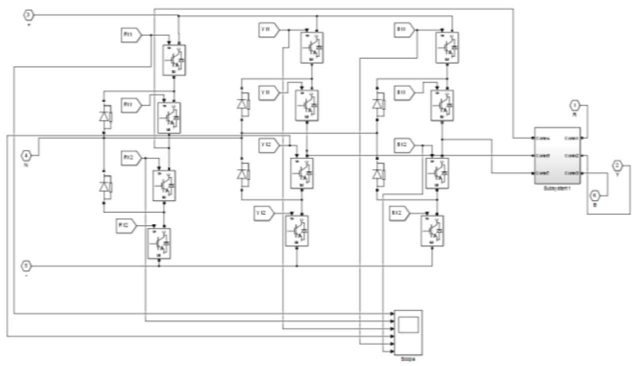

Fig.4 Implementation of NPC based Multilevel Inverter

DC Link voltages of the SEPIC converter are given by

$$V_{o1} = \frac{\delta V_{in}}{2(1-\delta)} \quad (1)$$

$$V_{o2} = \frac{\delta V_{in}}{2(1-\delta)} \quad (2)$$

$$E_m = K_m \omega_m \quad (3)$$

where V_{in} = input DC voltage, δ = Duty ratio, E_m = Back emf, ω_m = Rotor Speed in rad/s, K_m = Motor constant.

The DC bus voltage selector based SEPIC converter used to reduce the torque ripple content during the commutation period. It yields improved efficiency and noise reduction capabilities and reduced switch count [13]. Output current and voltage gets reduced with an increase in the number of levels, and when the number of switches is less, the complexity and size of the system get further reduced [14].

Design of Decoder

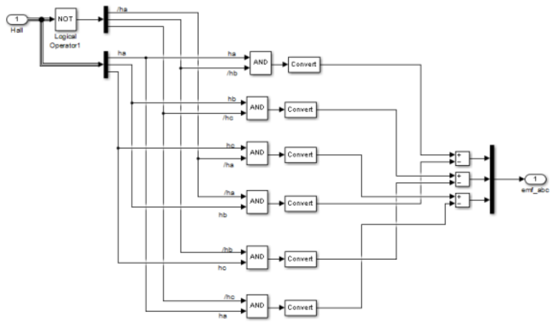

Fig. 5 Design of Decoder using AND and NOT gates

The signal from the Permanent Magnet Synchronous Machine fed to the NOT gate for the generation of three phase signals /ha, /hb and /hc while ha, hb and hc signals are obtained before the NOT logic gate of decoder block as in the Fig.5. The AND function processed between the different signals generates an output signal which in turn processed for the production of emf signals emf_a, emf_b and emf_c respectively and fed to the gate pulse generation block for the generation of gate signals to switches of the multilevel inverter.

ha	hb	hc	emf_a	emf_b	emf_c
0	0	0	0	0	0
0	0	1	0	-1	+1
0	1	0	-1	+1	0
0	1	1	-1	0	+1
1	0	0	+1	0	-1
1	0	1	+1	-1	0
1	1	0	0	+1	-1
1	1	1	0	0	0

Fig. 6 Truth table for Decoder

Figure 6 shows the truth table for the decoder block which uses “NOT” and “AND” gates for the generation of three phase emf signals as in Fig. 5.

Figure 7 shows the gate signal generation for six switches of NPC based Multilevel Inverter. If the input emf “a” value exceeds the value of ‘0’ then ‘Q_1’ transistor is turned ‘ON’ or if emf ‘a’ value is less than ‘0’ then ‘Q_2’ transistor is ‘ON’ and similar process takes place in phase ‘b’ and ‘c’ respectively for the transistors Q_3, Q_4, Q_5 and Q_6 respectively. Figure 8 shows the truth table for the generation of gate pulses for six transistors.

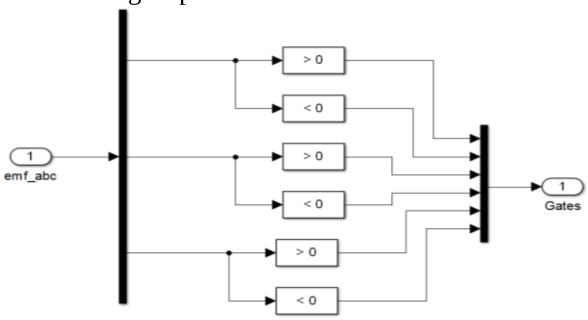

Fig. 7 Gate Pulse Generation from EMF signal

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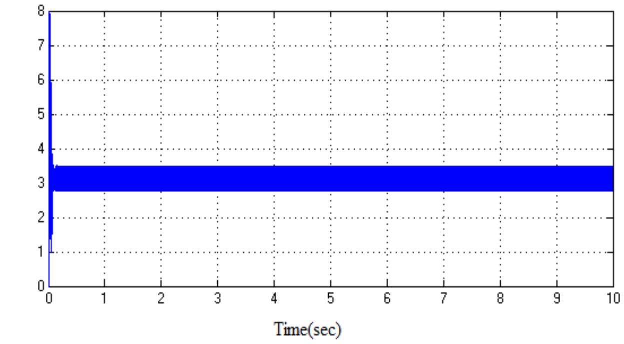
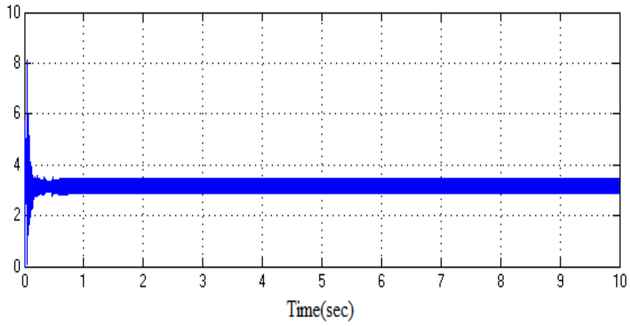
emf_a	emf_b	emf_c	Q1	Q2	Q3	Q4	Q5	Q6
0	0	0	0	0	0	0	0	0
0	-1	+1	0	0	0	1	1	0
-1	+1	0	0	1	1	0	0	0
-1	0	+1	0	1	0	0	1	0
+1	0	-1	1	0	0	0	0	1
+1	-1	0	1	0	0	1	0	0
0	+1	-1	0	0	1	0	0	1
0	0	0	0	0	0	0	0	0

Fig. 8 Truth table for the generation of gate pulses

Torque ripple waveforms:



(a)



(b)

Fig.9 Torque ripple waveform using the (a) PID and (b) Fuzzy Logic Controllers

Fig. 9 shows the torque ripple waveform obtained in the Matlab/Simulink tool using the PID and Fuzzy logic controllers respectively. Thus by using the fuzzy logic controller, the ripple content gets reduced to 18.75%. The settling time obtained at 0.2 seconds.

Ripple Content Calculations:

$$\text{Ripple Factor (\%)} = \frac{V_{ripple}}{V_{dc}} \times 100$$

Here the V_{ripple} represents the ripple voltage and V_{dc} represents the average DC voltage.

From the existing system, the ripple content obtained at 36.4 %. By using the PID controller and the fuzzy logic controller for the proposed configuration yields a ripple content of 31.2 % and 18.75% respectively. The maximum and minimum values of torque obtained at 3.7 and 2.7 N-m respectively. The torque ripple content of PID controller fed NPC three-level inverter achieved at 31.2%. While using a fuzzy logic based controller, the peak maximum and minimum values are at 3.5 and 2.9 N-m resulting in the torque ripple of 18.75 %.

Design of Fuzzy Logic Control

The Fuzzy rule base consists of the two membership functions Error (E) and Change in Error (DE). The membership variables of Error (E) and Change in Error (DE) is given by Negative Change in Error (NCE), Zero Change in Error (ZCE), Positive Change in Error (PCE) and Negative Error (NE), Zero Error (ZE), Positive Error (PE) respectively.

Fuzzy logic control uses the centroid method of defuzzification produces 3 x 3 variables as the output. The output variable 'P' represents the positive; 'N' represents the negative while 'NC' represents No Change as shown in Table 1. The duty ratio is obtained based on the fuzzy rules and based on this the gate terminal gets turned ON and OFF. For the implementation of Fuzzy rules the 'AND' function is used.

CHANGE IN ERROR (de)	**ERROR** (e)		
	NE	**ZE**	**PE**
NCE	N	N	P
ZCE	N	NC	P
PCE	N	P	P

Table 1 Fuzzy rule base & Results

Table 1 represents the fuzzy rule base for nine different combinations. Fig.10 shows the three-dimensional representation of the fuzzy rules used in the proposed system. Change in Error (CE) is the first input while Error (E) is the second input and the output is based on the fuzzy rule base. Both fuzzy logic and neural network controllers yield reduced steady-state error and better performance in comparison with conventional methods as it is insensitive to parameter variations [15]. For industrial and sensitive applications, the fuzzy logic-based BLDC are suitably preferred over the conventional PID based system to deal with the parameter variations [16]. Other methods of defuzzification such as Mean of Maxima, Center of Area, Center of Gravity, Fuzzy Mean, First of Maximum, last of maximum, mean of maxima and middle of maximum are available [17].

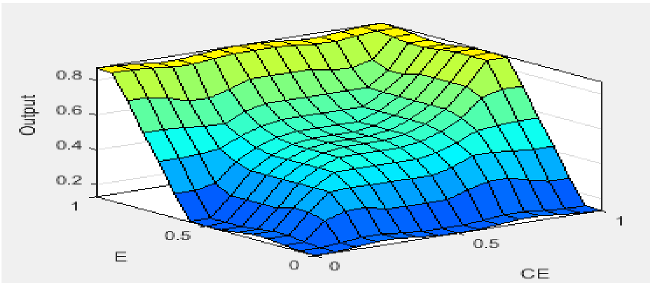
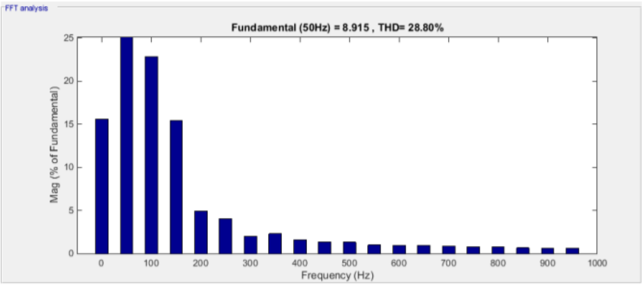


Fig.10 Three Dimensional representation of fuzzy rule base



Total Harmonic Distortion

Fig.11 THD waveform for Stator Current of BLDC Motor using Fuzzy Logic controller

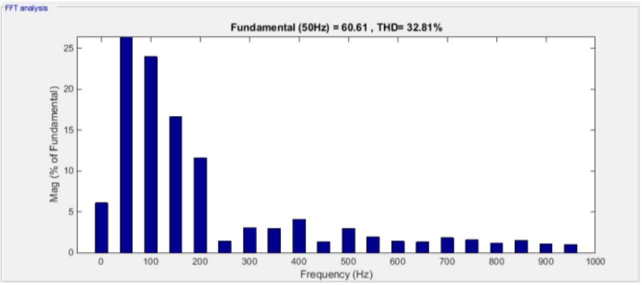


Fig.12 THD waveform for Stator Back EMF of BLDC motor using Fuzzy Logic controller

Figure 11 and 12 shows the harmonic content of the stator current and back emf of the BLDC motor using fuzzy logic controller obtained at 28.8% and 32.8% respectively.

II. CONCLUSION

The Proposed system uses the first stage, i.e. SEPIC converter whose switches are controlled using PID or Fuzzy Logic Controllers while the second stage is controlled using the Hall effect sensor. Considerable reduction in the torque ripple content of BLDC motor up to 18.75 %. The proposed method compared with the existing PI controller having reasonable harmonic content in the stator current and back emf waveforms. The proposed system is suitable for driving sensitive loads.

REFERENCES

1. Viswanathan V and Jeevananthan S, "Approach for torque ripple reduction for brushless DC motor based on three level neutral point clamped inverter with DC - DC converter," IET Power Electronics, January 2015.
2. Ki-Yong Nam, Woo-Taik Lee, Choon-Man Lee, and Jung-Pyo Hong, "Reducing torque ripple of brushless DC motor by varying input voltage," IEEE Transactions on Magnetics, April 2006.
3. S. Ramkumar, V. Kamaraj, S. Thamizharasan, and S. Jeevananthan, "A new series parallel switched multilevel dc-link inverter topology," International Journal of Electrical Power and Energy Systems, 2012.
4. Viswanathan V and Jeevananthan S, "A Novel Space Vector Current Control Method for Commutation Torque Ripple Reduction of Brushless DC Motor Drive," Arabian Journal for Science and Engineering, October 2013.
5. S. S. Bharatkar, R. Yanamshetti, D. Chatterjee, and A. K. Ganguli, "Dual-mode switching technique for reduction of commutation torque ripple of brushless dc motor," IET Electric Power Applications, 2011.
6. J. J. Jozwik and M. K. Kazimierczuk, "Dual sepic PWM switching-mode DC/DC power converter," IEEE Transactions on Industrial Electronics, 1989.
7. Chiang S J, Hsin Jang Shieh, and Ming Chieh Chen, "Modeling and Control of PV Charger System With SEPIC Converter," IEEE Transactions on Industrial Electronics, November 2009.
8. A. H. El Khateb, N. A. Rahim, and J. Selvaraj, "Fuzzy Logic Control Approach of a Maximum Power Point Employing SEPIC Converter for Standalone Photovoltaic System," Procedia Environmental Sciences, 2013.
9. J. Hu, A. D. Sagneri, J. M. Rivas, Y. Han, S. M. Davis, and D. J. Perreault, "High-Frequency Resonant SEPIC Converter With Wide Input and Output Voltage Ranges," IEEE Transactions on Industrial Electronics, January 2012.
10. R. Kumar, S. Kumar, N. Singh, and V. Agrawal, "SEPIC converter with 3-level NPC multi-level inverter for wind energy system (WES)," 4th International Conference on Power, Control & Embedded Systems (ICPCES), 2017.
11. N. Mazouz and A. Midoun, "Control of a DC/DC converter by fuzzy controller for a solar pumping system," International Journal of Electrical Power & Energy Systems, December 2011.
12. T. Shi, Y. Guo, P. Song, and C. Xia, "A New Approach of Minimizing Commutation Torque Ripple for Brushless DC Motor Based on DC–DC Converter," IEEE Transactions on Industrial Electronics, October 2010.
13. V. Viswanathan and J. Seenithangom, "Commutation Torque Ripple Reduction in the BLDC Motor Using Modified SEPIC and Three-Level NPC Inverter," IEEE Transactions on Power Electronics, January 2018.
14. D. Nazarpour, M. Sabahi, R. S. Alishah, and S. H. Hosseini, "New hybrid structure for multilevel inverter with fewer number of components for high-voltage levels," IET Power Electronics, January 2014.
15. B. R. Lin, "Power converter control based on neural and fuzzy methods," Electric Power Systems Research, December 1995.
16. R. Shanmugasundram, K. M. Zakariah, and N. Yadaiah, "Implementation and Performance Analysis of Digital Controllers for Brushless DC Motor Drives," IEEE/ASME Transactions on Mechatronics, February 2014.
17. Hilloowala R M and Sharaf A M, "A rule based fuzzy logic controller for a PWM inverter in a stand alone wind energy conversion scheme," IEEE Transactions on Industry Applications, January 1996.

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