Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY ASEE

A novel active power factor enhancement in hybrid buck dc-dc converter based BLDC drive system using average current follower technique

P. Sarala[1], S. F. Kodad[2], B. Sarvesh[3]

[1,2,3] Department of Electrical & Electronics Engineering
[1]Research Scholar, JNTUA, Ananthpur, A.P, India.
[2]Professor and HOD, PESITM, Sivamogga, Karnataka, India.
Professor, JNTUA, Ananthpur, A.P, India

Abstract: The development of industrial drive applications with active power-factor correction schemes is compulsory to meet the IEEE harmonic standards. The DC motors suffers so many issues due to presence of commutator and regular maintenance, wear-tear of mechanical elements. For this, DC motor is replaced by Brushless DC motor with favourable advantages and plays a vital role in many domestic and industrial applications. This paper proposes the novel PFC technique by interfacing Hybrid-Buck DC-DC converter in between the AC-DC rectifier and BLDC motor drive. The introduced Hybrid-Buck converter provides the improved power-factor at source and maintains DC-link voltage as constant with a high step-down ratio by using average current follower methodology. The critical evaluation of Hybrid-Buck converter fed BLDC motor drive is validated under various DC-link voltages by using Matlab/Simulink tool, illustrate the simulation results.

Keywords: Average Current Follower Technique**,** Brushless DC Motor, Hybrid-Buck Converter, Power-Factor Correction, Total Harmonic Distortion.

1 Introduction

Conventional DC motors suffers from set-back of producing unwanted losses because of presence of commutator. Mechanical commutator along with brush produces sparks due to uneven distribution of current. Though conventional motors have very good performance characteristics, presence of commutator makes to think while DC motor used for industrial applications producing additional losses. Brushless DC (BLDC) motor is an electro-mechanical machine constructed without commutator and brush assembly [1-3]. Electronic commutator senses the rotor position and sends feedback signal to control unit to achieve commutation. Electronic commutation is done using a voltage source converter (VSC) [4-5]. The control circuit produces gate pulses to the voltage source converter and the phase windings of BLDC motor gets excited. VSC and switching assembly together are responsible for producing unidirectional torque in BLDC motors.

Construction of BLDC motor consists of stator and rotor. Stator of BLDC motor consists of set of phase windings wounded on it and rotor consists of permanent magnets. BLDC motor is a synchronous motor with permanent magnets on its rotor with the only difference. Since brush and commutator assembly are eliminated physically, frequent maintenance is not required for BLDC motors. Rotor looks like a smooth cylinder with rotor permanent magnets on it and hence can rotate with high speeds which are very useful in high speed drive applications [6-8]. The basic need of front end converter for BLDC [9-11] might cause power system quality issues and needs to mitigate. Power electronic converter induces non-linearity in to the system and might lower the power factor in the system is the main motive.

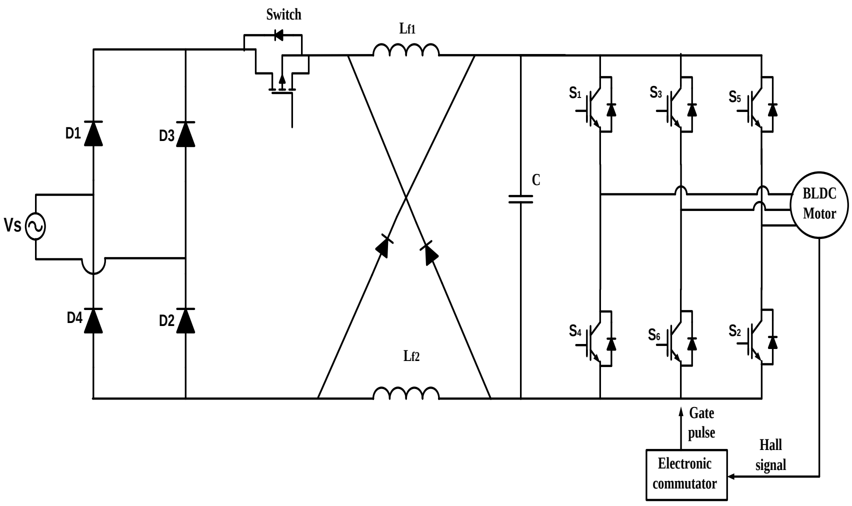


Fig.1 Hybrid Buck Converter as PFC converter for BLDC drive

2 Hybrid Buck DC-DC Converter

Hybrid buck DC-DC converter as power factor improvement (PFC) converter for BLDC drive is shown in Fig.1. The input AC source is converted to DC by using a diode bridge rectifier. Hybrid buck circuit is a DC-DC power electronic converter consisting of a power switch, two inductors, two diodes and a DC-link capacitor. Switch is controlled with a simple control such that power factor correction takes place by maintaining the power factor angle between source voltage and current as close to zero attaining nearer unity power factor. Operating modes of hybrid buck converter is explained below.

2.1 Switch ON Mode

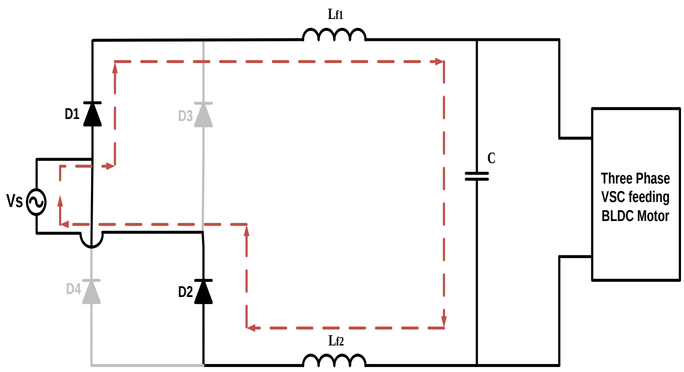


Fig.2 Hybrid Buck Converter in Switch is in ON Mode

The circuit representation and current path in hybrid buck converter is shown in Fig.2. When switch is ON, the source current starts flowing from source - diode D1 - charging inductor Lf1 - capacitor - inductor Lf2 - diode D2 and finally closes at source negative terminal as shown in figure 1. During this mode of operation, capacitor gets charged so also the inductors.

2.2 Switch OFF Mode

Hybrid buck converter when switch is open is shown in Fig.3 and corresponding current path during this mode of operation is also shown. The stored energy in inductors due to operating mode when switch is closed now starts discharging through diodes in hybrid buck converter.

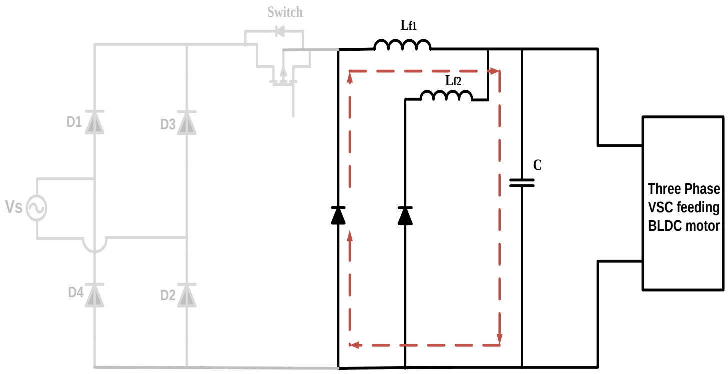


Fig.3 Hybrid Buck Converter in Switch is in OFF Mode

2.3 Zero sequence Mode

Hybrid buck converter operating in zero-sequence mode is shown in figure 4. The stored energy is fed to load from capacitor as no current flows from source. The current flows from capacitor to load only and this mode is said to be zero-sequence mode of operation of hybrid buck converter.

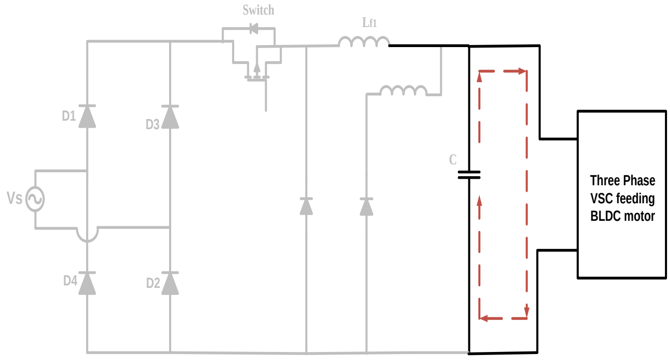


Fig.4 Hybrid Buck Converter in Zero-Sequence Mode

3 Selections of Inductor and Capacitor Elements for Hybrid-Buck Converter

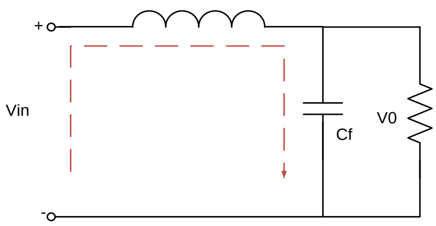
3.1 Sizing of Inductor

When switch is ON

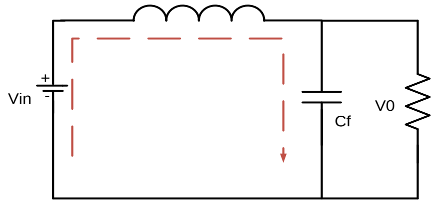
$$V_{in}-V_0=L\frac{di}{dt}$$

Assume di=ΔI, dt=t_1

$$t_1=\frac{\Delta iL}{V_{in}-V_0} \quad (1)$$



When switch is OFF



$$-V_0=L\frac{di}{dt}$$

Assume di=ΔI, dt=t_2

$$t_2=\frac{\Delta IL}{V_0} \quad (2)$$

Equate ΔI in switch ON & switch OFF modes, then we get,

$$\frac{V_{in}-V_0}{L}*t_1=\frac{V_0t_2}{L}$$

Substitute $t_1=DT_S$ & $t_2=(1-D)T_S$

$$V_0=DV_{in} \quad (3)$$

The switching period T can be written as

$$T=\frac{1}{f}=t_1+t_2=\frac{\Delta ILV_{in}}{V_0(V_{in}-V_0)}$$

$$\Delta I=\frac{V_{in}D(1-D)}{fL} \quad (4)$$

For continuous conduction mode

$$\Delta I = 2I_L = 2I_0$$

$$\frac{V_{in}D(1-D)}{fL} = 2*\frac{V_0}{R} =\frac{2DV_{in}}{R} \quad (5)$$

Then the critical inductance is given by

$$L_{critical} = \frac{(1-D)R}{2F} \quad (6)$$

Let us assume, V_{in}= 320v, P = 500W, f = 20 kHz, V_0 = 200

$$D = \frac{V_0}{V_{in}} = \frac{200}{320} = \frac{5}{8} = 0.625$$

$$R = \frac{V_0^2}{P} = \frac{200*200}{500} = 80\Omega$$

$$L_{critical} = \frac{(1-0.625)*80}{2*20*10^3} = \frac{3}{2}*10^3 = 1.5mH$$

For DCM operation

$$L_{operating} = \frac{1}{15}* L_{critical}$$

$$= 0.1mH$$

3.2 Sizing of Capacitor

$$Pin=\sqrt{2}V_{rms}\sin\omega t*\sqrt{2}I_{rms}\sin\omega t$$

$$Pin=V_{rms}*I_{rms}[1-\cos 2\omega t] \quad (6)$$

From the above equation (6) the instantaneous capacitor power is

$$V_{dc}*i_c(t)= - V_{rms}*I_{rms}\cos 2\omega t$$

The DC link voltage ripple can be expressed as

$$\Delta V_{dc}=\frac{1}{c}\int i_c(t)dt = \frac{-I_d}{2\omega c}*\sin 2\omega t \quad (7)$$

From (7) the peak ripple can be expressed as

Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

$$C_d = \frac{I_0}{2\omega\Delta V_{dc}}$$

Where

$$I_0 = \frac{P}{V_0} = \frac{500}{200} = 2.5A$$

We know, voltage ripple (ΔV_{dc}) is 1.5V and substitute I_0, ΔV_{dc} values in C_d

$$C_d = \frac{2.5}{2*314*1.5} = 2653\mu F$$

Therefore, the nearest capacitor value is 3000μF

4 Hybrid-Buck Converter with Simple Average Current Follower Technique

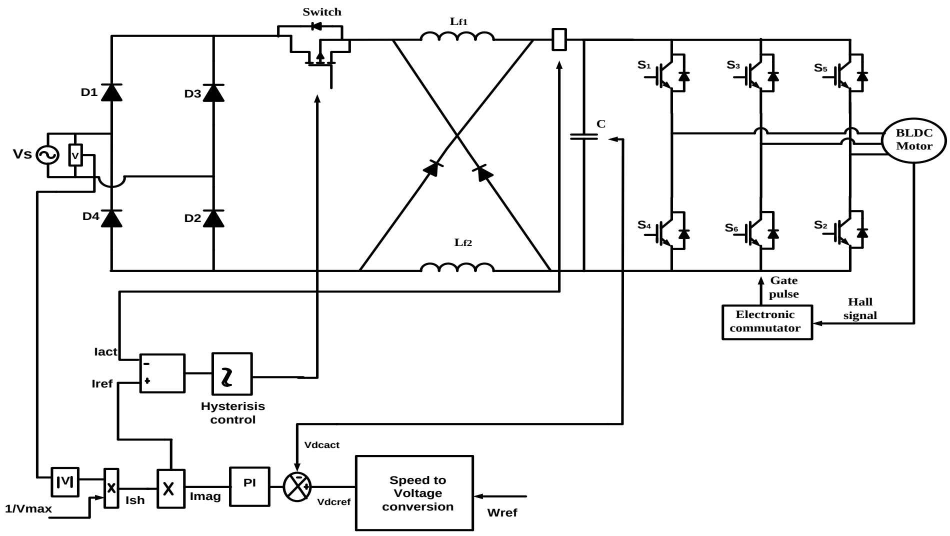


Fig.5 Hybrid Buck Converter with Average Current Follower Technique

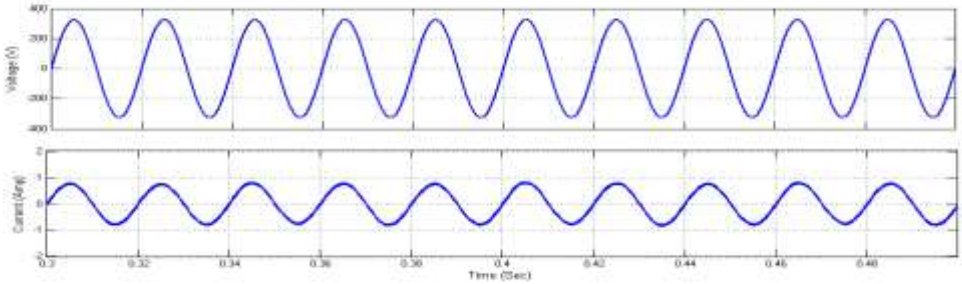
Hybrid buck converter as power factor correction converter for BLDC motor drive operated with simple current control strategy was shown in Fig.5. Reference speed signal is converted to voltage type of signal to produce reference DC voltage signal using speed to voltage conversion. DC voltage is observed from capacitor and contrasted to reference value. Slip in DC voltage is sent to PI controller yielding current signal. From the actual voltage signal, current shape is obtained and the same is multiplied to current magnitude to obtain current reference signal. Actual current from the line is measured and is compared with reference current signal and the error is fed to hysteresis current controller to produce pulses for switch in hybrid buck converter. These pulses produced turns ON and OFF the switch in hybrid buck converter.

5 Simulation Results & Discussion

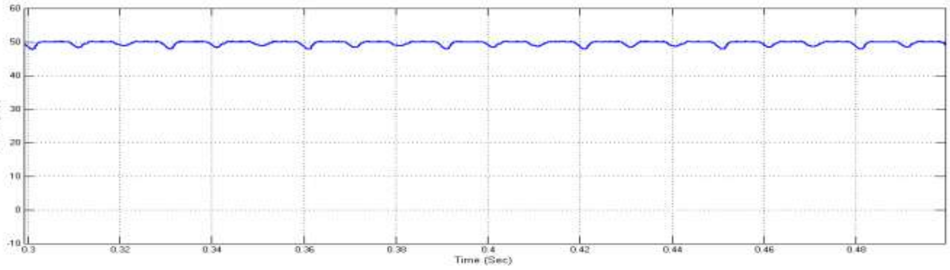
Simulation models were built using MATLAB/SIMULINK software and results were obtained for the different conditions of DC-link voltages.

Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316

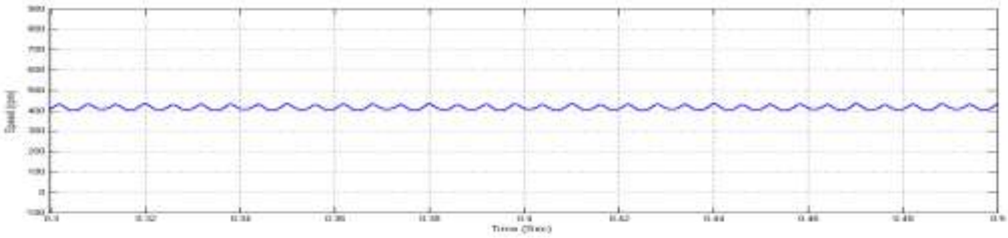
5.1 DC-Link Voltage is 50 V



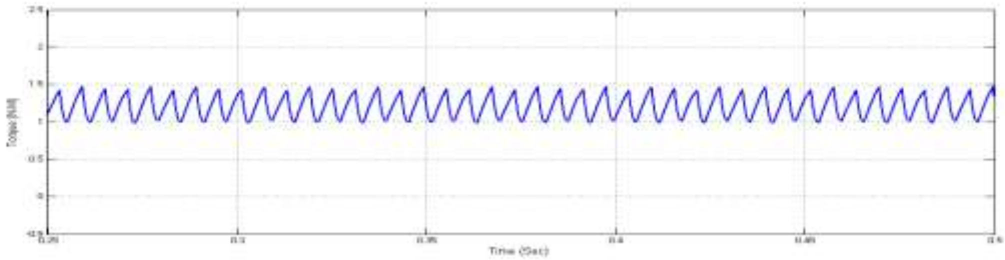
(a) Source Voltage & Current



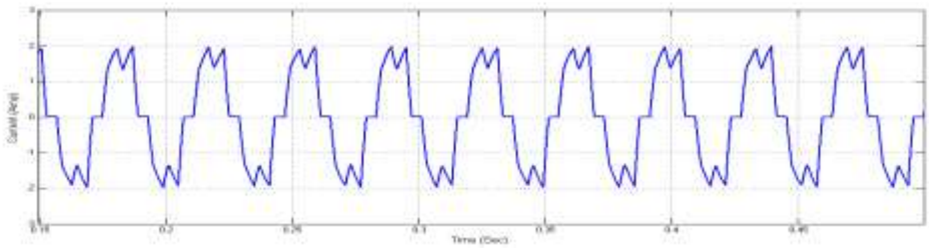
(b) DC-Link Voltage



(c) Speed of BLDC

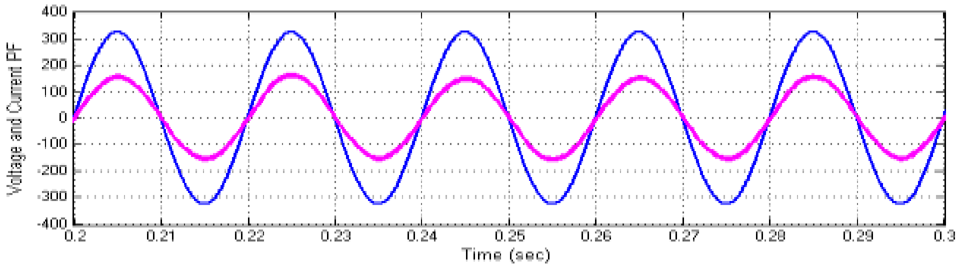


(d) Torque of BLDC

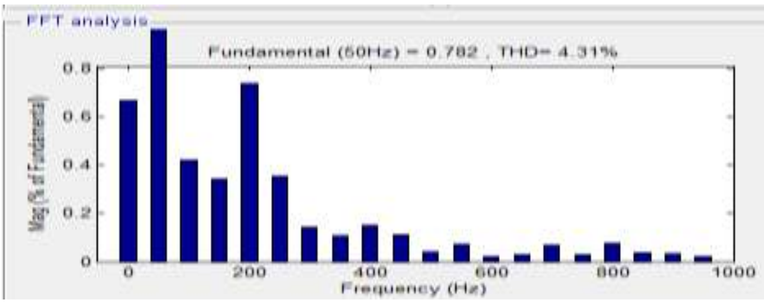


(e) Stator Currents of BLDC

Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY



(f) Power Factor Angle Between Source Voltage and Source Current

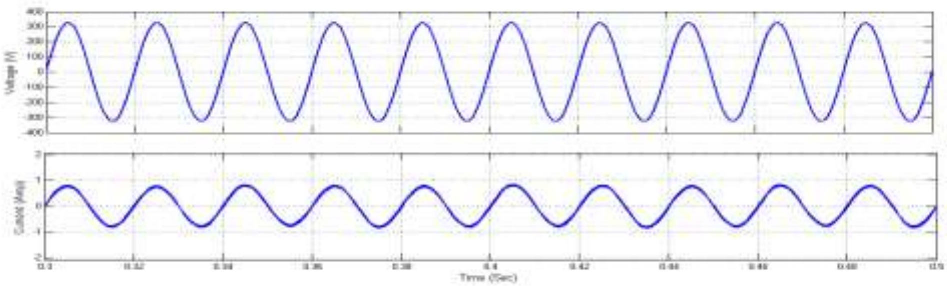


(g) THD of Source Current

Fig.6 Simulation Outcomes of Proposed Hybrid-Buck Converter based BLDC Drive under Reference DC-link Voltage as 50V

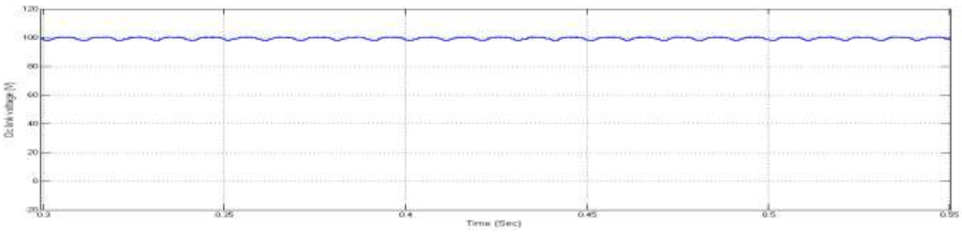
The Fig.6 shows the simulation outcomes of proposed hybrid-buck converter based BLDC drive under reference dc-link voltage as 50V. It shows the, (a) Source voltage & Current, (b) DC-link voltage, (c) Speed of BLDC, (d) Torque of BLDC, (e) Stator Currents of BLDC, (f) Power Factor Angle between Source Voltage and Source Current, (g) THD in Source Current. The voltage and current of main sinusoidal supply system to which BLDC motor drive is driven by hybrid-buck DC-DC converter and controlled by proposed average current follower technique. The sinusoidal source voltage is maintained at 360V and current at 0.8A, DC link voltage is maintained as constant with a reference voltage as 50V. With this DC link voltage, BLDC motor runs at 400 RPM with a constant speed and the torque produced in BLDC motor with DC link voltage of 50V is 1.5 N-m, small torque ripples are present as observed in waveform. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents. The angle between source voltage and current are represented as power-factor, based on phase angle between these wave-shapes is close to zero and thus indicates the power factor is maintained at nearer unity with DC link voltage of 50V. the harmonic distortion of source current should be less conveys that the power quality with good power factor is achieved and the source current THD is 4.31% which is well within acceptable limits.

5.2 DC-Link Voltage is 100 V

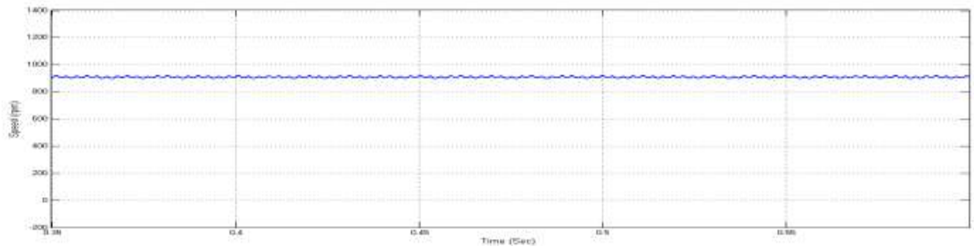


(a) Source Voltage and Current

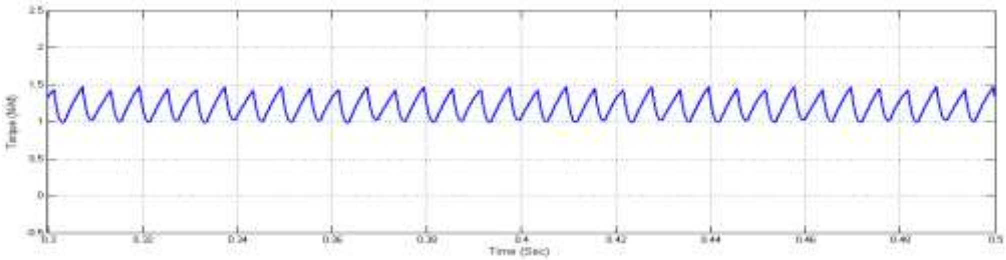
Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY



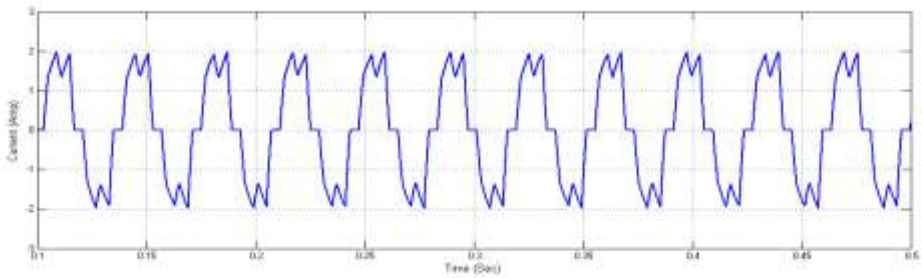
(b) DC-Link Voltage



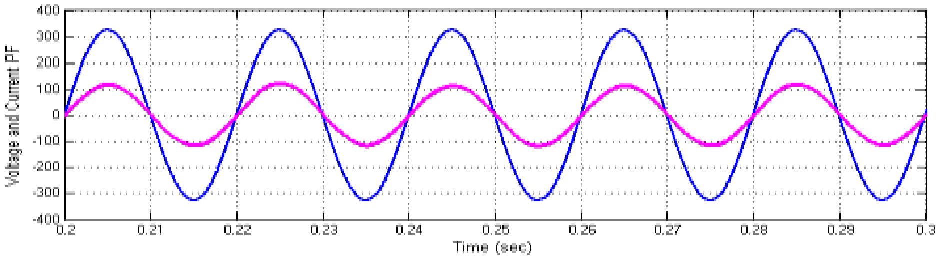
(c) Speed of BLDC



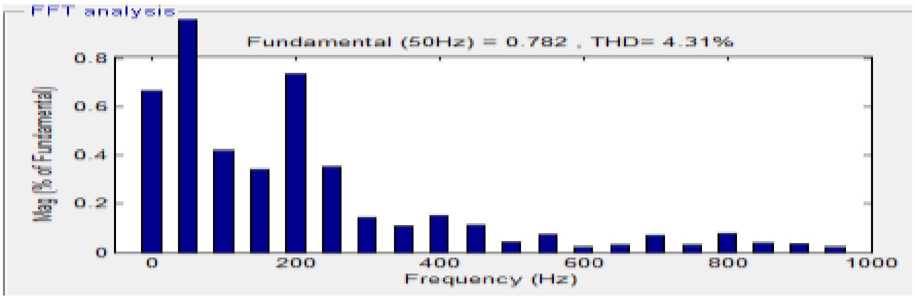
(d) Torque of BLDC



(e) Stator Currents of BLDC



(f) Power Factor Angle Between Source Voltage and Source Current

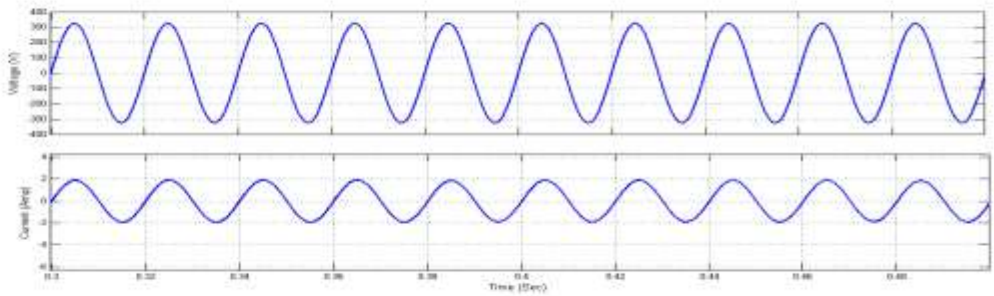


(g) THD of Source Current

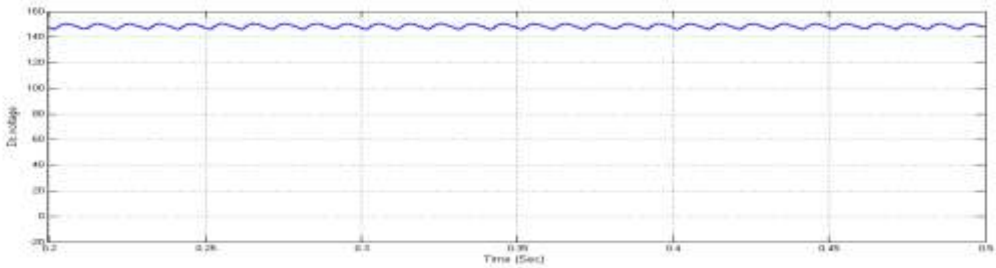
Fig.7 Simulation Outcomes of Proposed Hybrid-Buck Converter based BLDC Drive under Reference DC-link Voltage as 100V

The Fig.7 shows the simulation outcomes of proposed hybrid-buck converter based BLDC drive under reference dc-link voltage as 100V. It shows the, (a) Source voltage & Current, (b) DC-link voltage, (c) Speed of BLDC, (d) Torque of BLDC, (e) Stator Currents of BLDC, (f) Power Factor Angle between Source Voltage and Source Current, (g) THD in Source Current. The voltage and current of main sinusoidal supply system to which BLDC motor drive is driven by hybrid-buck DC-DC converter and controlled by proposed average current follower technique. The sinusoidal source voltage is maintained at 340V and current at 1A, DC link voltage is maintained as constant with a reference voltage as 100V. With this DC link voltage, BLDC motor runs at 900 RPM with a constant speed and the torque produced in BLDC motor with DC link voltage of 100V is 1.5 N-m, small torque ripples are present as observed in waveform. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents. The angle between source voltage and current are represented as power-factor, based on phase angle between these wave-shapes is close to zero and thus indicates the power factor is maintained at nearer unity with DC link voltage of 100V. the harmonic distortion in source current should be less conveys that the power quality with good power factor is achieved and the source current THD is 4.31% which is well within acceptable limits.

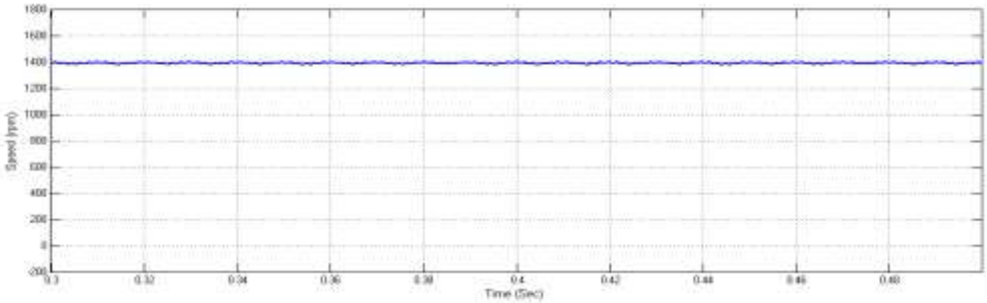
5.3 DC-Link Voltage is 150 V



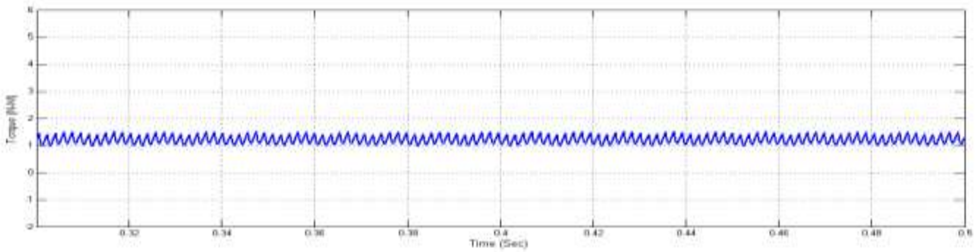
(a) Source Voltage and Current



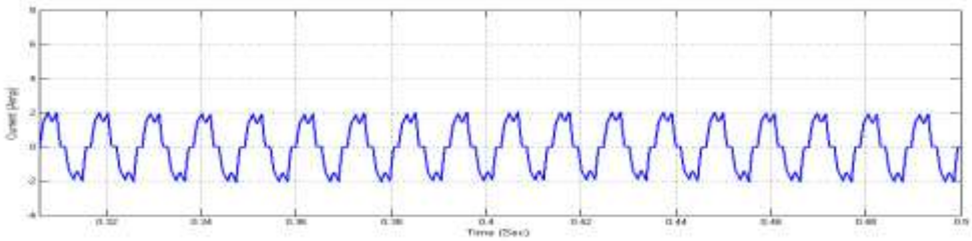
(b) DC-link Voltage



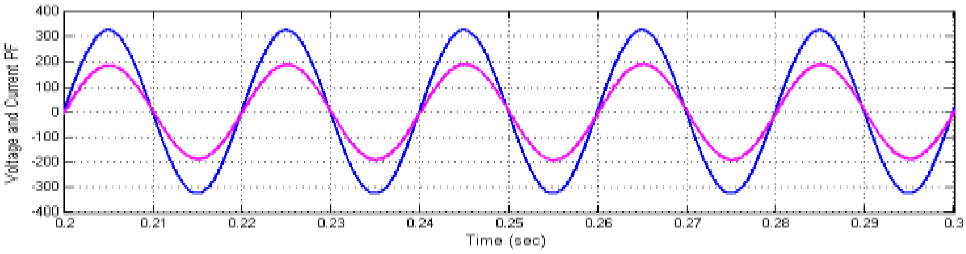
(c) Speed of BLDC



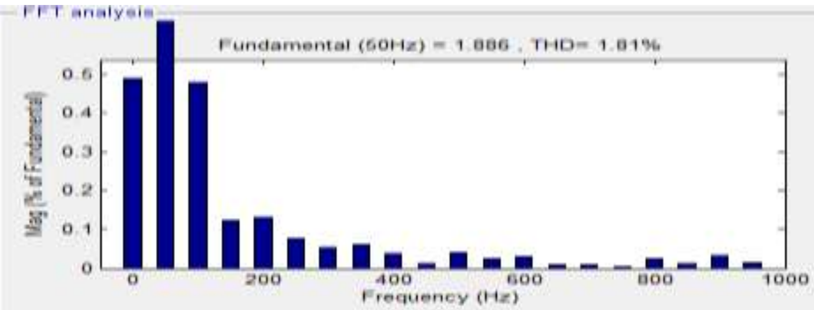
(d) Torque of BLDC



(e) Stator Currents of BLDC



(f) Power Factor Angle Between Source Voltage and Source Current



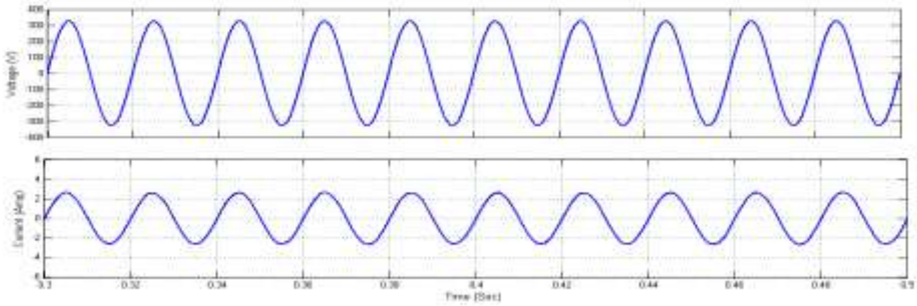
(g) THD of Source Current

Fig.8 Simulation Outcomes of Proposed Hybrid-Buck Converter based BLDC Drive under Reference DC-link Voltage as 150V

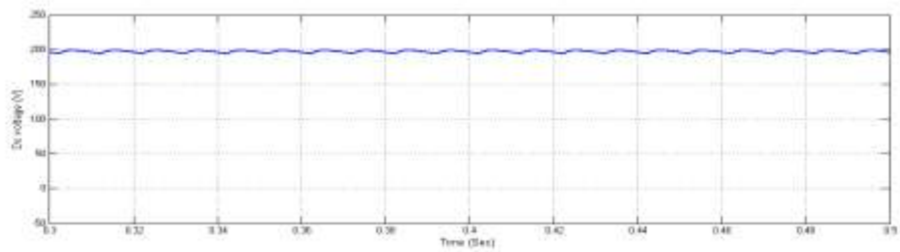
Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

The Fig.8 shows the simulation outcomes of proposed hybrid-buck converter based BLDC drive under reference dc-link voltage as 150V. It shows the, (a) Source voltage & Current, (b) DC-link voltage, (c) Speed of BLDC, (d) Torque of BLDC, (e) Stator Currents of BLDC, (f) Power Factor Angle between Source Voltage and Source Current, (g) THD in Source Current. The voltage and current of main sinusoidal supply system to which BLDC motor drive is driven by hybrid-buck DC-DC converter and controlled by proposed average current follower technique. The sinusoidal source voltage is maintained at 340V and current at 1A, DC link voltage is maintained as constant with a reference voltage as 150V. With this DC link voltage, BLDC motor runs at 1400 RPM with a constant speed and the torque produced in BLDC motor with DC link voltage of 150V is 1.5 N-m, small torque ripples are present as observed in waveform. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents. The angle between source voltage and current are represented as power-factor, based on phase angle between these wave-shapes is close to zero and thus indicates the power factor is maintained at nearer unity with DC link voltage of 150V. the harmonic distortion in source current should be less conveys that the power quality with good power factor is achieved and the source current THD is 1.81% which is well within acceptable limits.

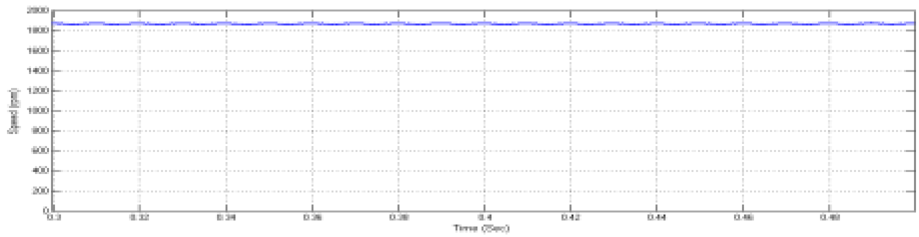
5.4 DC-link Voltage is 200 V



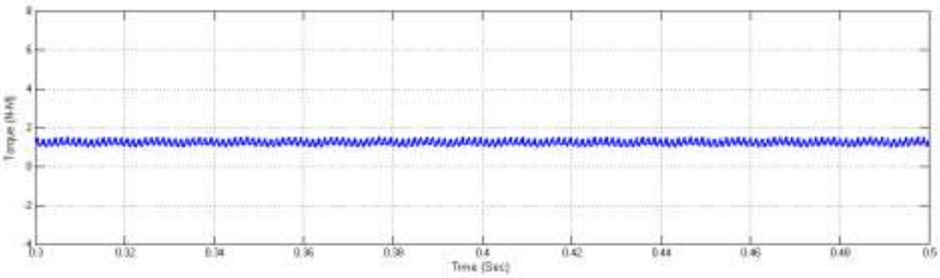
(a) Source Voltage and Current



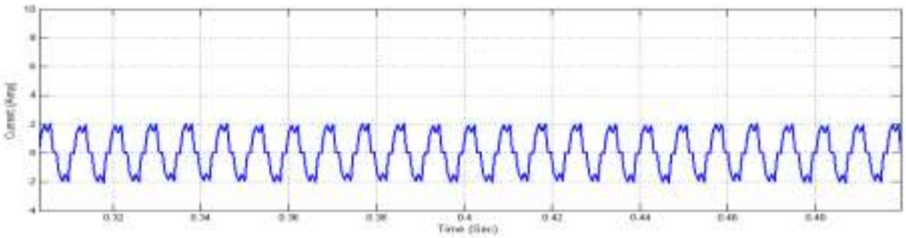
(b) DC-Link Voltage



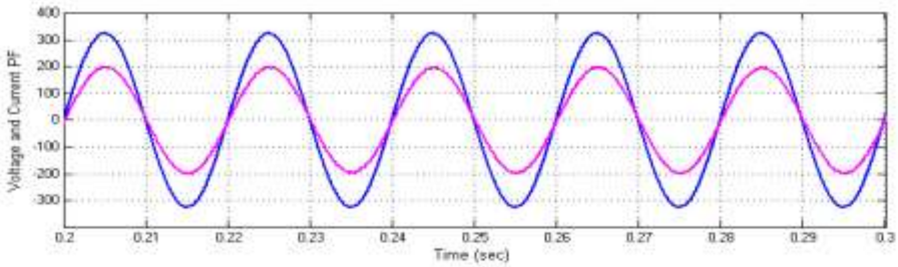
(c) Speed of BLDC



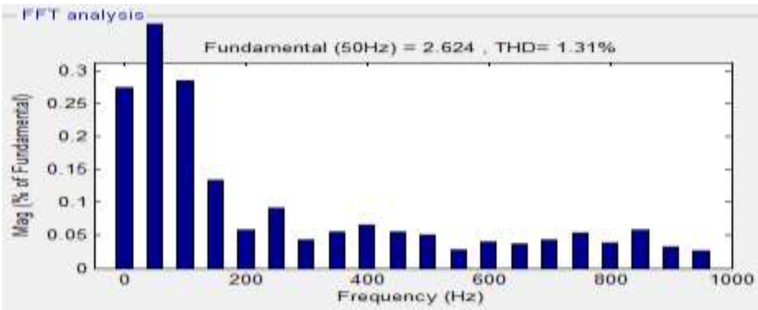
(d) Torque of BLDC



(e) Stator currents of BLDC



(f) Power Factor Angle Between Source Voltage and Source Current



(g) THD in source current

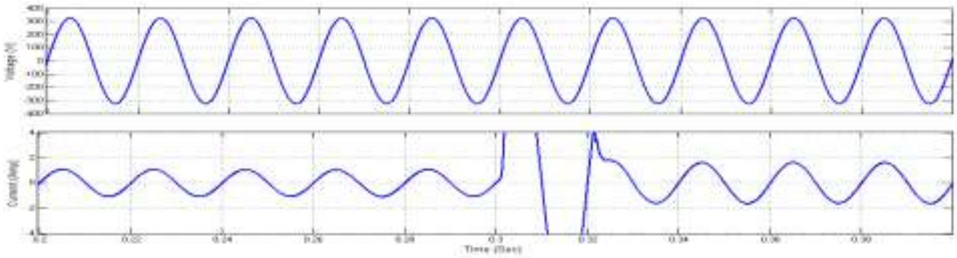
Fig.9 Simulation Outcomes of Proposed Hybrid-Buck Converter based BLDC Drive under Reference DC-link Voltage as 200V

The Fig.9 shows the simulation outcomes of proposed hybrid-buck converter based BLDC drive under reference dc-link voltage as 200V. It shows the, (a) Source voltage & Current, (b) DC-link voltage, (c) Speed of BLDC, (d) Torque of BLDC, (e) Stator Currents of BLDC, (f) Power Factor Angle between Source Voltage and Source Current, (g) THD in Source Current. The voltage and current of main sinusoidal supply system to which BLDC motor drive is driven by hybrid-buck DC-DC converter and controlled by proposed average current follower technique. The sinusoidal source voltage is maintained at 340V and current at 1.2 A, DC link voltage is maintained as constant with a

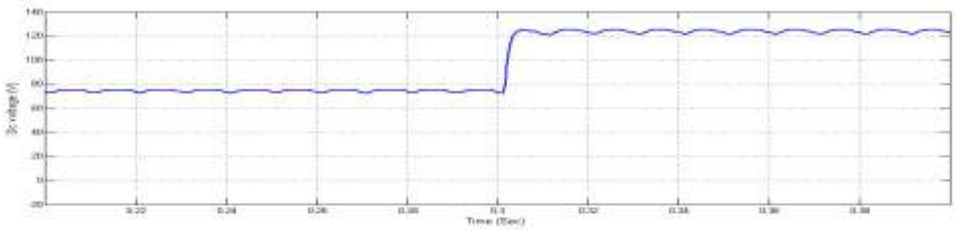
Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY

reference voltage as 200V. With this DC link voltage, BLDC motor runs at 1900 RPM with a constant speed and the torque produced in BLDC motor with DC link voltage of 200V is 1.6 N-m, small torque ripples are present as observed in waveform. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents. The angle between source voltage and current are represented as power-factor, based on phase angle between these wave-shapes is close to zero and thus indicates the power factor is maintained at nearer unity with DC link voltage of 200V. the harmonic distortion in source current should be less conveys that the power quality with good power factor is achieved and the source current THD is 1.31% which is well within acceptable limits.

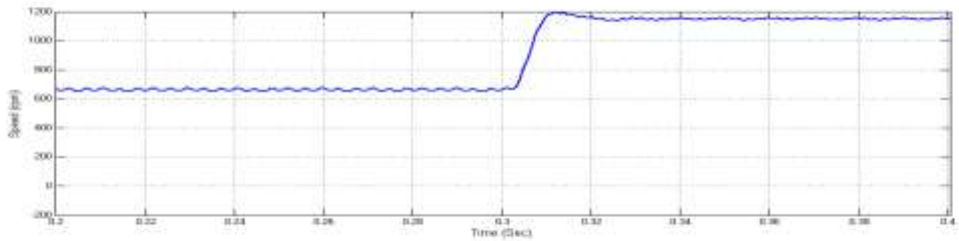
5.5 Variable DC-Link Voltage



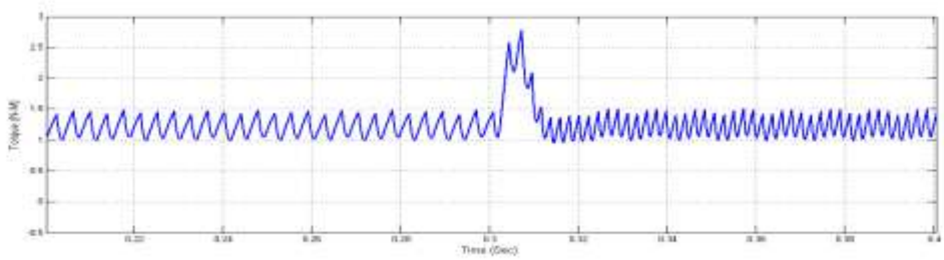
(a) Source Voltage and Current



(b) DC-Link voltage

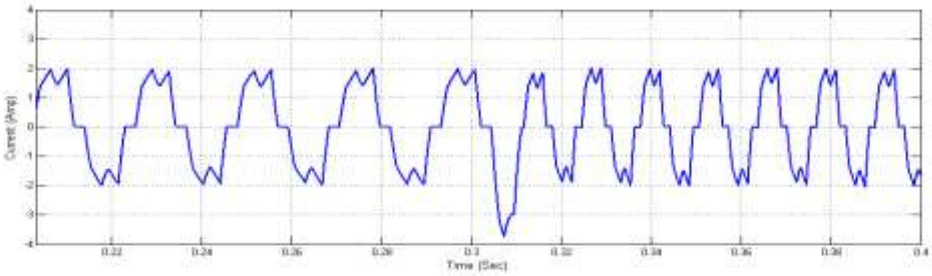


(c) Speed of BLDC

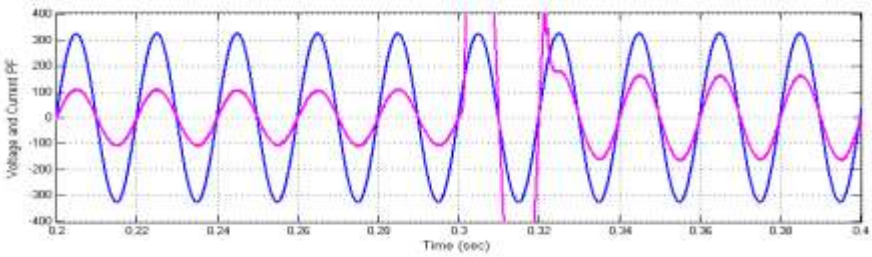


(d) Torque of BLDC

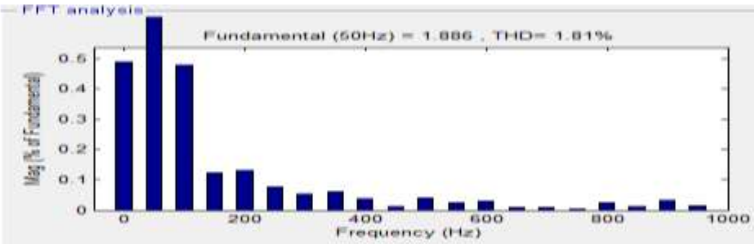
Journal of Engineering Technology
Volume 6, Issue 2, July. 2018, PP. 301-316
RESEARCH ARTICLE -ENGINEERNG TECHNOLOGY ASEE



(e) Stator Currents of BLDC



(f) Power Factor Angle Between Source Voltage and Source Current



(g) THD of Source Current

Fig.10 Simulation Outcomes of Proposed Hybrid-Buck Converter based BLDC Drive under Variable Reference DC-link Voltage as 80V to 120V

The Fig.10 shows the simulation outcomes of proposed hybrid-buck converter based BLDC drive under variable reference dc-link voltage as 80V to 120V. It shows the, (a) Source voltage & Current, (b) DC-link voltage, (c) Speed of BLDC, (d) Torque of BLDC, (e) Stator Currents of BLDC, (f) Power Factor Angle between Source Voltage and Source Current, (g) THD in Source Current. The voltage and current of main sinusoidal supply system to which BLDC motor drive is driven by hybrid-buck DC-DC converter and controlled by proposed average current follower technique. The sinusoidal source voltage is maintained at 340V and current at 1.6 A, DC link voltage is varied with a reference voltage of 80V to 120V at a time instant of 0.3 sec. With this variable DC link voltage, BLDC motor speed also varies with respect to DC-link voltage at a time instant of 0.3 sec as 650 rpm to 1200 rpm and the torque produced in BLDC motor with variable DC link voltage of 80V to 120V is 1.6 N-m, the torque of BLDC motor is maintained constant under variable DC-link and load achievement is possible under several variations in DC-link voltage. As stator windings of BLDC are of non-linear nature, non-linear currents are observed in stator currents with respect to variations in DC-link voltage, stator current also slightly affected. The angle between source voltage and current are represented as power-factor, based on phase angle between these wave-shapes is close to zero and thus indicates the power factor is maintained at nearer unity under variable DC link voltage condition. The harmonic distortion in source current should be less conveys that the power quality with good power factor is achieved and the source current THD is 1.81%% which is well within acceptable limits under variations in DC-link voltage.

6 Conclusion

Due to constructional advantages of BLDC motor, it is widely used in many applications. Only stator will have windings and due to absence of windings in rotor part, BLDC motor can be employed in high speed drives. Need of front end converters for BLDC motor drive disturbs the power quality and compensation of power factor is necessary. This paper depicts the use of hybrid buck DC-DC converter as power factor improvement converter in BLDC motor drive applications. Modes of operation of hybrid buck converter were explained and the simple current control scheme to trigger power switch in hybrid buck converter was explained. Design of inductor and capacitors in hybrid buck converter was discussed. Hybrid buck converter controlled with current follower technique as power factor improvement converter in BLDC drive is validated with different conditions of DC link voltages. Also the same was validated with variable DC link voltage. THD is shown for all cases and is maintained within limits. Power factor angle of voltage and current is shown for every case which validates hybrid buck converter as power factor correction converter. The further recommendation is carried on novel high-voltage step-down converters for enhancing power-quality features by using advanced intelligent controllers.

References

[1] B. Singh et al., “A review of single-phase improved power quality AC–DC converters,” IEEE Trans. Ind. Electron., vol. 50, no. 5, pp. 962–981, Oct. 2003

[2] Singh, S. Singh, A. Chandra, and K. Al-Haddad, “Comprehensive study of single-phase AC–DC power factor corrected converters with high frequency isolation,” IEEE Trans. Ind. Informat., vol. 7, no. 4, pp. 540–556, Nov. 2011.

[3] G. Moschopoulos and P. Jain, “A novel single-phase soft-switched rectifier with unity power factor and minimal component count,” IEEE Trans. Ind. Electron., vol. 51, no. 3, pp. 566–576, Jun. 2004

[4] V. Ramesh, Y. Kusuma Latha, “Soft Switching Of Interleaved Boost Converter Fed PMBLDC Motor Using PI and Fuzzy Controllers,” Journal of Electrical Engineering, Volume 16, Edition : 2, 2016, pp 282-292.

[5] Pragsen Pillay and R. Krishnan, “Modeling, simulation and analysis of permanent-magnet motor drives The brushless DC motor drive”, IEEE Transactions on Industrial Electronics, vol.25,no. 2, pp. 274 – 279, Mar/Apr 1989.

[6] D. Chandra Sekhar and G.V. Marutheshwar, “Modeling and Direct Torque Control of Induction Motor by Using Fuzzy Logic Control Technique”, Journal of Electrical Engineering, Vol-15/2015.

[7] Raja Siti Nur Adiimah Raja Aris, “Enhancement of Variable Speed Brushless DC Motor using Neural Network,” Indian Journal of Science and Technology, Volume 9, Issue 14, April 2016.

[8] Hong W, Lee W, Lee BK. Dynamic simulation of Brushless DC motor drives considering phase commutation for automotive applications. Proceedings of the IEEE Electric Machines and Drives Conference; Antalya, Turkey, 2007 May 3-5. p. 1377–83.

[9] V. Ramesh, Y. Kusuma Latha, "An Interleaved Boost Converter Based PFC Control Strategy for BLDC motor," International Journal of Electrical and Computer Engineering (IJECE) Vol. 5, No. 5, October 2015, pp. 957~966.
[10] Ivan V. Abramov et al., "Control and Diagnostic Model of Brushless DC Motor," Journal of Electrical Engineering, The Journal of Slovak University of Technology, Volume 65, Issue 5 (Sep 2014).
[11] P. K. Singh, B. Singh and V. Bist, "PFC converter based power quality improvement and ripple current minimization in BLDC motor drive," 2016 IEEE 6th International Conference on Power Systems (ICPS), New Delhi, India, 2016, pp. 1-6.
[12] B. Singh and V. Bist, "A PFC based switched-capacitor buck-boost converter fed BLDC motor drive," 2013 Annual IEEE India Conference (INDICON), Mumbai, 2013, pp. 1-6.
[13] Narasimham PVRL et al., "Novel low cost converter topologies to drive spindle motor at high speed with high starting torque," Journal of Electrical Engineering, pp 1-9.