



# Adaptive Variable Speed Control Scheme for Wind Based on PFC of BLDC Drive Applications

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## ABSTRACT

*The wind turbine acts as a prime-mover for doubly fed BLDC generator. To make the system stable, proper monitoring is required or sometimes an auxiliary system can also be a good option, which can support the primary system during undesirable conditions. The simulation results show a significant enhancement in shortening development time and improving dynamic performance of the BLDC motor compared to the conventional speed control of BLDC motor drive. The wind turbine acts as a prime-mover for doubly fed BLDC generator. The three phase BLDC motor has wide applications in industries due to its rugged construction, efficiency and low cost. Neutral point clamped is used for estimation of feedback controller parameters for three phase BLDC motor fed from wind turbine. Neutral point clamped offers certain advantages such as simple steps. The PFC BL-Luo converter has been designed to operate in DICM and to act as an inherent power factor pre-regulator. An electronic commutation of the BLDC motor has been used which utilizes a low-frequency operation of VSI for reduced switching losses. The simulation results show a significant enhancement in variable industrial applications and improving dynamic performance of the BLDC motor compared to the conventional speed control of BLDC motor drive. The proposed concept can be implemented to adaptive variable speed control scheme for wind energy based BLDC motor using Matlab/Simulink software*

**KEYWORDS:** Bridgeless Luo (BL-Luo) converter, brushless dc (BLDC) motor, power factor correction (PFC), power quality, voltage source inverter (VSI).

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## I. INTRODUCTION

Since 1980's a new plan idea of changeless magnet brushless engines has been created. The Changeless magnet brushless engines are ordered into two sorts based upon the back EMF waveform, brushless Air conditioning (BLAC) and brushless DC (BLDC) engines [1-2]. BLDC engine has trapezoidal back EMF and semi rectangular current waveform. BLDC engines are quickly getting to be well known in businesses, for example, Appliances, HVAC industry, restorative, electric footing, car, airplanes, military gear, hard plate drive, mechanical computerization gear and instrumentation due to their high effectiveness, high power element, noiseless operation, minimized, dependability and low support [3-5]. To

supplant the capacity of commutators and brushes, the BLDC engine requires an inverter and a position sensor that distinguishes rotor position for legitimate substitution of current. The revolution of the BLDC engine is in light of the criticism of rotor position which is gotten from the corridor sensors [6]. BLDC engine ordinarily employments three lobby sensors for deciding the recompense Grouping. In BLDC engine the force misfortunes are in the stator where warmth can be effectively exchanged through the edge or cooling frameworks are utilized as a part of expansive machines [7-8]. BLDC engines have numerous focal points over DC engines and prompting engines. A percentage of the favorable circumstances are better speed versus torque qualities, high element reaction, high proficiency,

long working life, quiet operation; higher pace ranges [9]. Up to now, more than 80% of the controllers are PI (Relative and vital) controllers on the grounds that they are effortless and straightforward. The velocity controllers are the routine PI controllers and current controllers are the P controllers to accomplish superior commute [10]. Can be considered as scientific hypothesis joining multi esteemed rationale, likelihood hypothesis, and counterfeit consciousness to recreate the human approach in the arrangement of different issues by utilizing an estimated thinking to relate diverse information sets and to make choices [11]. It has been accounted for that fluffy controllers are more powerful to plant parameter changes than traditional PI or controllers and have better clamor dismissal capacities [12].

This paper presents a BL Luo converterfed BLDC motor drive with variable dc link voltage of VSI for improved power quality at ac mains with reduced components and superior control [13].

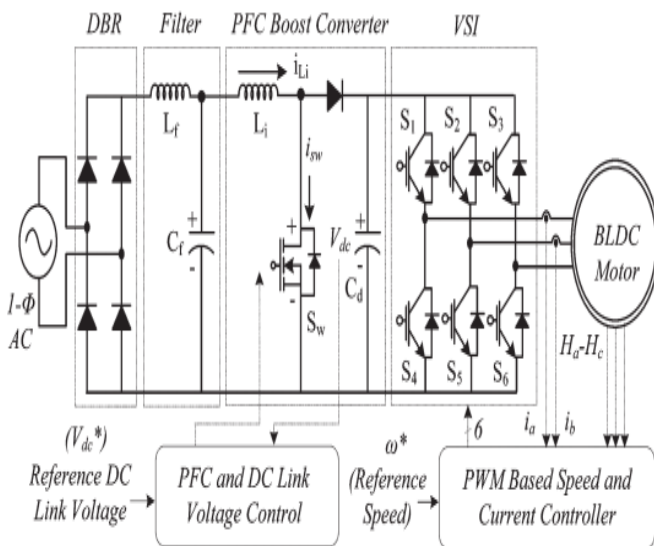


Fig. 1. Conventional PFC-based BLDC motor drive.

## II. PROPOSED PFC-BASED BLDC MOTOR DRIVE

Fig. 2 shows the proposed PFC-based bridgeless Luo (BL-Luo) converter-fed BLDC motor drive. A single phase supply followed by a filter and a BL-Luo converter is used to feed a VSI driving a BLDC motor. The BL-Luo converter is designed to operate in DICM to act as an inherent power factor preregulator. The speed of the BLDC motor is controlled by adjusting the dc-link voltage of VSI using a single voltage sensor. This allows VSI to operate at fundamental frequency switching (i.e., electronic commutation of the BLDC motor) and hence has low switching losses in it, which are

considerably high in a PWM-based VSI feeding a BLDC motor. The proposed scheme is designed, and its performance is simulated for achieving an improved power quality at ac mains for a wide range of speed control and supply voltage variations. Finally, the simulated performance of the proposed drive is validated with test resultson a developed prototype of the drive.

## III. OPERATING PRINCIPLE OF PFC BL-LUO CONVERTER

The operation of the proposed PFC BL-Luo converter is classified into two parts which include the operation during the positive and negative half cycles of supply voltage [see Fig. 3(a)–(c) and (d)–(f)] and during the complete switching cycle.

### A. Operation during Positive and Negative Half Cycles of Supply Voltage

Fig. 3(a)–(c) and (d)–(f) shows the operation of the PFC BL-Luo converter for positive and negative half cycles of supply voltage, respectively. The bridgeless converter is designed such that two different switches operate for positive and negative half cycles of supply voltages. As shown in Fig. 5(a), switch Sw1, inductors Li1 and Lo1, and diodes Dp and Dp1 conduct during the positive half cycle of supply voltage. In a similar manner, switch Sw2, inductors Li2 and Lo2, and diodes Dn and Dn1 conduct during the negative half cycle of supply voltage as shown in Fig. 5(d). Fig. 6(a) shows the associated waveforms demonstrating the variation of different parameters such as supply voltage (vs), discontinuous input inductor currents (iLi1 and iLi2), output inductor current (iLo1 and iLo2), and the intermediate capacitor's voltage (VC1 and VC2) during the complete cycle of supply voltage.

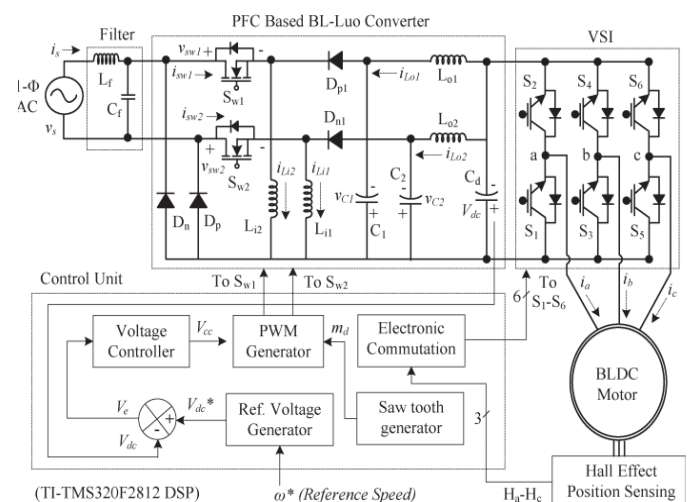
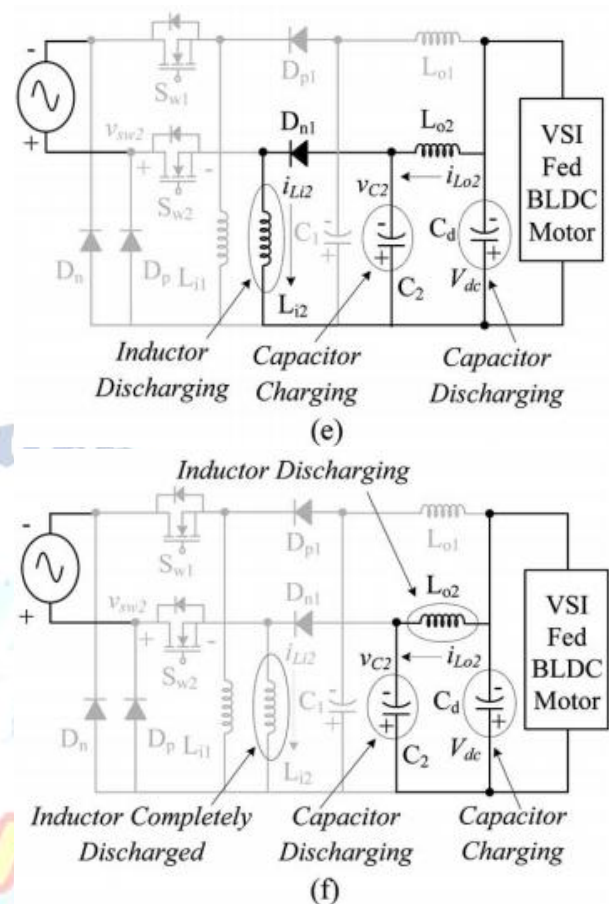
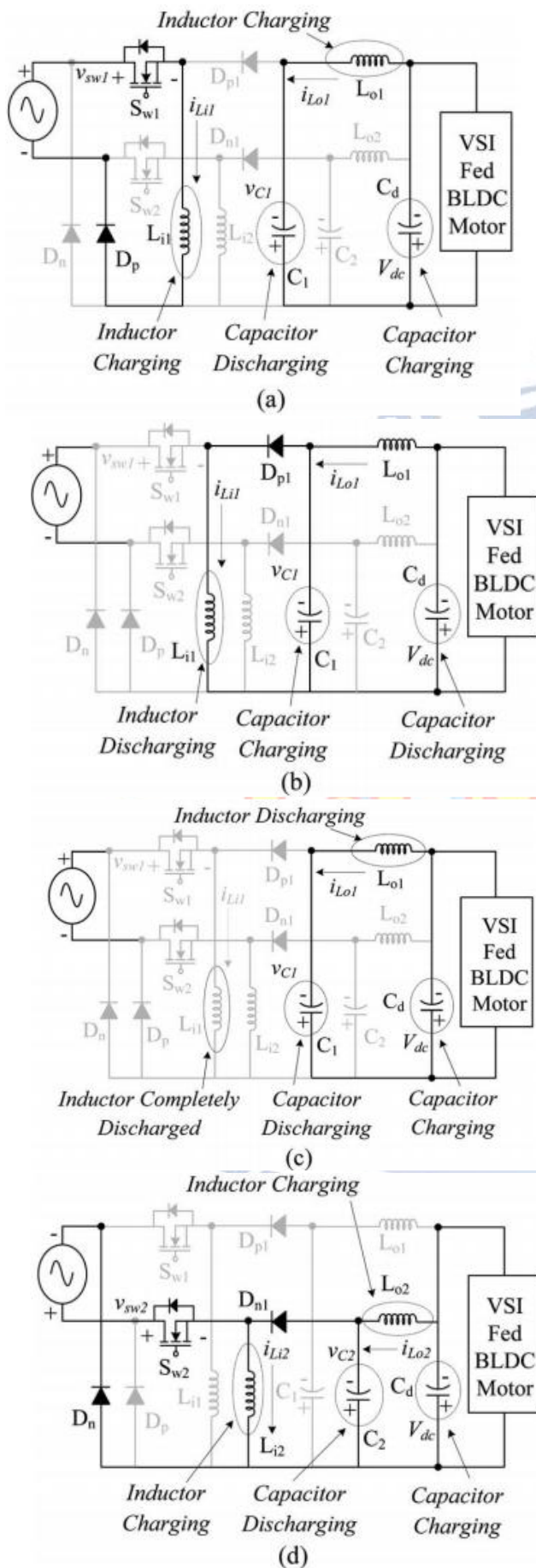


Fig. 2. Proposed PFC BL-Luo converter-fed BLDC motor drive.





**Fig. 3. Different modes of operation of the PFC BL-Luo converter during (a-c) positive and (d-f) negative half cycles of supply voltage. (a) Mode P-I. (b) Mode P-II. (c) Mode P-III. (d) Mode N-I. (e) Mode N-II. (f) Mode N-III.**

### **B. Operation during Complete Switching Cycle**

Fig. 4(b) shows the operation of the PFC BL-Luo converter during a complete switching period for a positive half cycle of supply voltage.

**Mode P-I:** As shown in Fig. 3(a), when switch  $S_{w1}$  is turned on, the input side inductor ( $L_{i1}$ ) stores energy, depending upon the current ( $i_{Li1}$ ) flowing through it and the inductor value ( $L_{i1}$ ). Moreover, the energy stored in the intermediate capacitor ( $C_1$ ) is transferred to the dc-link capacitor ( $C_d$ ) and the output side inductor ( $L_{o1}$ ). Hence, the voltage across the intermediate capacitor ( $V_{C1}$ ) decreases, whereas the current in the output inductor ( $i_{Lo1}$ ) and the dc-link voltage ( $V_{dc}$ ) are increased as shown in Fig. 4(b).

**Mode P-II:** As shown in Fig. 3(b), when switch  $S_{w1}$  is turned off, the input side inductor ( $L_{i1}$ ) transfers its energy to the intermediate capacitor ( $C_1$ ) via diode  $D_{p1}$ . Hence, the current  $i_{Li1}$  decreases until it reaches zero, whereas the voltage across the intermediate capacitor ( $V_{C1}$ ) increases as shown in

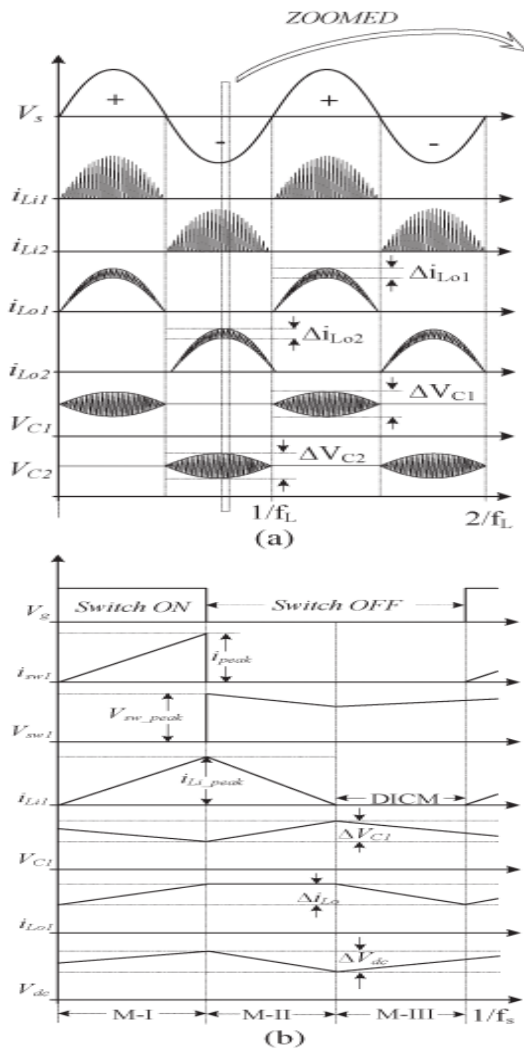


Fig. 4. Waveforms of BL-Luo converter during its operation for (a) complete line cycle and (b) complete switching cycle.

Fig. 4(b). The dc-link capacitor ( $C_d$ ) provides the required energy to the load; hence, the dc-link voltage  $V_{dc}$  reduces in this mode of operation. Mode P-III: As shown in Fig. 3(c), no energy is left in the input inductor ( $Li1$ ), i.e., current  $i_{Li1}$  becomes zero and enters the discontinuous conduction mode of operation. The intermediate capacitor ( $C1$ ) and output inductor ( $Lo1$ ) are discharged; hence, current  $i_{Lo1}$  and voltage  $V_{C1}$  are reduced, and dc-link voltage  $V_{dc}$  increases in this mode of operation as shown in Fig. 4(b). The operation is repeated when switch  $Sw1$  is turned on again. In a similar way, for a negative half cycle of supply voltage, the inductor's  $Li2$  and  $Lo2$ , diode  $Dn1$ , and intermediate capacitor  $C2$  conduct to achieve a desired operation.

#### IV. CONTROL OF PFC BL-LUO CONVERTER FED BLDC MOTOR DRIVE

The control of the PFC BL-Luo converter-fed BLDC motor drive is classified into two parts as follows.

##### A. Control of Front-End PFC Converter: Voltage Follower Approach

The control of the front-end PFC converter generates the PWM pulses for the PFC converter switches ( $Sw1$  and  $Sw2$ ) for dc-link voltage control with PFC operation. A single voltage control loop (voltage follower approach) is utilized for the PFC BL-Luo converter operating in DICM. A reference dc-link voltage ( $V_{dc}^*$ ) is generated as

$$V_{dc}^* = k_v \omega^* \quad (1)$$

Where  $k_v$  and  $\omega^*$  are the motor's voltage constant and reference speed.

The reference dc-link voltage ( $V_{dc}^*$ ) is compared with the sensed dc-link voltage ( $V_{dc}$ ) to generate the voltage error signal ( $V_e$ ) given as

$$V_e(k) = V_{dc}^*(k) - V_{dc}(k) \quad (2)$$

Where  $k$  represents the  $k$ th sampling instant.

This error-voltage signal ( $V_e$ ) is given to the voltage proportional-integral (PI) controller to generate a controlled output voltage ( $V_{cc}$ ) as

$$V_{cc}(k) = V_{cc}(k-1) + k_p \{V_e(k) - V_e(k-1)\} + k_i V_e(k) \quad (3)$$

Where  $k_p$  and  $k_i$  are the proportional and integral gains of the voltage PI controller. Finally, the output of the voltage controller is compared with a high frequency saw tooth signal ( $m_d$ ) to generate the PWM pulses as

$$\left\{ \begin{array}{l} \text{if } m_d(t) < V_{cc}(t) \text{ then } S_{w1} = S_{w2} = \text{"ON"} \\ \text{if } m_d(t) \geq V_{cc}(t) \text{ then } S_{w1} = S_{w2} = \text{"OFF"} \end{array} \right\} \quad (4)$$

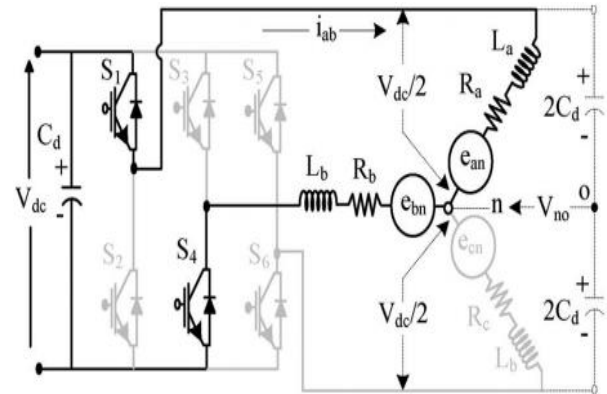


Fig. 5. VSI feeding a BLDC motor.

Table I  
Switching States of VSI to Achieve Electronic Commutation of BLDC Motor

$\theta(^\circ)$	Hall Signals			Switching States					
	$H_a$	$H_b$	$H_c$	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$
NA	0	0	0	0	0	0	0	0	0
0-60	0	0	1	1	0	0	0	0	1
60-120	0	1	0	0	1	1	0	0	0
120-180	0	1	1	0	0	1	0	0	1
180-240	1	0	0	0	0	0	1	1	0
240-300	1	0	1	1	0	0	1	0	0
300-360	1	1	0	0	1	0	0	1	0
NA	1	1	1	0	0	0	0	0	0

Where Sw1 and Sw2 represent the switching signals to the switches of the PFC converter. The modeling and stability issue of the proposed converter are discussed in the Appendix.

### B. Control of BLDC Motor: Electronic Commutation

An electronic commutation of the BLDC motor includes the proper switching of VSI in such a way that a symmetrical dc current is drawn from the dc-link capacitor for  $120^\circ$  and placed symmetrically at the center of each phase. A rotor position on a span of  $60^\circ$  is required for electronic commutation, which is sensed by Hall Effect position sensors. The conduction states of two switches (S1 and S4) are shown in Fig. 5. A line current  $i_{ab}$  is drawn from the dc-link capacitor, whose magnitude depends on the applied dc-link voltage ( $V_{dc}$ ), back electromotive forces (EMFs) ( $e_{an}$  and  $e_{bn}$ ), resistance ( $R_a$  and  $R_b$ ), and self- and mutual inductances ( $L_a$ ,  $L_b$ , and  $M$ ) of the stator windings. Table I shows the governing switching states of the VSI feeding a BLDC motor based on the Hall Effect position signals ( $H_a$ – $H_c$ ).

## V. WIND ENERGY BASICS

**Basic information on wind energy and wind power technology, resources, and issues of concern.**

**Wind Energy and Wind Power:** Wind is a form of solar energy. Winds are caused by the uneven heating of the atmosphere by the sun, the irregularities of the earth's surface, and rotation of the earth. Wind flow patterns are modified by the earth's terrain, bodies of water, and vegetative cover. This wind flow, or motion energy, when "harvested" by modern wind turbines, can be used to generate electricity.

**How Wind Power Is Generated:** The terms "wind energy" or "wind power" describe the process by which the wind is used to generate mechanical power or electricity. Wind turbines convert the kinetic energy in the wind into mechanical power. This mechanical power can be used for specific tasks (such as grinding grain or pumping water) or a generator can convert this mechanical power into electricity to power homes, businesses, schools, and the like.

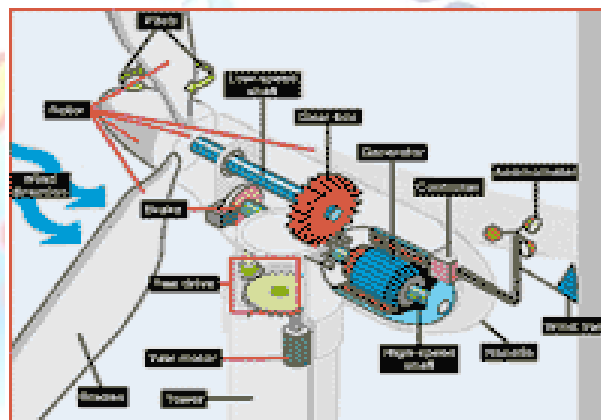
**Wind Turbines:** Wind turbines, like aircraft propeller blades, turn in the moving air and power an electric generator that supplies an electric current. Simply stated, a wind turbine is the opposite of a fan. Instead of using electricity to make wind, like a fan, wind turbines use wind to make electricity. The wind turns the blades, which spin a shaft, which connects to a generator and makes electricity.

**Wind Turbine Types:** Modern wind turbines fall into two basic groups; the horizontal-axis variety, like the traditional farm windmills used for pumping water, and the vertical-axis design, like the eggbeater-style Dairies model, named after its French inventor. Most large modern wind turbines are horizontal-axis turbines.

Turbine Components Horizontal turbine components include:

- **blade** or **rotor**, which converts the energy in the wind to rotational shaft energy;
- a **drive train**, usually including a gearbox and a generator;
- a **tower** that supports the rotor and drive train; and
- Other equipment, including controls, electrical cables, ground support equipment, and interconnection equipment.

### Wind turbine diagram



**Turbine Configurations:** Wind turbines are often grouped together into a single wind power plant, also known as a wind farm, and generate bulk electrical power. Electricity from these turbines is fed into a utility grid and distributed to customers, just as with conventional power plants.

**Wind Turbine Size and Power Ratings:** Wind turbines are available in a variety of sizes, and therefore power ratings. The largest machine has blades that span more than the length of a football field, stands 20 building stories high, and produces enough electricity to power 1,400 homes. A small home-sized wind machine has rotors between 8 and 25 feet in diameter and stands upwards of 30 feet and can supply the power needs of an all-electric home or small business. **Utility-scale turbines** range in size from 50 to 750 kilowatts. Single small turbines, below 50 kilowatts, are used for homes, telecommunications dishes, or water pumping.



### Wind Energy Resources in the United States:

Wind energy is very abundant in many parts of the United States. Wind resources are characterized by **wind-power density classes**, ranging from class 1 (the lowest) to class 7 (the highest). Good wind resources (e.g., class 3 and above, which have an average annual wind speed of at least 13 miles per hour) are found in many locations. Wind speed is a critical feature of wind resources, because the energy in wind is proportional to the cube of the wind speed. In other words, a stronger wind means a lot more power.

### Advantages and Disadvantages of Wind-Generated Electricity

**A Renewable Non-Polluting Resource:** Wind energy is a free, renewable resource, so no matter how much is used today, there will still be the same supply in the future. Wind energy is also a source of clean, non-polluting, electricity. Unlike conventional power plants, wind plants emit no air pollutants or greenhouse gases. According to the U.S. Department of Energy, in 1990, California's wind power plants offset the emission of more than 2.5 billion pounds of carbon dioxide, and 15 million pounds of other pollutants that would have otherwise been produced. It would take a forest of 90 million to 175 million trees to provide the same air quality.

**Cost Issues:** Even though the cost of wind power has decreased dramatically in the past 10 years, the technology requires a higher initial investment than fossil-fueled generators. Roughly 80% of the cost is the machinery, with the balance being site preparation and installation. If wind generating systems are compared with fossil-fueled systems on a "life-cycle" cost basis (counting fuel and operating expenses for the life of the generator), however, wind costs are much more competitive with other generating technologies because there is no fuel to purchase and minimal operating expenses.

**Environmental Concerns:** Although wind power plants have relatively little impact on the environment compared to fossil fuel power plants, there is some concern over the **noise** produced by the rotor blades, aesthetic (visual) impacts, and birds and bats having been killed (avian/bat mortality) by flying into the rotors. Most of these problems have been resolved or greatly reduced through technological development or by properly siting wind plants.

**Supply and Transport Issues:** The major challenge to using wind as a source of power is that it is intermittent and does not always blow when

electricity is needed. Wind cannot be stored (although wind-generated electricity can be stored, if batteries are used), and not all winds can be harnessed to meet the timing of electricity demands. Further, good wind sites are often located in remote locations far from areas of electric power demand (such as cities). Finally, wind resource development may compete with other uses for the land, and those alternative uses may be more highly valued than electricity

## VI. MATLAB/SIMULATION RESULTS

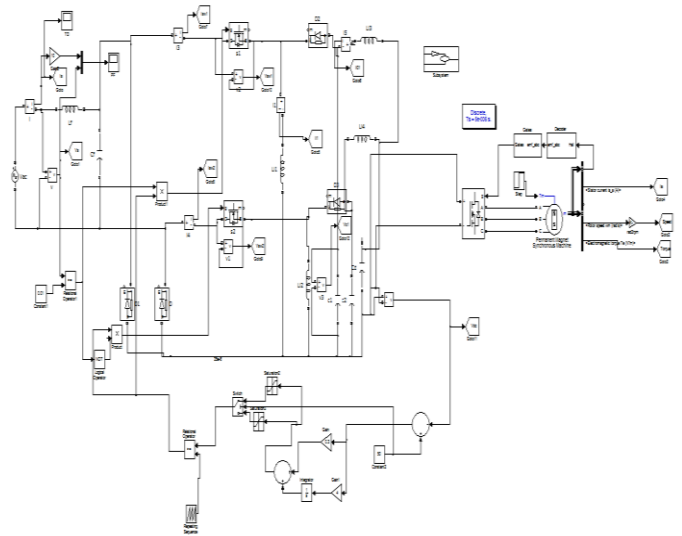


Fig.6. Matlab/Simulation model of bridge less LLC converter fed BLDC Motor.

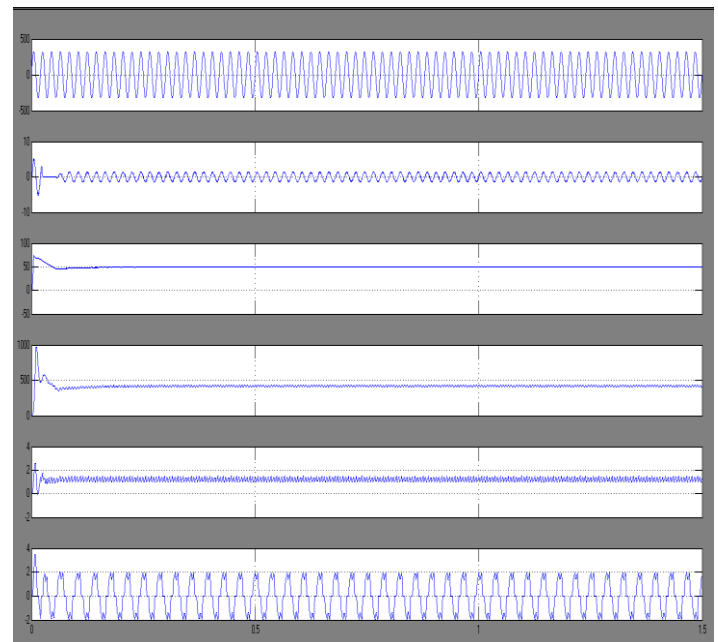
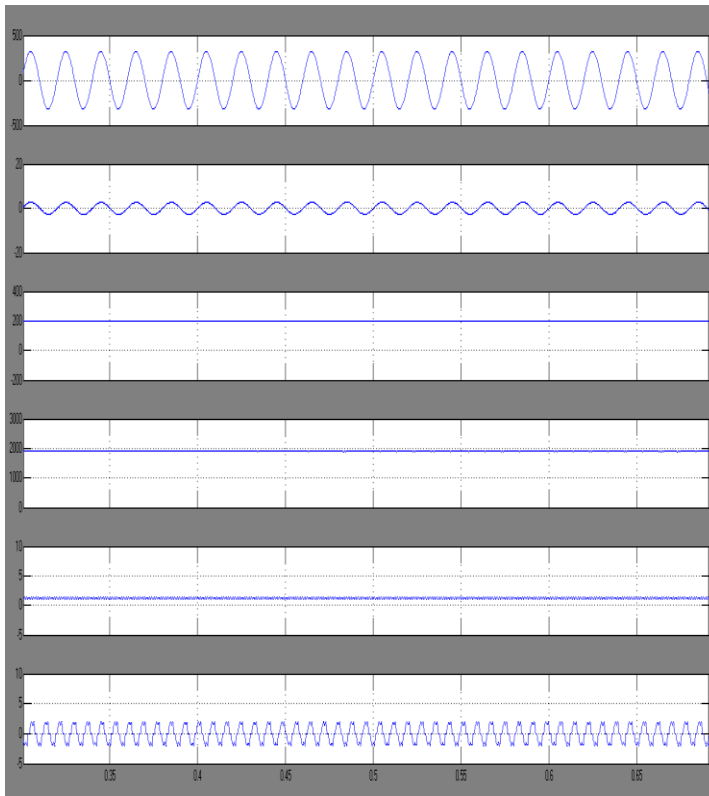
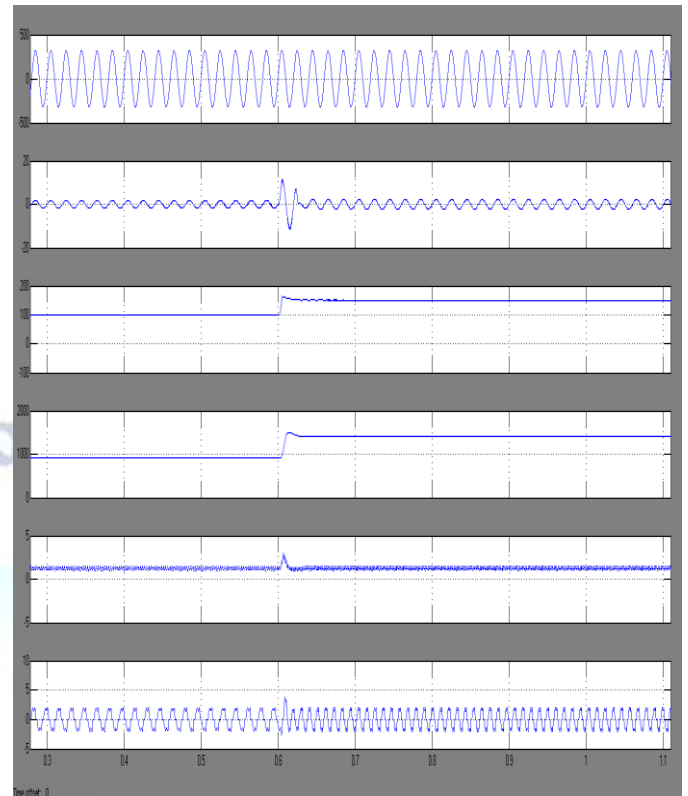


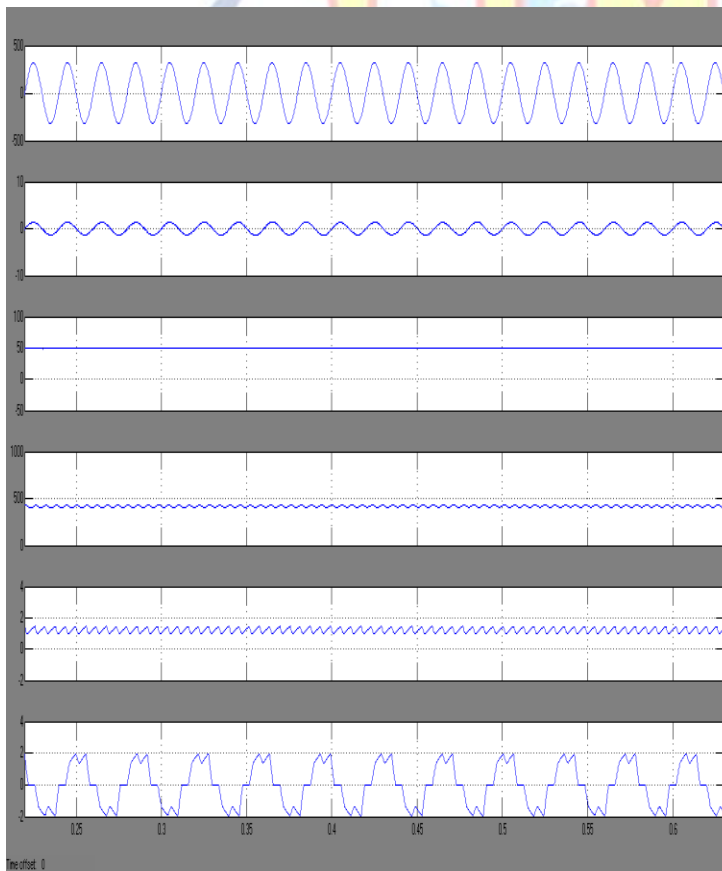
Fig.7. Test results of proposed BLDC motor drive At rated load torque on BLDC motor with  $V_{dc} = 50 \text{ V}$  and  $V_s = 220 \text{ V}$ .



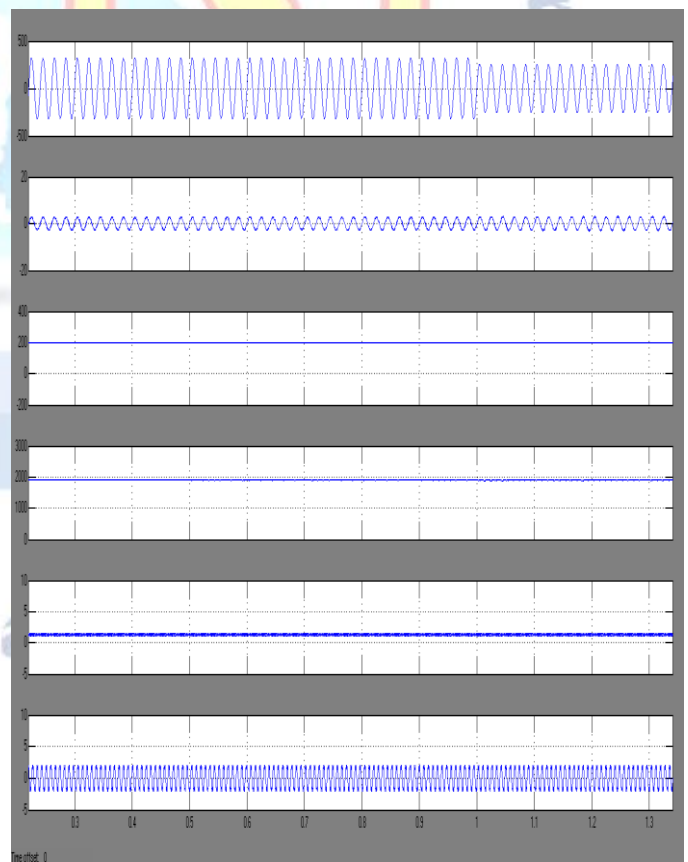
**Fig.8. Test results of proposed BLDC motor driveAt rated load torque on BLDC motor with  $V_{dc} = 200$  V and  $V_s = 220$  V**



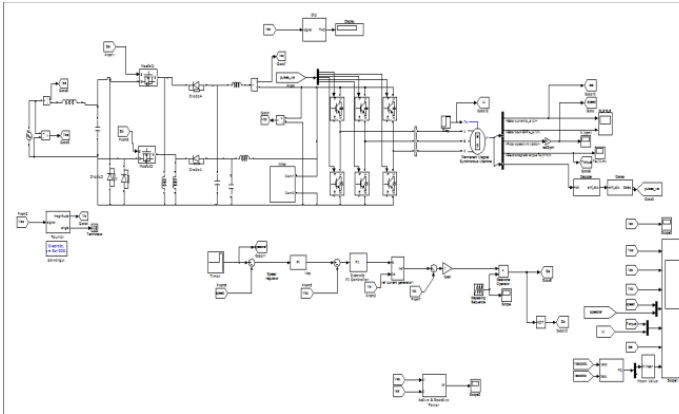
**Fig.10. Test results of proposed BLDC motor drive showing dynamic performance during change in dc-link voltage from 100 to 150 V.**



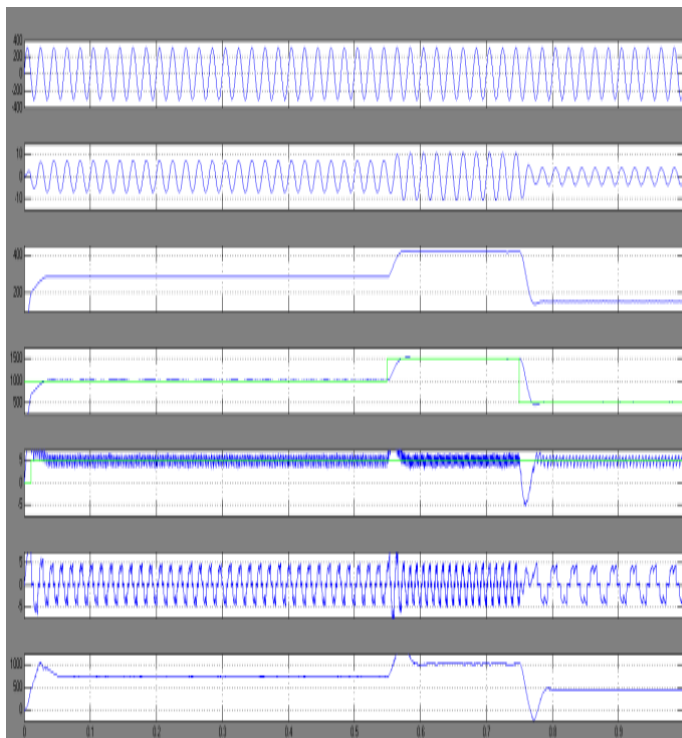
**Fig.9. Test results of proposed BLDC motor drive showing dynamic performance during starting at 50 V.**



**Fig.11. Test results of proposed BLDC motor drive showing dynamic performance of the during change in supply voltage from 250 to 180**



**Fig 12 Matlab/Simulation model of bridge less Lou converter fed BLDC Motor with wind**



**Fig 13 simulation wave form of output performance voltage current, dc voltage and speed torque**

## VII. CONCLUSION

A PFC BL-Luo converter-based VSI-fed BLDC motor drive has been proposed targeting low-power applications. A new method of speed control has been utilized by controlling the voltage at wind dc bus and operating the VSI at fundamental frequency for the electronic commutation of the BLDC motor for reducing the switching losses in VSI. The front-end BL Luo converter has been operated in DICM for achieving an inherent power factor correction at ac mains. Moreover, voltage and current stresses on the based PFC switch have been evaluated for determining the practical application of the proposed scheme. Finally, simulations of the proposed drive has been

developed to validate the performance of the proposed BLDC motor drive under speed control with improved power quality at ac mains. The proposed scheme has shown satisfactory performance, and it is a recommended solution applicable to low-power BLDC motor drives.

## REFERENCES

- [1] Bhim Singh, Fellow, IEEE, Vashist Bist, Student Member, IEEE, Ambrish Chandra, Fellow, IEEE, and Kamal Al-Haddad, Fellow, IEEE" Power Factor Correction in Bridgeless-Luo Converter-Fed BLDC Motor Drive" IEEE TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 51, NO. 2, MARCH/APRIL 2015
- [2] C. L. Xia, Permanent Magnet Brushless DC Motor Drives and Controls. Beijing, China: Wiley, 2012.
- [3] T. Kenjo and S. Nagamori, Permanent Magnet Brushless DC Motors. Oxford, U.K.: Clarendon, 1985.
- [4] R. Krishnan, Electric Motor Drives: Modeling, Analysis and Control. New Delhi, India: Pearson Education, 2001.
- [5] T. J. Sokira and W. Jaffe, Brushless DC Motors: Electronic Commutation and Control. Blue Ridge Summit, PA, USA: Tab Books, 1989.
- [6] H. A. Toliyat and S. Campbell, DSP-Based Electromechanical Motion Control. New York, NY, USA: CRC Press, 2004.
- [7] S. Singh and B. Singh, "A voltage-controlled PFC Cuk converter based PMBLDCM drive for air-conditioners," IEEE Trans. Ind. Appl., vol. 48, no. 2, pp. 832–838, Mar./Apr. 2012.
- [8] Limits for Harmonic Current Emissions (Equipment input current  $\leq 16$  A per phase), International Std. IEC 61000-3-2, 2000.
- [9] B. Singh et al., "A review of single-phase improved power quality acdc converters," IEEE Trans. Ind. Electron., vol. 50, no. 5, pp. 962–981, Oct. 2003.
- [10] B. Singh, S. Singh, A. Chandra, and K. Al-Haddad, "Comprehensive study of single-phase ac-dc power factor corrected converters with highfrequency isolation," IEEE Trans. Ind. Informat., vol. 7, no. 4, pp. 540–556, Nov. 2011.
- [11] S. B. Ozturk, O. Yang, and H. A. Toliyat, "Power factor correction of direct torque controlled brushless dc motor drive," in Conf. Rec. 42<sup>nd</sup> IEEE IAS Annu. Meeting, Sep. 23–27, 2007, pp. 297–304.
- [12] T. Y. Ho, M. S. Chen, L. H. Yang, and W. L. Lin, "The design of a high power factor brushless dc motor drive," in Int. Symp. Comput., Consum. Control, Jun. 4–6, 2012, pp. 345–348.
- [13] T. Gopalarathnam and H. A. Toliyat, "A new topology for unipolar brushless dc motor drive with high power factor," IEEE Trans. Power Electron., vol. 18, no. 6, pp. 1397–1404, Nov. 2003.