Middle-East Journal of Scientific Research 19 (8): 1040-1046, 2014
ISSN 1990-9233

DOI: 10.5829/idosi.mejsr.2014.19.8.1494

Advanced Controller Design for Pmbldc Motor-A Review

S. Prakash M.E

Department of E.E.E, Bharath University,
Chennai-600 073, Tamilnadu, India

Abstract: Permanent Magnet Brushless D.C. Motors and Drives find wide applications categorized as constant loads which includes Fans, Pumps, Blowers and with variable loads includes in Home Appliances-Washers, Dryers, Compressors. In Automotive- Fuel Pump Control, Engine Control, Electric Vehicle Control. In Aerospace-Robotic Arm Control, Gyroscope Control. This has been made possible with the advanced high performance permanent magnets that make the PMBLDC to have Long Operational Life, Noiseless Operation, High speed range, High Efficiency, High Dynamic response, Better Speed versus Torque Characteristics. This paper surveys the literature of the PMBLDC motor and drives. It describes the efficient modeling, dynamic behavior, various power converter topology, fault analysis, speed control, sensorless control of PMBLDC motor. This paper provides necessary information for the research personalities and working engineers in the field of developing PMBLDC motor and Drives.

Key words: PMBLDC Motor · Drives · Controllers · Topologies

INTRODUCTION

In permanent magnet motors, the field is generated by permanent magnets mounted on the rotor and the rotating field is generated by means of stator windings. A permanent magnet rotor field can be of two shapes, sinusoidal and trapezoidal. The motors having a sinusoidal rotor field and hence a sinusoidal back-emf (Fig-2) behave like synchronous ac machines and are usually called Permanent Magnet Synchronous Machine. (PMSM) [1]. For a brushless dc (BLDC) motors, the rotor field and hence the back-emf is trapezoidal as shown in (Fig-2).

The brushless dc motor is actually a permanent magnet ac motor whose torque-current characteristics similar to dc motor. Instead of commutating the armature current using brushes, electronic commutation is used. This eliminates the problems associated with the brush and the commutator segments, thereby making a BLDC more rugged as compared to a dc motor. BLDC is a modified PMSM motor with the modification being that the back-emf is trapezoidal instead of being sinusoidal as in the case of PMSM. The "commutation region" of the back-emf of a BLDC motor should be as small as possible, while at the same time it should not be so narrow as to

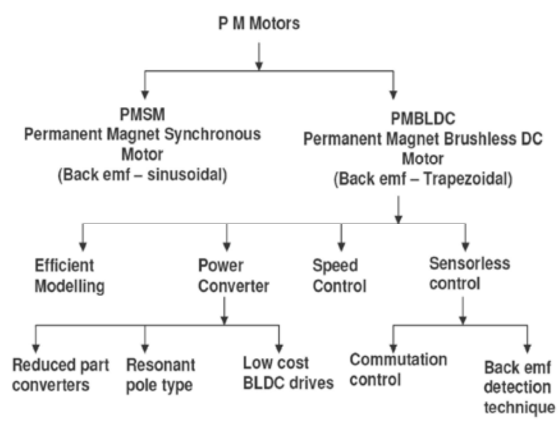

Fig. 1: Survey chart of PMBLDC motor drives and Improvements

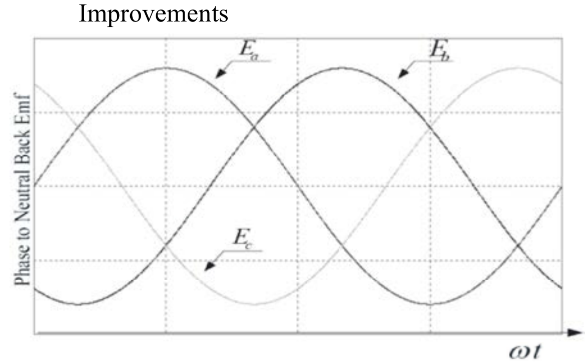

Fig. 2: Sinusoidal Back-emf of three Phase PMSM

Corresponding Author: S. Prakash M.E, Department of E.E.E, Bharath University, Chennai-600 073, Tamilnadu, India.

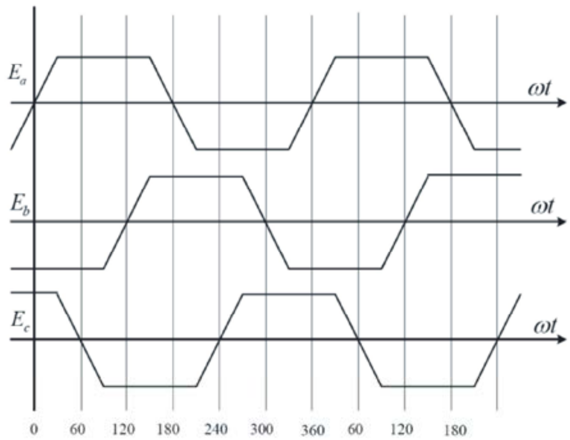

Fig. 3: Trapezoidal back-emf of a three-phase PMSM (BLDC)

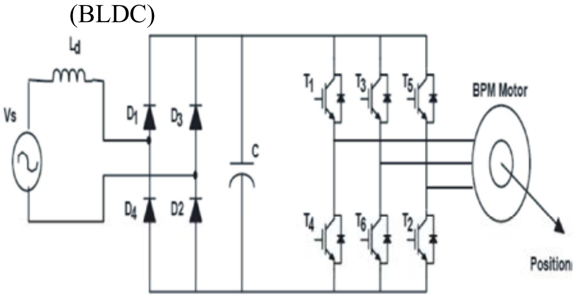

Fig. 4: Voltage Source Inverter fed BLDC Drive.

make it difficult to commutate a phase of that motor when driven by a Current Source Inverter. The flat constant portion of the back-emf should be 120° for a smooth torque production.

The position of the rotor can be sensed by using an optical position sensors and its associated logic. Optical position sensors consist of phototransistors (sensitive to light), revolving shutters and a light source, or even Hall effect position sensors are also used. Genarally named as Hall_A, Hall_B and Hall_C, each having a lag of 120° w.r.t. the earlier one [8]. Three Hall position sensors are used to determine the position of the rotor field. These particular Hall position sensors, based on Hall effect principle, generate a TTL compatible output. Depending on the Back-emf, signal is generated and rotor position is sensed.

A conventional BLDC drive is illustrated in Fig. 3. It consists of a dc voltage supplied by a rectifier arrangement, a dc link capacitor for energy storage, a Voltage Source Inverter (VSI) consisting of transistor switches and finally, the three-phase output of the inverter is supplied to the motor. For rotor position sensing, either a Hall position sensor or an optical shutter arrangement is used along with some sort of microcontroller/microprocessor.

$$T_{em} = \frac{e_a i_a + e_b i_b + e_c i_c}{\omega_m}$$

e_a = phase-to-neutral back-emf of phase A (in volts),

e_b = phase-to-neutral back-emf of phase B (in volts),

e_c = phase-to-neutral back-emf of phase C (in volts),

i_a = current in phase A (in amperes),

i_b = current in phase B (in amperes),

i_c = current in phase C (in amperes) and

ω_m = angular velocity of the rotor shaft (in radians/second).

Modelling of PM Brushless DC Motor: [15] The flux distribution in a PM brushless dc motor is trapezoidal, that is non sinusoidal flux distribution, it is prudent to derive a model of the PMBLDC motor in phase variables. Here the assumptions made are induced currents in the rotor due to stator harmonic fields are neglected; iron and stray losses are also neglected. The motor is considered to have three phases, even the procedure supports for multi phases.

The coupled circuit equations of the stator windings in terms of motor electrical constants are

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = R_s * \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \mathrm{p} \begin{bmatrix} L & M & M \\ M & L & M \\ M & M & L \end{bmatrix} \begin{bmatrix} I_a \\ I_b \\ I_c \end{bmatrix} + \begin{bmatrix} E_a \\ E_b \\ E_c \end{bmatrix}$$

where Rs is the stator resistance per phase, assumed to be equal for all three phases. The induced emfs Eas, Ebs and Ecs are all assumed to be trapezoidal, where Ep is the peak value, derived as Ep = (Blv)N = N(Blrω_m) = N$\varphi_a\omega_m$ where N is the number of conductors in series per phase, v is the velocity, l is the length of the conductor, r is the radius of the rotor bore, ω_m is the angular velocity. Adjusting the inductance and after some assumptions, the electromagnetic torque is given by

$T_e = [E_a I_a + E_b I_b + E_c I_c]/\omega$ (in N.m)|

And the induced emfs are given by

$E_a = \mathrm{fa}(\theta)\ \lambda\ \omega.$
$E_b = \mathrm{fb}(\theta)\ \lambda\ \omega.$
$E_c = \mathrm{fc}(\theta)\ \lambda\ \omega.$

The state space model [1] is given by

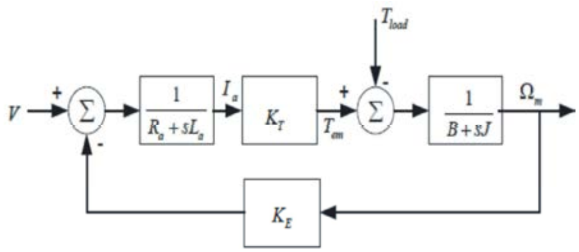

Fig. 5: Model of BLDC motor

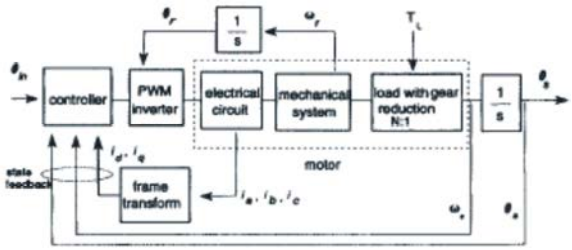

Fig. 6: System Block Diagram.

Following the Efficient Modelling for a brushless DC Motor Drive, Luk and Lee advised by cost efficient simulation of the system at the design stage is desirable [16]. The proposed mathematical model, developed in the de facto industry standard MATLAB environment, allows design engineers a quick investigation into the performance of the system when variations such as load or sampling rate of the digital controller occur. A user-friendly interface to the input of simulation parameters has been incorporated [17]. The modular approach adopted facilitates program maintenance and further development. Some simulation and Validating results are included. Since the practical implementations will usually involve such frame of transformation and other real time computations, a delay in outputting the actuation signal is incurred. Such delays are therefore included in the model. The paper shows the system model, controller model and load model. The software development with the proposed model of the drive system constitutes the main.

Modules as shown in the above Fig. 6 for each module he created mat lab statements and M-files are created. Modular approach is adopted to facilitate good software maintenance and future development. This is supported by programming environment by mat lab. Structure chart is developed it supports controlled variables, system error, actuation command, phase currents, electromechanical torque and harmonic contents...etc.

The discussed BLDC motor drive model offers an efficient and user friendly environment to examine implementation aspects encountered in the design of such drive systems. The software allows the user to trade off implementation details of the drive system at the design stage and is particularly useful for cost-critical projects. Since it runs on the platform of the industry accepted MATLAB simulation package, high portability and good software support are assured in the future. The package is both a viable tool for designing BLDC motor control systems and has been used as an invaluable teaching tool.

Dynamic Behaviour of BLDC motor using Finite Element Analysis: Finite element method has long been used for deriving the motor model,s lumped parameters, the prediction and optimization of the system's behaviour is often performed using a circuit simulation software.[3] New and powerful features, namely the coupling of circuit equations to the finite element solution and the integration of the rotor motion within the solving process, open new ways for modern finite element software to directly model the drive system's dynamic behaviour.

Moving air-gap technique and coupling with external circuits deals through process of understanding the moving air gap technique and the analysis deals with multiple static positions, constant speed and mechanical coupling. The external coupling effects are also considered. Stator no load voltage, flux density harmonics and related rotor positions are analysed. Cogging torque and stator phase inductances both the effects of self and mutual inductances are studied. From the paper it is possible to use a FEM technique to obtain a direct prediction of a motors dynamic behaviour. It produces best results and shows circuit simulation for dynamic studies [18]. The FEM direct prediction of the dynamic behaviour of Brushless DC motors must take into account the rotor motion and the drive and electrical control circuits.

Power Converter Topology a Review: Cost minimization of the permanent magnet brushless dc motor drive is of immense interest to the industry at present, due to the opening up of a large number of applications to variable-speed operation [4]. The designed converter topology which is same as "C dump" as used in Switched reluctance motor, this topology uses more than one switch per phase for operation but less than two switches per phase that is with n+1 switches for n-pase machines.

In this article it is reviewed for four quadrant operation The C-dump converter for a three-phase system, shown in Fig. 1, is considered for this paper. It has four power switches and four power diodes, with

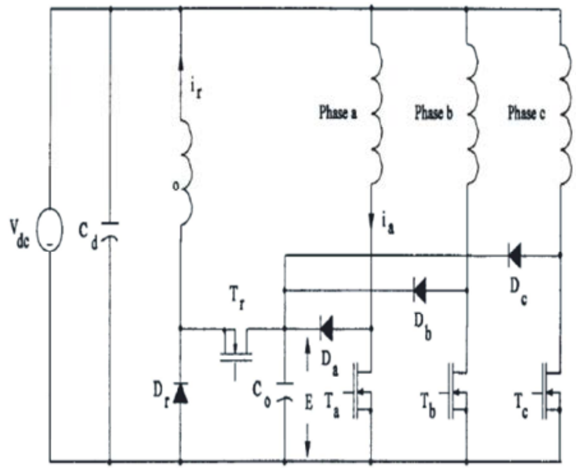

Fig. 7: C-Dump topology.

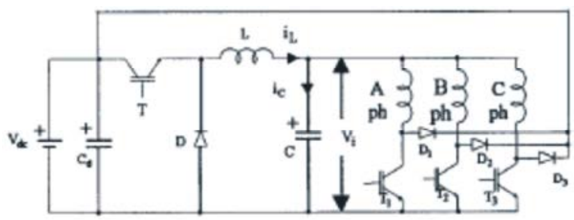

Fig. 8: A new n+1 Switch Topology

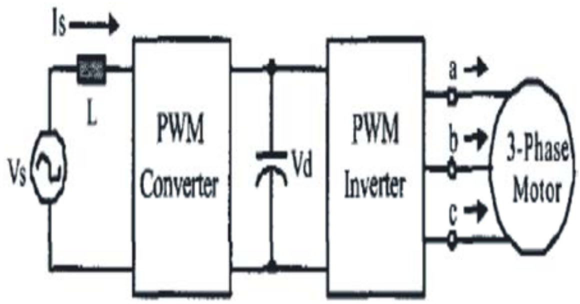

Fig. 9: Cascaded type PWM system

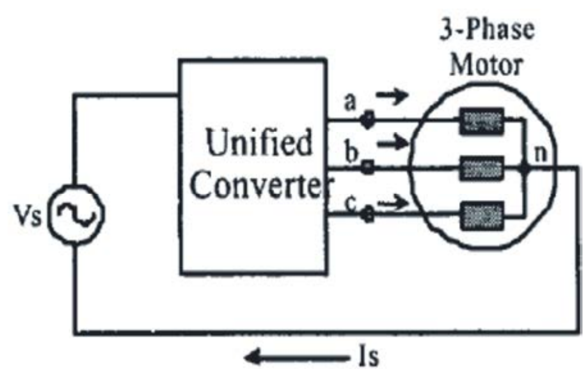

Fig. 10: Unified type PWM System

one of each for each phase winding and one set for energy recovery from the capacitor. Since the phase has only one switch, the current in it could only be unidirectional and, hence, it is very much similar to the half-wave-converter-driven PMBDC in operation. It can be able to perform both motoring and regenerative operation successfully. Design guidelines for the c-dump topology include a close watch on DC link voltage, phase switches, phase diodes, energy recovery chopper and capacitor.

The drawback from C-Dump topology is it has twice the copper loss as compared to full wave inverter and it improves the switching losses.

The next method of converter design sown in fig-8 includes same as n+1 switches for n phase machine but a switch T is made common with a diode D, inductor L and capacitor C form a step down chopper power stage. The chopper power stage varies the input DC source voltage to the machine windings. Since there is one switch per phase makes unidirectional and similar to a half wave converter driven PMBLDC motor [5]. Here also both motoring and regenerative operation is done successfully.

The drive system has feedback control over the phase currents, discrete rotor position signal and rotor speed signals. Poor utilization of the machine due to half wave operation and results in larger self inductance and torque response is also not up to the mark when compared to full wave converter fed drive.

Reduced part converter topology The reduced part converter topology results in cascade type and unified type [6]. Under cascaded type a separate PWM converter for powerfactor correction and the PWM inverter for speed control are connected in series with a large DC link capacitor and two static power converters are operated and controlled in separate. Here the required no of switches can be reduced which leads to reduced part converters.

But where as in Unified type, conventional concepts of PWM converter and inverter are merged together and the same converter handles the functions of PWM converter(power factor correction) and PWM inverter (motor control) at the same time. Input inductor used in PWM can be neglected and the motor inductor is used and this makes an added advantage.

While the above article gives details of reduced part converters for a three phase machine but where as a generalized design procedure is made for Multiphase's as two-phase, three-phase, four-phases and five-phase Machines. The design is carried out by back EMF and the winding distribution.

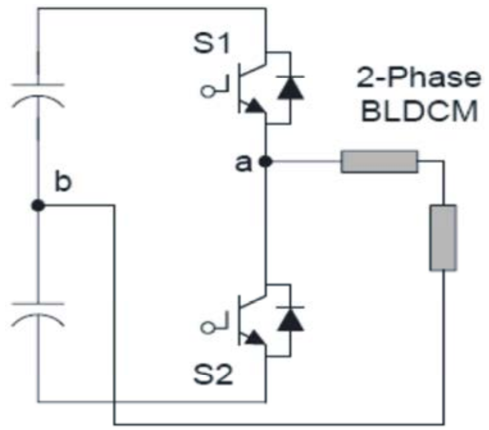

Fig. 11: Reduced Two Switch Configuration

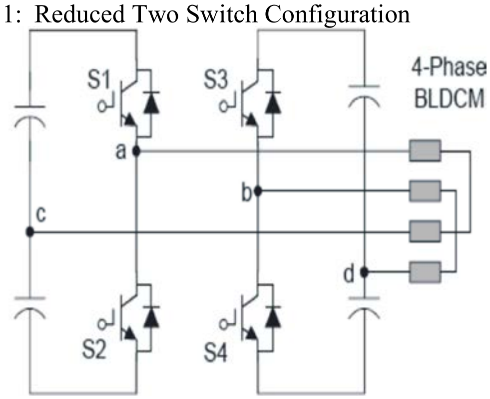

Fig. 12: Reduced Four switch Configuration

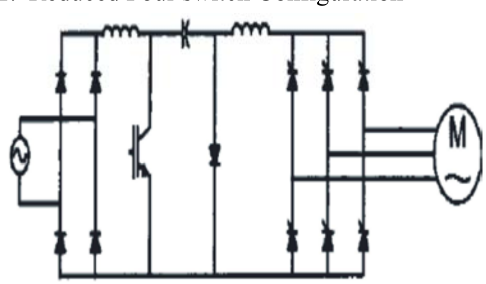

Fig. 13: Proposed cuk supplied BLDC motor drive.

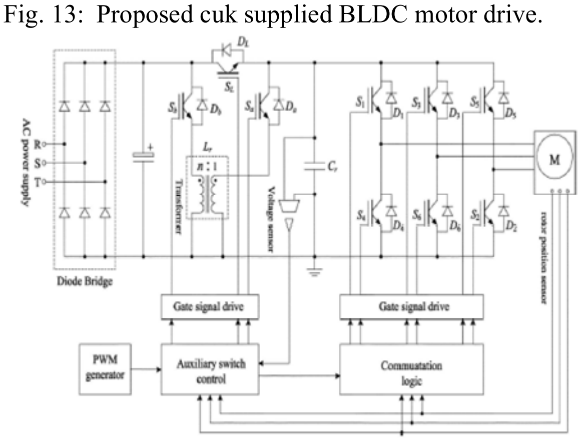

Fig. 14: Structure of the resonant DC link inverter for BDCM drive systems

Generalized Design Methodology Can Be Derived for N-phase BLDC Motors as Follows: Therefore, for n-phase BLDC motor, 2n number of switches is needed. In order to minimize the number of switches, the current profiles should be modified to the sum of phase current is equal to zero. Case of Ia+Ib+Ic+Id=0, [7] In this case, the converter can be designed as Even n-phase BLDC motors n number of switches is required along with split dc-link capacitors. Odd n-phase BLDC motors 2n-2 number of switches is required along with split dc-link capacitors.

Following the reduced part converters current source inverters are suggested where it is explained with three phase bldc motor, an ac-dc converter and a three phase inverter containing six SCR's. A microcontroller or a digital signal processor will be used to control the overall system [8]. The proposed system is fault tolerant due to the current regulated nature, where it can even withstand a solid short circuit at its output terminals. When comparing with the existing drives, the new topology reduces cost by 30%. Since all the switches used in the output three-phase inverter is current commutated, this drive has much lower switching losses than the conventional PWM drive [8]. It uses the Buck-Boost converter technology for successful converter design of BLDC motor Drive.

Transformer Based Resonant Soft DC Link Inverter for BLDC Motor Drive System [9]: Soft switching inverter based on transformer which generate dc link voltage notches during chopping switches commutation to guarantee all switches working in zero voltage switching condition. The operation principle and control scheme of the inverters are analyzed for the successful operation of the drive all the operating regions.

The resonant circuit consists of three auxillary switches, one transformer and one resonant capacitor. The auxillary switches are controlled at certain instant to obtain the resonance between transformer and capacitor. Thus the DC link voltage reaches zero temporarily (voltage notch) and the main switches of the inverter get ZVS condition for commutation. In this design all switches work under soft-switching condition, so their power losses are small. Simple auxiliary switches are used for control scheme this reduces the voltage stresses, dv/dt and di/dt. This makes further reduction in the EMI.

Discussing on the speed control of PMBLDC motor drive [10], a new control scheme to the conventional PMBLDC motor, aimed at improving control system robustness via complete decoupling of the design and performance of the control loops that ensures robustness by minimizing the mutual influence among the speed and current control loops. This robust decoupling control scheme would be applicable to both static and dynamic aspects.

Sensorless Techniques: Some of the sensorless techniques have been introduced and developed based on the reduction in cost of the entire drive system as well as reducing the complexity of the system [11]. Here the commutation signals are extracted directly from the specific average line to line voltages with simple RC circuits and comparators. By this the common mode interferences and noises are reduced, it leads to easy interface with the cost effective commercial hall effect sensors based commutation integrated circuits. This technique leads to elimination of the motor neutral voltage, elimination of the fixed phase shift circuit, insensitive to the back emf waveform and it proves as cost effective system.

Even sensorless control techniques used Field Programmable Logic Array(FPGA) [12] in this method also cost is reduced by switch device count, cost down of control and saving of hall sensor. The position information is estimated from the crossings of voltage waveforms in floating phases and a low cost FPGA is utilized to implement the control action. It results in smooth motor operation in all the regions and torque ripples are controlled.

EMF Detection technique is introduced which provides wide range control for BLDC drives [13]. It can be capable of handling both low and high duty-ratio control. The zero crossing point of back-emf which is used for generating proper commutation control of inverter is calculated by sampling the voltage of floating phase. it lead way to absence of current and position sensors. By reducing both the position and current sensors the cost effective system is introduced, complexity in the drive control circuit is reduced to a large extent.

CONCLUSIONS

Many areas in the associated design and development of Permanent magnet brushless DC motor drives have been covered by the paper; much is to be yet from the areas of machine design, control algorithms, drive design, sensorless techniques and speed control. As the technology for manufacturing the motors, development of drives-converter design by using latest technology deals with genetic algorithm, soft sensing process and advanced sensors leads to reduced cost and superior in performance, encouraging many more applications for the machines and drive systems.

REFERENCES

1. Krishnan, R., 2003. Electric Motor Drives, modeling, analysis and control. Prentice hall of India Pvt.ltd, New Delhi.
2. Luk, P.C.K. and C.K. Lee, 1994. Efficient modeling for a brushless DC motor Drive IEEE Paper.
3. Daho Taghezout, Patrick Lombard and Philippe Wending, September 1996. Finite Element Prediction of a brushless DC Motors Dynamic Behaviour intelligent Motion Systems. September 1996 Proceedings, pp: 57-67.
4. Krishnan, R., 1997. Senior Member, IEEE and Shiyoung Lee PM Brushless DC Motor Drive with a New Power-Converter Topology IEEE Transactions on industry applications, 33(4).
5. Krishnan, R. and P. Vijayaraghavan, 1998. A New Power Converter Topology for PM Brushless DC Motor Drives, IEEE Paper.
6. LEE, B.K., B. Fahimi and M. Ehsani, 2001. Overview of Reduced Parts Converter Topologies for AC Motor Drives IEEE paper.
7. Lee, B.K., J.P. Hong and M. Ehsani, 2003. Generalised Design Methodology of Reduced Parts Converters for Low Cost BLDC Motor Drives IEEE paper.
8. Rahul Khopkar, S.M. Madani, Masoud Hajiaghajani and Hamid A. Toliyat, 2003. A Low Cost BLDC Motor Drive using Buck-Boost Converter for residential and commercial Applications IEEE Paper.
9. Zhi Yang Pan, 2005. Student Member, IEEE and Fang Lin Luo, Senior Member, IEEE Transformer Based Resonant DC Link Inverter for Brushless DC Motor Drive System IEEE paper.
10. Thirusakthimurugan, P. and P. Dananjayan, 2006. A New Control Scheme for the speed control of PMBLDC Motor Drive IEEE paper.
11. Cheng-Hu Chen and Ming-Yang Cheng, 2007. Member IEEE A New Cost Effective Sensorless Commutation Method for Brushless DC Motors Without Phase Shift Circuit and Neutral Voltage IEEE paper.

12. Abolfazl halvaei Niasar, 2008. Member IEEE, Abolfazi Vahedi and Hassan Moghbelli, Member IEEE A Novel Position Sensorless Control of a Four Switch, Brshless DC Motor Drive Without Phase Shifter IEEE paper.
13. Yen-Shin Lai, 2008. Senior Member, IEEE and Yong-Kai Lin Novel Back-EMF Detection Technique of Brushless DC Motor Drives for wide range control without using Current and Position Sensors IEEE paper.
14. Shin-Young Cho and Gun-Woo Moon, Aug 2012. Interleaved Buck Converter Having Low Switching Losses and Improved Step-Down Conversion Ratio Power Electronics, IEEE Transactions, 27(8): 3664-3675.
15. Vijayaragavan, S.P., B. Karthik, T.V.U. Kiran Kumar and M. Sundar Raj, 2013. Analysis of Chaotic DC-DC Converter Using Wavelet Transform, Middle-East Journal of Scientific Research, ISSN:1990-9233, 16(12): 1813-1819.
16. Vijayaragavan, S.P., B. Karthik, T.V.U. Kiran Kumar and M. Sundar Raj, 2013. Robotic Surveillance For Patient Care In Hospitals, Middle-East Journal of Scientific Research, ISSN:1990-9233, 6(12): 1820-1824.
17. Vijayaragavan, S.P., T.V.U. Kiran Kumar and M. Sundar Raj, 2013. Study of effect of MAI and its reduction in an OCDMA system, Middle-East Journal of Scientific Research, ISSN:1990-9233, 16(12): 1807-1812.
18. Vijayaragavan, S.P., T.V.U. Kiran kumar and M. Sundar Raj, 2013. Study of Effect of Mai and its reduction in an OCDMA System, Middle-East Journal of Scientific Research, ISSN:1990-9233, 15(12): 1803-1808.
19. Kishwar Sultana, Najm ul Hassan Khan and Khadija Shahid, 2013. Efficient Solvent Free Synthesis and X Ray Crystal Structure of Some Cyclic Moieties Containing N-Aryl Imide and Amide, Middle-East Journal of Scientific Research, 18(4): 438-443.
20. Pattanayak Monalisa and P.L. Nayak, 2013. Green Synthesis of Gold Nanoparticles Using Elettaria cardamomum (ELAICHI) Aqueous Extract World Journal of Nano Science & Technology, 2(1): 01-05.
21. Chahataray Rajashree and P.L. Nayak, 2013. Synthesis and Characterization of Conducting Polymers Multi Walled Carbon Nanotube-Chitosan Composites Coupled with Poly (P-Aminophenol) World Journal of Nano Science & Technology, 2(1): 18-25.
22. Parida, U.K., S.K. Biswal, P.L. Nayak and B.K. Bindhani, 2013. Gold Nano Particles for Biomedical Applications, World Journal of Nano Science & Technology, 2(1): 47-57.