CHAPTER 2

SURVEY OF LITERATURE

The survey deals with various related works in sensor less BLDC motor control using different control algorithms for solar fed drive applications. Stand alone operation of solar power with and without the use of an active power converter is discussed in detail in the following review. Feasibility of the proposed work in MATLAB simulation and experimental implementation is also discussed in the literature.

2.1 Reported works on sensor less BLDC motor control powered from photovoltaic source

Chen et al., (2014) proposed Modeling and controller design of an autonomous PV module for DMPPT PV systems. The photo voltaic source based power generation invoked a great focus in recent days with advantages like renewable form of energy, pollution free power generation and even government promoting solar based power generation in large scale. Hence standalone operation of PV generation is considered for certain applications. For utilizing the PV power certainly in low voltage range power, electronic converters are proposed. This paper discussed the design of a buck-boost converter for solar power generation with the controller. This converter can operate in three modes buck, boost and buck-boost depending on duty period. R. Gonzalez introduced the Maximum power point tracking scheme is applied based on generated PV voltage and current which returns reference value for switching strategy of proposed converter. The proposed converter contains four power electronic switches and one inductor. It can generate a positive output voltage with the higher ratio in comparison with the input voltage. The proposed converter topology is suitable for high voltage medium power applications. Small signal model is created to analyze the advantages of the converter, the performance of the converter is verified by PC based simulation using MATLAB software and experimentally validated using

dspic controller using similar control system and circuit parameters used for simulation.

Walker et al., (2004) proposed a Cascaded DC-DC converter connection of photovoltaic modules. Normally a grid interfaced PV inverter involves a series connection of a large number of PV panels which develops voltage almost equal to the grid operating voltage followed by a single dc to ac inverter. The major drawback of this structure is PV voltage not constant at any instant of time rather it varies with time, and hence a dc-dc converter is utilized per panel for keeping PV voltage constant and maximum power is extorted from each PV panel using the various algorithm. For n number of PV panel, n number of dc-dc converter and a single dc to ac inverter is used in this scheme. In this paper for dc-dc converter different topologies were considered and performances are analyzed. The buck converter best suited for the highest number of strings used in PV generations and boost converter is employed if a lesser number of PV string is available.

Gules, Roger et al., (2008) proposed a maximum power point tracking system with parallel connection for PV stand-alone applications. In this paper design and analysis of parallel connection of maximum power point tracer for a photo, voltaic power generation is discussed. The parallel connection of PV systems decreases the overall losses of the PV power generation system and delivers power at high efficiency than series connected PV system. For a cost effective and a highly efficient scheme of solar power buck and boost, topologies show a great performance compared to special buck-boost converter topologies. Dc to ac converter for single panel and number of such combinations connected in series will not give an appropriate result because produced ac voltage will be very less regarding power rating.

Niapoor, S.K.M et al., 2010 explained the parallel connected PV system and MPPT technique scheme is implemented using a DSP platform. In this PV system, a high step up boost converter and bidirectional dc-dc converter for storing excess PV power in the battery are implemented. In parallel connected PV system a transformer is required in output for ac loads to enhance the voltage level to utility level. A

conventional two switch circuit is used for battery charging purpose which acts as a buck converter during battery charging mode and acts as a boost converter in battery discharging mode.

N. Pongratananukul and T. Kasparis explains the comparison is made between series and parallel connected PV systems with MPPT techniques which show that efficiency is higher in PV systems. An MPPT technique continuously senses the PV voltage and current, and it generates reference voltage as duty cycle command. Without MPPT controller one cannot obtain a reliable power from a PV panel because solar parameters vary under time of day and local climatic conditions. Efficiency curve of four different topologies buck, boost, buck-boost, and Cuk converter is obtained. From which we can observe that buck and boost converter has higher efficiency in relation with same generated power from different topologies.

Mangu, B et al., (2012) proposed a solar-wind based dual-input Cuk-SEPIC converter for telecom power supply for improving efficiency. This paper discussed a dual input dc-dc converter for telecom industry power supply applications. It utilized the hybrid source of wind and solar based power generation system for improved Cuk and SEPIC based dc-dc conversion system. This system combines the advantages of both Cuk and SEPIC converters. A Cuk converter produces a ripple free output voltage, and a SEPIC converter removes ripples in line currents with the use of two inductors.

Veerachary, Mummadi, 2011 presented to improved dual input Cuk SEPIC converter operates with lesser value of passive elements and shows high-efficiency performance with less power conversion losses. Dual input converter offers a highly reliable power supply for base trans-receiver station which operates in the presence of either photovoltaic source or wind source. The dual input converter operates in continuous conduction mode which supplies continuous dc power to the loads. The merits of the proposed dual input Cuk SEPIC converter is it operates with the lower rating of semiconductor switches and with less size of power storing device like battery and super capacitors.

Ol Orellana et al., (2010) proposed a four Switch Buck-Boost Converter for Photovoltaic DC-DC power applications. Photo voltaic source comes under green energy it involves a zero pollution power generation system. An intermediate power conversion system for PV source enables the maximum utilization of energy generated from solar cells. A high efficient model of four switch buck boost converter implementation is discussed in this paper. MPPT controller creates a very good performance on solar arrays.

R. Akhila and S. Nikhil (2012) explained the four switch converter offers lower loses but care has to be taken while implementing a switching strategy, short circuiting of sources and inductors must be avoided in the proposed four switch configuration. This topology consists of multiple switches but contains only a lesser number of passive elements. Thus it produces only less ripple in output voltage and current irrespective of switching frequencies. An adaptive MPPT algorithm is employed which selects either buck or boost operation depending on load voltage requirements. The proposed adaptive MPPT algorithm takes voltage and current feedback from both PV side and converter side.

Kim et al., (2004) developed a sensor less control method for BLDC motors from near-zero to high speeds. The permanent magnet brushless DC motor is widely used in space, military, and automotive industry applications. The sensor less control of such BLDC motor has created a great focus in modern research with cost effective approach. This paper utilized a control technique based on flux linkage estimation which is not a function of the speed of the motor. It overcomes the drawback of other sensor less control methodologies which makes it non-feasible for lower and very high-speed operation of the motor.

S. T. Lee and J. Hur (2017) explained the control method the BLDC motor can operate at low speeds to very high speed based on motor ratings. At low speeds, certain control techniques like back-EMF sensing and integration techniques cannot create commutation function for BLDC motor in sensor less control. Back-EMF is a function of motor speed and hence at low speeds detecting zero crossing of trapezoidal back-EMF of BLDC motor is not possible and also retrieving rotor

position by integrating back-EMF do not yield accurate position information. In flux linkage based control method motors, voltage and phase currents are measured and from machine model equations by integrating flux linkage can be obtained from starting position from which rotor position is obtained. This property makes it suitable to control the BLDC motor at very low speeds.

Wu, Yuanyuan, et al (2010) proposed a Position sensor less control based on coordinate transformation for brushless DC motor drives. This paper work deals with hardware implementation of sensor less BLDC motor drive. This paper presents a new control technique based on estimating back-EMF of BLDC motor from which rotor position can be originated for all three phases with the appropriate phase delay. S. Promthong and M. Konghirun explained the sensor less control technique is implemented using development board with a TMS320F2812 processor. This control method does not sense zero crossing of back-EMF rather measures the back-EMF of the BLDC motor. The proposed control technique offers dynamic speed control of brushless DC motor even under high load conditions.

Y.J. Lee et al., (2009) designed a compensation Technique for Smooth Transitions in a Non-inverting Buck–Boost Converter. This paper analyzed a linearization method for obtaining linear voltage boosting ratio for buck or boost converters. In general, for mode selection between buck or boost converter depend on sensing input and output voltage of a converter. This causes a sudden transient in output voltage in mode selection of converter. This adds to further loss of switching device used regarding discontinuity in its operation. A novel method to compensate transients or noises in output voltage is implemented in the proposed work and verified by analytical analyzes, simulation, and experimental validation. In the conventional controller of closed loop boost converter, a discontinuity compensator is added to reduce the transients caused in output voltage and to produce a noise and ripple free output voltage.

N. Femia et al., (2005) proposed a methodology for Optimization of perturbing and observe maximum power point tracking method. MPPT algorithms are added to PV system to increase the solar array generated power by continuously monitoring the

maximum power point of a PV array which depends on solar parameters like temperature and irradiance. Perturb and observe is the mostly used MPPT technique because of its simple algorithm. The major disadvantage of this algorithm is it does not produce a constant maximum power point voltage rather gives an oscillated value which could lead to wastage of energy obtained from PV panel. To overcome the significant drawback of P & O MPPT algorithm, its parameters need to be retuned according to the dc-dc converter employed for boosting purpose. The change in amplitude value of duty cycle for short duration is decreased when oscillations occur around maximum power point.

Chun et al., (2014) proposed a Sensor less control of BLDC motor drive for an automotive fuel pump using a hysteresis comparator. In general BLDC motors at starting do not offer high starting torque due to its property of electronic commutation. In this paper, a hysteresis comparator is used in sensor less control of brushless DC motor. The advantage of using a hysteresis comparator is it compensates the phase delay introduced due to filters used in sensor less control technique. Filter employed in control system is a low pass filter which rejects the high frequency switching noise contents in sensed three phase terminal voltage of the motor. This LPF adds a phase lag to estimated back-EMF which degrades the quality of torque developed, produces pulsations in the output torque. A new starting method called as potential startup method is added which develops a high starting torque of BLDC motor from its initial starting position.

2.2 Reported Works on Advanced Solar Power Generation and Sensor Less Vector Control of Brushless DC Motor

J. T. Bialasiewicz (2008) proposed a Renewable Energy Systems with Photovoltaic Power Generators. Photovoltaic power generation scheme has become a reliable non-renewable source over the years owing to the recent research works in the similar area. This has caused to increase installed capacity of solar power plants over the world. The general structure of this power generation scheme is solar array followed by an inverter with or without a boost converter for grid application as well as standalone operation. Several MPPT algorithms were introduced along with special

dc-dc converters to maximize the energy produced from the solar cell. Perturb and observe algorithm is invoked in major PV system for obtaining maximum power point. This method has failed to extort maximum power under varying solar conditions where incremental conductance algorithm shows better performance for P & O. But both the method suffer from the fact that maximum power point obtained is not stable within a point and they require a current sensing unit for obtaining maximum power criterion. This paper proposed and analyzed various configurations for a solar based power plant with boost converters and MPPT algorithms. The proposed scheme consists of two modes of operation of a typical PV system. Master mode in which PV alone supplies a particular power system and makes full control of voltage and frequency of the system maintaining high power quality. In slave mode PV system did not supply the system with generated power but keeping it idle by storing in the battery and the sources like diesel generator supply the loads.

Jinn-Chang et al., (2014) proposed a solar power generation system with a seven-level inverter. A dc-dc power converter and a multi level inverter is proposed in this paper. The dc-dc power converter is composed of a single boost converter and a transformer. It provides a two independent voltage sources containing many relations within the converter. Multi level inverter consists of a voltage selection circuit, the voltage stored across a capacitor and a full H-bridge dc to ac inversion circuit is discussed by Liu et al., 2013. The multilevel inverter tends to show less THD compared to conventional two level voltage source dc to ac inverters. Thus multi level inverters are preferred for solar power generation system as it shows greater power quality. But the major drawback of a multi level inverter is its switching strategy and control system is complex in comparison with two level inverters. In the proposed dc-dc power converter stage two voltage sources are generated which can be utilized by voltage selection circuit to select three different voltages. Hence the proposed converter can produce a seven level inverter output voltage with power quality enhanced at lower distortion. The major advantage of the proposed scheme is it can perform boost operation, enhance generated the voltage from PV array to grid level and can also convert it into ac for grid interconnection. The proposed scheme utilizes

only eight power switches, three diodes and two capacitors which are a far lesser count in comparison with conventional seven level inverter and boost converter topologies. A switching table is also not complex in this scheme because only two switches are employed in the level selection, and the remaining two switches are operated at high frequencies as employed in boost conversion stage. With reduced switches count the proposed topology exhibits low switching loss and high efficiency.

K. Xia et al., (2015) analyzed four-switch three-phase BLDC motor control scheme based on the quasi Z-source converter. Generally, in four switch inverters, dc-link voltage control is preferred more for improving the performance of the drive. The speed control is not given importance rather the current control is considered which influences the dynamic performance of the drive. Advantages of both four switch inverter and a quasi z-source are combined in the proposed topology. Four switches three phase inverters are preferred for motor control applications it operates at reduced switching losses with reduced number of switches and also cost and control the complexity of the drive is decreased by eliminating two switches. A quasi z- source inverter has produced the continuous ripple free current through DC-link which is utilized to produce constant power to drive BLDC motor. The proposed control scheme involves speed controller a conventional pi controller followed another current pi regulator. Another pi controller added for dc link voltage control which ensures the minimum reactive power of the drive. With the use of current controller dynamic performance of the drive is improved, by sensing three phase current of the BLDC motor error between the reference current and actual current is utilized to generate PWM switching pulse.

K. Suresh Kumar et al., (2014) proposed speed control of BLDC motor using fuzzy logic controller based on sensor less technique. Now a-days conventional brushed DC motors are substituted by brushless DC motor for its adaptability to various applications. It has excellent mechanical and electrical performances, simple in construction, lesser in size for the same rating of the motor. This literature used a sensor less control technique for brushless DC motor with fuzzy logic controller. It is based on obtaining rotor angle from estimated speed by sensing back-EMF of BLDC

motor. By simply adjusting the pulse on time of switches stator current of BLDC motor can be controlled which reduces the operating cost and complexity of the proposed drive control. The fuzzy logic controller acts as an excellent speed controller in the proposed controller of this sensor less scheme. Mandami type FLC is modeled using MATLAB software, and it is designed with two inputs error between original speed and measured speed along with the change in error and one output. Forty-nine set of rules have been framed for proposed fuzzy inference system. Speed sensor less control technique for brushless DC motor is simulated in Simulink, and it has excellent speed response with minimized ripple in developed torque by the motor.

R. Manikandan et al., (2013) proposed a fuzzy PI based speed sensor less speed control of position sensor less BLDC drive. In recent brushless DC motors have been preferred for applications like home appliances, robotic controllers and in the automotive industry due to its advantages over induction motors and brushed dc motors. This paper presents a sensor less control method using fuzzy pi for combined speed and position control of brushless DC motor. Indirect back EMF sensing methodology is proposed in this scheme. The proposed motor drive does not involve mounting proximity switches or Hall Effect sensors on motors for closed loop control of BLDC motor. Further closed loop action is completed by using the estimated speed by proposed technique. This method does not involve any integration operator to detect rotor angle moderately utilize zero crossing of three phase estimated back-EMF. From the simulated results it is proven that zero crossing detection of back EMF from sensing the terminal voltage of BLDC motors shown excellent speed response for a wide load operation.

W. S. Yan et al., (2009) proposed a sensor less direct torque controlled drive of brushless DC motor based on fuzzy logic. For controlling brushless DC motors, direct torque controller with fuzzy is analyzed. The conventional DTC scheme cannot control flux linkage of the motor because BLDC motor is an electronically commutated motor and its flux linkage changes every sixty degree of the control sequence. To improve the static and dynamic performance of the proposed sensor less BLDC motor drive fuzzy logic controller is added to the control scheme. Fuzzy seems

to be a robust controller over the conventional pi controller and does not involve tuning of the controller. It operates based on the predefined set of rules that will give automatically generated output with respect to the input. The proposed fuzzy controller has two inputs error between reference torque and actual torque and angle of flux linkage. Fuzzy logic controller ensures there is no ripple in developed electro-magnetic torque of the motor and also provides the high degree of control over torque. A state space model of BLDC motor is developed which is utilized to approximate back-EMF from which speed, torque, and flux angle of the motor can be calculated. DTC controller involves space vector modulation scheme for switching pulse generation. The advantage of DTC-SVM is that it reduces the pulsations or ripples in torque developed by the motor which tends to increase the efficiency of the motor and reduces the noise obtained due to vibrations of the motor.

S. M. M. Mirtalaei et al., (2008) proposed a novel sensor less control strategy for BLDC motor drives using a fuzzy logic-based neural network observer. BLDC motor is not a self-starting motor, and it requires a position sensor for motor starting. Three Hall Effect based position sensors are mounted in motor with the 120-degree phase shift between each sensor. This adds to the cost of the BLDC motor drive and also increases complexity in construction mechanical wise. Hall sensors operation is affected by surrounding temperature in motor winding, hence running a BLDC motor for a long time with almost full load is not possible. Therefore sensor less control of BLDC motor is created a huge attention for researchers in recent days. Three phase inverters are used to drive a BLDC motor, PWM generation scheme of BLDC motor requires the position of the rotor for providing proper commutation of the motor. In this paper, a novel scheme for sensor less BLDC motor control using neural network speed observers based on fuzzy logic inputs was proposed. The proposed neural network observers use fuzzy input and output data. Neural network observers produce back-EMF of the BLDC motor from its sensed three phase line to line currents and voltages value. This control method offered wide speed control of BLDC motor even under sensor less control.

An Advance Solar Power Generation and Control of Brushless DC Motor Using Phase Current Sensing of Sensor Less Vector Control. Design and analysis of a standalone PV system for a sensor less control of brushless DC motor are proposed in this paper. A buck-boost converter is used as a power converter for enhancing PV generated voltage to motors rated voltage is discussed by N. E. Zakzouk et al., (2016). A novel four switch buck boost converter with the lesser number of passive elements which produces a non-inverting output voltage is used to boost the input PV voltage and maximize the dc-link performance of the three phase inverter based BLDC drive is explained by Zhang et al., 2010. Incremental conductance algorithm which can observe rapidly varying solar parameters is added to the NFSBB converter to generate high step up voltage using buck boost converter and to obtain constant power for BLDC operation. For controlling both speed and torque of the motor, a phase current infusion technique is added to the control scheme along with space vector modulation. The robustness of the control algorithm is tested under varying load conditions. Three phase line currents of BLDC motor drive is sensed with the help of a current transducer and flux and speed of the motor is estimated using BLDC motor relation with its parameters and line currents. Then a conventional pi controller is used to regulate the speed of the drive. Then reference voltage signal for space vector modulation scheme is obtained using speed pi response. The Pi controller produces quadrature axis reference current and error in quadrature axis is obtained by deducting from the actual value of quadrature axis current. Similarly, error between direct axis reference and the actual converter is obtained. Now inverse Clarke transform is performed on quadrature and direct axis current and its output fed as a reference signal for space vector modulation. From the reference signal SVM initially, detects the sector of the reference signal and produces switching signal starting from the sector selected and rotates the switching vector with respect to the control frequency of the modulation. SVM scheme offers higher power quality and operates at reduced switching loss in an inverter.

2.3 Reported Works on PV FED BLDC Motor Drive Control Without Intermediate DC-DC Converter

Singh et al., (2016) proposed a solar photovoltaic array fed water pump driven by brushless DC motor using Landsman converter. Conventional water pumping scheme uses a single phase induction motor which draws a high current during starting of the pump. The idea of solar PV array based inverter scheme shows more difficulties in real time implementation. BLDC motors run at low voltage and provide necessary torque during its steady state operation. It is highly suitable for pumping applications. This paper proposed a special dc-dc converter for utilizing solar PV array for driving BLDC motor based water pumping system using conventional three phase inverter. The idea of introducing landsman converter is for controlling power delivered to BLDC motor from the solar array. The proper control of Landsman converter ensures soft starting of BLDC motor and its safer operation during heavy load condition. The structure of Landsman converter is quite simple, and it almost uses the same amount of passive elements present in a conventional boost converter. For continuous monitoring capability MPPT technique, incremental conductance MPPT algorithm is used in this scheme. This provides maximum power across inverters dc-link for maximizing the performance of the BLDC motor based water pumping system. The Landsman converter is forced to operate in continuous current mode irrespective of variations in the solar parameters. A soft switching topology is included for the converter it supplies continuous current to the inverter in both the mode of switch conducting and in switch off state, because of the high switching frequency of the pulse.

T. Esram et al., (2007) proposed performance comparison of different Maximum Power Point Tracking Techniques. This paper has discussed more than fifteen literatures for extracting maximum power from PV generation. It shows a detailed comparison of different MPPT algorithms which would be the excellent reference in future for standalone PV generation applications. The performance of an MPPT technique depended on various parameters number of sensors used, computational complexity, the time required for maximum power point convergence,

stability in the reached maximum power point and required cost for implementing the algorithm in hardware. The main objective of an MPPT technique is to find the stable voltage, current and power MPP of a PV system. Hill climbing perturb, and observer algorithm has created a wide range of focus in a PV array with the boost converter. This method involves decreasing or increasing a unit step magnitude of a duty cycle of a dc-dc converter. Similarly, it will also perturb PV voltage and current for unit time delay. The other efficient MPPT scheme is incremental conductance MPPT algorithm; it works on the principle that slope of the PV characteristic curve at maximum power point is zero. Once a maximum power point is obtained this algorithm does not change the MPPT value even if temperature and irradiance changes. Fractional open circuit voltage and short circuit current method are based on the principle that MPP voltage and open circuit voltage rating of a PV panel has a linear relationship even under changing irradiance. Fuzzy logic controllers provided a dynamic response of tracking maximum power of a solar panel. Fuzzy works on a predefined set of rules, the input of a conventional fuzzy logic controller are error and change in error. Error in the ratio of PV power and voltage is calculated from sensing the PV panel voltage and current.

Photovoltaic pumping system based BLDC using fuzzy logic MPPT control. Solar power requires a lesser cost for implementation compared with other renewable energy resources. A cost effective operation of water pumping scheme is possible by the use of solar power generation rather than utilizing grid to operate pumping motors. This idea not accepted in the past for installing in real time with tidy atmospheric conditions. But after the advancements in power electronic conversion systems, the use of MPPT technique to extract high power from PV cells and the modern controller system showed high reliability for powering pumping motors, lighting loads, cooling devices through PV. This paper discussed the performance improvement of a solar fed water pumping system with BLDC motor, the boost converter, and an inverter. A fuzzy logic controller is modeled as an MPPT controller for PV array. The conventional boost converter is used in this scheme which shows high efficiency when included with fuzzy based MPPT algorithm. A current controller is used to generate

switching pulse for three phase inverter driving BLDC motor which compares reference current with the actual current. The current controller ensures that the drive is operated with least possible power for producing necessary torque for driving the pump (Meridjet et al., (2013).

Kumar, R et al., (2014) proposed solar photovoltaic array fed Luo converter based BLDC motor driven water pumping system. In this research work, Luo converter with single power electronic switch and reduced passive elements is used as a converter for boosting solar PV voltage. This converter along with incremental conductance MPPT technique ensures excellent DC power supply to the inverter driving BLDC motor. Ramesh, G. P explained the Luo converter switching scheme adopts zero voltage switching which is necessary for safe starting of BLDC motor. This motor is initially coupled with a centrifugal water pump which draws a high current during starting. Conventional two level voltage source inverters with hall position signals are used for generating proper electronic commutation sequence for BLDC motor. This paper also discusses the design parameters of LUO converter, BLDC motor, and centrifugal pump. The performance of the proposed water pumping scheme with a change in load at a step time interval is simulated in Simulink and results verify the merits of the proposed scheme.

Pattanaphol, A et al., (2010) proposed a Z-source grid-connected inverter for solving the photovoltaic cell shading problem. In general, a grid connected solar based inverter system uses two configuration schemes. One is a number of PV panels connected in series with a single power inverter for grid feeding, and the other scheme is adding a dc-dc boost converter between PV panel and inverter. The first scheme suffers from low power extraction from PV sources because of series connection and the second scheme has a drawback of selecting efficient boost converter. In this paper, an impedance source network consisting of two inductors and two capacitors is added between PV source and inverter. It is shown that by performing a shoot through the state in an inverter that is turning on high and low switches of the same leg in the inverter, Z-source inverter provided a DC voltage boosting without any power loss. Conventional dc-dc boost converters add to the cost and size of the system whereas Z-

source inverter is a high performance cost effective solution for the solar inverter to interface with the grid. Z-source inverters can provide voltage boosting in the ratio similar to conventional boost converter fed inverter. A phase locked loop is used for generating a reference signal for space vector modulation technique to generate PWM pulse such that inverters output voltage is in phase with grid voltage.

Das, A. et al., (2009) proposed Z—Source inverter based permanent magnet brushless DC motor drive. Vehicles featuring with diesel engines create air pollution to the environment whereas PV or fuel cell based electrical vehicles with electrical motors is an environment-friendly solution to the present scenario. In this paper, a permanent magnet brushless DC motor drive powered from a PV cell through a Z-source inverter is proposed for an electrical vehicle application. The BLDC motors offer high-speed operation with dynamic torque response which makes it suitable for a vehicle application hence it has to take a maximum load. Z source inverter is a low-cost solution for a boost converter fed inverter for photovoltaic power generation systems. Z-source inverter shows high efficiency this leads to improve the performance of the BLDC drive. From the equivalent circuit of Z-source inverter with BLDC motor load the state space equation is derived. By using the state space equation the mathematical model of BLDC motor is obtained. The output current of brushless DC motor driven through a Z-source inverter is not sinusoidal as in the case of the induction motor. BLDC motors back-EMF is of trapezoidal shape, and its current waveform is square shape because of 120-degree conduction mode.

Zhou, Y et al., (2016) proposed A Single-Phase PV Quasi-Z-Source Inverter with Reduced Capacitance Using Modified Modulation and Double-Frequency Ripple Suppression Control. The voltage source fed typical Z-source inverters has replaced the conventional practice of boost converter with the inverter. The Grid feeding solar powered inverter suffered from frequency mismatch between dc power and inverters output power. This is compensated using a modified PWM scheme for grid connected inverters. A thin capacitor is used in the quasi-source network which still maintains the same voltage boosting the capacity of the inverter. Since the large values of capacitance look bulky and get damaged during long time continuous operation of the

inverter. But larger capacitance suits for stable operation and high dc-link performance. This type of inverter is suitable for drive applications where inverter has to supply a bulky load for most of the times. A proportional resonant controller is added to the closed loop operation of the inverter which eliminates the certain frequency components in the inverters output voltage. This eliminates the double frequency ripple occurred during power conversion from dc source to H-bridge through passive elements. This topology does not use any extra component to permit the use of thin film low capacitance for dc-link.

M. K. Nguyen, et al., (2011) proposed a new Switched-inductor quasi-Z-source inverter. Generally, a grid connected PV inverter has an intermediate power conversion system. This makes the system complex by adding additional elements to the system and control algorithm also tends to be tedious. Hence multi power conversion stages are avoided by the use of impedance source network in between inverter and PV source. Various topologies have been discussed for improving the performance of a Z-source inverter. The conventional z-source network is modified by adding more passive elements and diodes to improve characteristics like continuous dc-link current, dc power flow control, minimize high inrush current due to overshoot state during starting. A z-source network comprising of three diodes, two capacitors, and three inductors is proposed in this scheme. It is named as switched inductor quasi Z-source inverter and it showed optimum power performance at high efficiency. It involved boosting the input power supply from a photovoltaic source to a level equal to nominal grid voltage. The proposed switched inductor quasi Z-source inverter higher voltage step up ratio compared to the conventional Z-source inverter. However, it has certain other advantages like no starting inrush current and continuous dc current which makes it suitable for motor control applications. BLDC motor draws a high peaky current during starting and requires continuous power from the inverter for stable operation without any vibration. The switched inductor quasi Z-source inverter inhibits reduced voltage stress on capacitors and power switches, further by operating at nominal frequency switching losses are also minimum in the case of SLQZS inverter. Common mode voltage does not occur in this inverter topology because it

does not require earth point rather uses the dc ground point. A maximum boost control PWM technique further keeps the voltage gain of the SLQZSI higher, and the other advantage of switched inductor quasi Z-source inverter is it uses only lesser value and size of passive elements. Only lesser current flows in the circuit during shoot through state operation. During shoot through the state the inverter charges the inductor and capacitor with the dc source, and in other periods it functions as a conventional inverter.

2.4 Reported Works on Sensor Less Speed Estimation of BLDC Motor Drive and Torque Ripple Minimization

Y. Zhao et al., (2013) proposed a Model reference adaptive system-based speed estimators for sensor less control of interior permanent magnet synchronous machines. IPMSM motors have been used widely in electrical vehicle applications owing to its advantages like higher efficiency at maximum power can take the maximum load. Permanent magnet synchronous motors are not self-starting motors and require position sensors for starting it though back-EMF and current shape of this motor is sinusoidal. Zambada et al., 2010 model reference adaptive scheme is used to estimate the speed of PMSM motor in speed or position sensor less control algorithm. MRAS founds to be an efficient method for speed estimation, but estimated speed contains noises due to switching frequencies and motor vibration. For suppressing noise in the estimated speed, an adaptive line enhancer is used along with sliding mode observer which eliminates noise in sensed voltage and current. In this mode the PMSM motor operates in two modes of operation generator mode and motoring mode, MRAS is used to track speed of PMSM motor in both operating regions. The implemented MRAS technique initially estimates either position or speed of the motor and calculates the remaining parameter. MRAS speed estimation technique comes under machine mathematical model based technique and tuning requires if it is applied to motors of different rating and parameters. MRAS scheme employs a sliding mode observer which estimates back-EMF of the motor from three phase voltages and currents. The estimated back-EMF contains high-frequency harmonic components and noise which is eliminated using adaptive line enhancer.

C. Zheng et al., (2016) proposed a Sensor less Speed Control for Brushless DC Motors System Using Sliding-Mode Controller and Observers. In new research BLDC, motor control without speed or position sensor has created a wide focus. Speed or rotor position can be estimated or calculated using algorithms like MRAS model reference adaptive system, KALMAN filter, artificial neural network ANN, sliding mode observer SMO. In the above-mentioned methods, SMO tends to be robust algorithm and simple to implement. S. Chi et al., 2009 introduced the SMO along with a second order low pass filter estimates the speed of BLDC motor without any deviation. An efficient speed controlling algorithm for BLDC motor at varying load torque demand using sliding mode controller with a disturbance observer is proposed in this paper. This control algorithm eliminates deviations in speed from its reference value when there is increase or decrease in load torque. In conventional BLDC motor control pi speed regulators are preferred which has given excellent speed changes according to the speed reference within smaller settling time. However, in sensor, less control technique where speed or rotor position is estimated instead of sensing pi controller do not give optimum performance. Here a sliding mode controller found to be the robust controller for speed, and it controls fluctuation in speed when torque demand of motor is increased.

M. Tawadros et al., (2014) proposed a sensor less control of brushless DC motors using virtual back EMF mapping projection. Now-a-days BLDC motors have been preferred for many industrial applications over other electrical motors due to its high characteristic performance like efficiency, lower in size and produce high torque at even low speeds. Inverter fed BLDC motor operates in 120 degrees six step mode and has a trapezoidal back-EMF only two legs of inverter conducts and the third leg is kept open for every 60-degree of the electrical cycle. Conventional sensor less control algorithms use zero crossings of back-EMF for position sensing, in this paper, a back EMF line is constructed which is linear. This is used to obtain the rotor position at every 30-degree instants of time. The sensor less control using virtual estimating methods seems to be effective as physical hall position sensors. Zero crossing detection method is not able to control motor at very low speeds and also starting of a

motor at the stand still is also not possible. Hence special starting methods are required in back-EMF zero crossing method. The main objective of the proposed method is to control BLDC motor using virtual back-EMF projection method. Rotor displacement angle is obtained from the slope of BEMF at every 3o degree instants.

High performance low-cost incremental conductance PV MPPT technique to generate new clean energy resources solar power generation has created a wide attention for most researchers. It is a low-cost generation among various other renewable forms of energy like wind, fossil fuels. Rajasekar, S., and Rajesh Gupta 2012 introduced the power generated using solar cell has to be utilized to get maximum power from the photovoltaic source, various MPPT algorithms are in practice over the years. The performance of MPPT algorithm depends on dc-dc converters used. Perturb and observe, and incremental conductance MPPT algorithm has been used widely for solar power generation for both grid connected and stands alone applications. This paper presents an incremental conductance MPPT algorithm implemented in hardware using Arduino UNO atmega328 microcontroller platform. Incremental conductance technique involves changing step value of duty cycle over unit time delay to attain maximum power point. This algorithm has shown excellent MPP tracking and quick convergence under varying irradiance. This algorithm has the more complex decision-making condition based on the ratio between current power values of PV to its previous value. In this paper, a modified incremental conductance algorithm is proposed which reduces the above-mentioned complexes involved in the computation. A variable step size is added to the MPPT technique which reduces the MPP oscillations about the stable operating point. This modification allows the controller in reducing the computational time and implementation cost.

S. A. K. Mozafari Niapoor et al., (2010) proposed a PV power system based MPPT Z-source inverter to supply a sensor less BLDC motor. In this paper, a novel sensor less brushless DC motor control technique is used for PV fed water pumping system. A passive z-source network is added between PV source and inverter to obtain maximum power from PV cells. The Z-source network inhibits voltage boosting capacity owing to shoot through mode of operation of the inverter. In conventional

voltage source inverters two switches of the same leg are not turned on simultaneously to avoid short circuiting of the source. But in Z-source inverter for boosting of dc-link voltage two switches of the same leg were turned on for short duration of time in every conduction cycle.

Z-source inverter has shown great efficiency in converting dc to ac compared to buck-boost converter and inverter combination. The Z-source inverter further reduces the stress on power switches and by operating at fundamental frequency switching losses also minimized in the proposed scheme. A diode is added before the Z-source network to prevent power flow back to the source in this inverter operation. An indirect field oriented control scheme is used in the proposed water pumping system with BLDC motor as a prime mover. A current control scheme always improves the performance of the drive is discussed T. Banerjee et al., (2015).

Estimation of three phase induction motor using gravitational search algorithm for IFOC. In this paper, a model reference adaptive scheme is used to estimate the speed of induction motor in speed or position sensor less control algorithm. MRAS founds to be an efficient method for speed estimation, but estimated speed contains noises due to switching frequencies and motor vibration. For suppressing noise in the estimated speed an adaptive line enhancer is used along with sliding mode observer which eliminates noise in sensed voltage and current. L. Taneja et al., 2014 explained the induction motor operates in two modes of operation generator mode and motoring mode, MRAS is used to track speed of PMSM motor in both operating regions. The implemented MRAS technique initially estimates either position or speed of the motor and calculates the remaining parameter. MRAS speed estimation technique comes under machine mathematical model based technique and tuning requires if it is applied to motors of different rating and parameters. MRAS scheme employs a sliding mode observer which estimates back-EMF of the motor from three phase voltages and currents.

A. K. Akkarapaka et al., (2014) proposed the IFOC based speed control of induction motor fed by a high-performance Z-source inverter. In this paper, a permanent magnet brushless DC motor drive powered from a PV cell through a Z-

source inverter is proposed for an electrical vehicle application. The induction motors offer high-speed operation with dynamic torque response which makes it suitable for a vehicle application hence it has to take a maximum load. Z source inverter is a low-cost solution for a boost converter fed inverter for photovoltaic power generation systems. Z-source inverter shows high efficiency this leads to improve the performance of the induction motor drive. From the equivalent circuit of Z-source inverter with induction motor load the state space equation is derived. By using the state space equation the mathematical model of the induction motor is obtained. IFOC control scheme regulates current as well as torque developed by the motor.

V. Prabhash et al., (2016) proposed PV fed BLDC motor using zeta converter with minimized torque ripple for water pumping. In this paper work, Zeta converter with single power electronic switch and reduced passive elements is used as a converter for boosting solar PV voltage. This converter along with incremental conductance MPPT technique ensures excellent DC power supply to the inverter driving BLDC motor. The Zeta converter switching scheme adopts zero voltage and zero current switching which is necessary for safe starting of BLDC motor. This motor is initially coupled with a centrifugal water pump which draws a high current during starting. Conventional two level voltage source inverters with hall position signals are used for generating proper electronic commutation sequence for BLDC motor.

Parackal, R., Koshy, R.A discussed the design parameters of zeta converter, BLDC motor, and centrifugal pump. For improving the torque performance of the motor conventional electrolytic dc link capacitor is replaced by the ceramic capacitor and a power switch. The ceramic capacitance value is very less compared to an electrolytic capacitor used, and it minimizes ripple in torque caused by an electrolytic capacitor. The performance of the proposed water pumping scheme with a change in load at a step time interval is simulated in Simulink and results verify the merits of the proposed scheme.

Torque ripple reduction of BLDC motor using predicted current control. Back-EMF of BLDC motor is nonlinear in shape. Hence torque ripple occurs in the motor.

Ripples and harmonics of higher order in stator current of BLDC motor are other reason for ripple occurrence in torque. Ripples or pulsations in developed torque of BLDC motor is due to high switching frequency involved in switching pulse generation for inverter operation. Torque ripple occurs in both operating region of motor commutation period and also in conduction period. Continuous current flow to BLDC motor is ensured even if 120-degree conduction is involved because one phase of the motor is not energized at any instant of time. This is achieved using current prediction scheme during BLDC motor commutation period by maintaining the proper duty cycle. In the proposed control methodology two different current controllers are used to minimize torque ripple of BLDC motor because the source of torque ripple during commutation mode and conduction mode is different. Hence the proposed predictive control methodology can minimize the pulsations in produced torque is explained the June Park et al., (2016).

2.5 Inferences from Literature Survey

Sensor less speed estimation techniques use PI controller as adaptation method which involves complex tuning. Hence speed estimation methods should be based on mathematical model without any controllers. BLDC drives produce load torque with high ripple content and inject harmonics in current and back EMF. This is due to the switching frequency of the inverters used.