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A Review on Design and Implementation of Solar Powered BLDC Motor Driven Electric Vehicle

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Abstract- The DC (BLDC) motor is a perfect drive for low and medium power applications as a result of its high effectiveness, high torque/inertia ratio, high volume of energy, low maintenance requirement and an extensive variety of speed control The proposed control algorithm eliminates phase current sensors and adapts a fundamental frequency switching of the voltage source inverter (VSI), thus avoiding the power losses due to high frequency switching. No additional control or circuitry is used for speed control of the BLDC motor. The speed is controlled through a variable DC link voltage of VSI. An appropriate control of zeta converter through the incremental conductance maximum power point tracking (MPPT) algorithm offers soft starting of the BLDC motor The agriculture sector in our country is highly dependent on rainfall. The system is fully based on renewable energy which is always available without any limitations. Technological improvement in electricity generation by solar system makes the system more efficient. So this scheme can be implemented for irrigation purpose to solve the problem of load shedding. In this way solar power helps to farmer to reduce cost of electricity and have good advantage if additional power supplied to utility grid. This is a simple, cost effective and efficient brushless DC (BLDC) motor drive for solar photovoltaic (SPV) array fed water pumping system. A zeta converter is utilized in order to extract the maximum available power from the SPV array.

Keywords- Solar, BLDC motor, battery HEV, EV, sensor.

I. INTRODUCTION

Motors are often used due to high efficiency, high power density, large starting torque, noiseless operation, and low weight and smaller in size. Recent vehicles are powered by hub type BLDC motors, motors in-build in the wheel, to avoid complex power train mechanism.

The distance covered by the electric vehicle per one charge unit is called the range of the electric vehicle. Range is a very important parameter in electric vehicles because it defines energy required to the vehicle.

Manufacturers have been primarily trying to increase the range of the electric vehicle.

By improving the efficiency of overall components used in electric vehicle like motor, power converter, and Battery, the Range can be improved.

Range can also be improved by using Methods Used to Achieve Regenerative Braking in Electric Vehicle:

- Using DC/DC converters
- Using Ultra capacitors

Using electronic gear shift mechanism Conventionally, EVs use mechanical brake to increase the friction of wheel for the deceleration purpose. However, from the viewpoint of saving energy, the mechanical brake dissipates much energy. Since the EV's kinetic energy is converted into the thermal one.

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In view of this, this paper discusses how to convert the kinetic energy into the electrical one that can be recharged to the battery. Thus, both the electric brake and energy regeneration are achieved .The so-called energy regenerative brake mainly employs the back electromotive force (EMF) of the motor in the braking process. The back EMF is regarded as a voltage source to recharge in the battery.

However, the maximum back EMF is generally lower than the battery voltage even if the EV is driven at its highest speed. Thus, if one would like to recharge the back EMF to the battery, the back EMF voltage must be boosted. Therefore, many articles have proposed a dc/dc converter to achieve the braking energy regeneration. Unfortunately, these methods need an additional dc/dc converter to reach the purpose. Not to mention the cost increase, the converter also has the efficiency problem that results in additional energy dissipation.

II. RELATED WORK

By back EMF method, the accurate value of torque was determined. **Sung Jun Park et al (2000)** proposed a novel approach to minimize torque ripples and to increase the BLDC motor efficiency. In this approach, the phase back EMF waveforms in a-b-c reference frame were transformed to the d-q-0 reference frame. Accordingly, the optimum phase current waveforms were obtained by transforming the d-q-0 variables to a-b-c. Further the optimum phase current waveforms obtained are used as reference values and the motor winding currents were forced to track it by delta modulation technique. 11

Tae Sung Kim et al (2001) have proposed a new algorithm for conventional BLDC motor drive to reduce torque ripple which is generated by Unipolar PWM method. In this algorithm, the current harmonics were calculated within a permitted degree using Fourier series coefficients. After transforming these harmonic components into stationary frame, phase current similar to rectangular waveform was generated by applying Space Vector Pulse Width Modulation (SVPWM) method. Hence it reduces current ripple and also noise and vibration.

Byoung Hee Kang et al (2001) deal with torque ripple reduction of BLDC motor with the help of decaying phase back EMF. In many control methods, the torque ripple reduction was considered from the point of current control. But the torque ripple in commutation period of BLDC motor is unavoidable, even if the current control is successful. In this scheme, torque model with decaying phase back EMF was considered and the causes of commutation torque were analyzed.

Sang Hyun park et al (2003) have introduced a novel current control algorithm for torque ripple reduction of BLDC motor using four switch three phase inverter. The proposed scheme was compensated for the commutation current slopes of the incoming and outgoing phase during the commutation interval of the phase currents in various speeds. Hence torque ripple was not produced during commutation. Moreover by reducing the switch counts, it is possible to make the drive of BLDC motor cheaper and smaller for industrial applications.

An effective approach of BLDC spindle motor system was presented by **Quan Jiang et al (2003)** to predict its performance accurately. In this approach, a mathematical model based on direct analytical solutions is used for both characteristics analysis of spindle motor and MOSFET switches of the inverter.

III. ELECTRIC VEHICLE

Electric vehicle (EV) is based on electric propulsion system .No internal combustion engine is used. All the power is based on electric power as the energy source. The main advantage is the high efficiency in power conversion through its proposition system of electric motor.

1. Components of an Electric Vehicle:

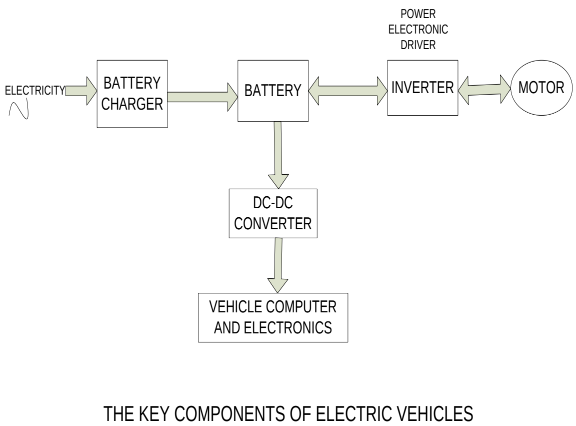

Fig 1. Components of an Electric Vehicle.

The battery is the main energy storage. The battery charger is to convert the electricity from mains to charge the battery. The battery voltage is DC and I is inserted into switched-mode signal through power electronic inverter to drive the motor. The other electronic components in a vehicle can be supplied to the battery through DC-DC converter that step down the voltage from the battery pack to lower voltage such as 5V-20V.

IV. LITERATURE SURVEY

Ming-Ji Yang [1] This paper proposes a simple but effective method of electric brake with energy regeneration for a brushless dc motor of an electric vehicle (EV). During the braking period, the proposed method only changes the switching sequence of the inverter to control the inverse torque so that the braking energy will return to the battery. Compared with the presented methods, the proposed solution simultaneously achieves dual goals of the electric brake and the energy regeneration without using additional converter, ultra capacitor, or complex winding-changeover technique.

Since the braking kinetic energy is converted into the electrical energy and then returns to the battery, the energy regeneration could increase the driving range of an EV. In addition to the braking period, the duration of release throttle is also included in the energy-regenerative mechanism such that the EV is similar to engine vehicles having the engine brake. Therefore, the electric brake can improve rider's comfort and enhance the EV's safety. Finally, the feasibility of the proposed method is demonstrated by experimental results. It shows that the driving range of the EV could be increased to about 16.2%.

A. Joseph Godfrey [2] A new electric braking system is proposed for a brushless DC (BLDC) motor driven electric vehicle (EV) in this paper based on stopping time and energy regeneration. This new braking system is developed by combining various regenerative methods and plugging. Other than the existing performance measures such as boost ratio, braking torque, and maximum conversion ratio; stopping time and energy recovery for various methods are studied for different running conditions. It is observed that the stopping time is less for plugging and increases in the order of two, three and single switch method. In addition, energy recovery is better for single and three switch method. Based on these performances, a new braking strategy is proposed which combine all the regenerative braking methods including plugging and switch among themselves based on the brake pedal depression. The effectiveness of the proposed method is shown using both simulation and experiment results.

Cheng-Hu Chen [4] In this paper, a cost effective single stage bidirectional DC/AC converter is designed and implemented using a general full-bridge inverter without any additional power switches or bulky passive components. According to different driving conditions, three switching strategies are developed and analyzed. These switching strategies, which are named after the operating number of the power switches, are called the single-switch, two-switches and three-switches control strategies.

Different performance indexes such as boost ratio, maximum voltage conversion ratio, braking torque, etc., are proposed and compared among different switching strategies. Theoretical analysis and experimental results have revealed that the cruising distance, braking torque, and reliability can be improved effectively using a variable braking control strategy according to the driving conditions. Since the additional power switches, passive components and costly position sensors are not required, the proposed method is particularly suitable for various light electric vehicles.

P.Balachennaiah et. al. [5] This paper proposes a method to minimize the real power loss (RPL) of a power system transmission network using a new meta-heuristic algorithm known as firefly algorithm (FA) by optimizing the control variables such as transformer taps, UPFC location and UPFC series injected voltage magnitude and phase angle. A software program is developed in MATLAB environment for FA to minimize the RPL by optimizing (i) only the transformer tap values, (ii) only UPFC location and its variables with optimized tap values and (iii) UPFC location and its variables along with transformer tap setting values.

P.Damodharan et.al[6] This paper describes a position sensor less operation of permanent magnet brushless direct current (BLDC) motor. The position sensor less BLDC drive proposed, in this paper, is based on detection of back electromotive force (back EMF) zero crossing from the terminal voltages. The proposed method relies on a difference of line voltages measured at the terminals of the motor. It is shown, in the paper, that this difference of line voltages provides an amplified version of an appropriate back EMF at its zero crossings. The commutation signals are obtained without the motor neutral voltage. The effectiveness of the proposed method is demonstrated through simulation and experimental results.

Eiji Sato et.al. [7] This paper, high-output motor control and variable voltage system are introduced as technologies, which increase the output of motor drive systems for hybrid vehicles. High-output motor control enabled 30% increase of output by driving the permanent magnet (PM) motor with a rectangular wave. The variable voltage system successfully managed to achieve both high output and low loss by increasing the battery voltage using a boost converter.

V. PROPSED METHODOLOGY

The photo voltaic (PV) system is proposed in this paper in order to replace the conventional energy sources like coal, nuclear, gas etc. BLDC motor is replaced with the commercial dc motor to achieve better performance, less maintenance and also less cost for water pumping applications.

A boost converter is used to step up the available low level dc voltage form solar panel into high voltage. An LC filter design is introduced in this paper to reduce the harmonics and to smoothen the out of the boost converter. A single phase inverter is used to convert boost output dc voltage into an ac voltage. The pulses for inverter are generated with SVPWM technique and the speed of the motor is adjusted with the help of PI controller.

Finally a absolute model of water pumping system with the proposed inverter Will be implemented in Matlab/Simulink. To obtain the optimum output this system is examined with conventional boost converter. Braking forms an important aspect of any on-road vehicle. For the widespread development of EVs and HEVs, developing an efficient braking method is one of the major research areas. The research objective focuses to develop a DC equivalent model of the motor and battery system excluding the conversions with the use of proper transformations.

To develop a logic to implement proper sharing of kinetic energy of the wheel between plugging (using auxiliary motor) and regeneration (using main motor).

To implement plug braking at lower speeds effectively where the method of regenerative braking fails.

- Comprehensive Literature review on various modelling and controlling techniques of the regenerative braking in electric vehicle.
- To braking system for vehicular system which uses single stage converter to achieve regenerative braking in electric vehicle. The proposed system will be comprises of a SPV array, a BB converter, VSI and a BLDC motor coupled to sensor and without sensor less designed Sunlight has an abundance of photons (i.e.) packets of energy.

They contain tremendous amount of energy that varies in accordance with dissimilar light wavelength. Upon striking a cell and the PN junction device, these photons are either Reflected or absorbed. If they get absorbed, a voltage appears across the junction that drives the DC current of the external circuit. Figure 2 shows the equivalent circuit of a PV cell. Here the model has been exemplified by a current source connected anti-parallely with a diode, and the non-idealities are shown by inserting shunt (R_p-parallel) and series resistances (R_s).

The simulation model of the Photovoltaic panel depends greatly on the output current (I) of the PV equivalent model. Its mathematical equation is illustrated by,

$$I = I_{ph} - I_r\left[\frac{e^q\left(V + I\cdot R_a\right)}{\eta^{k\cdot T}} - 1\right] - \frac{V + I\cdot R_s}{R_p} \quad (1)$$

Where V represents output voltage of PV; q is the electrical charge, $(1.6\times10^{-19}\text{ C})$; I_{ph} Represents the photocurrent; I_r represents reverse saturation current; η is the quality factor of solar cell; k is Boltzmann constant (1.38×10^{-23}); T-temperature in Kelvin.

Figure 3 shows the V-I characteristics of a PV array.

$$I_{ph} = I_{ref}\left[1 + ht\left(T - T_{ref}\right)\right] \times \frac{S}{S_{ref}} \quad (2)$$

Where I_{ref} is short circuit current; S is irradiance strength; S_{ref} is reference irradiance strength; T is temperature; T_{ref} is reference temperature and ht is the cell module temperature coefficient Power versus voltage characteristics for different irradiation level is shown in Figure 4. Equations (1) & (2) can be enforced for the simulation of solar cell characteristics.

The PV Array must function at Maximum Power Point [17] [18]. Operation at a unique point with specified voltage and current values at a specific load resistance needs to be ensured. This requires a separate power converter for MPPT [9] [2] This system illustrates, an interleaved DC-DC converter utilized for impedance matching between load and PV module by altering the duty cycle of the power electronic switches, in order to extract maximum power

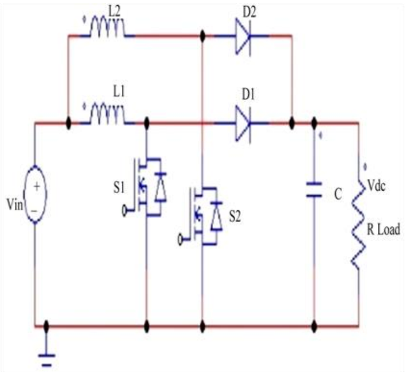

Fig 2. Two phases interleaved DC-DC boost converter.

A BLDC motor is a type of synchronous motor. This implies that the rotor has a permanent magnet rotating at the same frequency with the presence of a classic three phase stator like that of a synchronous motor.

For controlling the power electronic switches, the BLDC motors produce signals by accurately detecting the rotor position or magnetic pole position and hence are different from synchronous machines. Hall element is the most commonly used position sensor. However certain motors make use of optical sensors too. The variable voltage and variable frequency (VVVF) that is usually necessary for a BLDC drive is provided by a three phase full bridge inverter as shown in fig.2

The PWM inverter with a six switch voltage source con Figuration and with constant DC link voltage (V_{dc}), that is the same as permanent magnet synchronous motor and induction motor drives is developed.

A BLDC motor can be represented by,

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} R & 0 & 0 \\ 0 & R & 0 \\ 0 & 0 & R \end{bmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} L-M & 0 & 0 \\ 0 & L-M & 0 \\ 0 & 0 & L-M \end{bmatrix} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + \begin{bmatrix} e_a \\ e_b \\ e_c \end{bmatrix} \quad (4)$$

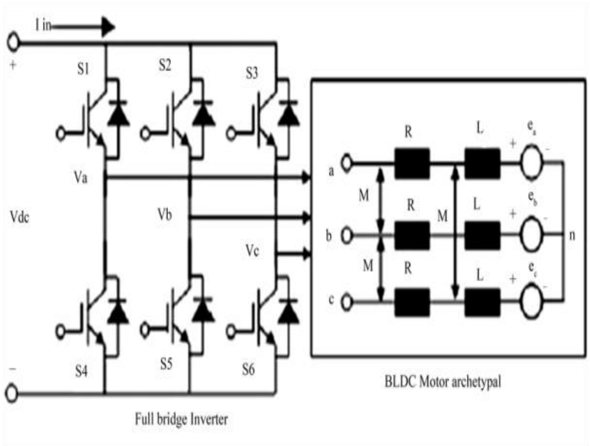

Fig 3. Equivalent circuit of brushless DC motor drive system.

Where V_a, V_b, V_c are represent the armature voltages; i_a, i_b, i_c are the armature currents; R is the resistance of the armature windings; e_a, e_b, e_c are the back emf; M & L are the mutual-inductance and self inductance of the winding respectively.

$$T_e = \left(e_a i_a + e_b i_b + e_c i_c\right) / w_r \quad (5)$$

Where T_e represents the electromagnetic torque; Wr represents the mechanical speed of Permanent Magnet rotor.

The equation representing a BLDC motor is,

$$\frac{dw_r}{dt} = \left(T_e - T_L - Bw_r\right) / w_r$$

Where, B is the damping constant; T_L represents the load torque and J represents the moment of inertia of the motor. The following Figure 8 illustrates the block diagram of a BLDC motor drive.

The system composed of a Proportional Integral (PI) speed controller & limiter, Hall sensor, PWM controller, reference current generator, three phase bridge inverter and the load are realized. The PI speed controller controls the error by matching the speed of the motor with the reference value. Based on the controller and the position sensor the three phase reference currents are produced with the help of a reference current generator.

The winding currents (i_a, i_b, i_c) are controlled by the PWM controller in a small set about the reference currents. The motor currents and the reference currents are compared and switching pulses are generated accordingly to drive the three phase bridge inverter. Due to its simple arrangement and ease of implementation, the Proportional Integral controller is mostly utilized in electrical drive systems.

The idealized equation of PI controller is,

$$u(t) = ke(t) + \frac{1}{T_i}\int_0^t e(t)\cdot dt \quad (7)$$

Where k is the gain; T_i is the integral time, and

$$e(t) = r(t) - y(t) \quad (8)$$

Where $e(t)$ represents feedback error; r(t) & y(t) represents the input and output respectively. In terms of torque, the PI controller output value, is stated as

$$T(n) = T(n-1) + K_p\{e(n) - e(n-1)\} + K_I\{e(n)\} \quad (9)$$

Where, e(n − 1) is the previous error value; e(n) represents the current error signal; K_I is the integral gain and K_p is the proportional gain. From the equivalent circuit, the transfer function of speed in S domain of a BLDC motor can be derived as

$$\frac{\theta}{V} = \frac{w}{V} = \frac{K_t}{2(R+Ls)(b+J_s)+K_tK_e} \quad (10)$$

Where the rotating speed (θ = w) is the output and the input obtained is the Voltage (V); R & L are the winding resistances and inductance respectively; b represents the damping factor; J is the PM rotor inertia; K_t represents the torque constant and K_e represents motor constant. The efficiency of a BLDC motor is evidently higher when

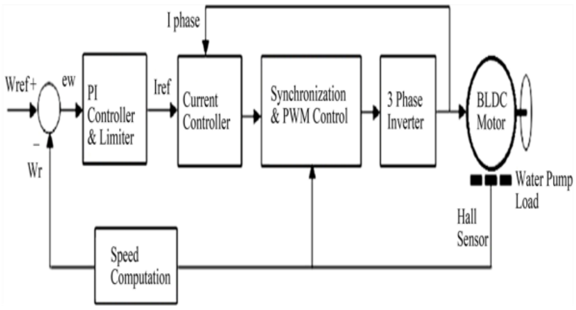

Fig 4. Block diagram of brushless DC (BLDC) drive system.

Compared to that of a commutator motor of equal size. The absence of brush friction contributes to this regard. Since brushes are eliminated, it no longer necessitates maintenance. So, this BLDC motor is the best choice of pumping application for rural areas.

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The variable Voltage and variable frequency (VVVF) that is usually necessary for a BLDC drive is provided by a three phase full bridge inverter as shown in Figure 7. The PWM inverter with a six switch voltage source con Figuration and with constant DC link voltage (V_{dc}), that is the same as permanent magnet synchronous motor and induction motor drives is developed.

VI. CONCLUSIONS

The simulation model of an MPPT controller and solar input voltage and three phases BLDC drive is will be developed using MATLAB/Simulink. Position control methods for BLDC motors will be presented.

The fundamentals of various techniques have been introduced, mainly back-EMF schemes and estimators, as a helpful reference for preliminary investigation of conventional methods. Advances in the position control and applications were additionally talked about.

To give knowledge in control method and their benefits a categorization of existing methods and newer methods were presented with their merits and drawbacks. From the above discussion, it is clears that the control for BLDC motors using position sensors, such as shaft encoders, resolvers or Hall-effect probes, can be enhanced by means of the reduction of these sensors to further reduce cost and improve reliability.

Furthermore, sensor less control is the only option for some applications where those sensors cannot function reliably due to harsh environmental conditions and a superior performance is necessary, mainly back-EMF schemes and estimators, as a useful reference for preliminary investigation of traditional methods. Advance in the position control and applications were also discussed.

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