Sensorless Pmbldc Motor Driven Solar-Pv Battery Fed EV System With Regenerative Braking Employing Zeta Converter

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Abstract- *This paper presents a sensorless Permanent Magnet Brushless DC (PMBLDC) motor driven electric vehicle (EV) system powered by a solar photovoltaic (PV) array and battery storage. To achieve high efficiency and reliable operation, a Zeta converter is employed as the power conditioning interface, enabling maximum power point tracking (MPPT) for solar PV utilization and bidirectional power flow for battery management. The proposed system eliminates the need for mechanical sensors, thereby reducing cost, complexity, and maintenance, while ensuring robust motor control through sensorless techniques. Additionally, regenerative braking is integrated to recover kinetic energy during deceleration and feed it back into the battery, improving overall system efficiency and extending driving range. The coordinated control of PV, battery, and motor drive ensures optimized energy management under varying driving and solar irradiance conditions. Simulation and analytical studies highlight the effectiveness of the system in achieving improved efficiency, reliability, and sustainability for electric vehicle applications.*

Keywords- Sensorless PMBLDC Motor, Solar Photovoltaic (PV), Battery Storage, Zeta Converter, Maximum Power Point Tracking (MPPT), Regenerative Braking, Electric Vehicle (EV), Energy Management.

I. INTRODUCTION

The rapid depletion of fossil fuels and the growing environmental concerns have accelerated the global shift toward clean and sustainable transportation systems. Electric vehicles (EVs) have emerged as a promising solution, offering reduced greenhouse gas emissions, lower dependence on conventional fuels, and enhanced energy efficiency. However, the effective integration of renewable energy sources, reliable motor drives, and advanced power converters remains critical for the widespread adoption of EV technology.

Among various motor technologies, the Permanent Magnet Brushless DC (PMBLDC) motor has gained significant attention in EV applications due to its high efficiency, high torque-to-weight ratio, wide speed range, and low maintenance requirements. The use of sensorless control techniques further enhances system reliability and reduces cost by eliminating mechanical position sensors.

For powering EVs, solar photovoltaic (PV) systems integrated with battery storage provide a sustainable and eco-friendly energy source. However, the intermittency of solar power necessitates efficient energy management and power conditioning. In this regard, the Zeta converter plays a vital role as a versatile DC–DC converter, capable of maintaining a regulated output voltage, enabling maximum power point tracking (MPPT), and ensuring seamless charging/discharging of the battery.

Furthermore, incorporating regenerative braking in EV systems significantly improves energy efficiency by capturing kinetic energy during braking and feeding it back into the battery. This not only extends the driving range but also reduces overall power consumption.

This work presents the design and analysis of a sensorless PMBLDC motor-driven solar-PV battery-fed EV system employing a Zeta converter with regenerative braking capability. The proposed system aims to optimize energy utilization, ensure robust motor control, and enhance the reliability and sustainability of EV operation.

II. DESIGN OF SOLAR PV ARRAY

An SPV array of 1.5 kW peak power capacities is preferred in such approach that the interpretation of the scheme is not affected by the losses connected in the midst of the converters. The parameters of the SPV array are estimated at the standard solar isolation level of 1000□□/ *m* 2 .As irradiance value changes it affects power and thus efficiency of the system is get affected, thus efficiency of the system is reduced.

Table I. Design of Solar PV array

For a PV Array	
Parameters	Values
Open circuit Voltage	20.76V
Short circuit current	6.22A
Temperature	25 ºC
Irradiance level	1000
For a PV Array	
Voltage at MPP	248.5
Power at MPP	1550W
Current at MPP	1550/248.5=6.23A
Number of cell connected in series	248.5/20.76=12
Number of cell connected in parallel	6.22/5.59=1

III. MPPT ALGORITHM

The MPPT proficiency is generally used to amend maximum benefits that is maximum efficiency in solar PV planted application. In this paper, incremental conductance MPPT controller is used which gives smooth and fast tracking Performance under any atmospheric condition. This MPPT gives better performance than P and o algorithm. The INC conductance MPPT is tracked via evaluating existing conductance with next incremental conductance. From incremental conductance flowchart [8], current and voltage are output of solar PV array at any time. The duty cycle of boost converter play very important role in order to gets maximum benefits from solar PV array. When solar PV voltage become constant after particular point, output current is going to increases, then duty ratio is also improved. If current declines then duty ratio falls. In generally, main purpose of algorithm is to look towards the appropriate duty cycle in which incremental conductance becoming instantaneous conductance due to that PV system is always operated around MPP. ΔD is incremental size which helps to determine how fast MPP is going to tracked , grater size ΔD fast tracking will be achieve. The major benefits of incremental conductance are that it can generate superior results beneath quickly changing environment condition. For tracking the maximum power from PV system, various methods have been developed over the decade which involves simple voltage and current relations. For this research work, Incremental Conductance algorithm is chosen due to its superiority over other algorithms.

- Incremental conductance

This MPP algorithm is based on the fact that at the Maximum power point, the P-V curve slope is zero. The power obtained from the PV is differentiated with respect to voltage.

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I + V\frac{dI}{dV}$$

At MPP, the rate of change of power w.r. to voltage is zero

$$\frac{dI}{dV} = -\frac{I}{V}$$

The algorithm of the Incremental Conductance works by comparing the incremental conductance ($\frac{dI}{dV}$) with instantaneous conductance ($-\frac{I}{V}$). Achieving the $\frac{dP}{dV} = 0$ is the control aim to achieve MPP of the array. Positive value of dP/dV refer that the operating region lies on the left hand side of MPPT and increase in array voltage would yield increase in power. Alternatively, negative value of dP/dV infers that the operating region had exceeded the MPPT and increase in voltage would reduce the power as shown in figure 2.11.

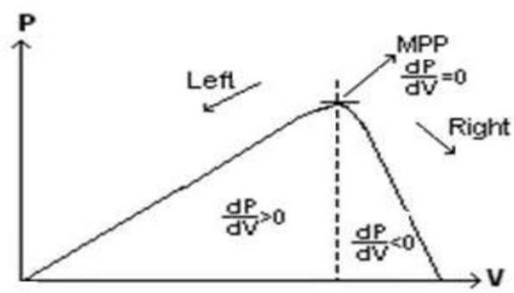


Figure 3.1 : P-V curve for IC

IV. SPEED CONTROL OF BLDC MOTOR

A Brushless DC (BLDC) motor is a class of electrical machines that converts direct current (DC) electrical power into mechanical power using the interaction of magnetic fields. Unlike conventional brushed DC motors, BLDC motors rely on either electromechanical or electronic commutation to periodically change the direction of current flow in the stator windings. Most BLDC motors are designed for rotary motion, although linear configurations also exist, producing direct linear force and motion. Their high efficiency, compact size, and superior torque characteristics make them well-suited for modern applications such as electric vehicles, renewable energy systems, and water pumping.

In conventional BLDC drives, phase current sensors are typically used for commutation and control, which increases cost and complexity. The proposed sensorless BLDC motor drive eliminates the need for such sensors, thereby reducing hardware requirements and improving reliability.

The drive is designed to maintain the motor's rated speed regardless of climatic variations by continuously regulating the DC bus voltage of the Voltage Source Inverter (VSI) to the rated DC value of the motor.

To ensure effective energy management, a bi-directional power flow control strategy is adopted. By regulating the DC bus voltage and, in turn, the operating speed, the system can supply the required power to operate the motor at full capacity under favorable conditions. However, under weak solar irradiation or in the absence of the grid, the DC bus voltage cannot always be maintained at the rated value. In such cases, the motor speed is governed by the available DC bus voltage, ensuring continued operation even under fluctuating climatic conditions.

This approach enhances the practicality of BLDC motor-driven systems in renewable energy and electric vehicle applications, offering an efficient, sensorless, and reliable solution.

V. PROPOSED SCHEME

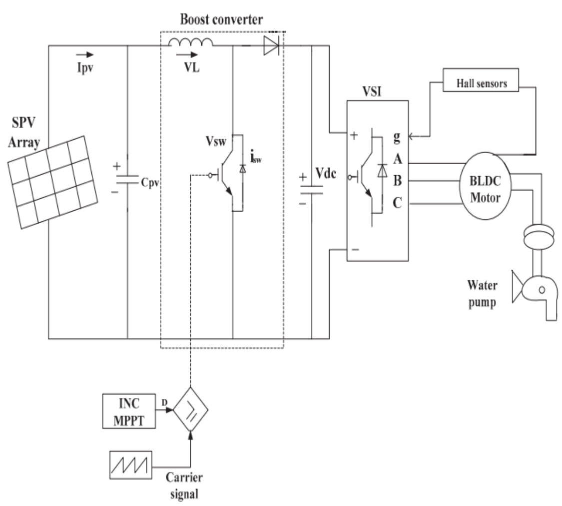


Fig. 5.1 Configuration of the SPV array fed BLDC motor driven water pumping system.

Fig.5.1 shows the proposed system configuration, in which BLDC motor is used for pumping system , BLDC motor is operated by voltage source inverter of DC-link.the proposed system gives energy from solar PV based boost converter for pumping load. Solar PV array generates energy gives to the boost converter; the switch of the boost converter is operated by MPPT algorithm such that maximum benefits from solar PV array is optimized and also gives smooth performance of BLDC motor for pumping application. The hall sensors are used in order to sense rotor position of motor. Hall sensors are electronically commuted circuit used for inverter switching.

VI. BI-DIRECTIONAL POWER FLOW CONTROL

The development of a reliable water pumping system and full utilization of the resources are realized by a grid interactive PV generation. To allow the flow of power in either direction, a bi-directional power control based on a UVT generation [20, 27-28] is applied as shown in Fig. 2. This is the simplest technique and is easy to implement as it does not require any complex mathematical model or algorithm. A single phase PLL (Phase Locked Loop) is used to synchronize the utility grid voltage and current. It generates a sinusoidal unit vector of supply voltage, sin θ at fundamental frequency. On the other hand, an amplitude of fundamental component of supply current, Isp is extracted by regulating the DC bus voltage, vdc.

A proportional-integral (PI) controller is used as a voltage regulator. Vdc is sensed and passed through a first-order low pass filter to suppress the ripple contents. The filtered vdc is then compared with a set value, Vdc*. A fundamental component of supply current, is* is extracted by multiplying Isp and sin θ. The sensed supply current, is is compared with is* and error is processed through a current controller to generate the gating pulses for VSC. When it is required to draw power from utility, the voltage regulator generates a positive Isp. Therefore, an in-phase supply current is drawn from the grid. Likewise, when the utility is fed by PV array, a negative Isp is generated resulting in an out-of-phase supply current. Thus, by reversing the direction of current, direction of power flow is controlled as per the requirement. An improved power quality at the utility grid is also ensured by the applied control technique in terms of total harmonic distortion (THD) and power factor. In case the grid is not available, the DC bus voltage cannot be regulated. Nevertheless, the PV array is able to feed the water pump in standalone mode although being sensitive to the climatic condition. The detailed analysis of proposed bidirectional power flow control is given in Appendices.

VII. SIMULINK MODEL

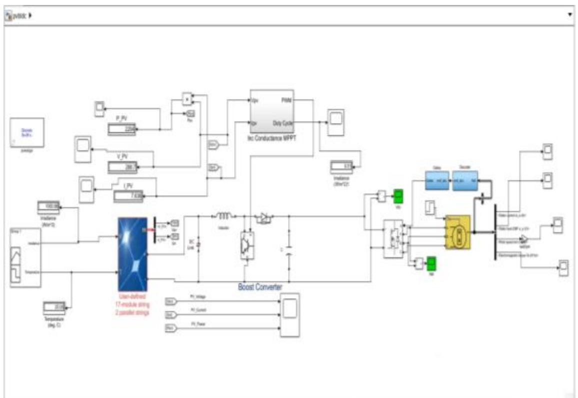
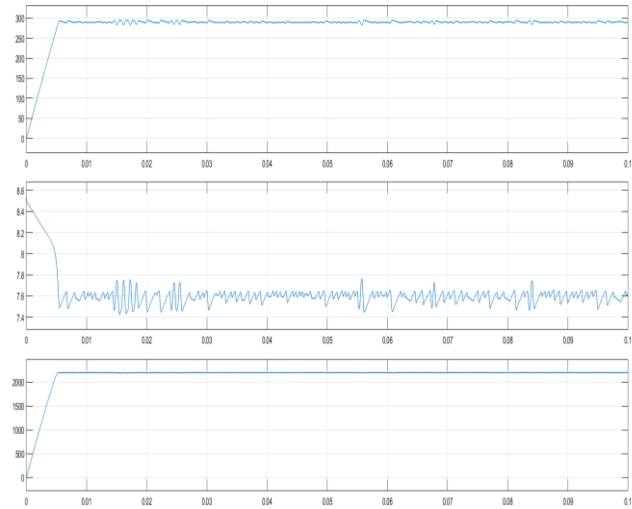


Fig.7.1 Simulink model for solar powered brushless dc motor drive for water pumping system

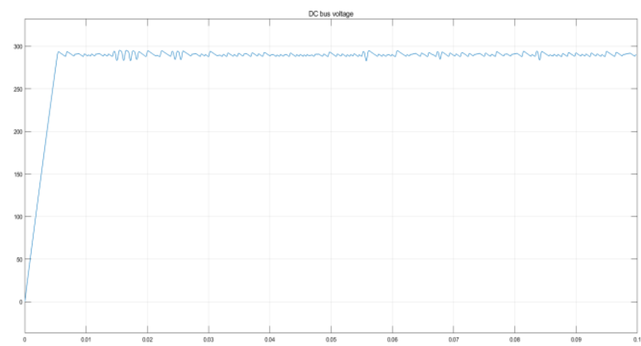
the proposed system configuration, in which BLDC motor is used for pumping system , BLDC motor is operated by voltage source inverter of DC-link.the proposed system gives energy from solar PV based boost converter for pumping load. Solar PV array generates energy gives to the boost converter; the switch of the boost converter is operated by MPPT algorithm such that maximum benefits from solar PV array is optimized and also gives smooth performance of BLDC motor for pumping application. The hall sensors are used in order to sense rotor position of motor. Hall sensors are electronically commuted circuit used for inverter switching.

Performance of the simulated system is shown below. The proposed system is simulated in MATLAB; following results are obtained, as shown below. The proposed system consist output of solar PV array, inverter, converter and BLDC motor pumping output. Each section results is extracted from proposed system by using MATLAB /Simulink. The simulated results are shown below

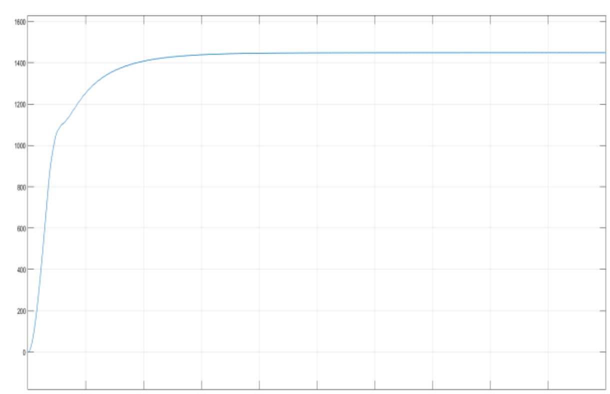
- **Solar PV System Power Output**



- **Solar PV System Volatage**



- **SIMULATION RESULTS FOR SPEED CONTROL OF BLDC MOTOR :**



The following proposed system gives benefits of solar PV based application driven by BLDC motor for water pump as shown infig.1.There are various ways to control speed of BLDC motor like hysteresis control and other control scheme are used. But following configuration is simple, low cost, noise free and having least component of the system; make configuration is suitable for water pumping system.

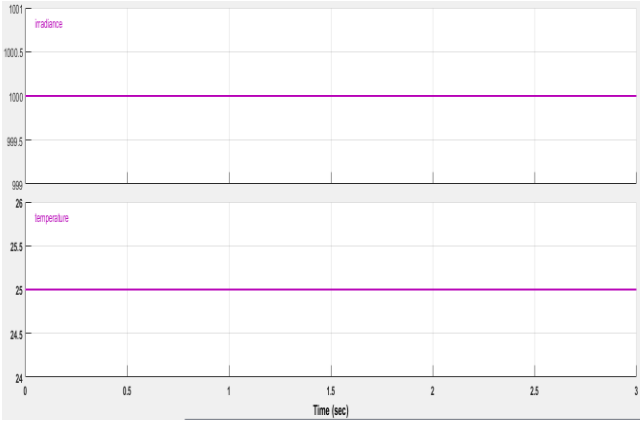


Fig. 6.2 Solar Irradiance and Temperature

The PV array output is shown in figure 6.2. For the given input of PV array the output is observe. In figure 6.2, it clearly seen that the solar irradiance is kept for 1000 W/m2 and Temp 250C for better efficiency of the panel. The PV array output voltage is obtained is near to 290 V and output current is near to 7.59 A so the PV array is designed at rated power output of 2.2 kW.

In this waveform Generally boost converter is used to operate system at higher voltage level. Proper design of converter helps for proper utilization of the system. As due to the only switch of boost converter had extremely excellent renovation efficiency. Boost converter helps to determine maximum power from solar PV array. Voltage of SPV array at maximum point is V Vpv ≡ 5.248 ,as source of input voltage, and Vdc is dc output voltage of boost converter, the input–output relationship of boost converter.

VI. CONCULSION

The proposed sensorless PMBLDC motor-driven solar-PV battery-fed EV system employing a Zeta converter with regenerative braking provides an efficient, reliable, and sustainable solution for modern electric transportation. By eliminating phase current sensors, the system reduces hardware complexity and cost while maintaining robust motor performance. The Zeta converter ensures regulated DC bus voltage, facilitates maximum power point tracking (MPPT), and enables effective battery charging and discharging under varying solar and load conditions.

The integration of regenerative braking enhances energy efficiency by recovering kinetic energy during deceleration and feeding it back into the battery, thereby extending the driving range of the EV. The coordinated energy management between the solar PV array, battery storage, and BLDC motor drive ensures continuous operation, even under fluctuating climatic conditions.

Overall, the proposed system demonstrates a practical and eco-friendly approach to EV powertrain design, combining renewable energy utilization, advanced power electronics, and sensorless motor control techniques. This work contributes toward the development of cost-effective, energy-efficient, and sustainable electric vehicle systems for the future.

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