A REVIEW SOLAR POWER BLDC MOTOR DRIVEN WATER PUMPING SYSTEM USING CUK CONVERTER

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***Abstract:** A solar photovoltaic (SPV) powered brushless DC (BLDC) motor drive for water pumping is presented in this study. The current sensors of BLDC motor and the voltage sensor at the DC bus of voltage-source inverter (VSI) are eliminated completely. Instead, the speed is controlled by adjusting the DC bus voltage of VSI. The fundamental frequency switching pulses are generated to operate the VSI in order to minimize the switching losses and to enhance the efficiency of proposed system. A DC–DC Cuk converter is utilized to operate the SPV array at its maximum power. The starting current of BLDC motor is bounded by an optimal initialization and selection of the control parameters, perturbation size and frequency while tracking the peak power of SPV array. The performance of proposed BLDC motor drive is thoroughly evaluated and its potential is demonstrated under realistic operating conditions. The simulated results and an experimental validation along with a comprehensive comparison with the existing techniques demonstrate prominence of the proposed drive for SPV-based water pumping.*

***Keywords:** BLDC motor, SPV, Cuk converter, PO-MPPT, soft starting*

I. INTRODUCTION

In spite of intermittent nature and low efficiency of solar photovoltaic (SPV) generating system, it has gained wide attention in recent years due to the energy security and various climate policies . A utilization of SPV energy in water pumping is conservative particularly in isolated regions where the transmission of power is either impractical or exorbitant. The DC (brushed) motor and AC induction motor are prominently used to run a SPV array fed water pump for irrigation and drinking water supply. In addition to low efficiency of a brushed DC motor, due to the mechanical commutators and carbon brushes, it needs a regular maintenance. These serious issues call for a brushless DC (BLDC) motor with an electronic commutator which offers a high efficiency and no maintenance requirement. In comparison with an induction motor, the BLDC motors have a high power density, high efficiency, high torque/inertia ratio and unity power factor . The efficiency of an induction motor drastically diminishes under light loading as the excitation losses dominate. Thus, it causes reduced volume of water delivery under bad weather condition as compared with a BLDC motor, wherein no excitation loss takes place owing to its permanent magnet excitation. A high efficiency BLDC motor substantially reduces the size of SPV array and hence its installation cost. Similarly, its high power factor results in a reduced capacity of the used voltage-source inverter (VSI). Besides these, unlike an induction motor, the speed of a BLDC motor is not limited by power frequency. This leads to a reduced size and an increased capacity of the motor ..

Fig. 1 presents a schematic diagram of the conventional BLDC motor drive for SPV-water pumping. The maximum power point tracking (MPPT) is performed by a DC–DC converter . Two phase currents and a DC bus voltage are required to be sensed for motor control. The pulse width modulated (PWM) pulses operate a VSI, inviting the additional switching losses. A Z-source inverter (ZSI) replaces the DC–DC converter in other components of Fig. 1 remaining unchanged, asserting a single-stage solution. However, the sensing of motor phase currents and DC bus voltage, and operation of the VSI in PWM mode are still required. In addition, the ZSI is unable to provide a soft starting to the BLDC motor without current control, which calls for the motor currents sensing. In order to resolve the aforementioned shortcomings, a cost-effective, simple and efficient photovoltaic (PV)-BLDC motor pumping system is proposed in this work.

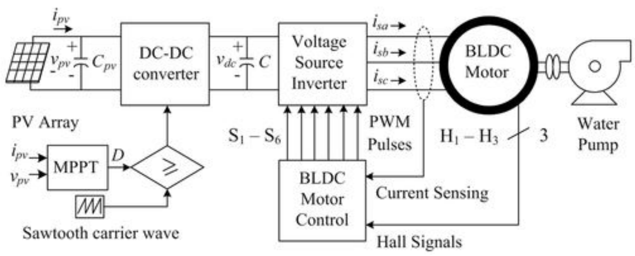

Fig 1.Schematic diagram of conventional water pumping system

II. LITERATURE REVIEW

In 2010, S.H. Hosseini et al. presented the performance of a BLDC motor operating a water pumping system using PV input. To obtain most of the power from the PV array and supply to the BLDC motor, the suggested system used a Z-source inverter (ZSI). Fuzzy logic controlled incremental conductance MPPT algorithm was created to eliminate operating point instability. The speed controller was regulated using particle swarm optimization (PSO) to obtain the reference speed for the BLDC motor and hence gain excellent dynamic response characteristics.

PSCAD/EMTDC connected to MATLAB software was used to simulate the performance of the proposed system under various operating parameters of the SPV array [14]. Low torque ripple was obtained through inverter's voltage regulation, according to simulation findings. The suggested system also has a minimal number of power switches, a cheap cost, and a high efficiency.

In 2012, Terki et al. investigated the performance of a brushless dc motor controlled by a hysteresis current loop in PV-fed water pumping systems. Standard PI and fuzzy logic (FL) speed controllers were utilised [15]. To improve the efficiency of the PV generators, a maximum power tracker was incorporated. Control of the system employing the two kinds of controllers was evaluated under no load and during loading conditions, as well as overall system performance. For both controllers, the simulation revealed that the speed converges to the reference value rapidly without overshoot and with null steady state error, but the FL controller provides substantially superior dynamic features for difficult and nonlinear control systems.

In 2013, Mahdi Ouada et al. [16] proposed an intelligent control scheme that used fuzzy logic control with an MPPT controller for a PV standalone water pumping 11 system, to increase the energy conversion efficiency, with a BLDC motor. As an intermediate converter, a DC–DC boost converter was employed. The hysteresis current control technique was used to create the PWM signals for the VSI. The system was simulated in the Matlab Simulink environment, and the proposed method's efficiency was demonstrated.

In 2013, M.H. Taghvaee et al analyzed non-isolated DC–DC boost, buck, buck– boost, Cuk, and SEPIC converters in order to develop a solution that best fits the Maximum Power Point application. The review was divided into four categories: converter topology, application, operating region and topologies' pros and cons [17]. A comparison among these converters was also performed. The buck-boost converter had the greatest efficiency rate of 96.2% when compared to other converters. The buck– boost DC–DC converter was found to be the ideal type of converter for PV systems, as it was able to assure optimum MPPT performance for any solar irradiation, load circumstances and cell temperature while also improving the system's performance.

In 2014, R.Kumar et al. analyzed and designed a canonical switching cell (CSC) converter as an auxiliary DC-DC converter for a PV-fed BLDC motor drive for a water pumping system. Unlike buck and boost converters, there is absence of MPPT operating range the CSC converter. The maximum power was tracked using the incremental conductance MPPT method. VSI's electronic commutation with fundamental frequency switching was applied, resulting in a dynamic DC output voltage and lower switching losses [18]. The suggested water pumping system's detailed performance for different modes of operation was simulated, and the results revealed that the system achieved steady state values for the assigned irradiances, as well as soft starting of the BLDC motor. In 2014, R. Kumar et al. developed a LUO converter-based BLDC motor-driven water pumping system that uses SPV as an input voltage source. A negative output elementary LUO converter was chosen because it offers features such as continuous conduction mode of operation, limitless MPPT operating zone, and reduced output current ripple [19]. The system's performance under varying environmental circumstances was investigated. According to the simulation results, the BLDC motorpump parameters reached their rated values in steady state, and the motor always reached a speed more than 1100 rpm, even at the least solar insolation

. In 2015, Le An et al, for a standalone PV-battery-powered pump system, developed a single-switch non-isolated dc-dc converter. The intermediate dc-dc converter was created by combining a buck converter and a buck-boost converter, resulting in increased conversion efficiency. MPPT and output voltage regulation were achieved using duty cycle modulation and variable switching frequency control to operate the pump at a constant flow rate. The dc-link capacitor's voltage stress problem in traditional single-stage converters was solved by using a battery, which gives a more stable dc-link voltage than a conventional converter [20]. A prototype of the suggested PV battery-powered water pump was created as an experiment. In the presence and absence of MPPT control, the transient state and steady state responses, as well as the 12 responsiveness under partial shade circumstances, were recorded. The advantages of the suggested system were demonstrated by the findings. When comparing the conversion efficiencies of the proposed converter to a traditional two-stage converter under various loading conditions, the suggested converter achieved a maximum efficiency of 92%. In 2015, Kumar et al, in a PV-fed BLDC motor-driven water pump, used a dc-dc boost converter as an auxiliary converter. A boost converter was employed to optimise the power of the solar PV array while also reducing the BLDC motor's starting inrush current. The desirable qualities of boost converters, such as increased conversion efficiency, high switch utilisation, minimal stress on semiconductor devices, and a small number of reactive components, prompted its utilisation for SPV array water pumps. The MPPT algorithm employed was incremental conductance. Electronic commutation was used to run the VSI. Because the BLDC motor's speed was governed by the variable DC link voltage, no separate sensors for speed control were needed [21]. The system's performance parameters were assessed under various circumstances. The motor reached its rated speed of 3000 rpm at 1000 W/m2 insolation, resulting in full capacity water pumping, and the designed water pumping system performed well even at 20% solar irradiation.

In 2015, Bhim Singh et al examined the behaviour of a SEPIC converter in a BLDC motor-driven SPV array-fed water pumping system. The SEPIC converter which is a buck-boost converter, has the advantages of non-inverting polarity output voltage, low input current ripple and a simple gate-drive circuit [22]. The SPV array was operated at its optimal operating point using the incremental conductance MPPT algorithm, which also accomplished soft starting of the BLDC motor. The VSI switching sequence was created by the BLDC motor's electrical commutation. The suggested system's performance was measured under various environmental conditions. Under each solar insolation level, the BLDC motor reached a speed greater than 1100 rpm, the minimum speed necessary to pump the water, indicating that the system performs excellently under a variety of operating conditions.

In 2016, Kumar et al. implemented and tested a buck-boost converter for use as an intermediary DC-DC converter in between SPV array and VSI for application of water pumping. A centrifugal kind of water pump was driven by a BLDC motor. The buck-boost converter has a high conversion efficiency, employs the incremental conductance MPPT algorithm to maximise SPV array efficiency, and softly starts BLDC motors. The electrical commutation of the BLDC motor generated the switching sequence for the VSI. The envisioned system's behaviour was examined using a hardware prototype at different irradiances ranging from 200W/m2 to 1000W/m2 [23]. According to both hardware and simulated findings, the MPP was successfully tracked and the throughput was unaffected even under varying weather conditions. Furthermore, the analysis indicated that the BLDC motor always runs at a speed greater than 1100 rpm, which is the lowest speed essential to pump water at a solar insolation level of 200W/m2 . The envisioned technology has various advantages over traditional buck and boost converter techniques. 13 In 2016, Bhim Singh et al suggested a layout of a zeta converter, employed to solar PV array fed BLDC motor-driven water pump, used to retrieve the maximum available power from the SPV array. The Zeta converter has a number of benefits over traditional buck, boost, buck–boost, and Cuk converters, such as continuous ripple–free output current, an unbounded MPPT region, and non–inverting output voltage. The zeta converter was operated using an incremental conductance MPPT algorithm, ensuring that the SPV array always functions at its MPP and the BLDC motor starts softly. Because the suggested control algorithm does not need sensors, it is a simple and costeffective system. The VSI's fundamental frequency switching prevents power losses caused by high frequency. The variable dc link voltage of VSI [24] was used to govern the speed of a BLDC motor. The suggested system was conceived, modeled, and tested while taking into account stochastic and instantaneous fluctuations in solar irradiation. Weather conditions had little effect on the performance of the BLDC motor-pump, according to simulations. A better tracking efficiency was reported when the performance of the created prototype was evaluated for solar irradiation levels ranging from 400 to 1000 W/m2

. In 2016, R. Kumar et al, suggested a water pumping system using a DC–DC Landsman converter, based on an SPV array driven BLDC motor. The Landsmann converter [25], which is based on buck-boost converter, was employed to optimize the power output of the SPV array and to enable safe and soft starting of the BLDC motor by using the incremental conductance MPPT technique. For speed control, no further circuitry was required. The suggested system's starting, dynamic, and steady-state responses were all simulated. The incremental conductance MPPT approach demonstrated that MPP was tracked accurately with little fluctuation around the peak power point at 1000 W/m2 . Also, the findings shows that even at a low solar irradiation level of 200 W/m2 , the motor achieves the minimum speed necessary to pump the water. The suggested system's viability for water pumping was further demonstrated by hardware tests. The total efficiency of the suggested system was calculated using experimental data for various irradiances. At rated load and 1000 W/m2 insolation, the proposed system has an efficiency of 83.3%, with a minimum efficiency of 74.4% at insolation 200 W/m2 . In 2017, R. Kumar et al. proposed a single-stage energy conversion system for water pumping applications using a PV-fed BLDC motor drive. The BLDC motor pump was fed directly from the SPV array through a VSI. When compared to an induction motor-driven system, the suggested system with the abolition of phase current sensors and DC-DC converters provided a high efficiency power conversion [26]. Control of the solar PV array operating point through INC-MPPT technique, electronic commutation of BLDC motor, switching signal generation for VSI, and monitoring the speed of the BLDC through the optimum power of the solar PV array were the four major parts of the single-stage system's control. Even under dynamic situations, the motor maintained its smooth performance. Experiments on a prototype under varied operating circumstances further confirmed the system's satisfactory operation. A comparison was done between the existing single stage system and the suggested single stage system. The efficiency of the two systems was calculated at different irradiance levels and under similar operating conditions. Irrespective of the operating conditions, the suggested system appeared to be more efficient than its traditional ones, demonstrating the single stage system's superiority in every regard.

In 2017, Ulliboina Suribabu et al presented BLDC motor-driven water pumping system based on solar PV array using a Landsman converter as an intermediary dc-dc converter. For speed control, a fuzzy logic controller (FLC) was employed. The INCMPPT algorithm was used to control the Landsman converter, which served as an interface between both the VSI and the SPV array, in order to extract the maximum available power from the SPV array. The VSI feeds the BLDC motor pump and also enables soft starting through electronic commutation. For speed control, no extra phase current sensors or accompanying circuits were required [27]. Simulated results were used to examine the various performance characteristics of the proposed water pumping system. Even though there were abrupt atmospheric disturbances, the functioning and performance remained satisfactory

. In 2017, R. Kumar et al proposed a BLDC motor drive for water pumping fed by SPV array using Cuk converter as intermediate dc-dc converter. For tracking MPP, the MPPT algorithm utilised is incremental conductance. The VSI feeds the BLDC motor that operates the pump load. Utilising hall effect position signals, electronic commutation was used to create switching pulses. When compared to other non-isolated dc-dc converters, the Cuk converter had benefits such as decreased current ripples, continuous input and output currents, reduced switching losses, soft motor starting, high efficiency, and so on. Simulated results using matlab/simulink were used to determine the effectiveness of the proposed scheme under various weather conditions. A performance comparison with a traditional DC–DC boost converter proved the advantages of the presented topology.[28]. Experimental data were used to assess the efficiency of both conventional and recommended systems at varied insolation levels and under similar operating circumstances. The Cuk Converter was shown to be more efficient than its traditional version regardless of the operating circumstances. To demonstrate commercial viability, a cost study of the recommended scheme with a PV fed induction motor water pumping system, a single-stage PV-ZSI fed BLDC motor and a single-stage oriented water pumping system was done. The Cuk converter-based system was found to be relatively cost-effective.

In 2017, for a solar PV array fed water pumping system, S. Sarada et al proposed a fuzzy logic-based BLDC Motor Drive. The DC-DC converter used was a cascaded pair of DC-DC boost and buck converters that met the MPPT and soft starting requirements of the BLDC motor. It has features such as high efficiency, better switch utilisation, least stress on power electronics switches and non-inverting output voltage. The recommended converter's control was divided into three categories: Buck converter voltage control, incremental conductance MPPT control algorithm and BLDC motor electronic commutation [29]. The system's performance was examined, and it was realised that the motor's speed never drops below 1100 rpm, even at very low 15 irradiances. The efficiency at 200 W/m2 was 78.3% whereas at 1000 W/m2 maximum efficiency of 86.8% was obtained from the experimental results.

In 2017, Aboul Zahaba et al. demonstrated a standalone PV water pumping system that supplied a water pump powered by a BLDC motor and stored energy in lead acid batteries. A single PV module, dc-dc boost converter, a MPPT, an energy storage system with charging controller, BLDC motor control and a BLDC motor running a positive displacement pump, are all part of the proposed system. Three control units contribute in the control strategy [30]. The first unit is used to regulate the speed of a BLDC motor via hysteresis current control. The MPPT is the second control unit, and it was here that the P&O-based MPPT algorithm and the fuzzy logic-based method were investigated. The third controller manages the battery charging and discharging system, which employs intermittent charging regulation method. The system was simulated using the two MPPT techniques using the same motor control (hysteresis current control). From the simulation results it was found out that Fuzzy Logic Control was faster and has lower oscillation around the maximum power point than the perturb & observe (P&O) algorithm.

In 2018, Neeraj Priyadarshi et al. showed a Luo converter-based BLDC-driven PV pumping system with MPPT control using the hybrid adaptive neuro-fuzzy inference system or adaptive network-based fuzzy inference system (ANFIS) flower pollination optimization algorithm (FPA). The Luo converter features a greater voltage transfer gain, higher power density, and a smoother output waveform with the least amount of ripple content and improved transformation efficiency. The hybrid ANFISFPA is easy to implement, has a fast convergence rate with tuned parameters, and is easier to code [31]. It is used to provide the needed pulse for the Luo converter's power semiconductor switch. The VSI BLDC motor is controlled by an electronic commutation mechanism. Experimentally the dSPACE controller was used to test the behaviour of BLDC-driven PV pumping with a Luo converter. The system's performance was evaluated at both steady state (1000W/m2) and variable irradiance levels (300W/m2 to 1000W/m2). The ANFIS-FPA based MPPT delivers effective tuning with an excellent performance index, and hence the system functions efficiently under all operating situations, according to the experimental results.

In 2018, S. Sashidhar et al designed a single-stage sensor-less control using ferrite permanent magnet BLDC motor drive which can be submerged in a deep bore well. By employing only six switches, the control scheme was able to conduct both MPPT and phase commutation utilising a single-stage three-phase VSI. The system's efficiency and reliability were improved by eliminating the requirement for a specialised dc-dc converter for MPP operation and hall sensors. The MPPT process was accomplished using the P&O method. The Matlab/Simulink platform was used to simulate the sensor less pre-positioning, start-up, and transition to operating mode of the submersible BLDC motor drive. It was discovered that the PV voltage remained constant amidst the step variation in insolation, demonstrating the MPPT's efficacy. [32]. The system's prototype was built, and the BLDC motor and inverter efficiencies at rated power were found to be 87% and 92%, respectively. A cost comparison was made 16 between a two-stage induction motor design and the suggested one, revealing that the proposed technology was significantly less expensive. According to the findings of the literature research, direct fed PV water pumping systems are less efficient than dc-dc converter fed water pumping systems.load.

III. CONCLUSION

In this research work, The proposed PV-water pumping scheme has been validated through a demonstration of its various steady state, starting and dynamic performances. The performance of the system has been simulated using the MATLAB toolboxes, and implemented on an experimental system. The DC link voltage and motor phase current sensing elements have been absolutely eliminated, resulting in a simple and cost-effective drive. The VSI has adopted a fundamental frequency switching, offering an enhanced efficiency due to the reduced switching losses in VSI. The other desired functions are speed control through variable DC link voltage without any additional circuit and a soft starting of the motor–pump. The Cuk converter has provided an unbounded MPPT region and non-pulsating currents, eliminating the ripple filters. The detailed comparative analysis of the proposed and the existing work have ultimately manifested the superiority of the proposed framework.

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