Abstract: To model an efficient solar water pumping system driven by BLDC motor in MATLAB SIMULINK. Methods/Statistical Analysis: A BLDC motor driven water pumping system employing Zeta converter controlled by INC-MPPT is modelled in MATLAB SIMULINK. The BLDC motor of 2.89 kW, 2000 rpm, 3.6 A is used. A voltage source inverter working in 120 degree conduction mode is used to drive the BLDC motor. Zeta converter is used as the dc/dc converter. INC-MPPT is used to control the duty cycle of the zeta converter and there by maximum power tracking can be achieved from the solar panel. Findings: The performance of the water pump is improved due to the highly efficient INC-MPPT controlled zeta converter. Improvement/Applications: Water pumping requires electricity. But the availability of electricity is very limited and sometimes unavailable in certain rural areas. This problem can be overcome by replacing electricity with a renewable source of energy preferably, solar energy. Hence arises the applicability of solar powered water pumping system.

Keywords: Brushless dc (BLDC) Motor, Incremental conductance maximum power point tracking (INC-MPPT) switch, Insulated Gate Bipolar Transistor (IGBT) solar photovoltaic array (SPV array), voltage source inverter (VSI).

I. INTRODUCTION

Solar irrigation system using BLDC is an idea to replace the grid power by the solar power and existing submersible pump by the BLDC motor. The availability of solar power in abundance, depletion of the non-renewable energy sources and the reducing capital cost of photovoltaic panels leads to emerging trends in solar energy. Many researches are being done and have resulted in new technologies in this field. The power that can be utilized from the panel varies with the atmospheric and load conditions. Hence Maximum Power Point Tracking (MPPT) algorithm becomes an indispensable part of the photovoltaic system to extract the maximum power from the panel. Recently many techniques have been proposed for the online tracking of the maximum power point. The methods differ in cost, complexity, ease of implementation, number of sensors used, efficiency, speed and so on. Incremental Conductance (INC) MPPT is given as a prominent method. The basic idea behind this is that at MPP point, the derivative of the power with respect to the voltage equals zero. Presently many Artificial Intelligence based algorithms are also used.

Different converters are discussed in the literature. The buck, boost and buck-boost are the basic converter topologies. The buck converter works as a step-down converter and is not suitable for power factor correction applications. On the other side, boost converter can be used only to boost the input. It does not have overcurrent protection. The buckboost converter can be used either to increase or decrease the voltage. But the problem is that the output voltage has opposite polarity with respect to the source and so it is not widely used. The cuk converter also suffers from the problem of polarity reversal on the output. SEPIC is single-ended primary inductance converter. It is also a buck-boost converter, with no reversal of the polarity. But cuk and sepic converters need additional circuit to limit the inrush current. Also they do not have any overload protection. These limitations could be avoided by the usage of zeta converter. Zeta converter provides positive output from input voltage and it can be used to increase or decrease the voltage. The converter is good for power factor correction applications and has short circuit protection. The voltage of zeta converter is controlled by INC-MPPT algorithm, so as to track the maximum power point. The features of special electric machines like BLDC motors have gained the attention of the mankind. Because of the numerous advantages over the conventional motors, the BLDC motors are replacing them in many areas like automotive, medical, instrumentation and consumer specific application. Instead of using brushes for commutation, the BLDC motors are electronically commutated. This is provided by sensing the rotor position with the help of hall sensor. Zeta Converter fed BLDC drive is proposed and the same is simulated.

II. PROPOSED WATER PUMPING SYSTEM

The electrical power demanded by the pump is developed by the SPV array. This electrical power is fed to the BLDC motor through the zeta converter and then to pump. INC-MPPT is used to adjust the duty cycle of the zeta converter to capture the maximum power point. The proposed system is shown in Fig. 1. The pulses generated by the pulse generator, through INC-MPPT algorithm is used to switch IGBT (Insulated Gate Bipolar Transistor) switch of the zeta converter. The voltage and current from the SPV array is given as the input of the INC-MPPT algorithm. Zeta converter is a DC/DC converter which can be operated...
either in buck or boost mode by adjusting the duty cycle. In the proposed system, the zeta converter is assigned to operate in the boost mode hence the output of the SPV array is boosted and we will get a regulated output at the zeta converter’s terminals.

![Fig. 1. Configuration of proposed water pumping system](image)

The output from the zeta converter is given to the VSI. The VSI is operated in 120-degree mode, which results in the reduced commutation losses. The switches of the VSI is switched based on the hall signals from the BLDC motor. In this way, the maximum power can be extracted and hence the efficiency of the water pump can be improved.

III. DYNAMIC MODELING OF THE PROPOSED SYSTEM

A. BLDC motor modelling

BLDC motor is a synchronous motor. It will always work synchronous speed and there will not be any slip. As the name indicates BLDC motor does not have brushes. Instead of using brushes for commutation, the BLDC motors are electronically commutated. This is provided by sensing the rotor position with the help of hall sensor.

![Fig. 2. 6 pole BLDC motor](image)

The following assumptions are made to derive the dynamic model:

1. The motor is three phase and symmetric.
2. The stator is star wound and rotor is permanent magnet type.
3. Stator resistance, self and mutual inductance of all the phases are identical.
4. Hysteresis and eddy current losses are neglected.
5. All semiconductor switches are identical.

![Fig. 3. MATLAB/ Simulink model of BLDC motor](image)

The dynamic equation of voltages phase a, phase b, phase c of the stator are as follows:

\[
V_a = R_i \frac{di_a}{dt} + L \frac{di_a}{dt} + M \frac{di_b}{dt} + M \frac{di_c}{dt} + e_a \quad (1)
\]

\[
V_b = R_i \frac{di_b}{dt} + L \frac{di_b}{dt} + M \frac{di_a}{dt} + M \frac{di_c}{dt} + e_b \quad (2)
\]

\[
V_c = R_i \frac{di_c}{dt} + L \frac{di_c}{dt} + M \frac{di_a}{dt} + M \frac{di_b}{dt} + e_c \quad (3)
\]

For a balanced system,

\[
i_a + i_b + i_c = 0 \quad (4)
\]

Rearranging (1) and substituting (4)

\[
V_a = R_i \frac{di_a}{dt} + L \frac{d(i_a + i_b)}{dt} + e_a \quad (5)
\]

\[
V_a = R_i \frac{di_a}{dt} + L \frac{d(i_a - i_c)}{dt} + e_a
\]

\[
V_a = R_i \frac{di_a}{dt} + (L - M) \frac{di_a}{dt} + e_a
\]

Let \( L = L_s \)

\[
V_a = R_i \frac{di_a}{dt} + L_s \frac{di_a}{dt} + e_a \quad (5)
\]
Similarly, equations (2) and (3) can be written as

\[ V_b = R_b i_b + L_b \frac{di_b}{dt} + e_b \]  \hspace{1cm} (6)

\[ V_c = R_c i_c + L_c \frac{di_c}{dt} + e_c \]  \hspace{1cm} (7)

\[ T_a = k_a f(\theta) i_b \]  \hspace{1cm} (8)

\[ T_b = k_b f(\theta - \frac{2n}{3}) i_b \]  \hspace{1cm} (9)

\[ T_c = k_c f(\theta + \frac{2n}{3}) i_c \]  \hspace{1cm} (10)

**B. Modelling of INC-MPPT**

The basic concept of Incremental conductance on a PV curve of a solar module is shown in figure 4. The slope of the P-V module power curve is zero at the MPP, increasing on the left of the MPP and decreasing on the right hand side of the MPP. The dP/dV is defined as Maximum power point identifier factor. By utilizing this factor, the IC method is proposed to effectively track the MPP of PV array.

The basic equations of this method are as follows.

\[
\frac{dP}{dV} = 0 \text{ at MPP} \\
\frac{dP}{dV} > 0 \text{ left of MPP} \\
\frac{dP}{dV} < 0 \text{ right of MPP} \\
\frac{dP}{dV} = \frac{d(VI)}{d(V)} = I + V \cdot \frac{dI}{dV}
\]

The following definitions are considered to track the MPP.

\[ \Delta I/\Delta V = -I/V \text{ at MPP, } \Delta V_n = 0 \]

**C. Modelling of Zeta converter**

The ZETA converter is an efficient option for regulating an unregulated input-power supply. Similar to the SEPIC converter topology, the zeta converter topology will generate a positive output voltage from an input voltage that varies above and below a particular voltage value. The ZETA converter needs two inductors and a series capacitor, sometimes called a flying capacitor. The advantages of zeta converter over other converters are reduced output ripple, it does not require over current protection etc.

Transfer function:

\[ V_{out} = V_{in} \left[ D/(1-D) \right] \]

Where D is the duty ratio, \( V_{out} \) is the output voltage of the zeta converter and \( V_{in} \) is the input voltage of the zeta converter. The output of the zeta converter can be controlled by adjusting the duty ratio.
C. MODELLING OF PROPOSED SYSTEM

The model of proposed water pumping system in MATLAB/Simulink is shown in figure 8.

IV. RESULTS AND DISCUSSION

The following figures show the outputs obtained from the modeling of water pumping system.

Fig. 8 MATLAB model of the proposed water pumping system

Fig. 9 Emf Vs time graph of BLDC motor

Fig. 10 Torque and speed waveform of BLDC motor

Fig. 11 Output of zeta converter

Fig. 12 Output of zeta converter and PV panel for G=1000 W/m²

Fig. 13 Output of zeta converter and PV panel for G=400 W/m²
Modeling of BLDC motor is done in MATLAB SIMULINK and is presented. Water pumping requires electricity. But the availability of electricity is very limited and sometimes unavailable in certain rural areas. This problem can be overcome by replacing electricity with a renewable source of energy preferably, solar energy. Hence arises the applicability of solar powered water pumping system. The output waveforms of zeta converter, BLDC motor and solar panel is demonstrated.

VI. REFERENCES

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