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MPPT BASED SOLAR PV ARRAY WATER PUMPING SYSTEM EMPLOYED TO BLDC MOTOR

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Abstract - *This study presents a non-electrical input-based method of tracking maximum power points (MPPT) in a solar-powered water pumping mechanism that uses a Brushless DC (BLDC) motor. The main goal is to design an MPPT method that is independent of step size, specifically for water pumping applications. A DC–DC boost converter, regulated by MPPT, is used to draw the maximum available power from the solar photovoltaic (SPV) array while also ensuring a smooth start for the BLDC motor. The BLDC motor is to be examined by the curves of rotor speed, stator current, electromagnetic torque, and back EMF with respect to time. The efficiency of the BLDC motor-driven pumping system is assessed under various solar irradiation circumstances, and its overall performance is examined and simulated in MATLAB/Simulink.*

Key Words: **Maximum power point tracking (MPPT), Artificial Neural Network (ANN), Solar Photovoltaic Array (SPV), Brushless DC Motor (BLDC) ,MATLAB/Simulink etc.**

1.INTRODUCTION

Energy extraction under temperature, irradiance fluctuations is optimized utilizing methods from Maximum Power Point Tracking (MPPT). Oscillations at the MPPT and dependency on preset step sizes are two drawbacks of traditional MPPT systems, such as Incremental Conductance (INC) and Perturb and Observe (P&O), which reduce overall efficiency. An MPPT technique based on Artificial Neural Networks (ANN) for solar-powered water pumping applications using Brushless DC (BLDC) motor drives [1]. Among irrigation methods, micro-irrigation is highly efficient, reducing water wastage compared to traditional flood irrigation. designing solar-powered water pumping systems for a 14.7-hectare grape farm. It evaluates three system configurations: without storage, with battery storage, and with water tank storage [2]. Solar energy provides a sustainable alternative for powering irrigation pumps, reducing dependence on fossil fuels and lowering operational expenses. Which focuses on developing a solar-powered water pumping system with an automatic switching mechanism [3].

Photovoltaic (PV) systems are becoming a more appealing option for water pumping applications due to rising need for energy. For such systems, brushless DC (BLDC) motors are recommended because to their low maintenance requirements, small design, and great efficiency. However, standalone solar pumps face issues during low sunlight or night hours, leading to interrupted water supply. suggests a BLDC motor drive-based grid-interfaced solar PV system that is backed by a power factor-corrected boost converter to enable smooth power sharing between the grid and PV [4].

The system ensures continuous water delivery, improved power quality, and reliable motor operation under varying solar conditions. Although standalone photovoltaic (PV) systems are inexpensive, particularly when battery-free, they must function well to optimize energy use. To make sure the PV array runs at its highest power point, MPPT approaches are used, such as the Perturb Observe (P&O) algorithm [5]. PV-based pumping system with an induction motor drive and vector control to achieve efficient operation under varying solar irradiance [5]. Simulation results demonstrate that the proposed control method maintains stable motor performance and consistent water discharge.

The two MPPT algorithms that are most commonly used when taking the water pumping system into account are incremental conductance (INC) and perturb and observe (P&O). However, in a standalone SPVWPS, the MPPT method's step size is a crucial component that governs control attributes [6]. In order to circumvent the detrimental impact of step size, the ANN-based MPPT technique is chosen. Using solar photovoltaic (PV) energy for pumping is a cost-effective and eco-friendly alternative to diesel or grid-powered pumps [7]. A model of a solar-powered centrifugal pump system driven by a BLDC motor, designed and simulated in MATLAB/Simulink. The model helps analysed system performance and optimize design parameters for efficient water pumping under different conditions.

The design and simulation of a solar-powered pumping system using a single-phase induction motor, DC-

DC boost converter, and SPWM inverter [8]. The proposed model improves efficiency, reduces harmonics through LC filtering, and provides a reliable solution for irrigation and rural water supply applications. Maximum Power Point Tracking (MPPT) is crucial for effective energy consumption [9]. Traditional MPPT methods like Perturb & Observe and Incremental Conductance often struggle under partial shading, leading to power loss. MPPT technique combining a scanning algorithm with an Artificial Neural Network (ANN) to accurately track the global maximum power point (GMPP).

The modeling and also simulation of a solar-powered water pumping system that drives a hydraulic load using a separately excited DC motor and centrifugal pump. The PV voltage is increased using a DC-DC boost converter to ensure smooth motor running [10]. The performance of the suggested system is assessed in several environmental scenarios using MATLAB/Simulink simulation.

1.1 Objective

- To utilize Maximum Power Point Tracking (MPPT) to model a system uses solar energy to power a brushless DC (BLDC) motor for water pumping.
- To create a boost converter that will control and increase the solar photovoltaic (PV) array's voltage in order to satisfy the motor's needs.
- Evaluation of results in MATLAB / Simulink for its effectiveness in real-life scenarios.

1.2 Proposed Methodology

The system also has PV array, an ANN based MPPT driving DC-DC Boost converter, DC capacitor link which is regulated by PWM signal generated by electronics commutation to control VSI and pump system. SPV array is selected carefully to ensure optimal and CCM operation of the DC-DC boost converter

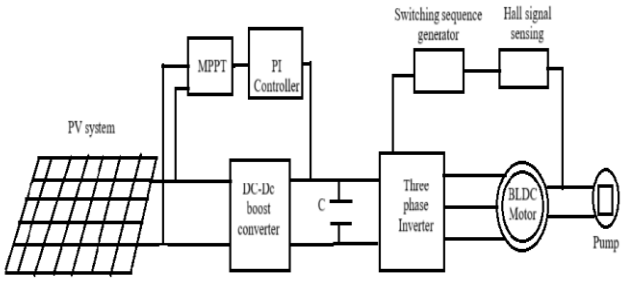

Fig 1.2: Block diagram PV based water pumping model

The diagram shows the block representation of a solar-powered BLDC motor-driven water pumping system. The PV array generates DC power, which is fed to a DC-DC boost converter. This converter steps up the voltage to the required level and maintains a stable DC link voltage. The PV array's maximum power extraction is guaranteed by an MPPT controller., and a PI controller regulates the converter output. The three-phase inverter converts the boosted DC voltage into a three-phase AC supply drive the BLDC motor. Hall sensors provide rotor position feedback to the switching sequence developed, which controls the inverter to ensure appropriate motor commutation, switch. The BLDC motor drives the pump, enabling water flow, making the entire setup efficient for irrigation or water supply applications.

1)PV array produces DC; the MPPT algorithm measures conditions and sets the target duty for maximum power.

2)The DC–DC boost raises and stabilizes the PV voltage to the DC-link level under PI control.

3)The inverter converts the DC-link to three-phase waveforms; Hall sensors feed rotor position to the switching logic.

4)Correctly timed commutation drives the BLDC motor, which turns the centrifugal pump to deliver water.

2. MODELLING OF MPPT BASED SOLAR POWERED WATER PUMPING USING MATLAB/SIMULINK

From solar PV array block parameters Trina Solar TSM-200DA01A.05 SPV module is selected which is available in the module section of PV array block in MATLAB/Simulink.

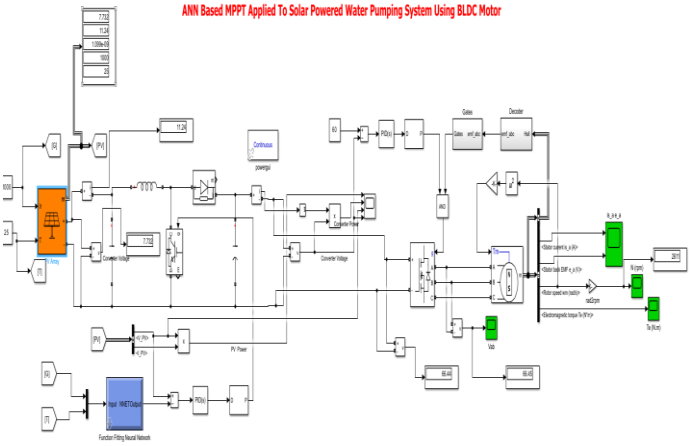

Fig 2: PV array model in MATLAB/Simulink

The simulation shows a solar PV-powered BLDC motor water pumping system with ANN-based MPPT control. The PV array generates DC power depending on solar irradiance and temperature. This power is fed to a DC-DC boost converter, which steps up the voltage and maintains a stable DC-link voltage. The ANN-based MPPT block calculates the reference voltage and adjusts the duty cycle of the boost converter for maximum power extraction. The boosted DC is converted into three-phase AC by the inverter, which drives the BLDC motor. Hall sensors provide rotor position feedback to control the switching sequence of the inverter, ensuring smooth motor operation. The motor runs the pump, delivering water, and the model monitors

parameters like speed, torque, and current to analyze performance.

2.1 PV Array Module: SPV array of rating 2.81 kW feeding 2.38 kW motor is selected. Excess power is required to overcome all the losses occur during various stages of the SPVWPS system. To generate 2.81 kW. maximum voltage (Vmpp) selected as 267.4, Maximum Current (Impp) which is required to get 2.81 kW is to be verified by using this below formula. Module maximum power (w) = 200.93 (per module) Total number of modules = 14

Pmpp = 200.93 x 14 = 2813 w

Impp= Pmpp/ Vmpp = 2813/267.4 = 10.52 A

So, to generate maximum power of 2.81 kW at standard test condition (STC) 7 module are connected in series and 2 modules are connected in parallel. Formula is given as below

Number of modules connected in series ***Ns*= Vmpp/ Vm = 267.4/38.2 = 7**

Number of modules connected in parallel ***Np*= Impp/ Im =10.52/5.26 =2**

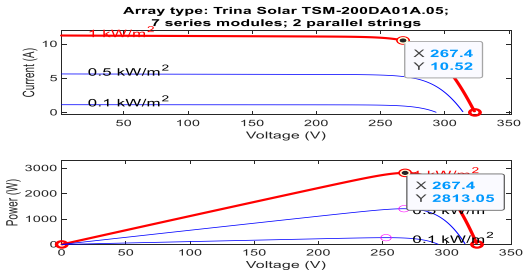

Fig 2.1: I~V and P~V curve of selected SPV array

2.2 ***Design Boost Converter*:** At standard test condition array maximum output voltage is Vmpp and output of boost converter maintained to be at DC link (Vdc) which is rated voltage of BLDC motor. So, to verified duty cycle(D).

Vout = 48 V; Iout max = 11.4A; Vin = 30.7V

Switching frequency (F_S) for the boost converter is selected to be 10,000 Hz. The motive behind selecting such a high value is to reduce ripples in the inductor current (iL) and to improve the transient performance of the boost converter. At maximum power point, Impp calculated. Limiting the current ripple, ΔIL in iL is to be calculate.

Δ IL = 0.01x Iout max x Vout = 0.1782A
Vin

ΔVout = 0.01 x Vout = 0.48 V

Inductance **L= (Vin - Vin) = 30.7** (48- 30.7) = 6.21 m H
Fs × ΔIL x Vout 0.178 x 10000x48

Capacitor **C = Iout max (1- Vin/ Vout)** = 8.5599 x10^-4 F
Fs x Vout

Implied Duty to Boost (30.7 V to 48 V)

D = 1- Vin = 1 – 30.7 = 0.36
Vout 48

Ideal boost output power **Pout = Vout x Iout max =** 48 x 11.4 = 547.2 W

Ideal input current **Iin = Pout** = 547.2 = 17.82 A
Vin 30.7

Restricting the voltage ripple, ΔVdc in Vdc, C is estimated as **ω = 2×Π×N_r×*p***
120

For simulation, capacitor C is taken a higher value. A higher value of C reduces ripple at DC bus.

2.3 SELECTION OF CENTRIFUGAL PUMP: In terms of designing, a centrifugal pump is selected by estimating the proportionality constant, *K* utilizing the accompanying relationship as

K = P = 2813 = 1.37x10^-4 W/(rad/sec)²
***ω*³** 273.3³

Where P is motor power, ***ω*** r is rated speed of BLDC motor in rad/sec and pump rated torque (T rated) of the BLDC motor under steady state condition.

2.4 Brushless DC Motor (BLDC): BLDC motors operate on the basis of the interaction between the rotor and stator magnetic fields. When the rotor's permanent magnets interact with the stator's revolving magnetic field, a torque is created that rotates the rotor. It is the BLDC motor that powers the water pump. The DC-DC boost converter provides the motor with a DC voltage that regulates its speed. In a three-phase BLDC motor, the rotor position determines the back electromotive force (EMF), and the back EMF of each phase varies by 120° electrical degrees between phases.

ω = 2×Π×N_r×*p* = 2x Π (2611x 4) = 273.3 rad/s
120 120

2.5 Position Sensors: Position sensors installed in the BLDC motor detect the rotor's position and convert it into an electrical signal, which provides the correct commutation information to the logic switching circuit. Commutation in a BLDC motor follows a six-step sequence. During each step, the six switches in the Voltage Source Inverter (VSI) are turned ON and OFF in a specific pattern to generate six current flow vectors. These vectors advance the rotor by 60° each time. To perform this commutation, Hall-effect position sensors are used. These sensors detect the rotor position over every 60° span and generate three Hall signals. The signals are then decoded to produce the appropriate switching pulses for the VSI switches. Figure3.2.6 illustrates the electronic commutator switching states. The Hall sensors are positioned so that they detect rotor magnet changes slightly before the rotor reaches the exact commutation point. This ensures that commutation occurs just in time, preventing the rotor from stopping or getting locked in one position.

θ(°)	Hall Signals			Switching States					
	H_1	H_2	H_3	S_1'	S_2'	S_3'	S_4'	S_5'	S_6'
0-60	1	0	1	0	1	1	0	0	0
60-120	0	0	1	0	1	0	0	1	0
120-180	0	1	1	0	0	0	1	1	0
180-240	0	1	0	1	0	0	1	0	0
240-300	1	1	0	1	0	0	0	0	1
300-360	1	0	0	0	0	1	0	0	1

Table 2.5: Control structure of water pumping system

3.RESULTS

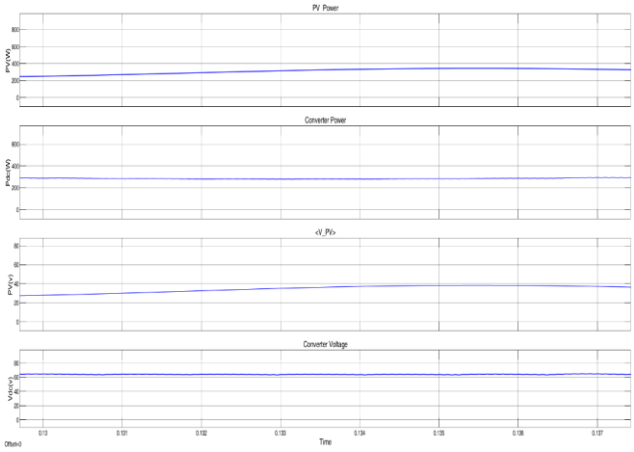

Fig 3.1: Performance of SPV array and Boost converter (power and voltage).

Figure3.1 shows the operation of the boost converter, where the inductor current (iL) was measured at approximately 10.50 A. The output voltage (Vdc) was successfully regulated and maintained at 300 V, which is the required DC link voltage to drive the BLDC motor.

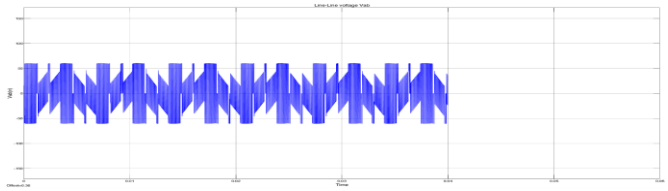

Fig 3.2: Performance curve of line-to-line voltage.

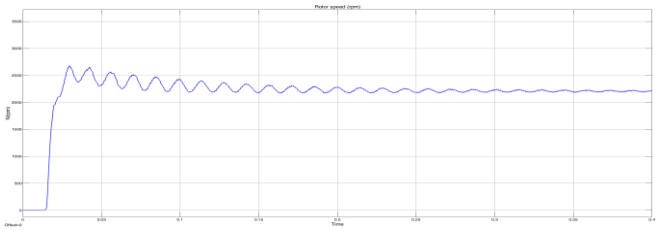

Fig 3.3: performance of rotor speed(rpm)

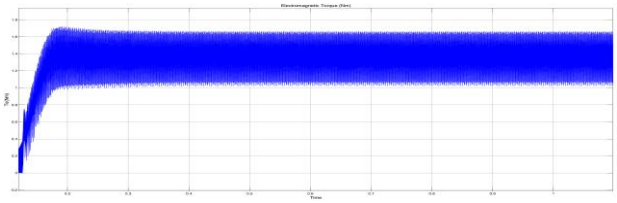

Fig 3.4: Performance of Electromagnetic Torque (Nm).

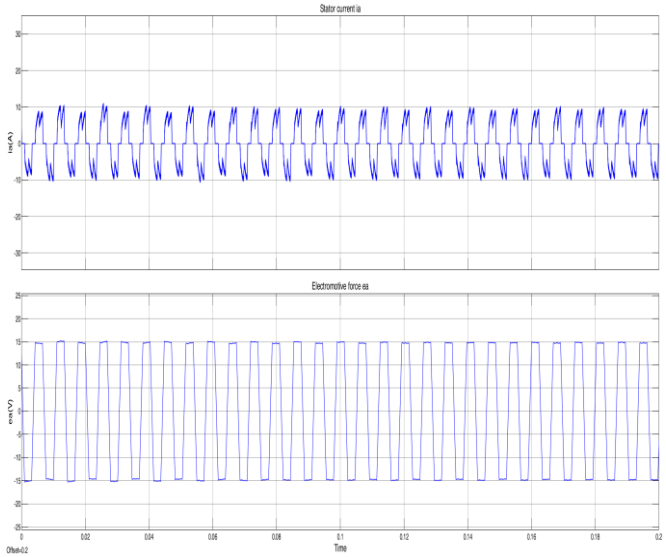

Fig 3.5: Performance of Stator current(I) and EMF(v) with respect to time.

3.2The Efficiency of the overall system at various irradiance.

For different irradiance from solar panel is boosted and converted to AC signals by inverter generates the mechanical output as motor speed.

Irradiance G (W/m^2)	Ppv (W)	Pw (W)	Efficiency %
200	547.2	368.5	67.34
300	831.9	585.2	70.3
400	1118	821.3	73.4
500	1403	1081	77.0
600	1688.3	1346	79.73
700	1972	1555	82
800	2254	1903	84
900	2534	2160	85
1000	2813	2611	92.81

Table 3.2: Efficiency of the overall system at various irradiance

Table 3.2 shows the percentage efficiency in various irradiance so, with the use of MPPT tracing technology. The overall system gives 92.81% efficiency at 1000 irradiance.

4. CONCLUSIONS

The study successfully developed a solar-powered BLDC motor-driven water pumping system using an MPPT strategy based on non-electrical inputs. The proposed algorithm operates independently of step size, addressing the limitations of conventional tracking methods. Simulation results confirmed reliable performance of the PV array, boost converter, and BLDC drive, maintaining smooth operation under changing irradiance. The system achieved a peak efficiency of 92.81% at standard conditions and sustained 67.34% efficiency even at low sunlight. Additionally, the MPPT control enabled soft starting of the BLDC motor, reducing current surges and enhancing the durability of the pump system.

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