APPLICATION OF ARTIFICIAL NEURAL NETWORK (ANN) FOR MAXIMUM POWER POINT TRACKING (MPPT) IN A SOLAR-POWERED WATER PUMPING SYSTEM USING BRUSHLESS DC (BLDC) MOTOR

Shaik. Reshma PG Scholar, Department of Electrical Engineering, Andhra University Visakhapatnam, India
Dr. K. Padma Associate Professor, Department of Electrical Engineering, Andhra University Visakhapatnam, India
K. Manohar Research Scholar, Department of Electrical Engineering, Andhra University Visakhapatnam, India
M. Ravindra Babu Assistant Professor, Department of Electrical Engineering, JNTUK-Narasaraopet, Palnadu, India

Abstract:

This paper introduces non-electrical input based artificial neural network (ANN) maximum power point tracking (MPPT) technique to the solar powered water pumping system using brush less DC (BLDC) motor. The objective is to model a step independent MPPT using neural network for water pumping application. A DC-DC boost converter is being utilized which is driven by ANN based MPPT to extract maximum power out of solar photovoltaic (SPV) array and also responsible for soft starting of BLDC motor. Pulse width modulated (PWM) control of the voltage source inverter (VSI) using DC link voltage controller is used to control the speed of the BLDC motor .PWM signal is generated using the inbuilt encoder to perform the electronic commutation by hall signal sensing. Performance analysis of a BLDC motor driving pump system is carried out under the MATLAB Simulink.

Key words: Solar PV, Artificial Neural Network (ANN), BLDC Motor, Boost Converter, Maximum Power Point Tracking (MPPT).

I.INTRODUCTION

The surge in population has led to a rapid escalation in energy demands, placing a strain on conventional energy sources. This results in a shift of emphasis from fossil fuel-based energy generation to the adoption of cleaner and greener sources of energy. Solar Photovoltaic technology can be seamlessly integrated on a larger scale, providing an environmentally favorable alternative to traditional water pumps powered by non-renewable energy sources such as oil and coal. A standalone solar photovoltaic water pumping system (SPVWPS) is one of the possible solutions to meet the water demand. This method widely receiving an appraisal for irrigation, household application and industrial automation. This paper is based on the work carried out in [1,2]. The DC link voltage varies with a change I solar irradiance [1] and speed control of BLDC motor is done by keeping DC link voltage at rated value [2]. This paper explores the second approach to system modelling. A DC-DC boost converter is utilized which is operated in continuous conduction mode (CCM) driven by ANN based MPPT to provide optimal duty cycle. Several MPPT techniques are discussed in the literature [3,4]. MPPT algorithms widely accepted include Perturb and Observe(P&O) [5,6] as well as Incremental Conductance (INC) [7,8] when the water pumping system is considered.

A few studies using induction motors, synchronous reluctance motors (SyRM), and switching reluctance motors (SRM) for SPV array driving water pumping have been published in the literature [12] [13]. It has been shown that an induction motor's efficiency decreases with light loads due to the predominance of excitation losses. Additionally, an induction motor powered system has a low power conversion efficiency. SyRM is capable of operating effectively within a specific range of sun irradiation levels. Because the torque ripple and acoustic noise for SPVWPS are so large, an SRM has not received much attention [10]. Thus, BLDC motor was chosen for this specific application. BLDC motors operate silently, have a longer lifespan, and don't require brushes. BLDC motors are widely used in many applications that require optimal performance and dependable operation.

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Because BLDC motors have permanent magnets, they have higher torque to speed ratios than conventional motors of the same size, making them suitable for applications where space and weight are critical. Compared to other motors, it has wider speed ranges, better torque, and faster speed. reduces rotor inertia, which improves dynamic performance and shortens the overall operating cycle promoting more agile and responsive system behaviour due to low rotor inertia [14].

In a standalone SPVWPS, the step size of the MPPT method is a crucial factor that rules control qualities [9]. To avoid the negative effect of step size, ANN based MPPT technique is selected. It has been proposed for better dynamic performance, particularly under rapidly changing environmental conditions. Several DC-DC conversion techniques are discussed in the literature boost, boost-buck ,luo and landsman converter [1] [7][8][10].But boost converter is selected because of its inherent nature of least possible switching stress with high transformation effectiveness, very good switch utilization to reduce input ripple current because the input inductor itself behaves as a ripple filter and a fewer number of components required to design it [11].

Proposed Solar Powered Water Pumping System (SPVWPS) uses two Proportional-Integral controllers so, proper tuning is required for optimal performance of the model. MATLAB/Simulink environment is used to study the performance of the overall system and to evaluate efficiency at different solar irradiance value.

II.THE TOPOLOGY OF THE PROPOSED SYSTEM

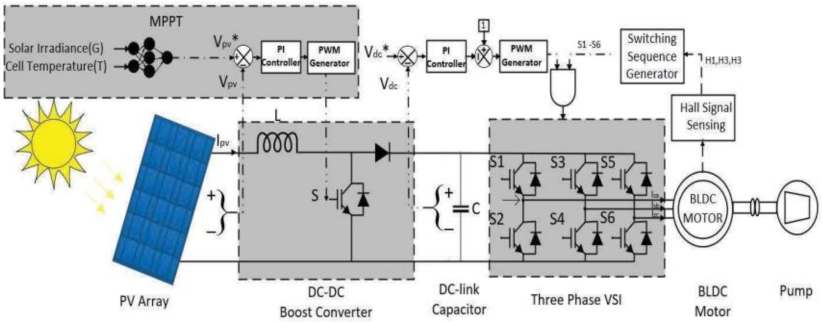

Fig.1 Visual Representation of the Proposed System Topology

The Schematic model of SPVWPS with bldc motor is given in Fig.1. This system comprises of Solar Photovoltaic (SPV) Array which undergoes Artificial Neural Network (ANN)-based Maximum Power Point Tracking (MPPT). The energy is then directed to a DC-DC Boost Converter, ensuring optimal and Continuous Conduction Mode (CCM) operation. The output of the converter charges a DC link capacitor, regulated by Pulse Width Modulation (PWM) signals generated through electronic commutation. These signals control a Voltage Source Inverter (VSI) connected to a Brushless DC (BLDC) motor coupled to a pump. The BLDC motor's power and performance are specified at 2.38 kW (3.2 hp). The detailed schematic model represents the interconnections between these components, emphasizing their roles in achieving an efficient and responsive SPVWPS.

DESIGN OF SOLAR PV ARRAY: Solar PV module is selected which is available in the module section of PV array block in MATLAB Simulink. Solar PV array of rating 2.81kW feeding 2.38 kW motor is selected. The surplus power is imperative in the Solar Powered Water Pumping System (SPVWPS) to compensate for losses encountered at different stages of the system. These losses occur throughout the process, from the initial capture of solar energy by the photovoltaic array to the eventual conversion and utilization of this energy for driving the pump. Factors contributing to losses include inefficiencies in the DC-DC Boost Converter, electrical losses in the DC link capacitor, losses during electronic commutation and pulse width modulation, and mechanical losses in the BLDC motor and pump. By considering these losses and including excess power in the system design, the SPVWPS ensures that sufficient energy is available to meet the intended water pumping requirements while maintaining overall efficiency and reliability.

PV module specification is given in Table 2. I~V and P~V curve at various irradiance is given in Fig.2. To generate 2.81 KW, maximum voltage (Vmpp) selected as 267.4 V.

Maximum Current Impp which is required to get 2.81 kW is estimated to be

$$Impp = \frac{Pmpp}{Vmpp} = \frac{2810}{267.4} = 10.50 \text{ A} \quad (1)$$

Number of modules connected in series $Ns = \frac{Vmpp}{Vm} = \frac{267.4}{38.2} = 7$ (2)

Number of modules connected in series $Np = \frac{Impp}{Im} = \frac{10.50}{5.26} \approx 2$ (3)

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.

TABLE I: NOMINAL VALUE AND SPECIFICATION OF BLDC MOTOR

BLDC Motor Specification	
Power, P	2.38 KW
Speed, N_r	2600 rpm
DC Voltage, V_{dc}	325 V
Current, I	7.35 A
Inertia, J	7.05 kg cm^2
Poles, P	12 P
Voltage Constant, k_e	88.86 V_{peak} L-L/K_{rpm}
Torque Constant, k_t	0.85 N_m/A_{peak}
Phase to Phase resistance, Rs	0.957 ohm
Phase to Phase inductance, Ls	3.8 mH

TABLE II: SOLAR PV ARRAY SPECIFICATION

TSM-200DA01A.05 SPV module	
Maximum Power	200.932 W
Open Circuit Voltage V_{oc}	46.2 V
Voltage at maximum power point V_m	38.2 V
Short-circuit current I_{sc}	5.62 A
Current at maximum power point I_m	5.26 A
Cells per module (N_{cell})	72
Series connected modules per strings (N_s)	7
Parallel connected modules per strings (N_p)	2

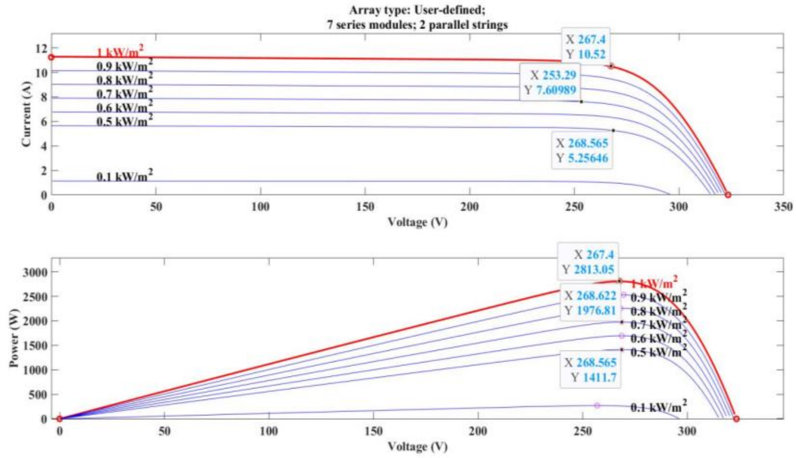

Fig.2.1 I~V and P~V Curve of selected Solar PV array

BOOST CONVERTER DESIGN: At standard test condition (STC), Solar PV array maximum output voltage is Vmpp = 267.4 V and Vdc is the output voltage of the boost converter maintained at 325 V at DC link (Vdc) which is rated voltage of BLDC motor. So, the duty cycle (D) in a boost converter is the ratio of the ON time of the switch to the total switching period. For a boost converter operating in Continuous Conduction Mode (CCM), the duty cycle is typically given by the formula:

$$D= \frac{Vdc-Vpv}{Vdc} = \frac{325-267.4}{325} = 0.177 \approx 0.18 \quad (4)$$

The duty cycle cannot exceed 1 in a typical boost converter.in a boost converter. If your calculated duty cycle exceeds 1, it may indicate that the boost converter is not operating in Continuous Conduction Mode (CCM) or that there's an error in the input values.

The Switching frequency (F_{sw}) for a boost converter is the frequency at which the switch in the converter turns on and off. It is measured in Hertz (Hz). In this case, the switching frequency is specified as 20KHz.The reason to select such a high value is to reduce ripples in inductor current (i_L) and to improve transient performance of the boost converter. At the maximum power point (I_{mpp}), the calculated current is 10.52. Limiting the current ripple, ΔI_L in i_L at 8%, L is estimated as [9]

$$L = \frac{Vpv \times D}{Fsw \times \Delta IL} = \frac{267.4 \times 0.18}{20000 \times 10.52 \times 0.08} = 2.86\ mH \approx 3mH \quad (5)$$

The average output current of the boost converter (I_{dc})=P_{mpp}/V_{dc} ,

Where P_{mpp} is the maximum power point (MPP) power and V_{dc} is the output voltage of the boost converter.

$$I_{dc} = \frac{Pmpp}{Vdc} = \frac{2813}{325} = 8.66\ A.$$

The voltage ripple is restricted to ΔV_{dc} in V_{dc} at 2%, C is estimated as

$$\omega = 2 \times \pi \times f = \frac{2 \times \pi \times Nr \times p}{120} = \frac{2 \times 3.14 \times 2600 \times 12}{120} = 1632.8\ rad/sec \quad (6)$$

$$C = \frac{Idc}{6 \times \omega \times Vdc} = \frac{8.66}{6 \times 1632.8 \times 0.02 \times 325} = 136\mu F. \quad (7)$$

(Sixth harmonic component of AC voltage is dominating on the DC link of the Voltage Source Inverter (VSI)" indicates the presence of a specific harmonic in the system, which may have implications for the operation of the motor)

In simulation studies, a capacitance (C) value of 200 µF is chosen for the DC bus of the Voltage Source Inverter (VSI). To use a higher C is motivated by the aim to reduce ripple on the DC bus.

SELECTION OF CENTRIFUGAL PUMP: The design of a centrifugal pump involves estimating the proportionality constant (K), a critical parameter in the pump's performance [7],[15].

$$K= \frac{P}{\omega r^3} = \frac{2810}{(2\times \pi \times 2600/60)^3} = 1.39 \times 10^{-4}\ W/(rad/sec)^3 \quad (8)$$

Here P is the motor power, ω_r is the rated speed of BLDC motor in rad/sec and pump load torque (T_L) is equal to the rated torque (T_{rated}) of the BLDC motor under steady state condition.

III.MAXIMUM POWER POINT TRACKING

As outlined in reference [4] discusses various Artificial Neural Network (ANN) based Photovoltaic (PV) Maximum Power Point Tracking (MPPT) Techniques. However, this particular paper introduces a novel non-electrical input-based ANN MPPT approach. In this method, irradiance (G) and temperature (T) as inputs to the ANN, producing V_{mpp} as output denoted by V_{pv}*, serves as the reference voltage. The instantaneous Vpv is then compared with V_{pv}*, generating an error signal fed into a Proportional-Integral (PI) controller. The PI controller's output is directed to the Pulse Width Modulation (PWM) signal generator, determining the duty cycle for the converter. The crucial step of optimal tuning for the PI controller is emphasized to enhance the system's overall performance. This innovative approach highlights the utilization of non-electrical parameters for MPPT, showcasing potential benefits for solar power systems.

IV.TRAINING OF NEURAL NETWORK

The training of the neural network involves a crucial step in the development of the proposed non-electrical input parameters based MPPT system. After calculating the V_{mpp} values at different irradiance and temperature conditions the data is used for training the neural network. During training, the neural network learns the patterns between the input parameters (irradiance and temperature) and correlate with Vmpp values. The training process typically involves adjusting the weights and biases of the neural network to minimize the difference between the predicted V_{mpp}

values and the actual V_{mpp} values from the derived data. This allows the neural network to generalize its learning and make accurate predictions for unknown data, ensuring effective MPPT under varying environmental conditions. Total of 552 data points are generated for the training process and these data points undergo training using 2 hidden neurons in the neural network. The results of the training process are visualized through a regression plot. The regression plot illustrates the high accuracy achieved by the trained model, showcasing the effectiveness of the neural network in order to get the relationship between the input parameters (irradiance and temperature) and the corresponding Vmpp values.

V.POSITION SENSOR

The motor's position sensors are able to detect changes in the rotor position and convert them into an electrical signal, which gives the logic switch circuit's suitable commutation information. A BLDC motor must be commutated in six steps. Six flow vectors were produced by turning each of these six VSI switches ON or OFF. The BLDC motor points 60° to the next place to these vectors. The commutation process requires the Hall effect position sensor. The BLDC motor's rotor position is sensed by the hall-effect position sensor, which spans θ to 60º. Three hall signals are produced, which are then decoded to produce the appropriate switching pulses for the switches of the VSI position sensor in Figure 4. The hall effect sensors are positioned so that the magnets adjust their values before the rotor reaches its full compensation position. This takes into consideration when there is a need to make the next conversion before the rotor really ends up being stuck at one place.

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

Fig.3 Control structure of the water pumping system

VI.SIMULATION AND DISCUSSION

The simulation was executed using MATLAB/Simulink R2023a, and Fig.5 displays the system's overall performance curve. The SPV array's performance under STC conditions shows that the ANN-based MPPT technique can track a maximum power of 2812 W at a maximum voltage of 267.4 V and a maximum current of 9.78 A. In addition, it is noted that the proposed MPPT has excellent tracking efficiency. The boost converter's performance where the maintained V_{dc} of 325 V and the inductor current i_L of 10.50 A are shown. The ideal duty cycles for CCM are displayed. To drive the water pump in the BLDC motor increases its rated speed and electromagnetic torque (T_e) at full load. There is a slight variation in T_e due to the ripples in the current at the DC link of the VSI. The speed and time characteristics of BLDC motors also exhibit smooth starting.

It shows how the level of solar irradiation affects every variable of the BLDC motor, including speed, electromagnetic torque, pump load torque (T_L), back emf of phase A (e_a), and stator current of phase A (I_{sa}). The BLDC motor is seen to be able to achieve steady-state values rapidly. Pump load torque resisted by electromagnetic torque at different irradiances illustrates the motor's steady performance. The efficiency of the SPVWPS is given in Table 3 at various irradiance level.

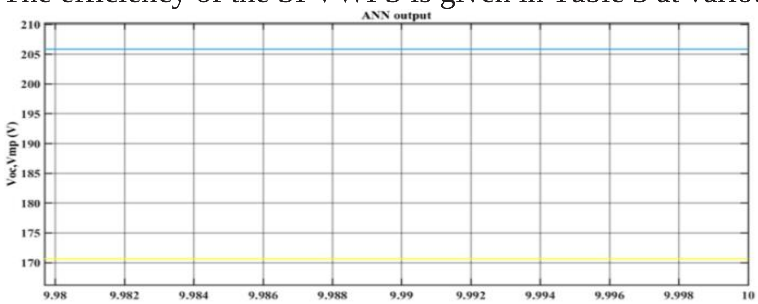

Fig.4 Output of ANN

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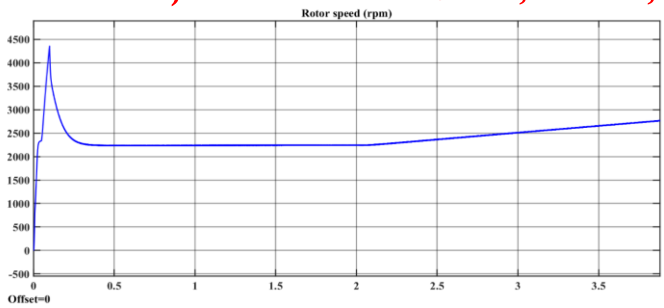

Fig.5. Rotor Speed (rpm)

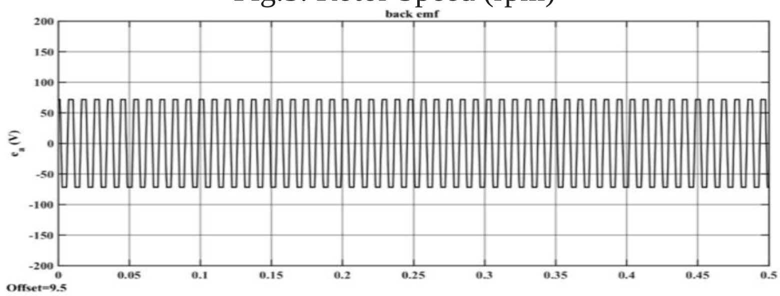

Fig.6. Back emf ea (V)

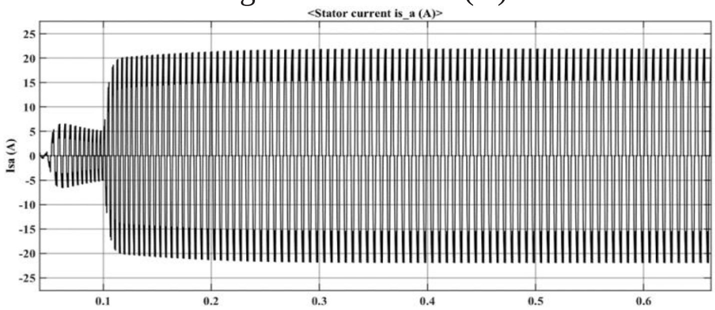

Fig.5.9. Stator Current output

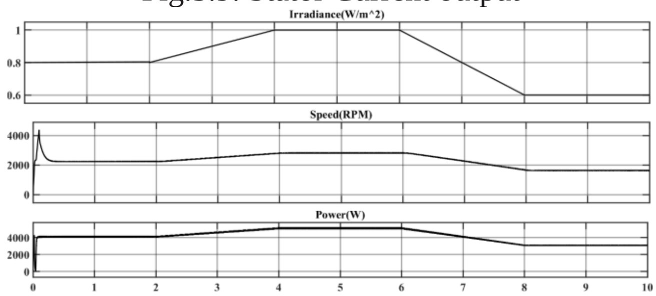

Fig.5.Performances of BLDC motor

TABLE III. THE EFFICIENCY OF THE OVERALL SYSTEM AT VARIOUS IRRADIANCE

G (W/m^2)	P_{pv} (W)	P_m (W)	η (%)
200	547.2	377.78	69.03
300	831.9	614.02	73.80
400	1118	854	76.39
500	1403	1094.48	78.01
600	1688	1336.38	79.17
700	1972	1577	79.97
800	2254	1817.42	80.63
900	2534	2055.58	81.12
1000	2813	2294	81.55

VII. CONCLUSION

This paper represents a non-electrical input-based artificial neural network (ANN) MPPT for solar power water pumping system using BLDC motors. The aim is to implement an MPPT technique that is independent of step size and to model the system effectively. The results have shown that one practical option for the design of a step-size-independent water pumping system driven by a photovoltaic array using a BLDC motor is to implement ANN-based MPPT. Excellent transient and steady-state performance over a wide range of irradiance has been observed in the system. Results shows that the system operates at peak efficiency of 81.55% and maintains a steady water flow even in low-light conditions with an efficiency of 69.03%. A proposed approach is also used to achieve soft starting of BLDC motors, which is advantageous for the motor pump set's smooth operation.

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