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ADAPTIVE NEURAL NETWORK ENHANCED **SOLAR-POWERED WATER PUMPING SYSTEM WITH ADVANCED MPPT AND HYBRID ENERGY INTEGRATION**

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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 brushless DC (BLDC) motor. The objective is to model a step size 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 environment and efficiency of the overall system is calculated under various irradiance condition.

Index Terms **–Artificial Neural Network (ANN), BLDC motor, Boost Converter, Maximum Power Point Tracking (MPPT), Solar photovoltaic (SPV) array.**

I. INTRODUCTION

Due to increase in population, the requirement of the energy is increased rapidly which put the burden on the existing conventional source of the energy, results in the shifting focus from fossil fuel-based energy generation to clean and green source of energy generation. The solar photovoltaic technology can be connected on a bigger scale and it additionally shows a naturally ideal contrasting option to a non-renewable energy source (oil and coal-based power) controlled customary water pumps. 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. Introducing SPVWPS has numerous points of interest to the pumping locales, where the national electricity grid connection is not accessible, solar energy is accessible inexhaustibly, and transport facilities are sufficiently feeble. This paper is based on the work carried out in [1,2]. The DC link voltage varies with a change in solar irradiance [1] and speed control of BLDC motor is done by keeping DC link voltage at rated value [2]. In this paper second approach of the system modelling is considered. A DCDC boost converter is utilized which is operate in continuous conduction mode (CCM) driven by ANN based MPPT to provided optimal duty cycle. Several MPPT techniques are discussed in the literature [3,4]. MPPT algorithms which widely receive acceptance are perturb and observe (P&O) [5,6] and incremental conductance (INC) [7,8] when the water pumping system is considered. But in a standalone SPVWPS, the step size of the MPPT method is an imperative 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 condition. 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 innate 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]. A few researches in the field of SPV array driving water pumping utilizing induction motor, synchronous reluctance motor (SyRM) and switched reluctance motor (SRM) have been made in the literature [12-15]. It has been seen that the proficiency of an induction motor reduces under light loading as the excitation losses dominate, moreover an induction motor driven system has low power conversion efficiency. In case of SyRM can run satisfactorily for a restricted range of solar irradiance level. An SRM has not gotten much prominence due to a very high acoustic and torque ripple for SPVWPS [10]. So, BLDC motor selected for this purpose. BLDC motors don't utilize brushes, they have extended life, versatility and silent operation. BLDC motors have been utilized broadly in numerous applications that demand a reliable operation and optimum performance. BLDC motor has a permanent magnet, so it has high torque speed proportion than other motor of the same size and it is applicable for those operations where weight and space are crucial. It has extended speed ranges, preferable torque and speed than other motors. Enhances dynamic performance while shortening the operating cycle due to low rotor inertia 9140. Proposed SPVWPS uses two PI controller 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.

SAMPLING AND SYSTEM MODELLING

2.1 Photo Voltaic System

The most commonly used renewable energy source is solar energy. Increasing the number of solar cells in a panel can increase its voltage output .A photovoltaic, or PV, system is used to convert the solar light energy into electrical energy. The basic component of a PV system is known as a solar cell. A single solar cell has the capacity to produce about 0.5 volts of electricity. A solar panel, or solar module, is a combination of several solar cells connected in series to generate usable voltage. The solar panel voltage can be increased by increasing the number of solar cells. For example, 30 solar cells connected in series will produce an output of 15 volts. A combination of solar panels connected together is known as a solar array and can be used to achieve the required current and voltage. It works by generating electricity when exposed to sunlight, known as the photovoltaic effect. This principle is used by solar cells to produce electricity. The solar cells are made of semiconductors. Mostly, silicon comprises three layers; the top layer, called the N-type layer, is comparatively thin and contains a high concentration of electrons. The bottom layer, called the P-type layer, contains a high concentration of holes. When the p-type and n-type semiconductors join together and form a p-n junction. On forming a p-n junction, the electrons of the n-type material try to reach the p-region, creating a negatively charged layer. Similarly, the holes in the p-type material try to reach the n-region, creating a positively charged layer. This region between the two layers is known as the depletion region of the semiconductor. Sunlight penetrates the top thin layer easily to reach the depletion region. Due to the deficiency of charge in the depletion region, it contains neutral atoms. These neutral atoms are broken, and when the photons from the sun strike the depletion layer, this knocks the electrons from the neutral atoms, leaving behind the holes and using free charge carriers. Then the electrons move towards the n-type layer, and the holes move towards the p-type layer. Due to the electric field present in the depletion region, when connecting an electronic circuit, electrons flow through generating electricity to electrical devices like bulbs, fans, etc.

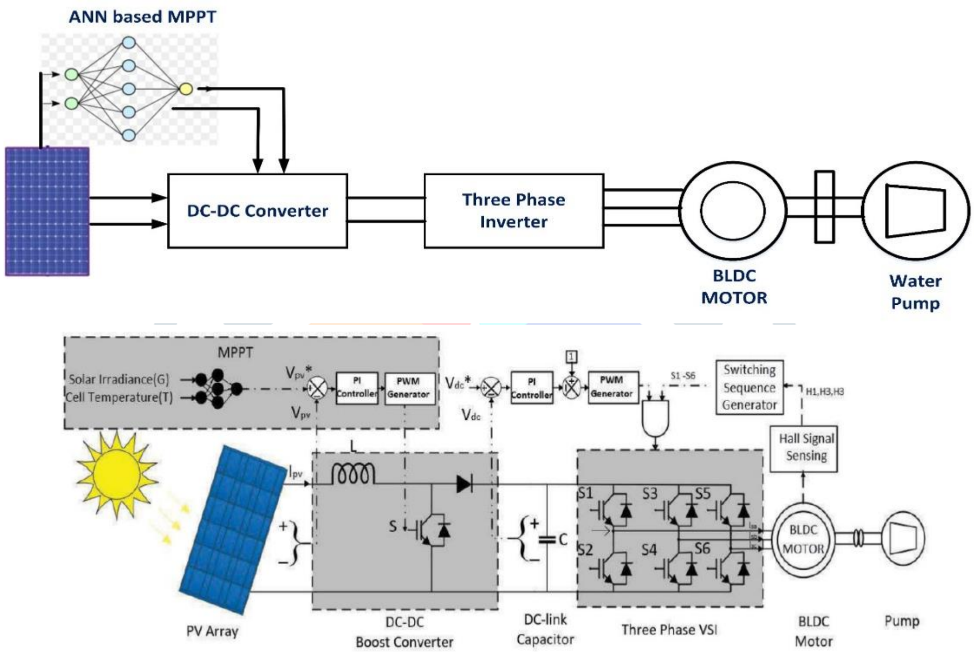


Fig : 1 Block Diagram of Proposed System

Detailed schematic model SPVWPS using BLDC motor is given in Fig. 1. This system consists of 2.38 (3.2) kW (hp) BLDC motor coupled to a pump whose specification is given in Table 1. The system also has PV array, an ANN based MPPT driving DC-DC boost converter, DC link capacitor 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.

Trina Solar TSM-200DA01A.05 SPV module is selected which is available in the module section of PV array block in MATLAB/Simulink. SPV array of rating 2.81kW feeding 2.38 kW motor is selected. Excess power is required to overcome all the losses occur during various stages of the SPVWPS system. PV module specification is given in Table 2. I-V and P-V curve at various irradiance is given in Fig. 2. To generate 2.81kW, maximum voltage (Vmpp) selected as 267.4V.

Table 1. Nominal value and specifications of BLDC motor

BLDC Motor Specification	
Power, P (kW)	2.38
Speed, Nr (rpm)	2600
DC voltage, Vdc(V)	325
Current, I (A)	7.35
Poles, p	12
Inertia, J (kg cm2)	7.05
Voltage constant, ke (Vpeak L-L/Krpm)	88.86
Torque constant, kt (Nm/Apeak)	0.85
Phase to Phase resistance, Rs (Ohm)	0.957
Phase to Phase inductance, Ls(mH)	3.8

Table 2. SPV array specification

TSM-200DA01A.05 SPV module	
Maximum power (W)	200.932
Open circuit voltage Voc (V)	46.2
Voltage at maximum power point Vm (V)	39.2
Short-circuit current Isc (A)	5.62
Current at maximum power point Im (A)	5.26
Cells per module (Ncell)	72
Parallel-connected modules per strings (NS)	2
Series-connected modules per string (Np)	7

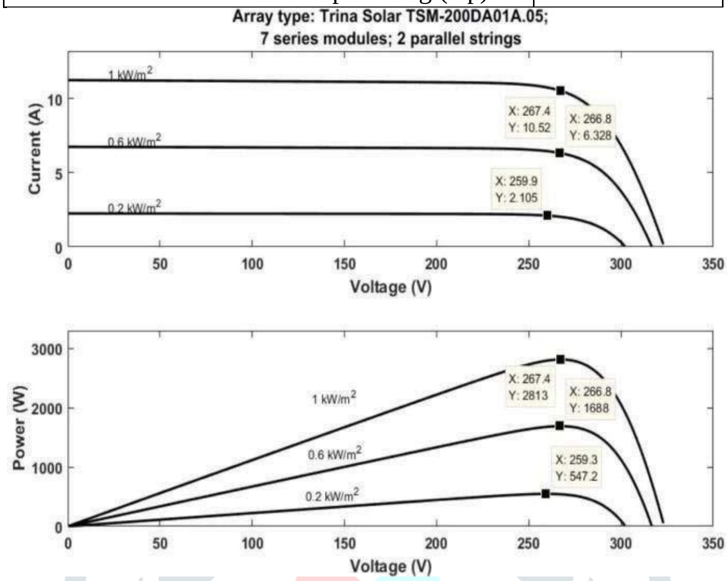


Fig.2 I~V and P~V curve of selected SPV array

BOOST CONVERTER DESIGN

At STC, SPV array maximum output voltage is Vmpp = 267.4V and output of the boost converter maintained to be at 325V at DC link (Vdc) which is rated voltage of BLDC motor. So estimated Duty cycle (D) is given by

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

Switching frequency (Fsw) for the boost converter is selected to be 20,000 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 powerpoint.

II. MAXIMUM POWER POINT TRACKING

Several ANN based PV MPPT techniques are discussed [4]. In this paper non-electrical input-based ANN based MPPT is used which uses irradiance (G) and temperature (T) as input and give Vmpp as an output which is taken as reference Vpv*. This Vpv* is then compared with instantaneous Vpv and then an error is generated which will be feed to the PI controller. The PI controller's output will be provided to the PWM signal generator to generate the required duty cycle. Optimal tuning of PI controller should be performed for better performance.

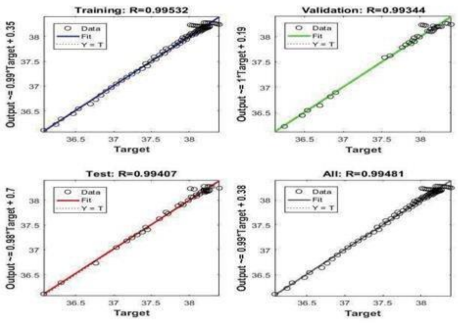
III. TRAINING OF NEURAL NETWORK

The training of neural network carried out after calculating the Vmpp value at different irradiance and temperature. For training 552 data points are generated. These data points are trained using 2 hidden neurons. Regression plot is given in Fig.3. which depicts the high accuracy of the trained model.

IV. POSITION SENSOR

The position sensors placed in the motor can distinguish rotor position and change it into an electrical signal, provide the correct commutation information for the logic switch circu

Fig.3 Regression plot of neural network MPPT model



Commutation for BLDC motor is a six-step process. All six switches of VSI turned ON/OFF to create six flow vectors. These vector makes BLDC motor points 60° to the next position. Hall effect position sensor is required for commutation process. The hall-effect position sensor senses the rotor position of the BLDC motor, 0 to 60o span and produces three hall signals which are decoded to create the suitable switching pulses for the switches of VSI. Fig.4 shows the switching state electronic commutator. The hall effect sensors are usually placed in such a way that the magnets change its values previously the rotor is entirely the following compensation position. This consider for the following commutation to be made before the rotor really winds up and stuck 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

Fig.4 Control structure of the water pumping system

V. SIMULATION AND DISCUSSION

The simulation ran in the MATLAB/Simulink 2016a and performance curve of the overall system is shown in Fig.5-10. Fig. 5 shows the performance of the SPV array at STC condition. From the Fig. 5, it is observed that ANN based MPPT technique able to track maximum power of 2812 W with maximum voltage267.4 V and current 9.78 A. It is also observed that the proposed MPPT have excellent tracking efficiency. Fig. 6 shows the performance of the boost converter where inductor current iL is found to be 10.50 A and Vdc is maintained at 325 V. Duty cycles in Fig.6 desirable for CCM is shown. In Fig. 7 the BLDC motor builds up the rated speed and electromagnetic torque, (Te) at full load to drive the water pump. Due to present of ripples current at the DC link of the VSI, a minor fluctuation in Te is observed. Smooth starting of BLDC motor is also observed in speed~ time characteristics.

Dynamic characteristics of SPVWPS is shown in Fig. 8-10. Dynamic change in solar irradiance is applied; 1000 W/m2 form 0-0.4 s, 200 W/m2 from 0.4 to 0.7 s. and 600 W/m2 from 0.7-1 s. With respect to a dynamic change in solar irradiance, proposed MPPT successfully able to track maximum power in all the cases immediately as shown in Fig.8. In Fig.9 Vdc is maintained at 325 V and inductor current change in accordance with the solar irradiance. In Fig. 10 all variables of the BLDC motor i.e. speed, electromagnetic torque, pump load torque (TL), back emf of phase A (ea) and stator current of phase A (Isa) change in accordance with solar irradiance level. It is observed that the BLDC motor quickly able to reach steady-state value. At various irradiance pump load torque countered by the electromagnetic torque that depicts the steady performance of the motor. The efficiency of the SPVWPS is given in Table 3 at various irradiance level.

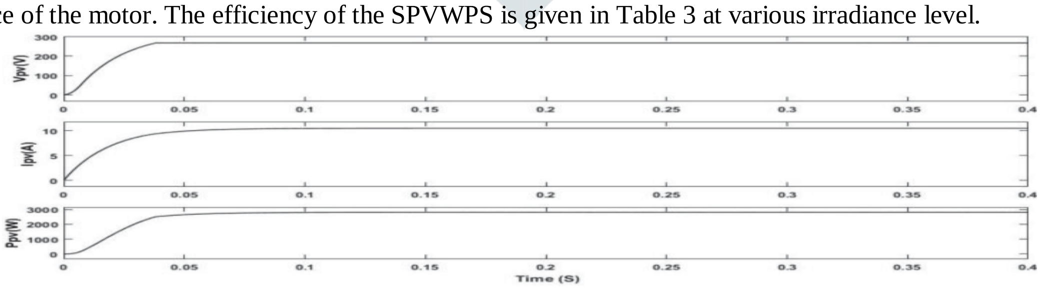


Fig.5 Performances of SPV array under STC

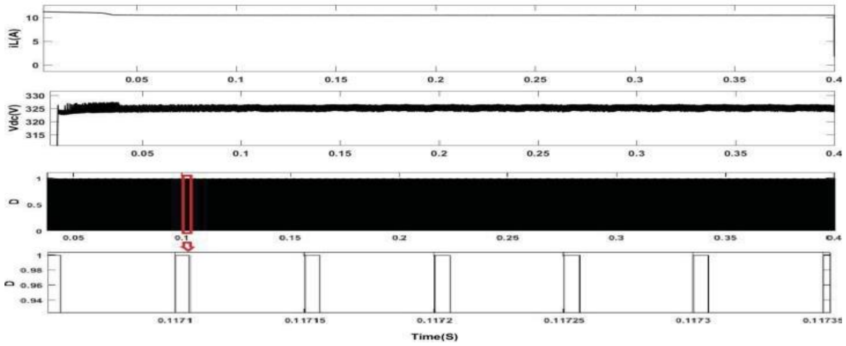


Fig.6 Performances of DC-DC Boost converter under STC of SPV array

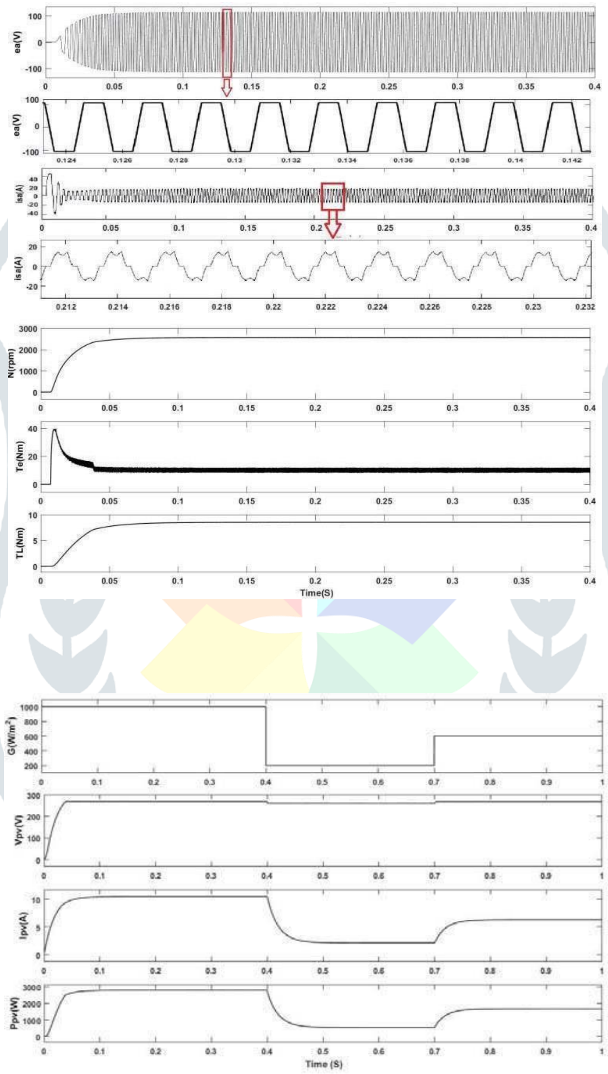


Fig.7 Performances of BLDC motor under STC of SPV array

Fig.8 Dynamic performances of SPV array

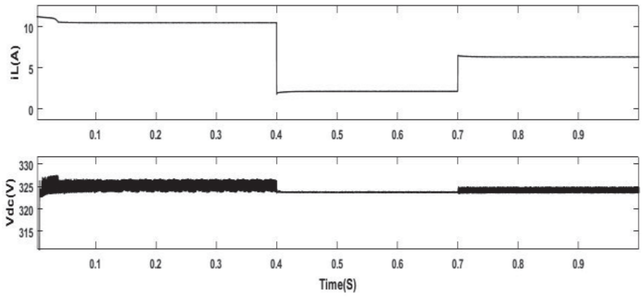


Fig.9 Dynamic performances of DC-DC Boost Converter

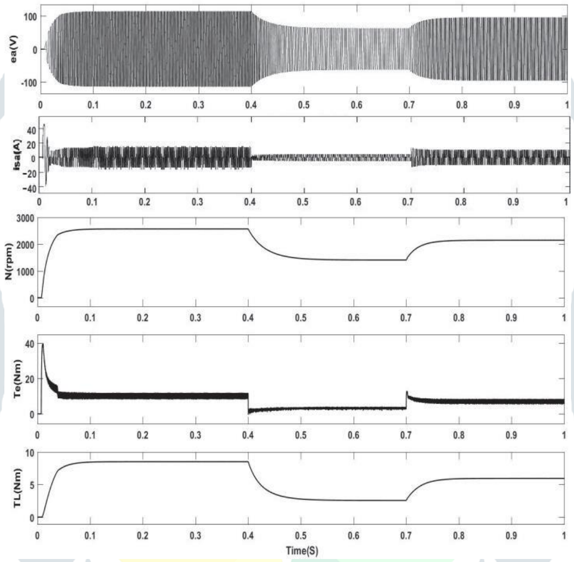


Fig.10 Dynamic performances of BLDC motor

Table 3. Efficiency of the overall system at various irradiance

G (W/m2)	Ppv(W)	Pm(W)	4 (%)
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

VI. CONCLUSION AND FUTURE SCOPE

In this paper, a non-electrical input-based ANN MPPT is introduced for solar power water pumping system using BLDC motor. The objective was to introduce a step size independent MPPT technique and optimal modeling of the system. The outcomes have demonstrated that usage of ANN-based MPPT is one of conceivable option design step size independent operation of PV array driving water pumping system using BLDC motor. It has been observed that the system has excellent transient and steady-state performance over a wide range of irradiance. Results have proven the optimal performance of the system with the highest efficiency of 81.55% and maintain a continuous flow of water even at the lowest irradiance with an efficiency of 69.03%. Soft starting of BLDC motor is also achieved using a proposed method which is desirable for smooth operation of the motor pump set.

The output voltage THD values are not improved much so that the research should be carried out in this area; a filter circuits configuration should be improved. For the inverter circuits, the grid tied inverters are having the problem that if the grid fails, the customer will not get any supply even though there is power generation from the PV system. The BLDC motor can be used for electric vehicle applications. This should be considered as a serious problem and the research should be carried out in these areas.

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