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DESIGN AND IMPLEMENTATION OF TYPE-2 FUZZY LOGIC CONTROLLER FOR ANN BASED MPPT APPLIED TO SPVWPS USING BLDC MOTOR

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ABSTRACT:

Renewable energy sources are being used to lessen reliance on fossil fuels, which are deteriorating at an alarming rate. Renewable energy sources are therefore being prioritized in order to fulfill the increasing demand for power caused by the expanding human population. The goal is to create a novel solar-powered water pumping system that makes use of a Type-2 Fuzzy Logic Controller (T2FLC) to regulate a Brush Less DC (BLDC) motor. The torque ripples and noise of the BLDC motor are eliminated and the system's performance is enhanced with efficient and dependable water pumping under varied environmental circumstances by integrating a T2FLC into the current system. The device in question is a Voltage Source Inverter (VSI) that has a built-in decoder and a DC link voltage controller, also known as a PWM controller. The BLDC (Brush Less DC) motor's characteristics are controlled by the decoder, which executes electronic commutation by Hall signal detection. The system's performance is further confirmed using Proportional-Integral (PI), FLC/Type-1 FLC controllers. When tested in a MATLAB/SIMULINK setting, the suggested Type-2 FLC outperforms the other two controllers. In this study, we evaluated the BLDC motor's torque under static and dynamic irradiance circumstances to those of PI, Type-1, and Type-2 fuzzy logic controllers.

Keywords: ANN, type-2 Fuzzy, BLDC, VSI, SPV, irradiance, MPPT, Efficient operation, DC-DC converter.

I INTRODUCTION

As the world's population rises, so does the need for energy, putting a strain on our current conventional energy sources. As a consequence the focus is shifting from fossil fuel based energy generation to clean and green sources of energy generation.

Connecting solar photovoltaic systems on a larger scale also demonstrates a suitable alternative to conventional water pumps powered by non-renewable energy sources like oil and coal [1, 2]. To fulfill the water requirement, one option is to install a Solar Photovoltaic Water Pumping System (SPVWPS) that operates independently [1]. Irrigation, home usage, and industrial automation are some of the many areas that are giving this technology high marks. Keeping the DC connection voltage at its rated value allows the BLDC (Brush Less DC) motor to adjust its speed, which in turn is affected by changes in solar irradiation [2]. The ideal duty cycle is achieved by means of a DC-DC boost converter that runs in Continuous Conduction Mode (CCM) and is controlled by Maximum Power Point Tracking (MPPT) based on Artificial Neural Networks (ANNs) [4].

The literature discusses several Maximum Power Point Tracking (MPPT) approaches. When thinking about the water pumping system, two popular Maximum Power Point Tracking (MPPT) algorithms are Incremental Conductance (INC) and Perturb and Observe (P&O) [3, 5]. However, the control characteristics of a standalone SPVWPS (Solar Photovoltaic Water Pumping System) are heavily influenced by the step size of the MPPT (Maximum Power Point Tracking) approach [6, 9]. The literature discusses a number of DC-DC conversion strategies, including Boost, Boost Buck, Luo, and Landsman converter [7, 8, 10, 11]. A Boost Converter is used because of its excellent switching characteristics and the fact that its inductor acts as a ripple filter [1].

A water pumping system that uses SPV (Solar Photovoltaic) arrays with induction motors, synchronous reluctance motors, and switching reluctance motors also created [12][13]. The permanent magnet of a BLDC (Brush Less DC) motor allows it to outperform similarly sized motors in terms of torque-speed proportion, making it ideal for tasks where space and weight are paramount. It outperforms competing motors in terms of speed, torque, and expanded speed ranges [1][2][14]. Many industries rely on traditional P-I (Proportional Integral) controllers for controlling systems[15]. These controllers have a few drawbacks, such as being sensitive to controller gains, slow to respond to sudden disturbances (noise), and having a hard time getting complex nonlinear systems with uncertainties to perform satisfactorily under control.

Type 1 fuzzy logic controllers are known as FLCs [16]. To handle the uncertainties of several complicated nonlinear systems, FLC, first suggested by Zadeh in 1965, may draw on human knowledge and experience. One of the main draws of FLC is simple to construct, doesn't need precise mathematical formulae, and may perform well depending on things like rules and membership functions [16, 17]. A torque ripple reduction mechanism called FLC has been developed and put into use for BLDC motors [17][18]. However, type-2 fuzzy logic controllers were introduced by Zadeh in 1975 as an expansion of type-1 fuzzy logic control (type-1 FLC) [18], as type-1 FLC was unable to manage greater uncertainties [18][19]. Type-2 fuzzy logic controllers combine the Upper and Lower membership functions of type-1 FLCs, and they have three dimensions, whereas type-1 FLCs only have two. This is the main difference between type-2 and type-1 fuzzy logic controllers [20]. A type-2 FLC was developed and put into operation to remove torque ripples from BLDC motors in the system.

II LITERATURE SURVEY

By including a DC-DC boost converter as an intermediary power conditioning unit into a Solar Photovoltaic (SPV) array fed Brushless DC (BLDC) motor powered water pump, Rajan Kumar and Bhim Singh [1] created a system that is economical, efficient, dependable, and environmentally friendly.

Brushless DC (BLDC) motor powered water pumps that use solar photovoltaic (SPV) electricity were first proposed by Bhim Singh and Ranjan Kumar, [2]. The pulse width modulation (PWM) control of the voltage source inverter (VSI) via the DC link voltage regulator is what allows the BLDC motor's speed to be adjusted.

In their extensive study, B. Subudhi and R. Pradhan [3] covered every method for maximum power point tracking (MPPT) in a PV power system. The advantages and disadvantages of each MPPT method are unique. Therefore, it is crucial to conduct a thorough evaluation of these methods.

For the purpose of improving efficiency and maximum power point tracking (MPPT) of PV arrays, ANN based MPPT was presented by M. Elobaid et.al. [4].

Although there is a simpler framework offered by standard MPPT approaches.

Since PV arrays have a nonlinear voltage-current characteristic with a distinct point where the power generated is maximized, MPPT algorithms are deemed required by Najet Rebei et.al. [5]. Solar irradiation, temperature, and load all have a role in the electricity that a solar panel produces. Various photovoltaic (PV) water pumping system performances were shown.

Water pumping for irrigation and drinking water may be accomplished using a cost-effective standalone Photovoltaic (PV) system that does not need batteries, as proposed by S.G. Malla et.al. [6]. Connected to this system is a Maximum Power Point Tracker (MPPT) algorithm-based perturb and observe (P&O) system with the aim of boosting system efficiency.

An efficient, simple, and inexpensive brushless DC (BLDC) motor drive for a water pumping system that is supplied by solar photovoltaic (SPV) arrays was suggested by B. Singh and R. Kumar [7]. No further control circuitry is needed for speed control of the BLDC motor since they used a DC Link converter in conjunction with fundamental frequency switching of the voltage source inverter (VSI).4
Researchers Rajan Kumar and Bhim Singh[8] examined a Solar Photovoltaic (SPV) array-based water pump powered by a permanent magnet brushless DC (BLDC) motor and how a Landsman converter may be used to detect the highest power point. In addition to providing a gentle and secure start for the BLDC motor, it maximizes the power output of the SPV array.

In their proposal for an independent solar pumping system, Songbai Zhang et al.[9] noted that the stability and dynamics of the system are significantly impacted by the step size in maximum power point tracking (MPPT) algorithms. The pump in this system is powered by an induction motor.

A boost-buck (BB) DC-DC converter was presented by Rajan Kumar et.al., [10], for use in water pumping systems that are supplied by solar photovoltaic (SPV) arrays and driven by permanent magnet brushless DC (BLDC) motors. Designing it with a cascade of DC-DC boost and buck converters allows it to soft start the BLDC motor and achieve maximum power point tracking (MPPT).

III PROPOSED SYSTEM

The BLDC motor's rotor has permanent magnets, while the stator is equipped with windings. This rotor flux is created by permanent magnets. The rotor is attracted to and rotated by the stator windings, which generate electromagnetic poles. The problems associated with connecting electricity to the moving armature are eliminated with BLDC motors because the permanent magnets revolve around an immovable armature [1, 2]. Electronic controllers in BLDC motors cycle the winding phases many times. Instead of a brush and commentator combo, a solid-state circuit may be used to provide similarly timed power distribution from the controller. There are several stages to a BLDC motor's operation; the three-phase motor is the most common and well-liked because of its precise control, low torque output, and great efficiency [5, 6].

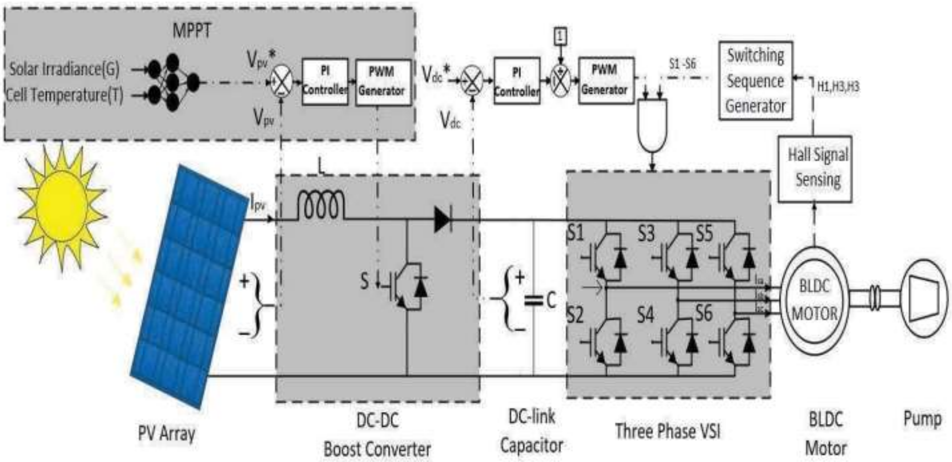

Fig.1. Topology of SPVWPS using PI Controller and BLDC motor

The methodology shown in Fig.1. is the most efficient way to control a Brushless Direct Current Motor (BLDC). Managing the bridge converter's input DC voltage is the foundation of the suggested approach. The motor windings generate a magnetic field, which controls the rotation of the motor, and the input DC voltage of the bridge converter is regulated in the same way [17]. The artificial neural network (ANN) with fuzzy controllers regulates the DC voltage input to the bridge converter. The integral and proportional gain parameters, which are the primary gains, are crucial [18]. All aspects of the ANN's performance while using fuzzy controllers are impacted by them. In this case, we use artificial neural networks (ANNs) with fuzzy controllers to get the same result—a non-integration output—from the input we provided [4]. The error computation for artificial neural networks (ANNs) with fuzzy controllers is done by using and logic in the Sugeno FIS-Fuzzy Inference System Editor of T2FLC.

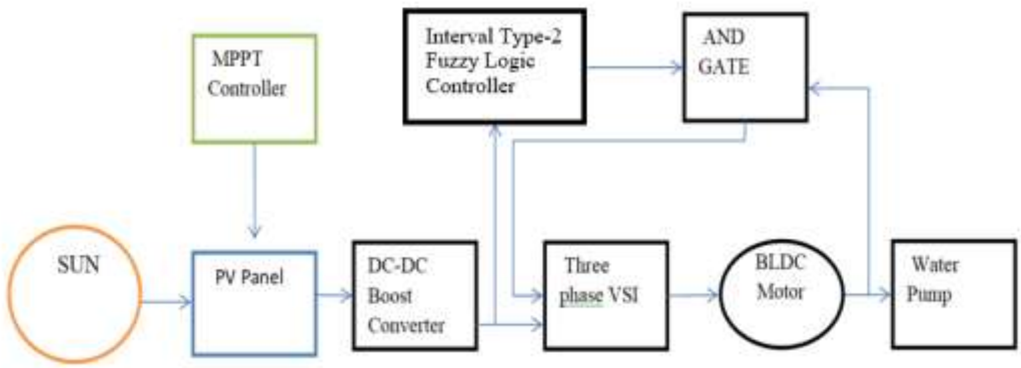

Fig.2. Proposed block diagram of SPVWPS using T2FLC with ANN

A PV array, an ANN-based MPPT driven DC-DC Boost converter, and a DC link capacitor are all components of the system shown in fig.2. The VSI and pump system are controlled by a PWM signal created via electronic commutation. For the DC-DC boost converter to function optimally and with CCM, the SPV array must be properly chosen [1, 2].

Controller being suggested:

Lotfi Zadeh invented the Type 2 Fuzzy Logic Controller (T2FLC) in the early 2000s [18], it is an upgraded version of the standard Fuzzy Logic Controller (FLC). Its introduction allowed for greater leeway in operating complicated systems and helped FLC overcome its shortcomings when dealing with uncertainty. A well-liked control system, fuzzy logic controllers (FLCs) employ fuzzy logic to convert inputs into outputs. Mathematically, fuzzy logic makes use of linguistic variables and fuzzy sets to describe information that is either imprecise or uncertain. A number of applications make use of FLC, including process control in manufacturing, temperature management, and speed control of electric motors [20].

Type 2 Fuzzy Logic Controllers (T2FLCs) basically work the same way as regular FLCs. On the other hand, T2FLC represents the uncertainty related to the input and output variables' membership functions using type 2 fuzzy sets. The fundamental procedures for operating a T2FLC are as follows.

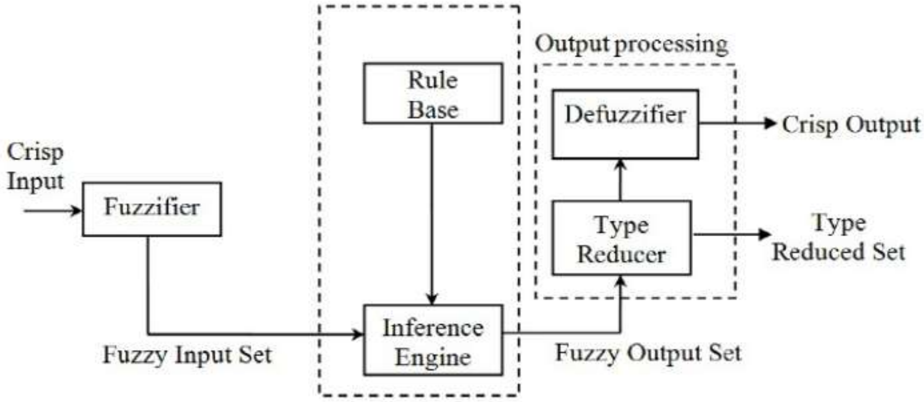

Fig.3. Type -2 Fuzzy Controller model.

Proposed controller methodology:

PI controller with ANN:

An innovative approach to solar-powered water pumping utilizing a brushless DC (BLDC) motor is introduced in this project maximum power point tracking (MPPT), which is based on artificial neural networks (ANNs) and does not need electrical input. We want to use neural networks to create a step-size independent maximum power point tracking (MPPT) for use in water pumping. To get the most juice out of the solar photovoltaic (SPV) array and to soft start the BLDC motor, we're using a DC-DC boost converter that's powered by an ANN-based MPPT. The BLDC motor's speed is controlled by pulse width modulation (PWM) of the voltage source inverter (VSI) using a DC link voltage controller. To carry out electrical commutation by hall signal detection, a pulse width modulation (PWM) signal is produced by means of the built-in encoder. The total system's efficiency is determined under different irradiation conditions after a BLDC motor driving pump system undergoes performance analysis in the MATLAB/Simulink environment.

FUZZY and ANN controller:

A water pumping system utilizes solar PV panels to keep costs down, The brushless dc motors used in this system are preferred over BDC motors due to their ease of maintenance, long lifespan, reduced noise, and high efficiency. The system is also easier to build [16][17]. Therefore a Fuzzy Logic Controller is used to overcome the drawbacks of PI Controller. The fuzzy logic control system is a mathematical framework for analyzing analogue input values and converting them into logic variables with continuous values between 1 and 0. These variables are used to control the BLDC parameters using the boost converter's gate driver circuit. The boost converters used here are really just DCDC converters, and their purpose is to increase the amount of electricity consumed by the solar panels. Maximum power point tracking (MPPT) is used to manage the boost converters.

Type -2 Fuzzy controller with ANN:

To enhance the BLDC motor performance by eliminating torque ripples and to to get rated speed of BLDC motor, a Type-2 fuzzy logic controller (T2FLC) is integrated into the system. T2FLC handles with more uncertainty than FLC with its two dimensional membership functions and upper and lower limits. Therefore T2FLC reduced noise and energy consumption of BLDC motor. Optimal performance of BLDC motor has been achieved with T2FLC.

Table-1: Rules of T2FLC

e	**∆e**		
	D	N	A
D	D	D	N
N	D	N	A
A	N	A	A

The inputs of T2FLC in the system are e- error and **∆e-** delerror or change in error and the membership functions of the inputs are D-Depreciation, N-neutral, A-appreciation shown in Table-1.

IV SIMULATION & RESULTS

The models used for simulation are created using MATLAB/Simulink 2021a shown in fig.4. The input temperature is 25^{o}C and the first model is run with an irradiance constant of 1000W/m^2. An irradiance step signal of 1000W/m^2 and an input temperature of 25°C are used to run the second model. The building components and functioning of both simulation models are identical. The inputs used to train the models are the only differentiating factor. A constant input is used by the first simulation model. The inputs to the second simulation model are variable. By comparing its output with the voltage produced by the solar panel, V_{pv}, and using the non-electrical inputs of irradiance and temperature, ANN-MPPT supplies voltage to the boost converter. Inverters that are based on voltage sources are fed by boost converters. In addition, the Type-2 FLC (Fuzzy Logic Controller) and PWM (Pulse Width Modulator) are notified of the results after comparing them to the rated voltage of the BLDC motor. To power the BLDC motor, a voltage source based inverter (VSI) is used. A hall effect sensor determines the rotational position of BLDC motors. The Hall sensor output can be deciphered by the decoder. The AND block receives pulse width modulator (PWM) pulses and decoder output. For the BLDC motor to run smoothly, the AND block's output is sent to the VSI (Voltage Source based Inverter).

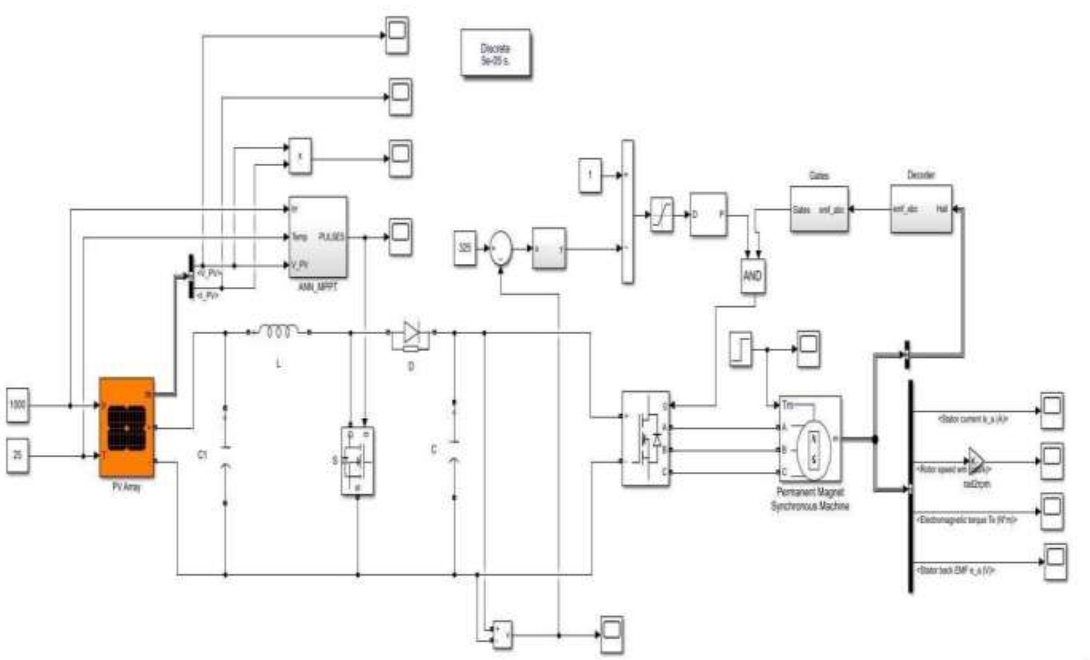

Fig.4. Simulation diagram

Fig.5 to Fig.9 displays the system-wide performance curve obtained from the simulation conducted in MATLAB/Simulink 2021a. As seen in the figure below, the SPV array performed well under STC conditions, with an ANN-based MPPT approach capable of tracking a maximum power of 2809 W, 270 V, and 10.38 A. Not only that, but the suggested MPPT has top-notch tracking efficiency. Boost converter performance while Vdc is held constant at 325 V. It is shown that CCM has favourable duty cycles. With the proposed Type-2 FLC Controller, the water pump may be driven by the BLDC motor at full load, which increases the rated speed and electromagnetic torque, Te. The speed and torque ~ time curves also show that the BLDC motor starts smoothly.

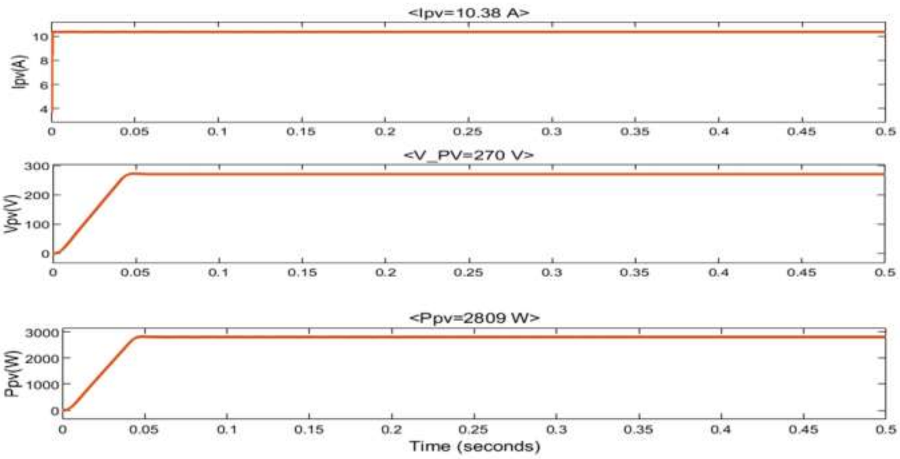

Fig.5. Performances of SPV Array under STC

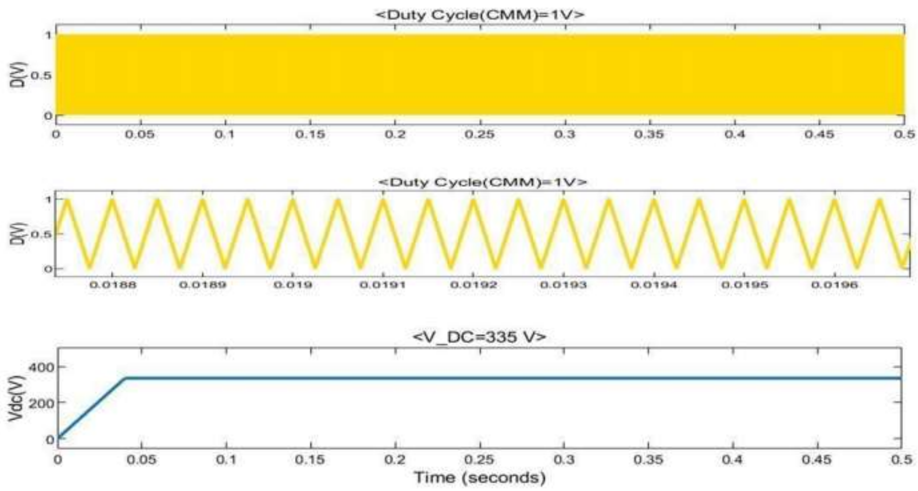

Fig.6. Performances of DC-DC Boost converter under STC of SPV Array

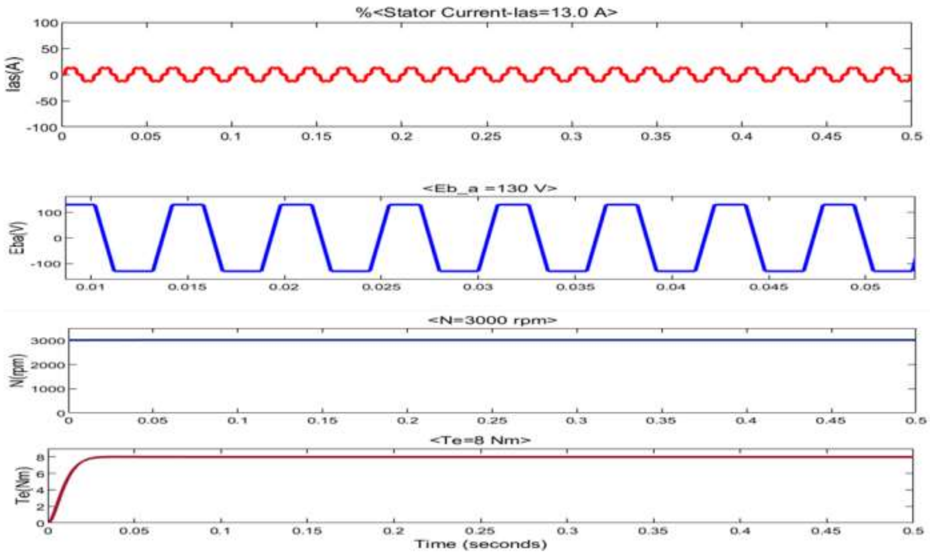

Fig.7. Performances of BLDC motor under STC of SPV Array

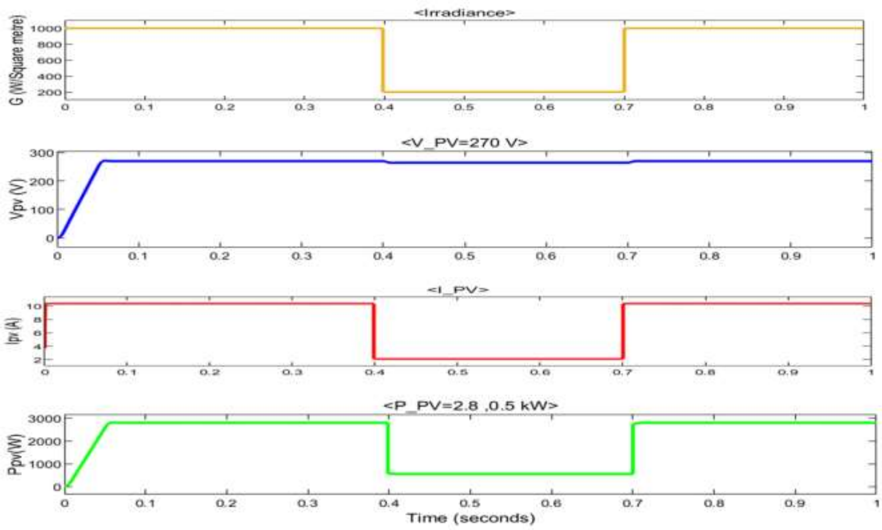

Fig.8. Dynamic Performances of SPV Array

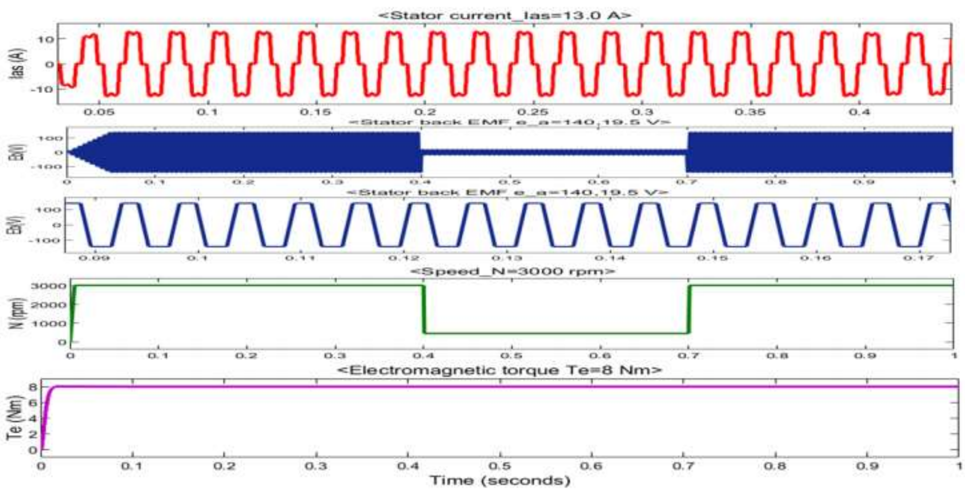

Fig.9.Dynamic Performance of BLDC Motor

Comparison Of Torques of BLDC Motor with FLC And Type-2 FLC Under Static And Dynamic Conditions

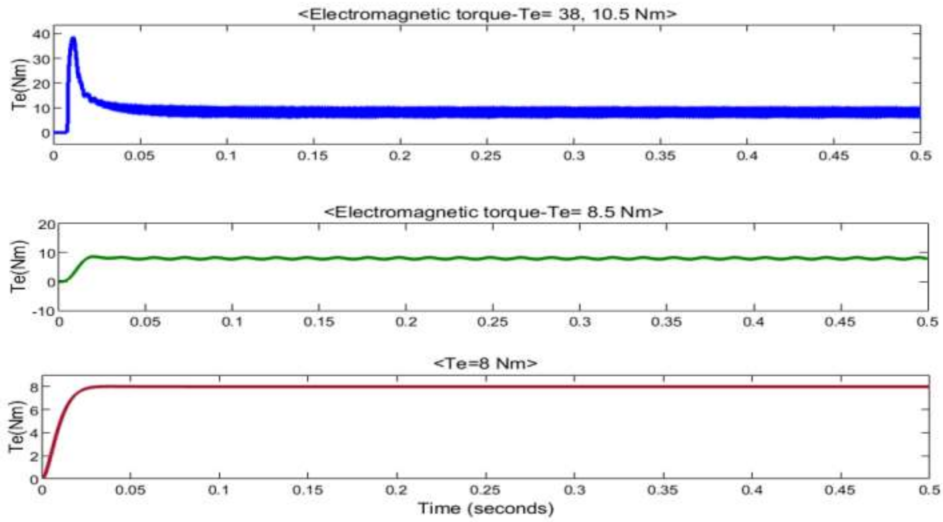

Fig.10 Torques of BLDC motor with PI, FLC, T2FLC under static condition with ANN

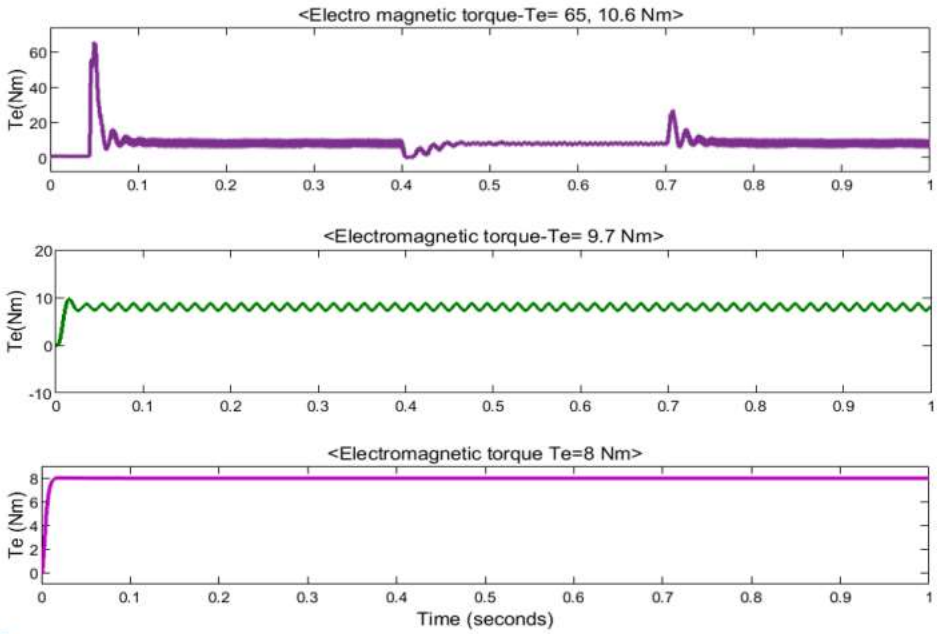

Fig.11 Torques of BLDC motor with PI, FLC, T2FLC under dynamic condition with ANN

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Under dynamic conditions, ANN measures the torques of BLDC motors with PI, FLC, and T2FLC. Applying an ANN-based maximum power point tracking (MPPT) controller with PI, FLC, and T2FLC for a solar photovoltaic water pumping system with a BLDC motor produces good simulation results in both steady-state and transient scenarios shown in fig.10 to fig.11. Additionally, it is less complicated than existing controllers for reducing torque ripple in BLDC motors. Using a Fuzzy Logic Controller (FLC) instead of a Proportional Integral (PI) Controller has decreased ripples in the torque waveform. By switching to Type-2 FLC from FLC/T1FLC (Type-1 FLC), torque ripples have been eradicated.

TABLE-2: Specifications of BLDC motor [15]

BLDC Motor Specifications	
Power, P (kW)	2.38
Speed, Nr (rpm)	3000
DC voltage, V_{dc}(V)	325
Current, I(A)	7.35
Poles, p	2
Inertia, J (kg cm2)	7.05
Voltage constant, k_e (V peak L-L/K rpm)	88.86
Torque constant, k_t (Nm/A peak)	0.85
Phase to Phase resistance, R_s (Ohm)	0.957
Phase to Phase inductance, L_s (mH)	3.8

TABLE-3: Comparison of parameters of BLDC motor with PI, FLC & T2FLC

Irradiation	**Static Condition (constant Irradiation)**			**Dynamic Condition (changing Irradiation)**		
BLDC Motor Parameters/Controllers	PI Controller	Fuzzy Controller	Type-2 Fuzzy Controller	PI Controller	Fuzzy Controller	Type-2 Fuzzy Controller
E_b (V)	130	130	130	130	140	140
I_s (A)	12.4	13.0	13.0	12.7	13.0	13.0
Speed-N(rpm)	2960	3008	3000	2987	3008	3000
Torque-T(N-m)	38 |10.5	8.5	8.0	65 |10.6	9.7| 8.7	8.0

CONCLUSION

For BLDC motor-powered solar water pumping systems, we provide an ANN MPPT that does not rely on electrical inputs. Using a PI controller, the system exhibits poor transient and steady-state performance over a broad spectrum of irradiances. Applying a Fuzzy Logic Controller (FLC) to the current setup lessens the swells in the system's output waveforms. The current system's torque output from the BLDC motor was smoothed out by adding a Type-2 Fuzzy Logic Controller (T2FLC) shown in table-2&3. As a result, the BLDC motor's jerky motions and vibrations will be lessened. The BLDC motor's noise level drops. The system's performance will be enhanced. The BLDC motor has a longer lifespan. Energy savings are achieved by reducing the power consumption of BLDC motors. The results show that the system is performing optimally and can keep water flowing continuously even when the irradiance is quite low. The suggested approach also accomplishes soft starting of BLDC motors, which is ideal for motor pump set smooth operation.

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