Modeling and Implementation of Neural Network Controller for Solar Water Pumping System using PMSM with a Battery for Continuous Power Supply

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ABSTRACT

From the last two decades onwards, the population has been increasing drastically, leading to increased electrical energy consumption. Presently conventional energy sources are depleting and inadequate to meet the sharp increase in demand. Hence, renewable energy sources play a vital role in meeting the increasing demand. Specially, solar energy is abundant in regions like Rayalaseema. Rainfall in regions like Rayalseema is less when compared with coastal areas. Hence, people mainly depend on pumping water from the ground for various regions like farming and domestic purposes in their daily lives. Hence, it's motivated to do research in an area like renewable energy sources for pumping water from the ground. The existing system consists of a Solar Photo Voltaic (SPV) array, a Three-phase Voltage Source Inverter (VSI), a Permanent Magnet Synchronous Motor (PMSM), and a pump. The VSI acts as a Power Processing Unit (PPU), which supplies desired currents to drive the PMSM. As the PMSM rotates, the pump coupled to the motor accomplishes the objective of water pumping. This work contributes development of Vector Control to improve the torque response of the PMSM and achieve fast maximum power point tracking (MPPT) using variable step size incremental conductance technique. In literature, it is understood that continuous power supply is not available due to the intermittent nature of the solar system. In addition to this power quality has to improve by reducing harmonics in the system. Hence, a continuous power supply will be achieved by incorporating a battery into the system is proposed. In addition to this, a PI controller is also replaced by a Neural Network Controller to improve power quality. The proposed method is developed in MATLAB Simulink environment.

Keywords:- Solar Water Pumping, Incremental Conductance Algorithm, Maximum Power Point Tracking, Permanent Magnet Synchronous Motor, Vector Control.

I. INTRODUCTION

The population of the society has been rapidly growing over the past 20 years, which has increased the need for electrical energy. The current conventional energy sources are running out and cannot keep up with the rapid rise in demand. Thus, using renewable energy sources is essential to supply the growing demand. In particular, areas like Rayalaseema have an abundance of solar energy. Compared to coastal regions, locations like Rayalseema receive less rainfall. Therefore, in their daily lives, people mostly rely on pumping water out of the ground for diverse uses like farming and household needs.

The energy density of renewable energy must be at least as high as that of fossil fuels, and clean energy must not release any pollutants like dust, sulfate compounds, or nitrogen compounds. To avert the impending depletion of fossil fuels, many nations have recently concentrated a significant amount of their efforts on development of renewable energy.[1] Solar Photo Voltaic (SPV) energy generation is one of the most significant renewable energy sources and one of the greenest choices available. Utilizing solar energy for water pumping can solve the problems of people like Rayalaseema region. The availability of conventional sources may not reach some remote areas for we have to implement an SPV system for water pumping without depending on conventional energy or grid interaction.[2]

But without proper mechanisms and control techniques, we may fail to execute the required system

A popular technique for solar cell functions is the maximum power point tracker, which recovers converting competence based on the commission power of the matrix. To discover the maximum power position of a PV panel, a Variable Step Size (VSS) Incremental Conductance (INC) MPPT controller is employed as a solution.[3-4] along with this Proportional Integral (PI) controllers are used as voltage controllers, speed controllers, and torque controllers of the Permanent Magnet Synchronous Motor.[5-6]

Amid this search, a particularly interesting path is emerging. The integration of Artificial Neural Networks into photovoltaic control frameworks and water pumping systems using Permanent Magnet Synchronous Motors (PMSM). ANNs represent a paradigm shift in the way we think about control mechanisms. These computational models are particularly effective at learning patterns from data, adapting to changing conditions, and managing the nonlinear interactions intrinsic to solar power generation. The combination of artificial intelligence, in the form of ANNs PV systems, and electrical machines represents a ground-breaking combination capable of improving the efficiency, adaptability, and reliability of solar energy technology as well as PMSM.

Design of Solar PV Array

The size of the solar PV array utilized for solar waterpumping depends upon the size of the load, it is a common practice that the power rating of the solar PV array is selected a bit higher than that of the load for accounting for the losses occurring in intermediate stages between the solar PV array and the pump, in this work, a 7.8 kW PMSM is utilized for rotating the pump, various specifications of PMSM are utilized, to feed the rated power to the pump, and a solar PV array of 8.4 kW is selected.[5]A standard solar PV module KC200GT manufactured by Kyocera, is selected for the modeling of the required rating of solar PV array. These modules are attached in series and parallel depending upon the required voltage and current level of the solar PV array, Various ratings of solar PV module KC200GT manufactured by Kyocera under standard test conditions (STC Insolation: 1000 W/m²; Temperature: 25^°C) are indexed.[6] A solar PV array-powered water pumping system utilizing vector-controlled PMSM has been modeled in MATLAB/Simulink using the Simscape sim power system toolbox, and its performance is validated during dynamic conditions during irradiance and temperature changes performance is depicted.

The donations mentioned in Section I Artificial Neural Networks (ANNs) are completed by doing the subsequent actions, along with the outcomes. Section II presents the main findings, remarks, and technique comparisons. Section II presents the results regarding the existing system and proposed system section III and section IV contain conclusions.

I.IMPLEMENTATION OF ARTIFICIAL NEURAL NETWORK FOR SOLAR WATER PUMPING SYSTEM USING PMSM

One of the current system's drawbacks is that, although the PI controller functions admirably in steady-state conditions, it has some challenges in dynamic ones.[7] Restricted Accuracy: Complex nonlinear dynamics may be difficult for PI controllers to correctly portray because they are linear and reliant on fixed parameters (integral and proportional gains).

Tuning can be difficult, particularly for systems with nonlinearities or large disturbances One of the current system's drawbacks is that, although the PI controller functions admirably in steady-state conditions, it has some challenges in dynamic ones. Restricted Accuracy: Complex nonlinear dynamics may be difficult for PI controllers to correctly portray because they are linear and reliant on fixed parameters (integral and proportional gains). Deciding which proportional and integral gains are right for a PI controller can be challenging.[8] PI controllers have little adaptability to changes in process dynamics or operating circumstances unless manually retuned, making them less resilient in dynamic conditions.

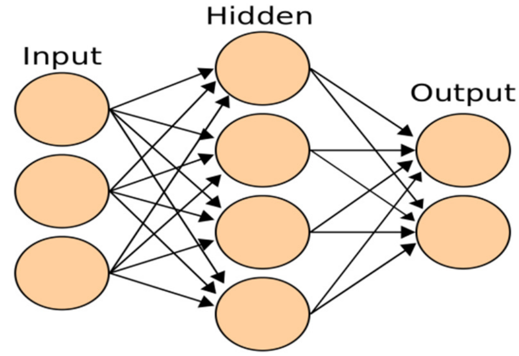
This means that the PI controller parameters will need to be changed, and an online technique will not be able to accomplish this. Such constraints serve as the main motivations for using adaptive control approaches.

Modeling of ANN, which is a simulation of the human nervous system which, like the brain, learns from the environment to process information. The concept is gaining increasing recognition for its excellent accuracy and promising pattern prospects. An Artificial Neural Network (ANN) has various applications, each with its own algorithm and setup, such as recognition and data classification. Adapting to one's surroundings is like changing a set of weights called synaptic weights that link different neurons. Both an ANN and the biological nervous system function in this way. Vast amounts of inherently complex and flawed data can be used to extract useful findings using neural networks. It is nearly hard for humans to recognize patterns and trends that other computer systems find difficult to detect, but they can extract patterns and identify trends with remarkable output.

The issue appears when we need to compute an output from a network that has connections pointing in all directions, similar to the brain in a multilayer feed-forward ANN, every neuron in a layer is paired with every other neuron in the later layer. It is recognized as a fully linked network. Two factors must be selected when the ANN is being trained: the value in the activation functions and the weights given to the different inputs.

The system would be easier to control if just one parameter were altered, however, such a configuration is not conceivable. To tackle this issue, a bias neuron is developed.

The bias neuron regularly yields a value of 1. The bias neuron is solely connected to the neurons in the following layer, not to any of the neurons in the prior layer. Figure 3. represents The ANN's structure an artificial neural network model that exhibits real-world behaviour. An Artificial Neural Network may include many "nodes" that represent individual brain cells. Via these connections, neurons can interact and communicate with one another. Nodes receive input data, process it, and then send it to other nodes. The output of a node is the value or node that activates it. It is also thought that the linkages have weight and that the fluctuation of this weight influences the learning capacity of the system.[9]



These artificial neurons are trained to respond as approximated by a random function based on the data. Throughout the training process, we used Levenberg-Marquardt backpropagation.

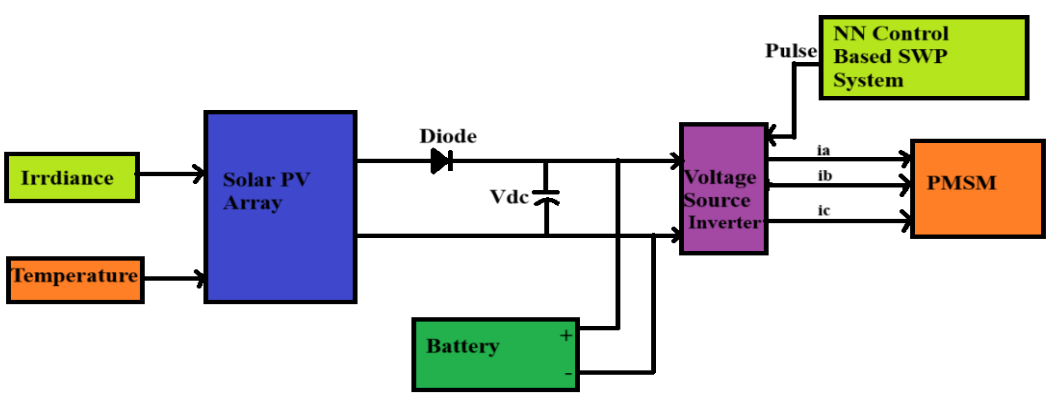


Fig 4. Block diagram of the System with a Battery and NN control-based Solar Water Pumping system

Fig.4 represents a block diagram of a water pumping system using PMSM as a motor and a single-stage -

Solar PV system as a source. solar PV array absorbs the irradiance and temperature from the solar energy and converts it into DC voltage. These are limited by using a DC link Capacitor which is connected between the PV array and a Three Phase Voltage Source Inverter this inverter converts the DC voltage into a Three Phase voltage and current which is fed to the PMSM and the Pump Coupled to the PMSM accomplishes its work to pump the water. A Neural Network Controller Solar Water Pumping (SWP) system is used to control the PMSM characteristics and DC link voltage of the system using Modified Vector Control.[10] A diode is used to eliminate DC ripple currents into the PV

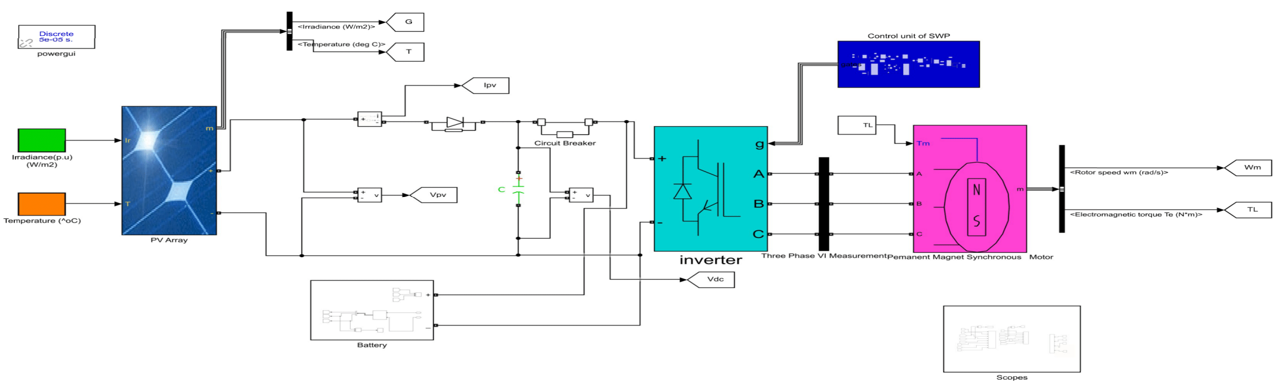


Fig.5. Simulink Model of Modeling and Implementation Neural Network Controller for Water Pumping System Using PMSM with a Battery for Continuous Power Supply

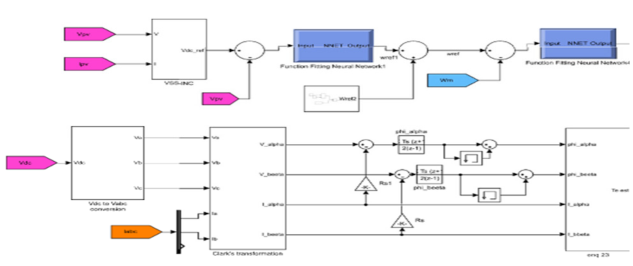


Fig.6. Simulink Model of Solar Water Pumping System Using ANN Controllers

system from the DC link capacitor. In the SWP system, the PMSM is controlled by reference voltage from VSS

and dc link voltage and processed through ANN controllers for voltage control, speed using feed-forward term, and torque control by estimating torque by Clark's alpha, beta transformation respectively, to generate In this way, the iq ref is generated. For water pumping operation, the motor is operated below ratedspeed. Since the speed of the motor is to be controlled below the base speed, no field weakening operation is required. Therefore, the reference direct axis current (id ref) is kept at zero. This also ensures unity power factor operation. After the generation of iq ref and id ref, dq0 to abc transformation is used to generate the reference currents (ia ref, ib ref and ic ref). These reference currents are compared with the sensed motor currents (ia, ib, and ic) and a hysteresis current controller is used for the generation of switching signals.
pulses for the inverter.

In order to give the PMSM a constant power supply, a battery has been incorporated into the setup. This means that even in the absence of solar energy, the pump can still function.
The current system uses proportional and integral (PI) controllers to regulate the PMSM's voltage, speed, and torque. Traditional PI controllers have limits, thus we are switching to ANN controllers in their place.[10]

The below figures Fig.5 and Fig.6 represent the Simulink models of the system and subsystem (control unit of SWP) with Modified Vector Control [MVC].

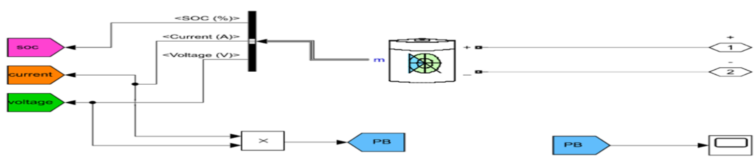


Fig.7.Simulink diagram of a battery

The above figure Fig.10 represents the Simulink model of battery which we incorporated in the existing system for continuous power supply, which can give power supply to the PMSM when the PV system is unable to supply to it.

For a single-stage topology, SPV array MPP voltage Vmpp is chosen near about to the DC link voltage (Vdc). The Vdc for the PMSM model selected in this work is 560 V.[12]
In this MPPT is used for reference voltage to compare with other parameters for controlling purposes.

- In the proposed method, a battery is incorporated into the existing system with an aim to provide Continuous power to run the PMSM even during nighttime or winter season.
- A circuit breaker is also injected into the system when the PV module is unable to discharge the circuit breaker open and the battery starts discharging.
- The PI controllers in the existing system are replaced with the Neural network controller for better performance in the system.
- Thereby performance of the system is improved the Torque response in the existing system is improved.

The advantages are,

- **Non-linearity**: Neural networks can learn and model non-linear relationships between inputs and outputs, which makes them well-suited for controlling complex systems that have non-linear dynamics.
- **Adaptability**: Neural networks can adapt to changes in the system being controlled, such as changes in the environment or the system itself, without needing to be explicitly re-programmed.
- **Fault tolerance**: Neural networks can continue to operate even if some of their components fail, making them more robust than traditional controllers.

Learning: Neural networks can learn from data, allowing them to improve their performance over time with experience, and potentially reducing the need for human intervention.

Overall, neural network controllers have the potential to offer improved performance, flexibility, and robustness compared to traditional control methods.

II. RESULTS AND DISCUSSION

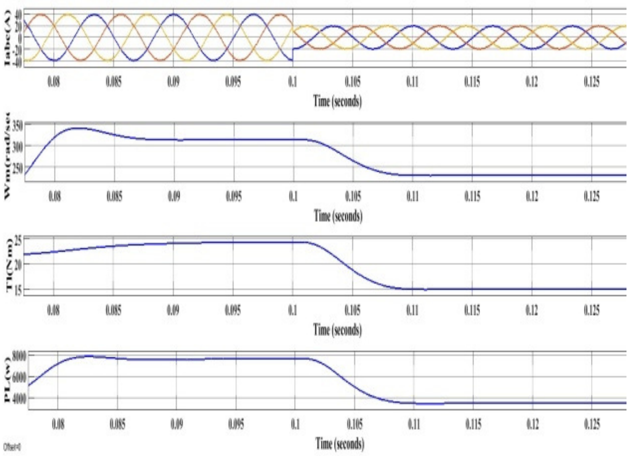


Fig.8. Dynamic performance of the system during Irradiance Change from 1000 W/m² to 500 W/m² at Constant Temperature 25 ºC.

above Figure 8 gives us the graphical representation of Dynamic performance during insolation change (a) from 1000 W/m², to 500 W/m², here we observed power (P_L), TI(n_m), W_m(rad/sec), current(I_{abc}) concerning time(T).

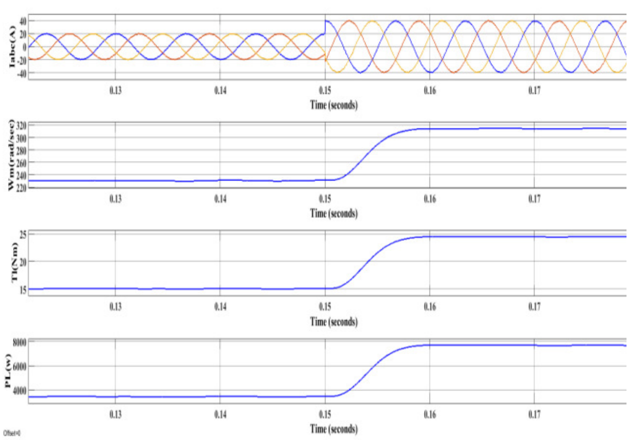


Fig.9.Dynamic performance during Irradiance change from 500 W/m² to 1000 W/m² at Constant Temperature 25 ºC.

Here we observed power(P_L), TI(n_m), W_m(rad/sec), current(I_{abc}) with respect to time(T). Figure 9, shows the graphical representation of Dynamic performance during insolation change (a) from 500 W/m² to 1000 W/m²

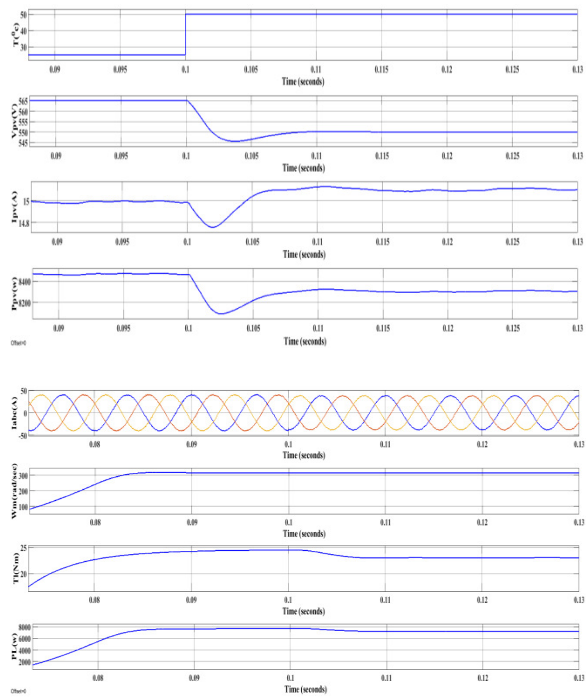


FIG.10. Dynamic performance of the system at Temperatures 25 ºC and 50 ºC at Constant Irradiance 1000 W/m²

figure 10, gives us the graphical representation of dynamic response concerning temperatures 25 ºC and 50 ºC, here we observed parameters of power, voltage, currents, and temperature concerning time(t).

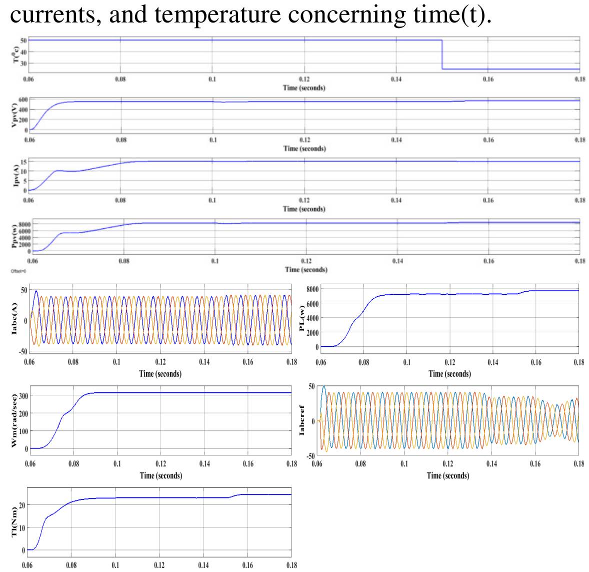


Fig.11. Dynamic response concerning temperature T= 50 ºC to 25 ºC at constant Irradiance 1000 W/m²

Here we observed parameters of power, voltage, currents, and temperature concerning time(t). Figure 11 gives us the graphical representation of the dynamic response concerning temperature T=50 ºC to 25 ºC

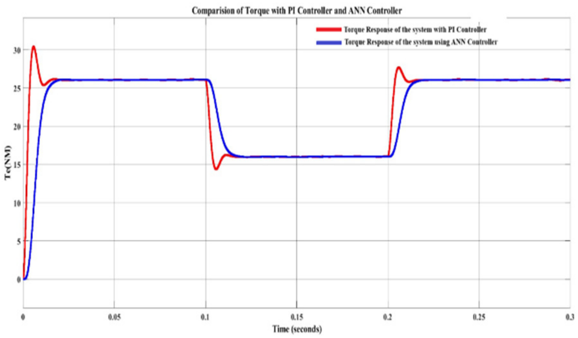


Fig.12 Comparison of torque response with PI controller and ANN controller.

Figure 12, gives us the graphical representation of the comparison of torque response with the PI controller and artificial neural network controller concerning time.

battery performance characteristics concerning time are shown in Fig. 13 below.

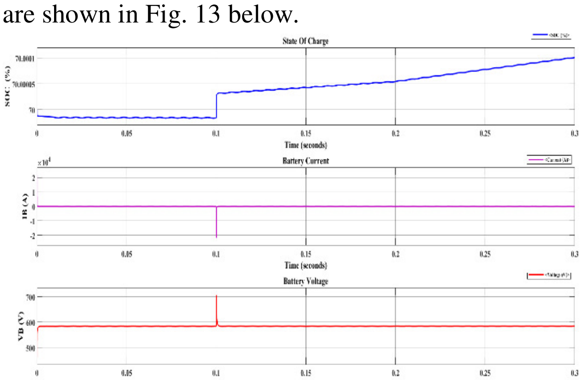


Fig.13. Performance Characteristics of battery

III.CONCLUSION

In this paper, a maximum energy harvesting technique utilizing an artificial neural network is introduced and compared with PI controllers to find which algorithm gives better performance. MPPT Voltage compared with DC link voltage and its error is processed by other ANN controllers for voltage, speed, and Torque control of PMSM. ANNs are trained in the MATLAB/SIMULINK model. Comparison results show that ANN-based controller gives better performance.

In addition to this for maintaining a continuous power supply to the PMSM a battery is incorporated.

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