

A Comparative Performance Analysis of ANN Algorithms for MPPT Energy Harvesting in Solar System

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Abstract: The generation of clean power has placed solar photovoltaic (PV) systems in the range of very high-demand clean energy sources. However, the capacity of the sunlight and temperature to variation in efficiency requires effective Maximum Power Point Tracking (MPPT) plans. Comparative analysis of artificial neural network (ANN)-based MPPT algorithms and other conventional algorithms such as Perturb and Observe, Incremental Conductance and Fuzzy Logic Control has been given in this paper. Accuracy, response time and stability: These algorithms are tested on MATLAB/Simulink. The results show that ANN-based approaches are more suitable in the application of solar energy in a predictable manner, as they have higher tracking and adaptability to evolving circumstances. Results provide useful data on the selection of the appropriate MPPT strategies to enhance the efficiency and sustainability of PV systems.

Keywords: Maximum Power Point Tracking (MPPT), artificial neural network (ANN), solar photovoltaic (PV), Fuzzy Logic Control.

I. INTRODUCTION

Renewable sources of energy have been brought into the limelight by increasing energy consumption in the world and alarm over the scarcity of fossil fuel reserves. Among them, much attention has been paid to solar photovoltaic (PV) systems because they are sustainable, scalable, and can generate clean energy. The operating characteristics of PV systems however rely heavily on variations in solar irradiance and temperature to produce nonlinear current voltage (Ivoltage) characteristics. To avoid this limitation, Maximum Power Point Tracking (MPPT) techniques will be employed to ensure that PV systems operate at optimum efficiency at all times [12], [15].

In recent studies, the opportunities of artificial neural networks (ANN) in MPPT have been identified due to their nonlinear mapping and flexibility. The comparative study of ANN algorithms by Roy et al. [1] showed that the algorithms outperformed the conventional methods in solar PV MPPT on convergence and tracking performance. Similarly, Hussain et al. [2] evaluated the performance of ANN-based methods in dynamic conditions and determined their validity in the case of real time solar energy capture. Bhattacharjee et al. [3] also compared ANN to perturb and observe (P&O) algorithms and it was found that ANN methods gave a smoother tracking and reduced oscillations at maximum power point.

Hybrid and intelligent systems have been discussed elsewhere. Kumar et al. [4] integrated Adaptive Neuro-Fuzzy Inference Systems (ANFIS) and ANN models and it was shown that the enhanced accuracy and resilience did occur in varying weather conditions. Kiran et al. [5] examined variable step-size ANN-based MPPT algorithms of partially shaded PV systems, with ANN approaches being faster to respond and improved steady-state response than the traditional controls. In a similar manner, Rojas-Galvana et al. [6] experimented with bio-inspired optimization algorithms with ANN to forecast MPPT. They obtained the results that the ANN based on Gray Wolf Optimizer (GWO) was better in terms of accurate and computationally efficient balancing compared to other approaches.

The wider application of ANN within a renewable energy system is also supported by supporting studies. Rokonzaman et al. [7] elaborated IoT-based solar PV systems, noting the role of smart

control in the distributed systems. Mishu et al. [8], and Bhatti et al. [10] evaluated efficient energy harvesting methods to IoT applications and PV-EV charging systems using optimization methods, respectively. Together, these studies make ANN and hybrid AI models good contenders to improve the stability and reliability of solar PV systems.

It is on this basis that we are working on a comparative performance of three ANN based algorithm namely the Levenberg-Marquardt (LM), Bayesian regularization (BR), and Scaled conjugate gradient (SCG) algorithms in the MPPT in solar PV systems. The proposed model was trained and also tested in MATLAB/Simulink with datasets of irradiance, temperature and voltage and measured using regression and error measures. The findings reveal that SCG performs better in terms of overall, whereas LM exhibits better deep correlation of the dataset and is therefore quite effective in practical applications of MPPT. The value of this paper lies in its ability to give an insight into the comparative merits of ANN-based algorithms and gives some recommendations on which methods are to be used to optimize solar PV efficiency.

II. LITERATURE SURVEY

MPPT systems have been developed to maximize the energy output of solar PVs using the algorithms of artificial neural network (ANN) Levenberg-Marquardt (LM), Bayesian Regularization (BR) and Scaled Conjugate Gradient (SCG). A comparative analysis of 1000 datasets of irradiance, temperature and voltage trained showed that SCG and LM have shown greater overall and dataset correlation performance, respectively. This demonstrates that ANN models can be dynamic to the constantly varying solar conditions and provide plausible tracking outputs [1].

A third paper extrapolated this comparison to LM, BR, resilient back propagation (RP), gradient descent momentum (GDM), Broyden-Fletcher-Goldfarb-Shannon (BFGS) and SCG algorithms. Matlab / simulink in 1000 datasets the LM and BFGS had a better gradient behavior, although RP and BR also had good results. It was also realized that SGC and GDM were not so effective, so the relevance of appropriate choice of algorithms when using MPPT is underlined [2].

Studies on solar PV systems focus on the contribution of solar PV systems in mitigating the depletion of fossil fuels and climate change. The methods of ANN-based MPPT (particularly the Levenberg-Marquardt method) were found to be significantly faster and more precise than classical algorithms such as Perturb and Observe (P&O). These models reacted quickly to abrupt irradiance variations and diminished oscillations thus increasing the system efficiency. Simulations during MATLAB/Simulink proved the stability of the ANN-based MPPT to provide optimal energy harvesting [3].

One more article was on Adaptive Neuro-Fuzzy Inference System (ANFIS) with ANN-based LM, BR and SCG algorithms. In MATLAB/Simulink, a 2.0 kW PV array including a DC-DC boost converter has been modeled. The findings indicated that ANFIS-LM model was more correlated to input-output data and minimized the errors, so it is superior to the other methods that were tested. This throws light on the possibility of AI hybrid techniques in solar MPPT systems [4].

This has been furthered through the implementation of variable step size ANN-based MPPT techniques. They were compared with adaptive P&O, ANN-based incremental conductance, ANN-based P&O, ANN-based hill climb, and fuzzy controllers in the partial shading scenario. The ANN models were faster settling, had lower oscillation and efficiency and could be used in real-world applications where more shading and dynamic weather conditions restricted the use of conventional methods [5].

Lastly, ANN has been integrated with bio-inspired optimization methods to enhance MPPT projections in the condition of shading. Different algorithms were compared including: at least: Grey Wolf Optimizer (GWO), Particle Swarm Optimization (PSO), Squirrel Search Algorithm (SSA), and Cuckoo Search (CS). The best trade-off between accuracy and speed was provided by GWO, and PSO had a small advantage in absolute error minimization. These findings verify that the optimized ANN techniques can greatly enhance the solar energy collection in large scale systems [6].

III. PROPOSED METHOD

This paper conducts a comparative performance study of three artificial neural network (ANN) algorithms: Levenberg-Marquardt (LM), Bayesian

Regularization (BR) and Scaled Conjugate Gradient (SCG) in maximum power point tracking (MPPT) of solar photovoltaic (PV) systems.

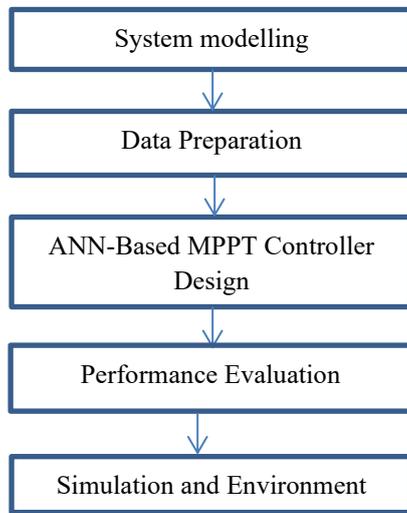


Fig. 3.1 Block diagram

The approach can be divided into multiple major steps:

3.1 System Modeling:

The model in MATLAB/Simulink is a solar PV array with environmental variations, e.g. solar irradiance and temperature. The PV output will also have a DC-DC boost converter that will regulate the operating point to the maximum power point.

3.2 Dataset Preparation:

In order to train and assess the ANN algorithms, a sample size of 1000 samples in terms of irradiance, temperature, and voltage values is obtained. The data is divided into 70% of training, 15% of validation, and 15% of test in order to evaluate the performance without any bias.

3.3 ANN-Based MPPT Controller Design:

Three algorithms are typically employed in the training of the Artificial Neural Network (ANN), namely, Levenberg-Marquardt (LM), Bayesian Regularization (BR), and Scaled Conjugate Gradient (SCG). LM algorithm only works well with small datasets since it is an algorithm meant to reduce error with high accuracy. Conversely, BR can assist with the overfitting problem by injecting some regularization into the training process, making the model more capable of generalization. Simultaneously, the SCG algorithm is associated

with a faster convergence speed and a reduced cost of computation, which can be applied to large data sets and multidimensional models.

3.4 Performance Evaluation:

The trained models are tested based on regression analysis, gradient values, momentum parameters and error histograms. Some measures of key performance are accuracy of tracking, convergence speed, and stability at steady state.

3.5 Simulation Environment:

The models are implemented in MATLAB/Simulink using ANN toolbox. The MPPT controller dynamically regulates the duty cycle of the boost converter to keep the PV array at the maximum power point in response to changing irradiance, and temperature.

3.6 Comparative Analysis:

The findings are compared between LM, BR and SCG algorithms. As the analysis indicates, SCG is more effective in terms of performance with better convergence in errors, whereas LM gives stronger results in terms of input and output datasets correlation. BR gives a trade-off, as it helps with the generalization and decreases over fitting.

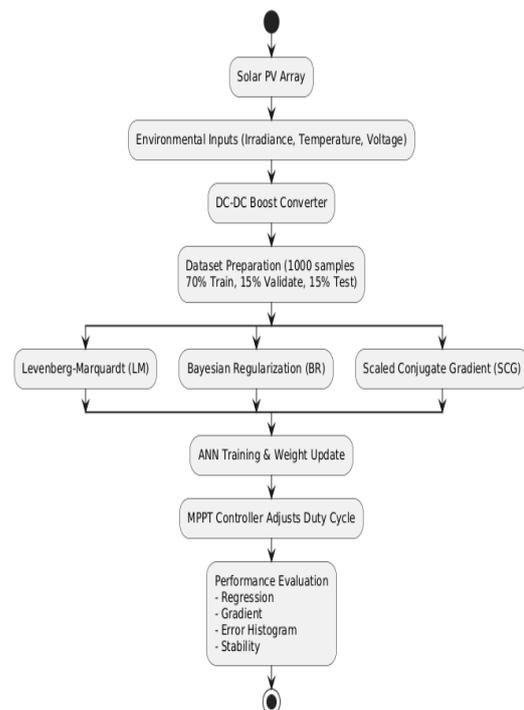


Fig.3.2 Flowchart

IV. RESULTS

ANN-MPPT Simulation Diagram:

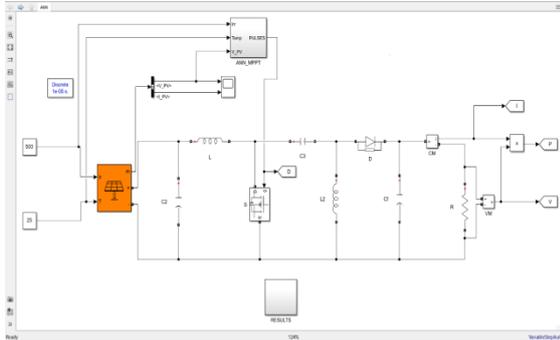


Fig.4.1 ANN-MPPT Simulation diagram

Output results:



Figure 4.2. Output Results

The output curve shows the reaction of the ANN algorithms to a changing irradiance and temperature. It establishes that the system is able to track the maximum power point and has minimum error.

ANN subsystem:

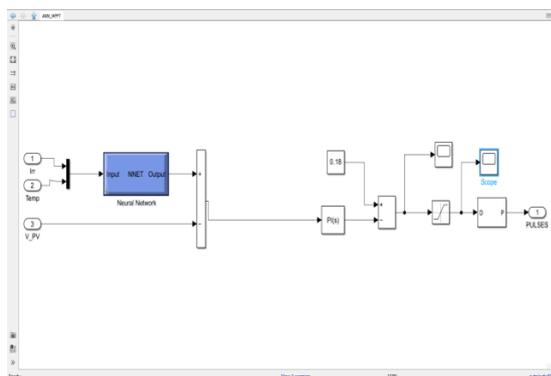
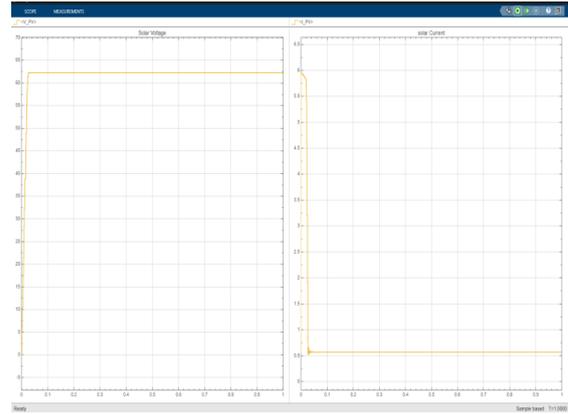


Figure 4. 3. ANN Subsystem

This block diagram is a representation of an ANN controller that is applied in the internal ANN controller of MPPT. It demonstrates the processing of inputs of solar irradiance, temperature and voltage to determine the optimum working point.



PV array and EV load Converter system:

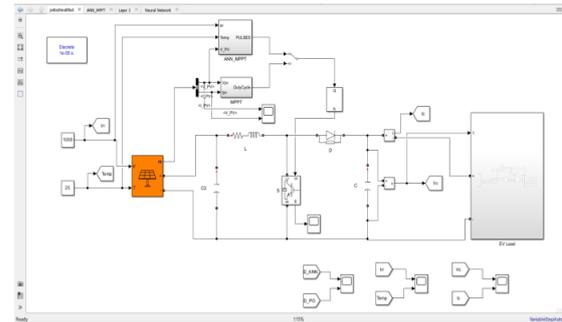


Figure 4.4. PV Array and EV Load Converter System

This image shows that the PV array is connected to the DC-DC boost converter and EV load. It emphasizes the transfer of energy on the solar panels to the load with an efficiency that is maintained,

MPPT Subsystem:

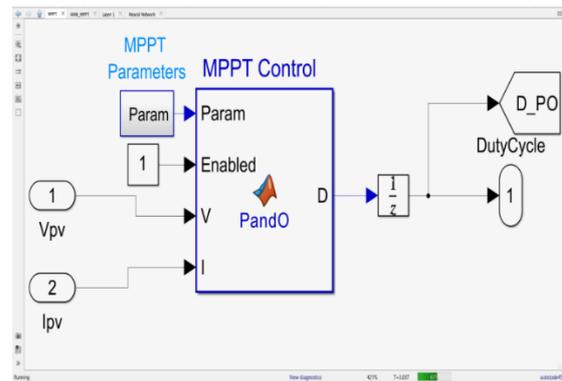


Figure 4.5. MPPT Subsystem

The MPPT subsystem diagram describes the control logic behind the duty cycle of the converter adjustment. It makes sure that the system runs in optimal power even in an environmental fluctuation.

Scope and Measurement Results:

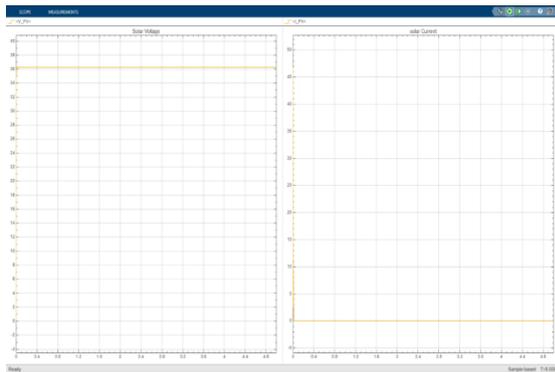
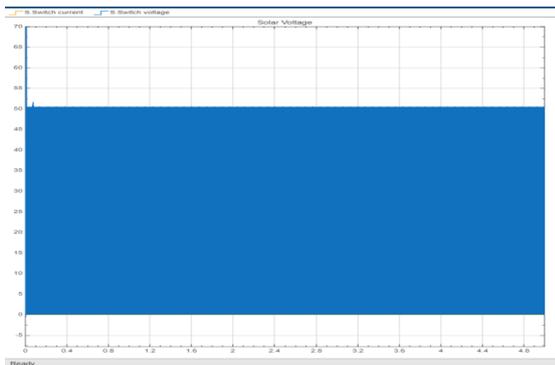


Figure 4.6. Scope and Measurement Results

The following figure displays the voltage, current, and power waveforms that are monitored. The stable and even curves justify the fact that ANN-based approaches reduce oscillations and enhance the stability of the system.



EV Load Subsystem:

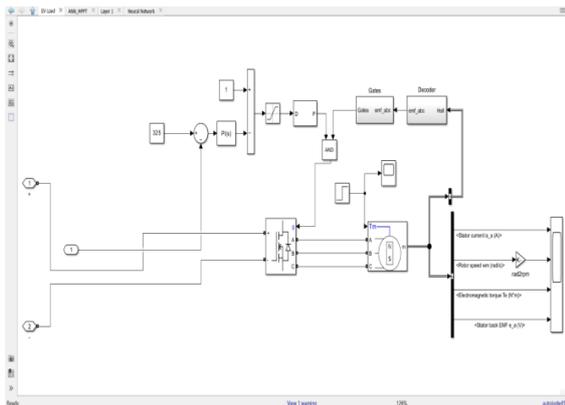
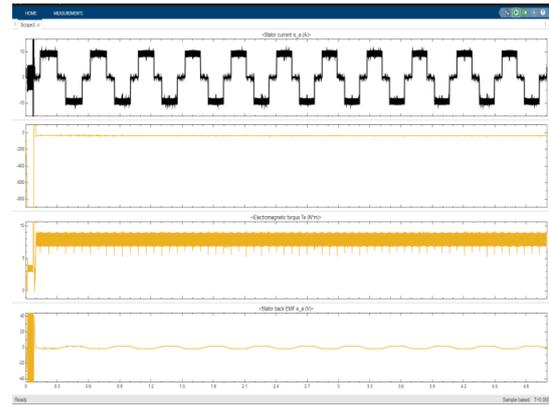


Figure 4.7. EV Load Subsystem

The EV load subsystem indicates the way the solar power that has been harnessed is used to power the loads of electric vehicles. It validates the feasibility of the suggested ANN-MPPT model to be used in practice in green energy.



V. CONCLUSION

This paper has shown that MPPT controllers are relevant in ensuring that solar photovoltaic systems can be optimized in a manner that is the most efficient. The comparison of various approaches, among them ANN-based algorithms, revealed that neural network approaches are more accurate and flexible than conventional ones. A simulation of the PV system with fuzzy logic controllers and boost converters after the use also enhanced the energy output of the system. In general, the discussion shows that ANN-based MPPT algorithm can be used to achieve much higher power extraction and reliability of the system. Such lessons can inform researchers, engineers, and policymakers to come up with more effective renewable energy solutions as well as to encourage the more extensive use of solar energy.

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