COMPARATIVE PERFORMANCE EVALUATION OF PSO-TUNED ANFIS MPPT ALGORITHM & GA-TUNED ANFIS MPPT ALGORITHM FOR SOLAR ENERGY CONVERSION SYSTEM

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Abstract- This paper introduces the development and performance evaluation of an Adaptive Neuro-Fuzzy Inference System (ANFIS) based MPPT controller designed for a DC-to-DC converter. The proposed system comprises a 2.0 kW PV array, a DC-to-DC boost converter, and a load. Leveraging the advantages of both neural and fuzzy networks, the proposed algorithm aims to optimize solar photovoltaic system parameters through the integration of an adaptive neuro-fuzzy inference system (ANFIS) controller, employing Particle Swarm Optimization (PSO) and Genetic Algorithm (GA). The comparison between PSO and GA-based optimization techniques is conducted using MATLAB/SIMULINK software, with a focus on enhancing the converter's performance. The primary objective is to determine whether the GA-tuned ANFIS MPPT algorithm outperforms in terms of tracking Maximum Power Point (MPP), tracking accuracy, and steady-state oscillation—critical parameters for solar energy conversion systems. Simulation results indicate that, across a broad range of input irradiance levels, the GA-tuned ANFIS MPPT algorithm demonstrates superior performance in tracking MPP, accuracy, and steady-state oscillation compared to the PSO-tuned ANFIS MPPT algorithm under various operating conditions.

Keywords: ANFIS, MPPT, PSO, GA. DC to DC boost converter.

1. INTRODUCTION

In the contemporary world, rapid industrial development has heightened our dependence on energy, with fossil fuels dominating electricity production. The reliance on conventional energy sources, constituting approximately 87% of global energy consumption, poses significant environmental challenges, including greenhouse gas emissions and safety concerns such as nuclear accidents. In 2020 alone, a staggering 36.5 billion tons of CO2 were emitted. Addressing these issues necessitates a shift towards alternative energies, among which solar energy harnessed through Photovoltaic Modules (PVM) has witnessed an impressive annual growth rate exceeding 40% in the past decade. Despite the commendable growth, PVMs face challenges, notably their low efficiency and associated high costs. To mitigate this efficiency dilemma, various techniques for optimizing PVM-generated power have been proposed. These techniques aim to pursue the maximum power achievable by the modules, a value contingent on factors such as weather conditions, irradiation, and temperature. In uniform conditions, PVMs exhibit a singular optimal point, simplifying the convergence to the Maximum Power Point (MPP). However, under non-uniform conditions, multiple optimal points emerge, demanding sophisticated algorithms capable of discerning the global optimum from local optima. This necessitates a comprehensive exploration of the search space to guide the system towards the global MPP. Classical methods like the Perturb and Observe (P&O) method and Incremental Conductance (InC) method have been widely employed. While the P&O method, rooted in voltage disturbance and power variation observation, is prevalent in the literature, it has limitations related to response time and oscillations around the MPP. The InC method, proposed as an alternative, has demonstrated superior performance according to results presented.

To surmount the challenges posed by the limitations of classical methods, especially under variable climatic conditions, Soft Computing methods utilizing Meta-heuristic algorithms and Artificial Intelligence (AI) algorithms are recommended. Maximum Power Point Tracking (MPPT) techniques predominantly rely on these diverse and numerous Soft Computing approaches, encompassing Evolutionary Algorithms (e.g., Genetic Algorithm), Meta-heuristic algorithms (e.g., Optimization by Particle Swarms), and AI algorithms (e.g., Artificial Neural Networks, Fuzzy Logic, ANFIS.

In this paper GA tuned ANFIS MPPT algorithm shows provides better performance in terms of tracking MPP, tracking accuracy, and steady-state oscillation than PSO tuned ANFIS MPPT algorithm at various operating conditions.

2. PV SYSTEM MODEL

PV module is composed of solar cells. Individual solar cells are connected in series and parallel and mounted on a single panel. Single diode model of PV cell is most widely used model. Output power can be calculated by current voltage relationship. This current voltage relationship is based on electrical characteristics of the model. An equivalent circuit of a single diode model is shown in the figure 2.1.

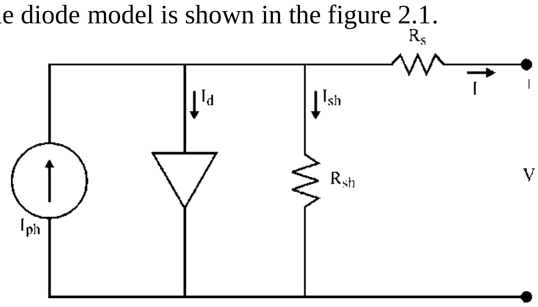

Fig. 2.1: Equivalent Circuit of Solar PV Cell

The voltage-current relationship can be written as:

$$I = I_L - I_D = I_L - I_s \left\{ e \frac{q(V + \text{Re})}{AKT} - 1 \right\} - \frac{V + IR_e}{R_{sh}} \tag{2.1}$$

It is possible to enumerate I_L:

$$I_L = \frac{\phi}{\phi_{ref}} \left[I_{L,ref} + \mu_{sc} \left(T_C - T_{c,ref} \right) \right] \tag{2.2}$$

Saturation current I_s can be expressed at the reference condition as:

$$I_s = I_{C,ref} \left(\frac{T_{C,ref} + 273}{T_C + 273} \right)^3 \exp \left[\frac{e_{gap} N_S}{q_{ref}} \left(1 - \frac{T_{C,ref} + 273}{T_C + 273} \right) \right] \tag{2.3}$$

$I_{s,rf}$ can be expressed as:

$$I_{s,ref} = I_{L,ref} \exp \left(-\frac{V_{oc,ref}}{\alpha_{ref}} \right) \tag{2.4}$$

The value of open circuit voltage at reference condition is given by manufacturer.
Value of α_{ref} can be calculated by:

$$\alpha_{ref} = \frac{2V_{mpp,ref} - V_{oc,ref}}{\frac{I_{sc,ref}}{I_{sc,ref} - I_{mpp,ref}} + In \left(1 - \frac{I_{mpp,ref}}{I_{sc,ref}} \right)} \tag{2.5}$$

α = function of temperature. The value of α can be calculated by following equation:

$$\alpha = \frac{T_c + 273}{T_{c,ref} + 273} \alpha_{ref} \tag{2.6}$$

The value of series resistance is provided by some manufacturers. To estimate the value of R_s following equation can be used:

$$R_s = \frac{\alpha_{ref} In \left(\frac{I_{mpp,ref}}{I_{sc,ref} - I_{mpp,ref}} \right) + V_{oc,ref} - V_{mpp,ref}}{I_{mpp,ref}} \tag{2.7}$$

After the study of the PV module, it can be said that the temperature plays an important role in the performance of PV module. It is necessary to design a thermal module for the PV system as temperature is major aspect to be considered. Temperature of PV module varies when there is a change in irradiance, its output current and voltage, and the equation can be expressed as:

$$C_{pv} \frac{dT_c}{dt} = k_{a,PV} \phi - \frac{VI}{A} - k_{loss} (T_c - T_a) \tag{2.8}$$

3. PROPOSED APPROACH

The proposed design and implementation of various components of the proposed system details about modelling of PV array, study of Power electronics interfacing devices such as DC-DC converter and GA &PSO-Tuned ANFIS (Adaptive-Network-Based Fuzzy Inference System) based MPPT Controller. It gives overall idea about proposed system. The proposed system is developed using MATLAB/Simulink. A simple block diagram of DC-DC converter for SECS using GA &PSO-Tuned ANFIS based MPPT Controller is shown in Figure 3.1. Proposed system consist of PV array, power electronics interfacing devices such as DC-DC Boost converter, load arrangement and GA &PSO-Tuned ANFIS based MPPT Controller. In order to improve the performance of maximum power point tracking of solar PV system, an effective ANFIS based MPPT Controller is developed and compared with the conventional ANN based MPPT controller.

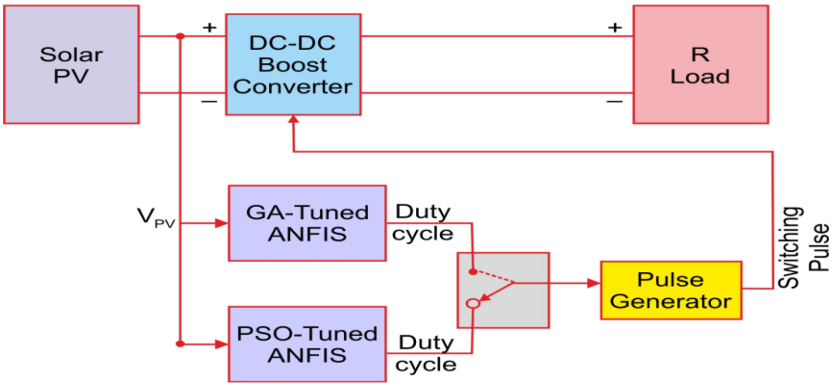

Fig. 3.1 Block Diagram of DC-DC Converter for SECS using GA &PSO-Tuned ANFIS MPPT Controller

4. COMPARATIVE SIMULATION RESULTS OF GA TRAINED AND PSO TRAINED ANFIS MPPT ALGORITHM FOR PV SOLAR ENERGY CONVERSION SYSTEM

The simulation and results are performed in the MATLAB/Simulink software. Simulink blocks and their required interfacing circuitry used for more reliable power generation from solar energy conversion system. This system consists of renewable energy source which generates continuous power according to input applies to the system. This system consists of PV solar energy conversion system with resistive load. The boost converter is used to regulate PV output power according to duty cycle generated by MPPT block to achieve maximum power. The intelligent MPPT algorithms are used to achieve maximum power. These intelligent MPPT algorithms include GA Trained ANFIS algorithm and PSO Trained ANFIS algorithm. These algorithms continuously monitor input irradiance & temperature and generate duty cycle according to it.

Case-1: Simulation results at step-changes irradiance from 600w/m^2 to 1000 w/m^2& constant temperature of 25°C

In this case, irradiance is step changes from 600w/m^2 to 1000 w/m^2 between time duration of t=0 to t=1 sec & t=1 to t=2 sec, respectively. Temperature and 10ohm load are kept constant for whole simulation time. The simulation results are shown in the following figures. Fig. 4.1 shows waveforms of irradiance and temperature applied at the input of PV panel.

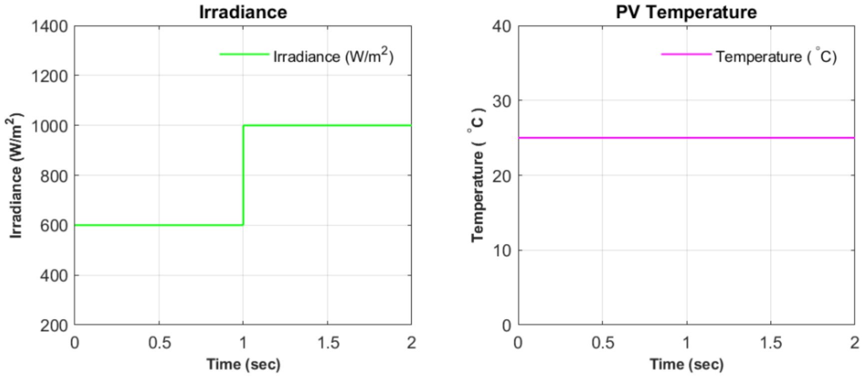

Fig. 4.1 Simulation results at step-changes irradiance from 600w/m^2 to 1000 w/m^2& constant temperature of 25°C, respectively, waveform of irradiance and temperature

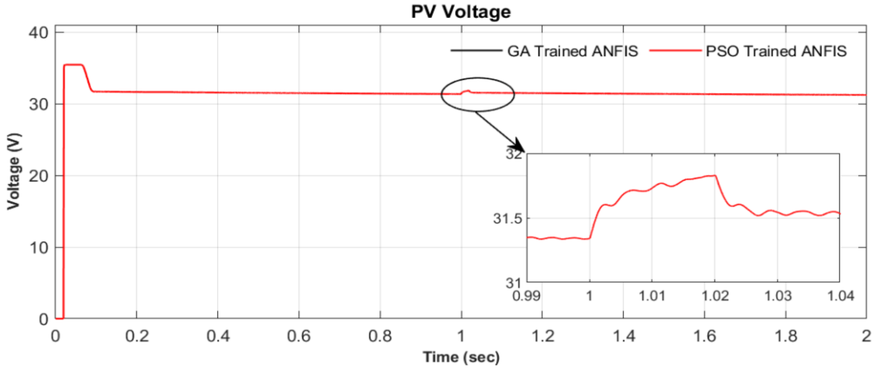

Fig. 4.2 Simulation results at step-changes irradiance from 600w/m2 to 1000 w/m2& constant temperature of 25°C, respectively, Waveform of PV voltage

Fig. 4.2 shows, waveform of PV module voltage. As shown in figure, the PV voltage is around 31.45v for whole simulation time, expect at time t=1sec when irradiance changes from 600 w/m^2 to 1000 w/m^2 it experiences a slight increase which can be observed through zoom in window and again become constant. PV Voltage is same for both GA Trained ANFIS algorithm and PSO Trained ANFIS algorithm.

Fig. 4.3 shows, waveform of PV current generated by PV module. There are two zoomed subplot windows taken to show the difference between GA Trained ANFIS MPPT algorithm and PSO Trained ANFIS algorithm MPPT algorithms. In first zoom in window we can observe that PV current is higher in case of GA trained ANFIS MPPT algorithm i.e. 4.82A as compared to the current value in case of PSO Trained ANFIS algorithm i.e. 4.7A. At time t=1sec current increases to 8.2A and 7.9A for GA Trained ANFIS MPPT algorithm & PSO Trained ANFIS algorithm MPPT algorithm respectively and remain constant for remaining simulation time.

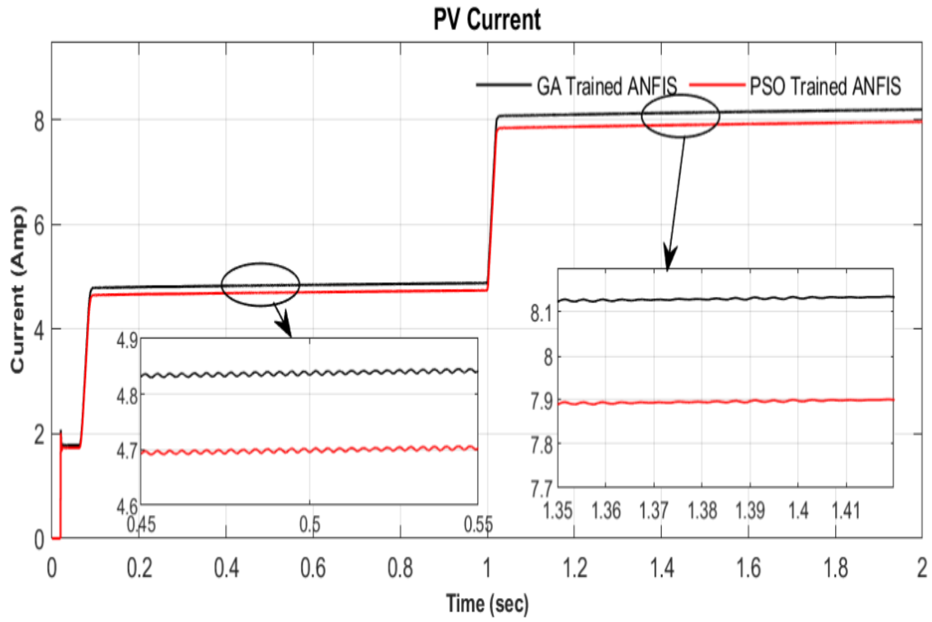

Fig. 4.3 Simulation results at step-changes irradiance from 600 w/m^{2}to 1000 w/m^2& constant temperature of 25°C, respectively, waveform of PV current

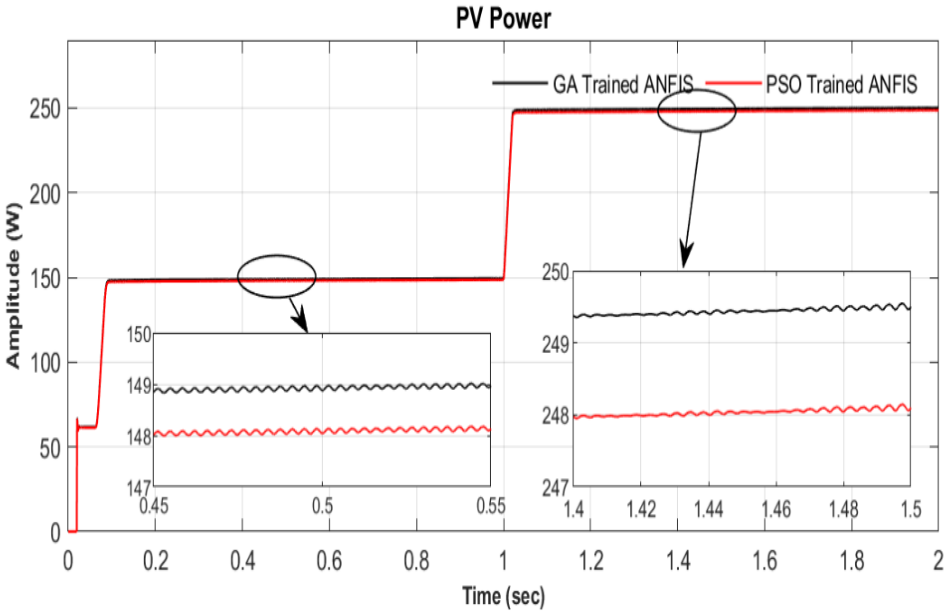

Fig. 4.4 Simulation results at step-change irradiance from 600 w/m2 to 1000 w/m2& constant temperature of 25°C, respectively, Waveform of PV output power

Fig. 4.4 shows the waveform of PV output power. The PV power at 600w/m2 irradiance is 149W for GA Trained ANFIS algorithm and 148W for PSO Trained ANFIS algorithm and at 1000w/m2 irradiance PV power increases to 249.4W for GA Trained ANFIS algorithm and 248W for PSO Trained ANFIS algorithm.

Fig. 4.5 shows the waveform of Boost Converter Duty Cycle for both between GA Trained ANFIS MPPT algorithm and PSO Trained ANFIS algorithm MPPT algorithm separately, we can observe that value of Duty Cycle is same for both the algorithm expect, it changes w.r.t. change in irradiance at time t=1sec and remain constant for whole simulation time.

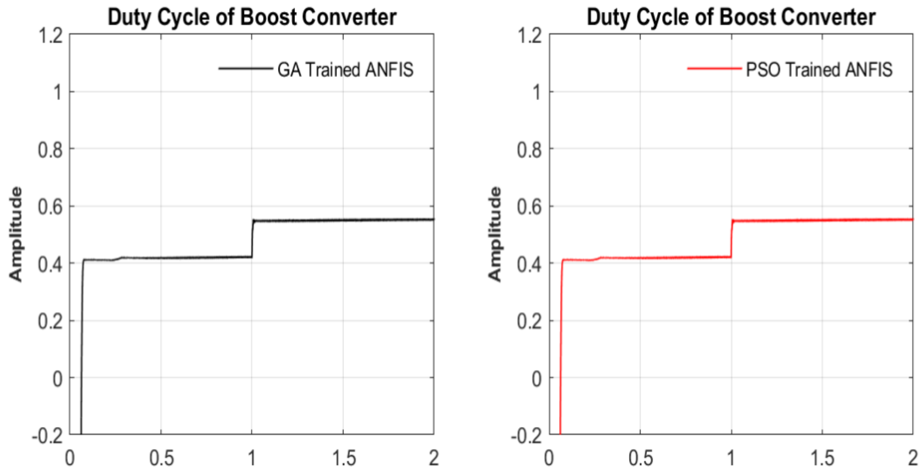

Fig. 4.5 Simulation results at step-change irradiance from 600 w/m^2 to 1000 w/m^2& constant temperature of 25°C, respectively, Waveform of boost converter duty cycle

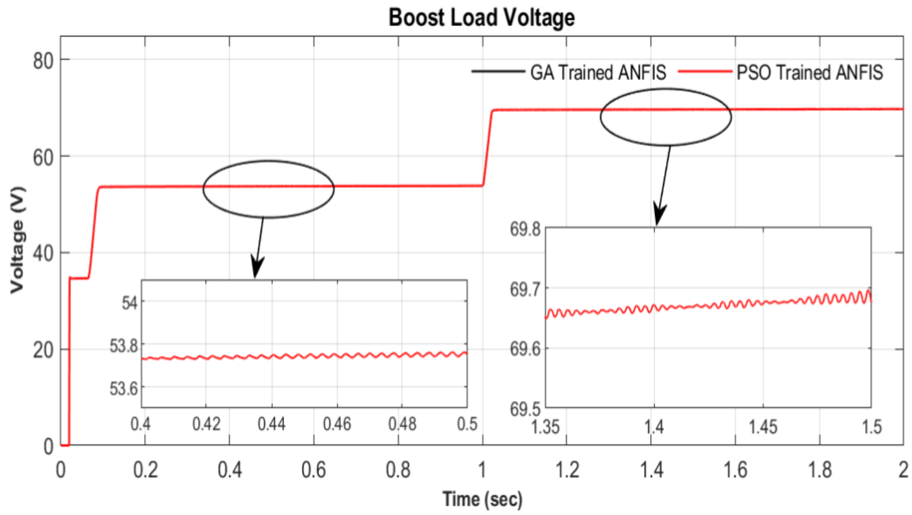

Fig. 4.6 Simulation results at step-change irradiance from 600 w/m2to 1000 w/m2& constant temperature of 25°C, respectively, Waveform of boost load voltage

Fig. 4.6 shows, the waveform of Boost Load voltage which is same for both types of algorithms i.e. GA Trained ANFIS algorithm and PSO Trained ANFIS algorithm. It increases w.r.t. to increase in irradiance at time t=1sec from 53.68V to 69.66V.

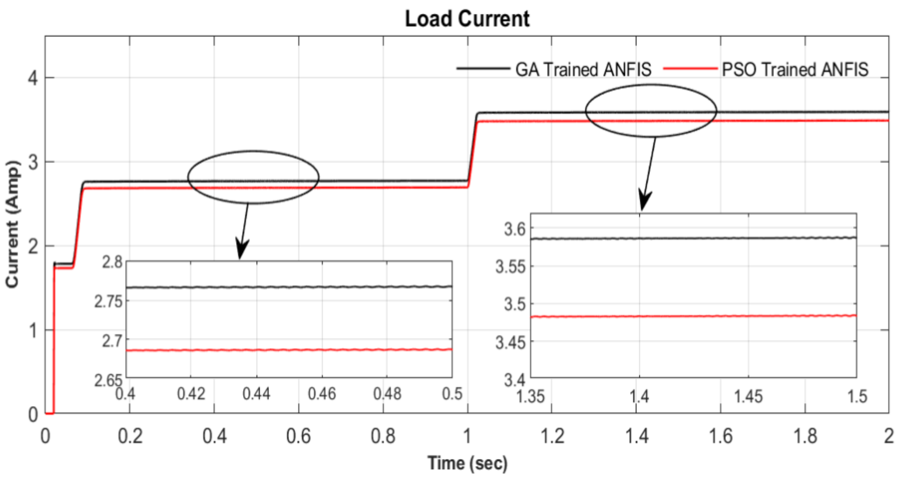

Fig. 4.7 Simulation results at constant irradiance and temperature of 1000w/m2 & 25°C, respectively, Waveform of load Current

In fig. 4.7 Load Current is constant till time t=1sec after that it increases w.r.t. change in irradiance at t=1sec and remain constant for remaining simulation time. In first zoom in window it loads current is 2.76A for GA Trained ANFIS algorithm and 2.68A for PSO Trained ANFIS algorithm at 600w/m^2 irradiance and it increases to 3.58A for GA Trained ANFIS algorithm and 3.48A for PSO Trained ANFIS algorithm for at 1000w/m^2.

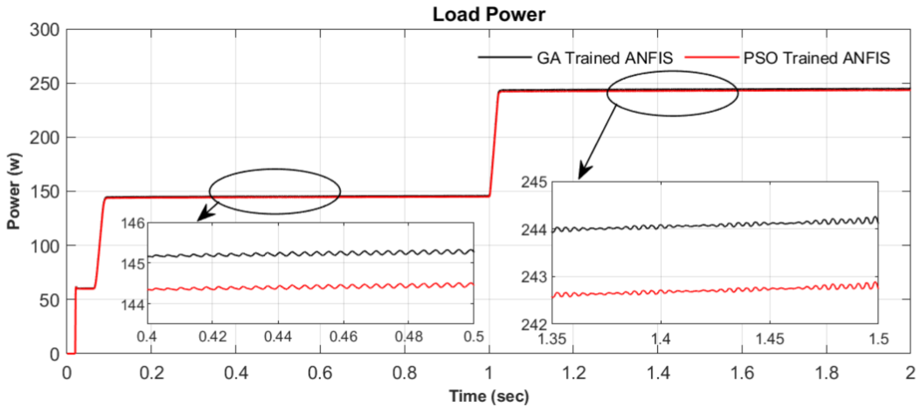

Fig. 4.8 Simulation results at constant irradiance and temperature of 1000w/m2 & 25°C, respectively, Waveform of load Power

In fig. 4.8 Load Power is constant till time t=1sec after that it increases w.r.t. change in irradiance at t=1sec and remain constant for remaining simulation time. In first zoom in window it loads power is 145.1W for GA Trained ANFIS algorithm and 144.3W for PSO Trained ANFIS algorithm at 600w/m^2 irradiance and it increases to 244W for GA Trained ANFIS algorithm and 242.8W for PSO Trained ANFIS algorithm at 1000w/m^2.

CONCLUSION

This paper details the development of a DC-DC converter for a standalone solar energy conversion system, incorporating a maximum power point tracking (MPPT) technique to optimize power output. The focus is on achieving maximum power utilization through an ANFIS (Adaptive-Network-Based Fuzzy Inference System) based MPPT Controller. The paper compares ANFIS algorithms for MPPT with Levenberg-based Artificial Intelligence Technique-based MPPT algorithms for PV systems. Additionally, the solar photovoltaic system may incorporate optional features such as a Maximum Power Point Tracker (MPPT), battery system, charger, electricity tracker, software, and other equipment. The optimization of solar photovoltaic system parameters is conducted through an Adaptive Neuro Fuzzy Inference System (ANFIS) controller, utilizing Particle Swarm Optimization (PSO) and Genetic Algorithms (GA). An in-depth comparative analysis, implemented using MATLAB/SIMULINK software, indicates that the GA-tuned ANFIS MPPT algorithm surpasses its PSO-tuned counterpart in terms of Maximum Power Point (MPP) tracking, tracking accuracy, and steady-state oscillation under diverse operating conditions. Simulation results underscore the superior performance of the GA-tuned ANFIS MPPT algorithm across a broad spectrum of input irradiance levels.

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