A Project Presentation
on

# Exploring Performance Enhancement of MPPT Techniques for Boost Converter in Solar PV System


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# CONTENTS:

# Introduction:

- Renewable Energy Adoption: The global shift towards renewable energy sources like solar, wind, and tidal power is driven by increasing energy demand and the depletion of fossil fuels, owing to their environmental benefits and abundance.

- Photovoltaic Systems: Solar PV systems, supported by semiconductor manufacturing advancements, are versatile and cost-effective options in the renewable energy landscape.

- MPPT Techniques and Challenges: Researchers explore various MPPT methods such as P&O, Inc Cond, FLC, ANFIS, and PSO, comparing accuracy, power output, settling time, efficiency, and complexity amidst challenges like formulation complexity, aiming to optimize PV system performance.

# Objectives:

- To develop the Simulink models for closed loop PI Control and various MPPT techniques, including Perturb and Observe, Incremental Conductance, Fuzzy Logic Controller with P&O and Incremental Conductance, Particle Swarm Optimization and Adaptive Neuro Fuzzy Inference System with DC-DC Boost Converter using MATLAB/SIMULINK 2023b version.
- To compare and evaluate the performance of each MPPT method in terms of maximum power, settling time, rise time, steady state error, efficiency for DC-DC Boost converter.

# Design of Solar PV Array:

## Solar PV Cell:

- A PV array comprises multiple solar panels, each containing photovoltaic cells that convert sunlight into electricity.
- The solar panels within the array are interconnected to form a single system. This arrangement allows for efficient collection and distribution of the generated electricity.
- PV arrays harness solar energy, a renewable and abundant resource. They provide a sustainable alternative to fossil fuels, contributing to efforts to mitigate climate change and reduce dependence on non-renewable energy sources.
- PV arrays are used in various applications, including residential, commercial, and industrial settings. They can power homes, businesses, remote locations, and even large-scale solar farms.

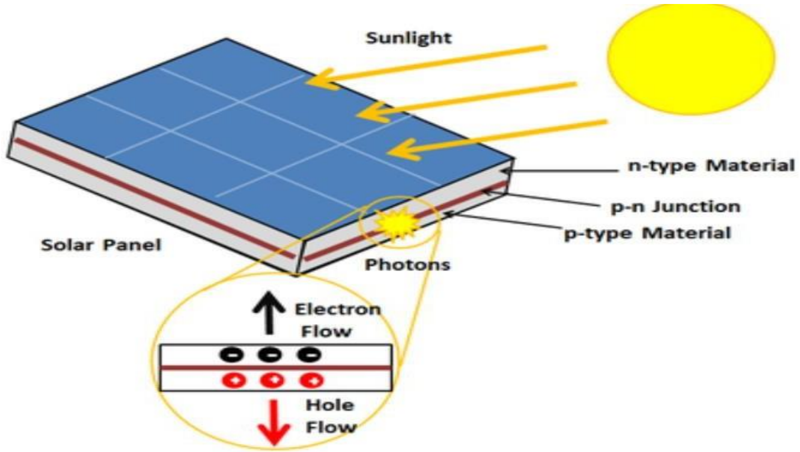


Fig.1 Photovoltaic Cell

Table.1: PV Module Specifications

| S. No. | Parameter | Value |
|---|---|---|
| 1 | Parallel strings | 1 |
| 2 | Series-connected modules per string | 1 |
| 3 | Series-connected modules per string | 60 |
| 4 | Voltage generated per cell | 0.5v |
| 5 | Short-circuit current (Isc) | 8.84A |
| 6 | Open circuit voltage (Voc) | 37.6V |
| 7 | Voltage at maximum power point (Vmax) | 30.6V |
| 8 | Current at maximum power point (Imax) | 8.33A |
| 9 | Maximum Output Power (Pmax) | 255w |

# Design of Solar PV System:

Fig 2 The variable irradiance signal graph given to the solar PV panel, which is used in all the MPPT methods.

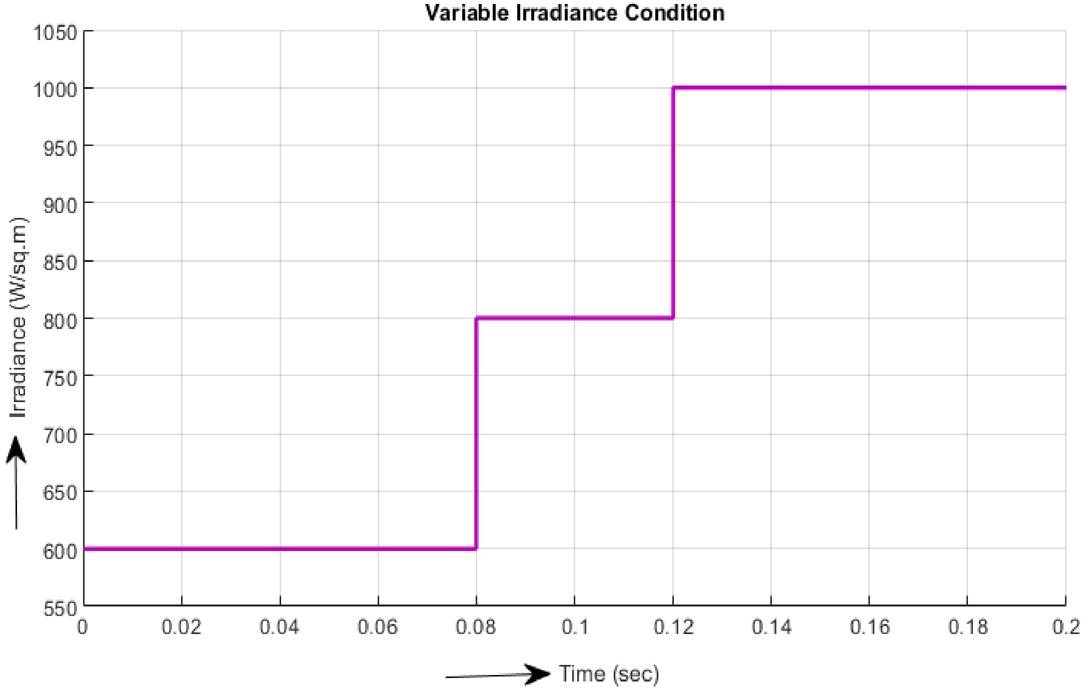


Fig.2 Variable irradiance signal graph given to the solar PV panel.

Fig.3 shows I-V and P-V curves of solar panels at irradiance levels of 1KW/m$^2$ 0.8KW/m$^2$ and 0.6KW/m$^2$ at a temperature of 25$^o$C.The panels were designed for the power of 1019.59watts.

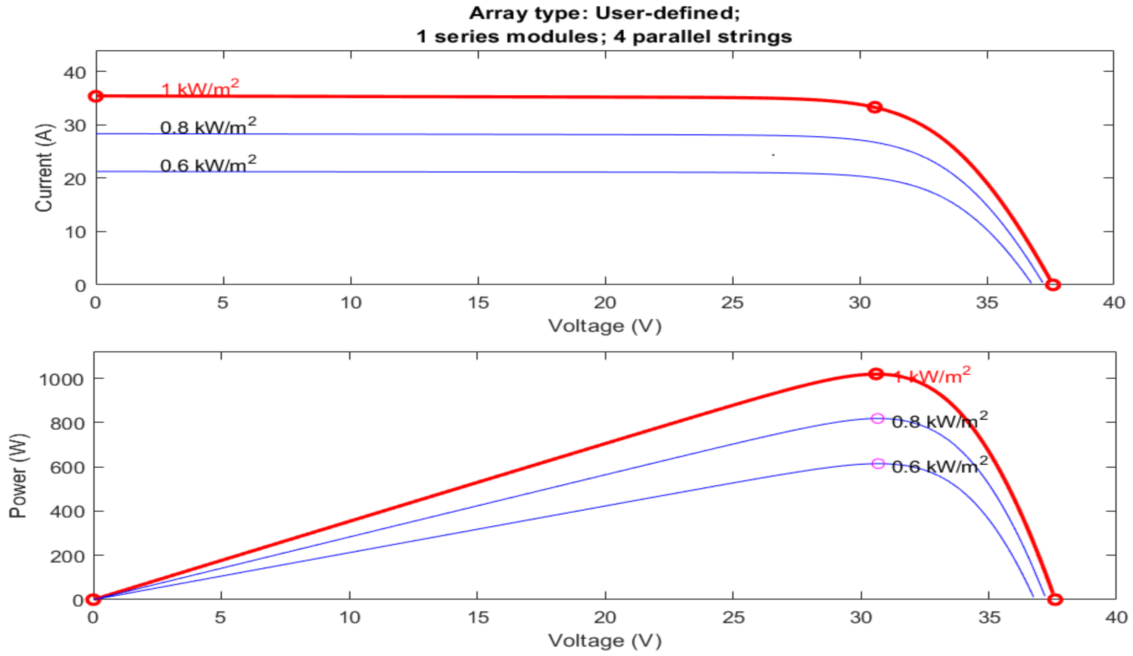


Fig.3 I-V and P-V curves of solar panel at a different irradiance level of 1000W/m$^2$,800W/m$^2$ and 600W/m$^2$

# Designing of DC-DC Boost Converter:

A boost converter, also known as a step-up converter, is a type of DC-DC converter that increases the voltage level of a DC input to a higher voltage level at the output. It is widely used in various applications, including power supplies, battery charging systems, and renewable energy systems.

It consists of an inductor, a switch (usually a transistor), a diode, and a capacitor . When the switch is closed, energy is stored in the inductor, and when the switch is open, the inductor releases energy, raising the output voltage.

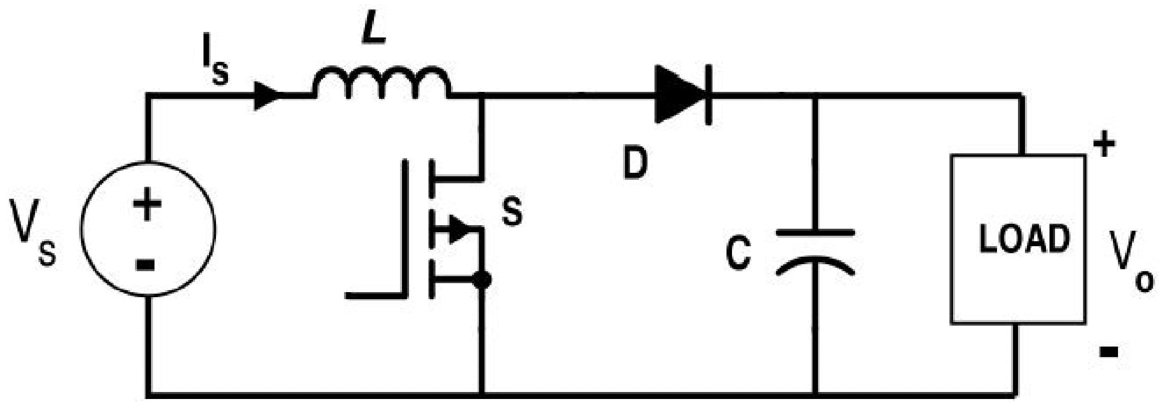


Fig.4 DC-DC Boost Converter

**Design Calculations of Boost Converter :**

- The design calculations for the boost converter given as,
- Consider, the switching frequency as ($f_s$) = 40KHZ
- The input voltage for the converter ($V_{in}$) = 30v

- Consider, the Duty cycle (D) = 0.7

$$D = 1-\frac{V_{in}}{V_0}$$

$$0.7 = 1-\frac{30}{V_0}$$

- Take output voltage ($V_0$) =100
- Let us consider,
- The resistance (R) =10Ω
- The output current ($I_0$) =100/10

$$I_0 = 10A$$

- The change in Current ($\triangle I_L$ ) = $0.2 \times I_0 \times -\frac{V_0}{V_i}$

$$= 0.2\times10\times100/30$$

$$= 6.66A$$

- The inductance of a Inductor (L) = $\frac{V_{in}(V_0 - V_{in})}{\triangle I_L \times f_{sw} \times V_0}$

$$= \frac{30(100-30)}{6.66\times40\times10^3\times100}$$

$$L=78.75\times10^{-6}H$$

- The Change in output voltage ($\triangle V_0$) = $0.1\times V_0$

$$= 0.1\times100$$

$$\triangle V_0 = 10V$$

- The capacitance of a Capacitor (C) = $\frac{I_0 \times D}{f_s \times \triangle V_0}$

$$= \frac{10\times0.7}{40\times10^3\times10}$$

$$C=17.5\times10^{-6}F$$

# Solar PV System With Closed Loop Proportional Integral Control:

- Closed-Loop Proportional Integral (PI) Control: Utilizes feedback mechanisms to optimize the performance of solar PV systems by adjusting system components like inverters or charge controllers.
- Feedback Mechanisms: Continuous monitoring of system output using sensors measuring parameters such as solar irradiance, PV panel voltage, current, temperature, and power output.
- PI Control Strategy: Integrates proportional control, responding to current errors between desired and actual values, and integral control, accumulating past errors over time to eliminate steady-state errors, thereby regulating parameters like the duty cycle of power converters in solar PV systems.

# Simulink Model of closed loop PI Control

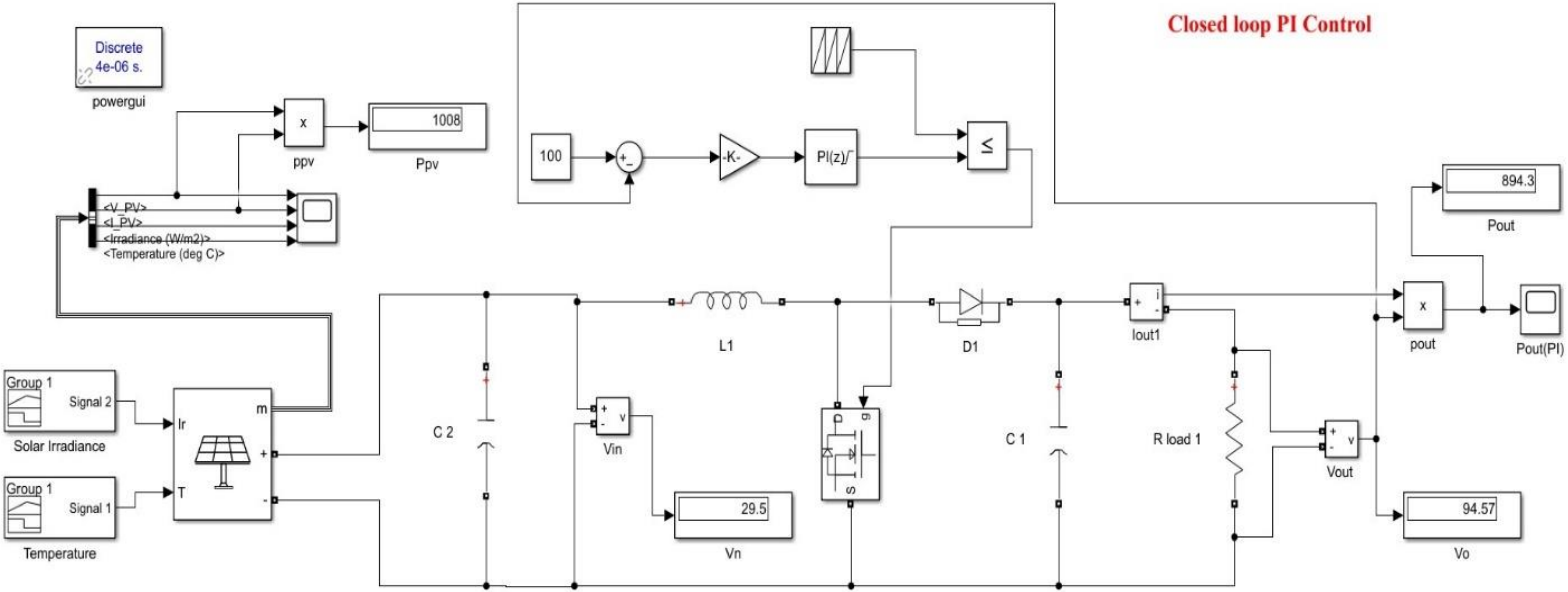


Fig.5 Simulink Model for Closed loop PI Control

# Results of closed loop PI Control

The Simulink model graph drawn between Output power in watts versus Time in seconds for PI control. The maximum power obtained for PI control is 894.3W, the settling time is 0.198sec, rise time is 60.855ms, steady state error is 1.136% and efficiency is 88.72%.

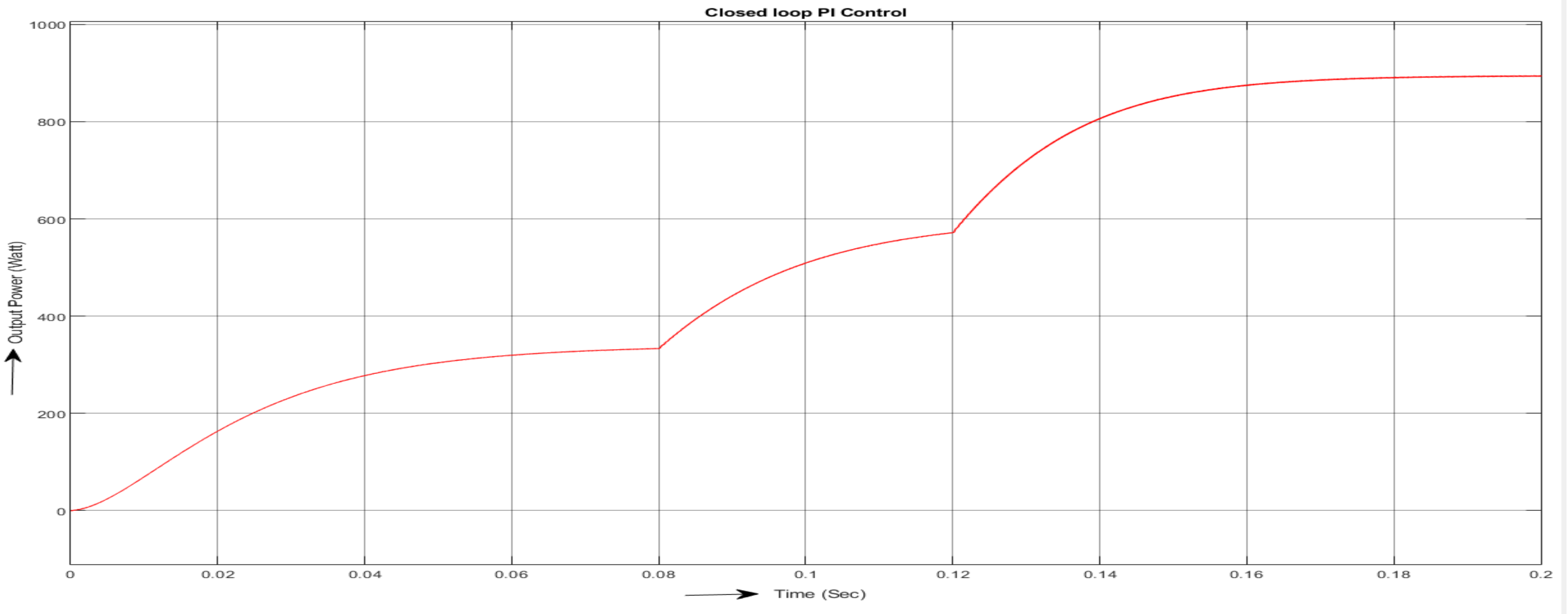


Fig.6 Output Power Vs Time for Proportional Integral Control

# Solar PV System with MPPT controller:

- Energy Efficiency: Enhancing energy efficiency and cost reduction are primary challenges for PV systems.
- Importance of MPPT: MPPT techniques like Perturb and Observe (P&O) with Buck-Boost converters are essential for maximizing solar panel energy extraction.
- Operating Point Adjustment: MPPT adjusts the PV system's operating point to ensure optimal efficiency, crucial for large arrays.
- Environmental Challenges: Non-linear behaviour of power-voltage curves due to environmental changes makes MPPT complex.
- Tailored Design: Designing MPPT methods specific to system characteristics minimizes losses and maximizes power output, improving overall efficiency and cost-effectiveness of PV applications

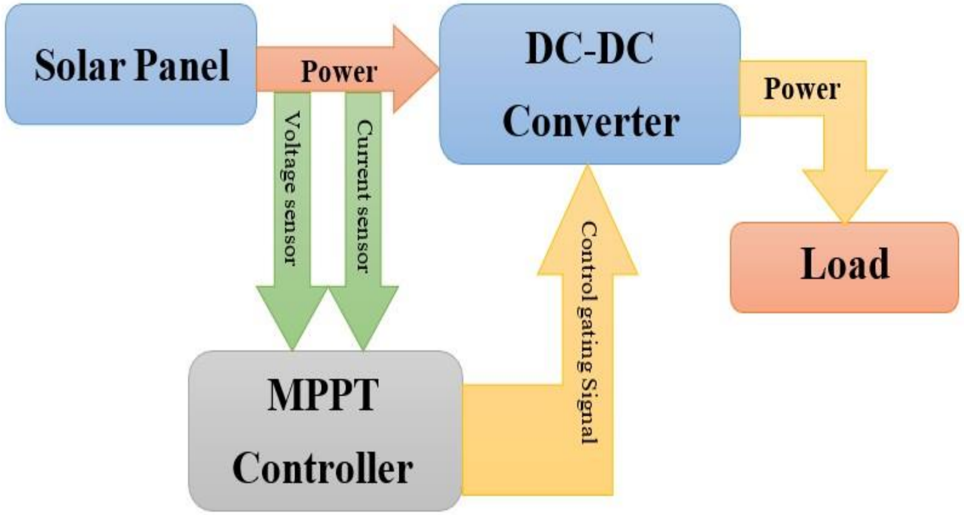


Fig. 7 Solar PV System with MPPT Controller

# Various types of MPPT Techniques

There are different techniques used to track the maximum power point. Few of the most popular techniques are:

- Perturb and Observe method.
- Incremental Conductance method.
- Fuzzy logic control with P&O.
- Fuzzy Logic Control with Incremental Conductance.
- Particle Swarm Optimization.
- Adaptive Neuro Fuzzy Interface System.

The choice of the algorithm depends on the time complexity of the algorithm takes to track the MPP, implementation cost and the ease of implementation.

# PERTURB AND OBSERVE TECHNIQUE:

- P&O (Perturb and Observe) method: Widely utilized in maximum power point tracking (MPPT) for photovoltaic (PV) systems.
- Objective: Optimize solar panel output power by continuously adjusting the operating point to track the maximum power point (MPP) under varying environmental conditions.
- Basic Principle: Periodically perturb the operating point and observe resulting changes in power output to determine proximity to MPP.
- Perturbations: Applied to either PV module or array voltage.
- Adjustment Process: Analyze power output response to perturbations; increase in power indicates deviation from MPP, requiring further adjustment towards optimal point.

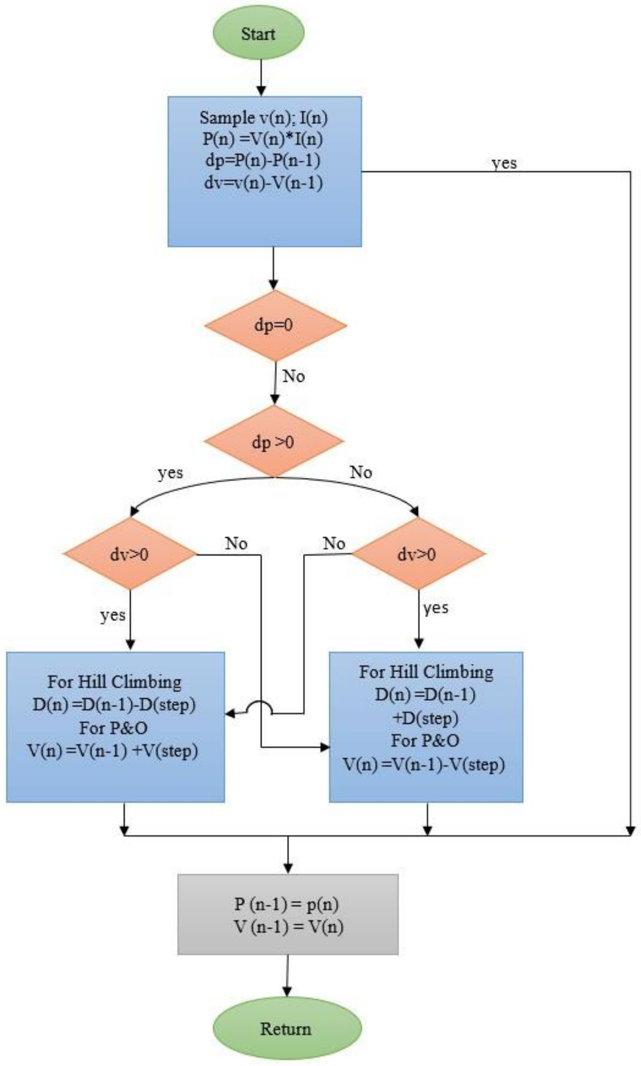


Fig.8 P&O Algorithm

# Simulink Model of Perturb and Observe:

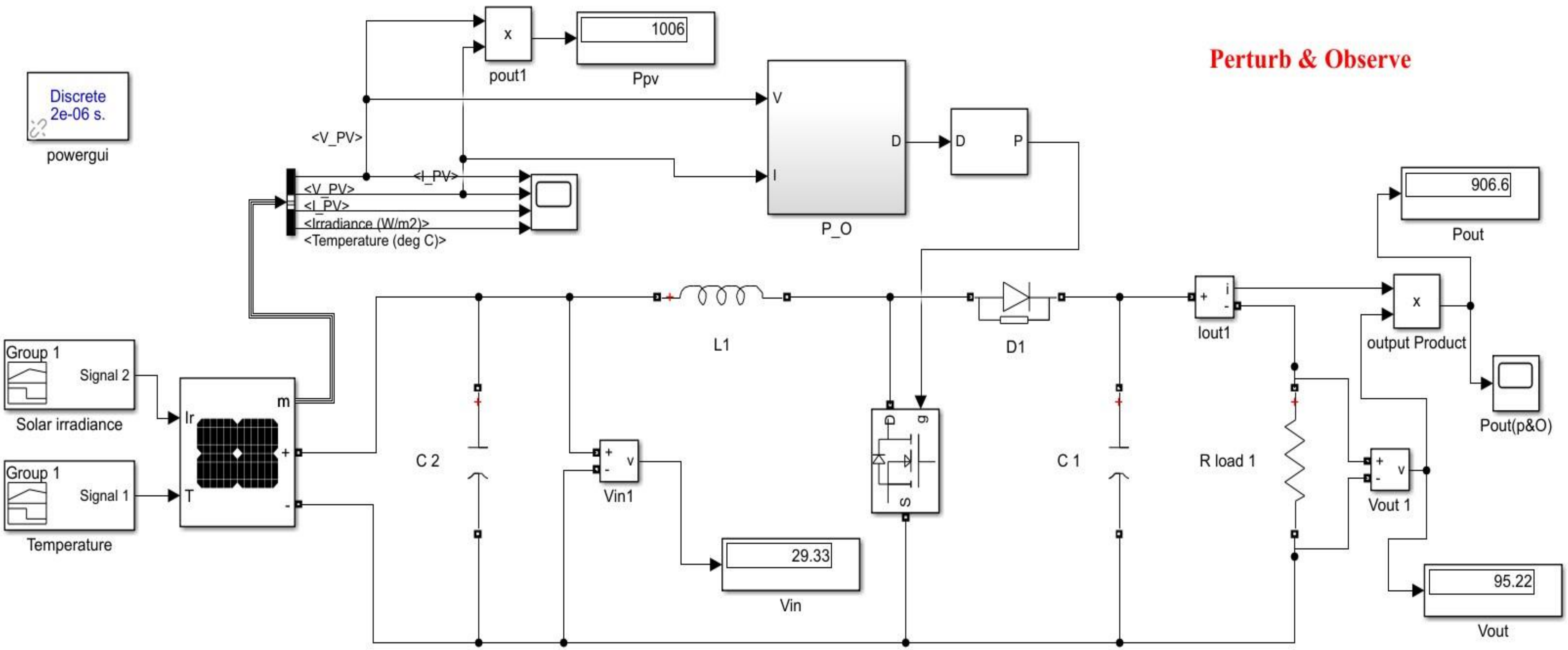


fig. 9 Simulink Model with Perturb and Observe Technique

# Results of Perturb and Observe:

The Simulink model graph drawn between Output power in watts versus Time in seconds for P&O. The maximum power obtained for P&O is 906.6W, the settling time is 0.196sec, rise time is 60.754ms, steady state error is 1.132% and efficiency is 90.119%.

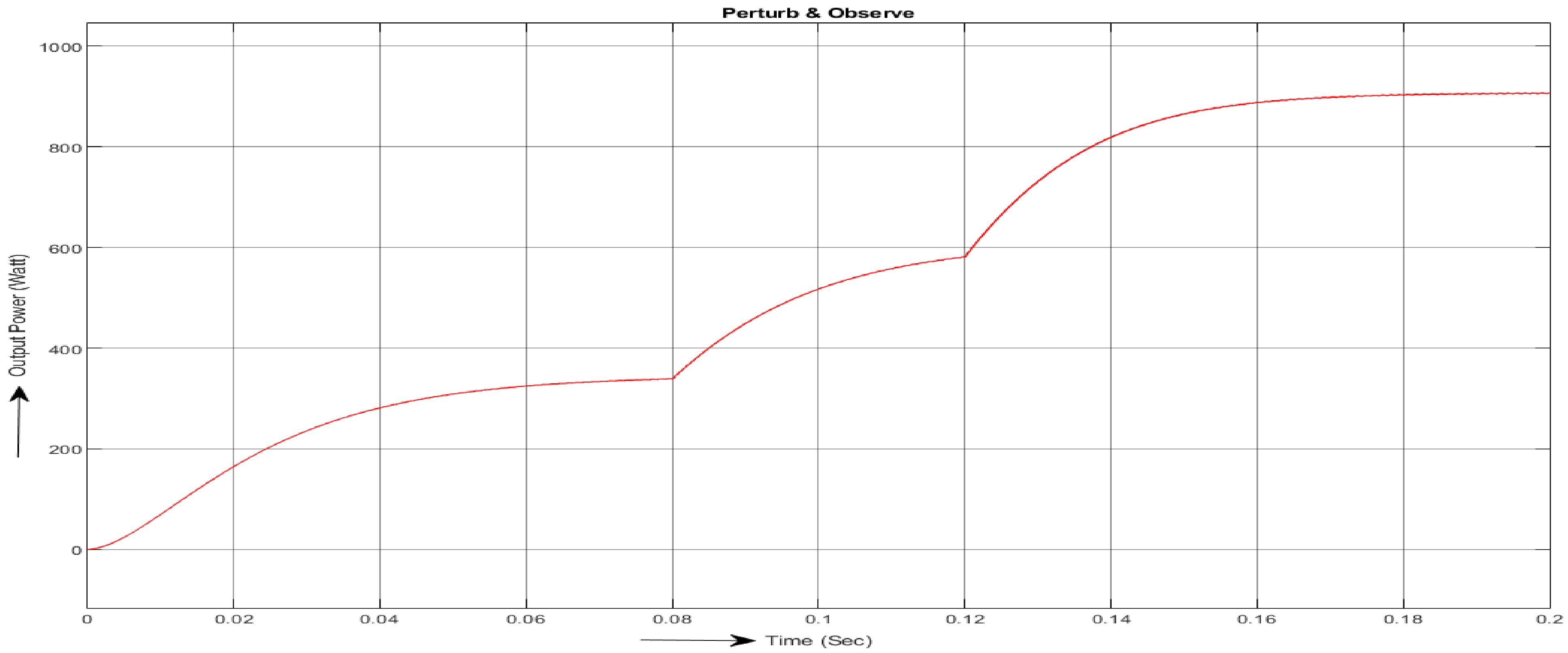


fig. 10 Output Power Vs Time for Perturb and Observe Technique

# INCREMENTAL CONDUCTANCE TECHNIQUE:

- Incremental Conductance (IncCond) Method: Utilized in MPPT algorithms for PV systems to track MPP.
- Principle: Observes changes in system conductance concerning voltage or current variations.
- Analysis: Determines MPP proximity by examining incremental conductance.
- Applicability: Widely used in standalone and grid-connected PV systems to maximize energy harvest and performance.
- Implementation: Suitable for various PV technologies and can be realized through microcontroller-based MPPT controllers or dedicated integrated circuits.

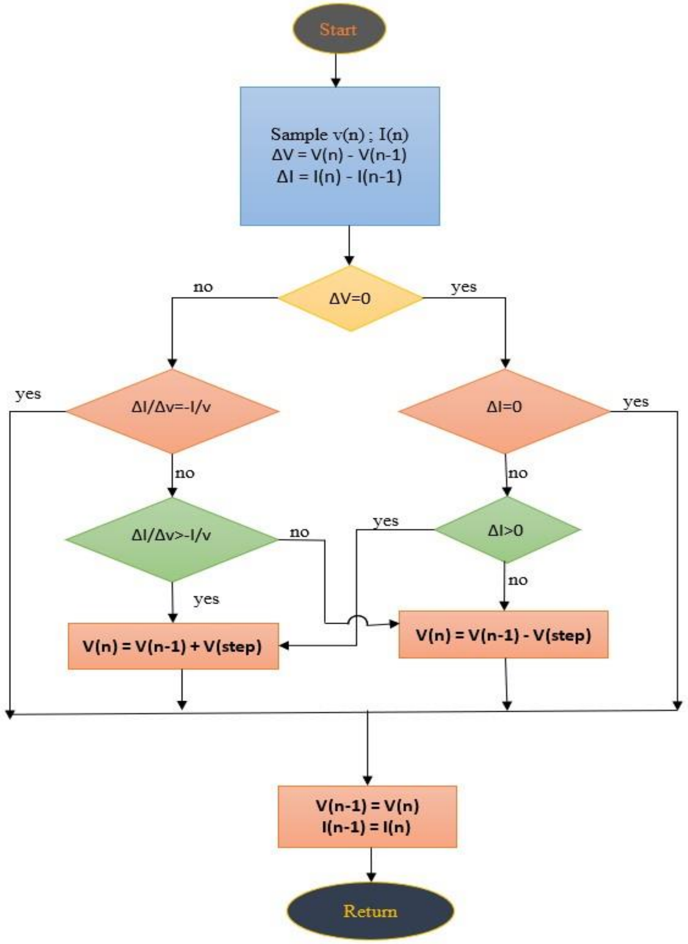


Fig.11 Algorithm of Incremental Conductance

# Simulink Model of Incremental Conductance

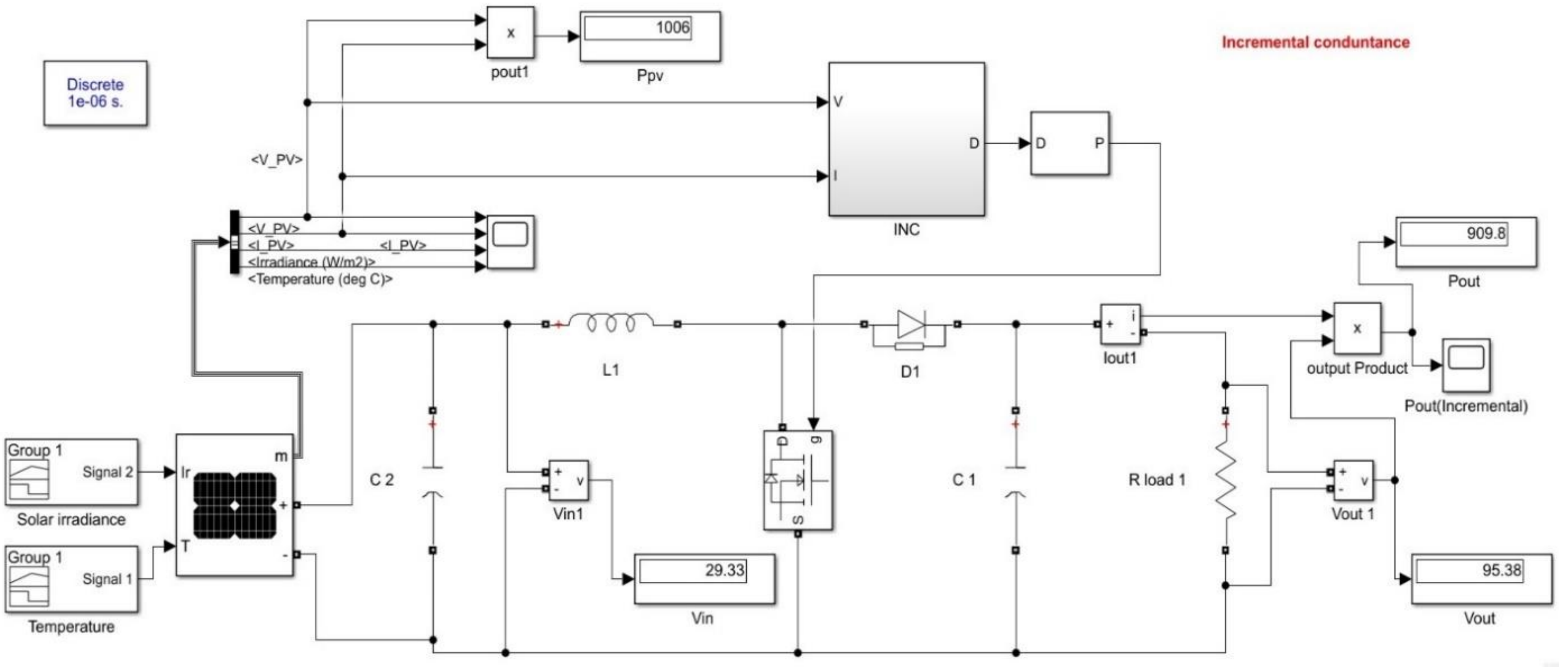


Fig. 12 Simulink Model with Incremental Conductance Technique

# Results of Incremental Conductance

The Simulink model graph drawn between Output power in watts versus Time in seconds for Inc Cond. The maximum power obtained for Inc Cond is 909.8W, the settling time is 0.189sec, rise time is 60.681ms, steady state error is 1.132% and efficiency is 90.437%.

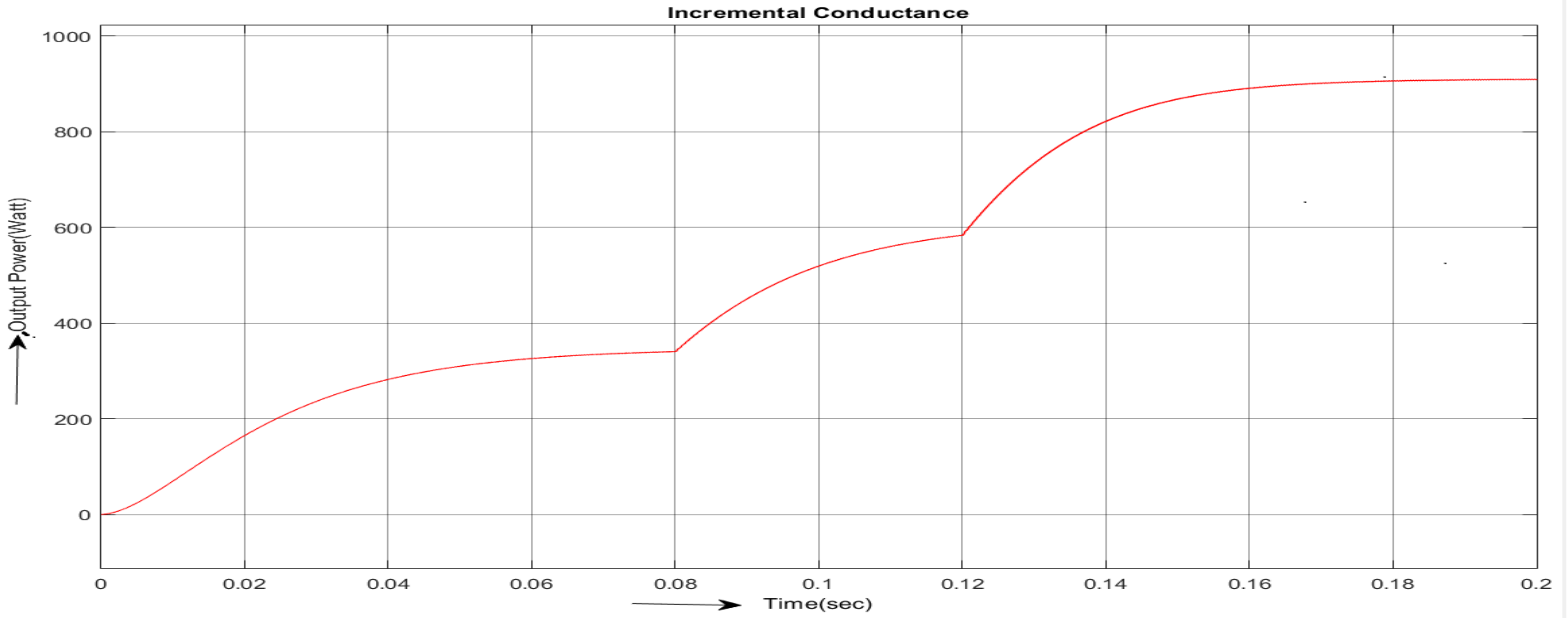


Fig.13 Output Power Vs Time for Incremental Conductance Technique

# FUZZY LOGIC CONTROL TECHNIQUE:

- Fuzzy Logic Control (FLC): Draws inspiration from human decision-making, employing fuzzy logic to handle imprecise data.
- Representation: Fuzzy sets defined by membership functions assign degrees of membership, enabling nuanced handling of uncertainty.
- Suitability: Ideal for systems with nonlinear dynamics, uncertainty, and imprecision, accommodating complex relationships.
- Parameter Tuning: Involves adjusting membership functions, rule base, and defuzzification methods to optimize performance.
- Optimization Methods: Parameters adjusted based on domain knowledge, empirical data, or automated algorithms for desired system behavior.

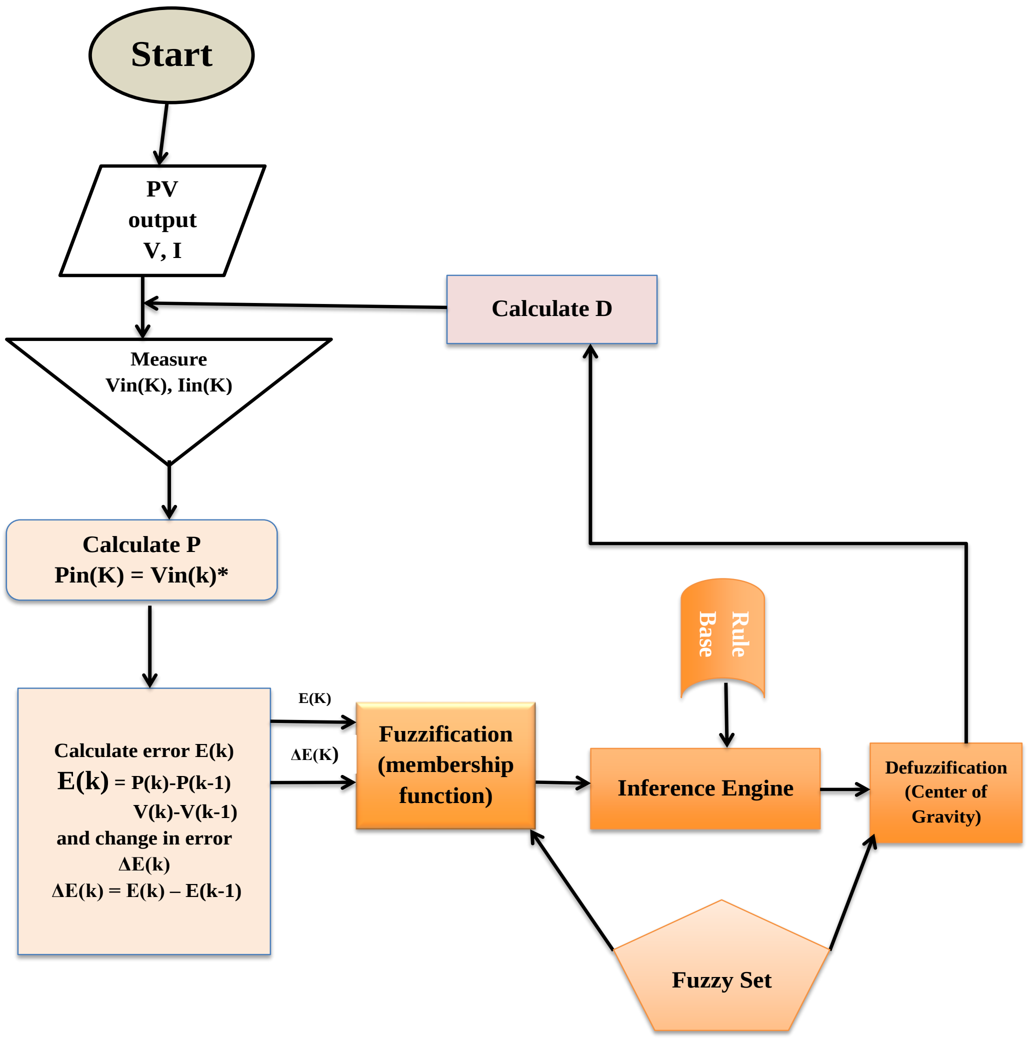


Fig.14 Algorithm of Fuzzy Logic Control

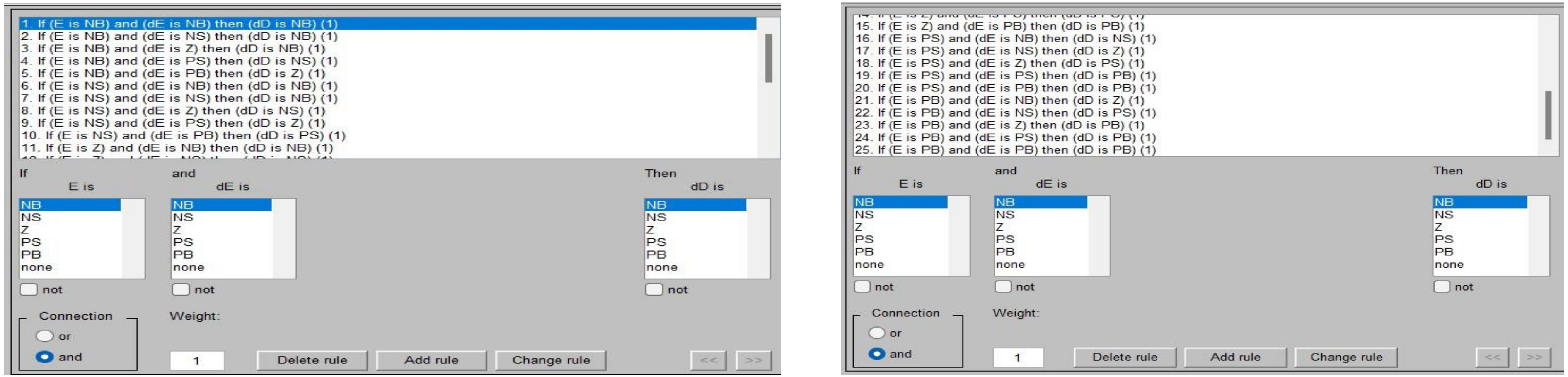


Fig.15 Rules developed in a Fuzzy Logic Control Block

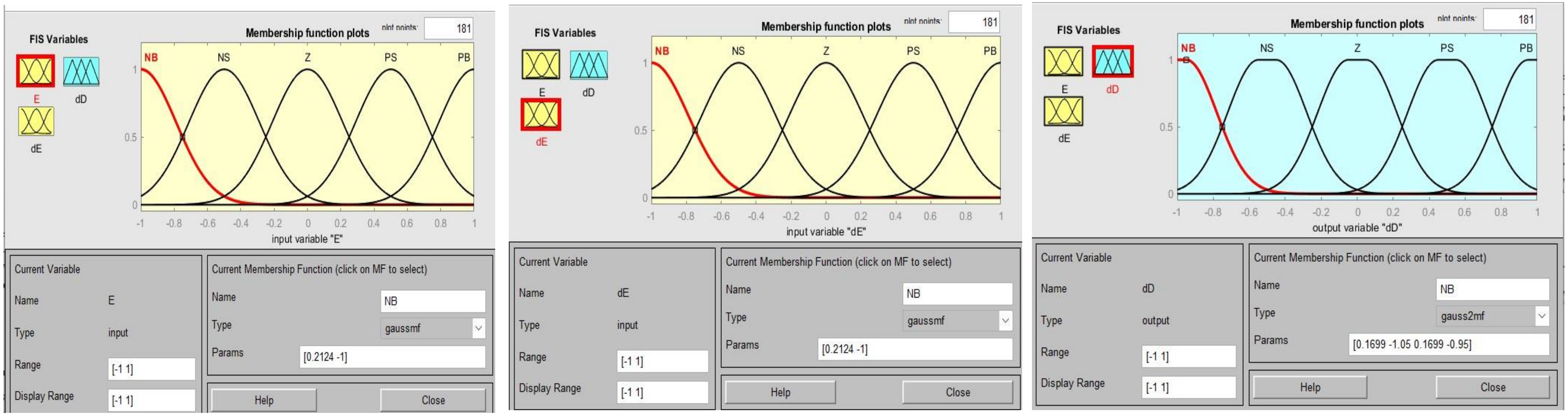


Fig.16 Membership function plots for input variables

# Simulink Model of fuzzy logic control with P&O :

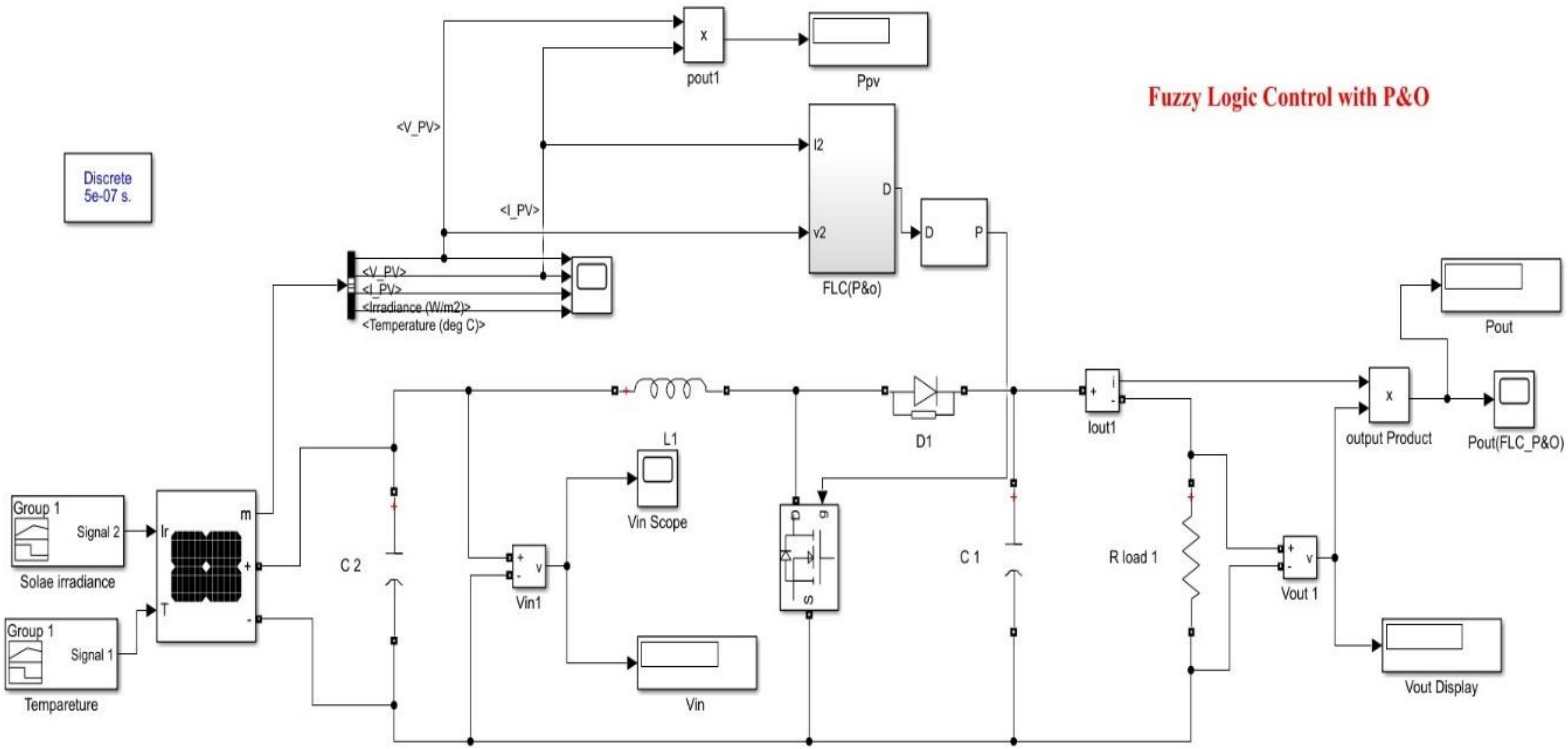


Fig.17 Simulink Model of Fuzzy Logic Control with P&O method

# Results of fuzzy logic control with P&O

The Simulink model graph drawn between Output power in watts versus Time in seconds for FLC with P&O. The maximum power obtained for FLC with P&O is 910.6W, the settling time is 0.188sec, rise time is 59.607ms, steady state error is1.132% and efficiency is 90.516%.

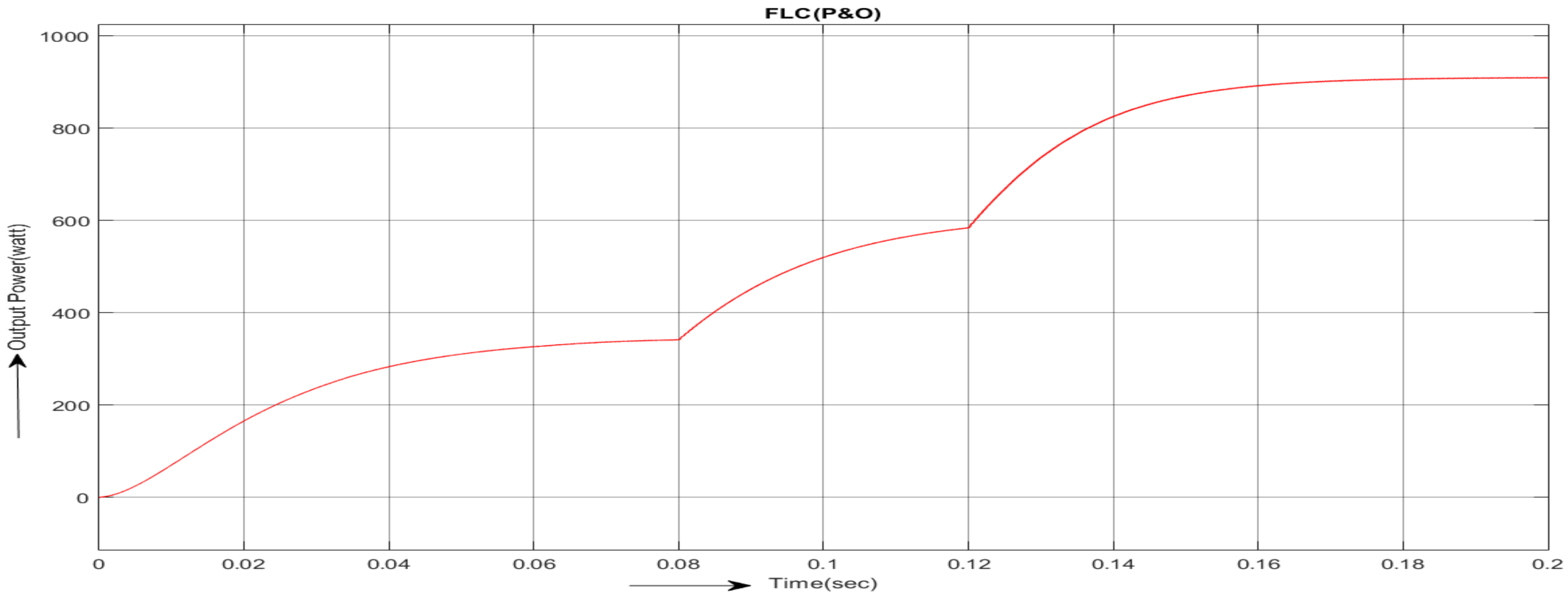


Fig.18 Output Power Vs Time for Fuzzy Logic Control with P&O method

# Simulink Model of fuzzy logic control with Incremental Conductance

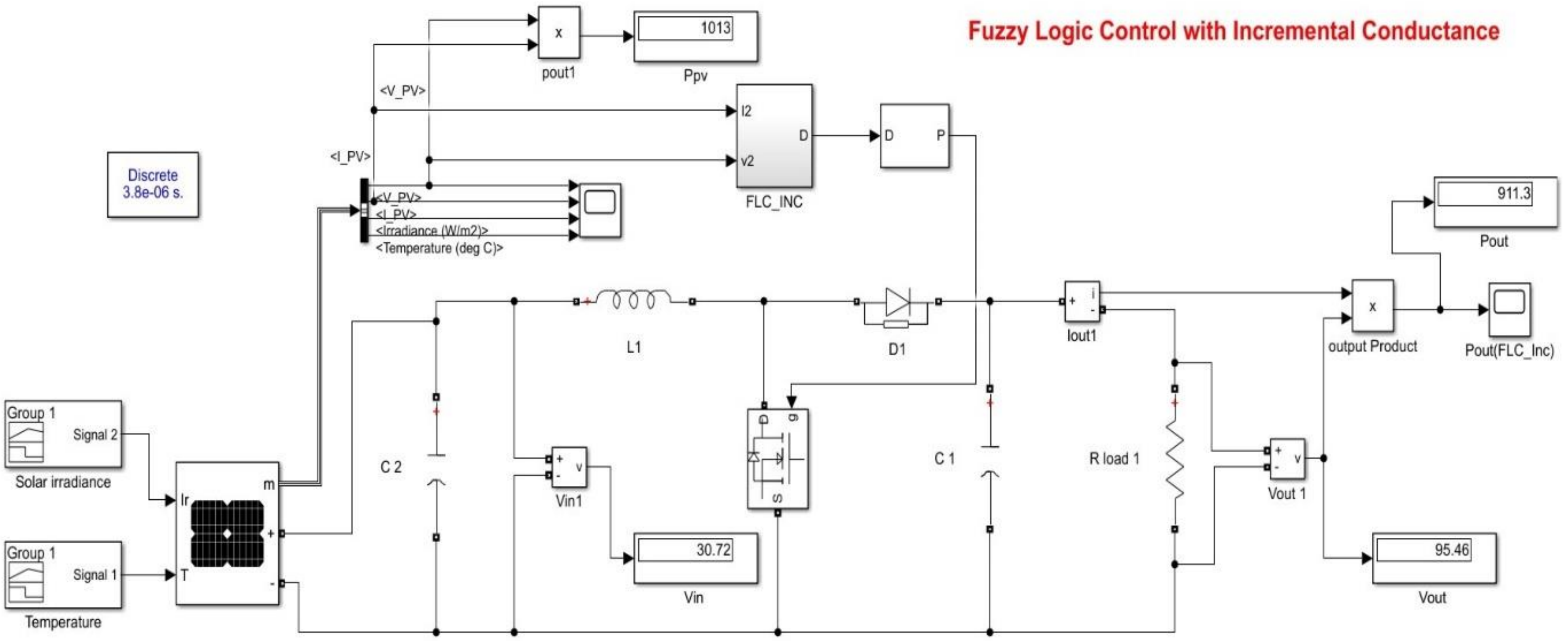


Fig.19 Simulink Model of Fuzzy Logic Control with Incremental conductance method

# Results Of Fuzzy Logic Control With Incremental Conductance

The Simulink model graph drawn between Output power in watts versus Time in seconds for FLC with Inc Cond. The maximum power obtained for FLC with Inc Cond is 911.3W, the settling time is 0.17sec, rise time is 54.428ms, steady state error is 0.646% and efficiency is 89.96%.

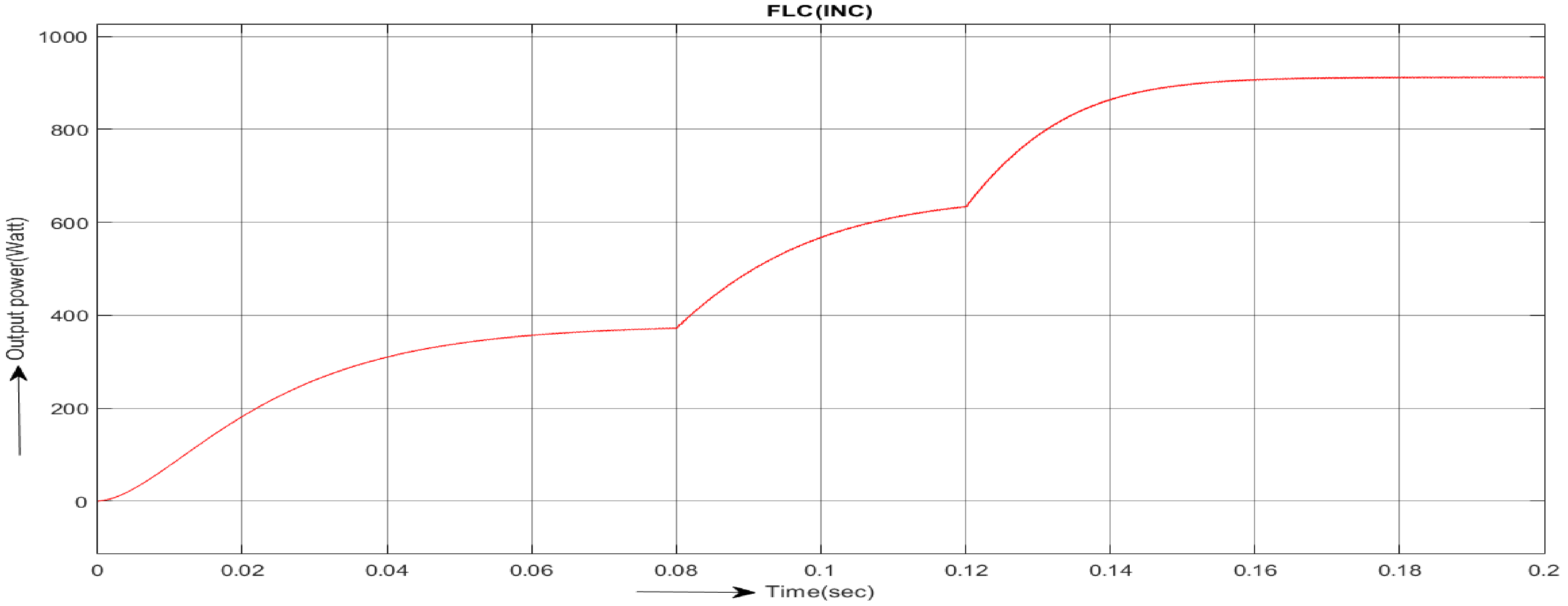


Fig.20 Output Power Vs Time for Fuzzy Logic Control with Incremental conductance method

# ADAPTIVE NEURO-FUZZY INFERENCE SYSTEM TECHNIQUE:

- ANFIS: Adaptive Neuro-Fuzzy Inference System, a hybrid intelligent system integrating fuzzy logic and neural networks.
- Purpose: Models complex and nonlinear systems, especially suitable for addressing uncertainty, imprecision, and nonlinearity.
- Components: Begins with a Fuzzy Inference System, comprising fuzzy rules describing input-output relationships.
- Fuzzy Sets: Input variables defined by fuzzy sets with membership functions representing linguistic terms (e.g., low, medium, high).
- Inference Process: Input values fuzzified based on degree of membership, undergo fuzzy logic operations to generate fuzzy output sets.

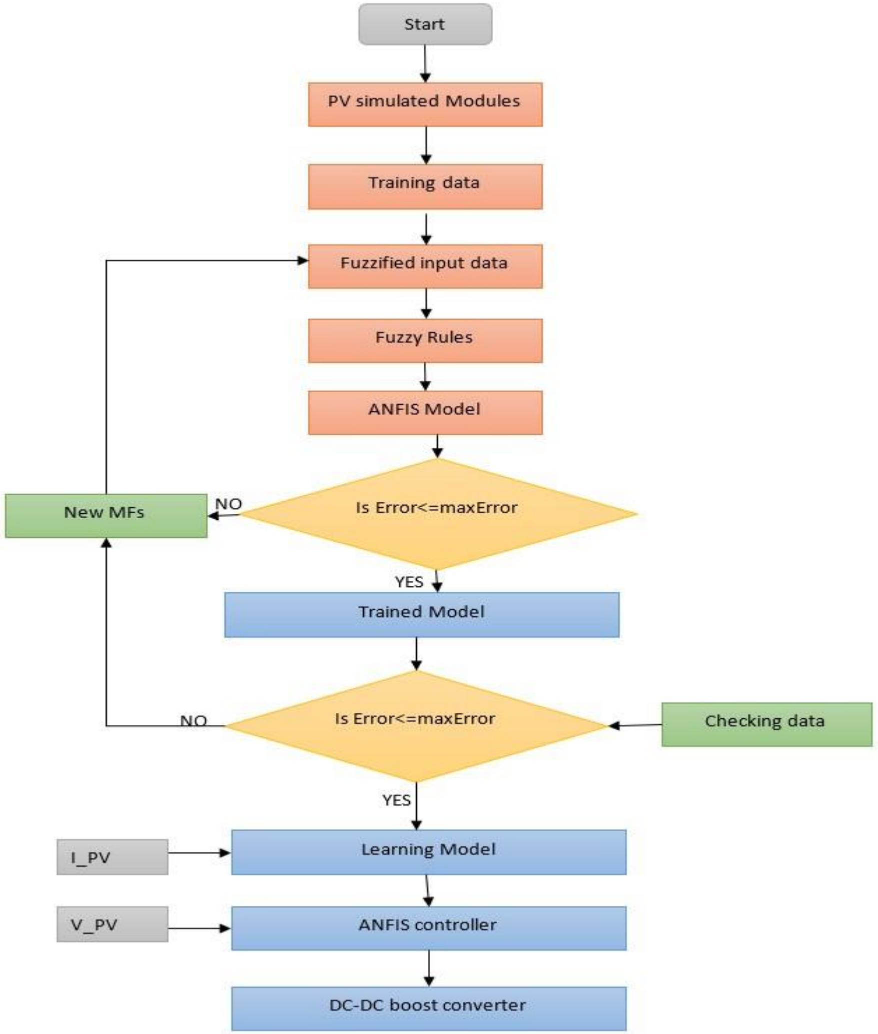


Fig.21 Algorithm of ANFIS

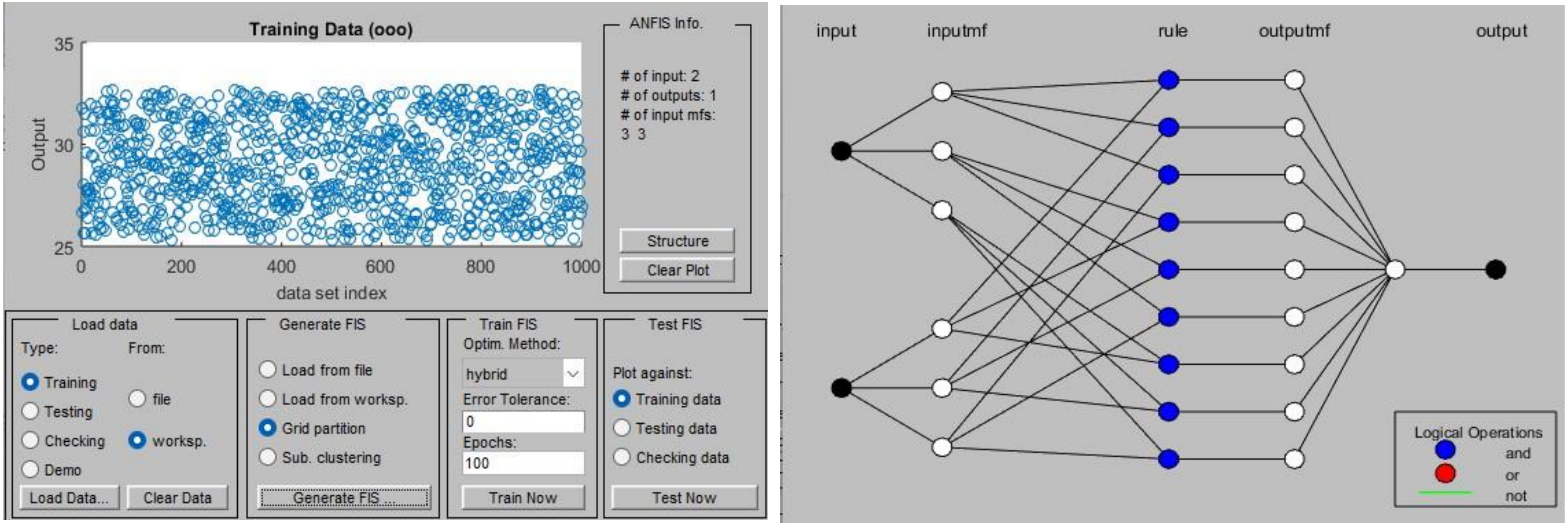


Fig . 22 Data training and Structure block

# Simulink Model of ANFIS Technique

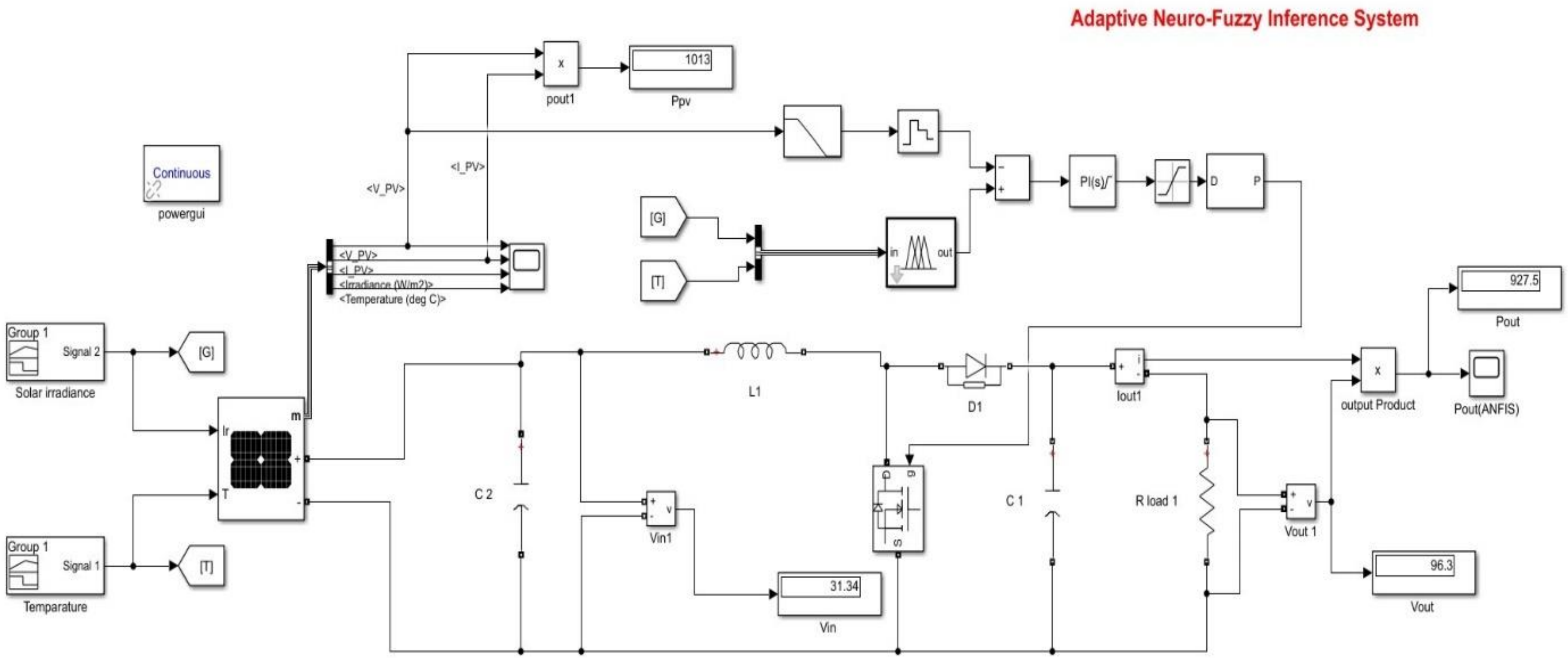


Fig.23 Simulink Model with ANFIS Technique

# Results Of  ANFIS Technique

The Simulink model graph drawn between Output power in watts versus Time in seconds for ANFIS. The maximum power obtained for ANFIS is 927.4W, the settling time is 0.170sec, rise time is 52.006ms, steady state error is 0.646% and efficiency is 91.549%.

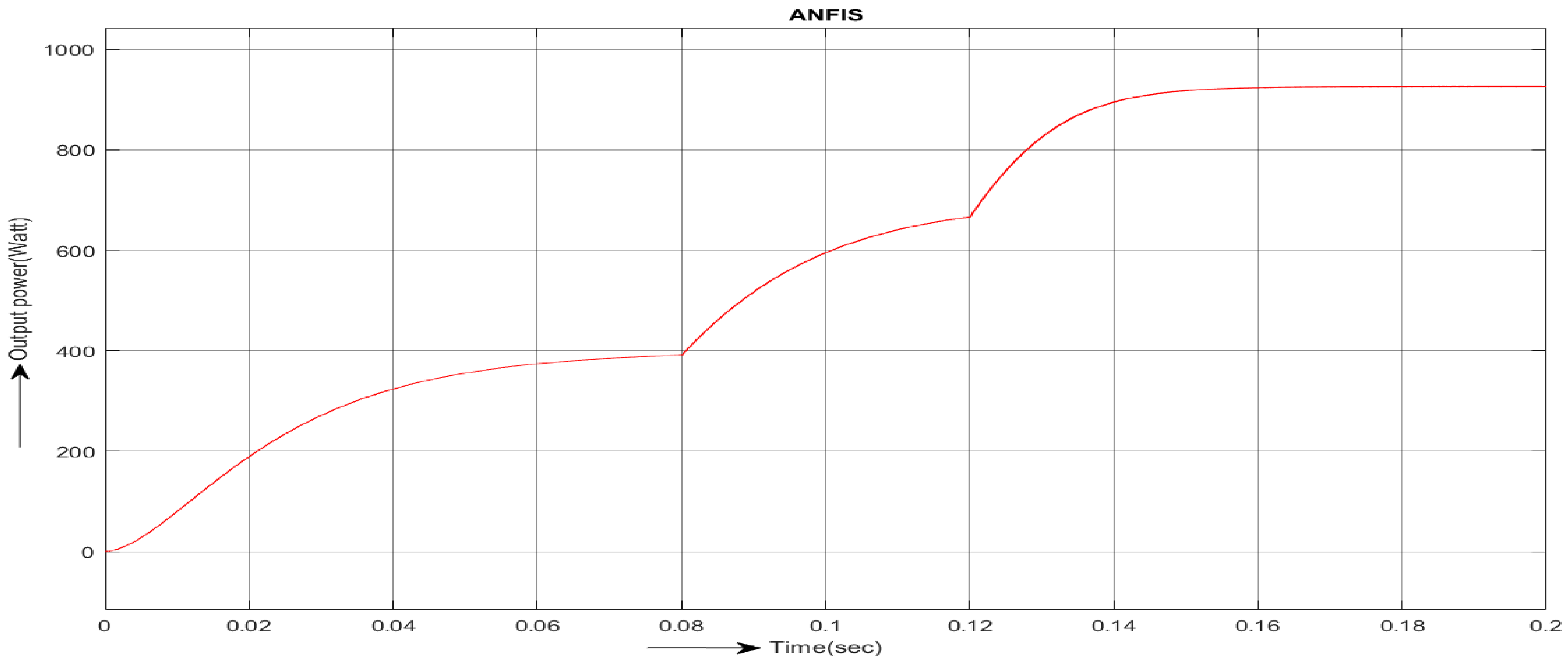


Fig.24 Output Power Vs Time for ANFIS Technique

# PARTICLE SWARM OPTIMIZATION TECHNIQUE:

- Initialization: PSO begins by creating a population of candidate solutions known as particles, each representing a potential solution to the optimization problem.
- Random Initialization: Particles are randomly positioned within the search space and assigned velocity vectors.
- Velocity Update: Particle velocities are adjusted based on their current velocity, deviation from their personal best (pBest), and deviation from the global best (gBest) position.
- Iteration: PSO iterates through velocity updates for a predefined number of iterations or until a termination criterion is met.
- Termination: Upon termination, the particle with the best fitness value (gBest) represents the optimized solution to the problem.

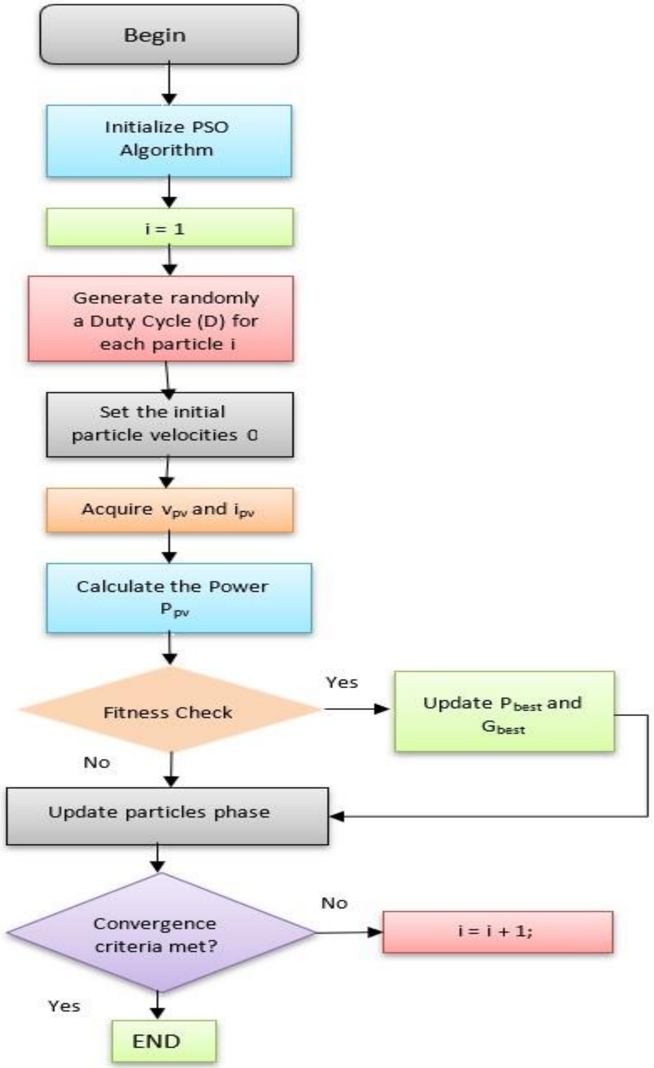


Fig.25 Algorithm of PSO

# Simulink Model Of Particle Swarm Optimization

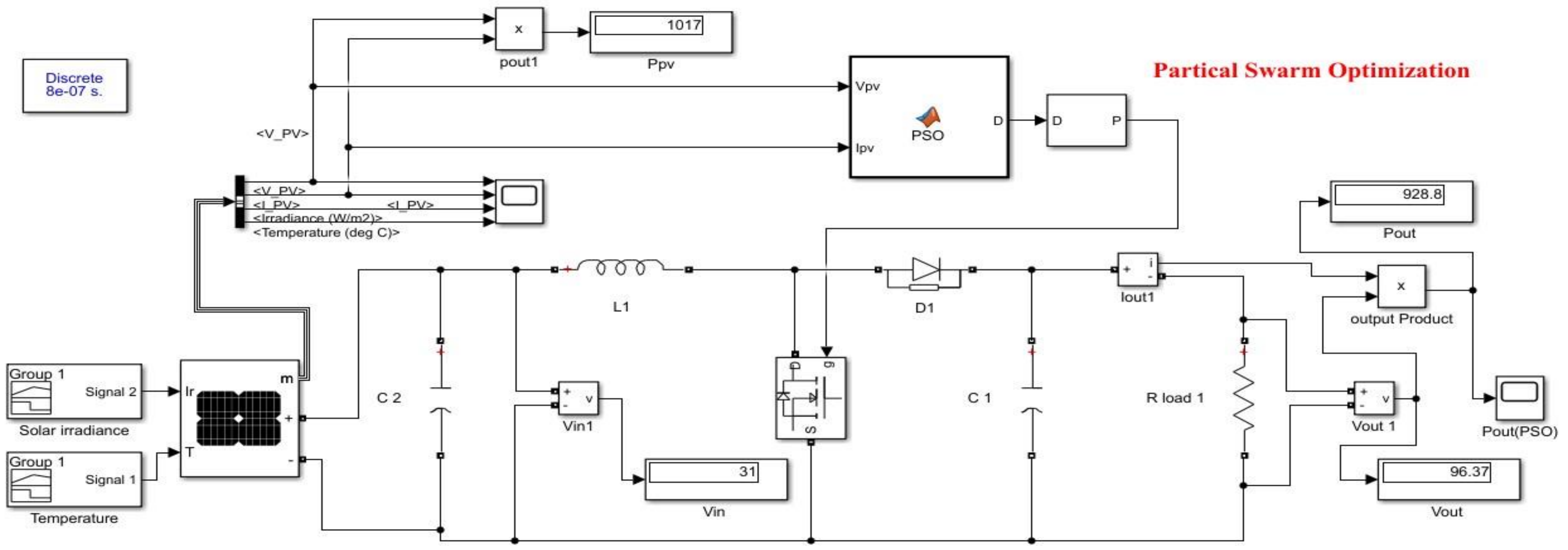


Fig.26 Simulink Model with Particle Swarm Optimization Technique

# Results of Particle Swarm Optimization

The Simulink model graph drawn between Output power in watts versus Time in seconds for PSO. The maximum power obtained for PSO is 928.8W, the settling time is 0.172sec, rise time is 53.157ms, steady state error is 0.254% and efficiency is 91.327%.

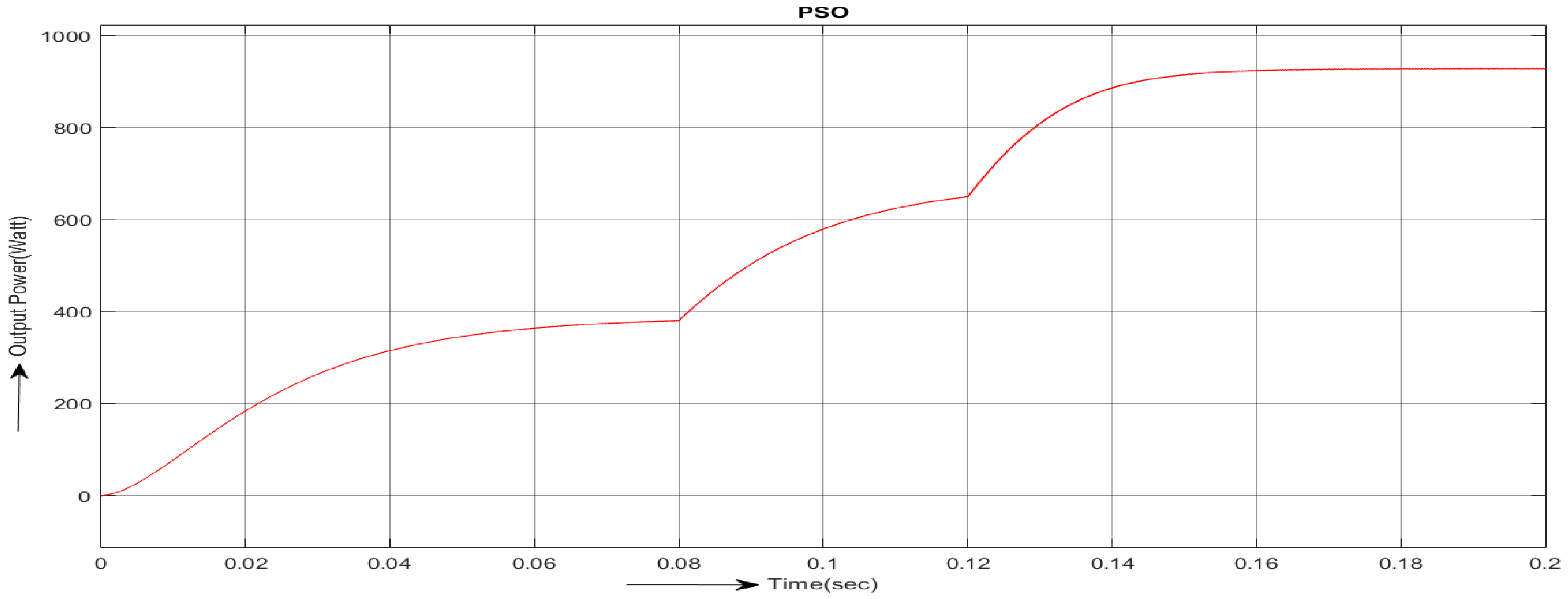


Fig.27 Output Power Vs Time for Particle Swarm Optimization Technique

# COMPARISON AND DISCUSSIONS OF VARIOUS MPPT TECHNIQUES

Fig. 28 shows the Output Power Vs Time for PI, P&O, Inc, Fuzzy(P&O), Fuzzy (Inc), ANFIS and PSO whereas color curve line indicates the output power range of different methods.

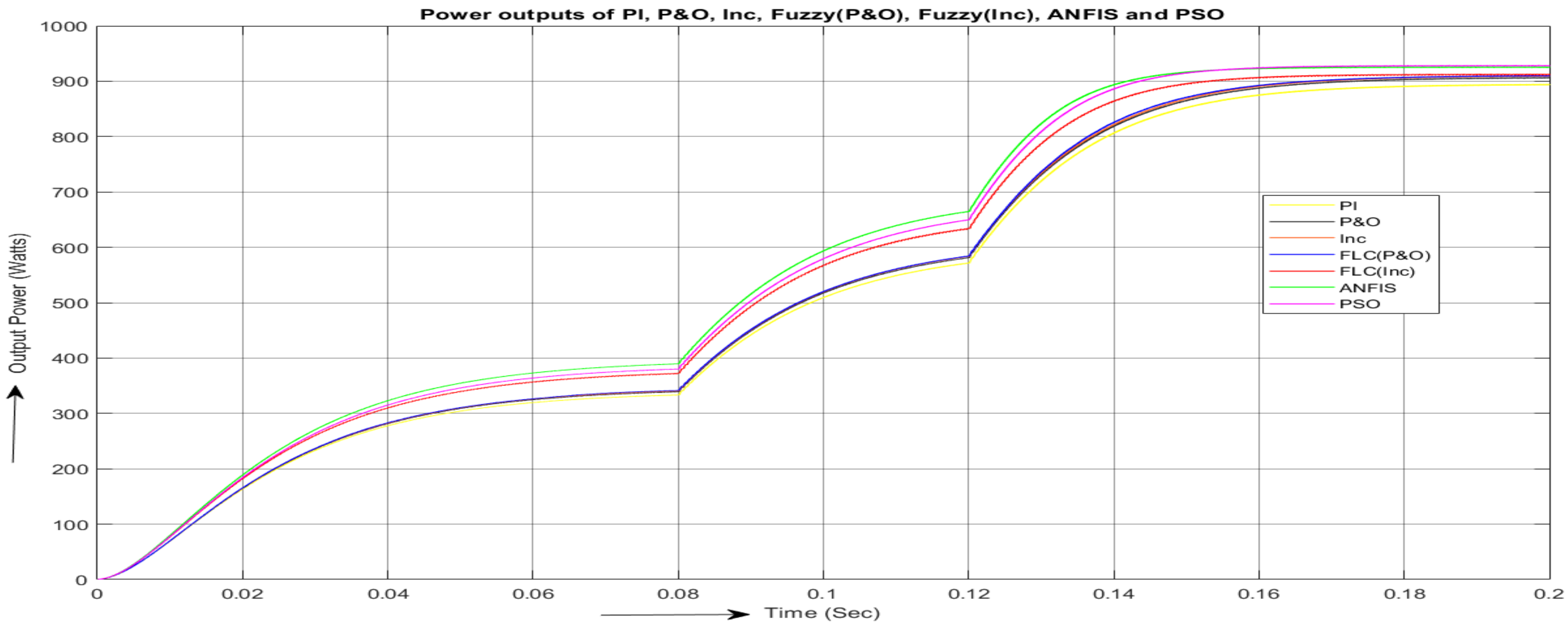


Fig .28 Output Power Vs Time for PI, P&O, Inc, Fuzzy(P&O), Fuzzy (Inc), ANFIS and PSO.

# COMPARISON OF VARIOUS MPPT TECHNIQUES

The Comparison between various types of MPPT techniques for different parameters. In such parameters, it includes the maximum power, settling time, rise time, steady state error, and efficiency for various techniques in table.2.

Table.2: Comparison of Maximum power, settling time, rise time, steady state error, and efficiency for various techniques.

| Parameter / Method | Ppv (w) | Pout (W) | Settling Time (sec) | Rise Time (ms) | Steady State Error (%) | Efficiency (%) |
|---|---|---|---|---|---|---|
| PI | 1008 | 894.3 | 0.198 | 60.855 | 1.136 | 88.720 |
| P&O | 1006 | 906.6 | 0.196 | 60.754 | 1.332 | 90.119 |
| Inc Cond | 1006 | 909.8 | 0.189 | 60.681 | 1.332 | 90.437 |
| FLC (P&O) | 1006 | 910.6 | 0.188 | 59.607 | 1.332 | 90.516 |
| FLC (Inc Cond) | 1013 | 911.3 | 0.170 | 54.428 | 0.646 | 89.96 |
| ANFIS | 1013 | 927.4 | 0.170 | 52.006 | 0.646 | 91.549 |
| PSO | 1017 | 928.8 | 0.172 | 53.157 | 0.254 | 91.327 |

# DISCUSSIONS:

Based on the comparative study on Solar PV System MPPT Techniques for Boost Converter, the conclusion highlights the performance metrics including Maximum Power Extraction, Settling Time, Rise Time, Steady State Error, and Efficiency for various MPPT methods compared to the closed-loop PI controller.

- ***Maximum Power Extraction:***

Among the MPPT methods investigated, Particle Swarm Optimization (PSO) and Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the highest maximum power extraction, with PSO achieving 928.8W and ANFIS achieving 927.4W.
Closed-loop PI controller achieved a maximum power output of 894.3W, lower compared to advanced MPPT methods.

- ***Settling Time:***

Fuzzy Logic Control with Incremental Conductance and Adaptive Neuro Fuzzy Interface System exhibited the fastest settling times at 0.170sec, closely followed by Particle Swarm Optimization at 0.172sec.
Closed-loop PI controller had a settling time of 0.198sec, comparatively slower than some of the MPPT methods.

# DISCUSSIONS:

- ***Rise Time:***

Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the fastest rise time at 52.006ms, followed by Fuzzy Logic Control with Incremental Conductance at 54.428ms.
Closed-loop PI controller had a rise time of 60.855ms, slower compared to most of the MPPT methods.

- ***Steady State Error (%):***

Particle Swarm Optimization exhibited the lowest steady-state error at 0.254%, followed by Fuzzy Logic Control with Incremental Conductance at 0.646%.
Closed-loop PI controller had a steady-state error of 1.136%, higher than most of the advanced MPPT methods.

- ***Efficiency (%):***

Adaptive Neuro Fuzzy Interface System (ANFIS) demonstrated the highest efficiency at 91.549%, followed closely by Particle Swarm Optimization at 91.327%.
Closed-loop PI controller had an efficiency of 88.720%, lower compared to several MPPT methods.

# CONCLUSION:

The Simulink models for closed-loop PI control and diverse MPPT techniques, including Perturb and Observe, Incremental Conductance, and advanced methods like PSO and ANFIS, demonstrate the efficiency of intelligent control strategies in optimizing solar PV system efficiency, highlighting their importance in renewable energy system development.

After that a comparative study, it's evident that intelligent techniques like Particle Swarm Optimization (PSO), Adaptive Neuro Fuzzy Interface System (ANFIS), and Fuzzy Logic Control with Incremental Conductance outperform the traditional closed-loop PI controller across all performance metrics. These intelligent methods consistently demonstrate superior maximum power extraction, faster settling and rise times, lower steady-state errors, and higher efficiency levels. Among them, ANFIS stands out as the top performer, followed closely by PSO and Fuzzy Logic Control with Incremental Conductance. This highlights the effectiveness of adaptive and intelligent control strategies in optimizing solar PV system performance.

# FUTURE ENHANCEMENT

Future research could further explore hybrid approaches and real-world implementation to validate these findings and facilitate broader adoption of efficient MPPT technologies in renewable energy systems. It also involves investigating hybrid MPPT techniques that combine the strengths of multiple methods. For instance, integrating machine learning and deep learning algorithms with traditional controllers like PI or FLC could leverage the adaptive learning capabilities of ML and DL to enhance the robustness and accuracy of MPPT systems.

# PUBLICATION DETAILS

[1]. M. S. Sujatha, K. Madhusudhan, K. G. Yamunappa, S. Prameela, P. Sai Chandana, S. Mahesh Kalyan, ***"A Review Across Diversified Applications of Solar Energy"*** has been submitted at the *"2024 IEEE International Conference on Recent Innovation in Smart and Sustainable Technology (ICRISST 2024)",* held at Presidency University, Bengaluru, Karnataka, India, on March 15-16, 2024.

[2]. M. S. Sujatha, K. Madhusudhan, K. G. Yamunappa, S. Prameela, P. Sai Chandana, S. Mahesh Kalyan, **"*Implementation of Perturb & Observe MPPT Strategy with Buck and Boost Converters in Photovoltaic System*"** has been submitted at the *"5th International Conference on Energy, Control, Computing, and Electronic Systems (ICECCES 2024)" held at Mohan Babu University (Erst While Sree Vidyanikethan Engineering College), Tirupati, Andhra Pradesh, India*, on March 22-24, 2024. ISBN Number : 978-93-340-1488-4

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