Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Comparative Analysis of Fuzzy Logic and Incremental Conductance MPPT Techniques for Enhancing Photovoltaic System Efficiency

Manishkumar S Patel[1], Dr. Samir H. Patel [2], Dr. Dattesh Y. Joshi[3]

[1] *Ph. D Scholar, Department of Electrical Engineering, Krishna School of Emerging Technology and Applied Research (KSET), Drs. Kiran & Pallavi Patel Global University (KPGU), Vadodara, Gujarat, India*

[2] *Research Supervisor, Associate Professor & Head, Department of Electrical Engineering, Krishna School of Emerging Technology and Applied Research (KSET), Drs. Kiran & Pallavi Patel Global University (KPGU), Vadodara, Gujarat, India*

[3] *Associate Professor & Director, Krishna School of Diploma Studies (KSDS), Drs. Kiran & Pallavi Patel Global University (KPGU), Vadodara, Gujarat, India*

ARTICLE INFO

Received: 15 Oct 2024

Revised: 12 Dec 2024

Accepted: 20 Dec 2024

ABSTRACT

Solar photovoltaic (PV) systems offer a clean and sustainable energy source, but their efficiency varies with changing environmental conditions. To optimize power extraction, Maximum Power Point Tracking (MPPT) techniques are crucial. This paper presents a comparative analysis of Fuzzy Logic and Incremental Conductance (INC) MPPT algorithms for enhancing photovoltaic system efficiency. Both techniques are implemented and tested using the PSIM simulation platform, which also supports the hardware-oriented design and validation of the control circuits. Key performance parameters such as tracking speed, accuracy, and adaptability to irradiance variations are analyzed. The study further explores the integration of a DC-DC converter to regulate output voltage for broader application utility. The results demonstrate the effectiveness of both MPPT methods and provide insights into their practical suitability for real-time solar energy systems.

Keywords – Fuzzy Logic, Solar Photovoltaic, MPPT, Incremental Conductance, Renewable Energy.

INTRODUCTION

The sun has long been revered by humans as a plentiful supply of energy and a giver of life. With depleting conventional sources of energy, we have been forced to shift towards renewable energy sources. India is bestowed with vast solar energy with approximately 5000 trillion kWh energy incident per year, which can generate sufficient electrical energy [1]. Life is not easy without electricity and when it can be harnessed from renewable energy source such as solar energy, wind energy, biomass, tidal energy etc., it benefits us socially and economically. India was ranked sixth globally for its utilization of solar power. India's solar power capacity is growing quickly, going from 2.6 GW in March 2014 to 30 GW in July 2019[2].Using the photovoltaic effect, solar insolation can be converted to electrical energy but low efficiency is one of the challenging aspects for utilizing the maximum power output of solar photovoltaic cell. With varying temperature, sun radiations and climatic conditions, it becomes difficult to extract the maximum energy from solar cell. Solar cell efficiency can be improved by operating it at maximum power point through maximum power point tracker [2]. There are various MPPT techniques that can be implemented to extract maximum power from solar cell. Solar photovoltaics are being adopted as a RES whether it is grid connected or standalone system. With varying climatic conditions, output of solar PV also varies and thus we add a DC-DC converter being controlled by the MPPT techniques so that it generates a rated constant output [3]. Conventional MPPT methods such as P&O, Incremental conductance, Fractional open circuit voltage, Fractional short circuit current are proposed in literature which can be implemented with solar PV cell. A design of PV module with DC-DC converter controlled by MPPT has been developed in PSIM under varied climatic conditions and simulating results are validated through it hardware implementation [1]. The block diagram for the proposed system can be [3, 12]:

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

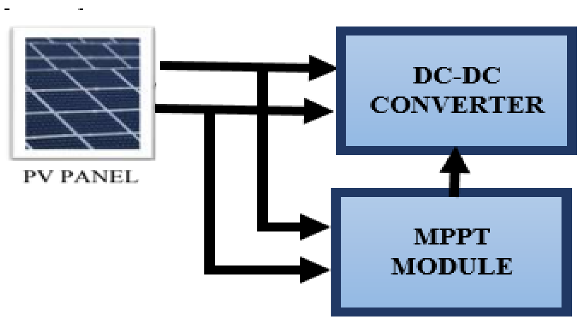

Fig. 1.1 Block diagram of proposed system

SOLAR PHOTOVOLTAIC CELL

PHOTOVOLTAICS – a solar energy system proves to be the most critical advancement in the development of solar technology. Photovoltaics are the best known method that uses semiconductors to produce electricity from solar radiations through direct conversion. Generating electric power with the use of semiconductors to convert sun's energy into a flow of electrons is known as "PHOTOVOLTAIC EFFECT". Such process occurred when a material (semiconductor) absorbed light to produce electrical voltage. Thus, solar cells are developed using various semiconductor materials (usually silicon) using photovoltaic effect. PV modules can be linked together to form a PV panel, providing power in range of few watts to tens of megawatts[2,3].

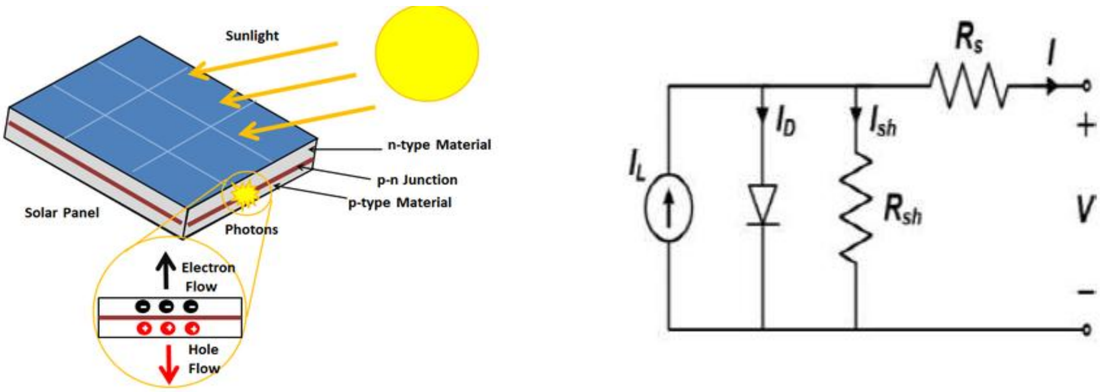

Fig. 1.2 Working of PV Cell with its equivalent mathematical circuit

Figure 1.2 depicts the working of PV cell with its equivalent circuit modeled as current source with a diode in parallel, shunt and series resistances. Ideally PV Cell is modeled as current source because from I-V characteristics, it is observed that current is approximately constant for a given range of voltage. Parallel connected diode also called as bypass diode, prevents current flowing back to the well exposed to sunlight, good solar cells, overheating, burning out weaker or partially shaded solar cells by providing current path around bad cell[11]. R_s = series resistance that act as internal resistance to the flow of current which is ideally zero. Practically its value is minimum to deliver maximum output to the load. R_{sh} = shunt resistance for leakage current which is ideally infinite. Mathematically, PV cell is modeled with following equations[2,4]:

1. Thermal Voltage: $V_t = \frac{k*T_{op}}{q}$

   k = Boltzmann's constant (1.38×10^{-23} J/K)

   q = Electron Charge (1.602×10^{-19} C)

   T_{op} = Operating Temperature of Cell (˚C)

2. Diode Current: $I_d = I_s N_p[\frac{\frac{V+IR_s}{N_s}}{V_t n N_s} - 1]$

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

3. Shunt Current: $I_{sh} = \frac{V+IR_s}{R_p}$

Where,

R_s & R_p = Series and Parallel Resistances respectively

n = Diode Ideality Factor

N_s & N_p = Number of cells connected in series and parallel respectively

I_s = Diode Saturation Current

4. Reverse Saturation Current: $I_s = I_{rs} \left(\frac{T_{op}}{T_{ref}}\right)^3 \{(\frac{qE_g}{kn}) [(\frac{1}{T_{op}}) - (\frac{1}{T_{ref}})]\}$

5. Reverse Saturation Current atT_{op}: $I_{rs} = I_{sc}\ [e^{\frac{qV_{oc}}{kCnT_{op}}} - 1]$

Where,

V_{oc} = Open Circuit Voltage

I_{sc} = Short Circuit Voltage

C = Number of Cells in a Module

E_g = Band Gap Energy

T_{op} = Operating Temperature

T_{ref} = Reference Temperature

6. Photocurrent: $I_{ph} = I_{rr}\ [I_{sc} + k_i\ (T_{op} - T_{ref})]$

7. Load Current: $\mathrm{I} = I_{ph}N_p - I_sN_p\ [e^{\frac{q(V+IR_S)}{kT_{op}n}} - 1] - \frac{V+IR_S}{R_p}$

Where,

I_{rr} = Solar Irradiations (W/m^2)

k_i = Temperature Coefficient of I_{sc} (A/$^\circ$C)

MAXIMUM POWER POINT TRACKER

Practically, solar cells are only 15-17% efficient. Researchers are investing their best efforts to improve solar cell efficiency. As per the latest reports on 26 February 2018 by Fraunhofer Institute for Solar Energy Systems, ISE monocrystalline solar cell had recorded laboratory efficiency of 26.7% and 22.3% for multicyrstalline silicon wafer-based technology[5]. Over 10 years of consistent efforts, researchers were successful in improving efficiency of solar cells by setting benchmark of 46% efficient multijunction solar cells[5].

The overall efficiency of PV systems needs to be increased, considering high initial capital cost of PV source as well as its low energy conversion efficiency and this could be done by employing power electronic devices in conjunction with a maximum power point tracking method. PV sources have a unique maximum power point and nonlinear I-V characteristics that make them difficult to operate[12]. This dependence of characteristics on varying solar irradiations and temperature results in varying maximum power point. Therefore, Maximum Power Point Tracking is employed to oversee the optimal power output of the photovoltaic system. The greatest Power Point Tracking (MPPT) technique is utilized to discover the optimal voltage at which the photovoltaic (PV) cell generates its greatest power. This algorithm is employed to achieve the maximum power output at the Maximum Power Point (MPP). MPPT works on Maximum Power Transfer theorem to extract maximum power when load impedance matches source impedance. MPPT is employed with DC-DC converter coupled with the PV module so that it operates on the duty cycle when

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

source impedance becomes equal to the load impedance, thus maximum power can be extracted from the PV array and efficiency of PV system can be improved[5,6].

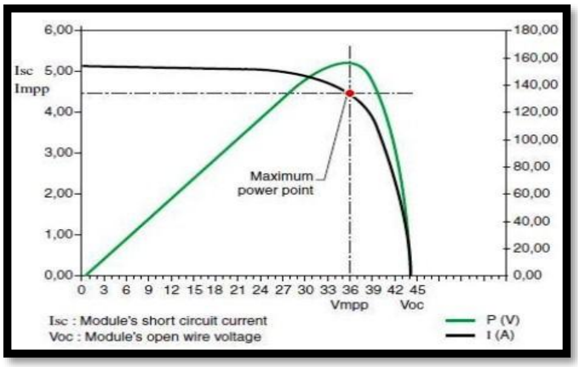

Figure 1.3 Maximum Power Point

There are number of different MPPT algorithms enlisted in literature with different ways of implementation. Few of the most popular techniques are [5]:

1. Perturb and Observe/Hill Climbing: Both of these methods involve system to perturb by incrementing or decrementing operating voltage or directly acting on the duty cycle of DC-DC converter to observe the output power of the PV panel. Any operating point on P-V characteristics perturbs according to principle – with increase (decrease) in voltage, power also increases (decreases) if operating point is to the left of the MPP and decreases (increases) if operating point is to the right of the MPP. In In summary, when power increases, perturbation either progresses in the same direction or retreats when power decreases. The process keeps periodically repeating till MPP is reached. Once the system reaches a stable state, the algorithm fluctuates about the highest point. The perturbation size is kept at a minimum to reduce the power variation. The method is designed in a way that establishes a reference voltage for the module that matches its peak value. The PI controller adjusts the module's operating point to the desired voltage level. It has been shown that this disruption leads to significant power reduction, making it challenging to monitor power under quickly fluctuating atmospheric circumstances. An inherent limitation of the Perturb and Observe approach is its inability to track peak power during swiftly fluctuating meteorological conditions [2,13].
2. Incremental Conductance: The technique is based on the observation that, depending on whether the operating point is to the left, right, or at the MPP, the slope of the PV module power curve, dp/dv is positive, negative, or zero.. MPP is tracked by comparing instantaneous conductance ($\frac{I}{V}$) to incremental conductance ($\frac{dI}{dV}$). The algorithm can be understood as following [1].

   $\frac{dP}{dV}$ = 0 [at MPP]

   $\frac{dP}{dV}$ > 0 [to the left side of MPP]

   $\frac{dP}{dV}$ < 0 [to the right side of MPP]

   Where, $\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV}$

   $\frac{1}{V}\frac{dP}{dV} = \frac{I}{V} + \frac{dI}{dV}$

The PV panel voltage can be adjusted relatively w.r.t MPP voltage by measuring the incremental conductance, di/dv and the instantaneous conductance, I/V. It was observed that realized that the oscillation stops once the MPP is reached. When di/dv=I/V gets satisfied, it indicates that the MPP has been reached.

DC-DC BOOST CONVERTER

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

The output collected from the PV panel keeps continuously varying with small magnitude that cannot be directly connected to the load so the voltage needs to be boosted up with the help of power electronic converter namely - boost converter, also known as the step-up converter[1]. It is a switching converter with a power semiconductor switch, a diode, an inductor, a capacitor and a PWM controller as shown in fig. 1.5.

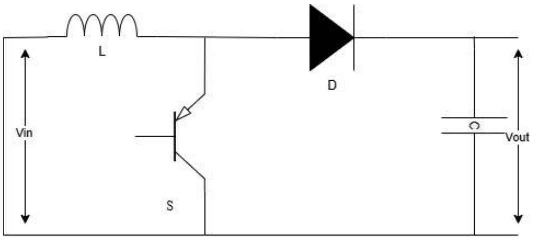

Fig. 1.5 Boost Converter Circuit

The boost converter works in two modes of operation with appropriate switching pulses of the semi-conductor switch. The switching is done in synchronization with MPPT controller that controls the duty cycle of boost converter to generate boosted voltage of appropriate magnitude.

PSIM SIMULATION

The proposed system was implemented through the hardware to validate the results obtained with simulations. The PVsyst program has recorded the instantaneous solar radiation and related temperature for several days during the hot spell. The overall fluctuation in radiation and temperature has been shown to be consistent throughout all days. As an example, we took the observations of Latitude – 23.1, Longitude – 72.6 & Altitude – 58m of one particular bright sunny day. The data for the instant solar radiation & temperature recorded are shown in the table 1.

Table 1

TIME	Instant Temperature [°C]	Instant Solar Radiation [W/m²]
05:30 A.M	30	12
06:00 A.M	30	104
06:30 A.M	30	219
07:00 A.M	30	337
07:30 A.M	31	453
08:00 A.M	31	561
08:30 A.M	32	663
09:00 A.M	32	755
09:30 A.M	33	836
10:00 A.M	34	904
10:30 A.M	35	959
11:00 A.M	36	998
11:30 P.M	37	1022

TIME	Instant Temperature [°C]	Instant Solar Radiation [W/m²]
12:00 Noon	38	1030
12:30 P.M	40	1022
01:00 P.M	40	998
01:30 P.M	41	959
02:00 P.M	42	904
02:30 P.M	43	836
03:00 P.M	44	755
03:30 P.M	45	663
04:00 P.M	45	561
04:30 P.M	46	452
05:00 P.M	44	337
05:30 P.M	43	219
06:00 P.M	42	104
06:30 P.M	36	12

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

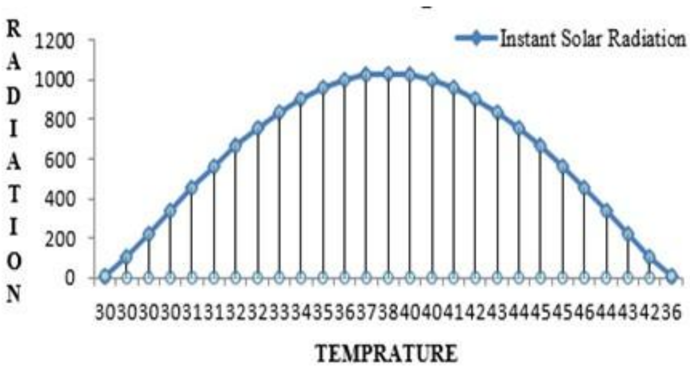

Fig 1.6 Graph of Solar Radiation & Temperature throughout the day

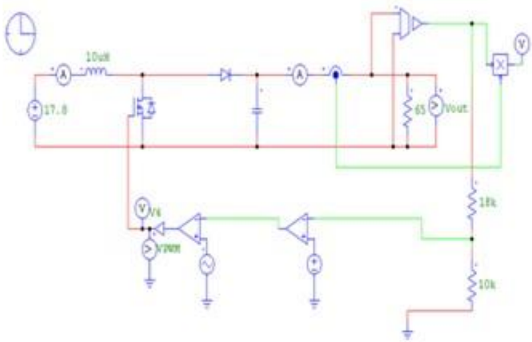

Fig. 1.7. Circuit of Boost Converter in PSIM

Instant solar radiations were compare with the instant solar temperature and the output graph of radiation v/s temperature has shown in Fig 1.6. The developed boost converter in PSIM software is as shown in the fig. 1.7. The simulated results for output voltage, output current and power of boost converter are shown in the fig 1.8.

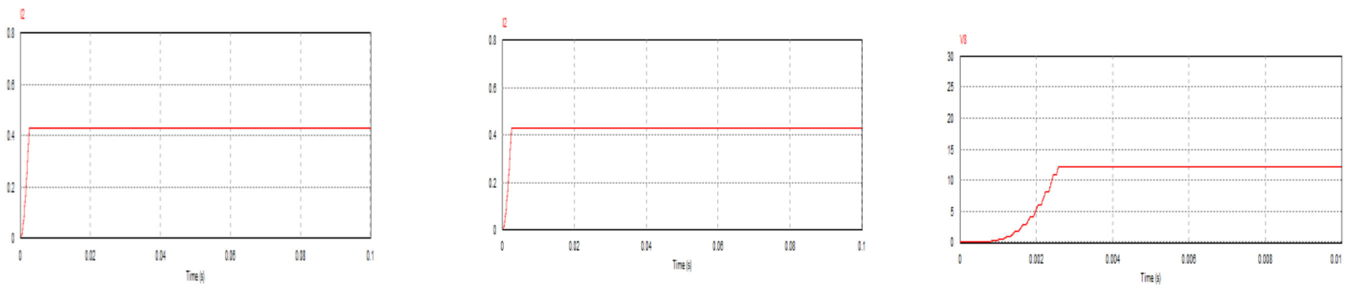

Fig. 1.9 Output Current, output voltage and output current (at 10 V input voltage)

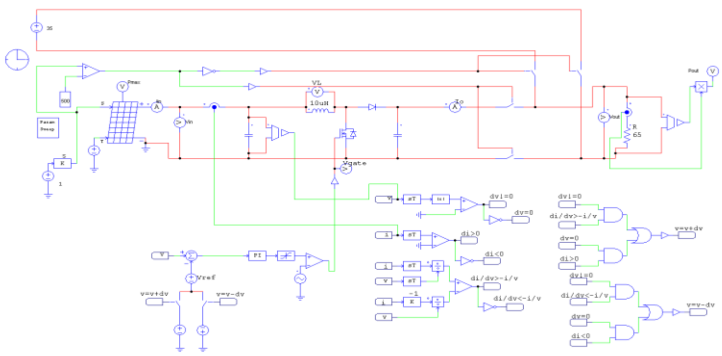

Fig. 1.10 Circuit diagram of Boost converter with MPPT in PSIM

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

Boost converter with Incremental & Conductance algorithm is simulated for 25 W solar panel and all the output result is taken at STC conditions (25°C temperature and solar radiation of 1000 W/m²). Output results for this configuration has shown in Fig 1.11.

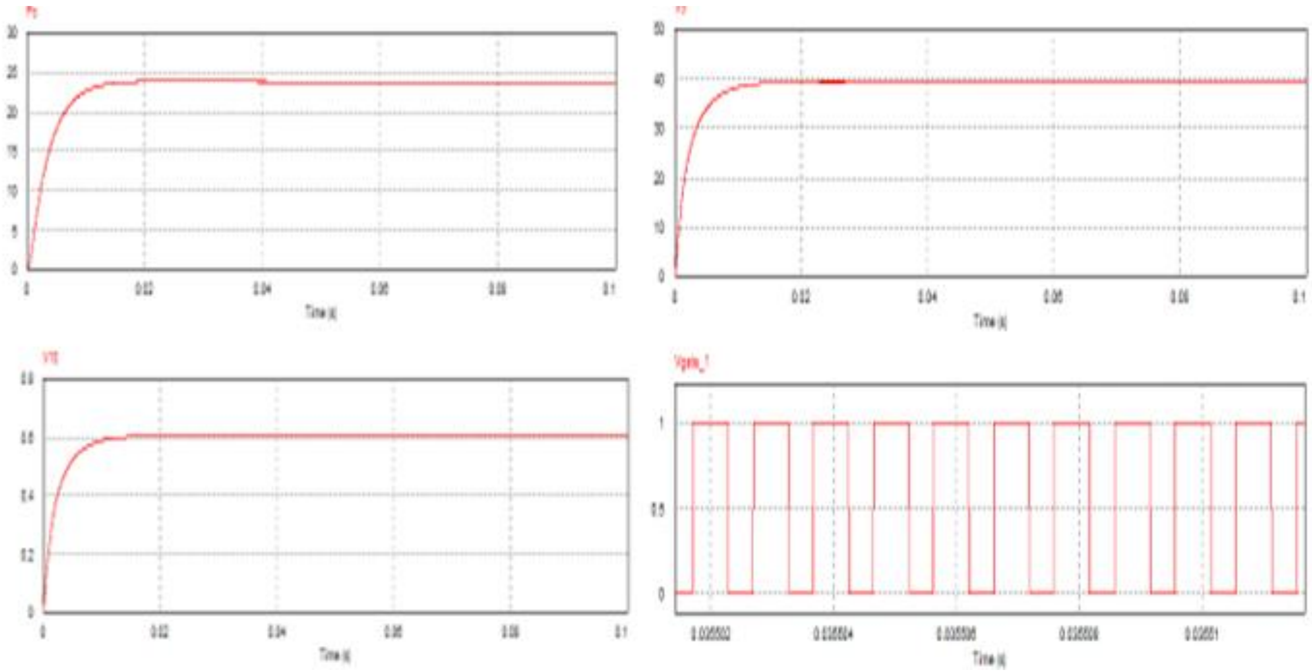

Fig. 1.11 Output Voltage, Power & Current of Boost converter with MPPT algorithm, and gate pulse

Table 2: Parameter Tabulation with MPPT – INC and Fuzzy logic

Time	Solar Radiation	Temperature	PMax	Solar Input Current	Solar Input Voltage	Output Current	Output Voltage	INC Output Power	Fuzzy Output Power	Efficiency
05:30 A.M	12	30	0.3259	0.0261	2.3973	0.0261	1.6973	0.0443	0.047844	13.59%
06:00 A.M	104	30	2.4236	0.1671	11.5672	0.1671	10.8672	1.8168	1.962144	74.96%
06:30 A.M	219	30	5.1973	0.3044	16.8075	0.2746	17.853	4.9035	5.050605	94.34%
07:00 A.M	337	30	8.0928	0.4981	16.2174	0.3437	22.3446	7.6812	7.911636	94.91%
07:30 A.M	453	31	10.918	0.6274	17.1763	0.3998	25.9886	10.3908	10.70252	95.17%
08:00 A.M	561	31	13.5608	0.8583	15.0256	0.446	28.9943	12.9334	13.06273	95.37%
08:30 A.M	663	32	15.9869	0.9328	17.0458	0.4854	31.5569	15.3206	15.47381	95.83%
09:00 A.M	755	32	18.2027	1.2223	16.1062	0.5186	33.7115	17.484	17.65884	96.05%

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

09:30 A.M	836	33	20.0621	1.2773	14.9131	0.5456	35.4667	19.3522	19.54572	96.46%
10:00 A.M	904	34	21.5839	1.2934	16.6743	0.5669	36.8507	20.8919	21.10082	96.79%
10:30 A.M	959	35	22.777	1.3756	16.5511	0.5832	37.9106	22.1109	22.33201	97.07%
11:00 A.M	998	36	23.5838	1.4334	16.448	0.5941	38.6195	22.9456	23.17506	97.29%
11:30 P.M	1022	37	24.0345	1.4574	16.4735	0.6002	39.0169	23.420	23.6545	97.44%
12:00 Noon	1030	38	24.1149	1.4494	16.5721	0.6015	39.1006	23.520	23.75611	97.53%
12:30 P.M	1022	40	23.7298	1.4274	16.5195	0.5969	38.003	23.609	23.84509	97.60%
01:00 P.M	998	40	23.1891	1.5045	16.1351	0.5899	38.3484	22.6246	22.85085	97.56%
01:30 P.M	959	41	22.2129	1.4362	15.3053	0.5772	37.5198	21.6575	21.87407	97.49%
02:00 P.M	904	42	20.8819	1.3224	15.7843	0.5593	36.3589	20.338	20.54138	97.39%
02:30 P.M	836	43	19.264	1.2558	15.1946	0.5367	34.8876	18.7253	18.91255	97.20%
03:00 P.M	755	44	17.3591	1.1285	15.3111	0.5587	33.0706	16.8256	16.99386	96.92%
03:30 P.M	663	45	15.2127	0.994	15.2433	0.4752	30.8918	14.6816	14.82842	96.50%
04:00 P.M	561	45	12.898	0.7723	16.3544	0.4366	28.3812	12.3922	12.51612	96.07%
04:30 P.M	452	46	10.377	0.6189	16.2859	0.3895	25.3192	9.8625	10.15838	95.04%
05:00 P.M	337	44	7.8088	0.5123	15.2319	0.3367	21.89	7.3718	7.592954	94.40%
05:30 P.M	219	43	5.1201	0.3316	15.4072	0.2696	17.5291	4.7272	4.869016	92.32%
06:00 P.M	104	42	2.5183	0.1834	12.6247	0.1834	11.9247	2.1876	2.362608	86.86%
06:30 P.M	12	36	0.4346	0.0353	2.9967	0.0353	2.2967	0.0811	0.087588	18.66%

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

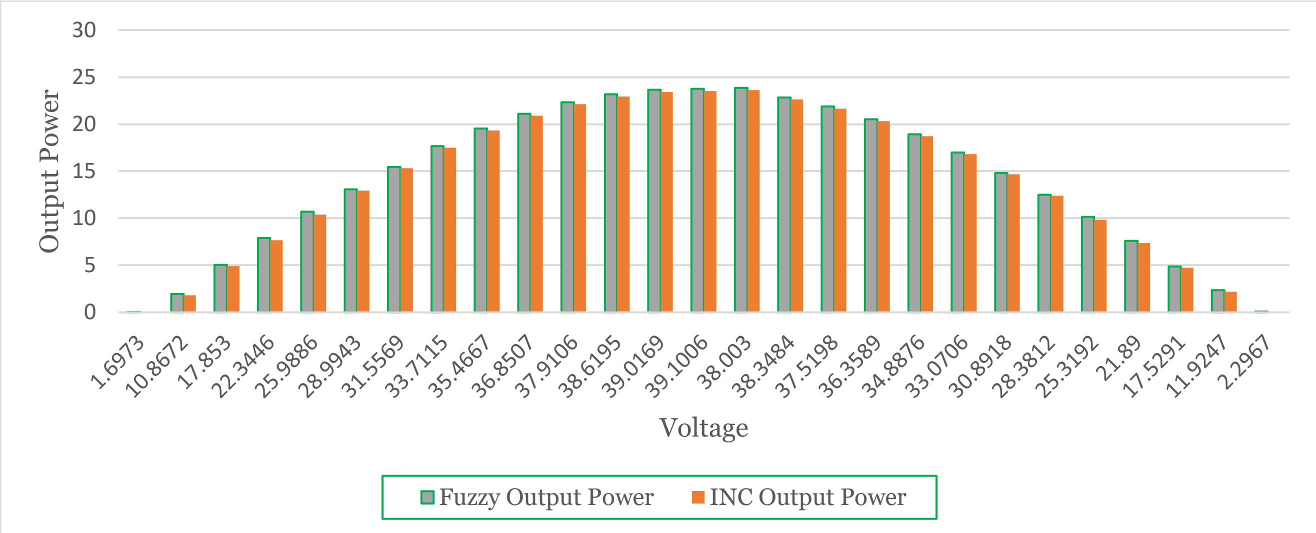

Fig. 1.12 Output Power V/S Output Solar Panel Voltage with Incremental & Conductance and Fuzzy Logic

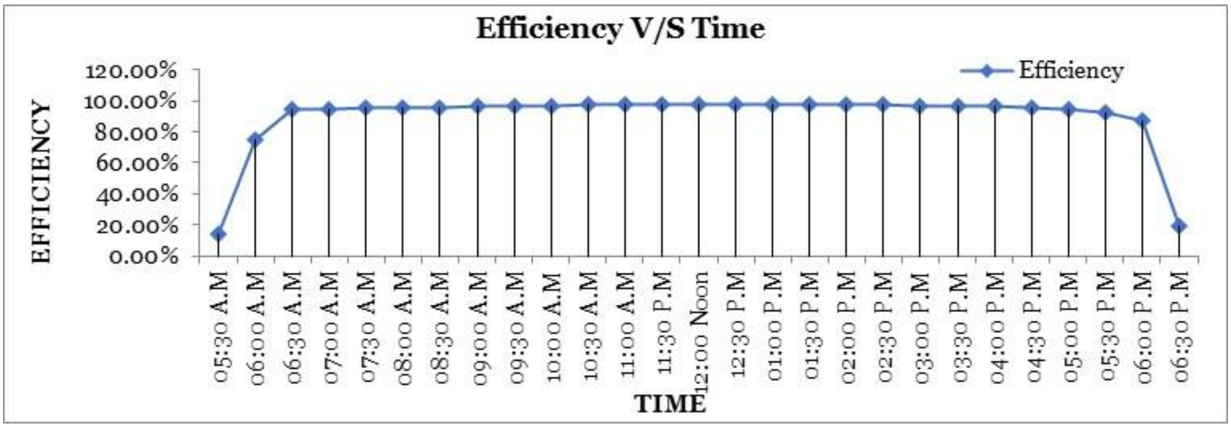

Fig. 1.13 Efficiency v/s Time

HARDWARE IMPLEMENTATION

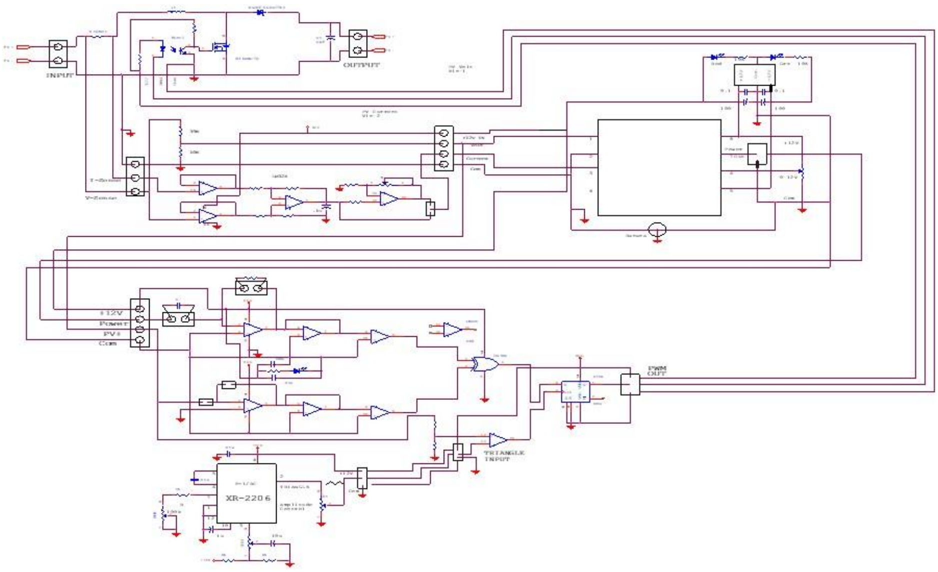

Fig. 1.14 Circuit Diagram for hardware implementation

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

The hardware consist of following components:

i) Voltage & Current Sensing Circuit (LM 324)
ii) Analog Multiyear AD 633
iii) Analog Circuit of MPPT
iv) Pulse Generation circuit (XR 2206)

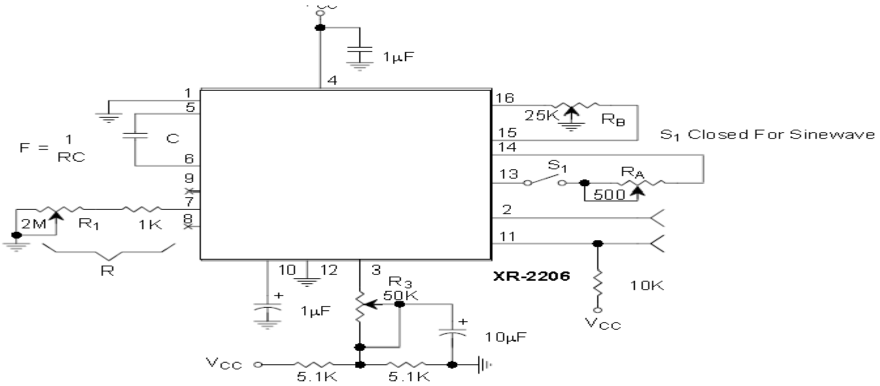

Fig. 1.15 Pulse Generation circuit (XR 2206)

18 V DC given to the Boost converter. A resistor is added in series with the boost inductor to sense the current & voltage. Then differential voltage and current input are converted to power through AD 633 converter. Then power & voltage will get through differentiator to analog circuit of MPPT and after that comparator will compare the condition & Boolean expression use to execute by XOR gate. XR 2206 is use to generate the triangle wave. Now comparator will compare triangular wave and dc signal to generate the clock pulse. Now this clock pulse and XOR gate pulse is given to D flip- flop. D flip-flop will generate pulses to make switch ON/OFF. Due to that duty cycle will very and maximum power track every time. Hence maximum efficiency is achieved.

RESULTS AND DISCUSSION

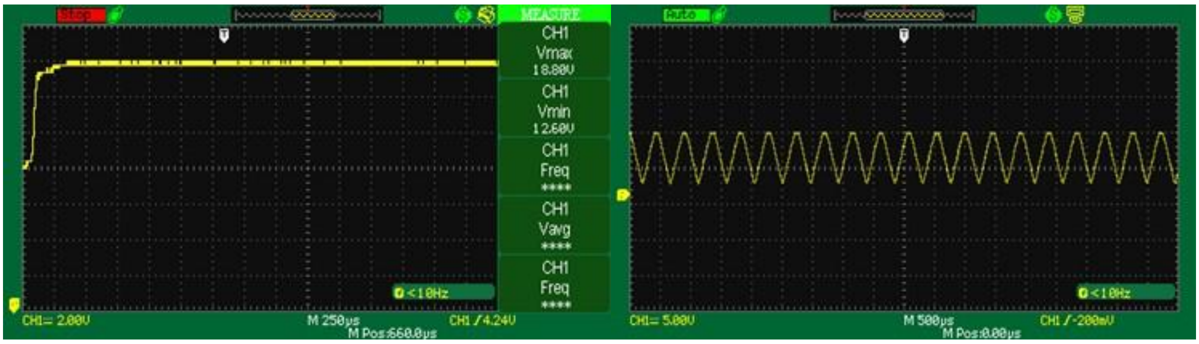

Fig.1.16 Input Voltage of Hardware Analog MPPT Algorithm & triangular wave of XR 2206

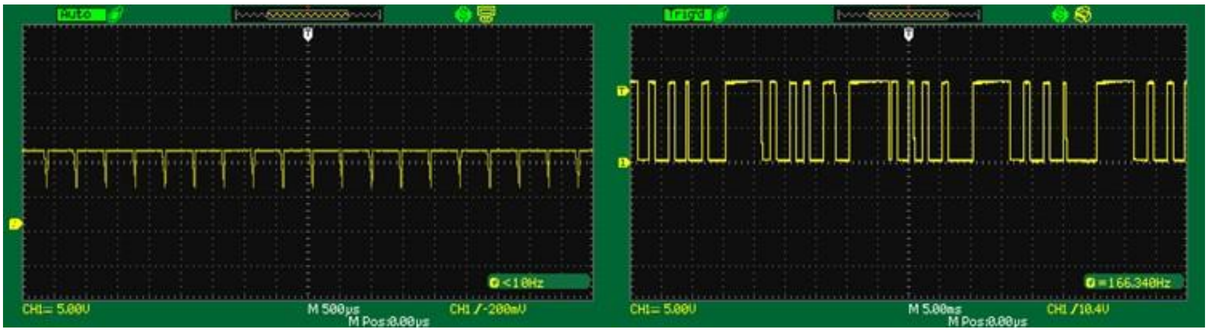

Fig.1.17 Clock pulse and Gate pulse

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

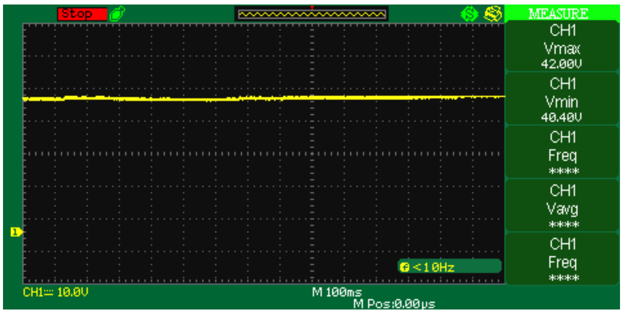

Fig.1.18 Output voltage

CONCLUSION

This paper addresses the efficiency challenges in solar photovoltaic systems by implementing advanced Maximum Power Point Tracking (MPPT) techniques. MPPT improves energy conversion efficiency, maximizes power extraction, and enhances the reliability of the system. A comparative simulation was conducted using the PSIM power electronics simulator to evaluate two MPPT algorithms: Incremental Conductance (INC) and Fuzzy Logic Control. The results demonstrate that both methods significantly improve tracking performance, with Fuzzy Logic offering faster dynamic response and better handling of rapidly changing environmental conditions. Based on these results, the hardware implementation was carried out using the Incremental Conductance algorithm. As the complexity of the analog control circuit increases, careful selection of hardware components becomes essential to ensure accurate real-time operation. The hardware performance closely matches the simulation results, validating the effectiveness and practicality of the implemented MPPT strategy.

REFRENCES

[01] Eftichios Koutroulis, Kostas Kalaitzakis, Member, IEEE, and Nicholas C. Voulgaris "Development of a Microcontroller-Based Photovoltaic Maximum Power Point Tracking Control System" IEEE Transactions On Power Electronics, Vol. 16, No. 1, January 2001.

[02] Trishan Esram, Student Member, IEEE, and Patrick L. Chapman, Senior Member, IEEE "Comparison of Photovoltaic Array Maximum Power Point Tracking Techniques" IEEE Transactions On Energy Conversion, Vol. 22, No. 2, June 2007

[03] Ashish Kumar Singhal, "PSIM and MATLAB based simulation of PV array for enhance the performance by using MPPT algorithm" Elec. Engg. 37 (2011) 3703-3706 international journal

[04] D. P. Hohm and M. E. Ropp "Comparative Study of Maximum Power Point Tracking Algorithms" Progress In Photovoltaics: Research And Applications Prog. Photovolt: Res. Appl. 2003; 11:47–62, Published online 22 November 2002

[05] Yi-Hua Liu, Zong-Zhen Yang, Shun-Chung Wang, Jia-Wei Huang "A Novel Analog MPPT Technique for Low Power Photovoltaic Systems" 978-1-4577-0255-6/11/$26.00 ©2011 IEEE

[06] Roger Gules, Juliano De Pellegrin Pacheco, Hélio Leães Hey, *Member, IEEE*, and Johninson Imhoff "A Maximum Power Point Tracking System with Parallel Connection for PV Stand-Alone Applications" IEEE Transactions On Industrial Electronics, Vol. 55, No. 7, July 2008

[07] Usha Bajpai and Kalpana Singh "Estimation of instant solar radiation by using of instant temperature" Renewable Energy Research Laboratory, Department of Physics, University of Lucknow, Lucknow 226 007, India

[08] Yan Hong Lim and D.C. Hamill "Simple maximum power point tracker for photovoltaic arrays" Electronics 25th May 2000 Vol. 36 No. 11

[09] G.El-Saady, El-NobiA.Ibrahim, Mohamed EL-Hendawi "Simulated Annealing Modeling and Analog MPPT Simulation for Standalone Photovoltaic Arrays" International Journal on Power Engineering and Energy (IJPEEISSN Print (2314 – 7318) January 2011

[10] Mousumi Biswal, Sidharth Sabyasachi "A Study on Recent DC-DC Converters" Mousumi Biswal, Sidharth Sabyasachi / International Journal of Engineering Research andApplications (IJERA) Vol. 2, Issue 6, November- December 2012, pp.657-663

Journal of Information Systems Engineering and Management
2024, 9(4s)
e-ISSN: 2468-4376
https://www.jisem-journal.com/

Research Article

[11] Hairul Nissah Zainudin, Saad Mekhilef "Comparison Study of Maximum Power Point Tracker Techniques for PV Systems" Proceedings of the 14th International Middle East Power Systems Conference (MEPCON'10), Cairo University, Egypt, December 19-21, 2010, Paper ID 278

[12] Gazi Mohammad Sharif, S. M. Mohaiminul Islam, Khosru Mohammad Salim "Design & Construction of Microcontroller Based Maximum power point PWM Charge Controller for Photovoltaic Application"

[13] Nand Kishor, Member, IEEE, Marcelo Gradella Villalva, Soumya Ranjan Mohanty, Member, IEEE,"Modeling of PV Module with Consideration of Environmental Factors" Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES

[14] Mukund R Patel "Wind and Solar Power System Design, Analysis And Operation"2ndedition Taylor & Francis Group 2006, NewYourk.

[15] Chetan Singh Solanki "Solar Photovoltaic – Fundamental, Technology and Application" – second edition, PHI Learning Private Limited

[16] Sandra Upson, "How Free is Solar Energy," IEEE spectrum, pp. 56-57, Feb.2008.

[17] T. A. Rangamani, "Approach for Feed-in Tariffs for Boost in Solar Photovoltaic Power Systems in India," Research and Development, INDIA POWER, Oct.-Dec. 2007.

[18] Oliva Mah NSPRI, "Fundamentals of Photovoltaic Materials", National Solar power institute, Inc. 12/21/98.).

[19] F. D. Kanellos, A. I. Tsouchnikas, and N. D. Hatziargyriou, "Microgrid Simulation during Grid-Connected and Islanded Mode of Operation," in Int. Conf. Power Systems Transients (IPST'05), June. 2005.

[20] Xiong Liu, Peng Wang, and Poh Chiang Loh, "A Hybrid AC/DC Microgrid and Its Coordination Control," IEEE Trans. Smart Grid, vol. 2, no. 2, pp. 278-286 June. 2011.

[21] Pratapsinh G. Parmar Manish S Patel,Urvashi D. Patel; "Closed Loop Control of Bi-directional DC-DC Converter" Vol-4,issue-2, 2016.

[22] Singh, Jaswant, Singh, S. P., Verma, K. S. and Kumar, Bhavnesh;, "Comparative Analysis of MPPT Control Techniques to Enhance Solar Energy Utilization and Convergence Time Under Varying Meteorological Conditions and Loads" Volume 10 – 2022.