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Analysis of Grid-Connected Solar PV Systems Using Perturb & Observe Based MPPT

Tripathi Hemlata Mani Rampravesh[1], Dr Shweta Chourasia[2]

[1]Research Scholar, Electrical & Electronics Engineering Department, BITS, Bhopal

[2]Professor, Electrical & Electronics Engineering Department, BITS, Bhopal,

Abstract: *The development of any village, city, or country in the modern era depends significantly on electrical energy. While fossil fuels have been a primary energy source, they contribute heavily to pollution, suffer from efficiency losses, and are limited in availability. Renewable energy sources such as solar, wind, and hydro offer a cleaner, sustainable, and inexhaustible alternative. This study models a Solar Photovoltaic (PV) system and employs the Perturb and Observe (P&O) Maximum Power Point Tracking (MPPT) technique to ensure consistent energy output. The system's performance is evaluated under varying solar irradiance and load conditions, demonstrating its ability to provide stable energy for diverse applications. This work underscores the importance of MPPT in optimizing solar energy systems for sustainable energy solutions.*

Index Terms *- Solar PV, MPPT, Insolation, Insolation, Perturb and Observation*

1. *INTRODUCTION*

The growing demand for affordable energy, combined with increasing environmental concerns, has driven the shift towards renewable energy sources such as solar energy. Issues such as health hazards, acid rain, and global warming caused by conventional energy sources have further highlighted the need for sustainable alternatives. Solar energy, being abundant, inexhaustible, and freely available, offers a promising solution. It can be efficiently converted into electrical energy through photovoltaic (PV) systems, which are widely regarded for their benefits. These systems have low maintenance costs, involve no moving parts, and provide a clean, pollution-free method of energy generation. Despite its advantages, PV technology comes with certain limitations. Solar energy cannot be harnessed effectively at night, under low irradiance conditions, or during partial shading, which can significantly reduce its performance. Additionally, the high initial capital cost of installing PV systems remains a major obstacle for widespread adoption. However, thanks to technological advancements and supportive government policies in many countries, PV systems have become increasingly popular as a sustainable alternative to conventional energy sources[1-2].

One of the main challenges with PV systems arises from their nonlinear current-voltage (I–V) and power-voltage (P–V) characteristics, which vary significantly based on changing environmental conditions. Parameters such as solar irradiance, temperature, and shading have a direct impact on the system's performance. These factors are not static; they fluctuate frequently and rapidly, causing continuous shifts in the Maximum Power Point (MPP) of the PV system. Operating the PV system at its MPP is essential to maximize power output and improve overall efficiency[3]. While the energy conversion efficiency of PV systems remains relatively low and the initial costs are high, maintaining operation at the MPP ensures optimal energy generation. This emphasizes the importance of employing advanced Maximum Power Point Tracking (MPPT) techniques, which enable PV systems to dynamically adjust to varying conditions and sustain maximum power output. As a result, PV technology continues to emerge as a viable and environmentally friendly energy solution, helping to address global energy challenges while contributing to sustainable development [4-5].

2. *MAXIMUM POWER POINT TRACKER*

Solar radiation can be directly converted into electrical energy using photovoltaic (PV) cells, offering several advantages over conventional energy sources. PV modules are known for their unique nonlinear characteristics, as revealed through their power-voltage (P–V) relationship. This relationship indicates that the module delivers maximum power at a specific point, referred to as the Maximum Power Point (Pmax).The location of this Maximum Power Point depends on factors such as load variations and environmental conditions. By operating the PV system at this point, the highest possible power output is achieved, ensuring optimal energy transfer efficiency. This makes the study and analysis of the P–V characteristics crucial for improving the performance and efficiency of PV systems in diverse applications[5-7].

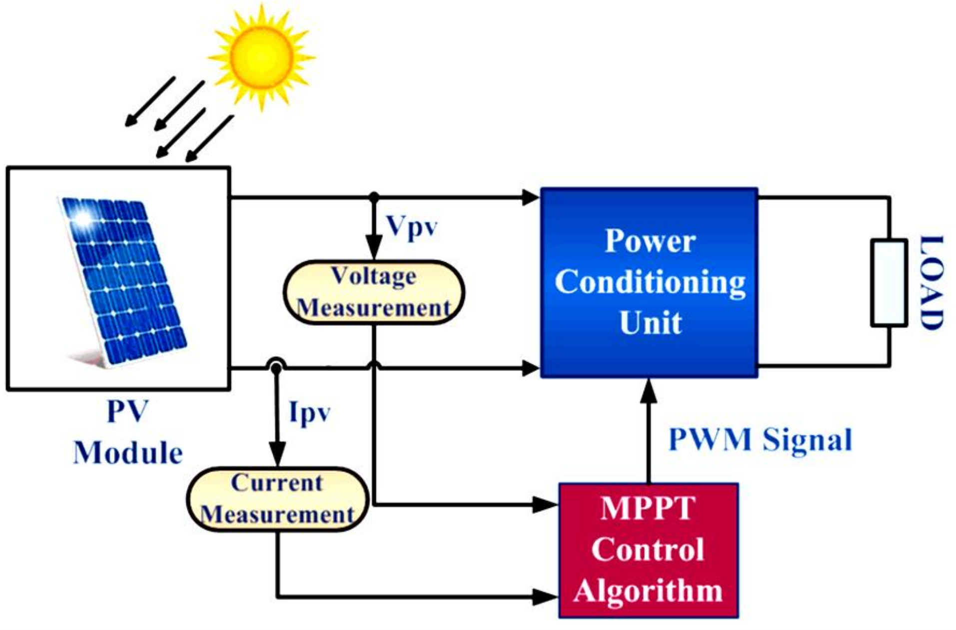


Fig 1: Maximum power point tracker system

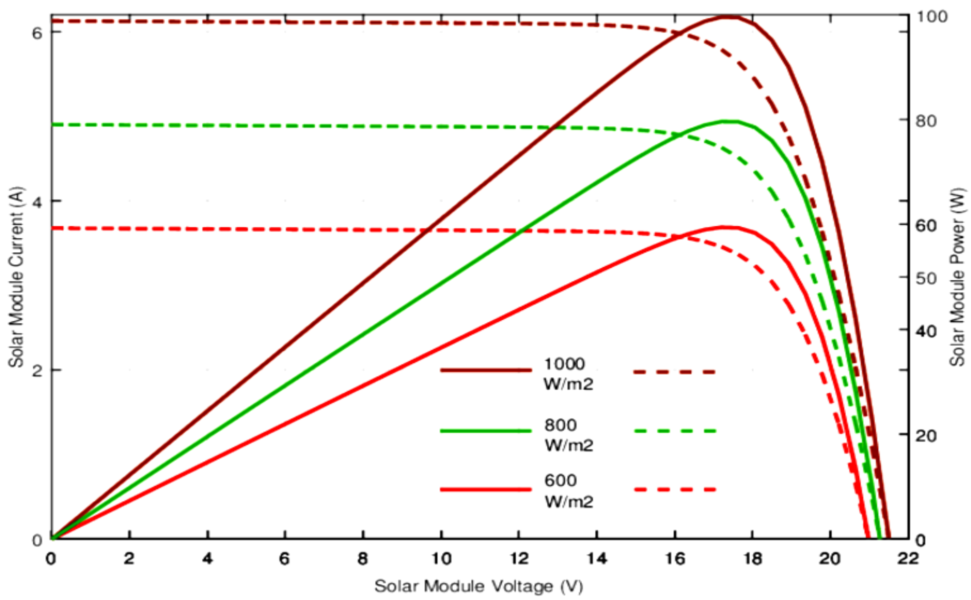
Tracking the Maximum Power Point (MPP) of a solar PV array is a critical aspect of ensuring the efficient performance of PV systems. MPP tracking is achieved through a range of algorithms designed to maximize the power output of the PV array by dynamically adjusting its operating point. Commonly used algorithms include the Constant Voltage Method, Hill Climbing, Constant Current Method, Incremental Conductance (INC), and Perturb and Observe (P&O). Among these, Incremental Conductance and P&O are particularly notable for their effectiveness and widespread application. These algorithms work by regulating the PV array's voltage to maintain an optimal operating point under varying environmental conditions, such as changes in solar irradiance and temperature. Each algorithm differs in complexity, sensor requirements, response speed, cost, implementation, and efficiency range. These variations influence their suitability for different applications and environments. Due to their relative simplicity and effectiveness, P&O and Incremental Conductance are considered superior options for achieving MPP tracking.

In this paper, a solar PV system is modeled using the Perturb and Observe (P&O) MPPT technique to ensure a consistent and stable power output. This approach allows the harnessing of solar energy for various applications, even under fluctuating solar irradiance and load conditions. The performance of the proposed system is evaluated to determine its efficiency and reliability. The study is designed to identify the most suitable MPPT method by analyzing the system's response to dynamic conditions. The findings aim to optimize the MPPT algorithm, ensuring maximum power extraction and improved overall performance of solar PV systems. By addressing these considerations, the paper contributes to the development of more efficient and adaptable solar energy solutions.

3. *REQUIREMENT OF MPPT*

The nature of MPPT is mostly influenced by three factors of environmental changes. The quality of each cells of solar are chiefly influenced by –a)Insolation b)Temperature c) Partial criteria of shading.

Their impacts like that of an environmental affects various factor which are shown under:



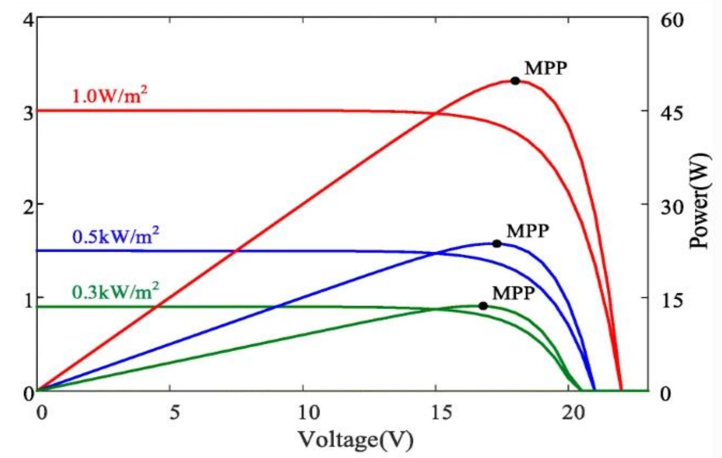


Fig 3: Solar I–V and P–V curve (a) with different insolation and (b) MPP for different Insolation

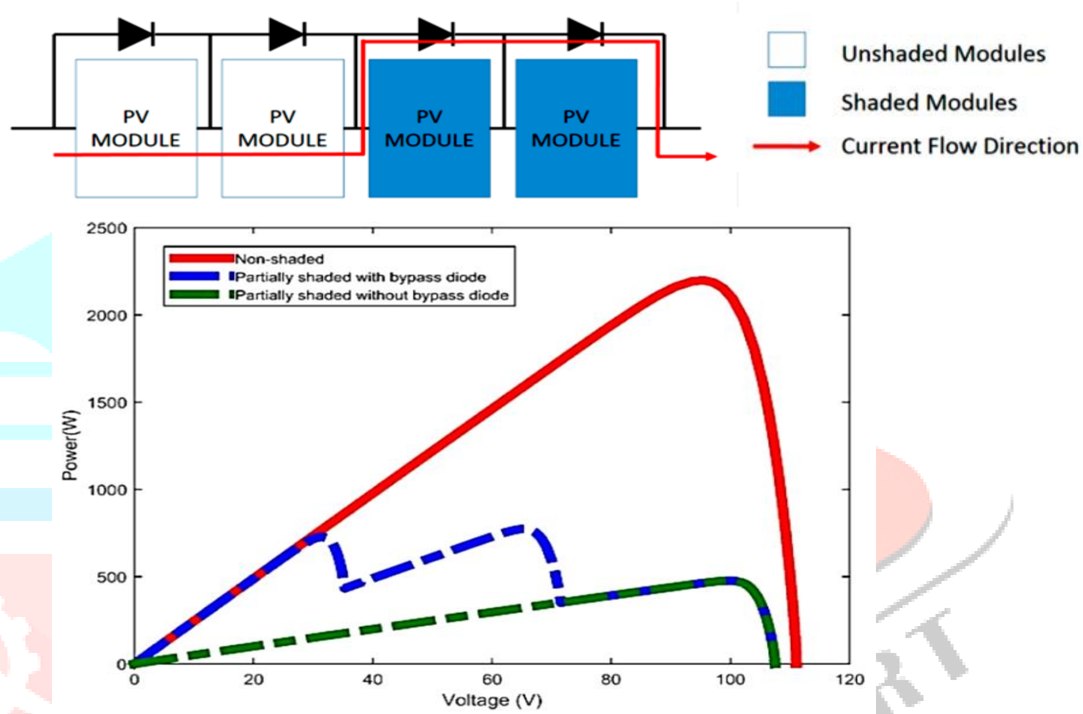


Fig 4(c) Operation of solar P-V under partial shading condition, (d) P–V graph under same partial shading criteria

From fig 4(c) : Connected solar cell with its terminal. It is seen that all these time variant and environmental dependent factors shows a major contribution in the adjustments of the operation point or highest or maximum power point tracker [MPP] throughout the whole day. Its behavior i.e. high power point tracker is there to make a shift in the continuously varying operating point [P max] here PV module delivers highest power.

Photons energy is defined on the wavelength and the frequency; also calculate it from the Einstein’s law, which is:

$$E = h\upsilon \qquad (1)$$

E - energy of photon

h -Plank’s constant = $6.626\times10^{-34}\ Js$

υ -Photon frequency

Photon frequency Released electrons obtained by such process of a photo electric effect is known as photo electron. The amount of energy required for the releasing the valence electron, from the atom on which photon are collided is known a work out Wi and it defines on the kind of material on which all such process of “photo electric effect”, is being done. The process is as follow:

$$hv = W_i + E_{kin} \qquad (2)$$

Where,

hv - Photon energy

Wi, - work out

Ekin - kinetic energy of emitted

4. CHARACTERISTIC OF PHOTO-VOLTAIC CELL

Photovoltaic (PV) generators do not function as fixed current or voltage sources. Instead, they are best approximated as current sources with dependent voltage characteristics. This unique behavior is a result of the photovoltaic cell's semiconductor properties and its interaction with light. Under conditions of darkness, the solar cell becomes inactive, producing neither current nor voltage. Essentially, the solar cell requires exposure to light to become operational. At the core of a solar cell's operation is a **PN-junction semiconductor**. When exposed to light, photons are absorbed by the semiconductor material, exciting electrons and generating a flow of direct current (DC). This phenomenon, known as the photovoltaic effect, underpins the operation of solar cells. The amount of current generated is directly proportional to the level of solar irradiance—the intensity of sunlight falling on the surface of the solar cell. As irradiance increases, the current output of the solar cell also increases in a linear manner, making it essential to optimize the exposure to sunlight for maximum efficiency.

The equivalent electrical circuit of an ideal solar cell can be modeled using a current source in parallel with a diode and additional series and shunt resistances to account for real-world inefficiencies. **Figure 5** illustrates the equivalent circuit of a solar cell, showing how the generated current flows through the circuit. In this model:

- **The current source** represents the photo-generated current, which varies with sunlight intensity.
- **The diode** represents the pn-junction's characteristic behavior, where it allows current flow under certain conditions and blocks it under others.
- **Series resistance (Rs)** models the internal resistance due to the movement of charge carriers through the semiconductor material and the connections within the cell.
- **Shunt resistance (Rsh)** accounts for leakage currents within the cell.

This idealized model helps in understanding the fundamental operation of solar cells and forms the basis for designing and optimizing photovoltaic systems. However, real-world solar cells often deviate from this ideal behavior due to imperfections in materials and environmental factors. The performance of the solar cell is also influenced by temperature and load conditions. For instance, higher temperatures can reduce the open-circuit voltage of the cell, impacting its efficiency. Therefore, comprehensive analysis and modeling are crucial for designing systems that maximize power output under varying conditions. This equivalent circuit provides engineers and researchers with a powerful tool to simulate and analyze solar cell performance, enabling the development of innovative techniques to improve efficiency and reliability in photovoltaic systems.

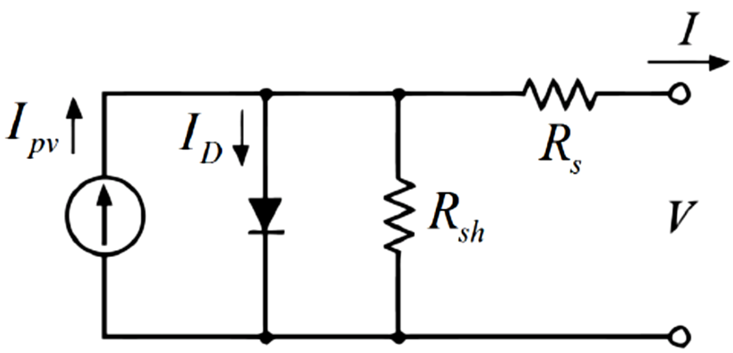


Fig. 5. Equivalent circuit of a solar cell

Applying Kirchhoff's law to the node where I_{ph}, diode, R_P and R_s meet, we get

$$I = I_{ph} - I_s\left(exp^{\frac{q(V+IRs)}{NKT}-1}\right) - (V + IR_s)/R_{sh} \quad (3)$$

$$I = n_p I_{ph} - n_p I_s \left(exp^{\frac{q(V+IRs)}{(NKT)n_s}} - 1 \right) \quad (4)$$

$$I_d = I_s \left(exp^{\frac{q(V+IRs)}{NKT}} - 1 \right) \quad (5)$$

R_S = intrinsic sequence resistance, value is highly small.

$R_{p=}$ shunt resistance which has a highly high value.

Applying KCL in fig at node where I_{ph}, diode, R_p & R_s we get We obtain the given equation for the photo-voltaic I

Where, I_{ph} = Insulation I,

I = Cell I,

Io = Reverse saturation I,

V = Cell voltage,

Rs = Sequence resistance,

R_p = Parallel resistance,

V_t is the Thermal voltage

[KT/q] K =Boltzmann constant,

T = Temperature in Kelvin,

q = Charge of an electron.

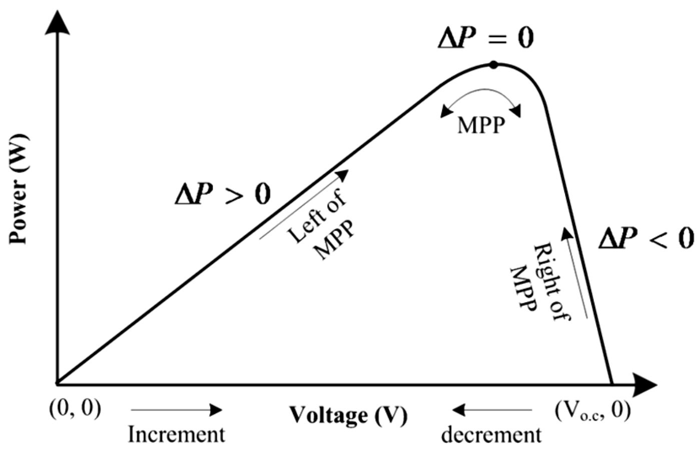
5. *Perturb & Observe [P&O] Algorithm*

Solar cell power module changes continuously, in case of power increment, the perturbation will be continued in (same) as previous direction.

TABLE 1: FOR PERTURB & OBSERVATION METHOD

Sign of dv	Sign of dp	Direction of next step.
Positive	Positive	+C
Negative	Negative	+C
Negative	Positive	-C
Positive	Negative	-C

The power will then at next step will decrease as soon as maximum power is attained, and after this perturbation will reverse. The algorithm starts oscillating around its highest point as soon as the steady value is reached. Size of perturbation is kept very small, thus power variation small. Even then this algorithm is important in mega service as it is simple. The algorithm can be understood from study of flow chart, which is shown below:



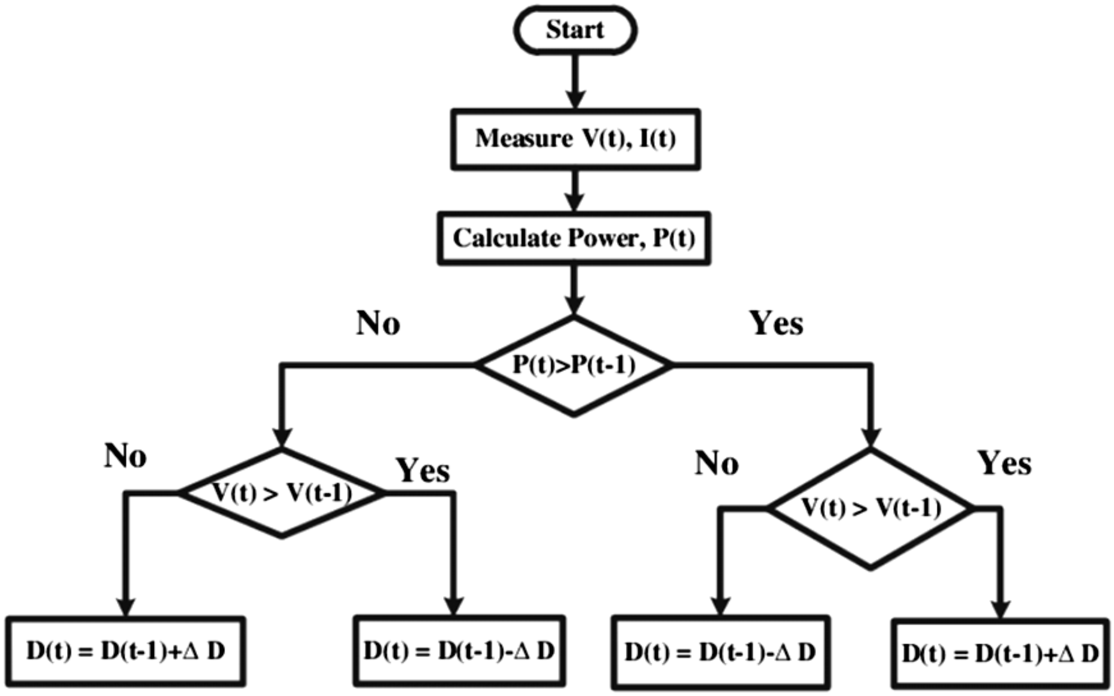


Fig 5 : Flow chart of Perturbation and observation

6. Incremental Conductance (IC)

The Incremental Conductance (Inc) algorithm addresses some of the limitations inherent in the Perturb and Observe (P&O) method, particularly when tracking the maximum power point (MPP) under rapidly fluctuating environmental conditions. This method offers a more accurate and reliable approach to achieving MPP, especially in scenarios where irradiance levels change quickly. Unlike the P&O method, which perturbs the operating point of the photovoltaic (PV) system continuously and may oscillate around the MPP, the Incremental Conductance algorithm calculates the MPP directly by analyzing the slope of the power-voltage (P-V) curve. The algorithm determines whether the system has reached the MPP by using the relationship between the derivative of current (dI/dV) and the negative value of the current-to-voltage ratio (−I/V).

The algorithm is based on the principle that the slope of the P-V curve (dP/dV) provides critical information about the location of the MPP:

- **If dP/dV > 0**: The operating point is on the left side of the MPP, and the system needs to increase the voltage to move closer to the MPP.
- **If dP/dV < 0**: The operating point is on the right side of the MPP, and the system needs to decrease the voltage to move closer to the MPP.
- **If dP/dV = 0**: The system has reached the MPP, and no further adjustment is necessary.

Advantages of Incremental Conductance

1. **Reduced Oscillations**: Unlike P&O, which causes the operating point to oscillate around the MPP, the Incremental Conductance algorithm can precisely determine when the MPP is reached, thereby reducing power losses due to oscillation.
2. **Rapid Response to Irradiance Changes**: The Inc algorithm is capable of accurately tracking the MPP during rapid changes in solar irradiance, ensuring efficient power output under dynamic conditions.
3. **Higher Accuracy**: By using real-time voltage and current measurements to determine the MPP, the algorithm provides greater accuracy in tracking compared to P&O.

Disadvantages of Incremental Conductance

Despite its advantages, the Incremental Conductance algorithm has some drawbacks:

1. **Complexity**: The algorithm involves more complex calculations compared to P&O, requiring advanced hardware and higher computational resources for implementation.

2. **Hardware Requirements**: The need for precise real-time measurement of voltage and current adds to the cost and complexity of the system.
3. **Execution Time**: The algorithm's iterative calculations can lead to slower execution times under certain conditions, particularly in systems with limited processing capability.

The given algorithm is shown below by which an idea of its following procedure can easily obtain as shown in fig:

The InC depends on a particular condition that the given slope of a PV array power graph is is zero when its MPP, positive at its left of a MPP, & is negative on its right as given

ಜಿ/ಜತ ≥ 0	ಟಜಜಿಣ ಠಜಿ ಒಕಕ	(4)
ಜಿ/ಜತ ≤ 0	ಡುಝಿಣ ಠಜಿ ಒಕಕ	(5)
ಜಿ/ಜತ =0	ಚಿಣ ಒಕಕ	(6)
ಖುಟಿಛಿಜ,		
ಜಿ/ಜತ=ಜ(ುತ)/ಜತ	=ಐ +ಗಿಜು/ಜತ	(7)
ಜು/ಜತ≥–ು/ತ	ಟಜಜಿಣ ಠಜಿ ಒಕಕ	(8)
ಜು/ಜತ≤–ು/ತ	ಡುಝಿಣ ಠಜಿ ಒಕಕ	(9)
ಜು/ಜತ=0	ಚಿಣ ಒಕಕ	(10)

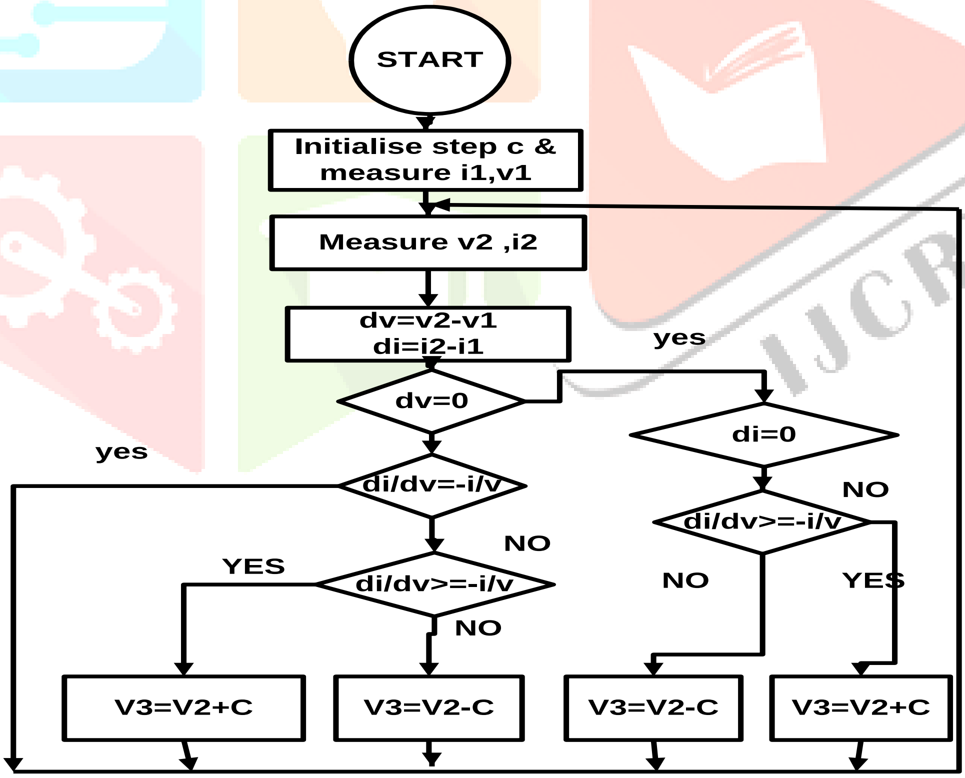


Fig: 6: Incremental conductance flow chart

7. SIMULATIONS AND RESULTS

The Photo voltaic array simulation model shown below in fig 7, Since the Irradiance effect is not constant all the time but do changes, therefore different Irradiance value is taken at 1000 W/m^2, 800 W/m^2, 600 W/m^2 and again at 1000 W/m^2 and the temperature constant is 25. The output obtained from Solar photo voltaic cell is fed into Inverter which then changes the Solar photo voltaic cell output voltage into suitable AC voltage and frequency. A 33/11 kV grid which is connected in parallel to the solar photo voltaic model, then 11 kV voltage is stepped down to suitable voltage i.e., 440 V. A load of 2 kV connected initially and an additional load of 6 kV is also connected by three phase circuit breakers.

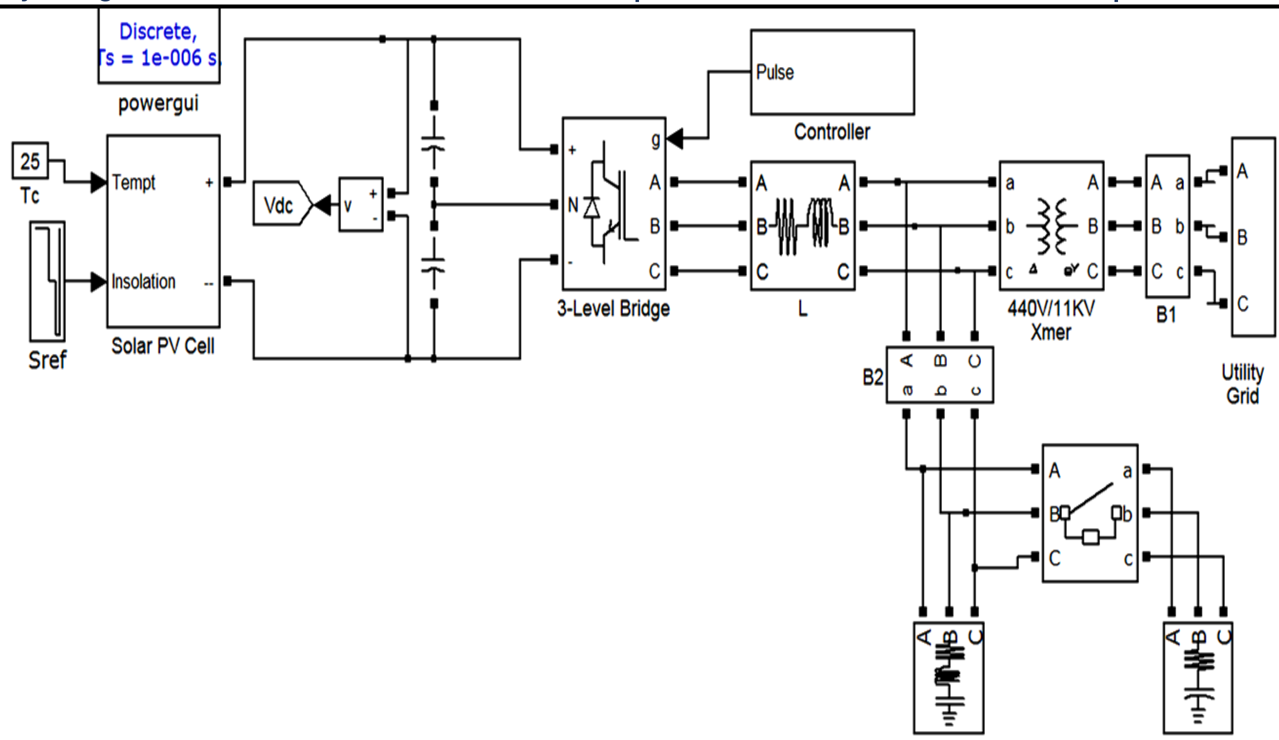


Fig 7 Simulink model of Grid connected Solar photo voltaic system

Below shown photo voltaic curve shows that, MPPT always tracks maximum current though the voltage varies. The maximum voltage i.e., V_{OC} = 44V. However, the current is maintained at its maximum value i.e., I_{SC} =6.2A

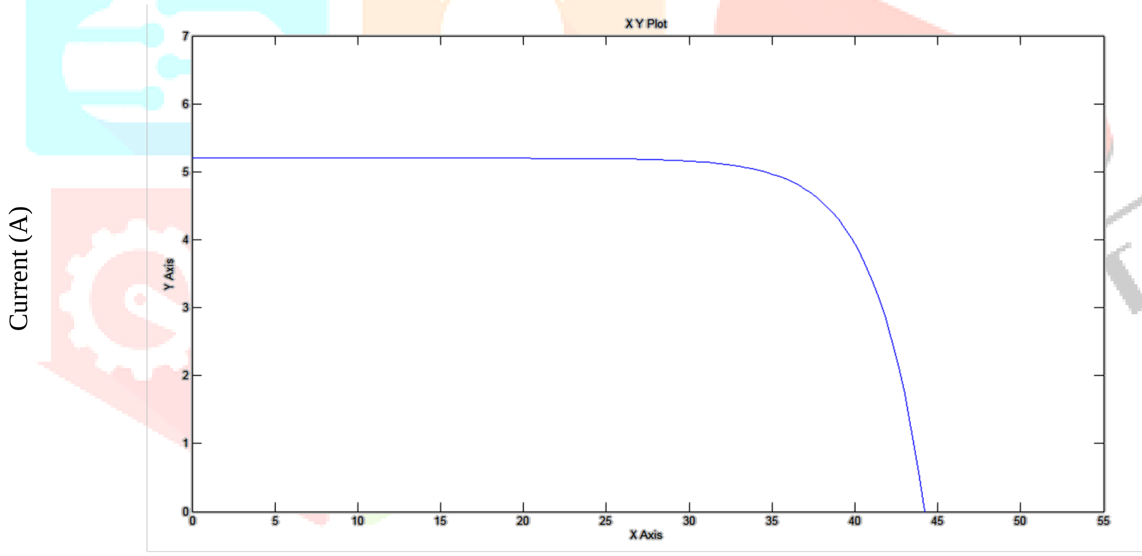


Fig 8: I-V curve

Below shown fig: 9; Current voltage curve sl[illegible]lways tracks maximum current though the voltage varies. The maximum voltage i.e., V_{OC} = 44V. However, the current is maintained at its maximum value i.e., I_{SC} =6.2A.

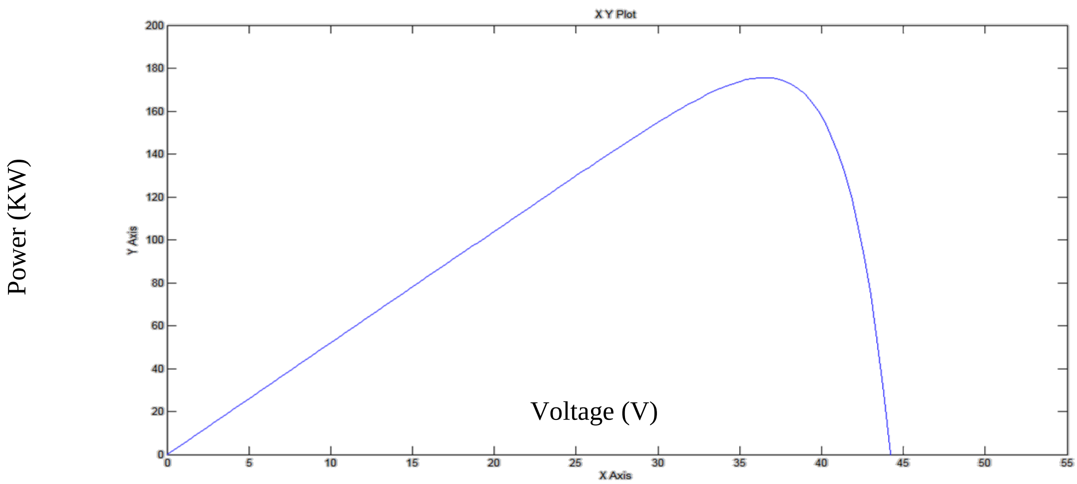


Fig 9: P-V curve

Above figures 9 shows that MPPT maintains maximum Power i.e. (Short circuit current) I_{SC}= 6.1A, and V_{OC} =44 V. And power obtained is 6.2 KW. Simulink model for Solar photo voltaic cell is shown in fig 10

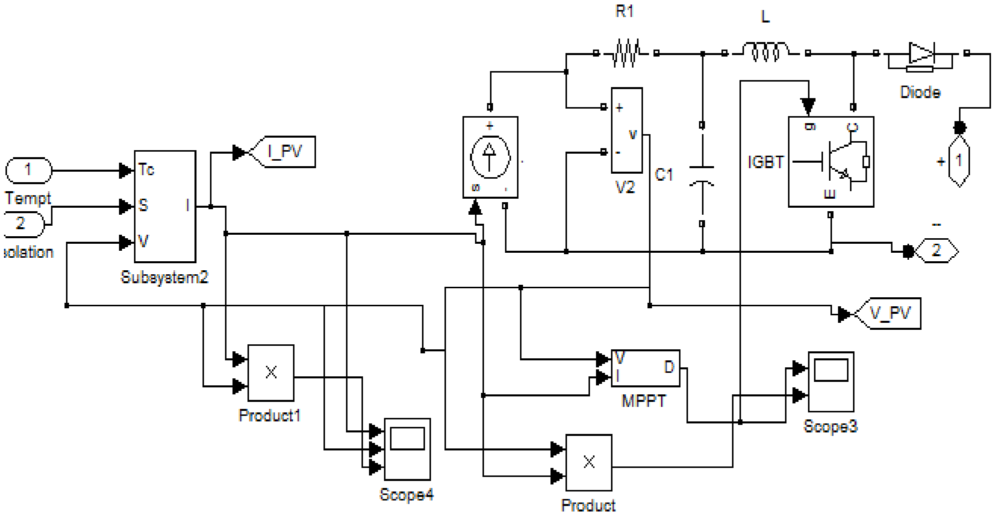


Fig 10: Simulink model for Solar photo voltaic cell

As explained above since the parameters do not remains constant but changes with time. And therefore, simulation results for perturb & observe method is shown below; When Irradiance = 1000 w/m^2, from 0 to1second photo voltaic voltage before MPPT is 40 V and after MPPT it variants about 660 V. As irradiance drops to 800 w/m2, (t)=1 to 1.6sec

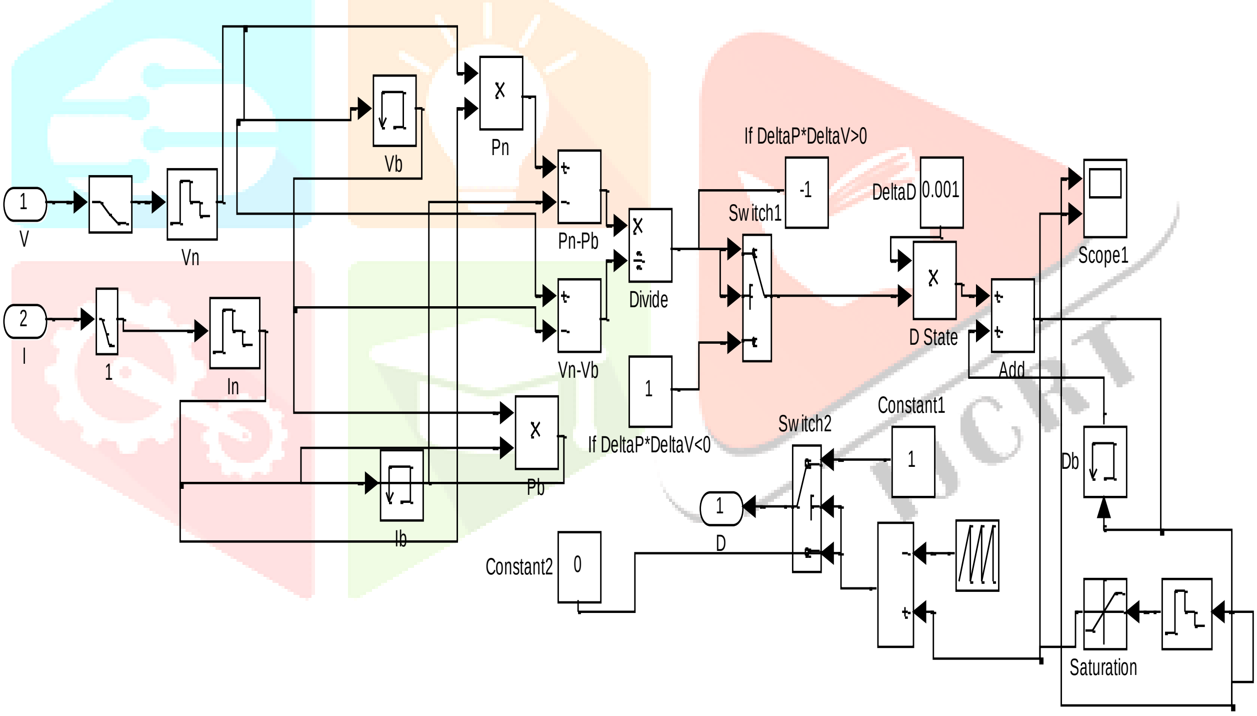


Fig 11: Simulink model for Perturb and observation

As explained above since the parameters do not remains constant but changes with time. AT irradiance of 1000 watt per meter square, voltage of solar pv cell =272V. as irradiance reduces to 800 watt per meter square, in parallel voltage also goes down to 250 V. Furthermore, when voltage is reduced again at 600 watt per meter square, of course the voltage also reduces to 190 V. Moreover, again if the irradiance value is increased to 1000 watt per meter square the value of voltage before MPPT is also increased to 272 V.

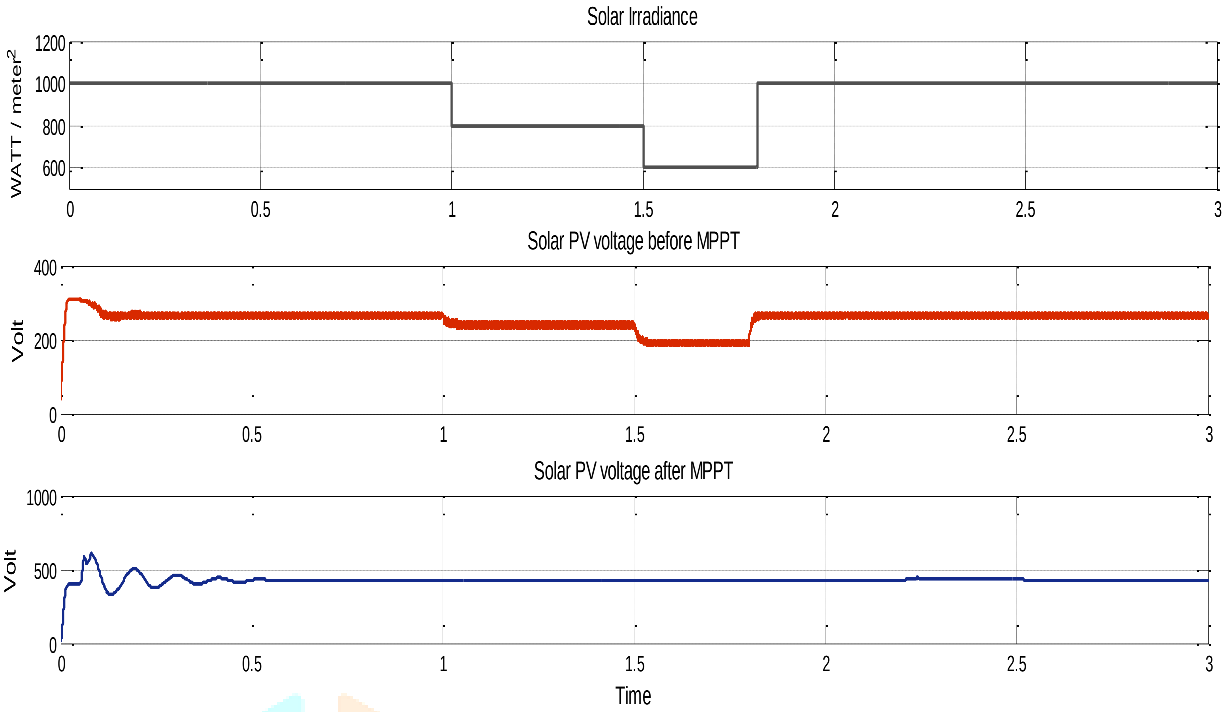


Fig 12: Effect of solar Irradinace on the photo voltaic cell voltage before and after MPPT

AT irradiance of 1000 watt per meter square, starting after some variation it is clearly seen that voltage is maintained almost constant, whatever may be the irradiance variation, i.e. at 1000,800,6000, watt per meter square there is no effect in voltage, but it is maintained constant at .volt..

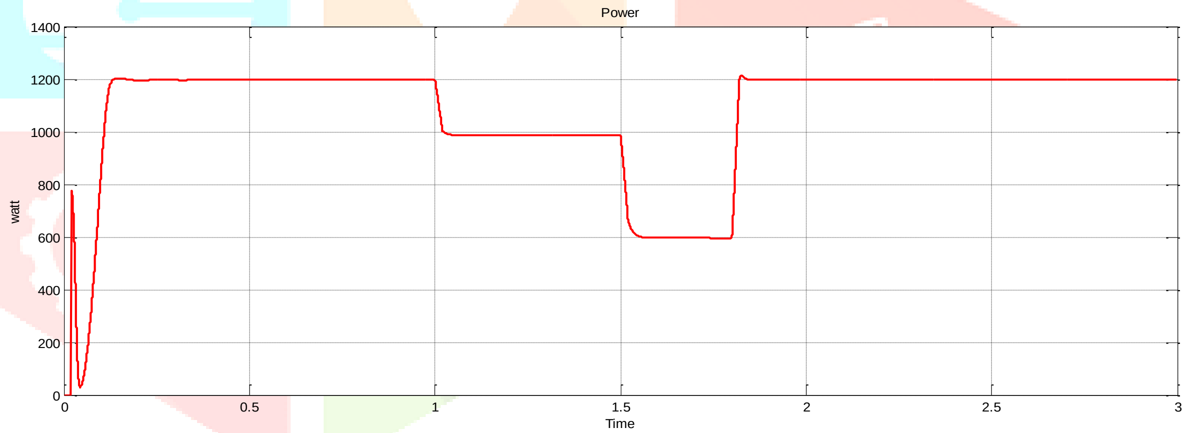


Fig 13 : Power obtained from photo voltaic cell

From fig:13 Since Irradiance is 1000 watt/meter square, so the power 1200 watt from 0 to 1second, as Irradiance value lowers at 800 watt/meter square, and so the power drops to 998 watt, from 1 to 1.6 second. Similarly, between 1.6 to 1.8 second power drops to 600 watts, since irradiance goes down to 600 watt per meter square. Now again as Irr increases &reaches 1000w/m^2 with times the power output also increases to 1200 watt. An Inverter is placed for changing the DC power obtained from solar photo voltaic cell into AC suitable power required by the load. The results of simulation model for inverter /output voltage are shown below in Fig. 14.

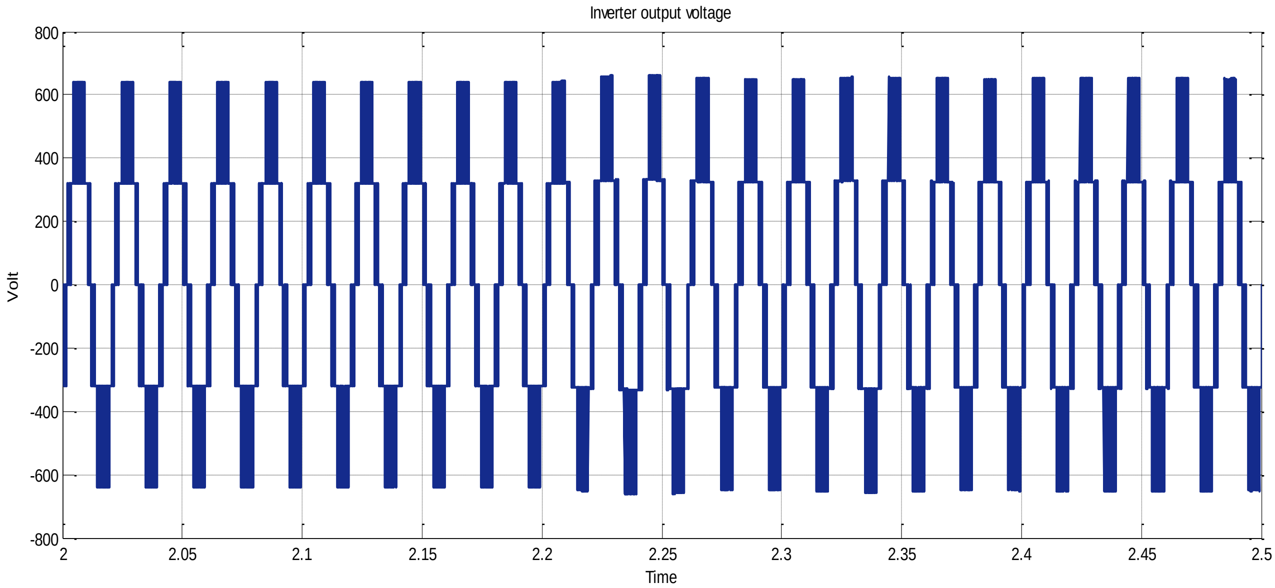


Fig 14: Inverter Voltage

Inverter Voltage DC voltage obtained from photo (voltaic cell MPPT) is changed into ac by three level multi-inverter which alternates Voltage, at frequency 60 Hz. Grid of 33 KV is interconnected to photo voltaic model which is stepped down 33/11 KV & further (11KV/440V) by the step-down transformer to meet the load requirement. The results of Grid are shown below in Fig. 15,where, per unit AC voltage variation of grid voltage (Phase to ground) is between 1 &-1. The AC current drawn by the load between 2 to 2.2 second is .5 ampere (constant), since initial connected load is of 2kw.When additional load of 5kw is switched ON via three phase circuit breaker at t=2.2 to 2.6second, so the current drawn by the load increases to .8 ampere.

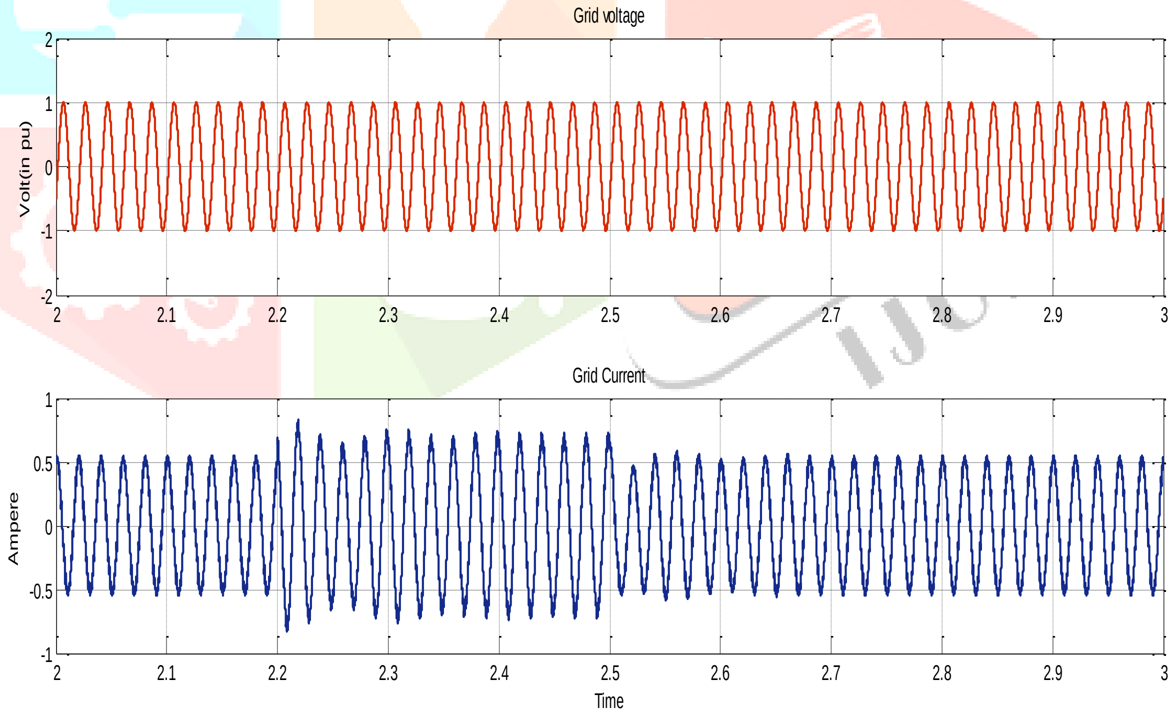


Fig 15: Grid voltage &current

Again after 2.6 second when the load is removed, current drawn is again 0.5 A. Thus, the voltage &the current waveform are unaffected. Three phases to ground voltage of 440 V is supplied to the initial connected load of 2 KW.

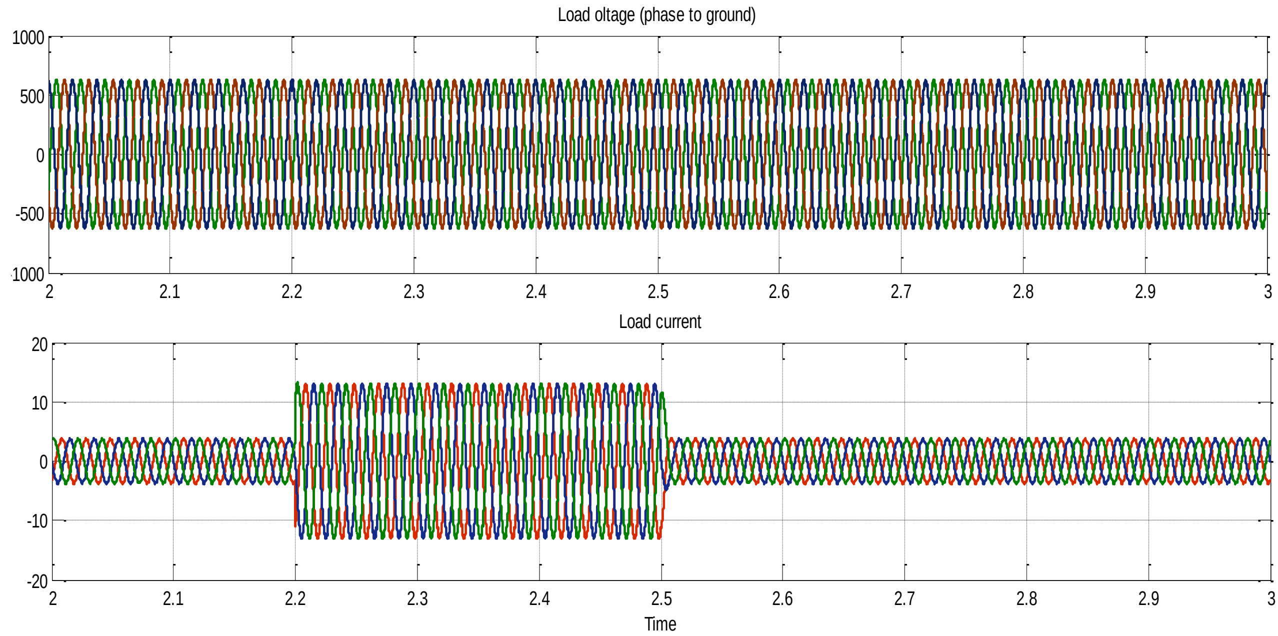


Fig 16: Load voltage &load current

The current drawn is 2 A at time t=2.2 sec, an additional load of 5 KW is switched ON with the help of circuit breaker, the load current increases to the value 10 A as shown in Fig. 16..

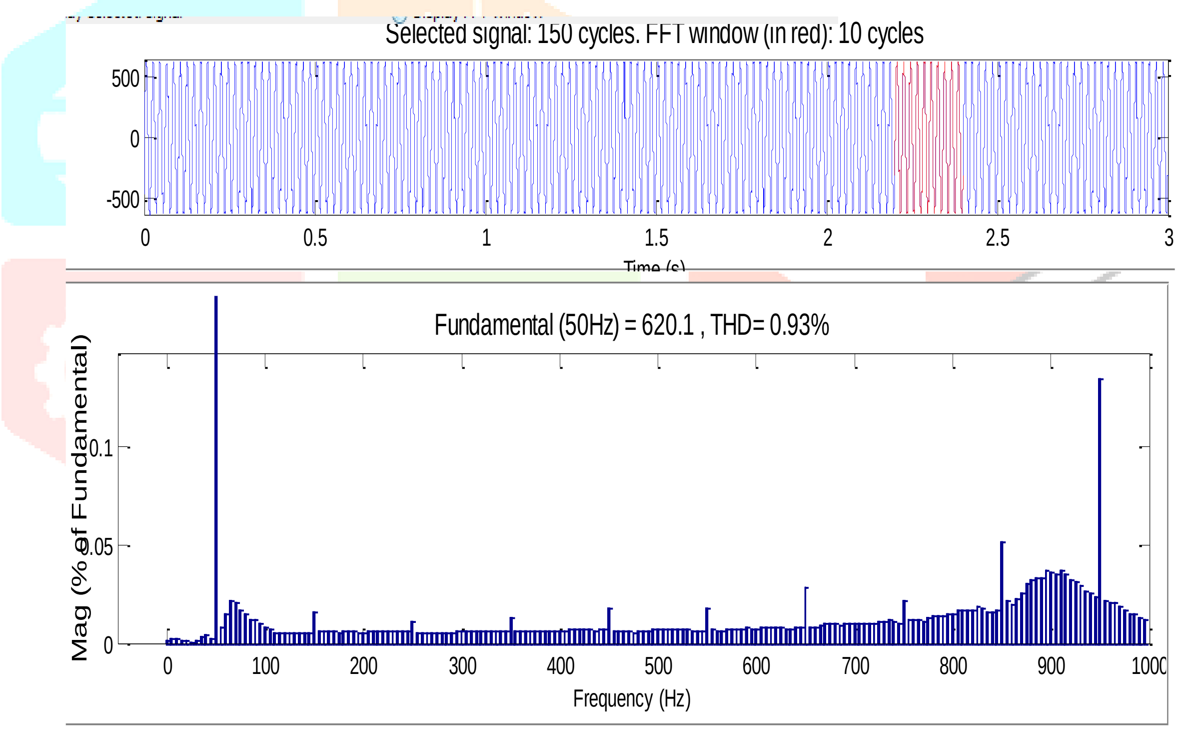


Fig 5.17: THD

Moreover, the THD is also under (IEEE -519-1992) standard is less than 5%. &At= 2.6second this load has been removed. It is observed that during input of this load the voltage &the current waveforms are unaffected. It's clear that THD obtained by P & O method is 0.93% . Thus, total harmonic distortion is reduced.

8. *CONCLUSION:*

The Perturb and Observe (P&O) MPPT algorithm is simulated under dynamic load conditions to assess its performance. Under constant or gradually changing environmental conditions, the P&O algorithm oscillates around the Maximum Power Point (MPP) and delivers satisfactory results. Additionally, even under rapidly fluctuating atmospheric conditions, the P&O algorithm demonstrates notable accuracy in tracking the MPP, making it a reliable choice for certain applications. A comprehensive analysis of the P&O algorithm is conducted across various performance parameters, including tracking efficiency, response time, stability, and adaptability to dynamic weather conditions. This evaluation sheds light on both the strengths and limitations of the P&O method, offering valuable insights into its effectiveness and suitability for different solar PV system applications.

REFERENCES

[1] Deepak Verma ,Savita Nema ,Shandhiya, Soubhaghya dash,'Maximum power point tracking(MPPT)techniques : Recaptulation of solar photovoltaic system. Jacob- James Nedumgat, Jayakrishna & K. B., Kothari D. .,"Perturb &Observe MPPT Algorithm of a Solar PV Systems-Modeling &Simulation'', IEEE conf. on Power electronics application in renewable energy,2013, pp. 1-6

[2] S.K. Kollimalla &M.K. Mishra, N.PGupta "Adaptive Perturb &Observe MPPT Algorithm for PV system", IEEE Conf. on Renewable energy, 2013, pp. 1-6

[3] Hiren Patel &Vivek Agarwal , ," Maximum Power Point Tracking Scheme for PV Systems Operating Under Partially Shaded Conditions", IEEE Transactions On Industrial Electronics, Vol. 55, No. 4, pp. 963-973,April 2008.

[4] M. A. Elgendy, B. Zahawi &D. J. Atkinson," Evaluation Of Perturb&Observe Mppt Algorithm Implementation Techniques" IEEE conf. on Renewable energy conversion,May2009,pp.P.73-79.

[5] R.K. Nema1, Savita Nema1, &Gayatri Agnihotri1," Computer Simulation Based Study of Photovoltaic Cells /Modules &their Experimental Verification" International Journal of Recent Trends in Engineering, Vol 1, No. 3, May 2009.

[6] Rajesh Kumar Nema, Savita Nema &Gayatri Agnihotri," Design, development &simulation of PC-based scheme for characterization of solar photovoltaic modules".

[7] Vikas Khare, Savita Nema, Prashant Baredar," Solar–wind hybrid renewable energy system: A review Renewable &Sustainable Energy Reviews 58(2016)23–33.

[8] Pratik U. Mankar1 and2R.M. Moharil," comparative analysis of thePerturb-and-observe &incremental Conductance mppt methods",International Journal of Research in Engineering &Applied Sciences

[9] William Christopher &Dr.R.Ramesh," Comparative Study of P&O &InC MPPT Algorithms", American Journal of Engineering Research (AJER) e-ISSN : 2320-0847 p-ISSN : 2320-0936 Volume-02, Issue-12, pp-402-408.

[10] Ms. Sangita S. Kondawar1, U. B. Vaidya," A Comparison of Two MPPT Techniques for PV System in Matlab Simulink", International Journal of Engineering Research andDevelopment e-ISSN : 2278-067X, p-ISSN : 2278- 800X, www.ijerd.com Volume 2, Issue 7 (August 2012), PP. 73-79

[11] Savita Nema, R.K.Nema, Gayatri Agnihotri, " Matlab / simulink based study of photovoltaic cells / modules / array &their experimental verification", Volume 1, Issue 3, 2010 pp.487-500Journal homepage: www.IJEE.IEEFoundation.org.

[12] Xuan Hieu Nguyen & Minh Phuong Nguyen, "Mathematical modeling of photovoltaiccell/module/arrays with tags in Matlab/Simulink", Nguyen &Nguyen Environ Syst Res (2015) 4:24DOI 10.1186/s40068-015-0047-9.

[13] Deepak Verma†, S. Nema‡ &A. M. Shandilya, "A Different Approach to Design Non-IsolatedDC–DC Converters for Maximum Power Point Tracking in Solar Photovoltaic Systems', Journal of Circuits, Systems,&Computers Vol. 25, No. 8 (2016) 1630004World Scientific Publishing Company10.1142/S021812661630004X.

[14] Habbati Bellia a, Ramdani Youcef b, Moulay Fatima," A detailed modeling of photovoltaic module using MATLAB", NRIAG Journal of Astronomy &Geophysics (2014) 3, 53–61

[15] M .Lokanadham, &K.Vijaya Bhaskar / International Journal of Engineering Research &Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 2,Mar-Apr 2012, pp.1420-1424

[16] Savita Nema, R. K. Nema& Gayatri Agnihotr," Inverter topologies &control structure in photovoltaic Applications : A review",JOURNAL OF RENEWABLE & SUSTAINABLE ENERGY 3, 012701 _2011