Performance Analysis of PV with MPPT, considering temperature and irradiation effect and Linear and Non-Linear Loads.

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***Abstract*— PV module always affected by the temperature and irradiation effect. The output power of PV system is always depends on whether condition. MPPT (Maximum Power Point Tracking) is used in Photovoltaic system to maximize the PV system output irrespective of the temperature and radiation condition and also load of electrical characteristics. The output power of PV is used to directly control the dc/dc converter. Thus the proposed system should be high efficient with reducing complexity at lower cost. This paper present the experimental simulation study showing the I-V characteristics of PV system under different loading condition. The experimental analysis has been performed by using ecosense insight solar PV kit.**

Keywords – PV module, resistive load, variable temperature and irradiation

I. INTRODUCTION

The renewable energy has increased much attraction these days as it can be recycled. The solar energy can be able to transform solar energy in to electrical energy, more efficient than other renewable sources. Though, compare to hydro, wind, geothermal. The solar energy are not widely used worldwide, due to high initial cost of solar cell. So, it is essential to recover as much energy as possible. Separately from the quickly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution related with their combustion. Contrastingly, renewable energy sources are well-known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts [1].

PV arrays consist of parallel and series combination of PV cells that are used to generate electrical power depending upon the atmospheric conditions (e.g. solar irradiation and temperature). So it is necessary to couple the PV array with a boost converter. Moreover the system is designed in such a way that with variation in load, the change in input voltage and power fed into the converter follows the open circuit characteristics of the PV array. The system can be used to supply constant stepped up voltage to dc loads. Therefore the aim is to increase the efficiency and power output of the system. It is also required that constant voltage be supplied to the load irrespective of the variation in solar irradiance and temperature [2], [3], [4].

The task of a maximum power point tracker (MPPT) in a photovoltaic (PV) energy conversion system is to continuously tune the system so that it draws maximum power from the solar array regardless of weather or load conditions. Since the solar array has a non-ideal voltage - current characteristic and the conditions such as irradiation and atmospheric temperature affect the output of the solar array are unpredictable, the tracker must contend with a nonlinear and time-varying system. Many tracking algorithms simulation of closed loop controlled boost converter for solar installation and techniques have been developed. The perturbed and observed method and the incremental conductance method, as well as variants of those techniques are the most widely used. The perturbed and Observe method is known for its simple implementation, but it deviates from and observe method oscillates close to a maximum power Point (MPP) in the atmospheric conditions are constant or slowly changed. However when weather rapidly changes perturb and observe method fails to track the maximum power point effectively [15], [16], [17].

Other methods for solar array MPP tracking include short circuit current and the open circuit voltage of the PV module techniques. The MPP tracking method using the short circuit current of the PV module exploits the fact that the operating current at the MPP of the solar array is linearly proportional to its short circuit current. Thus, under rapidly changing atmospheric conditions. This method has a relatively fast response time for tracking the MPP. However, the control circuit is still somewhat complicated and both the conduction loss and the cost of the MPPT converter are still relatively high. Furthermore, the assumption that the operating current at the MPP of the PV module is linearly proportional to the short circuit current of the PV module is only an approximation. In reality, the application of this technique always results in PV module operation below the maximum power point [13], [14], [18], [19].

Open circuit voltage of the PV module employs the fact that the open circuit voltage of the solar array at the MPP is linearly proportional to its open circuit voltage. This technique has some limitations and disadvantages as the short circuit current of PV module method described above. Although the method is cost efficient, its application results in considerable errors in MPP tracking and consequent energy losses. The general requirement for MPPT is simplicity, quick tracking under changing condition, cost and small output power fluctuation. Efficient method to solve this problem become critically important. This paper presents performance of PV module with and without MPPT at changing resistive load also considering irradiation effect.

This paper is organized as follows; section II presents PV module section III DC-DC Boost converter with MPPT IV calculation of linear and non-linear loads on system and conclusion and future work have been presented in section V.

II. PV MODULE

It is an assembly of photovoltaic (PV) cells, also known as solar cells. To achieve a required voltage and current, a group of PV modules (also called PV panels) are wired into large array that called PV array. A PV module is the essential component of any PV system that converts sunlight directly into direct current (DC) electricity. PV modules can be wired together in series and/or parallel to deliver voltage and current in a particular system requires. The module data sheet format and the information that should be included has been standardized, which is the "data sheet and nameplate information for photovoltaic modules".

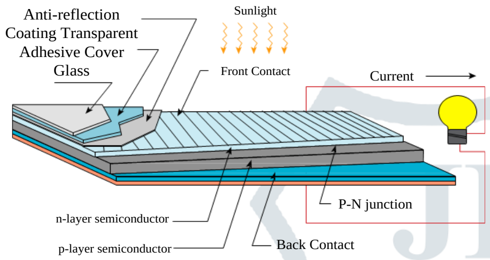


Figure 1 Structure of a Solar Cell

A typical solar cell is a multi-layered unit consisting of a: Cover - a clear glass or plastic layer that provides outer protection from the Elements. Transparent Adhesive - holds the glass to the rest of the solar cell.

Anti-reflective Coating - this substance is designed to prevent the light that strikes the cell from bouncing off so that the maximum energy is absorbed into the cell.

Front Contact - transmits the electric current.

N-Type Semiconductor Layer - This is a thin layer of silicon which has been mixed (Process if called doping) with phosphorous to make it a better conductor.

P-Type Semiconductor Layer - This is a thin layer of silicon Which has been mixed or doped with boron to make it a better conductor.

Back Contact - transmits the electric current.

N-Layer- is often formed from silicon and a small amount of Phosphorus. Phosphorus gives the layer an excess of electrons and therefore has a negative character. The n-layer is not a charged layer- it has an equal number of protons and electrons-but some of the electrons are not held tightly to the atoms and are free to move.

P-Layer- is formed from silicon and Boron and gives the layer a positive character because it has a tendency to attract electrons. The p-layer is not a charged layer and it has an equal number of protons and electrons.

P-N Junction - when the two layers are placed together, the free electrons from the n-layer are attracted to the p-layer. At the moment of contact between the two wafers, free electrons from the n-layer flow into the p-layer for a split second, then form a barrier to prevent more electrons from moving from one layer to the other. This contact point and barrier is called the p-n junction.

Once the layers have been joined, there is a negative charge in the p-layer and a positive charge in the n-layer section of the junction. This imbalance in the charge of the two layers at the p-n junction produces an electric field between the p-layer and the n-layer. If the PV cell is placed in the sun, radiant energy strikes the electrons in the p-n junction and energizes them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-layer and are repelled by the negative charge in the p-layer.

A wire can be attached from the p-layer to the n-layer to form a circuit. As the free electrons are pushed into the n-layer by the radiant energy, they repel each other. The wire provides a path for the electrons to flow away from each other. This flow of electrons is an electric current that we can observe. The electron flow provides the current, and the cell's electric field causes a voltage. With both current and voltage, we have power, which is the product of the two.

1.1 Characteristics of solar cell

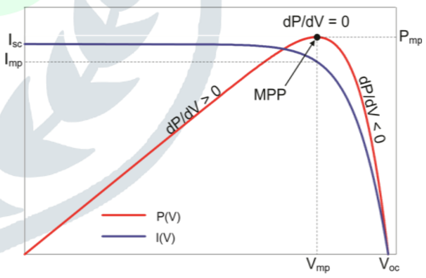
Ideally solar cell works as a current source. But no solar cell is ideal. It follows particular characteristics depending on the load under the constant illumination and temperature. When the light shines on a solar cell, the current flows in the opposite direction to that of the generated voltage, overall effect of light is to shift the I-V curve of the diode downwards in the current-voltage axis. Hence this results in negative power.

This negative power implies that power can be extracted from the device. Hence, a solar cell generates the power. As the current is caused by light, it is also known as light-generated current and voltage across the cell is known as photo-voltage. Generated photo-voltage due to light biases the P-N junction in forward bias mode reducing the barrier potential. Hence the net current flow is from N-side to P-side, which is opposite to that of forward biased diode current. I-V and P-V characteristic of the solar cell is as shown in figure 2.

Figure 2 I-V and P-V Curve

Short Circuit Current (Isc): This is the maximum current which flows in the solar cell when its terminals are shorted.

Open Circuit Voltage (Voc): This is the maximum voltage generated across terminals of the solar cell when they are kept open.



Maximum power point voltage (Vmp) and current (Imp): These are voltage and current at the maximum power point.

Fill Factor (FF): Fill factor represents the squareness of the solar cell I-V curve.

When the P-V curve of the module is observed, one can locate single maxima of power where the solar panel operates at its optimum. In other words, there is a peak power that corresponds to a particular voltage (Vmp) and current (Imp). Obtaining this peak power requires that the solar panel operate at or very near the point where the P-V curve is at the maximum. However, the point where the panel will operate will change and deviate from the maxima constantly due to changing ambient conditions such as insolation or temperature levels. The result is a need for a system to constantly track the P-V curve to keep the operating point as close to the maxima as much as possible while energy is extracted from the PV array.

1.2 PV Panel Model

A PV array consists of several photovoltaic cells in series and parallel connections. Series connections are responsible for increasing the voltage of the module whereas the parallel connection is responsible for increasing the current in the array. Typically a solar cell can be modelled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to P junction and parallel resistance is due to the leakage current.

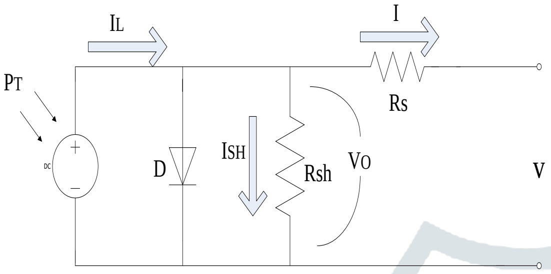


Figure 3 PV Mathematical Model

In this model we consider a current source (IL) along with a diode and series resistance (Rs). The shunt resistance (RSH) in parallel is very high, has a negligible effect and can be neglected. The output current from the photovoltaic array is

$$I = I_L - I_d - \frac{V_0}{R_{sh}}$$

Where,

$$V = V_0 - R_s I$$

The basic equation for the ideal case of the elementary PV cell does not represent the I–V characteristic of a practical PV array, actually Practical arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV Array is expressed by considering one the parameter called "I" which is given by:

$$I = I_l - I_d\left[\exp\left(\frac{q(V + R_s I)}{nktN_s}\right)\right] - 1$$

In the above mentioned equation, the parameter I_L and I_0 are expressed as:

$I_l = I_{L(T_r)}(1 + \alpha_{I_{se}}(T - T_r))$

$$I_o = I_{0(T_r)}\left(\frac{T}{T_r}\right)\exp\left[\frac{qV_g}{nk}\left(\frac{1}{T} - \frac{1}{T_r}\right)\right]$$

$I_{L(T_r)}$ is :

$I_{L(T_r)} = G\left(\frac{I_{sc(T_{r,nom})}}{G_e}\right)$

$I_{0(T_r)}$ is a reverse saturation curren.,

$$I_{0(T_r)} = \frac{I_{sc(T_r)}}{\exp\left(\frac{q(V_{oc(T_r)})}{nkT_rN_s}\right) - 1}$$

Where,

$$\alpha_{I_{sc}} = \frac{dI_{sc}}{dT}$$

Here,

IL: Is light or photo current.

Io: Is reverse saturation current of the diode.

Vs.: the output current and voltage of the photovoltaic generator respectively.

q: Is charge on electron.

K: Is the Boltzmann's constant.

Rs: Is the series resistance.

n: Ideality factor for P-N junction.

1.3 Solar Panel Ratings

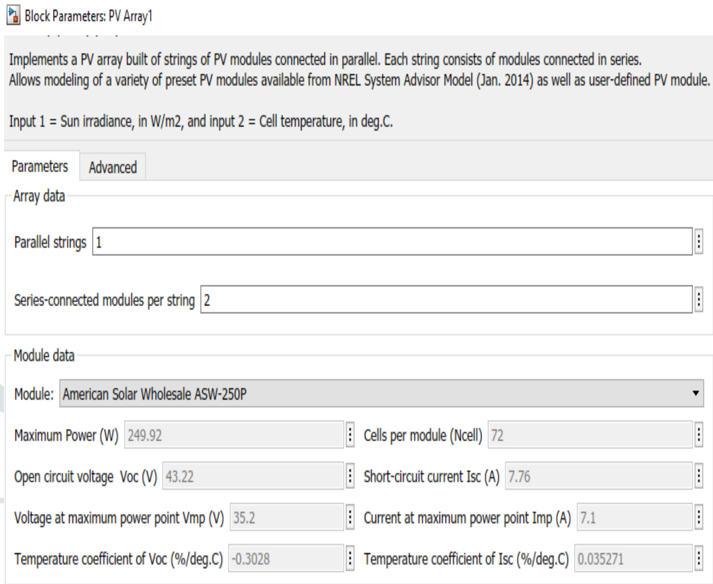


Figure 4 Solar Panel Ratings

III. DC-DC BOOST CONVERTER WITH MPPT

3.1 MPPT:

Maximum Power Point Tracking is main part of solar inverter. In photovoltaic systems the I-V curve is non-linear, thereby making it difficult to be used to power a certain load. MPPT algorithms are necessary because PV arrays have a nonlinear voltage-current characteristic with a unique point where the power produced is maximum. This point depends on the temperature of the panels and on the irradiance conditions. Both conditions change during the day and are also different depending on the season of the year. Furthermore, irradiation can change rapidly due to changing atmospheric conditions such as clouds. It is very important to track the MPP accurately under all possible conditions so that the maximum available power is always obtained.

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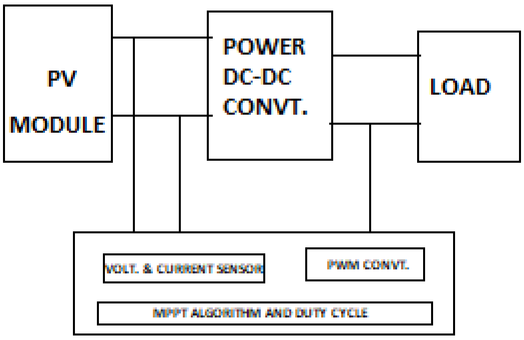

Figure 5 DC-DC Boost Converters with MPPT

DC-DC converters are used for extracting the maximum power of the solar cell or module. Converter uses the fact that by varying the duty ratio D, Rin i.e. input impedance of converter can be changed. Rin is equal to Rpv i.e. impedance of the solar PV module. Also by using principle of "IMPEDANCE MATCHING" when Rin becomes equal to RL i.e. Load resistance, maximum power will be transferred from panel.

MPPT mechanism makes use of an algorithm. Many techniques have been developed for the maximum power point techniques. These techniques use the principle of impedance matching between load and PV-module. The impedance matching is done with the help of DC to DC-Converter.

The power from solar module is calculated by measuring the voltage and current. This sensed voltage and current is given to MPPT algorithm which adjusts the duty cycle of switch, resulting in the adjustment of the reflected load impedance according to power output of the PV module. Input resistance of the converter reflected across the array is equal to PV array resistance. Hence by varying the duty ratio of the converter impedance matching can be done.

$$R_{in} = R_{pv} = \frac{V_{Pv}}{I_{pv}}$$

Here,
R_{in}= Resistance of the Converter reflected Across the PV array.
R_{pv} =Resistance of the PV array.
V_{pv}, I_{pv} = PV array output voltage and current.

3.2 Different MPPT Techniques

A lot of MPPT algorithms have been developed by researchers and industry delegates all over the world. There are many methods used for maximum power point tracking a few are listed below:

- Perturb and Observe
- Incremental Conductance method
- Fractional short circuit current
- Fractional open circuit voltage

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

3.2.1 Perturb & Observe (P&O)

Perturb & Observe (P&O) is the simplest method is as shown in figure. In this technique use only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. The time complexity of this algorithm is very less but on reaching very close to the MPP it doesn't stop at the MPP and keeps on perturbing on both the directions. When this happens the algorithm has reached very close to the MPP and we can set an appropriate error limit or can use a wait function which ends up increasing the time complexity of the algorithm. However the method does not take account of the rapid change of irradiation level (due to which MPPT changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP.
If the operating voltage of the PV array is perturbed in a given direction and dP/dV > 0, it is known that the perturbation moved the array's operating point toward the MPP. The P&O algorithm would then continue to perturb the PV array voltage in the same direction. If dP/dV < 0, then the change in operating point moved the PV array away from the MPP and the P&O algorithm reverses the direction of the perturbation as shown in figure.

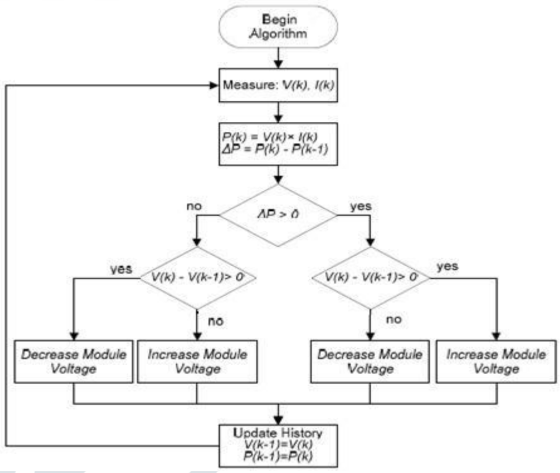

Figure 6 Flow Chart of P&O Method

The main advantage of the P&O method is that it is easy to implement, it has low computational demand, and it is very generic, i.e. applicable for most systems, as it does not require any information about the PV array, but only the measured voltage and current.
The main problem of the P&O is the oscillations around the MPP in steady state conditions and poor tracking (possibly in the wrong direction, away from MPP) under rapidly-changing irradiations.

3.2.2 Incremental Conductance

The disadvantage of the Perturb and Observe method to track the peak power under fast varying atmospheric condition is overcome by Incremental Conductance method. The Incremental Conductance can determine that the MPPT has reached the MPP and stop perturbing the operating point.

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

At MPP the slope of the PV curve is 0.

$$\left(\frac{dP}{dV}\right)_{mpp} = \frac{d(VI)}{dV}$$

$$0 = I + \frac{VdI}{dV_{mpp}}$$

I/V > dI/dV for dP/dV > 0 Left of MPP
I/V < dI/dV for dP/dV < 0 Right of MPP
I/V = -dI/dV for dP/dV = 0 At the MPP

If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculated using the relationship between dl/dV and –I/V. This relationship is derived from the fact that dP/dV is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P&O in that it can determine when the MPPT has reached the MPP, where P&O oscillates around the MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance conditions with higher accuracy than perturb and observe. One disadvantage of this algorithm is the increased complexity when compared to P&O. The flowchart for the IC method algorithm is shown in Figure.

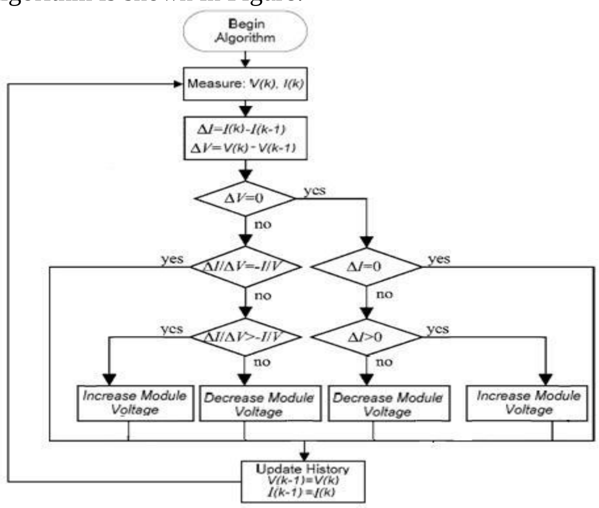

Figure 7 Flow Chart of Incremental Conductance Method

3.2.3 Fractional open circuit voltage

The near linear relationship between V_{MPP} and V_{OC} of the PV array, under varying irradiance and temperature levels, has given rise to the fractional V_{OC} method.

$$V_{mpp} = k_1 * V_{oc}$$

Where, k_1 is a constant of proportionality. Since k1 is dependent on the characteristics of the PV array being used, it usually has to be computed beforehand by empirically determining V_{MPP} and V_{OC} for the specific PV array at different irradiance and temperature levels. The factor k_1 has been reported to be between 0.71 and 0.78. Once k1 is known, V_{MPP} can be computed with V_{OC} measured periodically by momentarily shutting down the power converter. However, this incurs some disadvantages, including temporary loss of power.

3.2.4 Fractional short circuit current

Fractional ISC results from the fact that, under varying atmospheric conditions, IMPP is approximately linearly related to the ISC of the PV array.

$$I_{mpp} = k_2 I_{sc}$$

Where, k_2 is a proportionality constant. Just like in the fractional V_{OC} technique, k_2 has to be determined according to the PV array in use. The constant k_2 is generally found to be between0.78 and 0.92. Measuring I_{SC} during operation is problematic. An additional switch usually has to be added to the power converter to periodically short the PV array so that I_{SC} can be measured using a current sensor.

Table 1 Characteristics of different MPPT Techniques
Characteristics of different MPPT techniques

MPPT technique	Convergence	Implementation	Periodic tuning	Sensed paramete
Perturb & observe	Varies	Low	No	Voltage
Incremental	Varies	Medium	No	Voltage,
Fractional V_{OC}	Medium	Low	Yes	Voltage
Fractional I_{SC}	Medium	Medium	Yes	Current

3.3 DC DC Boost Converter

DC-DC Boost converter is used to step up DC voltage. The given below boost converter input voltage is given to 72V with constant output 110V at resistive load 25 Ω, Inductor 5.58E-03, Input Capacitor 4e-3F, Nominal Switching Frequency 5 KHz Output Capacitor 3.46e-4F.

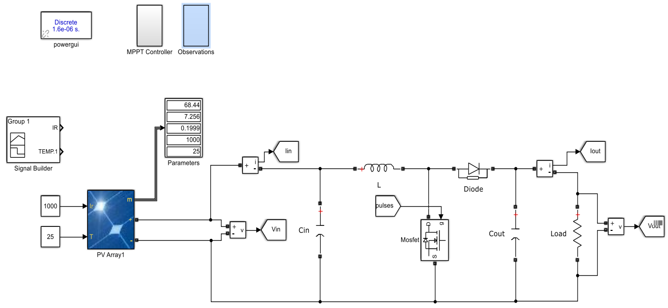

Figure 8 MATLAB simulation of DC-DC Boost Converter

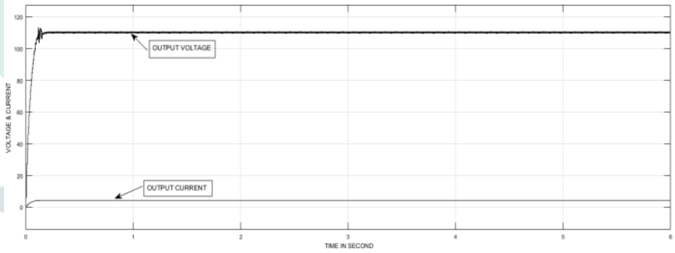

Figure 9 MATLAB Results of DC-DC Converter

Table 2 Solar Panel data:

Sr. No.	Parameter	Rating
1	Power Rating	250Wp
2	Maximum power voltage	35.0V
3	Maximum power current	7.14A
4	Open circuit voltage	43.2V
5	Short circuit current	7.5A
6	Module dimension	980*1745mm
7	Panel Type	Poly Crystalline Type

IV. CALCULATION OF LINEAR AND NON-LINEAR LOADS WITH THEIR EFFECTS ON SYSTEM:

The use of power electronics devices increase day by day in the power system due to its simplicity, highly reliable and low cost. Using these power electronics based apparatus, for example Inverter, the non-linear current to flow in the electrical circuit. The concepts should be clear that linear load and non-linear load with observing wave forms in power scope. Mathematical calculation understand by some basic definitions and formulas given as below.

Displacement factor: it is represented as cosine angle between fundamental component of voltage and current. If Φ is angle between voltage and current's fundamental, the displacement factor (DF) is given as COSØ [4], [7], [11], [12].

THD and Distortion Factor (DF): it is measure of distortion present in the signal.

$$THD = \frac{\sqrt{V2^2 + V3^2 + V4^2 + V5^2 + \cdots\ldots}}{V_{rms}} \quad (1)$$

$$V_{rms} = \sqrt{V_1^{\,2} + V2^2 + V3^2 + V4^2 + V5^2 + \cdots} \text{--} \quad (2)$$

$$DF = \frac{V_1}{V_{rms}} \quad (3)$$

Where V_{rms} = fundamental voltage

Power factor: for purely sinusoidal loads, Displacement factor and Power factor are the same as distortion factor same as unity. But when the load is non-sinusoidal or non-linear Power factor is given as

Power factor = Displacement factor × Distortion factor

$$PF = \frac{V_1}{\sqrt{V_1^{\,2} + V2^2 + V3^2 + V4^2 + V5^2 + \cdots -}} \times COSØ \quad (4)$$

TABLE 3.
OBSERVATION TABLE FOR 210 Vrms.

Sr. No.	LOAD	Φ	THD IN C	D.F.	PF	F. VOLTAGE	F. CURRENT
1	100W lamp load	359	5.09	209.45/210 = 0.9974	0.9995	209.45V	0.42A
2.	Laptop Charger	338.4	33.78	196.99/210 = 0.9380	0.92	196.99V	0.23A

TABLE 4

Sr. No.	ACTIVE POWER P IN KW	REACTIVE POWER Q IN KVAR	APPARENT POWER S IN KVA	MEASURED APPARENT POWER S IN KVA
1.	0.090	-0.001	0.090	0.09088
2.	0.055	-0.012	0.059	0.060

TABLE 5
OBSERVATION TABLE FOR 230 Vrms.

Sr. No.	LOAD	Φ	THD IN C	D.F.	PF	F. VOLTAGE
1	100W lamp load	4.89	229.44/230 = 0.9975	0.9998	229.44V	0.45
2.	Laptop Charger	39.96	210.81/230 = 0.9167	0.9	210.81V	0.255

TABLE 6

Sr. No.	ACTIVE POWER P IN KW	REACTIVE POWER Q IN KVAR	APPARENT POWER S IN KVA	MEASURED APPARENT POWER S IN KVA
1.	0.102	-0.001	0.102	0.102
2.	0.053	-0.012	0.058	0.058

V. CONCLUSION

By performing experiments on ecosense insight solar panels, situated at LE College Morbi, acquire some results mentioned above and as per that results conclude that

1. Output power decrease with increase in temperature and decrease in irradiance.
2. MATLAB Simulation given the results of DC-DC Boost converter of constant 110V with proper the value design.
3. It can be seen that current is highly distorted and THD is more than in non-linear load compare to linear load at the PCC.
4. When non-linear load is connected at the PCC voltage is decreased with increased the value of inductance and also increased THD.
5. The phase angle (angle between voltage and current) decreased when capacitance is increased and THD also increased.

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