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Comparison of THD for various Loads connected to a PV System using Fly back Converter

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Abstract: Photovoltaic (PV) energy is the most important energy resource since it is clean, pollution free, and inexhaustible. The studies on the photovoltaic system are extensively increasing because of a large, secure, essentially exhaustible and broadly available resource as a future energy supply. Due to rapid growth in the semiconductor and power electronics techniques, it is important to operate PV energy conversion systems near the maximum power point to increase the output efficiency of PV systems. The output of PV is given to flyback converter to boost the voltage and to drive a resistive load or incandescent bulb of 40W, inductive load and motor load.

Keywords: Photovoltaic system, flyback converter, Maximum power point tracking (MPPT).

I. INTRODUCTION

Worldwide energy consumption has increased rapidly due to world population growth. Among the renewable energy resources, the energy through the solar photovoltaic effect can be considered the most necessary and prerequisite sustainable resource because of the ubiquity, large quantity, and sustainability of solar energy.Since amount of fossil energy source has no longer enough, renewable energy sources such as solar power, wind power, geothermal power, and fuel cell are considered to meet the global demand for energy in the coming years [3]. Solar energy is one of the most important renewable energy sources. Compared to conventional non renewable resources such as gasoline, coal, etc., solar energy is clean, inexhaustible and free.Solar energy is a very attractive renewable source with a long service life and high reliability. But because of its high cost and low efficiency, energy contribution is less than other energy sources. It is therefore essential to have effective and flexible models, which perform easy manipulation of data such as irradiance and temperature to investigate how to get its maximum performance as possible [4].The fundamental element in solar power generation system is the solar cell or photovoltaic (PV) cell. The photovoltaic (PV) cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The solar energy is directly converted to electricity through photovoltaic effect. PV cell exhibits a nonlinear P-V and I-V characteristics which vary with cell temperature (T) and solar irradiance (S). Different equivalent circuit models of PV cell have been discussed in literature [5].The system performance can be optimized by connecting the PV model with buck-boost converter [6].

The basic device of a photovoltaic system is the photovoltaic cell. Cells may be grouped to form modules or panels. Panels can be grouped to form large photovoltaic arrays. The term array is usually employed to describe a photovoltaic panel (with several cells connected in series and/or parallel) or a group of panels. The term array used henceforth means any photovoltaic device composed of several basic cells. The use of new efficient photovoltaic solar cells (PVSCs) has emerged as an alternative measure of renewable green power, energy conservation and demand-side management. The performance of a PV array system depends on the operating conditions as well as the solar cell and array design quality. The output voltage, current and power of PV array vary as functions of solar irradiation level, temperature and load current. Therefore the effects of these three quantities must be considered in the design of PV arrays so that any change in temperature and solar irradiation levels should not adversely affect the PV array output to the load/utility, which is either a power company utility grid or any stand alone electrical type load.

Photovoltaic (PV) generation is becoming increasingly important as a renewable source since it offers many advantages such as incurring no fuel costs, not being polluting, requiring little maintenance, and emitting no noise, among others. The photovoltaic array is an unstable source of power since the peak power point depends on the temperature and the irradiation level. A maximum peak power point tracking is then necessary for maximum efficiency [7, 8]. The V-I and V-P characteristic curves specify a unique operating point at which maximum possible power is delivered. At the MPP, the PV operates at its highest efficiency.

Therefore, many methods have been developed to determine MPPT [8]. In this work, maximum power point tracker i.e. perturb and observe method is used such that solar panel maximum power is generated under different operating conditions and given to the load which is incandescent bulb of 40W. A photovoltaic system including a solar panel, a DC-DC converter and a resistive load or incandescent bulb is modelled and simulated [7].The below Fig 1 shows MPPT based flyback converter for PV module which is used to drive resistive load or incandescent bulb of 40W, inductive load and RLE load or motor load.

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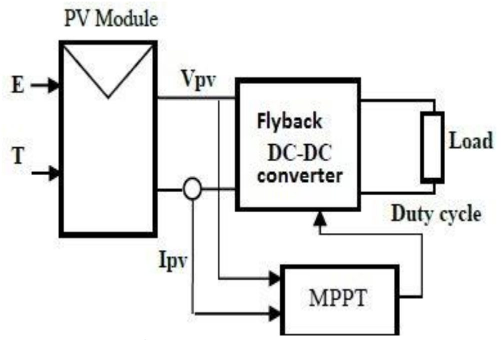

Fig.1.PV with flyback converter and resistive load

II. PV MODULE

A simple PV cell from a modelling perspective is an ideal current source in parallel with an ideal diode as seen in Fig.2 [9]. The two parameters used to model and characterize a PV cell are: the open circuit voltage (Voc) and the short circuit current (ISC). The Voc is the maximum voltage which a solar cell can provide at zero current. The ISC is the maximum current which a solar cell can provide at zero voltage.

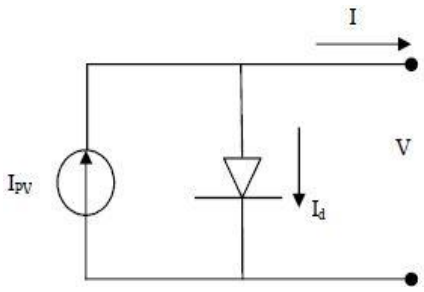

Fig.2.An ideal PV cell

The output current from the PV cell can be found using the equation (1)

$$I = I_{PV} - Id \qquad (1)$$

Where
IPV is the photon generated current that is equal to the short circuit current ISC
and Id is the current shunted thought the intrinsic diode.
By Shockley equation, the diode current Id is given by Eq. (2)

$$Id = Io\left[e^{\left(\frac{qv}{kt}\right)} - 1\right] \qquad (2)$$

Where
IO = reverse saturation current or leakage current
q = elementary electron charge (1.602x10-19 °C),
V = diode voltage,
k = Boltzmann constant 1.381x10-23 (J/K)
T = temperature in Kelvin (K)
Thus combining equations (1) and (2) yields

$$I = I_{PV} - IO\left[e^{\left(\frac{qv}{kt}\right)} - 1\right] \qquad (3)$$

In this case V is the voltage that exists across the PV cell and I is the output current of the ideal circuit model.
The voltage generated by a single solar cell is very low, around 0.5V. So, a number of solar cells are connected in both series and parallel connections to achieve the desired output. In case of partial shading, diodes may be needed to avoid reverse current in the array. Good ventilation behind the solar panels is provided to avoid the possibility of less efficiency at high temperatures. The same basic modelling equations as in a PV cell are also followed for the module. The simple PV cell model neglects to take into consideration a series of parameters that create a more accurate model. They are:

1. RS: Series resistance that accounts for any resistance in the current paths through the semiconductor material, the metal grid, contacts and currents controlling the system. This value also accounts for the loss associated with connecting a number of cells in series.
2. RP: Parallel resistance to take into account the loss associated with a slight leakage current through a parallel resistive path to the device. In most models it is neglected because its effect isn't as noticeable unless a large amount of cells are connected in parallel.
3. a: diode ideality factor, the value of a is equal to 1 for ideal diode. A recombination factor related directly to the depletion region of PV cells and to the amount of cells connected in series.

The equivalent model of PV cell is depicted in Figure 3.

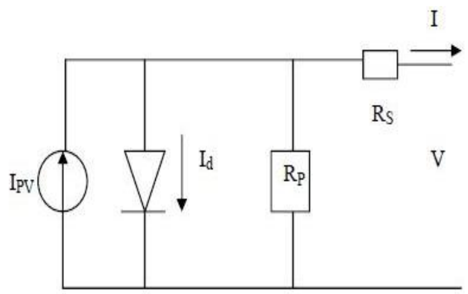

Fig.3: Equivalent model of PV module

Taking into account all the additional elements mentioned above the Equation (3) changes to (4)

$$I = I_{PV} - IO\left[e^{\left(\frac{qv}{aN_Skt}\right)} - 1\right] - \frac{V + IR_S}{R_p} \qquad (4)$$

Where, Ns denote the number of cells in series.
The current generated by the solar cells IPV can be approximated with the short circuit current ISC. The assumption is generally used in the modelling of PV devices because in practical devices the series resistance is low and the parallel resistance is high. The light-generated current of the PV cell depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation

$$I_{PV} = [I_{SC} + K_i(T - T_{ref})] * \frac{G}{G_n} \qquad (5)$$

Where,
I_{SC} = is the light-generated current at the nominal condition (usually 25^0C and 1000 W/m^2) in amperes.
Ki = the temperature coefficient of Isc in percent change per degree
T = actual temperature in Kelvin
Tref = reference temperature in Kelvin (usually at 25^0C)

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G = actual irradiation
Gn = nominal irradiation (usually 1000 W/m^2)
The reverse saturation current Io depends on the temperature T. It is calculated by the following equation (6)

$$Io = Ion * \left(\frac{T}{T_{ref}}\right)^3 * \left(e^{\frac{qE_g}{ak}\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)}\right) \quad (6)$$

Where, Eg is the band gap energy of the semiconductor and Ion is the nominal saturation current and is represented by the following equation (7)

$$Ion = \frac{I_{SCn}}{\left[e^{\left(\frac{qV_{oc}}{aN_sT_{ref}k}\right)}-1\right]} \quad (7)$$

by using the above equations we have modelled a photovoltaic module as shown in Fig .4 and using the parameters shown in table 2.

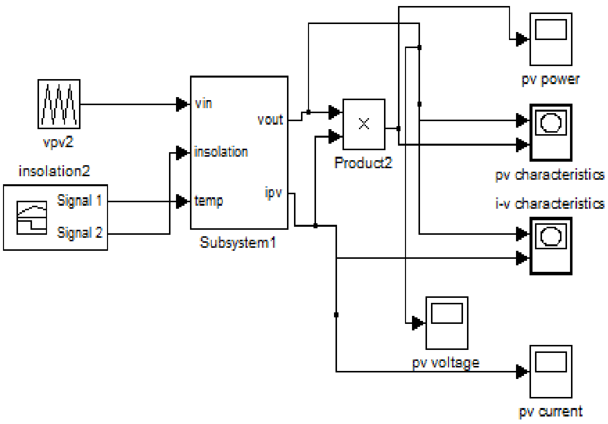

Fig. 4: Simulink model of PV module

III. MPPT TRACKING

To insure compatibility with storage batteries or loads, it is necessary to know the electrical characteristics of photovoltaic modules. A photovoltaic module will produce its maximum current when there is essentially no resistance in the circuit. This would be a short circuit between its positive and negative terminals. This maximum current is called the short circuit current I_{SC}. When the module is shorted, the voltage in the circuit is zero.

Conversely, the maximum voltage is produced when there is a break in the circuit. This is called the open circuit voltage VOC. Under this condition the resistance is infinitely high and there is no current, since the circuit is incomplete.

These two extremes in load resistance, and the whole range of conditions in between them, are depicted on a graph called an I-V (current-voltage) curve shown in Fig. 5. Current, expressed in amps, is on the vertical Y-axis. Voltage, in volts, is on the horizontal X-axis. Power v/s Voltage characteristics are also shown. It is necessary to track the maximum power point so that maximum amount of power can be transferred to the load from PV system.

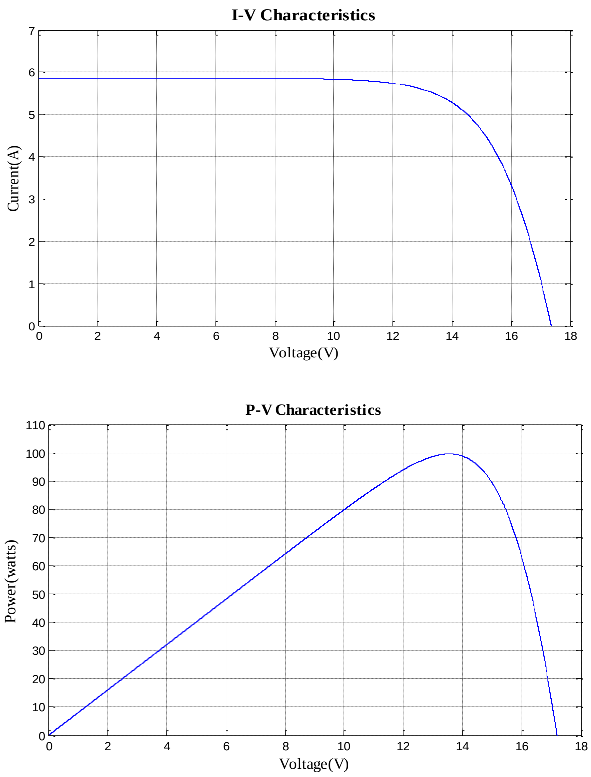

Fig.5: I-V and P-V characteristics of 100W PV module

Perturbation and Observation method is one of the most popular algorithms. In this method very less number of sensors are utilized. As the name implies the method will perturb the system by either increasing or decreasing the systems operating voltage point and comparing the result to the one obtained in the previous perturbation cycle. If the perturbation leads to an increase or decrease in photovoltaic power, the subsequent perturbation is made in the same or opposite direction as shown in Fig.6. In this manner, the peak power tracker continuously seeks the peak power condition. With this algorithm the voltage V is constantly perturbed with every step calculation meaning V will oscillate around the ideal Vmpp [2]. This algorithm is not suitable when the variation in the solar irradiation is high. The voltage never actually reaches an exact value but perturbs around the maximum power point (MPP). This iteration is continued until the algorithm finally reaches the MPP.

In order to keep the power variation small the perturbation size is also kept small, this introduces an obvious drawback as the time required to reach the peak power point is large. If the variation is large, then the oscillation around the Vmpp will be larger, causing power loss. The value of the optimal step size is unique to each system. The starting value of the duty cycle is set at 50%. The system oscillates around the MPP with this method. The process of incrementing and decrementing can fail under rapid change in irradiation. The system diverges away from MPP if the irradiance increases suddenly. To rectify those problems, improved methods of perturb and observe are used which incorporate reduced perturbation step size, variable step size, three points weights comparison methods and optimized sampling rate.[11]

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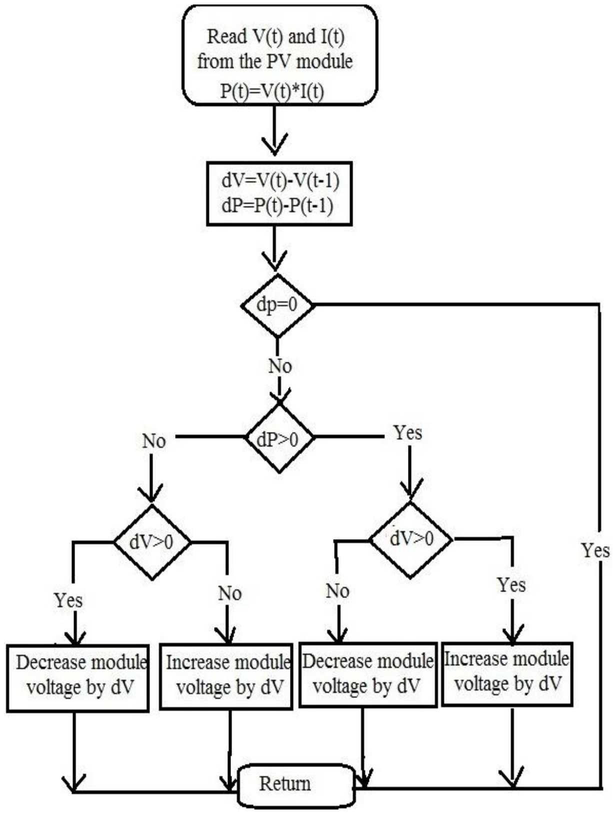

Fig.6: Flowchart of perturb and observe method

The P&O algorithm is also called “hill-climbing”, but both names refer to the same algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique.[1]

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. It can be seen that incrementing (decrementing) the voltage increases (decreases) the power when operating on the left of the MPP and decreases (increases) the power when on the right of the MPP. Therefore, if there is an increase in power, the subsequent perturbation should be kept the same to reach the MPP and if there is a decrease in power, the perturbation should be reversed. This algorithm is summarized in Table 1. The process is repeated periodically until the MPP is reached.

TABLE 1: SUMMARY OF P AND O ALGORITHM

Perturbation	Change in power	Next perturbation
Positive	Positive	Positive
Positive	Negative	Negative
Negative	Positive	Negative
Negative	Negative	Positive

IV. FLYBACK CONVERTER

The flyback converter is used in both DC/DC and AC/DC conversion with galvanic isolation between input and output as shown in Fig 7. The flyback converter is a buck-boost converter with the inductor split to form a transformer, so that the voltage ratios are multiplied with an additional advantage of isolation. Flyback converter is being used here in order to get less ripples and low distortion in the output

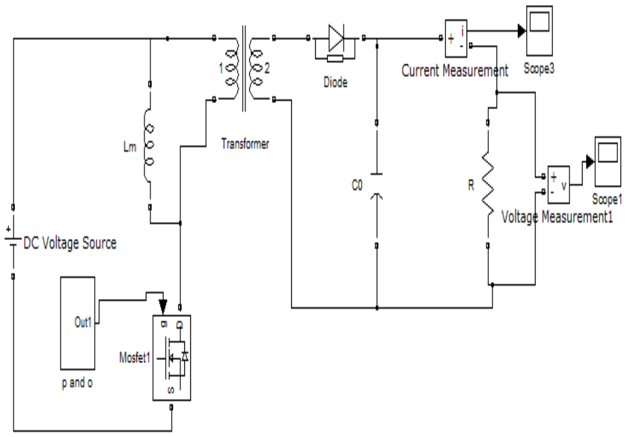

Fig.7: Flyback converter

The inductor of the buck-boost converter has been replaced by a flyback transformer, input dc source VS and switch S are connected in series with the transformer primary. The diode D and the RC output circuit are connected in series with the secondary of the flyback transformer. Fig.7 shows the converter with a simple flyback transformer model that includes a magnetizing inductance Lm and an ideal transformer with a turns ratio of n = N1/N2. The flyback transformer leakage inductances and losses are neglected in the model. It should be noted that leakage inductances, although not important from the viewpoint of the principle of operation, affect adversely switch and diode transitions [10]. Therefore, snubbers are usually required in flyback converters. The operating principle of flyback converters is as shown below

When the switch is closed, the primary of the transformer is directly connected to the input voltage source. The primary current and magnetic flux in the transformer increases, storing energy in the transformer. The voltage induced in the secondary winding is negative, so the diode is reverse-biased (i.e., blocked). The output capacitor supplies energy to the output load.

When the switch is opened, the primary current and magnetic flux drops. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer core recharges the capacitor and supplies the load.

The operation of storing energy in the transformer before transferring to the output of the converter allows the topology to easily generate multiple outputs with little additional circuitry, although the output voltages have to be able to match each other through the turns ratio. Also there is a need for a controlling inductance which has to be loaded before voltage is applied to the load. The switch must be allowed to open up to supply enough energy to the transformer. The dc voltage transfer function of the flyback is converter is shown in (8)

$$M_V = \frac{V_o}{V_S} = \frac{D}{n(1-D)} \quad (8)$$

It differs from the buck-boost converter voltage transfer function by the turn's ratio factor n. A positive sign has been obtained by an appropriate coupling of the transformer windings. The magnetizing inductance Lm of the flyback transformer is an important design parameter. The value of the magnetizing is given by Eq. (9)

$$L = \frac{n^2 (1-D)^2 R}{2f} \quad (9)$$

The value of the filter capacitance can be calculated using the formula as shown in Eq. (10)

$$C = \frac{DV_O}{V_r Rf} \quad (10)$$

R load: Resistive load is taken as output for flyback converter. This resistive load can be changed with incandescent bulb of 40W if required. An incandescent bulb is resistive load, because it produces light due to heat loss which is equal to I^2RT, shaped like a coil for just producing more light. This is the purely resistive load, and the consumed power is converted into heat and radiation. In this type of load voltage and current are in phase with each other. Since there's no phase shift, voltage and current always have the same sign, and power is always positive. There's no energy stored in either magnetic fields or electric fields, and no energy re-released.

RL load: Inductive load is taken as output for flyback converter. An inductive load consists of an iron-core reactive element which creates a lagging power factor load. Inductive load resists changes in current and as such, when the current is measured, it lags (is behind) the voltage. Electromagnetic fields are the key to inductive load. The important thing to remember about inductive loads is that they have two types of power namely, **real** power and **reactive** power. The real power is based on the work done by the device. The reactive power is that which is drawn from the source to produce magnetic fields. The total power consumed is real and reactive power combined, which is measured in VAR (volts-amps-reactive).The output voltage and current of flyback converter with RL load is similar to that of R load as the value of inductance considered here is very small i.e. equal to 0.001H.

RLE load: RLE load or motor load can also be taken as output for flyback converter. The simulink model of permanent magnet dc shunt motor is shown in Fig.8. In a dc motor, an armature rotates inside a magnetic field. Basic working principle of DC motor is based on the fact that whenever a current carrying conductor is placed inside a magnetic field, there will be mechanical force experienced by that conductor. All kinds of DC motors work in this principle only. Hence for constructing a dc motor it is essential to establish a magnetic field. The magnetic field is obviously established by means of magnet. The magnet can by any types i.e. it may be electromagnet or it can be permanent magnet.

When permanent magnet is used to create magnetic field in a DC motor, the motor is referred as permanent magnet dc motor or PMDC motor. These types of motor are essentially simple in construction. These motors are commonly used as starter motor in automobiles, windshield wipers, for blowers used in heaters and air conditioners, to raise and lower windows. As the magnetic field strength of a permanent magnet is fixed it cannot be controlled externally, field control of this type of dc motor cannot be possible. Thus permanent magnet dc motor is used where there is no need of speed control of motor by means of controlling its field. Small fractional and sub fractional kW motors are constructed with permanent magnet.

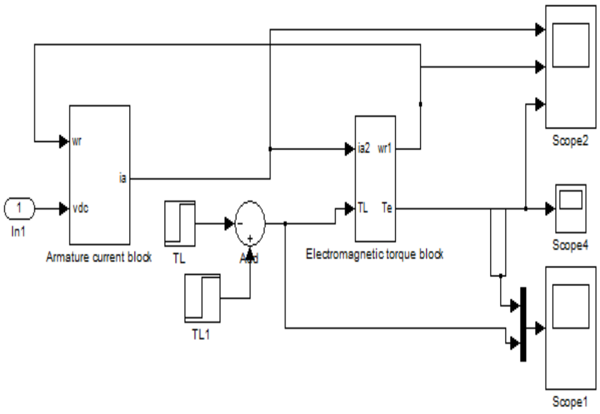

Fig 8: Simulink model of permanent magnet dc shunt motor

V. SIMULATION RESULTS

A 100W PV module is taken as the reference module for simulation and the name-plate details are given. The following parameters shown in Table 2 are used in the simulation of PV module in order to get Vmp and Imp.

TABLE 2: PARAMETERS OF PV MODULE

Rated Power	100 W
Open circuit voltage (VOC)	21.75 V
Short circuit current (ISC)	6.43 A
Voltage at Maximum power (Vmp)	17.1 V
Current at Maximum power (Imp)	5.85 A

Standard test conditions of $1000 w/m^2$ and 25^0C are taken in order to model the PV module. In order to get required voltage four PV modules are connected in series thus giving a voltage of 68.4 V and the current of PV module is 5.85A as shown in Figs. 8 and 9.The output power of PV module is shown in Fig 10.

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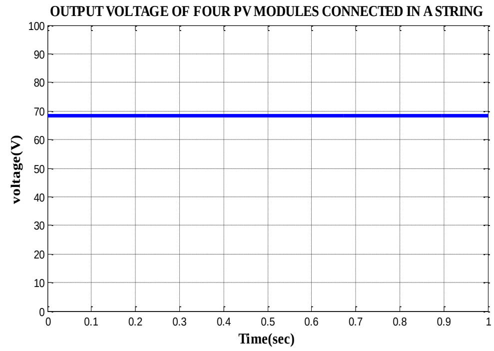

Fig. 8. Output voltage of four PV modules connected in string

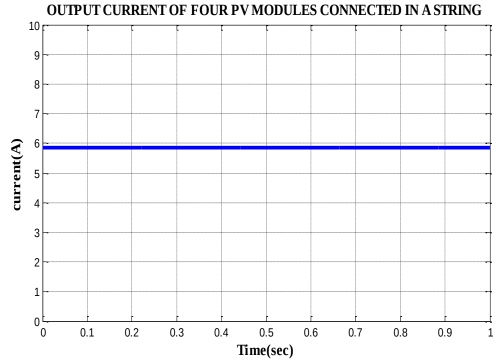

Fig. 9. Output current of four PV modules connected in a string

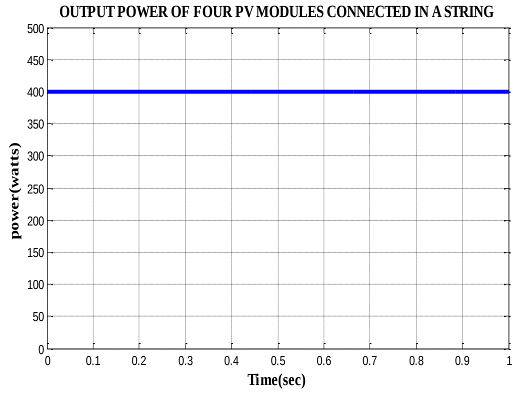

Fig. 10. Output Power of four PV modules connected in a string

The output voltage and output current of PV module are given to MPPT converter in order to obtain the pulses for the flyback converter as shown in Fig. 11.

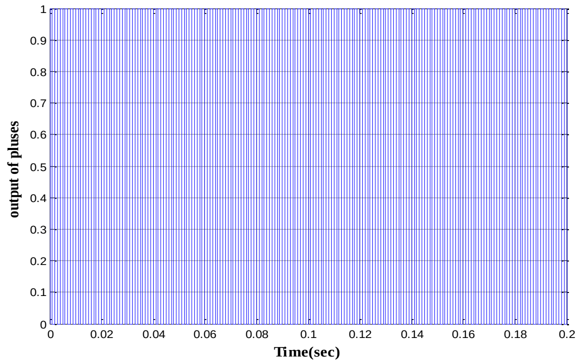

Fig. 11. Output pulses of MPPT method

The output voltage of PV module is given to the flyback converter in order to boost up the voltage to 110V as shown in Fig. 12. The output current of flyback converter is also shown in Fig. 13.

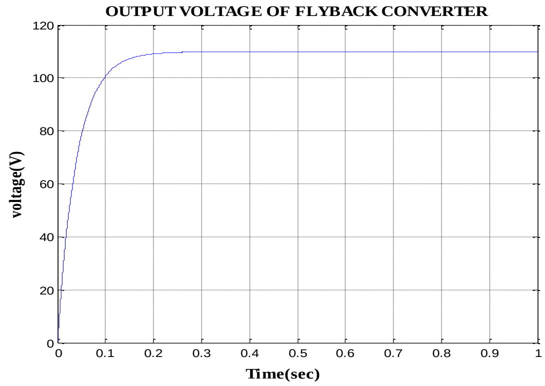

Fig. 12. Output voltage of Flyback converter with R load

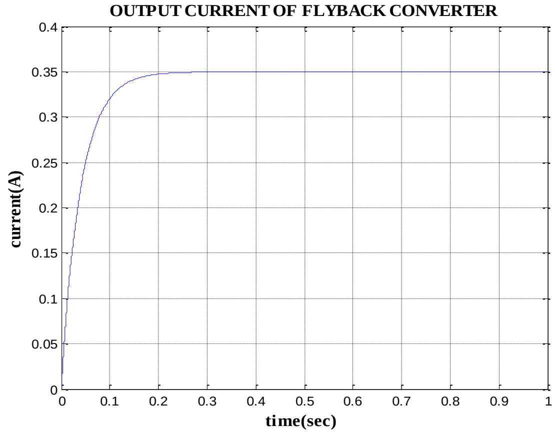

Fig. 13. Output current of Flyback converter with R load

This boosted up voltage of 110V is required to drive the incandescent bulb of 40W and thus giving a current of 0.35A. The voltage current characteristics of resistive load or incandescent bulb are shown in Fig. 14. Resistive loads are used for applications such as incandescent lighting, cooking, and heating. The I-V characteristic of a resistive load is governed by Ohms law, V = IRL where RL is the load resistance.

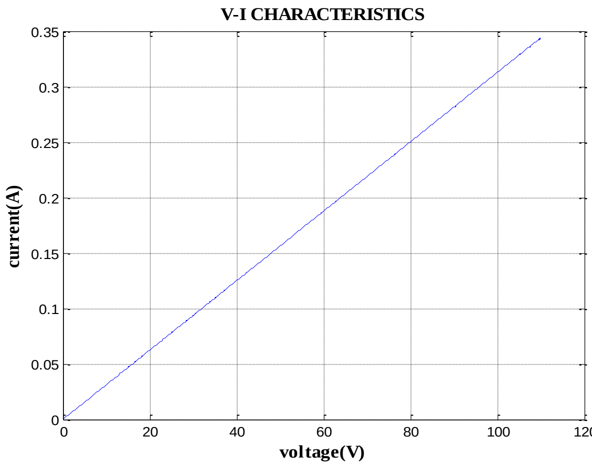

Fig. 14. V-I characteristics of 40W bulb

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The I-V curves for a resistive load is a straight line beginning at the origin, with a slope of 1/ RL. The load I-V line continues out to the maximum current and voltage of the device.

When motor or RLE load is taken as output of flyback converter then the output waveforms of permanent magnet dc motor can be observed in below figures. The armature current of dc motor is shown in Fig.15. The speed and torque of permanent magnet dc motor can be shown in below Figures 16 and 17.

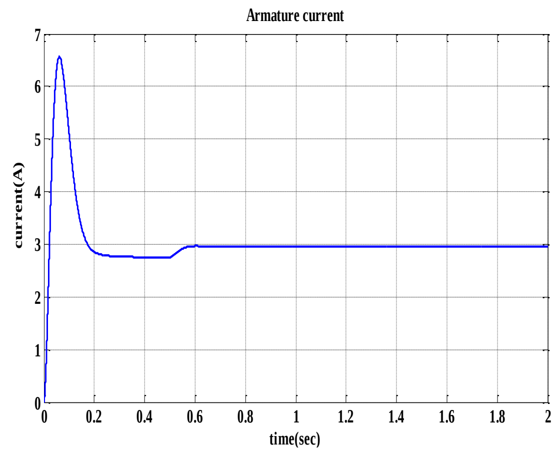

Fig.15. Armature current of dc motor

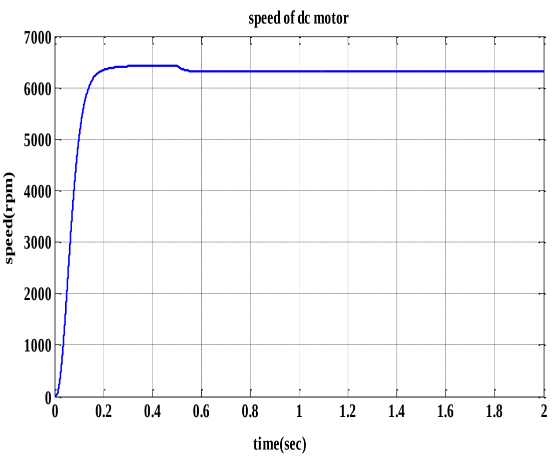

Fig.16. Speed of dc motor

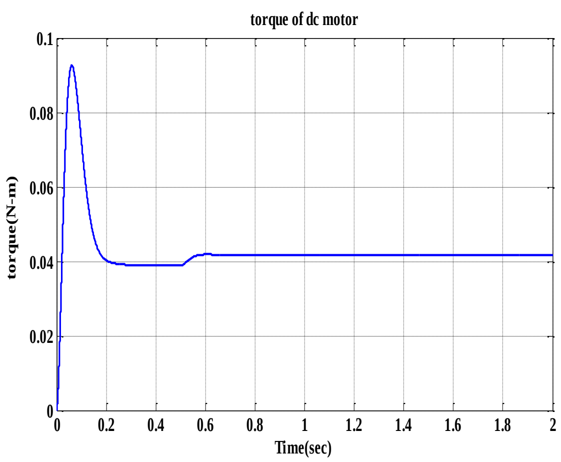

Fig.17.Torque of dc motor

VI. THD COMPARISON

The THD comparison of output current of flyback converter for different loads(R, RL and RLE loads) is shown in table 3

TABLE 3: COMPARISON OF THD OF OUTPUT CURRENT OF FLYBACK CONVERTER FOR DIFFERENT LOADS

Type of load	THD of output current of flyback converter
R load	10.21%
RL load	7.86%
RLE load	3.79%

VII. CONCLUSION

The proposed paper is capable of driving an incandescent bulb or resistive load of 40W.It can also be used to drive inductive or motor load. There is decrease in total harmonic distortion for RL and RLE load compared to R load as inductance opposes sudden changes in current.

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